Swami Keshvanand Institute of Technology,
Management & Gramothan

Approved by AICTE, Ministry of HRD, Government of India
Recognized by UGC under Section 2(f) of the UGC Act, 1956
Affiliated to Rajasthan Technical University, Kota

1.1.1 Sample Course File
(Session 2021-22)

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A

Course File

on

(Microwave Theory and Techniques: 5EC4-05)

Programme: B.Tech in ECE

Semester: V EC

Session: 2021-2022

Mr. Harshal Nigam
(Assistant Professor)
(ECE)

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Ramnagaria, Jagatpura, Jaipur-302017, INDIA
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Contents

Note:

1.*1st lecture of the course should cover prerequisite
2. **E: Easy, M: Moderate, D: Difficult
3. Format for Points 8-11 should be referred from AICTE's Recommendations for Examination Reforms

1. Institute Vision/Mission/Quality Policy

Vision
To promote higher learning in advanced technology and industrial research to make our country a global player

Mission
To promote quality education, training and research in the field of Engineering by establishing effective interface with industry and to encourage faculty to undertake industry sponsored projects for students

Quality Policy
We are committed to 'achievement of quality' as an integral part of our institutional policy by continuous self-evaluation and striving to improve ourselves.

Institute would pursue quality in
• All its endeavors like admissions, teaching- learning processes, examinations, extra and co-curricular activities, industry institution interaction, research & development, continuing education, and consultancy.

• Functional areas like teaching departments, Training & Placement Cell, library, administrative office, accounts office, hostels, canteen, security services, transport, maintenance section and all other services."

2. Departmental Vision/Mission

Vision: To evolve the department as a center of excellence in the field of Electronics & Communication Engineering for enriched education, higher learning, research and development.

Mission: To empower students by imparting quality education in Electronics and Communication Engineering for better employability and preparing them to be competent in dealing with industrial and societal challenges.

3. RTU Scheme & Syllabus

THEORY

SN	Category	Course		Contact hrs/week			Marks				Cr
		Code	Title	L	T	P	Exam hours	IA	ETE	Total	
1	ESC	5EC3-01	Computer Architecture	2	0	0	2	20	80	100	2
2	PCC/PEC	5EC4-02	Electromagnetic Waves	3	0	0	3	30	120	150	3
3		5EC4-03	Control System	3	0	0	3	30	120	150	3
4		5EC4-04	Digital Signal Processing	3	0	0	3	30	120	150	3
5		**5EC4-05**	**Microwave Theory & Techniques**	**3**	**0**	**0**	**3**	**30**	**120**	**150**	**3**
6		Professional Elective 1 (any one)		2	0	0	2	20	80	100	2
		5EC5-11	Bio- Medical Electronics								
		5EC5-12	Embedded Systems								
		5EC5-13	Probability Theory & Stochastic process								
		5EC5-14	Satellite Communication								
		Sub Total		**16**	**0**	**0**		**160**	**640**	**800**	**16**
PRACTICAL & SESSIONAL											
7	PCC	5EC4-21	RF Simulation Lab	0	0	3	2	45	30	75	1.5
8		5EC4-22	Digital Signal Processing Lab	0	0	3	2	45	30	75	1.5
9		5EC4-23	Microwave Lab	0	0	2	2	30	20	50	1
10	PSIT	5EC7-30	Industrial Training	0	0	1		75	50	125	2.5
11	SODECA	5EC8-00	Social Outreach, Discipline & Extra Curricular Activities	0	0	0			25	25	0.5
		Sub Total		**0**	**0**	**9**		**195**	**155**	**350**	**7**
		TOTAL of V SEMESTER		**16**	**0**	**9**		**355**	**795**	**1150**	**23**

Syllabus

S.N	CONTENT	HOURS
1.	**Introduction:** Objective, scope and outcome of the course	1
2.	**Introduction to Microwaves**-History of Microwaves, Microwave Frequency bands; Applications of Microwaves: Civil and Military, Medical, EMI/ EMC	4
3.	**Mathematical Model of Microwave Transmission**-Concept of Mode, Features of TEM, TE and TM Modes, Losses associated with microwave transmission, Concept of Impedance in Microwave transmission.	5
4.	**Analysis of RF and Microwave Transmission Lines**-Coaxial line, Rectangular waveguide, Circular waveguide, Strip line, Micro strip line	4
5.	**Microwave Network Analysis**-Equivalent voltages and currents for non TEM lines, Network parameters for microwave circuits, Scattering Parameters.	4
6.	**Passive and Active Microwave Devices**-Microwave passive components: Directional Coupler, Power Divider, Magic Tee, Attenuator, Resonator. Microwave active components: Diodes, Transistors, Oscillators, Mixers. Microwave Semiconductor Devices: Gunn Diodes, IMPATT diodes, Schottky Barrier diodes, PIN diodes. Microwave Tubes: Klystron, TWT, Magnetron	6
7	**Microwave Design Principles**-Impedance transformation, Impedance Matching, Microwave Filter Design, RF and Microwave Amplifier Design, Microwave Power Amplifier Design, Low Noise Amplifier Design, Microwave Mixer Design, Microwave Oscillator Design. Microwave Antennas- Antenna parameters, Antenna for ground based systems, Antennas for airborne and satellite borne systems, Planar Antennas.	6
8	**Microwave Measurements**-Power, Frequency and impedance measurement at microwave frequency, Network Analyzer and measurement of scattering parameters, Spectrum Analyzer and measurement of spectrum of a microwave signal, Noise at microwave frequency and measurement of noise figure. Measurement of Microwave antenna parameters.	6
9	**Microwave Systems**-Radar, Terrestrial and Satellite Communication, Radio Aidsto Navigation, RFID, GPS. Modern Trends in Microwaves Engineering- Effect of Microwaves on human body, Medical and Civil applications of microwaves, Electromagnetic interference and Electromagnetic Compatibility (EMI & EMC), Monolithic Microwave ICs, RFMEMS for microwave components, Microwave Imaging.	6
		Total 42

4. Prerequisite of Course (Microwave Theory and Techniques)

i. **Basics of Electromagnetic waves**

The Microwaves are basically Electromagnetic waves, having higher frequency, so for the Microwave propagation, students should have a clear understanding of how an Electromagnetic wave propagates, also the basic concepts of Electromagnetic waves will be discussed in the "Electromagnetic Waves" subjects, running in the same Semester, so the student should clear his concepts regarding Electromagnetic waves to have a better understanding of Microwave propagation

ii. **Basics of Network theory**

The student should have a clear understanding of different parameters of Network including Z, Y and ABCD parameters as studied in the previous year in the "Network Theory" subject because Microwave network analysis will again include the above parameters along with a new parameter called "Scattering Parameters" including inter relation between all the parameters

iii. **Working of Low frequency electronic devices and components**

The student should have clear concepts related to working of different components including Diodes, Transistors along with working of Filters, Amplifiers, Oscillators and Mixers as studied in the previous year because all the above were related to a low frequency signal, now for high frequency Microwaves, some modifications in the previous designs would be done so the basic working of the devices and components should be clear before studying the Microwave Semiconductor devices, Microwave Amplifier, Mixers and Oscillators

5. List of Text and Reference Books

i. D.M Pozar, Microwave Engineering, John Wiley & sons 2012.
ii. K.C .Gupta, et. al., CAD of Microwave Circuits, ArtechHouse,1981.
iii. R.E Collin, Foundation of Microwave Engineering, McGraw Hill, 2001
iv. S. Y. Liao, Microwave circuit Analysis and Amplifier Design,Prentice Hall,1987.

Reference Books on Antenna

i. J. D. Kraus, Ronald J. Marhefka, Ahmad Khan, Antenna & Wave Propagation, 4th edition Tata McGraw Hill,2017.
ii. Constantine A. Balanis, Antenna Theory: Analysis & Design, Wiley 4th edition 2016

6. Timetable

Swami Kwshvanand Institute of Technology,Management & Gramothan, Jaipur

Department of Electronics & Communication Engineering

Session 2021-22

Harshal Nigam

	1 08:00 - 09:00	2 09:00 - 10:00	3 10:00 - 11:00	4 11:00 - 11:30	5 11:30 - 12:30	6 12:30 - 01:30	7 01:30 - 02:30	8 02:30 - 03:30
Mo		MTT HN				EW HN		
Tu	MW Lab 5EC C							
We								
Th		MTT HN			EW HN			
Fr			MTT HN		MW Lab 5EC C			
Sa	EW HN							

Faculty:
HN - Harshal Nigam

Subjects:
EW - Electro Magnetic Wave
MTT - Microwave Theory Techniques
MW Lab - Microwave Lab

HoD, ECE

7. Syllabus Deployment: Course Plan & Coverage

Course Plan

Microwave Theory and Techniques

Subject Code- 5EC4-05

(Total lectures :43)

Unit No.	Name	No. of Lectures Required
1	Introduction: Objective, scope and outcome of the course.	1
2	Introduction to Microwaves	2
3	Mathematical Model of Microwave Transmission	3
4	Analysis of RF and Microwave Transmission	5
5	Microwave Network Analysis	4
6	Passive and Active Microwave Devices	10
7	Microwave Design Principles	8
8	Microwave Measurements	6
9	Microwave Systems	4
	Total lectures	**43**

Unit No.	Lecture No.	Contents
1	L1	Introduction: Objective, scope and outcome of the course.
2	L2	Introduction to Microwaves: What are Microwaves, History of Microwaves
	L3	Microwave Frequency bands, Applications of Microwaves: Civil and Military, Medical, EMI/ EMC
3	L4	Mathematical Model of Microwave Transmission- Review of Maxwell Equations
	L5	Concept of Modes, Features of TEM, TE and TM Modes
	L6	Losses associated with microwave transmission, Concept of Impedance in Microwave transmission.
4	L7	Microwave Transmission lines: Analysis of Coaxial transmission lines
	L8	Waveguides, Rectangular waveguide: Solution of wave equations in rectangular waveguide and different cases for wave propagation
	L9	Modes in Rectangular waveguide, Numerical on Waveguide
	L10	Circular waveguide: Solution of Wave equations, modes in circular waveguide and numerical on the same
	L11	Strip line and Microstrip line: Structure, Modes, field patterns, Characteristic impedance, design formulas, applications
5	L12	Microwave Network Analysis: Equivalent voltages and currents for non-TEM lines
	L13	Network parameters: Analysis of Impedance, Admittance ABCD parameters and Scattering parameters (S- parameters) along with their interconnections

	L14	S-parameter for two port and multi-port networks, Properties of Scattering parameters
	L15	Lossless Networks, Reciprocal networks and Matched network, Conditions for different networks
6	**L16**	Microwave passive components: Directional Coupler and Power Dividers
	L17	Study of E and H plane Tee, Parallel Coupled Microstripline and Stripline (Beyond Syllabus 1)
	L18	Magic Tee, Attenuators and Resonators
	L19	Microwave active components: Microwave Diodes and Transistors
	L20	Microwave oscillators and Mixers
	L21	Microwave Semiconductor Devices: Gunn diodes, PIN diode
	L22	Schottky Barrier diode, IMPATT diode
	L23	Microwave tubes: Two cavity Klystron: Concept of velocity modulation, electron bunching, working and efficiency,
	L24	Reflex Klystron: Working, Modes, Numerical on two cavity and reflex klystron
	L25	Travelling Wave Tubes, Magnetron, Numericals on the same
7	**L26**	Microwave design principles: Impedance transformation and matching
	L27	Smith chart solutions, Single stub Tuning in microwave circuits

	L28	Microwave filter designing and numerical on the same
	L29	Microwave amplifier design, Power amplifier design, LNA design and Numerical
	L30	Microwave mixer and Oscillator design, numerical examples
	L31	Antennas and Antenna parameters, numerical examples
	L32	Planar Antennas
	L33	Antenna for ground-based systems, Airborne and satellite borne systems
8	**L34**	Study of Microwave test bench and its components (Beyond Syllabus 2)
	L35	Microwave Measurements: Frequency and Impedance Measurement at Microwave Frequency
	L36	Network Analyzer and Measurement of Scattering Parameters
	L37	Spectrum Analyzer and measurement of Spectrum of microwave signal
	L38	Noise at Microwave frequency, Measurement of Noise Figure
	L39	Measurement of Microwave Antenna Parameters
9	**L40**	Microwave Systems: Radar, Terrestrial and Satellite Communication, Radio Aidsto Navigation, RFID, GPS
	L41	Modern trends in Microwave Engineering: Effect of Microwaves on human body
	L42	Monolithic Microwave integrated circuits
	L43	RFMEMS for microwave components, Microwave Imaging

Coverage

Subject – Microwave Theory & Techniques Branch -ECE Semester- Vth SEM C

Lecture no.	Date	Coverage
1.	21/9/2021	Students in Lecture Series of Department RTECE
2	22/9/2021	Students in Lecture Series of Department RTECE
3	24/9/2021	Introduction: Objective, scope and outcome of the course.
4	28/9/2021	Introduction to Microwaves: What are Microwaves, History of Microwaves
5	29/9/2021	Microwave Frequency bands, Applications of Microwaves:
6	1/10/21	Civil and Military, Medical, Applications, EMI/ EMC
7	5/10/21	Propagation of Electromagnetic waves
8	6/10/21	Review of Maxwell equations
9	8/10/21	Mathematical Model of Microwave Transmission
10	12/10/21	Concept of Modes, Features of TEM, TE and TM Modes
11	13/10/21	Losses associated with microwave transmission, Concept of Impedance in Microwave transmission.
12	19/10/21	Microwave Transmission lines: Analysis of Coaxial transmission lines
13	20/10/21	Waveguides, Rectangular waveguide, Cases of Propagation
14	22/10/21	Solution of Wave equation TE and TM modes

15	26/10/21	Circular waveguide, Planar Transmission Lines
16	12/11/21	Microwave Network Analysis:
17	15/11/21	Network parameters: Analysis of Impedance, Admittance ABCD parameters and Scattering parameters (S- parameters)
18	18/11/21	S-parameter for two port and multi-port networks, Properties of Scattering parameters
19	19/11/21	Microwave passive components: Directional Coupler and Power Dividers
20	22/11/21	Study of E and H plane Tee, Parallel Coupled Microstripline and Stripline (Beyond Syllabus 1)
21	25/11/21	Magic Tee, Attenuators and Resonators
22	26/11/21	Microwave active components: Microwave Diodes and Transistors
23	29/11/21	Microwave oscillators and Mixers
24	2/12/21	Microwave Semiconductor Devices: Gunn diodes, PIN diode
25	3/12/21	Schottky Barrier diode, IMPATT diode
26	6/12/21	Study of Microwave test bench and its components
27	9/12/21	Microwave Measurements: Frequency and Impedance Measurement at Microwave Frequency
28	10/12/21	Network Analyzer and Measurement of Scattering Parameters
29	13/12/21	Spectrum Analyzer and measurement of Spectrum of microwave signal
30	16/12/21	Noise at Microwave frequency, Measurement of Noise Figure
31	17/12/21	Measurement of Microwave Antenna Parameters

32	24/12/21	Microwave amplifier design, Power amplifier design, LNA design and Numerical
33	27/12/21	RADAR, Satellite, Microwave effects
34	28/12/21	MMIC, RF MEMS

8. PO/PSO-Indicator-Competency

The following table gives a suggestive list of competencies and associated performance indicators for each of the PO in Electronics and Communication Engineering Program.

PO 1: Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization for the solution of complex engineering problems.	
Competency	**Indicators**
1.1 Demonstrate competence in mathematical modelling	1.1.1 Apply mathematical techniques such as calculus, linear algebra, and statistics to solve problems
	1.1.2 Apply advanced mathematical techniques to model and solve electronics and communication engineering problems
1.2 Demonstrate competence in basic sciences	1.2.1 Apply laws of natural science to an engineering problem
1.3 Demonstrate competence in engineering fundamentals	1.3.1 Apply fundamental engineering concepts to solve engineering problems
1.4 Demonstrate competence in specialized engineering knowledge to the program	1.4.1 Apply electronics and communication engineering concepts to solve engineering problems.
PO 2: Problem analysis: Identify, formulate, research literature, and analyses complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.	
Competency	**Indicators**
2.1 Demonstrate an ability to identify and formulate complex engineering problem	2.1.1 Articulate problem statements and identify objectives
	2.1.2 Identify engineering systems, variables, and parameters to solve the problems

	2.1.3 Identify the mathematical, engineering and other relevant knowledge that applies to a given problem
2.2 Demonstrate an ability to formulate a solution plan and methodology for an engineering problem	2.2.1 Reframe complex problems into interconnected sub-problems
	2.2.2 Identify, assemble and evaluate information and resources
	2.2.3 Identify existing processes/solution methods for solving the problem, including forming justified approximations and assumptions
	2.2.4 Compare and contrast alternative solution processes to select the best process
2.3 Demonstrate an ability to formulate and interpret a model	2.3.1 Combine scientific principles and engineering concepts to formulate model/s (mathematical or otherwise) of a system or process that is appropriate in terms of applicability and required accuracy.
	2.3.2 Identify assumptions (mathematical and physical) necessary to allow modeling of a system at the level of accuracy required.
2.4 Demonstrate an ability to execute a solution process and analyze results	2.4.1 Apply engineering mathematics and computations to solve mathematical models
	2.4.2 Produce and validate results through skillful use of contemporary engineering tools and models
	2.4.3 Identify sources of error in the solution process, and limitations of the solution.
	2.4.4 Extract desired understanding and conclusions consistent with objectives and limitations of the analysis

PO 3: Design/Development of Solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for public health and safety, and cultural, societal, and environmental considerations.

Competency	Indicators
3.1 Demonstrate an ability to define a complex / open-ended problem in engineering terms	3.1.1 Recognize that need analysis is key to good problem definition
	3.1.2 Elicit and document, engineering requirements from stakeholders

	3.1.3 Synthesize engineering requirements from a review of the state-of-the-art
	3.1.4 Extract engineering requirements from relevant engineering codes and standards.
	3.1.5 Explore and synthesize engineering requirements considering health, safety risks, environmental, cultural and societal issues
	3.1.6 Determine design objectives, functional requirements and arrive at specifications
3.2 Demonstrate an ability to generate a diverse set of alternative design solutions	3.2.1 Apply formal idea generation tools to develop multiple engineering design solutions
	3.2.2 Build models/prototypes to develop diverse set of design solutions
	3.2.3 Identify suitable criteria for evaluation of alternate design solutions
3.3 Demonstrate an ability to select optimal design scheme for further development	3.3.1 Apply formal decision making tools to select optimal engineering design solutions for further development
	3.3.2 Consult with domain experts and stakeholders to select candidate engineering design solution for further development
3.4 Demonstrate an ability to advance an engineering design to defined end state	3.4.1 Refine a conceptual design into a detailed design within the existing constraints (of the resources)
	3.4.2 Generate information through appropriate tests to improve or revise design
PO 4: Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.	
Competency	**Indicators**
4.1 Demonstrate an ability to conduct investigations of technical issues consistent with their level of knowledge and understanding	4.1.1 Define a problem, its scope and importance for purposes of investigation.
	4.1.2 Examine the relevant methods, tools and techniques of experiment design, system calibration, data acquisition, analysis and presentation
	4.1.3 Apply appropriate instrumentation and/or software tools to make measurements of physical quantities

	4.1.4 Establish a relationship between measured data and underlying physical principles.
4.2 Demonstrate an ability to design experiments to solve open ended problems	4.2.1 Design and develop experimental approach, specify appropriate equipment and procedures.
	4.2.2 Understand the importance of statistical design of experiments and choose an appropriate experimental design plan based on the study objectives
4.3 Demonstrate an ability to analyze data and reach a valid conclusion	4.3.1 Use appropriate procedures, tools and techniques to conduct experiments and collect data
	4.3.2 Analyze data for trends and correlations, stating possible errors and limitations.
	4.3.3 Represent data (in tabular and/or graphical forms) so as to facilitate analysis and explanation of the data, and drawing of conclusions.
	4.3.4 Synthesize information and knowledge about the problem from the raw data to reach appropriate conclusions

PO 5: Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations.

Competency	**Indicators**
5.1 Demonstrate an ability to identify / create modern engineering tools, techniques and resources	5.1.1 Identify modern engineering tools such as computer aided drafting, modeling and analysis; techniques and resources for engineering activities
	5.1.2 Create/adapt/modify/extend tools and techniques to solve engineering problems
5.2 Demonstrate an ability to select and apply discipline specific tools, techniques and resources	5.2.1 Identify the strengths and limitations of tools for (i) acquiring information, (ii) modeling and simulating, (iii) monitoring system performance, and (iv) creating engineering designs.
	5.2.2 Demonstrate proficiency in using discipline specific tools
5.3 Demonstrate an ability to evaluate the suitability and limitations of tools used to solve an engineering problem	5.3.1 Discuss limitations and validate tools, techniques and resources
	5.3.2 Verify the credibility of results from tool use with reference to the accuracy and limitations, and the assumptions inherent in their use.

PO 6: The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal, and cultural issues and the consequent responsibilities relevant to the professional engineering practice.	
Competency	**Indicators**
6.1 Demonstrate an ability to describe engineering roles in a broader context, e.g. pertaining to the environment, health, safety, legal and public welfare	6.1.1 Identify and describe various engineering roles; particularly as pertains to protection of the public and public interest at global, regional and local level
6.2 Demonstrate an understanding of professional engineering regulations, legislation and standards	6.2.1 Interpret legislation, regulations, codes, and standards relevant to your discipline and explain its contribution to the protection of the public
PO 7: Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.	
Competency	**Indicators**
7.1 Demonstrate an understanding of the impact of engineering and industrial practices on social, environmental and in economic contexts	7.1.1 Identify risks/impacts in the life-cycle of an engineering product or activity
	7.1.2 Understand the relationship between the technical, socio economic and environmental dimensions of sustainability
7.2 Demonstrate an ability to apply principles of sustainable design and development	7.2.1 Describe management techniques for sustainable development
	7.2.2 Apply principles of preventive engineering and sustainable development to an engineering activity or product relevant to the discipline
PO 8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.	
Competency	**Indicators**
8.1 Demonstrate an ability to recognize ethical dilemmas	8.1.1 Identify situations of unethical professional conduct and propose ethical alternatives
8.2 Demonstrate an ability to apply the Code of Ethics	8.2.1 Examine and apply moral & ethical principles to known case studies
PO 9: Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.	
Competency	**Indicators**
9.1 Demonstrate an ability to form a team and define a role for each member	9.1.1 Recognize a variety of working and learning preferences; appreciate the value of diversity on a team

	9.1.2 Implement the norms of practice (e.g. rules, roles, charters, agendas, etc.) of effective team work, to accomplish a goal.
9.2Demonstrate effective individual and team operations-communication, problem solving, conflict resolution and leadership skills	9.2.1 Demonstrate effective communication, problem solving, conflict resolution and leadership skills
	9.2.2. Treat other team members respectfully
	9.2.3 Listen to other members. Maintain composure in difficult situations
9.3Demonstrate success in a team based project	9.3.1 Present results as a team, with smooth integration of contributions from all individual efforts

PO 10: Communication: Communicate effectively on complex engineering activities with the engineering community and with the society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

Competency	Indicators
10.1 Demonstrate an ability to comprehend technical literature and document project work	10.1.1Read, understand and interpret technical and non-technical information
	10.1.2 Produce clear, well-constructed, and well-supported written engineering documents
	10.1.3 Create flow in a document or presentation - a logical progression of ideas so that the main point is clear
10.2 Demonstrate competence in listening, speaking, and presentation	10.2.1 Listen to and comprehend information, instructions, and viewpoints of others
	10.2.2 Deliver effective oral presentations to technical and non-technical audiences
10.3 Demonstrate the ability to integrate different modes of communication	10.3.1 Create engineering-standard figures, reports and drawings to complement writing and presentations
	10.3.2 Use a variety of media effectively to convey a message in a document or a presentation

PO 11: Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

Competency	Indicators
11.1 Demonstrate an ability to evaluate the economic and financial	11.1.1 Describe various economic and financial costs/benefits of an engineering activity

performance of an engineering activity	11.1.2 Analyze different forms of financial statements to evaluate the financial status of an engineering project
11.2 Demonstrate an ability to compare and contrast the costs/benefits of alternate proposals for an engineering activity	11.2.1 Analyze and select the most appropriate proposal based on economic and financial considerations.
11.3 Demonstrate an ability to plan/manage an engineering activity within time and budget constraints	11.3.1 Identify the tasks required to complete an engineering activity, and the resources required to complete the tasks.
	11.3.2 Use project management tools to schedule an engineering project so it is completed on time and on budget.
PO 12: Life-long learning: Recognize the need for, and have the to engage preparation and ability in independent and life-long learning in the broadest context of technological change.	
Competency	**Indicators**
12.1 Demonstrate an ability to identify gaps in knowledge and a strategy to close these gaps	12.1.1 Describe the rationale for requirement for continuing professional development
	12.1.2 Identify deficiencies or gaps in knowledge and demonstrate an ability to source information to close this gap
12.2 Demonstrate an ability to identify changing trends in engineering knowledge and practice	12.2.1Identify historic points of technological advance in engineering that required practitioners to seek education in order to stay current.
	12.2.2 Recognize the need and be able to clearly explain why it is vitally important to keep current regarding new developments in your field
12.3 Demonstrate an ability to identify and access sources for new information	12.3.1 Source and comprehend technical literature and other credible sources of information
	12.3.2 Analyze sourced technical and popular information for feasibility, viability, sustainability, etc.
PSO 1: Understand principles and applications of electronic components,circuits and devices.	
Competency	**Indicators**
1.1 Demonstrate an ability to explain the principles of electronics	1.1.1 Illustrate information and knowledge of in depth concepts of circuit and systems.

and communication.	1.1.2 Define a problem, its scope and importance for purposes of investigation.
	1.1.3 Assemble information and knowledge about the problems from the raw data to reach appropriate conclusions.
	1.1.4 Identify and produce solution methods for solving the problems related to electronics and communications.
1.2 Demonstrate an ability to apply the concepts of circuit/system designing to solve engineering problems.	1.2.1 Apply the principles of circuits and analyze the performance of systems or devices.
	1.2.2 Understand appropriate circuits and it's designing procedure.
	1.2.3 Use of mathematical principles and graphical solutions to solve Electronics and Communication Engineering Problems. .

PSO 2: Develop proficiency in Electronics and Communication Engineering to enhance employability skills.

Competency	Indicators
2.1 Demonstrate an ability to work effectively as a leader in a team.	2.1.1 Demonstrate leadership skills and problem solving capabilities in the field of Electronics & Communication Engineering.
	2.1.2 Present results as a team, with smooth integration of contributions from all individual efforts.
2.2. Demonstrate an ability to Excel in ECE Profession.	2.2.1 Identify requirement of higher education to become competent in recent and future advancements.
	2.2.2 Develop proficiency in latest tools,software and circuit designing to excel in practicing ECE Profession.

Bloom's Taxonomy (Revised)

Level	Descriptor	Level of Attainment	Keywords
1	Remembering	Recalling from memory	List, define, tell, describe, recite, recall, identify, show, label, tabulate, quote, name, who, when, where, etc.
2	Understanding	Explaining ideas or concepts	Describe, explain, paraphrase, restate, associate, contrast, summarize, differentiate interpret, discuss
3	Applying	Using information in another familiar situation	Calculate, predict, apply, solve, illustrate, use, demonstrate, determine, model, experiment, show, examine, modify
4	Analysing	Breaking information into part to explore understandings and relationships	Classify, outline, break down, categorize, analyze
5	Evaluating	Justifying a decision or course of action	Assess, decide, choose, rank, grade, test, measure, defend, recommend, convince, select, judge, support, conclude, argue, justify, compare
6	Creating	Generating new ideas, products or views to do things	Design, formulate, build, invent, create, compose, generate, derive, modify, develop, integrate

** It may be noted that some of the verbs in the above table are associated with multiple Bloom's Taxonomy level. These verbs are actions that could apply to different activities. We need to keep in mind that it's the skill, action or activity we need out students to demonstrate that will determine the contextual meaning of the verb used in the assessment question.

9. Course Outcomes Competency Level

Course Code	Course Name	Course Outcomes	Unit Map ping	Bloom's Level	PO Indicators	PSO Indicators
5EC4-05	Microwave Theory and Techniques	**Identify** different active and passive microwave components	5,6	2	1.2.1,1.3.1,1.4.1,2.1.1,2.1.2,2.1.3,2.2.1,2.4.1, 3.1.1,3.1.6, 10.1.1, 12.1.1,12.1.2,12.2.1,12.2.2,12.3.1,12.3.2	1.1.1, 1.1.4, 2.2.1
		Understand the basic microwave parameters and analyse different Microwave transmission lines	2,3,4	2	1.1.1,1.2.1, 1.3.1,1.4.1, 2.1.1,2.1.2,2.1.3,2.2.1,2.2.3,2.3.1,2.4.1, 2.4.2,2.4.4 ,3.1.1,3.1.4,3.1.6 10.1.1,12.1.1,12.1.2,12.2.1,12.2.2,12.3.1,12.3.2	1.1.1, 1.1.2, 1.1.4, 2.2.1
		Determine the different Microwave parameters by using different measurements and testing techniques	8	3	1.1.1, 1.1.2,1.2.1, 1.3.1,1.4.1, 2.1.1,2.1.2,2.1.3,2.2.1,2.2.3, 2.4.1, 2.4.2,2.4.3, 2.4.4,3.1.1,3.1.6,3.4.2, 4.1.1,4.1.2,4.1.3, 10.1.1,	1.1.1, 1.1.2, 1.1.4, 1.2.1, 1.2.3,2.2.1

					12.1.1,12.1.2,12.2.1,12.2.2,12.3.1,12.3.2	
		Analyse the characteristics of different microwave devices for different practical applications	6,7	4	1.1.1,1.1.2,1.2.1, 1.3.1,1.4.1, 2.1.1,2.1.2,2.1.3,2.2.1,2.2.3,2.2.4,2.3.1, 2.4.1, 2.4.2,2.4.3, 2.4.4,3.1.1,3.1.6, 3.3.1,3.4.1, 3.4.2 4.1.1,10.1.1,12.1.1,12.1.2,12.2.1,12.2.2,12.3.1, 12.3.2	1.1.1, 1.1.2, 1.1.4, 1.2.1, 1.2.3,2.2.1
		Compare the structural parameters, characteristics, operation, gain, output power and efficiency of various microwave sources used for different applications	6,7	4	1.1.1,1.1.2,1.2.1,1.3.1,1.4.1,2.1.1,2.1.2,2.1.3, 2.2.1,2.2.3,2.2.4,2.3.1, 2.4.1, 2.4.2,2.4.3, 2.4.4,3.1.1,3.1.6, 3.3.1,3.4.1,3.4.2,4.1.1,10.1.1, 12.1.1,12.1.2,12.2.1,12.2.2,12.3.1,12.3.2	1.1.1, 1.1.2, 1.1.4, 1.2.1, 1.2.3,2.2.1

10. CO-PO-PSO Mapping Using Performance Indicators (PIs)

	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10	PO 11	PO 12	PSO 1	PSO 2
CO1	2	2	1	-	-	-	-	-	-	1	-	3	2	1
CO2	3	3	1	1	-	-	-	-	-	1	-	3	3	1
CO3	3	3	1	2	-	-	-	-	-	1	-	3	3	1
CO4	3	3	2	1	-	-	-	-	-	1	-	3	3	1
CO5	3	3	2	1	-	-	-	-	-	1	-	3	3	1
	3	3	2	1	-	-	-	-	-	1		3	3	1

11. CO-PO-PSO Mapping: Formulation and Justification

The CO-PO/PSO mapping is based on the correlation of course outcome (CO) with Program Outcome Indicators. These indicators are the breakup statements of broad Program Outcome statement.

The correlation is calculated as number of correlated indicators of a PO/PSO mapped with CO divided by total indicators of a PO/PSO. The calculated value represents the correlation level between a CO & PO/PSO. Detailed formulation and mathematical representation can be seen below in equation 1:

Input: ***CO_i:*** *The i^{th} course outcome of the course*

PO_j*: The j^{th} Program Outcome*

Ij_k: *The k^{th} indicator of the j^{th} Program Outcome*

α (I_{jk}, CO_i): *level of CO-PO mapping*

= 1, *if*, $0<\alpha<0.33$

2, *if*, $0.33\geq\alpha<0.66$

3, *if*, $0.66\geq\alpha<1$

λ: *Degree of correlation*

$$\alpha\left(I_{jk}, CO_i\right) = \frac{count(\ \lambda(I_{jk},CO_i))}{count\ (I_k,PO_j)}$$

12. Attainment Level (Internal Assessment)

Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur
B.Tech III Year V Semester (Session 2021-2022)

CO's Attainment (Theory Mid Term : I)	Department: ECE
Faculty Name: Harshal Nigam	Course Name with CODE: Microwave Theory and Thechniques 5EC4-05

Upon successful completion of this course, students will be able to:

CO1: Identify different active and passive microwave components

CO2: Compare the structural parameters, characteristics, operation, gain, output power and efficiency of various microwave devices

CO3: Calculate Microwave parameters by using different measurements and testing techniques

CO4: Analyse different Microwave transmission lines

CO5: Analyse the characteristics of different microwave devices for different practical applications

MID TERM EVALUATION Set-A								Section-C				
		Note→	Attempt All					Total (50)	Total (24)	Assignment (6)	Total (30)
		QUESTION NO. →	Q1	Q2	Q3	Q4	Q5				
		COURSE OUTCOME(S) SATISFIED →	CO2	CO2	CO2	CO2	CO2				
		MAXIMUM MARKS →	10	10	10	10	10				
		MINIMUM QUALIFYING MARKS (50%) →	5	5	5	5	5				
		NAME OF STUDENT ↓									
1	19ESKEC112	Rashi Sharma	8.5	6.5	7.5	9.5	7.5	39.5	19	5	24
2	19ESKEC113	Ritrik Rohra	8.5	0	6	9.5	7	31	15	6	21
3	19ESKEC115	Roshan Kumar Jha	8.5	7.5	8.5	10	8	42.5	21	5	26
4	19ESKEC116	Rudra Pratap Singh	8	6.5	2	9.5	0	26	13	NS	13
5	19ESKEC117	Saloni Chhaparwal	8.5	7.5	4	10	8	38	19	6	25
6	19ESKEC118	Samriti Devi	9	8.5	6	9.5	9	42	21	6	27
7	19ESKEC119	Sanjana Jawaria	7.5	9	9	9	9	43.5	21	6	27
8	19ESKEC120	Sanjay Kumar	8	8.5	8	9.5	8	42	21	6	27
9	19ESKEC121	Sarim Ur Rehman	8	8	4	9.5	7	36.5	18	6	24
10	19ESKEC122	Sarthak Bhatia	7	8.5	5	9	8.5	38	19	6	25
11	19ESKEC123	Sarthak Sharma	7.5	8.5	4	10	7.5	37.5	18	5	23
12	19ESKEC124	Saurabh Choudhary	8.5	7	2	9.5	8.5	35.5	17	NS	17
Total No. of DEBARRED (DB)			NIL	NIL	NIL	NIL	NIL				
Total No. of ABSENT (AB)			NIL	NIL	NIL	NIL	NIL				
Total Students Appreaed for Exam (A)			12	12	12	12	12				
Total Students Attempted the Question (A)			12	12	12	12	12				
No. of Students scored >=50% marks (B)			12	11	7	12	11				
Percentage Attainment of Criterion (B/A)			100.00	91.67	58.33	100.00	91.67				
CO Attainment Level			3	3	1	3	3				
Attainment of CO-2			88.33	3							

MID TERM EVALUATION Set-B								Section-C			
		Note→	Attempt All					Total (50)	Total (24)	Assignment (6)	Total (30)
		QUESTION NO. →	Q1	Q2	Q3	Q4	Q5				
		COURSE OUTCOME(S) SATISFIED →	CO2	CO2	CO2	CO2	CO2				
		MAXIMUM MARKS →	10	10	10	10	10				

		MINIMUM QUALIFYING MARKS (50%) →	5	5	5	5	5				
		NAME OF STUDENT ↓									
1	19ESKEC125	Saurabh Singh Jat	8	8	7.5	10	8.5	42	21	5	26
2	19ESKEC126	Sharad Sourabh Jha	8	8	8	10	8	42	21	6	27
3	19ESKEC127	Shiv Pratap Singh Chouhan	8.5	6.5	6.5	10	8	39.5	19	6	25
4	19ESKEC128	Shivam Garg	8	8.5	6.5	10	8	41	20	6	26
5	19ESKEC129	Shivansh Dosi	AB	AB	AB	AB	AB	AB	AB	5	5
6	19ESKEC130	Shubham Jain	8.5	8	7	10	8.5	42	21	6	27
7	19ESKEC131	Siddharth Harshit	7.5	8	8	10	8.5	42	21	6	27
8	19ESKEC132	Siddhi Saxena	8.5	8	8.5	10	5	40	20	6	26
9	19ESKEC133	Simran Rathore	8	8	8.5	10	8.5	43	21	6	27
10	19ESKEC134	Somil Jain	8	8	7	10	8.5	41.5	20	6	26
11	19ESKEC135	Sonali Nishad	7.5	8	8	10	7	40.5	20	5	25
12	19ESKEC136	Soumya Agarwal	8	8	8.5	10	8.5	43	21	6	27
Total No. of DEBARRED (DB)			NIL	NIL	NIL	NIL	NIL				
Total No. of ABSENT (AB)			1	1	1	1	1				
Total Students Appreaed for Exam (A)			12	12	12	12	12				
Total Students Attempted the Question (A)			11	11	11	11	11				
No. of Students scored >=50% marks (B)			11	11	11	11	11				
Percentage Attainment of Criterion (B/A)			100.00	100.00	100.00	100.00	100.00				
CO Attainment Level			3	3	3	3	3				
Attainment of CO-2			100%	3							

MID TERM EVALUATION Set-C								Section-C			
		Note→	Attempt All								
		QUESTION NO. →	Q1	Q2	Q3	Q4	Q5				
		COURSE OUTCOME(S) SATISFIED →	CO2	CO2	CO2	CO2	CO2				
		MAXIMUM MARKS →	10	10	10	10	10	Total (50)	Total (24)	Assignment (6)	Total (30)
		MINIMUM QUALIFYING MARKS (50%) →	5	5	5	5	5				
		NAME OF STUDENT ↓									
1	19ESKEC137	Sourabh Vyas	8	7.5	6.5	10	0	32	16	5	21
2	19ESKEC138	Suhani Jain	7	7	6.5	10	8.5	39	19	5	24
3	19ESKEC139	Sumit Gupta	8	7.5	7	10	7	39.5	19	6	25
4	19ESKEC140	Tanisha Jain	8	8.5	7	10	7	40.5	20	6	26
5	19ESKEC141	Tanu Gambhir	8.5	8	8.5	10	8.5	43.5	21	6	27
6	19ESKEC143	Tanvi Nemnani	8	8.5	7.5	10	8.5	42.5	21	6	27
7	19ESKEC145	Tushar Mittal	8	7.5	6.5	10	8	40	20	NS	20
8	19ESKEC146	Udiesha Gautam	8	8.5	7	10	8	41.5	20	6	26
9	19ESKEC147	Utsav Jain	8	7.5	7	10	7	39.5	19	5	24
10	19ESKEC148	V Vighnesh Rajan	8	8.5	6.5	9	8	40	20	NS	20
11	19ESKEC149	Vansh Agrawal	8	6.5	4	10	8	36.5	18	5	23
12	19ESKEC150	Vidhi Sukhnani	8	6.5	7	10	8	39.5	19	6	25
Total No. of DEBARRED (DB)			NIL	NIL	NIL	NIL	NIL				
Total No. of ABSENT (AB)			NIL	NIL	NIL	NIL	NIL				
Total Students Appreaed for Exam (A)			12	12	12	12	12				
Total Students Attempted the Question (A)			12	12	12	12	12				
No. of Students scored >=50% marks (B)			12	12	11	12	11				
Percentage Attainment of Criterion (B/A)			100.00	100.00	91.67	100.00	91.67				
CO Attainment Level			3	3	3	3	3				
Attainment of CO-2			96.67	3							

MID TERM EVALUATION Set-D								Section-C			
		Note→	Attempt All								
		QUESTION NO. →	Q1	Q2	Q3	Q4	Q5				
		COURSE OUTCOME(S) SATISFIED →	CO2	CO2	CO2	CO2	CO2				
		MAXIMUM MARKS →	10	10	10	10	10	Total (50)	Total (24)	Assignment (6)	Total (30)
		MINIMUM QUALIFYING MARKS (50%) →	5	5	5	5	5				
		NAME OF STUDENT ↓									
1	19ESKEC151	Vikas Mittal	8.5	6.5	7	10	8	40	20	5	25

2	19ESKEC152	Vinayak Gupta	8.5	8.5	8.5	10	8	43.5	21	5	26
3	19ESKEC153	Vishal Dandia	8	8	8	10	8.5	42.5	21	6	27
4	19ESKEC155	Yaman Kumar Malik	8	8.5	9	10	8	43.5	21	6	27
5	19ESKEC156	Yash Dubey	8.5	8	6.5	10	8.5	41.5	20	6	26
6	19ESKEC157	Yash Raj Mishra	8	6.5	8.5	10	6.5	39.5	19	5	24
7	19ESKEC158	Yatharth Jain	8	8	5	10	7	38	19	6	25
8	19ESKEC159	Yayati	8.5	8.5	8.5	10	8	43.5	21	6	27
9	19ESKEC160	Yogesh Sharma	8	8	5	10	8	39	19	6	25
10	19ESKEC300	Manish Manohar Chandwani	8.5	8.5	7.5	10	8	42.5	21	6	27
11	19ESKEC301	Mohit Kumawat	8.5	9	8	10	8	43.5	21	6	27
12	19ESKEC302	Smriti Sharma	8.5	8.5	8.5	10	8	43.5	21	5	26
13	19ESKEC303	Gaurav Kumar	8.5	8.5	7.5	10	7	41.5	20	5	25
14	19ESKEC304	Gaurav Singh Chouhan	8.5	8	2.5	10	8.5	37.5	18	5	23
Total No. of DEBARRED (DB)			NIL	NIL	NIL	NIL	NIL				
Total No. of ABSENT (AB)			NIL	NIL	NIL	NIL	NIL				
Total Students Appreaed for Exam (A)			14	14	14	14	14				
Total Students Attempted the Question (A)			14	14	14	14	14				
No. of Students scored >=50% marks (B)			14	14	13	14	14				
Percentage Attainment of Criterion (B/A)			100	100	92.8571	100	100				
CO Attainment Level			3	3	3	3	3				
Attainment of CO-2			98.57142857	3							
Final Attainment of CO-2			96%	3							
Criterion of Percentage for CO Attainment Le			Attainment Level								
Percentage attainment Below 60%			1								
Percentage attainment 60%-69.99%			2								
Percentage attainment Above and equal to 70%			3								
Harshal Nigam											
Faculty name with signature											

13. Learning Levels of Students through Marks Obtained in Assignment

S.N	Roll No	Name	Assignment-1 marks (6)
1	19ESKEC112	Rashi Sharma	5
2	19ESKEC113	Ritrik Rohra	6
3	19ESKEC115	Roshan Kumar Jha	5
4	19ESKEC116	Rudra Pratap Singh	NS
5	19ESKEC117	Saloni Chhaparwal	6
6	19ESKEC118	Samriti Devi	6
7	19ESKEC119	Sanjana Jawaria	6
8	19ESKEC120	Sanjay Kumar	6
9	19ESKEC121	Sarim Ur Rehman	6
10	19ESKEC122	Sarthak Bhatia	6
11	19ESKEC123	Sarthak Sharma	5
12	19ESKEC124	Saurabh Choudhary	NS
13	19ESKEC125	Saurabh Singh Jat	5
14	19ESKEC126	Sharad Sourabh Jha	6
15	19ESKEC127	Shiv Pratap Singh Chouhan	6
16	19ESKEC128	Shivam Garg	6
17	19ESKEC129	Shivansh Dosi	5
18	19ESKEC130	Shubham Jain	6
19	19ESKEC131	Siddharth Harshit	6
20	19ESKEC132	Siddhi Saxena	6
21	19ESKEC133	Simran Rathore	6
22	19ESKEC134	Somil Jain	6
23	19ESKEC135	Sonali Nishad	5
24	19ESKEC136	Soumya Agarwal	6
25	19ESKEC137	Sourabh Vyas	5
26	19ESKEC138	Suhani Jain	5
27	19ESKEC139	Sumit Gupta	6
28	19ESKEC140	Tanisha Jain	6

29	19ESKEC141	Tanu Gambhir	6
30	19ESKEC143	Tanvi Nemnani	6
31	19ESKEC145	Tushar Mittal	NS
32	19ESKEC146	Udiesha Gautam	6
33	19ESKEC147	Utsav Jain	5
34	19ESKEC148	V Vighnesh Rajan	NS
35	19ESKEC149	Vansh Agrawal	5
36	19ESKEC150	Vidhi Sukhnani	6
37	19ESKEC151	Vikas Mittal	5
38	19ESKEC152	Vinayak Gupta	5
39	19ESKEC153	Vishal Dandia	6
40	19ESKEC155	Yaman Kumar Malik	6
41	19ESKEC156	Yash Dubey	6
42	19ESKEC157	Yash Raj Mishra	5
43	19ESKEC158	Yatharth Jain	6
44	19ESKEC159	Yayati	6
45	19ESKEC160	Yogesh Sharma	6
46	19ESKEC300	Manish Manohar Chandwani	6
47	19ESKEC301	Mohit Kumawat	6
48	19ESKEC302	Smriti Sharma	5
49	19ESKEC303	Gaurav Kumar	5
50	19ESKEC304	Gaurav Singh Chouhan	5

We analysed the assignment of students and saw that 30% students have obtained average marks (5) and 10 % students got below average marks (less than 5) or not submitted assignment. So we have arranged remedial classes of given topic as per analysis

14. Planning for Remedial Classes for Average/Below Average Students

Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur

Department of Electronics and Communication Engineering

NOTICE

Date:11/11/2021

All the students of V & III semester ECE are hereby informed that remedial classes will be organized from 16/11/2021 to 7/12/2021 as per attached time table. Interested students may join.

Mukesh

HOD

ECE Department

Copy to:

1. Dy. HoD
2. Time Table Coordinator
3. Exam Coordinator
4. Notice Board
5. Concerned Faculty

Swami Keshvanand Institute of Technology, Management & Gramothan,
Ramnagaria, Jagatpura, Jaipur-302017, INDIA
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Swami Keshvanand Institute of Technology,

Management & Gramothan, Jaipur

Department of Electronics and Communication Engineering

Time Table

(Remedial Classes)

Session – 2021-22 **Semester: V**

The remedial classes are scheduled from 16/11/21 to 7/12/21 **Venue: 201**

Day	Time	Subject	Name of Faculty
Monday	2:30 PM-3:30 PM	CA	Manju Choudhary
Tuesday	2:30 PM-3:30 PM	EW	Pallav Rawal
Wednesday	2:30 PM-3:30 PM	CS	Rahul Pandey
Thursday	2:30 PM-3:30 PM	DSP	Suman Sharma
Friday	2:30 PM-3:30 PM	MTT	Harshal Nigam
Saturday	2:30 PM-3:30 PM	ES	Pooja Choudhary

HoD
ECE Department

Copy to:

1. Dy. HoD
2. Exam Coordinator
3. Notice Board
4. Concerned Faculty

1. No. of classes required: 2

2. Topics Covered: Attenuators, Measurement by Network Analyzer, Smart Antennas
3. Notes:

Attenuators (Topic 1)

In microwave circuits, the signal power is to be controlled at various points since the microwave devices are sensitive to high microwave powers. Many of the microwave devices will not function properly if the power of input device is not in the specified level. So the input power level of the device is to be controlled.

Microwave attenuators are devices which control the microwave signal power level at the appropriate point in the microwave circuit. Attenuator introduces attenuation of signal to the extent required and power level to the next stage of circuit will be acceptable level.

These attenuators are passive devices employing resistive films.

Attenuators may be classified as

1) Fixed attenuators
2) Variable attenuators

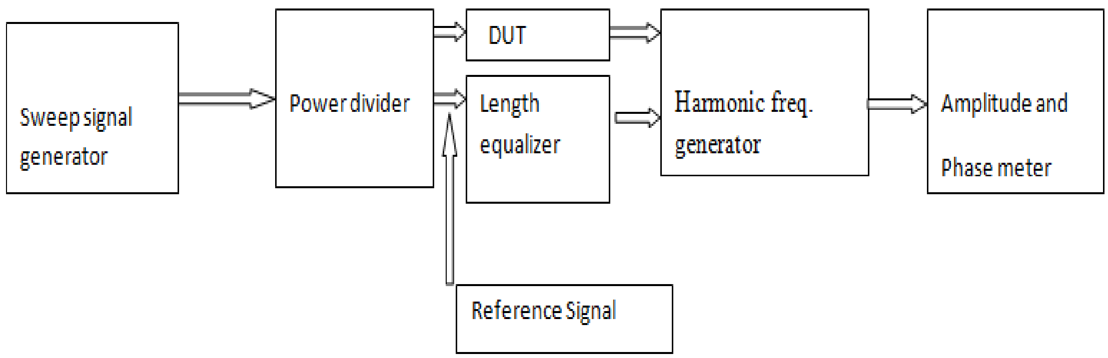
1) **Fixed Attenuators-** In a Coaxial cable a thin film with loss is applied on the inner conductor of the cable, which absorbs microwave power, and thus the loss in the signal power is achieved. The amount of resistive coating and length is determined based on the amount of attenuation required to be introduced as shown.

2) **Variable Attenuators-** In waveguides the dielectric slab coated with aquadag is placed at the Centre of the waveguide parallel to the maximum E-field for dominant TE_{10} Mode. Induced current on the loss material due to incoming microwave signal, results in power dissipation , leading to attenuation of signal.

The attenuation offered by the attenuator depends on the depth of insertion of the vane into waveguide through the slot in the broad wall of the guide. Maximum of 90dB Attenuation can be achieved with such attenuator with VSWR of the range of 1.05.

Measurement by Network Analyzer (Topic 2)

Block Diagram of Network Analyzer

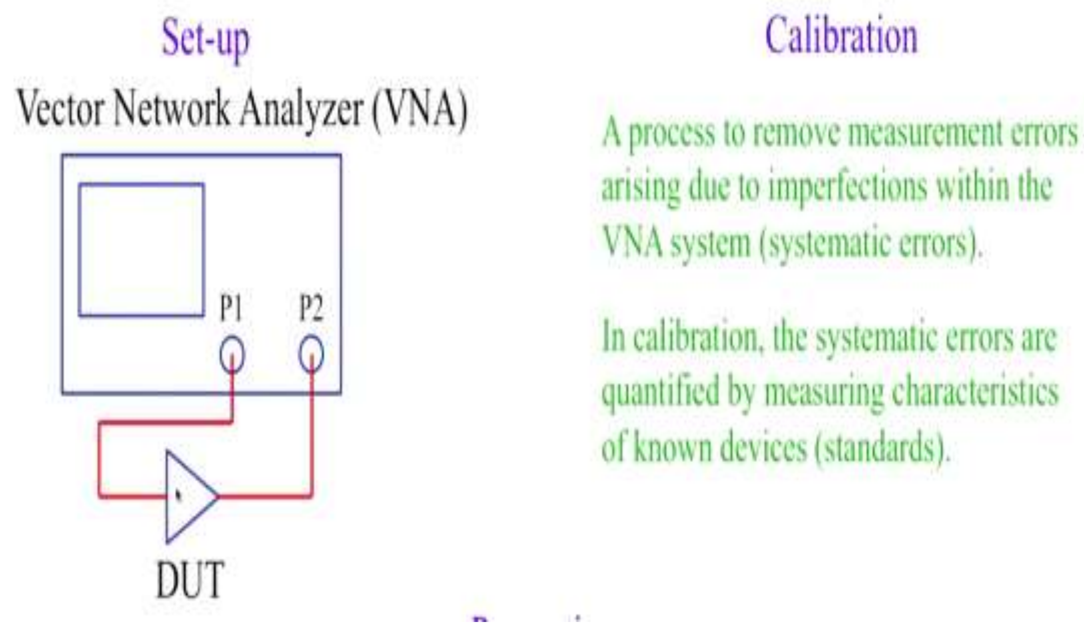


Network Analyzer is used for amplitude and phase measurement over a wide frequency range within a reasonable time. A network analyzer is useful for measurement of both passive as well as active microwave components.

Sweep signal generator is used to generate frequencies of entire range and feeds a power divider or splitter that converts into signals, the test signal and reference signal. The test signal passes through device under test (DUT), while the reference signal passes through a length equalizer .Since processing of microwave frequency is not practical, both the test and reference signals are converted to a fixed intermediate frequency by means of harmonic frequency converter. The outputs of frequency converter are then compared to determine the amplitude and phase of the test signal.

A network analyzer can be scaler or vector type. Scaler network analyzer provides only magnitude characteristics of microwave devices as a function of frequency. Vector network can measure complex reflection or transmission characteristics of microwave devices.

Measurement of Scattering parameter using Network Analyzer



Network analyzer is used for S-parameter measurements primarily. It can be also used to measure the impedance of a network which is input or output impedance is also used to measure the gain compression point which is $P_{1\text{-}dB}$ of a network.

Smart Antennas (Topic 3)

In antenna arrays, the main beam is steered via phase shifters to the directions of interest. These arrays are called phased arrays or scanning arrays. This general approach of phase shifting has been referred to as electronic beam steering and in this process the phase of the current at each antenna element is changed directly. This static synthesis approach to achieve the spatial diversity can not meet the recent requirements of wireless communication as the properties of these arrays remain static with time.

In recent years, it has been observed that the substantial increase in the development of broadband wireless access technologies and improved cellular systems, experiences an enormous rise in traffic for mobile and personal communications systems. The rise in traffic puts a demand on both manufacturers and operators to provide sufficient capacity in the networks. This becomes a major challenging problem for the service providers to solve.

A major limitation in capacity and performance is co-channel interference caused by the increasing number of users and the multipath fading and delay spread. Research efforts investigating effective technologies to mitigate such effects have been going on and among these methods smart antenna employment is the most promising technology.

Smart antennas have alternatively been called digital beam formed (DBF) arrays or adaptive arrays (when adaptive algorithms are employed). The term smart implies the use of signal processing in order to shape the beam pattern according to certain conditions.

Adaptive beam forming is a dynamic process which updates the antenna array's performance with time by collecting feedback (see Fig. 7.1) from the surrounding environment like the signals being propagated, interfering objects (i.e., buildings, trees, cars), outside electromagnetic interference (i.e., competing mobile users, radar jammers), etc. to keep the array in an optimum state. For an array to be smart implies sophistication beyond merely steering the beam to a direction of interest.

Smart essentially means computer control of the antenna performance. Smart antennas hold the promise for improved radar systems, improved system capacities with mobile wireless, and improved wireless communications through the implementation of space division multiple access(SDMA).

Smart antenna patterns are controlled via algorithms based upon certain criteria. These criteria could be maximizing the signal-to-interference ratio(SIR), minimizing the variance, minimizing the mean square error(MSE), steering toward a signal of interest, nulling the interfering signals, or tracking a moving emitter to name a few. The implementation of these algorithms can be performed electronically through digital signal processing.

In short smart antenna system combines:

Antenna array technology with digital signal processing algorithms to make the system smart

Types of smart antenna systems

Basically, there are two major configurations of smart antennas:

·Switched-Beam: A finite number of fixed, predefined patterns

·Adaptive Array: A theoretically infinite number of patterns (scenario-based) that are adjusted in real time according to the spatial changes of SOIs and SNOI.

Switched-Beam Systems:-

A switched-beam system is a system that can choose from one of many predefined patterns in order to enhance the received signal. When an incoming signal is detected, the base station determines the beam that is best aligned in the signal-of-interest direction and then switches to that beam to communicate with the user. The switched-beam, is based on a basic switching function, and select the beam that gives the strongest received signal. The overall goal of the switched-beam system is to increase the gain according to the location of the user.

Adaptive array:-

Adaptive antenna array is an array of multiple antenna elements that continuously adjusts its own pattern with time by collecting feedback from the surrounding environment to keep the array in optimum state. The principal purpose of an adaptive array sensor system is to enhance the detection and reception of certain desired signals. In addition to shape the pattern and steer the beam towards desired direction in space by applying the amplitude and phase weighting of the array elements, the adaptive arrays sense the interference sources from the environment and suppress them automatically by implementing advanced signal processing techniques. The major reason for the progress in adaptive arrays is their ability to automatically respond to an unknown interfering environment by steering nulls and reducing the side lobe level in the direction of interference, while keeping the desired Beam characteristics. Adaptive antenna arrays are commonly equipped with signal processors which can automatically adjust, by a simple adaptive technique, the variable antenna weights of a signal processor so as to maximize the signal to noise ratio.

4. Time table
   Classes are planned in the month of December, 2 classes each of 1 hour duration

5. No. of students present:
   It will be for average and below average students and other students can also join if they want to

15. Teaching-Learning Methodology

1. In each and every class, students are asked about the lesson they have learnt in the previous class and a brief recap is presented to students to link the current topic with the previous one.
2. Questions are regularly being asked from the students to make them attentive in the classroom.
3. Query session is arranged for last minutes in the class.
4. Two assignments of 19 questions each are given to the students after completion of three units.
5. The work of assignments and sessional exam marks shows the satisfaction of CO and PO.
6. Surprise Quiz also helps to notice the grasping power and attention for the subject of the students in the class.
7. Lecture recording facility is available in e-SLATE studios which enhances quality of teaching learning.

16. RTU Papers (Previous Years)

0316172

5E1395

Roll No. ______________________ [Total No. of Pages : 2

5E1395

B.Tech. V- Semester (Main) Examination, Nov. 2019
PCC/PEC Electronics and Comm. Engg.
5EC 4-05 Microwave Theory and Techniques

Time : 3 Hours

Maximum Marks : 120
Min. Passing Marks : 42

Instructions to Candidates:

*Attempt **all ten** questions from **Part A**, **five** questions out of **Seven** from **Part B** and **Four** questions out of **Five** from **Part C**.*

Schematic diagrams must be shown wherever necessary. Any data you feel missing suitably be assumed and stated clearly. Units of quantities used/calculated must be stated clearly.

PART - A

(Answer should be given up to **25** words only)

All questions are **compulsory** **(10×2=20)**

1. Define microwave.
2. Define TE mode for microwave transmission.
3. Draw the microstrip line structure.
4. Write down the S - matrix for a two port network.
5. Define coupling factor of a directional coupler.
6. Draw the energy band diagram of a Gunn diode.
7. Define transducer power gain for microwave amplifier.
8. Why do we require measuring VSWR in a microwave circuit?
9. Write down use of Network Analyzer.
10. What do you understand by monolithic microwave integrated circuits.

PART - B

(Analytical/Problem solving questions)

Attempt any **five** questions **(5×8=40)**

1. Describe the losses associated with microwave transmission.

2. A microstrip line is to be designed and its specification is strip thickness $t \le 0.005h$; substrate board is alumina; relative dielectric constant $\epsilon_r = 10$; ratio of w/h = 0.95; Calculate
   a) effective relative dielectric constant
   b) characteristics impedance Z_0.
3. A shunt impedance Z is connected across a transmission line with characteristics impedance Z_0. Find the S - Matrix of the junction.
4. Prove that it is impossible to construct a perfectly matched, lossless, reciprocal three - port junction.
5. Explain in detail the analytic approach to optimum oscillator design using S - Parameters.
6. Explain the experimental set - up for measurement of radiation pattern and beam width.
7. Draw the block diagram of a basic radar and explain how it works.

PART - C

(Descriptive/Analytical/Problem Solving/Design Questions)

Attempt any **Four** questions **(4×15=60)**

1. The S - parameters of a two - port network are given by

   $S_{11} = 0.2\angle 0,\ S_{22} = 0.1\angle 0$

   $S_{12} = 0.6\angle 90^\circ,\ S_{21} = 0.6\angle 90^\circ$

   a) Prove that the network is reciprocal but not lossless.
   b) Find the return loss at port 1 when port 2 is short circuited.
2. Explain the velocity modulation and bunching process in two - cavity klystron. Also derive the expression for bunching parameters.
3. Design a low - pass, maximally flat lumped - element fitter having a passband of 0-2 GHz, and an attenuation of at least 20dB at 3.4 GHz. The characteristics impedance is $50\,\Omega$.
4. Describe the method of frequency and impedance measurement at microwave frequency.
5. a) Describe the process involved in fabrication of MMICs.
   b) Write down the medical and civil applications with suitable diagram of microwaves.
   c) Write short notes on microwave imaging.

6E 6051

Roll No. 16ESKEC085 [Total No. of Pages : 3

6E 6051

B.Tech. VI Semester (Main & Back) Examination, April - 2019
Electronics & Communication Engineering
6EC1A Microwave Engineering-II

Time : 3 Hours

Maximum Marks : 80
Min. Passing Marks : 26

Instructions to Candidates:

*Attempt any **Five questions**, selecting **One question** from **each unit**. All Questions carry **equal** marks. (Schematic diagrams must be shown wherever necessary. Any data you feel missing suitably be assumed and stated clearly). Units of quantities used/calculated must be stated clearly.*

Unit - I

1. a) State the various design consideration for fabrication of lumped inductors and capacitors in MIC. What are the additional criteria for fabrication of sandwich-type capacitors? **(10)**

b) Determine the capacitance of an interdigitated capacitor fabricated on a substrate $E_r = 13$. other parameters are n=10, substrate height = 0.1 inch, finger length=0.001 inch , finger base width=0.02 inch. **(06)**

(OR)

1. a) Explain the process of L-section matching networks and stub matching of microstrip lines. **(08)**

b) What are the required length and impedance of a $\lambda_g/4$ transformer that will match a 100Ω load to a 50Ω, air filled line at 10GHz. Consider both rectangular waveguide (2.286 cm×1.016cm) and coaxial line cases. **(08)**

Unit - II

2. a) Describe the principle of working and draw the equivalent circuit of P-I-N (PIN) diode. **(06)**

b) How PIN diode can be used as modulator? Explain the use of PIN diode in switches and phase shifter. **(06)**

c) The drift velocity of electrons is 2×10^7 cm/sec through the active region of length 10×10^{-4}cm. Calculate the natural frequency of the diode and the critical voltage. **(04)**

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(OR)

2. a) Explain the IMPATT diode with following **(12)**
   i) DC operating principle
   ii) Mechanism of oscillation
   iii) Mounting and equivalent circuit

   b) A $p^+ - \pi - n^+$ silicon diode with a break down voltage of 1000V. The cutoff frequency is 30GHz. The breakdown electric field for Si is 3.0×10^5 V/cm. If Junction Capacitance is 0.3pf then calculate the total series Resistance. **(04)**

Unit - III

3. a) Draw a schematic of GaAs MESFET and explain its working with various biasing conditions. **(12)**

   b) A GaAs MESFET has channel height of 0.12µm electron concentration $N_d = 8\times10^{17}cm^{-3}$ and the relative dielectric constant 13.2. Calculate the Rinchoff voltage. **(04)**

(OR)

3. a) Write the various steps for designing a single stage microwave MESFET amplifier. **(08)**

   b) A GaAs MESFET amplifier is to be designed at 5GHz with 400MHz bandwidth for maximum power gain. The measured parameters at 5 GHz with a 50Ω reference are **(08)**

$$S_{11} = 0.52\angle -145°, S_{12} = 0.03\angle 20°$$

$$S_{21} = 2.56\angle 17°, S_{22} = 0.48\angle -20°$$

$$\Gamma S_{in} = 0.75\angle 170°, \Gamma L_{out} = 0.72\angle 105°$$

Determine $G_{A\,max}$.

Unit - IV

4. a) What is velocity and current modulation in reflex Klystron? Describe the reflex Klystron with aid of schematic diagram. **(10)**

   b) A reflex Klystron is to be operated at frequency of 10GHz with dc beam voltage 300V, repeller space 0.1cm for $1\frac{3}{4}$ mode. Calculate $P_{RF\,max}$ and corresponding repeller voltage for a beam current of 20 mA. **(06)**

(OR)

4. a) Describe the construction of a multicavity magnetron and obtain an expression for full cut off voltage for π-mode of operation. Explain how mode Jumping can be avoided. **(12)**

b) A frequency agile magnetron has duty cycle of 1ms and pulse duration of 0.20, 0.40 and 0.80µs. If the pulse rate on the target be N = 20 per scan determine : **(04)**

i) The agile excursion
ii) The signal frequency
iii) The agile rate.

Unit - V

5. Write short notes on **(any two)** **(2×8=16)**

i) Slow wave structures used in TWT.
ii) Two cavity Klystron amplifier.
iii) Backward wave oscillator.
iv) Coupled cavity TWT.

(OR)

5. A multicavity TWT is operating at cathode voltage 30kV and cathode current 7.5A. The output power is 60 kW and the collector voltage is –12kV. What is electronic and overall efficiency? **(16)**

6E6051

Roll No. : 15EEBEC036

Total Printed Pages : 4

6E6051

B.Tech. VI-Sem. (Main & Back) Examination, April-May 2018
Electronics & Communication Engg.
6EC1A Micriowave Engineering-II

Time : 3 Hours]

[Maximum Marks : 80
[Min. Passing Marks : 26

*Attempt any **five questions**, selecting **one question** from **each unit**. All Questions carry **equal** marks. Schematic diagrams must be shown wherever necessary. Any data you feel missing suitably be assumed and stated clearly. Units of quantities used / calculated must be stated clearly.*

Use of following supporting material is permitted during examination. (Mentioned in form No. 205)

1. Smith chart 2. NIL

UNIT - I

1 (a) What does impedance matching imply ? Mention a few techniques used for realizing impedance matching at microwave frequencies.

(b) Match a load impdance of $Z_L = 100 + j80$ to a 50 Ω line using a single series open-circuited stub. Assuming that the load is matched at 24 Hz and that the load consists of a resistor and inductor in series, plot the reflection coefficient magnitude from 1 to 3 GHz.

8+8 = 16

OR

1 (a) Describe the procedure of load matching with quarter wave transformer for different types of loads. What are the advantages and shortcomings involved in this method ?

8

(b) A lossless line of characteristics impedance $R_o = 50\ \Omega$ is to be matched to a load $Z_l = 50 / [2+j(2+\sqrt{3})]\ \Omega$ by means of a lossless short-circuited stub. The characteritic impedance of the stub is $100\ \Omega$. Find the stub position (closest to the load) and length so that a match is obtained. **8**

UNIT - II

2 (a) What is varactor diode ? Discuss how the voltage variable capacitance of a varactor can be used for harmonic generation. What is a snap-off varactor ? **8**

mid-II (10m)

(b) Describe the different modes of operation realizable with a Gunn diode. **8**

OR

2 (a) Discuss the principle of operation of an IMPATT diode and explain the origin of negative resistance in the operation of such a device. **8**

mid-II (10m)

(b) Explain the function of the PIN diodes. Describe its application as a single-pole PIN diode switches and single bit phase shifters. **8**

UNIT - III

3 (a) What are the salient features of Si microwave bipolar transistors ? What are the three physical structures used for microwave transistors ? Explain it. **8**

(b) A GaAs has a thickness of 0.40 μm and a doping concentration Na of 5×10^{17} em^{-3}. The relative dielectric constant Er of GaAs is 13.10. Calculate the pinch-off voltage in volts. **8**

OR

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3 (a) Discuss the structure and principle of operation of a MESFET device.

8

(b) Derive the expression for transducer gain with unilateral transistor. Explain design criteria for maximum gain.

8

UNIT - IV

4 (a) Explain the construction, principle of working, and operation of a reflex Klystron.

8

(b) A reflex Klystron operates at the peak of the n = 2 mode. The dc power input is 40 mW and $V_1/V_0 = 0.278$. If 20% of the power delivered by the beam is dissipated in the cavity walls, find the power delivered to the load.

8

OR

4 (a) Explain the construction and working of a cylindrical magnetron. Derive the equation for cut-off magnetic field for a cylindrical magnetron.

8

b) An X-band pulsed cylindrical magnetron has the following parameters : Anode Voltage V_o = 26 KV, beam current I_o = 27A, Magnetic flux density B_o = 0.336 Wb/m^2, Radius of cathode cylinder a = 5cm, Radius of vane edge to centre b = 10 cm.

Compute :

(i) The cyclotron angular frequency

(ii) The cutoff voltage for a fixed B_o

(iii) The cutoff magnetic flux density for a fixed V_o.

2+3+3=8

UNIT - V

5 (a) Explainthe velocity modulation and bunching process in two-cavity Klystron. Drive the expression for bunching parameters.

8

(b) A two-cavity amplifier Klystron has the following parameters : Beam voltage $V_0 = 900$ V, Beam current $I_0 = 30$ mA, frequency f = 8GHz, Gap spacing in either cavity d = 1 mm, spacing between centers of cavities L = 4 cm. Effective shunt impedance Rsh = 40 $K\Omega$.

Determine :

(i) The electron velocity

(ii) The dc electron transit time

(iii) The input voltage for maximum output voltage

(iv) The voltage gain in decibels.

2×4=8

OR

5 (a) Explain in detail the operation of a helix-type TWT amplifier. Derive the electronic and circuit equations for TWT.

8

(b) An O-type helix TWT operates at 8 GHz. The slow-wave structure has a pitch angle of 4.4 and an attenuation constant of 2 Np/m. Determine the propagation constant γ of the travelling wave in the tube.

8

5E5025

Roll No. 15EEBEC036 [Total No. of Pages : 4

5E5025

B.Tech. V Semester(Main/Back) Examination, Nov./Dec. - 2017
Electronics & Communication Engineering
5EC5A Microwave Engg. - I

Time : 3 Hours
Maximum Marks : 80
Min. Passing Marks : 26

Instructions to Candidates :

*Attempt any **five questions**, selecting **one question** from **each unit**. All Questions carry **equal** marks. (Schematic diagrams must be shown wherever necessary. Any data you feel missing suitable be assumed and stated clearly). Units of quantities used/calculated must be stated clearly.*

Unit - I

1\. a) Discuss the following in a rectangular waveguide,

i) Degenerate mode

ii) Dominant mode

(4 +4 = 8)

b) An air-filled rectangular waveguide of inside dimensions 7 × 3.5 cm operates in the dominant TE_{10} mode.

i) Find the cutoff frequency.

ii) Determine the phase velocity of the wave in the guide at a frequency of 3.5 GHz.

iii) Determine the guided wavelength at the same frequency.

(2 + 3 + 3 = 8)

OR

1\. a) A shielded stripline has the following parameters

Dielectric constant of the insulator, $\epsilon_r = 2.56$

Strip width, $w = 25$ mils

Strip thickness, $t = 14$ mils

Shield depth, $d = 70$ mils

i) The K factor.

ii) The fringe capacitance.

iii) The characteristic impedance of the line.

(2 + 2 + 2 = 6)

per —

b) A loss less parallel stripline has a conducting strip width w. The substrate dielectric separating the two conducting strips has a relative dielectric constant ϵ_{rd} of 6.0 (B_eO) and a thickness d of 4.0 mm.

Calculate:

i) The required width, w of the conducting strip in order to have a characteristic impedance of 50Ω.

ii) The strip-line capacitance.

iii) The strip-line inductance.

iv) The phase velocity of the wave in the parallel stripline.

(2½ × 4 = 10)

Unit - II

2. a) Derive the expression for average power flowing into the port-n of a n-port network, in terms of parameters proportional to incident wave and outgoing wave. *(8)*

b) Derive the following in terms of S-parameters when the ports are matched terminated in two port network.

i) Insertion loss.

ii) Transmission loss.

iii) Reflection loss.

iv) Return loss. **(2 × 4 = 8)**

OR

2. Discuss the following properties of S-parameters.

i) Zero property of [S] matrix.

ii) Unity property of [S] matrix.

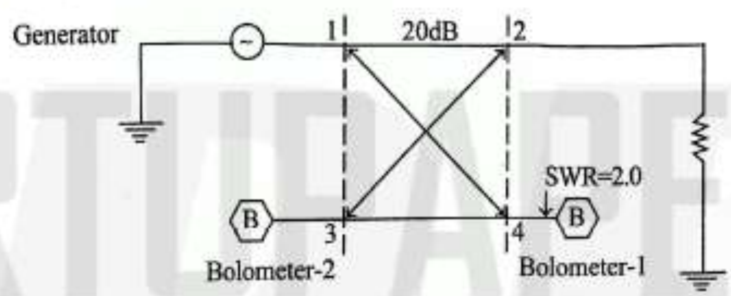
iii) Symmetric property of [S] matrix.

iv) Phase shift property of [S] matrix.

(4 × 4 = 16)

Unit - III

3. Discuss the [S] matrix of a directional coupler. A symmetric direction coupler with infinite directivity and a forward attenuation of 20 dB is used to monitor the power delivered to a load Z_l, as per fig (1) Bolometer-1 introduces a VSWR of 2.0 on arm 4; bolometer-2 is matched to arm 3. If bolometer-1 reads 8mW and bolometer-2 reads 2mW, find (a) the amount of power dissipated in the load Z_l; (b) the VSWR on arm 2.



(4 +6 + 6 = 16)

OR

3. With the help of a diagram, explain the following microwave components,
   i) Wilkinson Power Divider
   ii) Ring Resonator
   iii) Backward wave coupler

(5 + 5 + 6 = 16)

Unit - IV

4. a) With the help of diagram, discuss an arrangement to measure low microwave power within 1 to 10 mW range. **(8)**

   b) Draw and explain the block diagram of set-up for the measurement of VSWR at the input of the component under test. **(8)**

OR

4. a) What are the types of network analysers. Explain any one of them with the help of suitable block diagram. **(8)**

   b) Discuss how measurements are made using a noise-figure meter. **(8)**

5E5025 (3) [Contd....

Unit - V

5. a) In MMIC, a planar resistor has the following parameters,

Resistive film thickness, $t = 0.1\ \mu m$.

Resistive film length, $l = 10$ mm

Resistive film width, $w = 10$ mm

Sheet resistivity of gold film, $\rho = 2.44 \times 10^{-8}\ \Omega\text{-m}$.

Calculate the planar resistance and also draw the diagram of a thin film resister. **(5 + 3 = 8)**

b) An interdigitated capacitor fabricated on a GaAs substrate has the following parameters,

Number of fingers, $N = 8$

Relative dielectric constant of GaAs, $\epsilon_r = 13.10$

Substrate height, $h = 0.254$ cm

Finger length, $l = 0.00254$ cm

Finger base-width, $w = 0.051$ cm

Compute the capacitance. **(8)**

OR

5. a) Describe the MMIC techniques and also list the basic materials for MMIC. **(8)**

b) Explain the photolithography process with the help of suitable diagram. **(8)**

◆◆◆◆

17. Mid Term Papers (Mapping with Bloom's Taxonomy & COs)

Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur

I Mid Term Examination, October- 2021

Semester/Session: V / 2021-22 | **Branch: ECE**
Subject: MTT | **Subject Code : 5EC4-05**
Time: 1½ Hours | **Maximum Marks: 50**
Date/Time: 29.10.2021 / (09:00-10:30 AM)
Google classroom Code: we3zopt (Sec-A), 4jqohgw (Sec-B), tz3i6I6 (Sec-C)

SET-A

Important instructions:

1. All the questions are compulsory.
2. As suggested in the sample, do fill the entries on the top of the first page of the answer copy.
3. Upload the answer sheets in pdf format.
4. Besides 1.5 Hrs. of Exam duration, additional 15 minutes will be provided for uploading the answer sheets.

Q1. Describe the meaning of terms Electromagnetic interference and Electromagnetic compatibility also compare them. Write down the applications of Microwave [10]

Q2. Describe the mathematical model of Microwave transmission using Maxwell equations, write down the Maxwell equations in differential form and obtain the Maxwell equations in frequency domain using them. Define each of the constants used in Maxwell equations [10]

Q3. Explain the three different cases for wave propagation in rectangular waveguide and derive the expression for cut off frequency [10]

Q4. (a) Determine the Cut-off wavelength for the dominant mode in a rectangular waveguide of breadth 10cm, for a 2.5 GHz signal propagated in this waveguide in the dominant mode, calculate the guide wavelength, the group and the phase velocities?

(b) Write down the dominant modes for TE and TM modes respectively in a waveguide [8+2]

Q5. (a) Explain the meaning of Characteristic impedance and Wave Impedance

(b) Explain insertion loss and return loss along with their mathematical expressions [5+5]

Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur

I Mid Term Examination, October- 2021

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Subject: MTT **Subject Code : 5EC4-05**
Time: 1½ Hours **Maximum Marks: 50**
Date/Time: 29.10.2021 / (09:00-10:30 AM)
Google classroom Code: we3zopt (Sec-A), 4jqohgw (Sec-B), tz3i6I6 (Sec-C)

SET-B

Important instructions:
1. All the questions are compulsory.
2. As suggested in the sample, do fill the entries on the top of the first page of the answer copy.
3. Upload the answer sheets in pdf format.
4. Besides 1.5 Hrs. of Exam duration, additional 15 minutes will be provided for uploading the answer sheets.

Q1. (a) What do you mean by Microwaves, write down the different frequency bands of Microwaves along with their frequency ranges
(b) Explain the following Microwave parameters (i) Standing waves (ii) VSWR [5+5]

Q2. (a) What are the different types of losses in Microwave Transmission
(b) Explain the terms: dielectric loss, coupling loss and radiation loss in transmission lines [10]

Q3. Derive the solution of field equations for TM mode in a rectangular waveguide [10]

Q4. A rectangular waveguide is filled by dielectric material of $\varepsilon_r = 9$ and has inside dimensions of $7 \times 3.5\text{cm}^2$. It operates in the dominant TE_{10} mode. Then determine
1) Cut off frequency
2) Phase velocity in the guide at frequency of 2GHz.
3) Guide wavelength λg at the same frequency. [3+3+4]

Q5. (a) What are coaxial transmission lines? Explain their structure along with their advantages and disadvantages
(b) What are waveguides, explain wave propagation in waveguides [5+5]

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I Mid Term Examination, October- 2021

Semester/Session: V / 2021-22 **Branch: ECE**
Subject: MTT **Subject Code : 5EC4-05**
Time: 1½ Hours **Maximum Marks: 50**
Date/Time: 29.10.2021 / (09:00-10:30 AM)
Google classroom Code: we3zopt (Sec-A), 4jqohgw (Sec-B), tz3i6I6 (Sec-C)
SET-C

Important instructions:

1. All the questions are compulsory.
2. As suggested in the sample, do fill the entries on the top of the first page of the answer copy.
3. Upload the answer sheets in pdf format.
4. Besides 1.5 Hrs. of Exam duration, additional 15 minutes will be provided for uploading the answer sheets.

Q1.(a) What are microwaves, how is the microwave theory different from the conventional circuit theory
(b) Explain the following with respect to Microwaves: (i) Standing waves (ii) Return Loss [5+5]

Q2. (a) What are modes, explain the features of TE, TM and TEM modes
(b)Which modes are supported by rectangular waveguides, write down the expression for propagation constant and define each of the constants in the expression [7+3]

Q3. Derive the solution of field equations for TE mode in a rectangular waveguide [10]

Q4. A rectangular waveguide is designed to operate in TE10 mode at a frequency of 10GHz.It is desired that frequency of operation to be at least 15% above cut-off frequency of the propagating and 20% below cut-off frequency of next higher mode. Determine the dimensions of the waveguide. [10]

Q5. Explain the characteristics of planar transmission lines. Define Microstriplines and Striplines along with their structures and field patterns [10]

Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur

I Mid Term Examination, October- 2021

Semester/Session: V / 2021-22 **Branch: ECE**
Subject: MTT **Subject Code : 5EC4-05**
Time: 1½ Hours **Maximum Marks: 50**
Date/Time: 29.10.2021 / (09:00-10:30 AM)
Google classroom Code: we3zopt (Sec-A), 4jqohgw (Sec-B), tz3i6I6 (Sec-C)
SET-D

Important instructions:
1. All the questions are compulsory.
2. As suggested in the sample, do fill the entries on the top of the first page of the answer copy.
3. Upload the answer sheets in pdf format.
4. Besides 1.5 Hrs. of Exam duration, additional 15 minutes will be provided for uploading the answer sheets.

Q1. (a) Write down the advantages and disadvantages of Microwaves
(b) Write down the medical and civil applications of Microwave [5+5]

Q2. Explain how an Electromagnetic wave propagates. Describe the four Maxwell equations in integral and differential forms [10]

Q3. (a) Explain mathematically why do the TEM modes do not propagate in a waveguide
(b) What are dominant and degenerate modes. Draw the field patterns for TE_{10} and TE_{20} modes [7+3]

Q4. A Coaxial line has the following physical dimensions.
Diameter of inner conductor =0.49cm
Inner diameter of outer conductor =1.1 cm
Polyethylene dielectric $\varepsilon_r = 2.3$
Calculate
1) Inductance per unit length
2) Capacitance per unit length
3) Characteristic Impedance [10]

Q5. Explain the construction of Microstriplines and Striplines along with their characteristics. Write down the names of different types of planar transmission lines [10]

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A. Distribution of Course Outcome and Bloom's Level in Question Paper

Q. No	Question	Marks	CO	BL
	SET-A			
Q1	Describe the meaning of terms Electromagnetic interference and Electromagnetic compatibility also compare them. Write down the applications of Microwave	**10**	**2**	**1**
Q2	Describe the mathematical model of Microwave transmission using Maxwell equations, write down the Maxwell equations in differential form and obtain the Maxwell equations in frequency domain using them. Define each of the constants used in Maxwell equations	**10**	**2**	**3**
Q3	Explain the three different cases for wave propagation in rectangular waveguide and derive the expression for cut off frequency	**10**	**2**	**2**
Q4	(a) Determine the Cut-off wavelength for the dominant mode in a rectangular waveguide of breadth 10cm, for a 2.5 GHz signal propagated in this waveguide in the dominant mode, calculate the guide wavelength, the group and the phase velocities? (b) Write down the dominant modes for TE and TM modes respectively in a waveguide	**10**	**2**	**3**
Q5	(a) Explain the meaning of Characteristic impedance and Wave Impedance (b) Explain insertion loss and return loss along with their mathematical expressions	**10**	**2**	**2**

BL – Bloom's Taxonomy Levels (1- Remembering, 2- Understanding, 3 – Applying, 4 – Analyzing, 5 – Evaluating, 6 - Creating)

CO -Course Outcome

B. Question and course outcome (COs) mapping in terms of correlation (set A)

COs	Q1	Q2	Q3	Q4	Q5
CO1					
CO2	1	3	3	2	2
CO3					
CO4					
CO5					

1-Low Correlation; 2- Moderate Correlation; 3- Substantial Correlation

C. Mapping of Bloom's level and course outcomes with question paper (set A)

Bloom's level mapping		CO mapping	
Bloom's level	Percentage	CO	Percentage
BL1	20%	CO1	
BL2	40%	CO2	100%
BL3	40%	CO3	
BL4		CO4	
BL5		CO5	
BL6			

A. Distribution of Course Outcome and Bloom's Level in Question Paper

Q. No	Question	Marks	CO	BL
	SET-B			
Q1	(a) What do you mean by Microwaves, write down the different frequency bands of Microwaves along with their frequency ranges (b) Explain the following Microwave parameters (i) Standing waves (ii) VSWR	**10**	**2**	**1**
Q2	(a) What are the different types of losses in Microwave Transmission (b) Explain the terms: dielectric loss, coupling loss and radiation loss in transmission lines	**10**	**2**	**2**
Q3	Derive the solution of field equations for TM mode in a rectangular waveguide	**10**	**2**	**3**
Q4	A rectangular waveguide is filled by dielectric material of εr = 9 and has inside dimensions of 7 × 3.5cm2. It operates in the dominant TE10 mode. Then determine 1) Cut off frequency 2) Phase velocity in the guide at frequency of 2GHz. 3) Guide wavelength ƛg at the same frequency.	**10**	**2**	**3**
Q5	(a) What are coaxial transmission lines? Explain their structure along with their advantages and disadvantages (b)What are waveguides, explain wave propagation in waveguides	**10**	**2**	**1**

BL – Bloom's Taxonomy Levels (1- Remembering, 2- Understanding, 3 – Applying, 4 – Analyzing, 5 – Evaluating, 6 - Creating)

CO -Course Outcome

B. Question and course outcome (COs) mapping in terms of correlation (set B)

COs	Q1	Q2	Q3	Q4	Q5
CO1					
CO2	1	1	3	3	2
CO3					
CO4					
CO5					

1-Low Correlation; 2- Moderate Correlation; 3- Substantial Correlation

C. Mapping of Bloom's level and course outcomes with question paper (set B)

Bloom's level mapping		CO mapping	
Bloom's level	Percentage	CO	Percentage
BL1	40%	CO1	
BL2	20%	CO2	100%
BL3	40%	CO3	
BL4		CO4	
BL5		CO5	
BL6			

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A. Distribution of Course Outcome and Bloom's Level in Question Paper

Q. No	Question	Marks	CO	BL
	SET-C			
Q1	(a) What are microwaves, how is the microwave theory different from the conventional circuit theory (b) Explain the following with respect to Microwaves: (i) Standing waves (ii) Return Loss	**10**	**2**	**1**
Q2	(a) What are modes, explain the features of TE, TM and TEM modes (b)Which modes are supported by rectangular waveguides, write down the expression for propagation constant and define each of the constants in the expression	**10**	**2**	**1**
Q3	Derive the solution of field equations for TE mode in a rectangular waveguide	**10**	**2**	**3**
Q4	A rectangular waveguide is designed to operate in TE10 mode at a frequency of 10GHz.It is desired that frequency of operation to be at least 15% above cut-off frequency of the propagating and 20% below cut-off frequency of next higher mode. Determine the dimensions of the waveguide.	**10**	**2**	**3**
Q5	Explain the characteristics of planar transmission lines. Define Microstriplines and Striplines along with their structures and field patterns	**10**	**2**	**2**

BL – Bloom's Taxonomy Levels (1- Remembering, 2- Understanding, 3 – Applying, 4 – Analyzing, 5 – Evaluating, 6 - Creating)

B. Question and course outcome (COs) mapping in terms of correlation (set C)

COs	Q1	Q2	Q3	Q4	Q5
CO1					
CO2	1	1	3	3	2
CO3					
CO4					
CO5					

1-Low Correlation; 2- Moderate Correlation; 3- Substantial Correlation

C. Mapping of Bloom's level and course outcomes with question paper (set C)

Bloom's level mapping		CO mapping	
Bloom's level	Percentage	CO	Percentage
BL1	40%	CO1	
BL2	20%	CO2	100%
BL3	40%	CO3	
BL4		CO4	
BL5		CO5	
BL6			

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A. Distribution of Course Outcome and Bloom's Level in Question Paper

Q. No	Question	Marks	CO	BL
	SET-D			
Q1	(a) Write down the advantages and disadvantages of Microwaves (b) Write down the medical and civil applications of Microwave	**10**	**2**	**1**
Q2	Explain how an Electromagnetic wave propagates. Describe the four Maxwell equations in integral and differential forms	**10**	**2**	**2**
Q3	(a) Explain mathematically why do the TEM modes do not propagate in a waveguide (b) What are dominant and degenerate modes. Draw the field patterns for TE10 and TE20 modes	**10**	**2**	**2**
Q4	A Coaxial line has the following physical dimensions. Diameter of inner conductor =0.49cm Inner diameter of outer conductor =1.1 cm Polyethylene dielectric $\varepsilon r = 2.3$ Calculate 1) Inductance per unit length 2) Capacitance per unit length Characteristic Impedance	**10**	**2**	**3**
Q5	Explain the construction of Microstriplines and Striplines along with their characteristics. Write down the names of different types of planar transmission lines	**10**	**2**	**2**

BL – Bloom's Taxonomy Levels (1- Remembering, 2- Understanding, 3 – Applying, 4 – Analyzing, 5 – Evaluating, 6 - Creating)

B. Question and course outcome (COs) mapping in terms of correlation (set D)

COs	Q1	Q2	Q3	Q4	Q5
CO1					
CO2	1	2	2	3	2
CO3					
CO4					
CO5					

1-Low Correlation; 2- Moderate Correlation; 3- Substantial Correlation

C. Mapping of Bloom's level and course outcomes with question paper (set D)

Bloom's level mapping		CO mapping	
Bloom's level	Percentage	CO	Percentage
BL1	20%	CO1	
BL2	60%	CO2	100%
BL3	20%	CO3	
BL4		CO4	
BL5		CO5	
BL6			

I Mid Term Paper Solutions

SET: A

Q1. Describe the meaning of terms Electromagnetic interference and Electromagnetic compatibility also compare them. Write down the applications of Microwave . [10]

Answer:

EMI and EMC are both important aspects that should be considered when dealing with electronics. EMI stands for electromagnetic interference and is an electronic emission that interferes with components, RF systems, and most electronic devices. If a device is improperly shielded from EMI, it will not work. EMI can be the result of manmade or natural occurrences. In order to protect electronic devices and components from electromagnetic radiation, all equipment's must be shielded. EMI shielding is used to ensure that electronics remain fully operational and run without interference. If a component is vulnerable to interference, it will not work.
EMC is the abbreviation for electromagnetic compatibility. EMC is the term used to describe how well a device or system is able to function in an electromagnetic environment. Every electronic device generates electric noise, which interrupts cables and wires and causes problems for connected devices. The difference between EMI and EMC is that EMI is the term for radiation and EMC merely is the ability for a system to operate within the presence of radiation. A system is claimed to fulfill electromagnetic compatibility (EMC) requirement when it is in good function order and does not create electromagnetic interference. Rapid advancement in microwave and electronic technologies demands higher operating frequency and hence, electromagnetic interference (EMI) is more likely to occur in systems like printed circuit board (PCB), module or chip. Interference occurs when there exists an interfering path and the magnitude of culprit noise exceeds the immunity margin of the victim susceptor. The fundamental factors in any EMl problem are frequency, amplitude, separation and timing, abbreviated as FAST.

Applications:

There are wide applications of Microwave in different areas as:

Wireless Communications: For long distance telephone calls, Bluetooth, Transmitter and Receiver links, Direct Broadcast Satellite DBS, Personal Communication Systems PCS,
Wireless Local Area Networks WLAN, Cellular Video Systems, Automobile collision avoidance system.

Commercial uses:
Burglar alarms, Garage door Openers, Police speed detectors, Cell phones, pagers, wireless LANs, Satellite television, Motion detectors, Remote sensing.

Civil Application
landing system, Direction findings, Motion detectors, Vehicle collision avoidance, Distance measurement, Surveillance, Marine navigation, Radio astronomy, Terrestrial and satellite communication links.

Medical Applications:
Monitoring heartbeat, Lung water detection, Tumour detection, Regional hyperthermia, Therapeutic applications, Local heating, Microwave tomography, Microwave Acoustic imaging.

Q2. Describe the mathematical model of Microwave transmission using Maxwell equations, write down the Maxwell equations in differential form and obtain the Maxwell equations in frequency domain using them. Define each of the constants used in Maxwell equations .[10]

Answer.

Maxwell equations in differential form

- $\nabla . D = \rho$
- $\nabla . B = 0$
- $\nabla X E = -\frac{\partial B}{\partial t}$
- $\nabla X H = J + \frac{\partial D}{\partial t}$

Where,

- **E = electric field intensity in volts per meter**
- **H = magnetic field intensity in amperes per meter**
- **D = electric flux density in coulombs per square meter**
- **B = magnetic flux density in webers per square meter or in tesla**
- **J = electric current density in amperes per square meter**
- **ρ = electric charge density in coulombs per cubic meter**
- **ϵ_o= 8.854 x 10^-12 F/m is the dielectric permittivity of vacuum or free space**
- **μ_o= 4π x 10^-7 H/m is the permeability of vacuum or free space**

- **σ= conductivity of the medium in mhos per meter**
- **ϵ = dielectric permittivity**
- **μ= magnetic permeability**

If a sinusoidal time function in the form of $e^{j\omega t}$ is assumed, $\frac{\partial}{\partial t}$ can be replaced by $j\omega$.

