Rajeev Gandhi Memorial College of Engineering and Technology, Nandyal
Autonomous
Department of Electronics and Communication Engineering

COURSE FILE

ACADEMIC YEAR : 2022-23

SUBJECT : Microwave Engineering and Optical Communication

YEAR/SEM : III B.Tech II-Sem

DEPARTMENT : Electronics & Communication Engineering

FACULTY NAME : Mr. S. Kashif Hussain

Dr. Kethepalli Mallikarjuna
HOD of ECE

Dr. KETHEPALLI MALLIKARJUNA
[illegible] MISTE, FIETE, MIE
Professor & HOD
Department of ECE
RGM College of Engg. & Tech. (Autonomous)
NANDYAL - 518 501, Kurnool (Dist.) A.P.

Dr. T. Jayachandra Prasad
Principal

Dr. T. JAYACHANDRA PRASAD
M.E., Ph.D.
PRINCIPAL
R G M College of Engg. & Tech.,
(Autonomous)
NANDYAL-518 501, Nandyal (Dist),A.P.

R.G.M.COLLEGE OF ENGINEERING & TECHNOLOGY, NANDYAL – 518 501
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

III B.Tech., II-Semester **Academic Year: 2022-23**

w.e.f: 09-01-2023

A-Section : RB3130 **B-Section : RB3010**

C-Section : RB3020 **D-Section : RB3030**

Period/ Day	Section	1 9.00 AM To 9.50 AM	2 9.50 AM To 10.40 AM	3 11.00 AM To 11.50 AM	4 11.50 AM To 12.40 PM	5 1.50 PM To 2.40 PM	6 2.40 PM To 3.30 PM	7 3.30 PM To 4.20 PM
MON	A	DC	IEI/ISTE	MW&OC	DSP	DDV	VLSID	COI
	D	VLSID	MW&OC	DC	CO&A	MW&OC Lab/DC Lab		
	B	DSP Lab			CO&A	VLSID	COI	DC
	C	MW&OC Lab/DC Lab			VLSID	DC	CO&A	MW&OC
TUE	A	VLSID	DSP	MW&OC	CO&A	MW&OC Lab/DC Lab		
	D	DC	CO&A	DSP	VLSID	DSP Lab		
	B	MW&OC Lab/DC Lab			MW&OC	DC	CO&A	DDV
	C	DDV	IEI/ISTE	DSP	DC	VLSID	MW&OC	CO&A
WED	A	VLSID	CO&A	MW&OC	DDV	DSP	COI	DC
	D	MW&OC	DDV	DSP	IEI/ISTE	MW&OC Lab/DC Lab		
	B	DC	CO&A	MW&OC	DSP	VLSID	MW&OC	DSP
	C	VLSID	MW&OC	DSP	DC	DSP Lab		
THU	A	MW&OC	CO&A	DSP	DC	MW&OC Lab/DC Lab		
	D	DSP	DC	VLSID	MW&OC	CO&A	COU	COI
	B	MW&OC Lab/DC Lab			VLSID	CO&A	DSP	LIB
	C	DSP	COU	COI	CO&A	MW&OC	VLSID	LIB
FRI	A	MW&OC	CO&A	DC	DSP	VLSID	DDV	COU
	D	DDV	DSP	CO&A	VLSID	MW&OC	DC	LIB
	B	DSP	CO&A	VLSID	DDV	DC	COI	MW&OC
	C	MW&OC	DSP	COI	CO&A	DSP	DDV	DC
SAT	A	DSP Lab			VLSID	DC	CO&A	LIB
	D	VLSID	CO&A	DC	MW&OC	DSP	DDV	COI
	B	MW&OC	DDV	COU	VLSID	DSP	IEI/ISTE	DC
	C	MW&OC Lab/DC Lab			DDV	DC	VLSID	CO&A

Subject	Section	Name of the Faculty
DSP	A	Mr.N.Nagaraja Kumar
MW&OC	A	Mr.S.Kasif Hussain
DC	A	Mr.D.Rajesh Setty
VLSID	A	Smt.M.Maheswari
CO&A	A	Mr.S.V.Ratan Kumar
DDV	A	Mr.J.Leela Mahendra Kumar
COI	A	Mr.Raja Sekar
DSP Lab	A	**Mr.NNK**/PCS/Mr.SLVK/BI
DC Lab	A	**Mr.DRS**/Smt.MM/Mrs.KM
MW&OC Lab	A	**Mr.SKH**/Dr.JSP&Miss.GBB
IEI/ISTE	A	Miss.NFS/Mr.SAB
Councelling	A	Miss.N.Fouzia Sulthana

Subject	Section	Name of the Faculty
DSP	B	Mr.K.Nagendra Kumar
MW&OC	B	Mr.S.Kashim Noor Basha
DC	B	Mr.M.A.Vijaya Kamalnath
VLSID	B	Smt.B.Nazma
CO&A	B	Mrs.K.Mounika
DDV	B	Mr.Y.S.Ponselvan
COI	B	Mr.K.Rama Krishna
DSP Lab	B	**Mr.KNK**/Mr.NNKMr.SLVK/
DC Lab	B	**Mr.MAK**/Smt.BN&PM/Mr.CD
MW&OC Lab	B	**Mr.SKNB**/Mr.KAK
IEI/ISTE	B	Miss.NFS/Mr.SAB
Councelling	A	Miss.N.Fouzia Sulthana

Subject	Section	Name of the Faculty
DSP	C	Mr.K.Nagendra Kumar
MW&OC	C	Mr.S.Kashim Noor Basha
DC	C	Mr.C.Dastagiraiah
VLSID	C	Smt.B.Nazma
CO&A	C	Mr.K.Anil Kumar
DDV	C	Mrs.N.Lakshmi Prasanna
COI	C	Dr.Aliya Sulthana
DSP Lab	C	**Dr.VNVSP**/Mr.KNK/PCS/SL
DC Lab	C	**Smt.BN**/Mr.MAVK/Mr.CD
MW&OC Lab	C	**Mr.KAK**/Mr.SKNB
IEI/ISTE	C	Miss.NFS/Mr.SAB
Councelling	C	Mr.J.Leela Mahendra Kumar

Subject	Section	Name of the Faculty
DSP	D	Mr.Y.Praveen Kumar Reddy
MW&OC	D	Mr.S.Kasif Hussain
DC	D	Mr.D.Rajesh Setty
VLSID	D	Smt.M.Maheswari
CO&A	D	Mrs.G.Yashaswini
DDV	D	Mr.J.Leela Mahendra Kumar
COI	D	Mr.Raja Sekar
DSP Lab	D	**Mr.SAB**/Mr.KNK/Mr.NNK/S
DC Lab	D	Mr.DRS& Smt.MM/Mrs.KM
MW&OC Lab	D	**Mr.MVRS**/Mr.SKH
IEI/ISTE	D	Miss.NFS/Mr.SAB
Councelling	A	Miss.N.Fouzia Sulthana

Dr.K.Mallikarjuna
HOD OF ECE

MALLIKARJUNA
M.Tech, Ph.D, MISTE, FIETE, MIE
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Dr.T.Jaya Chandra Prasad
Principal

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NANDYAL-518 501, Nandyal (Dt), A.P.

III B.Tech, II-Sem (ECE)

L	T	C
2	1	3

(A0424206) MICROWAVE ENGINEERING AND OPTICAL COMMUNICATION

COURSE OBJECTIVES:

- To analyse microwave circuits incorporating hollow, dielectric and planar waveguides, transmission lines, filters and other passive components, active devices.
- To explain how microwave devices and circuits are characterized in terms of their S-Parameters.
- To use microwave components such as isolators, Circulators, Tees, Gyrators etc.
- To give students an understanding of basic microwave devices (both amplifiers and oscillators).
- To learn the basic concepts of fibre optics communications.
- To make the students learn the system with various components or process for various applications.

COURSE OUTCOMES: At the end of this course the students are

- Apply the knowledge of mathematics for analyzing the propagation of different microwaves in different transmission lines.
- Analyze the working principles of different wave guide components using S-parameters.
- Study the performance of specialized microwave tubes such as klystron, reflex klystron, magnetron, travelling wave tube anddifferent solid state devices.
- Attain the knowledge of basic optical fiber communication systems and learn the latest trends in optical communications.
- Recognize and classify the structures, types and channel impairments like losses and dispersion in optical fibers.

MAPPING WITH COS & POS:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2		1												
CO2		3	2										1	2	
CO3		2		1										1	
CO4	2	2	1										1		2
CO5	1	3	2										2	1	

UNIT I

Introduction, Advantages and applications of Microwaves.

Guided Waves: Introduction, Transverse Electric waves(TE), Transverse Magnetic waves(TM), TEM Modes – Concepts, expressions and Analysis, Cutoff Frequencies, Velocities, Wavelengths expressions. Wave equations of Rectangular waveguides, Propagation of TE and TM waves in Rectangular waveguide, Filter Characteristics-Dominant and Degenerate Modes. Mode Characteristics – Phase and Group Velocities, Wave Impedance Relations, Illustrative Problems.

UNIT II

WAVEGUIDE COMPONENTS AND APPLICATIONS: Scattering Matrix– Significance, Formulation and Properties. S Matrix Calculations for – Two port Junction, E plane and H plane Tees, Magic Tee, Two hole Directional Coupler , Ferrites Composition and Characteristics, Faraday rotation; Ferrite Components-Gyrator, Isolator, Circulator.

UNIT III

Microwave Amplifiers and oscillators:

Microwave Tubes: (i) Linear Beam Tubes: Two cavity Klystron amplifier –Construction, Operation, Applegate diagram, output power and efficiency. Reflex Klystron oscillator-Construction, Operation, Applegate diagram output power and efficiency. Travelling Wave Tube (TWT) –Construction, Operation, amplification process and Gain considerations.(ii) Crossed Field Tubes :Magnetron oscillator-Construction, pi-mode operation, power output and efficiency.

Microwave Semiconductor Devices: Gunn Oscillator – Principle of operation, Characteristics, Two valley model, IMPATT, TRAPATT diodes, Parametric Amplifier.

UNIT IV

OVERVIEW OF OPTICAL FIBER COMMUNICATION: Historical development, the general system, Advantages of optical fiber communications. Introduction to Ray theory transmission, Total Internal Reflection, Acceptance angle, Numerical Aperture, Skew rays, V-number, Mode coupling, Step Index fibers, Graded Index fibers, Mode Field Diameter.

UNIT V

Signal degradation inoptical fibers: Signalattenuation- absorption, scattering losses, Bending Losses,Coreand Claddinglosses, Groupdelay, Dispersion-Material dispersion, waveguidedispersion,Inter model dispersion.

UNIT VI:

OpticalSourcesandDetectors:Introduction,LEDs–structure –Lightsource, Quantum efficiency, Modulation of an LED, LASER diodes, Sourceto Fiberpower launching, Fiber Splicing, Optical Fiber connectors, Photodiodes– Principle of Photodiodes, Avalanche Photodiodes, detector response time, Comparisonof Photo diodes.

TEXT BOOKS:

1. Microwave Devices and Circuits – Samuel Y. Liao, PHI, 3rd Edition,1994.
2. Microwave Principles – Herbert J. Reich, J.G. Skalnik, P.F. Ordung and H.L. Krauss, CBS Publishers and Distributors, New Delhi, 2004.
3. Optical Fiber Communications – Gerd Keiser, Mc GrawHill International edition, 4th Edition, 2008.
4. Optical Fiber Communications – John M. Senior, PHI, 2nd Edition, 2002.

REFERENCES:

1. Elements of Microwave Engineering – R. Chatterjee, Affiliated EastWest Press Pvt. Ltd., New Delhi, 1988.
2. Foundations for Microwave Engineering – R.E. Collin, IEEE Press, John Wiley, 2nd Edition, 2002.
3. Microwave Engineering by Pozar,
4. Microwave Engineering and its applications by Om.P.Gandhi.
5. Microwave Circuits and Passive Devices – M.L. Sisodia and G.S.Raghuvanshi, Wiley Eastern Ltd., New Age International Publishers Ltd., 1995.
6. Microwave Engineering Passive Circuits – Peter A. Rizzi, PHI, 1999.
7. Electronic and Radio Engineering – F.E. Terman, McGrawHill, 4th ed., 1955.
8. Micro Wave and Radar Engineering – M. Kulkarni, Umesh Publications, 1998
9. Text Book on Optical Fibre Communication and its Applications – S.C.Gupta, PHI, 2005.
10. Fiber Optic Communication Systems – Govind P. Agarwal, John Wiley, 3rdEdiition, 2004.
11. Fiber Optic Communications – Joseph C. Palais, 4th Edition, Pearson Education, 2004.

RAJEEV GANDHI MEMORIAL COLLEGE OF ENGINEERING AND TECHNOLOGY
AUTONOMOUS
LECTURE PLAN

RGMCET/TP/F-01

NAME OF THE FACULTY: Mr. S.Kashif Hussain
SUBJECT: MICROWAVE ENGINEERING AND OPTICAL COMMUNICATIONS
BRANCH: ECE (A & D-Sections) **YEAR: III** **SEMESTER: II**
Academic year :2022-23

UNIT	TOPIC	NUMBER OF PERIODS	NUMBER OF CUMULATIVE PERIODS
I	Introduction, Advantages and applications of Microwaves. Guided Waves: Introduction, Transverse Electric waves (TE), Transverse Magnetic waves (TM), TEM	2	2
	Modes – Concepts, expressions and Analysis. Propagation of TE and TM waves in rectangular waveguide.	3	5
	Cutoff Frequencies, Velocities, Wavelengths expressions. Wave equations of rectangular waveguides,	3	8
	Filter Characteristics- Dominant and Degenerate Modes. Mode Characteristics	2	10
	Phase and Group Velocities, Wave Impedance Relations,	2	12
	Illustrative Problems	2	14
II	**WAVEGUIDE COMPONENTS AND APPLICATIONS**: Scattering Matrix– Significance, Formulation and Properties.	2	16
	S Matrix Calculations for – Two port Junction, E plane and H plane Tees, Magic Tee	3	19
	Two-hole Directional Coupler, Ferrites Composition and Characteristics,	2	21
	Faraday rotation; Ferrite Components- Gyrator, Isolator, Circulator	3	24
III	**Microwave Amplifiers and oscillators:** Microwave Tubes: (i) Linear Beam Tubes: Two cavity Klystron amplifier – Construction, Operation, Applegate diagram, output power and efficiency.	2	26
	Reflex Klystron Oscillator-Construction, Operation, Applegate diagram	2	28
	output power and efficiency.	1	29
	Travelling Wave Tube (TWT) –Construction, Operation, amplification process and Gain considerations.	2	31
	(ii) Crossed Field Tubes: Magnetron Oscillator-Construction, pi-mode operation.	2	33
	power output and efficiency	1	34
	Microwave Semiconductor Devices: Gunn Oscillator – Principle of operation, Characteristics, Two valley model,	3	37
	IMPATT, TRAPATT diodes, Parametric Amplifier	3	40
IV	OVERVIEW OF OPTICAL FIBER COMMUNICATION: Historical development, the general system, Advantages of optical fiber communications.	2	42
	Introduction to Ray theory transmission, Total Internal Reflection,	3	45
	Acceptance angle, Numerical Aperture, Skew rays, V-number,	2	47
	Mode coupling, Step Index fibers, Graded Index fibers, Mode Field Diameter	3	50
V	Signal degradation in optical fibers: Signal attenuation-absorption, scattering losses,	3	53

	Bending Losses, Core and Cladding losses	2	55
	Group delay. Dispersion-Material dispersion, waveguide dispersion,	3	58
	Inter model dispersion.	2	60
VI	Optical Sources and Detectors: Introduction, LEDs–structure –Light sources, Quantum efficiency,	3	63
	Modulation of an LED, LASER diodes,	2	65
	Source to Fiber power launching, Fiber Splicing, Optical Fiber connectors,	2	67
	Photodiodes– Principle of Photodiodes,	1	68
	Avalanche Photodiodes, detector response time, Comparison of Photo diodes.	2	70

S.kashif Hussain

FACULTY

(S.kashif Hussain)

HOD

RGM COLLEGE OF ENGINEERING & TECHNOLOGY

(AUTONOMOUS)

NANDYAL - 518 501. Kurnool (Dist.) A.P.

EDUCATION FOR PEACE

(ESTD-1995)

ATTENDANCE REGISTER

III - II MW&OC (A/S - ECE)

ACADEMIC YEAR	: 2022-23	SEM	: I / II
COURSE	: III B Tech	CLASS :	
BRANCH / SECTION	: ECE Sec A		
SUBJECT & CREDITS	: M.W & OC		
FACULTY	: S. KashifHossain.		

R.G.M. COLLEGE OF ENGINEERING
ATTENDANCE

Class : III B.Tech
Branch : E.C.E
II Semister / Year III

Roll No.	Name	10/1/23	11/1/23	12/1/23	18/1/23	19/1/23	20/1/23	23/1/23	24/1/23	25/1/23	25/1/23	27/1/23	30/1/23
		1	2	3	4	5	6	7	8	9	10	11	12
403	S. Almas Bhanu	1	2	3	4	5	6	7	8	9	10	11	12
404	S. Anitha rani	1	2	3	A	4	5	6	7	8	9	10	11
408	B. Aruna kumari	1	2	3	A	A	4	5	6	7	8	9	10
419	K. chandralekha	A	A	A	A	1	2	3	4	5	6	7	8
435	K. Ganga Sravani	1	2	3	4	5	6	7	8	9	10	11	12
436	K. Gayathri	A	A	A	A	A	1	2	3	4	5	6	7
437	S. Gayathri	1	2	3	4	5	6	A	7	8	9	10	11
439	S. Gousiya.	1	2	3	4	5	6	7	8	9	10	11	12
450	B. Indu	A	A	A	A	A	1	A	2	3	4	5	6
466	T. Kavya sri	1	2	3	4	5	6	7	8	9	10	11	12
469	M. keerthana.	A	A	A	A	1	2	3	4	5	6	7	8
470	Gowni keerthi	A	A	A	1	2	3	4	5	6	7	8	9
471	G. Keerthi	A	A	A	1	2	3	4	5	6	7	8	9
472	S. keerthi	1	2	3	A	4	5	6	7	8	A	A	9
475	G. Kri Deepthi	1	2	3	4	5	6	7	8	9	10	11	12
478	T. Lakshmi prasanna	1	2	3	A	4	5	6	7	8	9	10	11
479	G. Lakshmi priya	A	A	A	1	2	3	4	5	6	7	8	9
480	K. Likhitha	A	A	A	A	1	2	3	4	5	6	7	8
480	V. Maheswara Reddy	1	2	3	4	5	6	7	8	A	9	10	11
490	T. Manasa	A	A	A	1	A	2	3	4	A	A	5	6
497	B. Murali	1	2	3	A	4	5	6	7	8	9	10	11
4A3	A. Naga sudha Rohini	A	A	A	1	2	3	4	5	6	7	8	9
4C1	M. poojitha	A	A	A	A	A	1	2	3	4	5	6	7
4A4	R. Pradeep Reddy	A	A	A	A	A	A	1	2	A	3	4	5
4C9	O. Pravallika.	1	2	3	4	5	6	7	A	8	9	10	11
4D3	P. Pushpa Latha	A	A	A	A	1	2	3	4	5	6	7	8
4D7	C. Rajeshwari	A	A	A	1	2	3	4	5	6	7	8	9
4D9	T. Rakshitha	A	A	A	A	1	2	3	4	5	6	7	8
4E0	T. Rakshitha	A	A	A	1	2	3	4	5	6	7	8	9
4E1	V. Ramesh.	A	A	A	A	1	2	3	4	A	A	A	5
Signature of Teacher		d	d	d	d	d	d	d	d	d	d	d	d
Signature of H.O.D.													
Signature of Principal													

& TECHNOLOGY (Autonomous), NANDYAL.

REGISTER Academic Year from 2022 to 2023 Teacher

MWADC 803 Dept. ECE

	31/1/23	1/2/23	2/2/23	3/2/23	6/2/23	7/2/23	8/2/23	9/2/23	10/2/23	13/2/23	14/2/23
Roll No.	13	14	15	16	17	18	19	20	21	22	23
2	13	14	15	16	17	18	19	20	21	22	23
4	A	A	A	A	12	13	14	15	16	17	18
8	11	12	13	14	A	15	16	17	18	19	20
19	9	10	11	12	13	14	15	16	17	18	19
35	13	14	15	16	17	18	19	20	21	22	23
36	8	9	10	11	12	13	14	15	16	17	18
37	12	13	14	A	15	16	17	18	19	20	21
39	13	14	15	16	17	18	19	20	21	22	23
50	7	8	9	10	11	12	13	14	15	16	17
66	13	14	15	16	A	17	18	19	A	20	21
69	9	10	11	12	13	14	15	16	17	18	19
70	10	11	12	13	14	15	16	17	18	19	20
71	10	11	12	13	14	15	16	17	18	19	20
72	10	11	A	12	A	A	13	14	15	16	17
75	13	14	15	16	17	18	19	20	21	22	23
78	12	13	14	15	16	17	18	19	20	21	22
79	10	11	12	13	14	15	16	17	18	19	20
80	9	10	11	12	13	14	15	16	17	18	19
88	12	13	14	15	16	17	18	19	A	20	21
90	7	8	9	10	11	12	13	14	15	16	17
97	12	13	14	15	16	17	18	19	20	21	22
A3	10	11	12	13	14	15	16	17	18	19	20
C1	8	9	10	11	12	13	14	15	16	17	18
C4	6	7	8	9	10	11	12	13	14	15	16
C9	12	13	14	15	16	17	18	19	20	21	22
D3	9	10	11	12	13	14	15	16	17	18	19
D7	10	11	12	13	14	15	16	17	18	19	20
D9	9	10	11	12	13	14	15	16	17	18	19
E0	10	11	12	13	14	15	16	17	18	19	20
E1	6	A	7	8	9	A	10	11	12	13	14
	d	d	d	d	d	d	d	d	d	d	d

7/2/23

ECORD MARKS

ernal Marks		Final Internal (I+A)	Remarks
25%of MIN	Total (I)		
		29	402
		29	404
		29	408
		28	419
		28	435
		29	436
		27	437
		29	439
		28	450
		29	466
		29	469
		29	470
		29	471
		27	472
		29	475
		29	478
		27	479
		28	480
		29	488
		28	490
		26	497
		29	4A3
		29	4C1
		29	4C4
		29	4C9
		26	4D3
		29	4D7
		29	4D9
		29	4E0
		24	4E1

R.G.M. COLLEGE OF ENGINEERING
ATTENDANCE

Class : III B.Tech
Branch : ECE
II Semister / Year III

Roll No.	Name	10/1/23	11/1/23	12/1/23	18/1/23	19/1/23	20/1/23	23/1/23	24/1/23	25/1/23	25/1/23	27/1/23	30/1/23
	Date	1	2	3	4	5	6	7	8	9	10	11	12
4E5	V. Rishitha	A	A	A	1	2	3	4	5	6	7	8	9
4E6	S. Ruchitha	A	A	A	1	2	3	4	5	6	7	8	9
4E7	K. Rupa	1	2	3	4	5	6	7	8	9	10	11	12
4E8	M. sahithi krishna	1	2	3	A	A	4	A	A	A	A	A	5
4E9	M. Sahithi	1	2	3	4	5	6	7	8	9	10	11	12
4F1	T.K Sai kumar Reddy	A	A	A	1	2	3	4	5	6	7	8	9
4F8	V. sai suvarna	1	2	3	4	5	6	7	8	9	10	A	11
4F9	V. sai vamsi krishna	A	A	1	2	3	4	5	6	7	8	9	10
4G0	B. sai Varma	A	A	A	1	2	3	4	5	6	7	8	9
4G1	E. sai vyshnavi	A	A	A	A	A	1	2	3	4	5	6	7
4G2	S. sai kirupa Reddy	1	2	3	A	4	5	6	7	A	A	A	8
4G3	S. Sameer	1	2	3	4	5	6	7	8	9	10	11	12
4G5	S. samrin	1	2	3	4	5	6	7	8	9	10	11	A
4H5	T. sireesha	A	A	A	A	1	2	3	4	5	6	7	8
4H7	Y. siva Manasa	A	A	A	A	A	1	A	2	3	4	5	6
4H8	K. siva sai Revanth	A	A	A	1	2	3	A	A	A	A	A	4
4H9	P. sivaji	A	A	A	1	2	3	4	5	6	7	8	9
4J0	S. sneha latha	A	A	A	1	2	3	4	5	6	7	8	9
4J3	P. sravalya	A	A	A	A	1	2	3	4	5	6	7	8
4J9	R. sridhar	A	A	A	1	2	3	4	5	6	7	8	9
4K1	D. srinivasa Reddy	1	2	3	A	A	4	5	6	7	8	9	10
4K5	K. sujith Kumar Reddy	A	A	A	A	1	2	3	4	A	5	6	A
4K6	V. sumanth	A	A	A	A	1	2	3	4	5	6	7	8
4M3	S. swapna	A	A	A	1	2	3	4	5	6	7	8	9
4M7	M. Teja swini	A	A	A	A	A	1	2	3	4	5	6	7
4M9	N. uma	A	A	A	1	2	3	4	5	6	7	8	9
4N6	B. Venkata Muralidhara	1	2	3	A	4	5	A	6	7	8	9	10
4N7	T. Venkata Sneha	A	A	A	A	1	2	3	4	5	6	7	8
4P0	G. venkatesh	1	2	3	4	5	6	7	8	9	10	A	11
4P8	P. Yamuna	A	A	A	1	2	3	4	5	6	7	A	8
Signature of Teacher		d	d	d	d	d	d	d	d	d	d	d	d
Signature of H.O.D.													
Signature of Principal													

& TECHNOLOGY (Autonomous), NANDYAL.

REGISTER Academic Year from 2022 to 2023 Teacher

1.W.8.06 8.03 Dept. ECE

ECORD MARKS

Roll No.	31/1/23	1/2/23	2/2/23	3/2/23	6/2/23	7/2/23	8/2/23	9/2/23	10/2/23	13/2/23	14/2/23	ernal Marks		Final Internal (I+A)	Remarks
	13	14	15	16	17	18	19	20	21	22	23	25%of MIN	Total (I)		
E5	10	11	12	13	A	14	15	16	17	18	19			28	4E5
E6	10	A	11	12	13	14	15	16	17	18	19			28	4E6
E7	13	14	15	16	17	18	19	20	21	22	23			29	4E7
E8	6	7	8	9	10	11	12	13	14	15	16			29	4E8
E9	13	14	15	16	17	18	19	20	21	A	22			29	4E9
F1	10	11	12	13	14	15	16	17	A	18	19			29	4F1
F8	12	13	14	15	16	17	18	19	20	21	22			29	4F8
F9	11	12	13	14	15	16	17	18	19	20	21			29	4F9
G0	10	A	11	12	13	14	15	16	17	18	19			29	4G0
G1	8	9	10	11	12	13	A	A	A	14	15			28	4G1
G2	9	A	10	11	12	13	14	15	16	17	18			28	4G2
G3	13	14	15	16	17	18	19	20	21	22	23			29	4G3
G5	A	13	14	A	15	16	17	18	19	20	21			28	4G5
H5	9	10	11	12	13	14	15	16	17	18	19			29	4H5
H7	7	8	9	10	11	12	A	13	14	15	16			28	4A7
H8	5	6	7	8	9	10	11	12	13	14	15			29	4H8
H9	10	11	12	13	14	15	16	17	18	19	20			29	4A9
J0	10	11	12	13	14	15	16	17	18	19	20			29	4J0
J3	9	10	11	12	13	14	15	16	17	18	19			29	4J3
J9	10	11	12	13	14	15	16	17	18	19	20			28	4J9
K1	11	12	13	14	15	A	16	17	A	18	19			29	4K1
K5	7	8	9	10	11	12	13	14	15	16	17			29	4K5
K6	9	10	11	12	13	14	15	16	17	18	19			28	4K6
M3	10	11	12	13	14	15	16	17	18	19	20			29	4M3
M7	8	A	A	A	9	10	11	12	13	14	A			29	4M7
M9	10	11	12	13	14	15	16	17	18	19	20			29	4M9
N6	11	12	13	14	15	16	17	18	19	20	21			28	4N6
N7	9	10	11	12	13	14	15	A	A	16	17			29	4N7
P0	12	13	14	15	16	17	18	A	19	20	21			27	4P0
P8	9	10	11	12	13	14	15	16	17	18	19			25	4P8

R.G.M. COLLEGE OF ENGINEERING

ATTENDANCE

Class : III B. Tech

Branch : E.C.E

II Semister / Year III

Roll No.	Name	10/1/23	11/1/23	12/1/23	18/1/23	19/1/23	20/1/23	23/1/23	24/1/23	25/1/23	25/1/23	27/1/23	30/1/23
		1	2	3	4	5	6	7	8	9	10	11	12
404	B.charitha	A	1	A	A	2	3	4	5	6	7	A	8
412	B. Lochan	1	2	3	A	A	A	3	4	A	A	5	6
417	B. Neeraja	1	2	3	A	4	5	6	7	A	8	9	10
430	M. venkata Deepthi	1	2	3	A	4	5	6	7	A	A	8	9
432	G. yogasree	1	2	3	A	4	5	6	7	A	8	9	10
Signature of Teacher		d	d	d	d	d	d	d	d	d	d	d	d
Signature of H.O.D.													
Signature of Principal													

& TECHNOLOGY (Autonomous), NANDYAL.

REGISTER

Academic Year from 2022 to 2023 Teacher

W 20C 803 Dept E.C.E

	31/1/23	1/2/23	2/2/23	3/2/23	6/2/23	7/2/23	8/2/23	9/2/23	10/2/23	13/2/23	14/2/23
Roll No.	13	14	15	16	17	18	19	20	21	22	23
4	9	10	11	A	12	13	A	14	15	16	17
12	7	A	8	9	10	11	12	13	14	15	16
17	11	12	13	14	15	16	17	18	19	20	21
30	A	10	11	A	12	13	14	15	16	17	18
32	11	12	13	14	15	16	17	18	19	20	21
		7/2/23									
	d	d	d	d	d	d	d	d	d	d	d

ORD MARKS

al Marks		Final Internal (I+A)	Remarks
5%of MIN	Total (I)		
		28	21-404
		29	412
		29	417
		28	430
		29	432

& TECHNOLOGY (Autonomous), NANDYAL.

REGISTER

Academic Year from 2022 to 2023 Teacher

Subject & Credits MW&OC 803 Dept. ECE

INTERNAL / RECORD MARKS

Roll No.	Assignments 1	Assignments 2	Average (A)	Internal Test 1	Internal Test 2	Internal Marks 75% of MAX	Internal Marks 25%of MIN	Internal Marks Total (I)	Final Internal (I+A)	Remarks
2	10	10		19	16				29	402
4	10	10		19	16				29	404
8	10	10		19	17				29	408
19	10	10		19	14				28	419
35	10	10		18	16				28	435
36	10	10		19	18				29	436
37	10	10		17	17				27	437
39	10	10		19	19				29	439
50	10	10		19	13				28	450
66	10	10		19	16				29	466
69	10	10		19	18				29	469
70	10	10		19	19				29	470
71	10	10		19	17				29	471
72	10	10		17	17				27	472
75	10	10		19	19				29	475
78	10	10		19	19				29	478
79	10	10		18	11				27	479
80	10	10		19	14				28	480
88	10	10		19	18				29	488
90	10	10		18	16				28	490
97	10	10		18	10				26	497
A2	10	10		18	19				29	4A3
C1	10	10		19	19				29	4C1
C4	10	10		19	19				29	4C4
C9	10	10		19	19				29	4C9
D3	10	10		16	16				26	4D3
D7	10	10		19	19				29	4D7
D9	10	10		19	18				29	4D9
E0	10	10		19	19				29	4E0
E1	10	10		18	AB				24	4E1

& TECHNOLOGY (Autonomous), NANDYAL.

REGISTER

Academic Year from 2022 to 2023 Teacher

Subject & Credits MW&OC & 03 Dept ECE

INTERNAL / RECORD MARKS

	Assignments			Internal Test		Internal Marks			Final Internal (I+A)	Remarks
Roll No.	1	2	Average (A)	1	2	75% of MAX	25%of MIN	Total (I)		
E5	10	10		18	18				28	4E5
E6	10	10		18	17				28	4E6
E7	10	10		18	19				29	4E7
E8	10	10		19	17				29	4E8
E9	10	10		19	18				29	4E9
F1	10	10		19	19				29	4F1
F8	10	10		19	18				29	4F8
F9	10	10		19	16				29	4F9
G0	10	10		19	19				29	4G0
G1	10	10		18	15				28	4G1
G2	10	10		18	15				28	4G2
G3	10	10		19	18				29	4G3
G5	10	10		18	18				28	4G5
H5	10	10		19	18				29	4H5
H7	10	10		18	16				28	4A7
A8	10	10		19	18				29	4H8
H9	10	10		19	19				29	4A9
J0	10	10		19	18				29	4J0
J3	10	10		19	19				29	4J3
J9	10	10		18	17				28	4J9
K1	10	10		19	18				29	4K1
K5	10	10		18	19				29	4K5
K6	10	10		18	18				28	4K6
M3	10	10		19	19				29	4M3
M7	10	10		19	19				29	4M7
M9	10	10		18	19				29	4M9
N6	10	10		19	13				28	4N6
N7	10	10		19	19				29	4N7
P0	10	10		19	10				27	4P0
P8	10	10		15	14				25	4P8

& TECHNOLOGY (Autonomous), NANDYAL.

REGISTER

Academic Year from 2022 to 2023 Teacher

Subject & Credits MW &IC 803 Dept. E.C.E

INTERNAL / RECORD MARKS

Assignments				Internal Test		Internal Marks			Final Internal (I+A)	Remarks
Roll No.	1	2	Average (A)	1	2	75% of MAX	25%of MIN	Total (I)		
4	10	10		18	18				28	21-404
12	10	10		19	19				29	412
17	10	10		19	17				29	417
30	10	10		18	18				28	430
32	10	10		19	19				29	432

LECTURE RECORD

Subject : MW&OC

Total Exams 02

Credits : 03

Each for 02 hrs.

Internal Mid Exam Marks :

Total quizes

Internal Quiz Marks :

No. of Assignment 02

UNIT NO	S.No.	Date	Topic Covered / Exercise Completed	No of Periods	Remarks Cumulative No of periods
I	1.	10/1/23	Unit-I Guided waves	1	1
	2.	11/1/23	Introduction	1	2
	3.	12/1/23	TE, TM & TEM modes	1	3
	4.	18/1/23	Propagation of EM waves	1	4
	5.	19/1/23	Propagation of TM waves	1	5
	6.	20/1/23	Propagation of TE waves	1	6
	7.	23/1/23	cut off wavelength (λ_c)	1	7
	8.	24/1/23	Cut off frequencies (f_c)	1	8
	9.	25/1/23	wave characteristics	1	9
	10.	25/1/23	Group velocity & phase velocity	1	10
	11.	27/1/23	Guided wavelength	1	11
	12.	30/1/23	wave impedance relations	1	12
	13.	31/1/23	Filter characteristics	1	13
	14.	1/2/23	problems.	1	14
				1	15
				2/2/23.	7/2/23
Unit-II		3/2/23	Microwave components & applications	1	16
		6/2/23	significance of S-matrix	1	17
		7/2/23	H-plane Tee junction	1	18
		8/2/23	E-plane Tee junction	1	19
		9/2/23	Magic-Tee junction	1	20
		10/2/23	Directional coupler	1	21
		13/2/23	Ferrite materials	1	22
		14/2/23	Gyrator, Isolator	1	23
		15/2/23	Cif Training	1	24

LECTURE RECORD

S.No.	Date	Topic Covered / Exercise Completed	Remarks
	16/2/23	Training	1 25
	17/2/23	Training	1 26
	20/2/23	Training	1 27
	21/2/23	Training	1 28
	22/2/23	Training	1 29
	23/2/23	Training	1 30
	24/2/23	Training	1 31
	25/2/23	Training	1 32
	1/3/23	Training	1 33
	2/3/23	Training	1 34
	3/3/23	Training	1 35
	4/3/23	Circulator	1 36
	6/3/23	Problems	1 37
Unit-III	7/3/23	Microwave amplifiers & oscillators	1 38
	9/3/23	Two cavity klystron amplifier	1 39
	10/3/23	output power & efficiency	1 40
	14/3/23	Reflex klystron oscillator	1 41
	15/3/23	output power & efficiency	1 42
	16/3/23	Travelling wave Tube (TWT)	1 43
	17/3/23	slow wave structure	1 44
	20/3/23	Gain considerations	1 45
	21/3/23	Magnetrons	1 46
	31/3/23	output power & efficiency	1 47
	3/4/23	TED	1 48
	4/4/23	Gunn diode & characteristics	1 49
	6/4/23	Two valley model theory.	1 50
	10/4/23	RWH Theory	2 52

11/4/23

LECTURE RECORD

S.No.	Date	Topic Covered / Exercise Completed	Remarks No. of periods	 Cumulative
Unit-IV	10/4/23	Overview of optical communication	1	53
	12/4/23	Historical development	1	54
	13/4/23	Ray theory, Total internal reflection	1	55
	15/4/23	Acceptance angle, NA, skew rays	1	56
Unit-V	17/4/23	Signal degradation in OC	1	57
	18/4/23	Signal attenuation mechanism	1	58
	20/4/23	absorption losses	1	59
	21/4/23	scattering losses	1	60
	24/4/23	group delay, dispersion	1	61
	25/4/23	Material dispersion	1	62
	26/4/23	waveguide dispersion		
Unit-VI	27/4/23	optical sources	1	63
	29/4/23	LED structures	1	64
	1/5/23	quantum efficiency	1	65
	2/5/23	Modulation of led	1	66
	4/5/23	laser diode structures	1	67
	5/5/23	Principle of photo diodes	1	68
	8/5/23	Avalanche photo diodes	1	69
	9/5/23	comparision of photo diodes	1	70
	11/5/23	problems	1	71

MWOC

1) Define & Derive the Expressions for Group Velocity & Phase Velocity?

1) **Phase Velocity**: Its denoted by 'Vp' defined as amount of Phase change with respect to the Guided. wave length.

$V_p \Rightarrow \frac{\lambda g}{t}$ (1) $V_p = \lambda g f$ we know that $, \omega = 2\pi f$ $\boxed{f = \frac{\omega}{2\pi}}$

$V_p = \frac{\omega}{\left(\frac{2\pi}{\lambda g}\right)} = \frac{\omega}{\beta}$ $\boxed{\therefore \frac{2\pi}{\lambda g} = \beta}$ $V_p = \frac{\omega}{\beta} \rightarrow (2)$

Consider the Characteristic wave Eqn. of the rectangular waveguide

$\gamma^2 + \omega^2 \mu \varepsilon \Rightarrow \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$ $\gamma^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - \omega^2 \mu \varepsilon$ -(3)

$\Rightarrow \gamma = 0$ $\Rightarrow 0 + \omega^2 \mu \varepsilon = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$

$\Rightarrow \omega_c^2 \mu \varepsilon \Rightarrow \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 \rightarrow (4)$

from Eq(3) & Eq(4) γ^2 is

$\gamma^2 = \omega_c^2 \mu \varepsilon - \omega^2 \mu \varepsilon$

$\gamma = \alpha + j\beta$; $\alpha = 0$ $\boxed{\gamma = j\beta}$

$(j\beta^2) = \omega_c^2 \mu \varepsilon - \omega^2 \mu \varepsilon$

$\beta = \omega^2 \mu \varepsilon - \omega_c^2 \mu \varepsilon$

$\boxed{\beta \rightarrow \sqrt{\omega^2 \mu \varepsilon - \omega_c^2 \mu \varepsilon}}$

$V_p = \frac{\omega}{\beta}$

$\boxed{V_p = \frac{\omega}{\sqrt{\mu\varepsilon}\sqrt{\omega^2 - \omega_c^2}}}$

w.k.t $\frac{1}{\sqrt{\mu\varepsilon}} = c$

$V_p = \frac{\omega}{c\sqrt{\omega^2 - \omega_c^2}}$

$V_p = c \cdot \frac{\omega}{\sqrt{\omega^2 - \omega_c^2}}$

$\boxed{\omega_c = 2\pi f_c}$

$\boxed{\omega = 2\pi f}$

$V_p = c \cdot \frac{\omega}{\omega\sqrt{1 - \left(\frac{\omega_c}{\omega}\right)^2}}$

$V_p = \frac{c}{\sqrt{1 - \left(\frac{\omega_c}{\omega}\right)^2}}$

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

$f=\frac{c}{\lambda_0}; f_c=\frac{c}{\lambda_c}$ $\quad V_p=\frac{c}{\sqrt{1-\left(\frac{c/\lambda_c}{c/\lambda_0}\right)^2}}$ $\Rightarrow \boxed{V_p=\frac{c}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}}$

Group Velocity:- denoted by Vg. It defined as rate of change of the wave within the waveguide. Given as $\boxed{V_g=\frac{d\omega}{d\beta}}$

wkt. $\beta=\sqrt{\omega^2\mu\varepsilon.\omega_c^2\mu\varepsilon}$

Consider $\beta=\sqrt{\mu\varepsilon}\sqrt{\omega^2-\omega_c}$

$\frac{d\beta}{d\omega}=\sqrt{\mu\varepsilon}\frac{\omega}{\sqrt{\omega^2-\omega_c^2}}$ $\quad V_g=\frac{d\omega}{d\beta}; \frac{1}{\mu\varepsilon}=c$

$\frac{d\omega}{d\beta}=\frac{1}{\mu\varepsilon}\frac{\sqrt{\omega^2-\omega_c^2}}{\omega} \Rightarrow \frac{d\omega}{d\beta}=c.\sqrt{\omega^2 1-\left(\frac{\omega_c}{\omega}\right)^2}$ $\quad \frac{d\omega}{d\beta}=c.\sqrt{1-\left(\frac{\omega_c}{\omega}\right)^2}$

$\frac{d\omega}{d\beta}=c.\sqrt{1-\left(\frac{2\pi f_c}{2\pi f}\right)^2}=\frac{d\omega}{d\beta}=c.\sqrt{1-\left(\frac{f_c}{f}\right)^2}$, $f=\frac{c}{\lambda_0}$, $f_c=\frac{c}{\lambda_0}$

$\frac{d\omega}{d\beta}=c.\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}$. $\frac{d\omega}{d\beta}=c.\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}$ $\quad V_g=c.\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}$

2) Derive the expression for field components when propagating in the Rectangular wave guide for TM wave, if z is the direction of the propagation then only the magnetic field will be perpendicular as the 'z' direction

A) The wave eqn. for TM wave in rectangular wave guide is given by. $\nabla^2 E_z = -\omega^2\mu\varepsilon E_z \rightarrow ①$

$$\frac{\partial^2 E_z}{\partial x^2}+\frac{\partial^2 E_z}{\partial y^2}+\frac{\partial^2 E_z}{\partial z^2}=-\omega^2\mu\varepsilon E_z$$

$\frac{\partial}{\partial z}=-\gamma; \frac{\partial^2}{\partial z^2}=\gamma^2 \Rightarrow \frac{\partial^2 E_z}{\partial x^2}+\frac{\partial^2 E_z}{\partial y^2}+\gamma^2 E_z=-\omega^2\mu\varepsilon E_z$

$$\frac{\partial^2 E_z}{\partial x^2} + \frac{\partial^2 E_z}{\partial y^2} \cdot h^2 . E_z = 0 \rightarrow (3)$$

let consider $E_z = x \cdot y$

$$\frac{\partial^2 E_z}{\partial x^2} + \frac{\partial^2 E_z}{\partial y^2} + h^2 . x \cdot y$$

(differentiate the above Expression with respect to x

$$\frac{\partial E}{\partial x} = \Rightarrow y \cdot \frac{\partial x}{\partial x} \Big] \quad \text{Sub} = \boxed{E_z = x \cdot y}$$

substitute above Expression in Eq ⑧

divide above eqn with xyz on both sides

$$\frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E_z}{\partial y^2} + h^2 . E_z = 0 \Rightarrow \frac{y . \frac{\partial x^2}{\partial x^2}}{xy} + \frac{\cancel{x} . \frac{\partial^2 y}{\partial y^2}}{\cancel{x} y} + \frac{h^2 (x y)}{xy}$$

$$\frac{1}{x}\frac{\partial^2 x}{\partial x^2} + \frac{1}{y}\frac{\partial^2 y}{\partial y^2} + h^2 = 0$$

let $\frac{1}{x}\frac{\partial^2 x}{\partial x^2} = -B^2$; $\frac{1}{y}\frac{\partial^2 y}{\partial x^2} = -A^2$; $h^2 = A^2 + B^2$

$$= -B^2 + (-A^2) + A^2 + B^2 = -B^2 - A^2 + h^2 = 0 \Rightarrow \boxed{h^2 = A^2 + B^2}$$

The above Eqn is 2nd order differential Eqn whose solution can be given as:

$$x = C_1 \cos Bx + C_2 \sin Bx$$
$$y = C_3 \cos Ay + C_4 \sin Ay$$

w.k.t $E_z = x \cdot y$

$$E_z = (C_1 \cos Bx + C_2 \sin Bx)(C_3 \cos Ay + C_4 \sin Ay) \rightarrow (5)$$

Boundary Conditions.

(1) Bottom wall: $E_z = 0$, $y = 0$, $x = 0$ to a, ② left side wall

$E_z=0, y=0$ to b, $x=0$

3) Top wall :- $E_z=0$, $x=0$ a x $y=b$

4) Right side wall :- $E_z=0, x=a, y=0$, to b

Apply 1st boundary in Eqn (5)

$E_z=(C_1\cos Bx+C_2\sin Bx)(C_3\cos Ay+C_4\sin Ay)$

$0=(C_1\cos Bx+C_2\sin Bx)(C_3\cos(0)+C_4\sin(0))$

$0=(C_1\cos Bx+C_2\sin Bx)(C_3)$

$=(C_1\cos Bx+C_2\sin Bx)\neq 0$ $\boxed{C_3=0}$

Sub $C_3=0$ in Eqn(5)

$E_z=(C_1\cos Bx+C_2\sin Bx)(C_3\cos Ay+C_4\sin Ay)$

$=(C_1\cos Bx+C_2\sin Bx)(0.\cos Ay+C_4\sin Ay)$

$=(C_1\cos Bx+C_2\sin Bx)(C_4\sin Ay)\rightarrow 6)$

Apply second boundary in Eqn(6)

$0=(C_1)(C_4\sin Ay)$ $C_4\sin Ay\neq 0$ $\boxed{C_2=0}$

$E_z=(C_2\sin Bz)(C_4\sin Ay)\rightarrow(7)$

Apply 3rd boundary in Eqn (7)

$E_z=(C_2\sin Bx)(C_4\sin A(b))$.

$E_z=(C_2\sin Bx)(C_4\sin Ab))$

$C_4\sin Ab=0;$ $C_2\sin Bx\neq 0$

$\sin Ab=0;$ $Ab=n\pi$

$\therefore \boxed{A=\frac{n\pi}{b}}$

Sub: A, B in Eqn (7)

$E_z = C_2 \sin\left(\frac{m\pi}{a} x\right) \cdot C_4 \sin\left(\frac{n\pi}{b}\right) y$

$E_z = C_2 \cdot C_4 \sin\left(\frac{m\pi}{a}\right)x \cdot \sin\left(\frac{n\pi}{b}\right)y$

$\boxed{\text{let } C_2 C_4 = C}$ $\boxed{E_z = C \sin\left(\frac{m\pi}{a}\right) x \sin\left(\frac{n\pi}{b}\right) y \cdot e^{j\omega t - \gamma z}}$ -(8)

$E_x = -\frac{j\omega\mu}{h^2} \frac{\partial H_z}{\partial y} - \frac{\gamma}{h^2} \frac{\partial E_z}{\partial x}$ $E_x = -\frac{\gamma}{h^2} \frac{\partial E_z}{\partial x}$

$E_x = -\frac{\gamma}{h^2} \left[C \cos\left(\frac{m\pi}{a}\right) x \left(\frac{m\pi}{a}\right) \sin\left(\frac{n\pi}{b}\right) y e^{j\omega t - \gamma t}\right]$

$E_y = \frac{j\omega\mu}{h^2} \cdot \frac{\partial H_z}{\partial x} - \frac{\gamma}{h^2} \frac{\partial E_z}{\partial y}$, $E_y = -\frac{\gamma}{h^2} \cdot \frac{\partial E_z}{\partial y}$

$E_y = -\frac{\gamma}{h^2} \left[C \cdot \sin\left(\frac{m\pi}{a}\right) x \cos\left(\frac{n\pi}{b}\right) y \left(\frac{n\pi}{b}\right) e^{j\omega t - \gamma z}\right]$

$H_x = \frac{1}{j\omega\mu} \frac{\partial E_z}{\partial y} - \frac{\gamma}{j\omega\mu} \frac{\partial H_z}{\partial x}$ $\therefore H_x = \frac{1}{j\omega\mu}\left(\frac{\partial E_z}{\partial y}\right)$

$= \frac{1}{j\omega\mu} \left[C \cdot \sin\left(\frac{m\pi}{a}\right) x \cos\left(\frac{n\pi}{b}\right) y \left(\frac{n\pi}{b}\right) e^{j\omega t - \gamma z}\right]$

$H_y = \frac{1}{j\omega\mu} \frac{\partial E_z}{\partial x} \cdot \frac{\gamma}{j\omega\mu} E_x = -\frac{\gamma}{h^2} \frac{\partial H_z}{\partial y} + \frac{j\omega\varepsilon}{h^2} \frac{\partial E_z}{\partial x}$

$H_y = \frac{j\omega\varepsilon}{h^2} \frac{\partial E_z}{\partial x} \Rightarrow H_y = \frac{j\omega\varepsilon}{h^2} \left[C \cdot \cos\left(\frac{m\pi}{a}\right) x \left(\frac{m\pi}{a}\right) \sin\left(\frac{n\pi}{b}\right) y \; e^{j\omega t - \gamma t}\right]$.

3) Derive the S.Matrix for magic tee junction.