- **$\frac{\partial}{\partial t}$ is the time derivative or rate of change with respect to time that can be replaced with frequency**
- **Then Maxwell's equations in frequency domain are given by:**

➢ $\nabla X E = -j\omega\,\mu H$

➢ $\nabla X H = (\sigma + j\omega\epsilon)\,E$

➢ $\nabla . D = \rho$

➢ $\nabla . B = 0$

Now we define:

$$\gamma = \sqrt{(j\omega\,\mu(\sigma + j\omega\,\epsilon))} = \alpha + j\beta$$

γ is called the intrinsic propagation constant of a medium

α = attenuation constant in nepers per meter

β = phase constant in radians per meter

ω = frequency in radians per sec

for a uniform plane wave propagating in a lossless dielectric medium, conductivity of medium becomes zero (σ = 0), the characteristics of wave propagation would become ($\alpha = 0$) from above equation, means attenuation becomes zero.

So, the Maxwell equations for a lossless dielectric medium becomes in frequency domain as:

➢ $\nabla X E = -j\omega\,\mu H$

➢ $\nabla X H = j\omega\epsilon E$

(By putting (σ = 0))

Suppose, i,j,k are unit vectors along X, Y and Z directions

- **Electric field Vector E= *Ex i + Ey j + Ez k***

- **Magnetic field Vector H=** ***Hx i + Hy j + Hz k***

Then by opening the curl above equations becomes as:

- $\frac{\partial Ez}{\partial y} - \frac{\partial Ey}{\partial z} = -j\omega\, \mu Hx$
- $\frac{\partial Ex}{\partial z} - \frac{\partial Ez}{\partial x} = -j\omega\, \mu Hy$
- $\frac{\partial Ey}{\partial x} - \frac{\partial Ex}{\partial y} = -j\omega\, \mu Hz$
- $\frac{\partial Hz}{\partial y} - \frac{\partial Hy}{\partial z} = j\omega\, \epsilon Hx$
- $\frac{\partial Hx}{\partial z} - \frac{\partial Hz}{\partial x} = j\omega\, \epsilon Ey$
- $\frac{\partial Hy}{\partial x} - \frac{\partial Hx}{\partial y} = j\omega\, \epsilon Ez$

Now, using the boundary conditions of the waveguide the above equations can be solved for TE, TM and TEM modes as we will do in future lectures of waveguide

Q3. Explain the three different cases for wave propagation in rectangular waveguide and derive the expression for cut off frequency. [10]

Answer.

Three cases for the wave propagation in rectangular waveguide-

Case –I:

If $\omega^2\mu\epsilon = K_C{}^2$

γ_g **= 0 i.e no propagation**

This is critical condition for cut off propagation

$$\omega_c = \frac{1}{\sqrt{\mu\epsilon}}\sqrt{kx^2 + ky^2}$$

$$f_{c} = \frac{1}{2\pi\sqrt{\mu\epsilon}}\sqrt{kx^2+ky^2}$$

Case –II:

If $\omega^2\mu\epsilon > {K_C}^2$

$$\gamma_{g=} \pm j\beta g\sqrt{\mu\epsilon}\sqrt{1-\left(\frac{f_c}{f}\right)^2}$$

This shows that operating frequency should be greater than critical frequency to propagate the wave in a waveguide.

Case - III:

If $\omega^2\mu\epsilon < {K_C}^2$

$\gamma_{g=} \pm \alpha g = \ \pm\omega\sqrt{\mu\epsilon}\sqrt{\left(\frac{f_c}{f}\right)^2\text{-1}}$

This shows that if operating frequency is below the cut off frequency the wave will decay exponentially wrt to a factor -$\alpha_g z$ and there will be no wave propagation.

Expression for cut off frequency

The cut –off wave number k_c is defined as

$$K_c = \sqrt{kx^2 + ky^2}$$

Where $k_x = \frac{m\pi}{a}$ and $k_y = \frac{n\pi}{b}$

$$K_C = \sqrt{\left(\frac{m\pi}{a}\right) + \left(\frac{n\pi}{b}\right)^2}$$

Now from $\gamma^2 g = \gamma^2 + k^2 c$

For the cut off condition, there will be no wave propagation in waveguide

i.e $\gamma^2 g = 0$

we know that propagation constant for lossless dielectric $\gamma^2 = -\omega^2\mu\epsilon$

Then,

$k^2 c$ = $-\omega^2\mu\epsilon$

(Replacing ω by cut-off angular frequency ω_c)

$k_c = \omega_c\sqrt{\mu\epsilon}$

Or $\sqrt{\left(\frac{m\pi}{a}\right) + \left(\frac{n\pi}{b}\right)^2} = \omega_c\sqrt{\mu\epsilon} = 2\pi f_c\sqrt{\mu\epsilon}$

$f_c = \frac{1}{2\sqrt{\mu\epsilon}}\sqrt{\left(\frac{m\pi}{a}\right) + \left(\frac{n\pi}{b}\right)^2}$

We know that $\frac{1}{\sqrt{\mu\epsilon}}$ =c = velocity of light (if dielectric is air)

$f_c = \frac{c}{2}\sqrt{\left(\frac{m\pi}{a}\right) + \left(\frac{n\pi}{b}\right)^2}$

In term of wavelength (c=fλ)

$$\lambda_c = \frac{2}{\sqrt{\left(\boldsymbol{\frac{m}{a}}\right)^2 + \left(\boldsymbol{\frac{n}{b}}\right)^2}}$$

Q4. (a) Determine the Cut-off wavelength for the dominant mode in a rectangular waveguide of breadth 10cm, for a 2.5 GHz signal propagated in this waveguide in the dominant mode, calculate the guide wavelength, the group and the phase velocities? [8]

Answer.
In a rectangular waveguide the dominant mode is the TE_{10} mode

λ_c for TE_{10} = 2a =$2\times 10 = 20cms$

Given: f= 2.5GHz

$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$

$\lambda_0 = \frac{c}{f} = \frac{3\times10^{10}}{2.5\times10^9} =$ 12 cm

$\lambda_g = \frac{12}{\sqrt{1-\left(\frac{12}{20}\right)^2}} = \frac{12}{0.8}$ =15 cm

$V_P = \frac{c}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_C}\right)^2}}$

From the calculation of λ_g we know that

$\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}$

$= \sqrt{1-\left(\frac{12}{20}\right)^2}$ =0.8

$V_{p}= \frac{3\times10^8}{0.8} = 3.75\times 10^{10}$ cm/sec

$V_{P.}V_g = c^2$

$V_g = \frac{c^2}{V_P} = \frac{(3\times10^{10})^2}{3.75\times10^{10}} = 2.4\times 10^{10}$ cm/sec

(b) Write down the dominant modes for TE and TM modes respectively in a waveguide.
Answer.
In a rectangular waveguide the corresponding $\mathrm{TE_{mn}}$ and $\mathrm{TM_{mn}}$ modes are always degenerate
The $\mathrm{TE_{10}}$ mode has the longest operating wavelength and is designated as the dominant mode. It is the mode for the lowest cut off frequency that can be propagated in a waveguide [2]
For TM modes the dominant mode is $\mathrm{TM_{11}}$.

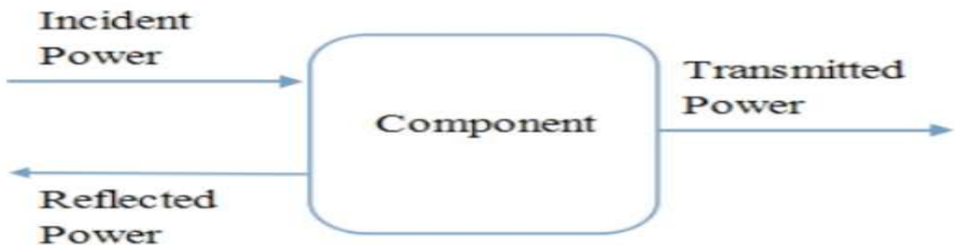
Q5. (a) Explain the meaning of Characteristic impedance and Wave Impedance . [5]
Answer.

Wave Impedance
Wave impedance is a characteristic of the wave which describes the radiation property of the wave, it is the ratio between the two corresponding transverse electric and magnetic field components that carry the power in the propagation direction Wave impedance can be defined for TE, TEM or TE waves.It can be the ratio of the field components 'Ey' and 'Hx' for the wave travelling in z direction Wave impedance depends only on the frequency of the AC source and material properties of the medium It describes the radiation property of the wave
Characteristic Impedance
Characteristic impedance is the ratio between the voltage and current of the TEM wave in a transmission line. It is the property of transmission line supporting the wave Characteristic impedance depends on geometry of the line, frequency of the source and the material properties of medium filling

the transmission line It describes the power transport property of the structure supporting the wave. The characteristic impedance of a transmission line should be perfectly matched to the load impedance at the end of transmission line for no reflection

(b) Explain insertion loss and return loss along with their mathematical expressions. [5]

Answer.
Consider, a Microwave component as below, the Insertion and Return Loss are given as:



$$\text{Insertion Loss} = \frac{\text{Incident Power}}{\text{Transmitted Power}}$$

$$\text{Return Loss} = \frac{\text{Incident Power}}{\text{Reflected Power}}$$

Microwave power is sent down a transmission line from the left and it reaches the component. This power is the incident power When it reaches the component, a portion is reflected back down the transmission line where it came from and never enters the component, rest of the power gets into the component There some of it gets absorbed and the remainder passes through the component into the transmission line on the other side. The power that actually comes out of the component is called the transmitted power.Transmitted power is less than the incident power for two reasons: (1) some of the power gets reflected. (2) some of the power gets absorbed inside the component The ratio of incident power to transmitted power, in dB terminology, is the insertion loss. The ratio of incident power to the reflected power, in dB terminology, is the return loss

- $\text{Insertion Loss (dBm)} = 10 \log\left(\frac{\text{Incident power (W)}}{\text{Transmitted power (W)}}\right)$
- $\text{Insertion Loss (dBm)} = \text{Incident power (dBm)} - \text{Transmitted power (dBm)}$
- $\text{Return Loss (dBm)} = 10 \log\left(\frac{\text{Incident power (W)}}{\text{Reflected power (W)}}\right)$
- $\text{Return Loss (dBm)} = \text{Incident power (dBm)} - \text{Reflected power (dBm)}$

SET: B

Q1. (a) What do you mean by Microwaves, write down the different frequency bands of Microwaves along with their frequency ranges. **[5]**

Answer:

Microwaves are a form of electromagnetic radiation with wavelengths ranging from about one meter to one millimetre with frequencies between 300 MHz (1 m) and 300 GHz (1mm). Short wavelength energy offers distinct advantages in many applications. **Microwave theory different from the conventional circuit theory** because it is based on voltages and currents while microwave theory is based on Electromagnetic fields. Apparatus and techniques may be described qualitatively as "microwave" when the wavelengths of signals are roughly the same as the dimensions of the equipment. As a consequence, practical microwave technique tends to move away from discrete resistors, capacitors, and inductors that are used with lower frequency radio waves

IEEE Microwave Frequency Bands

Designation	Frequency range	Applications
L band	1 to 2 GHz	military telemetry, GPS, mobile phones (GSM), amateur radio
S band	2 to 4 GHz	weather radar, surface ship radar, and some communications satellites (microwave ovens, microwave devices/communications, radio astronomy, mobile phones, wireless LAN, Bluetooth, ZigBee, GPS, amateur radio)
C band	4 to 8 GHz	long-distance radio telecommunications
X band	8 to 12 GHz	satellite communications, radar, terrestrial broadband, space communications, amateur radio
Ku band	12 to 18 GHz	satellite communications
K band	18 to 26.5 GHz	radar, satellite communications, astronomical observations, automotive radar
Ka band	26.5 to 40 GHz	satellite communications

(b) Explain the following Microwave parameters (i) Standing waves (ii) VSWR [5]

Answer

(i) Standing waves:

The standing wave forms as a result of the superposition of two waves of the same frequency and amplitude propagating in opposite directions. The frequency of the standing wave is identical to the frequency of the waves. The incident wave on a transmission line gets superposed with the reflected wave from the end of transmission line, then a standing wave is formed.

(ii) VSWR

Electromagnetic waves travel from source to the feed line to the antenna and finally into the free space. As a result, they may experience differences in impedance at each of the interface. Some part of the energy of wave will reflect back to the source depending on the impedance matching conditions and forming a standing wave pattern in the feed line. Voltage standing wave ratio (VSWR) is defined as the ratio of the maximum power to the minimum power in the wave. In ideal condition, numerical value of VSWR is 1. But in low power applications, VSWR of 1.5:1 is marginally acceptable. To minimizing the impedance differences at each interface, there will be reduction in VSWR and it maximize power transfer through each part of the system. The VSWR can be given as:

$$\mathrm{VSWR} = \frac{V_{max}}{V_{min}} = \frac{1+|\Gamma|}{1-|\Gamma|}$$

Q2. (a) What are the different types of losses in Microwave Transmission. [5]

Answer.
Microwave power transmits through Coaxial cable, Metallic waveguides, Optical fibers, Microstrip lines etc. and all practical lines are lossy. These transmission structures are made up of either conductors or dielectrics or mixture of both.

For ex: coaxial cable has got two conductors, microstrip lines have a dielectric between a conductor and a conducting ground plane and so on, An ideal conductor has infinite conductivity so it is lossless and ideal dielectric has zero conductivity .A practical conductor has finite conductivity, and the practical dielectric also has finite conductivity Loss is given by attenuation constant. A transmission line structure can have both conductor loss and dielectric loss. So, the total power loss is the sum of conductor loss and the dielectric loss. The total attenuation constant (α) is the sum of attenuation constant by conductor (α_c) and attenuation constant by dielectric (α_d)

$$\alpha = \alpha_c + \alpha_d$$

(b) Explain the terms: dielectric loss, coupling loss and radiation loss in transmission lines .[5]

Answer-

Dielectric Heating Loss: A difference of potential between two conductors of a metallic transmission line causes dielectric heating. Heat is form of energy and must be taken from the energy propagating down the line. For air dielectric transmission lines, the heating is negligible. For solid core transmission lines, dielectric heating loss increases with frequency. **Coupling Loss**: -Coupling loss occurs whenever a connection is made to or from transmission line or when two sections of transmission line are connected together. There is no physical connection between the sections of transmission line and there is a small gap between the transmission line sections. The gaps radiate energy and dissipate power .It can occur in parallel coupled lines and Coupled line directional couplers. **Radiation Loss:** If the separation between conductors in a metallic transmission line is appreciable fraction of wavelength, the electrostatic and electromagnetic fields that surround the conductor cause the line to act as if it were an antenna and transfer energy to any nearby conductive material. The energy radiated is called radiation loss and depends on dielectric material conductor spacing and length of transmission line.It reduces by properly shielding the cable. It is also directly proportional to the frequency

Q3. Derive the solution of field equations for TM mode in a rectangular waveguide. [10]

Answer-

The TM modes in a rectangular waveguide are characterized by H_z = 0. In other words, the z component of the magnetic field, E_z, must exist in order to have energy transmission in the guide. Consequently, from a given Helmholtz equation, E_z is not equal to zero

$$\nabla^2 E_z = \gamma^2 E_z$$

A solution will be of the form

$$E_z = \left(\text{Am Sin}\left(\frac{m\pi x}{a}\right) + \text{Bm Cos}\left(\frac{m\pi x}{a}\right)\right)\left(\text{Cn Sin}\left(\frac{n\pi y}{b}\right) + \text{Dn Cos}\left(\frac{n\pi y}{b}\right)\right) e^{-j\beta_g z}$$

The boundary conditions are applied to the field equations such that the tangent E field is zero at a surface

E_z = 0 at x = 0, a then Bm = 0,

and for E_z = 0 at y = 0, b then Dn = 0

Therefore the electric field is given by:

$E_z = E_{0z} \mathrm{Sin}(\frac{m\pi x}{a})\mathrm{Sin}(\frac{n\pi y}{b})e^{-j\beta_g z}$

E_{0z} is a constant

If either *m* = 0 or *n* = 0, the field intensities all vanish. So there is no TM_{01} or TM_{10} mode in a rectangular waveguide

On again expanding the curl of equations

$\nabla X E = -j\omega\, \mu H$

$\nabla X H = j\omega \epsilon E$

We have

- $\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} = -j\omega\, \mu H_x$
- $\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} = -j\omega\, \mu H_y$
- $\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} = -j\omega\, \mu H_z$
- $\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} = j\omega\, \epsilon E_x$
- $\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} = j\omega\, \epsilon E_y$
- $\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} = j\omega\, \epsilon E_z$

If we assume exponential variation of fields with z then, $\frac{\partial}{\partial z}$ can be replaced by $-j\beta_g$

H_z= 0 for TM modes

Also,

$k_c^2 = \omega^2\ \mu\epsilon - \beta_g^2$

- $H_x = \frac{j\omega\epsilon}{k_c^2}\frac{\partial E_z}{\partial y}$
- $H_y = \frac{-j\omega\epsilon}{k_c^2}\frac{\partial E_z}{\partial x}$
- $H_z = 0$
- $E_x = \frac{-j\beta_g}{k_c^2}\frac{\partial E_z}{\partial x}$
- $E_y = \frac{-j\beta_g}{k_c^2}\frac{\partial E_z}{\partial y}$

$E_z = E_{0z}\ \mathrm{Sin}(\frac{m\pi x}{a})\mathrm{Sin}(\frac{n\pi y}{b})e^{-j\beta_g z}$

On substituting E_z the other components will become

- $E_x = E_{0x}\mathrm{Cos}(\frac{m\pi x}{a})\mathrm{Sin}(\frac{n\pi y}{b})e^{-j\beta_g z}$
- $E_y = E_{0y}\mathrm{Sin}(\frac{m\pi x}{a})\mathrm{Cos}(\frac{n\pi y}{b})e^{-j\beta_g z}$
- $E_z = E_{0z}\mathrm{Sin}(\frac{m\pi x}{a})\mathrm{Sin}(\frac{n\pi y}{b})e^{-j\beta_g z}$
- $H_x = H_{0x}\mathrm{Sin}(\frac{m\pi x}{a})\mathrm{Cos}(\frac{n\pi y}{b})e^{-j\beta_g z}$
- $H_y = H_{0y}\mathrm{Cos}(\frac{m\pi x}{a})\mathrm{Sin}(\frac{n\pi y}{b})e^{-j\beta_g z}$
- $H_z = 0$

Q4. A rectangular waveguide is filled by dielectric material of $\varepsilon_r = 9$ and has inside dimensions of $7 \times 3.5 cm^2$. It operates in the dominant TE_{10} mode. Then determine

4) Cut off frequency

5) Phase velocity in the guide at frequency of 2GHz.
6) Guide wavelength ƛg at the same frequency. [3+3+4]

Answer-
Given

Mode=TE_{10}

A= 7cm

B= 3.5cm

ϵ_r=9

F= 2GHz

a) Cut off frequency

$$f_{c=}\ \frac{c}{2\sqrt{\varepsilon_r}}\ \sqrt{\left(\frac{m}{a}\right)^2+\left(\frac{n}{b}\right)^2}$$

For TE_{10} i.e m=1, n=0

$$f_{c=}\frac{c}{2\sqrt{\epsilon_r}}.\frac{1}{a}$$

f_c = 0.714 GHz Ans

b) Phase Velocity (V_P)

$$V_{P=}\frac{\omega}{\beta_g}$$

$$=\frac{c}{\sqrt{\epsilon_r}\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$

$$=\frac{c}{\sqrt{\epsilon_r}\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

$$=\frac{3\times10^8}{\sqrt{9}\sqrt{1-\left(\frac{0.714}{2}\right)^2}}$$

$= 1.07\times 10^8$m/s

c) Guide wavelength λ_g

$$\lambda_g = \frac{\lambda_o}{\sqrt{\epsilon_r}\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$

$$= \frac{\lambda_o}{\sqrt{\epsilon_r}\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

$$= \frac{\frac{c}{f}}{\sqrt{\epsilon_r}\sqrt{1-\left(\frac{f_c}{f}\right)^2}} = \frac{c}{\sqrt{\epsilon_r}\sqrt{1-\left(\frac{f_c}{f}\right)^2}.f}$$

Where

$$\frac{c}{\sqrt{\epsilon_r}\sqrt{1-\left(\frac{f_c}{f}\right)^2}} = \text{phase velocity}$$

$$\lambda_{g} = \frac{v_p}{f}$$

$$\lambda_{g} = \frac{1.07\times10^8}{2\times10^9}$$

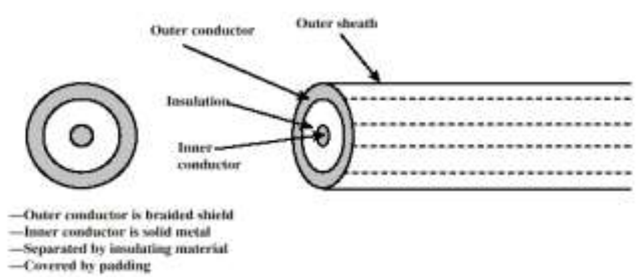
$$= 0.0535$$

λ_g =5.35 cm

Q5. (a) What are coaxial transmission lines? Explain their structure along with their advantages and disadvantages.

Answer-

Coaxial lines are the most common, basic transmission lines They are used to transmit electrical energy, or signals, from one location to another: to connect a source to a load, such as a transmitter to an antenna. A coaxial line consists of two conductors separated by a dielectric mate.The center conductor and the outer conductor, are configured in such a way that they form concentric cylinders with a common axis. Hence the term and name co-axial.



Construction

The center conductor may be made of various materials and constructions.
Most common constructions are solid or seven-strand conductors. Solid conductors are used in permanent and infrequently handled applications.
Seven stranded conductors are used in flexible cable applications. Common materials include copper, tinned or silver plated, copper clad steel and copper clad aluminum.
Data is transmitted through the center wire, The outer braided layer serves as a line to ground, both of these conductors are parallel and share the same axis. That's is why the wire is called coaxial.
The insulation, or dielectric material, is used to provide separation between the conductors. It is desirable that the material has stable electrical characteristics across a broad frequency range.

Advantages of Coaxial Line:

- They are most common means of data transmission over short distances.
- They are cheap to make
- Cheap to install
- Easy to modify
- Good bandwidth
- Great channel capacity

Disadvantages of Coaxial Line:

- Signals entering the cables can cause unwanted noise, making it useless.
- A continuous current flow, even if small, along the imperfect shield of a coaxial cable can cause visible and audible interference.
- More expensive than twisted pairs and is not supported for some network standards.
- It is also having high attenuation, have the need to implement repeaters.

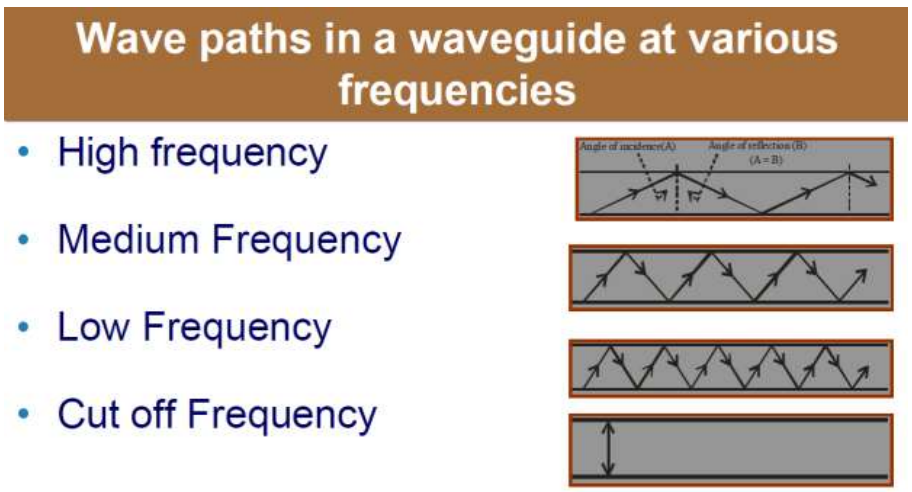
(b) What are waveguides, explain wave propagation in waveguides [5+5]

Answer

A waveguide is a structure used to guide electromagnetic signals of higher frequency It is a hollow metallic tube of uniform cross section.The wave travels inside the waveguides by successive reflections from the walls of the waveguide. A rectangular waveguide is a hollow metallic tube with a rectangular cross section. The conducting walls of the waveguide confine the electromagnetic fields and thereby guide the electromagnetic wave. The rectangular waveguide is basically characterized by its dimensions i.e., length 'a' and breadth 'b'.

Wave propagation

When a probe launches energy into the waveguide, the electromagnetic fields bounce off the side walls of the waveguide. The angles of incidence and reflection depend upon the operating frequency. At high frequencies, the angles are large and therefore, the path between the opposite walls is relatively long .At lower frequency, the angles decrease and the path between the sides shortens.When the operating frequency reaches the cutoff frequency of the waveguide, the signal simply bounces back and forth directly between the side walls of the waveguide and has no forward motion. At cut off frequency and below, no energy will propagate.



SET: C

Q1.(a) What are microwaves, how is the microwave theory different from the conventional circuit theory**.**

Answer:
Microwaves are a form of electromagnetic radiation with wavelengths ranging from about one meter to one millimetre with frequencies between 300 MHz (1 m) and 300 GHz (1mm). Short wavelength energy offers distinct advantages in many applications. **Microwave theory different from the conventional circuit theory** because it is based on voltages and currents while microwave theory is based on Electromagnetic fields. Apparatus and techniques may be described qualitatively as "microwave" when the wavelengths of signals are roughly the same as the dimensions of the equipment. As a consequence, practical microwave technique tends to move away from discrete resistors, capacitors, and inductors that are used with lower frequency radio waves

(b) Explain the following with respect to Microwaves: (i) Standing waves (ii) Return Loss

(a) Standing waves:

The standing wave forms as a result of the superposition of two waves of the same frequency and amplitude propagating in opposite directions. The frequency of the standing wave is identical to the frequency of the waves. The incident wave on a transmission line gets superposed with the reflected wave from the end of transmission line, then a standing wave is formed.

(b) Return Loss:

When a signal is transmitted through a transmission line, some signal power is always reflected or returned to the source due to discontinuities in the transmission line. The measure of this reflected power is called **Return Loss**. The Return Loss is expressed in dB

$$RL\ (dB) = -20 \log (\rho)\ dB$$

[5+5]

Q2. (a) What are modes, explain the features of TE, TM and TEM modes

Answer-

The mode of electromagnetic radiation describes the field pattern of the propagating waves. Modes are mutually independent solutions, of Maxwell's equation, such that, every possible electromagnetic field configuration can be expressed as a linear combination of the modes.There are various solutions of Maxwell's laws, light signal is one such solution, mobile phone signal is another such solution, RADAR signal is another such solution and so on. There are a minimum number of independent solutions of the Maxwell equations, such that, all EM signals can be expressed as a linear combination of them. These minimum numbers of independent solutions are called modes.

TEM (Transverse Electromagnetic Modes)

- Considering the wave to be propagating along ‘z’ direction
- Here, Electric and magnetic field vectors are both orthogonal to the direction of wave propagation
  $E_z=0$ and $H_z=0$
- To any wave propagation direction one can draw infinite number of perpendiculars, which will lie in a plane. This plane is called transverse plane
- Electric field vector can lie along any of these infinite number of perpendiculars
- In the transverse plane, we can always find a perpendicular to the electric field vector which is the magnetic field vector
- Unguided fields produced by a point source at a far off point have many TEM waves propagating in all possible direction

TE (Transverse Electric Modes)

- In this mode, the electric field is purely transverse to the direction of propagation, whereas the magnetic field is not
  $E_z=0$ and $H_z\neq0$
- Electric field vector can lie along any of the infinite number of perpendiculars which are drawn perpendicular to the direction of propagation of waves
- Magnetic field vector should have a component in the transverse plane (z=0) and also some component along z direction
- A rectangular waveguide supports TE modes but not TEM modes because there is only one conductor in a rectangular waveguide. TE mode is dominant in waveguides

TM (Transverse Magnetic Modes)

- In this mode, the magnetic field is purely transverse to the direction of propagation, whereas the electric field is not

Hz=0 and Ez≠0

- Magnetic field exists in a plane transverse to the direction of propagation of wave
- Electric field has some component in the transverse plane and also some along the direction of propagation
- A rectangular waveguide supports both TE modes and TM modes but not TEM modes, higher order modes are also supported by TE and TM modes
- TE and TM modes also have a limited bandwidth, none of these modes can propagate at frequencies below a minimum frequency known as the cutoff frequency.

(b)Which modes are supported by rectangular waveguides, write down the expression for propagation constant and define each of the constants in the expression. [7+3]
Answer-

A rectangular waveguide supports both TE modes and TM modes but not TEM modes, higher order modes are also supported by TE and TM modes

$$\boldsymbol{\gamma} = \sqrt{(\,\boldsymbol{j\omega}\ \mu(\boldsymbol{\sigma} + \boldsymbol{j\omega}\ \epsilon))} = \boldsymbol{\alpha} + \boldsymbol{j\beta}$$

γ is called the intrinsic propagation constant of a medium

α = attenuation constant in nepers per meter

β = phase constant in radians per meter

σ= conductivity of the medium in mhos per meter

$\epsilon = \textbf{dielectric permittivity}$

μ= **magnetic permeability**

$\boldsymbol{\omega} = \textbf{frequency in radians per sec}$

for a uniform plane wave propagating in a lossless dielectric medium, conductivity of medium becomes zero ($\sigma = 0$), the characteristics of wave propagation would become ($\alpha = 0$) from above equation, means attenuation becomes zero.

Q3. Derive the solution of field equations for TE mode in a rectangular waveguide. [10]

Answer-

The TE modes in a rectangular waveguide are characterized by $E_z = 0$. In other words, the z component of the magnetic field, H_z, must exist in order to have energy transmission in the guide. Consequently, from a given Helmholtz equation, H_z is not equal to zero, so:

$$\nabla^2 H_z = \gamma^2 H_z$$

A solution will be of the form

$$H_z = (\mathrm{Am}\ \mathrm{Sin}\,(\tfrac{m\pi x}{a}) + \mathrm{Bm}\ \mathrm{Cos}(\tfrac{m\pi x}{a}))(\mathrm{Cn}\ \mathrm{Sin}(\tfrac{n\pi y}{b}) + \mathrm{Dn}\ \mathrm{Cos}(\tfrac{n\pi y}{b}))\ e^{-j\beta_g z}$$

The Maxwell equations for a lossless dielectric medium becomes in frequency domain as:

$$\nabla X E = -j\omega\,\mu H$$

$$\nabla X H = j\omega \epsilon E$$

Suppose, i,j,k are unit vectors along X, Y and Z directions

Electric field Vector E= $E_x\, i + E_y\, j + E_z\, k$

Magnetic field Vector H= $H_x\, i + H_y\, j + H_z\, k$

On expanding the curl equations

- $\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} = -\, j\omega\, \mu H_x$
- $\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} = -\, j\omega\, \mu H_y$
- $\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} = -\, j\omega\, \mu H_z$

- $\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} = j\omega\, \epsilon E_x$
- $\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} = j\omega\, \epsilon E_y$
- $\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} = j\omega\, \epsilon E_z$

If we assume exponential variation of fields with z then,

$\frac{\partial}{\partial z}$ can be replaced by $-j\beta_g$

E_z=0 for TE modes

Also, from, Case II (Propagation Case)

$\omega^2\, \mu\epsilon > k_c^2$

$\gamma_g = \pm j\beta g = \sqrt{k_c^2 - \omega^2\, \mu\epsilon}$

$k_c^2 = \omega^2\, \mu\epsilon - \beta_g^2$

$$\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} = -j\omega\, \mu H_x$$

$$\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} = -j\omega\, \mu H_y$$

$$\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} = -j\omega\, \mu H_z$$

$$\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} = j\omega\, \epsilon E_x$$

$$\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} = j\omega\, \epsilon E_y$$

$$\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} = j\omega\,\epsilon E_z$$

$$E_x = \frac{-j\omega\mu}{k_c^2}\frac{\partial H_z}{\partial y}$$

$$E_y = \frac{j\omega\mu}{k_c^2}\frac{\partial H_z}{\partial x}$$

$$E_z = 0$$

$$H_x = \frac{-j\beta_g}{k_c^2}\frac{\partial H_z}{\partial x}$$

$$H_y = \frac{-j\beta_g}{k_c^2}\frac{\partial H_z}{\partial y}$$

$$H_z = (\text{Am Sin}(\frac{m\pi x}{a}) + \text{Bm Cos}(\frac{m\pi x}{a}))(\text{Cn Sin}(\frac{n\pi y}{b}) + \text{Dn Cos}(\frac{n\pi y}{b}))\ e^{-j\beta_g z}$$

The boundary conditions are applied to the field equations such that the tangent E field is zero at a surface.

- Since $E_x = 0$, then $\frac{\partial H_z}{\partial y} = 0$ at y = 0, b. Hence Cn = 0.
- Since $E_y = 0$, then $\frac{\partial H_z}{\partial x} = 0$ at $x = 0, a$ Hence Am=0

On substitution of H_z the other components become

$$E_x = \frac{-j\omega\mu}{k_c^2}\frac{\partial H_z}{\partial y}$$

$$E_y = \frac{j\omega\mu}{k_c^2}\frac{\partial H_z}{\partial x}$$

$$E_z = 0$$

$H_X = \frac{-J\beta_g}{kc^2}\frac{\partial HZ}{\partial X}$

$H_y = \frac{-J\beta_g}{kc^2}\frac{\partial HZ}{\partial Y}$

$E_x = E_{0x} \, Cos\,(\frac{m\pi x}{a}) Sin(\frac{n\pi y}{b}) e^{-j\beta_g z}$
$E_y = E_{0y} \, Sin\,(\frac{m\pi x}{a}) Cos(\frac{n\pi y}{b}) e^{-j\beta_g z}$
$E_z = 0$
$H_x = H_{0x} \, Sin\,(\frac{m\pi x}{a}) Cos(\frac{n\pi y}{b}) e^{-j\beta_g z}$
$H_y = H_{0y} \, Cos\,(\frac{m\pi x}{a}) Sin(\frac{n\pi y}{b}) e^{-j\beta_g z}$
$H_z = H_{0z} \, Cos\,(\frac{m\pi x}{a})\, Cos(\frac{n\pi y}{b}) e^{-j\beta_g z}$

Q4. A rectangular waveguide is designed to operate in TE10 mode at a frequency of 10GHz.It is desired that frequency of operation to be at least 15% above cut-off frequency of the propagating and 20% below cut-off frequency of next higher mode. Determine the dimensions of the waveguide. [10]

Answer-

Given

Mode = TE_{10}

Operating frequency = 10 GHz

If operating frequency is 15% above the cut-off frequency ,then

$1.15 f_{c\,1}$ = 10GH

$f_{c\,1} = \frac{10}{1.15}$ GHz

Where $f_{c\,1}$ is the cut -off frequency of TE_{10} mode

For dominant TE_{10}mode

$f_{c\,1} = \frac{c}{2a}$

a = $\frac{c}{2 f_{c\,1}}$

a = $\frac{3\times10^8\times1.15}{2\times10\times10^9}$

a = 0.01725 m

a= 1.725cm

Another condition is that operating frequency is 20% below cut-off frequency of next higher mode. The next higher mode is TE_{11}

Thus 0.80f_{c2}= 10GHz

Where f_{c2} is the cut-off frequency of TE_{11}mode

f_{c2}= $\frac{10}{0.8}$ GHz

The cut-off frequency for TE_{11} mode is given by

$$f_{c2} = \frac{c}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

Since m=n=1

$$f_{c2} = \frac{c}{2}\sqrt{\frac{1}{a^2} + \frac{1}{b^2}}$$

or $\frac{1}{a^2} + \frac{1}{b^2} = \left(\frac{2f_{c2}}{c}\right)^2$

substitute the value of a and f_{c2} ,we get

$$\frac{1}{(1.725)^2} + \frac{1}{b^2} = \left(\frac{2\times10\times10^9}{3\times10^8\times0.80}\right)^2$$

$\frac{1}{b^2}$ = 6943.55

b = 0.012 m

b = 1.2 cm

Thus dimension of the waveguide are

a = 1.725 cm

b = 1.2 cm

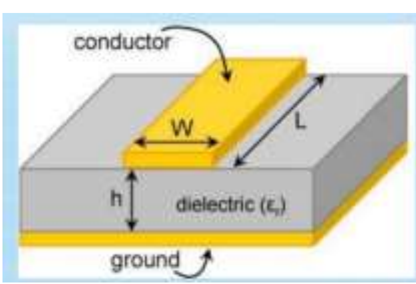
Q5. Explain the characteristics of planar transmission lines. Define Microstrip lines and Strip lines along with their structures and field patterns. [10]

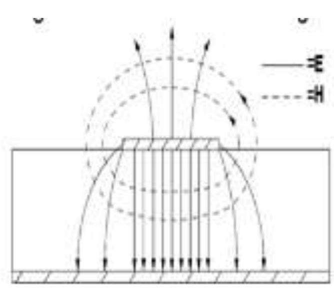
Answer-

Planar transmission line is a type of connector used in RF and microwave PCBs. The planar transmission lines in microwave and RF circuits are not only interconnection paths, but also perform as lumped elements. Passive elements, such as inductors and capacitors, can be realized by arranging planar transmission lines in a specific fashion. This method mitigates the crowding of components in circuits and makes the circuit more affordable. The use of planar transmission lines can also help in matching the impedance between the source and load.

Microstrip lines-

The Microstrip line has become the best known and most widely used planar transmission line for RF and Microwave circuits**.** This popularity and widespread use are due to its planar nature, ease of fabrication using various processes, easy integration with solid-state devices, good heat sinking, and good mechanical support A microstrip is a type of transmission line that consists of a conductor fabricated on dielectric substrate with a grounded plane.



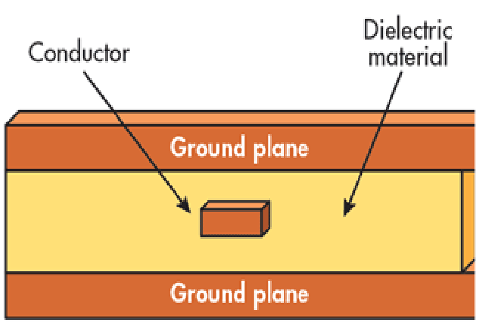


Structure of Microstrip Line **Field Pattern**

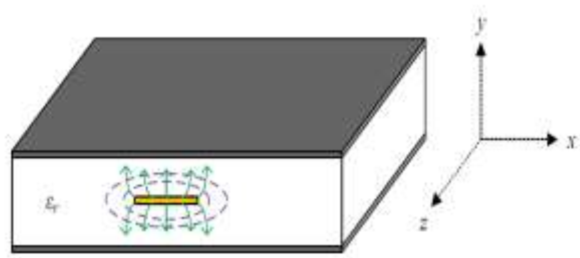
A microstrip line consists of a conductor of width W, a dielectric substrate of of thickness h and permittivity ε_r. The presence of the dielectric concentrates the field lines in the region between the between the conductor and the ground plane, with some fraction being in the air region above the conductor, leading to quasi-TEM modes of propagation. In simple terms, Microstrip is the printed circuit version of a wire over a ground plane, and thus it tends to radiate as the spacing between the ground plane and the strip increases. A substrate thickness of a few percent of a wavelength (or less) minimizes radiation without forcing the strip width to be too narrow. The Microstrip line is dispersive, with increasing frequency, the effective dielectric constant gradually climbs towards that of the substrate, so that the phase velocity gradually decreases. A microstrip line consists of a conductor of width W, a dielectric substrate of thickness h and permittivity ε_r. The presence of the dielectric concentrates the field lines in the region between the between the conductor and the ground plane, with some fraction being in the air region above the conductor, leading to quasi-TEM modes of propagation.

Striplines

Stripline transmission line requires three layers of conductors where the internal conductor is commonly called the "hot conductor," while the other two, always connected at signal ground, are called "cold" or "ground" conductors. The hot conductor is embedded in a homogeneous and isotropic dielectric, of dielectric constant. The dielectric completely surrounds the hot conductor.



Structure of Strip line



Field Pattern

Stripline is more insensitive to lateral ground planes of a metallic enclosure, since the electromagnetic field is strongly contained near the center conductor and the top–bottom ground planes. Because the region between the two outer plates of Stripline contains only a single medium, the phase velocity and the characteristic impedance of the dominant mode TEM do not vary with frequency. Stripline is often required for multilayer circuit boards because it can be routed between the layers. In a Stripline, the return current path for a high frequency signal trace is located directly above and below the signal trace on the ground planes. The high frequency signal is thus contained entirely inside the PCB, minimizing emissions, and providing natural shielding against incoming spurious signals.It is a combination of two wire lines and co-axial lines.These are basically planar transmission lines and are widely used for frequencies from 100 MHz to 100 GHz. A Strip line consists of a central thin conducting strip of width W which is greater than its thickness t. It is placed inside the low loss dielectric (ε_r) substrate of thickness b between two wide ground plates.The width of the ground plates is five times greater than the spacing between the plates.The fundamental and dominant mode in Strip lines is TEM mode.

SET: D

Q1. (a) Write down the advantages and disadvantages of Microwaves.

Answer:

Advantages:

- Wider bandwidth due to higher frequency
- Smaller component size leading to smaller systems
- Better resolution for radars due to smaller wavelengths
- High antenna gain possible in a smaller space
- Able to Transmit Large Quantities of Data
- Microwave radio communications do not require too many repeaters
- Low power consumption as the signals are of higher frequencies
- Effect of fading gets reduced by using line of sight propagation
- Satellite and terrestrial communications with high capacities are possible
- Miniature microwave components can be developed
- Effective spectrum usage with wide variety of applications in all available frequency ranges of operation

Disadvantages:

- Cost of equipment or installation cost is high
- Electromagnetic interference may occur
- Variations in dielectric properties with temperatures may occur
- Signal losses may be high
- Requires use of high-speed semiconductor devices

(b) Write down the medical and civil applications of Microwave . [5+5]

Civil Applications include:

- Air traffic control of commercial applications
- Aircraft landing system
- Direction findings
- Motion detectors
- Vehicle collision avoidance
- Distance measurement
- Surveillance
- Marine navigation
- Radio astronomy

- Terrestrial and satellite communication links

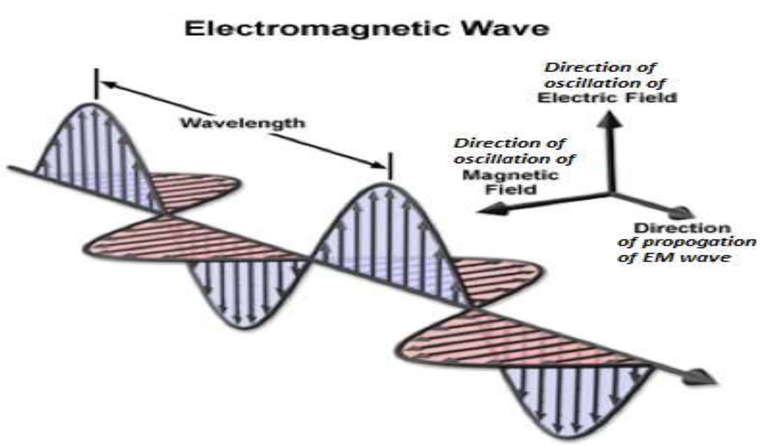
Medical Applications include:

- Monitoring heartbeat
- Lung water detection
- Tumour detection
- Regional hyperthermia
- Therapeutic applications
- Local heating
- Microwave tomography
- Microwave Acoustic imaging

Q2. Explain how an Electromagnetic wave propagates. Describe the four Maxwell equations in integral and differential forms [10]

Answer-
Electromagnetic waves (EM) consist of synchronized oscillations of electric and magnetic fields. The electric field and magnetic field oscillates perpendicular to each other and the direction of propagation of the EM wave is perpendicular to both of the direction of oscillation of the magnetic field and direction of oscillation of electric field. As seen in the figure, Electric field, Magnetic field and direction of wave propagation are all perpendicular to each other.

Maxwell equations in integral and differential forms



Maxwell equations in integral and differential forms

These are the four Maxwell equations in **integral form**

- Gauss' law:

$$\int_S \mathbf{E} \cdot d\mathbf{a} = \frac{1}{\epsilon_0} \int \rho \, dV$$

- Gauss' law for magnetism:

$$\int_S \mathbf{B} \cdot d\mathbf{a} = 0$$

- Faraday's law:

$$\int_{\text{loop}} \mathbf{E} \cdot d\mathbf{s} = -\frac{d}{dt} \int_S \mathbf{B} \cdot d\mathbf{a}$$

- Ampère's law:

$$\int_{\text{loop}} \mathbf{B} \cdot d\mathbf{s} = \mu_0 \int_S \mathbf{J} \cdot d\mathbf{a} + \epsilon_0 \mu_0 \frac{d}{dt} \int_S \mathbf{E} \cdot d\mathbf{a}.$$

`

Four Maxwell equations in **differential form** are

$$\nabla . D = \rho$$

$$\nabla . B = 0$$

$$\nabla X E = -\frac{\partial \mathrm{B}}{\partial \mathrm{t}}$$

$$\nabla X H = J + \frac{\partial \mathrm{D}}{\partial \mathrm{t}}$$

Q3. (a) Explain mathematically why do the TEM modes do not propagate in a waveguide.

Answer-
Ampere's law states that the line integral of H about any closed path is equal to the current enclosed by that path.

$$\oint \mathrm{H.dl} = \mathrm{I}$$

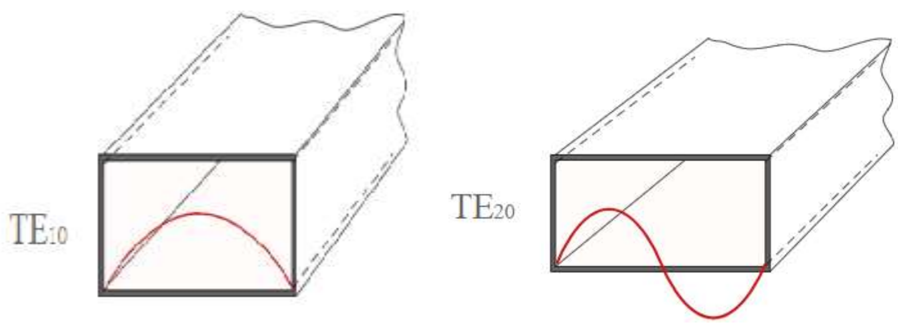
When I is the current that must be supported by the center conductor of a coaxial line. Thus we can say that TEM mode can exist in the two conductor system. We can understand this fact like in hollow waveguide cannot support a TEM Mode since two dimensions the cross section of such guide ia an area completely enclosed by a conducting wall. It is well known result that the electromagnetic field within such space must be zero. This is the Principle of Faraday cage. An electrostatic potential can be established .This clearly demonstrates that the TEM Mode can only exist in the two conductor system not in hollow waveguide because the centre conductor does not exist.

(b) What are dominant and degenerate modes. Draw the field patterns for TE_{10} and TE_{20} modes.

Answer- [7+3]

Whenever two or more modes have the same cutoff frequency, they are said to be degenerate modes. In a rectangular waveguide the corresponding TE_{mn} and TM_{mn} modes are always degenerateThe TE_{10} mode has the longest operating wavelength and is designated as the dominant mode. It is the mode for the lowest cut off frequency that can be propagated in a waveguideFor TM modes the dominant mode is $TM_{11.}$

Draw the field patterns for TE_{10} and TE_{20} modes



Q4. A Coaxial line has the following physical dimensions.
Diameter of inner conductor =0.49cm
Inner diameter of outer conductor =1.1 cm
Polyethylene dielectric $\varepsilon_r = 2.3$

Calculate

3) Inductance per unit length
4) Capacitance per unit length
5) Characteristic Impedance [10]

Answer-

$ln\frac{D}{d} = ln\frac{1.1}{0.49}=$

1) L= $2 \times 10^{-7} \ln \frac{D}{d} = (2 \times 10^{-7})X0.808 = 1.616 \times 10^{-7} H/m$

2) C= $55.56 \times 10^{-12} \frac{\epsilon_r}{In\frac{D}{d}}$ =103.83 pF/m

3) $R_{o=} \frac{60}{\sqrt{\epsilon}} ln \frac{D}{d} =$ 32.105 Ω/m Ans.

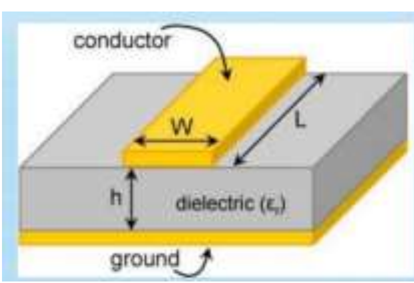
Q5. Explain the construction of Microstrip lines and Striplines along with their characteristics. Write down the names of different types of planar transmission lines. [10]

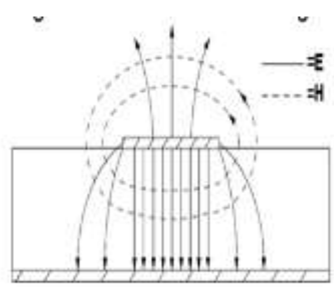
Answer-

Construction of Microstrip lines and Striplines along with their characteristics

Microstrip lines-

The Microstrip line has become the best known and most widely used planar transmission line for RF and Microwave circuits**.** This popularity and widespread use are due to its planar nature, ease of fabrication using various processes, easy integration with solid-state devices, good heat sinking, and good mechanical support A microstrip is a type of transmission line that consists of a conductor fabricated on dielectric substrate with a grounded plane.



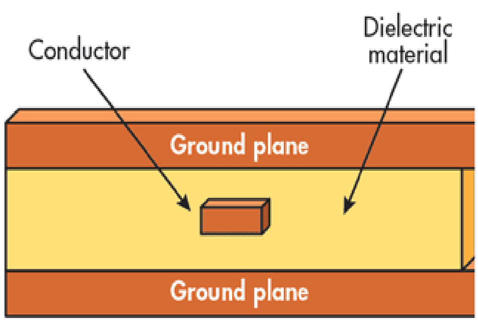


Structure of Microstrip Line **Field Pattern**

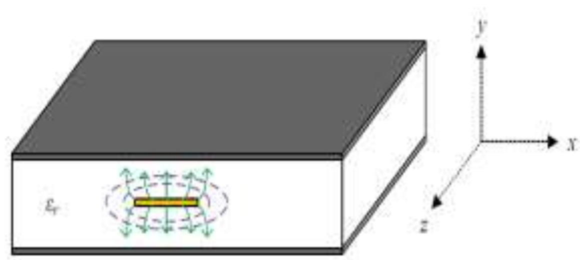
A microstrip line consists of a conductor of width W, a dielectric substrate of of thickness h and permittivity ε_r. The presence of the dielectric concentrates the field lines in the region between the between the conductor and the ground plane, with some fraction being in the air region above the conductor, leading to quasi-TEM modes of propagation. In simple terms, Microstrip is the printed circuit version of a wire over a ground plane, and thus it tends to radiate as the spacing between the ground plane and the strip increases. A substrate thickness of a few percent of a wavelength (or less) minimizes radiation without forcing the strip width to be too narrow. The Microstrip line is dispersive, with increasing frequency, the effective dielectric constant gradually climbs towards that of the substrate, so that the phase velocity gradually decreases. A microstrip line consists of a conductor of width W, a dielectric substrate of thickness h and permittivity ε_r. The presence of the dielectric concentrates the field lines in the region between the between the conductor and the ground plane, with some fraction being in the air region above the conductor, leading to quasi-TEM modes of propagation.

Striplines

Stripline transmission line requires three layers of conductors where the internal conductor is commonly called the "hot conductor," while the other two, always connected at signal ground, are called "cold" or "ground" conductors. The hot conductor is embedded in a homogeneous and isotropic dielectric, of dielectric constant. The dielectric completely surrounds the hot conductor.



Structure of Strip line



Field Pattern

Stripline is more insensitive to lateral ground planes of a metallic enclosure, since the electromagnetic field is strongly contained near the center conductor and the top–bottom ground planes. Because the region between the two outer plates of Stripline contains only a single medium, the phase velocity and the characteristic impedance of the dominant mode TEM do not vary with frequency. Stripline is often required for multilayer circuit boards because it can be routed between the layers. In a Stripline, the return current path for a high frequency signal trace is located directly above and below the signal trace on the ground planes. The high frequency signal is thus contained entirely inside the PCB, minimizing emissions, and providing natural shielding against incoming spurious signals.It is a combination of two wire lines and co-axial lines.These are basically planar transmission lines and are widely used for frequencies from 100 MHz to 100 GHz. A Strip line consists of a central thin conducting strip of width W which is greater than its thickness t. It is placed inside the low loss dielectric (ε_r) substrate of thickness b between two wide ground plates.The width of the ground plates is five times greater than the spacing between the plates.The fundamental and dominant mode in Strip lines is TEM mode.

Write down the names of different types of planar transmission lines

Different types of planar transmission lines

- Striplines
- Microstriplines
- Slot lines
- Coplanar Lines

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RAMNAGARIA, JAGATPURA, JAIPUR - 302017

Branch : Electronics & Comm. Engg. III B.Tech. V SEM 2021-22
(Microwave Theory & Tech) **Award List**
SUB MTT **1st Mid Term Test** MM. 30

SR. NO.	EXAM ROLL NO.	STUDENT'S NAME	MARKS OBTAINED Mid Term Marks (24)	Assignment Marks (6)	Total (30)
1	19ESKEC112	RASHI SHARMA	19	5	24
2	19ESKEC113	RITRIK ROHRA	15	6	21
3	19ESKEC115	ROSHAN KUMAR JHA	21	5	26
4	19ESKEC116	RUDRA PRATAP SINGH	13	NS	13
5	19ESKEC117	SALONI CHHAPARWAL	19	6	25
6	19ESKEC118	SAMRITI DEVI	21	6	27
7	19ESKEC119	SANJANA JAWARIA	21	6	27
8	19ESKEC120	SANJAY KUMAR	21	6	27
9	19ESKEC121	SARIM UR REHMAN	18	6	24
10	19ESKEC122	SARTHAK BHATIA	19	6	25
11	19ESKEC123	SARTHAK SHARMA	18	5	23
12	19ESKEC124	SAURABH CHOUDHARY	17	NS	17
13	19ESKEC125	SAURABH SINGH JAT	21	5	26
14	19ESKEC126	SHARAD SOURABH JHA	21	6	27
15	19ESKEC127	SHIV PRATAP SINGH CHOUHAN	19	6	25
16	19ESKEC128	SHIVAM GARG	20	6	26
17	19ESKEC129	SHIVANSH DOSI	AB	5	5
18	19ESKEC130	SHUBHAM JAIN	21	6	27
19	19ESKEC131	SIDDHARTH HARSHIT	21	6	27
20	19ESKEC132	SIDDHI SAXENA	20	6	26
21	19ESKEC133	SIMRAN RATHORE	21	6	27
22	19ESKEC134	SOMIL JAIN	20	6	26
23	19ESKEC135	SONALI NISHAD	20	5	25
24	19ESKEC136	SOUMYA AGARWAL	21	6	27
25	19ESKEC137	SOURABH VYAS	16	5	21
26	19ESKEC138	SUHANI JAIN	19	5	24
27	19ESKEC139	SUMIT GUPTA	19	6	25
28	19ESKEC140	TANISHA JAIN	20	6	26

HARSHAL NIGAM
Name of Examiner

Head of Deptt.
SKIT/ Section EC-C
Page [1] of [1]

Signature

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Microwave Theory & Tech.
SUB MTT

1st Mid Term Test

MM. 30

SR. NO.	EXAM ROLL NO.	STUDENT'S NAME	MARKS OBTAINED Mid Term Marks (24)	Assignment Marks (6)	Total (30)
29	19ESKEC141	TANU GAMBHIR	21	6	27
30	19ESKEC143	TANVI NEMNANI	21	6	27
31	19ESKEC145	TUSHAR MITTAL	20	NS	20
32	19ESKEC146	UDIESHA GAUTAM	20	6	26
33	19ESKEC147	UTSAV JAIN	19	5	24
34	19ESKEC148	V VIGHNESH RAJAN	20	NS	20
35	19ESKEC149	VANSH AGRAWAL	18	5	23
36	19ESKEC150	VIDHI SUKHNANI	19	6	25
37	19ESKEC151	VIKAS MITTAL	20	5	25
38	19ESKEC152	VINAYAK GUPTA	21	5	26
39	19ESKEC153	VISHAL DANDIA	21	6	27
40	19ESKEC155	YAMAN KUMAR MALIK	21	6	27
41	19ESKEC156	YASH DUBEY	20	6	26
42	19ESKEC157	YASH RAJ MISHRA	19	5	24
43	19ESKEC158	YATHARTH JAIN	19	6	25
44	19ESKEC159	YAYATI	21	6	27
45	19ESKEC160	YOGESH SHARMA	19	6	25
46	19ESKEC300	MANISH MANOHAR CHANDWANI	21	6	27
47	19ESKEC301	MOHIT KUMAWAT	21	6	27
48	19ESKEC302	SMRITI SHARMA	21	5	26
49	19ESKEC303	GAURAV KUMAR	20	5	25
50	19ESKEC304	GAURAV SINGH CHOUHAN	18	5	23

HARSHAL NIGAM
Name of Examiner

Head of Deptt.
SKIT/ Section EC-C
Page [1] of [1]

Signature of Examiner

18. Tutorial Sheets (with EMD Analysis)

Course Name-Microwave Theory &Techniques

Course code- 5EC04-05 Topic –Waveguides and Network Analysis

Q1. A Rectangular waveguide is filled by dielectric material of εr=9 and has inside dimension of 7* 3.5 cm. It operates in the dominantTE10 mode Determine

a) Cut off Frequency
b) Phase velocity in guide at frequency 2GHz.
c) Guide wavelength at same frequency

Q2. A Coaxial line has the following physical dimensions.

Diameter of inner conductor =0.49cm

Inner diameter of outer conductor =1.10cm

Polyethylene dielectric $\varepsilon_r = 2.3$

Calculate:

1) Inductance per unit length
2) Capacitance per unit length
3) Characteristic Impedance
4) Velocity of propagation

Q3. A rectangular waveguide is designed to operate in TE_{10} mode at a frequency of 10GHz.It is desired that frequency of operation to be at least 15% above cut-off frequency of the propagating and 20% below cut-off frequency of next higher mode. Determine the dimensions of the waveguide.

Q4. An air filled hollow rectangular waveguide of 150m long and is tapped at the end with a metal plate .If a short pulse of frequency 7.2GHz is introduced into the input end of the guide. How long it takes the pulse to return to the input end. Assume Cut –off Frequency f_c is 6.5GHz.

Q5. Determine the Cut-off wavelength for the dominant mode in a rectangular waveguide of breadth 10cm.For a 2.5 Ghz signal propagated in this waveguide in the dominant mode, calculate the guide wavelength, the group and the phase velocities?

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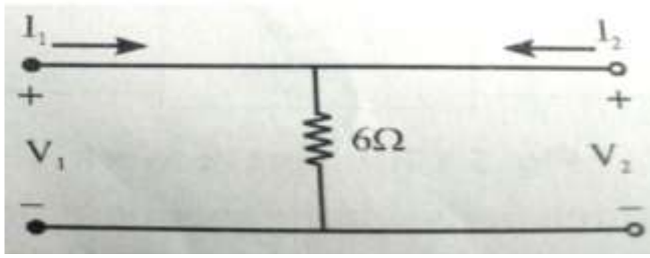
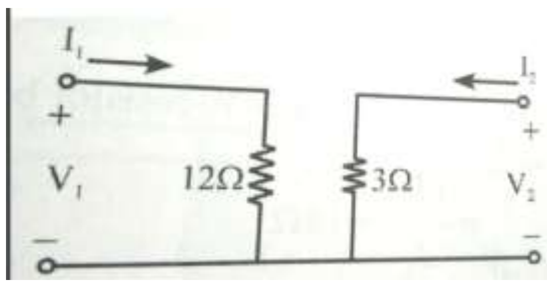
Q6. An air filled circular waveguide is to be operated at a frequency of 6GHz and is to have dimensions such that fc=0.8f for TE_{11} mode .Determine the diameter of the waveguide and guide wavelength.

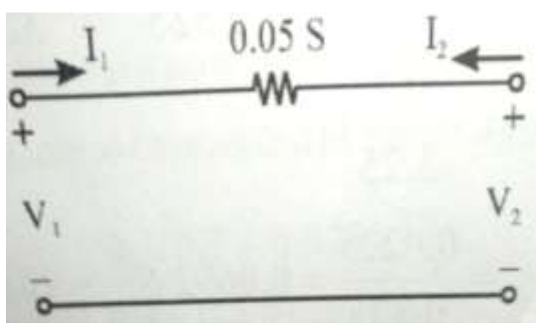
Q7. Find the impedance parameters for two port network



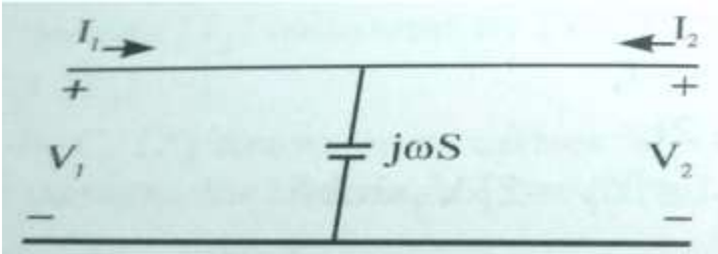
Q8. Find the impedance parameters for two port network



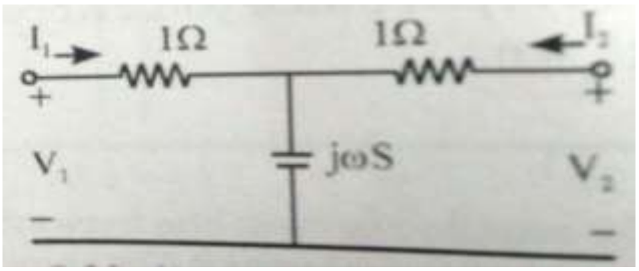
Q9. Find the admittance parameters of the circuit shown in figure



Q10. Determine the transmission parameters of the network



Q11. Determine the transmission parameters of the network?



Q12. Prove that for a reciprocal, lossless, three port network, that all ports cannot be perfectly matched

Q13. Consider two port network with individual scattering matrices [S^A] and [S^B].Show that the cascade of these two networks is given by-

$$S_{21} = \frac{S_{21^A} S_{21^B}}{1 - S_{22^A} S_{11^B}}$$

Assume $a_2=0$ (perfectly matched)

Q14. A two port network has the scattering matrix

$$[S] = \begin{bmatrix} 0.15\angle 0 & 0.85\angle -45 \\ 0.85\angle 45 & 0.2\angle 0 \end{bmatrix}$$

Verify that the network is reciprocal and lossless .If port(2) is terminated with matched load .What is the return loss at port (1). If port (2) is terminated with a short circuit. What is the return loss at port (1)

Q15. If the impedance matrix of a device is-

$$\begin{bmatrix} 4 & 2 \\ 2 & 4 \end{bmatrix}$$

Find out the Scattering matrix

Tutorial Sheet (EMD Analysis)

Q No.	**Cos**	**Remarks**
1	1	E
2	1	E
3	1	D
4	1	D
5	1	M
6	1	M
7	2	E
8	2	E
9	2	E
10	2	E
11	2	E
12	2	M
13	2	M
14	2	D
15	2	E

**E: Easy, M: Moderate, D: Difficult

Faculty Members of Concerned Subject
Dr. Shubhi Jain
Mr. Harshal Nigam

19. Technical Quiz Papers

(Answer in single line for no option questions)

1. At microwave frequencies, the waveguides are preferred in comparison to transmission lines for transporting EM energy because

   a) waveguides have larger bandwidth
   b) waveguides support TEM mode
   c) waveguides have lower signal attenuation
   d) None of these

2. What is the purpose of waveguide flanges?

   ----

3. What is a waveguide?

   ----

4. The Excessive use of cell phone over long period of time may cause:

   a) Hearing problem
   b) Increase in cancer risk
   c) Irreversible infertility
   d) All Above

5. What is standing wave ratio? What are the important controls of a VSWR Meter?

   ----

6. The fundamental mode in a rectangular waveguide with a= 4 cm and b= 2 cm is:

   a) TM01
   b) TM10
   c) TE00
   d) TE10

7. Why the waveguide is air filled?

----

8. Name various methods that can be used to measure frequency / Wavelength.

----

9. What is full Scale Deflection?

----

10. The value of voltage standing wave ratio (VSWR) is approximately in which range for better transmission

----

11. For a matched transmission line VSWR Value is

   a. 0
   b. 2
   c. 1
   d. infinite

12. What is the use of isolator in Microwave Test Bench.

----

13. Which modulation we do in Klystron to observe square waves on CRO and What is the need of modulation?

----

14. What is the range for X band Frequency in microwaves (in GHz)

   a. 1-2
   b. 2-4
   c. 8-12
   d. 12-16

15. Reflection coefficient at Port ‘n’ in an n-port network is equal to Snn.

   a. Always true
   b. True only when all ports are short circuited
   c. True only when all ports are open circuited
   d. True only when all ports are terminated with matched load

20. Assignments (As Per RTU QP Format)

Assignment-1

Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur

B.Tech/Semester: III/ V **Branch: ECE**
Subject: MTT **Subject Code: : 5EC4-05**

PART A (Short Answer Questions)

Q.1 Draw the field lines for-
1. TE_{10} mode
2. TE_{20} mode

Q.2 What are Rectangular Waveguides.

Q.3 What is the relation between ABCD matrix and Impedance Matrix.

Q.4 What are Dominant and Degenerate modes for Rectangular Waveguide.

Q.5 Why TEM mode does not exist in rectangular waveguides

Q.6 What are the different modes that exist in waveguides

Q.7 What are two types of losses in Rectangular Waveguide.

Q.8 What are microwaves, write down their applications

Q.9 Explain the terms VSWR and Reflection loss for Microwaves

Q.10 Define the terms Characteristic and Wave Impedance for Microwaves

PART B

Q.1 A Rectangular waveguide is filled by dielectric material of $\varepsilon r=9$ and has inside dimension of $7\times 3.5\ cm^2$. It operates in the dominant TE_{10} mode Determine:-

a- Cut off Frequency

b- Phase velocity in guide at frequency 2GHz.

c- Guide wavelength at same frequency

Q.2 Derive the field equations for TM modes in Rectangular waveguides

Q.3 Derive field equations for TE modes in Rectangular waveguides.

Q.4 Derive the expressions for:-

a) Phase Velocity b) Group Velocity

Q.5 Explain S parameters, and derive the expressions for incident and reflected powers in n^{th} port

PART C

Q.1 Describe the mathematical model of Maxwell equations for the analysis of Microwave Transmission line

Q.2 Derive the relation between S parameters and ABCD parameters

Q.3 What are coaxial lines, explain their structure and their applications

Q.4 Describe the properties of scattering parameters with required derivations and explanations.

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Assignment-2

Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur

B.Tech/Semester: III/ V **Branch: ECE**
Subject: MTT **Subject Code: : 5EC4-05**

PART A (Short Answer Questions)

Q.1 Draw the structure for a
a) Bethe Hole Directional Coupler
b) Two hole Coupled directional coupler
Q.2 Give the drawbacks of klystron amplifiers.
Q.3 What are the importance of Attenuators in measurement?
Q.4 Draw a neat and clean diagram for
a) Impatt Diode
b) Schottky diode
Q5. Draw the following
a) E-Plane Tee b) H-plane Tee c) Magic Tee
Q6. Draw the Structure of MESFET and MOSFET
Q7. Draw a 3dB Branch line coupler with coupled and isolated ports
Q8. Draw the diagram of the following microwave components.
a) Wilkinson power divider b) Ring Resonator
Q9. What are the applications of Reflex klystron?
Q10. Define transducer power gain for microwave Amplifier

PART B (Problem Solving Questions)

Q1. A Two Cavity Klystron amplifier has following parameters
$V_o = 1000V$
$R_o = 40K\ \Omega$

I_o =25mA

F= 3GHz

Gap spacing in both cavity d=1mm

Spacing between the two cavity L=4cm

Effective shunt impedance excluding beam loading R_{sh}=30KΩ

Determine

a) Input gap voltage to give Maximum Voltage V_2.
b) Voltage gain, neglecting the beam loading in Output Cavity.
c) Efficiency of Amplifier.

Q2- A travelling wave tube has the following parameters

Beam current I_o = 50mA

Beam Voltage V_o= 2.5KV

Characteristic impedance of Helix Z_0 = 6.75 K Ω

Circuit Length N=45

Frequency f=8GHz

Determine

a) Gain Parameter C.
b) Output Power gain in dB
c) All four Propagation Constant

Q3- In an O-type travelling wave tube operates at 8GHz.The slow wave structure has a pitch angle 4.4 ° and attenuation Constant of $2N_P$/m. Determine the Propagation Constant γ of the travelling wave in the tube.

Q4- A frequency agile coaxial magnetron has the following operating parameters.

Pulse Duration τ = 0.30, 0.60, 0.90 µsec.

Duty Cycle DC= 0.0011

Pulse on target N= 15 per scan

Compute the Following

a) Agile excursion
b) Pulse to pulse frequency separation
c) Signal Frequency
d) Time for N pulses
e) Agile rate

Q5- An X-band pulsed cylindrical magnetron has V_0 = 30KV, I_o =80A, B_0 = 0.01 wb/m^2, a= 4cm, b=8 cm. Calculate.

1) Cyclotron angular Frequency
2) Cut-off voltage
3) Cut-off magnetic Flux Density

PART C (Descriptive/Design Questions)

Q1. What is PIN Diode. Describe its application as a single pole switch and transmission type switched line phase shifter.

Q2. Explain velocity modulation and bunching process in two cavity klystron. Derive the expression for bunching parameters.

Q.3 How Gunn diode is able to exhibit Negative Differential Conductivity with its V-I Characteristics. Draw different modes of operation Realizable with Gunn diode.

Q4. What are mixers. Explain single ended and double ended mixers

21. Details of Efforts Made to Fill Gap Between COs and POs (Expert Lecture/Workshop/Seminar/Extra Coverage in Lab etc

The gap between CO and PO were filled by following efforts:

Efforts made to fill the gap

1. **Beyond Syllabus Topics**
   - Study of E and H plane Tee, Parallel Coupled Microstripline and Stripline
   - Assemble Microwave test bench using Microwave components
2. Students are advised to enroll in related MOOC courses
3. The identification of different Microwave components was carried out by explaining the designs of components on HFSS software also, which is covered under "RFS Lab" running in this semester only. This gave a better understanding and design concepts for Microwave components along with practical exposure to students
4. The measurement of different Microwave parameters is mostly done on Microwave test bench, so the theory of Microwave test bench is also introduced as a beyond syllabus topic to give a better understanding
5. A lecture was conducted during FDP "Emerging Tools and Techniques in Communication Systems" on 14 September 2020 by Prof. Ananjan Basu, IIT Delhi on Recent Microwave Antenna Designs, on different Microwave systems and design of different Microwave components and Antennas which would be helpful for students to clear their concepts
6. Analysis of Microwave sources including Gunn diode and Klystron was also covered in "Microwave Lab" to give a better understanding to students
7. NPTEL Course related to "Microwave Theory and Techniques" has also been joined by students, the video lectures and assignments will give a better understanding of concept to students

Microwave Theory and Techniques

Known gaps in curriculum

Based on mapping of CO PO/PSO it is observed that this course is well mapped with the identification and formulation of complex engineering problems but there is a gap in the designing of a certain measurement tool using different microwave components. The gaps can be

Fourth Unit give introduction about Microwave Transmission lines. So it is necessary to give idea about E, H Plane Tee as they are the basic microwave components. The study of Magic tee given in syllabus is complete only after studying E and H plane tees. The study of Parallel coupled microstriplines and striplines are also required as it is used for the design of Coupled line couplers.

Microwave Test Bench is precision microwave systems. It consists of rectangular waveguide components .They are used for test and measurement of various microwave modules. The study of test bench and the working of each and every component of test bench are very much required to carry out microwave measurements in the lab.

Topics are covered (taught) beyond syllabus to bridge the gap between theoretical knowledge and practical applicability of the subject. The beyond Syllabus topics helps to achieve most of the programm outcomes.

(Beyond Syllabus Topics)

B.1. Assemble Microwave test bench using Microwave components

B.2. Understand E and H plane Tee, Design characteristics of Parallel Coupled Micro stripline and Stripline

Mapping of Beyond Syllabus with PO ,PSO

Beyond syllabus↓	**PO1**	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO 2**
5EC4-05 B1	2	1	3	2	-	-	-	-	-	1	-	3	2	1
5EC4-05 B2	3	3	2	-	-	-	-	-	-	1	-	3	2	1

Unit-I

Introduction: Objective, scope and outcome of the course

L-1

Importance of Subject

The study of the subject will be very helpful for students to understand the basics of Microwave, transmission of microwaves, basic components and understanding microwave systems.

It will be also helpful for them to understand "Antennas and Propagation" and "Mobile Communication and Network" subjects in future semesters and "Electromagnetic Field Theory" subject in current semester. The subject is also important from GATE exam point of view and other PSU's. In the GATE syllabus it comes under topic "Electromagnetics" and some topics from this subject cover a greater part under this.

Microwaves as a part of radio frequencies and have been a subject of academic interest in research centers,

The subject will be very helpful for students who pursue higher studies in the field of Antenna design, Microwave and Digital Communication

There is renewed interest in microwave engineering and technology with the advent of mobile communication and the potentially attractive applications in transportation, health and medicine, and safety and security.

Introduction of Microwave Theory and Techniques

The subject Microwave Theory & Techniques pertains to the study and design of circuits, components, and systems that operate at microwave frequencies. Microwaves are basically electromagnetic waves whose frequency range varies from 1 GHz to 300 GHz

Till now, the conventional circuit theory was studied which was based on voltages and currents at low frequencies, but now we will study higher frequency microwaves which are based on electromagnetic field theory

The study at higher frequencies is necessary as it offers many advantages when we are using Microwaves for communication

As, we go at higher frequencies, the behavior of conventional transmission lines and components at low frequencies change, so we need to study about Microwave transmission lines and Microwave components. The Microwave theory part includes the basics of Microwaves, Microwave transmission lines, Microwave components and the measurement of Microwave parameters

The Microwave technique part includes the Microwave design principles to design Microwave circuits and Microwave systems
Microwave frequency usage is significant for the design of equipment such as shipboard radar because it makes possible the detection of smaller targets and many other applications

Objectives

The objective of the course are:

- To get a basic understanding of Microwaves, its applications, frequency bands along with advantages and disadvantages
- To be able to analyze different Microwave transmission lines along with their parameters
- To understand the working of different active and passive components used for Microwaves
- To be able to perform measurements of different Microwave parameters
- To understand Microwave systems

Outcomes

After completion of course, students would be able to:

1. Explain the basics of microwaves and analyze different Microwave transmission lines

Justification: The students will be able to describe Microwave basics, their applications and frequency bands along with analysis of Maxwell equations for Microwave transmission lines such as : Coaxial lines, Waveguides, Microstriplines and striplines

2. Identify different active and passive microwave components

Justification: The students will study different active and passive microwave components, analyze the components along with their use for different applications

3. Evaluate the performance of various microwave integrated circuits by using different measurements and testing techniques

Justification: The Microwave measurements will be described for measuring parameters such as: Frequency, Impedance, Scattering parameters, VSWR and noise.

4. Design microwave systems for different practical applications

Justification: The students will study different Microwave systems including, RADARs, Satellite Communication Systems, RFID, GPS etc.

5. Analyze the structure, characteristics, operation, equivalent circuit, gain expression, output power efficiency and applications of various microwave solid state active devices

Justification: The students will study the analysis of various Microwave solid state active devices including: Diodes, Oscillators, Mixers, Microwave sources including Klystron, TWT and Magnetron

Scope

The scope of the course includes:

- Basics of Microwave, Microwave frequency bands and applications
- Microwave transmission lines and their analysis
- Microwave active and passive components along with their working
- Microwave systems design and their working principle
- Microwave measurements

Teaching Learning Process for the Subject

- ➢ In each and every class, students will be asked about the lesson they have learnt in the previous class and a brief recap will be presented to students to link the current topic with the previous one.
- ➢ Questions will be asked regularly from the students to make them attentive in the classroom.

- Query session will be arranged for last 10 minutes in the class along with summary of the lecture.
- Assignments I & II will be given to the students whose marks will be added in internal marks

Marking Scheme

There will be two Internal Exams (1st and 2nd Mid Term)

1st Mid term (covering nearly 40% syllabus)
2nd Mid term (covering the remaining 60% syllabus)

Total marks – 30 marks internal including the assignment marks
External University Exam: 120 marks (covering entire syllabus)
Total 30+120=150 marks
Credits: 3

Summary of the lecture

- In this lecture, we covered objective, scope, outcome and a brief introduction of the course
- In the next lecture, we will start with Unit-I covering basic definition of Microwaves, history of microwaves and some parameters of microwaves

Text and Reference books

1. D.M Pozar, Microwave Engineering, John Wiley & sons 2012.
2. K.C .Gupta, et. al., CAD of Microwave Circuits, ArtechHouse,1981.
3. R.E Collin, Foundation of Microwave Engineering, McGraw Hill, 2001
4. S. Y. Liao, Microwave circuit Analysis and Amplifier Design,Prentice Hall,1987
5. J. D. Kraus, Ronald J. Marhefka, Ahmad Khan, Antenna & Wave Propagation, 4th edition ,Tata McGraw Hill,2017.
6. Constantine A. Balanis, Antenna Theory: Analysis & Design, Wiley 4th edition 2016.

Unit-II

Introduction to Microwaves

L-2
Introduction to Microwaves

Microwaves are a form of electromagnetic radiation with wavelengths ranging from about one meter to one millimeter; with frequencies between 300 MHz (1 m) and 300 GHz (1 mm). Short wavelength energy offers distinct advantages in many applications.

The prefix micro- in microwave is not meant to suggest a wavelength in the micrometer range. Rather, it indicates that microwaves are "small" (having shorter wavelengths), compared to the radio waves used prior to microwave technology.

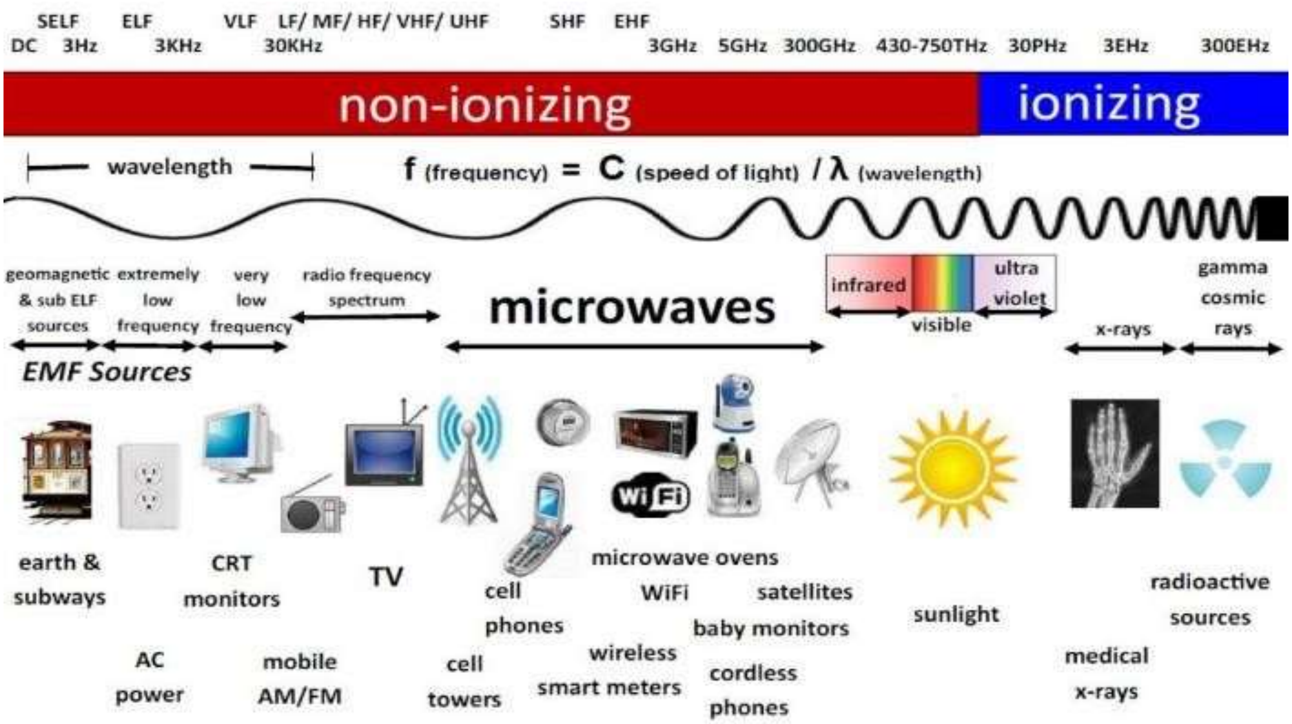
Conventional circuit theory is based on voltages and currents while microwave theory is based on Electromagnetic fields. Apparatus and techniques may be described qualitatively as "microwave" when the wavelengths of signals are roughly the same as the dimensions of the equipment

As a consequence, practical microwave technique tends to move away from discrete resistors, capacitors, and inductors that are used with lower frequency radio waves. Instead, distributed circuit elements and transmission-line theory are more useful methods for design and analysis. The same equations of electromagnetic theory apply at all frequencies

Electromagnetic Spectrum

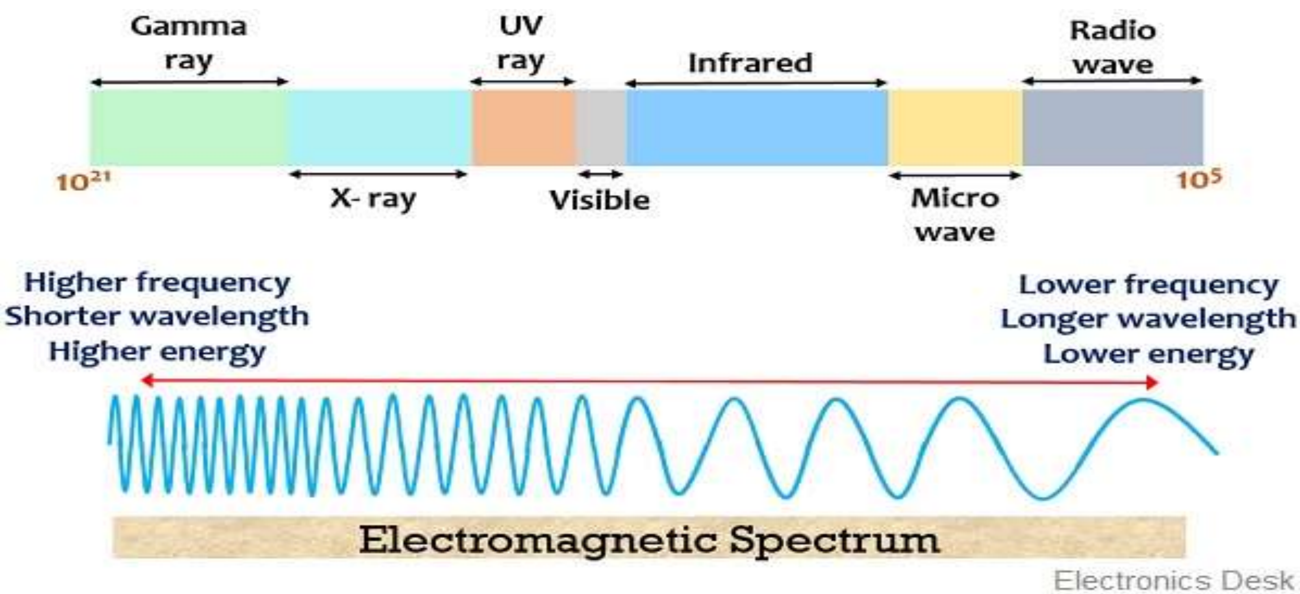
The higher frequencies of EM radiation, consisting of x-rays, gamma rays and ultraviolet (UV) are types of ionizing radiation.

Lower frequency radiation, consisting of infrared (IR), microwave (MW), Radio Frequency (RF), and extremely low frequency (ELF) are types of non-ionizing radiation. The different bands with their designation, frequency and wavelengths are as shown below:



Designation	Abbreviation	Frequencies	Wavelengths
Very Low Frequency	VLF	3 kHz - 30 kHz	100 km - 10 km
Low Frequency	LF	30 kHz - 300 kHz	10 km - 1 km
Medium Frequency	MF	300 kHz - 3 MHz	1 km - 100 m
High Frequency	HF	3 MHz - 30 MHz	100 m - 10 m
Very High Frequency	VHF	30 MHz - 300 MHz	10 m - 1 m
Ultra High Frequency	UHF	300 MHz - 3 GHz	1 m - 100 mm
Super High Frequency	SHF	3 GHz - 30 GHz	100 mm - 10 mm
Extremely High Frequency	EHF	30 GHz - 300 GHz	10 mm - 1 mm

The different regions of electromagnetic spectrum are as shown:

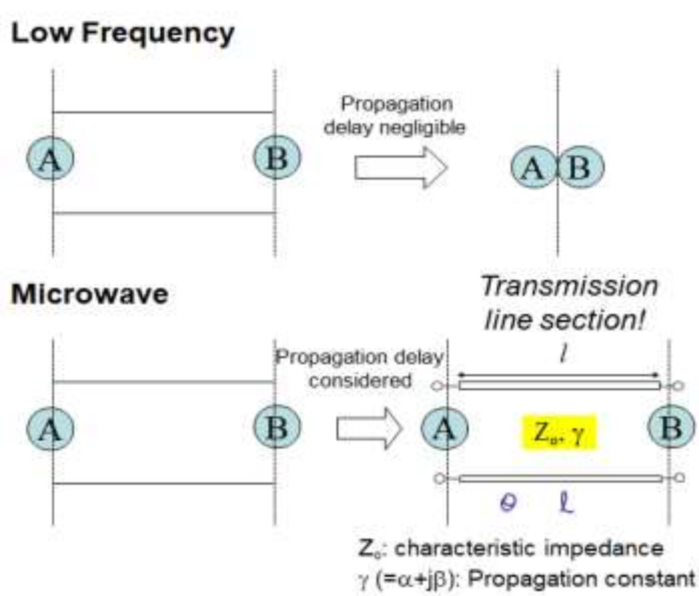


Region	***Frequency (Hz)***	***Wavelength (m)***
Radio waves	$< 10^{9}$	> 0.3
Microwaves	10^{9} - $3x10^{11}$	0.001 - 0.3
Infrared	$3x10^{11}$ - $3.9x10^{14}$	$7.6x10^{-7}$ - 0.001
Visible	$3.9x10^{14}$ - $7.9x10^{14}$	$3.8x10^{-7}$ - $7.6x10^{-7}$
Ultraviolet	$7.9x10^{14}$ - $3.4x10^{16}$	$8x10^{-9}$ - $3.8x10^{-7}$
X-rays	$3.4x10^{16}$ - $5x10^{19}$	$6x10^{-12}$ - $8x10^{-9}$
Gamma Rays	$> 5x10^{19}$	$< 6x10^{-12}$

Microwaves: 30 cm – 1 cm *(centimeter waves)*
l= 30 cm:
$f = 3 \times 10^8 / 30 \times 10^{-2} = 1$ GHz
l= 1 cm:
$f = 3 \times 10^8 / 1 \times 10^{-2} = 30$ GHz

Millimeter waves: 10 mm – 1 mm
l= 10 mm:
$f = 3 \times 10^8 / 10 \times 10^{-3} = 30$ GHz
l= 1 mm:
$f = 3 \times 10^8 / 1 \times 10^{-3} = 300$ GHz

RF
f =10 kHz, l= c/f = $3 \times 10^8 / 10 \times 10^3 = 3000$ m
Electrical length =1 cm/3000 m = 3.3×10^{-6} , Phase delay = 0.0012°
Microwave (Assuming physical length of 1 cm)
f =10 GHz, l= $3 \times 10^8 / 10 \times 10^9 = 3$ cm
Electrical length = 0.33 , Phase delay = 118.8°
Electrically long - The phase of a voltage or current change significantly over the physical extent of the device
There is a phase delay at microwave frequencies which can be neglected for low frequencies



History of Microwaves

The term microwaves usually refer to electromagnetic waves with wavelengths ranging from about one meter to one millimeter.
Microwaves were first introduced in the technical literature in 1932 by Nello Carrara to designate electromagnetic waves having wavelength smaller than 30 cm, that is frequency above 1 GHz.
Foundation of modern electromagnetic theory was formulated by James Clark Maxwell in 1873, Maxwell’s formulation was cast in its modern form by Oliver Heaviside during the period from 1885 to 1887. He introduced vector notation and provided a foundation for practical application of guided waves and transmission lines.
During the period 1887 to 1891, Heinrich Hertz a noted German physicist and experimentalist provided experimental validation of Maxwell’s theory of electromagnetic waves
Due to the lack of reliable microwave sources and other components, the growth of radio technology in early 1900s occurred primarily in the high-frequency (HF) band, which covers 3 to 30 MHz to very high-frequency or VHF band which covers 30 to 300 MHz range.
During 1895 Marconi designed, built and experimented with a microwave communication system that worked at a wavelength of 10 inches, which corresponds to a center frequency of about 1.18 GHz in the present day L band.
Marconi’s early experiment on radio, during 1894 to 1896, were at frequencies on the order of 1000 MHz, although his major efforts in developing commercial wireless device were read very much lower frequencies in order to achieve practical long-distance communication.
In the late 1930s, it became evident that several effects limit the operation of vacuum tubes in microwave frequency band, as wavelength becomes comparable to the dimension of the tube.
Possibility of microwave generation by utilizing transit time effects together with lumped circuits were suggested by A. A. Heil and O. Heil in 1935. In 1939 W.C. Hahn and J. F. Metcalf proposed the theory of velocity modulation.
In the same year, klystron amplifier and oscillator, which use velocity modulation, were developed by R.H. Varian and S.F. Varian, although Hull invented magnetron in 1921, it remained as a laboratory device till cylindrical magnetron was developed by Boot and Randall in early 1940.
In 1944, R. Kompfner invented helix type travelling wave tube.

Radar, radio detection and ranging, the first major application of microwave technology, was intensively developed during World War II, with the advent of radar, microwave theory and technology received substantial interest.

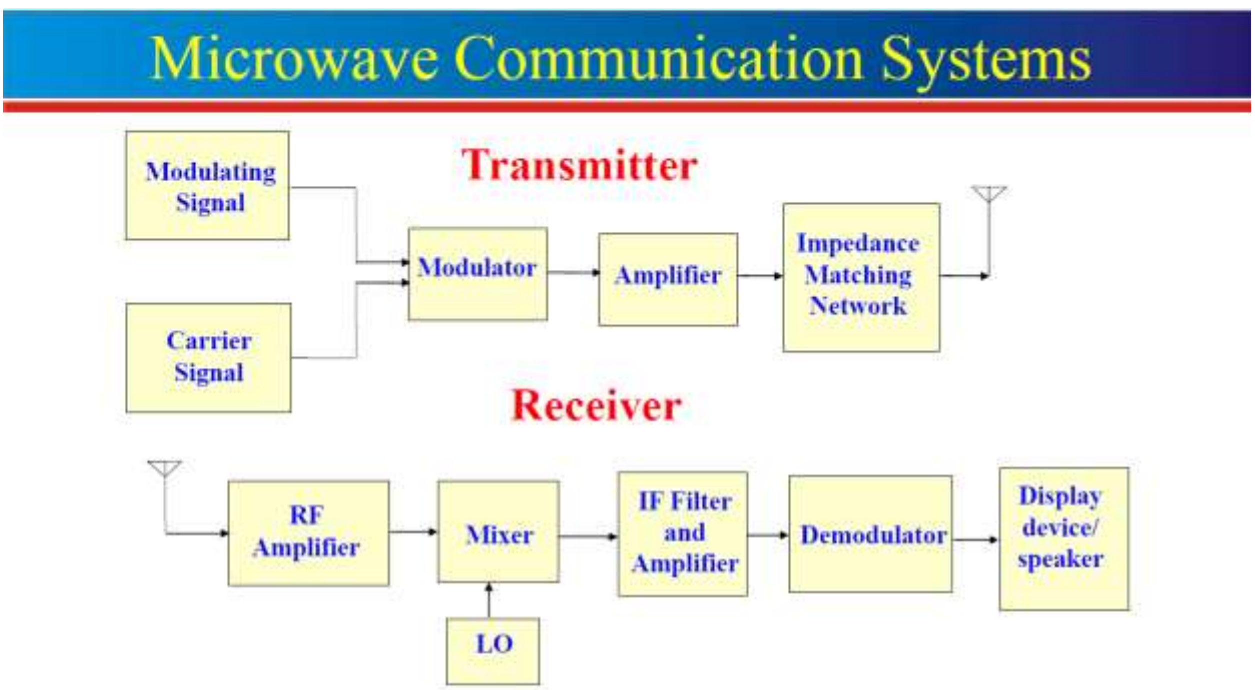
Radiation laboratory was established at the MIT to develop radar theory and practice, several renowned scientists contributed to the theoretical and experimental treatment of waveguide components, microwave antennas, small aperture coupling theory, and microwave network theory.

Early 1960s saw the emergence of solid-state microwave sources and microwave integrated circuits.

Hybrid microwave integrated circuits started maturing in mid-1970s and monolithic microwave integrated circuits, known as MMIC, such technology became popular in 1990s.

The recognition of microwave engineering as a major field within electrical engineering resulted in creation of IRE group of MTT in 1952, IRE later became IEEE.

Microwave Communication Systems



- Modulating and the carrier signal are first modulated using an appropriate modulating technique in the modulator
- The modulated signals are amplified to reach a particular amplitude level

- Impedance matching network is used to match impedance of source with that of transmitting antenna to avoid any reflection losses
- The RF signal is received and passed through RF amplifier to increase the amplitude level of signal
- The RF signal is mixed with a Local oscillator frequency to get a desired frequency at the output. The frequency at the output of mixer is called intermediate frequency.
- The IF frequency is filtered and amplified which is further demodulated to get the required signal at the output of display device or speaker

Advantages of Microwave Communication:

- Because of high frequency more data can be sent
- Higher bandwidth and higher speeds can be achieved
- Shorter antennas are required due to shorter wavelength of microwave signals
- Smaller antennas produce a more focused beam

Disadvantages of Microwave Communication:

- They require that no obstacle is present in the transmission path
- The cost of implementing communication infrastructure is high
- Microwaves are susceptible to rain, snow and electromagnetic interference

Parameters of Microwaves

1. Reflection Coefficient:

Reflection coefficient is a parameter that describes how much of a wave is reflected by an impedance discontinuity in the transmission medium. It is equal to the ratio of the amplitude of the reflected wave to the incident wave

Reflection Coefficient (ρ) 0< ρ<1

$$\rho = \frac{Vr}{Vi}$$

2. Standing waves:

The standing wave forms as a result of the superposition of two waves of the same frequency propagating in opposite directions. The frequency of the standing wave is identical to the frequency of the waves. The incident wave on a transmission line gets superposed with the reflected wave from the end of transmission line, then a standing wave is formed.

3. VSWR (Voltage standing wave ratio):

It is the ratio of the peak amplitude of a standing wave to the minimum amplitude of a standing wave, Now Vmax or peak amplitude is obtained when incident and reflected signal amplitudes add and Vmin is obtained on subtraction.

VSWR is given by 1<VSWR<infinite for perfect matching, with no loss, VSWR=1 and ρ=0

$$VSWR = \frac{Vmax}{Vmin}$$

$$VSWR = \frac{Vi + Vr}{Vi - Vr}$$

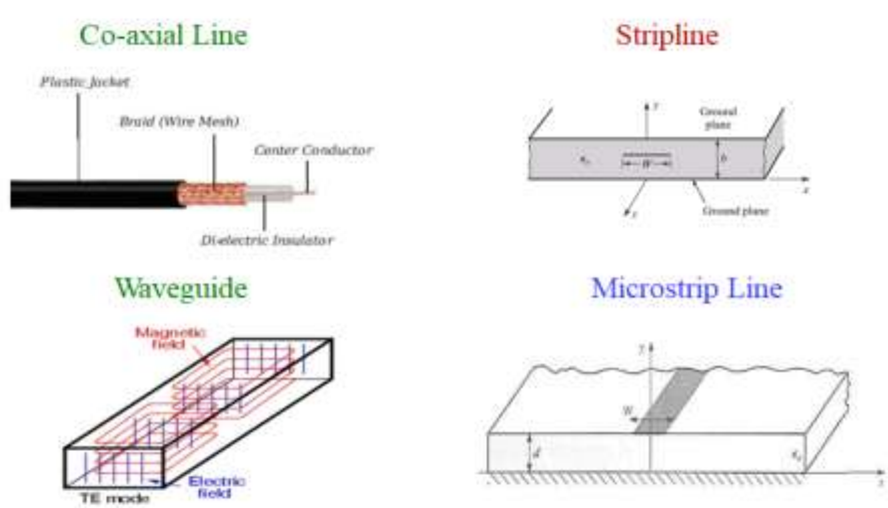
$$VSWR = \frac{1 + |\rho|}{1 - |\rho|}$$

4. Return Loss:

When a signal is transmitted through a transmission line, some signal power is always reflected or returned to the source due to discontinuities in the transmission line. The measure of this reflected power is called Return Loss. The Return Loss is expressed in dB

$$RL\ (dB) = -20 \log(\rho)\ dB$$

Microwave Transmission Lines



L-3

Microwave Frequency Bands

Microwaves occupy a place in the electromagnetic spectrum with frequency above ordinary radio waves, and below infrared light as can be seen below

Name	Wavelength	Frequency (Hz)
Gamma ray	< 0.02 nm	> 15 EHz
X-ray	0.01 nm – 10 nm	30 EHz – 30 PHz
Ultraviolet	10 nm – 400 nm	30 PHz – 750 THz
Visible light	390 nm – 750 nm	770 THz – 400 THz
Infrared	750 nm – 1 mm	400 THz – 300 GHz
Microwave	1 mm – 1 m	300 GHz – 300 MHz
Radio	1 m – 100 km	300 MHz – 3 kHz

IEEE Microwave Frequency Band

Microwave frequency bands			
Designation	Frequency range	Wavelength range	Typical uses
L band	1 to 2 GHz	15 cm to 30 cm	military telemetry, GPS, mobile phones (GSM), amateur radio
S band	2 to 4 GHz	7.5 cm to 15 cm	weather radar, surface ship radar, and some communications satellites (microwave ovens, microwave devices/communications, radio astronomy, mobile phones, wireless LAN, Bluetooth, ZigBee, GPS,

			amateur radio)
C band	4 to 8 GHz	3.75 cm to 7.5 cm	long-distance radio telecommunications
X band	8 to 12 GHz	25 mm to 37.5 mm	satellite communications, radar, terrestrial broadband, space communications, amateur radio
K_u band	12 to 18 GHz	16.7 mm to 25 mm	satellite communications
K band	18 to 26.5 GHz	11.3 mm to 16.7 mm	radar, satellite communications, astronomical observations, automotive radar
K_a band	26.5 to 40 GHz	5.0 mm to 11.3 mm	satellite communications

Some common frequency bands

- FM Radio – Frequency: 88 to 108 MHz
- CDMA – 824 to 890 MHz
- GSM900 - 890 to 915 and 935 to 960 MHz
- GPS – 1575 $\pm$ 10 MHz
- GSM1800 – 1710 to 1780 and 1810 to 1880 MHz
- 3G - 1920 to 1980 and 2110 to 2170 MHz
- 4G – 2300 to 2400 MHz
- Wi-Fi – 2400 to 2483 MHz and 5.2/5.8 GHz Band

Applications of Microwave

There are wide applications of Microwave in different areas as:

Wireless Communications:

- For long distance telephone calls
- Bluetooth
- Transmitter and Receiver links
- Direct Broadcast Satellite DBS
- Personal Communication Systems PCS
- Wireless Local Area Networks WLAN
- Cellular Video systems
- Automobile collision avoidance system

Commercial Uses:

- Burglar alarms
- Garage door openers
- Police speed detectors
- Cell phones, pagers, wireless LANs
- Satellite television
- Motion detectors
- Remote sensing

Civil Applications:

- Air traffic control of commercial applications
- Aircraft landing system
- Direction findings
- Motion detectors
- Vehicle collision avoidance
- Distance measurement
- Surveillance
- Marine navigation
- Radio astronomy
- Terrestrial and satellite communication links

Medical Applications:

- Monitoring heartbeat
- Lung water detection
- Tumour detection

- Regional hyperthermia
- Therapeutic applications
- Local heating
- Microwave tomography
- Microwave Acoustic imaging

Military and Radar:

- Air traffic control
- Weather forecasting
- Navigation of ships
- Speed limit enforcement
- Electronic warfare including guided weapons, and satellite communications

Microwaves will play a vital role in future defense systems. They will enable the integration and interdependent operation of military ground, surface, air, missile, space-based radar and communication systems for enhanced overall defense effectiveness.
Varieties of modern radar are working on different microwave bands
Food Industry:

- Microwave ovens used for reheating and cooking
- Food processing applications
- Pre-heating applications
- Pre-cooking
- Roasting food grains/beans
- Drying potato chips
- Moisture removal

EMI / EMC

EMI and EMC are both important aspects that should be considered when dealing with electronics. EMI stands for electromagnetic interference and is an electronic emission that interferes with components, RF systems, and most electronic devices.
If a device is improperly shielded from EMI, it will not work.
EMI can be the result of manmade or natural occurrences.
In order to protect electronic devices and components from electromagnetic radiation, all equipment's must be shielded

EMI shielding is used to ensure that electronics remain fully operational and run without interference. If a component is vulnerable to interference it will not work

EMC is the abbreviation for electromagnetic compatibility

EMC is the term used to describe how well a device or system is able to function in an electromagnetic environment

Every electronic device generates electric noise, which interrupts cables and wires and causes problems for connected devices.

The difference between EMI and EMC is that EMI is the term for radiation and EMC merely is the ability for a system to operate within the presence of radiation.

Electromagnetic interference (EMI) can plague even the best microwave/RF designs and requires careful planning to control.

Designers working with electromagnetic (EM) energy are constantly faced with the threat of leaks that could lead to stray EM energy making its way into other parts of a circuit or system.

EMI can disrupt the performance of the circuit or system it originates from as well as other circuits and systems nearby.

In addition to EMI shielding, it is of considerable importance for a microwave/RF system to have good uniform electrical contacts between separate parts (i.e., a microwave component and a cavity wall) to realize an EM field with little reflection, leak-free connections, and leak-free sealing are required.

A system is claimed to fulfill electromagnetic compatibility (EMC) requirement when it is in good function order and does not create electromagnetic interference. Rapid advancement in microwave and electronic technologies demands higher operating frequency and hence, electromagnetic interference (EMI) is more likely to occur in systems like printed circuit board (PCB), module or chip.

Interference occurs when there exists an interfering path and the magnitude of culprit noise exceeds the immunity margin of the victim susceptor. The fundamental factors in any EMl problem are frequency, amplitude, separation and timing, abbreviated as FAST.

To cause an interference, frequency band of the culprit must overlap with the operating frequencies of the victim, the culprit and victim must be operating at the same time, the separation between culprit and victim is close enough, and the amplitude of the culprit noise is large enough to affect the victim.

Different EMI mechanisms dominate in different frequency bands. Conducted emission like cross talk or common-impedance coupling dominates when frequency is lower than 30 MHz.

Radiated emission from large objects like cables dominates when frequency is between 30 MHz and 300 MHz.
Radiated emission from small objects like circuit boards or slots dominates when frequency is higher than 300 MHz.

Advantages of Microwave

- Wider bandwidth due to higher frequency
- Smaller component size leading to smaller systems
- Better resolution for radars due to smaller wavelengths
- High antenna gain possible in a smaller space
- Able to Transmit Large Quantities of Data
- Microwave radio communications do not require too many repeaters
- Low power consumption as the signals are of higher frequencies
- Effect of fading gets reduced by using line of sight propagation
- Satellite and terrestrial communications with high capacities are possible
- Miniature microwave components can be developed
- Effective spectrum usage with wide variety of applications in all available frequency ranges of operation

Disadvantages of Microwave

- Cost of equipment or installation cost is high
- Electromagnetic interference may occur
- Variations in dielectric properties with temperatures may occur
- Signal losses may be high
- Requires use of high-speed semiconductor devices

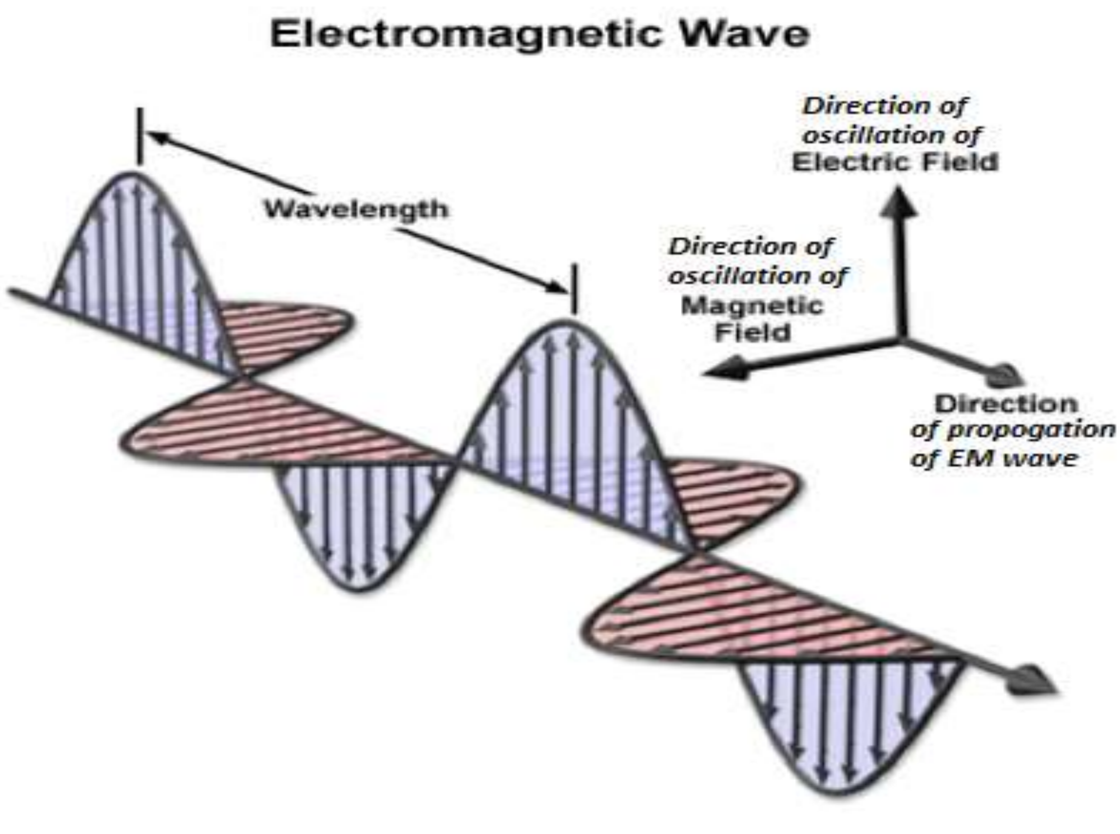
Unit-III

Mathematical Model of Microwave Transmission

L-4

Electromagnetic wave propagation

Electromagnetic waves (EM) consist of synchronized oscillations of electric and magnetic fields.
The electric field and magnetic field oscillates perpendicular to each other and the direction of propagation of the EM wave is perpendicular to both — the direction of oscillation of the magnetic field and direction of oscillation of electric field.
As seen in the figure, Electric field, Magnetic field and direction of wave propagation are all perpendicular to each other



Electromagnetic waves have crests and troughs similar to those of ocean waves.
The distance between crests is the wavelength.
The crest and troughs can be seen in figure

An electromagnetic wave can also be described in terms of its energy—in units called electron volts (eV)

An electron volt is the amount of kinetic energy needed to move an electron through one volt potential difference. Moving along the spectrum from long to short wavelengths, energy increases as the wavelength shortens as seen in figure

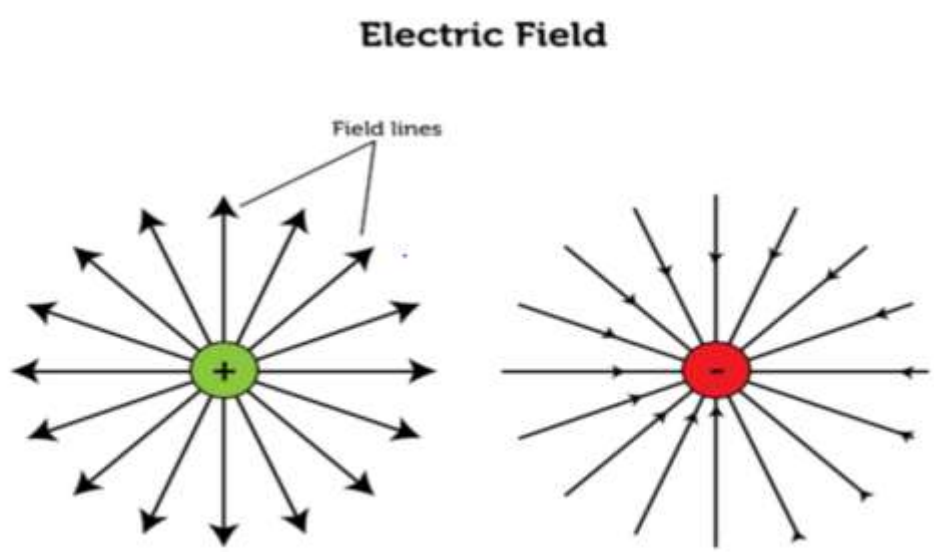
A charged particle at rest only produces an electric field. A charged particle at uniform motion will produce a magnetic field. An accelerating charged particle produces an EM wave (with the magnetic and electric field oscillating perpendicular to each other) thus, accelerating charges produce changing electric and magnetic fields.

Changing electric fields produce magnetic fields and changing magnetic fields produce electric fields. This interplay between induced electric and magnetic fields leads to propagating electromagnetic waves. The magnet exerts magnetic force over an area all around it. This area is called a magnetic field. The field lines in the diagram represent the direction and location of the magnetic force.

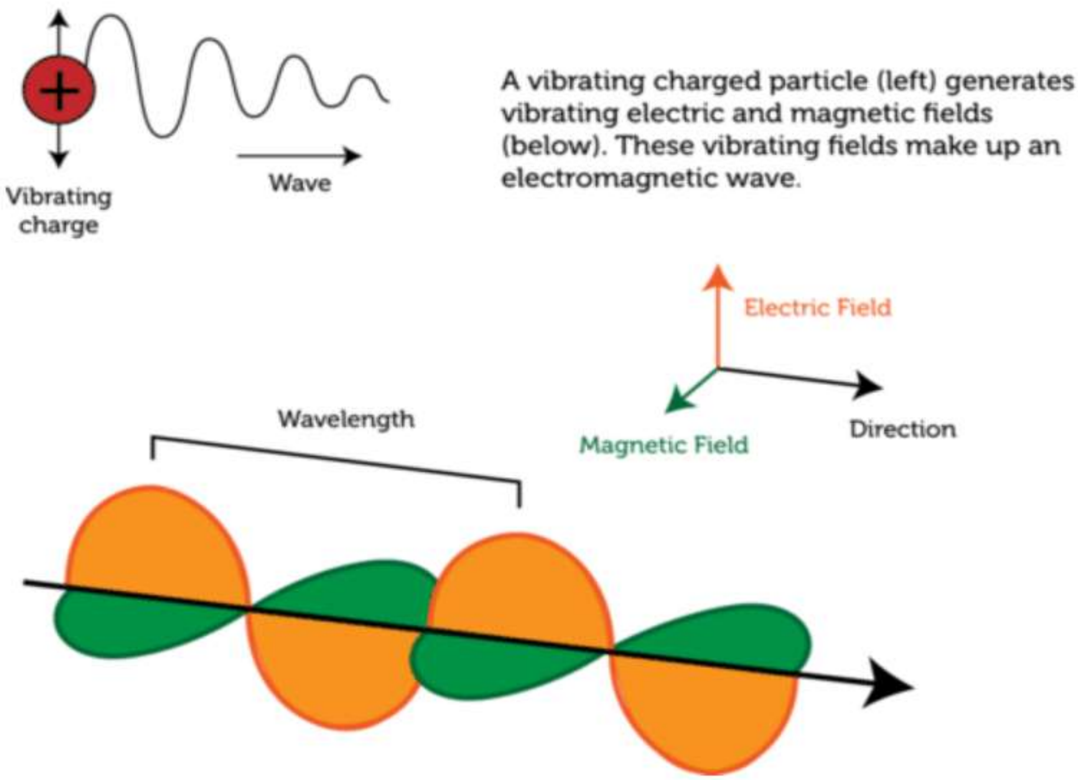
Because of the field surrounding a magnet, it can exert force on objects without touching them. They just have to be within its magnetic field

An electric field is similar to a magnetic field.It is an area of electrical force surrounding a positively or negatively charged particle.

Like a magnetic field, an electric field can exert force on objects over a distance without actually touching them.



An electromagnetic wave begins when an electrically charged particle as it vibrates.
A vibrating charged particle causes the electric field surrounding it to vibrate as well.
A vibrating electric field, in turn, creates a vibrating magnetic field.
The two types of vibrating fields combine to create an electromagnetic wave.



Electromagnetic waves are waves that consist of vibrating electric and magnetic fields. They transfer energy through matter or across space. The transfer of energy by electromagnetic waves is called electromagnetic radiation.
An electromagnetic wave begins when an electrically charged particle vibrations. This causes a vibrating electric field, which in turn creates a vibrating magnetic field. The two vibrating fields together form an electromagnetic wave.
An electromagnetic wave is a transverse wave that can travel across space as well as through matter. When it travels through space, it doesn't lose energy to a medium as a mechanical wave does.
When electromagnetic waves strike matter, they may be reflected, refracted, or diffracted. Or they may be absorbed by matter and converted to other forms of energy.
The most important source of electromagnetic waves on Earth is the sun. Many other sources of electromagnetic waves depend on technology.

Review of Maxwell Equations

Maxwell's equations are a set of four differential equations that form the theoretical basis for describing classical electromagnetism: The four equations are based on different laws as:

1. **Gauss's law:** It states that the electric flux across a closed surface is proportional to the charge enclosed.

$$\int_S^{surface} E.da = \frac{1}{\epsilon o}\int \rho dV \tag{1}$$

- Where, E=*electric field intensity* in volts per meter
- ϵo= 8.854 x 10-12 F/m is the dielectric permittivity of vacuum or free space
- $\int_S^{surface} E.da$ is the total electric flux through entire surface
- The total charge is expressed as the charge density ρ integrated over a region

2. **Gauss's law for magnetism:** It states that the magnetic flux across a closed surface is zero.

$$\int_S^{surface} B.da = 0 \tag{2}$$

B = *magnetic flux density* in webers per square meter or in tesla

3. **Faraday's law:** It states that time-varying magnetic fields produce an electric field

$$\int_l^{loop} E.ds = -\frac{d}{dt}\int_S^{surface} B.da \tag{3}$$

(around a closed loop) (around a surface)

4. **Ampère's law:** It states that steady currents and time-varying electric fields produce a magnetic field.

$$\int_l^{loop} B.ds = \mu o\int_S^{surface} J.da + \epsilon o \mu o\frac{d}{dt}\int_S^{surface} E.da \tag{4}$$

- J = electric current density in amperes per square meter

- $\mu_o = 4\pi \times 10^{-7}$ H/m is the permeability of vacuum or free space

Curl, Gradient and Divergence

Del operator:

Operator del ∇ is called vector differential operator, defined as:

$$\nabla = \frac{\partial}{\partial \mathrm{x}} i + \frac{\partial}{\partial \mathrm{y}} j + \frac{\partial}{\partial \mathrm{z}} k$$

Where i, j, k are the unit vectors along three perpendicular axis as X, Y and Z respectively

Gradient of a Scalar function:

If Φ(x,y,z) is a scalar function of three variables, Φ is differentiable. Then the gradient of Φ defined as

$$\mathrm{grad}\Phi = \nabla\Phi = \frac{\partial \Phi}{\partial \mathrm{x}} i + \frac{\partial \Phi}{\partial \mathrm{y}} j + \frac{\partial \Phi}{\partial \mathrm{z}} k$$

where
Φ is a scalar function
∇Φ is a vector function

Divergence of a vector:

If vector A= *Ax i* + *Ay j* + *Az k*, the divergence of A is defined as
div A = ∇. A

$$=\left(\frac{\partial}{\partial \mathrm{x}} i + \frac{\partial}{\partial \mathrm{y}} j + \frac{\partial}{\partial \mathrm{z}} k\right) . (Ax\, i + Ay\, j + Az\, k)$$

$$=\left(\frac{\partial \mathrm{Ax}}{\partial \mathrm{x}} + \frac{\partial \mathrm{Ay}}{\partial \mathrm{y}} + \frac{\partial \mathrm{Az}}{\partial \mathrm{z}}\right)$$

Curl of a vector:

If vector A= *Ax i* + *Ay j* + *Az k*, the curl of A is defined as curl A = ∇ X A

$=\left(\frac{\partial}{\partial x} i + \frac{\partial}{\partial y} j + \frac{\partial}{\partial z} k\right) X \left(Ax\, i + Ay\, j + Az\, k\right)$

$$curl\, A = \begin{bmatrix} i & j & k \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ Ax & Ay & Az \end{bmatrix}$$

Maxwell Equations in Differential form

Differential form of Gauss's Law:

The divergence theorem holds that the volume integral of the divergence of a field 'E' in a volume 'V 'in space equals the outward flux of 'E' across the boundary 'S' of 'V' Thus:

$$\iint E.da = \iiint \nabla.E\, dV$$

- $\iiint \nabla.E\, dV$= Volume integral of divergence of the electric field 'E' in a volume 'V', considering a small volume 'dV' and integrating for entire volume 'V'
- $\iint E.da =$ Surface integral of the electric field, it is the total outward flux through the surface 'S' in a volume 'V', considering flux through a small area 'da', and integrating it for entire surface 'S'

Now as described previously Gauss's law states that

$$\iint E.da = \frac{1}{\epsilon o} \iiint \rho dV$$

So, using divergence theorem

$\nabla.E = \frac{\rho}{\epsilon o}$

ρ is the charge density over a region

Now, we define 'D' as:

$$D = \epsilon o\, E$$

- D = electric flux density in coulombs per square meter
- Єo= 8.854 x 10^-12 F/m is the dielectric permittivity of vacuum or free space
- So, the gauss's law equation in differential form becomes:
- $\nabla.D = \rho$

Similarly, Gauss's law of electromagnetism states that

$\iint B.da = 0$

By divergence theorem

$$\iint B.da = \iiint \nabla.B\,dV$$

Thus, it follows that

$$\nabla.B = 0$$

Differential form of Faradays laws:

- The Stokes theorem relates a surface integral over a surface S to a line integral around the boundary curve C of surface (a space curve) Thus,

$$\int E.ds = \iint (\nabla X E).da$$

- $\iint(\nabla X E).da$ = Surface integral of the curl of electric field, considering a small area 'da', and integrating it for entire surface 'S'
- $\int E.ds =$ Line integral of Electric field E over a boundary curve C of the surface, considering a small part of curve ds and integrating for entire curve C

Now as described previously Faraday's law states that

$$\int E.ds = -\frac{d}{dt}\iint B.da$$

So, by using stoke's theorem

$$\nabla X E = -\frac{dB}{dt}$$

$$\nabla X E = -\frac{\partial B}{\partial t}$$

(Partial derivative is taken because magnetic field B is a function of many variables, and we require only derivative with time, with other variables kept constant)

Differential form of Ampere's law:

Ampere's law states that

$$\int B.ds = \mu o \iint J.da + \epsilon o \mu o \frac{d}{dt}\iint E.da$$

- J = electric current density in amperes per square meter
- μo= 4π x 10^-7 H/m is the permeability of vacuum or free space
- Єo= 8.854 x 10^-12 F/m is the dielectric permittivity of vacuum or free space

By using stoke's theorem:

$$\iint (\nabla X B).da = \mu o \iint J.da + \epsilon o \mu o \frac{d}{dt} \iint E.da$$

Thus, we have

$$\nabla XB = \mu o J + \epsilon o \mu o \frac{dE}{dt}$$

Now, we define: (D= ЄoE, B= μoH)

H = magnetic field intensity in amperes per meter

- $\nabla XH = J + \frac{dD}{dt}$

Using, partial derivatives

- $\nabla XH = J + \frac{\partial D}{\partial t}$

Thus, the four Maxwell equations in differential form are:

- $\nabla.D = \rho$
- $\nabla.B = 0$
- $\nabla XE = -\frac{\partial B}{\partial t}$
- $\nabla XH = J + \frac{\partial D}{\partial t}$

Where,

- E = electric field intensity in volts per meter
- H = magnetic field intensity in amperes per meter
- D = electric flux density in coulombs per square meter
- B = magnetic flux density in webers per square meter or in tesla
- J = electric current density in amperes per square meter
- ρ = electric charge density in coulombs per cubic meter
- Єo= 8.854 x 10^-12 F/m is the dielectric permittivity of vacuum or free space
- μo= 4π x 10^-7 H/m is the permeability of vacuum or free space
- σ= conductivity of the medium in mhos per meter
- Є = dielectric permittivity

- μ= magnetic permeability

If a sinusoidal time function in the form of $e^{j\omega t}$ is assumed, $\frac{\partial}{\partial t}$ can be replaced by $j\omega$. $\frac{\partial}{\partial t}$ is the time derivative or rate of change with respect to time that can be replaced with frequency

Then Maxwell's equations in frequency domain are given by:

$$\nabla X E = -j\omega\,\mu H$$

$$\nabla X H = (\sigma + j\omega\epsilon)E$$

$$\nabla . D = \rho$$

$$\nabla . B = 0$$

Where, in general terms,

$D=\epsilon E$, $\epsilon=\epsilon_r\epsilon_0$

$B=\mu H$, $\mu=\mu_r\mu_0$

$J=\sigma E$

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L-5

Concept of Mode

- The mode of electromagnetic radiation describes the field pattern of the propagating waves
- Modes are mutually independent solutions, of Maxwell's equation, such that, every possible electromagnetic field configuration can be expressed as a linear combination of the modes
- If we understand the field distribution in a mode, we can construct the entire signal
- To understand the propagation of Microwaves we need a mathematical model of EM signals

- The EM spectrum graph, includes all: X ray, light ray, infrared microwave, TV, radio, radar, mobile telephone, landline, telephone etc. all these comes under EM signal
- In the above, microwave, TV, radar, and somewhat mobile telephone, comes under the microwave zone
- All the above signals are EM signals and they follow Maxwell laws and it follows that all the EM signals are just various solutions of Maxwell equations
- It can be said as an example say light and mobile phone signal, both are EM signals, but light can be seen and mobile phone signal cannot be seen, and still both of them obeys Maxwell's equation

- So, there are various solutions of Maxwell's laws, light signal is one such solution, mobile phone signal is another such solution, RADAR signal is another such solution and so on
- There are a minimum number of independent solutions of the Maxwell equations, such that, all EM signals can be expressed as a linear combination of them
- These minimum number of independent solutions are called modes

Classification of mode

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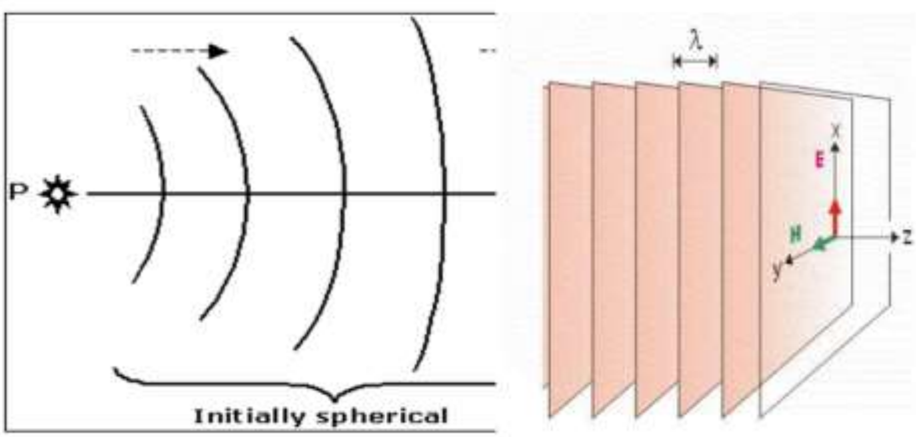
Electromagnetic modes are analogous to the normal modes of vibration in other systems, such as mechanical systems.

Some of the classifications of electromagnetic modes include:

1. **Free space modes:**

- These modes exist in plane waves
- Plane waves are those in which the electric and magnetic fields are both orthogonal to the direction of travel of the wave. These are the waves that exist in free space far from any antenna

- The plane wave is a wave whose wave fronts (surfaces of constant phase) are parallel planes(Theoretically infinite planes)
- A plane wave's wave-fronts are equally spaced , and a wavelength apart
- EM plane wave fronts propagate at the speed of light
- Initially EM waves emitted from a point source have spherical wave fronts, but once they extend to infinity they can be considered as plane wave fronts
- Plane waves are generated from a point source P, which were initially spherical then became plane wave fronts as seen in figure, the wave is travelling in the z direction



2. Transverse modes:

- These modes occur in waveguides and transmission lines, and have at least one of the electric field and magnetic field entirely in a transverse direction
- A transverse mode of electromagnetic radiation is a particular electromagnetic field pattern of the radiation in the plane perpendicular (i.e., transverse) to the radiation's propagation direction
- They occur because of boundary conditions imposed on the wave by the waveguide
- The allowed modes can be found by solving Maxwell's equations for the boundary conditions of a given waveguide

- Transverse modes occur in radio waves and microwaves confined to a waveguide, and also in light waves in an optical fiber and in a laser's optical resonator

The transverse modes can be of three types:

- Transverse electromagnetic mode (TEM)
- Transverse electric (TE) modes
- Transverse magnetic (TM) modes

The three modes are described in the coming slides of lecture

3. Hybrid electromagnetic (HEM) modes:

- HEM modes are those modes that have both an electric field and a magnetic field component longitudinally in the direction of travel of the propagating wave
- They can be analyzed as a linear superposition of the corresponding TE and TM modes
- They are classified as:
    - HE modes: hybrid modes in which the TE component dominates
    - EH modes: hybrid modes in which the TM component dominates
    - Longitudinal-section modes: They have a component of either magnetic or electric field that is zero in one transverse direction. In longitudinal-section electric (LSE) modes this field component is electric. In longitudinal-section magnetic (LSM) modes the zero field component is magnetic

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TEM, TE and TM mode

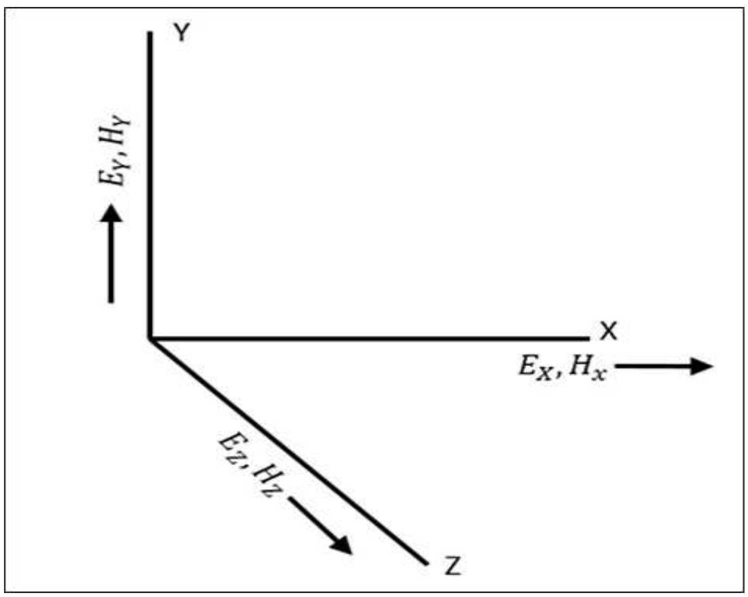
The Electric and Magnetic fields vectors can be written for three directions as:

Vector E= *Ex i +Ey j +Ey k*

Vector H= *Hx i + Hy j +Hz k*

where i,j,k are the unit vectors along X, Y and Z directions respectively

The direction of the electric and the magnetic field components along three mutually perpendicular directions x, y, and z are as shown in the following figure



TEM

- Considering the wave to be propagating along 'z' direction
- Here, Electric and magnetic field vectors are both orthogonal to the direction of wave propagation
- Ez=0 and Hz=0
- To any wave propagation direction one can draw infinite number of perpendiculars, which will lie in a plane. This plane is called transverse plane
- Electric field vector can lie along any of these infinite number of perpendiculars

- In the transverse plane, we can always find a perpendicular to the electric field vector which is the magnetic field vector
- Unguided fields produced by a point source at a far off point have many TEM waves propagating in all possible directions

TE

- In this mode, the electric field is purely transverse to the direction of propagation, whereas the magnetic field is not
- $E_z=0$ and $H_z \neq 0$
- Electric field vector can lie along any of the infinite number of perpendiculars which are drawn perpendicular to the direction of propagation of waves
- Magnetic field vector should have a component in the transverse plane (z=0) and also some component along z direction
- A rectangular waveguide supports TE modes but not TEM modes because there is only one conductor in a rectangular waveguide. TE mode is dominant in waveguides

TM

- In this mode, the magnetic field is purely transverse to the direction of propagation, whereas the electric field is not
- $H_z=0$ and $E_z \neq 0$
- Magnetic field exists in a plane transverse to the direction of propagation of wave
- Electric field has some component in the transverse plane and also some along the direction of propagation
- A rectangular waveguide supports both TE modes and TM modes but not TEM modes, higher order modes are also supported by TE and TM modes
- TE and TM modes also have a limited bandwidth, none of these modes can propagate at frequencies below a minimum frequency known as the cutoff frequency
- More details about modes will be studied on studying waveguides and other Microwave transmission lines in future lectures

Mathematical analysis of modes

We have studied the Maxwell equations in frequency domain as in precious lecture:

- $\nabla X E = -j\omega\, \mu H$
- $\nabla X H = (\sigma + j\omega \epsilon)E$
- $\nabla . D = \rho$
- $\nabla . B = 0$

Now we define:

$$\gamma = \sqrt{(\, j\omega\, \mu(\sigma + j\omega\, \epsilon))} = \alpha + j\beta$$

γ is called the intrinsic propagation constant of a medium
α = attenuation constant in nepers per meter
β = phase constant in radians per meter
ω = frequency in radians per sec

Other terms have been described in previous lecture

for a uniform plane wave propagating in a lossless dielectric medium, conductivity of medium becomes zero ($\sigma = 0$), the characteristics of wave propagation would become ($\alpha = 0$) from above equation, means attenuation becomes zero

So, the Maxwell equations for a lossless dielectric medium becomes in frequency domain as:

- $\nabla X E = -j\omega\, \mu H$
- $\nabla X H = j\omega \epsilon E$

(By putting ($\sigma = 0$))

Suppose, i,j,k are unit vectors along X, Y and Z directions

Electric field Vector E= *Ex i* + *Ey j* + *Ez k*

Magnetic field Vector H= *Hx i* + *Hy j* + *Hz k*

Then by opening the curl above equations becomes as:

- $\frac{\partial Ez}{\partial y} - \frac{\partial Ey}{\partial z} = -\, j\omega\, \mu Hx$
- $\frac{\partial Ex}{\partial z} - \frac{\partial Ez}{\partial x} = -\, j\omega\, \mu Hy$
- $\frac{\partial Ey}{\partial x} - \frac{\partial Ex}{\partial y} = -\, j\omega\, \mu Hz$

- $\frac{\partial Hz}{\partial y} - \frac{\partial Hy}{\partial z} = j\omega \, \epsilon Ex$
- $\frac{\partial Hx}{\partial z} - \frac{\partial Hz}{\partial x} = j\omega \, \epsilon \mathrm{Ey}$
- $\frac{\partial Hy}{\partial x} - \frac{\partial Hx}{\partial y} = j\omega \, \epsilon \mathrm{Ez}$

Now, using the boundary conditions of the waveguide the above equations can be solved for TE,TM and TEM modes as we will do in future lectures of waveguide

L-6

Losses in microwave transmission

- Microwave power transmits through Coaxial cable, Metallic waveguides, Optical fibers, Microstrip lines etc. and all practical lines are lossy
- These transmission structures are made up of either conductors or dielectrics or mixture of both
- For ex: coaxial cable has got two conductors, microstriplines have a dielectric between a conductor and a conducting ground plane and so on
- An ideal conductor has infinite conductivity so it is lossless and ideal dielectric has zero conductivity
- A practical conductor has finite conductivity, and the practical dielectric also has finite conductivity
- At microwave frequency we choose transmission structures having small loss
- As the technology is improving day by day so we are moving at a higher frequency to get advantages of increased bandwidth and data rate
- For ex: In earlier days, satellite communication was done on 4 and 6 GHz, but now we are moving towards Ku band (12-18 GHz) for satellite communication
- At higher frequencies as we go, the loss also increases as loss depends on frequency
- So, we should know about different types of losses in Microwave transmission so that it can be minimized to avoid any kind of microwave power loss which is very costly
- Loss is given by attenuation constant
- A transmission line structure can have both conductor loss and dielectric loss
- So, the total power loss is the sum of conductor loss and the dielectric loss
- The total attenuation constant (α) is the sum of attenuation constant by conductor (α_c) and attenuation constant by dielectric(α_d)
- $\alpha = \alpha_c + \alpha_d$

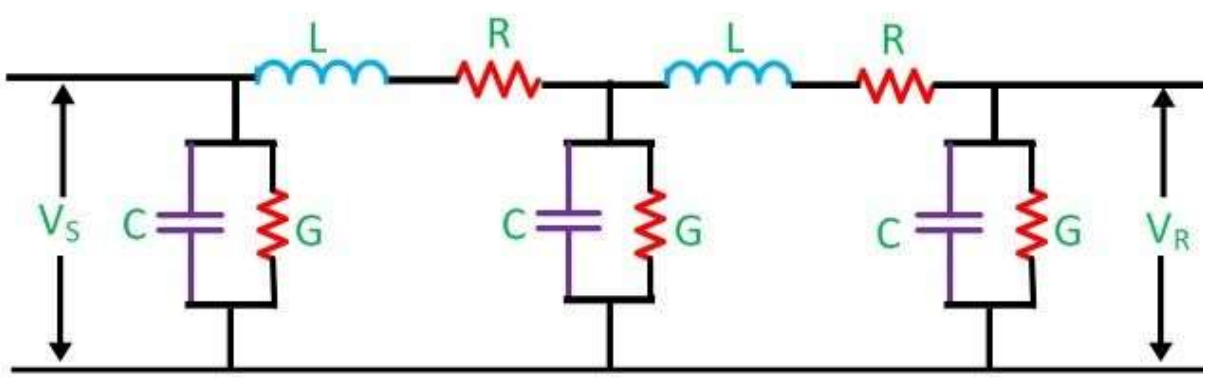
Losses in Transmission Lines

- A transmission line is used for the transmission of signal from one place to another

- It transmits the wave of voltage and current from one end to another. The transmission line is made up of a conductor having a uniform cross-section along the line
- The performance of transmission line depends on the parameters of the line
- The transmission line has mainly four parameters, resistance, inductance, capacitance and conductance. These parameters are uniformly distributed along the line. Hence, they are also called the distributed parameter of the transmission line

Transmission line model:

- The equivalent circuit model of transmission lines has got series resistance and inductance and shunt capacitance and conductance which are all distributed along the length of transmission line. The total series impedance is Z and total shunt conductance is Y as shown in figure



Tranmission Line Model
Z = R + jwL, Y = G + jwC

The different parameters are:

- R- resistance per unit length for the transmission line (Ohms/meter), it represents the D.C resistance of one meter of the transmission line
- L - inductance per unit length for the transmission line (Henry/meter), it represents the inductance of one meter of the transmission line
- G - conductance per unit length for the transmission line (Siemens/meter), it represents the isolation between the two conductors of the transmission line

- C - capacitance per unit length for the transmission line (Farad/meter), it represents the capacitance between the two conductors that make up the transmission line

Now, the propagation constant of transmission line is given as:

- $\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$
- In terms of R,L,G,C
- It can be written as:
- $\gamma = \sqrt{(j\omega L)(j\omega C)(1 + \frac{R}{j\omega L})(1 + \frac{G}{j\omega C})}$
- $\gamma = j\omega\sqrt{LC}\ \sqrt{(1 - j\left(\frac{R}{\omega L} + \frac{G}{\omega C}\right) - \frac{RG}{\omega^2 LC})}$

Now, talking about microwaves at higher frequency:

- ωL>>R (small conductor loss at higher frequency)
- ωL>>G (small dielectric loss at higher frequency)

So combined, ω^2LC>> RG

So, on neglecting RG compared to ω^2LC, we have:

$$\gamma \approx j\omega\sqrt{LC}\ \sqrt{(1 - j\left(\frac{R}{\omega L} + \frac{G}{\omega C}\right))}$$

On using identity $\sqrt{1 + x} = 1 + \frac{x}{2}$ (when x is small)

$$\gamma \approx j\omega\sqrt{LC}\ (1 - \frac{j}{2}\left(\frac{R}{\omega L} + \frac{G}{\omega C}\right))$$

- (as ωL>>R and ωL>>G)

On comparing with:

- $\gamma = \alpha + j\beta$
- $\alpha \approx \frac{1}{2}(R\sqrt{\left(\frac{C}{L}\right)} + G\sqrt{\left(\frac{L}{C}\right)})$ (attenuation constant for a transmission line)
- $\beta \approx \omega\sqrt{LC}$ (phase constant of transmission line)

Other losses

- Dielectric Heating Loss
- Radiation Loss
- Coupling Loss
- Insertion loss and Return Loss

Dielectric heating loss

- A difference of potential between two conductors of a metallic transmission line causes dielectric heating
- Heat is form of energy and must be taken from the energy propagating down the line
- For air dielectric transmission lines, the heating is negligible
- For solid core transmission lines, dielectric heating loss increases with frequency

Radiation loss

- If the separation between conductors in a metallic transmission line is appreciable fraction of wavelength, the electrostatic and electromagnetic fields that surround the conductor cause the line to act as if it were an antenna and transfer energy to any nearby conductive material
- The energy radiated is called radiation loss and depends on dielectric material conductor spacing and length of transmission line
- It reduces by properly shielding the cable
- It is also directly proportional to the frequency

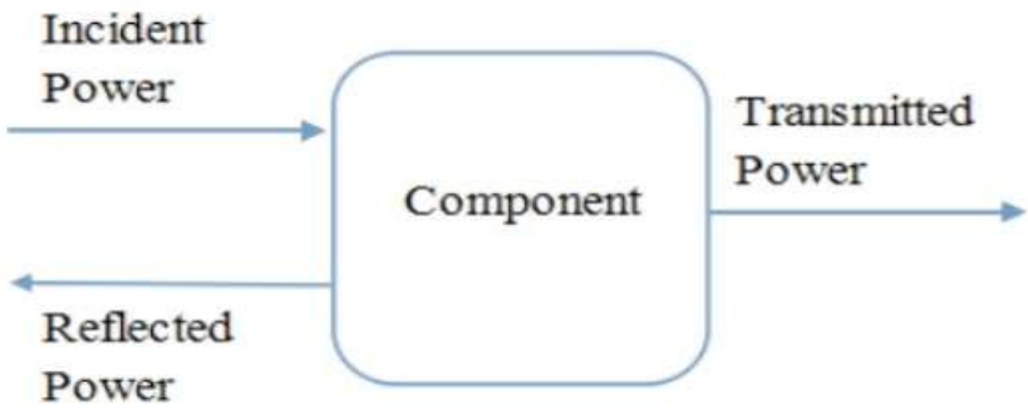
Coupling loss

- Coupling loss occurs whenever a connection is made to or from transmission line or when two sections of transmission line are connected together
- There is no physical connection between the sections of transmission line and there is a small gap between the transmission line sections

- The gaps radiate energy and dissipate power
- It can occur in parallel coupled lines and Coupled line directional couplers

Insertion Loss and Return Loss

Consider a Microwave component as below, the Insertion and Return Loss are given as:



$$\text{Insertion Loss} = \frac{\text{Incident Power}}{\text{Transmitted Power}}$$

$$\text{Return Loss} = \frac{\text{Incident Power}}{\text{Reflected Power}}$$

Microwave power is sent down a transmission line from the left and it reaches the component. This power is the incident power

When it reaches the component, a portion is reflected back down the transmission line where it came from and never enters the component, rest of the power gets into the component

There some of it gets absorbed and the remainder passes through the component into the transmission line on the other side. The power that actually comes out of the component is called the transmitted power

Transmitted power is less than the incident power for two reasons: (1) some of the power gets reflected. (2) some of the power gets absorbed inside the component

The ratio of incident power to transmitted power, in dB terminology, is the insertion loss. The ratio of incident power to the reflected power, in dB terminology, is the return loss

- $\textbf{Insertion Loss (dBm)} = \mathbf{10\ log}\left(\frac{\textbf{Incident power (W)}}{\textbf{Transmitted power (W)}}\right)$
- $\textbf{Insertion Loss (dBm)} =$
  $\textbf{Incident power (dBm)} - \textbf{Transmitted power (dBm)}$
- $\textbf{Return Loss (dBm)} = \mathbf{10\ log}\left(\frac{\textbf{Incident power (W)}}{\textbf{Reflected power (W)}}\right)$
- $\textbf{Return Loss (dBm)} =$
  $\textbf{Incident power (dBm)} - \textbf{Reflected power (dBm)}$

Wave impedance

- Wave impedance is a characteristic of the wave which describes the radiation property of the wave, it is the ratio between the two corresponding transverse electric and magnetic field components that carry the power in the propagation direction
- Wave impedance can be defined for TE, TEM or TE waves
- It can be the ratio of the field components ‘Ey’ and ‘Hx’ for the wave travelling in z direction , this will be derived for different modes when we study waveguides in future lectures
- Wave impedance depends only on the frequency of the AC source and material properties of the medium
- It describes the radiation property of the wave

Characteristic impedance

- Characteristic impedance is the ratio between the voltage and current of the TEM wave in a transmission line. It is the property of transmission line supporting the wave

- Characteristic impedance depends on geometry of the line, frequency of the source and the material properties of medium filling the transmission line
- It describes the power transport property of the structure supporting the wave
- The characteristic impedance of a transmission line should be perfectly matched to the load impedance at the end of transmission line for no reflection

- For a given transmission line, the characteristic impedance (Z0) is given as:
- Z0= $\frac{\sqrt{R+j\omega L}}{\sqrt{G+j\omega C}}$
- In terms of parameters R,L,G and C
- For a given transmission line, terminated by a load impedance Zl
- The reflection coefficient ($\boldsymbol{\rho}$) is given as: ($\boldsymbol{\rho}$ should be as small as possible for no reflection loss, this requires perfect impedance matching between load and the transmission line)

$$\rho = \frac{Zl - Z0}{Zl + Z0}$$

Unit IV

Analysis of RF and Microwave Transmission Lines

L-7

Microwave Transmission Lines

A transmission line can be defined as the conductive connection between system elements that carry signal power

A transmission line is a connector which transmits energy from one point to another.

At low frequencies transmission is very straightforward, but at higher frequencies the make-up of the connection starts having appreciable effect on circuit action that results on strange behavior (losses, radiation, reflection, etc.)

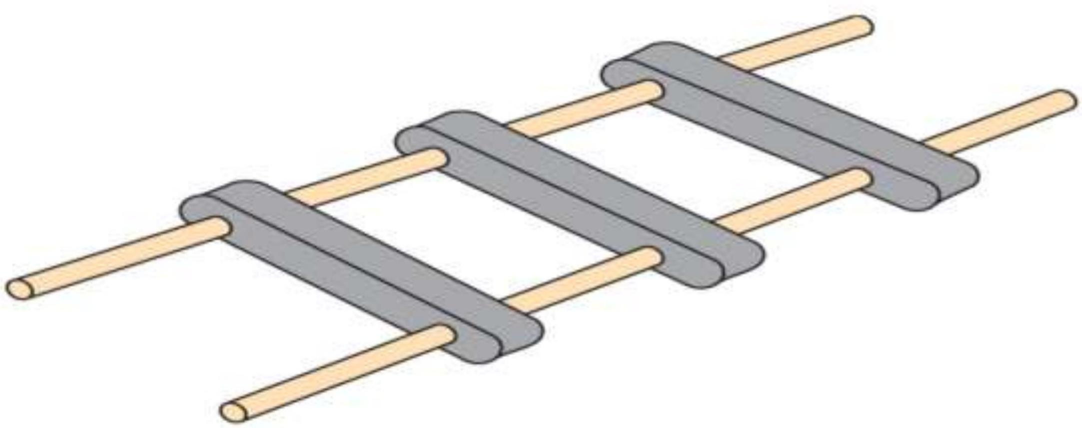
There are basically four types of transmission lines −

1. **Two-wire parallel transmission lines**

Can be used as transmission line between antenna & transmitter or antenna & receiver

Parallel two-wire line

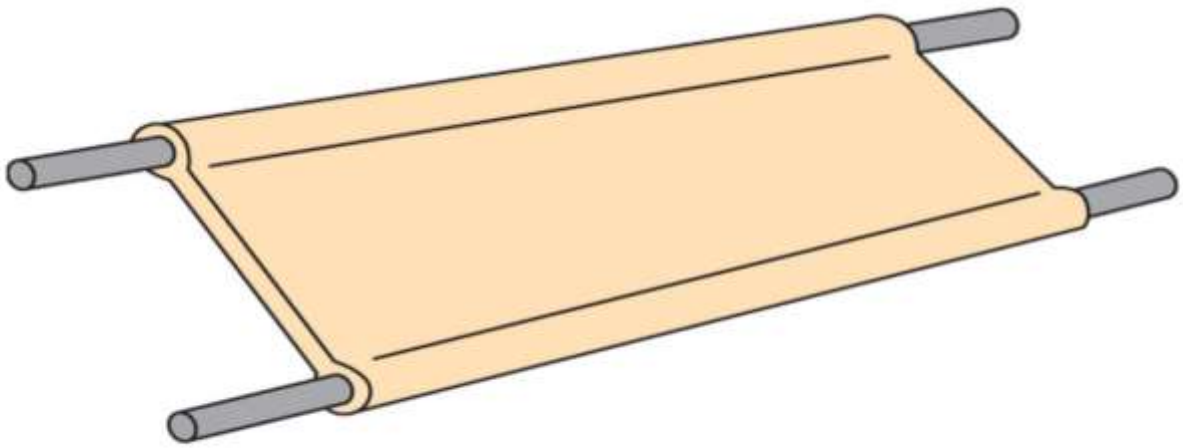
Two conductors are spaced 0.25 - 6 inches apart, they are spaced by insulating spacers, in order to maintain an equal distance between the two conductors throughout as shown in figure



Twin Lead or two-wire ribbon-type line

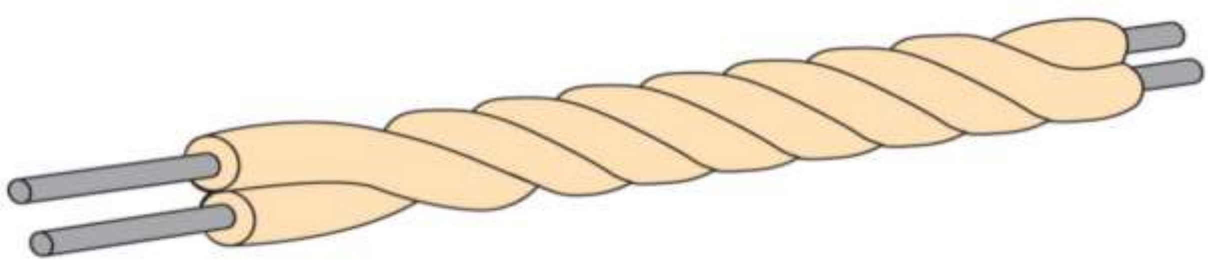
Low loss dielectric (e.g. polyethylene) is used for spacing between the conductors

The two conductors are kept parallel to each other throughout as shown in figure



Twisted type transmission line

It consists of two insulated wires twisted to form a flexible line without the use of spacer. It is not used at high frequencies because high losses occur in rubber isolation, losses increase when line is wet. It is as shown in figure

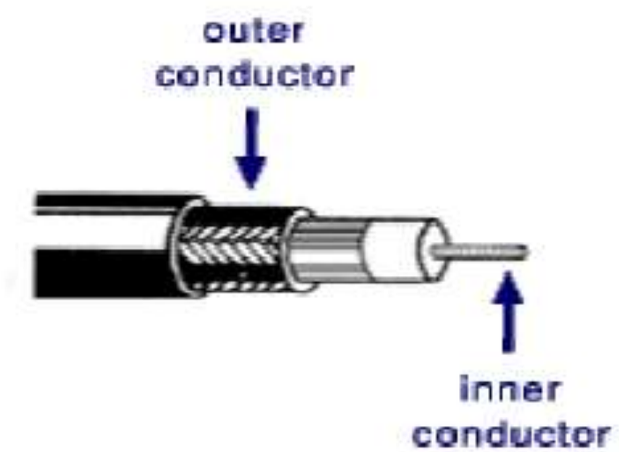


The two wire transmission lines are not used for high frequency microwave transmission because losses occur in them due to skin effect.
Skin effect is a tendency for alternating current (AC) to flow mostly near the outer surface of an electrical conductor, such as metal wire.The effect becomes more and more apparent as the frequency increases.

The main problem with skin effect is that it increases the effective resistance of a wire for AC at moderate to high frequencies, compared with the resistance of the same wire at direct current (DC) and low AC frequencies.
The effect is most pronounced in radio-frequency (RF) systems, especially antennas and transmission lines.

2. Coaxial lines

This is the most common type of transmission line and can be used for higher frequencies
The transmission line consists of an inner conductor – a wire – and an outer conductor – usually a metal braided jacket as shown in figure
More details will be studied later



3. Waveguides

A waveguide is a structure that guides waves, such as electromagnetic waves or sound waves They enable a signal to propagate with minimal loss of energy by restricting expansion to one or two dimension
A hollow metallic tube of uniform cross-section for transmitting electromagnetic waves by successive reflections from the inner walls of the tube is called as a waveguide
A waveguide is generally preferred in microwave communications. Unlike a transmission line, a waveguide has no center conductor.
Waveguides are easy to manufacture.

They can handle very large power in kilowatts.
Power loss is very negligible in waveguides.
They offer very low loss, low value of attenuation constant
When microwave energy travels through waveguide, it experiences lower losses than a coaxial cable.

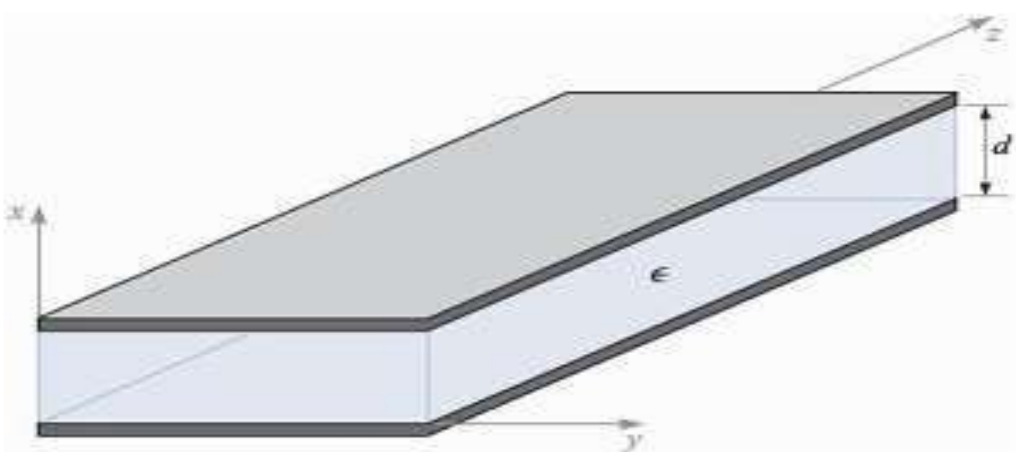
Types of waveguide:

- Parallel Plate wave guide
- Rectangular waveguide
- Circular waveguide
- Dielectric waveguide

Parallel plate waveguide

They are parallel metallic plates separated by a dielectric constant of dielectric permittivity at the centre as shown in figure, separated by a distance ‘d’

- Width in y-direction
- Height in x-direction
- Length in z-direction

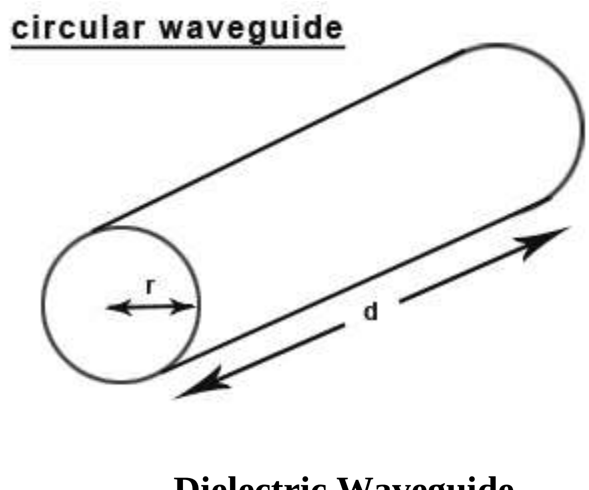


Rectangular Waveguide

This is the most commonly used form of waveguide and has a rectangular cross section, we will analyse it in next lecture

Circular Waveguide

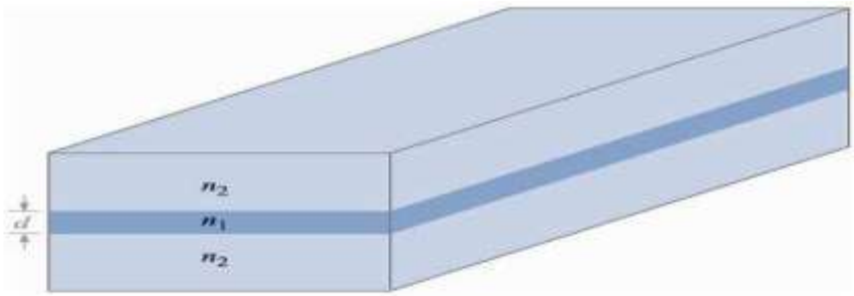
Circular waveguide is less common than rectangular waveguide.
They have many similarities in their basic approach, as RWG but here it has a circular cross section so mathematical analysis varies. This will be also analyzed in coming lectures



Dielectric Waveguide

It is a waveguide that consists of a dielectric material surrounded by another dielectric material, such as air, glass, or plastic, with a lower refractive index.

An example of a dielectric waveguide is an optical fiber.
It is an optical wave guide
It works at optical frequencies
Refractive index "n2" surrounding dielectric
Refractive index "n1" Dielectric
n2<n1



4. **Planar Transmission Lines**

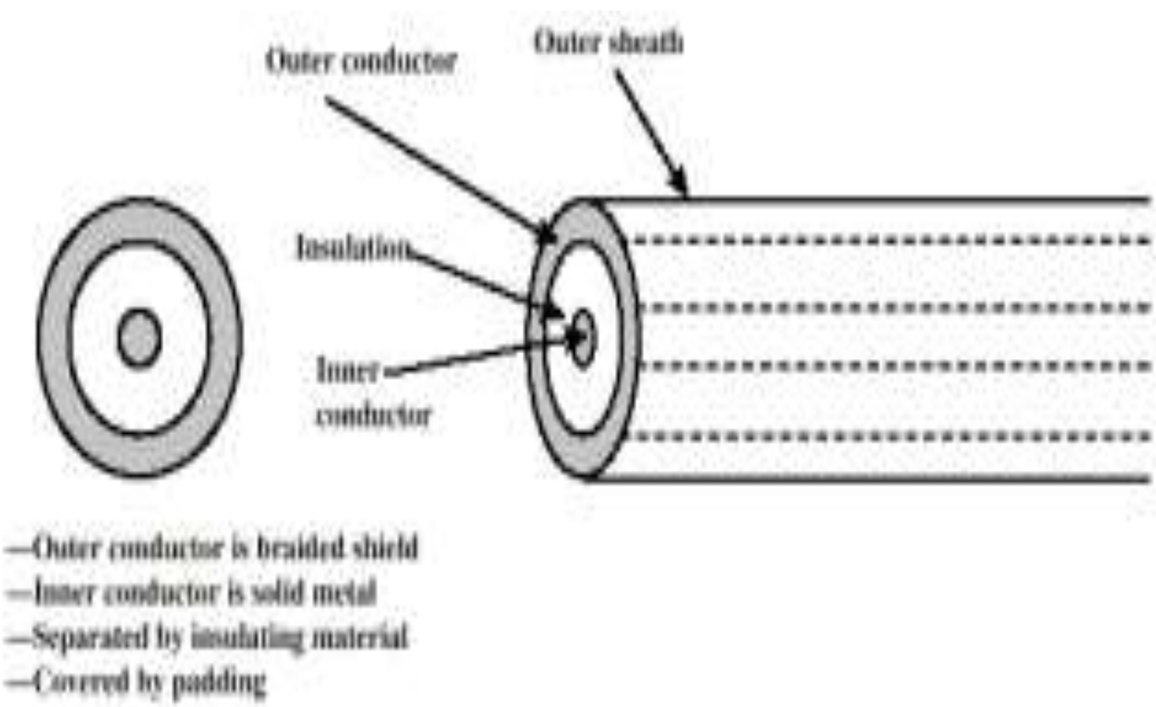
Most commonly used transmission lines are the planar types
They can be constructed precisely using low-cost printed circuit board materials and processes. A number of these open, multi conductor transmission lines comprise a solid dielectric substrate having one or two layers of metallization, with the signal and ground currents flowing on separate conductors.
In general, planar transmission lines consist of strip metallic conductors, usually produced by some photographic process, on a non-conducting substrate. Typical substrate materials are slabs of dielectric, ferrite or high resistivity semiconductors.
In most cases, there are metal ground planes that can either be printed on the same substrate or be a part of the metal housing of MIC.

- Microstriplines
- Striplines
- Coplanar lines
- Slot lines

These will be analyzed in coming lectures

Coaxial Transmission lines

Coaxial lines are the most common, basic transmission lines
They are used to transmit electrical energy, or signals, from one location to another: to connect a source to a load, such as a transmitter to an antenna. A coax line consists of two conductors separated by a dielectric material. The center conductor and the outer conductor are configured in such a way that they form concentric cylinders with a common axis. Hence the term and name co-axial



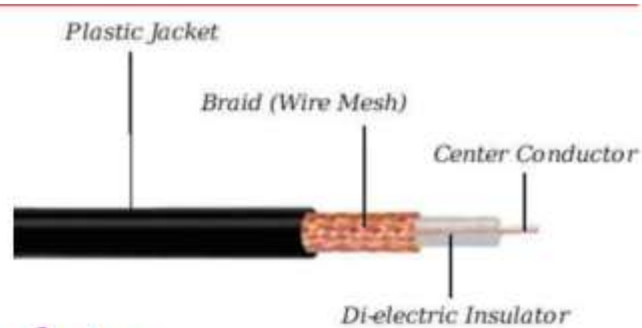
Construction

- The center conductor may be made of various materials and constructions.
- Most common constructions are solid or seven-strand conductors.
- Solid conductors are used in permanent and infrequently handled applications.
- Seven stranded conductors are used in flexible cable applications. Common materials include copper, tinned or silver plated, copper clad steel and copper clad aluminum.

- Data is transmitted through the center wire, The outer braided layer serves as a line to ground, both of these conductors are parallel and share the same axis. That's is why the wire is called coaxial.
- The insulation, or dielectric material, is used to provide separation between the conductors. It is desirable that the material has stable electrical characteristics across a broad frequency range.
- Coaxial cables are categorized by Radio Guide (RG).
- Each RG number denotes a unique set of specifications, including:
- The gauge of the inner conductor.
- The thickness and the type of the inner insulator.
- The construction of shield.
- The size and type of outer casing.

Category	*Impedance*	*Use*
RG-59	75 Ω	Cable TV
RG-58	50 Ω	Thin Ethernet
RG-11	50 Ω	Thick Ethernet

$$C = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\left(\frac{D}{d}\right)} \quad (F/m)$$



$$L = 0.2 \ln\left(\frac{D}{d}\right) \quad (\mu H/m)$$

d = Outer diameter of inner conductor

D = Inner diameter of outer conductor

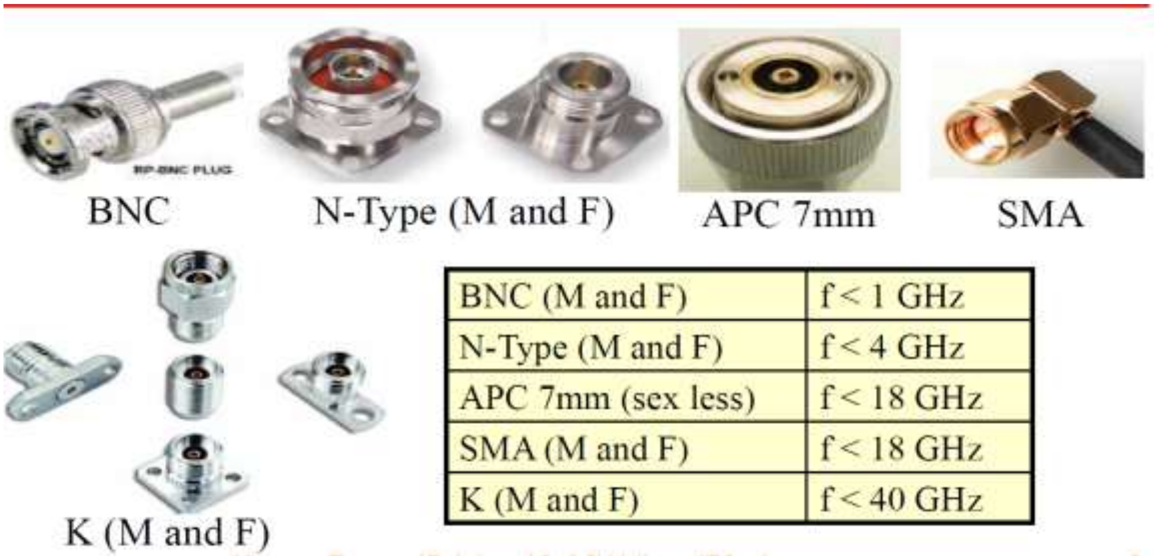
ε_r = Dielectric constant

$$Z_0 = \sqrt{(L/C)} \;\Rightarrow\; Z_o = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(\frac{D}{d}\right) \quad (\Omega/m)$$

Connectors:

The ends of coaxial cables usually terminate with connectors.

- Coaxial connectors are designed to maintain a coaxial form across the connection and have the same impedance as the attached cable.
- Connectors are usually plated with high conductivity metals such as silver or gold.
- In the case of computer networks, BNC (Bayonet Niell-Concelman) RF connectors are used.



BNC (M and F)	f < 1 GHz
N-Type (M and F)	f < 4 GHz
APC 7mm (sex less)	f < 18 GHz
SMA (M and F)	f < 18 GHz
K (M and F)	f < 40 GHz

Advantages of Coaxial Line:

- They are most common means of data transmission over short distances.
- They are cheap to make
- Cheap to install
- Easy to modify
- Good bandwidth
- Great channel capacity

Disadvantages of Coaxial Line:

- Signals entering the cables can cause unwanted noise, making it useless.
- A continuous current flow, even if small, along the imperfect shield of a coaxial cable can cause visible and audible interference.
- More expensive than twisted pairs and is not supported for some network standards.
- It is also has high attenuation, have the need to implement repeaters

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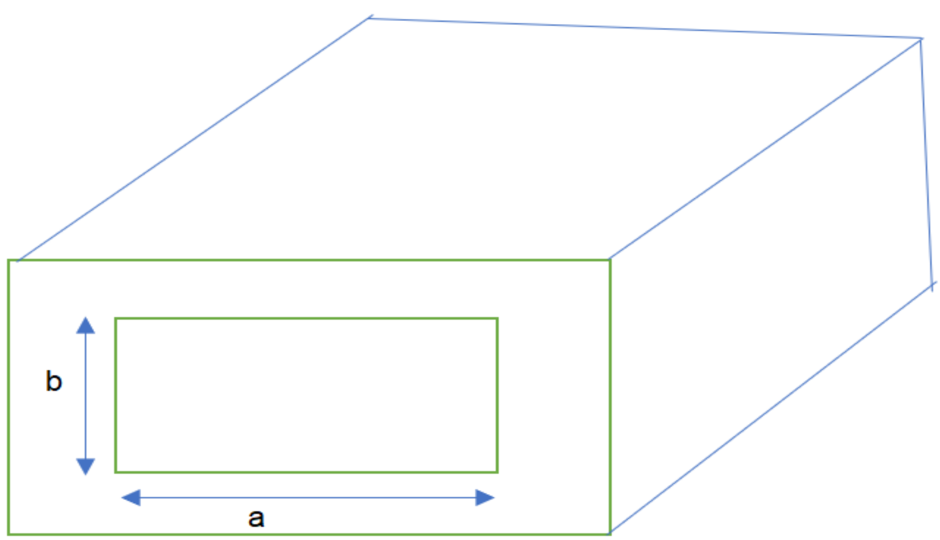
Rectangular Waveguides

A waveguide is a structure used to guide electromagnetic signals of higher frequency
It is a hollow metallic tube of uniform cross section
The wave travels inside the waveguides by successive reflections from the walls of the waveguide

Features

- A waveguide is preferred as a transmission line for high frequency signals
- It has got no center conductor, there is only a single conductor
- They can handle large powers in Kilowatts
- A high frequency signal experiences lower loss when it travels in a waveguide as compared to a coaxial cable
- Waveguides offer very low loss, with a very low attenuation constant (α)
- Waveguides are basically made of brass, copper or aluminum
- At a higher frequency, losses occur in transmission lines and coaxial lines as: Dielectric loss or Skin effect loss, so waveguides are more preferred



Dimensions:
'a' Longer Dimension
'b' Shorter Dimension

Waveguide designation

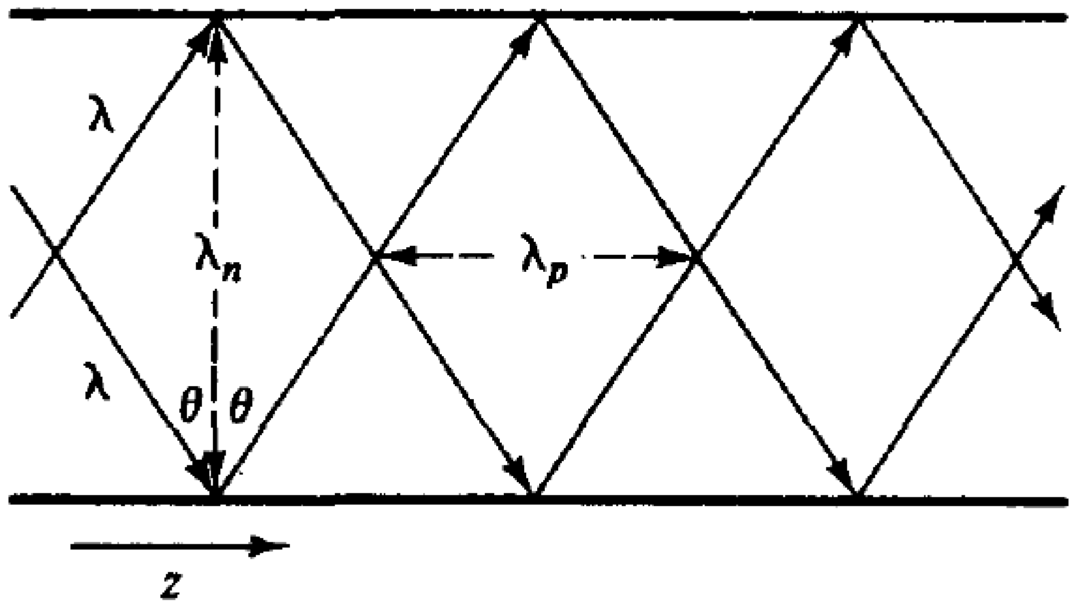
- Waveguides are designated as WRxxx
- where WR stands for waveguide rectangular and the numeral xxx denotes the longest dimension (a) in inches
- WR650 means a=6.50 inches
- WR90 means a=0.9 inches (Most Common Waveguide)
- and the shorter dimension
- $b \approx \frac{a}{2}$

A rectangular waveguide is a hollow metallic tube with a rectangular cross section.
The conducting walls of the waveguide confine the electromagnetic fields and thereby guide the electromagnetic wave.
The rectangular waveguide is basically characterized by its dimensions i.e., length 'a' and breadth 'b'.
A number of distinct field configurations or modes can exist in waveguides.

Wave propagation in waveguides

- When the waves travel longitudinally down the guide, the plane waves are reflected from wall to wall. This process results in a component of either electric or magnetic field in the direction of propagation of the resultant wave; therefore the wave is no longer a *transverse electromagnetic* (TEM) wave.
- Figure shows that any uniform plane wave in a lossless guide may be resolved into TE and TM waves.
- When the wavelength λ is in the direction of propagation of the incident wave, there will be one component λ_n in the direction normal to the reflecting plane and another λ_p parallel to the plane.
- A plane wave in a waveguide resolves into two components: one standing wave in the direction normal to the reflecting walls of the guide and one traveling wave in the direction parallel to the reflecting walls.

- In lossless waveguides the modes may be classified as either *transverse electric* (TE) mode or *transverse magnetic* (TM) mode.



- When a probe launches energy into the waveguide, the electromagnetic fields bounce off the side walls of the waveguide
- The angles of incidence and reflection depend upon the operating frequency.
- At high frequencies, the angles are large and therefore, the path between the opposite walls is relatively long
- At lower frequency, the angles decrease and the path between the sides shortens.
- When the operating frequency reaches the cutoff frequency of the waveguide, the signal simply bounces back and forth directly between the side walls of the waveguide and has no forward motion.
- At cut off frequency and below, no energy will propagate.

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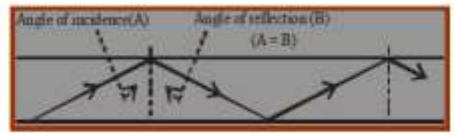
Wave paths in a waveguide at various frequencies

- High frequency



- Medium Frequency

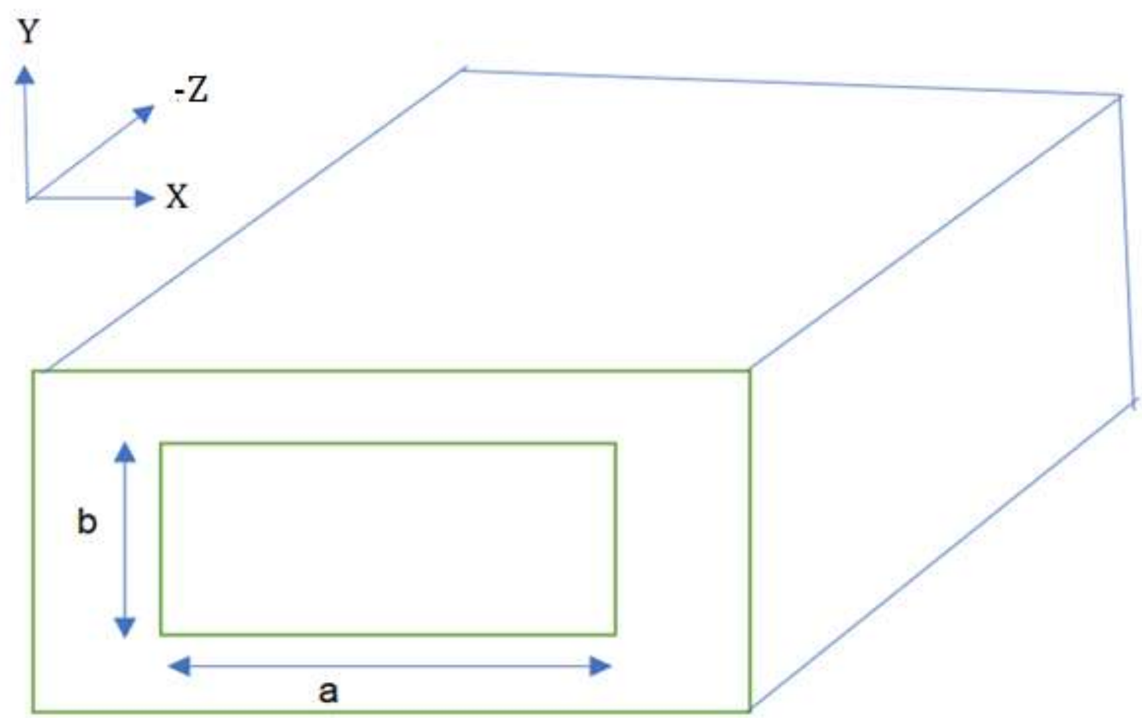
- Low Frequency

- Cut off Frequency

Solution of Wave Equations in Rectangular Coordinates

The process of analyzing the waveguide involves following steps:

- The desired wave equations are written in the form of either rectangular or cylindrical coordinate systems as required
- The boundary conditions are then applied to the wave equations
- The resultant equations are in the form of partial differential equations which can be solved by using the proper method
- A rectangular coordinate system is as shown in figure, with a rectangular waveguide having wave propagation along -z direction



As per the Helmholtz equation:

$$\nabla^2 \Psi = \gamma^2 \Psi$$

Where the function Ψ can be written as a function of x, y and z as:

$$\Psi = X(x)Y(y)Z(z)$$

by using separation of variables

Gamma is propagation constant as discussed previously

$$\gamma = \sqrt{(j\omega\,\mu(\sigma + j\omega\,\epsilon))}$$

Helmholtz equation in rectangular coordinates is given by:

$$\frac{\partial^2\Psi}{\partial x^2} + \frac{\partial^2\Psi}{\partial y^2} + \frac{\partial^2\Psi}{\partial z^2} = \gamma^2\,\Psi$$

Substitution of $\Psi = X(x)Y(y)Z(z)$

Gives

$$\frac{1}{X}\frac{d^2X}{dx^2} + \frac{1}{Y}\frac{d^2Y}{dy^2} + \frac{1}{Z}\frac{d^2Z}{dz^2} = \gamma^2$$

Since the sum of the three terms on the left-hand side is a constant and each term is independently variable, it follows that each term must be equal to a constant.
Let the three terms be k_x^2, k_y^2, k_z^2, respectively, then the separation equation becomes

$$-k_x^2 - k_y^2 - k_z^2 = \gamma^2$$

where

$$-k_x^2 = \frac{1}{X}\frac{d^2X}{dx^2}$$
$$-k_y^2 = \frac{1}{Y}\frac{d^2Y}{dy^2}$$
$$-k_z^2 = \frac{1}{Z}\frac{d^2Z}{dz^2}$$

The general solution of equation will be:

$$X = A\,\mathrm{Sin}(k_x x) + B\,\mathrm{Cos}(k_x x)$$
$$Y = C\,\mathrm{Sin}(k_y y) + D\,\mathrm{Cos}(k_y y)$$
$$Z = E\,\mathrm{Sin}(k_z z) + F\,\mathrm{Cos}(k_z z)$$

The total solution of the Helmholtz equation in rectangular coordinates is:

$$\Psi = (A\,\mathrm{Sin}(k_x x) + B\,\mathrm{Cos}(k_x x))(C\,\mathrm{Sin}(k_y y) + D\,\mathrm{Cos}(k_y y))(E\,\mathrm{Sin}(k_z z) + F\,\mathrm{Cos}(k_z z))$$

The propagation of the wave in the guide is assumed in the *z* direction, the propagation constant γ_g in the guide differs from the intrinsic propagation constant γ of the dielectric as:

$$(\gamma_g)^2=\gamma^2+(k_x)^2+(k_y)^2=\gamma^2+(k_c)^2$$

where

$$\text{kc}=\sqrt{k_x^2+k_y^2}$$

is called cut off wave number

For a lossless dielectric, σ=0, So,

$$\gamma^2=-\omega^2\,\mu\epsilon$$

Therefore,

$$\gamma_g=\pm\sqrt{-\omega^2\,\mu\epsilon+(\text{kc})2}$$

There are three cases for the propagation constant γ_g in the waveguide

Three cases for the wave propagation in rectangular waveguide-

Case –I:

If $\omega^2\mu\epsilon=K_C{}^2$

$\gamma_g=0$ i.e no propagation

This is critical condition for cut off propagation

$$\omega_c=\frac{1}{\sqrt{\mu\epsilon}}\sqrt{kx^2+ky^2}$$

$$f_{c=\frac{1}{2\pi\sqrt{\mu\epsilon}}\sqrt{kx^2+ky^2}}$$

Case –II:

If $\omega^2\mu\epsilon>K_C{}^2$

$$\gamma_{g=} \pm j\beta g\sqrt{\mu\epsilon}\sqrt{1-\left(\frac{f_c}{f}\right)^2}$$

This shows that operating frequency should be greater than critical frequency to propagate the wave in a waveguide.

Case - III:

If $\omega^2\mu\epsilon < {K_C}^2$

$\gamma_{g=} \pm \alpha g = \ \pm\omega\sqrt{\mu\epsilon}\sqrt{\left(\frac{f_c}{f}\right)^2}$-1

This shows that if operating frequency is below the cut off frequency the wave will decay exponentially wrt to a factor -$\alpha_g z$ and there will be no wave propagation .

Expression for cut off frequency

The cut –off wave number k_c is defined as

$$K_c = \sqrt{kx^2 + ky^2}$$

Where $k_x = \frac{m\pi}{a}$ and $k_y = \frac{n\pi}{b}$

$$K_C = \sqrt{\left(\frac{m\pi}{a}\right) + \left(\frac{n\pi}{b}\right)^2}$$

Now from $\gamma^2 g = \gamma^2 + k^2 c$

For the cut off condition , there will be no wave propagation in waveguide

i.e $\gamma^2 g = 0$

we know that propagation constant for lossless dielectric $\gamma^2 = -\omega^2\mu\epsilon$

Then,

$k^2c = -\omega^2\mu\epsilon$

(Replacing ω by cut-off angular frequency ω_c)

$$k_c = \omega_c\sqrt{\mu\epsilon}$$

Or $\sqrt{\left(\frac{m\pi}{a}\right) + \left(\frac{n\pi}{b}\right)^2} = \omega_c\sqrt{\mu\epsilon} = 2\pi f_c\sqrt{\mu\epsilon}$

$$f_c = \frac{1}{2\sqrt{\mu\epsilon}}\sqrt{\left(\frac{m\pi}{a}\right) + \left(\frac{n\pi}{b}\right)^2}$$

We know that $\frac{1}{\sqrt{\mu\epsilon}}$ =c = velocity of light (if dielectric is air)

$$f_c = \frac{c}{2}\sqrt{\left(\frac{m\pi}{a}\right) + \left(\frac{n\pi}{b}\right)^2}$$

In term of wavelength (c=fλ)

$$\lambda_c = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}}$$

So, considering the previous equation

$$-k_z^2 = \frac{1}{Z}\frac{d^2Z}{dz^2}$$

Its solution can also be written in the form as:

$$Z = e^{-jk_z z}$$

as the wave is propagating in -z direction also, k_z is replaced by β_g and the solution of Ψ becomes

$$\Psi = (A\,\mathrm{Sin}(k_x x) + B\,\mathrm{Cos}(k_x x))(C\,\mathrm{Sin}(k_y y) + D\,\mathrm{Cos}(k_y y))\, e^{-j\beta_g z}$$

Representation of Modes

The variables k_x and k_y can be written as :

$$k_x = \frac{m\pi}{a}$$

$$k_y = \frac{n\pi}{b}$$

The general symbol of representation will be TE m, n or TM m, n where: where m,n are integers as 0,1,2……the subscript 'm' indicates the number of half wave variations of the electric field intensity along the a (wide) dimension of the waveguide., the second subscript 'n' indicates the number of half wave variations of the electric field in the b (narrow) dimension of the guide.

The TE10 mode has the longest operating wavelength and is designated as the dominant mode. It is the mode for which the lowest frequency that can be propagated in a waveguide.

Phase and group velocities

$$\beta g = \omega\sqrt{\mu\epsilon}\sqrt{1-\left(\frac{fc}{f}\right)^2}$$

$$v_p = \frac{\omega}{\beta_g}$$

$$v_g = \frac{d\omega}{d\beta_g}$$

$$v_p = \frac{c}{\sqrt{1-\left(\frac{fc}{f}\right)^2}}$$

$$v_g = c\sqrt{1-\left(\frac{fc}{f}\right)^2}$$

$$\beta g = \omega\sqrt{\mu\epsilon}\sqrt{1-\left(\frac{fc}{f}\right)^2}$$

$$\beta g = \frac{2\pi}{\lambda_g} = 2\pi f\sqrt{\mu\epsilon}\sqrt{1-\left(\frac{fc}{f}\right)^2}$$

Relation between wavelengths

$$\frac{1}{(\lambda)^2} = \frac{1}{(\lambda g)^2} + \frac{1}{(\lambda c)^2}$$

λ is the free space wavelength

λg is the guided wavelength

λc is the cut off wavelength

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Solution of wave equation for TE modes

The *TE* modes in a rectangular guide are characterized by *Ez*= 0. In other words, the *z* component of the magnetic field, *Hz,* must exist in order to have energy transmission in the guide. Consequently, from a given Helmholtz equation, Hz is not equal to zero, so:

$$\nabla^2 Hz = \gamma^2\, Hz$$

A solution will be of the form

$$Hz = \left(\left(Am\ Sin\left(\frac{m\pi x}{a}\right) + Bm\ Cos\left(\frac{m\pi x}{a}\right)\right)\left(Cn\ Sin\left(\frac{n\pi y}{b}\right) + Dn\ Cos\left(\frac{n\pi y}{b}\right)\right)\right) e^{-j\beta gz}$$

Where, (a, b are the dimensions of waveguide and m, n are integers from 0,1,2…)

$$kx = \frac{m\pi}{a}$$

$$ky = \frac{n\pi}{b}$$

With the substitution

$\frac{\partial}{\partial z}$= -jβg (As wave is propagating in -z direction) and Ez=0 (TE mode) ,

The Maxwell curl equations as described previously become:

$$E_x = \frac{-j\omega\mu}{k_c^2}\frac{\partial H_z}{\partial y}$$

$$E_y = \frac{j\omega\mu}{k_c^2}\frac{\partial H_z}{\partial x}$$

$$E_z = 0$$

$$H_x = \frac{-j\beta_g}{k_c^2}\frac{\partial H_z}{\partial x}$$

$$H_y = \frac{-j\beta_g}{k_c^2}\frac{\partial H_z}{\partial y}$$

The boundary conditions are applied to the newly found field equations in such a manner that either the tangent E field or the normal H field vanishes at the surface of the conductor.