Ans) This junction is formed by cutting rectangular slots along the width, breadth of long wave guide and the H-arm & E-arm are attached as shown in fig the junction has 4 ports so the order of S matrix is 4x4

$$S = \begin{vmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{13} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{vmatrix}$$

→ This junction exhibit H plane Tee property $\boxed{S_{13} = S_{23}}$

→ This jun exhibits E plane Tee property $S_{24} = -S_{23}$

Port 3 & Port 4 has no-coupling b/w them so 3&4 ports are isolated ports in junction ie: $\boxed{S_{34} = S_{43} = 0}$

Port 3 & Port 4 are perfectly matched so: $\boxed{S_{33} = S_{44} = 0}$

S matrix is a symmetric so- $\boxed{S_{ij} = S_{ji}}$

$S_{21} = S_{12}$
$S_{23} = S_{13}$
$S_{24} = -S_{14}$

$S_{31} = S_{13}$
$S_{32} = S_{23} = S_{13}$
$S_{41} = S_{14}$
$S_{42} = S_{24} = -S_{14}$

Now the S-matrix for the junction

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{33} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix}$$

S matrix is unitary Matrix ie: $[S][S^*] = [I]$

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$R_1C_1 = S_{11}S_{11}^* + S_{12}S_{12}^* + S_{13}S_{13}^* + S_{14}S_{14}^*$

$= |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2 - 1 - (1)$

$R_2C_2 = S_{12}S_{12}^* + S_{22}S_{22}^* + S_{13}S_{13}^* + S_{14} - S_{14}^*$

$= |S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1$ ②

$S_{14}S_{14}^* + S_{14}S_{14}^*$

$= |S_{14}|^2 + |S_{14}|^2 + 0 = 1$

$= 2|S_{14}|^2 = \frac{1}{\sqrt{2}}$

$R_3C_3 = S_{13}S_{13}^* + S_{13}S_{13}^* \Rightarrow |S_{13}|^2 + |S_{13}|^2 + 0 = 1 - (3)$

$\Rightarrow 2|S_{13}|^2 = \frac{1}{\sqrt{2}}$

Compare Eqn (1) & (2) $\Rightarrow R_1C_1 = |S_{11}|^2 + |S_{12}|^2 + \cancel{|S_{13}|^2} + \cancel{|S_{14}|^2}$

$R_1C_2 = \cancel{|S_{12}|^2} + |S_{22}|^2 + \cancel{|S_{13}|^2} + \cancel{|S_{14}|^2}$ $\boxed{S_{11} = S_{22}}$

Sub = S_{13} & S_{14} in Eqn (1)

$|S_{22}| \mp |S_{22}| + \left|\frac{1}{\sqrt{2}}\right|^2 + \left|\frac{1}{\sqrt{2}}\right|^2 = 1$ $\quad |S_{11}| + |S_{12}| + \frac{1}{2} + \frac{1}{2} = 1$

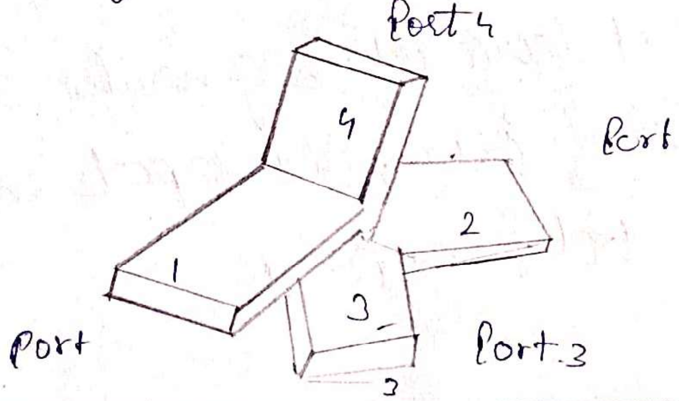
$\boxed{S_{11} = S_{12}} \rightarrow$ ⑤ Sub = Eq (5) (3) (4) $\Rightarrow$ (1)

$|S_{11}|^2 + |S_{11}|^2 + \frac{1}{2} + \frac{1}{2} = 1$ $\quad S_{11} = 0, S_{12} = 0, S_{22} = 0$

Now the S-matrix for the given Magic tee jn.

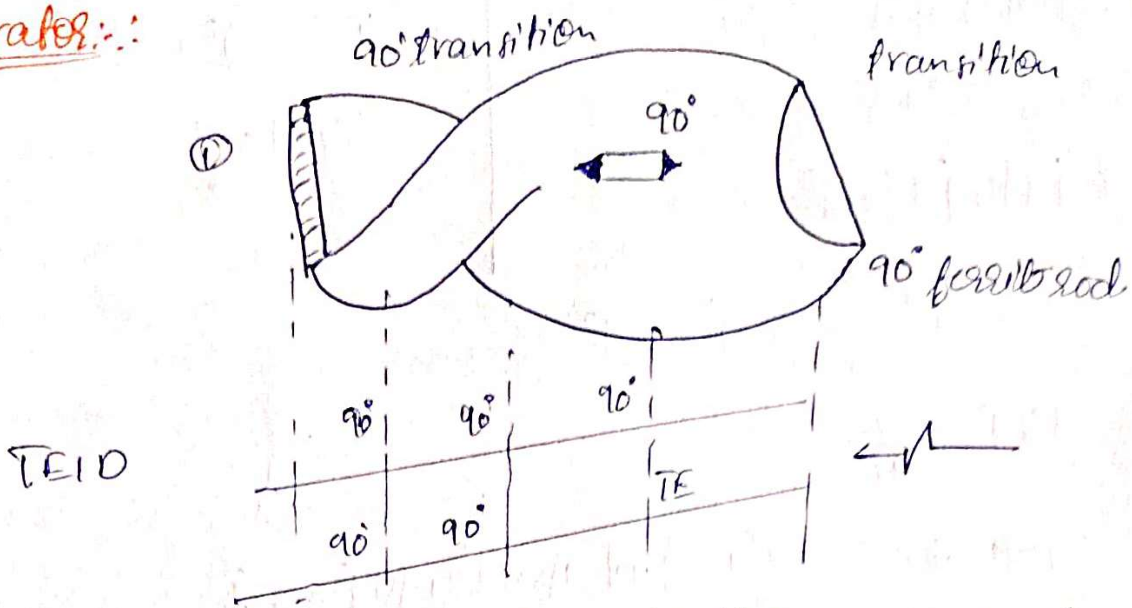
$$\begin{bmatrix} 0 & 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 0 & 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 & 0 \end{bmatrix}$$

$S_{21} = S_{12} = 0$. Even though Port1 & Port2 are colinear Port when the i/p is given at port 1 No o/p comes out of port 2, Hence this jn called Magic tee function



4) Explain the Construction & Working of Gyrator & Isolator

Gyrator:-:



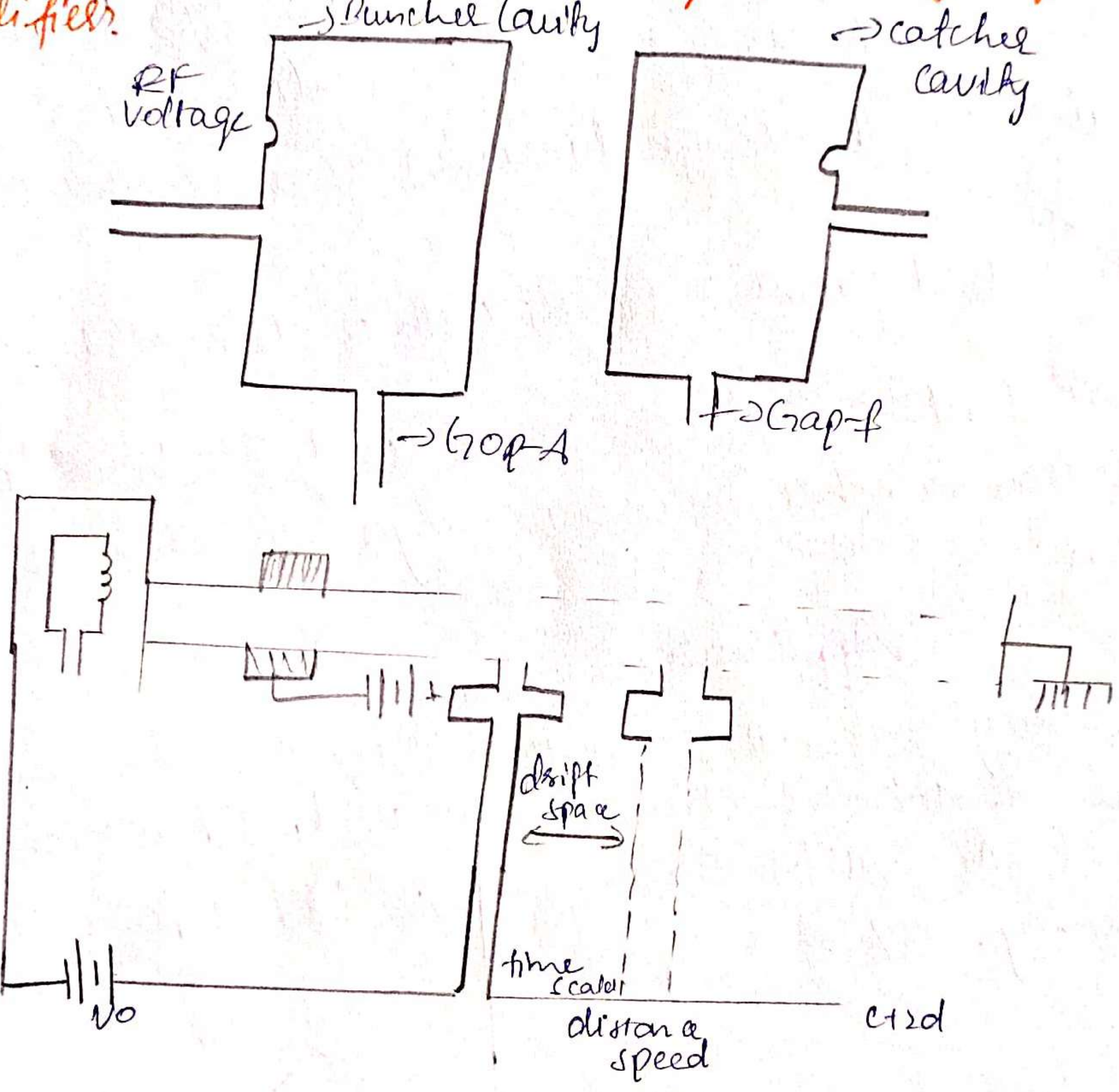
When the TE10 wave enters the port 1. It comes across the 90° twisted path in the wave guide. The wave will rotate by 90° in Anticlock wise direction. Now the wave enters by 90° Anticlock wise Sharpened. at both Ends to reduce the attenuation & for the smooth rotation of the wave

*) When the TE10 is transmitted from port2 to port1 comes across the ferrite rod & undergoes faradays rotation through 90° in Anticlockwise direction. The wave enters to 90° twisted wave guide & it lock to 90° in Clockwise direction. Hence the wave comes out of port2 with phase shift of 0°

Isolator: It is a 2port device which generates a phase shift of 0° when transmitted from port1 to port2 & no signal comes out of port1 when txd from P2 to P1

It consists of resistive cards placed at port1 & port2'. This device has 45° twisted path in the wave guide attached to the circular wave guide when the wave is txd from port1 to port2' comes across the resistive card placed at port1'. Now the waves enter to 45° twisted part & undergoes rotation through 45° in clockwise direction. Now wave come across the card placed at port2 & comes out of port2' without any attenuate. Hence the wave comes out port2 with 0° phase shift with respect to wave entered at port1.

⑤ Explain the Construction & working Of 2 Cavity Klystron amplifier.



1) This tube consists of two mainly
1) Buncher cavity 2) Catcher Cavity

2) The Space b/w buncher cavity & catcher cavity : known as driftspace

3) The Gap in the buncher Cavity known as Gap A'

4) The Gap in the Catcher Cavity are also known as i/p Cavity & output cavity.

Operation: This tube works on principle of Velocity modulation Process it is defined as variation in the line of velocity of the electron in accordance with the amplitude of the i/p AC signal

At the time instant 'A' the late electron (el) is subjected to +ve amplitude of the AC signal i.e. ($v>v_0$) & travels with increased velocity i.e. $>v_0$

→ At time instant 'B' the ē travels with unchanged Velocity $v=v_0$

→ At time instant 'C' = the e^- (ec) travel with less Velocity $v<v_0$

→ These electron bunches converts velocity modulation in current modulation.

Applications

1) frequency = 250 MHz – 100 GHz
2) Power → 10kw – 500kw
3) Power Gain → 15dB → 0dB
4) Efficiency → 58%

1) used in radar communication
2) used in satellite communication
3) used in high power ckts

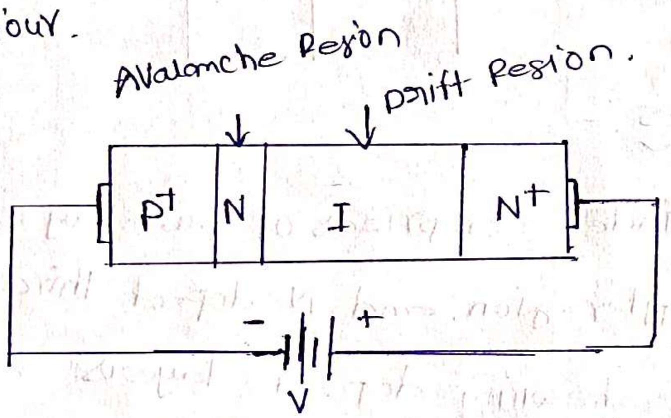
V. sumanth
20091A04K6
ECE - A
IIIrd year

MW&OC - Assaignment-2

1) explain the construction and operation of IMPATT and TRIPATT Diodes.

A) IMPATT Diode :-

-> The full form of impATT diode is ionization Avalanche Transist time. The construction of the IMPATT diode is shown below. This diode includes four regions like P+N-I-N+. The structure of both the PIN diode and ImpATT is the same, but it works on an extremeny high voltage gradient of approximatery 400 KV/cm to generate an avalanche current. usany different materials such as si, GaAs, InP or Ge are mainlly used for its construction. But material like GaAs is mostly prefered due to its less noise behaviour.

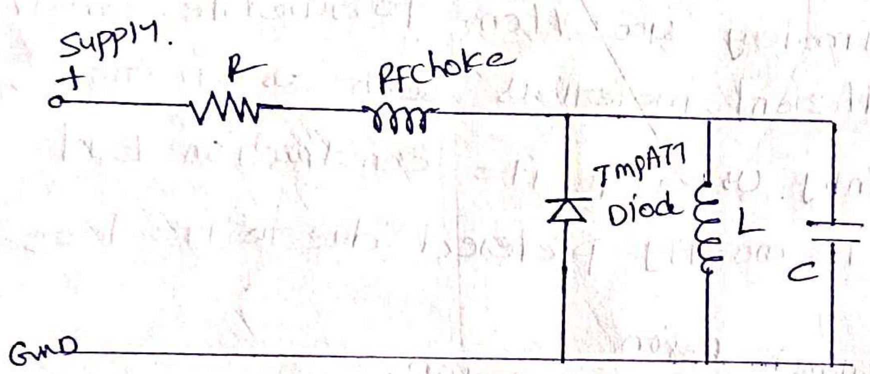


As compare to a normal diode this diode uses a somewhat different structure because; a normal diode will break down in an avalanche condition. As the huge amount of current generation causes the heat generation within it. so at microwave frequencies, deviation in structure is mainlly used to generate RF signals. Generally this diode is used in microwave generator.

IMPATT Diode circuit:-

-> application of IMPATT diode is shown below. Generally this kind of diode is mainly used at above 3 GHz frequencies. it is noticed the whenever a tuned ckt is given with a voltage in the region of the breakdown voltage toward the IMPATT ~~dion~~ oscillation will occur.

-> As compared to other ~~dev~~ diodes, this diode uses -ve resistance and this diode is capable of generating a high range of power typically ten watts or above based on the device



TRIPATT Diodes:-

construction:- Diode comprises of two layers of heavily doped. p^+ and N^+ region. and N-doped third layer is used to separate the heavily doped layers as shown in fig. The doping concentration of N region is behind depletion is in the region is just behind. at breakdown, p^+ region is kept thin and is 2.5 to 2.7 µm.

working:- Diode is operated in reverse bias. This reverse bias causes increases in the electric field b/w point D :- The voltage decreases at point D. A long time is required to decrease plasma.

point E :- The plasma is removed as charge of holes and electrons remain.

point E.F :- the po voltage increases as the residual charge is removed.

point G :- At point G, the diode current comes to zero for half a period.

2) Derive the expression for RMS pulse broding due to material dispersion in optical fiber.

A) The fiber is said to be material dispersion when the 2nd order differentiation of refractive index of the core w.r.to wave length is not equal to zero.

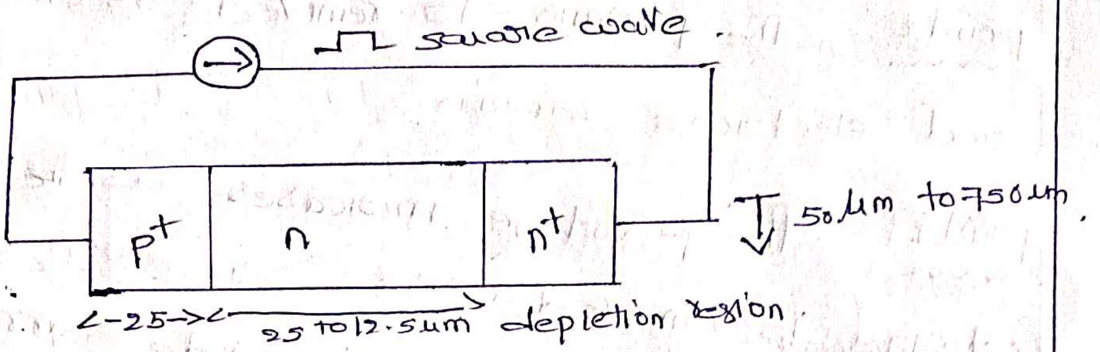
$$\frac{d^2 n_1}{d\lambda^2} \neq 0$$

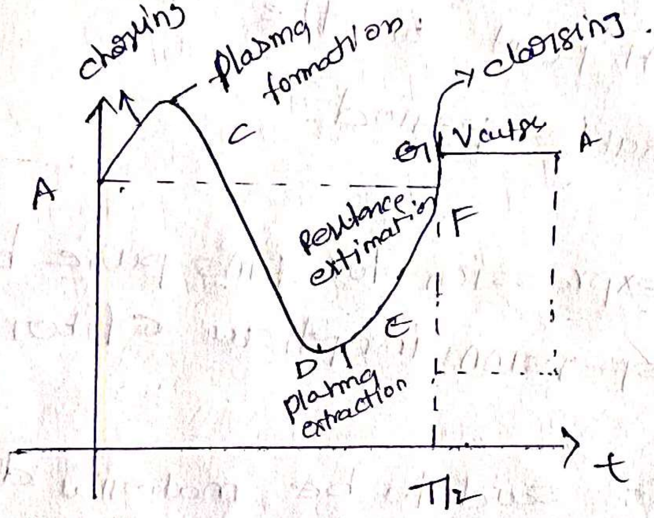
$$\beta = \frac{2\pi n_1}{\lambda_1}$$

Group delay in fiber

$$\frac{\tau_g}{L} = \frac{1}{V_g} = -\frac{\lambda^2}{2\pi c} \cdot d\beta/d\lambda,$$

p+ and N+ region and the minority carriers generated attains a very large velocity.





point A :- the charge carriers due to thermal generation results in the charging of diode and like a linear capacitor.

A-B :- At this point electric field increase. when a no. of charge carriers are generated this electric field is depressed. throughout the depletion region. causing the voltage to decrease from the B to C.

point C :- This charge is help to avalanche. to continue and hence plasma of electron or hole. is created.

material dispersion per unit length.

$$\frac{T_{mat}}{L} = \frac{-\lambda^2}{2\pi c}\left[\frac{d}{d\lambda}\left(\frac{2\pi n_1}{\lambda}\right)\right]$$

$$= \frac{-\lambda^2}{2\pi c}\cdot\frac{2\pi}{\lambda^2}\left[n_1 - \lambda\frac{dn_1}{d\lambda}\right]$$

$$= \frac{1}{c}\left[n_1 - \lambda\frac{dn_1}{d\lambda}\right]$$

$$T_{mat} = \frac{L}{c}\left[n_1 - \lambda\frac{dn_1}{d\lambda}\right]$$

dispersion parameter in material dispersion.

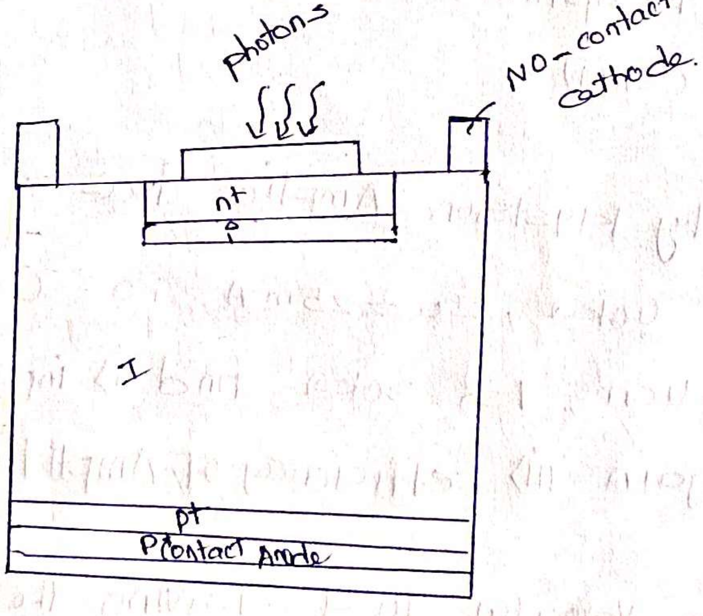
$$\sigma_{mat} = \frac{d}{d\lambda} T_{mat}\,\sigma_\lambda$$

$$= D_{mat}(\lambda)\,\sigma_\lambda$$

$$D_{mat}(\lambda) = \frac{-\lambda}{c}\frac{d^2 n_1}{d\lambda^2}$$

3) write a short note on Avalanche photo diode.

A)



The construction of the both the photo diode and Avalanche diode is same. This diode implants heavilly doped & lightly dopped regions those are p^+ and N^+ where lightly dopped are I and P.

* Here heavilly doped regions are p^+ and N^+ whereas lightly doped regions are I and P.

working principle:-

-> Avalanche break down occurs mainy once the photo diode is subjected to maximum reverse voltage. this voltage enhance the electric field beyond the depletion layer.

-> when incident light penetrates the p^+ region then it gets absorbed within the extremelly resistive p region than electron hole pairs are generated.

-> the optical fiber comunication system, the avalance photo diodes are generally used for recognisation of weeksignal but circuits to optimize enough so that high signal to noise ratio (S/N).

4) A Two cavity klystron Amplier has a following parameters, $V_0 = 1000V$, $R_0 = 40k\Omega$, $I_0 = 25mA$, $R_0 = 40k\Omega$, $f = 3GHz$, $d = 1mm$, $L = 4cm$, $R_{sh} = 30k\Omega$. find i) input Gap Voltage ii) Voltage gain iii) efficienay of Amplifier.

A) The electron velocity just leaving the cathode is

$$v_0 = (0.593\times10^6)\sqrt{10} = 1.88\times10^7 m/sec$$

The gap transit angle is

$$\theta_g = \frac{\omega \cdot d}{V_0} = 2\pi(3G)\frac{1m}{1.88\times10^7} = 1rad$$

The beam-coupling coeffient is

$$\beta_i = \beta_0 = \frac{\sin(\theta_g/2)}{\theta_g/2} = \frac{\sin(1/2)}{1/2} = 0.958.$$

The dc transit angle and cavity is

$$\theta_0 = \omega T_0 = \omega\frac{L}{V_0} = 2\pi(3G)\frac{4\times10^{-2}}{1.88\times10^7} = 40.105rad$$

The maximum i/p voltage V_1

$$V_{1max} = \frac{2V_0 X}{\beta_i \theta_0} = \frac{2\times10k\times(1.841)}{(0.958)(40.105)} = 95.83V$$

The voltage gain is

$$A_v = \frac{\beta_0^2\theta_0}{R_0}\cdot\frac{J_1(X)}{X}R_{sh}.$$

$$= ~~0.95~~ \ 8.595.$$

iii) efficiency $I_2 = 2I_0J_1(X) = 29.1\times10^{-3}A$

$V_2 = \beta_0 I_2 R_{sh} = 831V.$

$$\text{efficiency} = \frac{\beta_0 I_2 V_2}{2I_0V_0} = \frac{(0.952)(29.1\times10^{-3})(831)}{2(25\times10^{-3})(10^3)} = 46.2\%$$

5) A reflex klystron oscillator operates the following parameters $V_0 = 660V$, $L = 1mm$, $R_{sh} = 15k\Omega$, $f = 9GHz$, $\frac{e}{m} = 1.759\times10^{11}$ when the tube is oscillating at $1\frac{3}{4}$ mode. find (i) repeller voltage (ii) Direct current necessary to gap voltage of 200V (ii) what is electron efficiency.

(i) $$\frac{V_0}{(V_r+V_0)^2} = \frac{e}{m}\frac{(2\pi n-\pi/2)^2}{8\omega^2 L^2}$$

$$= (1.759\times10^{11})\left[\frac{2\pi(2)-(\pi/2)^2}{8(2\pi\times9\times10^9)^2(10^{-3})^2}\right] = 0.832\times10^{-3}.$$

$$(V_r+V_0)^2 = \frac{600}{0.832\times10^{-3}} = 0.721\times10^6$$

$$V_r = 250V.$$

ii) $\beta_0 = 1$ Assume

$$V_2 = I_2 R_{sh} = 2I_0 J_1(X')R_{sh}.$$

$$I_0 = \frac{V_2}{2J_1(X')R_{sh}} = \frac{200}{2(0.582)(15\times10^3)} = 11.45mA$$

(iii) efficiency $$= \frac{2X J_1(X')}{2\pi n-\pi/2} = \frac{2(1.841)(0.582)}{2\pi(2)-\pi/2} = 19.49\%.$$

6) A TWT operating under the following parameters. Beam Voltage $V_0 = 3kV$ Beam current $= 30mA$, $Z_0 = 10\Omega$, $N = 50$, $f = 10GHz$. Calculated the i) o/p power gain in dB and (ii) The gain parameter.

(ii) gain parameter

$$C = \left(\frac{I_0 Z_0}{4V_0}\right)^{1/3} = \left(\frac{30\times10^{-3}\times10}{4\times3\times10^3}\right) = 2.92\times10^{-2}$$

i) The o/p power gain is

$$A_p = -9.54 + 47.3\,NC$$

$$= -9.54 + 47.3\times50\times2.92\times10^{-2}$$

$$A_p = 59.52\,dB$$

7) An 8 cavity cylindrical magnetron has following parameters $V_0 = 26KV$ $I_0 = 27A$, $B_0 = 0.336$ wb/m2, $a = 5$, $b = 10cm$. Calcute i) angular frequency ii) cutoff vorlase (ii) cutt off magnetic flux density

i) Angular frequency is

$$\omega_c = \frac{e}{m} B_0$$

$$= 1.759 \times 10^{11} \times 0.0336 = 5.91 \times 10^{10} \text{ rad}.$$

(ii) The cutoff voltage B'_0 is

$$V_{oc} = \frac{1}{8} \times \frac{e}{m} B_0^2 \times (10 \times 10^{-2})^2 \left(1 - \frac{a^2}{b^2}\right)^2$$

$$= 139.50KV$$

(iii) cutt-off magnetic flux density.

$$B_{oc} = \left(8 \times V_0 \times \frac{m}{e}\right)^{1/2} \left[10 \times 10^{-2} \left(1 - \frac{a^2}{b^2}\right)\right]^{-1}$$

$$= 14.495 \text{ wb/m}^2$$

8) A linear magnetron has following parameters $V_0 = 15KV$, $I_0 = 1.2A$, $f = 8GHz$, $B_0 = 0.015$ wb/m2, $h = 2.77$ cm, $d = 5$ cm. calcuate the electron velocity & phase velocity of magnetron.

electron velocity is

$$V = \frac{e}{m} \times V_0 \times h = 1.759 \times 10^{1} \times 0.015 \times 2.77 \times 10^{-2}$$

$$= 0.73 \times 10^3 \text{ m/sec}$$

phase velocity is

$$V_{ph} = \frac{\omega}{\beta} = 0.7 \times 10^8 \text{ m/sec}$$

9) A 90 watts power source is connected to the i/p of directional coupler with C = 20dB, D = 35dB and Insertion losses is 0.5dB. find the o/p powers at the coupled and Isolated ports.

A) $C = 10\log_{10} P_i/P_f$

$20dB = \log_{10} P_i/P_f$

$10^2 = P_i/P_f = \frac{90}{P_f}$

$P_f = 0.9W$

Directivity

$D = 10\log_{10} \frac{P_f}{P_b}$ dB

$35\,dB = 10\log_{10} \frac{P_f}{P_b}$

$3.5 = \log_{10} \frac{P_f}{P_b}$

$10^{3.5} = \frac{P_f}{P_b}$

$P_b = 0.9/10^{3.5} = 0.2mW$

Isolated factor :-

$I = 10\log_{10} \frac{P_i}{P_b}$ dB

$= 10\log_{10} \frac{90}{0.2m}$

$I = 56.5dB$

10) IN H-plane Tee Junction a signal power of 32mW is fed into one of the collinear port. Determine the power in remaining ports when the other ports are terminated by matched terminator.

A) In port 2 & 3 are match terminated

power at $P_1 = 32mW$

at P2

$P_2 = P_1 \times (\frac{1}{2})^2$

$P_2 = 32 \times \frac{1}{4} = 8W$

at port 3

$P_3 = P_1 \times (\frac{1}{\sqrt{2}})^2$

$P_3 = 32 \times (\frac{1}{\sqrt{2}})^2 = 16W$

R-20

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III B.Tech II-Semester- Mid-I *Examinations*

MICROWAVE ENGINEERING AND OPTICAL COMMUNICATION

(ECE)

Max. Marks: 20 **Date:24-03-2023** **Time: 2 Hours**

Note: 1. Answer the FIRST question compulsorily. (5 x 1= 05 Marks)
2. Answer Any *THREE* from 2 to 5 questions. (3 x 5 = 15 Marks)

Q.No			Marks	CO	Blooms Level
Q.1	a)	Write short note on circulator.	1M	CO2	BL1
	b)	Compare Two cavity Klystron amplifier and Reflex Klystron oscillator.	1M	CO3	BL2
	c)	Mention the properties of S - Matrix.	1M	CO2	BL1
	d)	Define TE wave.	1M	CO1	BL1
	e)	Define guided and cutoff wavelengths of a rectangular waveguide.	1M	CO3	BL1
Q.2	a)	Define and derive the expression for phase velocity	3M	CO1	BL3
	b)	Derive the expression for Group velocity.	2M	CO1	BL3
Q.3	a)	Explain the construction and working of reflex klystron oscillator.	3M	CO3	BL2
	b)	Derive the expression for output power and efficiency of reflex klystron oscillator.	2M	CO3	BL1
Q.4	a)	Derive the S-matrix for Magic Tee junction	3M	CO2	BL3
	b)	Write short note on ferrite materials.	2M	CO2	BL1
Q.5	a)	Explain the construction and working of isolator.	3M	CO3	BL2
	b)	A rectangular wave guide has dimensions of a=8cm, b=4cm for the modes TE_{10}, TM_{11}, TM_{21}. Mention the modes which are propagate through a wave guide if the free space wave length is 10 cm	2M	CO1	BL3

MID-I

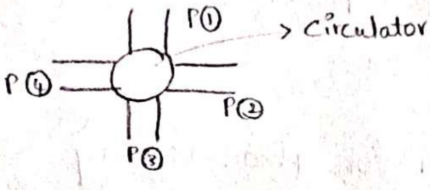
Q.1. a) Write short note on Circulator

* It is one of the ferrite material.

* It is a minimum 3 and maximum n port Device

* It works either in clockwise (or) anticlockwise direction.

* Consider 4-port circulators.



b) Compare two cavity clystron amplifier and Reflex klystron oscillator.

Two cavity klystron Amplifier	Reflex klystron oscillation
* In this two cavities are used.	* In this only one cavity is used
* frequency range is 1GHZ – 200GHZ	* frequency range is 250MHz – 100GHz
* Power is less	* Power is more.

c) Mention the Properties Of S-Matrix.

(1) It is a Square matrix

(2) It obeys symmetry Property

(3) It obeys Identity Property

(4) The sum of product of S-parameters in any row or colomn and its Conjugate of any row or colomn. is equal to '0'

$$\therefore \sum_{i=1}^{n} S_{ij} \cdot S_{ij}^{*} = 0.$$

d) Define TE wave.

Transverse electric wave can be defined as the wave in which the electric field is perpendicular to the direction of propagation and hence equal to '0' i.e. $E_z = 0$

The magnetic field exists which results in propagation i.e $H_z \neq 0$

c) Define guided and cutoff wavelengths of a rectangular waveguide.

guided wavelength:- It is the distance travelled by the wave which undergoes phase shift of 2π radians inside the wave guide.

Cutoff wavelength:- It is the wavelength at which the propagation of the wave will takes place.

2) a) Define and derive the expression for phase velocity

Phase Velocity (v_p):-

The phase velocity is defined as the phase change rate of the wave with respect to the guided wavelength inside the wave guide.

$$V_p = \frac{\lambda_g}{t}$$

w.k.T,

$$t = \frac{1}{f} \Rightarrow \frac{1}{t} = f$$

$$v_p = \lambda_g . f$$

$$v_p = \lambda_g \frac{\omega}{2\pi}$$

$$v_p = \frac{\frac{\omega}{2\pi}}{\lambda_g}$$

$$v_p = \frac{\omega}{\beta}$$

from waveguide characteristics,

$$\gamma^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - \omega^2 \mu \varepsilon \longrightarrow ②$$

for flight frequency,

$$\gamma = j\beta$$

$$j^2 \beta^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - \omega^2 \mu \varepsilon$$

$$\Rightarrow -\beta^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - \omega^2\mu\varepsilon \longrightarrow ③$$

for cutoff frequency

$\gamma = 0$, $\omega = \omega_c$

eq ② $\Rightarrow 0 = \left(\frac{n\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - \omega_c^2\mu\varepsilon \longrightarrow ④$

eq ③ - eq ④

$$\Rightarrow -\beta^2 = -\omega^2\mu\varepsilon + \omega_c^2\mu\varepsilon$$

$$-\beta^2 = (\omega_c^2 - \omega^2)\mu\varepsilon$$

$$\beta = \sqrt{(\omega^2 - \omega_c^2)\mu\varepsilon} \longrightarrow ⑤$$

Substitute eq ⑤ in eq ①

$$v_p = \frac{\omega}{\sqrt{(\omega^2 - \omega_c^2)\mu\varepsilon}}$$

$$= \frac{1}{\sqrt{1 - \left(\frac{\omega_c^2}{\omega}\right)}} \cdot \frac{1}{\sqrt{\mu\varepsilon}}$$

$$V_p = C_o \frac{1}{\sqrt{1 - \left(\frac{\omega_c}{\omega}\right)^2}}$$

Also,

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

$$v_p = C_o \frac{1}{\sqrt{1 - \left(\frac{\lambda_o}{\lambda_c}\right)^2}}$$

b) Derive the expression for group velocity.

Group velocity:- It is the rate of change of phase of wave inside the wave guide. $V_g = \frac{d\omega}{d\beta}$

from waveguide characteristics

$$\gamma^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - \omega^2\mu\varepsilon \longrightarrow ①$$

At high frequency,

$\gamma = j\beta$

eq① ⇒ $j^2\beta^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - \omega^2\mu\varepsilon$

$\Rightarrow -\beta^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{m\pi}{b}\right)^2 - \omega^2\mu\varepsilon \longrightarrow ②$

At cutoff frequency,

$\gamma = 0, \omega = \omega_c$

eq① ⇒ $0 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - \omega_c^2\mu\varepsilon \longrightarrow ③$

eq② − eq③

$\beta = \sqrt{(\omega^2 - \omega_c^2)\mu\varepsilon}$

Differentiate β w.r.t ω

$$\frac{d\beta}{d\omega} = \frac{d}{d\omega}\sqrt{(\omega-\omega_c)^2}\cdot\sqrt{\mu\varepsilon}$$

$$= \sqrt{\mu\varepsilon}\,\frac{1}{2\sqrt{\omega^2-\omega_c^2}}\cdot 2\omega$$

$$= \frac{\omega\cdot\sqrt{\mu\varepsilon}}{\sqrt{\omega^2-\omega_c^2}}$$

$$= \frac{\sqrt{\mu\varepsilon}}{\sqrt{1-\left(\frac{\omega_c}{\omega_0}\right)^2}}$$

$$\frac{d\beta}{d\omega} = \frac{1}{c}\cdot\frac{1}{\sqrt{1-\left(\frac{\omega_c}{\omega_0}\right)^2}}$$

$$\frac{d\omega}{d\beta} = c\cdot\sqrt{1-\left(\frac{\omega_c}{\omega_0}\right)^2}$$

$$\frac{d\omega}{d\beta} = c\sqrt{1-\left(\frac{\omega_c}{\omega}\right)^2}$$

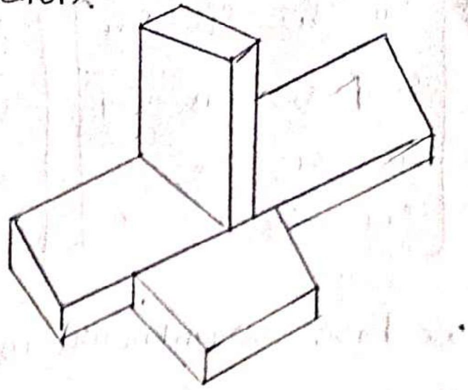
Also

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

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

3) a) Explain the construction and working of reflex klystron oscillator.

4) a) Derive the S-matrix for magic Tee junction.



- * Magic Tee junction is a 4 Port device
- * cuts are made through broders & narrows directions of the rectangles wave guide & Auxilary wave guide are attached along the cuts

By the properties of S-matrix, it is square matrix with n×n, n → no of port

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$

By the working principle of magic Tee junction

$$S_{31} = S_{32}$$
$$S_{41} = -S_{42}$$
$$S_{34} = 0 = S_{43}$$

By the symmetry property

$$S_{12} = S_{21}$$
$$S_{13} = S_{31} = S_{32} = S_{23}$$
$$S_{14} = S_{41} = -S_{42} = -S_{24}$$

Due to matched impedence $S_{33} = S_{44} = 0$

Now substitute above values in S-matrix

$$[S] = \begin{bmatrix} S_{4} & S_{21} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix}$$

By the Identify Property

$$[S][S^*] = I$$

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* & S_{14}^* \\ S_{12}^* & S_{22}^* & S_{13}^* & -S_{14}^* \\ S_{13}^* & S_{13}^* & 0 & 0 \\ S_{14}^* & -S_{14}^* & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

we have 5 unknown, To find them we need five equations.

$R_1C_1 = S_{11}S_{11}^* + S_{12}S_{12}^* + S_{13}S_{13}^* + S_{14}S_{14}^* = 1$

$|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1 \longrightarrow$ ①

$R_2C_2 = S_{12}S_{12}^* + S_{22}S_{22}^* + S_{13}S_{13}^* + S_{14}S_{14}^* = 1$

$|S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1 \longrightarrow$ ②

$R_3C_3 = S_{13}S_{13}^* + S_{13}S_{13}^* = 1$

$= |S_{13}|^2 + |S_{13}|^2 = 1 \Rightarrow 2|S_{13}|^2 = 1 \Rightarrow S_{13} = \frac{1}{\sqrt{2}}$

$R_4C_4 = S_{14}S_{14}^* + S_{14}^*S_{14}$

$\Rightarrow 2|S_{14}|^2 = 1 \Rightarrow S_{14} = \frac{1}{\sqrt{2}}$

$R_4C_1 = S_{14}S_{11}^* - S_{14}S_{12}^* = 0$

$S_{14}(S_{11}^* - S_{12}^*) = 0 \Rightarrow S_{11}^* - S_{12}^* = 0 \Rightarrow S_{11} = S_{12}$

eq ① - eq ② $\Rightarrow |S_{11}|^2 - |S_{22}|^2 = 0 \Rightarrow S_{11} = S_{22}$

Substitute above values in eq ①

$|S_{11}|^2 + |S_{11}|^2 + \frac{1}{2} + \frac{1}{2} = 1$

$2|S_{11}|^2 = 0$

$S_{11} = 0$

$$[S] = \begin{bmatrix} 0 & 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 0 & 0 & \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} & 0 & 0 \end{bmatrix}$$

This is the s-matrix for magic Tee-Junction.

b) Write short note on ferrite materials.

* These are non - metallic materials

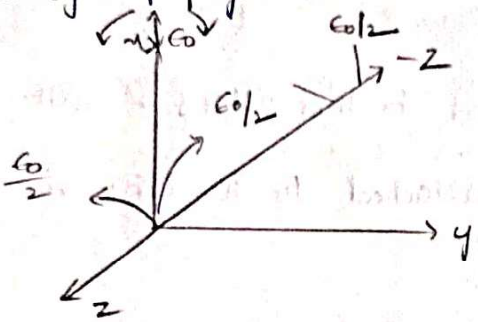
* These are manufacture by $MeOFe_2O_3$.

* The Resistivity will be in range of $10^{14} - 10^{15}$

* The Relative permeability (μ_r) = 100)

* The Ferrite materials work on the principle of "Faraday" propagation law.

* When the electric field of magnitude E_0 is propagated along the x-axis & incident at origin it divides into two parts equally in clockwise and anticlockwise direction with negative $\frac{E_0}{2}$ one part is propagated along the ferrite material placed along z-axis with a progressive shift of the distance of ferrite material. This is known as faraday's propagation law.



There are three types of ferrite materials.

(1) Isolator
(2) gyrator
(3) circulator

(1) gyrator :- It is a two- part device which allows 180° phase shift from Part ① to part ② 0° phase shift from P② to P①

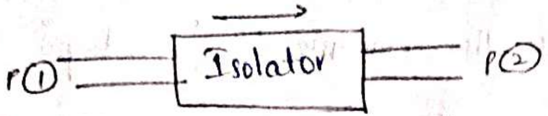
(2) Isolator:- It is two-part device which allow signal from port ① to Port ② but not from Port ② to Port ①

(3) Circulator:- It is min 3 port & maximum n Port device It works either in clockwise (or) anti clockwise direction.

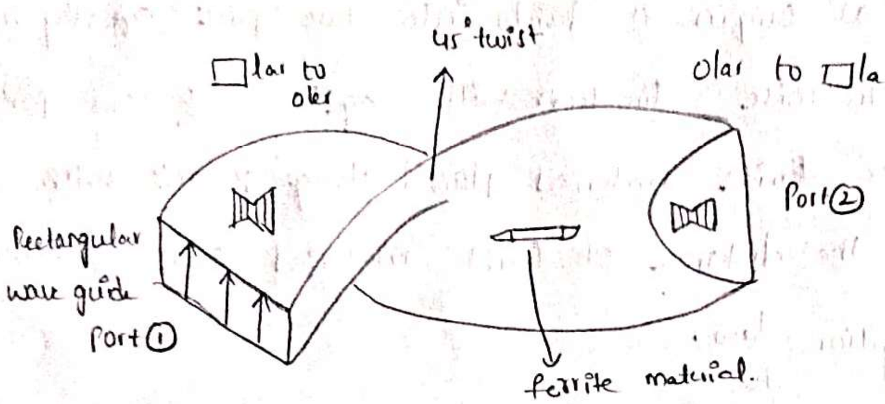
5)a)explain the Construction and working of isolator.

Isolator:-

- It is a two port device.
- It allows wave to travel from Port① to Port② but not from Port② to Port①.
- To seperate the microwave sour Isolator and load are used.

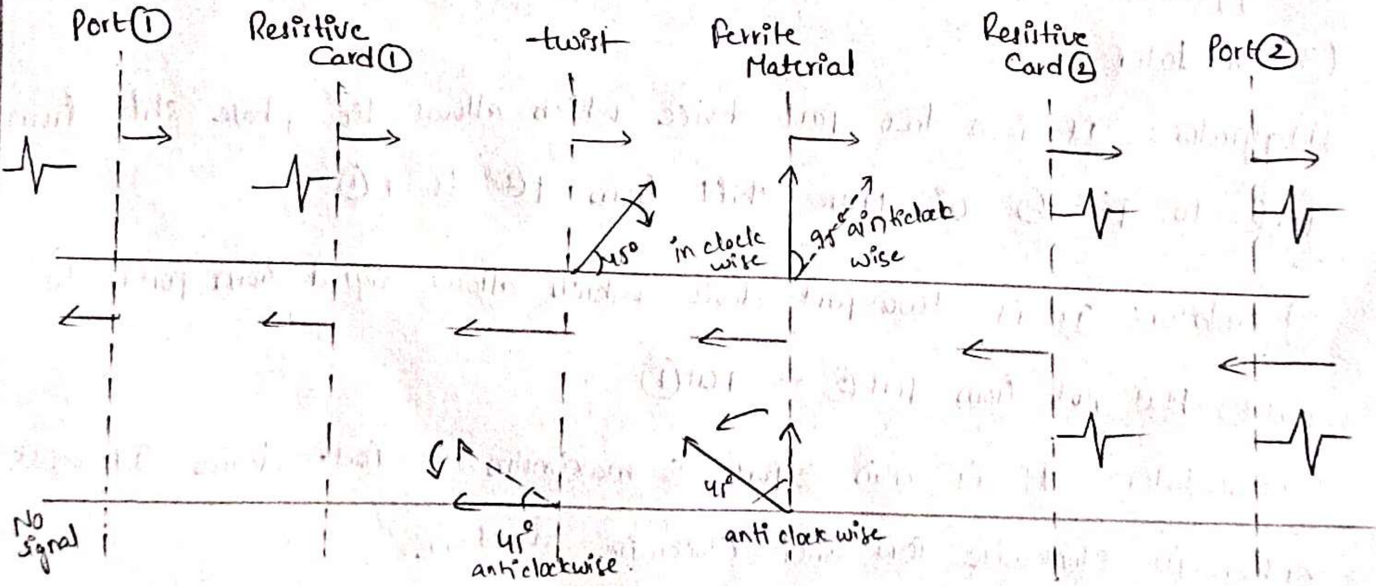


Construction:-



- consider a rectangular wave guide and to this attach a twist of 45°
- Again a circular waveguide is attached to the twist via Rectangular to Circular Transition
- Now a rectangular wave guide is attached to the circular wave guide via circular wav to rectangular transition.

working:-



* When input is given to the port ① it passes through the resistive card and undergoes 45° phase shift in clockwise at the twist

* And it undergoes 45° phase shift in anti-clockwise when reached to the ferrite material

* Therefore, it undergoes 0° phase shift and passes through resistive card and emerges out of the port ②

* Again when input is given at port ② it undergoes 45° phase shift in anticlockwise along ferrite material and another 45° shift in anticlockwise along the twist

* It undergoes plane of polarization and passes through resistive card Due to plane of polarization resistive card absorbs the signal.

* Hence no signal comes out from the port①

b) A rectangular wave guide has dimentions of a=8cm, b=4cm for the mode TE_{10}, TM_{11}, TM_{21}, Mention the modes which are propagate through a wave guide of the free space wave length is 10cm.

Given, $a=8cm$, $b=4cm$, $\lambda_0=10cm$

The mode progogates through the wave guide if $\lambda_c > \lambda_0$

(1) TE_{10}

$m=1$, $n=0$

$$\lambda_c = \frac{2ab}{\sqrt{(mb)^2+(na)^2}} = \frac{2\times4\times8}{\sqrt{(1)^2(4)^2+(0)}} = \frac{64}{4} = 16$$

$\lambda_c = 16cm$, $\therefore \lambda_c > \lambda_0$

(2) TM_{11}

$m=1$, $n=1$

$$\lambda_c = \frac{2ab}{\sqrt{(mb)^2+(na)^2}} = \frac{2\times4\times8}{\sqrt{4^2+8^2}} = \frac{64}{\sqrt{16+64}} = 7.15$$

$$\lambda_c > \lambda_0$$

(8) TM_{21}

$m = 2, n = 1$

$$\lambda c = \frac{2ab}{\sqrt{(mb)^2 + (na)^2}} = \frac{2 \times 4 \times 8}{\sqrt{8^2 + 8^2}} = \frac{64}{\sqrt{128}} = 5.65$$

Hence TE_{10} is only mode which can propagate through wave guide.

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Rajeev Gandhi Memorial College of Engineering & Technology

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III B.Tech II-Semester- Mid-II *Examinations*

MICROWAVE ENGINEERING AND OPTICAL COMMUNICATION

(ECE)

Max. Marks: 20 Date:16-05-2023 Time: 2 Hours

Note: 1. Answer the FIRST question compulsorily. (5 x 1= 05 Marks)

2. Answer Any *THREE* from 2 to 5 questions. (3 x 5 = 15 Marks)

Q.No			**Marks**	**CO**	**Blooms Level**
Q.1	a)	What is the Acceptance angle.	1M	CO4	BL1
	b)	Briefly explain the inter model dispersion losses occurs in optical fiber communication.	1M	CO5	BL2
	c)	Define internal quantum efficiency in LED.	1M	CO5	BL1
	d)	A multimode step index fiber has V-number of 75, NA=0.3, refractive index of the core is 1.458 and operates at 820nm. Find core radius.	1M	CO5	BL3
	e)	Classify different scattering losses in OFC.	1M	CO5	BL2
Q.2	a)	Explain the refractive index profile of step index fiber.	3M	CO4	BL2
	b)	A silica fiber has refractive indices $n_1 = 1.48$, $n_2 = 1.46$. Calculate the NA, critical angle and acceptance angle of the fiber.	2M	CO4	BL3
Q.3	a)	Derive the expression for dispersion parameter due to pulse broadening because of material dispersion.	3M	CO5	BL3
	b)	Write the short note on SBS.	2M	CO5	BL2
Q.4	a)	Explain about micro bending losses.	2M	CO5	BL2
	b)	Mention three mechanisms leading to absorption losses.	3M	CO5	BL1
Q.5	a)	Explain the construction and operation of SLED.	3M	CO5	BL2
	b)	A DH LED operating at 1310nm has radiative and non-radiative recombination times of 30ns and 100ns. The current injected in the LED is 40mA. Calculate bulk recombination life time, internal quantum efficiency and internal power.	2M	CO5	BL3

MID-II

1. a) what is Acceptance angle.