Since $Ex = 0$, then $\frac{\partial Hz}{\partial y} = 0$ at $y = 0, b$. Hence $Cn = 0$.

Since $Ey = 0$, then $\frac{\partial Hz}{\partial x} = 0 \; at \; x = 0, a$ Hence Am=0

It is generally concluded that the normal derivative of *Hz* must vanish at the conducting surfaces that is:

$\frac{\partial Hz}{\partial n} = 0$ at the guide walls

Therefore, the magnetic field in the positive *z* direction is given by:

$Hz = H_{0z} Cos(\frac{m\pi x}{a}) \; Cos(\frac{n\pi y}{b}) \; e^{-j\beta g \, z}$ H_{0z} is a constant

On substitution of Hz the other components become

$Ex = E_{0x} Cos(\frac{m\pi x}{a}) Sin(\frac{n\pi y}{b}) \; e^{-j\beta g \, z}$

$Ey = E_{0y} Sin(\frac{m\pi x}{a}) Cos(\frac{n\pi y}{b}) \; e^{-j\beta g \, z}$

Ez=0

$Hx = H_{0x} Sin(\frac{m\pi x}{a}) Cos(\frac{n\pi y}{b}) \; e^{-j\beta g \, z}$

$Hy = H_{0y} Cos(\frac{m\pi x}{a}) Sin(\frac{n\pi y}{b}) \; e^{-j\beta g \, z}$

The cutoff wave number k_c. as defined for the TE_{mn} modes, is given by

$$k_c = \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} = \omega_c\sqrt{\mu \epsilon}$$

where *a* and *b* are in meters. The cut off frequency, for the TE_{mn} modes, is

$$f_c = \frac{1}{2\sqrt{\mu\epsilon}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

The propagation constant (or the phase constant here) is expressed by

$$\beta_g = \omega\sqrt{\mu\epsilon}\sqrt{1-\left(\frac{f_c}{f}\right)^2}$$

The characteristic wave impedance of TE_{mn} modes in the guide can be derived

$$z_g = \frac{E_x}{H_y} = \frac{-E_y}{H_x} = \frac{\omega\mu}{\beta_g} = \frac{\eta}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

- $E_x = \frac{-j\omega\mu}{k_c^2}\frac{\partial H_z}{\partial y}$

$$H_y = \frac{-j\beta_g}{k_c^2}\frac{\partial H_z}{\partial y}$$

The wavelength in the guide for the TE_{mn} modes is given by

$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

$$\beta_g = \frac{2\pi}{\lambda_g} = \omega\sqrt{\mu\epsilon}\sqrt{1-\left(\frac{f_c}{f}\right)^2}$$

Solution of Wave equation for TM modes

The TM modes in a rectangular waveguide are characterized by $H_z = 0$. In other words, the z component of the magnetic field, E_z, must exist in order to have energy transmission in the guide. Consequently, from a given Helmholtz equation, E_z is not equal to zero

$$\nabla^2 E_z = \gamma^2 E_z$$

A solution will be of the form

$$E_z = (\text{Am Sin}(\frac{m\pi x}{a}) + \text{ Bm Cos}(\frac{m\pi x}{a}))(\text{Cn Sin}(\frac{n\pi y}{b}) + \text{ Dn Cos}(\frac{n\pi y}{b}))\ e^{-j\beta_g z}$$

The boundary conditions are applied to the field equations such that the tangent E field is zero at a surface

$E_z = 0$ at x = 0, a then Bm = 0,

and for $E_z = 0$ at y = 0, b then Dn = 0

Therefore the electric field is given by:

$$E_z = E_{0z}\,\text{Sin}(\frac{m\pi x}{a})\text{Sin}(\frac{n\pi y}{b})e^{-j\beta_g z}$$

E_{0z} is a constant

If either $m = 0$ or $n = 0$, the field intensities all vanish. So there is no TM_{01} or TM_{10} mode in a rectangular waveguide

On again expanding the curl of equations

$$\nabla X E = -j\omega\,\mu H$$

$$\nabla X H = j\omega \epsilon E$$

We have

- $\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} = -j\omega\, \mu H_x$
- $\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} = -j\omega\, \mu H_y$
- $\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} = -j\omega\, \mu H_z$
- $\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} = j\omega\, \epsilon E_x$
- $\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} = j\omega\, \epsilon E_y$
- $\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} = j\omega\, \epsilon E_z$

If we assume exponential variation of fields with z then, $\frac{\partial}{\partial z}$ can be replaced by $-j\beta_g$

H_z= 0 for TM modes

Also,

$k_c^2 = \omega^2\, \mu\epsilon - \beta_g^2$

- $H_x = \frac{j\omega\epsilon}{k_c^2} \frac{\partial E_z}{\partial y}$
- $H_y = \frac{-j\omega\epsilon}{k_c^2} \frac{\partial E_z}{\partial x}$
- $H_z = 0$

- $E_x = \frac{-j\beta_g}{k_c^2}\frac{\partial E_z}{\partial x}$
- $E_y = \frac{-j\beta_g}{k_c^2}\frac{\partial E_z}{\partial y}$

$E_z = E_{0z}\, \mathrm{Sin}(\frac{m\pi x}{a})\mathrm{Sin}(\frac{n\pi y}{b})e^{-j\beta_g z}$

On substituting E_z the other components will become

- $E_x = E_{0x}\mathrm{Cos}(\frac{m\pi x}{a})\mathrm{Sin}(\frac{n\pi y}{b})e^{-j\beta_g z}$
- $E_y = E_{0y}\mathrm{Sin}(\frac{m\pi x}{a})\mathrm{Cos}(\frac{n\pi y}{b})e^{-j\beta_g z}$
- $E_z = E_{0z}\mathrm{Sin}(\frac{m\pi x}{a})\mathrm{Sin}(\frac{n\pi y}{b})e^{-j\beta_g z}$
- $H_x = H_{0x}\mathrm{Sin}(\frac{m\pi x}{a})\mathrm{Cos}(\frac{n\pi y}{b})e^{-j\beta_g z}$
- $H_y = H_{0y}\mathrm{Cos}(\frac{m\pi x}{a})\mathrm{Sin}(\frac{n\pi y}{b})e^{-j\beta_g z}$
- $H_z = 0$

The cutoff wave number k_c. as defined for the TM_{mn} modes, is given by

$$k_c = \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} = \omega_c\sqrt{\mu\epsilon}$$

where a and b are in meters. The cutoff frequency, for the TM_{mn} , same as that for TE modes is

$$f_c = \frac{1}{2\sqrt{\mu\epsilon}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

The propagation constant (or the phase constant here) is expressed by

$$\beta_g = \omega\sqrt{\mu\epsilon}\sqrt{1 - \left(\frac{f_c}{f}\right)^2}$$

The characteristic wave impedance of TM_{mn} modes in the guide can be derived

$$z_g = \frac{E_x}{H_y} = \frac{-E_y}{H_x} = \frac{\beta_g}{\omega\epsilon} = \eta\sqrt{1 - \left(\frac{f_c}{f}\right)^2}$$

- $H_y = \frac{-j\omega\epsilon}{k_c^2}\frac{\partial E_z}{\partial x}$

$$E_x = \frac{-j\beta_g}{k_c^2}\frac{\partial E_z}{\partial x}$$

The wavelength in the guide for the TM_{mn} modes is given by

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$$

TEM mode in rectangular Waveguides

Considering, curl equations as before

- $\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} = -j\omega\,\mu H_x$
-
- $\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} = -j\omega\,\mu H_y$
-
- $\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} = -j\omega\,\mu H_z$
-

- $\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} = j\omega \in E_x$
-
- $\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} = j\omega \in E_y$
- $\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} = j\omega \in E_z$

TEM modes are characterized by both E_z and H_z as zero
By putting this all the field components become zero, so TEM modes do not exist in waveguides
Also, theoretically TEM modes exist only in the presence of more than one conductor but waveguides have a single conductor so, TEM modes do not exist in waveguides

Dominant and Degenerate modes

- Whenever two or more modes have the same cutoff frequency, they are said to be degenerate modes.
- In a rectangular waveguide the corresponding TE_{mn} and TM_{mn} modes are always degenerate
- The TE_{10} mode has the longest operating wavelength and is designated as the dominant mode. It is the mode for the lowest cut off frequency that can be propagated in a waveguide
- For TM modes the dominant mode is TM_{11}

Q1. An air-filled rectangular waveguide of inside dimensions 7 x 3.5 cm operates in the dominant TE_{10} mode
a. Find the cut off frequency.
b. Determine the phase velocity of the wave in the guide at a frequency of 3.5 GHz.
c. Determine the guided wavelength at the same frequency.
Solution:
Cut off frequency

$$f_c = \frac{1}{2\sqrt{\mu \in}} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

m=1 , n=0, a= 7 cm

c=$\frac{1}{\sqrt{\mu\epsilon}}$= 3X10^8 m/sec

f_c=2.14 GHz

b. Phase velocity

$$v_p = \frac{c}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$$

f= 3.5 GHz
f_c=2.14 GHz
v_p= 3.78 X 10^8 m/sec

c. Guided wavelength

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$$

f= 3.5 GHz
f_c=2.14 GHz
λ_g=10.8 cm

L-10

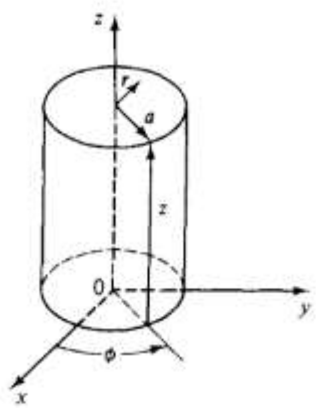
Circular Waveguide

Circular Waveguide

A circular waveguide is a tubular, circular conductor. A plane wave propagating through a circular waveguide results in a transverse electric (TE) or transverse magnetic (TM) mode. In general terms the behavior is the same as in Rectangular waveguide. However different geometry means different application hence a separate analysis. The law governing the propagation of waves in waveguides are independent of the cross sectional shape and dimensions of the guide. All the parameters and definitions evolved for Rectangular waveguide apply to circular with minor modification

Solution of Wave equation in Cylindrical Coordinates

A cylindrical coordinate system is as shown in figure



The scalar Helmholtz equation in cylindrical coordinates is given by

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \Psi}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 \Psi}{\partial \emptyset^2} + \frac{\partial^2 \Psi}{\partial z^2} = \gamma^2 \Psi$$

Using the method of separation of variables, the solution is assumed in the form of

$\Psi = R(r)\emptyset(\emptyset)Z(z)$

where R (r) = a function of the r coordinate only

$\emptyset(\emptyset)$ = a function of the $\emptyset$ coordinate only

Z (z) = a function of the z coordinate only

Substitution and division of above gives

$\frac{1}{rR}\frac{d}{dr}(r\frac{dR}{dr}) + \frac{1}{r^2\emptyset}\frac{d^2\emptyset}{d\emptyset^2}+\frac{1}{Z}\frac{d^2Z}{dz^2}=\gamma^2$

Since the sum of the three independent terms is a constant, each of the three terms must be a constant. The third term may be set equal to a constant

$\frac{d^2Z}{\partial z^2}=\gamma_g{}^2 z$

The solution of this equation is given in the form

$Z= Ae^{-\gamma_g z} + Be^{\gamma_g z}$

$\frac{r}{R}\frac{d}{dr}(r\frac{dR}{dr}) + \frac{1}{\emptyset}\frac{d^2\emptyset}{d\emptyset^2}-(\gamma^2 - \gamma_g{}^2)r^2=0$

The second term is a function of $\emptyset$ only, hence equating the second term to a constant ($-n^2$)

$\frac{d^2\emptyset}{d\emptyset^2}=- n^2 \emptyset$

The solution of this equation is also a harmonic function

$\emptyset=A_n\mathrm{Sin}(n\emptyset)+B_n\mathrm{Cos}(n\emptyset)$

$r\frac{d}{dr}(r\frac{dR}{dr}) + [(k_c r)^2 - n^2]R=0$

This is Bessel's equation of order *n* in which

$(\gamma_g)^2= \gamma^2 +(k_c)^2$

This equation is called the characteristic equation of Bessel's equation. For a lossless guide, the characteristic equation reduces to

$\beta g= \pm\sqrt{\omega^2\mu\epsilon - k_c^2}$

The solutions of Bessel's equation are

$R=C_nJ_n(k_c r)+D_nN_n(k_c r)$

where $J_n(k_c r)$ is the nth-order Bessel function of the first kind, representing a standing wave of cos $(k_c r)$ for $r < a$

$N_n(k_c r)$ is the nth-order Bessel function of the second kind, representing a standing wave of sin $(k_c r)$ for $r > a$

Therefore the total solution of the Helmholtz equation in cylindrical coordinates is given by

$$\Psi = (C_nJ_n(k_c r)+D_nN_n(k_c r)(A_n\mathrm{Sin}(n\emptyset)+B_n\mathrm{Cos}(n\emptyset)e^{\pm j\beta_g z}$$

Finally, the solution of the Helmholtz equation is reduced to

$$\Psi = \Psi_0(J_n(k_c r))\mathrm{Cos}(n\emptyset)e^{-j\beta_g z}$$

TE mode in Circular Waveguide

The TE modes in a circular waveguide are characterized by $E_z = 0$. In other words, the z component of the magnetic field, H_z, must exist in order to have energy transmission in the guide. Consequently, from a given Helmholtz equation, H_z is not equal to zero,

so: $\nabla^2 H_z = \gamma^2 H_z$

Its solution is of the form

$$H_z = H_{0z}(J_n(k_c r))\mathrm{Cos}(n\emptyset)e^{-j\beta_g z}$$

The Maxwell equations for a lossless dielectric medium becomes in frequency domain as:

$\nabla X E = -j\omega\,\mu H$

$\nabla X H = j\omega\epsilon E$

Suppose, i,j,k are unit vectors along X, Y and Z directions

Electric field Vector E= $E_x\, i + E_y\, j + E_z\, k$

Magnetic field Vector H= $H_x\, i + H_y\, j + H_z\, k$

On expanding the curl equations in cylindrical coordinates

The boundary conditions require that the $\emptyset$ component of the electric field $E_\emptyset$, which is tangential to the inner surface of the circular waveguide at r = a, must vanish or that the r component of the magnetic field H_r, which is normal to the inner surface of r = a, must vanish. Consequently

$E_\emptyset = 0$, at r=a, then $\frac{\partial H_z}{\partial r} = 0$ at r=a

$H_{0z}(J_n'(k_c a))\mathrm{Sin}(n\emptyset)e^{-j\beta_g z} = 0$

$J_n'(k_c a) = 0$

The permissible values are

$$k_c = \frac{X_{np}'}{a}$$

$E_r = E_{0r}\, J_n(\frac{X_{np}' r}{a})\mathrm{Sin}(n\emptyset)e^{-j\beta_g z}$

$E_\emptyset = E_{0\emptyset}\, J_n'\left(\frac{X_{np}' r}{a}\right)\mathrm{Cos}(n\emptyset)e^{-j\beta_g z}$

$E_z = 0$

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$$H_r = H_{0r}\, J_n\left(\frac{X'_{np} r}{a}\right) \mathrm{Cos}(n\emptyset) e^{-j\beta_g z}$$
$$H_\emptyset = H_{0\emptyset}\, J_n\left(\frac{X'_{np} r}{a}\right) \mathrm{Sin}(n\emptyset) e^{-j\beta_g z}$$
$$H_z = H_{0z}\, J_n\left(\frac{X'_{np} r}{a}\right) \mathrm{Cos}(n\emptyset) e^{-j\beta_g z}$$

Where n=0,1,2,3 and p=1,2,3,4

The first subscript *n* represents the number of full cycles of field variation in one revolution through *2π* rad of ∅. The second subscript *p* indicates the number of zeros of $E_\emptyset$,-that is, $J_n\left(\frac{X'_{np} r}{a}\right)$ along the radial of a guide, but the zero on the axis is excluded if it exists.

Mode propagation constant

$$\beta g = \sqrt{\omega^2 \mu \epsilon - \left(\frac{X'_{np}}{a}\right)^2}$$

The cutoff wave number of a mode is that for which the mode propagation constant vanishes. Hence

$$k_c = \frac{X'_{np}}{a} = \omega_c \sqrt{\mu \epsilon}$$

The cutoff frequency for TE modes in a circular guide is then given by

$$f_c = \frac{X'_{np}}{2\pi a \sqrt{\mu \epsilon}}$$

$$v_p = \frac{\omega}{\beta_g} \text{ (Phase velocity)}$$

$$v_p = \frac{c}{\sqrt{1 - \left(\frac{fc}{f}\right)^2}}$$

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$$

$$z_g = \frac{\omega\mu}{\beta_g} = \frac{\eta}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

TM modes in Circular Waveguide

The TM modes in a circular waveguide are characterized by $H_z = 0$. In other words, the z component of the electric field, E_z, must exist in order to have energy transmission in the guide. Consequently, from a given Helmholtz equation, H_z is not equal to zero,

so: $\boldsymbol{\nabla^2 E_z = \gamma^2 E_z}$

Its solution is of the form

$$\boldsymbol{E}_z = \boldsymbol{E}_{0z}(J_n(k_c\text{r}))\text{Cos}(\text{n}\emptyset)e^{-j\beta_g z}$$

The boundary condition requires that the tangential component of electric field Ez at $r = a$ vanishes. Consequently,

$J_n(k_c\text{a})$=0

The Maxwell equations for a lossless dielectric medium becomes in frequency domain as:

$\nabla X E = -j\omega\,\mu\text{H}$

$\nabla X H = \text{j}\omega\epsilon\text{E}$

Suppose, i, j, k are unit vectors along X, Y and Z directions

Electric field Vector E= $E_x\ i + E_y\ j + E_z\ k$

Magnetic field Vector H= $H_x\ i + H_y\ j + H_z\ k$, On expanding the curl equations in cylindrical coordinates

$E_r = E_{0r}\, J_n'\left(\frac{X_{np}r}{a}\right)\text{Cos}(n\emptyset)e^{-j\beta_g z}$

$E_\emptyset = E_{0\emptyset}\, J_n\left(\frac{X_{np}r}{a}\right)\text{Sin}(n\emptyset)e^{-j\beta_g z}$

$E_z = E_{0z}\, J_n\left(\frac{X_{np}r}{a}\right)\text{Cos}(n\emptyset)e^{-j\beta_g z}$

$H_r = H_{0r} J_n\left(\frac{X_{np}r}{a}\right)\text{Sin}(n\emptyset)e^{-j\beta_g z}$

$H_\emptyset = H_{0\emptyset}\, J_n'\left(\frac{X_{np}r}{a}\right)\text{Cos}(n\emptyset)e^{-j\beta_g z}$

$H_z = 0$

$v_p = \frac{\omega}{\beta_g}$ (Phase velocity)

$$v_p = \frac{c}{\sqrt{1-\left(\frac{fc}{f}\right)^2}}$$

$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{fc}{f}\right)^2}}$$

$$z_g = \frac{\beta_g}{\omega\epsilon} = \eta\sqrt{1-\left(\frac{f_c}{f}\right)^2}$$

TEM mode in circular waveguide

TEM modes are characterized by both E_z and H_z as zero.This means that the electric and magnetic fields are completely transverse to the direction of wave propagation. This mode cannot exist in hollow waveguides, since it requires two conductors, such as the coaxial transmission line and two-open-wire line. we covered analysis of Circular Waveguides.

Numerical -

Q1- An air filled circular waveguide is to be operated at a frequency of 6GHz and is to have dimensions such that fc=0.8f for TE_{11} mode. Determine the diameter of the waveguide and guide wavelength.

Solutions-

For TE_{11} mode in circular waveguide

Let r and D be the radius and the diameter of the waveguide respectively

$\lambda_c = \frac{2\pi r}{1.841}$

It is given that f_c= 0.8f

And f= 6GHz

$f_c = 0.8\times 6 \times 10^9$ =4.8GHz

$\lambda_c = \frac{c}{f_c} = \frac{3\times10^{10}}{4.8\times10} = \frac{30}{4.8}$ =6.25cms

$6.25= \frac{2\pi r}{1.841}$

2r=D

$6.25 = \frac{\pi D}{1.841}$

$D= \frac{6.25\times1.841}{\pi}$

= 3.6625cms.

$\lambda_g=\frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$

$\lambda_{0=}\ \frac{c}{f} = \frac{3\times10^8}{6\times10^9}$ =5 cms

$\lambda_{c=}$6.25cms

$\lambda_g=\frac{5}{\sqrt{1-\left(\frac{5}{6.25}\right)^2}} = \frac{5}{0.6}$ =8.33 cms ans

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l-11

Strip line and Microstripline

Planar Transmission Lines

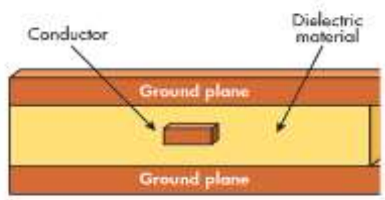
One of the most commonly used transmission lines are the planar types which can be constructed precisely using low-cost printed circuit board materials and processes. A number of these open, multi conductor transmission lines comprise a solid dielectric substrate having one or two layers of metallization, with the signal and ground currents flowing on separate conductors. Planar transmission lines used in microwave frequencies can be broadly divided into two categories: those that can support a TEM (or Quasi-TEM) mode of propagation, and those that cannot. In general, planar transmission lines consist of strip metallic conductors, usually produced by some photographic process, on a non-conducting substrate. Typical substrate materials are slabs of dielectric, ferrite or high resistivity semiconductors. In most cases, there are metal ground planes that can either be printed on the same substrate or be a part of the metal housing of MIC.

Types of Planar Transmission Lines

1) Strip lines
2) Microstriplines
3) Slot lines
4) Coplanar lines

Striplines

Stripline transmission line requires three layers of conductors where the internal conductor is commonly called the “hot conductor,” while the other two, always connected at signal ground, are called “cold” or “ground” conductors. The hot conductor is embedded in a homogeneous and isotropic dielectric, of dielectric constant. The dielectric completely surrounds the hot conductor.



Because the region between the two outer plates of Stripline contains only a single medium, the phase velocity and the characteristic impedance of the dominant mode TEM do not vary with frequency.

Stripline is often required for multilayer circuit boards because it can be routed between the layers. Stripline is more insensitive to lateral ground planes of a metallic enclosure, since the electromagnetic field is strongly contained near the center conductor and the top–bottom ground planes.

In a Stripline, the return current path for a high frequency signal trace is located directly above and below the signal trace on the ground planes. The high frequency signal is thus contained entirely inside the PCB, minimizing emissions, and providing natural shielding against incoming spurious signals.

It is a combination of two wire lines and co-axial lines. These are basically planar transmission lines and are widely used for frequencies from 100 MHz to 100 GHz. A Strip line consists of a central thin conducting strip of width W which is greater than its thickness t. It is placed inside the low loss dielectric (ε_r) substrate of thickness b between two wide ground plates.The width of the ground plates is five times greater than the spacing between the plates.The fundamental and dominant mode in Strip lines is TEM mode.The Characteristic Impedance Z_0 of the stripline depends on the dielectric constant and on the cross-sectional geometry of the strip center-conductor and ground planes. Characteristic impedance is very sensitive to the ratio of center-conductor width to dielectric thickness and relatively insensitive to the ratio of center-conductor thickness to dielectric thickness. Any vertical asymmetry in the Stripline structure could couple to waveguide-type modes bounded by the ground planes and the side walls. The following simple equation approximates Stripline impedance with 1% accuracy:

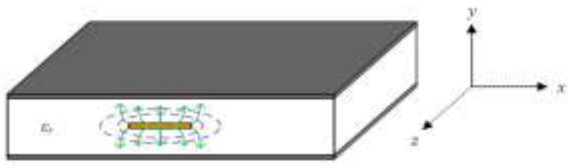
$$Z_0 = \frac{30\pi}{\sqrt{\varepsilon_r}} \frac{b}{W_e + 0.441\, b} \text{ (ohms)}$$

W_e is the effective width of centre strip conductor, given by

$$\frac{W_e}{b} = \frac{W}{b} - (0.35 - \frac{W}{b})^2 \text{ when } \frac{W}{b} < 0.35$$

$$\frac{W_e}{b} = \frac{W}{b} \text{ when } \frac{W}{b} > 0.35$$

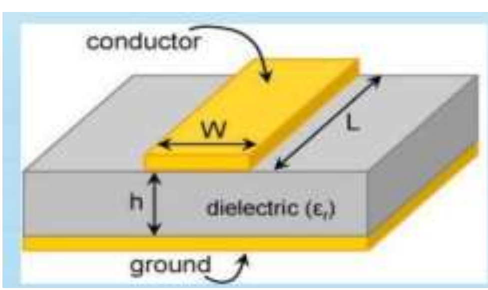
Field pattern of Striplines



A Stripline transmission line displays TEM mode of propagation. The green lines represent the E-field and purple lines the H-field. A stripline consists of a conductor of width *W*, centered in a dielectric material of thickness *b* and permittivity ε_r. Two ground planes separated by a distance *b* are placed above and below the stripline. The presence of the homogeneous dielectric between the conducting ground planes supports the TEM mode of propagation. Similar to coaxial lines, the stripline is also capable of supporting higher order modes of propagation, is non-dispersive and has no cutoff frequency.

Microstriplines

The Microstrip line has become the best known and most widely used planar transmission line for RF and Microwave circuits. This popularity and widespread use are due to its planar nature, ease of fabrication using various processes, easy integration with solid-state devices, good heat sinking, and good mechanical support. A microstrip is a type of transmission line that consists of a conductor fabricated on dielectric substrate with a grounded plane.



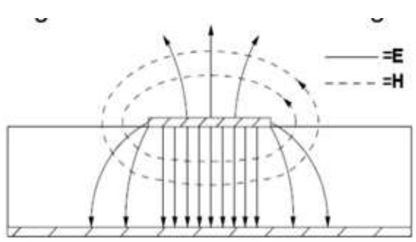
A microstrip line consists of a conductor of width W, a dielectric substrate of thickness h and permittivity $\in_r$. The presence of the dielectric concentrates the field lines in the region between the between the conductor and the ground plane, with some fraction being in the air region above the conductor, leading to quasi-TEM modes of propagation

In simple terms, Microstrip is the printed circuit version of a wire over a ground plane, and thus it tends to radiate as the spacing between the ground plane and the strip increases.
A substrate thickness of a few percent of a wavelength (or less) minimizes radiation without forcing the strip width to be too narrow.

In contrast to Stripline, Microstrip has its dominant mode to be hybrid (Quasi-TEM) not TEM, with the result that the phase velocity, characteristic impedance, and field variation in the guide cross section all become mildly frequency dependent. The Microstrip line is dispersive, with increasing frequency, the effective dielectric constant gradually climbs towards that of the substrate, so that the phase velocity gradually decreases. In Microstrip, a new concept of effective dielectric Constant ε_{eff} was introduced, which takes into account that most of the electric fields are constrained within the substrate, but a fraction of the total energy exists within the air above the board. The dispersion becomes more pronounced with the decreasing ratio of strip width to substrate thickness, W/h. Dispersion is less pronounced as the strip width becomes relatively wider, and the Microstrip line physically starts to approach an ideal parallel-plate capacitor.

The effective dielectric Constant ε_{eff} is expected to be greater than the dielectric constant of air ($\varepsilon = 1$) and less than that of the dielectric substrate.

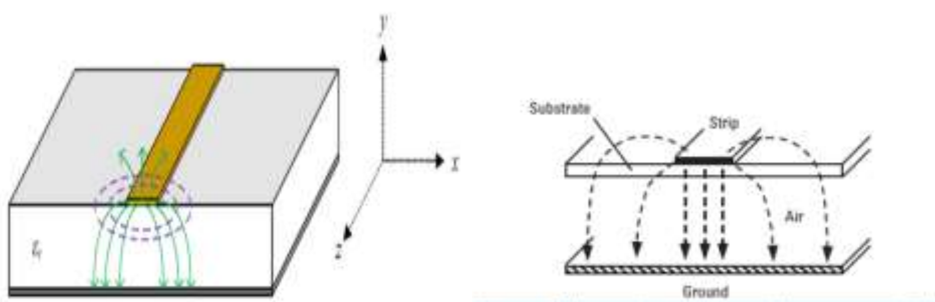
$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12h}{W}}}$$



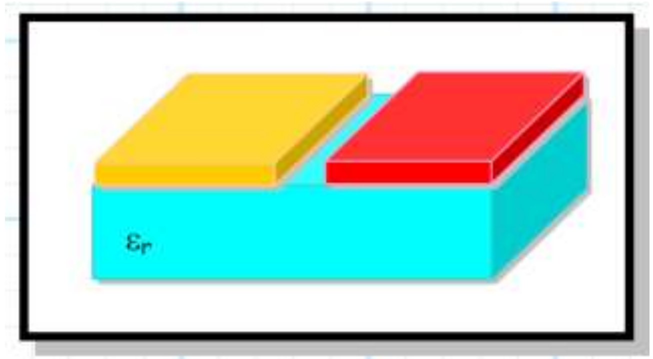
Microstrip frequency limitation is given mainly by the lowest order transverse resonance, which occurs when width of the line (plus fringing field component) approaches a half-wavelength in the dielectric. We should have to avoid using wide lines, for very wide lines, the fields are almost all in the substrate, while narrower lines will have proportionally more field energy in air.

Any practical Microstrip line has the following sources of attenuation, due to:
Finite conductibility of the line conductors. Finite resistivity of the substrate and its dumping phenomena. Waveguides and Striplines have no radiation losses, while in Microstrip case (since the Microstrip is an open transmission line) radiation effects are present at any discontinuity section, for Microstrip using high dielectric materials and accurate conductor shape and matching, conductor and dielectric losses are predominant in relation to the radiation losses.
Microstrip's primary advantages of low cost and compact size are offset by its tendency to be more lossy than coaxial line, waveguide, CPW and stripline. Radiation losses depend on the dielectric constant, substrate thickness, the circuit geometry and also depends on frequency. The lower the dielectric constant, the less the concentration of energy in the substrate region, and, hence greater the radiation losses. Higher the thickness of the material, higher the radiation losses. The real benefit in having a higher dielectric constant is not only reducing radiation losses but also that the package size decreases by approximately the square root of the dielectric constant

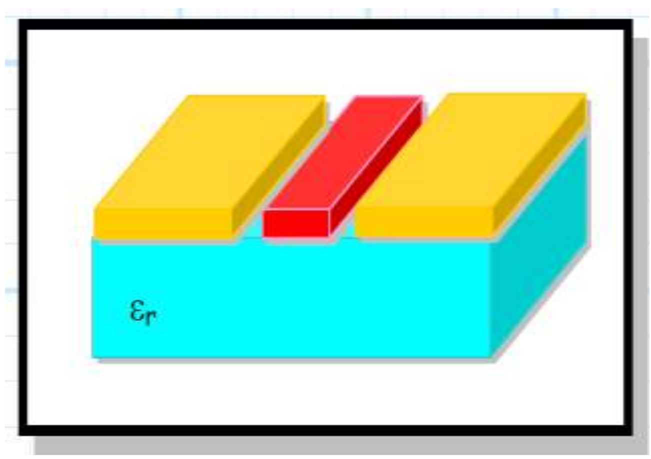
Field pattern of Microstripline



Slot Line



Coplanar Line



Unit V

Microwave Network Analysis

L-12

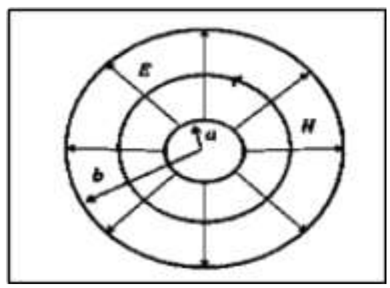
Equivalent voltages and currents for non-TEM lines

Equivalent Voltage and Current-

At Microwave Frequency Measurement of voltage or current is not practical unless a clearly defined terminal pair is available. Such a terminal pair may exist for TEM type lines but does not exist in a strict sense for non-TEM line. Therefore voltage and current as a measure of level of electrical excitation of a circuit does not play a primary role at microwave frequencies.. However introduction of equivalent voltage, current is helpful in extending circuit theory Concept in microwave network. For a Transmission line supporting TEM waves, the voltage and current are uniquely related to the transverse electric and magnetic field respectively. Let us illustrate this by some example figure shows Co axial transmission line.

$$\vec{E} = \frac{V_0}{\ln\frac{b}{a}} \frac{e^{-jk_0 z}}{\rho} \widehat{a_\rho}$$

$$k_0 = \omega\sqrt{\mu_0 \epsilon_0}$$



Where V_0 is potential difference between Inner and Outer Conductor . Here *a* is inner radius and *b* is outer radius

so, voltage wave associated with the electric field is

V= $V_{0e^{-jk_0 z}}$

Magnetic field is given by

$$\vec{H} = \frac{Y_0 V_0}{In\frac{b}{a}} \frac{\widetilde{a\phi}}{\rho} e^{-jk_0 z}$$

Current wave associated with the magnetic field is

I = $I_0 e^{-jk_0 z}$

Where $I_0 = \frac{Y_0 V_0 2\pi}{In\frac{b}{a}}$

Once we define these equivalent voltages and currents and relate them to the electric and magnetic fields. We can calculate the power that is going through such coaxial transmission line. Power is given by integration of the pointing vector over the cross-section of the transmission line

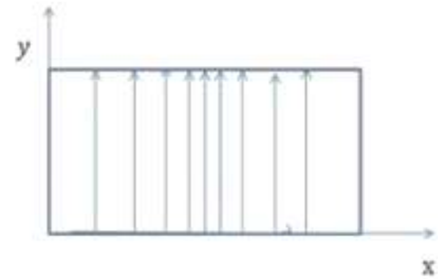
P= $\frac{1}{2}\int_a^b \int_0^{2\pi} \vec{E} \times \vec{H}.\,\tilde{a}_\rho d_p \mathrm{d}\emptyset = \frac{\pi Y_0 {V_0}^2}{In\left(\frac{b}{a}\right)}$

We find that

$\frac{1}{2} Re(VI^*) = \frac{\pi Y_0 {V_0}^2}{In\left(\frac{b}{a}\right)}$

and $Z_0 = \frac{V_0}{I_0}$

we can see that whatever power we calculate using these field equations, if we consider the equivalent voltage or current equation, the same power flow is evaluated on the coaxial lines. However, for waveguide there is difficulty in defining such voltages and current. For dominant TE_{10} mode of a rectangular waveguide, the electric field distribution is as shown



$$V = \frac{-J\omega\mu a}{\pi} A \sin\frac{\pi x}{a} e^{-j\beta z} \int_y dy$$

So voltage depend on the position X for this type of waveguide Propagating waveguide modes have the following properties:

- Power transmitted is given by integral involving the transverse electric and transverse magnetic fields only.
- In a loss free guide supporting several propagating modes, power transmitted is the sum of individual modes.
- Transverse Fields vary with distance along the guide according to a propagating factor $e^{\pm j\beta z}$.
- Transverse magnetic field is related to transverse electric field $Z_\omega \tilde{h} = \widehat{az} \times \bar{e}$.

These properties suggest that equivalent voltage and current can be introduced proportional to transverse electric and magnetic fields. Equivalent voltage and current can be defined in different ways as these Quantities are not unique for non -TEM lines. The following considerations are usually used-

- Voltage and current may be defined only for a particular waveguide mode.
- These are defined so that voltage is proportional to transverse electric field and current is proportional to transverse magnetic field.
- Equivalent voltage and current should be defined in such a way that their product gives the power flow of the waveguide mode.
- The ratio of voltage to the current for a single travelling wave should be equal to the characteristic impedance of the line.

- This impedance may be chosen arbitrarily, but it usually selected as equal to the wave impedance or else normalize to the unity.

So Equivalent Voltage and Current can be written as-

V(z) = $V^+e^{-j\beta z}$+ $V^-e^{j\beta z}$

I(z) = $I^+e^{-j\beta z}$ - $I^-e^{j\beta z}$

$Z_{0=}\ \frac{V^+}{I^+} = \frac{V^-}{I^-}$

Z_0 can be made equal to Z_ω or normalize to unity.

Example-1 For Equivalent Voltage and Current

Let us illustrate we can find equivalent voltage and currents in TE10 mode in a rectangular waveguide. For TE_{10} modes in a rectangular waveguide, when waves travelling in +z and –z direction are present the transverse field component can be written as-

$E_Y = A^+ \sin\frac{\pi x}{a}\, e^{-j\beta z} + A^- \sin\frac{\pi x}{a}\, e^{-j\beta z}$

$= (A^+e^{-j\beta z} + A^-e^{-j\beta z}) \sin\frac{\pi x}{a}$

We have

$\bar{h}$ = (X, Y) = $\hat{a}_z \times \frac{\bar{e}(x,y)}{z_\omega}$

Where $\bar{h}$ & $\bar{e}$ are Transverse Field Components $and\ Z_\omega$ is the wave Impedance.

$H_X = -\frac{1}{Z_{TE}}(A^+e^{-j\beta z} + A^-e^{-j\beta z}) \sin\frac{\pi x}{a}$

Power for incident wave is given by

$P^+ = \frac{1}{2}\int_0^a\int_0^b \frac{|A^+|^2}{Z_{TE}}\, sin^2\frac{\pi x}{a}$ dx dy = = $\frac{ab}{4ZTE}|A^+|^2$

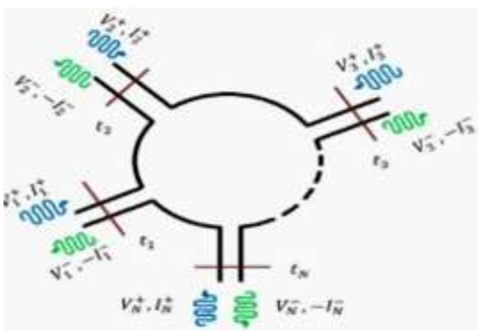
L-13

Network parameters

Analysis of Impedance, Admittance ABCD parameters and Scattering parameters (S-parameters) along with their interconnections

Impedance Parameters & Admittance Parameters

Consider an arbitrary N-Port Network below



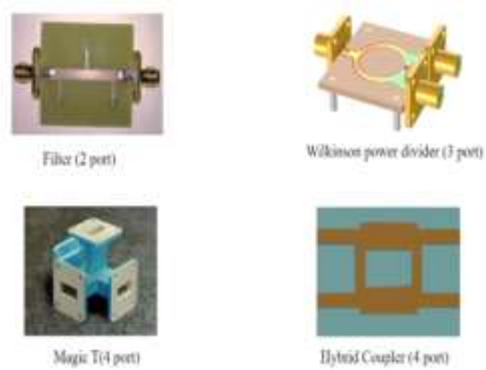
At the n_{th} terminal plane

$V_n = V_{n^+} + V_{n^-}$

$I_n = I_{n^+} - I_{n^-}$

In N-PORT Microwave Networks Let we consider an arbitrary N-Port microwave network as shown the ports may be any type of Transmission line equivalent of a single propagating mode. If the physical port of the network is a waveguide supporting more than one propagating mode such modes can be accounted for by considering additional electrical ports. At the n th port we define terminal plane t_n as well as equivalent voltage and currents for the incident waves (V^{n+} I^{n+}) &(V^{n-} I^{n-}) for the reflected waves.

The terminal planes are important for providing phase reference for voltage and current phasors. Physical Microwave Circuits or Networks



The impedance matrix [Z] of a microwave network relates this voltage and currents

$$\begin{pmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \end{pmatrix} = \begin{pmatrix} Z_{11} & Z_{12} & \cdots & Z_{1N} \\ Z_{21} & & & \vdots \\ \vdots & & & \vdots \\ Z_{N1} & \cdots & \cdots & Z_{NN} \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \end{pmatrix}$$

$$[V] = [Z]\,[I]$$

The Admittance matrix [Y] of a microwave network relates this Current and Voltages

Similarity Admittance Matrix can be defined as-

$$\begin{pmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \end{pmatrix} = \begin{pmatrix} Y_{11} & Y_{12} & \cdots & Y_{1N} \\ Y_{21} & & & \vdots \\ \vdots & & & \vdots \\ Y_{N1} & \cdots & \cdots & Y_{NN} \end{pmatrix} \begin{pmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \end{pmatrix}$$

[I] = [Y] [V]

Where [Y] is called the admittance Parameters of two port Network.

If port of this network has a short circuit, V_2 will be zero. In this condition

$$Y_{11} = \frac{I_1}{V_1}\bigg| V_2 = 0$$

$$Y_{21} = \frac{I_2}{V_1}\bigg| V_2 = 0$$

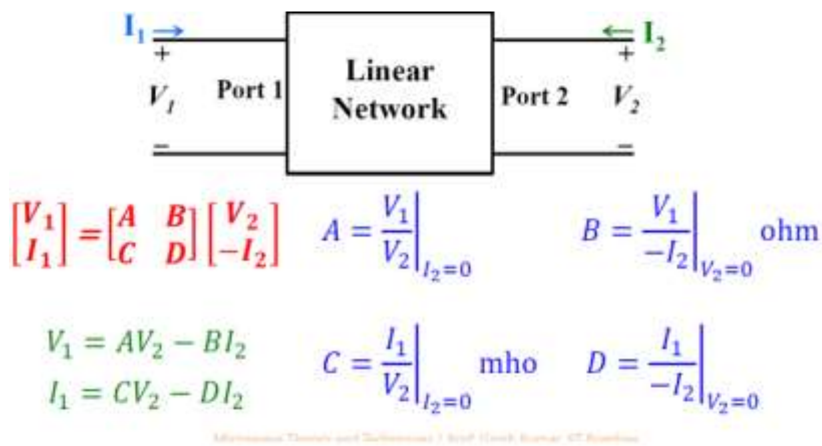
Similarly, with a source connected at port 2 and a short circuit at port 1.

$$Y_{12} = \frac{I_1}{V_2}\bigg| V_1 = 0$$

$$Y_{22} = \frac{I_2}{V_1}\bigg| V_1 = 0$$

ABCD Parameters (Transmission Parameters)

The Transmission Parameters are most useful when two-port networks are cascaded. Multiplying the matrices of the individuals two -port networks simplify gives the transmission matrix for the combination. We have seen that we can use different types of parameters such as Z, Y for the presentation of microwave networks. Now we introduce another set of parameters that are called ABCD parameters or Transmission parameters. These parameters will be particularly useful when we deal with cascaded systems, So, for a 2 port network the ABCD parameters will be defined. ABCD parameters are defined in terms of voltages and currents.



For a two port network the Transmission Matrix (T) is given by

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = [\mathrm{T}] \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix}$$

Or in terms of the individual matrix elements

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix}$$

Here A, B,C & D are often used as the symbols for the individual matrix elements and thus the transmission matrix is also commonly known as the ABCD matrix and the parameters as the ABCD.

It is important to note that the current variable on the port 2 side is takes $-I_2$.This is so as to make the output current in the same direction as the input current of the next stage in a cascade,thus making the matrix [T] of a cascade $[T_1]$ Followed by $[T_2]$.

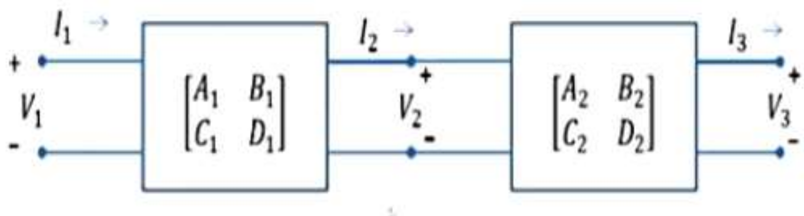
$$[\mathrm{T}] = [T_1]\ [T_2]$$

To determine individual A,B,C,D Parameters ,either V_2 or I_2 is set to zero in the appropriate defining equation to eliminate the parameter that is not required. Thus

$$A = \frac{V_1}{V_2}\bigg|\, I_2 = 0 \qquad B = \frac{V_1}{-I_2}\bigg|\, V_2 = 0$$

$$C = \frac{I_1}{V_2}\bigg|\, I_2 = 0 \qquad D = \frac{I_1}{-I_2}\bigg|\, V_2 = 0$$

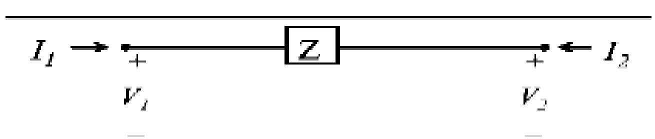
ABCD Parameters for Cascade



For Cascade we have

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} V_3 \\ I_3 \end{bmatrix}$$

For ABCD Parameters for series Impedance

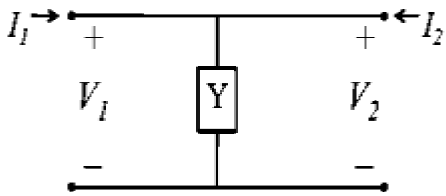


$$\boxed{\mathbf{V_1 = V_2 - Z\, I_2 \quad and \quad I_1 = -I_2}}$$

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$

For ABCD Parameters for Shunt Admittance

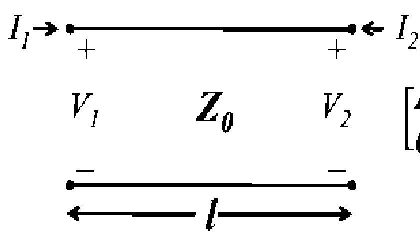


$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix}$$

$$V_1 = V_2 \quad \text{and} \quad I_1 = YV_2 - I_2$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}$$

For ABCD Parameters For Transmission Line

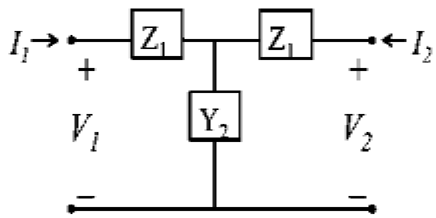


$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos(\beta l) & jZ_0 \sin(\beta l) \\ jY_0 \sin(\beta l) & \cos(\beta l) \end{bmatrix}$$

$$\text{For } l = \frac{\lambda}{4}, \ \beta l = \frac{2\pi}{\lambda} l = \frac{2\pi}{\lambda} \times \frac{\lambda}{4} = \frac{\pi}{2}$$

$$\Rightarrow \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 0 & jZ_0 \\ jY_0 & 0 \end{bmatrix}$$

For ABCD Parameters for Cascaded Network



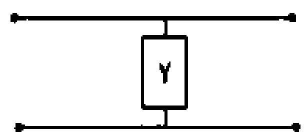
ABCD parameters of cascaded circuits are obtained by multiplying individual ABCD parameters.

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y_2 & 1 \end{bmatrix} \begin{bmatrix} 1 & Z_1 \\ 0 & 1 \end{bmatrix}$$

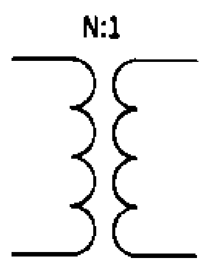
$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 + Z_1 Y_2 & 2Z_1 + Z_1^2 Y_2 \\ Y_2 & 1 + Z_1 Y_2 \end{bmatrix}$$

For Example ABCD Parameters in form of Shunt Impedance

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}$$



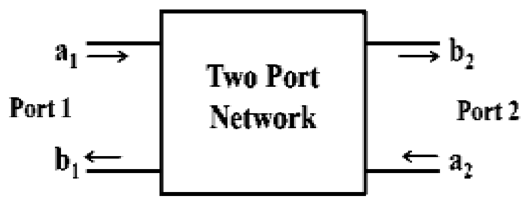
$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} N & 0 \\ 0 & \frac{1}{N} \end{bmatrix}$$



L-14

S-Parameters Representation and Interconnections

Representation of microwave network by impedance or admittance matrix is not very convenient as at microwave frequency, the voltage, current or impedances cannot be measured in a direct manner. The quantities that may be measured easily are reflection coefficient and transmission coefficient. This forms the basis of scattering matrix formulation. Then S-Parameters for Two Port Network



$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \qquad S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} \qquad S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1=0}$$

$$b_1 = S_{11}a_1 + S_{12}a_2 \qquad S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0} \qquad S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1=0}$$

$$b_2 = S_{21}a_1 + S_{22}a_2$$

Where S_{11} is Reflection Coefficient at Port 1

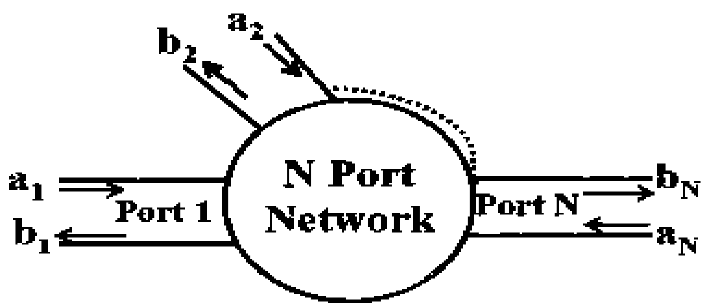
S_{22} is Reflection Coefficient at Port 2

S_{21} is a measure of gain or loss from Port 1 to Port 2

S_{12} is a measure of gain or loss from Port 2 to Port 1

S-parameter for two port and multi-port networks, Properties of Scattering parameters

Scattering Parameters for N-Port Network



$$b_1 = S_{11}a_1 + S_{12}a_2 + \ldots\ldots + S_{1N}\,a_N$$
$$b_2 = S_{21}a_1 + S_{22}a_2 + \ldots\ldots + S_{2N}\,a_N$$
$$\ldots$$
$$b_N = S_{N1}a_1 + S_{N2}a_2 + \ldots\ldots + S_{NN}\,a_N$$

We define:-

a_n= 0, also means that ‘n’ Port is perfectly matched

$$\rho = \frac{z_l - z_0}{z_l + z_0}$$

$$\rho = \frac{V_r}{V_i}$$

$z_L = R_L + jX_L$

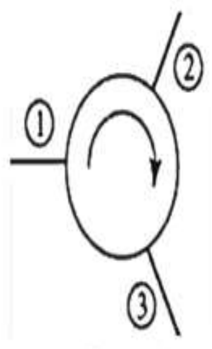
$a_n = \frac{V_{n+}}{\sqrt{Z_{0n}}}$

$$b_n = \frac{V_{n-}}{\sqrt{Z_{0n}}}$$

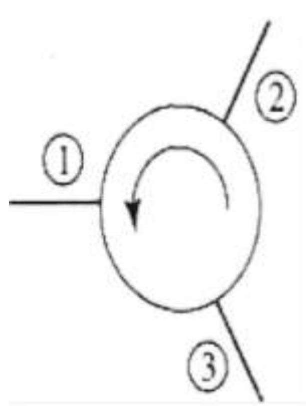
S-Parameters For Three Port Networks for Example Circulator

Circulators-

- A microwave circulator is a multiport waveguide junction in which the wave can flow only inone direction i.e. from the nth port to the (n+1)th port.
- It has no restriction on the number of ports 4-port microwave circulator is most common.
- One of its types is a combination of two 3-dB side hole directional couplers and a rectangular waveguide with two non -reciprocal phase shifters.



$$[S] = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$



$$[S] = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$$

- Each of the two 3db couplers introduce phase shift of 90 degrees Each of the two phase shifters produce a fixed phase change in a certain direction.
- Wave incident to port-1 splits into 2 components by coupler-1.
- The wave in primary guide arrives at port-2 with 180 degrees phase shift.
- The second wave propagates through two couplers and secondary guide and arrives at port-2
- Wave from coupler-1 and secondary guide arrives at port-4 with phase shift of 90 degrees.
- Power transmission from port-1 to port-4 =0 as the two waves reaching at port-4 are out of phase by 180 degrees.

Properties of S-Parameters

1. Zero Diagonal Elements for perfect Matched Network

   For an ideal N-Port network with matched termination s_{ii}=0 since there is no reflection for any port so under perfect matched conditions the diagonal elements of [S] are zero.

2. Symmetry of [S] for a reciprocal Network

   A reciprocal device has the same transmission characteristics in either direction of a pair of ports and is characterized by symmetric matrix.

   $s_{ij} = s_{ji}$ (i not equal to j)

3. Unitary property for a lossless Junction

   For any lossless network the sum of the product of each term of any row or of any column of the S matrix multiped by conjugate is unity.

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$$\sum_{n=1}^{N} S_{ni} \cdot S_{ni}^{*} = 1$$

If all $a_n = 0$, except a_i and a_k,

$$\sum_{n=1}^{N} S_{nk} \cdot S_{ni}^{*} = 0 \, ; i \neq k$$

$$[S^{*}]\,[S]_t = [U]$$

$$[S^{*}] = [S]_t^{-1}$$

Numerical –

Q- Prove that for a reciprocal , lossless ,Three port network ,the all ports cannot be perfectly matched.

Solution- If all three ports are matched then

$S_{11=}\ \ S_{22=}\ \ S_{33=}\ \ S_{44=}\ {}_0$ *and Scattering matrix reduces to*

$$[s] = \begin{bmatrix} 0 & s_{12} & s_{13} \\ s_{21} & 0 & s_{23} \\ s_{31} & s_{32} & 0 \end{bmatrix}$$

For reciprocal network

$$s_{12} = s_{12},\ \ s_{13} = s_{32},\ \ s_{23} = s_{32}$$

$$[s] = \begin{bmatrix} 0 & s_{12} & s_{13} \\ s_{12} & 0 & s_{23} \\ s_{13} & s_{23} & 0 \end{bmatrix}$$

Lossless junction S- Matrix is unitary

$\sum_{k=1}^{N} SK_{i.}\ SK_i SK_i^{*}$=1

$S_{12}S_{12}^{*}+ S_{13}S_{13}^{*}$=1

$S_{12}S_{12}^{*}+ S_{23}S_{23}^{*}$=1

$S_{13}S_{13}{}^{*}+S_{23}S_{23}{}^{*}$=1

i.e

$|s_{12}|^2+|s_{13}|^2=1$ - (A)

$|s_{12}|^2+|s_{23}|^2=1$ - (B)

$|s_{13}|^2+|s_{23}|^2=1$- (C)

Let us assume s_{13}=1

s_{23} = 1- s_{13}

1-(1)

$$s_{23}=0$$

$$s_{12}=1-s_{13}$$

= 1-(1)

= 0

$$s_{12}=0,\ s_{23}=0$$

Hence Equation B is not satisfied

Therefore reciprocal, lossless, three port junction cannot be perfectly matched

Q- A two port network is driven a both ports such that port voltage and currents are-

V1= $20\angle 0$ I1= $0.4\angle 0$

V2= $40\angle -90$ I2= $0.08\angle 0$

Find out-

1- Incident & Reflected voltage at each point.
2- Input Impedance Z_0= 50Ω

Solution- a) we know total voltage at any point

$$V_n = V_{n+} + V_{n-}$$

Current at any port

$$I_n = \frac{{V_n}^+}{Z_0} - \frac{{V_n}^-}{Z_0}$$

$$Z_0 I_n = V_{n^+} + V_{n^-}$$

$$Incident\ voltage\ V_{n^+} = \frac{V_n + Z_0 I_n}{2}$$

Reflected voltage $V_{n^-} = \frac{V_n - Z_0 I_n}{2}$

Incident voltage at port (1)

$$V_{1^+} = \frac{V_1 + Z_0 I_1}{2}$$

$$V_{1^+} = \frac{20<0^\circ + 50\times 0.4<0^\circ}{2}$$

$$= \frac{20\,(\cos 0 + i sin 0\,) + 50 \times 0.4\,(\cos 0 + i\ sin 0)}{2}$$

$$= \frac{40}{2} = 20$$

Reflected voltage at port 1

$$V_{1^-} = \frac{V_1 - Z_0 I_1}{2}$$

$$= \frac{20<0^\circ - 50\times 0.4(cos0^\circ + i\ sino)}{2}$$

$$= \frac{20-20}{2} = \frac{0}{2} = 0$$

Incident voltage at port 2

$$V_{2^+} = \frac{V_2 + Z_0 I_2}{2}$$

$$V_{2^+} = \frac{40<-90^\circ + 50(0.08<0^\circ}{2}$$

$$= \frac{40\ (\cos -90 + jsin0\ ) + 4\ (0 + j(-1)}{2}$$

$$= \frac{4-40j}{2}$$

$$= 2- 20j$$

$$= \sqrt{2^2 + 20^2 \tan^{-1}\frac{y}{x}}$$

$$= \sqrt{4+400}$$

$$\tan^{-1}\frac{y}{X}(\frac{-20}{2})$$

$$\tan^{-1}(-10) = -84.289\sqrt{404} = 20.09$$

Reflected voltage at port 2

$$V_{2^-} = \frac{V_2 - Z_0 I_2}{2}$$

$$= \frac{40<-90^{\circ} - 50(0.08)<0^{\circ}}{2}$$

$$= \frac{40\,(cos90 + j\,sin(-90^{\circ}) - 4(\cos 0 + isin\ 0\,)}{2}$$

$$= \frac{40(0+j(-1) - 4(1)}{2}$$

$$= \frac{-40j-4}{2}$$

$$= -\ 2 -\ 20j\ \tan^{-1}\ (\frac{-20}{2})$$

$$= \sqrt{2^2 + 20^2}$$

$$= \sqrt{4 + 400} = 20.09\tan^{-1} 5.7 \text{ ans}$$

Q- A 5 dB attenuator has voltage standing wave ratio of 1.6. Find S-Parameter of attenuator assuming that device is reciprocal?

Given attenuation= 5Db

VSWR=1.6

The attenuation of a two port device in Db is given by

$$= -20 \log 10\ |s_{12}|$$

$$\text{Therefore } \log 10|S_{12}| = -\frac{5}{10} = -0.25$$

$$|S_{12}| = 10^{-0.25}$$

$$|S_{12}| = 0.56$$

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And the reflection coefficient Γ is given by

$$\Gamma = s_{11} = s_{22} = \frac{VSWR-1}{VSWR+1}$$

$$s_{11} = s_{22} = \frac{1.6-1}{1.6+1} = \frac{0.6}{2.6}$$

$$s_{11} = s_{22} = 0.231$$

Since device is reciprocal

$$s_{12} = s_{21}$$

The scattering matrix of attenuator is given by

$$[s] = \begin{bmatrix} 0.231 & 0.56 \\ 0.56 & 0.231 \end{bmatrix}$$

Q- A two port Network has the scattering matrix

$$[S] = \begin{bmatrix} 0.15\angle 0 & 0.85\angle -45 \\ 0.85\angle 45 & 0.2\angle 0 \end{bmatrix}$$

Verify that the network is reciprocal and lossless. If port(2) is terminated with matched load .What is the return loss at port (1).If port (2) is terminated with a short circuit .What is the return loss at port(1)?

Solution-

Since given matrix is not symmetric ,so network is not reciprocal i.e [s] = $[s]_T$

We know that for lossless network ,[s] must be unitary,

$$0.745 \neq 1$$

So network is not lossless

When port (2) is terminated with matched load

The reflection at port (1) will be

$\Gamma = s_{11} = 0.15$

Then the return loss is

RL = -20log$|\Gamma|$ = -20log$|s_{11}|$

RL = -20log(0.15)

RL = 16.5dB

When port (2) is terminated with a short circuit the reflection coefficient port(1) can found as follows. From the definition of S- matrix

$$b_1 = s_{11a_1} + s_{12}a_2$$

$$b_2 = s_{21a_1} + s_{22a_2}$$

If port (2) is short circuit , then

$a_2 = -b_2$

$b_1 = s_{11}a_1 - s_{12}b_2$ - (a)

And $b_2 = s_{21}a_1 - s_{22}b_2$ - (b)

From equation (b)

$b_2 = \frac{s_{21}}{1+s_{22}} a_1$

$\frac{b_2}{a_1} = \frac{s_{21}}{1+s_{22}}$ - (c)

Dividing equation (a) by a_1

$\frac{b_1}{a_1} = \Gamma$(reflection coefficient)

$= s_{11} - s_{12}\frac{b_2}{a_1}$

Using equation (c) , we get

$\Gamma = s_{11} - s_{12}\frac{b_2}{a_1}$

$\Gamma = 0.15 - \frac{(0.85<-45°)(0.85<-45°)}{1+0.2}, \Gamma = -0.452$

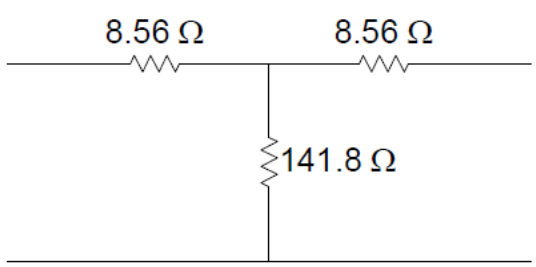
Thus return loss is

RL= -20log Γ = -20log$|s_{11}|$

RL =-20log(0.452)

RL= 6.9dB ans

Q- Find the S- parameters for the below two port circuit ?



Solution-

Let

Z_1=Z_2= 8.56 ohm and Z_3= 141.8 ohm

$$S_{11} = \left.\frac{V_{r1}}{V_{i1}}\right|_{V_{r2}=0} = \rho = \frac{Z_{in}-Z_o}{Z_{in}+Z_o}$$

By assuming the output port is terminated by Z_o = 50 ohm, then

$$Z_{in} = Z_1 + [Z_3 //(Z_2 + Z_o)]$$

$$= 8.56 + [141.8(8.56+50)/(141.8+8.56+50)] = 50\,\Omega$$

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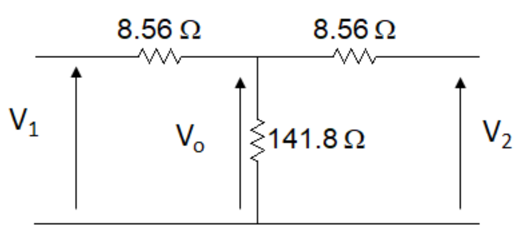
$$S_{11} = \frac{50-50}{50+50} = 0$$

Because of symmetry , then S_{22}=0

Now,

$$S_{21} = \left.\frac{V_{t2}}{V_{i2}}\right|_{V_{r2}=0}$$

From the fact that $S_{11}=S_{22}=0$, we know that $V_{r1}=0$ when port 2 is matched, and that $V_{i2}=0$. Therefore $V_{i1}= V_1$ and V_{t2}=V2



By Using KVL, two times, we have to calculate the ratio of V1 and V2, which comes

$\frac{V_2}{V_1}$ =0.707

Therefore $S_{12} = S_{21} = 0.707$

$$[S] = \begin{bmatrix} 0 & 0.707 \\ 0.707 & 0 \end{bmatrix}$$ ANS

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L-15

Lossless Networks, Reciprocal networks and Matched network, Conditions for different networks

Lossless network

For lossless n- network , total input power = total output power. Thus

$$\sum_{i=1}^{n} a_i a_i^* = \sum_{i=1}^{n} b_i b_i^*$$

Where a and b are the amplitude of the signal .

Putting in matrix form $a^t a^* = b^t b^*$
$= a^t S^t S^* a^*$

Note that $b^t = a^t S^t$ and $b^* = S^* a^*$

Thus $a^t (I - S^t S^*) a^* = 0$ This implies that $S^t S^* = I$ Called unitary matrix

In summation form

$$\sum_{k=1}^{n} S_{ki} S_{kj}^* = \left.\begin{matrix} 1 & for\, i = j \\ 0 & for\, i \neq j \end{matrix}\right\}$$

A lossless network is one which contains no resistors or other dissipative elements.
For a network to be lossless all of the power that is incident at any one port has to be accounted for by summing the power output at the other ports with the power reflected at the incident port. None of the power is converted to heat or radiated with in a lossless network.

Reciprocal Network

[S] Matrix for a reciprocal network is symmetric & for a lossless network is unitary.

Total voltage & current at the n^{th} port can be written as

$V_n = V_{n+} + V_{n-}$ - (1)

$I_n = I_{n+} - I_{n-} = V_{n+} - V_{n-}$ - (2)

Adding Equation (1)& (2)

$V_n{}^{+} = \frac{1}{2}(V_n - I_n)$

$[V^+] = \frac{1}{2}$ ([Z]+[U]) [I] - (3)

Where [U] is Unitary Matrix.

Subtracting Equation 1& 2 equation we get

$V_{n-} = \frac{1}{2}(V_n - I_n)$

$[V^-] = \frac{1}{2}$ ([Z]- [U]) [I] -(4)

Eliminating [I] in equation 3& 4 we get,

$[V^-]$ = ([Z] – [U])([Z] + [U]$^{-1}$ $[V^+]$

$[S]^T$ = ([Z] + [U])$^{-1}$}^{T} ([Z] – [U])^T -(5)

Taking transpose of equation (5)

$[S]^T$ = ([Z] + [U])$^{-1}$}^{T} ([Z] – [U])^T

Now [U] is diagonal i.e

$$[U] = \begin{bmatrix} 1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{bmatrix} \backslash$$

U^T = [U] , and if network is reciprocal , [Z] is symmetric so that $[Z]^T$ = [Z]

Therefore,

$[S]^T = ([Z] + [U])^{-1}$([Z]- [U])

Which is equivalent to equation (5)

Therefore,

[S] = $[S]^T$ for reciprocal Networks.

Table for Conversiom Between Two port Network Parameters

Q- The scattering parameters of a two port Network are

$$s_{11} = 0.3 + 0.7j$$

$$s_{12} = s_{21} + 0.6j$$

$$s_{22} = 0.3 - 0.7j$$

Find the equivalent parameters for this network if the characteristic impedance is 500ohm.

Solutions-

From table conversion between two port network

$$Z_{11} = Z_0 \frac{(1+S_{11})(1-S_{22}) + S_{12}.S_{21}}{(1-S_{11})(1-S_{22}) - S_{12}.S_{21}}$$

$$S_{12} = S_{21}$$

$$Z_{12} = Z_{21} = Z_0 \frac{2S_{12}}{(1-S_{11})(1-S_{22}) - S_{12}.S_{21}}$$

$$Z_{22} = Z_0 \frac{(1-S_{11})(1+S_{22}) + S_{12}.S_{21}}{(1-S_{11})(1-S_{22}) - S_{12}.S_{21}}$$

Substituting the given values in these equations

Z_{11}=2+50j

Z_{12}=Z_{21}= 4.5j Z_{22}=2+50j

$$[Z] = \begin{bmatrix} 2+50j & 4.5j \\ 4.5j & 2+50j \end{bmatrix} \text{ ans}$$

Q -A four port network has the scattering matrix

$$\begin{bmatrix} \mathbf{0.1\angle 90} & \mathbf{0.8\angle -45} & \mathbf{0.3\angle -45} & \mathbf{0} \\ \mathbf{0.8\angle -45} & \mathbf{0} & \mathbf{0} & \mathbf{0.4\angle -45} \\ \mathbf{0.3\angle -45} & \mathbf{0} & \mathbf{0} & \mathbf{0.6\angle -45} \\ \mathbf{0} & \mathbf{0.4\angle -45} & \mathbf{0.6\angle -45} & \mathbf{0} \end{bmatrix}$$

Determine

Network is lossless or not

Network is reciprocal or not

Return loss When port (2) and (4) ,when all other ports are terminated with matched load?

What is the reflection coefficient at port(1) ,if a short circuit is placed at the terminal plane of port (3) and all other ports are terminated with matched loads?

Solution-

a) for lossless network ,[s] must be unitary ,i.e

$s_{11}s_{11}^* + s_{12}s_{12}^* + s_{14}s_{14}^*$ must be 1

$|s_{11}|^2 + |s_{12}|^2 + |s_{13}|^2 + |s_{14}|^2$

$(0.1)^2 + (0.8)^2 + (0.3)^2 = 0.74 \neq 1$

Thus network is not lossless

b) For reciprocal network [S] must be symmetrical

thus [s] $= [s]^T$

Given matrix is symmetrical ,hence network is reciprocal

(c) When port (2) ,(3),and (4) are matched ,then

$\Gamma = S_{11}$

Then Return loss RL = -20 log $|\Gamma|$

RL = 20 log (0.1)

RL = 20 dB

(d) When port (1) and (3) are matched, then insertion loss between (2) and (4) is

IL = -20log $|S_{42}|$

IL = -20log (0.4)

IL = 8 dB

(e) For a short circuit at port (3) and matched loads at other ports

$a_2 = a_4 = 0$

$a_3 = -b_3$

$b_1 = s_{11}a_1 + s_{13} = s_{11}a_1 - s_{13}b_3$ (a)

$b_3 = s_{31}a_1$ (b)

But

[since s_{33}=0 (given) and $a_2 = a_4 = 0$]

Using equation (a) and (b)

$\Gamma^{(1)} = \frac{b_1}{a_1} = s_{11} - s_{13}s_{31}$

$\Gamma^{(1)}$= 0.1j- (0.3<-45°) $(0.3 < -45°)$

= 0.1j + 0.09j

= 0.19j= 19<-90° ans

UNIT-VI
Microwave Passive Components

L-16

Microwave Passive Components (DC & Power Divider)

Microwave Networks and circuit use many types of microwave passive components such as Waveguide Junctions , Joints ,Corners , Posts and Screw, Cavity Resonator, Directional Couplers, Ferrite device etc. All these components must be built with low standing wave ratio, Lower attenuation, lower insertion losses and other desirable characteristics to achieve the desired transmission of microwave signal. A microwave network is form when several microwave devices and components are coupled together by transmission line like waveguide, stripline, microstripline .Microwave networks and circuit use various type of microwave passive circuit such as

1) Two port Network :- Isolators , Attenuators
2) Three Port Networks:- E-Plane tee, H-Plane tee
3) Four port networks:- Magic Tee, Magic Ring,

Directional Coupler.

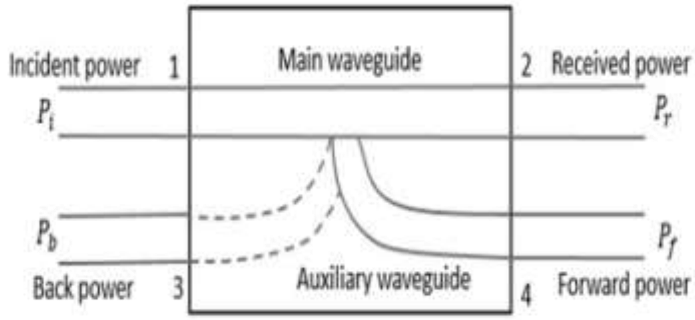
A Directional Coupler is a four port waveguide junction .It consist of primary waveguide having port (1) and port (2) and secondary waveguide port (3) and port (4).

With matched termination at all ports ,the properties of ideal directional couplers will be as follows:-

1. A portion of wave travelling from port (1) to port (2) is couples to port (4) but not to port (3).

2. A portion of wave travelling from port (2) to port (1) is coupled to port (3) but not to port (4).

3. A portion of wave travelling from port (3) to port (4) is coupled to port (2) but not to the port (1).



4. A Portion of wave travelling from port (4) to port (3) is coupled to port (1) but not to port (2).

A Directional coupler is characterized by the following parameters:-

1. Directivity (D):- It is the ratio of forward coupled power (P4) to back power (P3) in the secondary waveguide and expressed in dB.

$$D = \frac{Forward\ coupled\ power\ (p4)}{Back\ power\ (p3)} \text{ in dB}$$

$$D = 10 log_{10} \frac{P_4}{P_3} \text{ dB}$$

Ideally ,back power to port (3) should be zero .Therefore directivity is ∞.

Directivity is a measure of how well the directional coupler differentiate between forward and reverse travelling power.

2) Coupling Factor (C) : It is the ratio of input power (p1) to forward coupled power (p4) expressed in dB

$$C = \frac{\text{Input Power (p1)}}{\text{Forward Coupled power (p4)}} \quad \text{[In dB]}$$

$$C = 10\ log_{10} \frac{P_1}{P_4} \text{ dB}$$

The coupling factor is a measure of how much of the incident power is being sampled .

(3) Isolation (I) : It is defined as the ratio of incident power (p1) to back power (p3) in dB .

$$I = \frac{\text{Input Power(p1)}}{\text{Back power (p3)}} \quad \text{[In dB]}$$

$$\text{Isolation} = 10\ log_{10}\frac{p_1}{p_3}\ \text{dB}$$

Isolation is equal to the sum of coupling factor and directivity in dB

We know that

$$\text{Isolation} = 10\log_{10}\frac{p_1}{p_3}$$

$$= 10\log_{10}\frac{p_1}{p_3}.\frac{p_4}{p_4}$$

$$= 10\log_{10}\frac{p_4}{p_3} + 10\log_{10}\frac{p_1}{p_4}$$

$$I = D + C\ \ (\text{in dB})$$

(4) Insertion loss(IL): It specifies the total output power from all ports relative to the input power. The out put power is less than input power from two reasons.

1) Some of input power is absorbed. 2) Some gets reflected due to mismatch.

$$\text{Insertion loss} = \frac{\text{Output power from all ports}}{\text{Input Power}}$$

$$\text{IL} = 10\log_{10}\frac{p_2+p_3+p_4}{p_1}\ \text{dB}$$

(5) Bandwidth : Bandwidth is the range of frequencies with in which the performance with respect to some characteristic falls with in specific limits.

(6) Frequency Sensitivity: The maximum peak to peak variation in the coupling factor that may be expected over a specified frequency band is called the frequency sensitivity

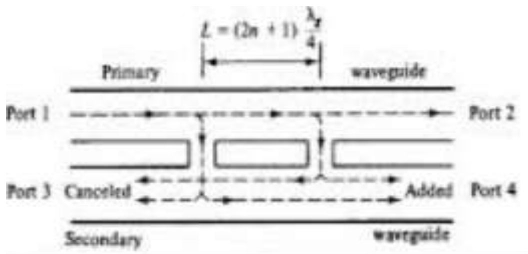
Two Hole Directional Coupler

A Two hole directional coupler consist of two waveguide the main and auxiliary waveguide with two holes common between them . The spacing between the centers of two holes must be.

$$L = (2n+1)\frac{\lambda_g}{4}, \quad n = 0,1,2,3----$$

λ_g = Guide Wavelength

For n= 0 ,The holes are at distance $\frac{\lambda_g}{4}$, operation of two hole directional coupler can be summarized as follows .



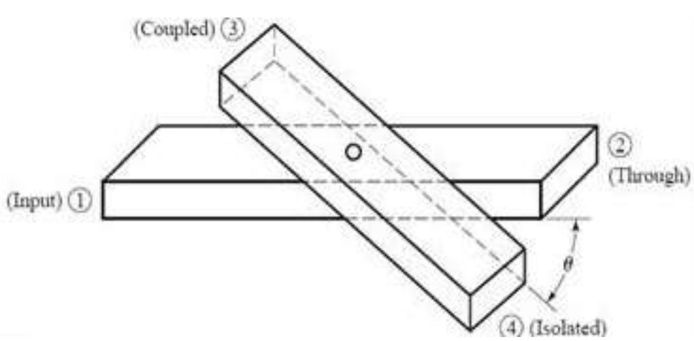
1. At the port (4) wave from hole A and B are in same phase , because waves from hole A and B travel a equal distance ($\frac{\lambda_g}{4}$) hence they add up contributing to p4.
2. At the port (3) waves from hole A and B are out of phase by 180°.

(Input power will have to travel a distance of $\frac{\lambda_g}{4} + \frac{\lambda_g}{4} = \frac{\lambda_g}{2}$

$\rightarrow \emptyset = \frac{2\pi}{\lambda g} \times \frac{\lambda_g}{2}$ =180°.

When it comes back from hole B compared to input power leakage through hole A) at the position of hole A and therefore they cancel each other and making back power p3=0 (ideally).

Single-Hole Directional (Bethe –hole) Coupler



- Single hole directional coupler in this power entering port (1) is coupled to the coaxial probe output and the power entering port (2) is absorbed by the matched load.
- The secondary guide is placed at such angle that the magnitude of magnetically excited wave is made equal to that of the electrically excited wave for improved directivity.
- In this coupler the waves in auxiliary guide are generated through a single hole which include both electric and magnetic fields. Because of phase relationship involved in the coupling process, the signals generated by the two types of coupling cancel in the forward direction and reinforce in the reverse direction .

S –Matrix of Directional Coupler

Directional Coupler is a four port network . So S -Matrix will be

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \quad - \quad (1)$$

In a directional coupler all four port are completely matched . Thus diagonal elements of s-matrix are zero.

$S_{11} = S_{22} = S_{33} = S_{44} = 0$

Also there is no coupling between port(1) and port (3) and between port(2) and port (4)

Thus

$S_{13} = S_{31} = S_{24} = S_{42} = 0$

The S-matrix of directional coupler becomes-

$$[S] = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{12} & 0 & S_{23} & 0 \\ 0 & S_{23} & 0 & S_{34} \\ S_{14} & 0 & S_{34} & S_0 \end{bmatrix} \quad - (2)$$

Since [s][s]*=[I] ,from Unitary property

$$\begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{12} & 0 & S_{23} & 0 \\ 0 & S_{23} & 0 & S_{34} \\ S_{14} & 0 & S_{34} & S_0 \end{bmatrix} \begin{bmatrix} 0 & s_{12*} & 0 & s_{14*} \\ s_{12*} & 0 & s_{23*} & 0 \\ 0 & s_{23*} & 0 & s_{34*} \\ s_{14}* & 0 & s_{34*} & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$|s_{12}|^2 + |s_{14}|^2 = 1$ $[R_1C_1]$---------------(3)

$|s_{12}|^2 + |s_{23}|^2 = 1$ $[R_2C_2]$---------------(4)

$|s_{23}|^2 + |s_{34}|^2 = 1$ $[R_3C_3]$------------- -(5)

$S_{12}\ s_{23*} + S_{14}\ S_{34*} = 0$ $[R_1C_3]$ --------(6)

Comparing equation (1) & (2)

$|S_{14}| = |S_{23}|$ - (7)

Comparing equation (2) & (3)

$|S_{12}| = |S_{34}|$ - (8)

Let S_{12} be real and positive

Let $S_{12} = S_{34} = p = S_{34^*}$ - (9)

(Where p is positive and real, then $S_{34^*} = S_{34}$)

From equation (6) & (9)

$S_{12}\, s_{23*} + S_{14}\ S_{34*} = 0$

$Since \quad S_{12} = S_{34*} = p$

p. S_{23*}+p S_{23}=0

P(S_{23*}+ S_{23})=0

Therefore

p≠ 0, $S_{23} + S_{23*} = 0$

S_{23}=jq

S^{*23}= - S_{23} = -jq

i.e S_{23} must be imaginary

S_{23}= S_{14}=jq

S_{12}= S_{34}=p

Now substituting value of S_{12}, S_{34}, S_{23} and S_{14} in equation

$$[S] = \begin{bmatrix} 0 & p & 0 & jq \\ p & 0 & jq & 0 \\ 0 & jq & 0 & p \\ jp & 0 & p & 0 \end{bmatrix}$$

Coupling factor

Note that the element s_{14}, s_{41} and s_{23}, s_{32} are voltage coupling coefficients of the coupler. The $|s_{14}|^2$ is the power coupling coefficient ,and the coupling factor written as-

Coupling factor (C) = $10 log_{10}|s_{14}|^2$ dB

Coupling factor (C) = 20log $|s_{14}|$ dB

Application of Directional Couplers

- They are used in measurement of parameters of antenna.
- They are used to sample incoming power.
- They are used for power monitoring.
- They are used in microwave mixer.
- They are used in balanced microwave amplified circuit.

Numerical

Q1 - A 10 m W signal is applied to a 20 dB directional coupler. Determine the power available at coupled port.

Solution –

If P_1 and P_4 are respectively the input and coupled powers then coupling factor (C) will be

$C = 10 \log_{10} \frac{P_1}{P_4}$ (in dB)

$20 = 10 \log_{10} \frac{P_1}{P_4}$

$\frac{P_1}{P_4} = 10^2 = 100$

Input power (P_1) = 10 mW (given)

$P_4 = \frac{P_1}{100}$

$= \frac{10}{100} = 0.1$m W

Therefore coupled power P_4 =0.1 m W =100 μW.

Q2- A directional coupler has a coupling factor of 10 dB .An input signal of 5mW is applied. Determine the directivity of the directional coupler if the power measured at the isolated port is 10 mW ?

Solution –

Given : Input power (P_1) = 5mW

Coupling factor = 10dB

Power at isolated port (P_3) = 10mW

Therefore

C= 10 =$10log_{10}\frac{p_1}{p_4}$

$\frac{p_1}{p_4}$ = 10

Coupled factor P_4= $\frac{P_1}{10}$ = 0.5 mW

Power measured at isolated port (P_3) = 10mW

Therefore Directivity (D)= $10log_{10}\frac{P_4}{P_3}$ dB

= 10 log $\left(\frac{0.5\times10^{-3}}{10\times10^{-6}}\right)$

= 10 $log_{10}\left(\frac{500}{10}\right)$

= 10 $log_{10}50$

D= 17 dB ans

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Q3- A 90 W power source is connected to the input of a directional coupler with C=20dB ,D=35dB and an insertion loss of 0.5dB .Find the ouput power at the through , coupled , and isolated ports. Assume all ports to be matched?

Solution-

Given C= 20dB

D = 35dB

P_1= 90W

IL = 0.5W

C= 20 = $10log_{10}\frac{\text{input power}}{\text{forward coupled power}}$

$\frac{P_1}{P_4}$ = 10^2 = 100

Forward coupled power

P_4= $\frac{P_1}{100}$ = $\frac{90}{100}$ = 0.9W

D= 35 = $10log_{10}\frac{Forward\ coupled\ power}{Back\ power}$

$\frac{p_4}{p_3}$ = $10^{3.5}$

Back power (p_2) = $p_1 - [p_3 + p_4]$

= 90-[0.9-284.6$\times 10^{-6}$]

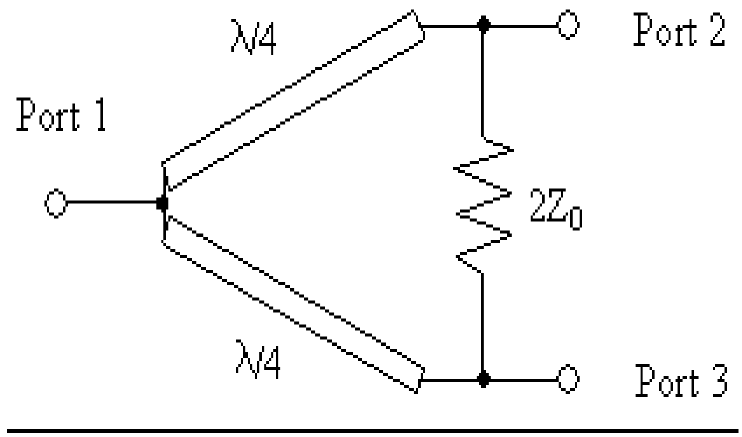
= 89.09 watt, So , effective received power

$p_2' = p_2 - insertion\ loss$

= 0.044-0.5

-0.455 dB Ans

Wilkinson power Divider



One useful power divider is Wilkinson three port power divider.An ideal Wilkinson two way power divider is shown in figure .It has a property that all ports are matched i.e the power from the input is equally divided between the two output ports .Another property is that the two output ports are isolated.Device consists of two quarter wave sections with characteristic impedance

Z_0connected in parallel with the input line which also has a characteristic impedan ce z_0 .A register R= $2z_0$ is connected between port 2 and 3 which are matched terminated. A signal into port (1) will split equally over ports (2) (3) on the other hand signal from port (2) and (3) will add up in port (1) when they have equal phase and amplitudes and will cancel in port(1) and the dissipated in the resistor when they have equal amplitude and opposite phase.

The following Scattering matrix satisfies these conditions:-

$$[s] = \frac{1}{\sqrt{2}}\begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

Wilkinson power divider is popular power divider because it is easy to construct and has some extremely useful properties

1) Matched at all ports
2) Large isolation between output ports
3) Reciprocal
4) Lossless when output ports are matched

Unequal power split in N-way Wilkin Divider

The Wilkinson type power dividers can also be made to perform unequal power division.A Wilkinson power divider in microstrip form having unequal power division .If the power ratio between port (2) and (3) is

$$K^2 = \frac{\Gamma_3}{\Gamma_2}$$

Then design equations for power divider are

$$Z_{03} = Z_0\sqrt{\frac{1+K^2}{K^3}} \quad -(1)$$

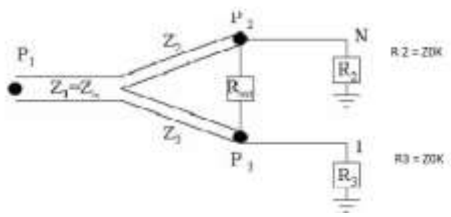
$$Z_{02} = K^2 \, Z_{03} = \sqrt{K(1+K^2}) \; -(2)$$

$$R = Z_0 \left(K + \frac{1}{K}\right) \quad -(3)$$

It is also observe that the output lines are matched to the impedances .

$$R_2 = Z_0 K, \qquad R_3 = \frac{Z_0}{K}$$

R_2 and R_3 are opposed to the impedances z_o and matching transformers can be used to transform these output impedances.The Wilkinson power divider can also be generalized to be an N –WAY divider or combiner .Thus circuit can also be matched at all ports with isolation between all ports. However the divider requires crossovers for resistors and it become difficult for fabrication in planar form



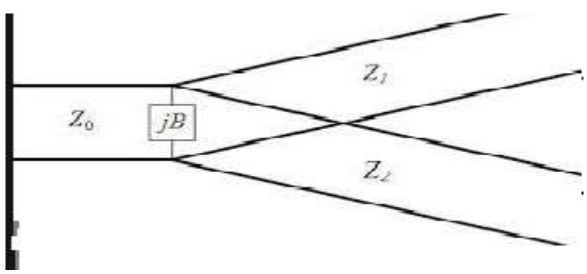
Numerical

Q -A Lossless T- Junction power divider has a source impedance of 50Ω. Find the output characteristic impedances so that the input power is divided in 2:1 ratio. Also determine the reflection coefficient seen looking into the output ports.

Solution-

Given

1) Power divider is lossless
2) Source impedance (z_0) = 50Ω
3) Power at output port 1(P_1) =2 (Power at output port 2,i.e,= 2 P_2.



Lossless T-Junction Power Divider

The input power to the matched divider is

$P_{in} = \frac{(V_0/\sqrt{2})^2}{z_{in}}$

(Since $z_{in} = z_0$)

$$P_{in} = \frac{{V_O}^2}{2Z_0}$$

Power at the output ports are

$$P_1 = \frac{1}{2}.\frac{{V_O}^2}{Z_1}$$

$$P_2 = \frac{1}{2}.\frac{{V_O}^2}{Z_2}$$

The input power is divided in a ratio of 2:1 ,thus, $P_1 = \frac{1}{2}.$

$$= \frac{1}{3}P_{in} = \frac{1}{3}.\frac{1}{2}\frac{{V_O}^2}{Z_0} \quad - \ (1)$$

$$P_2 = \frac{1}{2}.\frac{{V_O}^2}{Z_2} = \frac{2}{3}P_{in} = \frac{2}{3}.\frac{1}{2}\frac{{V_O}^2}{Z_0} \quad - \ (2)$$

Using equation (a) and (b) i

$Z_1 = 3Z_0 = 3\times 50 = 150\Omega$

$Z_2 = \frac{3}{2}Z_0 = \frac{3}{2}\times 50 = 75\Omega$

The input impedance as we see from input port. impedance $z_1$and z_2 will be parallel combination.

Thus

$z_{in} = z_1 /\!/ z_2 = \frac{z_1 z_2}{z_1+z_2} = \frac{75\times150}{75+150}$

$z_{in} = 50\Omega$

Now looking into port (1) (150Ω output line), we see that input impedance (z_1) and impedance $(z_2)$is in a parallelcombination , i. e

$z_1(\text{output}) = 50 /\!/ 75 = \frac{50\times75}{50+75}$

$z_1(\text{output}) = 30\Omega$

Now looking into port (2) (75Ω output line), we see that input impedance (z_{in}) and impedance (z_2) is in parallel combination ,i.e

$z_2\ (output) = 50 /\!/ 150$

$= \frac{50\times150}{50+150}$

$= 37.5\Omega$

Thus the reflection coefficient (Γ) is given as

$|\Gamma| = \frac{z_L - Z_0}{Z_L + Z_0}$

Thus reflection coefficient for output port (1)

$|\Gamma_1| = \frac{30-150}{30+150} = 0.667$

And reflection coefficient for output port (2)

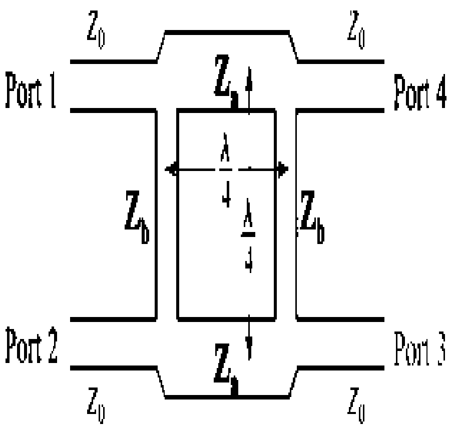
$|\Gamma_2| = \frac{37.5-75}{37.5+75} = 0.333$

$z_1(\text{output}) = 30\Omega$, z_2 (output) = 37.5Ω

$\Gamma_1 = 0.667$

$\Gamma_2 = 0.333$

Branch Line Coupler



S-matrix for 3-dB coupler

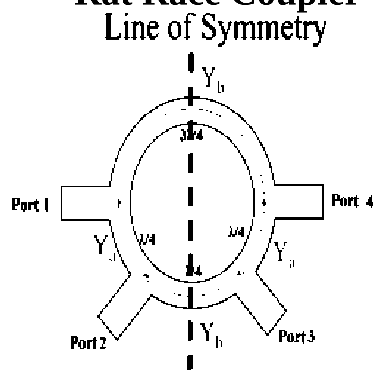
$$S = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 0 & -1 & -j \\ 0 & 0 & -j & -1 \\ -1 & -j & 0 & 0 \\ -j & -1 & 0 & 0 \end{bmatrix}$$

We have a port1, Port 2, port 3, port 4. Maximum coupling takes place when the length is equal to λ/4. So, this length is λ/4 . Length is λ/4 and now, put two branches in between these two lines and these lengths are also equal to λ/4. Let us Take the concept part and then we will try to complete the S- matrix for this 3 dB coupler. Let us say input at port 1 the input atport 1 part of the power will go here and part of the power will go here. This power when it reaches here it experiences a phase delay of minus 90 degree. Because length is λ/4 and phase which is $\theta = \beta l$. So, β is 2 $\pi/\lambda \times$ λ/4 is 90 °. Since there is a delay angle will be minus 90 °. Power gets divided part of that goes here part of that comes over here. So, phase difference at this point will be from here to here 90 °.Another 90 °so this will be minus 180 °. At Port 2 one path comes from here which is 90 degree. Another path which is there from here to here 90° another 90°, another 90°. So, the phase delay from here is minus 270° from here it is minus 90 °.

Minus 270 can also be represented as plus 90. So, we have a one path which is giving minus 90 degree another path which is giving plus 90 degree.Power coming from here and power coming from here these two things are of equal magnitude. Path from this and path from this will cancel each other.So, there will be no power which is going to port 2.
what we have designed for that there should be no reflection. So, no reflection means S11is equal to 0. So, from here to here no power goes here. So, that is also 0. So, in this particular case port 2 is known as isolated port, this is direct coupled port and this is

coupled port. From 1 to 3, so the path is 90 and 90, 180 degree. Similarly you can complete the rest of the terms you can use the symmetry of this particular network and complete the rest of the matrix.