The Acceptance angle can be defined as the maximum angle to the fibre axis in which the signal may enter in to fibre axis to be the propogated.

The acceptance angle

$$\phi_a = \sin^{-1}(\sqrt{n_1^2 - n_2^2})$$

b) Briefly explain the inter model dispersion losses occurs in the optical fiber communication.

The inter model dispersion losses occurs due to the signal having multiple modes will travelling in different speeds and due to this the propogation delay will be more. This causes the inter model dispersion losses. The inter model dispersion occurs in the multi-made fibre.

c) Define internal quantum efficiency in LED.

The Internal quantum efficiency of the LED can be defined as the ratio of photons generated by the LED to the ratio of photons generated internally.

$$n_{quant} = \frac{\text{ratio of photons generated by LED}}{\text{ratio of photons generated internally}}$$

d) A multimode step index fiber has V-number of 75. NA = 0.3. refractive index of the core is 1.458 and operates at 820nm. Find core radius.

Given,

$V = 75$

$N.A = 0.3$

$n_1 = 1.458$

$\lambda = 820 nm$

$a = ?$

$$V = \frac{2\pi a}{\lambda n_1}(NA)$$

$$a = \frac{V \lambda n_1}{2\pi (NA)}$$

$$a = \frac{75 \times 820 \times 10^{-9} \times 1.458}{2\pi \times 0.3}$$

$$a = 4.75 \times 10^{-5} m$$

$$\boxed{a = 0.475 \mu m}$$

e) classify different scattering losses in OFC.

There are two types of scattering losses in OFC.

1) Linear scattering losses
2) Non-linear scattering losses.

The linear scattering losses are of 3 types:

i) Rayleigh scattering losses
ii) Mei scattering losses
iii) wave guide scattering losses

The Non-linear scattering losses are of 2 types

i) stimulated Brillouni scattering (SBS)
ii) stimulated Raman scattering (SRS)

2 a) Explain the refractive index profile of step index fiber.

* The step index fibre is one of the fibres of optical fibre communications.

* In the step index fibre the refractive index is constant along the length and diameter of the fibre and abruptly changes in the step at core-cladding interface.

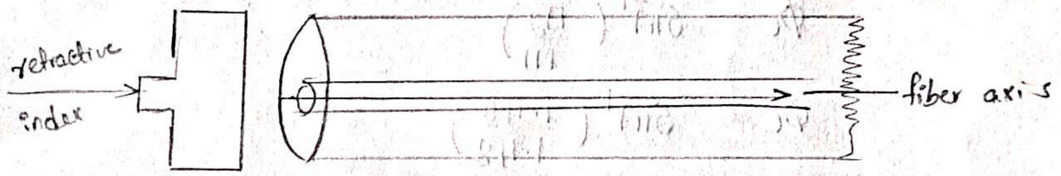
* Therefore, the refractive index will be uniform throughout the fibre. But at the core-cladding inteface it changes.

* In step index fibre the signal travels in zig-zag mode which results in the constant refractive index.

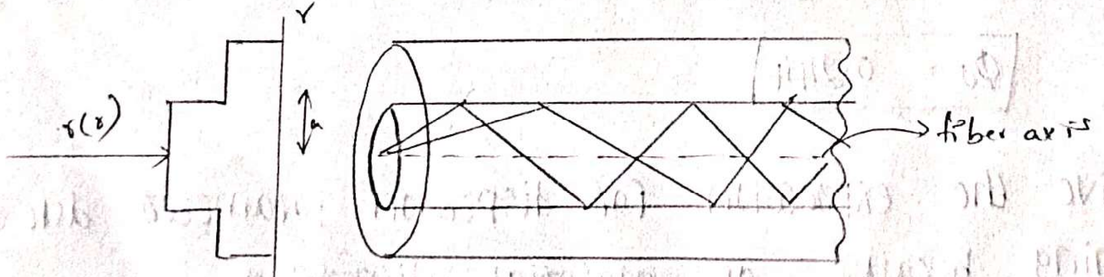
* The step index fibre will exists in both single-mode and multi mode signals.

* In single mode, the fibre only allows the mono-mode signal to pass through which is a fundamental mode (TEM 00).

* V-number is used to calculate the mode.



In multimode, the fibre allows the multi-mode signals to pass through.



The refractive index is given as,

$n(r) = n_1 \quad r<a$ (core)

$n(r) = n_2 \quad r \geq a$ (cladding)

b) A silica fiber has refractive indices $n_1 = 1.48$, $n_2 = 1.46$. Calculate the NA, critical angle and acceptance angle of the fiber.

Given that

$n_1 = 1.48$

$n_2 = 1.46$

i) Numerical Aperture

$$NA = \sqrt{n_1^2 - n_2^2}$$

$$NA = \sqrt{1.48^2 - 1.46^2}$$

$$\boxed{NA = 0.242}$$

ii) Critical Angle

$$\phi_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

$$\phi_c = \sin^{-1}\left(\frac{1.46}{1.48}\right)$$

$$\boxed{\phi_c = 1.406}$$

iii) Acceptance angle

$$\phi_a = \sin^{-1}(NA)$$

$$= \sin^{-1}(0.242)$$

$$\boxed{\phi_a = 0.244}$$

3 a) Derive the expression for dispersion parameter due to pulse broadening because of material dispersion.

The material dispersion causes due to the second order differenciation of refractive index w.R.T wavelength is not equal to zero.

$$\frac{d^2 n_1}{d\lambda^2} \neq 0$$

The group delay is given as

$$\tau_g/L = \frac{1}{V_g}$$

Dispersion is given as

$$D = \frac{d}{d\lambda}\left(\frac{1}{V_g}\right) \longrightarrow ①$$

The group velocity is given as

$$V_g = \frac{d\omega}{d\beta}$$

$$\frac{1}{V_g} = \frac{d\beta}{d\omega}$$

$$\frac{1}{V_g} = \frac{d\beta}{d\lambda}\,\frac{d\lambda}{d\omega} \longrightarrow ②$$

Now, $\frac{d}{d\omega}(\lambda) = \frac{d}{d\omega}\left(\frac{c}{f}\right)$

$$= \frac{d}{d\omega}\left(\frac{2\pi c}{2\pi f}\right)$$

$$= \frac{d}{d\omega}\left(\frac{2\pi c}{\omega}\right)$$

$$\boxed{\frac{d\lambda}{d\omega} = \frac{-2\pi c}{\omega^2}} \longrightarrow ③$$

W.K.T, The phase constant

$$\beta = \frac{2\pi n_1}{\lambda}$$

$$= \frac{2\pi n_1}{c/f}$$

$$\beta = \frac{2\pi f n_1}{c}$$

$$\beta = \frac{\omega n_1}{c}$$

$$\omega = \frac{\beta c}{n_1}$$

substitute ω in eq ③

$$\frac{d\lambda}{d\omega} = \frac{-2\pi c}{\left(\frac{\beta c}{n_1}\right)^2}$$

$$= \frac{-2\pi c n_1^2}{\beta^2 c^2}$$

$$= \frac{-2\pi n_1^2}{\beta^2 c}$$

$$= -\frac{(2\pi)^2 n_1^2}{2\pi \beta^2 c}$$

$$\frac{d\lambda}{d\omega} = \frac{-1}{2\pi c}\left(\frac{2\pi n_1}{\beta}\right)^2$$

substitute $\frac{d\lambda}{d\omega}$ in eq ②

$$\frac{1}{V_g} = \frac{d\beta}{d\lambda}\ \frac{-\lambda^2}{2\pi c}$$

$$= \frac{-\lambda^2}{2\pi c}\left(\frac{d\beta}{d\lambda}\right)$$

$$= \frac{-\lambda^2}{2\pi c}\left(\frac{d}{d\lambda}\left(\frac{2\pi n_1}{\lambda}\right)\right)$$

$$= \frac{-\lambda^2}{2\pi c}\left(-\frac{2\pi n_1}{\lambda^2} + \frac{2\pi}{\lambda}\ \frac{dn_1}{d\lambda}\right)$$

$$= \frac{-\lambda^2}{2\pi c}\ \frac{-2\pi}{\lambda}\left(\frac{n_1}{\lambda} - \frac{dn_1}{d\lambda}\right)$$

$$\frac{1}{V_g} = \frac{1}{c}\left(n_1 - \lambda\frac{dn_1}{d\lambda}\right)$$

$$D = \frac{-1}{c}\left(\frac{d^2 n_1}{d\lambda^2}\right)$$

b) write the short note on SBS

* The stimulated Brillouni scattering (SBS) is one of the scattering losses in optical fibre communication.

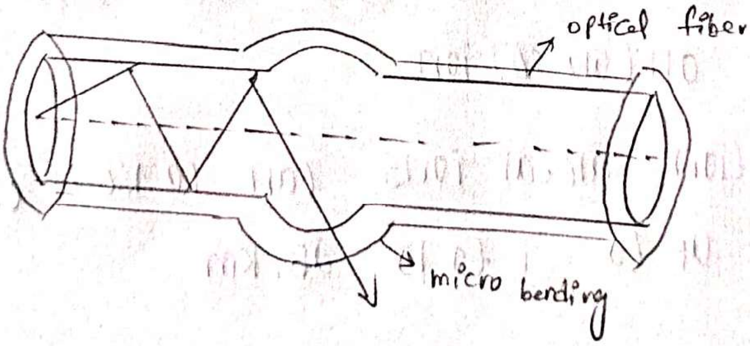
* The SBS will come under the non-linear scattering process of the optical fibre communication.

* The stimulated Brillouni scattering will occur regarding the modulation of light through the molecular or atomic vibrations within the fibre.

* Due to this vibrations within the optical fibre which may leads to the scattering loss.

4 a) Explain about micro bending losses.

- The bending losses occurs when there is a bending in the optical fibre.
- The bending losses are of two types
  i) macro bending
  ii) micro bending
- The micro bending losses occurs when there is a bending in the small surface of the optical fibre.



- When the micro bending occurs in the optical fibre, the reflection takes place in angle when there is no further reflection.

b) Mention three mechanism leading to absorption losses

The Absorption losses mechanism are of 3 types

i) Absorption due to atomic defect.
ii) Extrinsic absorption due to impurity atoms.
iii) Intrinsic absorption due to Basic constituent atoms.

i) Absorption due to atomic defects:

- In this mechanism the absorption losses is due to the defects in the structure of atoms like missing molecules, oxygen molecules vibrations.
- In this mechanism the absorption loss are less when compared to extrinsic and intrinsic absorption losses.
- They can be significant if expressed to the ionization radiation.
- The higher the radiation, the more the attenuation of signal.

ii) Extrinsic absorption losses due to impurity atoms.

- The extrinsic absorption losses are occuring due to the Transition metal ions present in the fibre such as cobalt, chromium, Iron, OH (water) ions.
- These transition metal ions can cause extrinsic absorption loss up to 1 to 10 dB/Km

iii) Intrinsic absorption losses due to the Basic constituent atoms.

- The Intrinsic absorption losses in the optical fibre are occuring due to the Basic atom present in the material called as pure silica.
- These type of losses occur when the fibre is in perfect state.
- perfect state means without any variations in the density and the impurities in the atoms.

Code: A0424206R0623

RGM COLLEGE OF ENGINEERING & TECHNOLOGY (AUTONOMOUS)

12th June 2023

III B.Tech. II Sem. (R20) End Examinations (Regular)

MICROWAVE ENGINEERING AND OPTICAL COMMUNICATION

ECE

Time: 3 Hrs **Total Marks: 70**

Note 1:Answer Question No.1 (Compulsory) and 4 from the remaining

2:All Questions Carry Equal Marks

1a Define cut off flux density in cylindrical magnetron.

b Explain the operation of a circulator.

c Mention the factors causing to extrinsic absorption.

d What is the importance of dominant mode for a waveguide?

e What are the requirements for a optical source such that it is suitable for optical communication.

f Give the relationship between cut-off wavelength and V-number.

g What is the major difference between TWT and klystron?

2 Explain the operation of a Reflex Klystron by using applegate diagram. Also find the efficiency of reflex klystron. (14)

3 a) Why single mode fibers are preferred over multi-mode fibers in telecommunication industry? (7)

b) What are the various applications of single mode fibers? (7)

4 a) What is attenuation? Explain the optical fiber attenuation as a function of wavelength (9)

b) Explain various linear scattering losses (5)

5 a) What are the different types of fiber connectors? (7)

b) Explain about the different splicing techniques in a fiber. (7)

6 a) What is the relation between λ_g, λ_o, λ_c in a waveguide? Derive it.

b) A rectangular waveguide of Cross section 5cm×2cm is used to Propagate TM_{11} mode at 9GHz. Determine the Cutoff wavelength & Wave impedance.

7 a) Sketch a 4 Port Hybrid junction. Derive its S-matrix. (7)

b) A 90W 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 output powers at the coupled and isolated ports. Assume all the ports to be matched. (7)

- xxx -

(1/11)

RGM college of Engineering & Technology (Autonomous)

code:- A0424206R0623

12th June 2023

III B.Tech II sem. (R20) End exam (Regular)

Microwave Engineering & optical communication

E.C.E

1)a) cut off Flux density in cylindrical magnetron:-

→ cylindrical magnetron is a M-type tube in which the electron will just touch the surface of anode cavity & return towards the ~~cad~~ cathode depending on the relative magnitudes of V_0 & B_0. (1M)

⇒ The Hull cut off flux density is given by

$$B_{0c} = \frac{\left(8V_0 \frac{m}{e}\right)^{1/2}}{b\left(1-\frac{a^2}{b^2}\right)} \quad -①$$ (1M)

where V_0 = Anode voltage

a = radius of cathode cylinder

b = radius ~~of~~ from center of cathode to the edge of the anode.

b) Operation of a circulator:-

→ It is a 4 port devices which has a peculiar property where is each terminal is connected to next clockwise terminal.

→ In circulator, port '1' is connected to port ② & not connected to port ③ and port ④, port ② is connected to port ③ not ~~port~~ for port ① & port ④

→ In the device when i/p signal is given to nth port output comes from $(n+1)^{th}$ port. (2M)

c) Extrinsic absorption:-

→ Extrinsic absorption results when a ~~transi~~ transition metal ions such as copper, cobalt, chromium & water (OH^-) are added to glass material

→ The transition metal impurities causes losses from 1-10 dB/km in the optical communication.

(2M)

(2/11)

d) Dominant mode in a waveguide:-

→ The dominant mode in a waveguide is defined as the mode having the highest cut off wavelength (or) lowest cut off frequencies.

→ TE_{10} mode is the dominant mode in the rectangular waveguide. It will allow maximum power flow.

(2M)

e) Requirements of optical source :-

→ Size and configuration compatible with launching light.

→ Capable of signal modulation over a wide bandwidth.

→ High coupling efficiency

→ High optical output power

→ High reliability

→ Low weight & low cost.

(2M)

f) **Relation between cut-off wavelength & V-number:-**

→ V-number is used to calculate the number of modes supported by fiber. It is also called as V-number (or) normalized frequency.

→ No. of modes supported by fiber $M = \frac{V^2}{2}$

→ The V-number is given by $V = \frac{2\pi a}{\lambda}(NA)$

let $\lambda \approx \lambda_c$

λ_c = cutoff wavelength

$$V = \frac{2\pi a}{\lambda_c}(NA) \quad -① \quad (1M)$$

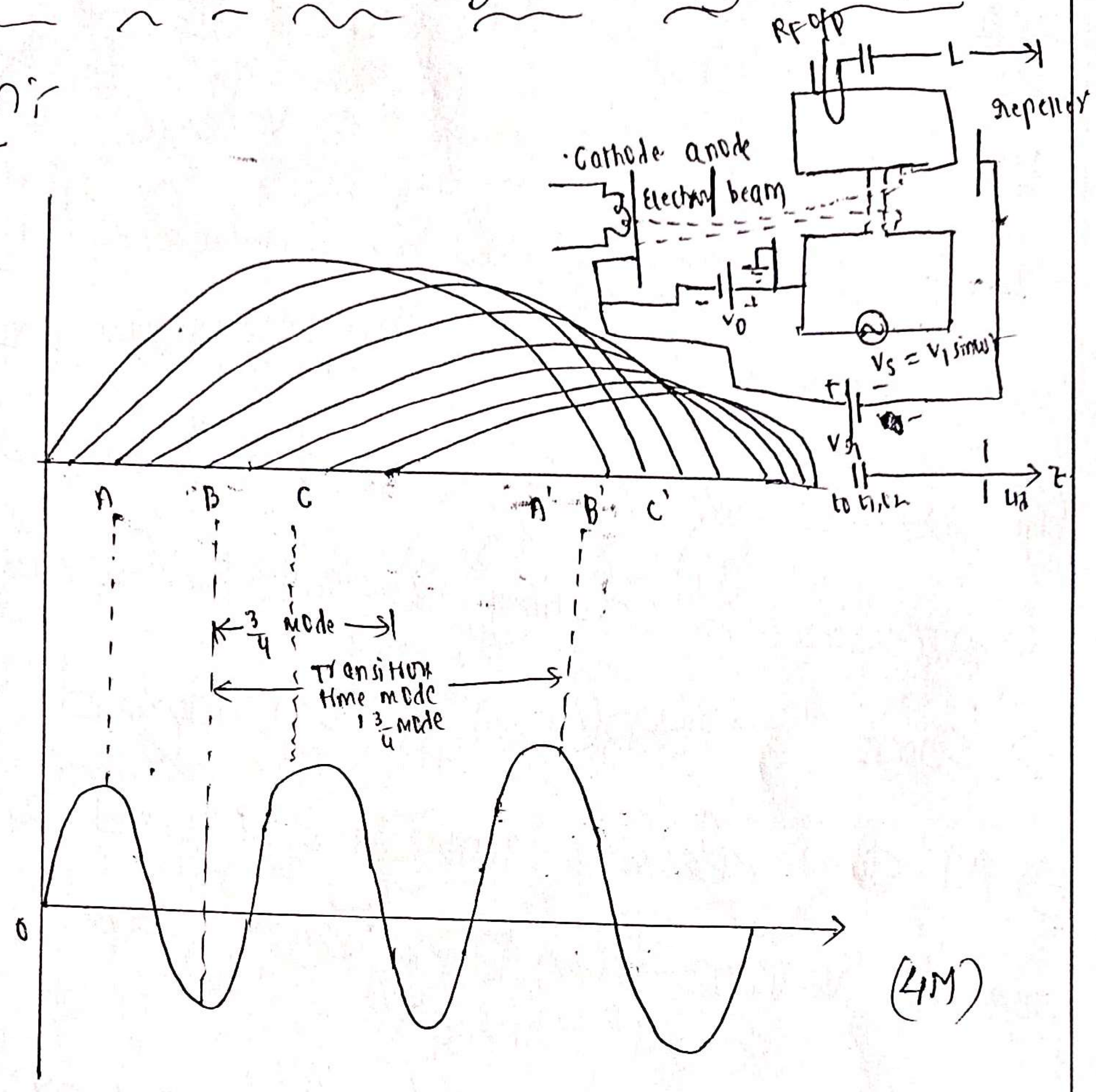
$$\lambda_c = \frac{2\pi a}{V}(NA) \quad -② \quad (1M)$$

g) **Differences between TWT & Klystrons:-**

Klystron tube	TWT
① Interaction between electron beam & input AC signal occurs only at cavity gaps	① Interaction between electron beam & input ac signal occurs continously across the entire length of circuit.
② cavities functions independently	② In TWT all the devices are effectively coupled.
③ In klystron the signal is not a propagating wave	③ In TWT the signal is a propagating wave.
④ It is having lower bandwidth	④ More Bandwidth & higher gain.

(2M)

2) Operation of a Reflex klystron using applegate diagram:-



(4M)

→ The principle of operation of reflex klystron oscillator is "velocity modulation."

→ In this tube, only a single cavity is available for velocity modulation process.

⇒ A repeller is attatched to the tube which is applied with negative voltage.

⇒ The ē beam is velocity modulated by the cavity gap voltage. Some electrons are accelerated by positive half cycle & some electrons are deaccelerated during negative half-cycle.

⇒ Some ē travel with unchanged velocity.

⇒ All the electrons turned around by the repeller voltage when they leave cavity gap.

⇒ These electrons are finally collected by the walls of the cavity. (6M)

output power & efficiency:

⇒ The round trip DC transit angle of reflex klystron oscillator is given as

$$\theta_0' = 2n\pi - \frac{\pi}{2} \quad ①$$

→ The fundamental component of the induced current at the cavity is given as

$$I_2 = 2\beta_i I_0 J_1(x') \rightarrow ②$$

→ Bunching parameter of reflex klystron oscillator is

$$x' = \frac{\beta_i V_1}{2V_0}\theta_0' - ③$$

→ From ③ $$V_1 \Rightarrow \frac{2V_0 x'}{\beta_i \theta_0'} - ④$$

→ Now consider the o/p ac power which is given as

$$P_{ac} = \frac{V_1 I_2}{2}$$

$$P_{ac} = \frac{2V_0 x' I_0 J_1(x')}{\left(2n\pi - \pi/2\right)}$$

→ Efficiency of reflex klystron is given as

$$\eta = \frac{P_{ac}}{P_{dc}} \Rightarrow \frac{2V_0 x' I_0 J_1(x')}{\left(2n\pi - \pi/2\right)} \times \frac{1}{V_0 I_0}$$

$$\boxed{\eta = \frac{2x' J_1(x')}{\left(2n\pi - \pi/2\right)}} = \frac{2(2.408) J_1(2.408)}{2\pi(2) - \pi/2} = 22.7$$

(4M)

$(\eta = 22.7\,\%)$

3)(a) Single mode fibers:-

⇒ The fiber which allows only single fundamental mode of light are called as single mode fibers.

⇒ Single mode fibes have small diameter of the core

⇒ Single mode fibers have low values of numerical aperture.

⇒ They are used for coherent optical sources.

⇒ These fibers have less attenuations

⇒ These fibers have possibility of upgradation

⇒ These fibers have no intermodal dispersion

⇒ So, single mode fibers are preferred over multimode fibers in optical communication.

(7M)

5/11

3) b) Applications of single mode fibers:-

→ Single mode fibers are mostly used in several applications where to need only one cable for sending at the multi frequency (WDM wavelength division multiplexing) such as

→ It is used in local area network as well as point to point links in many cities.

→ One and multiple buildings.

→ They are extensively used in small & medium scale companies.

→ They are used in educational & academic institutions.

(7M)

1a) Attenuation :- Attenuation of a light signal as it propagates along a fiber is an important factor in the design of optical communication. The basic attenuation mechanisms in a fiber are absorption, scattering & radiative losses. (2M)

→ As light travels along the fiber, its power decreases exponentially with distance. If $P(0)$ is the optical power in a fiber at the origin (at $z=0$), then the power $P(z)$ at a distance z further down the fiber is

$$P(z) = P(0)\, e^{-\alpha_p z} \quad -①$$

where

$$\alpha_p = \frac{1}{z} \log\left[\frac{P(0)}{P(z)}\right] \quad -②$$

α_p is the fiber attenuation co-efficient

→ This attenuation co-efficient in units of decibels per kilometer, denoted by dB/km. This parameter is denoted by 'α' we have

$$\alpha\,(\mathrm{dB/km}) = \frac{10}{z} \log\left[\frac{P(0)}{P(z)}\right] = 4.343\,\alpha_p\,(\mathrm{km}^{-1})$$

→ This parameter is referred as fiber loss (or) fiber attenuation & it is a function of wavelength. (2M)

6/11

i)b) Linear scattering losses:-

→ The various linear scattering losses are classified as
① Rayleigh scattering losses
② Mie scattering losses
③ Waveguide scattering losses.

① Rayleigh scattering losses:-

→ These losses occurs due to the microscopic variations in the material of the fiber.

→ It is also caused by unequal distribution of molecular densities (or) atomic densities leads in Rayleigh scattering losses.

→ For SiO_2 fiber, the scattering loss is given by $\alpha_{scat} = \frac{8\pi^3}{3\lambda^4} n^8 p^2 \beta_c T_F \, km^{-1}$

(2M)

② Mie scattering loss:-

→ These losses are occured due to compositional fluctuations, structural inhomogeneties in the fiber which causes the light to scatter outside of fiber. (2M)

③ Wave guide scattering losses:-

→ These losses are occured due to variations in diameter of the core.

→ It is also caused due to imperfections of core-cladding interface.

→ It is also caused due to the change in the refractive index of the core

(or) cladding (1M)

(7/11)

5) a) Types of fiber connectors:-

→ Fiber connectors are temporary joint between two fibers.

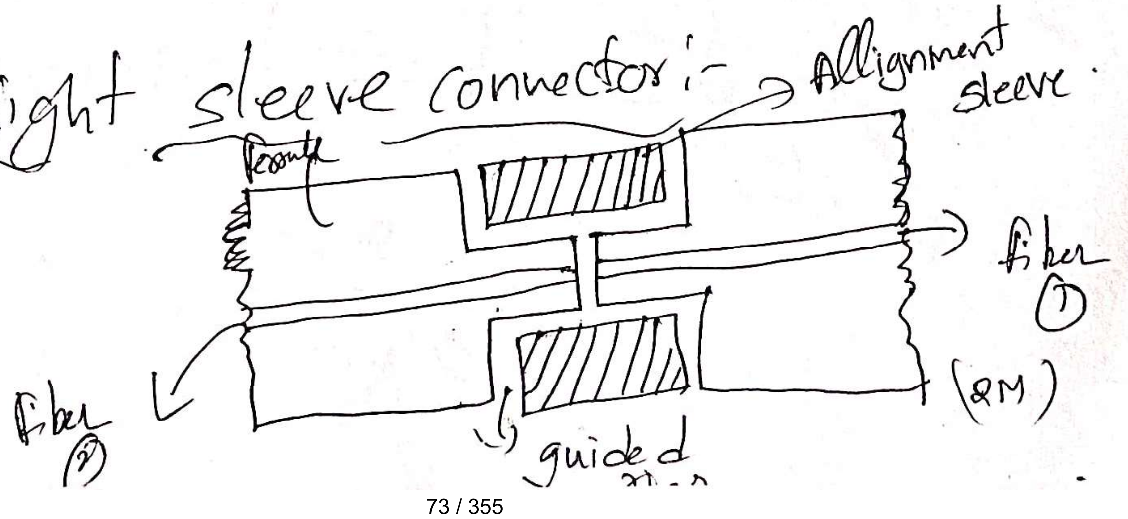
→ They are used in military and industrial applications

→ The most frequently used connectors are
- → ① Butt joint connectors
- → ② Expanded beam connectors.

① Butt joint connectors:-

→ Butt joint connectors are mainly used in single mode & multimode fibers. They are classified as 2 types namely ⓐ straight sleeve
ⓑ Tapered sleeve

a) straight sleeve connector:-



→ It employes a plastic container called as ferrule for each fiber. It consists of a allignment sleeve into which the ferrule is placed. A Precision pre cision hole is drilled into the ferrule into which the fiber is connected end to end.

② Tapered sleeve connector :-

It is also known as biconical connector. It consists of a tapered ferrule into which the fiber are placed. This tapered ~~fee~~ ferrule is placed into the tapered sleeve to maintain the fibre and seperation.

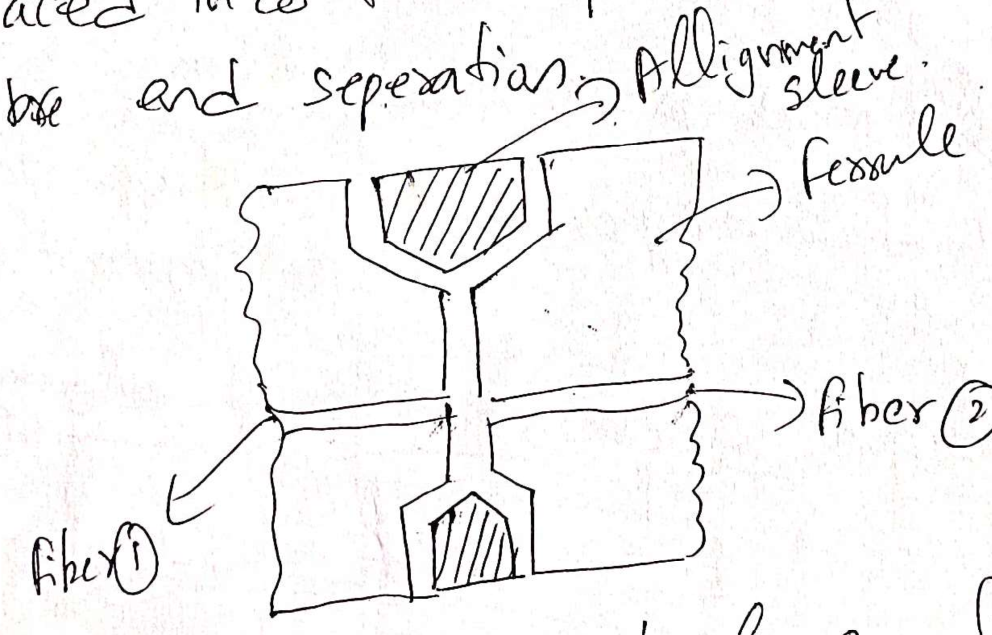


Fig:- Tapered sleeve (2M)

(8/11)

② Expanded beam connectors:-

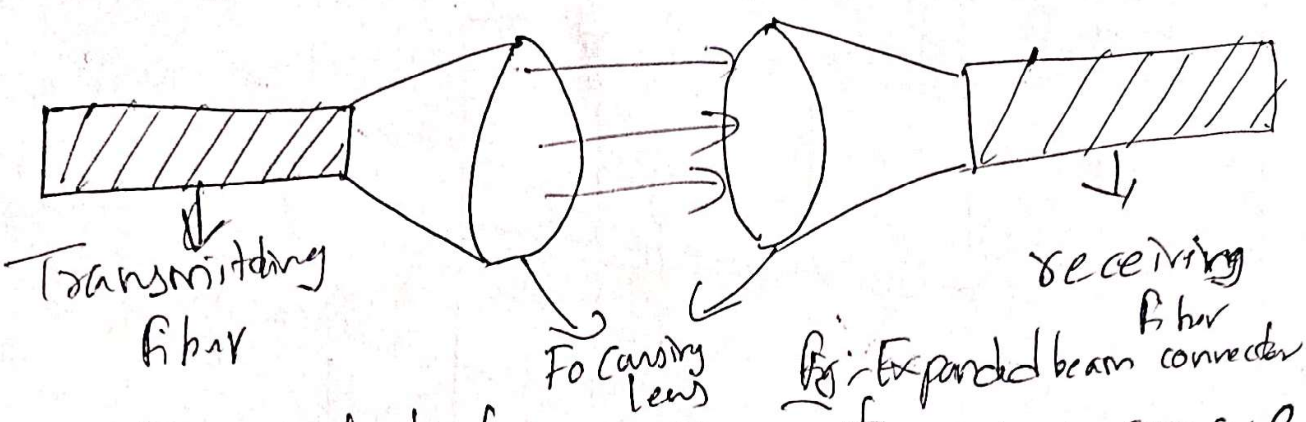


Fig:- Expanded beam connector

→ In Expanded beam connectors, we can use focusing lens on the end of fiber. The lens focus the expanded beam on to the core of receiving fiber. (3M)

3b) Different splicing techniques in a fiber:-

→ The fiber splice is a permanent (or) Semi permanent joint between two fibers.

→ The various splicing techniques are:-

① Fusion splicing

② V-groove splicing

③ Elastic tube splicing

a) Fusion splicing:-

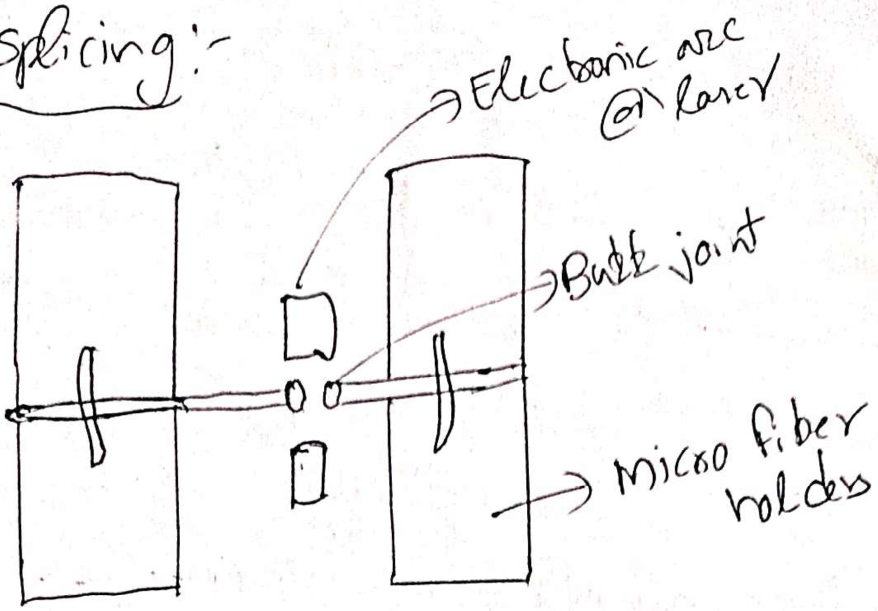


fig:- Fusion splicing

→ In this method the fiber ends are reallgned and placed together facing the ends in this micro fiber holders.

→ The but joint is then heated, with the help of Electric arc, the fiber ends are melted & bonded together.

→ This technique produce very low splice loss <0.06 dB. (3M)

9/11

5)b) b) V-groove splicing:-

In this technique the fiber ends which are prealigned in a V-shaped groove holder, then the '2' fibers are bended together by means of adhesive tape.

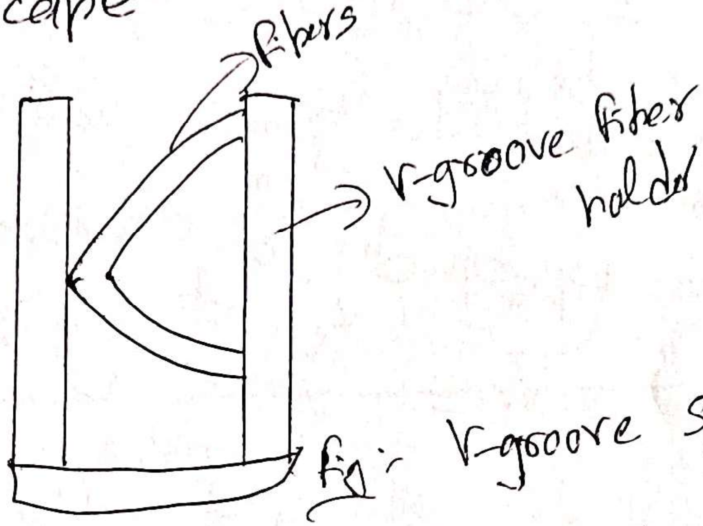


fig:- V-groove splicing (2M)

c) Elastic tube splice:- This method consists of a tube made up of elastic material.

→ The center rod ~~diament~~ diameter of elastic tube is made slightly smaller than the size of fiber to be splice.

→ The symmetrical force allows accurate allignment of the axis of '2' fibers to be joined.

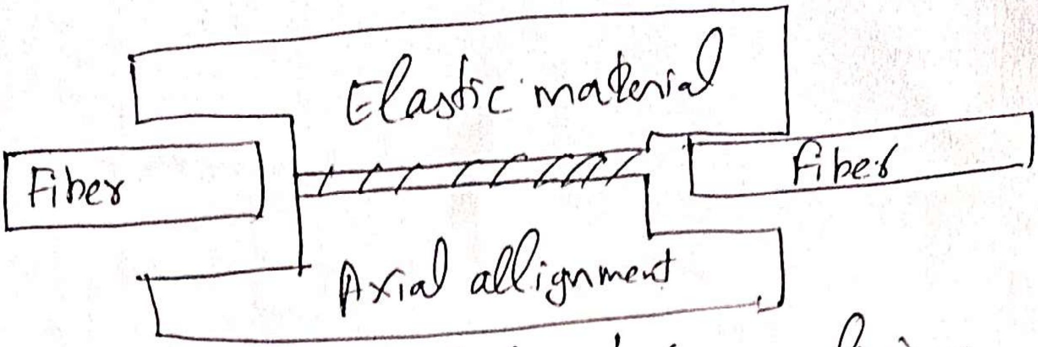


fig:- Elastic tube splicing. (2M)

6)a) Relation between $\lambda_g, \lambda_o, \lambda_c$ in a waveguide:-

→ We know that the phase velocity in a rectangular waveguide is known as

$$V_p = \frac{\lambda_g}{t} \quad -① $$

$$V_p = \lambda_g \cdot f \quad -② $$

$$V_p = \lambda_g \cdot \frac{c}{\lambda_o} \quad -③ $$

→ The phase velocity is also given by the equation

$$V_p = \frac{c}{\sqrt{1-\left(\frac{\lambda_o}{\lambda_c}\right)^2}} \quad -④ $$

(2M)

(10/11)

→ From ③ & ④ we get

$$\lambda g \cdot \frac{c}{\lambda o} = \frac{c}{\sqrt{1-\left(\frac{\lambda o}{\lambda c}\right)^2}}$$

$$\Rightarrow \lambda g = \frac{\lambda o}{\sqrt{1-(\lambda o/\lambda c)^2}} \quad — ⑤$$

The eauation ⑤ gives the relation between free space wavelength (λo), guide wavelength (λg) & cut off wavelength (λc). (5M)

b) Given: $a \Rightarrow 5\,cm$

$b \Rightarrow 2\,cm$

$f \Rightarrow 9\,GHz$

$$\lambda_0 \Rightarrow \frac{c}{f} \Rightarrow 3.33\,cm$$

$$\lambda_{c11} \Rightarrow \frac{2ab}{\sqrt{a^2+b^2}} \Rightarrow \frac{2(5)(2)}{\sqrt{25+4}} \Rightarrow 3.71\,cm$$

(2M)

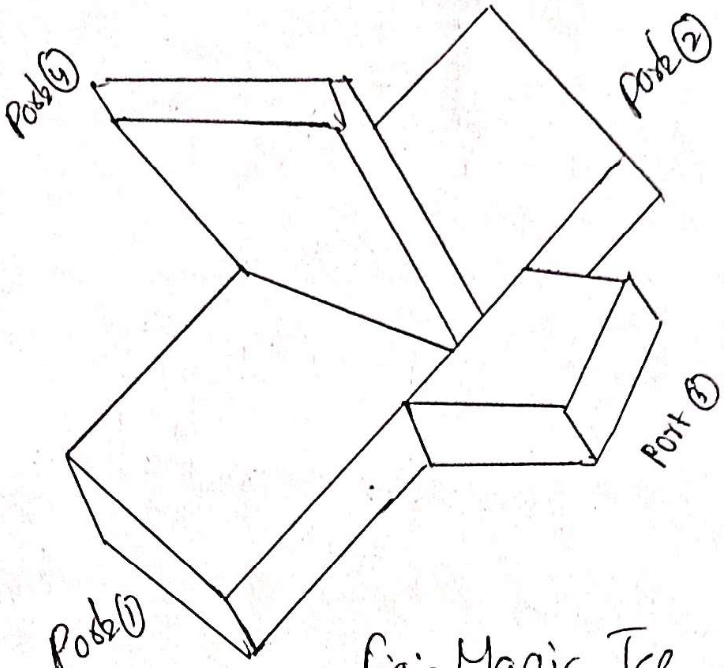
$$Z_{TM} \Rightarrow 120\pi\sqrt{1-(\lambda o/\lambda c)^2}$$

$$\Rightarrow 120\pi\sqrt{1-\left(\frac{3.33}{3.71}\right)^2}$$

$$Z_{TM} \Rightarrow 166.20\,\Omega$$

(5M)

7)a) 4-port Hybrid junction (or) Magic Tee junction:-



(2M)

fig: Magic Tee junction

→ E-H plane Tee junction is formed by cutting a rectangular slot along the width & breadth of the main waveguide & the side arm ie H-arm & E-arm are attatched as shown in fig.

→ Port ③ & port ④ are isolated ports in the junction ie $\boxed{S_{34} = S_{43} = 0}$

→ This junction has 4-ports, so the order of the S-matrix is 4x4 ie $S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$

→ Because of the H-plane Tee junction → $\boxed{S_{13} = S_{23}}$

→ Because of the E-plane Tee junction → $\boxed{S_{14} = -S_{24}}$

→ Port ③ & port ④ are perfectly matched to the junction ie $\boxed{S_{33} = S_{44} = 0}$

→ S-matrix is a symmetric matrix ie $S_{ij} = S_{ji}$

→ Then S-matrix is given by $S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix}$

→ S matrix is unitary matrix ie $[S] \times [S]^* = [I]$

$$\Rightarrow \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* & S_{14}^* \\ S_{12}^* & S_{22}^* & S_{13}^* & -S_{14}^* \\ S_{13}^* & S_{13}^* & 0 & 0 \\ S_{14}^* & -S_{14}^* & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

→ $R_1C_1 \Rightarrow |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2 \Rightarrow 1$ — ①

→ $R_2C_2 \Rightarrow |S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 + |S_{14}|^2 \Rightarrow 1$ — ②

→ $R_3C_3 \Rightarrow |S_{13}|^2 + |S_{13}|^2 = 1$ — ③ → $\boxed{S_{13} = 1/\sqrt{2}}$

→ $R_4C_4 \Rightarrow |S_{14}|^2 + |S_{14}|^2 = 1$ — ④ → $\boxed{S_{14} = 1/\sqrt{2}}$

→ From ① & ② ⇒ $\boxed{S_{11} = S_{22}}$

→ $R_4C_1 \Rightarrow S_{14} S_{11}^* - S_{14} S_{12}^* = 0$

$S_{14} \neq 0$; $\boxed{S_{11} = S_{12}}$

→ From ① ⇒ $2|S_{11}|^2 + 1/2 + 1/2 = 1$ ⇒ $\boxed{S_{11} = 0}$ $\boxed{S_{12} = 0}$.

→ The Final - S-matrix for Hybrid Tee (or) Magic Tee junction is given as

$$S = \begin{bmatrix} 0 & 0 & 1/\sqrt{2} & 1/\sqrt{2} \\ 0 & 0 & 1/\sqrt{2} & -1/\sqrt{2} \\ 1/\sqrt{2} & 1/\sqrt{2} & 0 & 0 \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 & 0 \end{bmatrix}$$

(5M)

7) b) Given $C = 20\,dB$, $D = 35\,dB$

Coupling coefficient $\Rightarrow C = 20 = 10\log\frac{P_i}{P_f} \Rightarrow \frac{P_i}{P_f} \Rightarrow 10^2 = 100$

$\Rightarrow P_i \Rightarrow 90\,W$

$\Rightarrow P_f \Rightarrow \frac{P_i}{100} = 0.9\,W$ (3M)

→ Directivity $\Rightarrow D \Rightarrow 35 \Rightarrow 10\log\frac{P_f}{P_b} \Rightarrow \frac{P_f}{P_b} \Rightarrow 10^{3.5}$

$\Rightarrow P_b \Rightarrow \frac{P_f}{10^{3.5}} = 284.6\,uW$
(2M)

→ Now the received power is given by $P_r \Rightarrow P_i - P_f - P_b$

$P_r \Rightarrow 90 - 0.9 - 284 \times 10^{-6}$

$P_r = 89.09\,W$. (2M)

14/6/23

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Code: A0424206S0923

RGM COLLEGE OF ENGINEERING & TECHNOLOGY (AUTONOMOUS)

12th September 2023

III B.Tech. II Sem. (R20) End Examinations (Supplementary)

MICROWAVE ENGINEERING AND OPTICAL COMMUNICATION

ECE

Time: 3 Hrs **Total Marks: 70**

Note 1:Answer Question No.1 (Compulsory) and 4 from the remaining
2:All Questions Carry Equal Marks

1a Define optimum bandwidth of fiber.

b Mention performance characteristics of two cavity klystron amplifier

c Define phase velocity of a microwave.

d What is Mode Field diameter?

e Define fusion splicing.

f Explain the operation of a circulator.

g What is signal attenuation in optical fibers? Mention different attenuation losses.

2 a) Explain the basic LED configuration used as optical source. (7)
b) Derive the expression for quantum efficiency and optical power generated by LED. (7)

3 a) Explain the working of two hole directional coupler with a neat diagram.
b) Explain about E-plane tee junction with a neat sketch. Why it is called a series Tee.

4 a) Distinguish between Optical Fiber Communication system and Conventional Communication System. (7)
b) The Core of an optical fiber is made of Glass of refractive index 1.55 and in cladd with another glass of refractive index 1.0.Determine
i) Numerical Aperture
ii) Acceptance angle
iii) Critical incidence angle (7)

5 a) Explain what is meant by the "Cut-off wavelength". Explain the term "dominant mode "of a waveguide.
b) Determine the cutoff wavelength for the dominant mode in a rectangular waveguide of breadth 10cm.For a 2.5GHz signal propagated in this waveguide in the dominant mode, calculate the guide wavelength ,the group and phase velocities.

6 a) Give the theory of waveguide dispersion and find the expression for rms waveguide dispersion. (9)
b) Why do we call intermodal dispersion as chromatic dispersion? Justify (5)

7 a) With a neat diagram explain the construction, operation of magnetron. (10)
b) Give the performance characteristics of a magnetron. (4)

- xxx -

Code : H0424206509 23

RGM college of Engineering & Technology (Autonomous)

12th September 2023

III B. Tech II sem (R20) End exam (Supplementary)

Microwave Engineering & optical communication

ECE.

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1)a) Optimum bandwidth of fiber:-

⇒ Most fiber optic cables have a bandwidth capacity of 1 Gbits/s, which is the typical fiber optic maximum speed. Fiber optics is indeed the fastest network offering symmetric upload & download speeds in gigabit. (2M)

---

b) Performance characteristics of two cavity klystron amplifier:-

The performance characteristics of two cavity klystron amplifier are:-

→ Frequency : 250 MHz to 100 GHz

→ Power : 10 KW – 500 KW

→ Power gain : 15 dB – 70 dB

→ Bandwidth : ~~15 dB~~ 10 – 60 MHz - generally used in fixed frequency applications. (2M)

c) Phase velocity:- It is defined as the rate at which the wave changes its phase in terms of guide wavelength & it is given by

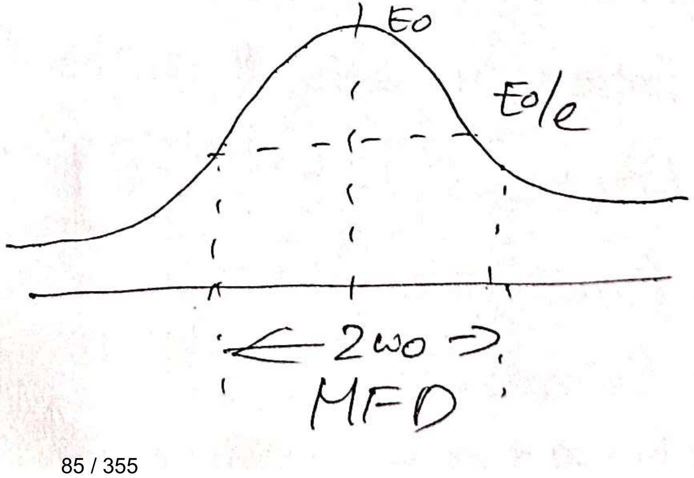
$$V_p = \frac{\omega}{\beta} \quad -①$$

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

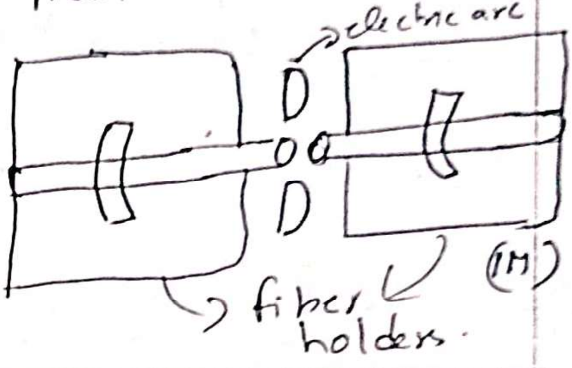
(2M)

d) Mode field diameter:- (MFD) (2M)

→ Mode field diameter is defined as the distance between the two opposite end points of field amplitude distribution, where electric field is $1/e = 0.367$ times the field along fiber axes.



e) **Fusion splicing:-** In this method the fiber ends are alligned & aplaced together facing the ends in the micro fiber holders. This joint is called as butt joint. The butt joint is then heated with the help of electric arc (or) laser so that the fiber ends are melted & bonded together as shown in fig (1M)



f) **Opertion of a circulator:-** (2M)

→A circulator is a four port microwave device in which each terminal is connected to the next clockwise terminal.

→If the input signal is given at nth position then the output is taken at (n+1)th port.

→ Circulators can be used as duplexer for radar antenna system.

g) Attenuation:- Attenuation in optical fiber is loss of light (or) signal. Attenuation limits the distance in which the signal can travel through optical fiber & is measured in dB.

⇒ The basic attenuation losses in a fiber are absorption, scattering & radiation losses. (2M)

2)a) LED configuration:

⇒ A light emitting diode is a semiconductor diode that emits light when an electrical current is applied in the forward direction of the device

⇒ The basic configuration for LED is "double hetero junction structure."

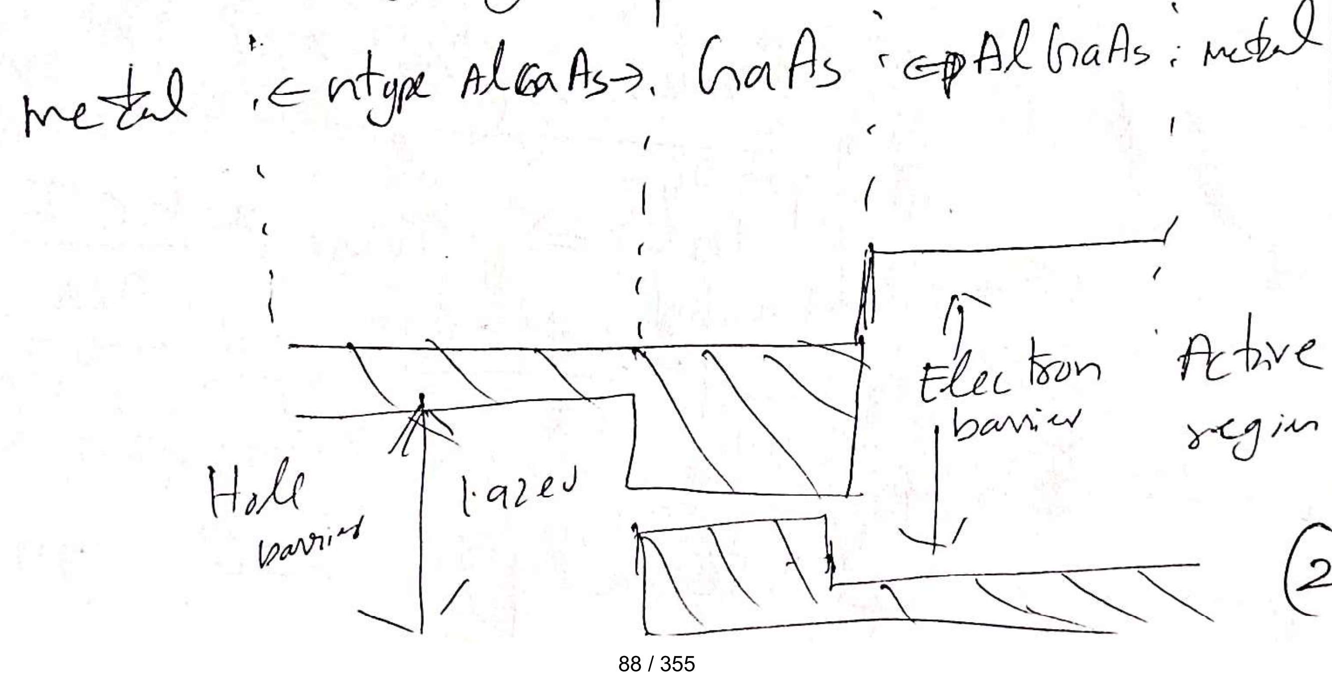
⇒ This type of LED are made from two (or) more different types of semi conductor materials. Each having different band gap energy

→ Two basic principles are involved:

a) confinement of electron hole recombination within a highly restricted active region (carrier confinement)

b) conduction of radiated light in one direction (optical confinement)

→ The first principle is achieved by placing a semi-conductor having lower band gap in between two layers of another semiconductor material having higher band gap energy. (5M)



(2M)

2) b) Quantum efficiency & optical power:-

→ The internal quantum efficiency (η_{int}) is defined as the ratio of radiative recombination rate to the total recombination rate

$$\rightarrow \eta_{int} = \frac{\gamma}{\gamma_r} \quad -①$$

$$\Rightarrow \eta_{int} \Rightarrow \frac{R_r}{I/q} = \frac{R_r}{I/q}$$

$$\Rightarrow R_r \Rightarrow \eta_{int} \times I/q$$

Optical power $\Rightarrow P_{int} \Rightarrow R_r \cdot h \cdot \nu$

$$P_{int} \Rightarrow \left(\eta_{int} \times \frac{I}{q}\right) h \cdot \nu$$

$$P_{int} \Rightarrow \left(\eta_{int} \times \frac{I}{q}\right) h \cdot \frac{c}{\lambda}$$

$$\boxed{P_{int} \Rightarrow \eta_{int} \times \frac{hcI}{q\lambda}} \quad -($$

Equation ② given the expression for optical power generated internally in LED. (7M)

3)(a) Two hole directional coupler:-

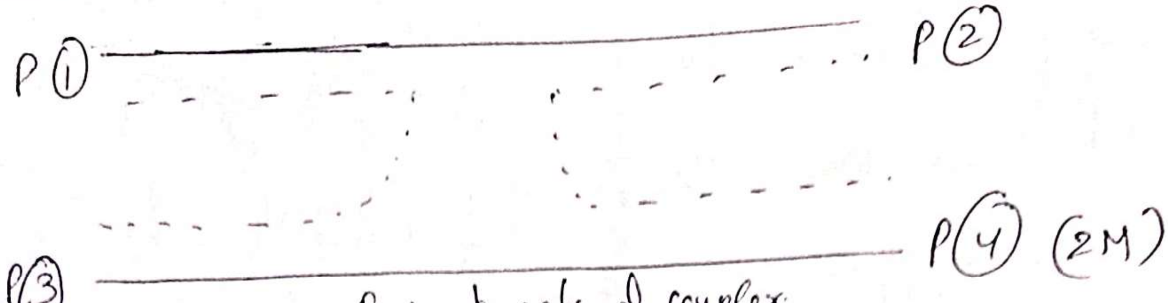


fig: directional coupler

→ It is a 4 port device & port ① & port ② is called as primary waveguide

→ Port ③ & port ④ are called as secondary waveguide.

→ The signal which is given at port ① travels to port ② & signal power is coupled to port ④ but not to port ③

→ Coupling factor: It is the ratio of incident power to the forward coupler power

$$C = 10\log_{10}\left(\frac{P_i}{P_f}\right) dB \quad - ①$$

→ Directivity: It is defined as ratio of forward coupled power to the back power.

$$D = 10\log_{10}\left(\frac{P_f}{P_b}\right) dB \quad - ②$$

⇒ S-matrix of directional coupler ⇒ $S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}_{4}$

⇒ Symmetric property $S_{ij} = S_{ji}$

⇒ Unitary matrix ⇒ $[S][S^*] = [I]$

$$\Rightarrow \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{12} & 0 & S_{23} & 0 \\ 0 & S_{23} & 0 & S_{34} \\ S_{14} & 0 & S_{34} & 0 \end{bmatrix} \begin{bmatrix} 0 & S_{12}^* & 0 & S_{14}^* \\ S_{12}^* & 0 & S_{23}^* & 0 \\ 0 & S_{23}^* & 0 & S_{34}^* \\ S_{14}^* & 0 & S_{34}^* & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

⇒ $R_1 C_1 \Rightarrow |S_{12}|^2 + |S_{14}|^2 = 1$ — ①

$R_2 C_2 \Rightarrow |S_{12}|^2 + |S_{23}|^2 = 1$ — ②

$R_3 C_3 \Rightarrow |S_{23}|^2 + |S_{34}|^2 = 1$ — ③

$R_4 C_4 \Rightarrow |S_{14}|^2 + |S_{34}|^2 = 1$ — ④

$R_1 C_3 \Rightarrow S_{12} S_{23}^* + S_{14} S_{34}^* = 0$ — ⑤

⇒ By solving the eq ① to ⑤, the S-matrix for directional coupler is given by

$$S = \begin{bmatrix} 0 & P & 0 & jq \\ P & 0 & jq & 0 \\ 0 & jq & 0 & P \\ jq & 0 & P & 0 \end{bmatrix}$$

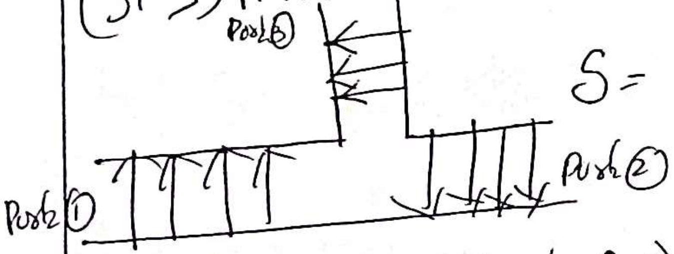
(5M)

3)(b) E-plane Tee junction

→ In E-plane Tee junction input signal is given at port ③, which will be divided equally across port ① & ② but with a phase difference of 180°

$$S_{13} = -S_{23} \quad -①$$

→ Since there are '3' ports, the S-matrix will be (3×3) matrix which is given by



$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}_{3\times3} \quad -②$$

fig:- E-plane tee (2M)

→ S-matrix is a symmetric matrix i.e. $\boxed{S_{ij} = S_{ji}}$

$$S_{12} = S_{21} \qquad S_{33} = 0$$

$$S_{13} = S_{31} \qquad S_{13} = -S_{23}$$

$$S_{23} = S_{32}$$

⇒ Now S-matrix is given by ⇒ $S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{23} \\ S_{13} & -S_{13} & 0 \end{bmatrix}$

Unitary matrix $\Rightarrow [S][S]^* = [I]$

$$\Rightarrow \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* \\ S_{12}^* & S_{22}^* & -S_{13}^* \\ S_{13}^* & -S_{13}^* & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$\Rightarrow \quad R_1C_1 \Rightarrow |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1$

$R_2C_2 \Rightarrow |S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1$

$R_3C_3 \Rightarrow |S_{13}|^2 + |S_{13}|^2 = 1$

$R_3C_1 \Rightarrow S_{13}S_{11}^* - S_{13}S_{12}^* = 0$

$$\Rightarrow \quad 2|S_{13}|^2 = 1$$

$$S_{13} = 1/\sqrt{2}$$

⇒ By solving the equations we get the s-matrix of E plane tee junction as

$$S = \begin{bmatrix} 1/2 & 1/2 & 1/2 \\ 1/2 & 1/2 & -1/\sqrt{2} \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 \end{bmatrix}$$

SM
(~~SM~~)

→ As the axis of the side arm is parallel to the electric field, this junction is called ~~E plane tees~~ "Series junction"

4) a Comparision between optical fiber communication & conventional communication system: (4M)

Optical fiber communication	Conventional communication systems
1) Requires a bandwidth of 10^3 to 10^{16} Hz	1) Requires a bandwidth of 500 MHz
2) Light weight	2) Heavier in weight.
3) Immune to R.F. interference	3) Needs external shielding
4) Electrical isolation	4) Exhibits earthing problems
5) Low loss of about 0.2 dB/km	5) Loss of about 10 dB/km
6) Secure signal propagation	6) signal can be tapped easily
7) Due to increased bandwidths higher data rates	7) Low data rates.

4)b) Given: $n_1 = 1.55$

$n_2 = 1.0$

i) Numerical Aperture :- $NA = \sqrt{n_1^2 - n_2^2}$

$NA = \sqrt{(1.55)^2 - (1.0)^2}$

$\boxed{NA = 1.1842}$ (2M)

ii) Acceptance angle :- $\theta_a = \sin^{-1}(NA)$

$\theta_a = \sin^{-1}(1.1842)$

(2M)

iii) Critical angle :- $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

$\theta_c = \sin^{-1}\left(\frac{1.0}{1.55}\right)$

$\boxed{\theta_c = 40.170^\circ}$ (3M)

5) a) · Cut-off wavelength:- (λ_c)

consider $\gamma^2 + \omega^2\mu\epsilon = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$

at cut off frequency $\gamma = 0$;

$$\omega = \omega_c$$

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

$$\omega_c^2 = \frac{1}{\mu\varepsilon}\left[\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2\right]$$

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

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

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

Now $\lambda_c = \frac{c}{f_c}$

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

$$\lambda_c = \frac{2ab}{\sqrt{m^2b^2 + n^2a^2}}$$ (5M)

Dominant mode:- The dominant mode is a mode which is having minimum cut-off frequency (or) maximum cut off wavelength. In rectangular wave guide (TE_{10}) mode is the dominant mode. (2M)

5)b) Given TE_{10} mode ; $m=1$, $n=0$

$a = 10\,cm$ $\quad f \Rightarrow 2.5\,GHz$

i) cut off frequency:- $f_c = \frac{c}{2}\sqrt{\left(\frac{m}{a}\right)^2+\left(\frac{n}{b}\right)^2}$

$$f_c = \frac{c}{2a} \Rightarrow 1.5\,GHz$$

$$\lambda = \frac{c}{f_c} \Rightarrow 12\,cm$$

ii) Guided wavelength:- $\lambda_g \Rightarrow \frac{\lambda_0}{\sqrt{1-\left(\frac{f_c}{f_0}\right)^2}}$ (2M)

$$\lambda_g \Rightarrow 15\,cm$$

iii) group velocity:- $V_g \Rightarrow c\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}$

$V_g \Rightarrow 0.24 \times 10^9\,m/s$ (2M)

iv) phase velocity:- $V_p \Rightarrow \frac{c}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$

(3M)

$$V_p \Rightarrow 0.375 \times 10^9\,m/s$$

6)(a) Waveguide dispersion:-

Let us consider the group delay 'τ_g' in terms of normalized propagation constant.

$$b(V) = \frac{\beta/k_0 - n_2}{n_1 - n_2} \quad -①$$

$$\Rightarrow \frac{\tau_g}{L} = \frac{1}{V_g} = \frac{d\beta}{d\omega}$$

$$\Rightarrow b(V)[n_1 - n_2] = \beta/k_0 - n_2$$

$$n_2 + (n_1 - n_2)b(V) = \beta/k_0$$

$$\beta = k_0 [n_2 + (n_1 - n_2)\, b(V)] \quad -②$$

$$k_0 = \frac{2\pi}{\lambda} = \frac{2\pi}{c/f} \Rightarrow \frac{\omega}{c}$$

$$\Rightarrow \beta = \frac{\omega}{c}\left[n_2 + (n_1 - n_2)\, b(V)\right]$$

$$\Rightarrow \frac{d\beta}{d\omega} = \frac{1}{c}\left[n_2 + \frac{n_1 - n_2}{n_2}\, n_2\left(b(V) + \omega\, \frac{d\, b(V)}{dV} \times \frac{dV}{dy}\right)\right]$$

$$\Rightarrow \frac{d\beta}{d\omega} = \frac{n_2}{c}\left[1 + \Delta\left(\frac{d}{dV}(b(V)V)\right)\right]$$

Now $\frac{\tau_g}{L} = \frac{1}{V_g} = \frac{n_2}{c}\left[1 + \Delta\left(\frac{d}{dV}(V \cdot b(V))\right)\right]$

$\Rightarrow$ Group delay $\tau_{wg} = \frac{n_2 L}{c}\left[1 + \Delta \frac{d}{dV}(V b(V))\right]$

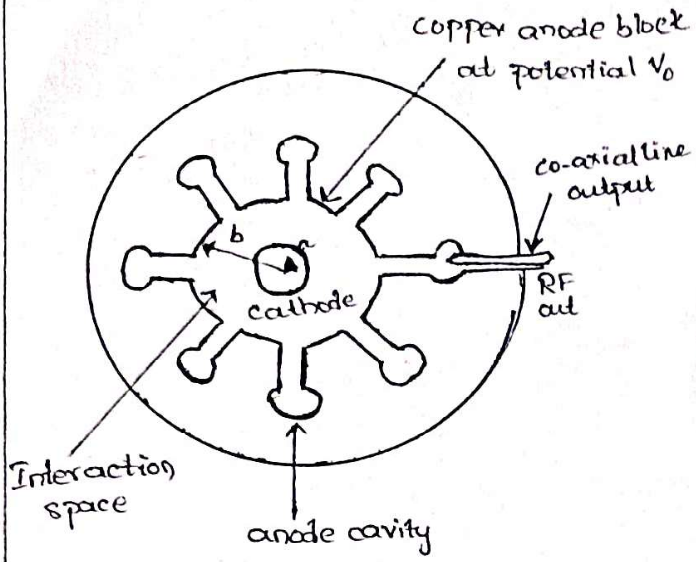
$$\boxed{\sigma_{wg} = \sigma_\lambda \cdot \frac{d\tau_{wg}}{d\lambda}}$$

The above equation gives the expression for waveguide dispersion. (9M)

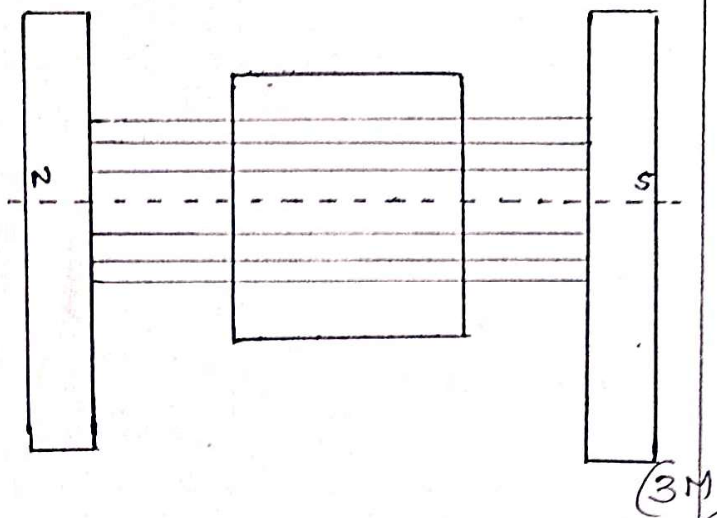
6)b) Intermodal dispersion: (5M)

→ Intermodal dispersion is also called as chromatic dispersion. chromatic dispersion is the phenomenon by which different spectral components of a pulse travel at different velocities. ~~I~~ Chromatic dispersion is pulse spreading that takes place within a single mode.

7a) · Construction & operation of Magnetron:-



construction details of a cavity Magnetron



(3M)

Magnetic flux lines in Magnetron (axial)

→ 8- cavity magnetron is a diode, which consists of a cylindrical configuration with a thick cylindrical cathode at the center that is surrounded by a cylindrical block of copper as anode.

→ The space between anode and cathode is called as " interaction space."

→ The anode block consists of eight number of slots, which acts as resonant cavities. The o/p is taken by connecting co-axial line (or) waveguide to any of the cavities.

→ The electrons in the absence of the magnetic field from cathode to anode in path (a) in fig. travells in a straight path

→ The path of the electron is slightly bent in the presence of magnetic field which is shown as path B in fig ①

→ when the magnetic field increases, then the electron from cathode reaches anode & again returns to cathode which is shown as path 'c' in fig ①. This magnetic field is known as "Hull's cut off magnetic field."

→ when the magnetic field is greater than the Hull's cutoff magnetic field, ~~is~~ then the electron returns back to cathode without touching anode which is shown as path 'd' in fig ① (7M)

7b) Performance characteristics of magnetron:- (4M)

① Frequency range → 500 MHz - 12 GHz

② Efficiency → 40% - 70%

③ Duty cycle → 0.1%

④ Power output : 25 kW

24/9/23

Prepared by
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E.C.E dept.

CO- PO Attainment Process(Model Calculations)

Academic Year 2022-23
Regulations R20
Year III **Sem** II
Batch 20
Branch ECE
Subject(Code) MWOC
Name of the Faculty SAYEDU KHASIM NOORBASHA

Note:Work out for all the subjects of 2022-23 (I-year to IV year)

....

External Question Paper Marks --> Cos

Q.No.	CO 1	CO 2	CO 3	CO 4	CO 5	CO 6	Total
1 a)	2						2
b)	2						2
c)	2						2
d)			2				2
e)	2						2
f)	2						2
g)			2				2
2 a)		14					14
b)							0
c)							0
3 a)				7			7
b)		7					7
c)							0
4 a)			9				9
b)		5					5
c)							0
5 a)	7						7
b)				7			7
c)							0
6 a)					7		7
b)						7	7
c)							0
7 a)					7		7
b)						7	7
c)							0
Total	17	26	13	14	14	14	98

Mid I Marks --> Cos

Q.No.	CO 1	CO 2	CO 3	CO 4	CO 5	CO 6	Total
1 a)	1						1
b)		1					1
c)	1						1
d)		1					1
e)	1						1
2 a)						3	3
b)		2					2
3 a)				3			3
b)	2						2
4 a)			3				3
b)	2						2
5 a)		3					3
b)					2		2
Total	7	7	3	3	2	3	25

Mid II Marks --> Cos

Q.No.	CO 1	CO 2	CO 3	CO 4	CO 5	CO 6	Total
1 a)	1						1
b)	1						1
c)		1					1
d)		1					1
e)	1						1
2 a)		3					3
b)		2					2
3 a)			3				3
b)						2	2
4 a)			3				3
b)				2			2
5 a)					3		3
b)					2		2
Total	3	7	6	2	5	2	25

Total	10	14	9	5	7	5	50

Assignment 1 Marks --> Cos

	CO 1	CO2	CO3	CO4	CO5	CO6	Total
	2	1	2	2	2	1	10
Total	2	1	2	2	2	1	10

Assignment 2 Marks --> Cos

	CO1	CO2	CO3	CO4	CO5	CO6	Total
	2	2	2	2	1	1	10
Total	2	2	2	2	1	1	10

Total	4	3	4	4	3	2	20
Total	4	3	4	4	3	2	20

S.No	Reg.No.	Internal marks	Assignment marks	Final Internal marks	Total Final Marks	External Marks	% of IM	% of AM	% of EM	N CO 1	N CO 2	N CO 3	N CO 4	N CO 5	N CO 6
1	20091A0402	19	10	29	68	39	95	100	55.7143	69.2576	66.8718	71.1653	67.6531	68.051948	65.1648
2	20091A0404	19	10	29	75	46	95	100	65.7143	75.9505	74.106	77.4033	74.7959	75.044955	72.8571
3	20091A0408	19	10	29	79	50	95	100	71.4286	79.775	78.2399	80.9679	78.8776	79.040959	77.2527
4	20091A0419	18	10	28	84	56	90	100	80	84.4094	83.35	85.1056	84.2857	84.055944	83.0769
5	20091A0435	18	10	28	73	45	90	100	64.2857	73.892	71.9819	75.303	73.0612	73.066933	70.989
6	20091A0436	19	10	29	79	50	95	100	71.4286	79.775	78.2399	80.9679	78.8776	79.040959	77.2527
7	20091A0437	17	10	27	78	51	85	100	72.8571	78.5264	77.092	79.4406	78.4694	78.081918	76.8132
8	20091A0439	19	10	29	81	52	95	100	74.2857	81.6873	80.3069	82.7502	80.9184	81.038961	79.4505
9	20091A0450	18	10	28	72	44	90	100	62.8571	72.9359	70.9484	74.4118	72.0408	72.067932	69.8901
10	20091A0466	19	10	29	84	55	95	100	78.5714	84.5557	83.4073	85.4236	83.9796	84.035964	82.7473
11	20091A0469	19	10	29	83	54	95	100	77.1429	83.5996	82.3738	84.5325	82.9592	83.036963	81.6484
12	20091A0470	19	10	29	71	42	95	100	60	72.126	69.9722	73.8388	70.7143	71.048951	68.4615
13	20091A0471	19	10	29	67	38	95	100	54.2857	68.3015	65.8383	70.2742	66.6327	67.052947	64.0659
14	20091A0472	17	10	27	78	51	85	100	72.8571	78.5264	77.092	79.4406	78.4694	78.081918	76.8132
15	20091A0475	19	10	29	86	57	95	100	81.4286	86.4679	85.4742	87.2059	86.0204	86.033966	84.9451
16	20091A0478	19	10	29	86	57	95	100	81.4286	86.4679	85.4742	87.2059	86.0204	86.033966	84.9451
17	20091A0479	17	10	27	77	50	85	100	71.4286	77.5703	76.0585	78.5495	77.449	77.082917	75.7143
18	20091A0480	18	10	28	74	46	90	100	65.7143	74.8481	73.0153	76.1941	74.0816	74.065934	72.0879
19	20091A0488	19	10	29	71	42	95	100	60	72.126	69.9722	73.8388	70.7143	71.048951	68.4615
20	20091A0490	18	10	28	67	39	90	100	55.7143	68.1552	65.7811	69.9561	66.9388	67.072927	64.3956
21	20091A0497	16	10	26	54	28	80	100	40	55.4331	52.2315	57.7351	54.2857	54.125874	50.7692
22	20091A04A3	19	10	29	81	52	95	100	74.2857	81.6873	80.3069	82.7502	80.9184	81.038961	79.4505
23	20091A04C1	19	10	29	71	42	95	100	60	72.126	69.9722	73.8388	70.7143	71.048951	68.4615
24	20091A04C4	19	10	29	77	48	95	100	68.5714	77.8628	76.173	79.1856	76.8367	77.042957	75.0549
25	20091A04C9	19	10	29	70	41	95	100	58.5714	71.1699	68.9387	72.9476	69.6939	70.04995	67.3626
26	20091A04D3	16	10	26	71	45	80	100	64.2857	71.6873	69.8005	72.8846	71.6327	71.108891	69.4505
27	20091A04D7	19	10	29	72	43	95	100	61.4286	73.0821	71.0056	74.7299	71.7347	72.047952	69.5604
28	20091A04D9	19	10	29	80	51	95	100	72.8571	80.7312	79.2734	81.8591	79.898	80.03996	78.3516
29	20091A04E0	19	10	29	80	51	95	100	72.8571	80.7312	79.2734	81.8591	79.898	80.03996	78.3516
30	20091A04E1	14	10	24	24	0	70	100	0	26.4567	21.113	30.3647	24.2857	24.195804	18.4615
31	20091A04E5	18	10	28	79	51	90	100	72.8571	79.6288	78.1827	80.6498	79.1837	79.060939	77.5824
32	20091A04E6	18	10	28	72	44	90	100	62.8571	72.9359	70.9484	74.4118	72.0408	72.067932	69.8901
33	20091A04E7	19	10	29	80	51	95	100	72.8571	80.7312	79.2734	81.8591	79.898	80.03996	78.3516
34	20091A04E8	19	10	29	72	43	95	100	61.4286	73.0821	71.0056	74.7299	71.7347	72.047952	69.5604
35	20091A04E9	19	10	29	78	49	95	100	70	78.8189	77.2065	80.0768	77.8571	78.041958	76.1538
36	20091A04F1	19	10	29	78	49	95	100	70	78.8189	77.2065	80.0768	77.8571	78.041958	76.1538
37	20091A04F8	19	10	29	82	53	95	100	75.7143	82.6434	81.3403	83.6413	81.9388	82.037962	80.5495
38	20091A04F9	19	10	29	82	53	95	100	75.7143	82.6434	81.3403	83.6413	81.9388	82.037962	80.5495
39	20091A04G0	19	10	29	88	59	95	100	84.2857	88.3802	87.5411	88.9882	88.0612	88.031968	87.1429
40	20091A04G1	18	10	28	85	57	90	100	81.4286	85.3656	84.3835	85.9967	85.3061	85.054945	84.1758
41	20091A04G2	18	10	28	77	49	90	100	70	77.7165	76.1157	78.8676	77.1429	77.062937	75.3846
42	20091A04G3	19	10	29	82	53	95	100	75.7143	82.6434	81.3403	83.6413	81.9388	82.037962	80.5495
43	20091A04G5	18	10	28	74	46	90	100	65.7143	74.8481	73.0153	76.1941	74.0816	74.065934	72.0879
44	20091A04H5	19	10	29	91	62	95	100	88.5714	91.2486	90.6415	91.6616	91.1224	91.028971	90.4396
45	20091A04H7	18	10	28	67	39	90	100	55.7143	68.1552	65.7811	69.9561	66.9388	67.072927	64.3956
46	20091A04H8	19	10	29	78	49	95	100	70	78.8189	77.2065	80.0768	77.8571	78.041958	76.1538
47	20091A04H9	19	10	29	82	53	95	100	75.7143	82.6434	81.3403	83.6413	81.9388	82.037962	80.5495
48	20091A04J0	19	10	29	84	55	95	100	78.5714	84.5557	83.4073	85.4236	83.9796	84.035964	82.7473
49	20091A04J3	19	10	29	79	50	95	100	71.4286	79.775	78.2399	80.9679	78.8776	79.040959	77.2527
50	20091A04J9	18	10	28	72	44	90	100	62.8571	72.9359	70.9484	74.4118	72.0408	72.067932	69.8901
51	20091A04K1	19	10	29	79	50	95	100	71.4286	79.775	78.2399	80.9679	78.8776	79.040959	77.2527
52	20091A04K5	19	10	29	66	37	95	100	52.8571	67.3453	64.8048	69.3831	65.6122	66.053946	62.967
53	20091A04K6	18	10	28	76	48	90	100	68.5714	76.7604	75.0823	77.9764	76.1224	76.063936	74.2857
54	20091A04M3	19	10	29	90	61	95	100	87.1429	90.2925	89.6081	90.7705	90.102	90.02997	89.3407
55	20091A04M7	19	10	29	65	36	95	100	51.4286	66.3892	63.7714	68.4919	64.5918	65.054945	61.8681
56	20091A04M9	19	10	29	80	51	95	100	72.8571	80.7312	79.2734	81.8591	79.898	80.03996	78.3516
57	20091A04N6	18	10	28	71	43	90	100	61.4286	71.9798	69.9149	73.5207	71.0204	71.068931	68.7912
58	20091A04N7	19	10	29	75	46	95	100	65.7143	75.9505	74.106	77.4033	74.7959	75.044955	72.8571
59	20091A04P0	17	10	27	74	47	85	100	67.1429	74.7019	72.9581	75.8761	74.3878	74.085914	72.4176
60	20091A04P8	15	10	25	62	37	75	100	52.8571	62.9359	60.442	64.5462	62.7551	62.137862	59.8901
61	21095A0404	18	10	28	84	56	90	100	80	84.4094	83.35	85.1056	84.2857	84.055944	83.0769
62	21095A0412	19	10	29	83	54	95	100	77.1429	83.5996	82.3738	84.5325	82.9592	83.036963	81.6484
63	21095A0417	19	10	29	86	57	95	100	81.4286	86.4679	85.4742	87.2059	86.0204	86.033966	84.9451
64	21095A0430	18	10	28	70	42	90	100	60	71.0236	68.8815	72.6296	70	70.06993	67.6923
65	21095A0432	19	10	29	83	54	95	100	77.1429	83.5996	82.3738	84.5325	82.9592	83.036963	81.6484
66	20091A0401	13	10	23	58	35	65	100	50	58.8189	56.1937	60.3455	59.2857	58.181818	56.1538
67	20091A0406	17	10	27	77	50	85	100	71.4286	77.5703	76.0585	78.5495	77.449	77.082917	75.7143
68	20091A0410	15	10	25	70	45	75	100	64.2857	70.5849	68.7098	71.6753	70.9184	70.12987	68.6813
69	20091A0411	18	10	28	82	54	90	100	77.1429	82.4972	81.2831	83.3233	82.2449	82.057942	80.8791
70	20091A0417	17	10	27	69	42	85	100	60	69.9213	67.7908	71.4203	69.2857	69.090909	66.9231
71	20091A0418	17	10	27	53	26	85	100	37.1429	54.6232	51.2553	57.1621	52.9592	53.106893	49.3407
72	20091A0426	18	10	28	72	44	90	100	62.8571	72.9359	70.9484	74.4118	72.0408	72.067932	69.8901
73	20091A0427	18	10	28	68	40	90	100	57.1429	69.1114	66.8145	70.8473	67.9592	68.071928	65.4945
74	20091A0438	17	10	27	64	37	85	100	52.8571	65.1406	62.6234	66.9646	64.1837	64.095904	61.4286
75	20091A0443	18	10	28	70	42	90	100	60	71.0236	68.8815	72.6296	70	70.06993	67.6923
76	20091A0444	13	10	23	64	41	65	100	58.5714	64.5557	62.3945	65.6923	65.4082	64.175824	62.7473
77	20091A0447	16	10	26	69	43	80	100	61.4286	69.775	67.7335	71.1023	69.5918	69.110889	67.2527
78	20091A0449	15	10	25	61	36	75	100	51.4286	61.9798	59.4085	63.6551	61.7347	61.138861	58.7912
79	20091A0452	16	10	26	74	48	80	100	68.5714	74.5557	72.9009	75.558	74.6939	74.105894	72.7473
80	20091A0454	13	10	23	71	48	65	100	68.5714	71.2486	69.6287	71.9304	72.551	71.168831	70.4396
81	20091A0455	13	10	23	55	32	65	100	45.7143	55.9505	53.0933	57.6721	56.2245	55.184815	52.8571
82	20091A0456	18	10	28	82	54	90	100	77.1429	82.4972	81.2831	83.3233	82.2449	82.057942	80.8791
83	20091A0459	16	10	26	73	47	80	100	67.1429	73.5996	71.8674	74.6668	73.6735	73.106893	71.6484
84	20091A0465	14	10	24	73	49	70	100	70	73.3071	71.7529	74.0307	74.2857	73.146853	72.3077
85	20091A0467	13	10	23	60	37	65	100	52.8571	60.7312	58.2606	62.1278	61.3265	60.17982	58.3516
86	20091A0473	18	10	28	75	47	90	100	67.1429	75.8043	74.0488	77.0853	75.102	75.064935	73.1868
87	20091A0476	12	10	22	60	38	60	100	54.2857	60.5849	58.2034	61.8097	61.6327	60.1998	58.6813
88	20091A0483	13	10	23	23	0	65	100	0	25.3543	20.0223	29.1555	23.5714	23.216783	17.6923
89	20091A0484	15	10	25	60	35	75	100	50	61.0236	58.3751	62.7639	60.7143	60.13986	57.6923
90	20091A0485	12	10	22	56	34	60	100	48.5714	56.7604	54.0695	58.2451	57.551	56.203796	54.2857
91	20091A0489	18	10	28	74	46	90	100	65.7143	74.8481	73.0153	76.1941	74.0816	74.065934	72.0879
92	20091A0494	11	10	21	56	35	55	100	50	56.6142	54.0122	57.9271	57.8571	56.223776	54.6154
93	20091A0495	14	10	24	71	47	70	100	67.1429	71.3948	69.686	72.2484	72.2449	71.148851	70.1099
94	20091A0496	13	10	23	67	44	65	100	62.8571	67.4241	65.4949	68.3658	68.4694	67.172827	66.044
95	20091A04A6	17	10	27	69	42	85	100	60	69.9213	67.7908	71.4203	69.2857	69.090909	66.9231
96	20091A04B0	14	10	24	59	35	70	100	50	59.9213	57.2844	61.5547	60	59.160839	56.9231
97	20091A04B5	10	10	20	55	35	50	100	50	55.5118	52.9215	56.7179	57.1429	55.244755	53.8462
98	20091A04B6	18	10	28	73	45	90	100	64.2857	73.892	71.9819	75.303	73.0612	73.066933	70.989
99	20091A04B7	16	10	26	70	44	80	100	62.8571	70.7312	68.767	71.9934	70.6122	70.10989	68.3516
100	20091A04B9	17	10	27	71	44	85	100	62.8571	71.8335	69.8577	73.2026	71.3265	71.088911	69.1209
101	20091A04C0	17	10	27	55	28	85	100	40	56.5354	53.3222	58.9443	55	55.104895	51.5385
102	20091A04C3	18	10	28	61	33	90	100	47.1429	62.4184	59.5803	64.6093	60.8163	61.078921	57.8022
103	20091A04C6	13	10	23	51	28	65	100	40	52.126	48.9594	54.1075	52.1429	51.188811	48.4615
104	20091A04D1	12	10	22	51	29	60	100	41.4286	51.9798	48.9021	53.7894	52.449	51.208791	48.7912
105	20091A04D8	15	10	25	62	37	75	100	52.8571	62.9359	60.442	64.5462	62.7551	62.137862	59.8901
106	20091A04F2	16	10	26	70	44	80	100	62.8571	70.7312	68.767	71.9934	70.6122	70.10989	68.3516
107	20091A04F7	16	10	26	65	39	80	100	55.7143	65.9505	63.5997	67.5377	65.5102	65.114885	62.8571
108	20091A04G6	13	10	23	73	50	65	100	71.4286	73.1609	71.6957	73.7126	74.5918	73.166833	72.6374
109	20091A04G8	13	10	23	71	48	65	100	68.5714	71.2486	69.6287	71.9304	72.551	71.168831	70.4396
110	20091A04G9	17	10	27	76	49	85	100	70	76.6142	75.025	77.6583	76.4286	76.083916	74.6154
111	20091A04H3	15	10	25	51	26	75	100	37.1429	52.4184	49.0739	54.7436	51.5306	51.148851	47.8022
112	20091A04J1	17	10	27	72	45	85	100	64.2857	72.7897	70.8912	74.0938	72.3469	72.087912	70.2198
113	20091A04J2	13	10	23	55	32	65	100	45.7143	55.9505	53.0933	57.6721	56.2245	55.184815	52.8571
114	20091A04J8	13	10	23	69	46	65	100	65.7143	69.3363	67.5618	70.1481	70.5102	69.170829	68.2418
115	20091A04K4	17	10	27	72	45	85	100	64.2857	72.7897	70.8912	74.0938	72.3469	72.087912	70.2198
116	20091A04M1	17	10	27	66	39	85	100	55.7143	67.0529	64.6904	68.7469	66.2245	66.093906	63.6264
117	20091A04M5	16	10	26	66	40	80	100	57.1429	66.9066	64.6331	68.4288	66.5306	66.113886	63.956
118	20091A04M6	17	10	27	66	39	85	100	55.7143	67.0529	64.6904	68.7469	66.2245	66.093906	63.6264
119	20091A04M8	17	10	27	62	35	85	100	50	63.2283	60.5565	65.1823	62.1429	62.097902	59.2308
120	20091A04N0	17	10	27	77	50	85	100	71.4286	77.5703	76.0585	78.5495	77.449	77.082917	75.7143
121	20091A04N3	17	10	27	60	33	85	100	47.1429	61.3161	58.4895	63.4001	60.102	60.0999	57.033
122	20091A04N4	17	10	27	64	37	85	100	52.8571	65.1406	62.6234	66.9646	64.1837	64.095904	61.4286
123	20091A04N9	15	10	25	59	34	75	100	48.5714	60.0675	57.3416	61.8728	59.6939	59.140859	56.5934
124	20091A04P7	14	10	24	60	36	70	100	51.4286	60.8774	58.3178	62.4458	61.0204	60.15984	58.022
125	20091A04P9	19	10	29	72	43	95	100	61.4286	73.0821	71.0056	74.7299	71.7347	72.047952	69.5604
126	21095A0411	18	10	28	73	45	90	100	64.2857	73.892	71.9819	75.303	73.0612	73.066933	70.989
127	21095A0415	17	10	27	69	42	85	100	60	69.9213	67.7908	71.4203	69.2857	69.090909	66.9231
128	21095A0416	19	10	29	88	59	95	100	84.2857	88.3802	87.5411	88.9882	88.0612	88.031968	87.1429
129	21095A0425	19	10	29	71	42	95	100	60	72.126	69.9722	73.8388	70.7143	71.048951	68.4615
130	21095A0427	18	10	28	81	53	90	100	75.7143	81.5411	80.2496	82.4321	81.2245	81.058941	79.7802
131	19091A0412	5	6	11	31	20	25	60	28.5714	31.2486	29.6287	31.9304	32.551	31.168831	30.4396
132	20091A0405	13	10	23	68	45	65	100	64.2857	68.3802	66.5283	69.2569	69.4898	68.171828	67.1429
133	20091A0407	14	10	24	50	26	70	100	37.1429	51.3161	47.9831	53.5344	50.8163	50.16983	47.033
134	20091A0415	14	10	24	58	34	70	100	48.5714	58.9651	56.2509	60.6636	58.9796	58.161838	55.8242
135	20091A0416	13	10	23	62	39	65	100	55.7143	62.6434	60.3275	63.9101	63.3673	62.177822	60.5495
136	20091A0422	14	10	24	59	35	70	100	50	59.9213	57.2844	61.5547	60	59.160839	56.9231
137	20091A0423	16	10	26	63	37	80	100	52.8571	64.0382	61.5327	65.7554	63.4694	63.116883	60.6593
138	20091A0424	17	10	27	67	40	85	100	57.1429	68.009	65.7238	69.6381	67.2449	67.092907	64.7253
139	20091A0428	12	10	22	60	38	60	100	54.2857	60.5849	58.2034	61.8097	61.6327	60.1998	58.6813
140	20091A0433	12	10	22	57	35	60	100	50	57.7165	55.1029	59.1363	58.5714	57.202797	55.3846
141	20091A0441	14	10	24	74	50	70	100	71.4286	74.2632	72.7864	74.9219	75.3061	74.145854	73.4066
142	20091A0442	14	10	24	72	48	70	100	68.5714	72.351	70.7195	73.1396	73.2653	72.147852	71.2088
143	20091A0448	11	10	21	49	28	55	100	40	49.9213	46.778	51.6891	50.7143	49.230769	46.9231
144	20091A0451	14	10	24	61	37	70	100	52.8571	61.8335	59.3513	63.337	62.0408	61.158841	59.1209
145	20091A0453	12	10	22	66	44	60	100	62.8571	66.3217	64.4042	67.1566	67.7551	66.193806	65.2747
146	20091A0457	18	10	28	69	41	90	100	58.5714	70.0675	67.848	71.7384	68.9796	69.070929	66.5934

R20 Regulation Weightage of Marks

Final exam	Internal tests	Ass/Quiz
70	20	10
0.7	0.2	0.1

Weightage marks for each CO

	CO 1	CO 2	CO 3	CO 4	CO 5	CO 6	Total
EM	17	26	13	14	14	14	98
IM	10	14	9	5	7	5	50
AM	4	3	4	4	3	2	20

% Weightage of each CO

	CO 1	CO 2	CO 3	CO 4	CO 5	CO 6	Total
EM (%)	17.347	26.531	13.265	14.286	14.286	14.286	100
IM (%)	20	28	18	10	14	10	100
AM (%)	20	15	20	20	15	10	100
Avg	18.143	25.671	14.886	14	14.3	13	100

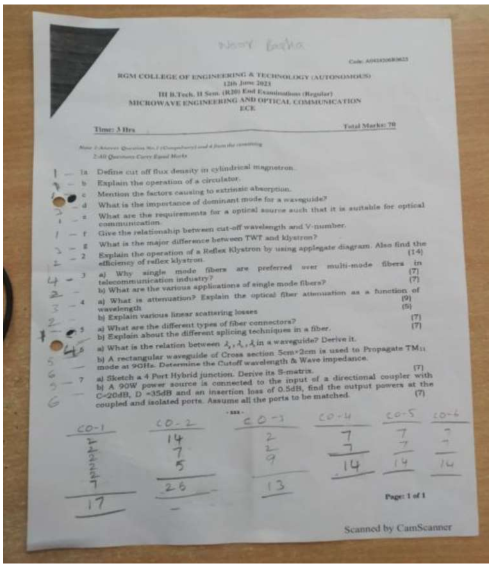
147	20091A0458	16	10	26	68	42	80	100	60	68.8189	66.7001	70.2111	68.5714	68.111888	66.1538
148	20091A0460	15	10	25	53	28	75	100	40	54.3307	51.1408	56.5259	53.5714	53.146853	50
149	20091A0462	15	10	25	68	43	75	100	61.4286	68.6727	66.6428	69.8931	68.8776	68.131868	66.4835
150	20091A0463	17	10	27	69	42	85	100	60	69.9213	67.7908	71.4203	69.2857	69.090909	66.9231
151	20091A0492	12	10	22	50	28	60	100	40	51.0236	47.8687	52.8983	51.4286	50.20979	47.6923
152	20091A04A0	15	10	25	70	45	75	100	64.2857	70.5849	68.7098	71.6753	70.9184	70.12987	68.6813
153	20091A04A4	15	10	25	65	40	75	100	57.1429	65.8043	63.5424	67.2196	65.8163	65.134865	63.1868
154	20091A04A5	15	10	25	64	39	75	100	55.7143	64.8481	62.5089	66.3285	64.7959	64.135864	62.0879
155	20091A04A7	13	10	23	38	15	65	100	21.4286	39.6963	35.5243	42.5226	38.8776	38.201798	34.1758
156	20091A04A9	13	10	23	51	28	65	100	40	52.126	48.9594	54.1075	52.1429	51.188811	48.4615
157	20091A04B2	12	10	22	37	15	60	100	21.4286	38.5939	34.4336	41.3134	38.1633	37.222777	33.4066
158	20091A04B3	10	10	20	48	28	50	100	40	48.8189	45.6873	50.4798	50	48.251748	46.1538
159	20091A04B4	13	10	23	58	35	65	100	50	58.8189	56.1937	60.3455	59.2857	58.181818	56.1538
160	20091A04B8	17	10	27	69	42	85	100	60	69.9213	67.7908	71.4203	69.2857	69.090909	66.9231
161	20091A04C2	17	10	27	57	30	85	100	42.8571	58.4477	55.3891	60.7266	57.0408	57.102897	53.7363
162	20091A04C5	14	10	24	57	33	70	100	47.1429	58.009	55.2174	59.7724	57.9592	57.162837	54.7253
163	20091A04D2	13	10	23	61	38	65	100	54.2857	61.6873	59.2941	63.0189	62.3469	61.178821	59.4505
164	20091A04D6	16	10	26	75	49	80	100	70	75.5118	73.9343	76.4491	75.7143	75.104895	73.8462
165	20091A04E3	12	10	22	54	32	60	100	45.7143	54.8481	52.0025	56.4628	55.5102	54.205794	52.0879
166	20091A04G4	14	10	24	70	46	70	100	65.7143	70.4387	68.6525	71.3573	71.2245	70.14985	69.011
167	20091A04G7	15	10	25	69	44	75	100	62.8571	69.6288	67.6763	70.7842	69.898	69.130869	67.5824
168	20091A04H1	14	10	24	61	37	70	100	52.8571	61.8335	59.3513	63.337	62.0408	61.158841	59.1209
169	20091A04H4	16	10	26	56	30	80	100	42.8571	57.3453	54.2984	59.5174	56.3265	56.123876	52.967
170	20091A04H6	19	10	29	80	51	95	100	72.8571	80.7312	79.2734	81.8591	79.898	80.03996	78.3516
171	20091A04J4	15	10	25	62	37	75	100	52.8571	62.9359	60.442	64.5462	62.7551	62.137862	59.8901
172	20091A04J5	15	10	25	56	31	75	100	44.2857	57.1991	54.2412	59.1993	56.6327	56.143856	53.2967
173	20091A04J6	17	10	27	75	48	85	100	68.5714	75.658	73.9916	76.7672	75.4082	75.084915	73.5165
174	20091A04J7	19	10	29	87	58	95	100	82.8571	87.4241	86.5077	88.0971	87.0408	87.032967	86.044
175	20091A04N5	16	10	26	63	37	80	100	52.8571	64.0382	61.5327	65.7554	63.4694	63.116883	60.6593
176	20091A04P2	11	10	21	62	41	55	100	58.5714	62.351	60.2131	63.2739	63.9796	62.217782	61.2088
177	20091A04P4	17	10	27	73	46	85	100	65.7143	73.7458	71.9246	74.9849	73.3673	73.086913	71.3187
178	20091A04Q0	16	10	26	68	42	80	100	60	68.8189	66.7001	70.2111	68.5714	68.111888	66.1538
179	21095A0401	16	10	26	68	42	80	100	60	68.8189	66.7001	70.2111	68.5714	68.111888	66.1538
180	21095A0402	18	10	28	76	48	90	100	68.5714	76.7604	75.0823	77.9764	76.1224	76.063936	74.2857
181	21095A0403	15	10	25	74	49	75	100	70	74.4094	72.8436	75.2399	75	74.125874	73.0769
182	21095A0405	13	10	23	67	44	65	100	62.8571	67.4241	65.4949	68.3658	68.4694	67.172827	66.044
183	21095A0406	14	10	24	67	43	70	100	61.4286	67.5703	65.5521	68.6838	68.1633	67.152847	65.7143
184	21095A0407	11	10	21	75	54	55	100	77.1429	74.7807	73.6481	74.8588	77.2449	75.204795	75.4945
185	21095A0409	17	10	27	64	37	85	100	52.8571	65.1406	62.6234	66.9646	64.1837	64.095904	61.4286
186	21095A0418	17	10	27	82	55	85	100	78.5714	82.351	81.2259	83.0052	82.551	82.077922	81.2088
187	21095A0421	15	10	25	58	33	75	100	47.1429	59.1114	56.3081	60.9816	58.6735	58.141858	55.4945
188	21095A0422	15	10	25	63	38	75	100	54.2857	63.892	61.4755	65.4373	63.7755	63.136863	60.989
189	21095A0428	11	10	21	55	34	55	100	48.5714	55.658	52.9788	57.0359	56.8367	55.224775	53.5165
190	21095A0433	13	10	23	65	42	65	100	60	65.5118	63.4279	66.5835	66.4286	65.174825	63.8462
191	19091A04B6	15	10	25	51	26	75	100	37.1429	52.4184	49.0739	54.7436	51.5306	51.148851	47.8022
192	19091A04N4	10	10	20	32	12	50	100	17.1429	33.5208	29.1518	36.2216	33.6735	32.267732	28.5714
193	19091A04R8	5	10	15	15	0	25	100	0	16.5354	11.2966	19.4818	17.8571	15.384615	11.5385
194	20091A0403	12	10	22	60	38	60	100	54.2857	60.5849	58.2034	61.8097	61.6327	60.1998	58.6813
195	20091A0409	12	10	22	55	33	60	100	47.1429	55.8043	53.036	57.354	56.5306	55.204795	53.1868
196	20091A0412	17	10	27	64	37	85	100	52.8571	65.1406	62.6234	66.9646	64.1837	64.095904	61.4286
197	20091A0413	18	10	28	73	45	90	100	64.2857	73.892	71.9819	75.303	73.0612	73.066933	70.989
198	20091A0414	11	10	21	27	6	55	100	8.57143	28.8864	24.0417	32.0839	28.2653	27.252747	22.7473
199	20091A0420	16	10	26	57	31	80	100	44.2857	58.3015	55.3319	60.4086	57.3469	57.122877	54.0659
200	20091A0421	13	10	23	35	12	65	100	17.1429	36.8279	32.4239	39.8492	35.8163	35.204795	30.8791
201	20091A0425	16	10	26	58	32	80	100	45.7143	59.2576	56.3654	61.2997	58.3673	58.121878	55.1648
202	20091A0430	18	10	28	54	26	90	100	37.1429	55.7255	52.346	58.3713	53.6735	54.085914	50.1099
203	20091A0431	19	10	29	63	34	95	100	48.5714	64.4769	61.7044	66.7096	62.551	63.056943	59.6703
204	20091A0432	16	10	26	59	33	80	100	47.1429	60.2137	57.3988	62.1908	59.3878	59.120879	56.2637
205	20091A0434	12	10	22	37	15	60	100	21.4286	38.5939	34.4336	41.3134	38.1633	37.222777	33.4066
206	20091A0440	19	10	29	64	35	95	100	50	65.4331	62.7379	67.6008	63.5714	64.055944	60.7692
207	20091A0445	10	10	20	30	10	50	100	14.2857	31.6085	27.0848	34.4393	31.6327	30.26973	26.3736
208	20091A0446	17	10	27	64	37	85	100	52.8571	65.1406	62.6234	66.9646	64.1837	64.095904	61.4286
209	20091A0461	7	10	17	17	0	35	100	0	18.7402	13.478	21.9002	19.2857	17.342657	13.0769
210	20091A0464	13	10	23	51	28	65	100	40	52.126	48.9594	54.1075	52.1429	51.188811	48.4615
211	20091A0468	18	10	28	56	28	90	100	40	57.6378	54.4129	60.1536	55.7143	56.083916	52.3077
212	20091A0474	13	10	23	49	26	65	100	37.1429	50.2137	46.8924	52.3252	50.102	49.190809	46.2637
213	20091A0477	15	10	25	53	28	75	100	40	54.3307	51.1408	56.5259	53.5714	53.146853	50
214	20091A0487	18	10	28	35	7	90	100	10	37.5591	32.7101	41.4395	34.2857	35.104895	29.2308
215	20091A0491	15	10	25	34	9	75	100	12.8571	36.1642	31.5049	39.5942	34.1837	34.165834	29.1209
216	20091A0499	15	10	25	28	3	75	100	4.28571	30.4274	25.3041	34.2473	28.0612	28.171828	22.5275
217	20091A04A2	8	10	18	18	0	40	100	0	19.8425	14.5687	23.1094	20	18.321678	13.8462
218	20091A04A8	19	10	29	66	37	95	100	52.8571	67.3453	64.8048	69.3831	65.6122	66.053946	62.967
219	20091A04B1	18	10	28	56	28	90	100	40	57.6378	54.4129	60.1536	55.7143	56.083916	52.3077
220	20091A04C7	15	10	25	62	37	75	100	52.8571	62.9359	60.442	64.5462	62.7551	62.137862	59.8901
221	20091A04D0	14	10	24	52	28	70	100	40	53.2283	50.0501	55.3167	52.8571	52.167832	49.2308
222	20091A04D4	14	10	24	50	26	70	100	37.1429	51.3161	47.9831	53.5344	50.8163	50.16983	47.033
223	20091A04D5	15	10	25	45	20	75	100	28.5714	46.6817	42.873	49.3968	45.4082	45.154845	41.2088
224	20091A04E2	12	10	22	52	30	60	100	42.8571	52.9359	49.9356	54.6806	53.4694	52.207792	49.8901
225	20091A04E4	15	10	25	60	35	75	100	50	61.0236	58.3751	62.7639	60.7143	60.13986	57.6923
226	20091A04F4	16	10	26	65	39	80	100	55.7143	65.9505	63.5997	67.5377	65.5102	65.114885	62.8571
227	20091A04F5	12	10	22	48	26	60	100	37.1429	49.1114	45.8017	51.116	49.3878	48.211788	45.4945
228	20091A04F6	18	10	28	64	36	90	100	51.4286	65.2868	62.6807	67.2827	63.8776	64.075924	61.0989
229	20091A04H2	14	10	24	37	13	70	100	18.5714	38.8864	34.5481	41.9495	37.551	37.182817	32.7473
230	20091A04K0	13	10	23	32	9	65	100	12.8571	33.9595	29.3235	37.1758	32.7551	32.207792	27.5824
231	20091A04K2	14	10	24	38	14	70	100	20	39.8425	35.5815	42.8407	38.5714	38.181818	33.8462
232	20091A04K3	17	10	27	56	29	85	100	41.4286	57.4916	54.3557	59.8355	56.0204	56.103896	52.6374
233	20091A04K7	19	10	29	60	31	95	100	44.2857	61.6085	58.604	64.0362	59.4898	60.05994	56.3736
234	20091A04K8	19	10	29	57	28	95	100	40	58.7402	55.5036	61.3628	56.4286	57.062937	53.0769
235	20091A04M2	17	10	27	55	28	85	100	40	56.5354	53.3222	58.9443	55	55.104895	51.5385
236	20091A04N1	18	10	28	56	28	90	100	40	57.6378	54.4129	60.1536	55.7143	56.083916	52.3077
237	20091A04N2	15	10	25	32	7	75	100	10	34.252	29.438	37.8119	32.1429	32.167832	26.9231
238	20091A04P1	18	10	28	61	33	90	100	47.1429	62.4184	59.5803	64.6093	60.8163	61.078921	57.8022
239	20091A04P3	10	10	20	35	15	50	100	21.4286	36.3892	32.2522	38.895	36.7347	35.264735	31.8681
240	20091A04P6	18	10	28	55	27	90	100	38.5714	56.6817	53.3794	59.2624	54.6939	55.084915	51.2088
241	21095A0408	16	10	26	55	29	80	100	41.4286	56.3892	53.265	58.6263	55.3061	55.124875	51.8681
242	21095A0410	18	10	28	65	37	90	100	52.8571	66.243	63.7141	68.1738	64.898	65.074925	62.1978
243	21095A0413	17	10	27	62	35	85	100	50	63.2283	60.5565	65.1823	62.1429	62.097902	59.2308
244	21095A0414	14	10	24	58	34	70	100	48.5714	58.9651	56.2509	60.6636	58.9796	58.161838	55.8242
245	21095A0419	17	10	27	66	39	85	100	55.7143	67.0529	64.6904	68.7469	66.2245	66.093906	63.6264
246	21095A0420	16	10	26	57	31	80	100	44.2857	58.3015	55.3319	60.4086	57.3469	57.122877	54.0659
247	21095A0423	17	10	27	61	34	85	100	48.5714	62.2722	59.523	64.2912	61.1224	61.098901	58.1319
248	21095A0424	15	10	25	57	32	75	100	45.7143	58.1552	55.2747	60.0905	57.6531	57.142857	54.3956
249	21095A0426	19	10	29	70	41	95	100	58.5714	71.1699	68.9387	72.9476	69.6939	70.04995	67.3626
250	21095A0429	19	10	29	58	29	95	100	41.4286	59.6963	56.5371	62.2539	57.449	58.061938	54.1758
251	21095A0431	13	10	23	55	32	65	100	45.7143	55.9505	53.0933	57.6721	56.2245	55.184815	52.8571