Rat Race Coupler



Port 1& 3 are input ports and Port 2 will give sum and port4 will give difference.

S - matrix

$$S = \frac{-j}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 0 & -1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ -1 & 0 & 1 & 0 \end{bmatrix}$$

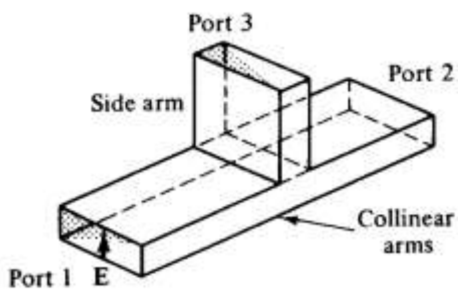
It is known as a hybrid coupler and there is a another name given, which is known as a rat race ok, but this rat race is the special name only given when we designed this whole thing for equal power division. why it is called a hybrid coupler? Just recall now in the case of two branch or 3-branch or four branch couplers, we had seen that the 2 outputs had a phase difference of 90 degree. But in this particular case we can design in such a way that when you give a input at one port. let us say port 1 then the output goes to let us say port 2 and port 4, but they are now at a phase difference of 180 degree. When input at port 3, then the output at port 2 and port 4 are in the same phases. So, port 1 here port 2 port 3 port 4. So, this length is λ/4, this is λ/4, this is λ/4 and this is 3 λ/4.So, do not compare with the 2 branches coupler; 2 branch couplers had all the things as λ/4 here the difference is this branch length is 3 λ/4.

L-17

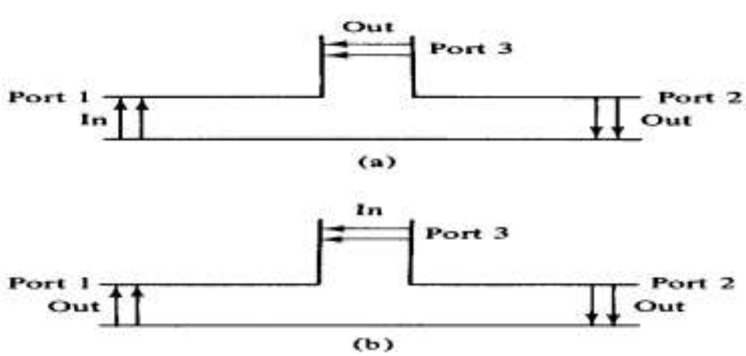
Study of E and H plane Tee, Parallel Coupled Microstripline and Strip line (BS)

E-plane Tee (Series Tee)

A waveguide tee in which the axis of its side arm is parallel to the E-field of the main guide. If the collinear arms are symmetric about the side arm, there are two different transmission characteristics.



Two way Transmission of E-plane tee a) i/p-main arm b)i/p-side arm



If E-plane tee is perfectly matched with the aid of screw tuners or inductive or capacitive windows at the junction, the diagonal components of the S- matrix, $S_{11,}$, S_{22} *and* S_{33} are zero because there will be no reflection. When the waves are fed into the side arm (port 3), the waves appearing at port1 and port 2 of the collinear arm will be in the opposite phase and in the same magnitude. Therefore,

s_{13} = -s_{23} (both have opposite signs)

Since there is a three port Junction the scattering matrix can be derived as follows:

1. [S] matrix of order 3× 3.

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} --(1)$$

2. The scattering Coefficients are-

$$s_{23} = -\, s_{13} \qquad \text{------(2)}$$

As the wave coming out of port (1) & (2) of the collinear will be of opposite phase and in same magnitude. Negative sign indicates phase difference

If port 3 is perfectly matched to the junction

S_{33}= 0 ------(3)

For Symmetric property

$$S_{ij} = S_{ji}$$

$$S_{12} = S_{21},\ S_{13} = S_{31}, S_{23} = S_{32} \quad \text{--------------(4)}$$

Write the above properties [S] becomes-

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix} \qquad \text{--------------(5)}$$

Since [s][s]*=[I] ,from Unitary property

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$$\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix} = \begin{bmatrix} S_{11}{}^{*} & S_{12}{}^{*} & S_{13}{}^{*} \\ S_{12}{}^{*} & S_{22}{}^{*} & -S_{13}{}^{*} \\ S_{13}{}^{*} & -S_{13}{}^{*} & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$|s_{11}|^2 + |s_{12}|^2 + |s_{13}|^2 = 1$ $[R_1C_1]$---------------(6)

$|s_{12}|^2 + |s_{22}|^2 + |s_{13}|^2 = 1$ $[R_2C_2]$---------------(7)

$0 + |s_{13}|^2 + |s_{13}|^2 = 1$ $[R_3C_3]$------------- -(8)

$S_{13}\ s_{11*} + S_{13}\ S_{12*} = 0$ $[R_1C_3]$ ---------------(9)

From equation (6) & (7)

$S_{11} = S_{22}$ ------ (10)

From Equation (8)

$S_{13} = \frac{1}{\sqrt{2}}$ ------- (11)

From equation (9)

$S_{13}\ (S_{11}{}^{*} - S_{12}{}^{*}) = 0$

but $S_{13} \neq 0$

$(S_{11}{}^{*} - S_{12}{}^{*}) = 0$

$S_{11}{}^{*} = S_{12}{}^{*} =$ $S_{11} = S_{12} = S_{22}$ -- (12)

Using the equation of values (10),(11),(12) in equation (6)

$|S_{11}|^2 + |S_{11}|^2 + \frac{1}{2} = 1$

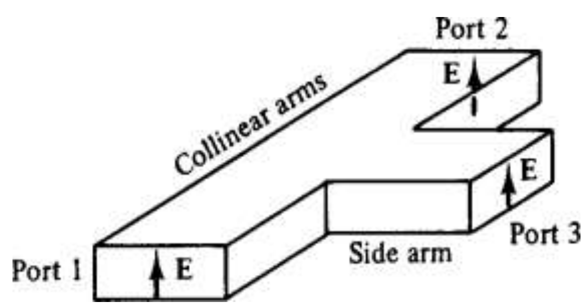
$S_{11} = \frac{1}{2}$ ---------------(13)

Substituting the value of eq 11,12,13 in eq-(5)

$$[s] = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{2} & \frac{1}{2} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 \end{bmatrix}$$

H-Plane Tee (Shunt Tee)

A waveguide tee in which the axis of its side arm is "shunting" the E-field or parallel to the H-field of the main guide.



If two input waves are fed into port 1 and port 2 of the collinear arm, the output wave at port 3 will be in phase and additive. If the input is fed into port 3, the wave will split equally into port 1 and port 2 in phase and in the same magnitude. Therefore the S matrix of H-plane tee is similar to E- plane tee except

i.e $S_{13} = S_{23}$

Since it is three port junction scattering matrix can be derived as follows: -

1.[S] matrix of order 3× 3

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \text{----------(1)}$$

2. Because of Plane of symmetry of the Junction the scattering coefficients are:-

$S_{23} = S_{13}$ -------(2)

As the waves coming out of port 1 and port 2 of the collinear arms will be of opposite phase and in same magnitude. Negative sign indicates phase difference.

3. If the port (3) is perfectly matched to the junction

$S_{33} = 0$ ---------(3)

4. For Symmetric Property

$S_{ij} = S_{ji}$

$S_{12} = S_{21}, S_{13} = S_{31}, S_{23} = S_{32} = S_{13}$ --------------(4)

Write the above properties [S] becomes-

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix} \qquad \text{--------------(5)}$$

Since $[s][s]^{*}=[I]$,from Unitary property

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix} = \begin{bmatrix} S_{11}^{*} & S_{12}^{*} & S_{13}^{*} \\ S_{12}^{*} & S_{22}^{*} & S_{13}^{*} \\ S_{13}^{*} & S_{13}^{*} & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$|s_{11}|^2 + |s_{12}|^2 + |s_{13}|^2 = 1$ $[R_1C_1]$---------------(6)

$|s_{12}|^2 + |s_{22}|^2 + |s_{13}|^2 = 1$ $[R_2C_2]$---------------(7)

$0 + |s_{13}|^2 + |s_{13}|^2 = 1$ $[R_3C_3]$------------- -(8)

$S_{13}\ s_{11*} + S_{13}\ S_{12*} = 1$ $[R_1C_3]$ ---------------(9)

From equation (6) & (7)

$S_{11} = S_{22}$ ------ (10)

From Equation (8)

$S_{13} = \frac{1}{\sqrt{2}}$ ------- (11)

From equation (9)

$S_{13}\,(S_{11}{}^{*} + S_{12}{}^{*}) = 0$

but $S_{13} \neq 0$

$(S_{11}{}^{*} + S_{12}{}^{*}) = 0$

$S_{11}{}^{*} = -\,S_{22}{}^{*}$ $S_{11} = -S_{22}$, $S_{12} = -S_{11}$ -- (12)

Using the equation of values (10),(11),(12) in equation (6)

$|S_{11}|^2 + |S_{11}|^2 + \frac{1}{2} = 1$

$S_{11} = \frac{1}{2}$ ---------------(13)

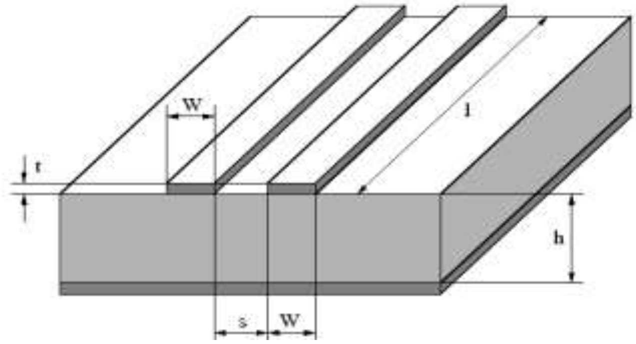
$\boldsymbol{S_{12} = -\frac{1}{2}}$ **----(14)**

$\boldsymbol{S_{22} = -\frac{1}{2}}$ **----(15)**

Substituting S_{11} , S_{12} , S_{13} , S_{22} the [S] matrix of equation becomes-

$$[s] = \begin{bmatrix} \frac{1}{2} & -\frac{1}{2} & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 \end{bmatrix}$$

Parallel Coupled Microstrip line and Stripline



A parallel strip line is a balanced line that can be used as a feed line for the center fed double sided printed dipole. The field distribution in this line remains uncharged if an infinite size perfect electric conductor is inserted at any plane inside the substrate and parallel to the strips. Placing this conductor at a distance h/2 from either strip will convert the parallel strips geometry into a combination of two identical microstrip lines placed back to back. Therfore design of **parallel strips line is simply related to the design of microstrip line.**

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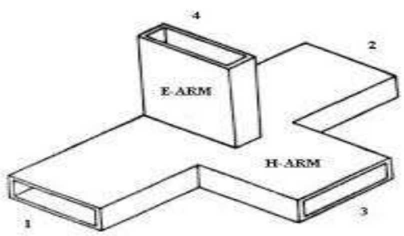
L-18

Magic Tee, Attenuators and Resonators

Structure of Magic Tee



Properties of S-matrix

[1] [S] is always a square matrix of order (n x n).

[2] [S] is a symmetric matrix. i.e $S_{ij} = S_{ji}$

[3] [S] is a Unitary Matrix i.e [S] [S]* =[I], where [S]* =Complex conjugate of [S]

[4] For perfect matched network diagonal elements will be zero. For an ideal N- port network with matched termination, $S_{ii}=0$, since there is no reflection from any port. Therefore perfect matched conditions the diagonal element of [S] will be zero.

[5] Symmetry of [S] for a reciprocal network: A reciprocal device has the same transmission characteristics in either direction of a pair of ports and is characterized by a symmetric scattering matrix.

$$S_{ij} = S_{ji} \quad (i \neq j)$$

S- Matrix of Magic Tee

[S] is a 4 x 4 matrix

-

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \quad \text{------------------}\mathbf{1}$$

Because of E plane tee section

$S_{24} = - S_{14}$ ----------------2

Because of H plane tee section

$S_{23}= S_{13}$ ----------------3

Because of geometry of junction an input at port (3) cannot come out at port (4).Similarily input at port(1) cannot come out of port (2) since they are isolated ports.

$S_{12}=S_{21}=0$ --------------------4

$S_{34}=S_{43}=0$

From symmetric property, i.e. Sij=Sji, we get

$S_{12}= S_{21}$ $S_{13}=S_{31}$ $S_{23}=S_{32}$

$S_{14}= S_{41}$ $S_{24}=S_{42}$ $S_{34}=S_{43}$ -----------------------5

If all ports are perfectly matched to junction

$S_{11}=S_{22}= S_{33}= S_{44} =0$ ------------------------6

Substituting equation no. 2 to equation no. 6 in equation no.1

$$[S] = \begin{bmatrix} 0 & 0 & s_{13} & s_{14} \\ 0 & 0 & s_{13} & -s_{14} \\ s_{13} & s_{13} & 0 & 0 \\ s_{14} & -s_{14} & 0 & 0 \end{bmatrix} \quad \text{------------------------}7$$

From Unitary property

[S] [S]* = [I]

$$\begin{bmatrix} 0 & 0 & s_{13} & s_{14} \\ 0 & 0 & s_{13} & -s_{14} \\ s_{13} & s_{13} & 0 & 0 \\ s_{14} & -s_{14} & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & s_{13*} & s_{14*} \\ 0 & 0 & s_{13*} & -s_{14}* \\ s_{13*} & s_{13*} & 0 & 0 \\ s_{14}* & -s_{14*} & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$|s_{13}|^2 + |s_{14}|^2 = 1$ $[R_1C_1]$---------------9

$|s_{13}|^2 + |s_{14}|^2 = 1$ $[R_2C_2]$---------------10

$|s_{13}|^2 + |s_{13}|^2 = 1$ $[R_3C_3]$---------------11

$|s_{14}|^2 + |s_{14}|^2 = 1$ $[R_4C_4]$----------------12

From equation 11 & 12, we get

$S_{13}= \frac{1}{\sqrt{2}}$ and $S_{14}= \frac{1}{\sqrt{2}}$----------13

The [S] of magic tee is obtained by substituting 13 in equation 7

$$[S] = \begin{bmatrix} 0 & 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 0 & 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 & 0 \end{bmatrix}$$

Attenuators and Resonators

In microwave circuits , the signal power is to be controlled at various points since the microwave devices are sensitive to high microwave powers.Many of the microwave devices will not function properly if the power of input device is not in the specified level. So the input power level of the device is to be controlled .

Microwave attenuators are devices which control the microwave signal power level at the appropriate point in the microwave circuit.

Attenuator introduces attenuation of signal to the extent required and power level to the next stage of circuit will be acceptable level. These attenuators are passive devices employing resistive films.Attenuators may be classified as

1) Fixed attenuators
2) Variable attenuators

1) Fixed Attenuators- In a Coaxial cable a thin film with loss is applied on the inner conductor of the cable ,which absorbs microwave power, and thus the loss in the signal power is achieved. The amount of resistive coating and length is determined based on the amount of attenuation required to be introduced

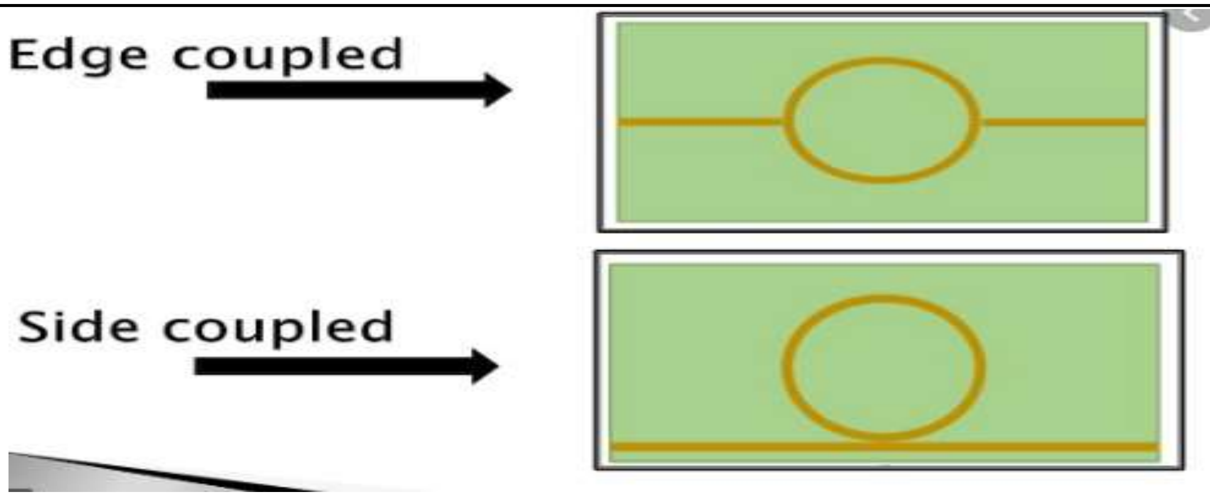
2) Variable Attenuators- In waveguides the dielectric slab coated with aquadag is placed at the Centre of the waveguide parallel to the maximum E-field for dominant TE_{10} Mode. Induced current on the lossy material due to incoming microwave signal, results in power dissipation , leading to attenuation of signal.

Ring resonator

Ring resonator is another type of distributed – line resonator, where r is the medium radius of the ring. The ring will resonate at its fundamental frequency F_0 when its median circumference is $2\pi r \sim \lambda g_0$. The higher resonant modes occur at f $\sim nf_0$ for n=2,3 ----.

The microstrip Ring resonator is a simple Transmission line in which resonator is excited at certain frequencies. Depending on the electrical length of the resonance a standing wave pattern forms around the circuit path of the resonator. The maximum voltage of the standing wave occurs at the exciting point.

The resonant frequencies correspond to a condition where the parameter of the ring is an integer multiple of the guided wavelength.



- Coupling gap is an important part of the ring resonator .It is the separation of the feed lines from the ring that allows the structure to only support selective frequencies.
- The size of the coupling gap also affects the performance of the resonator. If a very small gap is used , the losses will be lower but the fields in the resonant structure will also be greatly affected .
- A Larger Gap results in less field perturbation but greater losses. It is intuitive that the larger the percentage of the ring circumference the coupling region occupies, the greater the effect of Rings Performance.
- At resonant frequencies there exists a voltage minimum at $\frac{\pi}{2}$ away from the excitation point. By placing a transmission line at this voltage maximum point ,the field in the resonator can be probed to detect the resonant frequencies.
- The dissipated power in the ring resonator includes the dielectric loss, the conductor loss and Radiation loss.
- The End –Coupling structure provides a band pass whenever the ring is a multiple of wavelengths when the Edge-Coupling technique can be seen on the reflection coefficient (S11) .

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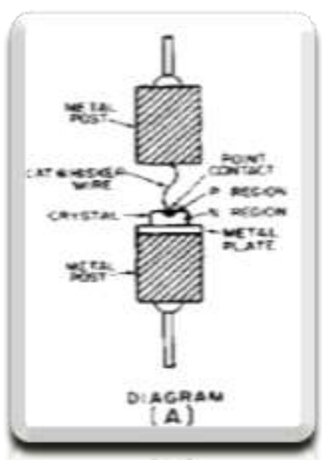
L-19

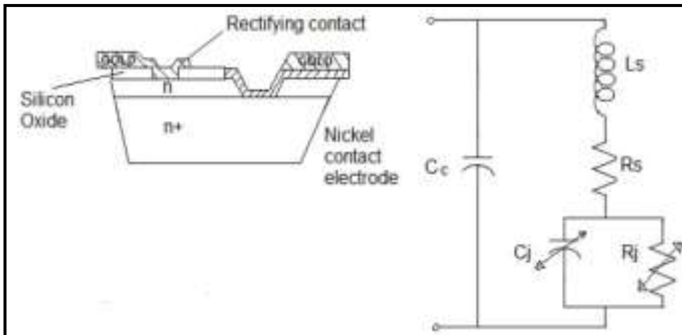
Microwave Active Components: Microwave Diodes and Transistors

Point contact diode

A gold or tungsten wire is used to act as the point contact to produce a PN junction region by passing a high electric current through it. A small region of PN junction is produced around the edge of the wire which is connected to the metal plate . In forward direction its operation is quite similar but in reverse bias condition the wire acts like an insulator. Since this insulator is between the plates the diode acts as a capacitor. In general the capacitor blocks the DC currents when the AC currents are flowing in the circuit at high frequencies. So, these are used to detect the high frequency signals. The pointed wire is used instead of a flat metal plate to produce a high-intensity electric field at the point contact without using a large external source voltage. It is not possible to apply large voltages across the average semiconductor because of the excessive heating.



Schottky Diode



Schottky diodes are metal Semiconductor barrier diodes The diode is constructed on a thin silicon (n^{+}-type) substrate by growing epitaxially on n-type active layer of about 2 micron thickness. A thin $Si0_2$ layer is grown thermally over this active layer. Metal semiconductor Junction is formed by depositing metal over Sio_2 .

Here equivalent circuit having

R_j = resistance of metallic junction

C_j = Barrier capacitance (0.3- 0.5pF)

R_s = Bulk resistance of heavily doped Si substrate (4-6 ohm)

L_s = inductance of gold whisker wire (0.4-0.9nH)

C_c= Case Capacitance

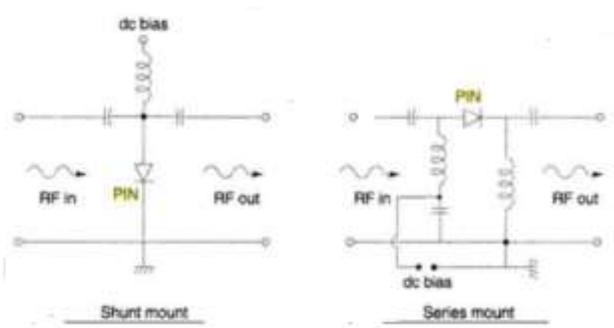
Here R_s and L_s are series lead resistance and inductance and

C_c is case capacitance and R_j & C_j are effective resistance and capacitance for the junction

PIN Diode

The PIN diode is a one type of photo detector, used to convert optical signal into an electrical signal. It comprises of three regions, namely P-region, I-region and N-region. Typically, both the P and N regions are heavily doped due to they are utilized for Ohmic contacts. The intrinsic region in the diode is in contrast to a PN junction diode. Silicon is widely used because of its power handling capacity and high resistivity in the intrinsic region and easy fabrication. PIN diode are widely used for microwave power switching, limiting and modulation.

Application as a switch-



It shows schematic circuits of a single PIN switch and series mounting Configurations.AC blocking inductor is realized from a high impedance strip line section and dc blocking capacitor is realized from a high impedance strip line section and dc blocking capacitor is realized from a gap in the line. For Shunt configuration reverse biasing produces transmission ON due to high impedance shunt and forward biasing producing transmission OFF due to low impedance shunt. For Series Configuration , Transmission is ON for forward bias and OFF for reverse bias. Due to non zero forward bias resistance ,isolation between input and output is not infinite .Similarily for reverse bias, shunt capacitor is not infinite and a non-zero insertion loss results.

IMPATT Diode

Its Avalanche Transit Time Device. IMPATT Diode is impact ionization avalanche transit time diode.

It is an RF semiconductor device that is used for generating microwave radio frequency signal with the ability to operate between 3 to 100 Ghz.

Main advantage of IMPATT Diode is relatively high power capability.

Although the IMPATT diode is not as widely used these days as other technologies have been able to provide higher levels of performance, it nevertheless fits a niche in the microwave signal generation market, especially where relatively cost effective sources are needed

Diode can be manufactured from Ge, Si, GaAs, Inp.

GaAs provide the highest efficiency, highest operating frequency and least noise figure. but fabrication process is more difficult and is more expensive than Si

IMPACT IONIZATION

If a free electron with sufficient energy strikes a silicon atom, it can break the covalent bond of silicon and liberate an electron from the covalent bond.

If the electron liberated gains energy by being in an electric field and liberates other electrons from other covalent bonds then this process can cascade very quickly into a chain reaction producing a large number of electrons and a large current flow.

This phenomenon is called impact avalanche.

PHYSICAL DESCRIPTION

n^+-p-i-p^+

+ very high doping

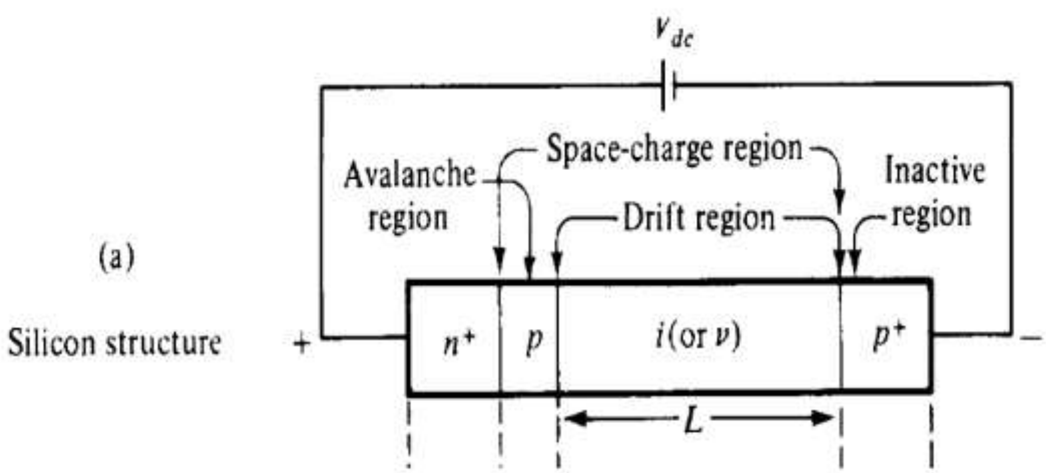
i or v intrinsic material

Two regions

1)Thin p region (High field/Avalanche region) – avalanche multiplication occurs

2) Intrinsic region (Drift region) – generated holes must drift towards the p+ contact

Physical Description



The space between n+ -p junction and the i –p+ junction is called the space charge region

The diode is reverse biased and mounted in a microwave cavity. The impedance of the cavity is mainly inductive which is matched with the capacitive impedance of the diode to form a resonant circuit.

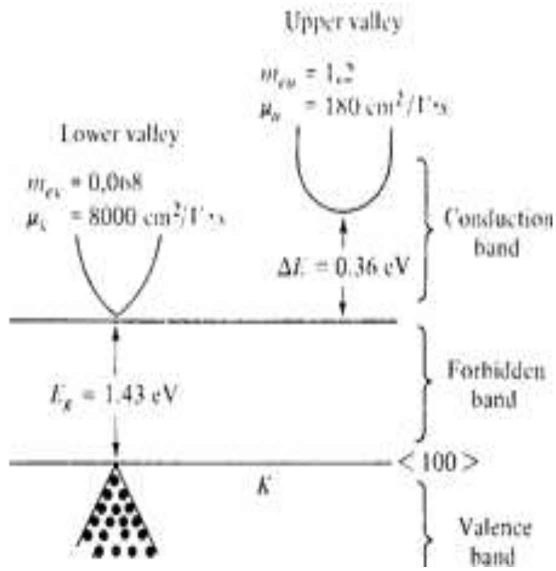
Such device can produce a negative ac resistance that in turns delivers power from the dc bias to the oscillation

Gunn Diode

Construction: -

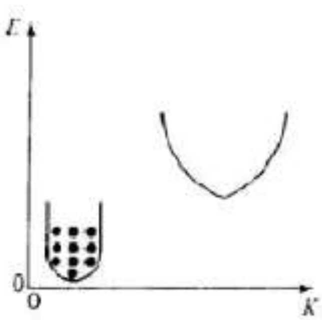
It has negative resistance property by which Gunn diode act as oscillator. To achieve this capacitance and shunt load resistance need to be tuned but not greater than negative resistance. The figure describes GUNN diode equivalent circuit. Here active region is about 6-18 μm long. It has negative resistance of about 100 Ohm with parallel capacitance of about 0.6 PF. Gunn diode will have efficiency of only few Percentage. Commercial GUNN diode need supply of about 9V with operating current of 950mA and available from 4GHz to 100GHz frequency band. It is preferably placed in a resonant cavity. The GUNN diode is basically a TED i.e. Transferred Electron Device capable of oscillating based on different modes. In a unresonant transit time mode, radio frequencies of up to 1-18GHz with power of up to 2 Watt can be achieved. In a resonant limited space charge mode, radiofrequencies of up to 100 Ghz with about 100watts of pulsed power can be achieved **.**

Working-

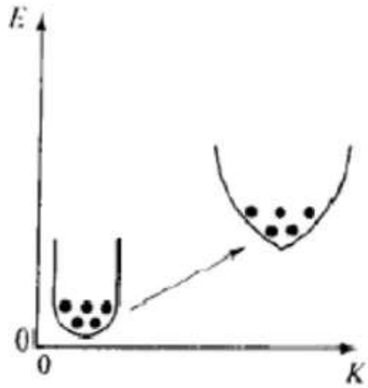


According to the energy band theory of then-type GaAs, a high-mobility lower valley is separated by an energy of 0.36 eV from a low-mobility upper valley.

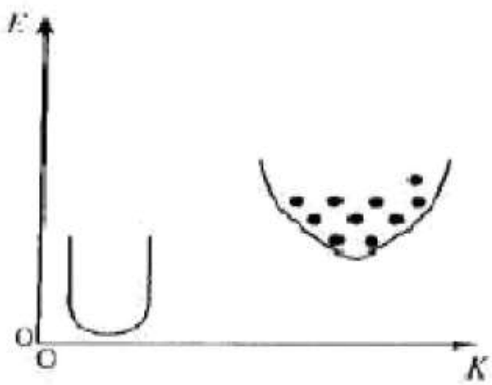
1) When the applied electric field is lower than the electric field of the lower valley ($E < E_c$), no electrons will transfer to the upper valley.



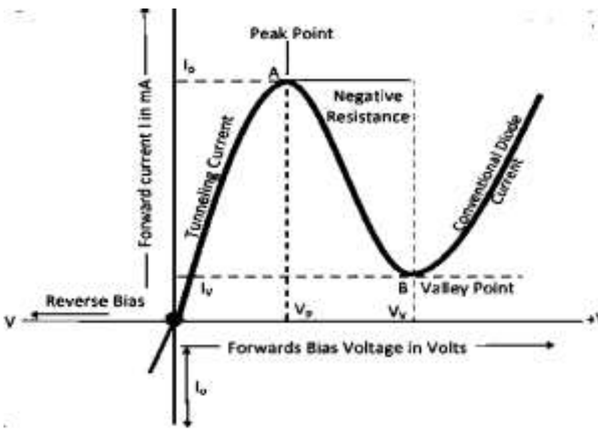
2) When the applied electric field is higher than that of the lower valley and lower than that of the upper valley **(Ec < E < Eu),** electrons will begin to transfer to the upper valley.



3) And when the applied electric field is higher than that of the upper valley **(Eu < E),** all electrons will transfer to the upper valley.



Draw I-V Characteristics of Gunn Diode-

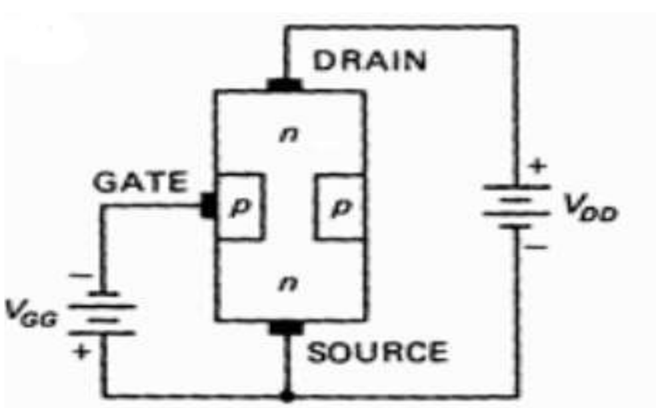


JFET

JFET-

1) JFET stands for Junction Field Effect Transistor.
2) JFET was originally Proposed By Schokley.
3) JFET is a Unipolar Device.

Construction of JFET-

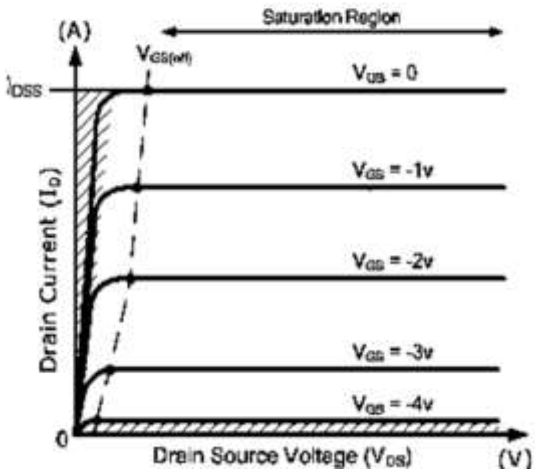


1) The N- Type material sandwiched between two highly doped layers of P-type material that is designated as P^+.
2) This type of device is called as an N-Channel JFET.
3) If the middle part is a p-Type semiconductor the device is called P-Channel JFET.
4) The two Ptype region is called gate.
5) Each end of the n-channel is joined by metallic contact.
6) The left hand contact which supplies the source of the flowing electrons is reflected to as the source.
7) The right hand contact which drains the electron out of the material is called drain.

Principle of Operation-

1) Under normal operating conditions when the gate voltage Vg is the drain current I_d Is also zero.
2) When the small drain voltage V_d is applied between the drain and source the n-type semiconductor bias acts as a resistor.
3) The current I_d increases linearly with V_d.
4) If a reverse gate voltage V_g is applied the majority of free electrons are depleted from the channel and the space charge region extended into the channel.
5) As the drain voltage further increased the space charge region expanded and join together. This condition is called Pinch Off.
6) When two channel is Pinched off ,the drain current I_d remains almost Consrtant.

I-V Characteristics of N-channel JFET



MOSFET

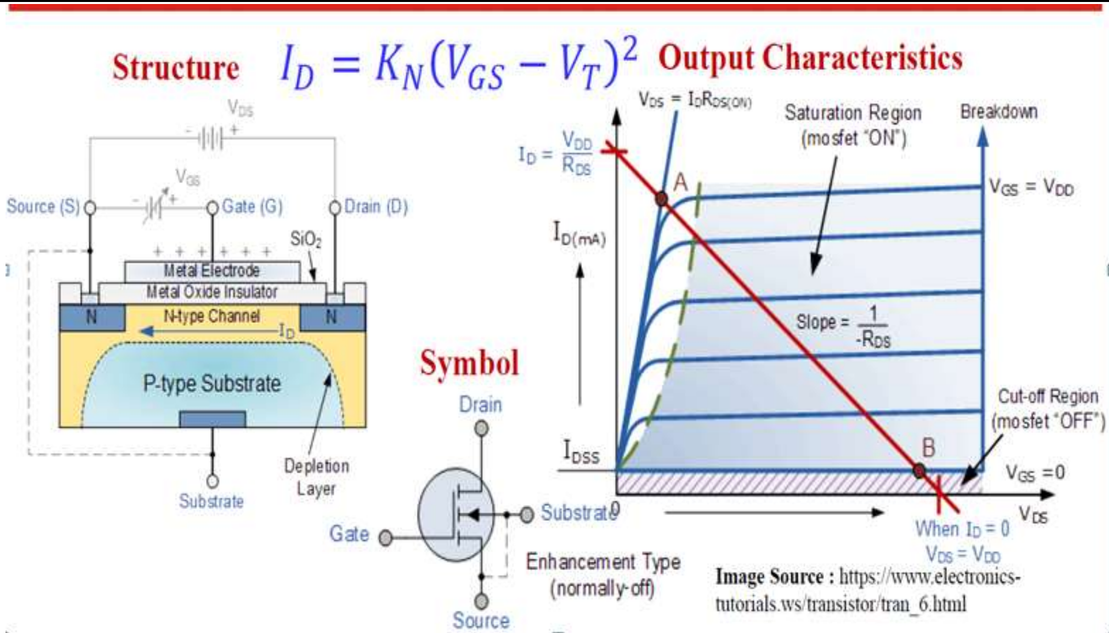
Metal semiconductor field effect transistor is a four terminal device.

Terminals are denoted as source, gate drain and substrate.

MOSFET current flow is controlled by an applied Vertical Electric field.

MOSFET can be formed in form of Al-$Si0_2$.

MOSFETs are used in very large scale integrated microwave circuits and in future its size should be further reduced and currently it available up to 1-µm compact size containing 1 million devices in it.



MOSFET can be designed in two forms as n-channel MOSFETs.

N-channel MOSFET consists of a slightly doped p-type semiconductor substrate into which two highly doped N+ sections are diffused.

Similarly p-channel MOSFET is made of a slightly doped n-type semiconductor with two highly doped p+ -type regions for the source and drain.

n+ Sections, act as the source and the drain, a thin layer of insulating Sio_2

is grown over the surface of the structure.

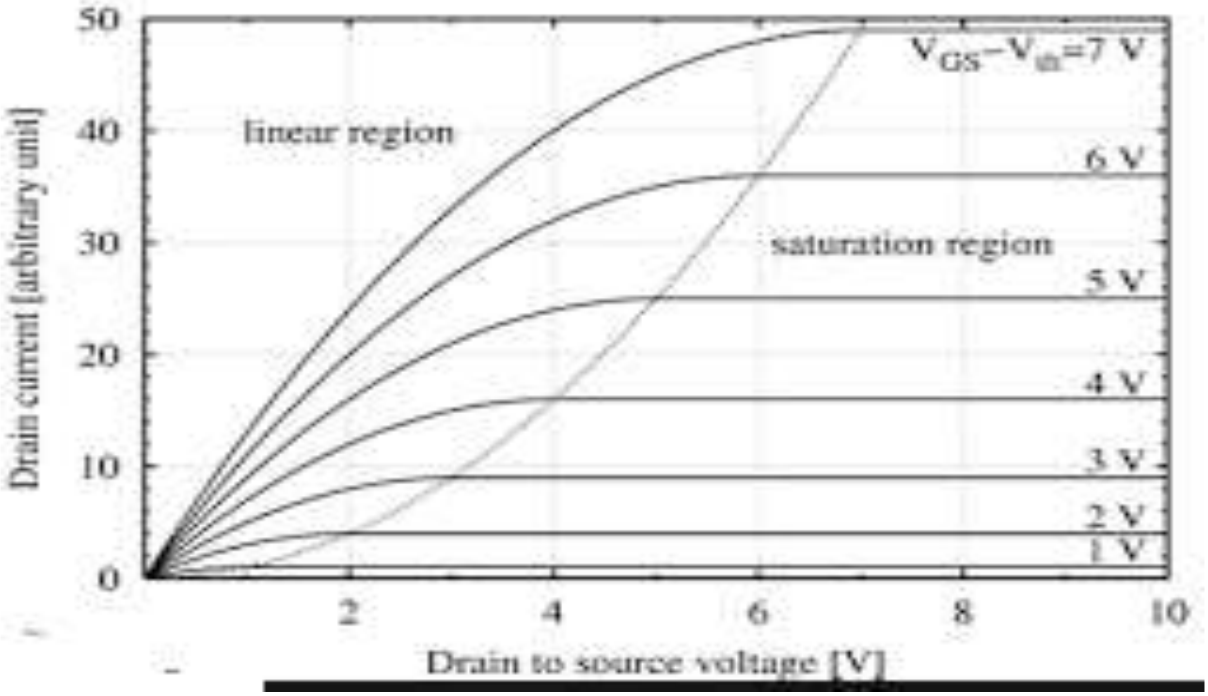
Metal contact on the insulator is called gate.

Basic parameters are-

L = Channel Length (distance between two n+-p Junctions just beneath the insulator)

Z= Channel depth

d= Insulator thickness of the n+ section.

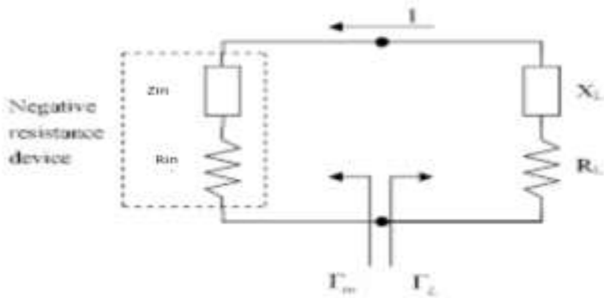

50
40
30
20
10
0
2
4
6
8
10
Drain current [arbitrary unit]
Drain to source voltage [V]
linear region
saturation region
V_GS−V_th=7 V
6 V
5 V
4 V
3 V
2 V
1 V

L-20

Microwave Oscillators and Mixers

Microwave Oscillators

Microwave Oscillators are universally found in all modern radar and wireless communications systems. To provide signal sources for frequency conversion and carrier generation. In this section we focus on oscillator circuits that are useful at microwave frequencies primarily employ negative resistance diodes or transistors.In this figure it shows the canonical RF circuit for a one port negative resistance oscillator, where Z_{in}= R_{in} + jX_L is the input impedance of the active device.



In General this impedance is current (or voltage) dependent as well as frequency dependent ,which we indicate by writing $Z_{in}(1, j\omega) = R_{in}(1,j\omega) + jX_{in}(1,j\omega)$.

Device is terminated with a passive load impedance , $Z_L = R_L + j_{XL}$. Applying Kirchoff's voltage law gives $(Z_L + Z_{in})$ I =0.If oscillation is occurring such that the RF current I is non Zero ,then following two condition must be satisfied:

$R_L + R_{in} = 0 \quad -(1)$

$X_L + X_{in} = 0 \quad - (2)$

Since the load is passive , $R_L > 0$.Positive resistance implies energy dissipation, a negative resistance implies an energy source .The condition controls the frequency of oscillation. $Z_L = -Z_{in}$ for steady –state oscillation, implies that the reflection coefficients Γ_L and Gain are related as-

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{-Z_{in} - Z_0}{-Z_{in} + Z_0} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} = \frac{1}{\Gamma_{in}}$$

The process of oscillation is critically dependent on the nonlinear behavior of $Z_{in.}$ as follows , initially it is necessary for the overall circuit to be unstable at a certain frequency ,that is $R_{in}(1,j\omega) + jX_{in}(1,j\omega)$, $R_L < 0$.Then any transient excitation or noise will cause an oscillation to build up at the frequency ω. As I increases , $R_{in}(1,j\omega)$ must become less negative until the current I_0 is reached such that $R_{in}(I_0, j\omega_0) + R_L = 0$ and $X_{in}(I_0, j\omega_0) + X_L(j\omega_0) = 0$. At this point the oscillator can run in a stable state. The final frequency ω_0 ,generally differs from the start up for frequency because X_{in} , is current dependent , so that $X_{in}(1, j\omega) \neq X_{in}(I_0, j\omega_0)$. Therefore we see that the conditions are not enough to guarantee a stable state of oscillation . In particular stability requires that any perturbation in current or frequency will be damped out, allowing the oscillator to return to its original state. This condition can be quantified by considering the effect of a small change. Here δI is current and a small change δs in the complex frequency $s = \alpha + j\omega$. let $Z_T(I,s) = Z_{in}(I,s) + Z_l(s)$,then we can write a Taylor series for $Z_T(I,s)$ about the stable operating point I_0, ω_0 *as*

$$Z_T(I,s) = Z_T(I_0, s_0) + \frac{\partial Z_T}{\partial s}\Big|_{s_0, I_0} \delta s + \frac{\partial Z_T}{\partial s}\Big|_{s_0, I_0} \delta I = 0. \quad - (A)$$

Since Z_T (I,s) must still zero if oscillation is occurring .In (I),

s_0=jω_0 is the complex frequency at the original operating point. Now use the fact that $Z_T\,(I_0, s_0)$ = 0 ,and that $\frac{\partial Z_T}{\partial s}$ = -j($\partial Z_T/\ \partial\omega$), to solve (A) for δs= $\delta\alpha + j\delta\delta s = \ \delta\alpha + j\omega = \ \frac{-\partial Z_T/\partial I}{\partial Z_T/\partial s}\Big| s_0,\ I_0$

$$\delta I = \ \frac{-J(\frac{\partial Z_T}{\partial I})(\frac{\partial Z^*{}_T}{\partial\omega})}{|\partial Z_T/\partial\omega|^2}\,\delta I \ \text{----(B)}$$

If the transient caused by δI and $\delta\omega\ is\ to\ decay$

we must have $\delta\alpha < 0$ when δI>0.Equation (B) then implies that

$$I_m = \left\{\frac{\partial Z_T}{\partial I}\ \ \frac{\partial {z_T}^*}{\partial\omega}\right\} <0$$

Or

$$\frac{\partial R_T}{\partial I}\frac{\partial R_T}{\partial\omega} - \frac{\partial X_T}{\partial I}\frac{\partial R_T}{\partial\omega} >0 \text{ –(C)}$$

This relation is sometimes known as Kurokawa's condition.

For a passive load , $\frac{\partial R_T}{\partial I} = \frac{\partial X_L}{\partial I} = \frac{\partial R_L}{\partial\omega}$ =0,So (c) reduces to

$$\frac{\partial R_{in}}{\partial I}\frac{\partial}{\partial\omega}\,(\,X_L + X_{in}\,)\ - \frac{\partial X_{in}}{\partial I}\frac{\partial R_{in}}{\partial\omega} > 0\ \text{ - (D)}$$

As discussed above , we usually have that $\frac{\partial R_{in}}{\partial I} > 0$, so (D) cab be satisfied if

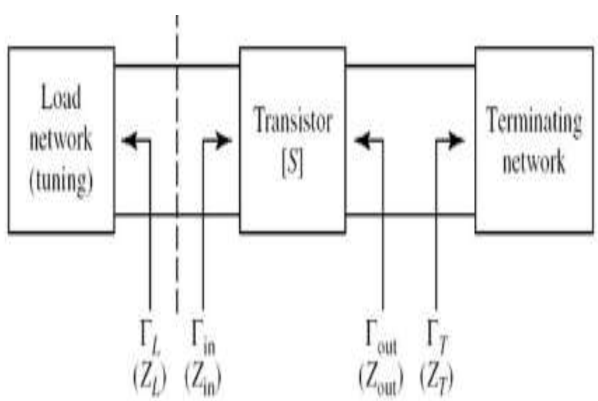
$$\frac{\partial(X_L+X_{in})}{\partial\omega} >>0$$

This implies that a high –Q circuit will result in maximum oscillator stability. Cavity and dielectric resonators are often used for this Purpose .

Transistor Oscillators

In a transistor oscillator , a negative resistance one –port network is effectively created by terminating a potentially unstable transistor with an impedance designed to drive the device in an unstable region .In this circuit the RF output port is part of the load network on the output side of transistor, but it is also possible to use the terminating network to the left of the transistor as the output port.

Circuit for two port Transistor Oscillator



In case of an Amplifier we preferred a device with a high degree of stability –ideally ,an unconditionally stable device. For an oscillator ,we require a device with a high degree of instability. Common source or common gate FET configurations are used often with positive feedback to enhance the stability of a device. After transistor configuration is selected output stability circle can be drawn in the Γ_L.Plane and Γ_L selected to produce a large value of negative resistance at the input to the transistor .Then the terminating impedances

$Z_s = R_s + jX_S$ can be chosen to match Z_{in}.

Such a design often relies on the small signal scattering parameters, and because R_{in} will becomes less negative as the oscillator power builds up. In practice, a value of

$$R_s = \frac{-R_{in}}{3} \quad \text{-(1)}$$

Reactive part of Z_s is chosen to resonate the circuit

$$X_s = -X_{in} \quad \text{- (2)}$$

When oscillations occurs between the termination network and the transistor, oscillation will simultaneously occur at the output port, which we can show as follows. For steady state oscillations at the input port, we must have $\Gamma_s \Gamma_{in}$ =1 analogous to the condition

$$\frac{1}{\Gamma_s} = \Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L} \quad \text{-(3)}$$

Where $\Delta = S_{11}S_{22} - S_{12}S_{21}$. Solving Γ_L gives

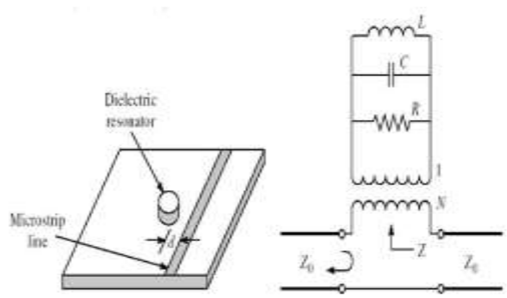
$$\Gamma_L = \frac{1-S_{11}\Gamma_s}{S_{22}-\Delta\Gamma_s} \quad \text{- (4)}$$

$$\Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1-S_{11}\Gamma_s} = \frac{S_{22}-\Delta\Gamma_s}{1-S_{11}\Gamma_s} \quad \text{- (5)}$$

Condition for oscillation at the local network is satisfied.

Dielectric Resonator Oscillators

Oscillator stability is enhanced with the use of a high-Q tuning network .Unloaded Q of a resonant network using lumped elements or microstrip lines and stubs is typically limited to a few hundred and while waveguide cavity resonators can have unloaded Qs of 10^4 or more ,they are not well suited for integration in miniature microwave integrated circuitry. Another disadvantage of metal cavities is the significant frequency drift caused by dimensional expansion due to temperature variations.Dielectric Cavity resonator overcomes most of these disadvantages, as it can have an unloaded Q as high as several thousand .It is compact and easily integrated with planar circuitry and it can be made from ceramic materials that have excellent temperature stability. Transistor dielectric resonator oscillators are in common use over the entire microwave and lower millimeter wave,Frequency range. A dielectric resonator is usually coupled to an oscillator circuit by positioning it in close proximity to a microstrip line .Resonator operates in the $TE_{01\delta}$ mode, and couples to the fringing magnetic field of the microstrip line.



Geometry of a Dielectric resonator coupled to a microstrip line

Strength of coupling is determined by the spacing d, between the resonator and microstrip line. Because coupling is via the magnetic field , the resonator appears as a series load on the microstrip line.

Microwave Mixers

Mixers is a three Port device that uses a nonlinear or time varying element to achieve frequency conversion.

Microwave mixers or mixers in general is a very vital component in the RX and TX, which is a receiver and transmitter chain of any communication system. So, be it GSM, be it mobile communication, be it satellite communication, mixers are very vital components.

Let us take Example of RF receiver Chain.

Up conversion

Up-conversion mixer, the input signal is given at the IF port. The signal at the IF port mixes with the signal at the LO port, and these mixing signals produce the sum and the difference frequencies. And in this case, we choose the sum frequency, which is the RF frequency. So, $f_{RF}$is equal to $f_{LO} + f_{IF}$.

Down conversionIn Case of Down Conversion Mixer ,Input is at the RF port, and the signal at the input RF port mixes with the signal at the LO. And these two signals after mixing with each other produces the sum and the difference frequency, and we choose the difference frequency in this case, which is output at the IF port.

So, f_{IF} is equal to $f_{LO} - f_{RF}$. This is the basic operation of a mixer in up-conversion and down-conversion case.

In a receiver the RF input signal at frequency f_{RF} is typically delivered from the antenna .

It may receive RF signals over a relatively wide band of frequencies.

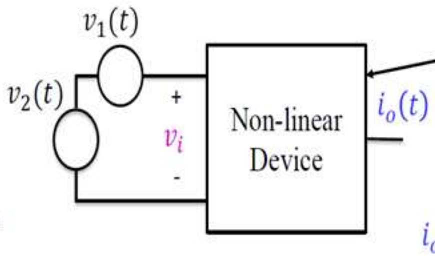
For a receiver with a local oscillator frequency f_{LO} and Intermediate frequency f_{IF} i.e $f_{IF}= f_{IF}-f_{LO}$ it gives the RF input frequency that will be down converted to the IF Frequency i.e

$$f_{RF} = f_{LO} + f_{IF}$$

$$(V_1(t) = A_1 \cos \omega_1 t \;, V_2(t) = A_2 \cos \omega_2 t) \quad \overset{?}{\rightarrow} \quad V_{out}(t) \Rightarrow (\omega_1 - \omega_2), (\omega_1 + \omega_2)$$

$$\begin{aligned} V_{out}(t) = V_1(t).V_2(t) &= A_1 \cos \omega_1 t \,.A_2 \cos \omega_2 t \\ &= (\tfrac{1}{2} A_1 . A_2) \cos(\omega_1 - \omega_2) t + (\tfrac{1}{2} A_1 . A_2) \cos(\omega_1 + \omega_2) t \end{aligned}$$

$$\boxed{\text{Mixer} \equiv \text{Multiplier}}$$



Diode / BJT Device ➡ $i_o(t) = ke^{v_i(t)/nv_T}$

Series Expansion ↓

$$i_o(t) = I_0 + av_i(t) + b[v_i(t)]^2 + c[v_i(t)]^3 + \cdots$$

$$v_i(t) = v_1(t) + v_2(t) = k_1 \cos\omega_1 t + k_2 \cos\omega_2 t$$

$$i_o(t) = \underbrace{I_0}_{\text{DC}} + \underbrace{k_1 \cos\omega_1 t + k_2 \cos\omega_2 t}_{\text{Input frequencies}} + \underbrace{bk_1^2(\cos\omega_1 t)^2 + bk_2^2(\cos\omega_2 t)^2}_{\text{DC + 2nd Harmonics of Input frequencies}} + \underbrace{2bk_1k_2 \cos\omega_1 t \, . \cos\omega_2 t}_{\text{Desired Mixing}} + \cdots$$

Desired mixing component is selected by filtering the output

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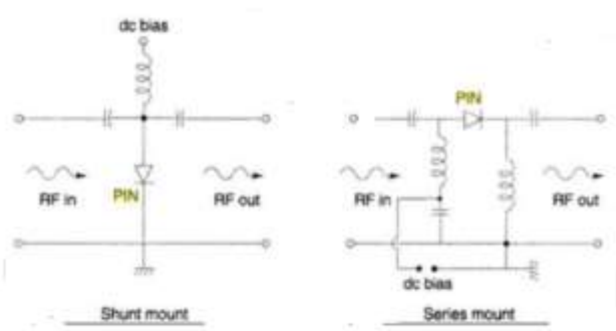
Microwave semiconductor devices : Gunn Diodes, PIN diode

PIN Diode

The PIN diode is a one type of photo detector, used to convert optical signal into an electrical signal. It comprises of three regions, namely P-region, I-region and N-region. Typically, both the P and N regions are heavily doped due to they are utilized for Ohmic contacts. The intrinsic region in the diode is in contrast to a PN junction diode. Silicon is widely used because of its power handling capacity and high resistivity in the intrinsic region and easy fabrication. PIN diode are widely used for microwave power switching, limiting and modulation.

Application as a switch-



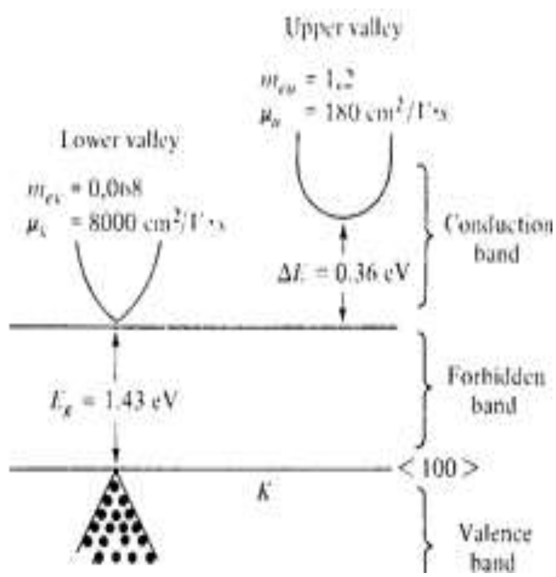
It shows schematic circuits of a single PIN switch and series mounting Configurations.AC blocking inductor is realized from a high impedance strip line section and dc blocking capacitor is realized from a high impedance strip line section and dc blocking capacitor is realized from a gap in the line. For Shunt configuration reverse biasing produces transmission ON due to high impedance shunt and forward biasing producing transmission OFF due to low impedance shunt. For Series Configuration , Transmission is ON for forward bias and OFF for reverse bias. Due to non zero forward bias resistance ,isolation between input and output is not infinite .Similarily for reverse bias, shunt capacitor is not infinite and a non-zero insertion loss results.

Gunn Diode

Construction: -

It has negative resistance property by which Gunn diode act as oscillator. To achieve this capacitance and shunt load resistance need to be tuned but not greater than negative resistance. The figure describes GUNN diode equivalent circuit. Here active region is about 6-18 µm long. It has negative resistance of about 100 Ohm with parallel capacitance of about 0.6 PF. Gunn diode will have efficiency of only few Percentage. Commercial GUNN diode need supply of about 9V with operating current of 950mA and available from 4GHz to 100GHz frequency band. It is preferably placed in a resonant cavity. The GUNN diode is basically a TED i.e. Transferred Electron Device capable of oscillating based on different modes. In a unresonant transit time mode, radio frequencies of up to 1-18GHz with power of up to 2 Watt can be achieved. In a resonant limited space charge mode, radiofrequencies of up to 100 Ghz with about 100watts of pulsed power can be achieved **.**

Working-



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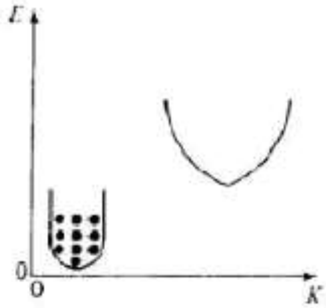
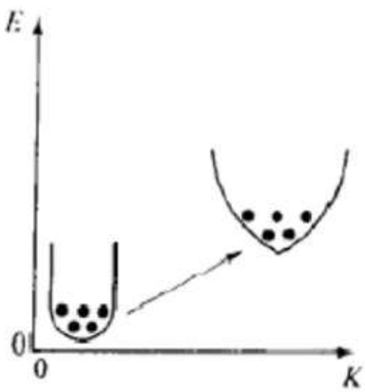
1) When the applied electric field is lower than the electric field of the lower valley

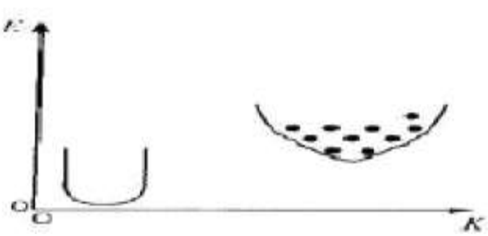
($E < E_c$), no electrons will transfer to the upper valley.



2) When the applied electric field is higher than that of the lower valley and lower than that of the upper valley ($E_c < E < E_u$), electrons will begin to transfer to the upper valley.



3) And when the applied electric field is higher than that of the upper valley ($E_u < E$), all electrons will transfer to the upper valley.



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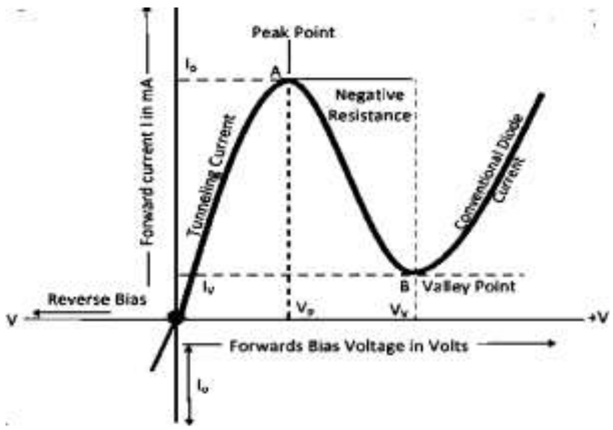

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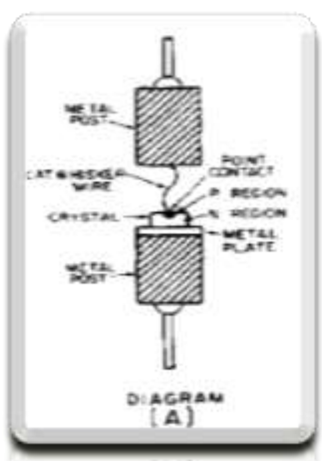
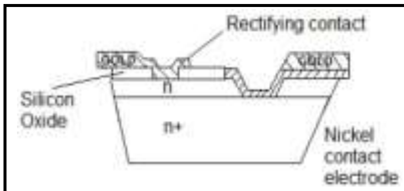
Schottky Barrier Diode , Impatt Diode

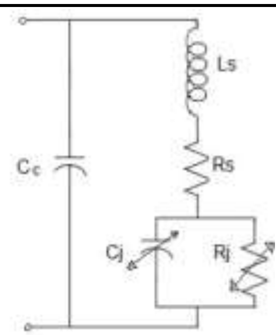
Schottky Barrier Diode

A gold or tungsten wire is used to act as the point contact to produce a PN junction region by passing a high electric current through it. A small region of PN junction is produced around the edge of the wire which is connected to the metal plate . In forward direction its operation is quite similar but in reverse bias condition the wire acts like an insulator. Since this insulator is between the plates the diode acts as a capacitor. In general the capacitor blocks the DC currents when the AC currents are flowing in the circuit at high frequencies. So, these are used to detect the high frequency signals. The pointed wire is used instead of a flat metal plate to produce a high-intensity electric field at the point contact without using a large external source voltage. It is not possible to apply large voltages across the average semiconductor because of the excessive heating.



Schottky Diode





Schottky diodes are metal Semiconductor barrier diodes The diode is constructed on a thin silicon (n^+-type) substrate by growing epitaxially on n-type active layer of about 2 micron thickness. A thin $Si0_2$ layer is grown thermally over this active layer. Metal semiconductor Junction is formed by depositing metal over Sio_2 .

Here equivalent circuit having

R_j = resistance of metallic junction

C_j = Barrier capacitance (0.3- 0.5pF)

R_s = Bulk resistance of heavily doped Si substrate (4-6 ohm)

L_s = inductance of gold whisker wire (0.4-0.9nH)

C_c= Case Capacitance

Here R_s and L_s are series lead resistance and inductance and

C_c is case capacitance and R_j & C_j are effective resistance and capacitance for the junction

IMPATT Diode

Its Avalanche Transit Time Device. IMPATT Diode is impact ionization avalanche transit time diode.

It is an RF semiconductor device that is used for generating microwave radio frequency signal with the ability to operate between 3 to 100 Ghz.

Main advantage of IMPATT Diode is relatively high power capability.

Although the IMPATT diode is not as widely used these days as other technologies have been able to provide higher levels of performance, it nevertheless fits a niche in the microwave signal generation market, especially where relatively cost effective sources are needed

Diode can be manufactured from Ge, Si, GaAs, Inp.

GaAs provide the highest efficiency, highest operating frequency and least noise figure. but fabrication process is more difficult and is more expensive than Si

IMPACT IONIZATION

If a free electron with sufficient energy strikes a silicon atom, it can break the covalent bond of silicon and liberate an electron from the covalent bond.

If the electron liberated gains energy by being in an electric field and liberates other electrons from other covalent bonds then this process can cascade very quickly into a chain reaction producing a large number of electrons and a large current flow.

This phenomenon is called impact avalanche.

PHYSICAL DESCRIPTION

n^{+}-p-i-p^{+}

+ very high doping

i or v intrinsic material

Two regions

1)Thin p region (High field/Avalanche region) – avalanche multiplication occurs

2) Intrinsic region (Drift region) – generated holes must drift towards the p+ contact

The space between n+ -p junction and the i –p+ junction is called the space charge region

The diode is reverse biased and mounted in a microwave cavity. The impedance of the cavity is mainly inductive which is matched with the capacitive impedance of the diode to form a resonant circuit.

Such device can produce a negative ac resistance that in turns delivers power from the dc bias to the oscillation

L-23

Microwave tubes: Two cavity Klystron: Concept of velocity modulation ,Electron bunching ,working and efficiency

Klystron:

Klystron is the simplest vacuum tube that can be used for amplification or generation of microwave signal. Operation of Klystron depends upon velocity modulation which leads to density modulation of electrons.

Concept of velocity and current modulation. All electrons injected from the cathode arrive at the first cavity with uniform velocity. Those electrons passing the first cavity gap at zeros of the gap voltage (or signal voltage) pass through with unchanged velocity; those passing through the positive half cycles of the gap voltage undergo an increase in velocity; those passing through the negative swings of the gap voltage undergo a decrease in velocity. As a result of these actions, the electrons gradually bunch together as they travel down the drift space. The variation in electron velocity in the drift space is known as velocity modulation. The density of the electrons in the second cavity gap varies cyclically with time. The electron beam contains an ac component and is said to be current-modulated.

Bunching Process

The maximum bunching should occur approximately midway between the second cavity grids during its retarding phase; thus the kinetic energy is transferred from the electrons to the field of the second cavity. Once the electrons leave the buncher cavity, they drift with a velocity along in the field-free space between the two cavities. The effect of velocity modulation produces bunching of the electron beam-or current modulation. The electrons that pass the buncher at Vs = 0 travel through with unchanged velocity vo and become the bunching center. Those electrons that pass the buncher cavity during the positive half cycles of the microwave input voltage Vs travel faster than the electrons that passed the gap when Vs = 0. Those electrons that pass the buncher cavity during the negative half cycles of the voltage Vs travel slower than the electrons that passed the gap when Vs = 0.At a distance along the beam from the buncher cavity, the beam electrons have drifted into dense clusters.

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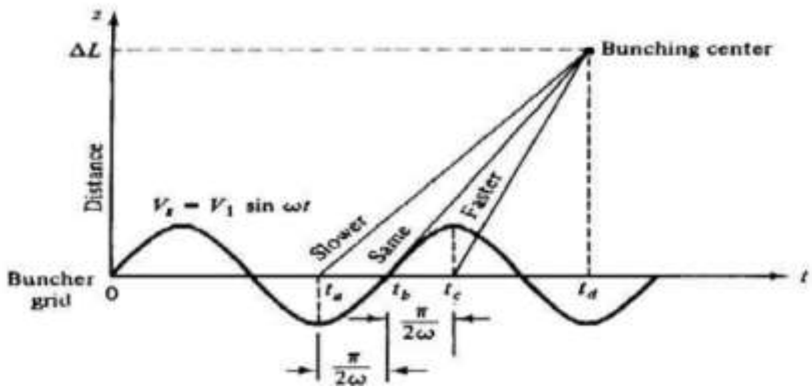

Q1. A Two Cavity Klystron amplifier has following parameters

Vo = 1000V

Ro= 40K Ω

Io =25mA

F= 3GHz

Gap spacing in both cavity d=1mm

Spacing between the two cavity L=4cm

Effective shunt impedance excluding beam loading Rsh=30KΩ

Determine

i) Input gap voltage to give Maximum Voltage V2

ii) Voltage gain, neglecting the beam loading in Output Cavity.

iii) Efficiency of Amplifier

Solution: -

a) Input gap voltage V_1 is

$V_1 = \frac{2V_0X}{\beta_i\theta_0}$ Form X= $\frac{\beta_i V_i}{2V_0}\theta_0$

For the maximum voltage V_2 , J_1(X) must be maximum ,i.e , J_1(X) will be maximum= 0.582 at X= 1.841

The electron velocity just leaving the cathode is

$v_0 = \sqrt{\frac{2eV_0}{m}}$ = $(0.593\times 10^6)\sqrt{V_0}$

$0.593\times 10^6\sqrt{10^3} = 1.88 \times 10^7$ m/sec

The gap transit angle θ_g is

$$\theta_g = \frac{\omega d}{v_0} = 2\pi f \frac{d}{v_0}$$

$$2\pi \times 3 \times 10^9 \times \frac{10^{-3}}{1.88\times10^7} = 1 \text{ radian}$$

The beam –coupling coefficient β_i & β_0

$$\beta_i = \beta_0 = \frac{sin\theta_g/2}{\theta_g/2} = \text{o.952}$$

The dc transit angle between the cavities is

$$\theta_0 = \omega T_0 = \frac{\omega L}{v_0} = \frac{2\pi\times3\times10^9 \times4\times10^{-2}}{1.88\times10^7} = 40 \text{ radian}$$

Substituting above values for V_1max when X= 1.841

$$V_1\text{max} = \frac{2V_0X}{\beta_i\theta_o} = 96.5 \text{ volt}$$

b) The voltage gain is given by

$$A_V = \frac{{\beta_0}^2\theta_0}{R_0}\frac{J_{1(X)}}{X}\text{R}s_h$$

$= 8.595$

c) The efficiency of amplifier is

$$\eta = \frac{\beta_0 I_2 V_2}{2I_0V_0}$$

$I_2 = 2I_0J_1(\text{X})$

$= 29.1\times 10^{-3}$ Amp

$V_{2= \beta_0 I_2 R_{sh}} = 0.952\times (29.1 \times 10^{-3}) \times (30 \times 10^3)$ 831 volt.

$$\eta = \frac{\beta_0 I_2 V_2}{2I_0V_0}$$

=0.462% Ans

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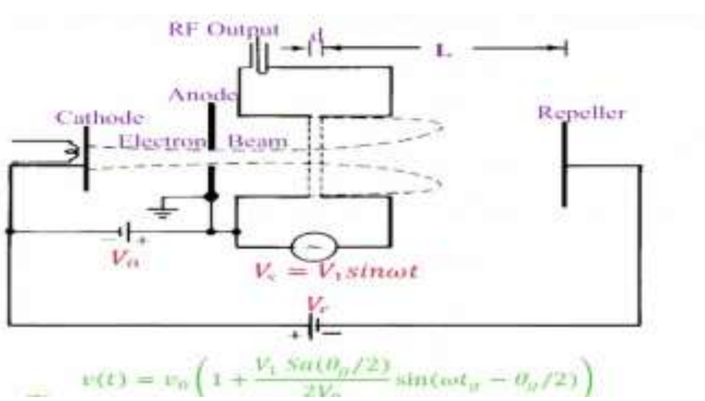
Reflex Klystron :Working ,Modes, Numerical on Two Cavity & Reflex Klystron

Reflex Klystron

Reflex Klystron is a single cavity Klystron that overcomes the disadvantages of the two cavity Klystron oscillator .It is a low power generator of 10- 500mW.Output at a range of 1 to 25GHz.Efficiency is about 20 to30%. This type widely used in the laboratory for microwave measurements and microwave receivers as local oscillator in commercial, military and airborne Doppler radars.Theory of two cavity Klystron can be applied to the analysis of the reflex klystron .Electron beam injected from the cathode is first velocity modulated by the cavity gap voltage . Some Electrons accelerated by accelerating field enter the repeller space with greater velocity those with unchanged velocity. Some electrons deaccelerated by retarding field enter the repeller region with less velocity. All electrons turned around by the repeller voltage then pass through the cavity gap in bunches that occur once per cycle. On their return journey the bunched electron pass through the gap during the retarding phase of the alternating field and give up their kinetic energy to the electromagnetic energy of the field in the cavity. Ocillator output energy is then taken from the cavity. The electrons are finally collected by walls of the cavity .Applegate diagram for $1\frac{3}{4}$ mode of a Reflex Klystron.



Analysis of Reflex Klystron is similar to that of a two cavity Klystron .For simplicity the effect of space charge forces on the electron motion will again be neglected .The electron entering the cavity gap from the cathode at Z=0 and time t_0 is assumed tohave uniform velocity. $v_0 = 0.593\times 10^6\sqrt{V_0}$ -(1)

Same electrons leaves the cavity gap at z=d at time t_1 with velocity
$v_{(t1)} = v_0[\ 1+ \frac{\beta_i V_1}{2V_0}\ \sin\ (\ \omega t_1 - \frac{\theta_g}{2}\ )\ ]$ -(2) .Same electrons back to cavity z=d and time t_2 by the retarding electric field E, which is given by

$$E = \frac{V_r+V_O+V_1\sin(\omega t)}{L} \quad -(3)$$

This retarding field E is assumed to be constant in the Z- direction .The force equation for one electron in the repeller region is

$$m\frac{d^2z}{dt^2} = -e\ E = -\ e\frac{V_r+V_0}{L} \quad -(4)$$

WHERE E = $-\nabla V$ *is used in the Z direction only,* V_r is the magnitude of the repeller voltage and $V_1\sin\omega t \ll V_r + V_0$ is assumed.

Integration of equation (4)

$$\frac{dz}{dt} = -\ e\frac{V_r+V_0}{mL}\int_{t_1}^{t} dt\ =\ \frac{-e(V_r+V_0)}{mL}\ (t- t_1) + K_1 \quad -(5)$$

At t = t_1 , $\frac{dz}{dt} = v_{(t1)} = K_1$, then

$$Z = \frac{-e(V_r+V_0)}{mL}\ \int_{t_1}^{t} (\ t- t_1)dt + v(t_1)\int_{t_1}^{t} dt$$

$$Z = \frac{-e(V_r+V_0)}{2mL}(\ t- t_1)^2 + v(t_1)\ (\ t- t_1) + d \quad -(6)$$

On the assumption that the electron leaves the cavity gap at z=d and time t_1 with a velocity of v(t_1) and returns the gap at z=d and time t_2 then t= t_2 ,z=d

$$0 = = \frac{-e(V_r+V_0)}{2mL}(\ t- t_1)^2 + v(t_1)\ (\ t_2- t_1)$$

Round trip transit time in the repeller region is given by-

$$T' = t_2- t_1 = \frac{2mL}{e(V_r+V_0)}v(t_1) = T_{0'}\ [1+ \frac{\beta_i V_1}{2V_0}\sin\ (\omega t_1\ - \frac{\theta_g}{2}\ )\ ] -(7)$$

$$T_{0'} = \frac{2mLV_0}{e(V_r+V_0)}$$

$$\omega(\ t_2- t_1)$$

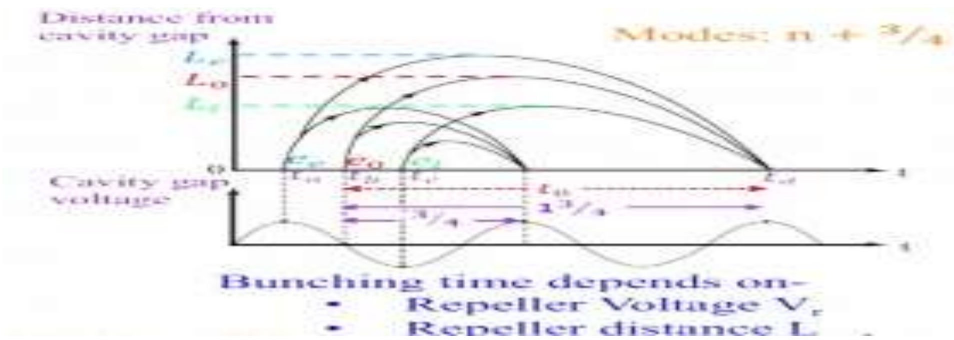
$$= \theta_0{}' + X'\ \sin\ (\omega t_1 - \frac{\theta_g}{2})- (9)$$

$\theta_0{}' = \omega t_o{}'$ -(10)
Is the round trip dc transit angle of the center of the bunch electron and

$$X' = \frac{\beta_i V_1}{2V_0}\,\theta_0{}'$$

Is the bunching parameter of the reflex Klystron Oscillator.

Bunch Process and Modes



Specifications of reflex Klystron

Frequency range – 1-200Ghz
Tuning ranges – 5Ghz at 2W -30Ghz at 10 Mw
Power output – 10mW -2.5W
Theoretical Efficiency- 22.78%
Practical Efficiency – 10- 20%

Applications of reflex Klystron

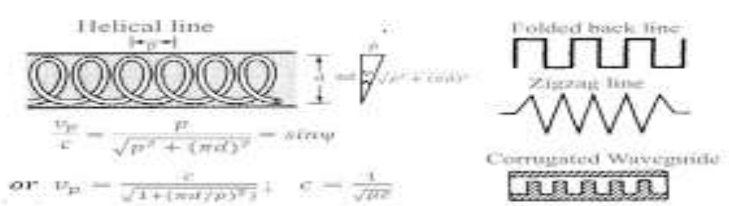
RADAR Receivers
Radio Receivers
Signal source in microwave generators
Local oscillators in receivers
Pump oscillators in Parametric Amplifiers
Portable microwave links

l-25
Travelling wave tubes, Magnetron ,Numericals

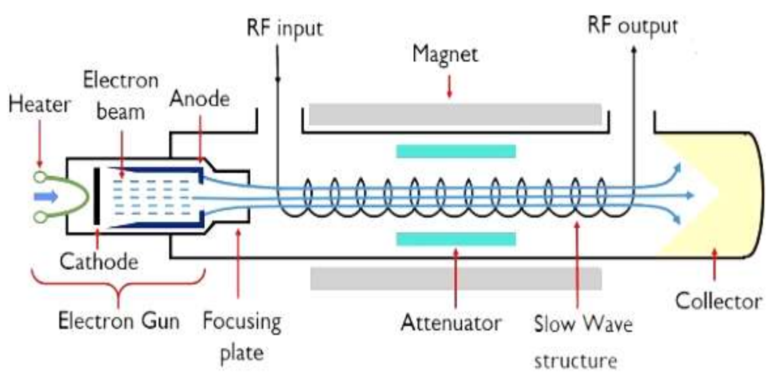
Travelling wave tubes

- Non Resonant Structures
- Helix TWTs
  - Slow wave structures
  - Broadband Applications
- Coupled Cavity TWTs
  - For High Power Applications(RADAR Transmitters)

Slow Wave Structures



Helix Travelling Wave tubes

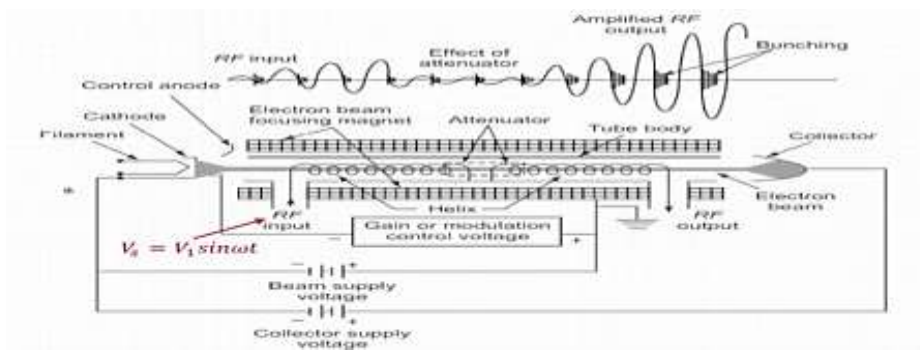


It contains Electron gun, RF Interaction circuit electron beam focusing magnet , attenuator and collector.

Electron Beam Focusing a magnetic field - to hold the electron beam. The beam tends to disperse out or spread out as a result of the natural repulsive forces between electrons.

Attenuator: To attenuate any reflected waves generated due to the impedance mismatch.

Helix TWT



Helix Specifications

- Frequency range – 1-100 GHz
- Power Output : up to 10KW Average
- Power Gain : up to 60dB
- Efficiency – 20 to40%

Application of Helix TWTs

1) Low noise RF Amplifier in broadband microwave receivers.
2) Repeater Amplifier in wideband Communications links and long distance telephony.
3) Due to long tube life TWT is power output tube in communication satellite.
4) For medium power and high power satellite transponder output.
5) Used in Air borne and ship borne pulsed high power radars.
6) Electronic Counter Measure System

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Comparison between Klystron and TWT Amplifiers

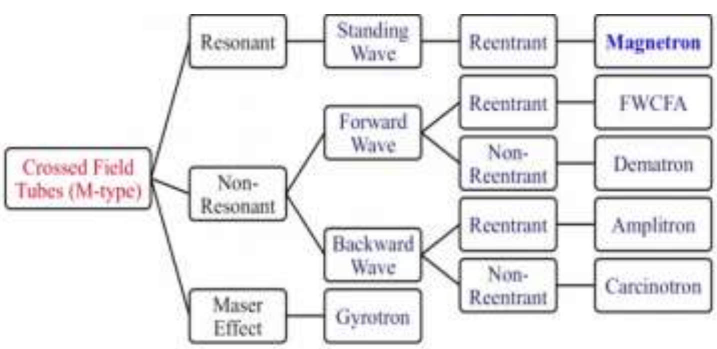
KLYSTRON AMPLIFIER

1. Resonant Cavities for input and output circuits .
2. Narrow band device
3. Higher efficiency
4. Frequency of operation up to 50GHz
5. Can handle power up to 2.5W
6. The interaction between electron beam and RF field occurs only at the gap of resonant cavities. Each cavity operates independently

TWT AMPLIFIER

1. Non resonant microwave circuit
2. Wideband device
3. Lower Efficiency
4. Frequency of operation up to 100GHz
5. Can handle continues power up to 200W
6. The interaction between electron beam and RF field is continues over the entire length of the circuit. TWT coupling exiting between the cavity.

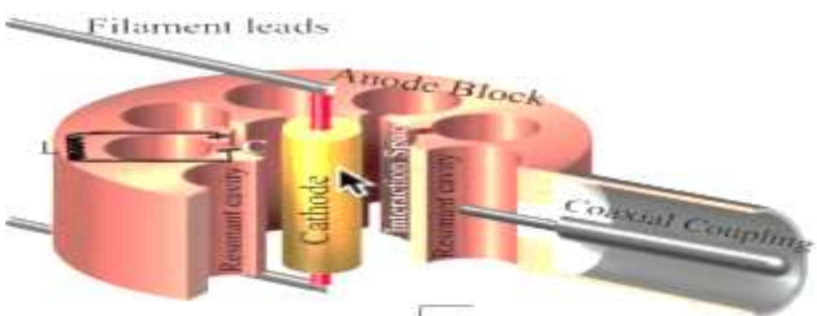
M –Type Microwave Tubes (Magnetron)



Magnetron Oscillator

1. Split Anode Magnetron – Static negative resistance Between two anode segments Below microwave region and low efficiency.
2. Cyclotron Frequency Magnetron - Synchronism between electric field and oscillation of electrons parallel to the field.Low output power and low efficiency
3. Travelling Wave Magnetron- Interaction of electrons with EM field . High Output Power,Cylindrical Magnetron,Co-axial Magnetron ,Inverted Coaxial Magnetron Linear/Planar Magnetron,Voltage Tunable Magnetron,Frequency Agile Magnetron

Multicavity /Cyclindrical Magnetron

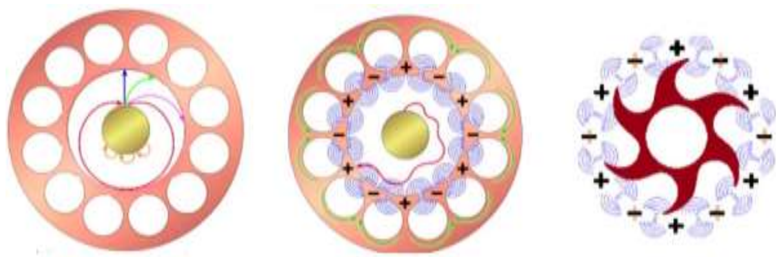


$$f_r = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$$

- ➢ Re-entrant Cavities - Connected to gaps.
- ➢ Cycloidal path of electrons –In cathode anode space and depends on
- DC Voltage :Hull Cut off Voltage Equation
- Magnetic Flux : Hull Cut of Magnetic Equation

Multi-Cavity Magnetron

- ➢ Magnetron Basic Operation
- Generation and acceleration of an electron beam in a dc field.
- Velocity Modulation of the electron beam in an ac field.
- Formation of electron bunches by velocity modulation (In form of space Charge wheel).
- Dispensing of energy to the AC Field.



A. a-Trajectory of an electron for different Magnetic Flux Densities.
B. b-The influence of high frequency electric field on trajectory of an electron.
C. Rotating Space Charge Wheel.
D. Positive voltage is given to this anode. And this is negative with respect to this anode. So, the electric field lines will be from positive to negative that is from anode to cathode radially inward. And the force on the electron will be F =q E.

E. Force on electron will be from cathode to anode radially outward. So, if there is no magnetic field then there will be only dc electric force from cathode to anode on electrons. So, all the electrons emitted from this cathode will move radially towards the anode like this blue line.

Weak magnetic field is applied, then the resultant force on the electron will be in this direction. So, electron will move in this path. Now, if we increase the magnetic field strength, then the path of electron will be bent more. Increase the magnetic field strength, then at one point there will be deflection of the electron from the anode and that will return to the cathode. And at this point of time, there will be no current in the tube. So, the strength of magnetic field, after which there is no current in the microwave tube it is called as cut off magnetic field and that is given by hull cut off magnetic equation. Similarly, the cut off dc voltage is given by hull cut off voltage equation. So, this is the effect of different magnetic flux densities on the path of electron beam. Effect of ac field on the path of electron beam. So, dc electric field is present from anode to cathode radially inward. One more thing if one cavity starts oscillating, then it excites the next cavity with the phase delay of 1800. And because of this there will be ac electric field in the cavity. And the overall electric field in this structure will be sum of dc electric field and the ac electric field. So, the electrons will move radially outwards from cathode to anode because of the dc electric field. Electron which moves towards the positive portion of the anode or the portion which is more positively charged those electrons will be accelerated and they will be deflected from this anode. And the electrons which move towards the less positively charged part of the anode those electrons will be decelerated and their energy will be transferred to the ac field present there. So, this is how the electron transfer their energy to the ac field present in the cavity. Space charge wheel formation, because of velocity modulation of electron by the fields present here, and the cumulative action of electrons going from cathode to anode and some electrons returning from anode to cathode. How oscillations are sustained in this structure. All the electrons which are emitted from this cathode get energy from the dc electric field some of those electron transfer their kinetic energy to the ac field present in the cavities. And those electrons help in sustaining the oscillations as they take energy from the dc fields and give up their energy to the ac fields. So, this is how the oscillations are sustained in multi-cavity magnetron.

Magnetron Specifications

- Frequency Range- 500MHz – 12GHz
- Power Output: Peak power output up to 40Mw, dc voltage 50Kv at 10GHz.
- Efficiency- 40-70%

Application of Magnetron

Magnetron Oscillators:

- Radar Transmitters
- Industrial Heating
- Microwave Oven

Standard Power = 600W

Frequency = 915MHz or 2450MHz

Numericals

Q- A Helical TWT has a circumference (of helix) to pitch ratio of 10. Determine the anode voltage for which the TWT can be operated for any useful gain.

Solution: For TWT to operate any useful gain the axial phase velocity of RF signal should approximately equal to the electron beam velocity.

Electron beam velocity

$$v_0 = \sqrt{\frac{2eV_0}{m}}$$

$$v_0 = \sqrt{\frac{2\times1.6\times10^{-19}\times V_0}{9.1\times10^{-31}}}$$

$$v_0 = 0.593\times 10^6\sqrt{V_0} \qquad - \quad \text{(a)}$$

Axial phase velocity of RF signal propagating in the slow wave structure is given by

Axial phase velocity $V_p \sim c\times \frac{\text{Pitch of helix}}{\text{circumference of helix}}$

$$V_p = 3\times 10^8 \times \frac{1}{10}$$

$$V_p = 3\times 10^7 \text{m/s} \qquad - \text{(b)}$$

From equation a & b

$$0.593\times 10^6\sqrt{V_0} = 3\times 10^7$$

$$V_o = \left(\frac{3\times10^7}{0.593\times10^6}\right)^2$$

$$V_0 = 2.56 \text{ KV}$$

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Q- A Helix travelling wave tube operates at 4GHz under a beam voltage V_0=6KV and beam current I_0= 30mA. If the helix impedance Z_0 is 100 ohm and circuit length N= 30 ,Find the output power gain .

Solution-

Given

Beam Voltage V_0= 6KV

Beam current I_0= 30mA

Circuit Impedance Z_0=100ohm

Circuit Length N=30

The Power gain of helix TWT in dB is given by

A_P = -9.54 +47.3NC dB

Where gain parameter C is given by

C= $\left(\frac{I_0 Z_0}{4V_0}\right)^{1/3}$ = 3.23× 10^{-2}

b) Output Power gain A_P is given by

A_P = -9.54 +47.3NC

= -9.54 +47.3×45×3.23× 10^{-2}

= 59.21dB

c) Phase constant of the velocity modulated electron beam β_e is $\frac{\omega}{V_0}$

Where v_0 is dc electron velocity ,equal to

$\sqrt{\frac{2e}{m}}V_0$ = 0.593× $10^6\sqrt{V_0}$

$\beta_e = \frac{\omega}{V_0} = \frac{2\pi\times 8\times 10^9}{0.593\times 10^6\ \sqrt{2.5\times 10^3}}$

= 1.69 × 10^3 rads/m

And four propagation constants are

γ_1 = -β_eC$\sqrt{\frac{3}{2}}$ + jβ_e (1+ $\frac{C}{2}$)

= -1.69 × 10^3 × 3.23× 10^{-2} × j1.69 × 10^3 × (1+1.61× 10^{-2})

γ_2 = β_eC$\sqrt{\frac{3}{2}}$ + jβ_e (1+ $\frac{C}{2}$)

= 47.49+j1717.2

γ_3 = jβ_e (1- C)

= j1.69 $\times$ 10^3(1-3.23 $\times$ 10^{-2})

γ_3 = j 1635.40

γ_4 = -jβ_e(1- $\frac{C^3}{4}$)

γ_4 = j1.69 $\times$ 10^3 $\left[1 - \frac{((3..23\times10^{-2})^2}{4}\right]$

γ_4 = -j1690

d) Forward wave with increasing amplitude is $e^{j\omega t-\gamma 1^Z}$,then wave equation for first mode

$= e^{j\omega t+47.49z-j1717.2z}$

$= e^{47.49z-e^{j(\omega t-1717.2z)}}$

Backward wave with increasing amplitude is $e^{j\omega t-\gamma 2^Z}$,then wave equation for 2nd mode

$= e^{j\omega t+47.49z-j1717.2z}$

$= e^{47.49z-e^{j(\omega t-1717.2z)}}$

Forward wave with increasing amplitude is $e^{j\omega t-\gamma 3^Z}$,then wave equation for 3rd mode

$= e^{j(\omega t-1635.4z)}$

Backward wave with increasing amplitude is $e^{j\omega t-\gamma 4^Z}$,then wave equation for 4th mode

$= e^{j(\omega t-1690z)}$.

Q- An X –band pulsed cylindrical magnetron has V_0 =300KV ,I_0= 80A, B_0= 0.01wb/m^2 ,a= 4cm, b= 8cm. Calculate

1) Cyclotron angular frequency
2) Cut-off voltage
3) Cut-off magnetic flux density

Solution-

1) Cyclotron angular frequency is given by

$$\omega = \frac{eB_0}{m}$$

$$\omega = \frac{1.6\times10^{-19}\times0.01}{9.1\times10^{-31}}$$

$$= 1.758\times 10^9 \text{rad/s}$$

2) Hull cut-off voltage is given by

$$V_c = \frac{e}{8m} {B_0}^2 b^2 \left(1 - \frac{a^2}{b^2}\right)^2$$

$$= 7.92V\ ans$$

3) Hull cut-off magnetic flux density

$$B_C = \frac{8\, V_0\, m/e^{1/2}}{b\left(1-\frac{a^2}{b^2}\right)}$$

$$= 19.468$$

Unit-VII
Microwave Design Principles

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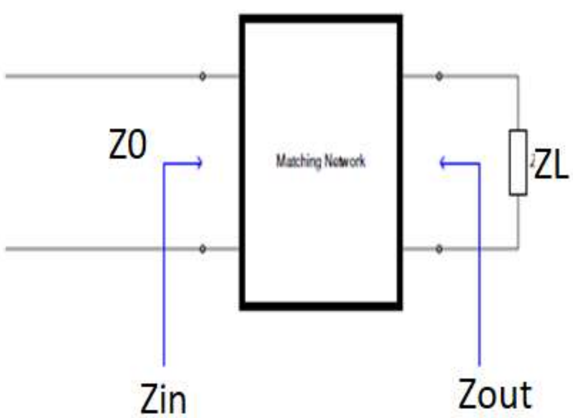
L-26
Microwave Design Principles: Impedance Transformation and Matching

Impedance matching

An impedance matching network is used between two dissimilar impedances in order to ensure maximum power transfer between them. We typically want to match an arbitrary load Z_L to a transmission line Z_0 The conditions for maximum power transfer are applicable here.