	CO 1		CO 2		CO 3		CO 4		CO 5		CO 6	
	No. of students Attained	Weightage Points	No. of students Attained	Weightage Points	No. of students Attained	Weightage Points	No. of students Attained	Weightage Points	No. of students Attained	Weightage Points	No. of students Attained	Weightage Points
>= 50%	226	3	215	3	229	3	228	3	225	3	213	3
40% to 50%	4	2	15	2	7	2	2	2	5	2	17	2
<40%	21	1	21	1	15	1	21	1	21	1	0	1
Total No. of stud	251		251		251		251		251		230	
Atainment value		2.82		2.77		2.85		2.82		2.81		2.93
% of Attainment		90.04		85.66		91.24		90.84		89.64		92.61
Attained or not		YES		YES		YES		YES		YES		YES

III Year Threshold
50

CO	CO Attainment Value	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	PSO 3
CO 1	2.82	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0
CO 2	2.77	0	3	2	0	0	0	0	0	0	0	0	0	1	2	0
CO 3	2.85	0	2	0	1	0	0	0	0	0	0	0	0	0	1	0
CO 4	2.82	2	2	1	0	0	0	0	0	0	0	0	0	1	0	2
CO 5	2.81	1	3	2	0	0	0	0	0	0	0	0	0	2	1	0
CO 6	2.93	**2**	**1**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**2**	**0**

MWOC		2.85	2.82	2.84	2.85	-	-	-	-	-	-	-	-	2.83	2.84	2.82



RGM COLLEGE OF ENGINEERING & TECHNOLOGY (AUTONOMOUS)
12th June 2023
III B.Tech. II Sem. (R20) End Examinations (Regular)
MICROWAVE ENGINEERING AND OPTICAL COMMUNICATION
ECE

Time: 3 Hrs **Total Marks: 70**

Note: 1. Answer Question No.1 (Compulsory) and 4 from the remaining
2. All Questions Carry Equal Marks

1a Define cut off flux density in cylindrical magnetron.
b Explain the operation of a circulator.
c Mention the factors causing to extrinsic absorption.
d What is the importance of dominant mode for a waveguide?
e What are the requirements for a optical source such that it is suitable for optical communication.
f Give the relationship between cut-off wavelength and V-number.
g What is the major difference between TWT and klystron?

2 Explain the operation of a Reflex Klystron by using applegate diagram. Also find the efficiency of reflex klystron. (14)

3 a) Why single mode fibers are preferred over multi-mode fibers in telecommunication industry? (7)
b) What are the various applications of single mode fibers? (7)

4 a) What is attenuation? Explain the optical fiber attenuation as a function of wavelength (9)
b) Explain various linear scattering losses (5)

5 a) What are the different types of fiber connectors? (7)
b) Explain about the different splicing techniques in a fiber. (7)

6 a) What is the relation between $\lambda_g, \lambda_c, \lambda$ in a waveguide? Derive it.
b) A rectangular waveguide of Cross section 5cm×2cm is used to Propagate TM_{11} mode at 9GHz. Determine the Cutoff wavelength & Wave impedance. (7)

7 a) Sketch a 4 Port Hybrid junction. Derive its S-matrix.
b) A 90W 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 output powers at the coupled and isolated ports. Assume all the ports to be matched. (7)

- ***** -

CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
2 2 2 2 2 7	14 7 5	2 2 9	7 7	7 7	7 7
17	26	13	14	14	14

Page: 1 of 1

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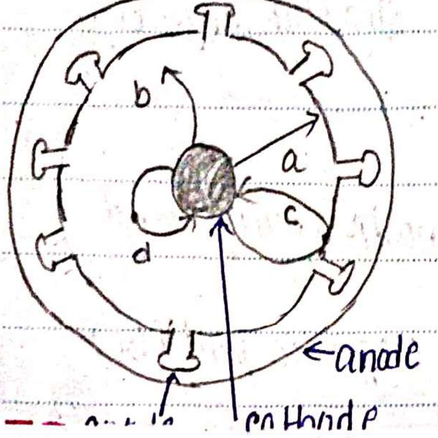
① a)

Cut off Flux density in cyclindrical Magnetron



* The magnetron is also called as "cross field tubes" as the electric and magnetic field components are perpendicular to each other.

* The Interaction between the electron

Subject: Microwave engineering & optical

Q.P. Code: A0424206R0623

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12424160

VALUATION-II							
Q.No.	1	2	3	4	5	6	7
A							
B							
C							
D							
E							
F							
G							
TOTAL							

GRAND TOTAL

(in words)

Signature of the Examiner

Signature of the Scrutinizer

Subject: microwave engineering & optical communication

Q.P. Code: A0424206R0623

12424160

For Office Use

VALUATION-I							
Q.No.	1	2	3	4	5	6	7
A	1	12	6	2	7	6	6
B	2		6	2	6	6	6
C	2						
D	2						
E	2						
F	2						
G	2						
TOTAL	13	12	12	4	13	12	12

GRAND TOTAL 62

(in words) Sixty two

G. Ramakrishna

Signature of the Examiner

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1
a)

Cut off flux density in cyclindrical Magnetron

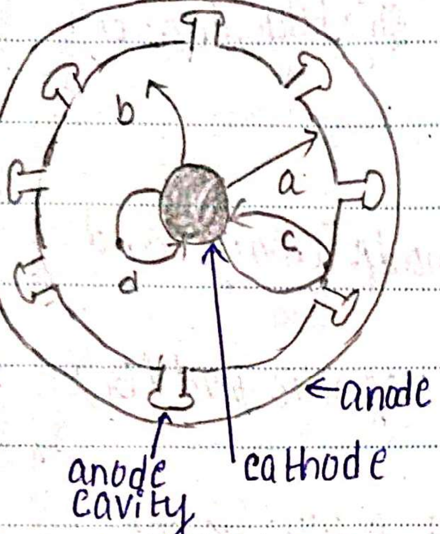


fig:- cylindrical magnetron.

* The magnetron is also called as "Cross field tubes" as the electric and magnetic field components are perpendicular to each other.

* The Interaction between the electron Beam and the RF input field is about longer duration.

* Magnetron is configured in cylindrical form as shown in fig.

* It consist of cathode, & co-axial copper anode material.

* Anode part consist of slots/cuts, in which they act as resonant cavities.

→ cut off flux density in cylindrical magnetron is denoted by '$J_{cut\text{-}off}$'

→ cutoff flux density can be defined as the minimum flux density of the electron particles (a,b,c&d), which are travelling from cathode to anode.

conditions

(i) In absence of magnetic field & presence of electric field (a)

→ The electrons directly travel from cathode to ande (a'particle) where $B =$ Magnetic field.

(ii) $B>0$

* Then the path of the electron bends slightly, due to lateral Excertion of force.

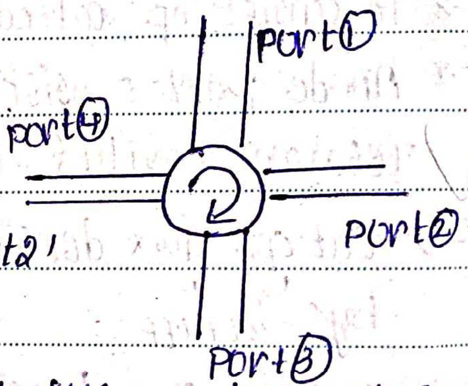
(iii) $B>>0$

* Then the electron only touches the anode cavity and return to cathode again.
* These magnetic field named as cutoff Magnetic field (B_c)

(iv) $B>B_c$

* The Electron accelerates from cathode & fastly reaches cathode again.

ⓑ Operation of Circulator



* Circulator is a 4port device.
* It has a pecular property, that is the port on '1' is coupled only with 'port2' and not with 'port 3' & port4'.
* Similarly the next port coupled with it's next port & not any other ports and follows.
* It can be defined as, if the input given at port 'n' and the output emerges from $(n+1)^{th}$ port respectively.

Applications :-

1) circular is used in parametric amplifiers
2) It is also used in tunnel diodes.

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Q.No	Marks

Q.No	Marks
1a	1

Q.No	Marks
1b	2

(3) And also used as deplexer in radars.

* Circular are used in low power devices, because it can handle only low power devices.

ⓒ

Factors causing to Extrinsic absorption

* Extrinsic absortion is the main cause for distortion in optical fiber.

* Due to the presence of impurity atoms in the optical fiber, Extrinsic absorption is caused.

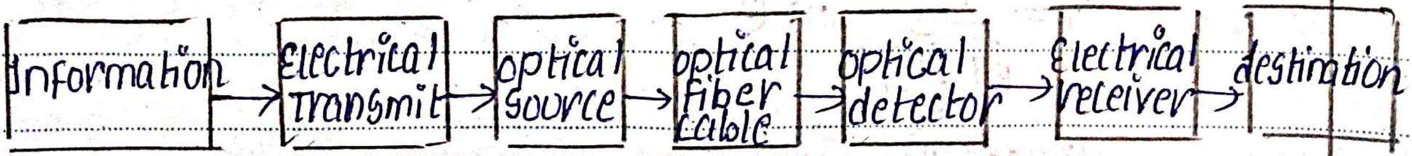
* Due to Imperfection in the fiber also cause extrinsic absorption.

* It can be reduced by removing the Impurity ions from the optical fiber.

* Absorption can also caused by Intrinsic absorption.

ⓓ
ⓔ

optical communication system



Optical Source:

* Optical source are used to convert Electrical Signal into light pulse, & transmit throgh optical fiber.

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Q.No	Marks
1c	2

Q.No	Marks
1e	2

Q.No	Marks

* Different types of optical sources are :

1) Lasers (light amplification by stimulated emission of radiation)
2) LED's (light emitting diode)

Requirements for an optical source to suit for optical communication system

1) High output power
2) High linearity
3) Temperature stability.

Ⓕ

Relationship between cut-off wavelength & V-number

we know that,

Phase velocity is given as in terms of guided wavelength :-

$$V_p = \frac{\omega}{\beta} \qquad V_p = \frac{\lambda_g}{T} = \lambda_g \cdot F \qquad f_0 = \frac{c}{\lambda_0}$$

$$V_p = \lambda_g \cdot \frac{c}{\lambda_0} \rightarrow ①$$

The phase velocity expression in terms of cuttoff wavelength:

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

Equate ① & ②

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

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

~~where λ_g = guided wavelength~~
~~λ_0 =~~

ⓕ Relation between cut-off wavelength & V-number

* V-number defines the no. of modes supported by fiber.

* V-number is a dimensionless quantity,

* V-number is given as :-

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}$$

a = radius of core.

$$\boxed{V = \frac{2\pi a}{\lambda}(N \cdot A)} \text{ (or) } \frac{2\pi a}{\lambda} n_1\sqrt{2\Delta}$$

$V \leq 2.405$ (single mode fiber)
$V > 2.405$ (Multimode fiber)

* where cuttoff wavelength is :

$$\boxed{\lambda_c = \frac{2\pi a (N \cdot A)}{V}}$$

∴ The cuttoff wavelength & V-number are inversly proportional to each other.

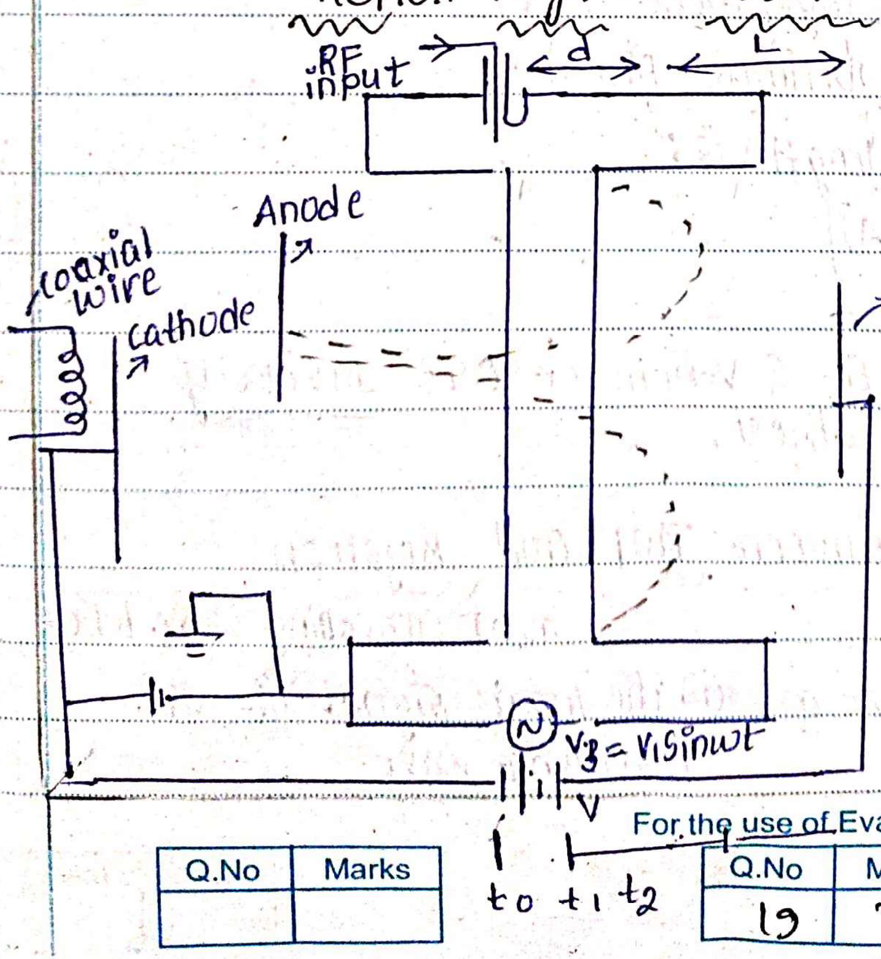
ⓖ Major different between TWT and Klystron

Klystron	TWT (Travelling wave tube)
① The input signal is not a travelling wave.	① The input signal is a travelling wave.

② The cavities present within klystron works Independently.	② All the devices within the TWT are tightly coupled.
③ The Interaction between Electron beam & Input RF Signal is only for short duration of time.	③ In twt, the Interaction between Electron beam & input RF Signal is for long duration of time.
④ Low output power compare to TWT	④ High output power.
⑤ low Efficiency	⑤ high efficiency & power.

②

Reflex klystron oscillator



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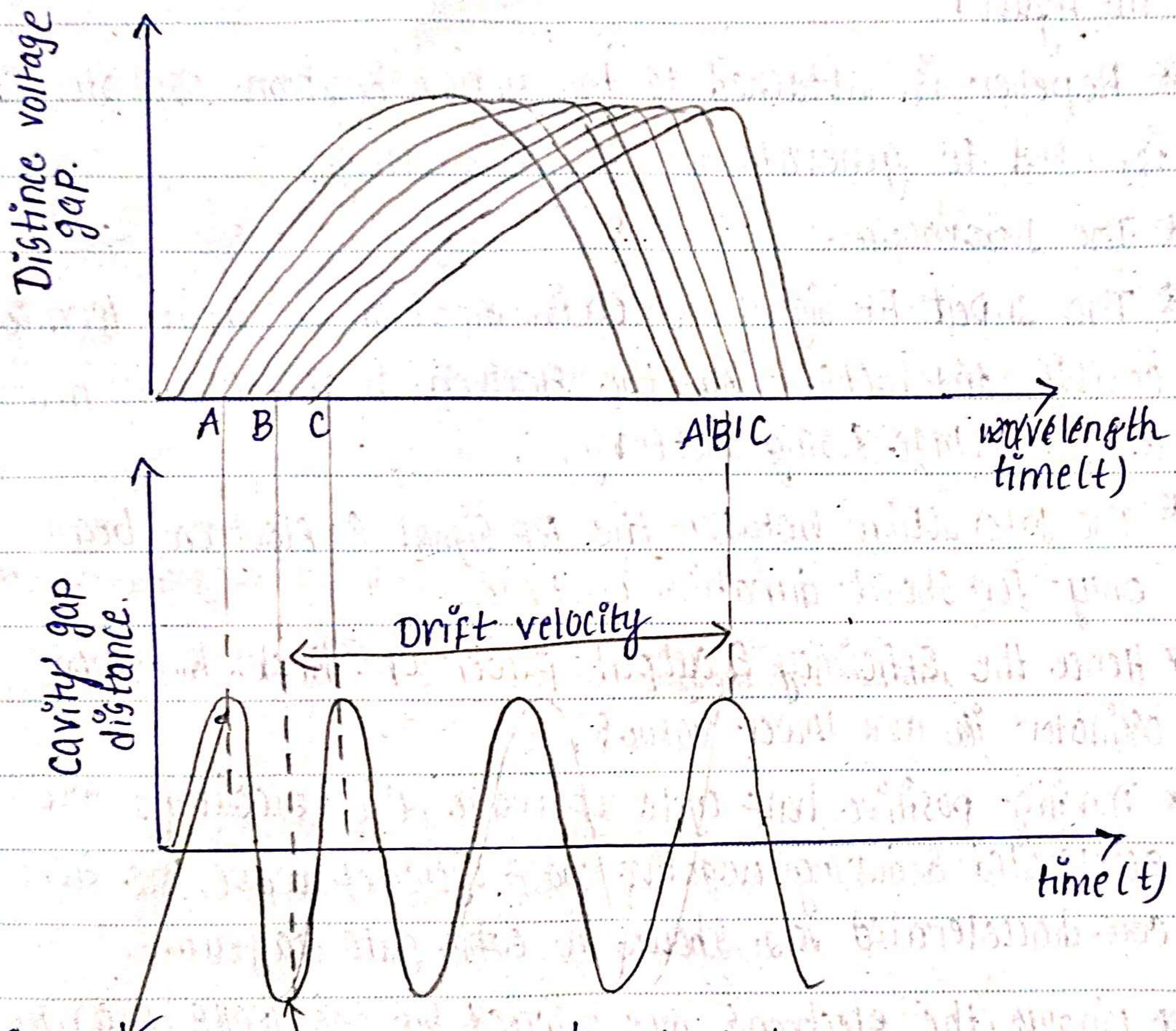
Q.No	Marks
19	2

Q.No	Marks

Apple gate diagram :-



Electrons are accelerated during positive half cycle.

electrons are deaccelerated during negative half cycle.

Operation :-

- * Reflex klystron oscillator have a single cavity.
- * Reflex klystron oscillator works based on the priciple of 'Velocity Modulation' Process.

Q.No	Marks

Q.No	Marks

Q.No	Marks

* The Input RF signal is applied to the cavity as shown in figure.
* Repeller is attached to the reflex klystron oscillator, it is used to generate the negative voltage.
* The Interaction.
* The Input RF signal, which is applied at input terminal cavity interacts with the Electron beam coming from the applied voltage using battery.
* The Interaction between the RF signal & Electron beam is only for short duration of time.
* Hence the Efficiency & output power of Reflex klystron oscillator is are lower values.
* During positive half cycle of wave, the electrons are accelerated & during negative half cycle of wave, the electrons are deaccelerated as shown in apple gate diagram.
* Finally, the electrons are collected by the walls of cavity.
* The Reflex klystron oscillator are mainly used to 'amplify the microwave signals'.

Applications:

* Reflex klyston oscillators are used in RADAR transmitters.
* They are used in FM amplifiers
* Used in Parametric amplifiers

Characteristics :

output power :- 1mw - 2.5mw

Efficiency :- 20% - 40%.

Frequency : 3GHz-200GHz

Efficiency of reflex klystron oscillator

* The ~~Input~~ output 'ac' power of reflex klystron oscillator is given as:

$$P_{ac} = \frac{I_2 V_1}{2} \rightarrow ①$$

we know that, the bunching parameter (x') is :-

$$X' = \frac{V_1 \beta_i \theta'}{2 V_0}$$

$$V_1 = \frac{2 V_0 X'}{V_1 \beta_i} \rightarrow ②$$

The induced current i_2/i_2 given at output port is :-

$$I_2 (\text{induced}) = 2 \beta_0 I_0 J_1(X') \rightarrow ③$$

Eq ② & ③ sub in ①

$$P_{ac} = \frac{\left(2 \beta_0 I_0 J_1(X')\right) \frac{2 V_0 X'}{V_1 \beta_i}}{2}$$

$$\boxed{P_{ac} = \frac{2 \beta_0 I_0 V_0 J_1(X') \cdot X'}{V_1 \beta_i}} \rightarrow \text{output ac power}$$

* effeciency of reflex klystron oscillator is the ratio between output power to input power.

$$P_{ac(input)} = I_0 V_0$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{\left(\frac{2\beta_0 X' J_1(X)\, I_0 V_0}{V_1 \beta_i}\right)}{I_0 V_0}$$

$$\eta = \frac{2\beta_0 X' J_1(X)\, I_0 V_0}{V_1 \beta_i I_0 V_0}$$

$$\boxed{\eta = \frac{2\beta_0 X' J_1(X)}{V_1 \beta_i}}$$ → Efficiency of Reflex klystron oscillator

---

⑤ a)

Fiber connectors

~~* The Semi-permen~~

* The connection between two on more fibers are known as fiber connectors.

* The connection between the fibers is not permenant.

The characteristics of fiber connectors:

① Low coupling losses:-

* There should low coupling loss, while connecting and disconnecting of fibers.

② Ease of connection:

* It should be easy to connect & disconnect fibers using hand.

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2	12

Q.No	Marks

③ Interchangability :-

* The Same type of fiber connectors, differ from one manufacturer to other.

④ Easy of assembly :-

* There should be availability of fiber connectors in local area, rather than going to 'connector' factory.

⑤ Low cost :

* It is manufactured to provide at low cost.

⑥ Low resistance to temperature :

* It should be designed in such a way that they are resistive to air, moisture etc.

Types of fiber connectors

① Butt joint connectors ② Expanded beam connectors

a) straigh sleeve connectors
b) Tappered sleeve connectors.

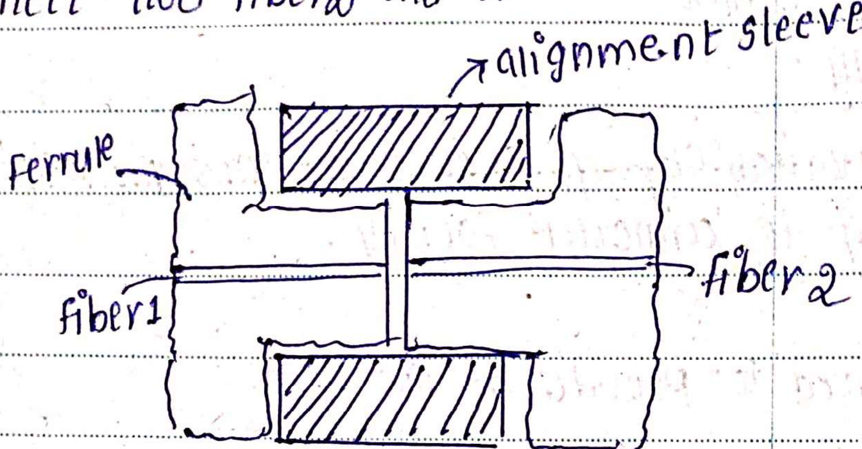
①Butt Joint connectors

* These fibers wre
* In these technique, the fibers are connected end to end

a) Straight sleeve connectors :

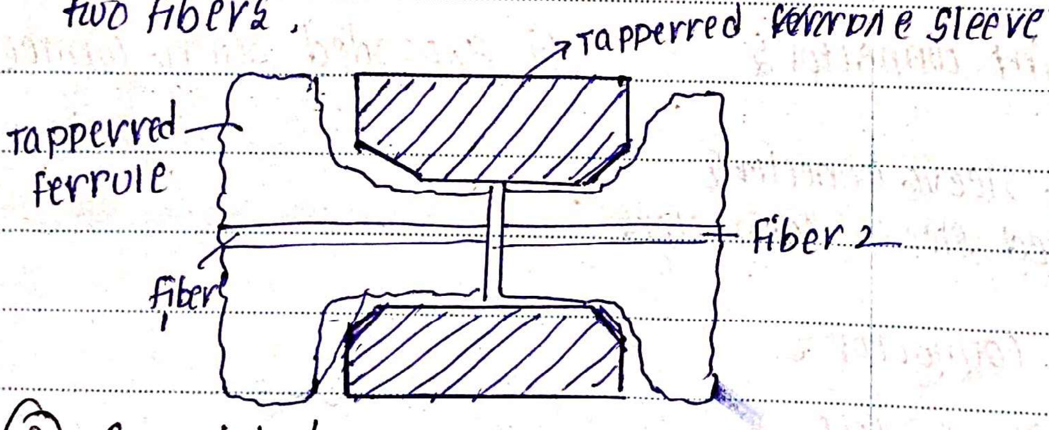
* In straight sleeve connectors, the alignment sleeve, ferrule & fibers are present.

* ferrule can be placed preciously in the alignment sleeve
* The precision hole is made in ferrule, in order to connect two fibers end to end.



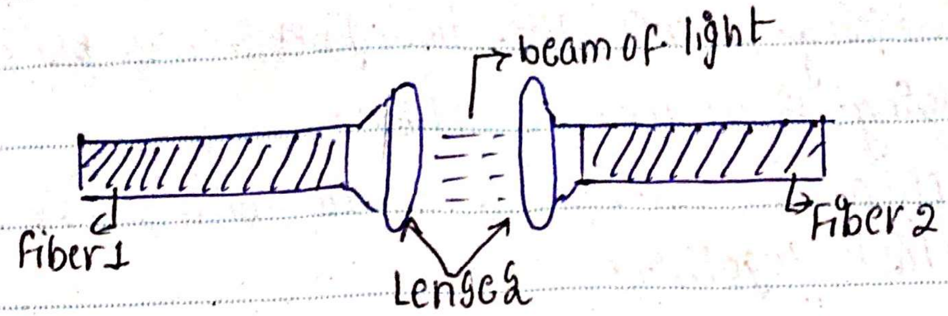
b) Tappered sleeve connector:

* ~~In~~ tappered sleeve connector consist of tappered ferrule in which placed into tapperred sleeve priciously,
* The precision hole is made in ferrule, in order to connect two fibers.



② Expanded beam connectors:

* In Expanded beam connectors the lens are connected at each end of fiber.
* These lens focus ~~on~~ the beam of light on the core of fiber material & hence the light is propagated through fibers.



ⓑ Splicing Techniques in a Fiber

* It is a process of permenent (or) semi-permenent connection between two fibers.

* These technique is used:

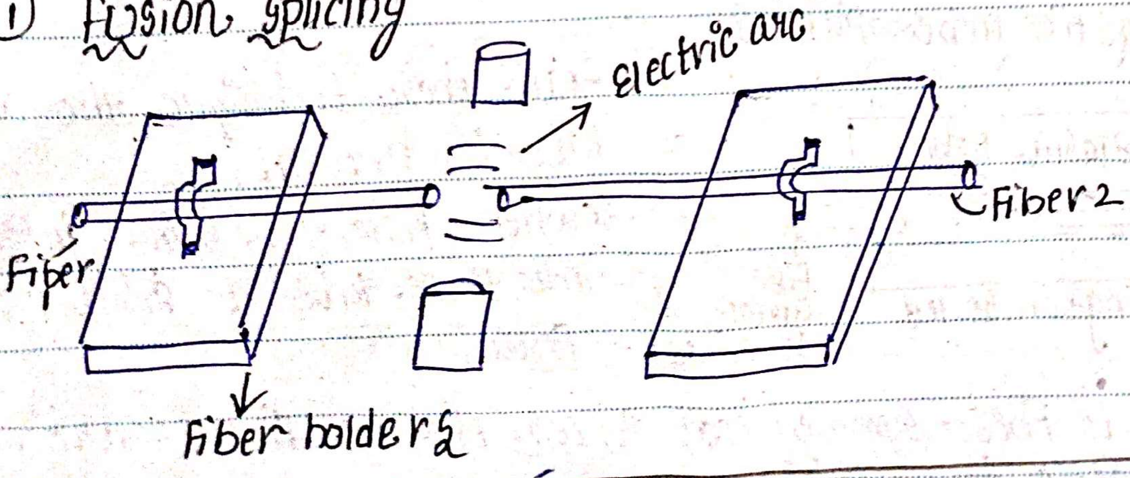
(i) where the numerous links of fiber connections are required.

(ii) where the frequent connection & disconnections are not required.

* These are 3 types:

① fusion splicing ② v-groove spliaing ③ Elastic tube splicing

① Fusion splicing



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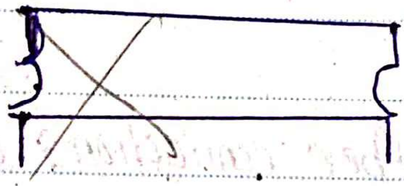
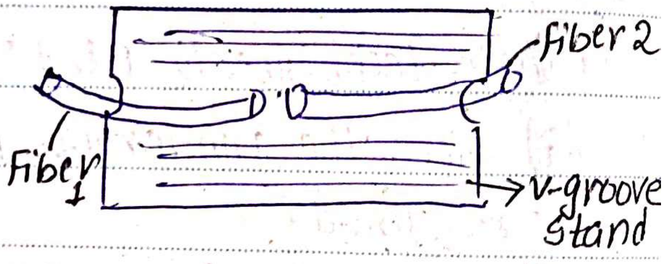
* In fusion slicing process, the two fibers are placed end t
end by using fiber conneal holders.
* when electric arc is applied on to these fibers, they melt & attach together.
* The main gole of these fusion splicing is the light enteri
into the fiber should not propaget outside.

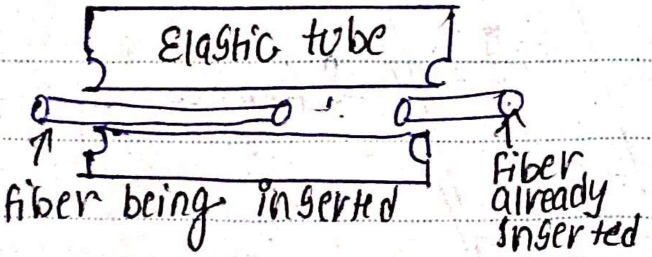
② V-groovesplicing:





* In these process the two fibers are placed near to each other with the help of V-groove stand.
* these two fibers are connected using adhesive tape.
* These adhesive take is responsible for fiber connection in V-groove splicing.

③ Elastic tube splicing:



*In these technique the elastic tube is present,
*when fiber is being inserted into these tube it exhibit symmet
force,

*Due to these symmetrical forces the two fibers are connecte
in elastic tube splicing,

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5a	7

Q.No	Marks
5b	6

⑥ ⓐ

Relation between λ_g, λ_o, λ_c in a waveguide

we know that phase velocity in terms of guided wavelength is:

$$V_g = \frac{\lambda_g}{t} = \lambda_g \cdot F \qquad \text{where } f = \frac{c}{\lambda_o}$$

$$V_g = \lambda_g \cdot \frac{c}{\lambda_o} \rightarrow ①$$

The phase velocity interms of cutoff wavelength & free space wavelength

$$V_g = \frac{c}{\sqrt{1-\left(\frac{\lambda_o}{\lambda_c}\right)^2}} \rightarrow ②$$

Equate ① & ②

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

$$\frac{\lambda_g}{\lambda_o} = \frac{1}{\sqrt{1-(\lambda_o/\lambda_c)^2}}$$

$$\boxed{\lambda_g = \frac{\lambda_o}{\sqrt{1-\left(\frac{\lambda_o}{\lambda_c}\right)^2}}} \rightarrow \text{relation between } \lambda_o, \lambda_g, \& \lambda_c$$

where λ_g = guided wavelength
λ_o = Free space wavelength
λ_c = cutoff wavelength.

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6a	6

Q.No	Marks

Q.No	Marks

ⓑ Given that a rectangular waveguit has :

cross section $= 5cm \times 2cm$

$a = 5cm$ (broader wavelength dimension)

$b = 2cm$ (shorter dimension)

$F_0 = 9GHz$

$\lambda_c = ?$

$Z_{TM11} = ?$

$$\lambda_0 = \frac{c}{F_0} = 0.0333/m = 3.33\times10^{-3}$$

$V = (2\pi a$ $\qquad m=1, n=1$

$$\lambda_c = \frac{2ab}{\sqrt{n^2a^2+m^2b^2}} = \frac{2(5\times2)}{\sqrt{25+4}} = 3.713$$

$$\boxed{\lambda_c = 3.713}$$

$$Z_{TM11} = \eta_0\left[\sqrt{1-(\lambda_0/\lambda_c)^2}\right] = 120\pi\left[1-\left(\frac{3.33\times10^{-3}}{3.713}\right)^2\right]^{1/2}$$

$$\boxed{Z_{TM11} = 376.990 \text{ mho}}$$

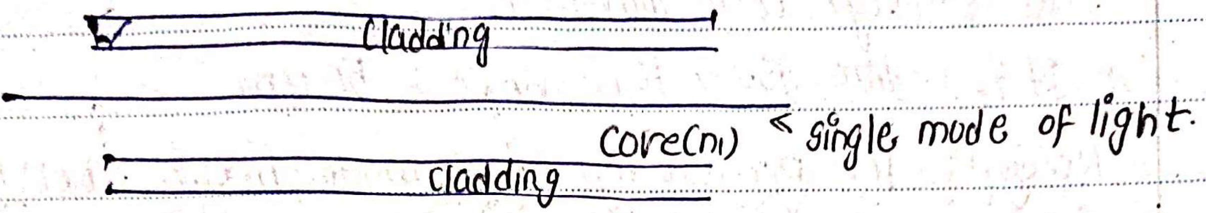
---

③ a) Single mode fibers are preffered over multi-mode communication system because

* single mode fibers :-

→ In single mode fibers, the The core diameter is very small, hence only $\overset{\text{allows}}{}$ single mode of light is propagated

Single mode fibers:-



* In single mode fibers the inter model dispersion is not present.

* Single mode fibers are become used for coherent beam of light propagation.

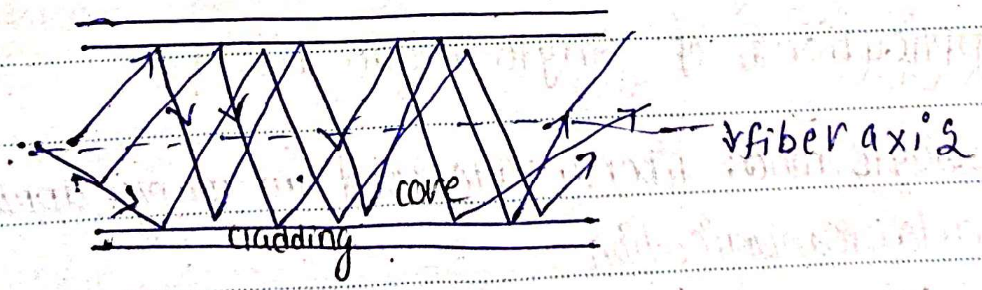
* The coupling efficiency is higher in single mode fibers.

* It's numerical aperture & V-number values are smaller because of low core diameter.

* It's core diameter is in range 2-10μm

Multimode fiber

* In multimode fiber, the core diameter is larger & hence it allows multiple modes of light to propagate through it.



* In multimode fiber the Intermodel dispersion is presen due to presence of multiple modes of light.

* multimode fibers are not used as coherent beam of source

* The coupling efficiency is low.

* It's Numerical aperture and V-number values increases due to large core diameter.
* It's radius is in the range : $50 \mu m$

Reasons for preferring single mode fibers over multimode fiber in Telecommunication :

* In single mode fibers the Intermodal dispersion is not present, because it consist of only single light & hence no time delay occurs, at output. & it is easy to construct rather than multimode fiber design.
* whereas in multimode fibers the Intermodal dispersion occurs because it have multiple modes of light, in which, they are travelling with different velocities & reach the output at different times, these cause Intermodal dispersion.

* Due to these intermodal dispersion, the signal strength is attenuated & hence it is not preffered in Telecommunication

---

b) Applications of single mode fibers

* Single mode fibers are used in many applications such as:

① Telecommunication
② d. Internet
③ LAN system
④ Mobile phones
⑤ optical communication system.

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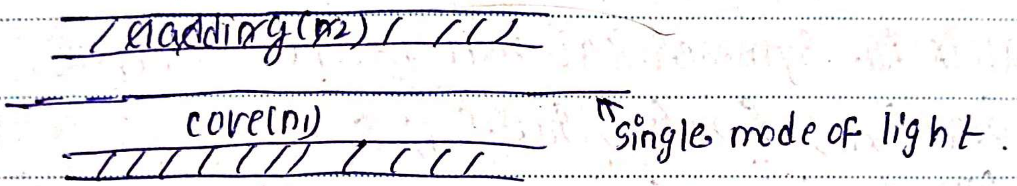
Q.No	Marks

Q.No	Marks
3a	6

Q.No	Marks

ⓑ *Single mode fibers have small core diameter of range 2-10μm

* Single mode fibers allows single mode of light.
* It's N.Americal aperture and V-number are less values
* low reliable data.



* No intermodel Interference.

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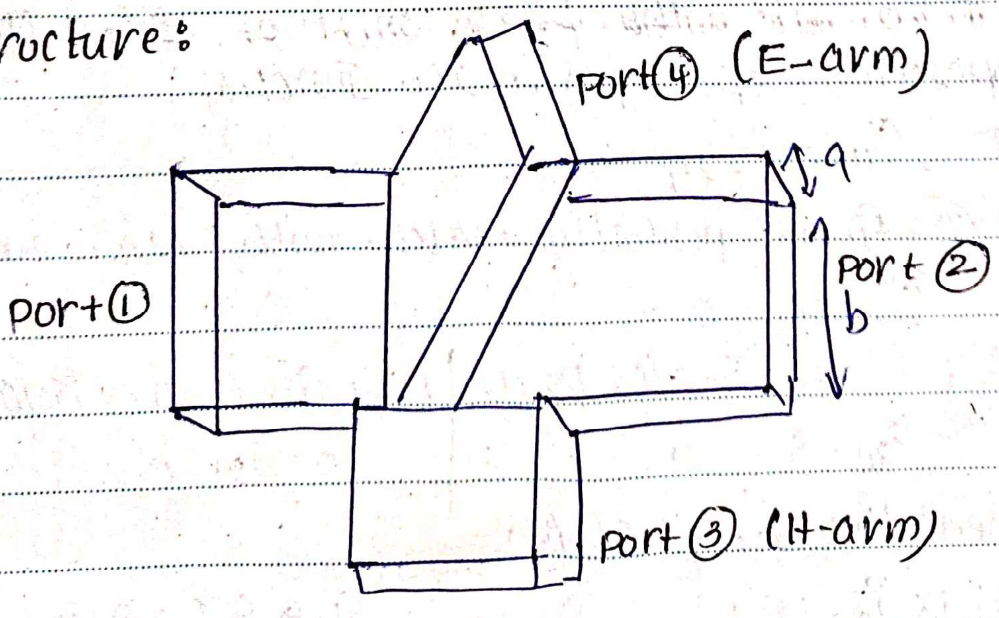
⑦ ⓐ

Hybrid Junction

* Hybrid Junction is also called as magic Tee Junction & E-H plane Tee Junction.

Structure:



* Hybrid Junction is a 4-port hybrid Junction i.e $S = (4\times4)$

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}_{(4\times4)}$$

* S-matrix is symmetrical matrix i.e:- $S_{ij} = S_{ji}$

$S_{12} = S_{21}$; $S_{13} = S_{31}$; $S_{14} = S_{41}$;
$S_{23} = S_{32}$; $S_{24} = S_{42}$;
$S_{34} = S_{43}$;

* when input is given at port ③, it gets divided b/w port① & port② according to the operation of H-plane Tee Junction, i.e

$$S_{13} = S_{23}$$

* when input is given at port④, it get divided between port ① & ② but with a phase shift of 180°, According to the operation of E-plane Tee Junction.

i.e $S_{14} = -S_{24}$

* port ③ & ④ are perfectly match with main waveguide

$$S_{33} = S_{44} = 0$$

* port ③ & ④ are isolated ports

$$S_{34} = S_{43} = 0$$

port ① & ② are isolated ports

$$S_{12} = S_{21} = 0$$

then the S-matrix is:

* S-matrix is unitary matrix i.e $S_{ij} * S_{ij}^{*} = \theta[I]$

$$S = \begin{bmatrix} S_{11} & 0 & S_{13} & S_{14} \\ 0 & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & 0 & S_{13}^* & S_{14}^* \\ 0 & S_{22}^* & S_{13}^* & -S_{14}^* \\ S_{13}^* & S_{13}^* & 0 & 0 \\ S_{14}^* & -S_{14}^* & 0 & 0 \end{bmatrix} =$$

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$R_1C_1 \Rightarrow |S_{11}|^2 + |S_{13}|^2 + |S_{14}|^2 = \phi$

$R_2C_2 \Rightarrow |S_{22}|^2 + |S_{13}|^2 + |S_{14}|^2 = \phi$

$R_3C_3 \Rightarrow |S_{13}|^2 + |S_{13}|^2 = \phi \quad \Rightarrow S_{13} = \frac{1}{\sqrt{2}}$

$R_4C_4 \Rightarrow |S_{14}|^2 + |S_{14}|^2 = \phi \quad \Rightarrow S_{14} = \frac{1}{\sqrt{2}}$

SUB S_{13} ·
from

$R_1C_1 \Rightarrow |S_{11}|^2 + |\frac{1}{2}| + |\frac{1}{2}| = \phi$

$|S_{11}|^2 = 0$

$\boxed{S_{11} = 0}$

$R_2C_2 \Rightarrow |S_{22}|^2 + \frac{1}{2} + \frac{1}{2} = 1$

$\boxed{S_{22} = 0}$

$$S = \begin{bmatrix} 0 & 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 0 & 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 & 0 \end{bmatrix}_{4\times4} \rightarrow$$

4-port hybrid Junction S-matrix.

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⑥ Given that :

Power source connected to i/p of directional coupler ;

$P = 90W$

$C = 20dB$ (coupling coefficient)

$D = 35dB$ (directivity)

$I = 0.5dB$

For directional coupler, S-matrix is ;

$$S = \begin{bmatrix} 0 & p & 0 & jq \\ p & 0 & jq & 0 \\ 0 & jq & 0 & p \\ jq & 0 & p & 0 \end{bmatrix}_{4\times4}$$

output powers at coupled ports ;

$$C = 10\log_{10}\left(\frac{P_i}{P_f}\right)$$

$$20 = 10\log_{10}\left(\frac{90}{P_f}\right)$$

$$2 = \log_{10}\left(\frac{90}{P_f}\right)$$

$$e^2 = \frac{90}{P_f}$$

$$7.389 = \frac{90}{P_f}$$

$$P_f = \frac{7.389}{90} = 0.0821$$

$$\boxed{P_f = 0.0821w}$$

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7a	6

Q.No	Mar

output powers at Isolated ports

$$I = 10\log_{10}\left(\frac{P_i}{P_b}\right)$$

$$54.5 = 10\log_{10}\left(\frac{90}{P_b}\right)$$

$$e^{5.45} = \frac{90}{P_b}$$

$$P_b = \frac{232.75}{90} = 2.58\,dB\ W$$

$$\boxed{P_b = 2.58\ W}$$

$I = 20+35$

$I = 55$ (remove Insortion lo

$I = 55-0.5$

$I = 54.5\,dB$

$a = 5cm$

$b = 2cm$ $f_0 = 9GHz$

$\lambda_c = ?$

$Z_{TM11} = ?$

$$\lambda_0 = \frac{c}{F_0} = 3.333$$

$$\lambda_c = \frac{2(5\times2)}{\sqrt{25+4}} = 3.713$$

$$\boxed{\lambda_c = 3.713}$$

$$Z_{TM11} = \eta_0\left[\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}\right] = 375.14\ mho$$

$$\boxed{Z_{TM11} = 375.14\,mho}$$

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Q.No	Marks
7b	6

Q.No	Marks
6b	6

Q.No	Marks

④ ⓑ

various linear scattering losses

* Scattering is due to Imperfections in optical fiber,
* Scattering means spereading of light in all the directions.

These are 2 types

① Linear Scattering
  a) Rayleigh Scattering
  b) Mie Scattering
  c) waveguid Scattering

ⓑ non-linear scattering
  a) SBS (stimulated bruliou scattering)
  b) SRS (stimulated raman scattering)

Q.1 ⓓ

Importance of dominant mode for waveguide

* dominant mode is TE_{10} mode
* where $m=1$ & $n=0$
* It is defined as the high cuttof wavelength & low cuttoff frequency it is most Important point in waveguide.

$$\lambda_c = \frac{2ab}{\sqrt{n^2a^2+m^2b^2}} = 2a$$

$$\boxed{\lambda_c = 2a}$$

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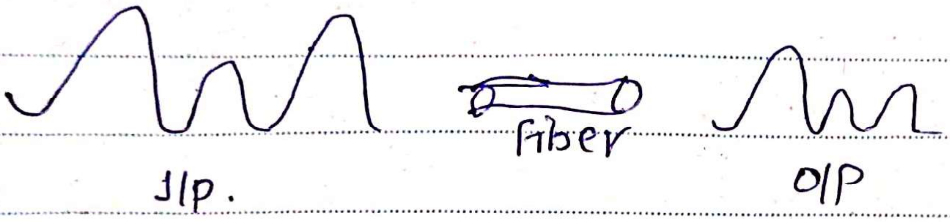
Q.No	Marks	Q.No	Marks	Q.No	Ma
		4b	2		

4a) Attenuation :- when a wave is propagated along a fiber then its power decreases.

$P(z) = P(0) e^{-\alpha z}$ $\alpha = \frac{1}{z} \ln\left[\frac{P(z)}{P(0}\right]$



Attenuation types:

1) Absorption losses
2) radiation losses
    - micro bending
    - Macro bending
3) scatterring losses.
    - linear
    - non-linear

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Q.No	Marks
1d	2

Q.No	Marks
4a	2

Q.No	Marks

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INTERNAL EXAMINATIONS ANSWER BOOKLET

Principal
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NANDYAL.

NAME OF THE STUDENT: S. Gousiya

Reg. No. 2 0 0 9 1 A 0 4 3 9

	1	2	3	4	5
A	1	3	3	2	3
B	1	2	1	2	2
C	1				
D	1				
E	1				
Total	5	5	4	4	5
Grand Total :(In Figures)	19				
(in Words):	One NINE				

NAME OF THE SUBJECT: MW & OC

INTERNAL EXAM : I / [✓ II]

Date of Exam: 16-05-2023. ([✓ FN]/AN)

Course : [✓ B.Tech.] / M.Tech./ MBA / MCA

Year : III rd Sem.: II

Branch: ECE - A

Signature of the Invigilator

(Start Writing From Here)

1a) Acceptance Angle: The maximum angle at which the light enters into the optical fiber for the propogation is called acceptance Angle. It is denoted by θ_a.

$$\theta_a = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$$

1b) Intermodel Dispersion Losses:- These intermodel dispersion losses occurs in multimode fibers.

1c) Internal Quantum Efficiency in LED (η_{int}): It is defined as the ratio of recombination rate to the total recombination rate.

$$\eta_{int} = \frac{R_r}{R_r + R_{nr}}$$

Where, R_r = recombination rate
R_{nr} = Non-recombination rate.

(or) $\eta_{int} = \frac{\tau}{\tau_r}$

1d. Given,

V-number, $V = 75$

Numerical Aperture, $NA = 0.3$

Refractive index of core, $n_1 = 1.458$

Wavelength $\lambda = 820nm$

WKT

$$V = \frac{2\pi a}{\lambda} n_1 \sqrt{2\Delta}$$

$$\boxed{V = \frac{2\pi a}{\lambda} NA}$$

Where, a = radius of core.

$$75 = \frac{2 \times \pi \times a}{820 \times 10^{-9}} \times (0.3)$$

$$a = 3.26 \times 10^{-5}$$

Radius, $a = 0.32 \times 10^{-6}$ m.

1e) Scattering : Some power is transfered from one mode to other mode i.e., guided mode to radiation mode.

Two Types of Sattering Losses

(1) Linear Scattering Losses
  (a) Rayleigh Scattering Loss
  (b) Mie Scattering Loss

(2) Non-Linear Scattering Loss
  (a) Stimulated Brillouins Scattering
  (b) Stimulated Raman Scattering.

3a) **Expression for dispersion parameter due to pulse Boardening because of Material Dispersion:-**

Dispersion due to material properties of guided wave cause Material Dispersion. The second order of refractive index with respect to the wavelength is not equal to zero in Material Dispersion.

$$\frac{d^2 n_1}{d\lambda^2} \neq 0$$

We know that, the propogation constant, $\beta = \frac{2\pi n_1}{\lambda}$

The group ~~β=~~ velocity $V_g = \frac{d\omega}{d\beta}$

$$\frac{\tau_g}{L} = \frac{1}{V_g} = \frac{d\beta}{d\omega} = \frac{-\lambda^2}{2\pi c} \frac{d\beta}{d\lambda}$$

$$\Rightarrow \frac{\tau_g}{L} = \frac{-\lambda^2}{2\pi c} \frac{d\beta}{d\lambda}$$

$$\frac{\tau_{mat}}{L} = \frac{-\lambda^2}{2\pi c} \frac{d}{d\lambda}\left[\frac{2\pi n_1}{\lambda}\right]$$

[$\tau_{mat} = \tau_g$ For material dispersion]

$$= \frac{-\lambda^2}{2\pi c}\left[\frac{2\pi}{\lambda}\frac{dn_1}{d\lambda} - \frac{1}{\lambda^2}\, 2\pi n_1\right]$$

3

$$= \frac{-\cancel{\lambda^2}}{\cancel{2\pi} c} \frac{\cancel{2\pi}}{\cancel{\lambda}} \frac{dn_1}{d\lambda} + \frac{\cancel{\lambda^2}}{\cancel{2\pi} c} \cdot \frac{1}{\cancel{\lambda^2}} \cancel{2\pi} n_1$$

$$\frac{\tau_{gmat}}{L} = \frac{1}{c}\left[n_1 - \lambda \frac{dn_1}{d\lambda}\right]$$

$$\tau_{mat} = \frac{L}{c}\left[n_1 - \lambda \frac{dn_1}{d\lambda}\right]$$

We know that, $\sigma_{mat} = \frac{d}{d\lambda}\tau_{mat} \cdot \sigma_{\lambda}$

$$\sigma_{mat} = D(\lambda)\ \sigma_\lambda$$

By solving σ_{mat} and comparing

$$D(\lambda) = \frac{-\lambda}{c}\frac{d^2 n_1}{d\lambda^2}$$

Dispersion Parameter, $D(\lambda) = \frac{-\lambda}{c}\frac{d^2 n_1}{d\lambda^2}$

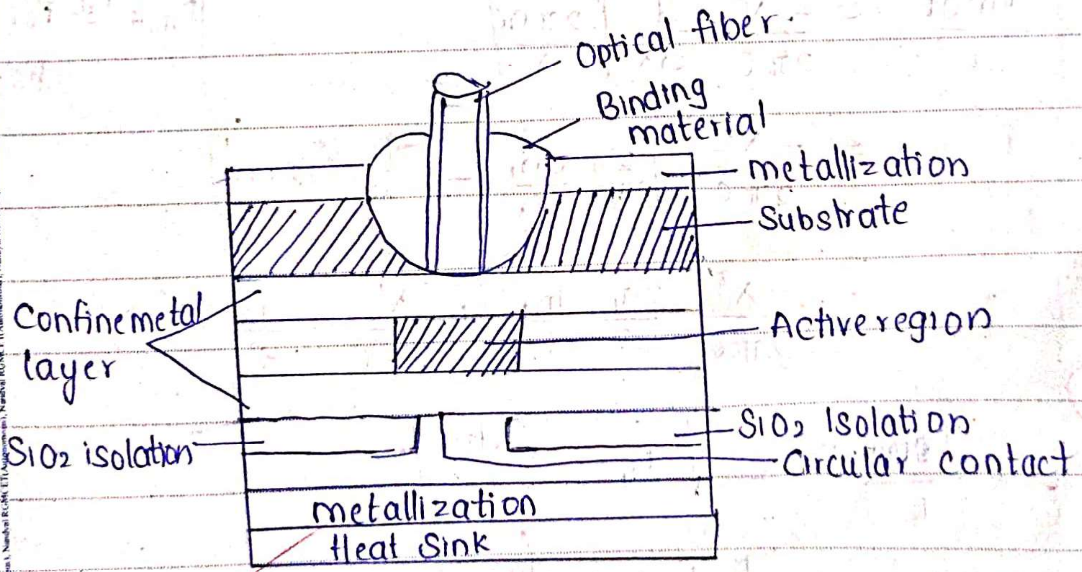
3b) Stimulated Brillounis Scattering (SBS):-

SBS is considered as modulation through molecular vibrations in the Optical Fiber. In this upper and lower side bands are produced separated by the wavelength of Incident light. The incident ray produces photos of acoustic frequency (sound photons) and incident photons. Due to presence of sound photons scattering will takes place in fiber.

SBS is a Non-linear Scattering loss. These locses occurs in high optical frequency fibers only.

5a) Surface Emitting LED:-

Construction and Operation:-



1. It is also called as Burrus (or) Front Emitter.
2. The Emitted light is perpendicular to the plane of PN Junction.
3. In SLED, some portion of substrate is etched away to decrease the distance between active region and dispersion region.
4. The light is emitted from the Surface of

the LED.

5. Surface Emitting LED's have high emission efficiency and high current density.

6. Due to High Current Density heat is produced in LED, so to reduce the heat we use heat sink.

7. Fabrication is Easy.

8. Spectral Width is Larger.

9. Maximum Efficiency is upto 60%.

10. Low system performance compare to ELED.

5b) Operating Wavelength, $\lambda = 1310\,nm$

recombination Time, $\tau_r = 30\,ns$

Non-recombination time, $\tau_{nr} = 100\,ns$

Current, $I = 40\,mA$

(i) Bulk recombination life time = τ

$$\boxed{\frac{1}{\tau} = \frac{1}{\tau_r} + \frac{1}{\tau_{nr}}}$$

$$= \frac{1}{30\,ns} + \frac{1}{100\,ns}$$

$$\tau = 23.07\,ns.$$

Bulk recombination time, $\tau = 23.07\,ns$.

(ii) Internal Quantum Efficiency $\boxed{\eta_{int} = \frac{\tau}{\tau_r}}$

2

$$\eta_{int} = \frac{23.07}{30}$$

$$\eta_{int} = 0.769$$

Internal Quantum Efficiency, $\eta_{int} = 0.769$.

(iii) Interal Power, $\boxed{P_{int} = \eta_{int} \cdot \frac{Ihc}{q\lambda}}$

$$P_{int} = (0.769)\left(\frac{40m \times 6.62\times10^{-34} \times 3\times10^{8}}{1.6\times10^{-19} \times 1310\,a\times10^{-9}}\right)$$

$P_{int} = 0.029$

Internal Power, $P_{int} = 0.029$.

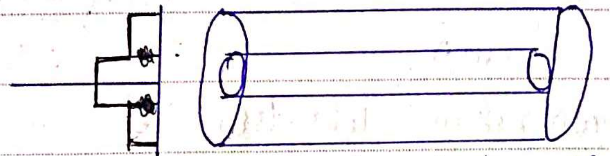
---

2 a) There are two types of fibers
(1) Step - Index Fiber
(2) Graded Index Fiber:

Step Index Fiber:-

In this fibers the refractive indexes of core and cladding are same respectivelly through out the length of the fiber. The indexing in refractive index is caused near the core- cladding variance.

This can be represented as:-



If n_1 is the refractive index of core and n_2 is the refractive index of cladding. The refractive index profile function can be written as

3

$$n(r) = \begin{cases} n_1 ; & r \leq a \\ n_2 ; & r \geq a \end{cases}$$

The refractive Index of core is slightly larger than the refractive index of cladding. Due to the step - index is formed.

Step- Index Fiber are mostly used in Single mode only. They are called Single mode Step- Indexed Fibers.

2b) Given,

Refractive Indices , $n_1 = 1.48$
$n_2 = 1.46$

(i) Numerical Aperture , $\boxed{NA = \sqrt{n_1^2 - n_2^2}}$

$$NA = \sqrt{(1.48)^2 - (1.46)^2}$$

$$NA = 0.242$$

(ii) Critical Angle $\boxed{\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)}$

$$\theta_c = \sin^{-1}\left(\frac{1.46}{1.48}\right)$$

$$\theta_c = 80.56^\circ$$

(iii) Acceptance Angle , $\boxed{\theta_a = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)}$

$$= \sin^{-1}(NA)$$

$$= \sin^{-1}(0.242)$$

$$\theta_a = 14.004^\circ$$

2

---

4 a) Micro Bending loss:-

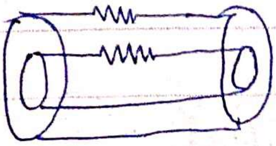
Bending losses are due to the bends in optical fiber. There are two types of Bending losses

(1) Macro Bending Loss

(2) Micro Bending Loss.

Micro Bending Loss: These type of losses are due to random micro bends of optical fiber. Micro bends occurs during fabrication of core (or) fiber also during insertion of wires in fibers etc. These Micro ~~stop~~ Bendings can be represented as

2



The zig-zag on fiber represent that there is a micro bend and cause micro bending losses.

4b) Absorption losses are caused mainly due to three mechanisms.

(1) Absorption due to atomic defect in glass Structure:

In, the glass structure there may be defect of single atom (or) molecule. Due to this defect absorption loss occur. These losses are negligable comparing to intrinsic and extrinsic losses. When fiber is exposed to ionisation radiation then the absortion loss can be increased.

~~(2) Absorption Losses:~~

(2) Extrinsic Absorption loss due to impure atoms in glass material:

2

Extrinsic losses are mainly due to the presence of transition elements in the glass material. Transition Elements can be Iron, Cobalt, Chronium, OH molecules etc.

(3) Intrinsic Absorption loss due to atoms of Constitute material:

Intrinsic losses occurs when there is defect in composition ratio during fabrication, This intrinsic losses are the lower limit for fiber fabrication and Selection.

S.No. 82945

RAJEEV GANDHI MEMORIAL COLLEGE OF ENGINEERING & TECHNOLOGY
AUTONOMOUS

Accredited by NAAC of UGC, New Delhi with 'A' Grade:: Accredited by NBA
Affiliated to JNT University Anantapur
Nandyal - 518 501, Kurnool Dist, A.P.
(ESTD-1995)

INTERNAL EXAMINATIONS ANSWER BOOKLET

NAME OF THE STUDENT: V. Maheswara Reddy Reg. No. 2 0 0 9 1 A 0 4 8 8

	1	2	3	4	5
A	1	3		3	2
B	1	2		2	2
C	1				
D	1				
E	1				
Total	5	5		5	4
Grand Total :(In Figures)	19				
(in Words):	One Nine				

NAME OF THE SUBJECT: MW & OC

INTERNAL EXAM : [✓ I] / II

Date of Exam: 24/03/2023 ([✓ FN]/AN)

Course : [✓ B.Tech.] / M.Tech./ MBA / MCA

Year : III Sem.: II

Branch: ECE-A

Signature of the Invigilator

(Start Writing From Here)

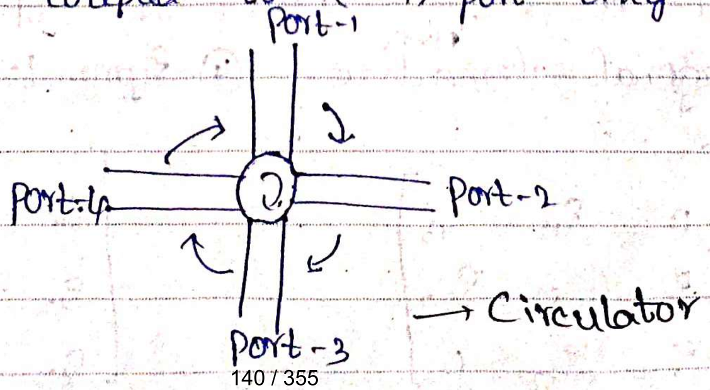
1a. Circulator:-

→It is a 4-port device, which is a ferrite composition device.

→In circulator, any port is connected with only one other port only.

→port-1, coupled to port-2 only, not to port-3 & port-4.
port-2, coupled to port3 only, not to port-4& port 1.
port-3, coupled to port4 only, not to port-1 & port2.
port-4, coupled to port1 only, not to port-2 & port-3

→n^{th} port coupled to $(n+1)^{th}$ port only.



1.b.

Two Cavity Klystron Amplifier	Reflex Klystron Oscillator
→ The operating frequency is 250MHz - 500GHz	→ The operating frequency is X-band range, i.e., 8GHz-12G
→ It works on the principle of Velocity modulation	→ It produces constant oscillations by rotating.
→ Efficiency is high (58%)	→ Efficiency is low.
→ The supply given to it is from Voltage Source.	→ The supply is given fro Klystron Power Supply.

1.c. **Properties of S-Matrix.**

→ The order of S-Matrix is n×n ; n = no. of port

→ S-Matrix is a Symmetric Matrix.

i.e., $S_{ij} = S_{ji}$

→ S-Matrix is a Unitary matrix, i.e.,

$$[S][S]^* = [I]_{n\times n}$$

→ The diagonal elements in a S-matrix is '0'.

→ The sum of ~~element~~ product of any row (or) column elements with corresponding comple conjugates of another row (or) column is '~~unity~~' 0.

$$\sum_{\substack{i=0\\ j=0}}^{n} S_{ij}\cdot S_{ji} = 0$$

→ S-matrix represents properties like Power, VSWR, ...

① S-Matrix

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}_{n\times n}$$

② Unitary Property

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \cdot \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* \\ S_{21}^* & S_{22}^* & S_{23}^* \\ S_{31}^* & S_{32}^* & S_{33}^* \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

③ Diagonal elements = 0

$$\begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{21} & 0 & S_{23} \\ S_{31} & S_{32} & 0 \end{bmatrix}$$

④ Symmetric matrix

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{23} \\ S_{13} & S_{23} & S_{33} \end{bmatrix}$$

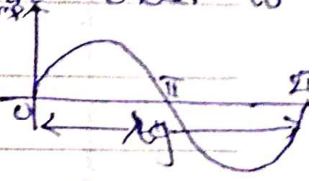
1.d. TE Wave (Transverse Electromagnetic wave):-

→ In TE wave, the Electric-field is perpendicular to the direction of propagation of input wave. If z-direction is of input wave, then $E_z = 0$ & $H_z \neq 0$

→ TE wave can be propagated through waveguide; i.e., a rectangular waveguide.

1.e. Guided wavelength (λg):-

→ It is denoted by 'λg' & defined as the distance covered by a wave, in order to cover a phase of 2π radians.



Cutoff wavelength (λ_c):- [λ at $f = f_c$]

→ It is defined as the wavelength of a wave, propagating through a rectangular waveguide, where, ~~Transfer function~~, Propagation constant is '0'. i.e., $\gamma = 0$, (or) at the cuttoff frequency

$$\Rightarrow \alpha + j\beta = 0$$

$$\boxed{\lambda_c = \frac{2ab}{\sqrt{n^2a^2 + m^2b^2}}}$$

→ Relation between λg & λ_c is given as,

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

; λg → guided wavelength

; λ_c → cutoff wavelength

; λ_0 → free space wavelength

2.a. Phase Velocity:-(V_P):-

→ Phase Velocity, denoted by 'V_P' & defined as the
difference in phase at cuttoff frequency
wavelength(λg) per unit time, required to change the phase of a guided wave.

→ we know that, Phase velocity,

$$V_P = \frac{\omega}{\beta}$$

where, β = Phase Constant.

$$\Rightarrow \beta = \sqrt{\omega^2 \mu\varepsilon - \omega_c^2 \mu\varepsilon}$$

$$\Rightarrow V_p = \frac{\omega}{\sqrt{\omega^2\mu\varepsilon - \omega_c^2\mu\varepsilon}}$$

$$V_p = \frac{\omega}{\sqrt{\mu\varepsilon}\cdot\sqrt{\omega^2-\omega_c^2}}$$

$$= \frac{1}{\sqrt{\mu\varepsilon}} \cdot \frac{\omega}{\sqrt{\omega^2\left(1-\left(\frac{\omega_c}{\omega}\right)^2\right)}}$$

$$= c \cdot \frac{\cancel{\omega}}{\cancel{\omega}\sqrt{1-\left(\frac{\omega_c}{\omega}\right)^2}} \quad \left(\because c = \frac{1}{\sqrt{\mu\varepsilon}}\right)$$

$$\therefore \boxed{V_p = \frac{c}{\sqrt{1-\left(\frac{\omega_c}{\omega}\right)^2}}}$$

(or) $\omega_c = 2\pi f_c$, $\omega = 2\pi f$

$$\Rightarrow V_p = \frac{c}{\sqrt{1-\left(\frac{2\pi f_c}{2\pi f}\right)^2}} \Rightarrow \boxed{V_p = \frac{c}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}}$$

(or) $f_c = \frac{c}{\lambda_c}$ & $f = \frac{c}{\lambda_0}$

3

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

; λ_0 → freespace wavelength ; f_c → cutoff frequen

λ_c → cutoff wavelength ; f → freespace frequenc

c → speed of light in vaccum

V_p → Phase Velocity

2.b. <u>Group</u> <u>Velocity</u>:- (<u>V_g</u>):-

→ It is denoted by 'V_g' & defined as the rate of change of phase of the input electromagnetic wave,

2

$$\text{i.e.,} \quad V_g = \frac{d\omega}{d\beta}$$

$$\Rightarrow \frac{1}{V_g} = \frac{d\beta}{d\omega}$$

where, we know $\beta=\sqrt{\omega^2\mu\epsilon-\omega_c^2\mu\epsilon}$

$$\Rightarrow \frac{1}{V_g} = \frac{d}{d\omega}\sqrt{\omega^2\mu\epsilon-\omega_c^2\mu\epsilon}$$

$$= \frac{1}{2\sqrt{\omega^2\mu\epsilon-\omega_c^2\mu\epsilon}}\cdot 2\omega\mu\epsilon$$

$$\Rightarrow V_g^{-1} = \frac{\omega\mu\epsilon}{\sqrt{\omega^2\mu\epsilon-\omega_c^2\mu\epsilon}}$$

$$\Rightarrow V_g = \frac{\sqrt{\omega^2\mu\epsilon-\omega_c^2\mu\epsilon}}{\omega\mu\epsilon}$$

$$= \sqrt{\frac{\omega^2-\omega_c^2}{\omega^2}}\cdot\sqrt{\frac{\mu\epsilon}{(\mu\epsilon)^2}}$$

$$V_g = \frac{1}{\sqrt{\mu\epsilon}}\cdot\sqrt{1-\left(\frac{\omega_c}{\omega}\right)^2}$$

$$\Rightarrow V_g = c\cdot\sqrt{1-\left(\frac{2\pi f_c}{2\pi f}\right)^2}$$

$$(\text{or})\ V_g = c\cdot\sqrt{1-\left(\frac{f_c}{f}\right)^2}$$

$$\therefore\ (\text{or})\ V_g = c\cdot\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}$$

; λ_0 → freespace wavele

; λ_c → cutoff wavelength

; c → speed of light

; V_g → Group velocity.

; f_c → cutoff frequenc

4.a. **Magic Tee Junction:-**

→ It is also called as Hybrid Tee Junction (or) E-H-plane Tee Junction.

→ It is a 4-port device and port 1- & port-2 are ~~port-3~~ opposite ports & port-3 is H-plane & port-4 is E-plane.

3

→ port-3 & port-4 are isolated ports; Port- Port-2 are isolated po

$$\Rightarrow \boxed{S_{34}=S_{43}=0}$$

→ we know that when i/p given at H-plane,

$$\boxed{S_{13}=S_{23}}$$

→ when input given at E-plane, $\boxed{S_{14} = -S_{24}}$

→ S-Matrix is of order-4 & applying symmetry, we get, $\boxed{S_{33} = S_{44} = 0}$ (∵ Perfectly matched)

$\boxed{S_{34} = 0}$ (∵ Isolated Ports)

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{23} & S_{24} \\ S_{13} & S_{23} & 0 & \cancel{S_{34}}\,0 \\ S_{14} & S_{24} & \cancel{S_{34}}\,0 & 0 \end{bmatrix}$$

→ On substituting all S-parameters,

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & \cancel{S_{34}}\,0 \\ S_{14} & -S_{14} & \cancel{S_{34}}\,0 & 0 \end{bmatrix}$$

→ S-Matrix is Unitary matrix, $[S][S]^* = [I]_{n\times n}$

$$\Rightarrow \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & \cancel{S_{34}}\,0 \\ S_{14} & -S_{14} & \cancel{S_{34}}\,0 & 0 \end{bmatrix} \cdot \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* & S_{14}^* \\ S_{12}^* & S_{22}^* & S_{13}^* & -S_{14}^* \\ S_{13}^* & S_{13}^* & 0 & \cancel{S_{34}^*}\,0 \\ S_{14}^* & -S_{14}^* & \cancel{S_{34}^*}\,0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$R_1C_1 \Rightarrow |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1 \rightarrow$ ①

$R_2C_2 \Rightarrow |S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1 \rightarrow$ ②

$R_3C_3 \Rightarrow |S_{13}|^2 + |S_{13}|^2 + \cancel{|S_{34}|^2} = 1 \rightarrow$ ③ $\Rightarrow \boxed{S_{13} = \frac{1}{\sqrt{2}}}$

$R_4C_4 \Rightarrow |S_{14}|^2 + |S_{14}|^2 + \cancel{|S_{34}|^2} = 1 \rightarrow$ ④ $\Rightarrow \boxed{S_{14} = \frac{1}{\sqrt{2}}}$

→ From ① & ② $\Rightarrow S_{11} = S_{22}$

From ③ & ④ $\Rightarrow S_{13} = S_{14}$

port-1 & port-2 are isolated ports $\Rightarrow \boxed{S_{12} = S_{21} = 0}$

$\boxed{S_{11} = S_{22} = 0}$ (∵ These are perfectly matched to the wave guide)

→ Now, the resultant S-matrix, is as follows:-

$$S = \begin{bmatrix} 0 & 0 & S_{13} & S_{14} \\ 0 & 0 & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix}$$

→ On substituting, S-parameter values we get,

$$S = \begin{bmatrix} 0 & 0 & \frac{1}{\sqrt{2}} & 1/\sqrt{2} \\ 0 & 0 & \frac{1}{\sqrt{2}} & -1/\sqrt{2} \\ 1/\sqrt{2} & 1/\sqrt{2} & 0 & 0 \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 & 0 \end{bmatrix}$$

Hence, above S-matrix is the Scattering-Parameter matrix, for a 4-port given Magic Tee Junction.

4.b. Ferrite materials:-

→ Ferrite composition materials are used in the applications of ~~Mag~~ where the polarized signal is ~~perpendicular~~ passed through them, undergo a phase-shift (or) change in angle, in a particular direction, by rotating themselves

→ When a polarized wave comes perpendicular to ferrite materials, they absorb the transmitted wave, no signal is passed outside.

→ The commonly used ferrite composition materials are, ① Gyrator,
② Isolator and
③ Circulator

2

① Gyrator:-

→ It is a 2-port device, ferrite rotates 90°.

→ If input is passed through port-1, the output at port-2 has a phase shift of 180°.

→If input is from port-2, the output wa has 0°-phase shift, with respect to input wa

②Isolator:

→Isolator is a 2-port device, which consists of resistive card to absorb. the polarized wa

→when input given at port-1 & port-2 outp has 0°-phase-shift with respect to input wav

→If input is port-2, then no signal is obtained at port-1, due to resistive absorpti

→Here, ferrite material rotates 45°.

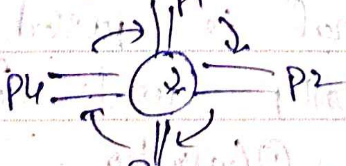
③Circulator:

→It is a 4-port device.

→Here, each port is connected to the next adjacent port only, i.e., n^{th} port coupled to $(n+1)^{th}$ port in clockwise direction.

→When input given at port-1, output is at port-2; similarly port-2 is input; port-3 will be output port.

→Input at port3, output is at port-4, if the input is at port-4, output is a port-1



5.b. Given, $a = 8cm$ & $b = 4cm.$, $\lambda_0 = 10cm.$

For a wave to propagate through waveguide cutoff ~~frequency~~ wavelength > free space wavelength.

i.e., $\lambda_c > \lambda_0$

2

⇒ TE_{10} mode, $\lambda_c = \dfrac{2ab}{\sqrt{n^2a^2+m^2b^2}}$

TE_{10}, m=1, n=0 ⇒ $\lambda_c = \frac{2\cdot8\cdot4}{\sqrt{0+1.4^2}} = 16$ cm

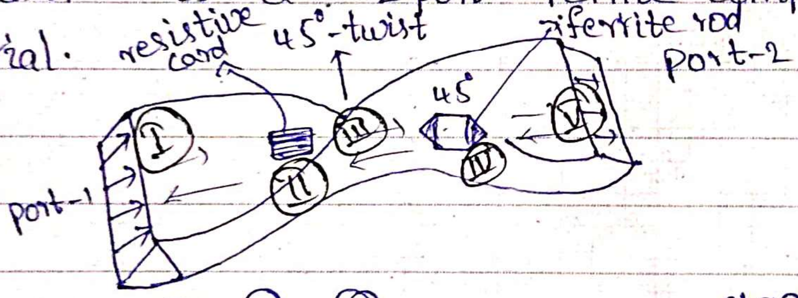
TE_{11}, m=1, n=1 ⇒ $\lambda_c = \frac{2\cdot8\cdot4}{\sqrt{1.8^2+1.4^2}} = 7.155$ cm

TE_{21} ⇒ m=2, n=1 ⇒ $\lambda_c = \frac{2\cdot8\cdot4}{\sqrt{1.8^2+2^2 4^2}} = 5.656$ cm

On observing cutoff wavelengths of TE_{10}, TE_{11}, TE_{21} modes, it is clear that only, λ_c=16cm is propagates through given waveguide, (TE_{10}).
∵ λ_0=10 cm, λ_c=16cm ⇒ $\lambda_c > \lambda_0$ ⇒ Propagates TE_{10}

5.a. **Isolator:-**

→Isolator is a 2-port ferrite composition material.



Ⓘ, Ⓘⅰ, (III), (IV), (V), are various stages, where the wave has to be passed.

→When input is given at port-1, it undergoes 45° phase shift at twist & then rotates in anti-clockwise direction. 2

→On reaching ferrite rod, it undergoes 45° phase shift in clockwise direction & hence the output collected at port-2.

→The output at port-2 is having 0°-phase shift with respect to input wave.

→If the same wave is given as input at port-2, it goes through ferrite rod & undergoes a phase shift of 45° in clock-wise

Unit-I

Guided Waves

Date : 17/1/23

Microwaves :

* Microwaves are electromagnetic waves, which consist of electric and Magnetic field components and wave length will be in the order of few micrometers.
* Microwaves are high frequency signals in the range of 1GHz to 300GHz and wavelength [$\lambda = 0.1m$ to 1mm].

Advantages of Microwaves :

The Basic Advantages of Microwaves are

1. larger Bandwidth : Microsignals have large Bandwidth so that more information can be transmitted compare to lower frequencies.

2. High Directive Properties : At microwave Frequencies It is easy to design Antennas with less complexity.

ex: Horn Antenna

$$D = \frac{140\lambda}{B} \quad B = \text{Beamwidth}$$

where $\lambda = \frac{c}{f}$ $\quad f\uparrow \ \lambda\downarrow \ D\downarrow$

Dimensions are less so we can easily design horn Antenna.

3. less 'Fading' Effect : There are some variations in the Transmission medium known as Fading effects which will be less at Microwave Frequencies making microwave communications more realiable.

4. less power requirements :

The Power requirements of Tx and Rx Antennas are very less at microwave frequencies.

5. Transparency of the wave :

Microwave signals creates a transparent window in

The Ionosphere layer which will be useful to study the radiation comming from the sun and stars.

Applications of Microwaves:

The Major application of Microwaves are

* They are used in Food Processing Technology like microwave ovens at f = 2.5GHz.

* They are extensively used in Telecommunications for long distance Communications.

* They are used in the Space and Satellite Communication purpose.

* They are used in the Radars to detect unidentified aircrafts [devices].

* They are used in the Industrial and Commercial Applications.

ex: drying machines

* Biomedical Applications for the treatment of diseases like cancer..etc..

Guided Waves

The high Frequency waves can not Be transmitted using the Transmission lines because of the losses occuring in Transmission lines.

* Wave guide is a Alternative to the Transmission lines which is a hallow metalic tube of uniform crosssectional area.

* This waveguide is used to guide the EM waves by successive reflection along the inner walls of the waveguide.

* The most frequently used waveguides are.
  1. Rectangular waveguide
  2. Circular "
  3. elliptical waveguide

* Rectangular waveguides are most frequently used waveguides for microwave communications.

* In Circular waveguides the wave bends as it propagates along waveguide.

* elliptical waveguides are flexible waveguides used in the waveguide section which require moment and stretching of the waves.

Modes in Waveguide (Rectangular):

The different Modes in Rectangular waveguide are

1. TE (Transverse electric wave)
2. TM (Transverse Magnetic wave)
3. TEM (Transverse electromagnetic wave)

1. TE (transverse electric wave):

In this mode only the electric field is Transverse (or) $\perp^{er}$ to the direction of the propagation of the wave

*If 'z' is the direction of propagation of the wave Then Electric Field component will not be present in z direction i.e $\boxed{E_z = 0 \ , H_z \neq 0}$

2. TM (Transverse Magnetic wave):

In this Mode only the Magnetic will be Transverse (or) ⊥er to the direction of propagation of the wave.

*If z is the direction of propagation of the wave. Then Magnetic Field component will not be present in z direction. i.e

$$\boxed{H_z = 0 \ , \ E_z \neq 0}$$

3. TEM (Transverse Electromagnetic wave):

In this Mode Both electric and Magnetic Field components are purely Transverse (or) ⊥er to the direction of propagation of the wave.

*If z is the direction of propagation of the wave Then Magnetic and electric Field components are will not be present in z direction i.e

$$\boxed{H_z = 0 \quad E_z = 0}$$

Note:

So, TEM wave is not possible to propagate in a Rectangular wave guide.

Wave Eqns of Rectangular Waveguide

Let us consider a AC Electric Field which given by the eqn $E = E_0 e^{j\omega t} \longrightarrow ①$

where E = Electric Field

E_0 = Maximum Amplitude of the Signal.

Let us Differentiat eqn① w.r.t time on Both Sides

$$\frac{dE}{dt} = E_0 \frac{d}{dt} e^{j\omega t} \longrightarrow ②$$

$$\frac{dE}{dt} = E_0 e^{j\omega t}(j\omega)$$

The above eqn can be given as

$$\boxed{\frac{dE}{dt} = E \cdot j\omega} \rightarrow ③$$

lly consider the magnetic field component

$$\boxed{\frac{dH}{dt} = H \cdot j\omega} \rightarrow ④$$

Let us consider the Maxwell's eqn

$$\nabla \times H = J + \frac{\partial D}{\partial t} \longrightarrow ⑤$$

$J = \sigma E$

σ = conductivity

D = electric flux density = ϵE

Let us consider $\sigma = 0$ then $J = 0$

from eqn ⑤

$$\nabla \times H = 0 + \frac{\partial}{\partial t}\epsilon E$$

$$\nabla \times H = \epsilon \frac{\partial E}{\partial t}$$

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

$$\boxed{\nabla \times H = \epsilon E j\omega} \longrightarrow ⑥$$

consider another Maxwell's eqn

$$\nabla \times E = -\frac{\partial B}{\partial t} \longrightarrow ⑦$$

B = Magnetic flux density = μH

μ = permeability

$$\nabla \times E = -\mu \frac{\partial H}{\partial t} \longrightarrow ⑧$$

$$\boxed{\nabla \times E = -\mu H \cdot j\omega} \longrightarrow ⑨$$

* apply ∇ operator on eqn ⑨

$$\nabla \times \nabla \times E = -\mu j\omega(\nabla \times H)$$

$$= -\mu j\omega(\epsilon E j\omega)$$

$$= -\mu\omega^2 \epsilon E j^2$$

$$\nabla \times \nabla \times E = \nabla \cdot \nabla E - \nabla^2 E$$

$$\nabla \cdot (\nabla E) - \nabla^2 E = \mu \epsilon \omega^2 E \longrightarrow ⑩$$

Now consider third Maxwell's eqn

$$\nabla\cdot D = \rho \longrightarrow ⑪$$

For medium $\rho = 0$

$$\nabla\cdot D = 0$$

$$\nabla\cdot \epsilon E = 0$$

$$\boxed{\nabla\cdot E = 0} \text{ and } \epsilon \neq 0$$

from Eqn ⑩

$$\nabla\cdot(0) - \nabla^2 E = \mu\epsilon E\omega^2$$

$$-\nabla^2 E = \mu\epsilon\omega^2 E$$

$$\boxed{\begin{array}{l} \nabla^2 E = -\mu\epsilon\omega^2 E \\ \nabla^2 H = -\mu\epsilon\omega^2 H \end{array}} \Rightarrow \text{wave eqn's}$$

lly

The Eqn For Guided waves

The wave eqn For TE wave in Rectangular waveguide is given By

condition For TE wave : $E_z = 0$ and $H_z \neq 0$

$$\boxed{\nabla^2 H_z = -\mu\epsilon\omega^2 H_z}$$

The wave eqn For TM wave in Rectangular waveguide is given by

Condition For TM wave : $H_z = 0$ $E_z \neq 0$

$$\boxed{\nabla^2 E_z = -\mu\epsilon\omega^2 E_z}$$

Propagation of EM Waves in Rectangular waveguide

consider a rectangular waveguide whose broader and narrow dimensions are 'a' and 'b' and z is the direction of propagation of wave inside the wave guide.

consider the wave eqn which is given as

$$\nabla^2 E_z = -\omega^2\mu\epsilon E_z \longrightarrow ①$$

$$\frac{\partial^2}{\partial x^2}E_z + \frac{\partial^2}{\partial y^2}E_z + \frac{\partial^2}{\partial z^2}E_z = -\omega^2\epsilon\mu E_z \longrightarrow ②$$

Let $\frac{\partial}{\partial z} = -\gamma$ (propagation const = γ)

from eqn ②

$$\frac{\partial^2}{\partial x^2}E_z + \frac{\partial^2}{\partial y^2}E_z + \gamma^2 E_z = -\omega^2\mu\epsilon E_z \longrightarrow ③$$

$$\frac{\partial^2}{\partial x^2}E_z + \frac{\partial^2}{\partial y^2}E_z + \gamma^2 E_z + \omega^2\mu\epsilon E_z = 0$$

$$\frac{\partial^2}{\partial x^2}E_z + \frac{\partial^2}{\partial y^2}E_z + E_z(\gamma^2 + \omega^2\mu\epsilon) = 0$$

Let asume a constant $h^2 = \gamma^2 + \omega^2\mu\epsilon$

$$\boxed{\frac{\partial^2}{\partial x^2}E_z + \frac{\partial^2}{\partial y^2}E_z + h^2 E_z = 0} \longrightarrow \text{wave eqn For TM wave}$$

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$$\boxed{\frac{\partial^2}{\partial x^2}H_z + \frac{\partial^2}{\partial y^2}H_z + h^2 H_z = 0} \longrightarrow \text{wave eqn For TE wave}$$

Now Consider The Maxwell's eqn

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

$$\begin{vmatrix} i & j & K \\ \partial/\partial x & \partial/\partial y & \partial/\partial z \\ H_x & H_y & H_z \end{vmatrix} = j\omega\epsilon(iE_x + jE_y + KE_z)$$

Substitute $\partial/\partial z = -\gamma$

$$\begin{vmatrix} i & j & K \\ \partial/\partial x & \partial/\partial y & -\gamma \\ H_x & H_y & H_z \end{vmatrix} = j\omega\epsilon(iE_x + jE_y + KE_z)$$

$$i\left(\frac{\partial}{\partial y}H_z + \gamma H_y\right) - j\left(\frac{\partial}{\partial x}H_z + \gamma H_x\right) + K\left(\frac{\partial}{\partial x}H_y - \frac{\partial}{\partial y}H_x\right) = j\omega\epsilon(iE_x + jE_y + KE_z$$

compr co.efficients

$$\frac{\partial}{\partial y}H_x + \gamma H_y = E_x(j\omega\epsilon) \longrightarrow ④$$

$$\frac{\partial}{\partial x}H_z + \gamma H_x = -(j\omega\epsilon)E_y \longrightarrow ⑤$$

$$\frac{\partial}{\partial x}H_y - \frac{\partial}{\partial y}H_x = (j\omega\epsilon)E_z \longrightarrow ⑥$$

Consider the Maxwell eqn

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

$$\nabla \times E_z = -\mu j\omega H_z$$

$$\begin{vmatrix} i & j & k \\ \partial/\partial x & \frac{\partial}{\partial y} & \partial/\partial z \\ E_x & E_y & E_z \end{vmatrix} = -j\omega\mu(iH_x + jH_y + kH_z)$$

$$\partial/\partial z = -\gamma$$

$$\begin{vmatrix} i & j & k \\ \partial/\partial x & \partial/\partial y & -\gamma \\ E_x & E_y & E_z \end{vmatrix} = -j\omega\mu(iH_x + jH_y + kH_z)$$

$$i\left(\frac{\partial}{\partial y}E_z + \gamma E_y\right) - j\left(\frac{\partial}{\partial x}E_z + \gamma E_x\right) + k\left(\frac{\partial}{\partial x}E_y - \frac{\partial}{\partial y}E_x\right) = -j\omega\mu(iH_x + jH_y + kH_z)$$

comp^{g} co-efficients

$$\frac{\partial}{\partial y}E_z + \gamma E_y = -j\omega\mu H_x \longrightarrow ⑦$$

$$\frac{\partial}{\partial x}E_z + \gamma E_x = +j\omega\mu H_y \longrightarrow ⑧$$

$$\frac{\partial}{\partial x}E_y - \frac{\partial}{\partial y}E_x = -j\omega\mu H_z \longrightarrow ⑨$$

From eqn ⑧

$$H_y = \frac{1}{j\omega\mu}\left(\frac{\partial}{\partial x}E_z + \gamma E_x\right)$$

$$\boxed{H_y = \frac{1}{j\omega\mu}\frac{\partial E_z}{\partial x} + \frac{\gamma}{j\omega\mu}E_x} \longrightarrow ⑩$$

substitute eqn ⑩ in eqn ④

$$\Rightarrow \frac{\partial H_z}{\partial y} + \gamma\left(\frac{1}{j\omega\mu}\frac{\partial E_z}{\partial x}\right) + \frac{\gamma^2}{j\omega\mu}E_x = j\omega\epsilon E_x$$

$$\frac{\partial H_z}{\partial y} + \gamma\left(\frac{1}{j\omega\mu}\frac{\partial E_z}{\partial x}\right) = j\omega\epsilon E_x - \frac{\gamma^2}{j\omega\mu}E_x$$

$$= E_x\left(j\omega\epsilon - \frac{\gamma^2}{j\omega\mu}\right)$$

* Multiply $j\omega\mu$ on Both sides of above eqn

$$j\omega\mu\frac{\partial H_z}{\partial y} + \gamma\cdot\frac{\partial E_z}{\partial x} = E_x(j^2\omega^2\mu\epsilon - \gamma^2)$$

$$= E_x(-\omega^2\mu\epsilon - \gamma^2)$$

$$j\omega\mu\frac{\partial H_z}{\partial y} + \gamma\frac{\partial E_z}{\partial x} \quad E_x(\gamma^2 + \omega^2\mu\epsilon)$$

$$\because \gamma^2+\omega^2\mu\epsilon = h^2$$

$$j\omega\mu \frac{\partial}{\partial y}H_z + \gamma\frac{\partial}{\partial x}E_z = -E_x h^2$$

$$\boxed{E_x = \frac{-j\omega\mu}{h^2}\frac{\partial H_z}{\partial y} - \frac{\gamma}{h^2}\frac{\partial}{\partial x}E_z} \longrightarrow ⑪$$

from eqn ⑦

$$\boxed{H_x = \frac{-1}{j\omega\mu}\frac{\partial E_z}{\partial y} + \frac{-\gamma}{j\omega\mu}E_y} \longrightarrow ⑫$$

substitute eqn ⑫ in eqn ⑤

$$\frac{\partial H_z}{\partial x} + \gamma\left(\frac{-1}{j\omega\mu}\frac{\partial E_z}{\partial y} + \frac{-\gamma}{j\omega\mu}E_y\right) = -j\omega\epsilon E_y$$

$$\frac{\partial H_z}{\partial x} - \frac{\gamma}{j\omega\mu}\frac{\partial E_z}{\partial y} = -j\omega\epsilon E_y + \frac{\gamma^2}{j\omega\mu}E_y$$

$$= E_y\left(\frac{\gamma^2}{j\omega\mu} - j\omega\epsilon\right)$$

Multiply $j\omega\mu$ on both sides

$$j\omega\mu\frac{\partial H_z}{\partial x} - \gamma\frac{\partial E_z}{\partial y} = E_y(\gamma^2 - j^2\omega^2\mu\epsilon)$$

$$= E_y(\gamma^2+\omega^2\mu\epsilon)$$

$$= E_y h^2$$

$$\boxed{E_y = \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial x} - \frac{\gamma}{h^2}\frac{\partial E_z}{\partial y}} \longrightarrow ⑬$$

from ⑨

$$\boxed{H_z = \frac{-1}{j\omega\mu}\left(\frac{\partial}{\partial x}E_y - \frac{\partial E_x}{\partial y}\right)} \longrightarrow ⑭$$

from ⑥

$$E_z = \frac{+1}{j\omega\epsilon}\left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y}\right)$$

lly

$$E_y = -\frac{\gamma}{h^2}\frac{\partial E_z}{\partial y} + \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial x} \longrightarrow ⑫$$

$$H_x = -\frac{\gamma}{h^2}\frac{\partial H_z}{\partial x} + \boxed{\frac{j\omega\epsilon}{h^2}\frac{\partial E_z}{\partial y}} \longrightarrow ⑬$$

Imp $E_x = \frac{-j\omega\mu}{h^2}\frac{\partial H_z}{\partial y} + \frac{\gamma}{h^2}\frac{\partial E_z}{\partial x}$

$$H_y = -\frac{\gamma}{h^2}\frac{\partial H_z}{\partial y} - \frac{j\omega\epsilon}{h^2}\frac{\partial E_z}{\partial x} \longrightarrow ⑭$$

For TEM both electric and Magnetic field components are $\perp^{er}$ to direction of propagation of wave.

$E_z = H_z = 0$.

In rectangular wave guide z is direction propagation of wave Then $E_z = H_z = 0$

* If we substitute these conditions in above eqns field components i.e E_x, E_y, H_x, H_y Then all the Field components will vanish So, TEM is not Possible in The Rectangular wave guide.

** Propagation of TM wave in Rectangular waveguide

Consider a rectangular waveguide whose broad and narrow dimensions are 'a' and 'b'. and z is direction of Propagation of The wave.