The need for Impedance Matching:
- In many applications we require Maximum Power Transfer into the load.
- This is achieved when the load to be matched to the line.
- An impedance matching network is required to present the optimum source impedance to the input of a low noise amplifier, in order to achieve minimum noise figure.



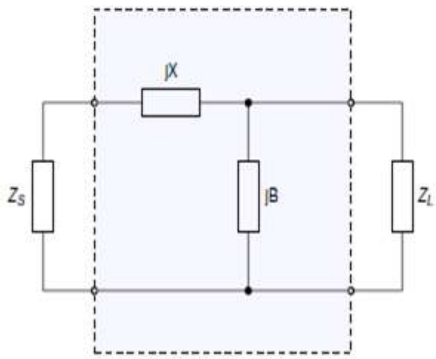
and

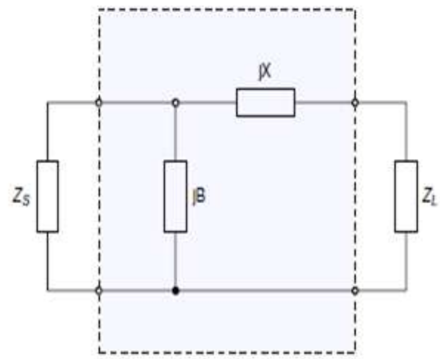
$$\boxed{Z_{in}^* = Z_o}$$

$$\boxed{Z_{out}^* = Z_L}$$

L section matching network

- This is the simplest lumped component matching network, consisting of only two lumped components : a shunt susceptance, jB, and a series reactance, jX.
- There are two basic configurations of L-Section matching network, depending on the location of the shunt element. We shall refer to these as 'type 1' and 'type 2'





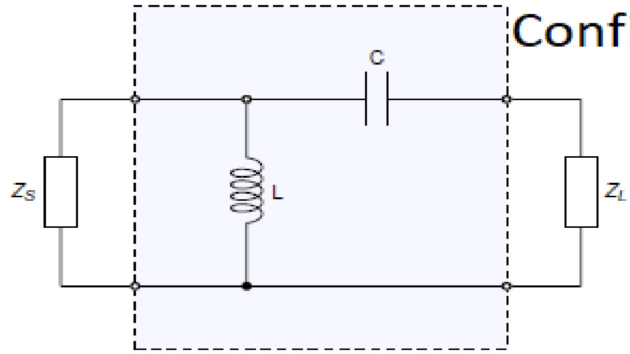
High Pass configuration:

- When the series component is a capacitor, it will block DC into the load. The shunt inductor will act as a short at low frequencies.

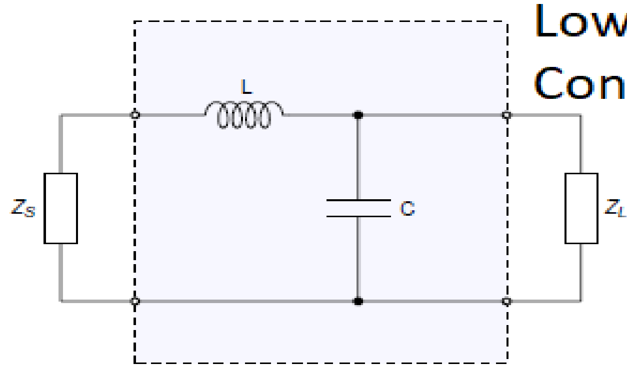
Low Pass configuration :

- When the series component is an inductor, it will allow DC into the load, but will attenuate higher frequencies. The shunt capacitor will act as a short at high frequencies.

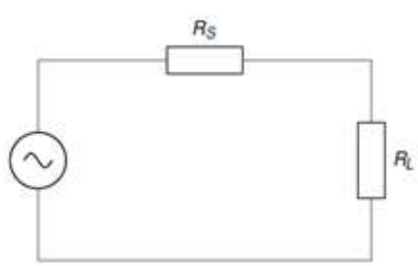
High pass Confiugration

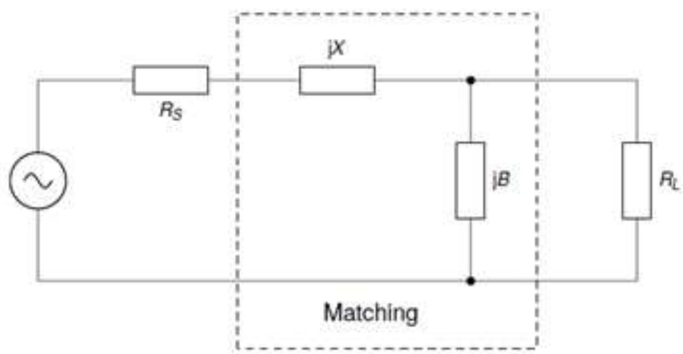


Low pass Confiugration



Let us assume that we need to connect a resistive load *RL* to a resistive source *RS*,, in the general case, *RS* is not equal to *RL*.





We need to place a matching network between *RS* and *RL*, to ensure that the source is terminated by an impedance equal to itself, thereby ensuring maximum power transfer.

Since we restrict ourselves to using only reactive elements in the matching network, the matching of the two resistive elements proceeds as follows :

- Firstly, we place a reactive element, represented by the susceptance *jB*, in parallel with *RL*, such that the resistive part of the resulting combination is equal to *RS*.
- Secondly, We then cancel the reactive part of the combination (*jB parallel to RL*) by adding the equal and opposite series reactive element *jX*.

We can analyze the circuit as follows:
the total impedance of the parallel combination (*jB* and *RL*) should be the complex conjugate of *RS* + *jX*, we can write

$$R_s + jX = \frac{1}{\left(\left(\frac{1}{R_L}\right) - jB\right)}$$
$$= \frac{R_L + jBR_L^2}{1 + B^2R_L^2}$$
$$R_s = \frac{R_L}{1 + B^2R_L^2}$$
$$X = \frac{BR_L^2}{1 + B^2R_L^2}$$

We need to match the complex load *ZL* to the system characteristic impedance, *Zo*.
As before, the choice of whether to use a type 1 or type 2 matching network will depend on the relationship between the resistive part of the load, *RL*, and *Zo*.
As was shown for the case of purely resistive loads, the parallel element, *jB*, should be placed in parallel with whichever is larger of *RL* or *Zo*, in other words :

- If *RL* > *Zo* : use type 1 L-section (shunt element is next to the load).
- If *RL* < *Zo* : use type 2 L-section (shunt element is next to the source).

l-27
Smith chart solutions, Single stub Tuning in microwave circuits

Smith chart Solutions

The Smith chart is plotted on the complex reflection coefficient plane in two dimensions and is scaled in normalised impedance (the most common), normalised admittance or both, using different colours to distinguish between them. These are often known as the Z, Y and YZ Smith charts respectively. Normalized scaling allows the Smith chart to be used for problems involving any characteristic or system impedance which is represented by the center point of the chart. The most commonly used normalization impedance is 50 ohms. Once an answer is obtained through the graphical constructions described below, it is straightforward to convert between normalised impedance (or normalized admittance) and the corresponding unnormalized value by multiplying by the characteristic impedance (admittance). Reflection coefficients can be read directly from the chart as they are unitless parameters.

The Smith chart has circumferential scaling in wavelengths and degrees. The wavelengths scale is used in distributed component problems and represents the distance measured along the transmission line connected between the generator or source and the load to the point under consideration. The degrees scale represents the angle of the voltage reflection coefficient at that point. The Smith chart may also be used for lumped element matching and analysis problems.

Use of the Smith chart and the interpretation of the results obtained using it requires a good understanding of AC circuit theory and transmission line theory, both of which are pre-requisites for RF engineers.

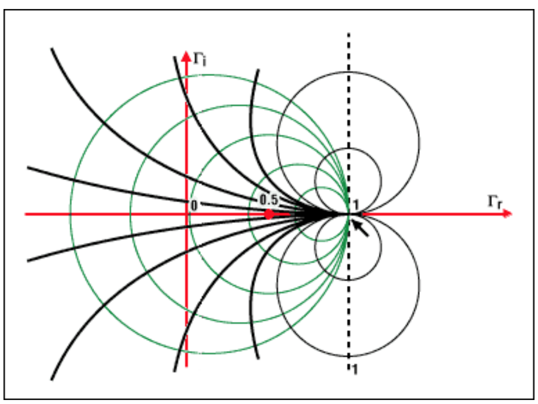
As impedances and admittances change with frequency, problems using the Smith chart can only be solved manually using one frequency at a time, the result being represented by a point. This is often adequate for narrow band applications (typically up to about 5% to 10% bandwidth) but for wider bandwidths it is usually necessary to apply Smith chart techniques at more than one frequency across the operating frequency band.

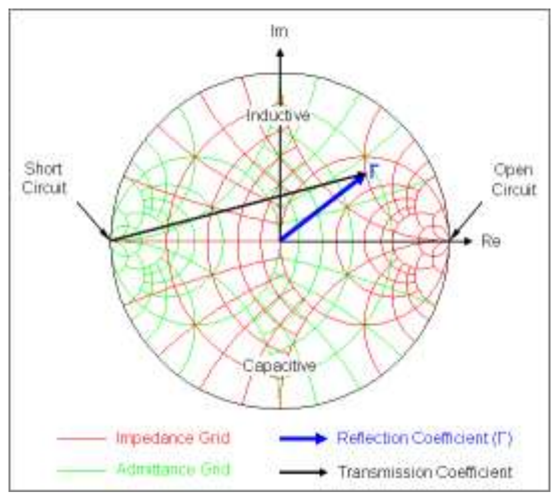
Provided the frequencies are sufficiently close, the resulting Smith chart points may be joined by straight lines to create a locus.

A locus of points on a Smith chart covering a range of frequencies can be used to visually represent:

- how capacitive or how inductive a load is across the frequency range
- how difficult matching is likely to be at various frequencies
- how well matched a particular component is.

The accuracy of the Smith chart is reduced for problems involving a large locus of impedances or admittances, although the scaling can be magnified for individual areas to accommodate these.



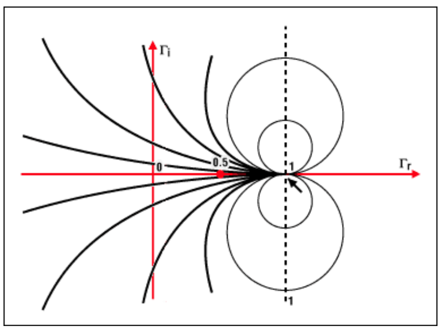


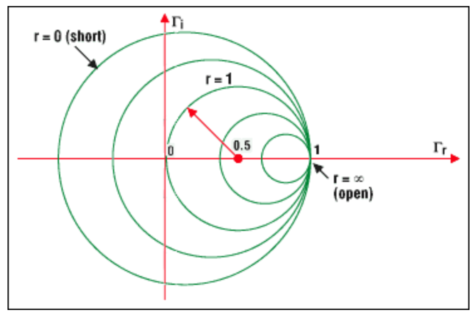
Fundamentals of impedance and the Smith chart. It is well known that, to get the maximum power transfer from a source to a load, the source impedance must equal the complex conjugate of the load impedance, or:

$R_S + jX_S = R_L - jX_L$

For this condition, the energy transferred from the source to the load is maximized. In addition, for efficient power transfer, this condition is required to avoid the reflection of energy from the load back to the source. This is particularly true for high-frequency environments like video lines and RF and microwave networks.

A Smith chart is a circular plot with a lot of interlaced circles on it. When used correctly, matching impedances, with apparent complicated structures, can be made without any computation. The only effort required is the reading and following of values along the circles.The Smith chart is a polar plot of the complex reflection coefficient (also called gamma and symbolized by Γ). Or, it is defined mathematically as the 1-port scattering parameter s or s_{11}.





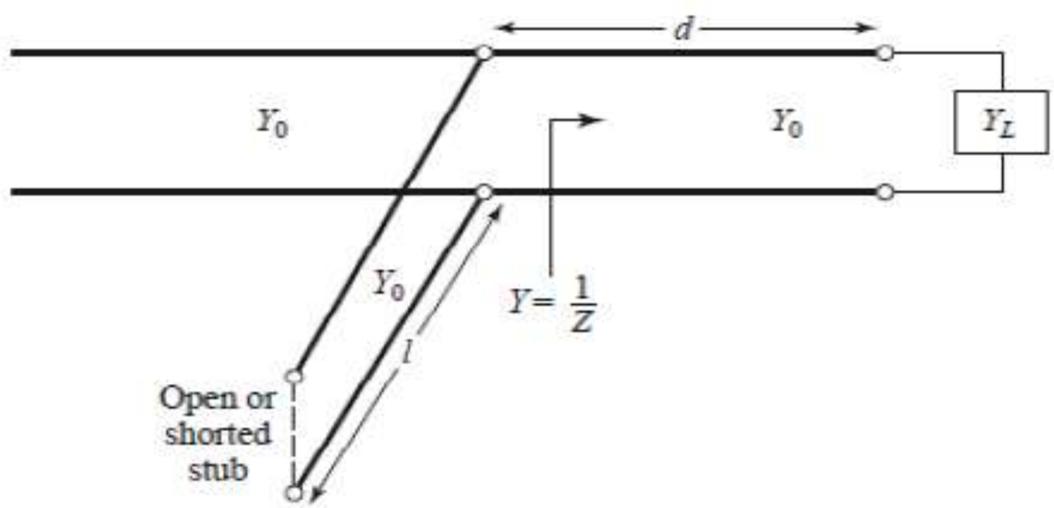
The points situated on a circle are all the impedances characterized by a same real impedance part value. For example, the circle, r = 1, is centered at the coordinates (0.5, 0) and has a radius of 0.5. It includes the point (0, 0), which is the reflection zero point (the load is matched with the characteristic impedance). A short circuit, as a load, presents a circle centered at the coordinate (0, 0) and has a radius of 1. For an open-circuit load, the circle degenerates to a single point (centered at 1, 0 and with a radius of 0). This corresponds to a maximum reflection coefficient of 1, at which the entire incident wave is reflected totally.
When developing the Smith chart, there are certain precautions that should be noted. These are among the most important:

- All the circles have one same, unique intersecting point at the coordinate (1, 0).
- The zero Ω circle where there is no resistance (r = 0) is the largest one.
- The infinite resistor circle is reduced to one point at (1, 0).
- There should be no negative resistance. If one (or more) should occur, we will be faced with the possibility of oscillatory conditions.
- Another resistance value can be chosen by simply selecting another circle corresponding to the new value.

Single stub tuning circuit is convenient because the stubs can be fabricated as a part of transmission line media of the circuit, and lumped elements are avoided.
Shunt stubs are preferred for microstrip line or stripline.
For lines like coax or waveguide, short-circuited stubs are preferred because the cross-sectional area of open-circuited line may be large enough (electrically) to radiate, in which case the stub is no longer purely reactive.

Numerical

Design a single stub shunt tuning network to match a 50 ohm transmission line to a load impedance 60-j80 ohm (resistor and capacitor in series) at 2GHz. The substrate given is FR4 with the following specifications: dielectric constant (er= 4.5), height of the substrate (h=1.6mm), thickness of the conductor (copper, t=.035mm), Loss tangent of the dielectric material (tan delta = 0.002)

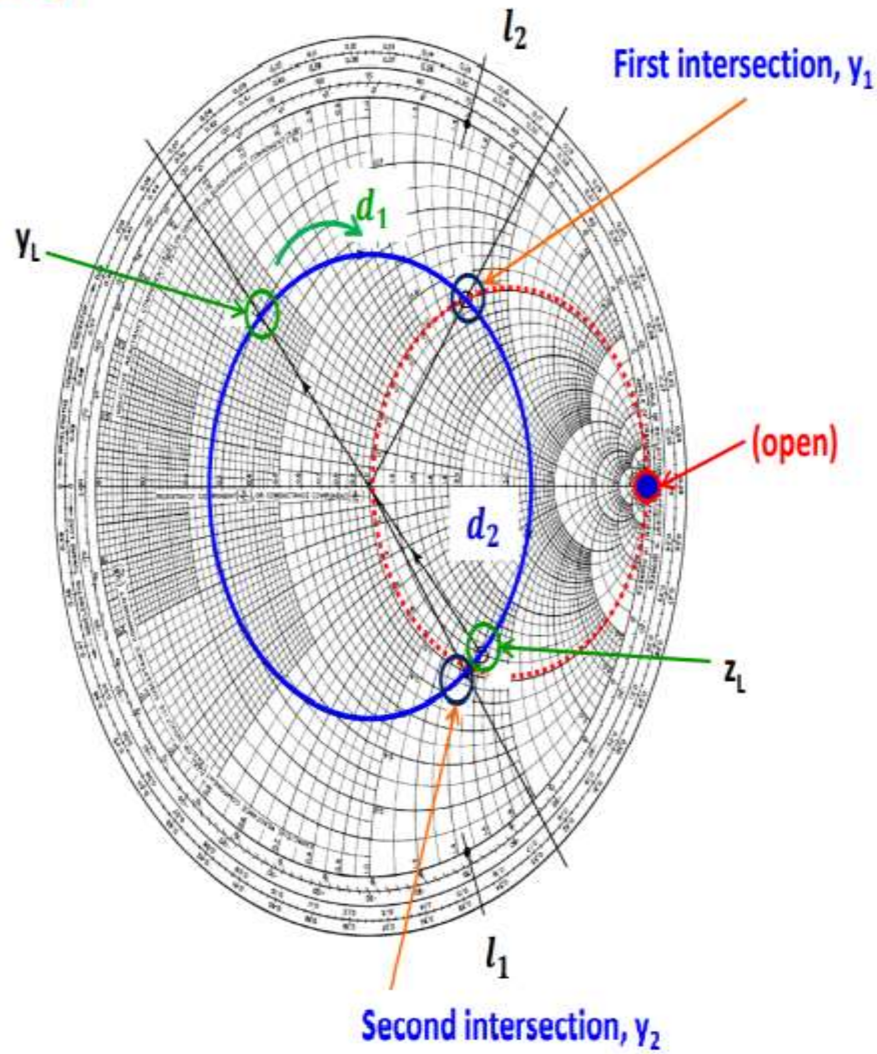


Example – 1 (contd.)

Solution

y_L to y_1 towards generator (clockwise) gives length d_1 (first solution)

y_L to y_2 towards generator (clockwise) gives length d_2 (second solution)



SMITH CHART:

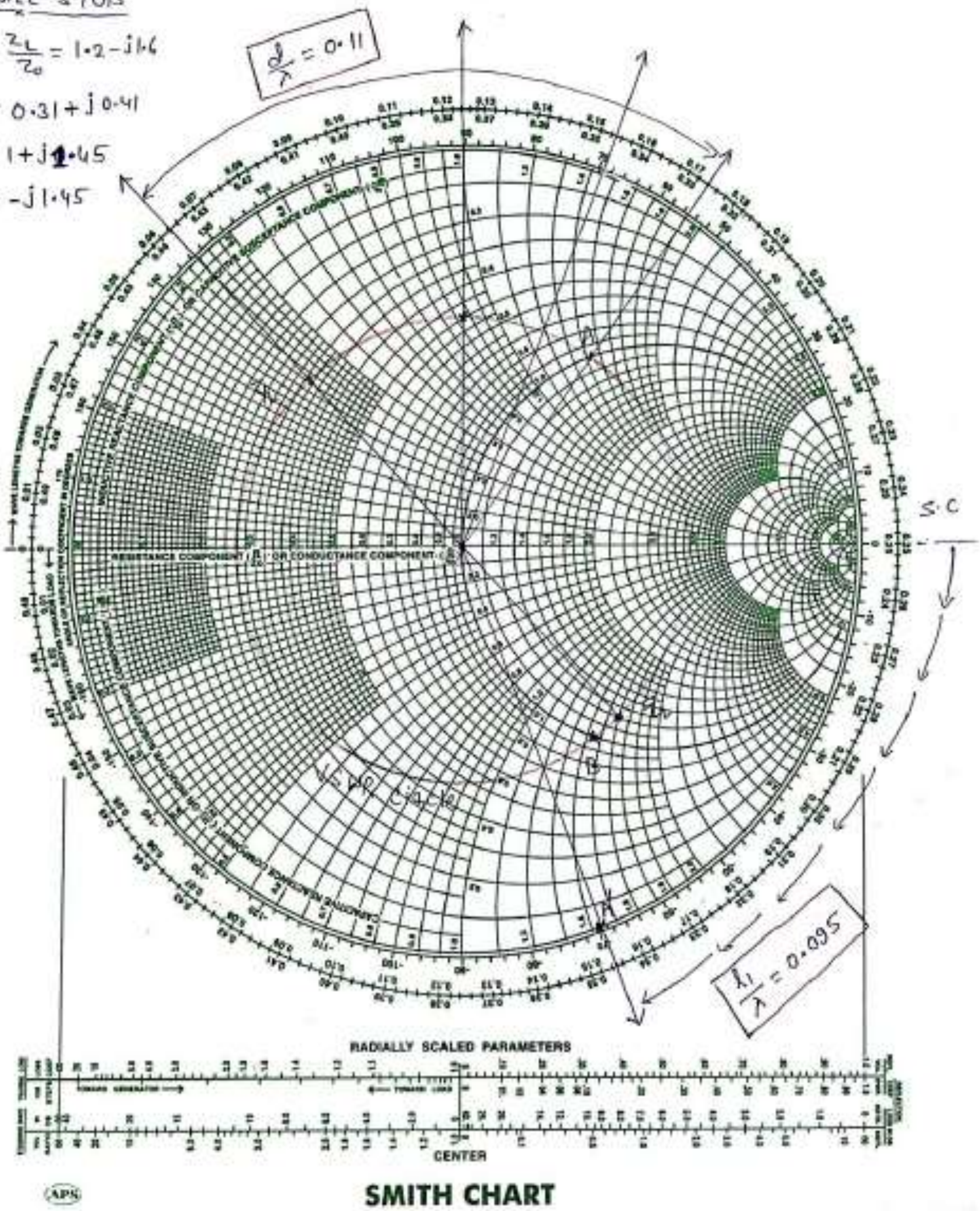
SINGLE STUB

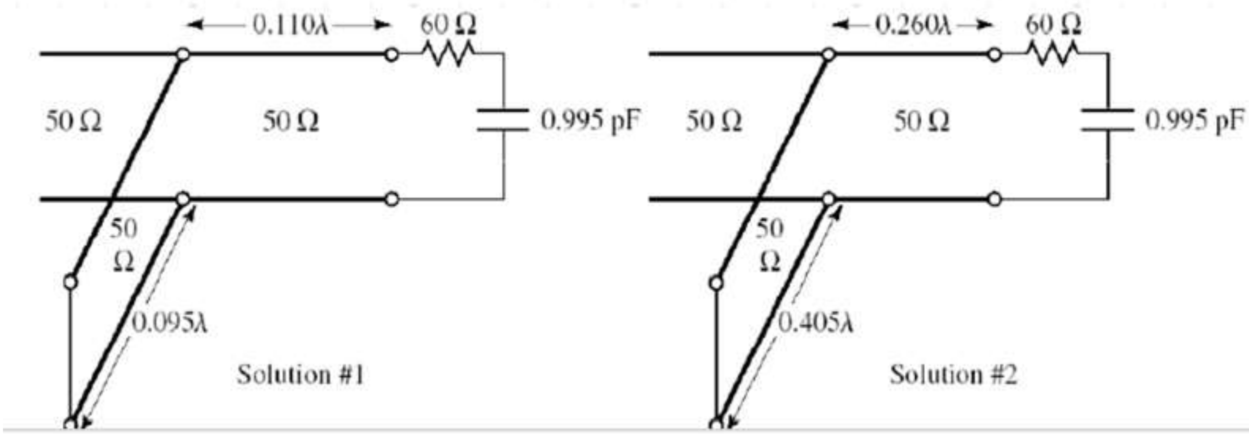
$\tilde{z}_L = \frac{z_L}{z_0} = 1.2 - j1.6$

$\tilde{Y}_L = 0.31 + j0.41$

$A = 1 + j1.45$

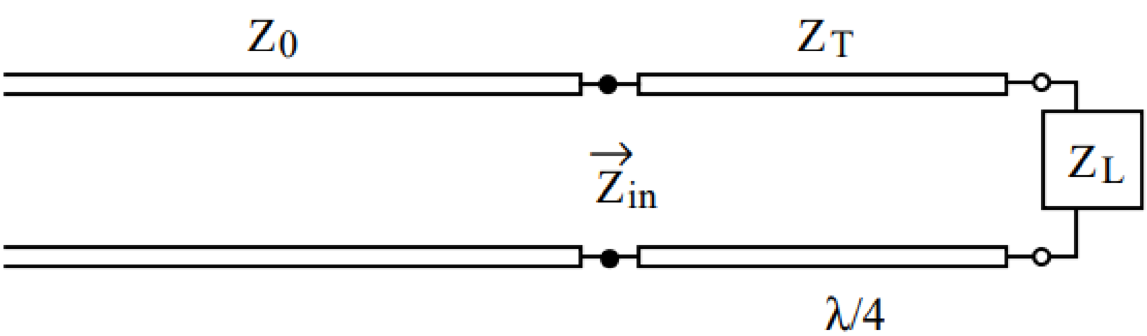
$A' = -j1.45$





Quarter wave matching

The quarter-wave transformer is simply a transmission line with characteristic impedance Z1 and length A = λ/ 4 (i.e., a quarter wave line).



$$Z_{in} = Z_T \frac{Z_L + jZ_T \tan(\beta l)}{Z_0 + jZ_L \tan(\beta l)}$$

l= λ/ 4 ,

$$Z_{in} = \frac{Z_T \,.\, Z_T}{Z_L}$$

$$Z_T = \sqrt{Z_{in}.Z_L}$$

L-28

Microwave filter designing and numerical

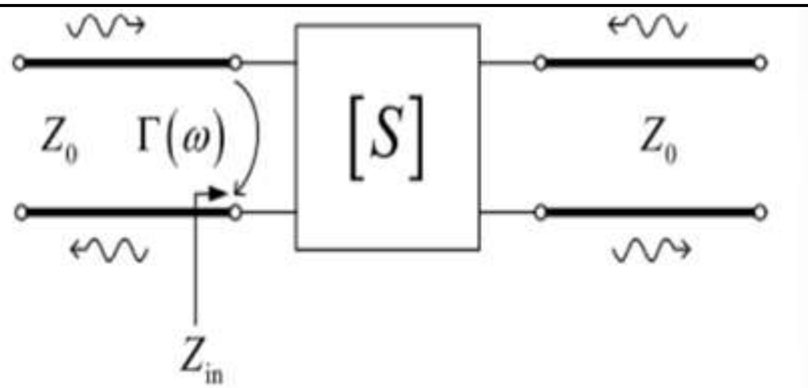
A filter is a two-port network used to control the frequency response at a certain point in an RF or microwave system by providing transmission at frequencies within the pass band of the filter and attenuation in the stop band of the filter.
Typical frequency responses include low-pass, high-pass, band pass, and band-reject characteristics.
Applications can be found in virtually any type of RF or microwave communication, radar, or test and measurement system.

The image parameter method of filter design was developed in the late 1930s and was useful for low-frequency filters in radio and telephony.
Filters designed using the image parameter method consist of a cascade of simpler two port filter sections to provide the desired cutoff frequencies and attenuation characteristics but do not allow the specification of a particular frequency response over the complete operating range.
The insertion loss method, uses network synthesis techniques to design filters with a completely specified frequency response.
The design is simplified by beginning with low-pass filter prototypes that are normalized in terms of impedance and frequency.
Transformations are then applied to convert the prototype designs to the desired frequency range and impedance level.

Insertion loss method

In this technique, the relative power loss due to a lossless filter with reflection coefficient $\Gamma(\omega)$ is specified in the power loss ratio PLR defined as:

$$P_{LR} = \frac{P_{in}}{P_{load}} = \frac{P_{in}}{P_{in}(1 - \Gamma(\omega))^2}$$



Butterworth filter

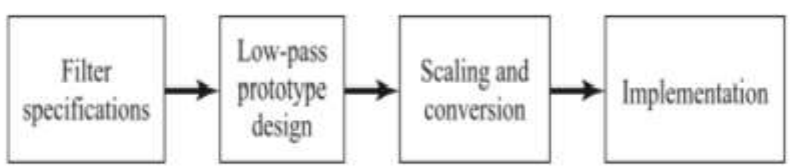
The Analog butterworth filter is designed by approximating the ideal analog filter frequency response $H(e^{j\omega})$ using an error function. The error function is selected such that the magnitude is maximally flat in the pass band and monotonically decreasing in the stop band.

- The butterworth filter is all pole designs.
- At the cutoff frequency $\Omega_c$the magnitude of normalized Butterworth filter is $\frac{1}{\sqrt{2}}$.
- The filter order N completely specifies the filter.
- The magnitude is maximally flat at the origin.
- The magnitude is a monotonically decreasing function.

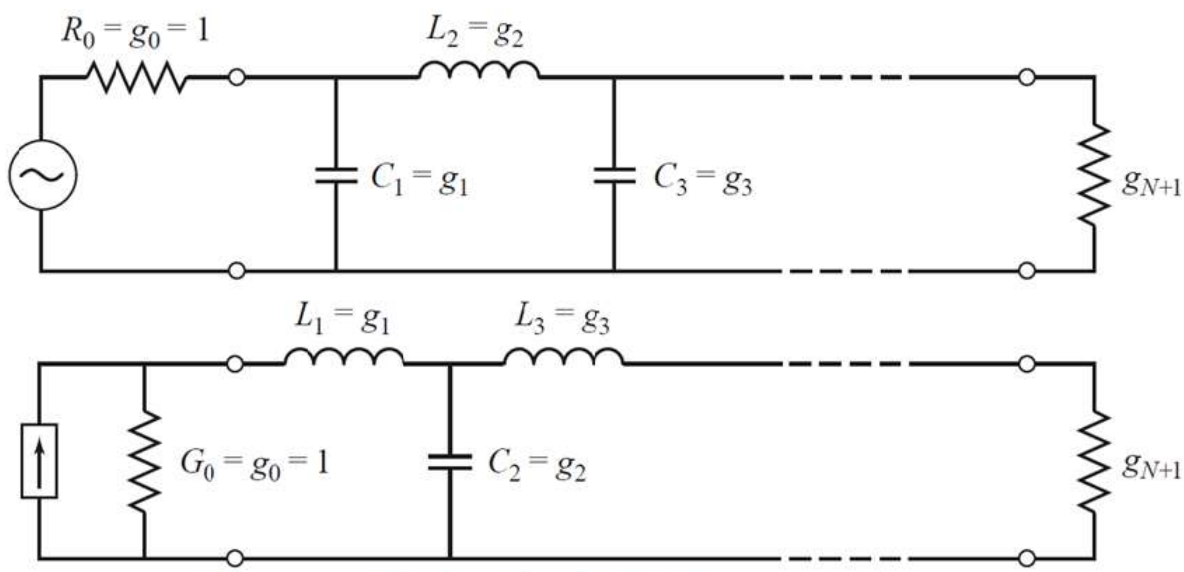
General Procedure for Filter Design

- The general procedure for designing a filter using the insertion loss method can be summarized in three steps

1. Filter specifications. These include the cutoff frequency, the stop-band attenuation, the pass-band insertion loss, the pass-band behavior, etc.
2. Design a "low pass **prototype**" circuit. In such a prototype, $R = 1\ \Omega$ and $\omega_c = 1$ rad/s. Filter tables are used for this step, or perhaps a computer package.
3. Scale and conversion. Finally, the filter is scaled to the proper impedance level and, if desired, to a high pass, band pass, or band stop topology.



Lumped Element Realization of LPF



Normalized prototype elements

- $g_k = 2Sin\left(\frac{(2k-1)\pi}{2n}\right)$
- k=1,2,3….n
- n is the order of filter
- $g_0 = g_{n+1}$ =1

Element values for Maximally flat LPF

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	2.0000	1.0000									
2	1.4142	1.4142	1.0000								
3	1.0000	2.0000	1.0000	1.0000							
4	0.7654	1.8478	1.8478	0.7654	1.0000						
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000					
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000				
7	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450	1.0000			
8	0.3902	1.1111	1.6629	1.9615	1.9615	1.6629	1.1111	0.3902	1.0000		
9	0.3473	1.0000	1.5321	1.8794	2.0000	1.8794	1.5321	1.0000	0.3473	1.0000	
10	0.3129	0.9080	1.4142	1.7820	1.9754	1.9754	1.7820	1.4142	0.9080	0.3129	1.0000

Practice Problem

Calculate inductance and capacitance values for a maximally flat LPF that has a 3dB bandwidth of 400MHz and attenuation of 20 dB at 1 GHz. The filter is to be connected to 50 ohm source and load impedances.

Solution:

Number of elements required:

$$n = \frac{\log_{10}\left(10^{A/10} - 1\right)}{2\log_{10}(\omega_1/\omega_c)}$$

$$= \frac{\log_{10}\left(10^{20/10} - 1\right)}{2\log_{10}(1000/400)} = 2.51$$

Choose n = 3

Prototype Values:

$$g_0 = g_{3+1} = 1$$

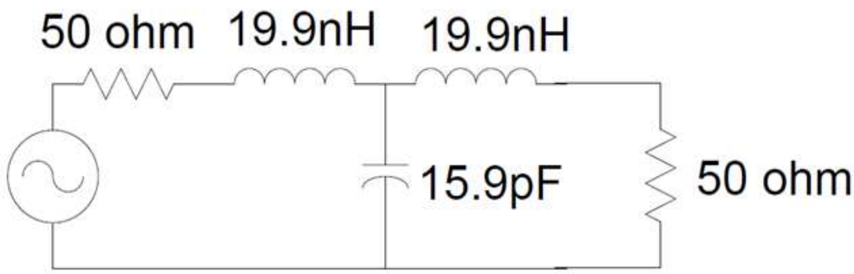
$$g_1 = 2\sin\left[\frac{(2-1)\pi}{2\times 3}\right] = 1$$

$$g_2 = 2\sin\left[\frac{(2\times 2-1)\pi}{2\times 3}\right] = 2$$

$$g_3 = 2\sin\left[\frac{(2\times 3-1)\pi}{2\times 3}\right] = 1$$

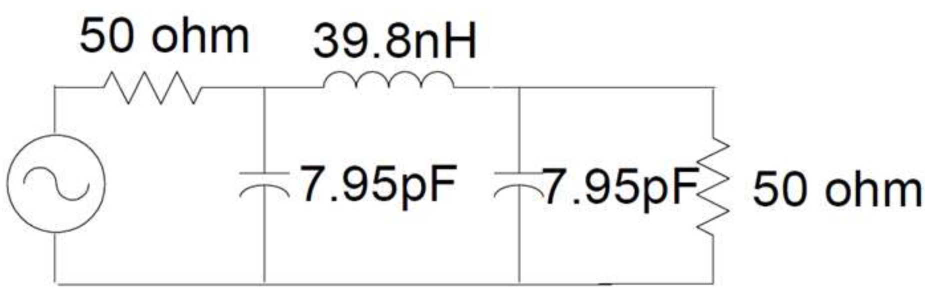
$$L_3 = L_1 = \frac{Z_o g_1}{\omega_c} = \frac{50 \times 1}{2 \times \pi \times 400 \times 10^6} = 19.9\text{nH}$$

$$C_2 = \frac{g_2}{Z_o \omega_c} = \frac{2}{50 \times 2 \times \pi \times 400 \times 10^6} = 15.9\text{pF}$$



$$C_3 = C_1 = \frac{g_1}{Z_o \omega_c} = \frac{1}{50 \times 2 \times \pi \times 400 \times 10^6} = 7.95\text{pF}$$

$$L_2 = \frac{Z_o g_2}{\omega_c} = \frac{50 \times 2}{2 \times \pi \times 400 \times 10^6} = 39.8\text{nH}$$

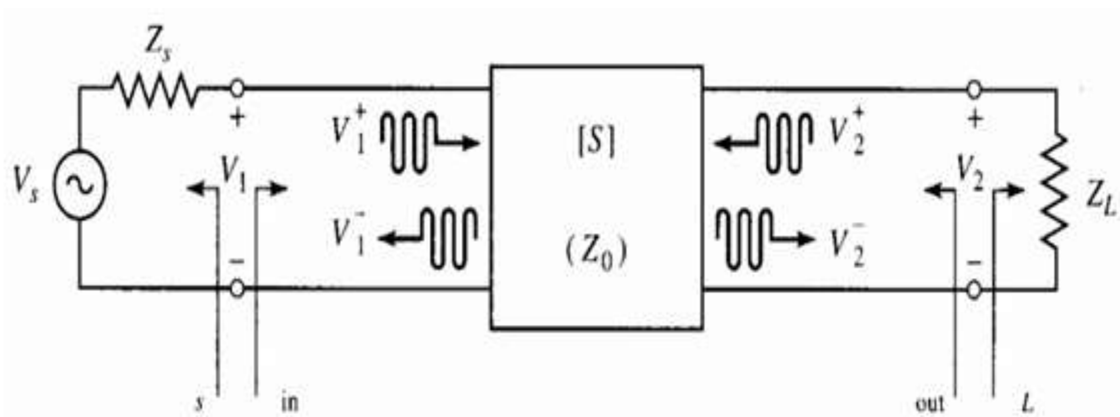


L-29
Microwave Amplifier design, Power amplifier, LNA design and Numerical

The gain and stability of a general two port amplifier in terms of parameters of transistor will be analyzed. The three types of power gains in Microwave amplifier are:

- Power Gain $G = \frac{P_L}{P_{in}}$
- Available Gain $G_A = \frac{P_{avn}}{P_{avs}}$
- Transducer Gain $G_T = \frac{P_L}{P_{avs}}$

- P_L= Power dissipated in load ZL
- P_{in}= Power delivered to input
- P_{avs}=Power available from source



We define source and load reflection coefficients as

- $T_L = \frac{Z_L - Z_0}{Z_L + Z_0}$
- $T_S = \frac{Z_S - Z_0}{Z_S + Z_0}$

$$V_2^+ = T_L V_2^-$$

The S parameter equations are

- $V_1^- = S_{11}V_1^+ + S_{12}V_2^+$
- $V_2^- = S_{21}V_1^+ + S_{22}V_2^+$

Now we substitute

$$V_2^+ = T_L V_2^-$$

$$T_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12}S_{21}\,T_L}{1 - S_{22}\,T_L} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

- Zin is impedance seen looking into port 1 of the terminated network
- Similarly, reflection coefficient seen looking from port 2 of network when port 1 is terminated by Zs

$$T_{out} = \frac{V_2^-}{V_2^+} = S_{22} + \frac{S_{12}S_{21}\,T_S}{1 - S_{11}\,T_S}$$

On further solving using voltage division

- $V_1^+ = \frac{V_S\,(1-T_S)}{2\,(1-T_S T_{in})}$
-

If peak values are assumed for all voltages, the average power delivered to network will be

$$P_{in} = \frac{|V_S|^2\ |1 - T_S|^2(1 - |T_{in}|^2)}{8\,Z_0|1 - T_S\,T_{in}|^2}$$

The power delivered to the load will be

- $P_L = \frac{|V_S|^2\ |S_{21}|^2\ |1-T_S|^2(1-|T_L|^2)}{8\,Z_0\left|1-T_S\,T_{in}\right|^2\left|1-S_{22}\,T_L\right|^2}$
-

Power Gain is then expressed as

Power Gain $G = \frac{P_L}{P_{in}}$

- $G = \frac{|S_{21}|^2\ (1-|T_L|^2)}{(1-|T_{in}|^2)\left|1-S_{22}\ T_L\right|^2}$

The power available from the source, Pavs, is the maximum power that can be delivered to the network. This occurs when the input impedance of the terminated network is conjugately matched to the source impedance

P_{avs}=P_{in}(T_{in}=T_s⋆)

- $P_{avs} = \frac{|V_S|^2\ |1-T_S|^2}{8\ Z_0(1-|T_s|^2)}$

Similarly,

P_{avn}=P_L(T_L=T_{out}⋆)

- $P_{avn} = \frac{|V_S|^2\ |S_{21}|^2\ |1-T_S|^2}{8\ Z_0\left|1-S_{11}\ T_S\right|^2(1-|T_{out}|^2)}$

$$\text{Available Gain } G_A = \frac{P_{avn}}{P_{avs}}$$

- $G_A = \frac{|S_{21}|^2\ (1-|T_S|^2)}{\left|1-S_{11}\ T_S\right|^2(1-|T_{out}|^2)}$

Transducer Gain $G_T = \frac{P_L}{P_{avs}}$

$$G_T = \frac{|S_{21}|^2\ (1-|T_L|^2)(1-|T_s|^2)}{|1-T_S\ T_{in}|^2|1-S_{22}\ T_L|^2}$$

Numerical

A silicon bipolar junction transistor has the following scattering parameters at 1.0 GHz, with a 50 ohm reference impedance. The source impedance is Zs = 25 ohm and the load impedance is ZL = 40 ohm
Compute the power gain, the available power gain, and the transducer power gain.

- S_{11}=0.38∠-158

- S_{12}=0.11∠54
- S_{21}=3.5∠80
- S_{22}=0.4∠-43

Solution

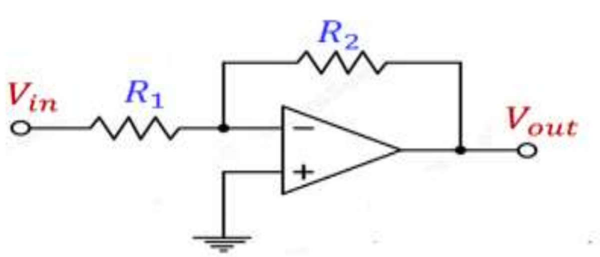
- $T_L = \frac{Z_L - Z_0}{Z_L + Z_0}$=-0.111
- $T_S = \frac{Z_S - Z_0}{Z_S + Z_0}$=-0.3333
- $T_{in} = S_{11} + \frac{S_{12}S_{21}\,T_L}{1-S_{22}\,T_L} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$=0.365∠-152
- $T_{out} = S_{22} + \frac{S_{12}S_{21}\,T_S}{1-S_{11}\,T_S}$=0.545∠-43
- $G = \frac{|S_{21}|^2\ (1-|T_L|^2)}{(1-|T_{in}|^2)\left|1-S_{22}\,T_L\right|^2}$=13.1

- $G_A = \frac{|S_{21}|^2\ (1-|T_S|^2)}{\left|1-S_{11}\,T_S\right|^2(1-|T_{out}|^2)}$=19.8
- $G_T = \frac{|S_{21}|^2\ (1-|T_L|^2)(1-|T_S|^2)}{\left|1-T_S\,T_{in}\right|^2\left|1-S_{22}\,T_L\right|^2}$=12.6

Microwave Amplifiers

Inverting Amplifier Using Op-Amp 741

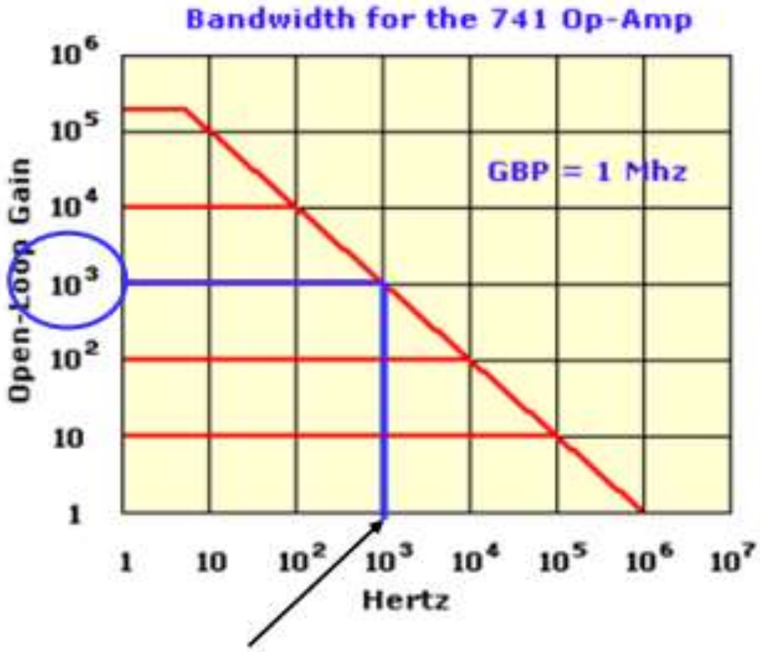
Design an inverting Amplifier for a gain of 1000(60dB)



Gain = $\frac{-R_2}{R_1}$

R_1 =? R_2 =?

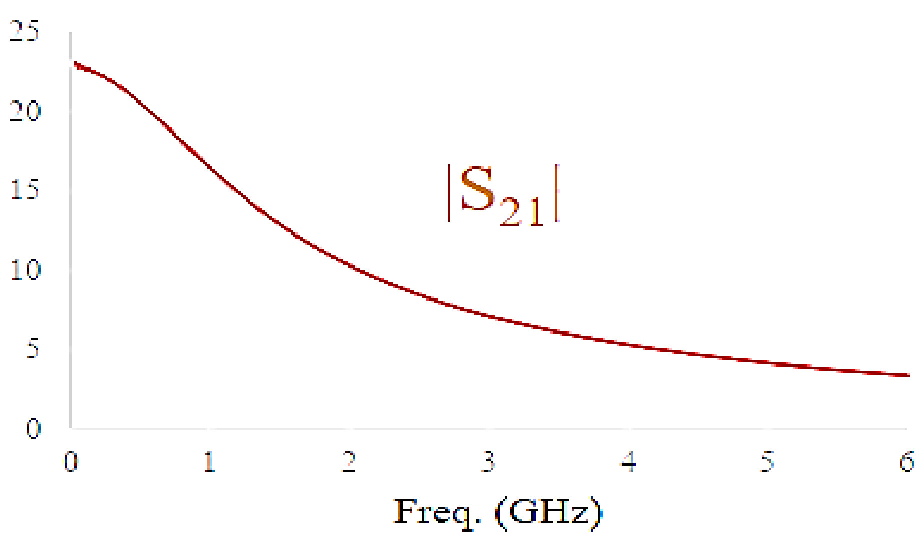
R_1	R_2
1Ω	1KΩ
10Ω	10 KΩ
100Ω	100 KΩ
1KΩ	1 MΩ



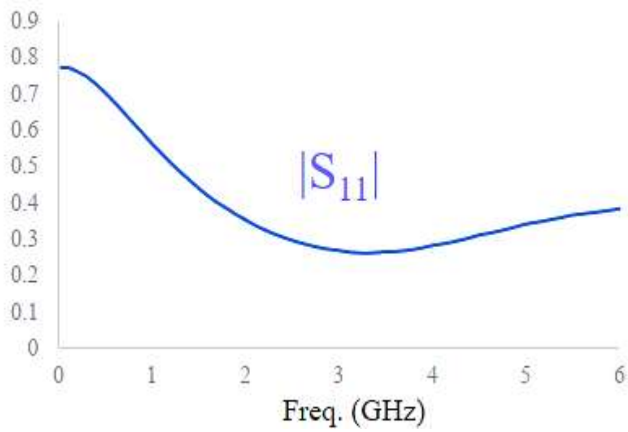
BFP520 Transistor S-Parameters

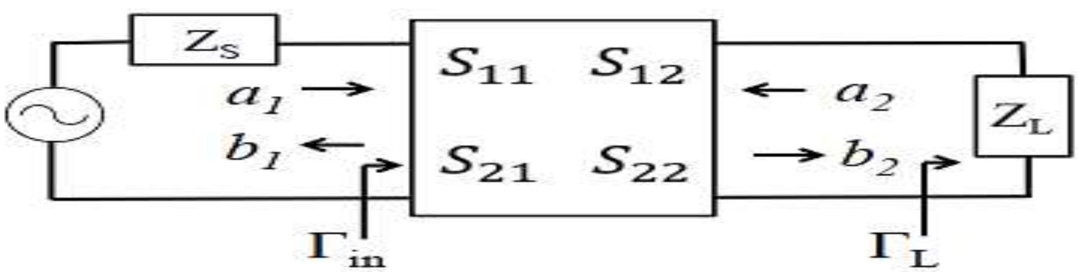
BFP520: Low Noise Si Bipolar Transistor

Biasing : V_{CE} = 2V , I_C= 10mA



Derivation of Γ_{in} of a Device Amplifier





S – Parameters:

$b_1 = S_{11}a_1 + S_{12}a_2$ ---------- (1)

$b_2 = S_{21}a_1 + S_{22}a_2$ ---------- (2)

$b_2 = S_{21}a_1 + S_{22}.\Gamma_L b_2$

$\Gamma_L = \frac{a_2}{b_2} = a_2 = \Gamma_L b_2$ ----------(3)

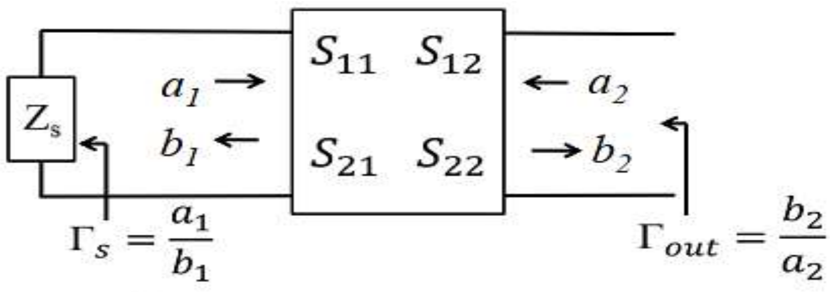
$b_2 = \frac{S_{21}a_1}{1-S_{22}\Gamma_L}$ ----------(4)

From (1) using (3) & (4)

$$\Gamma_{in} = \frac{b_1}{a_1} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L}$$

$$\Gamma_{in} = \frac{S_{11}-\Delta.\Gamma_L}{1-S_{22}\,\Gamma_L}$$

Where $\Delta = S_{11}S_{22} - S_{12}S_{21}$



S – Parameters:

$$b_1 = S_{11\,a_1} + S_{12a_2}$$

$$b_2 = S_{21}a_1 + S_{22}a_2$$

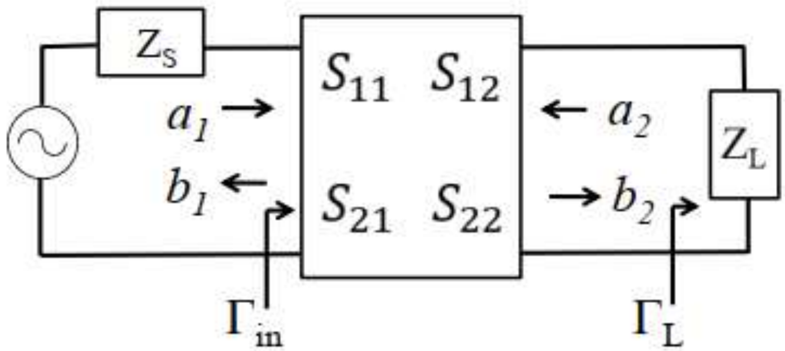
$$\Gamma_s = \frac{a_1}{b_1} = a_1 = \Gamma_s b_1$$

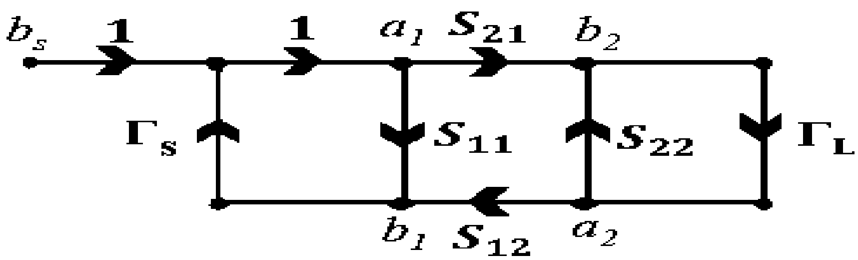
$$b_1 = S_{11}\,\Gamma_s\,b_1 + S_{12a_2}$$

$$b_1 = \frac{S_{12a_2}}{1-S_{11}\Gamma_s}$$

$$\Gamma_{out} = \frac{b_2}{a_2} = S_{22} + \frac{S_{22}-\Delta.\Gamma_s}{1-S_{11}\,\Gamma_s}$$

Gain using Mason's Signal Flow rules





S–Parameters:

$b_1 = S_{11}a_1 + S_{12}a_2$

$b_2 = S_{21}a_1 + S_{22}a_2$

$\Gamma_s = \frac{a_1}{b_1} = a_1 = \Gamma_s b_1$

$b_1 = S_{11}\Gamma_s b_1 + S_{12}a_2$

$b_1 = \frac{S_{12}a_2}{1-S_{11}\Gamma_s}$

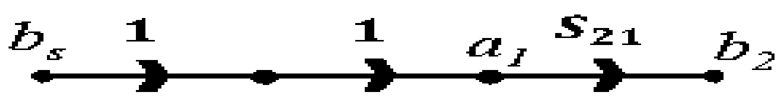
$\Gamma_{out} = \frac{b_2}{a_2} = S_{22} + \frac{S_{22}-\Delta.\Gamma_s}{1-S_{11}\Gamma_s}$

$a_2 = \Gamma_L b_2$
$a_1 = \Gamma_s b_1 + b_s$
$\Gamma_s = \frac{a_1}{b_1}$, if $b_s = 0$

$$\text{Transfer fun.} = \frac{P_1\left[1-\sum L(1)^1 + \sum L(2)^1 - \sum L(3)^1 - \cdots\right] + P_2\left[1-\sum L(1)^2 + \sum L(2)^2 - \sum L(3)^2 - \cdots\right]}{1-\sum L(1)+\sum L(2)-\sum L(3)}$$

$\sum L(1)$, $\sum L(2)$..=sum of all 1^{st} order,2^{nd}order loops
$\sum L(1)^1$, $\sum L(2)^1$ …= sum of all 1^{st} order,2^{nd}order loops that do not touch path P_1
$\sum L(1)^2$, $\sum L(2)^2$ …= sum of all 1^{st} order,2^{nd}order loops that do not touch path P_2

Path from b_s to b_2



$P_1 = S_{21}$ $P_2 = 0$

1) **Path: No node is touched more than once** $P_1 = S_{21}$
2) **First order loop: Three first order loops** $(S_{11}\Gamma_s)$,$(S_{22}\Gamma_L)$ $(S_{21}\Gamma_L S_{12}\Gamma_s)$
3) **Second order loop: Product of any two non-touching loops**
$(S_{11}\Gamma_s)$,$(S_{22}\Gamma_L)$

4) Third order loop : Product of any three non- touching loop (none)

$$\frac{b_2}{b_s} = \frac{s_{21}}{1-(s_{11}\Gamma_s+s_{22}\Gamma_L+s_{21}s_{12}\Gamma_s\Gamma_L)+s_{11}s_{12}\Gamma_s\Gamma_L}$$

$$= \frac{s_{21}}{(1-s_{11}\Gamma_s)(1-s_{22}\Gamma_L)-s_{21}s_{12}\Gamma_s\Gamma_L}$$

Power Gain of an Amplifier

Power Gain	Symbol	Formula

Transducer Power Gain	G_t	$\frac{P_l}{P_{avs}}$
Available Power Gain	G_a	$\frac{P_{avn}}{P_{avs}}$
Operating Power Gain	G_p	$\frac{P_l}{P_{in}}$

P_{in} = Input Power , P_{avs} = Power available from source

$= P_{in}$,when $\Gamma_{in} = \Gamma^*_s$

P_l = Power delivered to the load

P_{avn} = Power available from network

$= P_l$,when $\Gamma_L = \Gamma_{out}$

Transducer Power Gain :

$$G_t = \frac{P_1}{P_{avs}}$$

$$P_l = \frac{1}{2}\left(|b_2|^2 - |a_2|^2\right)$$

$$= \frac{1}{2}|b_2|^2(1 - |\Gamma_L|^2)$$

$$P_{avs} = \frac{\frac{1}{2}|b_s|^2}{(1 - |\Gamma_s|^2)}$$

$$P_{avs} = \frac{1}{2}|b_s|^2 \text{,if } |\Gamma_s| = 0$$

$$G_t = \frac{1 - |\Gamma_s|^2}{1 - |\Gamma_{in}\Gamma_s|^2}\,|s_{21}|^2\,\frac{1 - |\Gamma_L|^2}{|1 - s_{22}\Gamma_L|^2}$$

$$G_t = \frac{1 - |\Gamma_s|^2}{|1 - s_{11}\Gamma_s|^2}\,|s_{21}|^2\,\frac{1 - |\Gamma_L|^2}{|1 - \Gamma_{out}\Gamma_L|^2}$$

Three cases of Amplifier Gain

Case I: Matched Transducer Power Gain (G_{tm})

Both Input and Output Ports are matched $\Gamma_S = 0$ $\Gamma_L = 0$

$$G_t \quad G_{tm} = |s_{21}|^2$$

Case 2: Unilateral Transducer Power Gain (G_{tu})

$|s_{12}| = 0$, Power flow in one direction

$$G_{tu} = \frac{1-|\Gamma_s|^2}{|1-s_{11}\Gamma_s|^2} |s_{21}|^2 \frac{1-|\Gamma_L|^2}{|1-s_{22}\Gamma_L|^2}$$

Case 3: Maximum Unilateral Transducer Power Gain ($G_{tu\,max}$)

$\Gamma_s = s_{11}$ & $\Gamma_L = s_{22}$ Maximum gain

$$G_{tu}\text{max} = \frac{1}{|1-s_{11}|^2} |s_{21}|^2 \frac{1}{|1-s_{22}|^2}$$

Stability of an Amplifier

Unilateral case : $s_{12} = 0$ ⟶ Unconditionally Stable

$$\Gamma_{in} = S_{11} + \frac{s_{12}s_{21}\Gamma_L}{1-S_{22}\Gamma_L} = S_{11}$$

$$\Gamma_{out} = S_{22} + \frac{s_{12}s_{21}\Gamma_s}{1-S_{11}\Gamma_s} = S_{22}$$

2. Bilateral case: $s_{12} \neq 0$ Check stability of an Amplifier

Stability Factor (K):

$$k = \frac{1+|\Delta|^2-|s_{11}|^2 - |s_{22}|^2}{2|s_{12}s_{21}|}$$

$|\Delta| < 1$ ⟶ Amplifier is unconditionally stable
& K> 1

Derivation of Stability Circles

Unconditional Stability ⟶ $|\Gamma_{out}| \leq 1$

$$\Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1 - S_{11}\Gamma_s} = \frac{S_{22} - \Delta\Gamma_s}{1 - S_{11}\Gamma_s} \Rightarrow |\Gamma_{out}| = 1 \Rightarrow \left|\frac{S_{22} - \Delta\Gamma_s}{1 - S_{11}\Gamma_s}\right|^2 = 1$$

$$(S_{22} - \Delta\Gamma_s)(S_{22} - \Delta\Gamma_s)^* = (1 - S_{11}\Gamma_s)(1 - S_{11}\Gamma_s)^*$$

$$|S_{22}|^2 - S_{22}\Delta^*\Gamma_s^* - \Delta\Gamma_s S_{22}^* + |\Delta|^2|\Gamma_s|^2 = 1 - S_{11}\Gamma_s - S_{11}^*\Gamma_s^* + |S_{11}|^2|\Gamma_s|^2$$

$$|\Gamma_s|^2(|S_{11}|^2 - |\Delta|^2) - \Gamma_s(S_{11} - \Delta S_{22}^*) - \Gamma_s^*(S_{11}^* - \Delta^* S_{22}) + (1 - |S_{22}|^2) = 0$$

Equation of circle : $|\Gamma_s - c_s|^2$ where c_s $\rightarrow$ center , $r_s \rightarrow$ radius

$(\Gamma_s - c_s) - (\Gamma_s - c_s)^* = r_s^{\,2} \rightarrow |\Gamma_s|^2 - \Gamma_s c_s^{\,*} - c_s\Gamma_s^{\,*} + |c_s|^2 = r_s^{\,2}$ -(2)

From equation –(1) ,dividing by ($|s_{11}|^2 - |\Delta|^2$),

$|\Gamma_s|^2 - \Gamma_s \frac{(s^*{}_{11} - \Delta s^*{}_{22})}{|S_{11}|^2 - |\Delta|^2} - \Gamma_s^{\,*} \frac{(s^*{}_{11} - \Delta s^*{}_{22})}{|S_{11}|^2 - |\Delta|^2} + \frac{1 - |s_{22}|^2}{|S_{11}|^2 - |\Delta|^2} = 0$ -(3)

Comparing (2) & (3)

$c_s = \frac{(s_{11} - \Delta s_{22})^*}{|S_{11}|^2 - |\Delta|^2}$ $r_s = \left|\frac{s_{12}s_{21}}{|S_{11}|^2 - |\Delta|^2}\right|$ stability circle center and radius for source

Equation of a circle for load:

$|\Gamma_L - C_l|^2 = r_l^{\,2}$ $C_l \rightarrow Center,$ $r_l \rightarrow$ Radius

By symmetry:

$$\boxed{c_l = \frac{(S_{22} - \Delta S_{11}^*)^*}{|S_{22}|^2 - |\Delta|^2} \quad r_l = \left|\frac{S_{12}S_{21}}{|S_{22}|^2 - |\Delta|^2}\right|}$$

Stability circle center and radius for Load

Amplifier Stability Example

S-Parameters of a transistor at 800MHz are given .Determine the stability of the transistor and plot stability circles on smith chart.

S_{11} = 0.65< -95°

S_{12} = 0.035 < 40°

S_{21} = 5< 115°

S_{22} = 0.8 < -35°

Find K and Δ for stability test.

$\Delta = S_{11}S_{22} - S_{12}S_{21} = 0.504 < 249.6° \rightarrow |\Delta| < 1$

$K = \frac{1+|\Delta|^2-|S_{11}|^2-|S_{22}|^2}{2|S_{12}S_{21}|} = 0.504 > 1$

Transistor is conditionally stable at 800 MHz

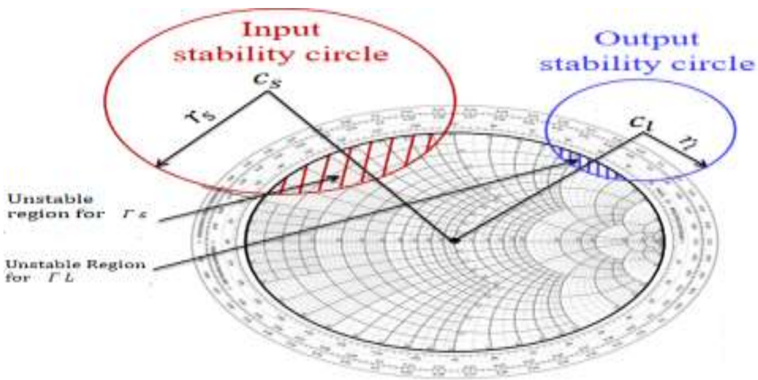
Stable region on smith chart needs to be located to choose Γ_s & Γ_L

Input source stability circle :

C_s = 1.79 < 122° , r_s = 1.04

Output load stability circle :

c_l = 1.3< 48° , r_l =0.45



Constant Gain circles: Unilateral case

$$G_{tu} = \underbrace{\frac{1-|\Gamma_s|^2}{|1-S_{11}\Gamma_s|^2}}_{g_s} |S_{21}|^2 \underbrace{\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2}}_{g_l}$$

$$G_{tu\,max} = \underbrace{\frac{1}{1-|S_{11}|^2}}_{g_{s\,max}} |S_{21}|^2 \underbrace{\frac{1}{1-|S_{22}|^2}}_{g_{l\,max}}$$

For desired G_{tu} gain choose g_s and g_l

$$g_{ns} = g_s(1-|S_{11}|^2)$$

Normalized $g_s = g_{ns} = \frac{g_s}{g_{s\,max}}$

$$g_{ns} = \frac{1-|\Gamma_s|^2}{|1-S_{11}\Gamma_s|^2}(1-|S_{11}|^2)$$

Solving for Γ_s in $\underline{|\Gamma_s - c_{gs}|^2 = r_{gs}{}^2}$

$$\boxed{\begin{aligned} c_{gs} &= \frac{g_{ns}S_{11}^*}{1-|S_{11}|^2(1-g_{ns})} \\ r_{gs} &= \frac{\sqrt{1-g_{ns}}\,(1-|S_{11}|^2)}{1-|S_{11}|^2(1-g_{ns})} \end{aligned}}$$

Center and radius of constant gain circle for Source

Unilateral figure of merit

Error when $|S_{12}| \neq 0$,but it is very small and is assumed to be zero

$$\frac{G_t}{G_{tu}} = \qquad\qquad = \frac{|1-S_{22}\Gamma_L|^2}{|1-\Gamma_{out}\Gamma_L|^2}$$

$$\frac{G_t}{G_{tu}} = \frac{|1-S_{22}\Gamma_L|^2}{1-(S_{22}+\frac{S_{12}S_{21}\Gamma_S}{|1-S_{11}\Gamma_S|^2}}$$

$$\Gamma_{out} = S_{22}+\frac{S_{12}S_{21}\Gamma_S}{1-S_{11}\Gamma_S}$$

$$= \frac{1}{\left|1-\frac{S_{12}S_{21}\Gamma_S\Gamma_L}{(1-S_{11}\Gamma_S)(1-S_{11}\Gamma_S)}\right|^2}$$

$$= \frac{1}{|1-X|^2}$$

When Γ_s=S_{11} & Γ_L=S_{22} $\quad G_{tu} \rightarrow G_{tu}$max

Maximum error introduced when using G_{tu}max is bounded by

$$\frac{1}{(1+M)^2} < \frac{G_t}{G_{tu}max} < \frac{1}{(1-M)^2}$$

$$M= \frac{|S_{12}||S_{21}||S_{11}||S_{22}|}{(1-|S_{11}|^2)(1-|S_{22}|^2)}$$

Unilateral figure of merit M should be less than 0.05

Design of an Amplifier

S-Parameters of a GaA_s MESFET at 8 GHz biased at v_{ds} =3v and I_{ds} = 30mA with a 50Ω reference are : Design an amplifier with a gain =10dB .

S_{11}=0.52< -145°

S_{12}=0.03< -145°

S_{21}=2.56 < 170°

S_{22}=0.48 < −20°

$\Delta = S_{11}S_{22} - S_{12}S_{21}$ = 0.168<197° < 1

$$K= \frac{1+|\Delta|^2-|S_{11}|^2-|S_{22}|^2}{2|S_{12}S_{21}|} = 3.53 > 1$$

Amplifier is unconditionally stable

$G_{tm} = |S_{21}|^2$ =6.55 =8.16dB

$$G_{tU}\text{max} = \frac{1}{1-|S_{11}|^2} |S_{21}|^2 \frac{1}{1-|S_{22}|^2} = 11.67=10.67\text{dB}$$

Maximum gain error

$$M= \frac{|S_{12}||S_{21}||S_{11}||S_{22}|}{(1-|S_{11}|^2)(1-|S_{22}|^2)} =0.04$$

$$\frac{1}{(1+M)^2} < \frac{G_t}{G_{tu}max} < \frac{1}{(1-M)^2}$$

$$0.92 < \frac{G_t}{G_{tu}max} < 1.09$$

-0.36dB < $\frac{G_t}{G_{tu}max}$ < +0.37dB

$$G_{tu\,max} = \frac{1}{1-|S_{11}|^2}|S_{21}|^2\frac{1}{1-|S_{22}|^2}$$

$$= \underset{g_{smax}}{1.37} \times 6.55 \times \underset{g_{lmax}}{1.3} = 11.67 = 10.67 \text{ dB}$$

Design of an amplifier for Gain = 10 dB = 10

Choose $g_s \leq g_{smax}$

Let g_s = 1.25, then g_l = 10 / (1.25 x 6.55) = 1.22

$g_{ns} = g_s(1 - |S_{11}|^2) = 1.25 \times (1 - 0.52^2) = 0.91$

$g_{nl} = g_l(1 - |S_{22}|^2) = 1.22 \times (1 - 0.48^2) = 0.94$

Calculate Center and radius of constant gain circles

$$c_{gs} = \frac{g_{ns}S_{11}^*}{1-|S_{11}|^2(1-g_{ns})}$$

$$r_{gs} = \frac{\sqrt{1-g_{ns}}\,(1-|S_{11}|^2)}{1-|S_{11}|^2(1-g_{ns})}$$

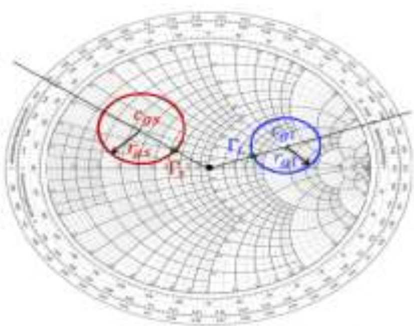
Design of an Amplifier (Γ_s & Γ_L selection)

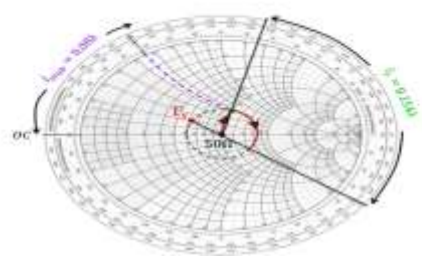
$c_{gs} = 0.485\angle 145^0$, $r_{gs} = 0.224$

$c_{gl} = 0.457\angle 20^0$, $r_{gl} = 0.19$

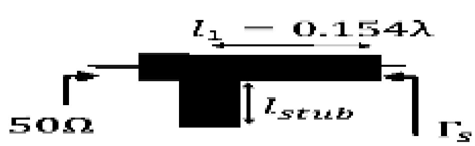
Since the transistor is unconditionally stable ,any point on the constant gain circles can chosen for Γ_s & Γ_L.

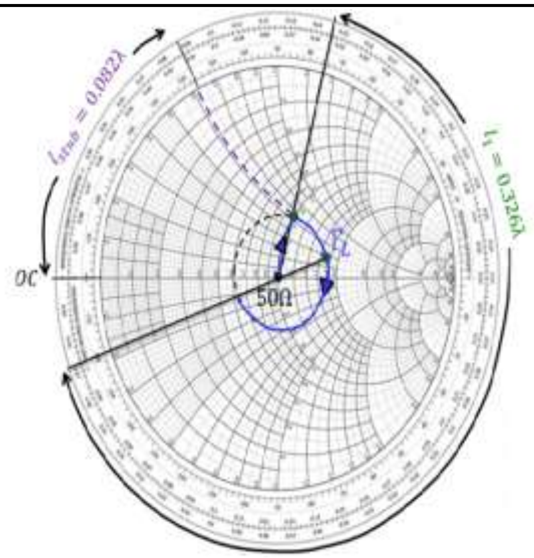
Chosen :Γ_s=0.261$< 145°$
Chosen :Γ_L=0.267$< 20°$

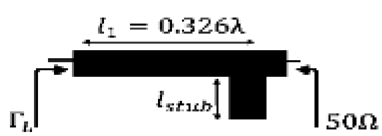




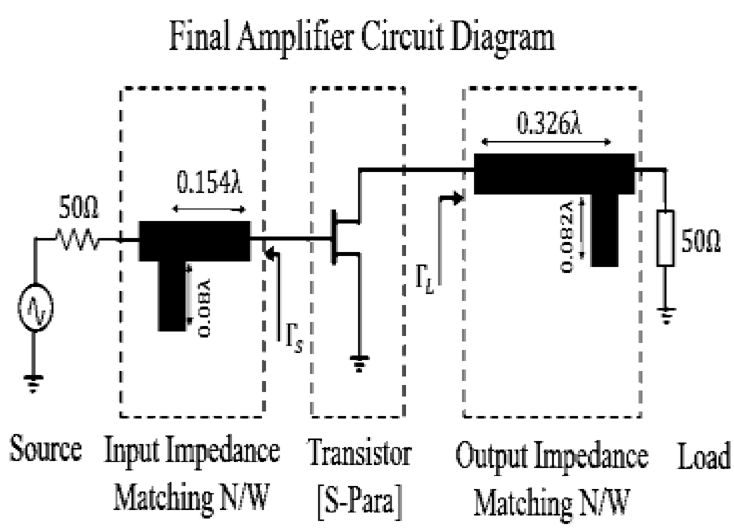
Γ_s=0.261$< 145°$

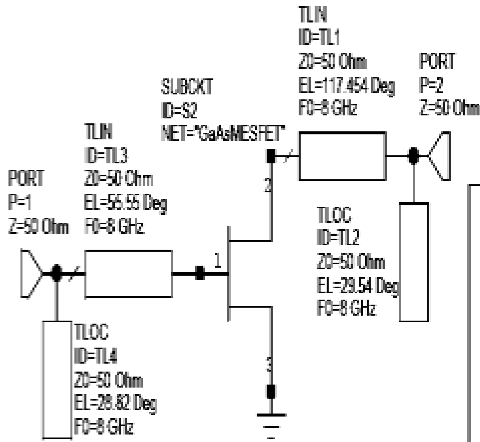






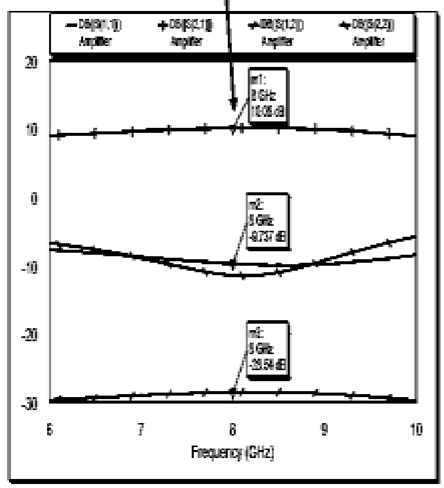
Design of an Amplifier (Final Circuit)





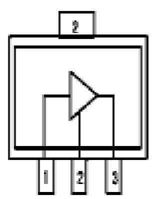
Desired Gain = 10 dB

Simulated Gain = 10.08 dB



Simulation Software:
Microwave Office (AWR)

Amplifier IC: MMG3003NT1

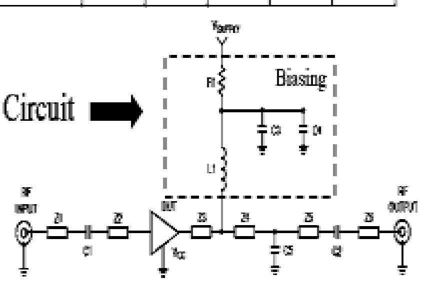


Pin Number	Pin Function
1	RF_{in}
2	Ground
3	RF_{out}/DC Supply

Table 4. Electrical Characteristics (V_{CC} = 6.2 Vdc, 900 MHz, T_A = 25°C, 50 ohm system, in Freescale Application Circuit)

Characteristic	Symbol	Min	Typ	Max	Unit
Small-Signal Gain (S21)	G_p	19.3	20	—	dB
Input Return Loss (S11)	IRL	—	-15	—	dB
Output Return Loss (S22)	ORL	—	-9.3	—	dB
Power Output @ 1dB Compression	P1dB	—	24	—	dBm
Third Order Output Intercept Point	OIP3	—	40.5	—	dBm
Noise Figure	NF	—	4	—	dB
Supply Current	I_{CC}	160	180	205	mA
Supply Voltage	V_{CC}	—	6.2	—	V

Typical Application Circuit



Available for Rs. 188 to 76 depending upon quantity from www.mouser.in

Figures and Tables Source: IC datasheet

Low Noise Amplifiers

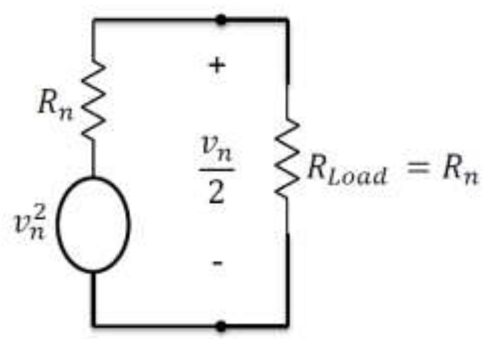
Thermal Noise

The most common form of intrinsic electrical noise in circuits is thermal noise, which is generated by the random thermal motion of electrons within any conducting or semi-conducting material.

Vn^2 =4kTRB (Mean square noise voltage)

- k=Boltzmann′s constant=1.38×10−23J/K
- T=Absolute Temperature(oK)
- B=Bandwidth(Hz)and R=Resistance(Ω)

Maximum available power from noise source when $R_{Load} = R_n$



$$P = \frac{(\frac{v_n}{2})^2}{R_{Load}} = \frac{4kTR_nB}{4R_n}$$

$$\boxed{P = kTB}$$

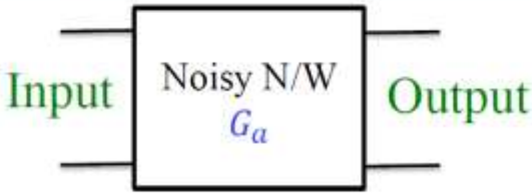
Shot noise

Shot noise in electronic devices arises from the discrete nature of electric current and relates to the arrival of charge carriers at a particular place, i.e. when electrons cross some type of physical 'gap', such as a pn or Schottky junction.

Unlike thermal noise, shot noise is characterized by the Poisson distribution, which describes the occurrence of independent and discrete random events.

Shot noise, just like thermal noise, can be characterized as 'white noise' due to its flat power spectral density.

In^2 = 2qIdcB (Mean square noise current)



Signal to Noise Ratio (SNR):

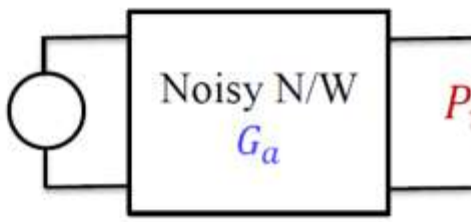
$$\boxed{SNR = \frac{P_s}{P_n} = \frac{v_s^2}{v_n^2}}$$

Noise Figure (NF):

$$\boxed{NF = \frac{SNR_{in}}{SNR_{out}} = \frac{P_{s,in}/P_{n,in}}{P_{s,out}/P_{n,out}}} = \frac{P_{n,out}}{P_{n,in}G_a}$$

where $G_a = \frac{P_{s,out}}{P_{s,in}}$

$$P_{n,in} = kTB$$

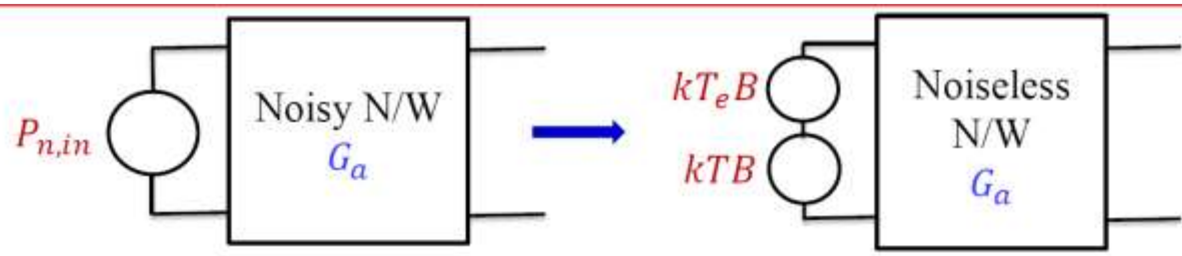


$$P_{n,out} = G_a kTB + P_{ne}$$
$$= G_a kB(T + T_e)$$

P_{ne} = Noise Power at output by internal noise of the N/W

$$\boxed{T_e = \frac{P_{ne}}{G_a kB}}$$

Noise Temperature and noise figure

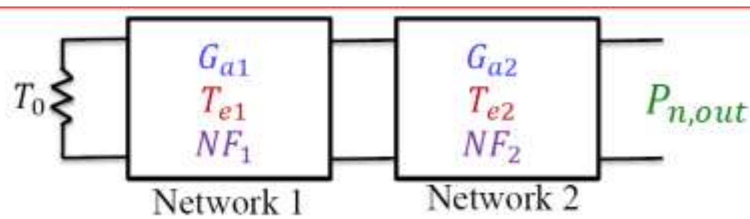


$$NF = \frac{P_{n,out}}{P_{n,in}\,G_a} = \frac{G_a kB(T+T_e)}{kTB\,G_a} = \frac{(T+T_e)}{T} = 1 + \frac{T_e}{T}$$

$$\boxed{NF = 1 + \frac{T_e}{T_0}} \longrightarrow \boxed{T_e = T_0(NF-1)}$$

In general, NF of a device is defined at standard temperature (T_o)

Noise figure of two cascade network



$$P_{n,out} = G_{a1}G_{a2}kT_0B + G_{a1}G_{a2}kT_{e1}B + G_{a2}kT_{e2}B$$

$$G_{a1}G_{a2}kB(T_0 + T_{e12}) = G_{a1}G_{a2}kB\left(T_0 + T_{e1} + \frac{T_{e2}}{G_{a1}}\right)$$

$$\boxed{T_{e12} = T_{e1} + \frac{T_{e2}}{G_{a1}}} \rightarrow T_0(NF_{12}-1) = T_0(NF_1-1) + \frac{T_0(NF_2-1)}{G_{a1}}$$

$$\boxed{NF_{12} = NF_1 + \frac{(NF_2-1)}{G_{a1}}}$$

For 3 Cascaded Networks $\rightarrow$ $\boxed{NF_{13} = NF_1 + \frac{(NF_2 - 1)}{G_{a1}} + \frac{(NF_3 - 1)}{G_{a1}G_{a2}}}$

Example: Find NF_{13}, if $\mathrm{NF_1} = 2\text{ dB}, \mathrm{G_{a1}} = 10\text{ dB}$

$\mathrm{NF_2} = 6\text{ dB}, \mathrm{G_{a2}} = 14\text{ dB}$ and $\mathrm{NF_3} = 10\text{ dB}, \mathrm{G_{a3}} = 18\text{ dB}$

Numeric values: $NF_{dB} = 10\log(NF) \rightarrow NF = 10^{\left(NF_{dB}/10\right)}$

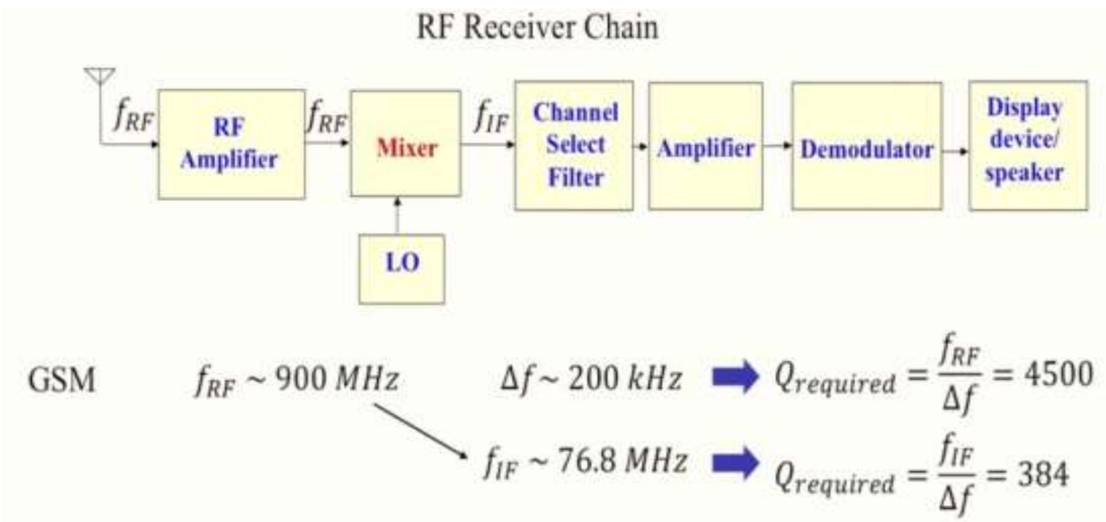
$NF_1 = 1.585, G_{a1} = 10$ $\qquad$ $NF_2 = 3.981, G_{a2} = 25.12$

$NF_3 = 10, G_{a3} = 63.10$

$$NF_{13} = 1.585 + \frac{3.981 - 1}{10} + \frac{10 - 1}{10 \times 25.12} = 1.919 = 2.83\text{ dB}$$

L-30
Microwave Mixer and Oscillator design

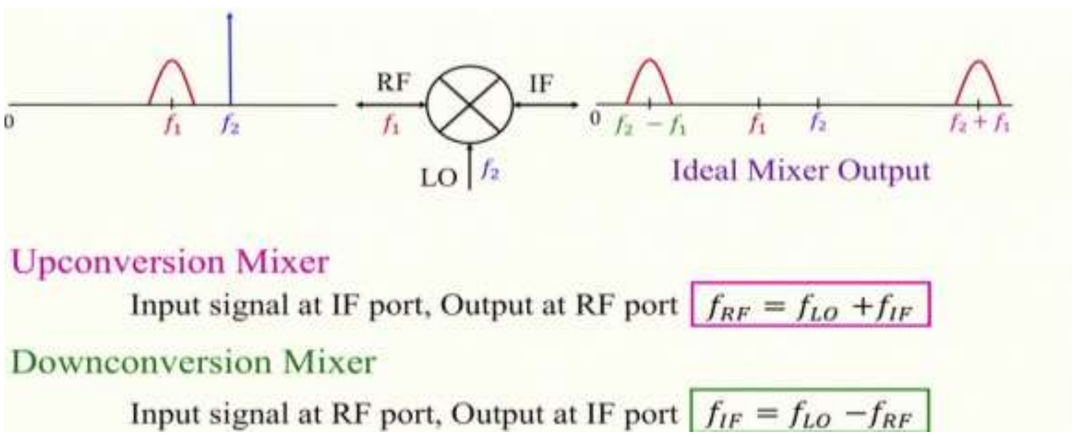
Mixers is a three Port device that uses a nonlinear or time varying element to achieve frequency conversion. Microwave mixers or mixers in general is a very vital component in the RX and TX, which is a receiver and transmitter chain of any communication system. So, be it GSM, be it mobile communication, be it satellite communication, mixers are very vital components. Let us take Example of RF receiver Chain.



Here antenna, which receives the signal. And we have an RF amplifier, which amplifies the signal, then we have a channel select filter, and the signal is further processed using amplifier, demodulator, and then finally given to a display or a speaker.let us take a case of a GSM mobile system, where the incoming signal is at a frequency of 900 MHz. and the channel select filter requires a bandwidth of 200 kHz. To achieve this bandwidth at this particular frequency, we require a Q of about 4500,which is like very big, and impossible to achieve at such a higher frequency. If now we convert this incoming signal of 900 MHz to lower frequency value or an intermediate frequency value. let us say of 76.8 MHz, we get a Q requirement of the filter to be 384, which is still high, but can be accomplished or can be achieved, and it is low compared to the 4500value in earlier case.

It is difficult to process, the signal at very high frequency. And hence, we have to convert this high frequency signal into a lower frequency value. So we need a block in between the RF amplifier and the channel select filter, and that block is nothing but mixer. Mixer is nothing but a frequency translation device, which translates a frequency from one value to another or it translates a signal from one frequency to another.This is the fundamental operation and need of a mixer.

Mixer Ports



Study of mixers in three parts. In first part, we will study the fundamentals of a mixer, we will study mixer as a circuit component, what are the input, output signals. Second part, we are going to study the devices and circuits, which are commonly used to implement a mixer. In the third part, we are going to study some of the design considerations using an example . Mixer has three ports. It is having RF port, and LO port, and an IF port. RF stands for Radio Frequency, LO is the Local Oscillator, IF is Intermediate Frequency. RF and LO are typically high frequency ports, whereas IF is low or intermediate frequency port. RF port and IF port can be used both as input and output ports depending on the application, while the LO port is always the input port.

let us see a basic operation of a mixer. If we have two frequencies at the input of the mixer f1 and f2, which are given in the spectral form here, so we have a f1 signal, which is a band limited signal. And we have local oscillator, which is at a frequency f2, then the mixer output is like this. So, ideally with 2 frequencies input, the mixer produces the sum and the difference frequency. So, at the mixer output, we should get f2+f1, and f2-f1 ideally.

So, depending on the application, we either choose one of this sidebands. So, this is called as the lower sideband, and this is called as the upper sideband . There are two kinds of mixer depending on which frequency signal that we choose at the output, and they are up conversion mixer and down conversion mixer.

Up-Conversion Mixer

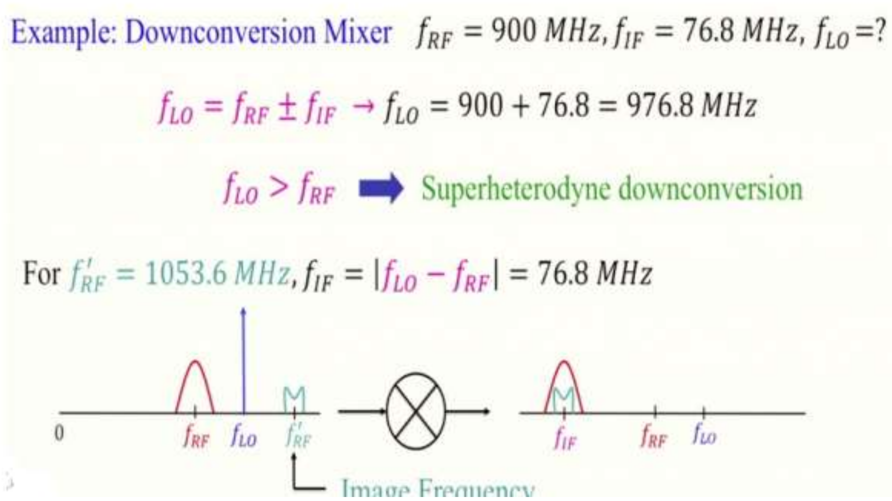
Up-conversion mixer, the input signal is given at the IF port. The signal at the IF port mixes with the signal at the LO port, and these mixing signals produce the sum and the difference frequencies. And in this case, we choose the sum frequency, which is the RF frequency. So, $\mathrm{f_{RF}}$is equal to $\mathrm{f_{LO}} + \mathrm{f_{IF}}$.

Down- Conversion Mixer

In Case of Down Conversion Mixer ,Input is at the RF port, and the signal at the input RF port mixes with the signal at the LO. And these two signals after mixing with each other produces the sum and the difference frequency, and we choose the difference frequency in this case, which is output at the IF port.So, f_{IF} is equal to $f_{LO} - f_{RF}$. This is the basic operation of a mixer in up-conversion and down-conversion case.

Image Frequency

In a receiver the RF input signal at frequency f_{RF} is typically delivered from the antenna .It may receive RF signals over a relatively wide band of frequencies. For a receiver with a local oscillator frequency f_{LO} and Intermediate frequency $\mathrm{f_{IF}}$ i.e $\mathrm{f_{IF}}$= $\mathrm{f_{IF}}$-$\mathrm{f_{LO}}$ it gives the RF input frequency that will be down converted to the IF Frequency i.e $\mathrm{f_{RF}} = \mathrm{f_{LO}} + \mathrm{f_{IF}}$

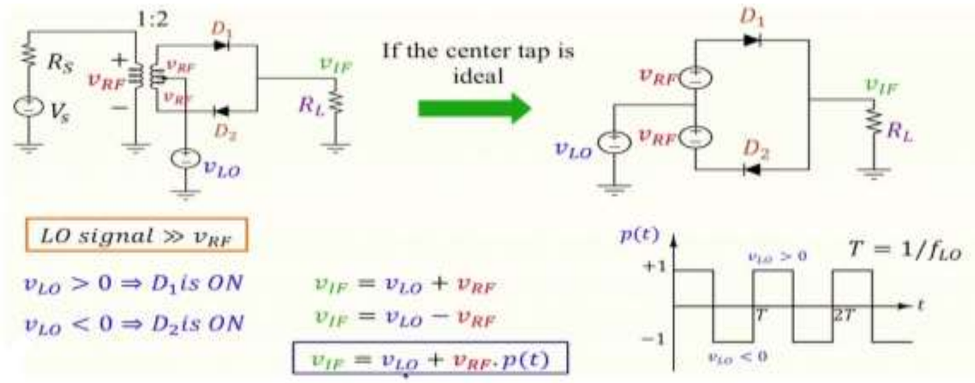


Example of a down conversion mixer. Let us say that, we have an incoming frequency at the RF band, which is equal to 900 MHz. And the IF desired is 76.8 MHz. And the question is the LO frequency that is required to produce this conversion.we have a formula f_{lo} is equal to f_{RF} plus or - f_{IF} using the basic mixer operation.Now, if I choose the plus sign here, I get the local oscillator frequency to be 900 + 76.8,which is equal to 976.8 MHz. In the frequency domain, local oscillator at this frequency, desired RF band. And this is the special frequency and after conversion both this signals mix with the LO, and they produce the same IF output. Basically if you see this kind of operation is really not desired, this is a mixing or scrambling of the desired signal and should be avoided. So, this frequency is called as the image frequency .

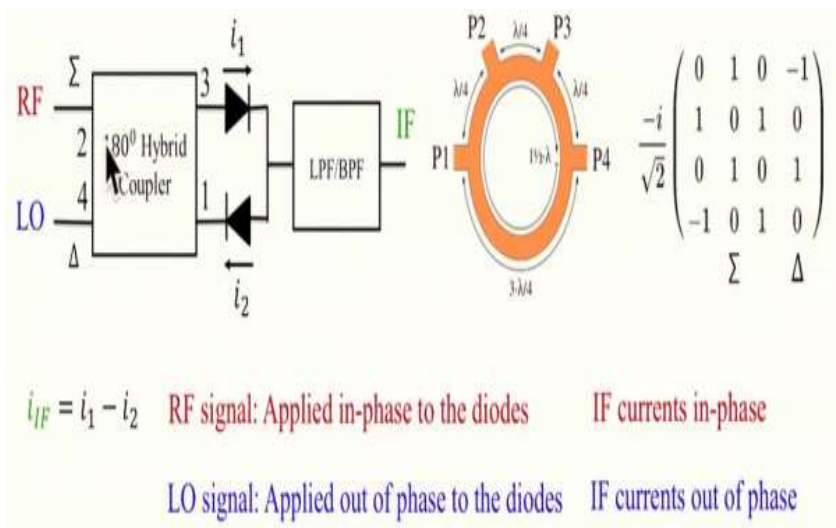
Mixer Circuits

- Single Balanced Mixer
- Double Balanced Mixer
- Sub Harmonically Pumped Mixer
- Image Reject Filter

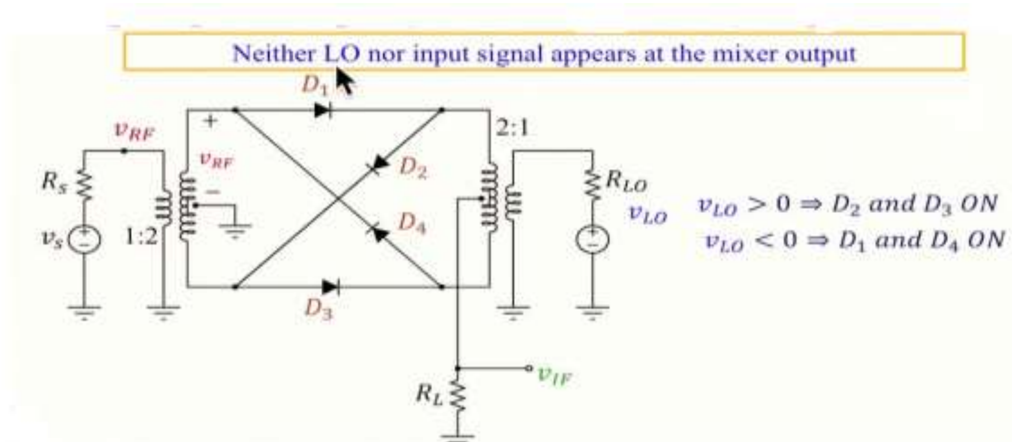
Single Balanced Mixer



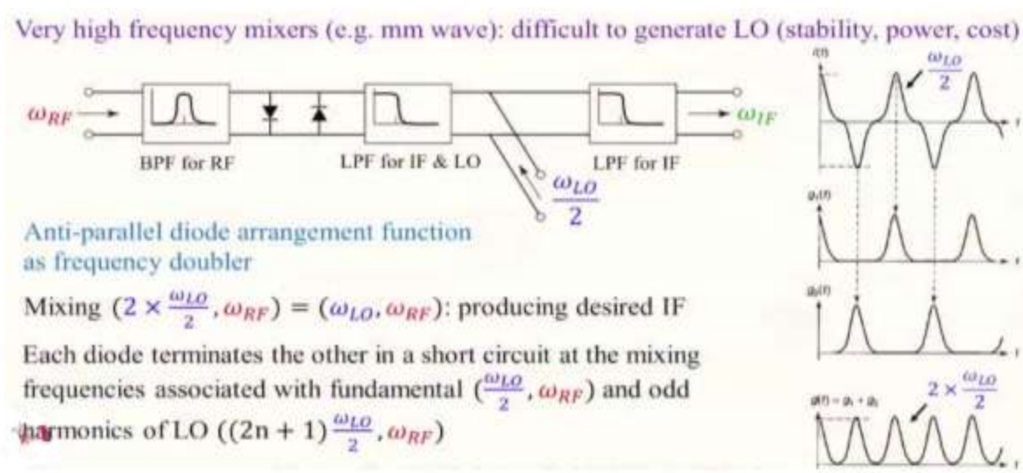
Single Balanced Mixer Using Hybrid Coupler



Doubled Balanced Mixer



Sub Harmonically Pumped Mixer



L-31
Antennas and Antenna Parameters

Antenna is transducer which converts electrical signals into electromagnetic waves and vice versa. So, if an antenna is excited with a voltage/current it generates electromagnetic waves, and if placed in front of an electromagnetic wave, it extracts power from the wave and delivers to the load connected to it.
The phenomenon of electromagnetic radiation is related to the acceleration of electric charges. An accelerated charge corresponds to the time-varying current (a steady flow of charge gives the DC current and the AC current requires acceleration of charges).In principle, every time-varying current can give EM radiation no matter how small the frequency of the current is.
An antenna however is a structure which generates EM radiation with high efficiency. Also it will be seen subsequently that the antennas do not generate EM waves uniformly in all direction. Every antenna preference for certain directions and no preference for other directions. Antenna design therefore focuses on two issues.
(1) How to get highest possible radiation efficiency from an antenna.
(2) How to design antenna structure to achieve desired spatial distribution of the EM waves.

Radiation characteristics of antenna

- Radiation Pattern
- Half power beam width
- Side lob levels
- Directivity
- Antenna gain
- Effective Aperture

Radiation pattern

- Radiation pattern is one of the important characteristic of an antenna as tells the spatial relative distribution of the electromagnetic wave generated by the antenna.
- The radiation pattern is a plot of the magnitude of the radiation field as a function of direction .

- The radiation pattern is essentially a 3-D surface. Since the radiation pattern is supposed to provide relative distribution of the fields, the absolute size of the 3-D surface does not have any significance.
- In practice therefore the maximum amplitude is normalized to unity. The radiation pattern for the Hertz dipole is-

HPBW

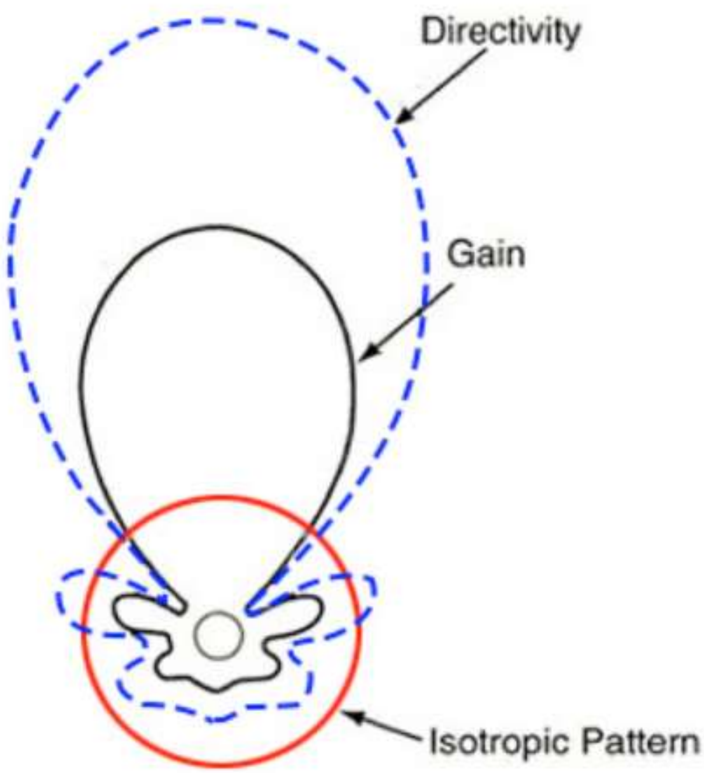
- The main beam is the angular region where primarily the radiation goes. The effective width of the antenna main beam called the HPBW is defined as the angular separation between directions where the field strength reduces to of its maximum value.
- Since the power density of a wave is proportional to the square of the electric field, when the electric field reduces to of its maximum value, the power density reduces to of its maximum value. That is, the power density reduces by 3-dB. The HPBW therefore is also referred to as the 3-dB Beam width.
- The HPBW is a better measure of the effective width of the main beam of the antenna compared to BWFN because there are situations when the effective width of the antenna beam changes but the BWFN remains same.

Side lobe levels

- The local maxima in the radiation pattern are called the side-lobes of the radiation pattern.
- Since ideally the antenna should radiate along the direction of the main beam the side-lobes essentially indicate the leakage of power in undesired directions. The side-lobes in general is an undesirable feature in a radiation pattern.
- The ratio of the main beam to the highest side-lobe is called the SSL of the radiation pattern. For a good communication antenna the SLL lies in the range of 30-40 dB.
- Since the Hertz dipole has only one maximum in the radiation pattern, there are no side-lobes for the Hertz dipoles.

Directivity

- The directivity is a parameter which quantifies the radiation focusing capability of an antenna. It is a measure of how the antenna guides power in the desired direction compared to the other directions.
- The directivity is one of the very important parameters used for comparing the performance of different antennas.
- Directivity is the measure of the concentration of an antennas's radiation pattern in a particular direction. Directivity is expressed in dB. The higher the directivity, the more concentrated or focused is the beam radiated by an antenna. A higher directivity also means that the beam will travel further.
- An antenna that radiated equally well in all directions would be omni-directional and have a directivity of 1 (0 dB)
- Gain is the product of directivity and efficiency. Where efficiency accounts for the losses on the antenna such as manufacturing faults, surface coating losses, dielectric, resistance, VSWR, or any other factor



Antenna gain

- Due to Ohmic losses on the antenna surface a part of the power supplied to the antenna terminals is lost in heating of the antenna. The full power supplied to the antenna is then not radiated. The efficiency of an antenna is-

$$\eta = \frac{\text{Total power radiated}}{\text{Total power supplied to the antenna}}$$

The antenna gain is

G

= Directivity X Antenna efficiency

$$v_i(t) = v_{RF}(t) + v_{LO}(t)$$
$$= A_{RF}\cos\omega_{RF}t + A_{LO}\cos\omega_{LO}t$$

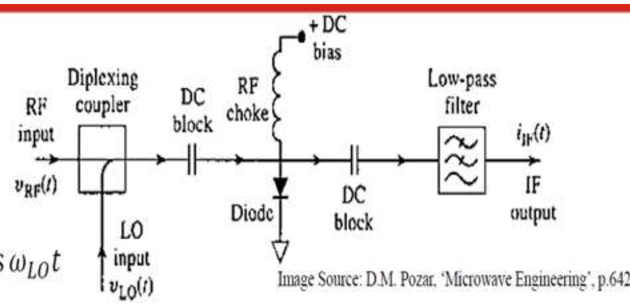


Image Source: D.M. Pozar, 'Microwave Engineering', p.642

$$i_{IF}(t) = I_0 + av_i(t) + b[v_i(t)]^2 + c[v_i(t)]^3 + \cdots$$

$$i_{IF}(t) = bA_{RF}A_{LO}\cos(\omega_{RF} - \omega_{LO})t$$

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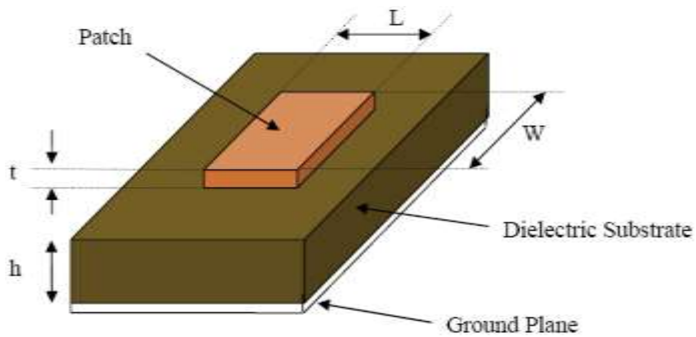
Planar Antennas

MICROSTRIP PATCH ANTENNA

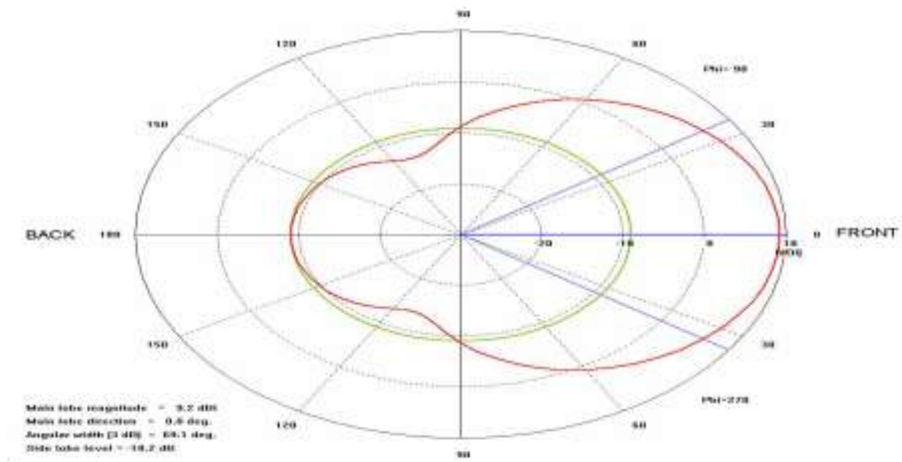
- Microstrip or patch antennas are becoming increasingly useful because they can be printed directly onto a circuit board.
- Microstrip antennas are becoming very widespread within the mobile phone market.
- Patch antennas are low cost, have a low profile and are easily fabricated.



Salient Features Of Microstrip Antennas

- It is a metal patch suspended over a ground plane.
- Simple to fabricate, easy to modify and customize
- Support both linear & circular polarization.
- Size of a microstrip antenna is inversely proportional to its frequency.
- Input impedance of MSA can be adjusted by probe connection.

Radiation Pattern



Advantages

- Light weight
- Low volume
- Low cost
- Conformal configuration
- Compatibility with integrated circuits
- Working in dual frequency range

Limitations

- Low bandwidth
- Low efficiency
- Low gain antennas
- Low power handing capacity
- Design complexity gets enhanced due to their smaller size.

Overcome from drawback

Main drawback of the microstrip antenna is narrow banding. The microstrip antennas are also used on broad band by using some of the optimization technique, which are taking slot from patch, changing the slot/slits position, changing probe position and changing dielectric constant. The quality of the microstrip antenna can be improved as per our requirement by improving some of the parameters like gain, return loss and antenna dimensions.

Applications

- Embedded antennas in handheld wireless devices such as cellular phones and pagers.
- Telemetry and communication antennas.
- Satellite communication.
- Airborne and spacecraft systems.
- Mobile vehicle & Navigation

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Antenna For Ground Based systems , Airborne and Satellite Borne Systems

Antenna Type

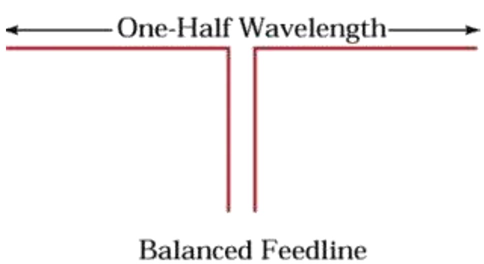
Angular Coverage	**Polarization**	**Bandwidth**	**Type**
360° azimuth	**Linear**	**Narrow** **Wide**	**Whip, dipole, loop** **Biconical, swastika**
	Circular	**Narrow** **Wide**	**Helix** **Conical spiral**
Directional	**Linear**	**Narrow** **Wide**	**Yagi, dipole array** **Log periodic, horn, dish***
	Circular	**Narrow** **Wide**	**Horn with polarizer** **Cavity-backed spiral, dish***

Wire Antenna

HALFWAVE DIPOLE ANTENNA

- A more practical antenna is the half-wave dipole
- Dipole simply means it is in two parts
- A dipole does not have to be one-half wavelength, but that length is handy for impedance matching
- A half-wave dipole is sometimes referred to as a *Hertz* antenna
- Typically, the length of a half-wave dipole is 95% of one-half the wavelength measured in free space

$$\lambda = \frac{c}{f}$$

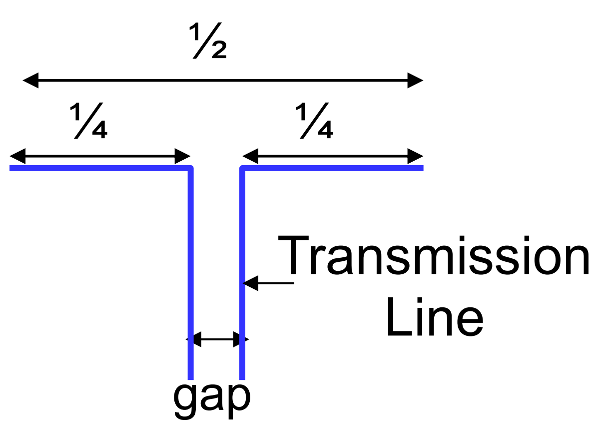


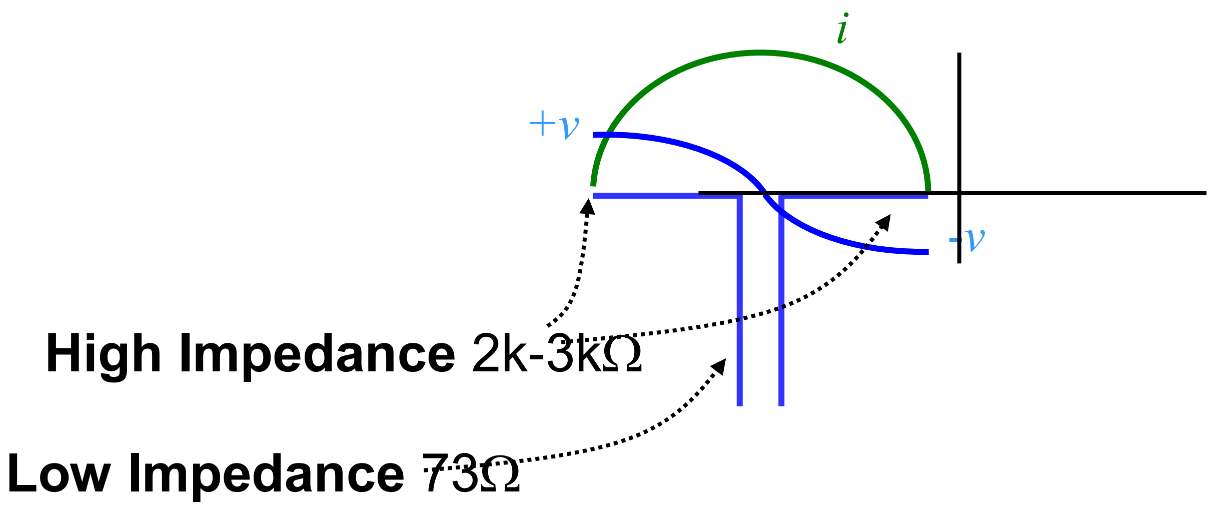
Half wave Dipole Antenna

- consists of 2 spread conductors of 2 wire transmission lines
- each conductor is ¼ λ in length
- total span = ½ λ + small center gap
- **Distinct voltage & current patterns**

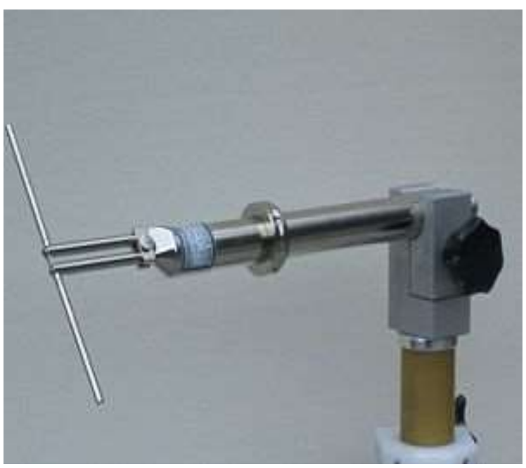
driven by *transmission line* at midpoint

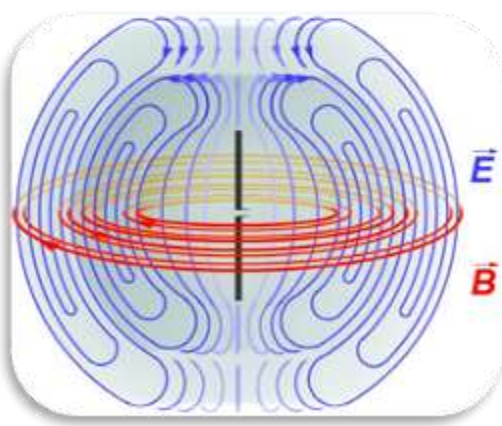
- $i = 0$ at end, maximum at midpoint
- $v = 0$ at midpoint, $\pm v_{max}$ at ends
- purely resistive impedance = 73Ω
- easily matched to many transmission lines





Dipole





Characteristics

- Polarization: vertical
- Beamwidth: 80° x 360°
- Bandwidth: 10%
- Gain: 2 dB

Typical Applications

- TV "Rabbit ears"
- FM radio (folded dipole)
- Radio mast transmitters

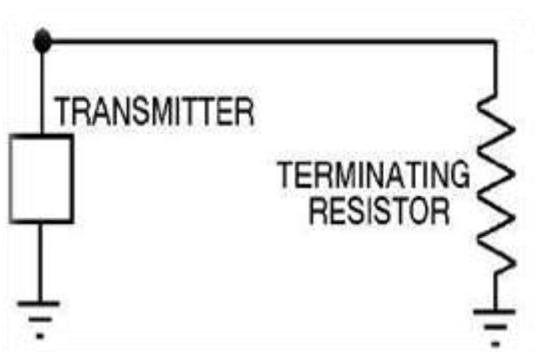
Half wave Dipole Antenna

- Isotropic reference antenna
  - in free space → beamwidth = 78°
  - maximum gain = 2.1dB
  - dipole often used as reference antenna
- - feed same signal power through ½ λ dipole & test antenna
- - compare field strength in all directions

Folded Dipole Antenna

- basic ½λ dipole folded to form complete circuit
- core to many advanced antennas
- mechanically more rugged than dipole
- 10% more bandwidth than dipole
- input impedance ≈ 292 Ω
- close match to std 300Ω twin lead wire transmission line
- use of different diameter upper & lower arms → allows variable impedance

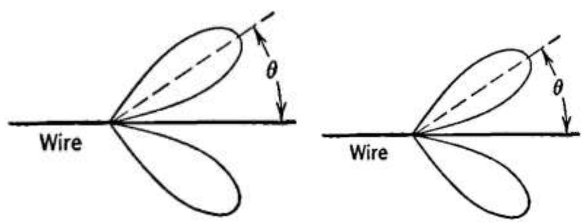
LONG WIRE ANTENNA



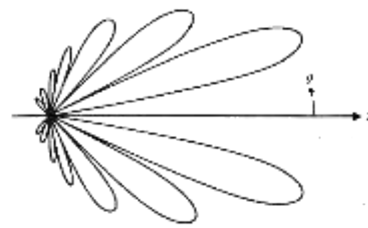
- Non-resonant aperiodic antenna – **no reflected wave**
- Larger Bandwidth
- It has End fire Pattern
- Uniform Current Distribution
- Acts as **Travelling Wave Radiator**

Radiation Pattern

- Length of wire the lobes get closer & narrower
- Lobes = Equal amplitude & opposite in direction
- Angle of Major Lobe =
- Amplitude of major lobe = 1.25 to 5.8



$\theta = 17^\circ$

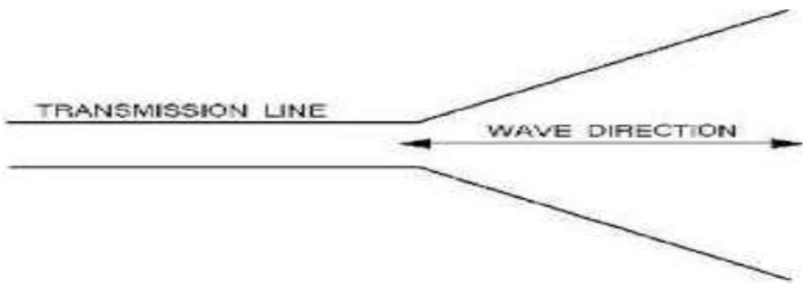


Long Wire Antennas

The physical length of a long wire antenna

- (Length) λ/2= feet if one half wavelength in length
- (Length)= feet if n half wavelength in length

V - ANTENNA



- V shaped bidirectional antenna
- Fed by Balanced Line at the apex
- Current out of phase – **Bidirectional Pattern**
- Two Types:
  - Resonant V antenna
  - Non-Resonant V antenna

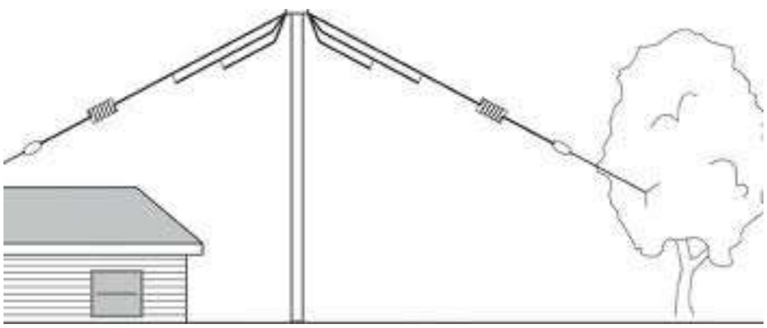
Advantages

- Easy to Construct
- Cheap
- Both End-fire and Broad-side are constructed

Disadvantages

Provides strong Minor Lobes

Applications:



On Light Aircraft

Military appliances

Commercial appliances

Yagi-Uda Antenna

- 3 element array of yagi antenna
  - Reflector length=492/ f (MHz) feet
  - Driven element length=478/f (MHz)feet
  - Director length=461.5 / f (MHz) feet
- Use of parasitic elements cause dipole impedance to fall below 73Ω
- Low as 25Ω ➔ use shunt feed or folded dipole

Characteristics

- 3 element array ➔ beam antenna
- Unidirectional beam with light weight, low cost and simplicity in feed design
- Gain-order of 8dB
- Front to back ratio=20dB
- Super gain or Super directive antenna
- Used at frequencies between 300MHz and 3GHz

Characteristics

- Polarization: horizontal
- Beamwidth: 90° x 50°
- Bandwidth: 5%
- Gain: 5 to 15 dB

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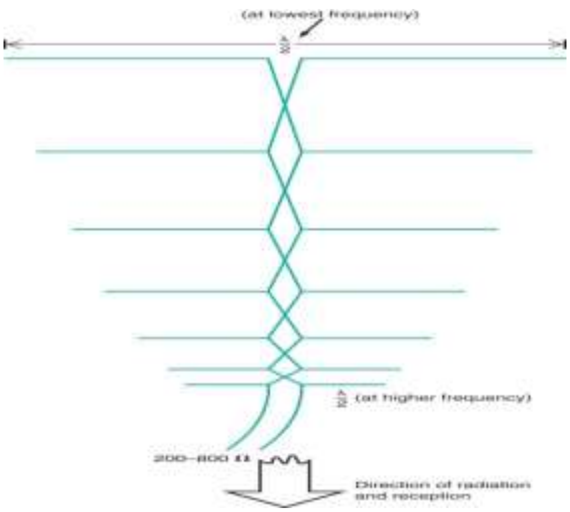
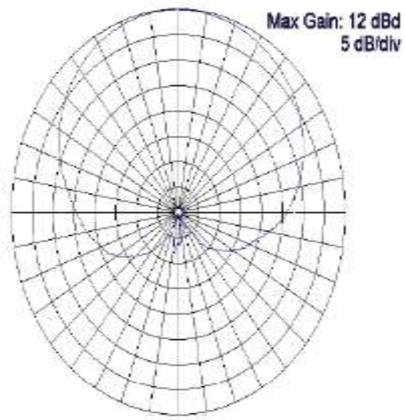
Typical Applications

- WWII airborne radar
- Amateur radio

LOG-PERIODIC ANTENNA

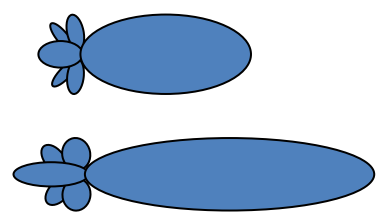
- Lengths of driven elements are related logarithmically
- The longest element has a length of ½ the wavelength of the lowest frequency
- The shortest element is ½ the wavelength of the highest frequency
- Advantage is very wide bandwidth





A typical log-periodic antenna **A log-periodic antenna horizontal-plane pattern**

Log Periodic



Characteristics

- Polarization: vertical / horizontal
- Beamwidth: 80° x 60°

Loop

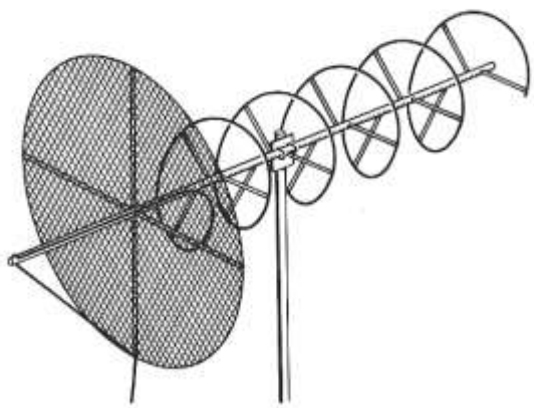
Characteristics

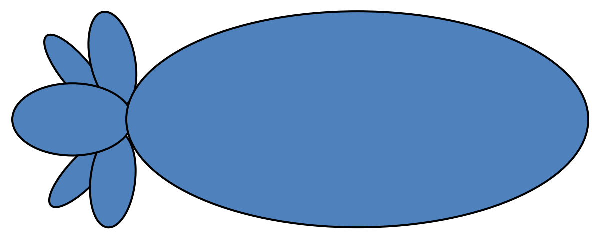
- Polarization: horizontal
- Beamwidth: 80° x 360°
- Bandwidth: 10%
- Gain: -2 dB

Typical Applications

- Direction finding of signal propagation
- Radio(AM/FM)reception
- Long distance point to point communication.

Helical



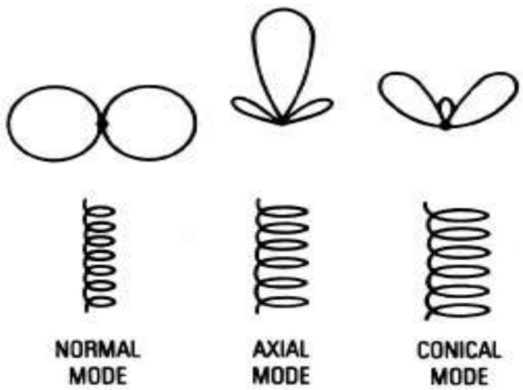


Characteristics

- Polarization: circular (axial mode)
- Beamwidth: 50° x 50°
- Bandwidth: 70%
- Gain: 10 dB

Typical Applications

- Mobile communications
- GPS
- Space communication
- Animal tracking
- Bandwidth & efficiency increases as size of the helix increases
- Monofiar axial mode helical antenna

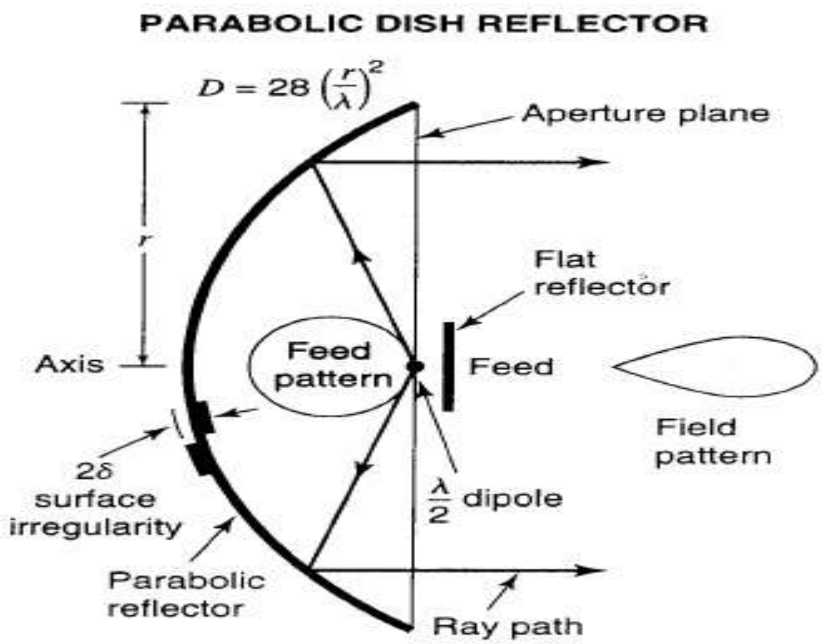


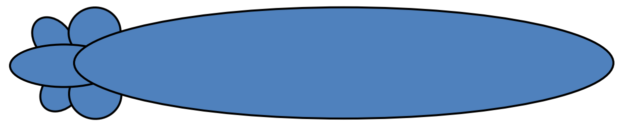
APERTURE ANTENN

REFLECTOR ANTENNA

- **Parabolic Reflector**
  - This is used to convert spherical wave into plane wave
  - The feed antenna is called primary antenna and reflector is secondary antenna.
  - Frequency range - 3GHz-30GHz
  - Reflections of rays from the feed point all contribute in phase to a plane wave leaving the antenna along the antenna bore sight (axis)
- **Application**
  - Radar communication.
  - Satellite communication

Parabolic Reflector Antenna





Characteristics

- Polarization: depends on feed
- Beamwidth: 0.5° x 30°
- Bandwidth: varies
- Gain: 10 to 55 dB

Typical Applications

- Satellite TV
- Cellular telephony, Wi-Fi
- Radio astronomy
- Search & track radar

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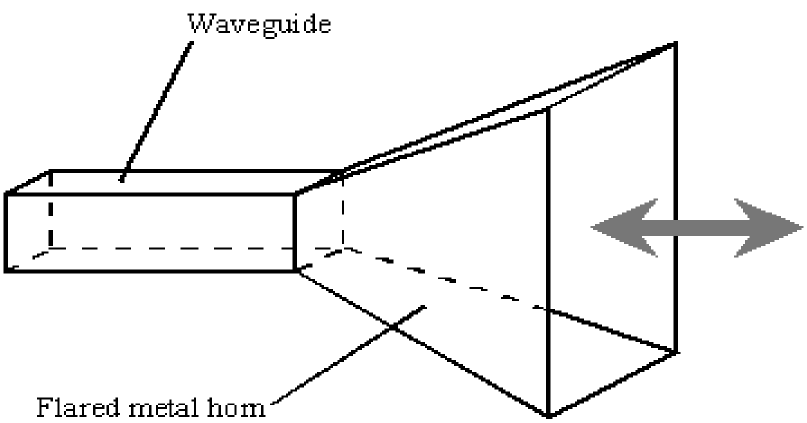
HORN ANTENNA

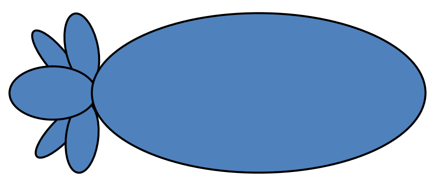
A **horn antenna** is an antenna that consists of a flaring metal waveguide shaped like a horn to direct radio waves in a beam.

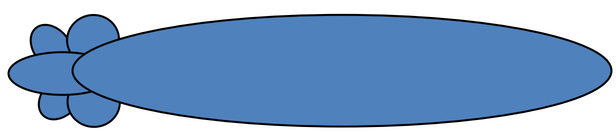


Horn Antenna as termination of waveguide: Waveguide terminated with horn antenna radiates effectively than open ended rectangular waveguide.

Horns are widely used as antennas at UHF and microwave frequencies, above 300 MHz.

Phased Array





Characteristics

- Polarization: linear / circular
- Beamwidth: 0.5° x 30°
- Bandwidth: varies
- Gain: 10 to 40 dB

Typical Applications

- Radio broadcasting
- Search & track radar
- Weather radar
- (severe storm watch)

Unit VIII

Microwave Measurements

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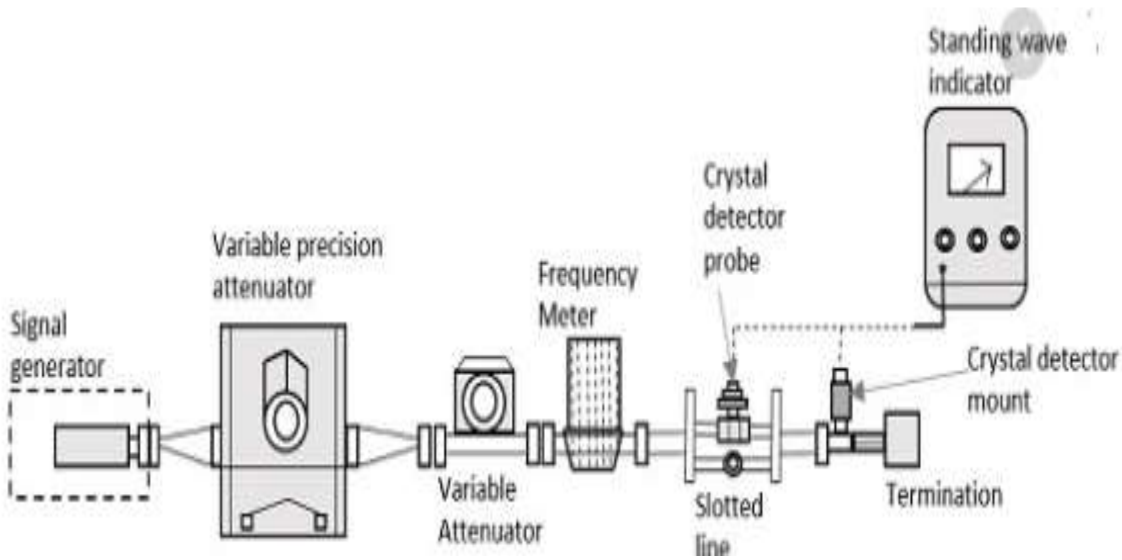
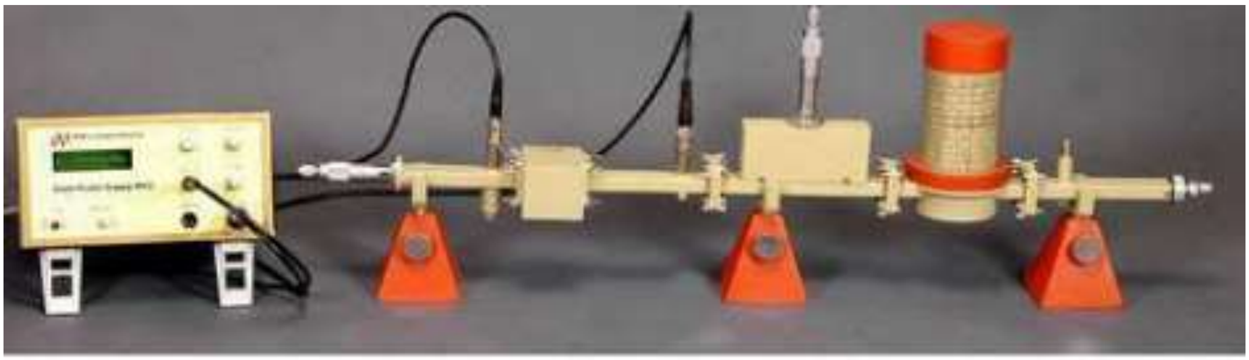
Study of Microwave Test Bench and its Components

Microwave Test Bench General measurement set up



Klystron based microwave test bench

Gunn diode based microwave test bench



Microwave Test Bench having following components

- Signal generator
- Isolator
- Attenuator
- Frequency Meter
- Slotted line
- Detector Probe
- VSWR Meter

Signal Generator

Signal generator is a microwave source whose output is of order of milliwatts. Generally there are two types of signal generator for the microwave test bench in X-band.

- Reflex Klystron tube based signal generator
- Gunn Diode based signal generator

Reflex Klystron tube based signal generator

- Klystron tube based signal generator consists of Klystron power supply, Reflex Klystron and Klystron Mount.

Klystron power supply

For the Klystron based microwave bench ,Klystron power supply generates requires beam and repeller voltage for X- band Klystron tube .It is very stable and contains the short circuit protection circuit. Also it has amplitude and frequency modulation circuits for the generation of 1 KHz square wave and saw tooth wave.

Reflex Klystron

Reflex Klystron is a single cavity variable frequency microwave generator of low power and low efficiency .It consist of elctron gun ,focusing electrode ,single cavity and repeller electrode at high negative voltage. Reflex klystron is used in application where variable frequency is desired in radar receiver.

Klystron Mount

It is a waveguide of suitable length having base on the broad wall of the waveguide for mounting the klystron tube. It consists of movable short at one end of the waveguide to direct the microwave energy generated by the Klystron tube.

Gunn Diode based Signal Generator

Gunn diode based signal generator consist of gunn power supply and gun oscillator.

- Gunn Power Supply

For Gunn based bench ,it is regulated power supply to operate the gunn oscillator .It also contains square wave generator to provide 1 KHz frequency to the PIN modulator for amplitude modulation.

Gunn Oscillator

This is an economical source of microwave power in which Gunn diode is used which work on negative resistance produced by application of DC bias .

Isolator

An isolator is an unidirectional ,two port device which provides very small amount of attenuation for transmission from port(1) to port(2) but provide maximum attenuation for transmission from port (2) to port (1). When isolator is inserted between generator and load generator is coupled to the load with zero reflections and attenuation .

Attenuators

For perfect matching sometimes it is required that the microwave power in a waveguide be absorbed completely without any reflection .For this attenuator s gain or loss in dBs for providing isolation between instruments for reducing power.to prevent uploading.

Frequency Meter

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In microwave benches direct reading frequency meter are generally used Direct reading are generally used because direct reading frequency meter is constructed from a cyclindrical cavity resonator with a variable short circuit termination. The shorting plunger is used to change the resonance frequency of the cavity length.

Microwave type Frequency meters

These frequency meters are intended for moderate accuracy application in microwave measurements and are usually best for this purpose .These permit full power flow down the transmission line except at the tuned frequency .It consist of cavity ,plunger and section of standard waveguide. The plunger ensures precise control of its position enabling frequency measurement with high accuracy.

Slotted line

This system consists of transmission line (waveguide)travelling probe carriage and facility for attaching /detecting instruments .The slot made in the center of the broad face do not radiate for any power of dominant mode. Slotted section is basically used to measure standing wave ratio (VSWR) . The precision built probe carriage having centimeters scale with a Vernier reading of 0.1mm least count is used to note the postion of the probe. Slotted section can be used to measure impedance,reflection coefficient,and return loss.

Tunable probe

A tunable probe helps in detecting the low frequency square wave modulated microwave signal. It is made by the use of crystal diode mounted in the transmission line. The probe is connected to the crystal detector so that the output from the detector is proportional to the square of the input voltage at the position of the probe.

Voltage Standing Wave Ratio Meters

It is ahigh gain, voltage amplifier tuned at the center frequency of 1 KHz. It is used for VSWR ,attenuation and total mismatch of the line.

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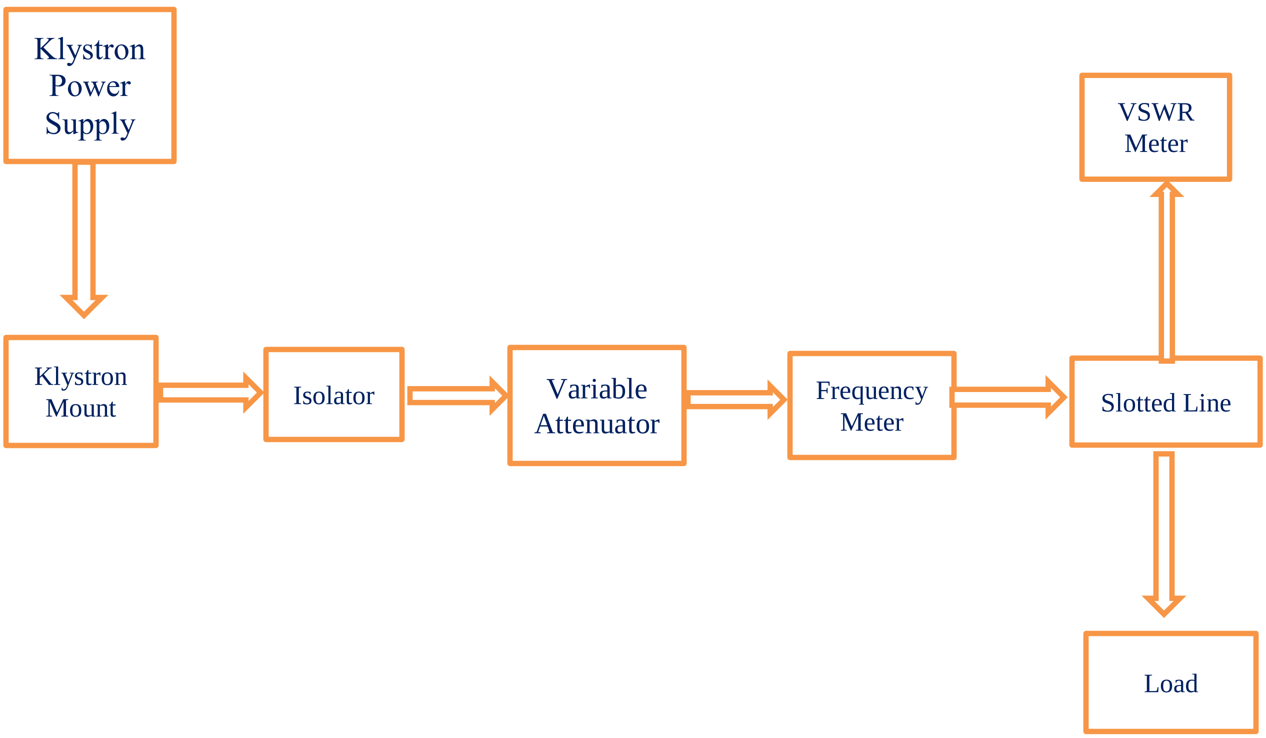
Microwave Measurements: Frequency and Impedance Measurement at Microwave Frequency

Block Diagram of Microwave Test Bench



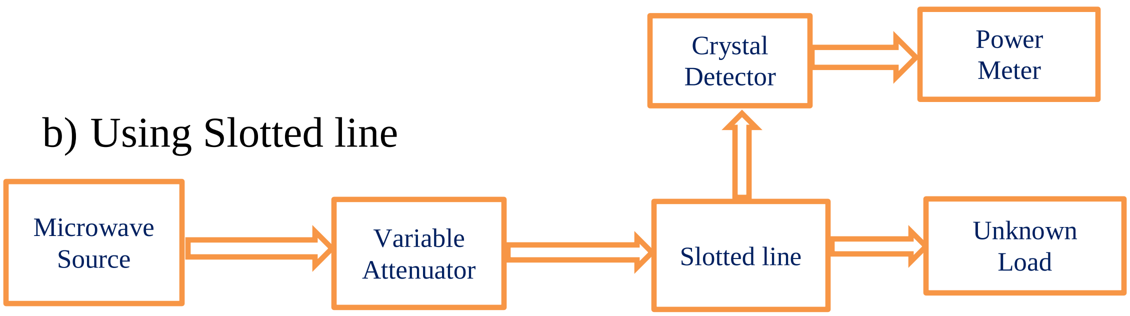
Measurement of Frequency

There are three methods involved in the measurements of Frequency

a) Direct method

Transmission Type Wave meter

b) Using Slotted line



Slotted line set up terminated by Unknown load

- From the procedure $\lambda_g = \dfrac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$
- Where λ_g= guided wavelength

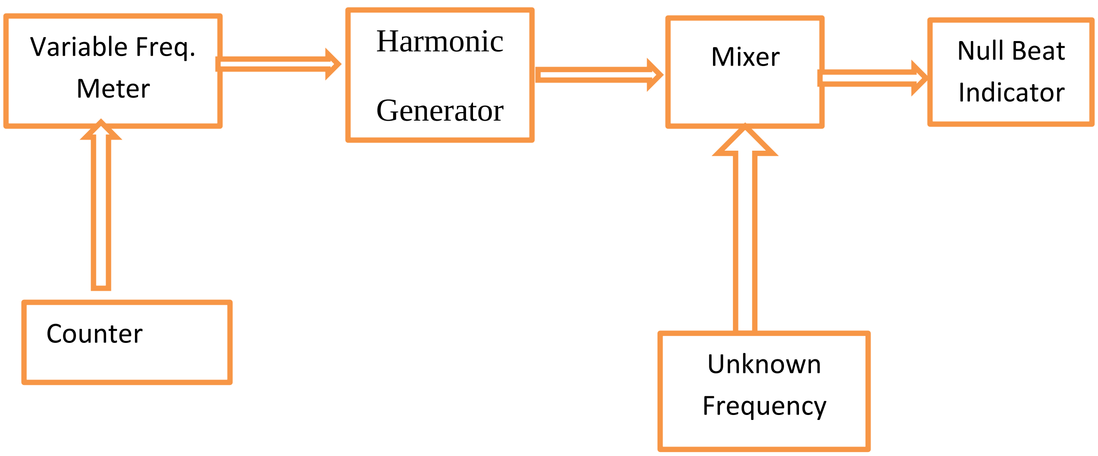
  λ_c = Cut –off wavelength = 2a for TE_{10} Mode
- We know that $\lambda_0 = \frac{c}{f_0} = \frac{3\times10^8}{f_0}$

where a= dimension of the waveguide

f_0= operating frequency which is measured directly from the frequency meter.

- Once λ_g is found the knowing value of λ_c =2a
- Once λ_0 is calculated their using the relation , $f_0=\frac{c}{\lambda_0}$ frequency is measured .

C) Electronic Techniques



- These are based on the principle of comparison of Unknown frequency with a harmonic of known standard frequency .
- Transfer Oscillators are the one which use null beating techniques for Comparison .
- Here Variable Frequency source feeds the signal of stable frequency to harmonic generator which provides a comb of frequencies.
- Output from the harmonics generator mixed with the unknown frequency in the mixer .
- It is connected to CRO in which Beat frequency Output is shown frequency of the source is adjusted.

Probe Detector

Consider two frequencies f_1 & f_2 .Let be the un known frequency which can be determined by following equations-

$$n f_1 = f \quad -(1)$$

$$(n-1)\, f_2 = f \quad -(2)$$

Eliminating 'n' we get -

$$n = \frac{f}{f_1}$$

From (1) we get-

$$\left(\frac{f}{f_1} - 1\right) f_2 = f$$

$$\frac{f f_2}{f_1} - f_2 = f$$

$$f\left(\frac{f_2}{f_1} - 1\right) = f_2$$

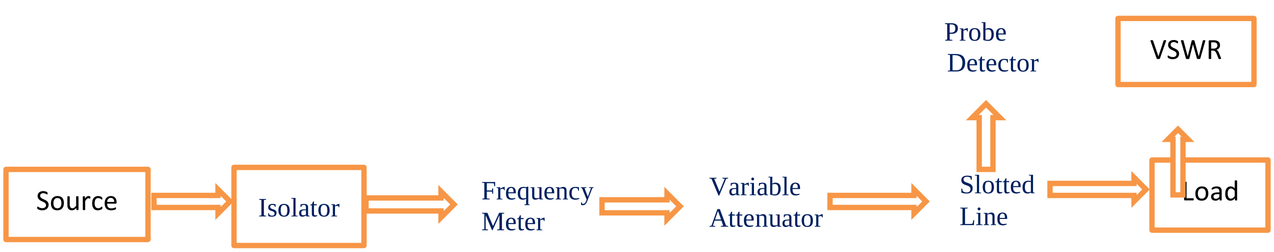
$$f\,(f_2 - f_1) = f_2 f_1$$

$$\mathbf{F} = \frac{\boldsymbol{f_1 f_2}}{\boldsymbol{f_2 - f_1}}$$

Measurement of Impedance

When an Unknown load impedance is connected to the output end of the slotted line due to impedance mismatch , standing waves are produced.

Measurement Using Smith Chart



By adjusting the probe and by moving the slotted line carriage from the load end towards the source, the position of the first minima is found.

By Knowing both VSWR d_{min} one can be find the phase and the magnitude of reflection co-efficient .

Using the smith chart we can find the value of Unknown load Impedance

$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$\text{VSWR} = \frac{1+|\rho|}{1-|\rho|}$$

ρ = Reflection Coefficient

Z_L = Unknown Load Impedance

Z_0 = Characteristic Impedance of the line

At the point of Voltage Minima, $Z_{min} = \frac{Z_0}{VSWR}$ Also we know $2\beta d_{min} = \emptyset + \pi$ Where $\emptyset$ (Phase angle of reflection coefficient)=($2\beta d_{min} - \pi$).Once we know the value of d and VSWR the following steps are to be followed in smith chart-

1) Draw the VSWR circle
2) Draw a line passing through the center of the chart and the phase angle of the reflection coefficient.

The point of intersection of the line and VSWR circle gives the value of normalized value of load impedance .From the value one can use the following relation to calculate the exact value of unknown load Impedance .

$$\frac{Z_L}{Z_0} = Z_l$$

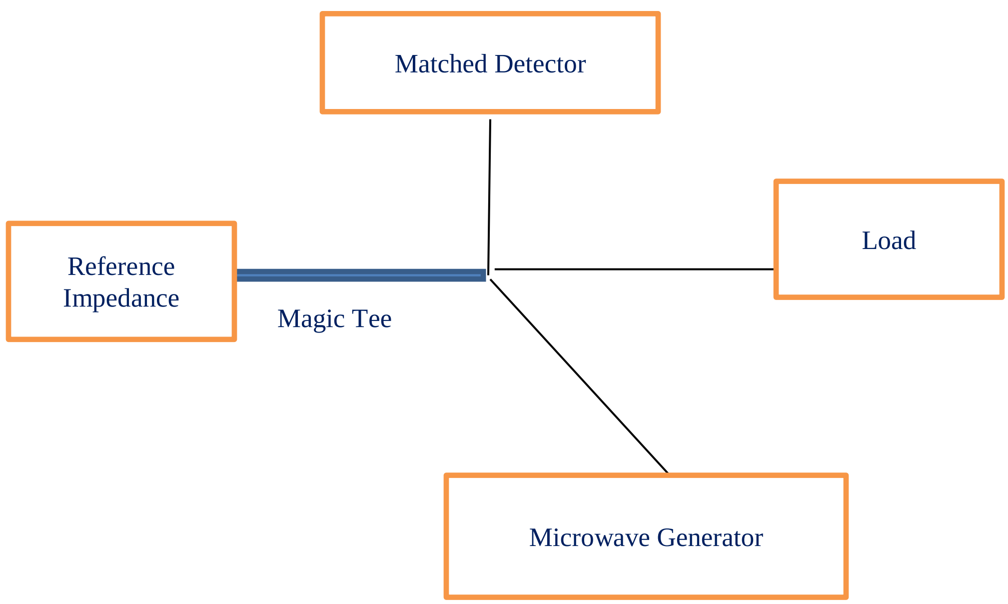
$$Z_L = Z_l \times Z_0$$

Z_l = Normalized Load Impedance

1 Z_0 = Characteristic Impedance

Z_L = Unknown Load Impedance

Impedance Measurement Using Magic Tee



Measurement Of Power

Measured Power can be divide in two Categories-

a) Measurement of low power (0.01mw – 10 mw)
   - Using Bolometer Technique

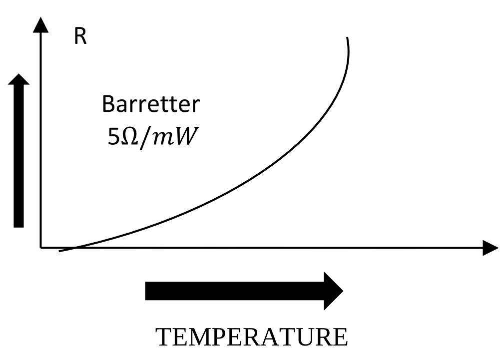
b) Measurement of High power (>10 mw)
   - Using Calorimetric Watt meter

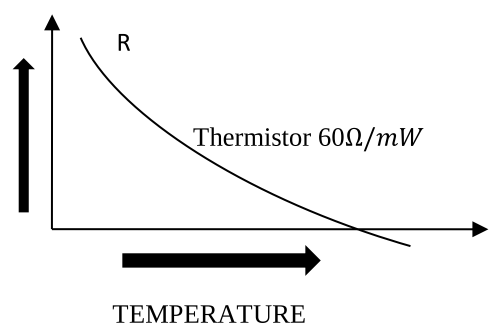
Measurements of Low Microwave Power

Bolometer are used for low power measurement . Their resistance change with the applied power. Mostly Bolometer is used . Bolometer is a temperature sensitive device whose resistance varies with temperature.

These are of two types

1. Barretters
2. Thermistors





A bolometer Such as crystal diode is a square law device because it produce current that is proportional to applied power.Inaccuracy occurs in previous measurement due to non linear characteristics this problem can be removed using balanced bolometer bridge technique.

Limitations: Barretters and Thermistors both are limited in their power handling ability about 10 mW so the power greeter than 10 mW cannot be measured with them directly

Measurements of High Microwave Power

Calorimetric watt meter technique is used for high power measurement

These meters can be either dry type or flow type

$$p = \frac{RK\,\rho(T_2 - T_1)}{4.18}$$

P = measured power in watts

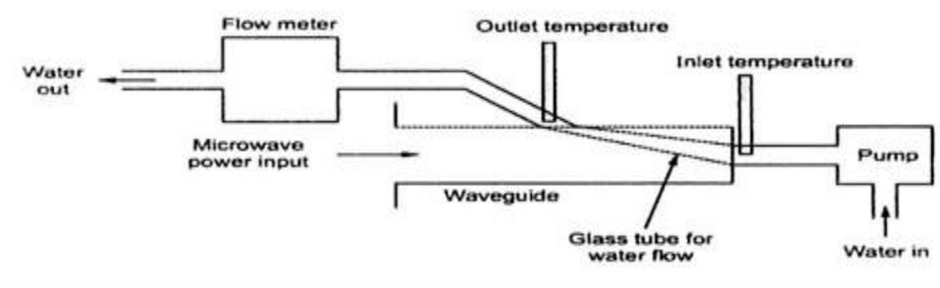
R = rate of flow in cm^3/s

K = Specific heat in cal/g

ρ = Specific gravity in g/Cm^3

$T_2 - T_1 =$ Temperature difference in ^{o}C

Flow Type Calorimetric Watt Meter



Q - Calculate the VSWR of a Transmission Line operating at 10 GHz .Assume TE_{10} wave Propagating inside a waveguide of dimensions a= 4cm, b= 3cm .The distance between twice minimum power points is 2mm on a slotted line?

Given :

Waveguide operating frequency f= 10GHz

Waveguide Dimensions a= 4cm, b=3cm

Distance between twice minimum power point $x_2 - x_1 = 2mm$

Mode of Propagation = TE_{10}

From the waveguide theory ,guide wavelength is given by-

$$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$

For the TE_{10} mode λ_c =2a = 2× 4 $= 8cm$

Free Space Wavelength $\lambda_0 = \frac{c}{f} = \frac{3\times10^8}{10\times10^9}$ = 3cm

$$\lambda_g = \frac{3}{\sqrt{1-(\frac{3}{8})^2}} = 3.24\text{cm}$$

For Double minima method, VSWR is given by

$$\text{VSWR}= \frac{\lambda_g}{\pi(x_2-x_1)} = 5.15$$

Q - A slotted line is used to determine the VSWR value of a waveguide .Adjacent null positions are located at 13.31cm and 15.45cm on slotted line scale. If the twice minimum power is 2mm .What is the value of VSWR?

We know that the distance between adjacent null is equal to the half of the guide wavelength.i.e

$$\frac{\lambda_g}{2} = 15.45 - 13.31 = 2.14\text{cm}$$

Guide Wavelength $\lambda_g = 4.28\text{cm}$

Distance between twice minimum power point($x_2 - x_1$) is given 2mm

For twice minimum method ,VSWR is given by

$$\text{VSWR} = \frac{\lambda_g}{\pi(0.2)}$$

$$\text{VSWR} = \frac{4.28}{\pi(0.2)}$$

$$\text{VSWR} = 6.81$$

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Network Analyzer and Measurement of Scattering Parameters

Network Analyzer

- Network Analyzer is an instrument that measures the network parameters of electrical networks.
- It Commonly measures S-Parameters because reflection & transmission of electrical networks are easy to measure high frequencies.
- Network Analyzers are used to characterize two-port networks such as amplifiers and filters but they can be used for networks with more than two ports.

There are basically two types of Network Analyzers:

1) Scaler Network Analyzer (SNA)
2) Vector Network Analyzer (VNA)
3) Scaler Network analyzers are used for amplitude measurements only where as the Vector Network Analyzer are used for amplitude as well as Phase Measurements.
4) Measurements Using VNA can be done over a wide frequency range with in a reasonable time which were slow and time consuming when done using slotted line.
5) Its operating frequency range from 5KHz to 1.05THz.
6) Measurement is done by two signals – reference signal & Test Signal.
7) Amplitude and Phase of test signal are measured w.r.t . an accurate reference signal.

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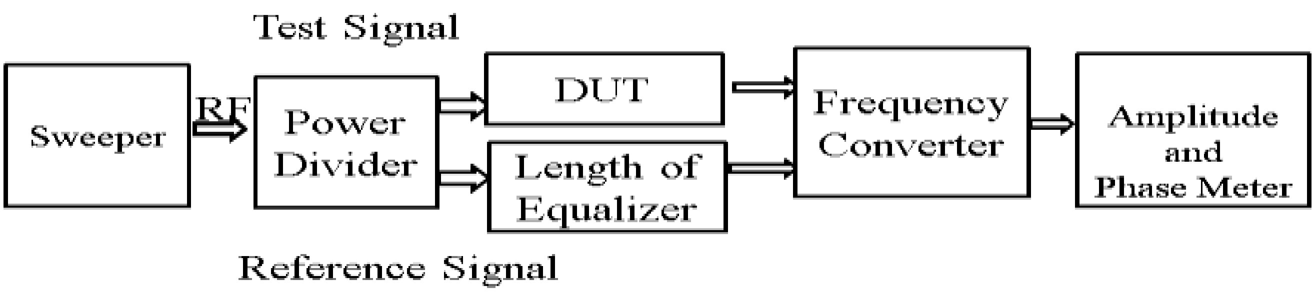
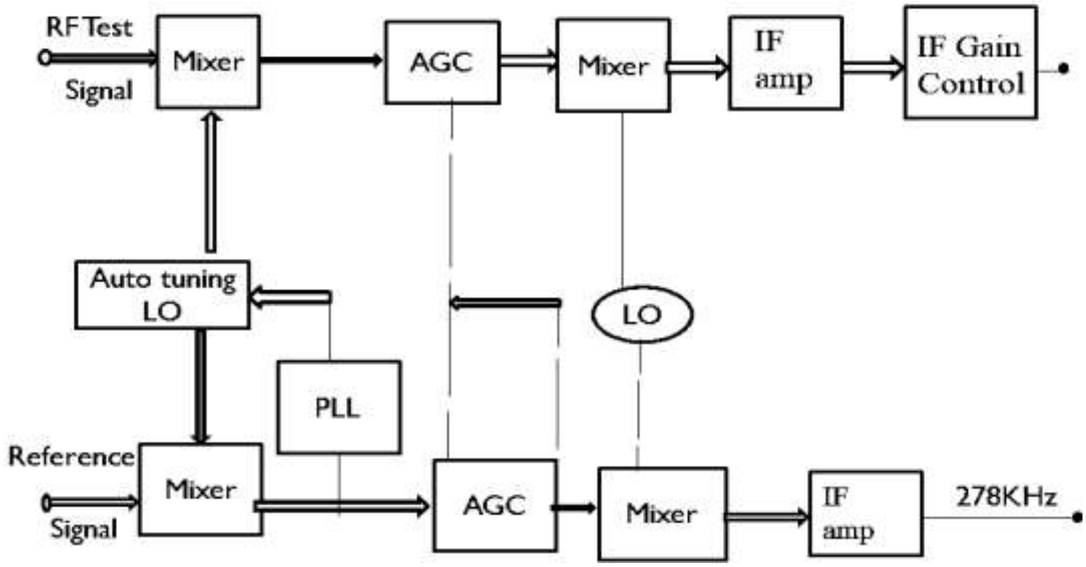
Diagram of Network Analyzer



Block Diagram of a Network Analyzer

- Sweep signal generator is used to generate frequencies of entire range .
- It feeds a Power divider or Splitter that converts into two signals, Test signal and reference signal.
- Test signal passes through the device Under Test(DUT).
- Reference signal passes through the length equalizer .
- Measurements become easy if the RF frequency is converted to some IF frequency .This is done by Frequency Converter.

Block Diagram of Frequency Converter



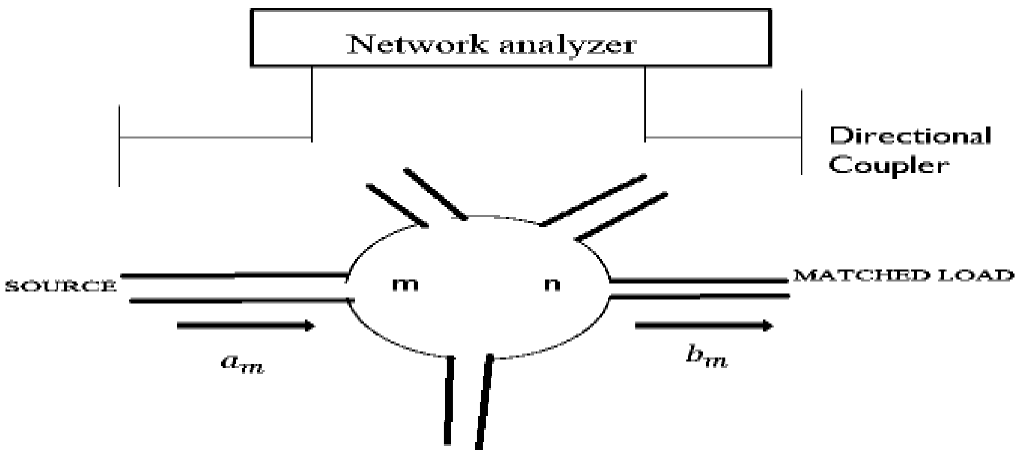
- Here Input signal is converted to a fixed IF Frequency at which amplitude and phase can be measured.
- Internal Phase lock Loop of the frequency converter is used to keep the reference channel tuned to the incoming signal.
- This is necessary to make the system capable of swept frequency operation.
- This PLL also ensures the accuracy of test measurements.

These are two AGC amplifiers, out of which one is used to keep the signal level of the reference channel constant.

Uses of Network Analyzer

- To measure S-Parameters.
- Transmission & Reflection measurements.
- For phase magnitude & Gain Display.

Measurement of Scattering Parameters



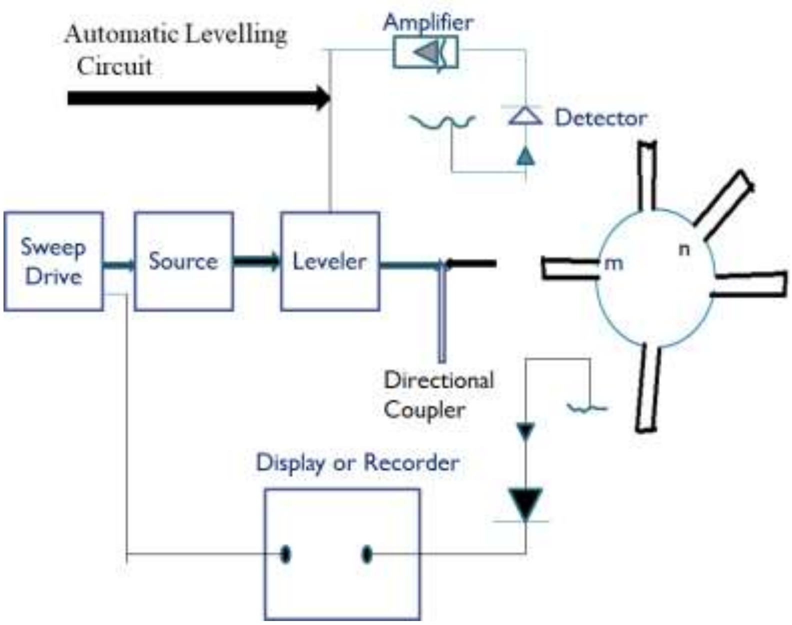
S- Parameter measurement set up

- Scattering parameter of a device under test (DUT) is derived by taking ratio of reflected waves to incident waves.
- Scattering parameters S_{nm} is the ratio of b_n to a_n

$$S_{nm} = \frac{b_n}{a_n}$$

Where n and m are the port of device.

Swept Frequency Measurement of S-Parameter



In swept frequency measurement the source frequency is varied Continuously and is obtained as a function of frequency either on CRO screen or on X-Y Recorder. It is a Sweep Oscillator i.e a source whose output frequency can be varied by a suitable voltage on current drive output of the sweep oscillator is passed through an automatic levelling circuit. ALC consists of directional coupler to sample the power output and a feedback loop consist of a detector and a DC Amplifier. At certain frequency output of sweep oscillator goes down and corresponding detector current is reduced and feedback reduces the attenuation in the leveler to maintain the output of the leveler at the desired value. ALC ensures the incident power remains constant. The scattering parameters S_{nm} is now proportional to the output at n^{th}part. Measurement may be carried out with network analyzer which gives both the magnitude and phase of scattering coefficient as a function of frequency.

Numerical

Q- The following experimental data is given for a 50Ω slotted line.

VSWR =1.5

l_{min} = 0.37 wavelength

$\boldsymbol{\lambda}$ = 4.0cm

Calculate the load Impedance:

a) Using equations

b) Using Smith charts

Solutions:

We Know that

$|\rho| = \frac{VSWR-1}{VSWR+1} = \frac{1.5-1}{1.5+1} = 0.2$

$\theta = \pi + 2\beta l_{min}$

$\pi + \frac{4\pi}{4.0}(4 \times 0.37) = 86.4°$

$\rho = 0.2e^{186.4°}$ = 0.0126+j0.1996

The load Impedance is then

$Z_L = Z_0 \left[\frac{1+\rho}{1-\rho}\right]$ = 47.3+J19.7Ω

b) Using Smith Chart

1) Draw SWR circle for SWR = 1.5 as in figure .

2) Locate a point A on the circle crosses the real axis to the left of the center .This point is called the minimum impedance point (minimum voltage ,maximum current).

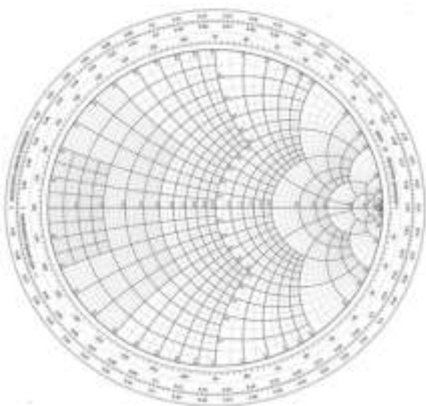
3) Starting from A move 0.37**λ** towards the load (counter clockwise) .This point represents normalize load impedance point.

$\frac{Z_L}{Z_0}$ = 0.95+j0.4

4) The actual load impedance is then ,

Z_L = 50(0.95+j0.4)

= 47.5+j20Ω



L-37

Spectrum Analyzer and measurement of Spectrum of microwave signal & Noise at Microwave frequency, Measurement of Noise Figure

Spectrum Analyzer

A Spectrum Analyzer is used to display signal amplitude w.r.t signal frequency as compared to an oscilloscope which is used to display signal amplitude w.r.t time .

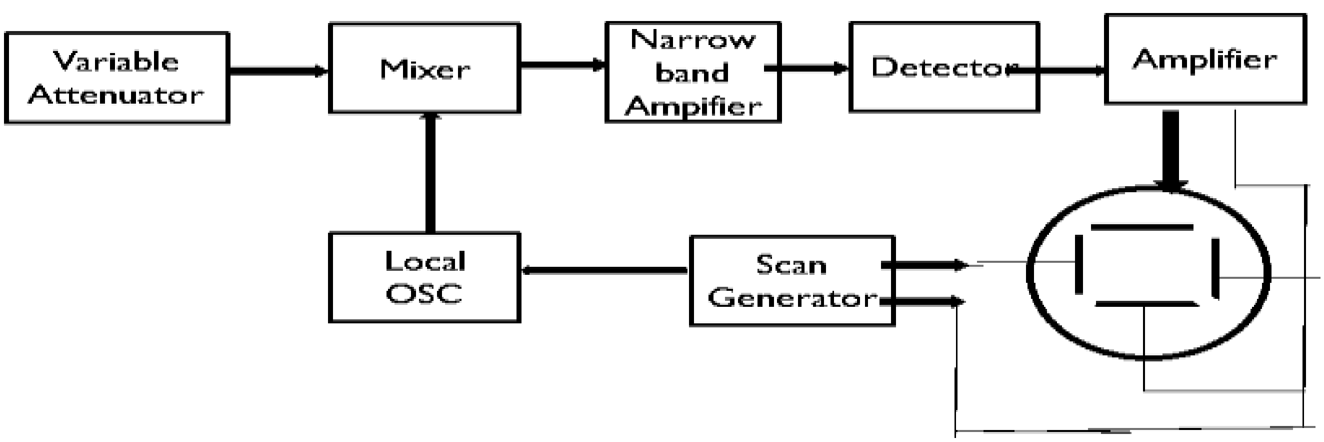
A Spectrum Analyzer looks like an oscilloscope and is used to measure the power of the spectrum of Known and Unknown signals.

There are basically two types of Spectrum Analyzers

1) Real time spectrum Analyzers

2) Swept tuned Spectrum Analyzers

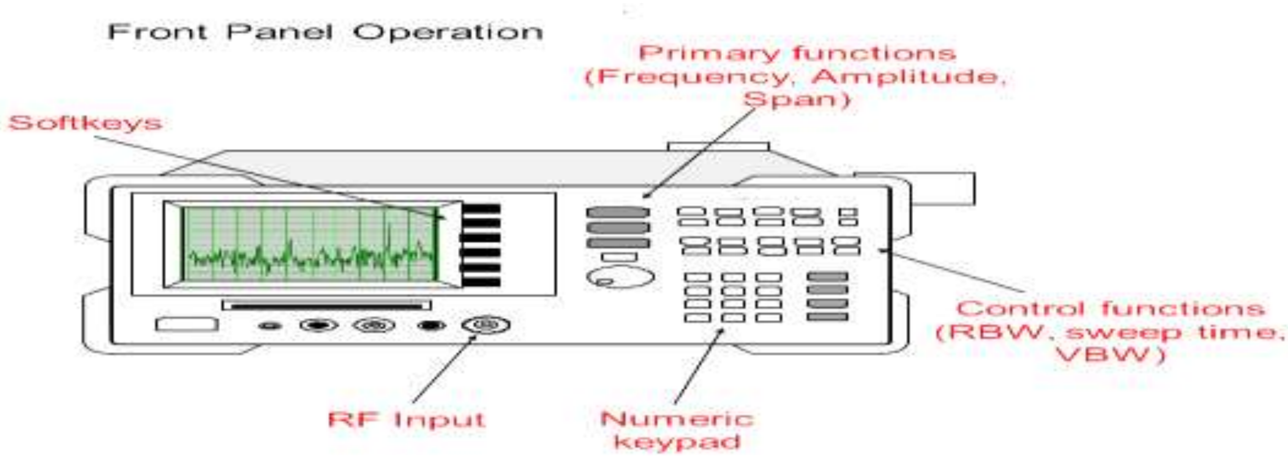
Swept Tuned Spectrum Analyzer



Accessories for use with Spectrum Analyzer

- To avoid damage to the front end of the Spectrum Analyzer.
- Signal generators, Function generators , Comb generators and frequency counters.
- Digital multi- memory storage unit.

Front Panel Controls of Spectrum Analyzers



Factors Responsible for Proper Operation of Spectrum Analyzer

- Frequency range of operation
- Stability of Operation
- Frequency response
- Resolution between Adjacent frequencies
- Calibration of the scales
- Time Domain Capability
- Range of Input levels allowed

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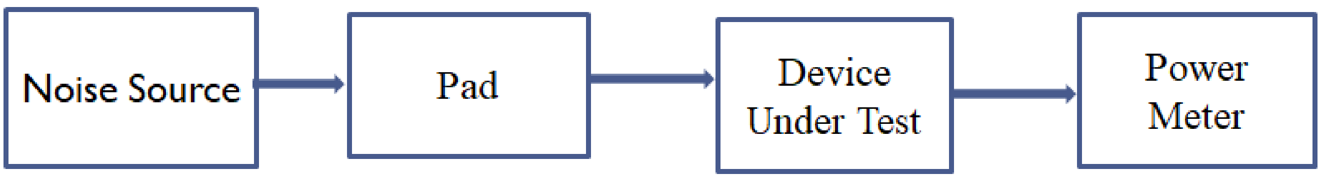
Noise Measurement



Noise Figure Calculations

- Number of methods of determining the sensitivity of radio receivers and their associated elements with in radio communication systems.
- Noise figure of the device can be written as

$$NF = \frac{\text{Signal to noise power at input}}{\text{signal to noise power at output}}$$

$$= \frac{(S_{in}/N_{in})}{(S_{out}/N_{out})}$$

$$\text{Gain} = \frac{S_{out}}{S_{in}}$$

Input Noise Power (Ni_n) = KTB

Where

T = Ambient temperature in K°

K = Boltzmann's Constant

B = Bandwidth of System in Hz

Thus,

$$\text{Noise Figure } (F) = \frac{N_{out}/KTB}{G}$$

$$F = \frac{N_{out}}{KTBG}$$

Thus noise figure contains the important information about the noise performance of RF System.

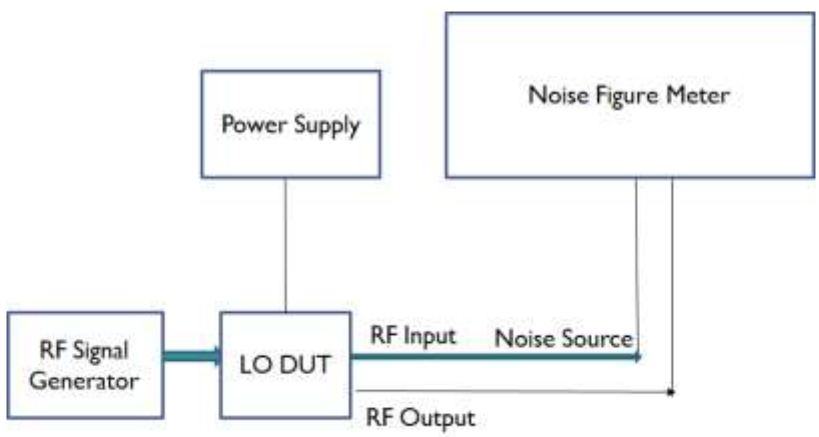
Where

KTBG = Output noise power due to input source o

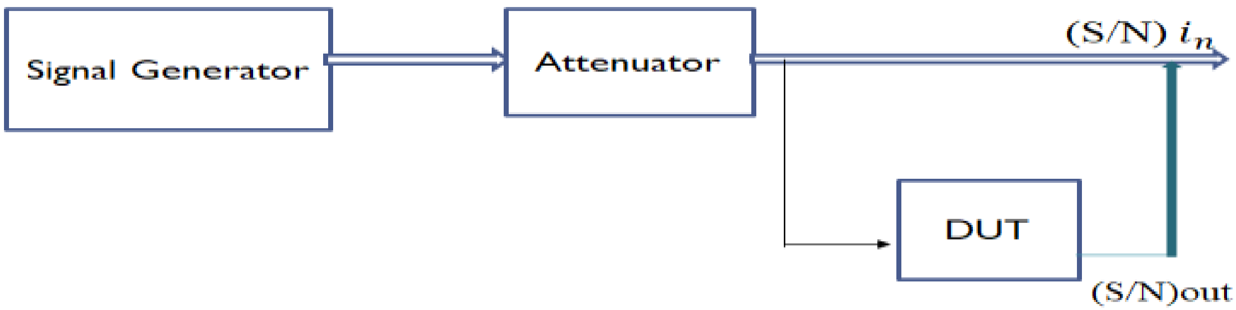
Thus

$$\text{Noise Figure} = \frac{\text{Total Output Noise Power}}{\text{Output Noise due to input source only}}$$

Noise Figure Meter



Noise Figure Measurement Using Spectrum Analyzer



Q- Two identical 30 dB Directional Coupler are used to sample the reflected power in waveguide .If VSWR is 3 and the output of the coupler sampling the incident power is 5.2mW .What will be the reflected power?

Given:

Coupling Coefficient of Couplers = 30dB

VSWR =3

Output of the forward Coupler = 5.2mW

We Know that

Reflection Coefficient $\rho = \frac{VSWR-1}{VSWR+1}$

$$\rho = \frac{3-1}{3+1} = 0.5$$

For 30dB coupler, output of the forward coupler is

$\frac{P_i}{10^3} = 5.2\text{mW}$

Incident power P_i = 5200mW

Reflection Coefficient $\rho = \sqrt{\frac{P_r}{P_i}}$ = 1300mW Ans

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Measurement of Microwave Antenna Parameters

Microwave Antenna Measurements

Most important parameters required to be measured to determine the performance characteristics of microwave antennas such as radiation amplitude patterns, absolute gain, radiation phase patterns, bandwidth, polarizations. So accurate measurements methods for these parameters require standard antenna test ranges.

Antenna Ranges

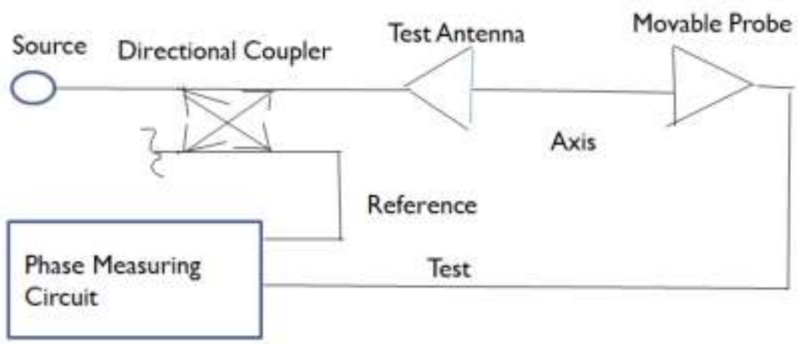
- Testing and evaluation of antenna are performed in antenna ranges .
- Antenna facilities are categorized as outdoor and indoor ranges and limitations are associated with both of them.
- Outdoor ranges are not protected from environmental conditions .
- Whereas indoor facilities are limited by space restrictions .
- Because some of the antenna characteristics are measured in the receiving mode and require far field criteria .
- To meet this specification , a large space is usually required and its limits the value of indoor facilities.

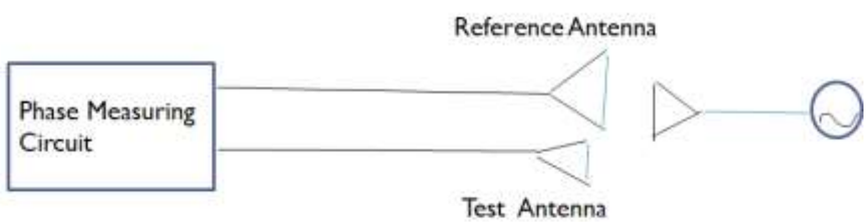
Radiation Pattern Measurements

- Radiation pattern is a representation of the radiation characteristics of the antenna as a function of elevation angle θ and azimuth angle $\emptyset$ for a constant radial distance and frequency.
- Three dimensional pattern is decomposed into two orthogonal two dimensional patterns in E and H field planes where the Z axis is the line joining the transmitting and receiving antennas and perpendicular to the radiation apertures

- Due to the reciprocal characteristics of antennas ,the measurements are performed with the test antenna placed in the reciprocal characteristics of antennas, the measurements are performed with the test antenna placed in the receiving mode .
- Source antenna is fed by a stable source and the received signal is measured using a receiver .
- Output of the receiver is fed to Y-axis input of an XY recorder.
- Receiving antenna positioner controller plane and the angle information is fed to X-axis input of the XY recorder. Thus the amplitude vs angle plot is obtained from the recorder output.
- Following precautions are taken for better accuracy in the measurements:
- Effect of curvature of the incident phase front produces phase variation over the aperture of test antenna and this restricts the range R. For a phase deviation at the edge $\leq \frac{\pi}{8}$ radians , R $\leq 2D^2\lambda$,Where D is the maximum size of the aperture.
- Effect of amplitude taper over the test aperture will give deviation of the measured pattern from the actual .This occurs if the illuminating field constant over the region of the test aperture .
- Interference from spurious radiating sources should be avoided.

Phase Measurement





- Phase of the radiated field is a relative quantity and is measured with respect to a reference .
- Reference is provided either by coupling a fraction of the transmitted signal to the reference channel of the receiver or by receiving the transmitted signal with a fixed antenna placed near the first antenna.
- The fixed antenna output is fed to the reference channel of the receiver and the phase pattern is recorded under test is rotated in the horizontal plane.

Phase Centre Measurement

- When an antenna radiates there is an equivalent point in the antenna geometry which represents the radiation center. At the far field region the phase pattern of this antenna remains constant with angle when measured with respect to this point.
- The phase centre of the test antenna is determined by positioning the rotational axis of the test antenna mast such that the phase pattern with in the main beam remains constant.
- Beamwidth of the antenna is calculated from the angle subtended by the 3 dB or 10dB points on the both sides of radiation maximum in the main lobe.

Gain Measurements

It is the most important parameter to be measured for microwave antennas because it is used directly in the link calculations.There are three basic methods that can be used to measure the gain ,Standard antenna method ,two antenna method and three antenna method.

Standard Antenna Method

- This method uses two sets of measurements with the test and standard gain antennas.
- Using the test antenna of gain G_r , in receiving power P_r is recorded in a matched recorder.
- Test antenna is then replaced by a standard gain antenna of gain G_s and the received power P_s is again recorded without changing the transmitted power and geometric configuration .Then

$$\frac{P_r}{P_s} = \frac{G_r}{G_s}$$

$$G_r(\text{dB}) = G_s(\text{dB}) + 10\log\left(\frac{P_r}{P_s}\right)$$

Thus by measuring the received power with test and standard gain antennas and knowing gain G_s of the standard gain antenna ,gain of test antenna can be found.

Two Antenna Method

- In this method ,the signal is transmitted from a transmitting antenna of gain G_t and the signal is received by the test antenna of gain G_r placed at far –field distance R.
- Received Power is expressed by

$$P_r = \frac{P_t G_t G_r \lambda^2}{4\pi R^2}$$

or , $G_r(\text{dB}) + G_t(\text{dB}) = 20\log\left(\frac{4\pi R}{\lambda}\right) + 10\log\left(\frac{P_r}{P_t}\right)$

Where P_r is the received power and P_t is the transmitted power.

- When two antennas are selected identical, $G_r = G_t$ so that $G_r(\text{dB}) = G_t(\text{dB}) = 10\log\left(\frac{4\pi R}{\lambda}\right) + 5\log\left(\frac{P_r}{P_t}\right)$

By measuring R, $\boldsymbol{\lambda}$ and $\frac{P_r}{P_t}$ the gain G_r can be determined

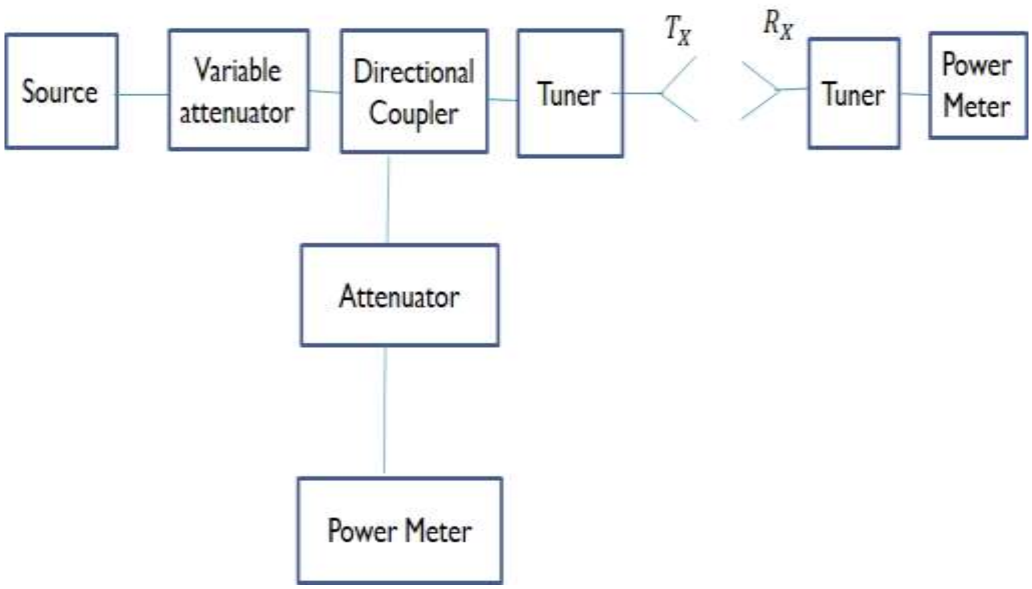
- In the two antenna method, the measuring systems are not exactly identical , error will be introduced.
- Three antenna method is the most general method to find gain of all three antennas.
- Any two antennas are used at a time i.e 1 and 2 ,2 and 3, and 3 and 1 respectively .Following equations can be developed for the received and transmitted powers.
- $G_1(\text{dB}) + G_2(\text{dB}) = 20\log\left(\frac{4\pi R}{\lambda}\right) + 10\log\left(\frac{P_{r_2}}{P_{t_1}}\right)$

$$G_2(\text{dB}) + G_3(\text{dB}) = 20\log\left(\frac{4\pi R}{\lambda}\right) + 10\log\left(\frac{P_{r_3}}{P_{t_2}}\right)$$

$$G_3(\text{dB}) + G_1(\text{dB}) = 20\log\left(\frac{4\pi R}{\lambda}\right) + 10\log\left(\frac{P_{r_1}}{P_{t_3}}\right)$$

Since R and **λ** are known and (P_r/P_t) are measured, the right hand side of the above equations are Known. Then three unknown quantities G_1 , G_2, G_3 can be determined from the above three equations .Block diagram of the measurement set-up for two and three antenna methods .