For TM wave :

$E_z \neq 0 \; ; \; H_z = 0$

The wave eqn for TM wave is given as:

$$\nabla^2 E_z = -\mu\epsilon\omega^2 E_z = -\mu\epsilon\omega^2 E_z \longrightarrow ①$$

$$\frac{\partial^2 E_z}{\partial x^2} + \frac{\partial^2 E_z}{\partial y^2} + \frac{\partial^2 E_z}{\partial z^2} = -\mu\epsilon\omega^2 E_z$$

$$\frac{\partial}{\partial z} = -\gamma$$

$$\frac{\partial^2 E_z}{\partial x^2} + \frac{\partial^2 E_z}{\partial y^2} + \frac{\partial^2 E_z}{\partial z^2} = -\mu\epsilon\omega^2 E_z$$

$$\frac{\partial^2 E_z}{\partial x^2} + \frac{\partial^2 E_z}{\partial y^2} + \gamma^2 E_z = -\mu\epsilon\omega^2 E_z$$

$$\frac{\partial^2 E_z}{\partial x^2}+\frac{\partial^2 E_z}{\partial y^2} = -(\gamma^2+\omega^2\mu\epsilon)E_z$$

Let $h^2 = \gamma^2+\omega^2\mu\epsilon$

$$\frac{\partial^2 E_z}{\partial x^2}+\frac{\partial^2 E_z}{\partial y^2} = -h^2 E_z$$

$$\frac{\partial^2 E_z}{\partial x^2}+\frac{\partial^2 E_z}{\partial y^2} + h^2 E_z = 0 \longrightarrow ②$$

Let $\boxed{E_z = X \cdot Y} \longrightarrow ③$

where X = Pure function of 'x'

Y = Pure function of 'y'

Differentiate eqn③ w.r.t x

$$\frac{\partial E_z}{\partial x} = Y\frac{\partial X}{\partial x}$$

$$\frac{\partial^2 E_z}{\partial x^2} = Y\frac{\partial^2 X}{\partial x^2} \longrightarrow ④$$

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$$\frac{\partial^2 E_z}{\partial y^2} = X\frac{\partial^2 Y}{\partial y^2} \longrightarrow ⑤$$

Sub eqn④ and eqn⑤ in eqn②

$$Y\frac{\partial^2 X}{\partial x^2} + X\frac{\partial^2 Y}{\partial y^2} + h^2(X\cdot Y) = 0 \longrightarrow ⑥$$

divide eqn⑥ with XY

$$\frac{1}{X}\frac{\partial^2 X}{\partial x^2} + \frac{1}{Y}\frac{\partial^2 Y}{\partial y^2} + h^2 = 0 \longrightarrow ⑦$$

from eqn⑦ Let us consider

$$\frac{1}{X}\frac{\partial^2 X}{\partial x^2} = -B^2 \qquad \frac{1}{Y}\frac{\partial^2 Y}{\partial y^2} = -A^2$$

from ⑦

$$-B^2 - A^2 + h^2 = 0$$

$$h^2 = A^2 + B^2 \longrightarrow ⑧$$

The eqn⑧ is a second order differential eqn whose solutions are given as

$$X = C_1\cos Bx + C_2\sin Bx \longrightarrow ⑨$$

$$Y = C_3\cos Ay + C_4\sin Ay \longrightarrow ⑩$$

$C_1 C_2 C_3 C_4$ are constants.

$$E_z = XY$$

$E_z = (C_1\cos Bx + C_2\sin Bx)(C_3\cos Ay + C_4\sin Ay) \longrightarrow ⑪$

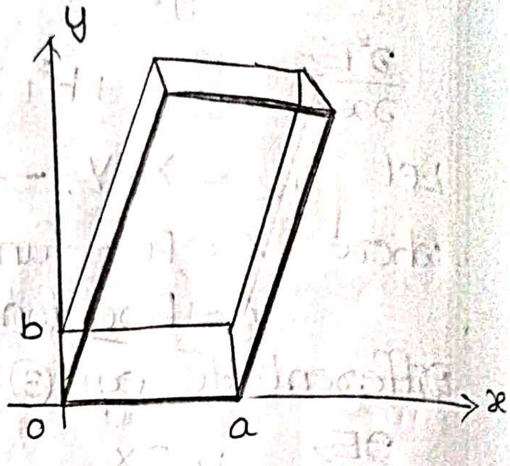
$= C_1C_3\cos$

Boundary conditions:

i) Bottom wall:

$E_z = 0 \Rightarrow x = 0$ to a

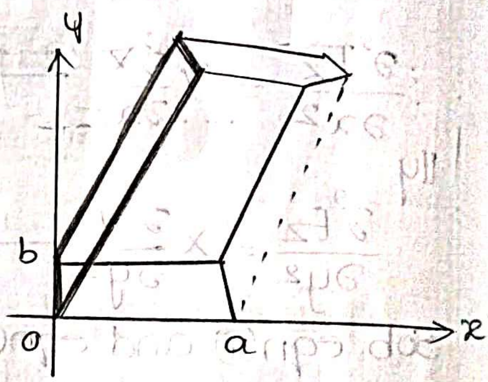
$y = 0$



ii) Leftside wall:

$E_z = 0 \; ; \; x = 0$

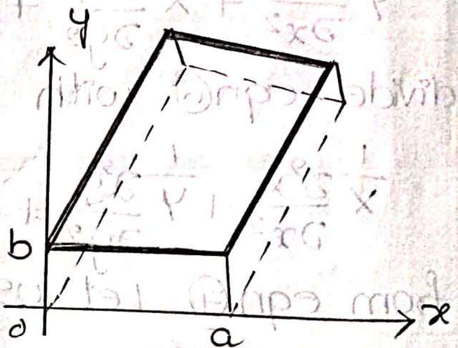
$y = 0$ to b



iii) Top wall:

$E_z = 0 \; ; \; x = 0$ to a

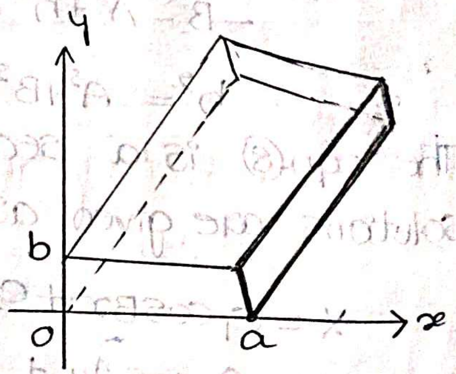
$y = b$



iv) Right side wall:

$E_z = 0 \; ; \; x = a$

$y = 0$ to b



From above eqns ⑪ i) Bottomwall:

$$E_z = (C_1 \cos Bx + C_2 \sin Bx)(C_3 \cos Ay + C_4 \sin Ay)$$

$$0 = (C_1 \cos Bx + C_2 \sin Bx)(C_3 + 0)$$

$$0 = (C_1 \cos Bx + C_2 \sin Bx)(C_3)$$

$\boxed{C_3 = 0}$ $\quad C_1 \cos Bx + C_2 \sin Bx \neq 0$

$$\boxed{E_z = (C_1 \cos Bx + C_2 \sin Bx)(C_4 \sin Ay)} \longrightarrow ⑫$$

ii) Left side wall:

$E_z = 0 \quad x = 0 \; ; \; y = 0$ to b

$$E_z = (C_1)(C_4 \sin Ay)$$

$\boxed{C_1 = 0}$ $\quad C_4 \sin Ay \neq 0$

$$\boxed{E_z = (C_2 \sin Bx)(C_4 \sin Ay)} \longrightarrow ⑬$$

iii) Top wall: $E_z = 0 \; ; \; x = 0$ to a
$y = b$

$$E_z = (C_2 \sin Bx)(C_4 \sin Ab)$$

$\boxed{C_4 \sin Ab = 0}$ $\quad C_2 \sin Bx \neq 0$

$$\sin Ab = 0$$

$$Ab = \sin^{-1}(0)$$

$$Ab = n\pi$$

$$\boxed{A = \frac{n\pi}{b}}$$

$$E_z = (C_2 \sin Bx)(C_4 \sin Ay)$$

iv) Right side wall: $E_z = 0 \; ; \; x = a \; ; \; y = 0$ to b

$$E_z = (C_2 \sin Ba)(C_4 \sin Ay)$$

$C_4 \sin Ay \neq 0 \qquad C_2 \sin Ba = 0$

$$\sin Ba = 0$$

$$\boxed{B = \frac{m\pi}{a}}$$

$$E_z = C_2 \sin \frac{m\pi}{a} x * C_4 \sin \frac{n\pi}{b} y$$

$$E_z = C_2 C_4 \sin \frac{m\pi}{a} x \cdot \sin \frac{n\pi}{b} y$$

Let $C_2 \cdot C_4 = C$

$$\boxed{E_z = C \cdot \sin\left(\frac{m\pi}{a}\right)x \cdot \sin\left(\frac{n\pi}{b}\right)y \cdot e^{j\omega t - \gamma z} \cdot}$$

For TM wave : $H_z = 0$ and $E_z \neq 0$

$$E_x = \frac{-j\omega\mu}{h^2}\frac{\partial H_z}{\partial y} + \frac{\gamma}{h^2}\frac{\partial E_z}{\partial x}$$

$$E_x = -\frac{\gamma}{h^2}\frac{\partial E_z}{\partial x}$$

$$E_x = \frac{-\gamma}{h^2}\frac{\partial}{\partial x}\left(C\sin\left(\frac{m\pi}{a}\right)x \sin\left(\frac{n\pi}{b}\right)y\, e^{j\omega t} \cdot e^{-\gamma z}\right)$$

$$E_x = \frac{-\gamma}{h^2} C \sin\left(\frac{n\pi}{b}\right)y\, e^{j\omega t} \cdot e^{-\gamma z}\left[\frac{\cos\left(\frac{m\pi}{a}\right)x}{\cancel{\frac{m\pi}{a}}}\right] \cdot \frac{m\pi}{a}$$

* $$\boxed{E_x = \frac{-\gamma}{h^2}\left[C \cdot \cos\left(\frac{m\pi}{a}\right)x \cdot \frac{m\pi}{a} \cdot \sin\left(\frac{n\pi}{b}\right)y \cdot e^{j\omega t - \gamma z}\right]}$$

$$E_y = \frac{-\gamma}{h^2}\frac{\partial}{\partial y}E_z + \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial x}$$

* $$\boxed{E_y = \frac{-\gamma}{h^2}\left[C \cdot \sin\left(\frac{m\pi}{a}\right)x \cos\left(\frac{n\pi}{b}\right)y \cdot \frac{n\pi}{b} \cdot e^{j\omega t - \gamma z}\right]}$$

$$H_x = \frac{-\gamma}{h^2}\frac{\partial H_z}{\partial x} + \frac{j\omega\epsilon}{h^2}\frac{\partial E_z}{\partial y}$$

* $$\boxed{H_x = \frac{j\omega\epsilon}{h^2}\left[C \cdot \sin\left(\frac{m\pi}{a}\right)x \cos\left(\frac{n\pi}{b}\right)y \cdot \frac{n\pi}{b}\, e^{j\omega t - \gamma z}\right]}$$

$$H_y = \frac{-\gamma}{h^2}\frac{\partial H_z}{\partial y} - \frac{j\omega\epsilon}{h^2}\frac{\partial E_z}{\partial x}$$

* $$\boxed{H_y = \frac{-j\omega\epsilon}{h^2}\left[C \cdot \cos\left(\frac{m\pi}{a}\right)x \cdot \frac{m\pi}{a} \sin\left(\frac{n\pi}{b}\right)y\, e^{j\omega t - \gamma z}\right]}$$

E_x, E_y, H_x, H_y are the Field components for TM wave.

Propagation of TE wave in Rectangular waveguide:

For TE wave : $E_z = 0$ and $H_z \neq 0$

The wave eqn For TE is given as

$$\nabla^2 H_z = -\omega^2 \mu \epsilon H_z \longrightarrow ①$$

$$\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + \frac{\partial^2 H_z}{\partial z^2} = -\omega^2 \mu \epsilon H_z$$

$$\frac{\partial^2}{\partial z^2} = \gamma^2$$

$$\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + \gamma^2 H_z = -\omega^2 \mu \epsilon H_z$$

$$\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + H_z(\gamma^2 + \omega^2 \mu \epsilon) = 0$$

Let $h^2 = \omega^2 \mu \epsilon + \gamma^2$

$$\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + H_z h^2 = 0 \longrightarrow ②$$

Let $H_z = X \cdot Y \longrightarrow ③$

Differentiate eqn③ w.r.t x ; Differentiate eqn③ w.r.t y

$$\frac{\partial H_z}{\partial x} = Y \frac{\partial X}{\partial x} \qquad \frac{\partial H_z}{\partial y} = X \frac{\partial Y}{\partial y}$$

$$\frac{\partial^2 H_z}{\partial x^2} = Y \frac{\partial^2 X}{\partial x^2} \longrightarrow ④ \qquad \frac{\partial^2 H_z}{\partial y^2} = X \frac{\partial^2 Y}{\partial y^2} \longrightarrow ⑤$$

Sub eqn④ and ⑤ in eqn②

$$Y \frac{\partial^2 X}{\partial x^2} + X \frac{\partial^2 Y}{\partial y^2} + H_z h^2 = 0$$

$$Y \frac{\partial^2 X}{\partial x^2} + X \frac{\partial^2 Y}{\partial y^2} + (X \cdot Y) h^2 = 0 \longrightarrow ⑥$$

divide with XY on both sides

$$\frac{1}{X} \frac{\partial^2 X}{\partial x^2} + \frac{1}{Y} \frac{\partial^2 Y}{\partial y^2} + h^2 = 0 \longrightarrow ⑦$$

Let $\frac{1}{X} \frac{\partial^2 X}{\partial x^2} = -B^2$

Let $\frac{1}{Y} \frac{\partial^2 Y}{\partial y^2} = -A^2$

$$A^2 + B^2 = h^2 \longrightarrow ⑧$$

eqn⑧ is a differential of order 2 so Solutions are

$$X = C_1 \cos Bx + C_2 \sin Bx \longrightarrow ⑨$$

$$Y = C_3 \cos Ay + C_4 \sin Ay \longrightarrow ⑩$$

$$H_z = XY$$

$$H_z = (C_1 \cos Bx + C_2 \sin Bx) * (C_3 \cos Ay + C_4 \sin Ay) \longrightarrow ⑪$$

Boundary conditions :

i) **Bottom wall:**

$H_z = 0$ $x = 0$ to a

$y = 0$

ii) **Leftside wall**

$H_z = 0$ $x = 0$

$y = 0$ to a

iii) **Topwall**

$H_z = 0$ $x = 0$ to a

$y = b$

iv) **Rightsidewall:**

$H_z = 0$ $x = a$

$y = 0$ to b

{fig. same as TM}

$$E_z = C \cdot \sin\left(\frac{m\pi}{a}\right)x \, \sin\left(\frac{n\pi}{b}\right)y \, e^{j\omega t - \gamma z}$$

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$$H_z = C \, \cos\left(\frac{m\pi}{a}\right)x \, \cos\left(\frac{n\pi}{b}\right)y \, e^{j\omega t - \gamma z}$$

$$\times E_x = \frac{-\gamma}{h^2}\left[C \cdot \cos\left(\frac{m\pi}{a}\right)x \left(\frac{m\pi}{a}\right) \cdot \sin\left(\frac{n\pi}{b}\right) e^{j\omega t - \gamma z}\right]$$

$$E_x = -\frac{\gamma}{h^2}\cancel{\frac{\partial E_z}{\partial x}}^{0} - \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial y}$$

For TE wave : $E_z \neq 0$ $H_z \neq 0$

$$E_x = \frac{-\gamma}{h^2}[0] - \frac{j\omega\mu}{h^2}\left[c \cos\left(\frac{m\pi}{a}\right)x \, -\sin\left(\frac{n\pi}{b}\right)y \, \frac{n\pi}{b} e^{j\omega t - \gamma z}\right]$$

$$\boxed{E_x = \frac{j\omega\mu}{h^2}\left[c \cos\left(\frac{m\pi}{a}\right)x \, \sin\left(\frac{n\pi}{b}\right)y \left(\frac{n\pi}{b}\right) e^{j\omega t - \gamma z}\right]}$$

$$E_y = \frac{-\gamma}{h^2}\cancel{\frac{\partial E_z}{\partial y}}^{0} + \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial x}$$

$$\boxed{E_y = \frac{-j\omega\mu}{h^2}\left[c \, \sin\left(\frac{m\pi}{a}\right)x \cdot \frac{m\pi}{a} \cos\left(\frac{n\pi}{b}\right)y \, e^{j\omega t - \gamma z}\right]}$$

$$H_x = \frac{-\gamma}{h^2}\frac{\partial H_z}{\partial x} + \frac{j\omega\mu}{h^2}\cancel{\frac{\partial E_z}{\partial y}}^{0}$$

$$\boxed{H_x = \frac{-\gamma}{h^2}\left[c \cdot \sin\left(\frac{m\pi}{a}\right)x \, \frac{m\pi}{a} \cos\left(\frac{n\pi}{b}\right)y e^{j\omega t - \gamma z}\right]}$$

$$H_y = \frac{-\gamma}{h^2}\frac{\partial H_z}{\partial y} - \frac{j\omega\mu}{h^2}\cancel{\frac{\partial E_z}{\partial x}}^{0}$$

$$\boxed{H_y = \frac{-\gamma}{h^2}\left[c \cdot \cos\left(\frac{m\pi}{a}\right)x \, \sin\left(\frac{n\pi}{b}\right)y \left(\frac{n\pi}{b}\right) e^{j\omega t - \gamma z}\right]}$$

TE_{mn} Modes :

In TE_{mn} Mode 'm' represents the no of variations of the wave along the broader dimension of the rectangular wave guide i.e 'a'. lly 'n' represents the no.of variations of the wave along the narrow dimension of the rectangular wave guide i.e 'b'.

1) TE_{00} Mode :

In this mode m=0 ; n=0 does not exist in rectangular wave guide since all field components becomes zero.

2) TE_{01} Mode :

m=0 ; n=1 It exist in rectangular wave guide since E_y and H_x are exist.

3) TE_{10} Mode :

m=1 ; n=0 This mode is exist in rectangular wave guide since E_x and H_y are exist.

4) TE_{11} Mode :

m=1 ; n=1 In this mode all field components are exist so, it is possible in rectangular waveguide.

Rectangular Wave guide as HPF (High Pass Filter) :

Consider a Rectangular wave guide whose characteristi wave eqn is given as

$$h^2 \Rightarrow ①$$

$$\gamma^2 + \omega^2 \mu \epsilon \Rightarrow ①$$

$$h^2 = A^2 + B^2 \longrightarrow ②$$

$$h^2 = \left(\frac{n\pi}{b}\right)^2 + \left(\frac{m\pi}{a}\right)^2 \longrightarrow ③$$

From the above we get

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

$$\gamma^2 = \left(\frac{n\pi}{b}\right)^2 + \left(\frac{m\pi}{a}\right)^2 - \omega^2 \mu \epsilon$$ from that

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

Where γ = propagation Constant

$$\gamma = \alpha + j\beta$$

α = attenuation constant

β = phase constant

$$\alpha + j\beta = \sqrt{\left(\frac{n\pi}{b}\right)^2 + \left(\frac{m\pi}{a}\right)^2 - \omega^2\mu\epsilon} \qquad \omega = 2\pi f$$

From The above eqn at low frequencies it's value becomes real and positive i.e nearly equal to α which means the wave is attenuated and low frequencies are not allowed.

At High Frequencies it's value becomes imaginary and nearly equal to β so it means The wave is propagating at high Frequencies

Hence Rectangular wave guide act as HPF.

Characteristics of Rectangular waveguide:

1) Cutoff Frequency of Rectangular waveguide: (Fc)

Cutoff Frequency is The Frequency at which $\gamma = 0$

i.e $\alpha + j\beta = 0$

consider the characteristic wave eqn of The rectangular wave guide

$$h^2 = \gamma^2 + \omega^2\mu\epsilon \;;\; h^2 = A^2 + B^2$$

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

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

At cutoff Frequency $\gamma = 0$; $\omega_c = 2\pi f_c$

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

$$F_c^2 = \frac{\left(\frac{n\pi}{b}\right)^2 + \left(\frac{m\pi}{a}\right)^2}{4\pi^2\mu\epsilon}$$

$$F_c = \sqrt{\left(\frac{n\pi}{b}\right)^2 + \left(\frac{n\pi}{a}\right)^2 / 4\pi^2\mu\epsilon}$$

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

$$\frac{1}{\sqrt{\mu\epsilon}} = c$$

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

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

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

f_c = cutoff Frequency c = velocity of wave (light)

m, n = mode

a, b = dimensions of rectangular waveguide

ii) Cutoff Wavelength (λ_c):

$$\lambda_c = \frac{c}{f_c}$$

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

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

$$\boxed{\lambda_c = \frac{2ab}{\sqrt{n^2a^2+m^2b^2}}}$$

Dominant and Degenerate Modes: in rectangular waveguide

Dominant Mode:

It is the Mode which is having the highest cutoff wave length (or) lowest cutoff frequency. (f_c)

* λ_c ↑ and f_c ↓

TE_{mn} modes

$m=0$; $n=0$: TE_{00} (×)

$m=0$; $n=1$; TE_{01} mode : $\lambda_c = \frac{2ab}{\sqrt{a^2}} = 2b$ b = narrow

TEmn Mode

m=1 ; n=0 : TE_{10} Mode : $\lambda_c = \frac{2ab}{\sqrt{b^2}} = 2a$ a = broader dimension

m=1 ; n=1 : TE_{11} Mode : $\lambda_c = \frac{2ab}{\sqrt{a^2+b^2}}$

From the above values TE_{10} Mode is having the highest cutoff wavelength so, TE_{10} Mode is the Dominant mode in Rectangular waveguide.

Degenerate Modes:

It is the Mode which is having equal cutoff wavelength (or) cutoff Frequencies.

eg: TE_{11} and TM_{11} are the Degenerate Modes in the rectangular wave guide

TE_{11} and TM_{11}

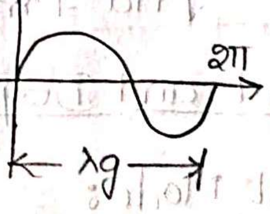
m=1 m=1

n=1 n=1

Wave characteristics

i) Guided Wavelength (λg):

It is denoted by λg and is defined as the Distance travelled by the wave to undergo a shift of 2π radians in the rectangular wave guide.



ii) Phase Velocity (V_p):

It is denoted by V_p and is defined as amount of phase change w.r.t the guided wavelength.

$$V_p = \frac{\lambda g}{t}$$

$$\boxed{V_p = \lambda g \cdot f}$$

$$\omega = 2\pi f \Rightarrow f = \frac{\omega}{2\pi}$$

$$V_p = \lambda_g \cdot \frac{\omega}{2\pi}$$

$$V_p = \frac{\omega}{\frac{2\pi}{\lambda_g}} \qquad \because \frac{2\pi}{\lambda_g} = \beta$$

$$\boxed{V_p = \frac{\omega}{\beta}}$$

consider the characteristic wave eqn of the rectangular waveguide. i.e

$$\gamma^2 + \omega^2\mu\epsilon = h^2 \longrightarrow ①$$

$$h^2 = A^2 + B^2 \longrightarrow ②$$

$$\gamma^2 + \omega^2\mu\epsilon = A^2 + B^2$$

$$\gamma^2 + \omega^2\mu\epsilon = \left(\frac{n\pi}{b}\right)^2 + \left(\frac{m\pi}{a}\right)^2 \longrightarrow ③'$$

$$\gamma = \alpha + j\beta$$

$$\alpha = 0 \; ; \; \gamma = j\beta \checkmark$$

$$-\beta^2 + \omega^2\mu\epsilon = \left(\frac{n\pi}{b}\right)^2 + \left(\frac{m\pi}{a}\right)^2$$

$$\boxed{-\beta^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - \omega^2\mu\epsilon} \longrightarrow ③$$

✓ At cutoff frequency $\gamma = 0$ $\omega = \omega_c$

$$\omega_c^2\mu\epsilon = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 \longrightarrow ④$$

from eqn's ③ and ④

$$-\beta^2 = \omega_c^2\mu\epsilon - \omega^2\mu\epsilon$$

$$-\beta^2 = \mu\epsilon(\omega_c^2 - \omega^2)$$

$$\beta^2 = \mu\epsilon(\omega^2 - \omega_c^2)$$

$$\beta = \sqrt{\omega^2\mu\epsilon - \omega_c^2\mu\epsilon}$$

$$V_\beta = \frac{\omega}{\beta} = \frac{\omega}{\sqrt{\omega^2\mu\epsilon - \omega_c^2\mu\epsilon}} \qquad c = \frac{1}{\sqrt{\mu\epsilon}}$$

$$V_p = \frac{\omega}{\sqrt{\mu\epsilon}\sqrt{\omega^2 - \omega_c^2}}$$

$$V_p = \frac{\omega c}{\sqrt{\omega^2 - \omega_c^2}}$$

$$V_p = \frac{\omega c}{\sqrt{\omega^2\left(1 - \left(\frac{\omega_c}{\omega}\right)^2\right)}} = \frac{c}{\sqrt{1 - \left(\frac{\omega_c}{\omega}\right)^2}}$$

$\omega_c = 2\pi f_c \quad ; \quad \omega = 2\pi f$

$$v_p = \frac{c}{\sqrt{1-\left(\frac{\omega_c}{\omega}\right)^2}}$$

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

$f_c = \frac{c}{\lambda_c}$ and $f = \frac{c}{\lambda_0}$

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

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

$\lambda_0 =$ freespace wavelength

$\lambda_c =$ cutoff wavelength

iii) Group Velocity (v_g):

It is denoted by v_g and it is defined as rate of change of the wave within the rectangular waveguide. It is given as.

$$v_g = \frac{d\omega}{d\beta} \longrightarrow ①$$

w.k.T

$$\beta = \sqrt{\omega^2\mu\epsilon - \omega_c^2\mu\epsilon}$$

$$\beta = \sqrt{\mu\epsilon}\sqrt{\omega^2-\omega_c^2}$$

$$\frac{d\beta}{d\omega} = \sqrt{\mu\epsilon}\,\frac{d}{d\omega}\sqrt{\omega^2-\omega_c^2}$$

$$= \sqrt{\mu\epsilon}\,\frac{1}{2\sqrt{\omega^2-\omega_c^2}}\,\frac{d}{d\omega}(\omega^2-\omega_c^2)$$

$$= \frac{\sqrt{\mu\epsilon}}{\cancel{2}\sqrt{\omega^2-\omega_c^2}}\,\cancel{2}(\omega)$$

$$\frac{d\beta}{d\omega} = \sqrt{\mu\epsilon}\,\frac{\omega}{\sqrt{\omega^2-\omega_c^2}}$$

$$v_g = \frac{d\omega}{d\beta} = \frac{1}{\sqrt{\mu\epsilon}\cdot\frac{\omega}{\sqrt{\omega^2-\omega_c^2}}}$$

$$v_g = \frac{c\cdot\sqrt{\omega^2-\omega_c^2}}{\omega}$$

$$v_g = c\,\frac{\cancel{\omega}\sqrt{1-(\omega_c/\omega)^2}}{\cancel{\omega}}$$

$$v_g = c.\sqrt{1-\left(\frac{\omega_c}{\omega}\right)^2}$$

$$v_g = c.\sqrt{1-\left(\frac{f_c}{f_0}\right)^2}$$

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

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

Relation between Phasevelocity and groupvelocity :

The product of phase velocity and groupvelocity is given by

$$V_p \cdot V_g = c.\cancel{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}} \cdot \frac{c}{\cancel{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}}$$

$$\boxed{V_p \cdot V_g = c^2}$$

Wave Impedance Relations:

The wave impedence is defined as ratio of electric field component in one direction to the magnetic Field component in another direction.

It is given as $Z = \frac{E_x}{H_y} \longrightarrow ①$

wave Impedance for TM wave;

z is the direction of the propagation of the wave then only the Magnetic Field will be $\perp^{er}$ to z-direction.

i.e $H_z = 0$ and $E_z \neq 0$

Now the wave impedence for TM wave is given as

$$Z_{TM} = \frac{E_x}{H_y}$$

$$Z_{TM} = \frac{\frac{-j\omega\mu}{h^2}\frac{\partial H_z}{\partial y} - \frac{\gamma}{h^2}\frac{\partial E_z}{\partial x}}{-\frac{\gamma}{h^2}\frac{\partial H_z}{\partial y} \mp \frac{j\omega\mu}{h^2}\frac{\partial E_z}{\partial x}} \longrightarrow ②$$

In eqn② sub $H_z = 0$

$$Z_{TM} = \frac{-\frac{\gamma}{\cancel{h^2}}\frac{\partial E_z}{\partial x}}{-\frac{j\omega\epsilon}{h^2}\cancel{\frac{\partial E_z}{\partial x}}} = \frac{\gamma}{j\omega\epsilon}$$

$\gamma = \alpha + j\beta$

$\alpha = 0 \quad \gamma = j\beta$

↳ b/c wave is propagating

$$Z_{TM} = \frac{j\beta}{j\omega\epsilon} = \frac{\beta}{\omega\epsilon}$$

$$\boxed{Z_{TM} = \frac{\beta}{\omega\epsilon}}$$

$$Z_{TM} = \frac{\sqrt{\mu\epsilon}\sqrt{\omega^2-\omega_c^2}}{\omega\epsilon} = \frac{\sqrt{\mu\epsilon}\,\cancel{\omega}\sqrt{1-\left(\frac{\omega_c}{\omega}\right)^2}}{\cancel{\omega}\epsilon}$$

$\beta = \sqrt{\omega^2\mu\epsilon - \omega_c^2\mu\epsilon}$

$$Z_{TM} = \sqrt{\frac{\mu}{\epsilon}}\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}$$

$\sqrt{\frac{\mu}{\epsilon}} = \eta_0 \qquad \eta_0$ = Intrinsic Impedence of freespace

$$\boxed{Z_{TM} = \eta_0\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$

Wave Impedence For TE wave:

condition For TE wave :

$E_z = 0$ and $H_z \neq 0$

wave impedence is given by $Z_{TE} = \frac{E_x}{H_y}$

$$Z_{TE} = \frac{-\frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial y} - \frac{\gamma}{h^2}\frac{\partial E_z}{\partial x}}{-\frac{\gamma}{h^2}\frac{\partial H_z}{\partial y} - \frac{j\omega\mu}{h^2}\frac{\partial E_z}{\partial x}} = \frac{-\frac{j\omega\mu}{\cancel{h^2}}\cancel{\frac{\partial H_z}{\partial y}}}{-\frac{\gamma}{\cancel{h^2}}\cancel{\frac{\partial H_z}{\partial y}}}$$

$$Z_{TE} = \frac{j\omega\mu}{\gamma}$$

$\gamma = \alpha + j\beta$

$\alpha = 0 \quad \gamma = j\beta$

$$Z_{TE} = \frac{\cancel{j}\omega\mu}{\cancel{j}\beta} = \frac{\omega\mu}{\beta} = \frac{\omega\mu}{\sqrt{\mu\epsilon}\sqrt{\omega^2-\omega_c^2}} = \sqrt{\frac{\mu}{\epsilon}}\,\frac{1}{\sqrt{1-\left(\frac{\omega_c}{\omega}\right)^2}}$$

$$Z_{TE\cancel{M}} = \eta_0 \cdot \frac{1}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}} \qquad \eta_0 = \sqrt{\frac{\mu}{\epsilon}}$$

$$\boxed{\begin{matrix}\cancel{Z_{TEM}} \\ Z_{TE}\end{matrix} = \frac{\eta_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}}$$

Relation between Z_{TE} and Z_{TM} :

$$Z_{TE} \cdot Z_{TM} = \frac{\eta_0}{\cancel{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}} \cdot \eta_0 \cancel{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$

$$\boxed{Z_{TE} \cdot Z_{TM} = \eta_0^2}$$

Relationship between $\lambda_0, \lambda_g \cdot \lambda_c$:

We know the phase velocity is given by $V_p = \frac{\lambda g}{t} \longrightarrow ①$

$$V_p = \lambda_g \cdot f \longrightarrow ②$$

$$V_p = \lambda_g \cdot \frac{c}{\lambda_0} \longrightarrow ③$$

$$V_p = \frac{c}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}} \longrightarrow ④$$

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

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

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

λ_g = guide wavelength
λ_0 = free space wavelength
λ_c = cutoff wavelength.

Q A rectangular wave guide with Dimensions $a = 3cm$, $b = 2cm$ Operates in TM_{11} mode at 10GHz calculate its wave impedance i.e $Z_{TM_{11}}$

$$Z_{TM} = \eta_0 \sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}$$

$\eta_0 = 120\pi$; $f_0 = 10GHz$

$c = \lambda f$

$\lambda_0 = \frac{c}{f} = 0.03m = 3cm$

$\lambda_c = \frac{2ab}{\sqrt{na^2 + mb^2}}$ $m=1, n=1$

$\lambda_c = 3.328cm$

$Z_{TM} = 120\pi \sqrt{1 - \left(\frac{3}{3.32}\right)^2}$

$\boxed{Z_{TM} = 163.198\Omega}$

② A Dominant mode is propagating in the rectangular wave guide having guide wave length = 4cm for a freq. of 90$\overset{0M}{0}$HZ, calculate the dimensions of rect. waveguide.

$\lambda g = 4cm$

f = ~~900MHZ~~ 9000MHZ

TE10 is the Dominant mode in rectangular waveguide

$\lambda = \frac{c}{f} = 0.333\,m$

$\lambda_c = 2a$

In Dominant mode $\boxed{b = a/2}$

$\lambda_c = \frac{2ab}{\sqrt{na^2 + mb^2}}$

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

$4 = \frac{0.33}{\sqrt{1 - \left(\frac{0.33}{\lambda_c}\right)^2}}$

$\sqrt{1 - \left(\frac{0.33}{\lambda_c}\right)^2} = \frac{0.33m}{4cm} = \cancel{0.083}\ 8.25$

$1 - \left(\frac{0.33}{\lambda_c}\right)^2 = \cancel{6.94 \times 10^{-3}} = 68.06$

$-67.066 = \left(\frac{0.33}{\lambda_c}\right)^2 \Rightarrow -67.066 = \frac{0.33^2}{\lambda_c^2}$

$\lambda_c = 0.3$ $a = 3cm$

$a = \frac{\lambda}{}$ $b = 1.5cm$

③ A rectangular waveguide has dimensions $a = 5cm$; $b = 2.5cm$ Find guide wavelength (λg), V_p, β, at $\lambda_0 = 4.5cm$ for The dominant mode

Dominant mode is TE_{10} :

$\lambda_c = 2a = 2 \times 5$

$\lambda_c = 10cm$

$\lambda_0 = 4.5cm$

$$\lambda g = \frac{\lambda_0}{\sqrt{1 - \left(\frac{\lambda_0}{\lambda_c}\right)^2}} = 5cm$$

$$V_p = \frac{c}{\sqrt{1 - \left(\frac{\lambda_0}{\lambda_c}\right)^2}} \qquad c = \frac{1}{\sqrt{\mu \epsilon}} = 3 \times 10^8 mt$$

$$V_p = \frac{3 \times 10^8 m}{\sqrt{1 - \left(\frac{4.5}{10}\right)^2}} = 3.35$$

$$\beta = \frac{2\pi}{\lambda g} = 1.25$$

④ When a dominant mode is propagating in the rectangular wave guide with Freq. 9GHz and having $\lambda g = 4cm$, calculate the larger dimension of Rect. waveguide

$f = 9GHz$

$\lambda g = 4cm$

$\lambda_0 = \frac{c}{f} = ~~33.33~~ = 0.033mt = 3.3cm$

In dominant mode TE_{10} : $\lambda_c = 2a$

$$\lambda g = \frac{\lambda_0}{\sqrt{1 - (\lambda_0/\lambda)^2}}$$

$$\lambda_C = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_g}\right)^2}} = \frac{3.3}{\sqrt{1-\left(\frac{3.3}{4}\right)^2}}$$

$\lambda_C = 5.8\text{cm}$

$\lambda_C = 2a$

$$a = \frac{\lambda_C}{2} = \frac{5.8}{2} = 2.91\text{cm}$$

$\boxed{a = 2.91\text{cm}}$

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

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

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

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

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

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

Important Formulae:

Wave eqns : TM wave = $\nabla^2 E_z = -\omega^2 \epsilon \mu \epsilon_z$

TE wave $\nabla^2 H_z = -\omega^2 \mu \epsilon H_z$

Propagation of EM waves : E_x, E_y, H_x, H_y.

Propagation of TM wave in R.W : $h^2 = \gamma^2 + \omega^2 \mu \epsilon$

Propagation of TE wave in R.W : $h^2 = \gamma^2 + \omega^2 \mu \epsilon$

TE_{mn} Modes : TE_{00}, TE_{10}, TE_{01}, TE_{11}

$m = a$; $n = b$.

Dominant mode : TE_{10} : $\lambda_C = 2a$

Degenated mode : TE_{11}, TM_{11}

waveguide act as a : HPF.

waveguide characteristics : Cutt off Freq. $f_c = \frac{c}{2}\sqrt{\left(\frac{n}{b}\right)^2 + \left(\frac{m}{a}\right)^2}$

Cut of wave $\lambda_C = \frac{c}{f_c}$

wave characteristics : phase velocity $v_p = \frac{\omega}{\beta} = \frac{c}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_C}\right)^2}}$

Groupvelocity $v_g = \frac{d\omega}{d\beta} = c \cdot \sqrt{1-\left(\frac{\lambda_0}{\lambda_C}\right)^2}$

wave impedence : $Z_{TM} = \frac{E_x}{H_y}$

$Z_{TM} = \eta_0 \sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}$

$Z_{TE} = \eta_0 / \sqrt{1-(\lambda_0/\lambda_c)^2}$

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

Q. ⑤ A rectangular waveguide with dimensions a=8cm, b=4cm for TE_{10}, TM_{11}, TM_{21} Modes, mention the modes in which the wave propagates through the waveguide if free space wavelength is 10cm

For Propagation of wave condition is : $\lambda_c > \lambda_0$

For TE_{10} :

$m=01$; $n=0$

$$\boxed{\lambda_c = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_g}\right)^2}} \text{ (or) } = \frac{c}{f_c} \qquad f_c = \frac{c}{2}\sqrt{\left(\frac{n}{b}\right)^2 + \left(\frac{m}{a}\right)^2}}$$

$$\lambda_c = \frac{2ab}{\sqrt{m^2b^2+n^2a^2}} = \frac{2\times8\times4}{\sqrt{(1)^2 4^2+0^2 8^2}}$$

$$\lambda_c = \frac{2\times8\times\cancel{4}}{\cancel{4}} = 16cm$$

$\lambda_c = 16cm > \lambda_0$

(or)

$\lambda_c = 16cm = 2a$

For TE_{11} : Degenerative mode

$$\lambda_c = \frac{2\times8\times4}{\sqrt{4^2+8^2}} = \frac{2\times8\times4}{\sqrt{16+64}} = 7.15cm$$

$\lambda_c = 7.15cm < \lambda_0$ (10cm)

For TE_{21} :

$$\lambda_c = \frac{2\times8\times4}{\sqrt{2^2(4^2)+8^2}} = 5.65cm < \lambda_0 \text{ (10cm)}$$

Hence only TE_{10} is Propagates through waveguide

⑥ A rectangular wave guide with dimensions a=3cm b=2cm operates in TM_{11} Mode at f=15GHz calculates it's characteristic wave impedence.

a=3cm b=2cm

TM_{11} : $Z_{TM} = \eta_0 \sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}$

$$\lambda_0 = \frac{c}{f} = \frac{3\times10^{10}}{15\times10^9} = 2cm$$

$$\lambda_c = \frac{2\times3\times2}{\sqrt{2^2+3^2}} = \frac{2\times3\times2}{\sqrt{4+9}} = 3.328cm$$

$$\boxed{Z_{TM} = 301.32\Omega}$$

unit-II

Waveguide Components and Applications

Date: 2/02/23

*The interconnection of two (or) more microwave Devices is known as "microwave junction".

*The most frequently used microwave junction in microwave communications are

1. E-plane Tee Junction
2. H-plane Tee Junction
3. EH-plane Tee Junction (or) magic Tee Junction/Hybrid

Scattering Matrix (or) S-Matrix:

* Scattering Matrix (or) S-Matrix is a square matrix which gives the Relation between the i/p and o/p ports of a microwave junction.

*The variables in the S-Matrix are known as S-parameters (or) scattering parameters.

* The S-parameters define the linear characteristics of the given microwave junction. ex: power, VSWR, etc..

Properties of S-Matrix: (Significance of S-Matrix)

1. S-Matrix is a Square Matrix of order $n \times n$ where n = no. of ports in the Microwave junction.

2. S-Matrix is a Symmetric Matrix i.e $S_{ij} = S_{ji}$

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$$

ex: $S_{12} = S_{21}$
$S_{31} = S_{13}$
$S_{23} = S_{32}$

3. In S-Matrix all diagonal elements will becomes 0. i.e $S_{11} = S_{22} = S_{33} = 0$

4. Unitary Property: S-Matrix is a unitary Matrix i.e

$[S][S]^* = [I]$ where $[S]^*$ = conjugate of S
$[I]$ = Identity Matrix

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{3} & S_{32} & S_{33} \end{bmatrix} \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* \\ S_{21}^* & S_{22}^* & S_{33}^* \\ S_{13}^* & S_{23}^* & S_{33}^* \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

where I Matrix is a Identity Matrix whose order should be same as that of S-Matrix.

5. The sum of product of each term of any row (or) column Multiplied by complex conjugate of the corresponding term of any other row (or) column will become zero i.e

$$\sum_{i=0}^{n} S_{ij} S_{ij}^* = 0$$

① H-plane Tee Junction:

①*It is a 3port Microwave junction and the order of S-Matrix will be S = 3x3.

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}_{3\times3}$$

② S-Matrix is a Symmetric Matrix i.e $S_{ij} = S_{ji}$

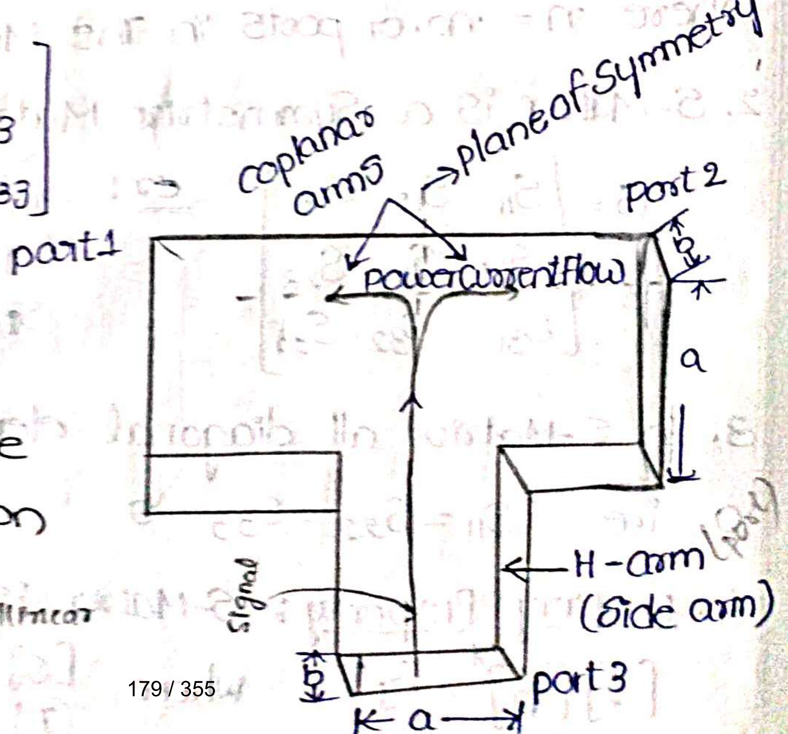
$S_{12} = S_{21}$; $S_{23} = S_{32}$; $S_{13} = S_{31}$

Then S-Matrix will become

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{23} \\ S_{13} & S_{23} & S_{33} \end{bmatrix}$$

$S_{33}=0$

$S_{23}=S_{13}$



∵ Fig H-plane Tee Junction

Port 1 and port 2 are collinear

2 S-Matrix is a square matrix of order $n \times n$ where $n=3$, so

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}_{3\times3}$$

③ Since the 3rd port is perfectly matched to the main wave guide in the H-plane Tee Junction Then $\boxed{S_{33}=0}$

④ Because of the plane of the symmetry of the Junction the S-parameters $\boxed{S_{13}=S_{23}}$ are equal i.e $S_{13}=S_{23}$ b/c the signal is divided into same parts.

⑤ Now the S-Matrix for Junction is given as

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix}$$

⑥ S-Matrix is a unitary Matrix $[S]_{3\times3}[S]^*_{3\times3} = [I]_{3\times3}$

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* \\ S_{12}^* & S_{22}^* & S_{13}^* \\ S_{13}^* & S_{13}^* & 0^* \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$R_1C_1 = S_{11}S_{11}^* + S_{12}S_{12}^* + S_{13}^*S_{13}$ $\qquad |x|^2 = xx^*$

$R_1C_1 = |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1 \longrightarrow ①$

$R_2C_2 = |S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1 \longrightarrow ②$

$R_3C_3 = |S_{13}|^2 + |S_{13}|^2 \Rightarrow 2|S_{13}|^2 = 1 \longrightarrow ③$

from③ $|S_{13}|^2 = \frac{1}{2}$

$$\boxed{|S_{13}| = \frac{1}{\sqrt{2}}}$$

①=② $|S_{11}|^2 + |S_{12}|^2 + \cancel{|S_{13}|^2} = |S_{12}|^2 + |S_{22}|^2 + \cancel{|S_{13}|^2}$

$|S_{11}|^2 + \cancel{|S_{12}|^2} = \cancel{|S_{12}|^2} + |S_{22}|^2$

$|S_{11}|^2 = |S_{22}|^2$

$$\boxed{S_{11} = S_{22}}$$

$R_3C_1 = S_{13}S_{11}^* + S_{13}S_{12}^* = 0 \longrightarrow ④$

$$S_{13}(S_{11}^{*} + S_{12}^{*}) = 0$$

$$S_{13} \neq 0 \qquad S_{11}^{*} + S_{12}^{*} = 0$$

$$S_{13} = \frac{1}{\sqrt{2}} \qquad S_{11}^{*} = -S_{12}^{*}$$

$$\boxed{S_{12} = -S_{12}}$$

from eqn ①

$$|S_{11}|^2 + |-S_{12}|^2 + |S_{13}|^2 = 1$$

$$|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1$$

$$2|S_{11}|^2 = 1 - \left[\frac{1}{\sqrt{2}}\right]^2$$

$$|S_{11}|^2 = \frac{1}{2}\left(1 - \left[\frac{1}{\sqrt{2}}\right]^2\right)$$

$$|S_{11}|^2 = \frac{1}{2}(1 - 1/2) = \frac{1}{4}$$

$$\boxed{\begin{matrix} S_{11} = \frac{1}{2} & S_{22} = 1/2 \\ S_{12} = -1/2 & S_{13} = \frac{1}{\sqrt{2}} \end{matrix}}$$

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix} = \begin{bmatrix} -\frac{1}{2} & -\frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{-1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \end{bmatrix}$$

consider $[b] = [S][a]$ b = o/p matrix (no-of ports = 3)
a = i/p matrix

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} 1/2 & -1/2 & +1/\sqrt{2} \\ -1/2 & 1/2 & 1/\sqrt{2} \\ 1/\sqrt{2} & 1/\sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$$

$$\left.\begin{aligned} b_1 &= \frac{1}{2}a_1 - \frac{1}{2}a_2 + \frac{1}{\sqrt{2}}a_3 \\ b_2 &= -\frac{1}{2}a_1 + \frac{1}{2}a_2 + \frac{1}{\sqrt{2}}a_3 \\ b_3 &= \frac{1}{\sqrt{2}}a_1 + \frac{1}{\sqrt{2}}a_2 \end{aligned}\right\}$$ o/p eqn's for H-plane Tee Jun.

consider input is given at port 3 and no i/p's are given at port 1 and port 2 i.e $a_3 \neq 0$, $a_1 = 0$, $a_2 = 0$

$$\boxed{b_1 = +\frac{1}{\sqrt{2}}a_3 \;;\; b_2 = \frac{1}{\sqrt{2}}a_3 \;;\; b_3 = 0}$$

$b_1 = b_2$ so collinear ports
$b_3 = 0$ perfectly matched port

Let P_3 be the power at Port3 then these power gets divided equally b/w port1 and port 2 inphase i.e $\boxed{P_1 = P_2}$

*The amount of power $P_3 = P_1 + P_2$

$$P_3 = P_1 + P_1$$

$$\boxed{P_3 = 2P_1}$$

*now the amount of power coming out of port1 (or) port 2 due to the input at port3. is given as. $\boxed{10\log\frac{P_1}{P_3}}$

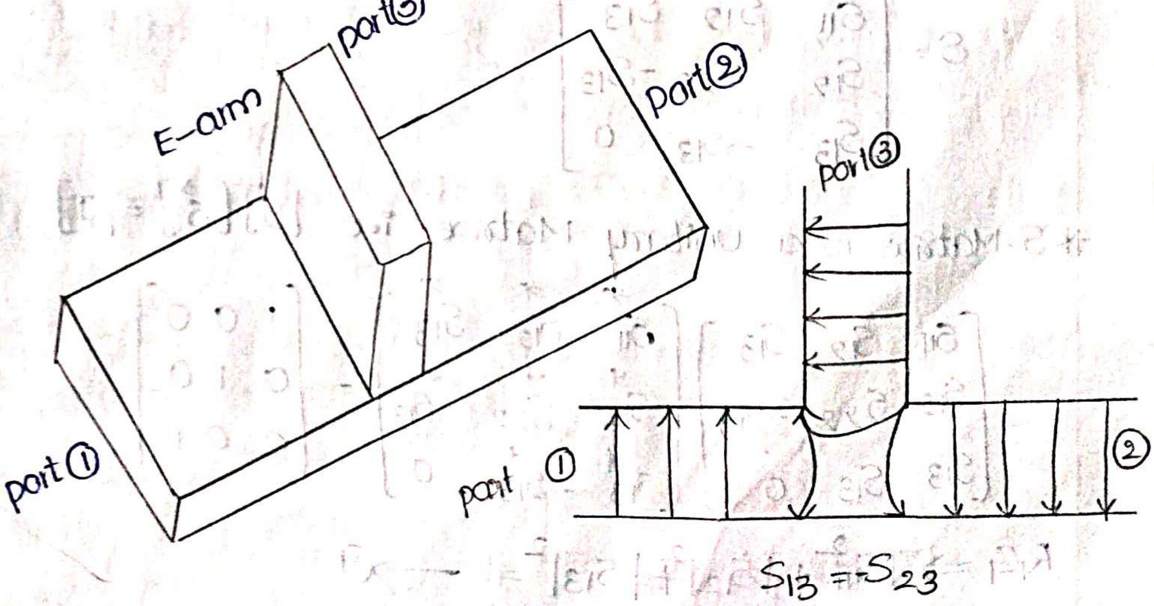
$$= 10\log_{10}\frac{P_1}{2P_1} = 10\log_{10}\frac{1}{2} = -3dB$$

⟹ so the power coming out of port1 (or) port2 is 3dB w.r.t input power at port3. hence H-plane Tee Junction is called as a "3dB splitter".

H-plane Tee Junction is formed by cutting a rectangular slot along the width of the main wave guide and attaching another waveguide as side arm/ H-arm as shown in Figure.

⟹ H-plane Tee Junction is also called as "current Junction" as all the 3 arms of the Junction lie in the plane of magnetic field and the Magnetic Field divide itself into the arms

② E-plane Tee Junction:



$S_{13} = -S_{23}$

In E-plane Tee Junction The Two o/p's Port1 and Port2 will have a phase shift of 180° as shown in fig

since The electric field lines change the direction when They come out of port1 and port 2 the S-parameters

$\boxed{S_{13} = -S_{23}}$ (or) $\boxed{S_{23} = -S_{13}}$

* E-plane Tee Junction is also called as voltage (or) Series Junction symmetrical about of the central arm hence any signal that is to be combined or split will be fed from E-arm.