Block Diagram of antenna gain measurements



For accuracy measurements ,care must be taken ,so that

1. All antennas meet the far field criteria : R ≥ $2D^2/\boldsymbol{\lambda}$.

2. The antennas are aligned for bore- sight radiation face to face.

3. The measuring system is frequency stable.

4. Impedance mismatched in the system components is minimum .

5. Polarization mismatch is minimum.

6.Reflection from various background and support structure is minimum.

Directivity Measurements

Directivity of an antenna can be determined from the measurements of its radiation pattern in two principal planes ,E and H planes and finding the half power beam widths θ_E and θ_H degree, in these planes respectively.

$$D_0 = \frac{41,253}{\theta_E \theta_H} \text{ or, } \frac{72,815}{\theta^2 E + \theta^2 H}$$

Polarization Measurements

Polarization of an antenna is conveniently measured by using it in the transmitting mode and probing the polarization by a dipole antenna in the plane that contains the direction of electric field .Dipole is rotated in the plane of polarization and the received voltage pattern is recorded and analyzed as follows.

- Linear Polarization
- Circular Polarization
- Elliptical Polarization

Radar Cross Section Measurements

Radar cross section of a target is defined by

$$\boldsymbol{\sigma} = \frac{4\pi \times \text{Power re radiated per unit solid angle}}{\text{Incident Power Density}}$$

It is expressed in terms of received Power

$$P_r(\theta) = \frac{P_t G_t A_e \sigma \theta}{(4\pi R^2)^2}$$

Where P_t = Transmitted Power

G_t=Gain of transmit antenna relative to an isotropic radiator.

A_e = Effective area of the receiving antenna

R = Distance of the target

θ = Aspect angle of the target which is the angle of direction of re − radiated power with respect to the line joining the T_X and the centre of the target.

When all the factors remain constant in the above equation,

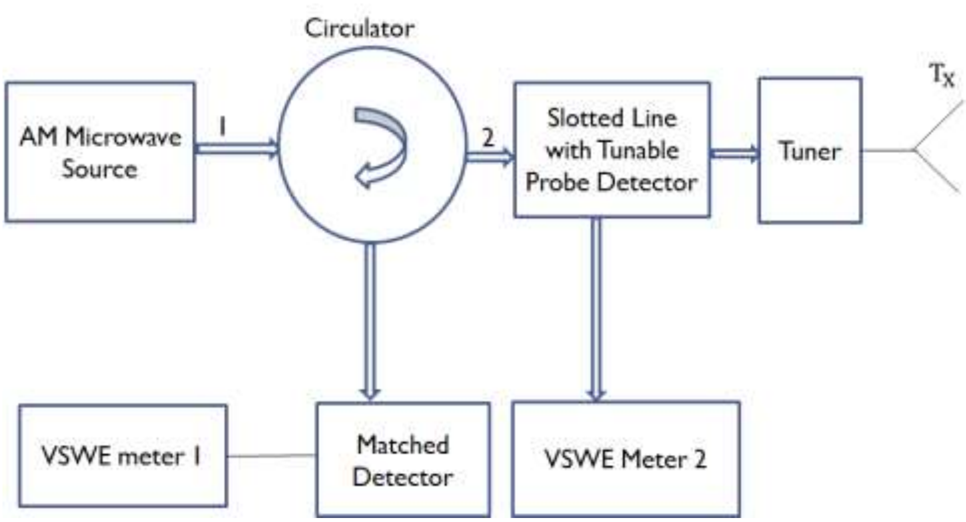
$$\boldsymbol{\sigma}(\theta) = K P_r(\theta)$$

Where K is a constant .Normalizing with respect to the angle $\theta = 0$,

$$\frac{\sigma(\theta)}{\sigma(0)} = \frac{P_r(\theta)}{P_r(0)}$$

Thus by measuring the received Power , the radar cross-section of a target placed at far field location ,can be determined.

Basic Radar Cross-Section Measurement Set-up



Unit-IX

Microwave Systems

L- 40

Microwave system: Radar ,Terrestrial and satellite Communication , Radio Aidsto Navigation, RFID,GPS

Over View of Radar

1. Radar,or radio detection and ranging is one of the oldest application of Microwave Technology.
2. In its basic operation a transmitter in a radar system sends out a signal,which is partly reflected by a distant target and the detected by a sensitive receiver.
3. If a narrow beam antenna is used,the target's direction is accurately given by angular position of the antenna/beam.
4. The distance to the target is determined by a time required

for a pulsed signal to travel to the target and back to the receiver.

Radar Application

Civilian applications	Military applications	Scientific applications
Air traffic control	Air and marine navigation	Astronomy
Marine navigation	Detection and tracking of aircraft, missiles, and spacecraft	Mapping and imaging
Weather radar	Missile guidance	Precision distance measurement
Altimetry	Fire control for missiles and artillery	Remote sensing of the environment
Security alarms	Search and rescue	
Speed measurement		
Geographic mapping		

Typical Radar Frequency Bands

Band	Frequency	Usage
VHF	50-330 MHz.	Very long-range surveillance
UHF	300-1,000 MHz.	Very long-range surveillance
L	1-2 GHz.	Long-range surveillance, trafic control
S	2-4 GHz.	Medium-range surveillance, traffic control, long-range weather
C	4-8 GHz.	Long-range tracking, airborne weather
X	8-12 GHz.	Short-range tracking, missile guidance, mapping, marine radar, airborne intercept
K_u	12-18 GHz.	High resolution mapping, satellite altimetry
K	18-27 GHz.	Little used (H_2O absorption)
K_a	27-40 GHz.	Very high resolution mapping, airport surveillance

Radar Configuration

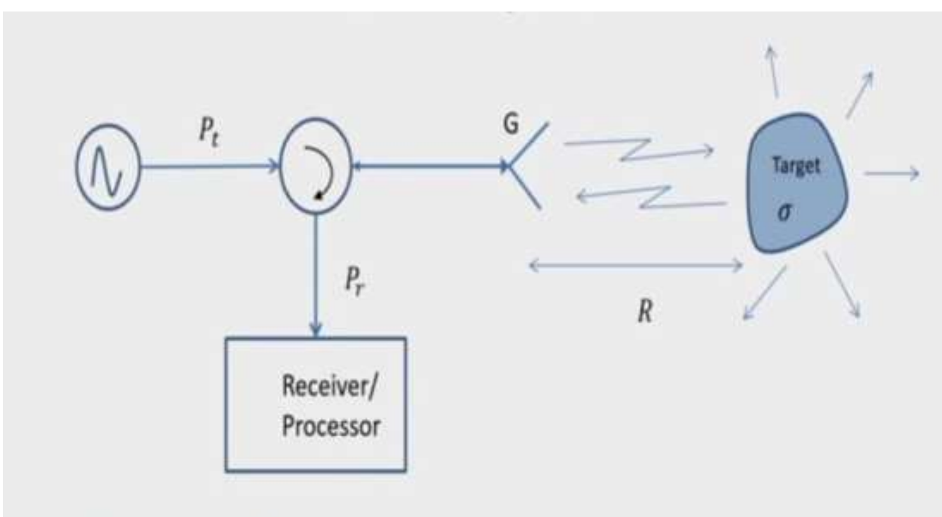
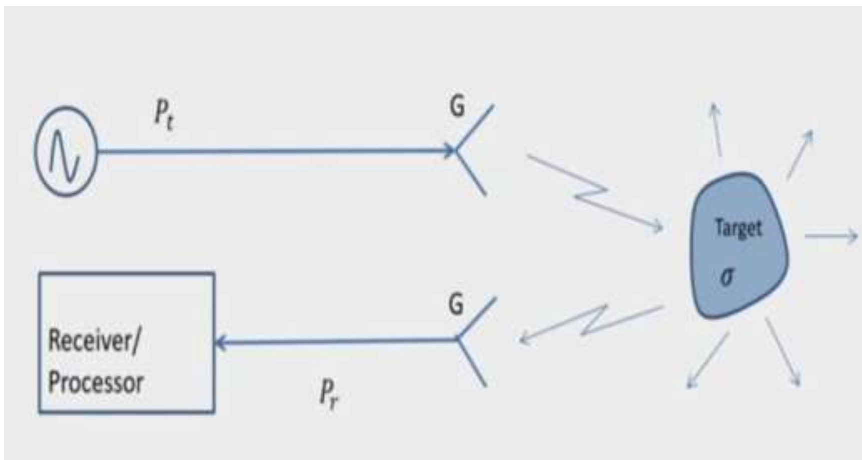


Fig- Monostatic Configuration: Same antenna is used for both transmit and receive.

Monostatic Configuration

we use the same antenna as for both transmit and receive,we havea signal transmitted, and we can see a circulator which will connect that Signal to the antenna; the signal will be radiated. Now we have a target, and this target will scatter the signal, and this backscattered signal will be picked up by the antenna, and this signal, when it goes to the circulator it will be delivered to the receiver, and then it will be further processed. So, this type of configuration which uses only 1 antenna for transmitting and receive these are called Monostatic Configuration.



Bistatic Configuration: Different antenna Transmit or Receive

Bistatic Configuration

Here we use different antenna for transmitting and receive. And the signal is transmitted from the first antenna. It is scattered back by the target, and the backscattered signal is picked up by the receiver antenna, which is given to the receiver for further processing. Nowadays there are some advance versions are also there like multi-static and even multi-dynamic radar are also being tried.

Radar Equation

Power density incident on the target is

$$S_t = \frac{P_t G}{4\pi R^2}$$

The target will scatter the incident power in various directions

The ratio of the scattered power in a given direction to the incident power density is defined as the *radar cross section, σ*

If P_s is the total power scattered

$$\sigma = \frac{P_s}{S_t} \text{ m}^2$$

Since the target scatters as a source of finite size, the power density of the reradiated field decays as $1/4\pi R^2$ away from the target.

$$S_r = \frac{P_t G \sigma}{(4\pi R^2)^2}$$

The maximum effective aperture area of an antenna is related to the directivity of the antenna as

$$A_e = \frac{D\lambda^2}{4\pi}$$

For electrically large aperture antennas the effective aperture area is often close to the actual physical aperture area.

However, for many other types of antennas, such as dipoles and loops, there is no simple relation between the physical cross-sectional area of the antenna and its effective aperture area.

To include the effect of losses in the antenna, D is replaced with gain G.

Received power is received power density multiplied by the effective area

$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$

This is the radar equation. As the received power varies as $1/R^4$, high-power transmitter and a sensitive low-noise receiver are needed to detect targets located at long ranges.

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There is noise received by the antenna and also generated in the receiver. Some minimum input power that is detectable by the receiver is required. This puts a restriction on the range. If this power is P_{min}, then we can find maximum range as

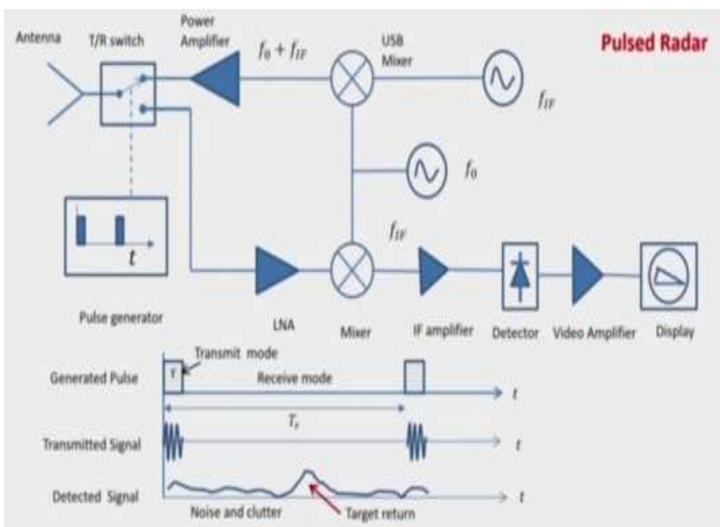
$$R_{max} = \left[\frac{P_t G^2 \sigma \lambda^2}{(4\pi)^3 P_{min}}\right]^{1/4}$$

Signal processing techniques can be used to can effectively reduce the minimum detectable signal, and so increase the usable range.
One very common processing technique used with pulse radars is pulse integration, where a sequence of N received pulses is integrated over time.
The effect is to reduce the noise level, which has a zero mean, relative to the returned pulse level, resulting in an improvement factor of approximately N .

So in actual radar system factors such as Propagation Effects the statistical nature of the detection process and external interference often reduce the usable range of the radar system.

Overview of Pulsed Radar

Pulsed RADAR sends high power and high frequency pulses towards the target object. It then waits for the echo signal from the object before another pulse is send. The range and resolution of the RADAR depends on the pulse repetition frequency. It uses the Doppler shift method. The principle of RADAR detecting moving objects using the Doppler shift works on the fact that echo signals from stationary objects are in same phase and hence Get cancelled while echo signals from moving object will have some changes in phase. Here we show systematic or the Block diagram of pulsed radar.



Doppler Radar

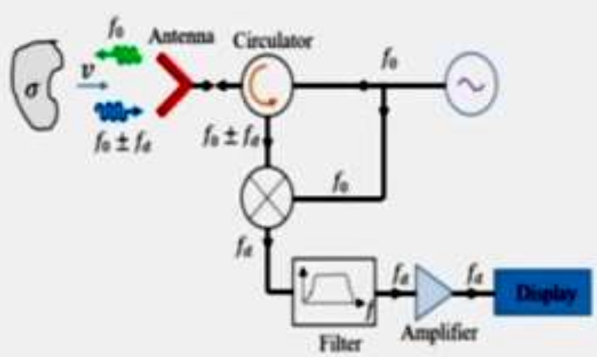
- In such radar, shift in frequency relative to the transmitted frequency occurs in the returned signal, whenever the target of a radar has a velocity component along the line of sight of the radar. This shift occurs due to the **Doppler effect.**
- This shift in frequency (Doppler frequency) can be expressed as:

$$f_d = \frac{2vf_0}{c}$$

where,

f_0 = transmitted frequency
v = radial target velocity
c = velocity of light

- The received frequency can be expressed as $f_0 \pm f_d$.
- The positive or negative sign corresponds to an approaching or receding target, respectively.



As shown in the figure, a continuous wave transmitter can be used as a local oscillator for the receive mixer as the received signal is frequency offset by the Doppler frequency.

- The mixer is followed by the filter having a passband corresponding to the expected minimum and maximum target velocities.
- The effect of clutter return and transmitter leakage at the frequency f_0 is eliminated by having high attenuation at zero frequency.
- This type of filter response also helps to reduce the effect of $\frac{1}{f}$ noise.
- However, an approaching or a receding target is indistinguishable in Doppler radar, as the sign of f_d is lost in the detection process.
- By using a mixer that produces separately the upper and lower sideband products the above information can be recovered.

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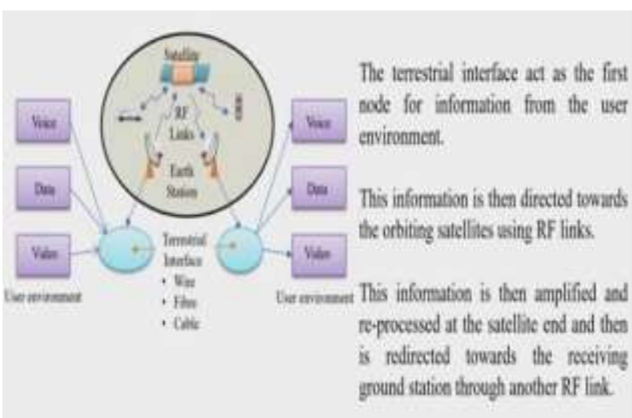
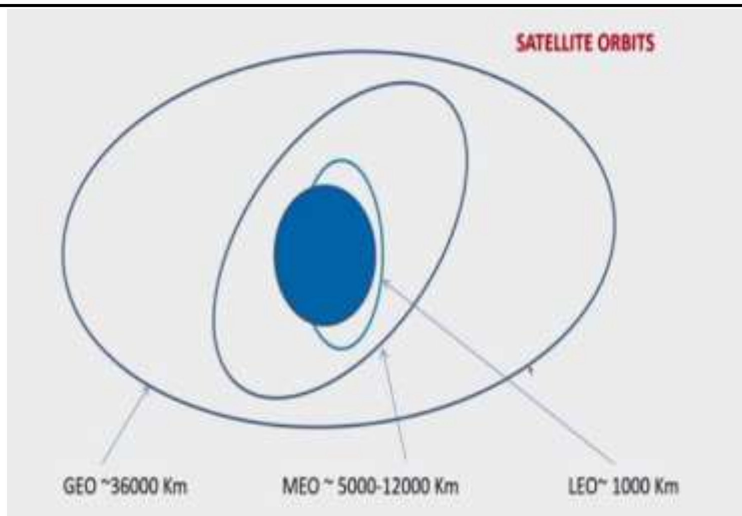
- A Pulse Doppler radar is a radar,which combines both the techniques of Pulse radar and Doppler Radar.
- The return of pulse radar from moving target will contain a doppler Shift,which can be used to determine both the range and velocity,of a target with single radar.
- A major disadvantage of pulse radar is that distinguishing a true target and clutter returns from the ground,buldings,trees etc is a tedious work.
- However for a moving target such as airport ,surveillance radar application,the doppler shift can be used to separate its return from clutter, which is stationary relative to the radar.

We discussed the fundamentalprinciples behind the operation of these radar system.

Terrestrial and Satellite Communication

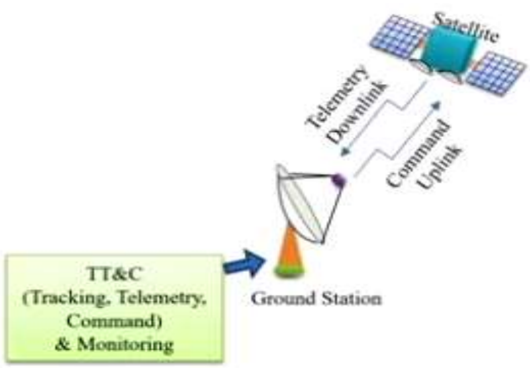




Advantages of Satellite Communication

- Wide Coverage
- Coverage of Remote Areas
- Distant Independent Costs
- Fixed Broadcast Cost
- High Capacity
- Low error rates can be achieved

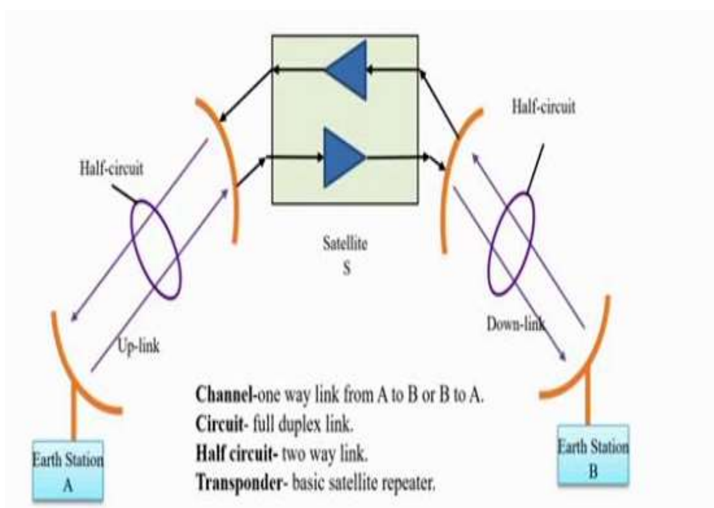
Satellite Communication Segments



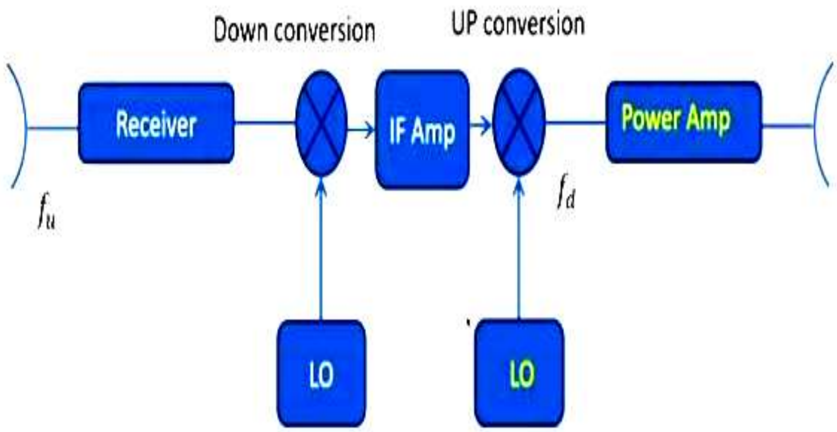
The space segment includes the satellite (or satellites) in orbit in the system, and the ground station that provides the operational control of the satellite(s) in orbit.
The ground station is referred to as the ***Tracking, Telemetry, Command (TT&C)*** or the ***Tracking, Telemetry, Command and Monitoring (TTC&M)*** station.

The ground segment of the communication satellite system consists of terminals that utilize the communications capabilities of the Space Segment.
The different types of ground terminals are **fixed (in-place) terminals , transportable terminals or mobile terminals.**

Base link parameters in Satellite Communications

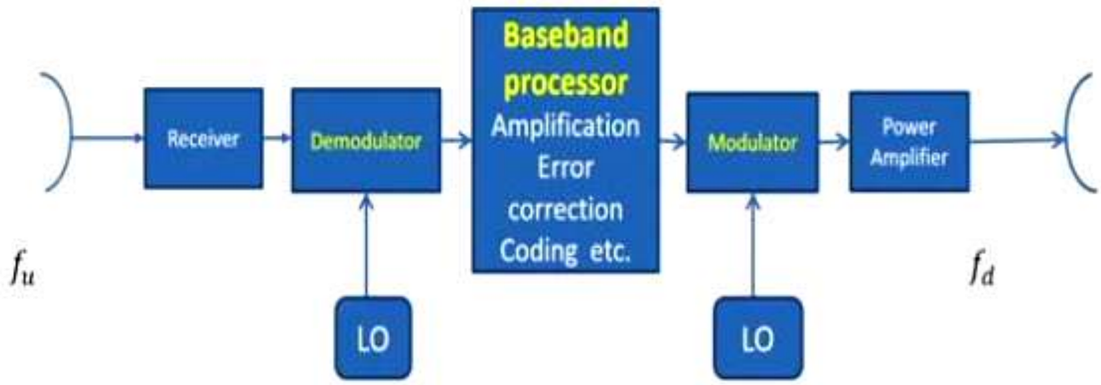


Frequency Translation Transponder(non regenerative type)



Because in the transponder, we can see we have an antenna, f_u isthe uplink frequency. Then we have a receiver, which might consist of the band pass filter, LNA. And, then we have down Conversion of this frequency to some intermediate frequency by multiplying with a local oscillator. And, then the amplification is performed at the intermediate frequency. And, after amplification it is up converted to another frequency f_d which is downlink frequency. And, here then it is given to a power amplifier where the signal power is raised to appropriate level for transmission, And then it is transmitted to the earth station located in the ground. So these devices particularly this power amplifier, it must provide enough power so that detectible signals are obtained. And, if you remember, the distance for a GEO stationary satellite was 36000 kilometers. So, what we required that enough power of transmitted so that the signal can cover this distance and still remain detectable at the ground station. So, this type of transponder does the frequency translation only, and of course it amplifies the signal. This is called a **non-regenerative type.**

Regenerative Transponder



We see that in a Regenerative transponder it is not only the frequency translation from f_u to f_d signal actually gets demodulated.

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Link Budget

From Friis' formula and when l represents losses other than free space loss,

$$C = EIRP\left(\frac{\lambda}{4\pi R}\right)^2 \frac{G_r}{l}$$

Carrier to noise ratio can be found as: $\frac{C}{N} = EIRP\left(\frac{\lambda}{4\pi R}\right)^2 \frac{G_r}{lkT_S B}$

$$\left[\frac{C}{N}\right]_{dB} = [EIRP]_{dBW} - \mathrm{FSL} - \mathrm{L} - \left[\frac{G_r}{T_s}\right]_{dB} + 228.6 - 10\log B$$

t

So to determine the power that we required to transmit i.e from satellite to the ground earth station, so this is calculated using link budget calculation. And, we outline a simple link budget calculation from Friis formula and if we consider representing the losses other than free-space loss. We have seen that the signal becomes weak when it propagates because of spreading, which we call free space loss. Other than that, there are several other losses as we have mentioned, there is absorption due to gaseous particle may be absorption due to rainfall, so all these losses are accounted by l. Then C usually is denoted as carrier power; it is equal to EIRP. EIRP is the effective isotropic radiated power. And, essentially represent the term PtGt in Friis formula

Radio Frequency Identification(RFID)

It uses electromagnetic fields to automatically identify and track tags to attached objects. The tags contain electronically stored information. Passive tags collect energy from a nearby RFID reader's interrogating radio waves. Active tags have a local power source and may operate hundreds of meters from the RFID Reader. RFID tags are used in many industries. For example RFID tag attached to an automobile during production can be used to track its progress through the assembly line, RFID tagged pharmaceuticals can be tracked through ware house, Since RFID tags can be attached to cash, clothing,or implanted in animals and people ,the possibility of reading personally linked information without consent has raised serious privacy concerns.

Types of RFID

With in the Electromagnetic Spectrum there are three primary frequency ranges used for RFID transmissions low frequency,High frequency,and Ultra High frequency.Low Frequency.

- General frequency Range :30-300KHz
- Primary frequency range: 125-134kHz
- Applications:Animal tracking,Access control,Applications with high volumes of liquids and metals.

High Frequency:

- Primary Frequency Range: 13.56MHz
- Applications: DVD kiosks , Library Books, Personal ID Cards.

Ultra -High Frequency

- General Frequency Range:300-3000MHz
- Primary Frequency Range:433MHz,860-960MHz

There are two types of RFID that reside within the Ultra High Frequency range:

1. Active RFID
2. Passive RFID

Active RFID

- Have built-in power cell
- Can be read and updated from hundreds of kilometers
- Transmit at higher power levels , more effective in "RF challenged" environments.
- Have a battery life of up to 10 years. They have larger memories
- Ability to store additional information sent by the transceiver

Passive RFID-

- No internal power supply
- Minute electrical current induced in the antenna by the incoming radio frequency signal provides power
- Antenna has to be designed to both collect power from the incoming signal and also to transmit the outbound backscatter signal
- The device can be quite small

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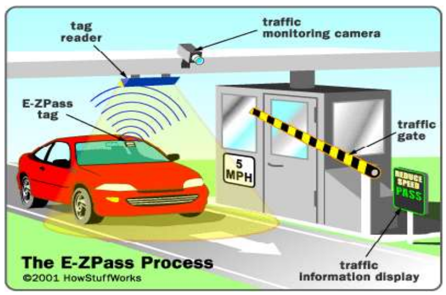
RFID Applications

Automatic Vehicle identification

E -Z pass used on US highways for automatic vehicle identification and toll extraction



Uses of RFID in Consumer products industry

RFID technology is widely used in the supply chain industry

- Just-in-time manufacturing
- Product loss and also identity the theft
- Warrantee claims and after sales support

Human Identification

- RFID technology in passport
- Identifications of persons to enter a certain restricted area
- Authenticity of the students

Uses in Libraries

- Maintain inventory
- Scan stacks of books at a time
- Simplifies issuing of books and also self-return.

RFID uses in health care industry

- Manage costly and critical equipments
- Improve supply chain efficiencies
- Ensure legitimate drugs enter the supply chain

GPS (GLOBAL POSITIONING SYSTEM)

It is a satellite navigation system that furnishes location and time information in all climate conditions to the user.GPS is used for navigation in planes,ships,cars and trucks also. The system gives critical abilities to military and civilian users around the globe.GPS provides continuoes real time,3-dimensional positioning ,navigation and timing worldwide.It consist of three segments:

- Space segment
- Control segment
- User segment
- Space Segment-
- The space segment is the number of satellites in the constellation. It Comprises of 29 satellites circling the earth every 12 hours at 12,000miles in altitude.

- Control Segment-The control segment comprises of a master control station and five monitor stations outfitted with atomic clocks that are spread around the globe.
- User Segment-The user segment comprises of the GPS receiver, which receives

the signals from the GPS satellites and determine how far away it is from each satellite.

Advantages of GPS

- GPS satellite based navigation system is an important tool for military, Civil and commercial users.
- Vehicle tracking systems GPS based navigation systems can provide us with turn by turn directions.
- Very high speed

Disadvantages of GPS

- GPS satellite signals are too weak when compared to phone signals, so it doesn’t work as well indoors, underwater, under trees etc.
- The highest accuracy requires line of sight from the receiver to the satellite, this is why GPS doesn't work very well in urban environment.
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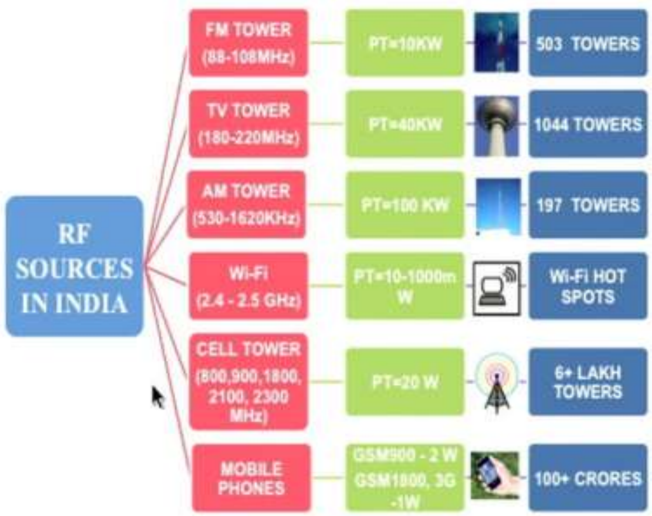
L-41

Modern Trends in Microwave Engineering: Effect of Microwaves on Human Body

RF Sources



RF Sources-Defense

Radar Systems – Pulsed and Continuous

High Power Microwave Sources

HF, VHF, UHF, and Microwave Transmitters

Microwave Bomb

Microwave Weapon

Microwave Heating Principle

Microwave radiation causes vibration in the water molecules, which leads to friction and heating. The radiation effects are classified as:

- **Non-thermal**
- **Thermal**

Current exposure safety standards are based on the thermal effects, which are inadequate.

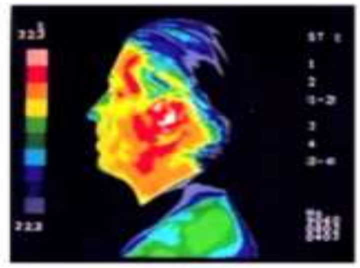
Non-thermal effects are several times more harmful than thermal effects.

How that is related with the human body?

Example- Human body consists of 70 percent liquid and in fact, our human brain consists of 80 percent liquid. So, what happens if we keep the phone like this here so, this microwave radiation which are coming so, they start vibrating water, fluid and blood molecules and these things start vibrating, if it is a 900 megahertz technology. Then they are vibrating at a speed of 900 million times per second and inside the body then these things actually cause DNA damage which Is known as non- thermal effect and that friction then leads to heat and that is known as thermal effect. Non thermal effects are several times more harmful than thermal effects.

Cell Phone Ear -Warming

Have you ever noticed warm sensation in ear after using mobile phone for a long time?



Temp. of ear lobes increases by $1^{0}C$ when cell phone is used for approx. 20 minutes.

Warm sensation ⟹ pain ⟹ irreversible hearing loss and/or Ear Tumor

SAR and cell phone use time limit

6 minutes/day usage.

A cell phone transmits 1 to 2 watts of power

SAR (Specific absorption rate) - Rate at which radiation is absorbed by human body, measured in watts per kg (W/kg).

In USA, max. SAR limit for cell phones is **1.6W/Kg** which is for **6 minutes.** It has a safety margin of 3 to 4, so a person should not use cell phone for more than **18 to 24 minutes per day.**

This information is not given to people in India.

I Phone 7 RF exposure information

The highest SAR values of Models A1660, A1780 are:

1.6 W/kg (over 1 g) SAR Limit

Head: 1.19, Body: 1.20

To reduce exposure to RF energy, use a hands-free option, such as built-in speakerphone, the supplied headphones, or other similar accessories.

Carry iPhone at least 5mm away from your body to ensure exposure levels remain at or below the as-tested levels.

WHO: cell phones can increase cancer risk

International Agency for Research on Cancer (IARC), a part of **WHO designates cell phones as "Possible Human Carcinogen" [Class 2B]**

Found evidence of increase in glioma and acoustic neuroma brain cancer for mobile phone

World Health Organization

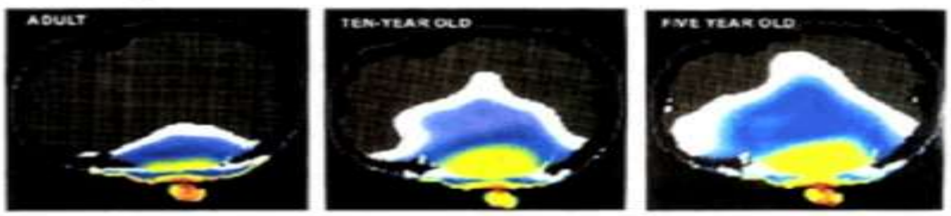
International Agency for Research on Cancer

World Health Organization

Risk to Children

Children are more vulnerable as:

- Skulls are smaller & thinner - ↑'s radiation absorption
- ↑rate of Cell division - more susceptible to genetic damage
- Myelin sheath not developed - Electrical brain-wave activity
- Immune system not well developed - less effective against fighting cancer growth



RF penetration in the skull of an adult (25%), 10 year (50%) and 5 year old (75%)

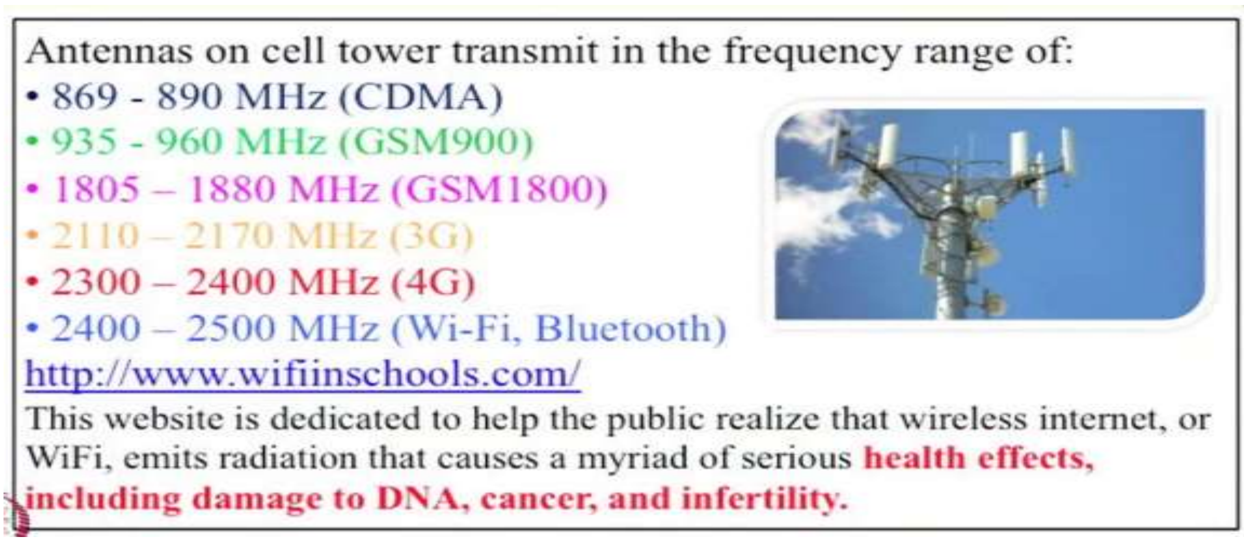
Brain Tumour among chidren on risk in India

THE ASIAN AGE: July 10, 2017

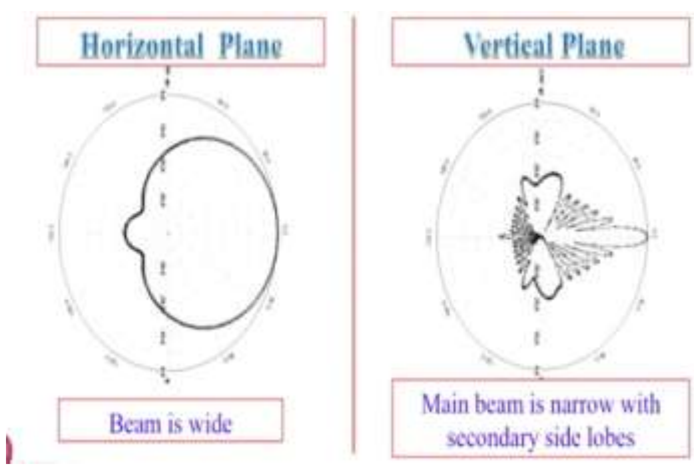
According to a study in 2016, every year 40,000-50,000 persons are diagnosed with brain tumour in India, out of which 20 per cent are children. The study showed a drastic increase in the cases of brain tumour in children post 2015. Doctors said that this could be attributed to long-term mobile use.

"There is a lot of literature that establishes a link between mobile radiation and brain tumour. Mobile phones emit radiation from their antennas and kids are at high risk as they possess soft tissues near the ear. It is advisable for children, adolescents, and also pregnant women, to use headphones while on call or use the speaker," said Dr P.K. Sethi, professor and consultant of the neurology department at Sir Ganga Ram Hospital.

Cell Tower Antenna Radiation

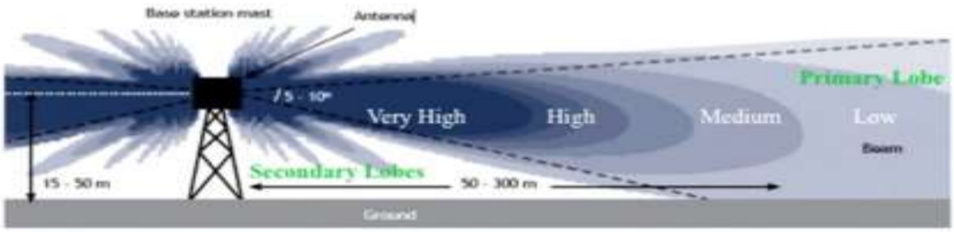


Radiation Pattern of Antenna



Radiation Pattern of cell tower Antenna

Power density varies by $1/R^2$, where R = Distance from tower



People living within 50 to 300 meter radius are in the high radiation zone (dark blue) and are more prone to ill-effects of electromagnetic radiation

People living at < 50m are in extremely high radiation zone

Biological Effects

Neurodegenerative Disorders –Alzheimer, Parkinson's

Immune System Degradation

Tinnitus and Ear Damage

Irreversible Infertility

Effect on Skin

DNA Damage

Increase in Cancer Risk

Most Common Complaints

- Sleep disruption
- Headache
- Concentration
- Forgetful memory
- Depression
- Fatigue
- Dizziness
- Palpitations of the Heart
- Visual Disorders
- Cardiovascular Problems
- Buzzing in the Head
- Altered Reflexes

DNA Damage

Single and double strand breaks observed in DNA from microwave exposure at levels below the current FCC exposure standard.

Fig.1 Unexposed control. Bundle of DNA (No-Tail)

Fig.2 X-ray calibration 25.6 rads. DNA breaks are very obvious

Fig.3 Cell Phone level microwave exposure 2hrs 2.45GHz reaching so called safe SAR levels Comet Tail = DNA Damage

Prof. Henry Lai
University of Washington
1995, Diem *et al. 2005*

When Damage to DNA > Rate of DNA repaired, there is possibility of retaining mutations and initiating cancer

Effects On Birds and Animals

Have you ever seen any bird near cell towers?
May be not, because birds have more volume and less weight, so heating effect is very fast.

Birds and Bees

- Interfere with navigation and reproduction

Animals

- Dairy cows – Decreased milk production, reproductive and developmental problems and decline in overall health.
- Sheep, dogs, cats, rabbits living near base stations affected.

- There is RF radiation from cell phones, cell towers, computers, laptops, AM, FM, and TV towers, leakage from microwave oven, Wi-Fi, Radars, etc., which are additive.
- In addition, there is radiation from overhead high voltage transmission lines, which has been classified by WHO as Class 2B (Possible Carcinogen) in 2002.
- **The awareness must be created among the people. People should unite to convince Govt. of India to adopt stricter radiation norms.**

L-42

Monolithic Microwave Integrated Circuits

Outlines of this Lecture

- Planar Transmission lines for MIC
- Lumped elements for MIC
- Hybrid Microwave Integrated Circuits
- Basics of Monolithic Microwave Integrated Circuits

Planar Transmission lines

- Planar structures are most suitable as circuit elements in MICs
- In a planar geometry, the characteristics of the element can be determined from the dimensions in a single plane.
- Different forms of transmission lines are: stripline, microstrip line, inverted microstrip line, slot line, coplanar waveguide, etc.
- Advantages: light weight, small size, improved performance, better reliability, and low cost.
- They are also compatible with solid state chip devices.

Strip Line

- Dominant mode in a stripline is TEM mode.
- Characteristic impedance can be expressed as:

$$Z_0 = \frac{30\pi}{\sqrt{\epsilon_r}} \frac{b}{W_e + 0.441b}$$

where, W_e is the effective width of the central conductor

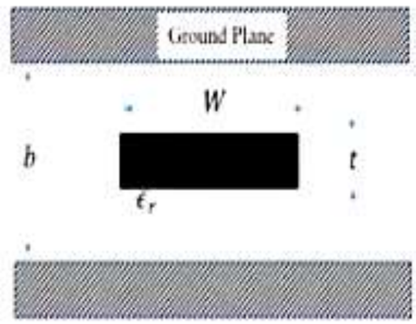
$$\frac{W_e}{b} = \frac{W}{b} - \begin{cases} 0 & \frac{W}{b} > 0.35 \\ (0.35 - W/b)^2 & \frac{W}{b} < 0.35 \end{cases}$$

For a given Z_0 ,

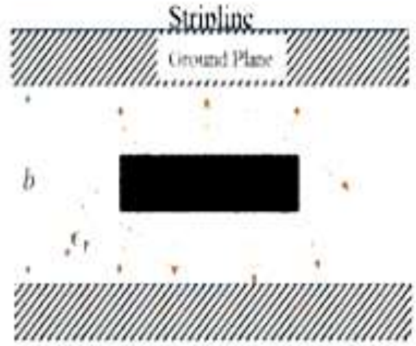
$$\frac{W}{b} = \begin{cases} x & \sqrt{\epsilon_r} Z_0 < 120\,\Omega \\ 0.85 - \sqrt{0.6 - x} & \sqrt{\epsilon_r} Z_0 > 120\,\Omega \end{cases}$$

where,

$$x = \frac{30\pi}{\sqrt{\epsilon_r} Z_0} - 0.441$$



Stripline



Stripline

The characteristic impedance for a finite conductor thickness can be expressed as:

$$Z_0 = \frac{30}{\sqrt{\epsilon_r}} \ln\left\{1 + \frac{4b - t}{\pi W^t}\left[\frac{8b - t}{\pi W^t} + \sqrt{\left(\frac{8b - t}{\pi W^t}\right)^2 + 6.27}\right]\right\}$$

$$\frac{W^t}{b - t} = \frac{W}{b - t} + \frac{\Delta W}{b - t}$$

$$\frac{\Delta W}{b - t} = \frac{x}{\pi(1 - x)}\left\{1 - \frac{1}{2}\ln\left[\left(\frac{x}{2 - x}\right)^2 + \left(\frac{0.0796x}{\frac{W}{b} + 1.1x}\right)^m\right]\right\}$$

$$m = 2\left[1 + \frac{2}{3}\frac{x}{1 - x}\right]^{-1}$$

$$x = \frac{t}{b}$$

Stripline

Cut off for higher order mode (GHz)

$$f_c = \frac{15}{b\sqrt{\epsilon_r}} \frac{1}{\left(\frac{W}{b} + \frac{\pi}{4}\right)}$$

The characteristic impedance for a finite conductor thickness can be expressed as:

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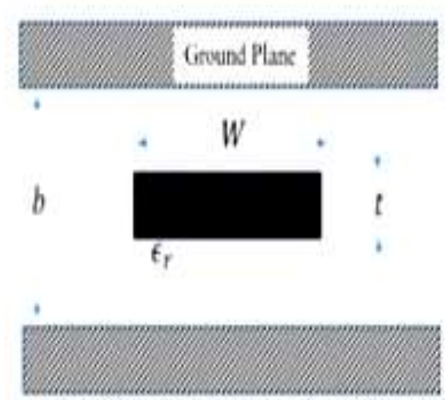


Stripline

Cut off for higher order mode (GHz)

$$f_c = \frac{15}{b\sqrt{\epsilon_r}} \frac{1}{\left(\frac{W}{b} + \frac{\pi}{4}\right)}$$

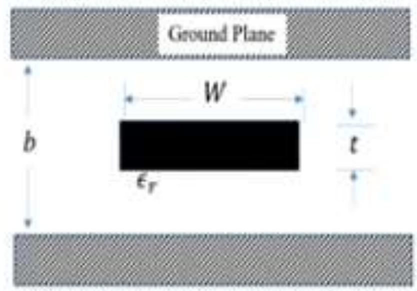
- The attenuation due to conductor loss is given by:

$$\alpha_c = \begin{cases} \dfrac{2.7\times 10^{-3} R_S \epsilon_r Z_0}{30\pi(b-t)} A & \sqrt{\epsilon_r} Z_0 < 120\,\Omega \\ \dfrac{0.16 R_S}{Z_0 b} B & \sqrt{\epsilon_r} Z_0 > 120\,\Omega \end{cases} \quad \text{Np/m}$$

where,

$$A = 1 + \frac{2W}{b-t} + \frac{1}{\pi}\frac{b+t}{b-t}\ln\left(\frac{2b-t}{t}\right)$$

$$B = 1 + \frac{b}{(0.5W + 0.7t)}\left(0.5 + \frac{0.414t}{W} + \frac{1}{2\pi}\ln\frac{4\pi W}{t}\right)$$



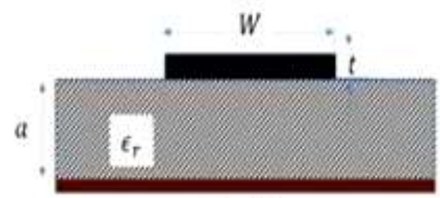
Stripline

Microstrip Line

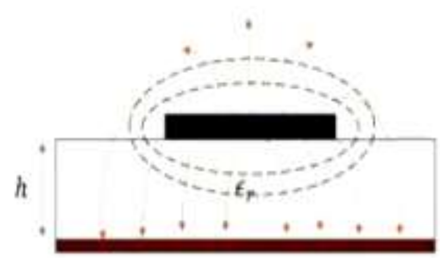
- It is a strip conductor of a width W and thickness t, situated on the top of a planar dielectric.
- Inhomogeneous transmission line as the fields are not contained between the strip and the ground plane.
- Mode of propagation is quasi TEM mode.
- For a given dimension, the characteristic impedance can be obtained as:

$$Z_0 = \begin{cases} \dfrac{60}{\sqrt{\epsilon_{eff}}}\ln\left(\dfrac{8h}{W} + \dfrac{W}{4h}\right), & \dfrac{W}{h} \le 1 \\ \dfrac{120\pi}{\sqrt{\epsilon_{eff}}\left[\dfrac{W}{h} + 1.393 + 0.667\ln\left(\dfrac{W}{h} + 1.444\right)\right]}, & \dfrac{W}{h} \ge 1 \end{cases}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12h/W}}$$



Microstrip line



Fringing in microstrip line

For a given Z_0 and ϵ_r, the $\frac{W}{h}$ can be obtained as

$$\frac{W}{h} = \begin{cases} \frac{8e^A}{e^{2A}-2}, & \frac{W}{h} < 2 \\ \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\epsilon_r - 1}{2\epsilon_r}\left\{\ln(B-1) + 0.39 - \frac{0.61}{\epsilon_r}\right\}\right], & \frac{W}{h} > 2 \end{cases}$$

where,

$$A = \frac{Z_0}{60}\sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1}\left(0.23 + \frac{0.11}{\epsilon_r}\right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}$$

- When the strip width and the substrate thickness are much smaller as compared to the wavelength in the dielectric material, quasi-static method can be used to analyse the microstrip lines.

- The transmission characteristics and the phase constant can be calculated as

$$Z_0 = \frac{1}{c\sqrt{CC_a}}$$

$$\beta = k_0\left(\frac{C}{C_a}\right)^{1/2} = k_0\sqrt{\epsilon_{eff}}$$

where,

C_a = capacitance per unit length of the microstrip with the dielectric materials replaced by air

C = capacitance per unit length of the microstrip with the dielectric materials present

$$\epsilon_{eff} = \left(\frac{\lambda_0}{\lambda_g}\right)^2 = \frac{C}{C_a}$$

- The attenuation due to dielectric loss can be obtained as:

$$\alpha_d = \frac{k_0\epsilon_r(\epsilon_{eff} - 1)\tan\delta}{2\sqrt{\epsilon_{eff}}(\epsilon_r - 1)} \quad \text{Np/m}$$

where, $\tan\delta$ is the loss tangent of the dielectric.

- The attenuation due to conductor loss can be obtained as:

$$\alpha_c = \frac{R_S}{Z_0 W} \quad \text{Np/m}$$

where, $R_S = \sqrt{\omega\mu_0/2\sigma}$ is the surface resistivity of the conductor.

Slot Line

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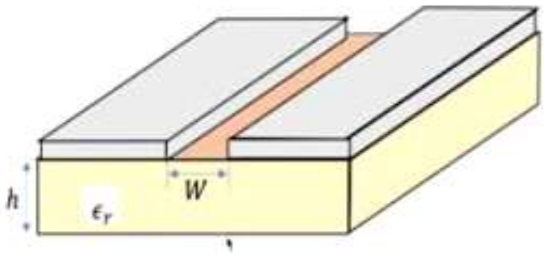


- Useful in circuits requiring high impedance lines, series stubs and short circuits and in hybrid combination with microstrip circuits in MICs.
- The mode of propagation is not TEM but almost TE in nature.
- Consists of a thin slot in the ground plane on one side of a dielectric substrate.
- The characteristic impedance of the line is controlled by the width of the slot.

For $9.7 \le \epsilon_r \le 20$

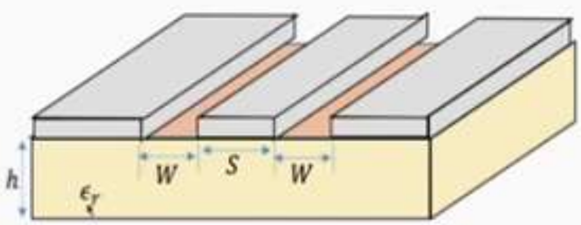
$$0.02 \le \frac{W}{h} \le 1.0$$

$$0.01 \le \frac{h}{\lambda_0} \le \left(\frac{h}{\lambda_0}\right)_c$$

where, $\left(\frac{h}{\lambda_0}\right)_c$ is the cut-off value for TE_{10} surface wave mode on the slot line and is given by

$$\left(\frac{h}{\lambda_0}\right)_c = \frac{0.25}{\sqrt{\epsilon_r - 1}}$$

Coplanar Lines



- Advantages: mounting of lumped element in shunt or series configuration is much easier.
- Support even or odd quasi-TEM modes, depending on whether the electric fields in the two slots are in the opposite direction or the same direction.
- All conductors are in the same plane.

Characteristic impedance is given by:

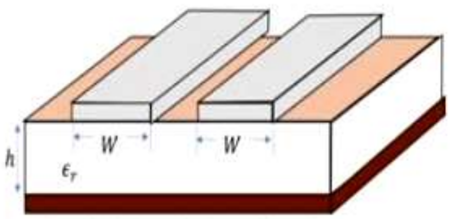
$$Z_0 = \frac{30\pi}{\sqrt{\epsilon_{eff}}} \frac{K(k')}{K(k)}$$

K represents a complete elliptic function of the first kind with K' as its complementary function.

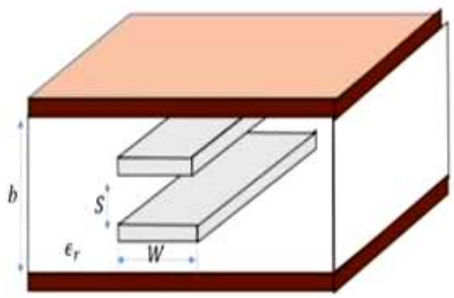
$$k = \frac{a}{b} \qquad a = \frac{S}{2}, \qquad b = \frac{S}{2} + W$$

$K'(k) = K(k')$ and $k' = \sqrt{1 - k^2}$

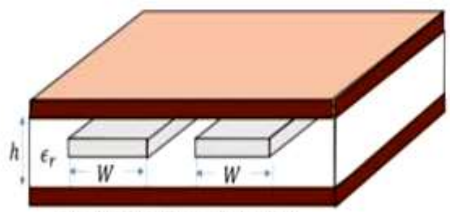
Coupled Transmission lines



Coupled Microstrip Transmission line

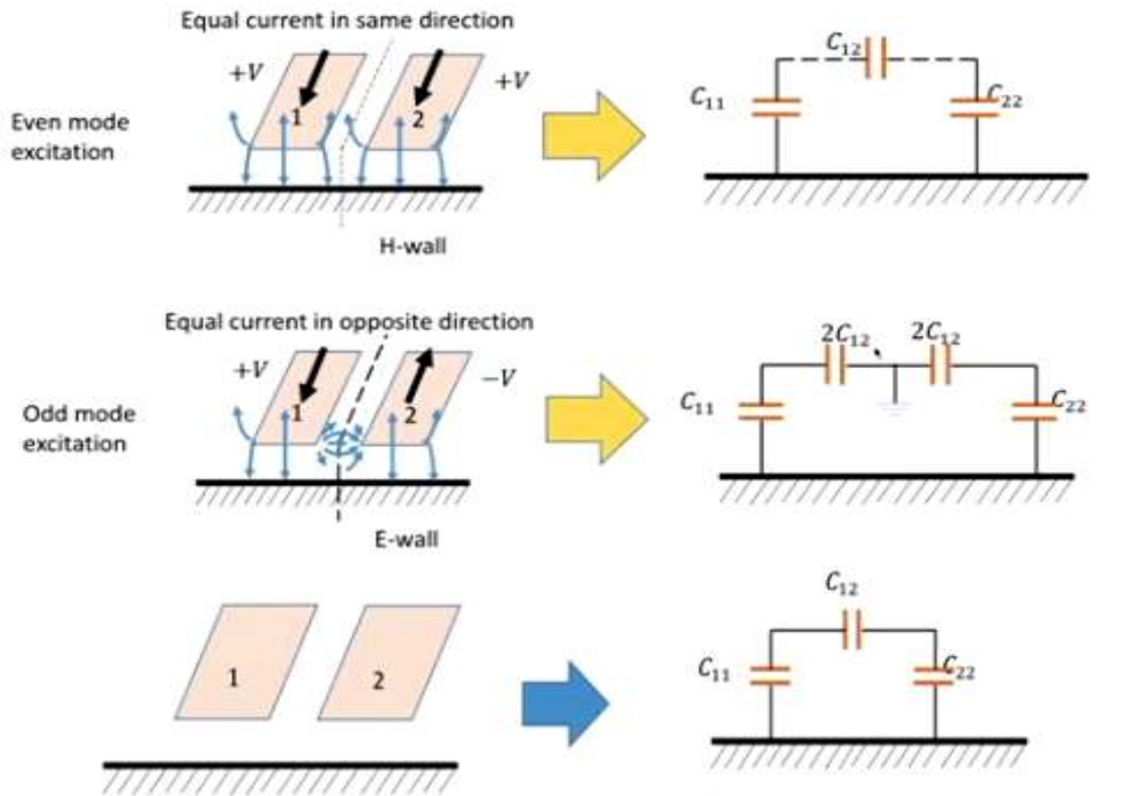


Broadside Strip



Coupled Strip Transmission line

Coupled Line Theory



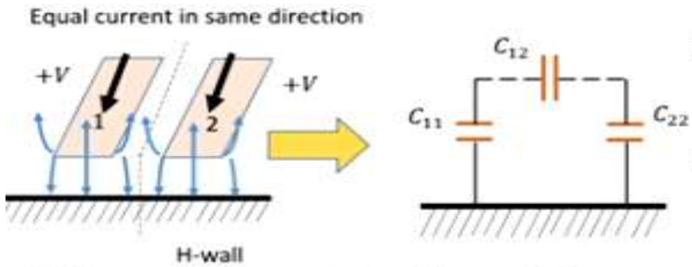
Coupled Lines

Equivalent capacitance circuit of Coupled Lines

C_{11} = Capacitance between the conductor strip 1 and ground.
C_{22} = Capacitance between the conductor strip 2 and ground.
C_{12} = Capacitance between the two conductor strips.

- Consider the lines to be symmetric, and fringing capacitances to be identical for even and odd modes i.e. $C_{11} = C_{22}$.
- In coupled lines, any arbitrary excitation can assumed as a superposition of appropriate amplitudes of even- and odd-mode excitations.

Even Mode Excitation



- Since no current flows between the two strip conductors, C_{12} becomes an open circuit.
- Therefore, the resulting capacitance in even mode excitation is given by:

$$C_e = C_{11} = C_{22}$$

- The characteristic impedance in this mode is

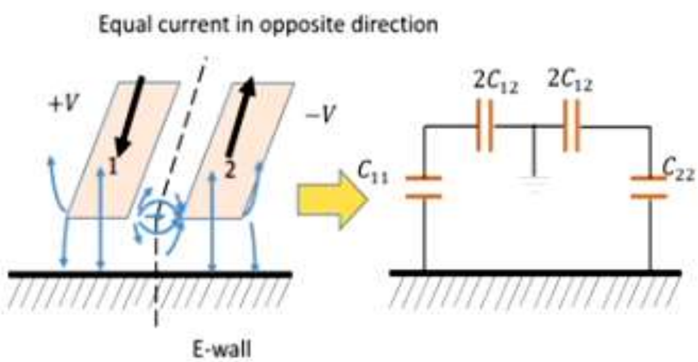
$$Z_{0e} = \sqrt{\frac{L_e}{C_e}} = \frac{\sqrt{L_e C_e}}{C_e} = \frac{1}{v_p C_e}$$

- The propagation constant and phase velocity are the same for both the modes of excitation for a given dielectric constant ϵ_r and are given as:

$$\beta = \frac{\omega}{v_p}$$

$$v_p = \frac{C}{\sqrt{\epsilon_r}} = \frac{1}{\sqrt{L_e C_e}} = \frac{1}{\sqrt{L_o C_o}}$$

Odd Mode Excitation



- Therefore, the resulting capacitance in even mode excitation is given by:

$$C_o = C_{11} + 2C_{12} = C_{22} + 2C_{12}$$

- The characteristic impedance in this mode is

$$Z_{0o} = \sqrt{\frac{L_o}{C_o}} = \frac{\sqrt{L_o C_o}}{C_o} = \frac{1}{v_p C_o}$$

- Due to odd symmetry about the centre line, a voltage null exists between the two conductor strips.
- A ground can be imagined through the middle of C_{12}.

Lumped Elements

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- A lumped element in microwave circuits is defined as a passive component whose size across any dimension is much smaller than the operating wavelength.
- There is no appreciable phase shift between the input and output terminals.
- Generally, maximum dimension less than $\lambda/20$ is a good approximation for the element being lumped, where λ is the guide wavelength.
- RF and microwave circuits use three basic lumped-element building blocks; capacitors, inductors and resistors.

- Lumped-element (LE) circuits typically exhibit a lower quality factor Q than distributed circuits due to smaller element dimensions and the multilevel fabrication process. However, they have the other advantages such as smaller size, lower cost, and wider bandwidth characteristics.
- These characteristics are especially suitable for monolithic MICs and for broadband hybrid MICs where small size requirements are of prime importance.
- Impedance transformations of the order of 20:1 can be accomplished using the lumped-element approach. Therefore, high-power devices with very low input and output impedance values can be matched to 50Ω with impedance transformers made using lumped elements.
- Because lumped elements are much smaller than the wavelength, coupling effects between them when they are placed in proximity are smaller than those of distributed elements.
- In LE-based compact circuits, amplitude and phase variations are smaller due to smaller phase delays. This feature helps further in realizing high-performance compact circuits.

Resistors

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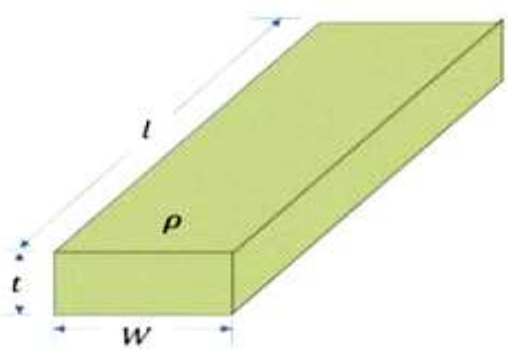
- Lumped-element resistors are used in RF, microwave, and millimetre wave ICs.
- The applications of resistors include terminations, isolation resistors, feedback networks, lossy impedance matching, voltage dividers, biasing elements, attenuators, gain equalizing elements, and as stabilizing or damping resistors that prevent parasitic oscillations.
- The design of these resistors requires a knowledge of several parameters such as: sheet resistance, thermal resistance, current-handling capacity, nominal tolerances, and temperature coefficient of the film.
- Resistors can be realized either by depositing thin films of lossy material on a dielectric base using thin-film, thick-film, or monolithic technologies or by employing semiconductor films on a semi-insulating substrate between two electrodes.
- Nichrome and tantalum nitride are the most popular and useful film materials for thin-film resistors.



Planar resistor geometry

$$R = \rho \frac{l}{A} = \rho \frac{l}{Wt} = \frac{l}{\sigma W t}$$

ρ is the bulk resistivity of the material expressed in Ω-m, σ is the bulk conductivity expressed in S/m

The resistance can also be calculated from the sheet resistance R_S (ohms/square) of the resistive film (for given thickness t)

$$R = R_S \frac{l}{A}, \text{where } R_S = \frac{\rho}{t} = \frac{1}{\sigma t}$$

RF and microwave resistors must have the following properties:

- Sheet resistance in the range of 1 to 1,000 Ω/square;
- Low temperature coefficient of resistance;
- Good stability;
- Required power dissipation capability;
- Low parasitic.

LE resistors can be divided into three categories: chip, monolithic, and multichip module resistors.

Chip resistors

Thin-film and thick-film hybrid technologies are used to make chip resistors.
In thin-film hybrid technology, resistive thin films consisting of nichrome (NiCr) or tantalum nitride (TaN) are deposited on alumina for low-power applications and on beryllia or aluminium nitride for high-power applications.

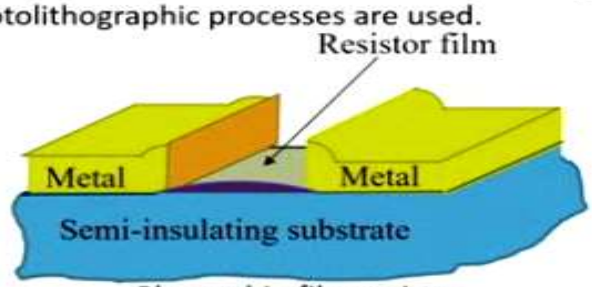
MCM Resistors

MCM (multichip module) technologies include PCBs, cofired ceramic, and thin film on silicon. In PCB technology, the resistor material is deposited on a polyimide layer and covered with another polyimide film for encapsulation.
The electrode connections through contact holes are made with copper using photolithographic techniques.
The resistive film materials used are NiCr, TaN, and CrSi.
The other two MCM technologies use resistor fabrication as used in hybrid and monolithic technologies.

Monolithic Resistors

Resistors are realized either by depositing thin films of lossy metal or by employing bulk semiconductor films on a semi-insulating substrate.

Resistors based on semiconductor (e.g., GaAs or Si) films can be fabricated by forming an isolated land of semiconductor conducting layer .
Photolithographic processes are used.



Planar thin film resistor

In monolithic resistors, the total resistance is the sum of resistive film and the resistance of the two ohmic contacts .

$$R = R_s \frac{l}{W} + 2R_{sc} \frac{l_c}{W_c}$$

Bulk semiconductor resistors form an integral part of MIC fabrication and no additional fabrication steps are required.

The sheet resistance value of such resistors depends on the doping of the material such as n^+, n, n^-.

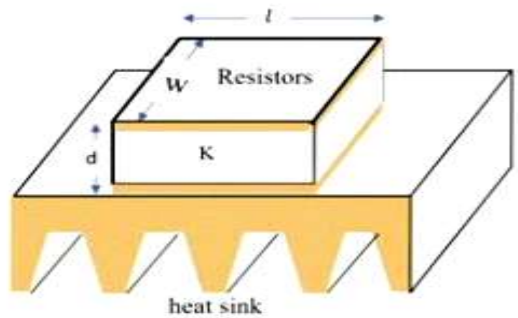
For GaAs semiconductors, the typical value of sheet resistance lies between 100 and 1,500 Ω/square, and is lowest for n^+layers and highest for n^- layers.

Change in surface potential, low current saturation, Gunn domain formation, and large temperature coefficient are some of the issues with GaAs resistors

MMICs use both metal film resistors and active semiconductor layer (e.g., n + ion-implanted) resistors.

Chip resistors are also designed for high power application

The power-handling capacity of a chip resistor is the maximum allowed power dissipation that does not cause the film to burn out and is determined by the temperature rise of the resistor film.



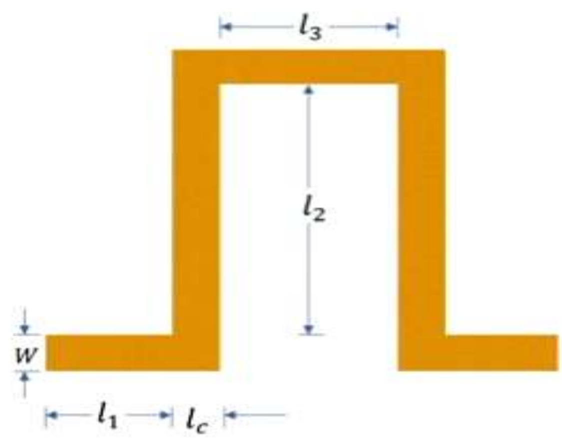
The parameters that determines the maximum power handling are: (1) total power dissipated in the resistor, (2) thermal conductivity of the substrate material, (3) surface area of the resistor film, (4) thickness of the substrate, (5) ambient temperature, or heat sink temperature, and (6) maximum allowed temperature of the resistor film.

Meander Line Resistor

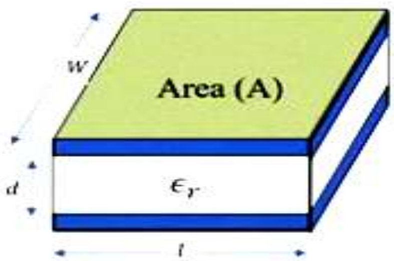
- Normally, small resistors are realized using straight sections of resistive materials.
- Larger and compact resistors take the shape of a meander line.

$$R = \frac{\rho}{W_t}[l + 4(0.44)l_c] \quad \Omega$$

$$l = 2l_1 + 2l_2 + l_3$$



Capacitors



$$C = \epsilon_0 \epsilon_r \frac{A}{d} = \epsilon_0 \epsilon_r \frac{W \times l}{d}$$

Basic parallel plate capacitor configuration

When selecting a capacitor, several parameters need to be considered which include capacitance value, tolerances, thermal stability or temperature coefficient, the quality factor Q, equivalent series resistance, series resonant frequency, parallel resonant frequency, dissipation factor, voltage rating, current rating, insulation resistance, time constant, physical requirements, and cost.

Quality Factor

Quality factor is measures the capacitor's capability to store energy. When a capacitor is represented by a series combination of capacitance C and resistance R_S The Q factor is given by

$$Q = \frac{1}{\omega C R_s} = \frac{1}{2\pi f C R_s}$$

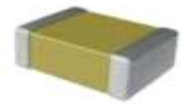
Dissipation Factor or Loss Tangent

The *dissipation factor* (DF) of a capacitor is defined as a ratio of the capacitor's series resistance to its capacitive reactance, that is

$$\mathrm{DF} = \omega C R_s = \frac{1}{Q} = \tan\delta$$

The dissipation factor tells us the approximate percentage of power lost in the capacitor and converted into heat.

Chip Capacitor



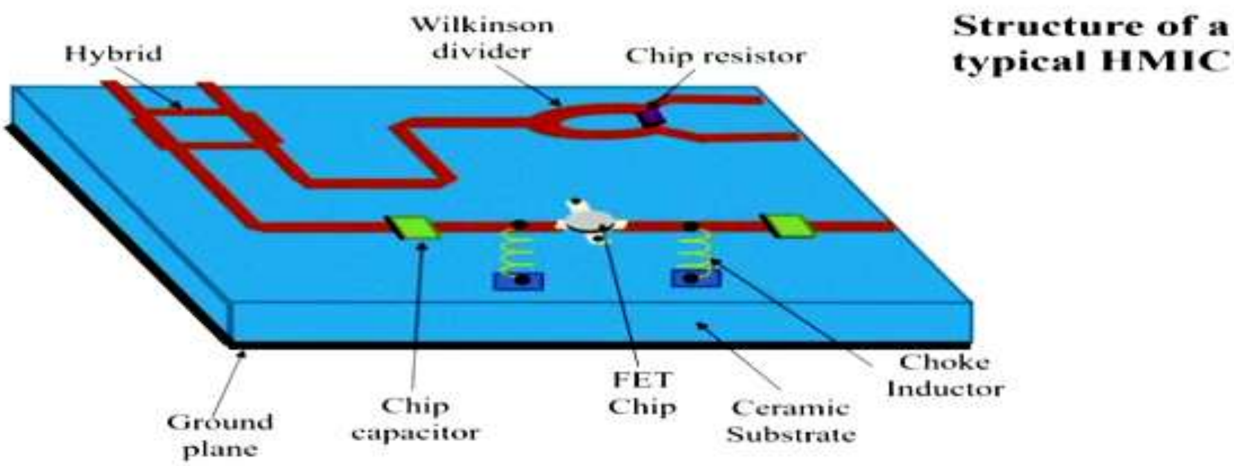
Chip capacitors are of the parallel plate type and are an integral part of RF and microwave ICs.
They are made by sandwiching high-dielectric-constant materials between parallel plate conductors.
Dielectric materials used are of ceramic or porcelain or similar type material.

These capacitors can be connected using surface mounting techniques or soldered or they are epoxied and connected with gold wires or ribbons.

The dielectric in a capacitor can be of the single layer type or of the multilayer dielectric type

Microwave Integrated Circuits(MIC)(HMIC and MMIC)

- Hybrid MIC (HMIC) and Monolithic MIC (MMIC)
- Standard hybrid MICs use a single-level metallization for conductors & transmission lines with discrete circuit elements (such as transistors, inductors, capacitors, etc.) bonded to the substrate.
- Miniature Hybrid MICs use multi-level processes in which passive elements (inductors, capacitors, resistors, transmission lines, etc.) are batch deposited on the substrate and the semiconductor devices are bonded on the substrate. These circuits are smaller than hybrid MICs but are larger than MMICs; therefore also called quasi-monolithic.
- The advantages of miniature hybrid as compared to standard hybrid circuits are: Smaller size, Lighter weight and Lower loss.



Advantages and Disadvantages of HMIC

Advantages:

- Each component can be designed for optimal performance by proper choice of materials.
- High power capability, optimal heat sink for high power generating elements
- Special-purpose devices for each function are not required
- Economical approach when small quantities of the circuits are required

Disadvantage: Wire bonds cause reliability problems

Micro strip Circuit Elements Commonly used in HMIC

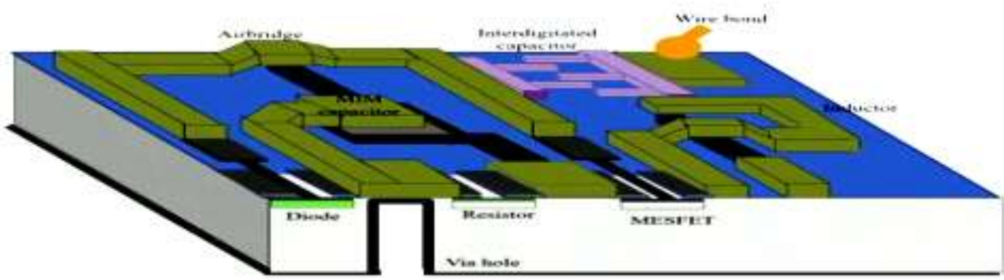
The components that can be fabricated as part of the microstrip transmission line are:

- Matching stubs and transformers
- Directional couplers
- Combiners and dividers
- Resonators
- Filters
- Inductors and capacitors
- Thin film resistors

Monolithic Microwave Integrated Circuits

- Active and passive elements as well as transmission lines are formed into the bulk or onto the surface of a substance by using suitable deposition schemes as epitaxy, ion implantation, sputtering, evaporation, diffusion.
- Designing an MMIC requires extensive use of CAD software for circuit design and optimization, as well as for mask generation. Careful consideration must be given to the circuit design to allow for component variations and tolerance.
- Masks are generated after finalization of circuit design. One or more masks are generally required for each processing step .
- Active layer in the semiconductor substrate is formed for the active devices. This can be done by ion implantation or by epitaxial techniques. Then, active areas are isolated by etching or additional implantation.
- Ohmic contacts are made to the active device areas by alloying a gold or gold/germanium layer onto the substrate. FET gates are then formed with a titanium/platinum/gold compound deposited between the source and drain areas.

- Next step is to deposit the first layer of metallization for contacts, transmission lines, inductors, and other conducting areas.
- Then, resistors are formed by depositing resistive films, and the dielectric films required for capacitors and overlays are deposited.
- A second layer of metallization is done to complete the formation of capacitors and any remaining interconnections.
- The final processing steps involve the bottom, or back, of the substrate. It is first lapped to the required thickness. Via holes are then formed by etching and plating. Via holes provide ground connections to the circuitry on the top side of the substrate, and also a heat dissipation path from the active devices to the ground plane.
- After completing the processing, the individual circuits can be cut from the wafer and tested.



Structure of a typical MMIC

Advantages and Disadvantages of MMICs

Advantages:

- Minimal mismatches and minimal signal delay
- There are no wire bond reliability problems
- Large number of devices can be fabricated at one time into a single MMIC.
- Least expensive when large quantities are to be fabricated.

Some Limitations

- Performance is often compromised, as the optimal materials cannot be used for each circuit element.
- Power capability is lower.
- Trimming and tuning adjustments are difficult.
- Unfavorable device-to-chip area ratio in the semiconductor material.
- MMICs tend to waste large areas of relatively expensive semiconductor substrate for components such as transmission lines and hybrids.
- Tooling is prohibitively expensive for small quantities of MMIC.

Material used for MIC

The basic materials for fabricating MICs, in general are divided into different categories:

- **Substrate materials:** sapphire, alumina, ferrite, silicon, PTFE, quartz, GaAs, Inp, etc.
- **Conductor materials:** copper, gold, silver, aluminum, etc.
- **Dielectric films:** SiO, SiO_2 etc.
- **Resistive films:** Nichrome (NiCr), tantalum nitride(TaN)

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RFMEMS for Microwave Components, Microwave Imaging

RF MEMS

- MEMS stands for micro electromechanical system. MEMS elements ranges in size from 1-100 µm.
- MEMS functional components are controlled under various methods of actuation (e.g. electrostatic, piezoelectric, electromagnetic, electrothermal)
- RF MEMS is one of emerging area of MEMS devices.

RF MEMS Components:

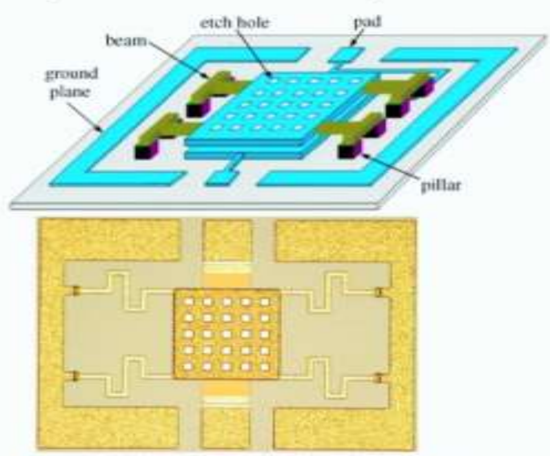
- Variable capacitors
- Inductors
- Switches
- Phase shifters
- Filters
- High Q Resonators
- Antennas
- Micromachined transmission lines

- RF MEMS provides components with reduced size and weight, very low loss, low power consumption, wide bandwidth, higher linearity, lower phase noise, better phase stability and high isolation.

RF MEMS CAPACITORS

- Most important characteristics of lumped capacitors are the tuning range and the quality factor (Q factor), which both should be as large as possible. RF MEMS capacitor is the solution.
- Tunable **RF MEMS capacitors** using
  - **Electrostatic** actuator
  - **Electro-thermal** actuator
  - **Piezoelectric** actuator

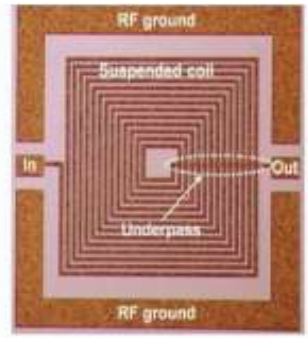
  Application Areas
  - VCO- "Voltage controlled oscillator"
  - Tunable filters
  - Tunable networks
  - Impedance matching
  - Phase shifters



RF MEMS INDUCTORS

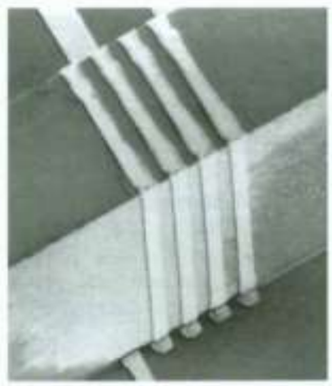
Micromachined inductors offers better performance than present CMOS inductors

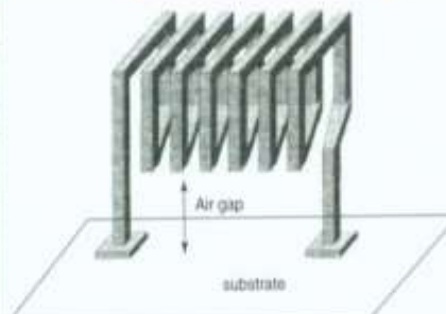
Planar inductors
Solenoids inductors



Applications

–Low noise oscillators
–Integrated LC-filters
–Amplifiers
–On-chip "matching" networks
–Impedance transformers
–Phase shifters





RF MEMS SWITCHES

A radio frequency (RF) microelectromechanical switch is a switching device that is fabricated using the micromachining technology, where the switching between the on- and off-states is achieved via the mechanical displacement of a freely movable structure.

Microwave switch-

- Mechanical-type (coaxial & waveguide)
- Semiconductor-type (PIN diode & FET)

MEMS switches promise to combine the advantageous properties of both mechanical and semiconductor switches.

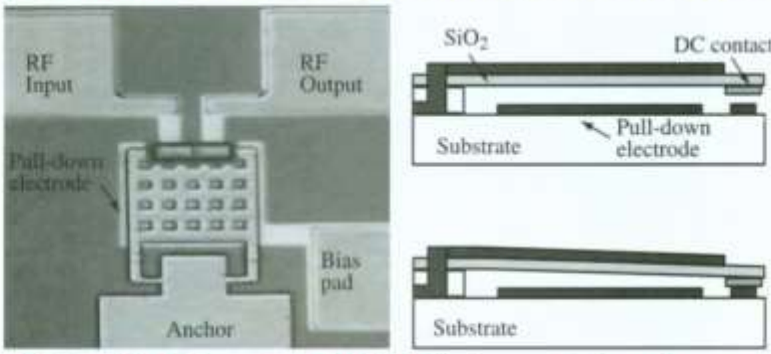
Benefits - Simple principle of electrostatic actuation, Ultra low power consumption, Ultra high isolation, High signal linearity (no intermodulation), Low DC standby power, Low insertion loss, broadband operation.

Challenges - Low switching speed (some µs), Low power handling capability, Reliability of metal contacts (stiction, micro welding, wear-out)

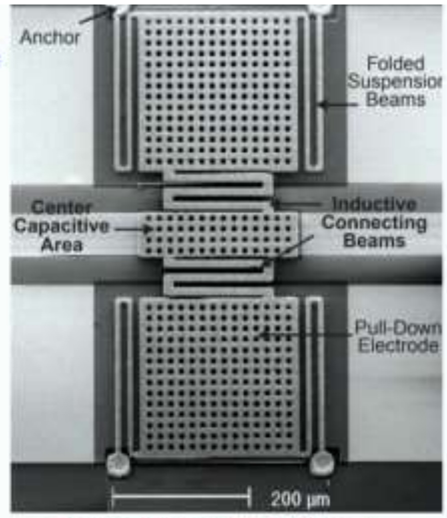
Basic Switch Structures

Series switch- Contact switch, ohmic (relay), Capacitive switch ("contact less")

Shunt switch- Shunt capacitive switch , Shunt contact switch



Motorola DC contact MEMS Series switch and cross section in up and down state



University of Michigan Low voltage MEMS Shunt switch

RF MEMS PHASE SHIFTERS

A. Analog Phase Shifters

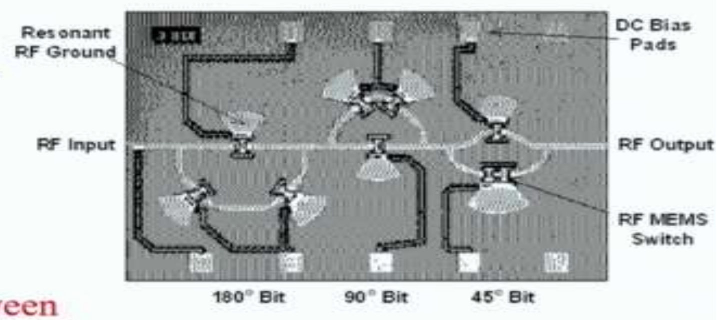
Using distributed, capacitive shunt-switches

B. Digital Phase Shifters-

Based on MEMS switches

–Discrete phase change

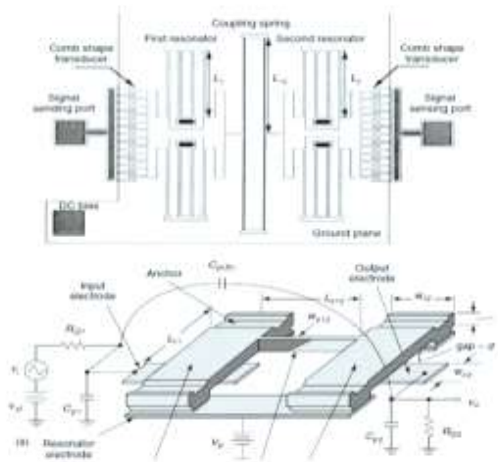
–Phase shift set by switching between different phase paths



Low insertion loss, High isolation, Negligible actuation power and standby power consumption

RF MEMS FILTERS

- The performance for RF MEMS filters is enhanced by using a series of resonator tanks connected together with coupling networks. The number of such tanks used is equal to the order of filter.
- Two resonator configurations are possible.
- In first configuration the structure is driven on one of the comb structures and sensed at the other, for capacitance variations.
- In second configuration, both comb structures are used to drive differentially, while sensing is achieved by monitoring shift in impedance at resonance.



Microwave Imaging

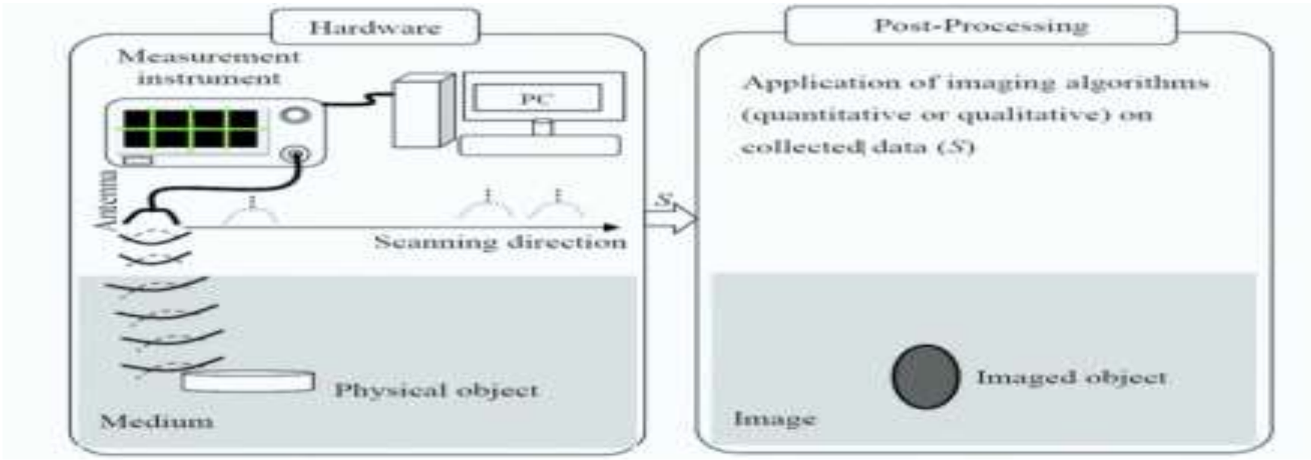
Microwave imaging is a science evolved from older detecting/ locating techniques in order to evaluate hidden or embedded objects in a structure using electromagnetic (EM) waves.

Classification of microwave imaging techniques

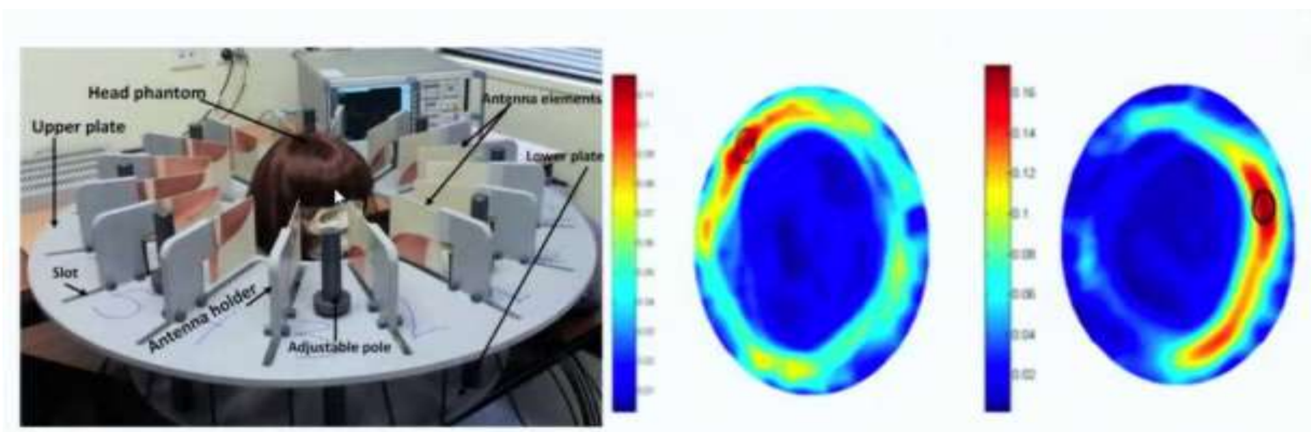
Quantitative techniques – These techniques give the electrical and geometrical parameters of an imaged object.
Qualitative techniques – These techniques calculate a reflectivity function to represent the object profile and use migration based algorithms to reconstruct the unknown image profile.

Synthetic aperture radar (SAR), ground-penetrating radar (GPR) range-Doppler algorithm belong to qualitative microwave imaging techniques.

Principle of Microwave Imaging

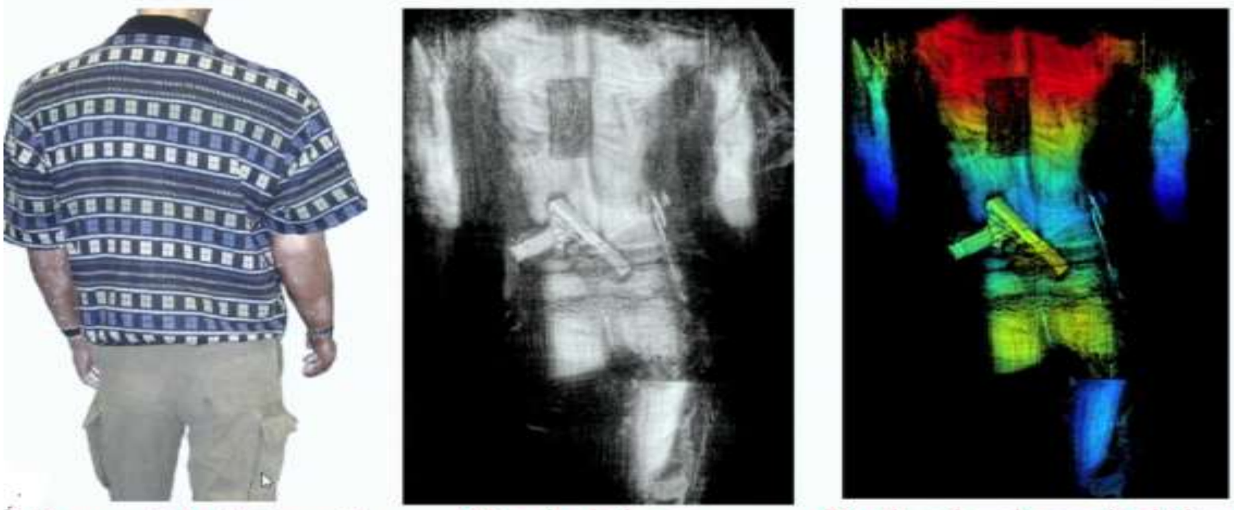


Medical Imaging –Brain stroke Detection



Configuration of the microwave imaging system and (b) reconstructed images with two different locations of a haemorrhagic stroke in a realistic head phantom

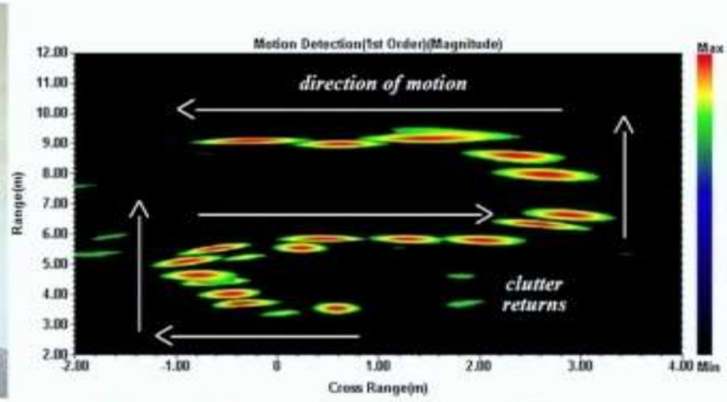
Concealed Weapon Detection



Mannequin's photograph | Magnitude image | Depth-colored magnitude image

Through the Wall Imaging

Through the wall imaging radar system brassboard



Composite image of motion of a person walking behind interior walls.

Doppler Weather Radar