*E-plane Tee Junction has 3 ports so, The S-Matrix is a 3x3 matrix i.e

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{23} \\ S_{13} & S_{23} & S_{33} \end{bmatrix}$$

① S-Matrix is a Symmetric Matrix i.e $S_{ij} = S_{ji}$

$S_{12} = S_{21}$; $S_{23} = S_{32}$, $S_{13} = S_{31}$

$S_{23} = S_{32} = -S_{13}$

* At Port 3 the o/p is zero b/c it is Perfectly matched

$S_{33} = 0$

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix}$$

* S-Matrix is a unitary Matrix i.e $[S][S^*] = [I]$

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* \\ S_{12}^* & S_{22}^* & -S_{13}^* \\ S_{13}^* & -S_{13}^* & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$R_1C_1 \Rightarrow |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1 \longrightarrow ①$

$R_2C_2 \Rightarrow |S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1 \longrightarrow ②$

$R_3C_3 \Rightarrow |S_{13}|^2 + |S_{13}|^2 = 1$

$$|S_{13}|^2 = \frac{1}{2}$$

$$S_{13} = \frac{1}{\sqrt{2}}$$

$R_3C_1 \Rightarrow |S_{13}|\, S_{11}^* + S_{12}^*(-S_{13}) = 0$

$$S_{13}\cdot S_{11}^* + S_{13}\cdot S_{12}^* = 0$$

$$S_{13}\left[S_{11}^* - S_{12}^*\right] = 0$$

$$S_{13} \neq 0 \qquad S_{11}^* - S_{12}^* = 0$$

$$S_{11}^* = S_{12}^*$$

$$\boxed{S_{11} = S_{12}}$$

from $|S_{11}|^2 + |S_{11}|^2 + |S_{13}|^2 = 1$; eqn ① = ② we get $\boxed{S_{11} = S_{22}}$

$$2S_{11}^2 = 1 - (1/\sqrt{2})^2 = 1/2$$

$$\boxed{S_{11} = \frac{1}{2}\ ; \quad S_{12} = 1/2\ ; \quad S_{13} = \frac{1}{\sqrt{2}}\ ; \quad S_{22} = 1/2}$$

$$S = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{2} & \frac{1}{2} & \frac{-1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} & 0 \end{bmatrix} \Longrightarrow$$ S-Matrix For E-plane Tee Junction

consider $[b] = [S][a]$

b = o/p Matrix

a = i/p Matrix

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} 1/2 & 1/2 & 1/\sqrt{2} \\ 1/2 & 1/2 & -1/\sqrt{2} \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$$

$$b_1 = \frac{a_1}{2} + \frac{a_2}{2} + \frac{a_3}{\sqrt{2}} = \frac{a_1 + a_2}{2} + \frac{a_3}{\sqrt{2}}$$

$$b_2 = \frac{a_1}{2} + \frac{a_2}{2} - \frac{a_3}{\sqrt{2}}$$

$$b_3 = \frac{a_1}{\sqrt{2}} - \frac{a_2}{\sqrt{2}}$$

Consider input is given at port 3, and no i/p's is given at port 1 and port 2 i.e $a_1 = a_2 = 0$ and $a_3 \neq 0$

$$b_1 = \frac{a_3}{\sqrt{2}} \qquad b_2 = \frac{-a_3}{\sqrt{2}} \qquad b_3 = 0$$

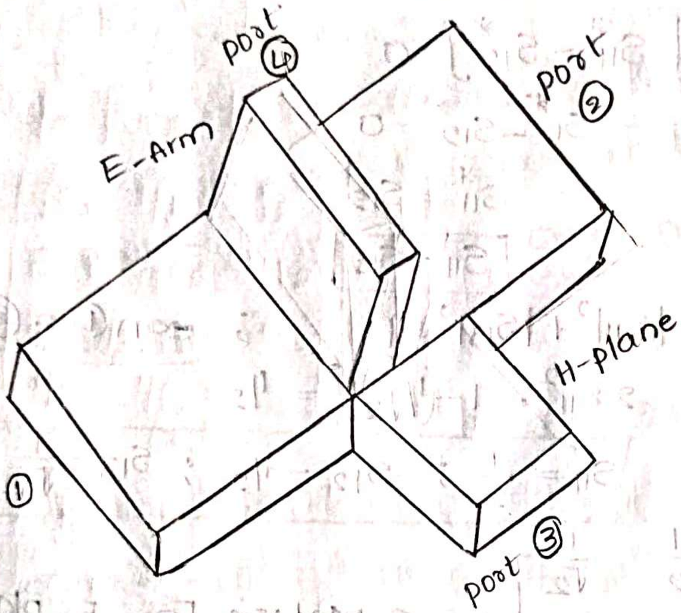
Now port 3 is perfectly matched so $b_3 = 0$ and port 1 and port 2 are opposite.

when i/p is given at port 3 it gets divided Equally port 1 and port 2 and introduces a phase shift of 180° so hence E-plane Tee Junction is also called as "3dB Splitter".

$a_1 = a_2 = a$; $a_3 = 0$

$b_1 = a$; $b_2 = +a$ $b_3 = 0$

③ EH-plane Tee Junction (or) Magic Tee (or) Hybrid Tee Junction:



*EH-plane Junction is Form By cutting rectangular slot along width and bredth of the main wave guide and the side arm i.e H-arm and E-arm are attatched as shown in Figure.

*Harm is the Part3 and E-arm is the Port4 in the Junction which are Isolated parts. (no connection) i.e $S_{34} = S_{43} = 0$

↳ if we give i/p at port 4 Then There is no o/p at port 3 (or) vice versa

*These Junction has Several usefull applications as Duplexer, Mixer etc.

*These Junction has 4 Ports so, The order of S-Matrix is 4x4 i.e

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}_{4\times4}$$

* Because of the H-plane Tee Junction $\boxed{S_{13} = S_{23}}$; because of the E-plane Tee Junction $\boxed{S_{14} = -S_{24}}$

* Port 3 and Port 4 are isolated ports i.e $\boxed{S_{34} = S_{43} = 0}$

* Port 3 and port 4 are Perfectly matched to the Junction i.e $\boxed{S_{33} = S_{44} = 0}$

1. S-Matrix is a Symmetric Matrix i.e $S_{ij} = S_{ji}$

$S_{12} = S_{21}$; $S_{13} = S_{31}$; $S_{23} = S_{32} = S_{13}$; $S_{41} = S_{14}$;

$S_{42} = S_{24} = -S_{14}$

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix}_{4\times4}$$

2. Apply the unitary property i.e $[S][S^*] = [I]_{4\times4}$

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix} \begin{bmatrix} S_{11}^* & S_{12}^* & S_{13}^* & S_{14}^* \\ S_{12}^* & S_{22}^* & S_{13}^* & -S_{14}^* \\ S_{13}^* & S_{13}^* & 0 & 0 \\ S_{14}^* & -S_{14}^* & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$R_1C_1 \Rightarrow |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1 \longrightarrow ①$

$R_2C_2 \Rightarrow |S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1 \longrightarrow ②$

$R_3C_3 \Rightarrow |S_{13}|^2 + |S_{13}|^2 = 1 \longrightarrow ③$

$$\boxed{S_{13} = \frac{1}{\sqrt{2}}}$$

$R_4C_4 \Rightarrow 2|S_{14}|^2 = 1 \longrightarrow ④$

$$\boxed{S_{14} = \frac{1}{\sqrt{2}}}$$

① = ②

$S_{11} = S_{22}$

from ① $\frac{1}{2} + \frac{1}{2} + |S_{11}|^2 + |S_{12}|^2 = 1$ from ①

$|S_{11}|^2 + |S_{12}|^2 = 0$

$S_{11} = S_{22} = S_{12} = 0$

$$\boxed{S_{11} = +S_{12}}$$

from ② $\boxed{S_{12} = -S_{22}}$

$$S = \begin{bmatrix} 0 & 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 0 & 0 & \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} & 0 & 0 \end{bmatrix}$$

o/p Matrix

Consider $[b] = [S][a]$ There 4 ports so, 4x4 Matrix

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1/\sqrt{2} & 1/\sqrt{2} \\ 0 & 0 & 1/\sqrt{2} & -1/\sqrt{2} \\ 1/\sqrt{2} & 1/\sqrt{2} & 0 & 0 \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 & 0 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix}$$

$b_1 = \frac{a_3}{\sqrt{2}} + \frac{a_4}{\sqrt{2}}$; $b_3 = \frac{a_1}{\sqrt{2}} + \frac{a_2}{\sqrt{2}}$

$b_2 = \frac{a_3}{\sqrt{2}} - \frac{a_4}{\sqrt{2}}$; $b_4 = \frac{a_1}{\sqrt{2}} - \frac{a_2}{\sqrt{2}}$

Case(i):

Consider i/p is given at port3 and NO i/p given at $a_1 = a_2 = a_4 = 0$; $a_3 \neq 0$

$b_1 = \frac{a_3}{\sqrt{2}}$; $b_2 = \frac{a_3}{\sqrt{2}}$; $b_3 = 0$, $b_4 = 0$

$\boxed{b_1 = b_2} \Rightarrow$ It is H-plane Tee Junction

Case(ii):

Consider i/p is given at port 4 so $a_4 \neq 0$ and There is no i/p at $a_1 = a_2 = a_3 = 0$

$b_1 = \frac{a_4}{\sqrt{2}}$; $b_2 = -\frac{a_4}{\sqrt{2}}$; $b_3 = 0$; $b_4 = 0$

The o/p at port 1 and port 2 is equal and There a 180° phase shift b/w port 1 and port 2 so it act as a E-plane Tee Junction

Case(iii): $a_1 \neq 0$; $a_2 = a_3 = a_4 = 0$

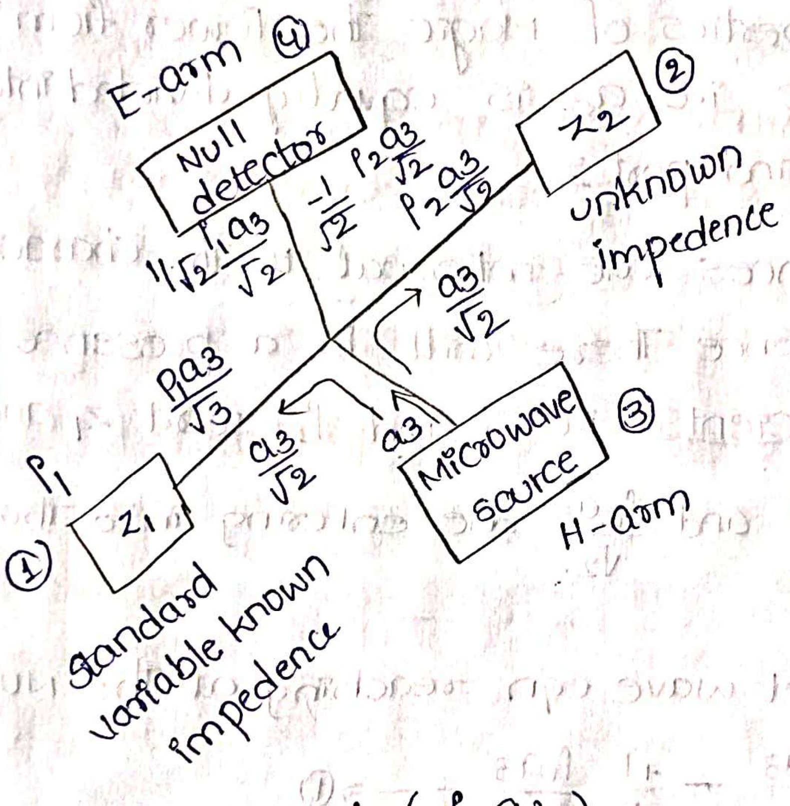
$b_3 = \frac{a_1}{\sqrt{2}}$; $b_4 = \frac{a_1}{\sqrt{2}}$; $b_1 = 0$; $b_2 = 0$

Eventhough The i/p signal is given at port1 There is no o/p at port2 so port1 and port2 are also isolated ports. when the Power fed in Port1 nothing comes out of port2 even though Port1 and port2 are collinear ports, so It these Junction is also called as "Magic Tee Junction".

It is a combination of E-plane and H-plane Tee Juns so it is also called as "Hybrid Tee Junction".

Applications of Magic Tee Junction:

① Magic Tee is used to measure The unknown impedence:



ρ_1 = reflection co-efficient

$$\frac{1}{\sqrt{2}}\left(\frac{\rho_1 a_3}{\sqrt{2}}\right) - \frac{1}{\sqrt{2}}\left(\frac{\rho_2 a_3}{\sqrt{2}}\right) = 0$$

$$\frac{1}{\cancel{\sqrt{2}}}\left(\frac{\rho_1 \cancel{a_3}}{\cancel{\sqrt{2}}}\right) = \frac{1}{\cancel{\sqrt{2}}}\left(\frac{\rho_2 \cancel{a_3}}{\cancel{\sqrt{2}}}\right)$$

$$\boxed{\rho_1 = \rho_2}$$

$$\frac{Z_1 - Z_Z}{Z_1 + Z_Z} = \frac{Z_2 - Z_Z}{Z_2 + Z_Z}$$

$$\boxed{Z_1 = Z_2}$$

$R_1 + jX_1 = R_2 + jX_2$

$R_1 = R_2$; $X_1 = X_2$

In Magic Tee Arm1 and arm2 are connected to Z_1 and Z_2 respectively where Z_1 = standard variable known imped.
Z_2 = unknown impedence

These 2 ports are isolated to each other.

*In Port3 (H-arm) Microwave source is are connected and at port4 (E-arm) Null detector is connected. and These Two ports are isolated to each other.

*By using the Properties of Magic Tee The Power from the microwave source i.e a_3 is equally divided into two ports i.e port1 and port 2.

*These impedences are <u>not equal to</u> the characteristics impedence hence there will be a presence of <u>reflextion co-efficients</u> i.e ρ_1 and ρ_2 w.r.t Z_1 and Z_2

*The powers $\frac{\rho_1 a_3}{\sqrt{2}}$ and $\frac{\rho_2 a_3}{\sqrt{2}}$ are entering into the Null Detector.

Hence The Net wave eqn reaching at The Null detector is $\frac{1}{\sqrt{2}}\frac{\rho_1 a_3}{\sqrt{2}} - \frac{+1}{\sqrt{2}}\frac{\rho_1 a_3}{\sqrt{2}} \longrightarrow ①$

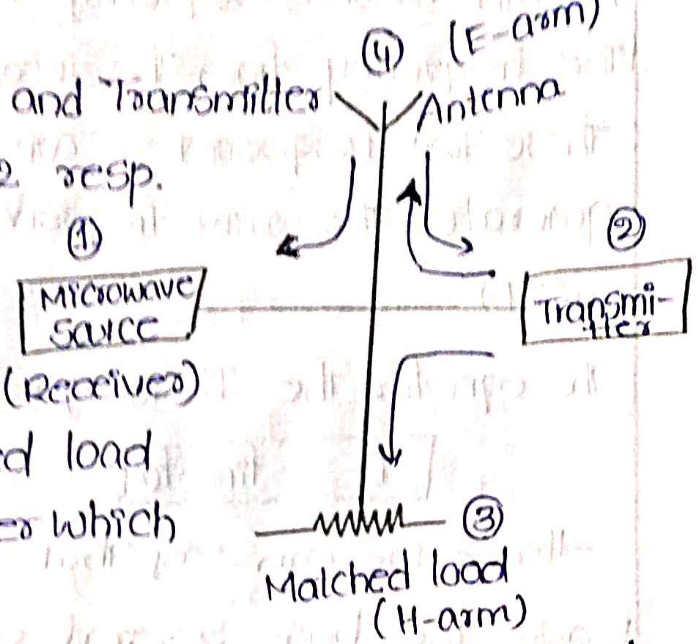
*To Balance The Bridge eqn① must be equated to 0

$$\frac{Z_1 - Z_2}{Z_1 + Z_2} = \frac{Z_2 - Z_2}{Z_2 + Z_2}$$

$$Z_1Z_2 + Z_1\cancel{Z_2} - Z_2^2 - Z_2Z_2 = Z_1\cancel{Z_2} - Z_1Z_2 + Z_2Z_2 - Z_2^2$$

Thus The unknown impedence value can be measured by adjusting the standard variable known impedence until bridge is balances. and Both impedences are equal.

(2) Magic Tee as a duplexer:



* Microwave Source (receiver) and Transmitter connected to port1 and port2 resp.

* Matched load, Antenna are connected to ports 3 & 4.

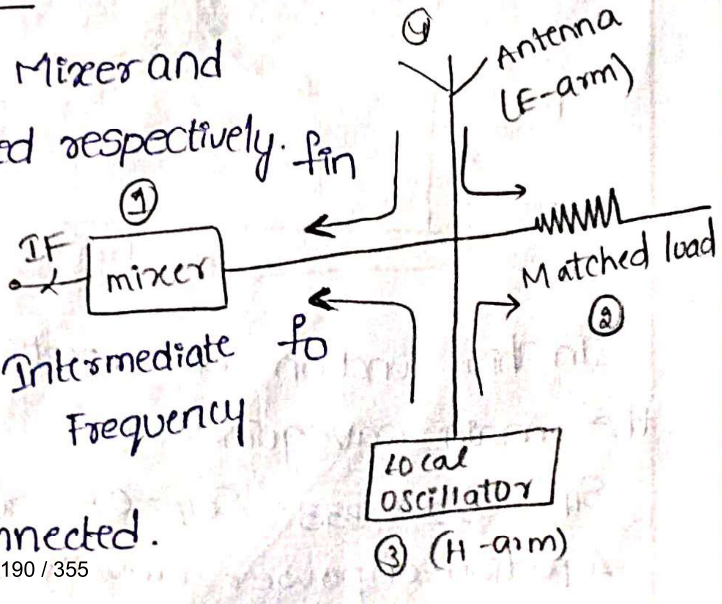
* Here the Purpose of Matched load is to observe the Enter power which is incident on it.

* During the Transmission Half of the power reaches to the the Matched load and another half power reaches to the Antenna. and there is no power transmitted to the receiver (i.e microwave source because (port 1 and port 2 are isolated to each other)

* During the reception the power from the antenna reaches half of the to the transmitter and another half of the power reaches to microwave source. and no power is transmitted to matched load b/c port 3 and port 4 are isolated to each other.

Thus we can say that Magic Tee act as a Duplexer

③ Magic Tee act as a Mixer:



* Here at port 1 and port 2 Mixer and Matched load are connected respectively.

* At port 3 local oscillator is connected. The purpose of LO is It generates it's own Frequency. and at port 4 antenna is connected.

Let fin be the Frequency From the antenna and fo be the Frequency from the local oscillator.

These Two Frequencies are mixed at the mixer and generate the new frequency i.e Intermediate Frequency(I.F)

The eqn for the IF is given by

$$\boxed{IF = f_{in} - f_o}$$

Hence we can say that Magic Tee acts as a Mixer.

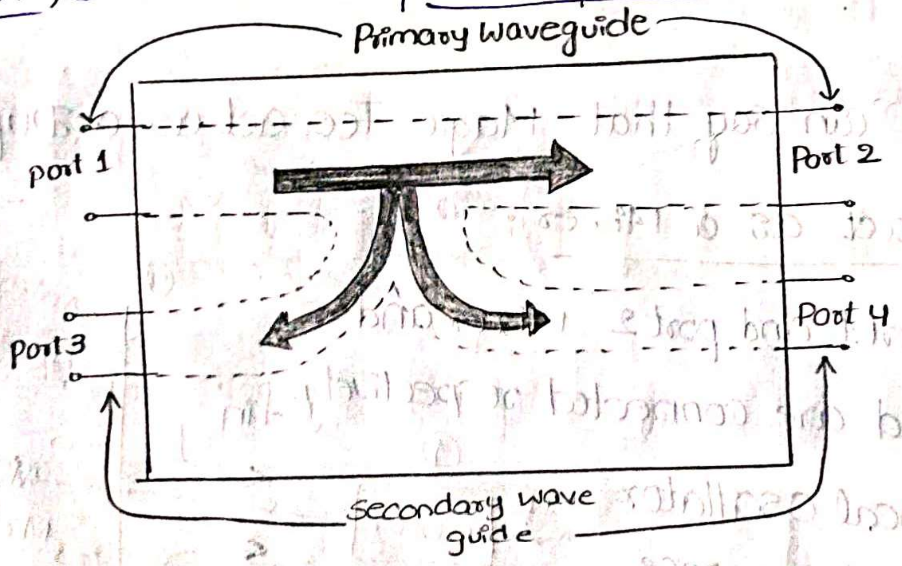
Magic Tee has several other applications such as Microwave discriminator, Microwave bridge etc...

Two hole Directional Coupler :

It is a 4 port wave guide, It consist of Primary wave guide and auxilary wave guide.

* when the input signal is propagating from port1 to port 2, It will be coupled to port 4 but not port 3.

* when the input signal is propagating from port2 to port1, It will be coupled to port 3 but not port 4.



In this Junction All 4 ports are Perfectly matched to the main waveguide so,

$$S_{11} = S_{22} = S_{33} = S_{44} = 0 \longrightarrow ①$$

A portion of power travelling From port 1 and port 2 can't travel in port3 so, $S_{13} = S_{31} = 0 \longrightarrow ②$

A portion of power travelling from port 2 to port1 can't travel in Port 4 so $S_{42} = S_{24} = 0 \longrightarrow ③$

Now S-Matrix will be

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}_{4\times4}$$

1. S-Matrix is a Symmetric Matrix i.e $S_{ij} = S_{ji}$

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{23} & S_{24} \\ S_{13} & S_{23} & S_{33} & S_{34} \\ S_{14} & S_{24} & S_{34} & S_{44} \end{bmatrix} = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{12} & 0 & S_{23} & 0 \\ 0 & S_{23} & 0 & S_{34} \\ S_{14} & 0 & S_{34} & 0 \end{bmatrix}$$

S-Matrix is a unitary Matrix $[S][S^*] = [I]$

$$\begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{12} & 0 & S_{23} & 0 \\ 0 & S_{23} & 0 & S_{34} \\ S_{14} & 0 & S_{34} & 0 \end{bmatrix} \begin{bmatrix} 0 & S_{12}^* & 0 & S_{14}^* \\ S_{12}^* & 0 & S_{23}^* & 0 \\ 0 & S_{23}^* & 0 & S_{34}^* \\ S_{14}^* & 0 & S_{34}^* & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$R_1C_1 \Longrightarrow |S_{12}|^2 + |S_{14}|^2 = 1 \longrightarrow ①$

$R_2C_2 \Longrightarrow |S_{12}|^2 + |S_{23}|^2 = 1 \longrightarrow ②$

$R_3C_3 \Rightarrow |S_{23}|^2 + |S_{34}|^2 = 1 \longrightarrow ③$

$R_4C_4 \Rightarrow |S_{14}|^2 + |S_{34}|^2 = 1 \longrightarrow ④$

① - ② $\boxed{S_{14} = S_{23}}$

from ② & ③ $\boxed{S_{12} = S_{34}}$

from ③ & ④ $S_{23} = S_{14}$

Let us consider $\boxed{S_{12} = S_{34} = P = S_{34}^*}$

P = real and +ve integer

$R_1C_3 \Rightarrow S_{12} S_{23}^* + \underset{S_{23}}{\underline{S_{14}}} S_{34}^* = 0 \longrightarrow ⑤$

$P S_{23}^* + S_{23} P = 0$

$P(S_{23} + S_{23}^{*}) = 0$

$P \neq 0 \quad S_{23}^{*} = -S_{23}$

Let $S_{23} = jq$

Now S-Matrix S is given by

$$S = \begin{bmatrix} 0 & P & 0 & jq \\ P & 0 & jq & 0 \\ 0 & jq & 0 & P \\ jq & 0 & P & 0 \end{bmatrix}$$

$\Longrightarrow$ The performance of Directional coupler is defined in term two parameters namely

1. Coupling Factor [C]
2. Directivity [D]

1. Coupling Factor [C] :

It defined as ratio of Incident Power P_i to the Forward power P_f in dB, It is given as

$$C = 10\log \frac{P_i}{P_f} \qquad \boxed{C = 10 \log_{10} \frac{P_i}{P_f}\ \text{dB}} \longrightarrow ①$$

2. Directivity [D] :

It is defined as ratio of Forward Power P_f to the Backword power P_b in dB, It is given as

$$\boxed{D = 10 \log_{10} \frac{P_f}{P_b}\ \text{dB}} \longrightarrow ②$$

$$C+D = 10\log_{10} \frac{P_i}{P_f}\ \text{dB} + 10 \log_{10} \frac{P_f}{P_b}\ \text{dB}$$

$$= 10 \log P_i - 10\cancel{\log P_f} + 10\cancel{\log P_f} - 10 \log P_b$$

$$\boxed{C+D = 10 \log_{10} \frac{P_i}{P_b}\ \text{dB}} \Longrightarrow$$

Isolation Factor (I) : ratio b/w P_i to P_b i.e C+D

$$C+D = \boxed{I = 10 \log_{10} P_i/P_b\ \text{dB}}$$

Ferrites Composition and characteristics:

Imp

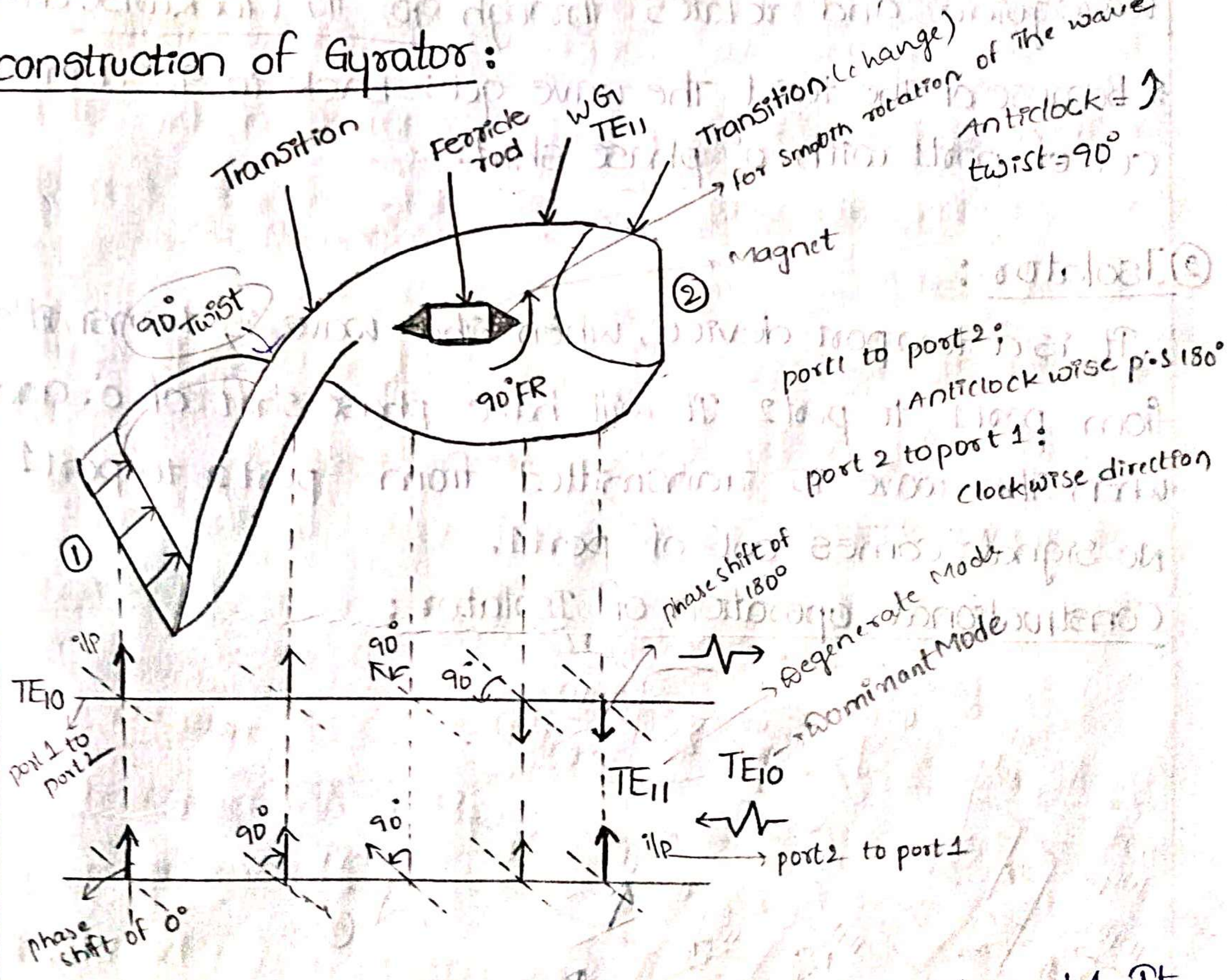
The Ferrite materials works on the principle "Faraday's laws of rotation." which states that when a polarized wave comes across a Magnet placed in the waveguide It will rotate by a perticular angle (or) direction. (90° in Figure)

* The most frequently used ferrite devices are.
  1. Gyratore
  2. Isolator
  3. Circulator

① Gyrator:

It is a two port device when the wave is transmitted from port 1 to port 2, It will have a phase shift of 180°. when the wave is transmitted from port 2 to port 1 It will have a phase shift of 0°.

construction of Gyrator:



In This device when The wave enters at port1 It comes across the 90° twisted waveguide and It's plane of polarization is rotates by 90° in Anticlock wise direction

* Now the wave enters the Main wave guide and comes across the Ferrite rod which is sharpened at the both the end to reduce the attenuation and also for the smooth rotation of the wave.

* Because of the Ferrite rod the wave undergoes Faraday's rotation through 90° in the Anticlockwise direction.

* Now the wave comes out of port2 will have a phase shift 180° compare to the wave entered at port1

* But when the same wave enters at port 2 It comes across the Ferrite rod and rotates through 90° in Anticlockwise direction.

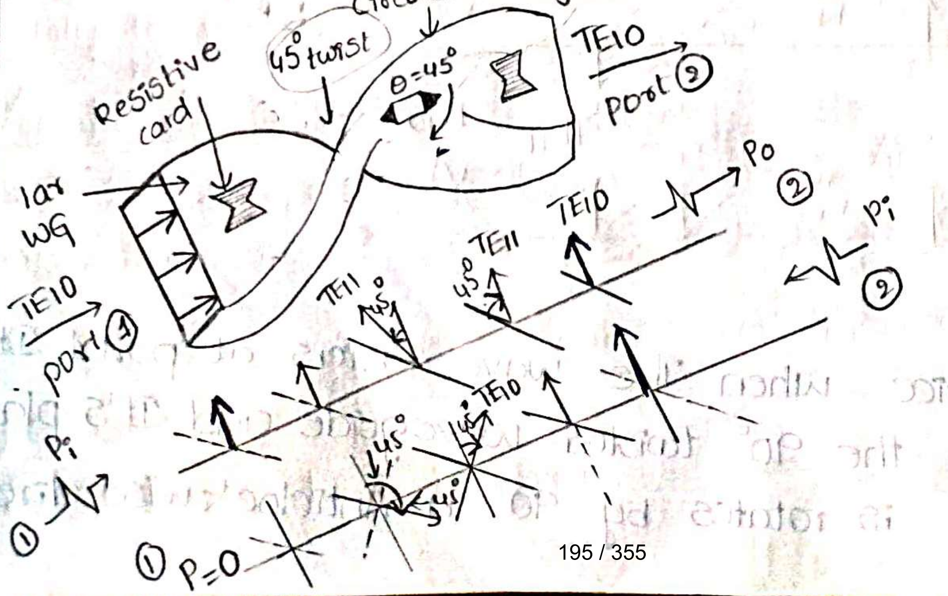
* Now the wave reaches the 90° Twisted part in the waveguide and rotates through 90° in clockwise direction

* Because of the twist the wave gets back to 90° and comes out of port1 with 0° phase shift.

② Isolator:

It is a two port device, when the wave is transmitted from port1 to port2, It will have phase shift of 0°. and when the wave is transmitted from port2 to port1 No signal comes out of port1.

Constructional operation of Isolator:



Clock wise = ↲
twist = 45°
resistive cards are present

*The resistive cards are placed at near port1 and port2 which will observe the wave whose plane of polarization $\perp^{er}$ to it. absorption

*when the wave enters form port1 passes the resistive cards and comes across the 45° twisted part in wave guide

*Now the wave rotates through 45° in Anticlockwise direction.

*Now, the wave comes across ferrite rod and rotates through 45° in clockwise direction.

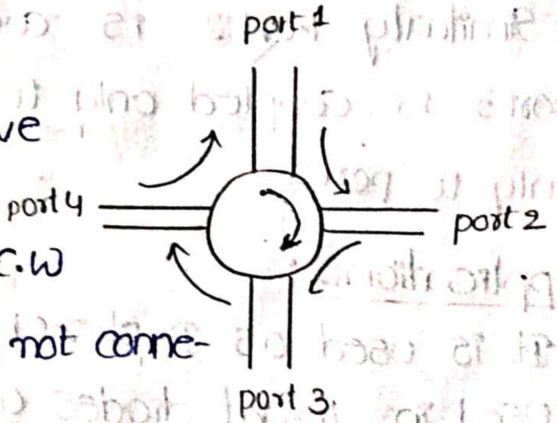
*Now, the wave passes the resistive card and comes out of port2 with 0° P.S w.r.t the wave entered at port1

*The Same wave enters at port2 passes the Resistive cards and comes across the ferrite rod to ~~A~~ Rotate through 45° in C.W direction.

*Now, The wave enters the 45° twist in the wave guide and rotates through 45° in C.W direction.

*Now, The plane of polarization of wave is $\perp^{er}$ to the resistive card so, The wave gets absorbed by The resistive card and no signal comes out of port1.

③ Circulator:



*Circulator is 4 port microwave device which is a 'Perculiar' each terminal connected to next C.W terminal.

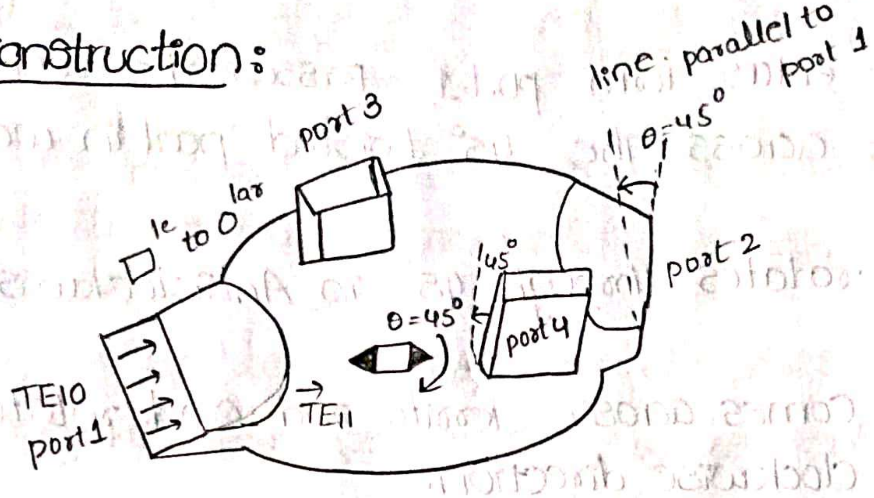
*port1 is connected port 2 and not connected to port3 and 4

*port 2 is connected to port3 and not connected to port4, and part 1

*port3 is connected to port4 only and not connected to port 1 and port 2

* In this device, The input is given to n^{th} port and The o/p will be taken at $(n+1)^{th}$ port

Construction:



* The Power entering at port 1 is TE10 Mode and is converted into TE_{11} Mode b/c of $\square^{lar}$ to O^{lar} transition.

* This Power doesn't passes through Port 3 out off phase with port 1 Since The electric field not significantly cut and it is rotate Through 45° due to ferrite rod.

* After passes Through Port 4 → outp1 unaffected. b/c it is also not significantly cut. electric Field, Finally emerges Out of port 2.

* power from port 2 will have Plane of polarization already, tilted by 45° w.r.t The Port 1.

* Similarly Port 2 is coupled only to The Port 3 and port 3 is coupled only to port 4, and port 4 is coupled only to port 1.

Applications:

* It is used as Duplexer in radar Antenna
* Used in ternal diodes and Parametric amplifiers
* used as low Power devices, as They can handle low powers only.
* used in tunnel device.

Microwave Junctions
- H-plane Tee Jun. (3ports)
- E-plane Junc. (3portsts)
- E-Hplane / Magic Teel (4ports.
  hybrid Junction
  - unknown impedence
  - Duplexer .
  - mixer
- Two hole directional Coupler (4ports)
  - Coupling Factor $C = 10 \log \frac{Pi}{Pf}$
  - Directivity $D = 10 \log \frac{Pf}{PB}$
  - Isolation Factor $I = C + D$

    $I = 10 \log \frac{Pf}{PB}$

S-matrix:
Scattering matrix
S-parameters.

Ferrite : principle : Faradays law of polarization.
rod
- Gyrator (2Ports) $① \Longrightarrow ② : 180°$ $② \Longrightarrow ① : 0°$
- Isolator (2ports) $① \Longrightarrow ② : 0°$ $② \Longrightarrow ①$: NO signal attenuated by resistive cards
- Circulator (4ports) i/p : n^{th} port
  o/p : $(n+1)^{th}$ port

unit-3:

Microwave Amplifiers and Oscillators

Date: 14/03/23

Microwave Tubes are the basic source for the high Freq. microwave signals

There are some limitations in ~~Microwave~~ conventional Tubes namely:

1. LI [lead Inductance] Effect
2. IEC [Inter Electrode capacitance] effect
3. Transit Angle
4. Gain - Band width product

To overcome these limitations O-type Tubes and M-type Tubes are used

O-type Tubes:

O-type Tubes are linear Beam Tubes which are classified as.

1. Two cavity klystron Amp^r
2. Reflex klystron oscillator.
3. TWT (Travelling wave tube)

M-type Tubes:

M-type Tubes are cross field Tubes where electric and magnetic Fields are ⊥er each other. The best exam of M-type Tubes is

1. Magnetron.

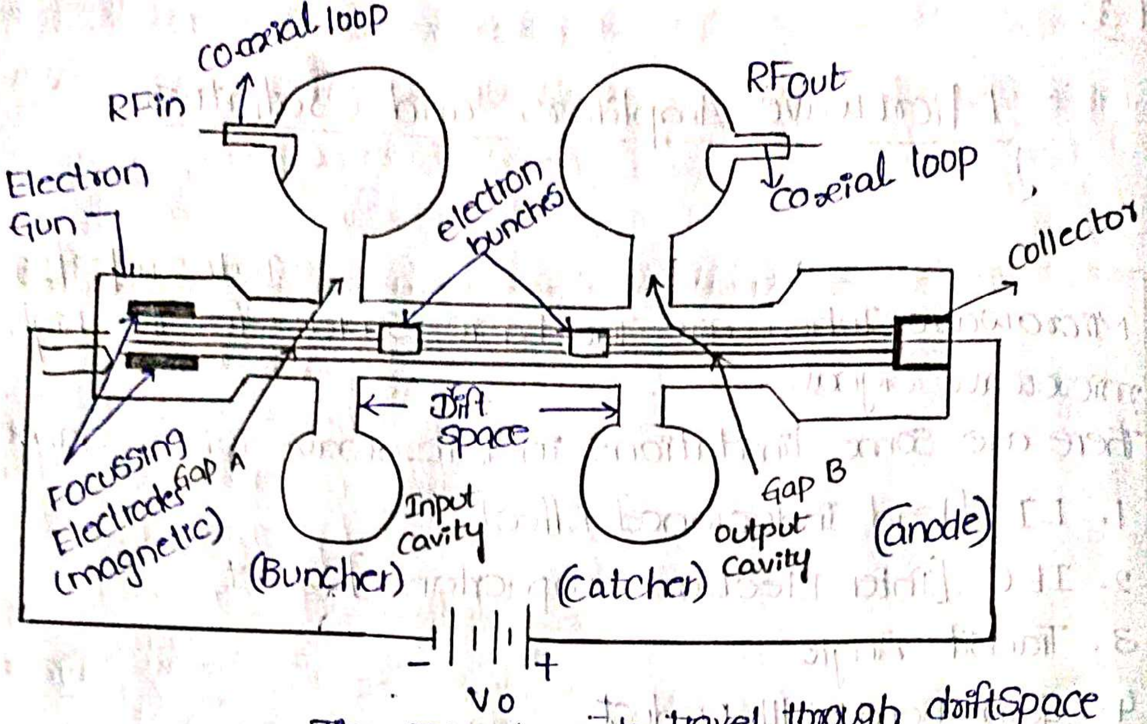
O-type Tubes

① Two Cavity Klystron Amplifier:

Construction:

* The Two cavity klystron amp^r consists of Two cavities

1. Buncher Cavity / input Cavity
2. Catcher Cavity / output Cavity



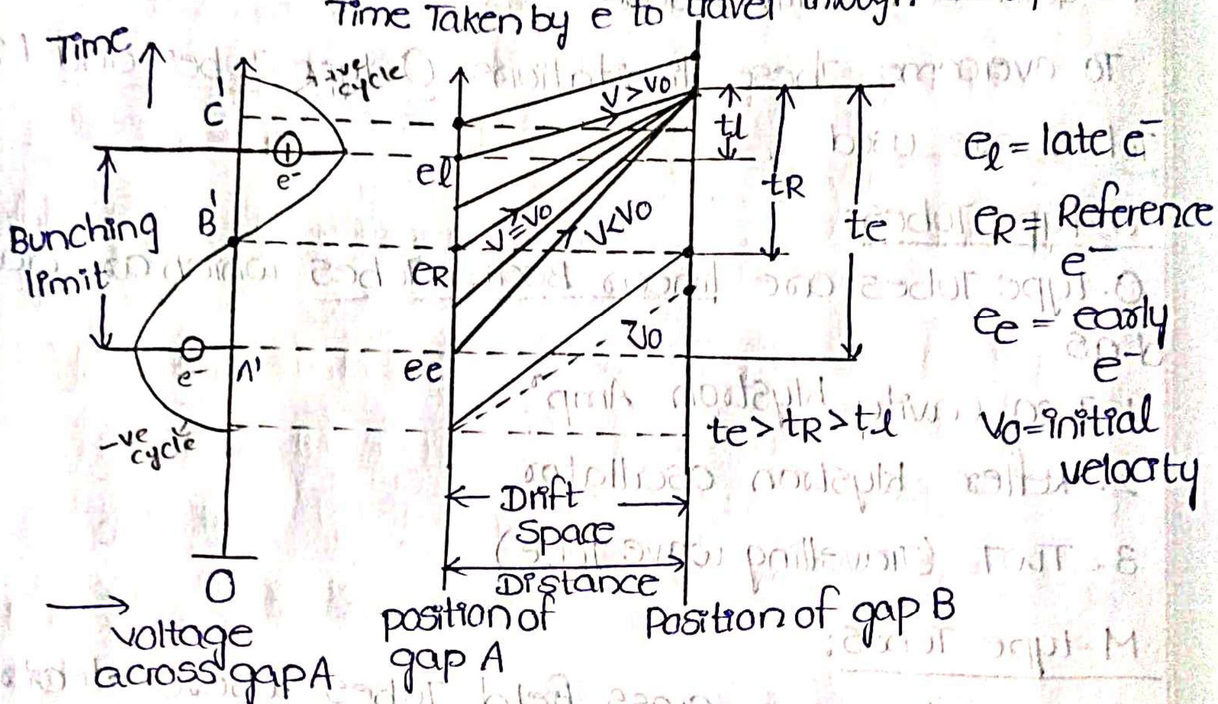


Fig: Apple Gate Diagram.

*The Space b/w The i/p cavity and o/p Cavity is called as "driftspace." These Tube works on The principle of "velocity Modulation Process".

*In velocity Modulation, The electron velocity is beeing beam varied in accordance with The amplitude of The input RF voltage.

* Let us consider a voltage V is applied to The Tube, and Time taken by The electron to enter The i/p Cavity is denoted by to

* The Gap in The i/p is denoted by Gap A and The Small gap in The o/p cavity is denoted by Gap B

* The opr of The tube is explained by considering a input RF signal applied at gap A of The input cavity. as shown in applegate diagram.

* In The applegate diagram at time instant B' of The i/p RF Signal, The alternating v/g is 0 and +ve, so at these instant Reference e^- (e_R) passes The gap with unchanged velocity / initial velocity i.e $v = V_0$.

* At point C' i/p RF signal the e^- leaves The gap A and is called as late e^- (e_l). and thravells Throug towards gap B. i.e $V > V_0$

* At time instant A' the e^- passes The gap A and it is subjected to -ve Field and This electron known as early e^- (e_e). It travells towards gap B with reduced velocity $V < V_0$.

resistive-ee
acceration
Forces - el

Now, The late e^-, reference e^-, and early e^- catches and form a bunch known as electron Bunches. travels towards gap B and Finally collected at The collector.

∴ The velocity of The e^- varies inaccordance with The RF i/p voltage resulting in, velocity Modulation Process.

<u>characteristics:</u>

1. Frequency (250MHZ - 100GHZ) 0.25GHZ - 100GHZ
2. power (10kw - 500kw)
3. Power Gain (15dB - 70dB) 15 - 70dB
4. Noise Figure (15 - 20 dB)
5. Theoritical Efficiency (58%)

<u>Applications:</u>

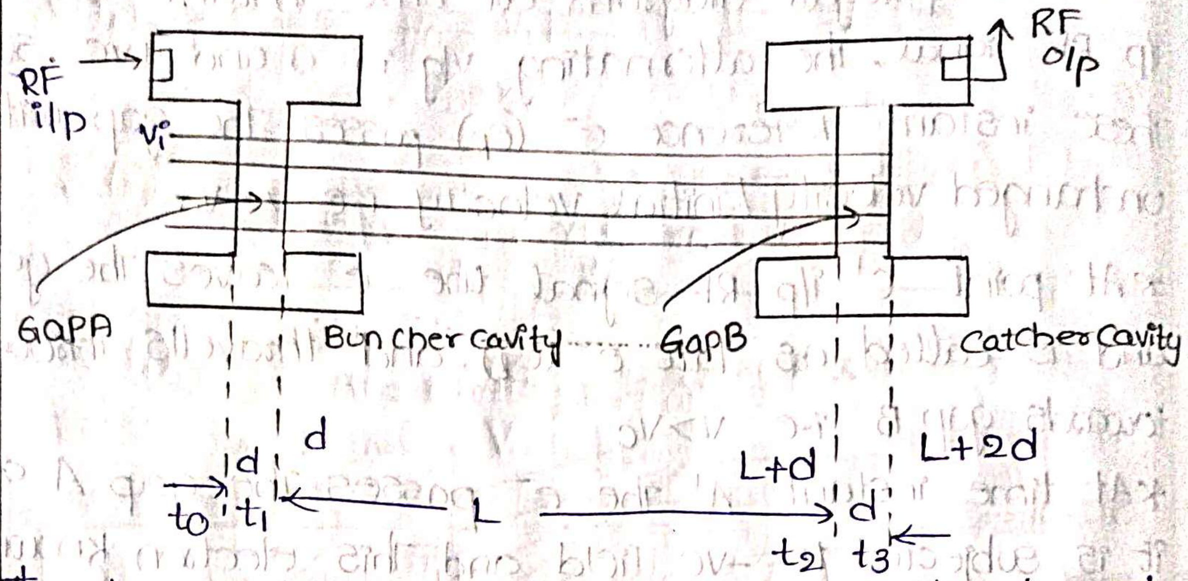
* Used in <u>UHF TV</u> transmitters.

*used in satellite communications

*used in radar Transmitters

*used as power oscillators if it is used as klystron oscillator

Expression for exit velocity : $V(t_1)$



The above L represents the space b/w the i/p and o/p cavities.

t_0 = Time taken by $\bar{e}$ to enter at i/p cavity

t_1 = Time taken by $\bar{e}$ to leave the i/p cavity

t_2 = Time taken by $\bar{e}$ to enter the o/p "

t_3 = Time taken by $\bar{e}$ to leave the o/p cavity

W.K.T

The potential energy $(PE) = e\overset{\text{voltage}}{V_0}$

$$KE = \frac{1}{2} m \overset{\text{velocity}}{v_0}^2$$

$$PE = KE$$

$$eV_0 = \frac{1}{2} m v_0^2$$

$$v_0 = \sqrt{\frac{2eV_0}{M}} \xrightarrow{} \text{voltage}$$

where V_0 = Anode to cathode to DC v/g

M = mass of $\bar{e}$

e = charge of $\bar{e}$

→ In this Tube the transit time of i/p cavity is given as

$$\text{Transit Time } (\tau) = t_1 - t_0 = \frac{d}{v_0}$$

→ The Transit angle in The Tube is given as

$$\text{Transit angle } (\theta_g) = \omega\tau$$

$$= \omega(t_1 - t_0)$$

$$\theta_g = \frac{\omega d}{v_0}$$

$$\omega\tau = \frac{\omega d}{v_0}$$

$$\omega(t_1 - t_0) = \frac{\omega d}{v_0}$$

$$\omega t_1 - \omega t_0 = \frac{\omega d}{v_0}$$

$$\boxed{\omega t_1 = \omega t_0 + \frac{\omega d}{v_0}} \longrightarrow ①$$

the gap vlg in the i/p cavity is given as

$$V_{gs} = V_1 \sin\omega t$$ — Amplitude of RF Signal

The avg gap vlg is given as

$$\text{avg}(V_s) = \frac{1}{\tau}\int_{t_0}^{t_1} V_1 \sin\omega t \, dt = \frac{1}{\tau} V_1 \left(\frac{-\cos\omega t}{\omega}\right)_{t_0}^{t_1}$$

$$= \frac{-V_1}{\omega\tau}(\cos\omega t_1 - \cos\omega t_0)$$

$$= \frac{V_1}{\omega\tau}(\cos\omega t_0 - \cos\omega t_1)$$

from eqn ① ωt_1 is

$$V_s = \frac{V_1}{\omega\tau}\left[\cos\omega t_0 - \cos\left(\omega t_0 + \frac{\omega d}{v_0}\right)\right]$$

Let $A = \omega t_0 + \frac{\omega d}{2v_0}$; $B = \frac{\omega d}{2v_0}$

$A+B = \omega t_0 + \frac{\omega d}{v_0}$; $A-B = \omega t_0$

$$V_s = \frac{V_1}{\omega\tau}\left[\cos(A-B) - \cos(A+B)\right]$$

$$= \frac{V_1}{\omega\tau}(2\sin A \sin B)$$

$$= \frac{2V_1}{\omega\tau}\left[\sin\left(\omega t_0 + \frac{\omega d}{2v_0}\right)\sin\left(\frac{\omega d}{2v_0}\right)\right]$$

$\omega\tau = \theta_g$

$$V_s = \frac{2V_1}{\theta_g}\left[\sin\left(\omega t_0 + \overset{\theta_g}{\cancel{\frac{\omega d}{2v_0}}}\right)\sin\left(\frac{\omega d}{2v_0}\right)\right]$$

$$= V_1 \sin\left(\frac{\theta_g}{2} + \omega t_0\right)\frac{\sin(\theta_g/2)}{(\theta_g/2)}$$

avg gap vlg $V_S = V_1 \sin\left(\omega t_0 + \frac{\theta_g}{2}\right) \beta_i$

where $\beta_i = \frac{\sin(\theta_g/2)}{\theta_g/2}$ electron beam coupling co-efficie

nt of input cavity

Now the exit velocity is given as $\to$ avg vlg

$$v(t_1) = \sqrt{\frac{2e(V_0 + V_1 \beta_i \sin(\omega t_0 + \theta_g/2)}{M}}$$

$$v(t_1) = \sqrt{\frac{2eV_0^{\text{vlg}}}{M}}\sqrt{1+\frac{V_1\beta_i}{\underset{\to \text{vlg}}{V_0}}\sin\left(\omega t_0+\frac{\theta_g}{2}\right)}$$

$$v(t_1) = \underbrace{v_0}_{\text{Initial velocity}}\sqrt{1+\frac{V_1\beta_i}{\underset{\to \text{vlg}}{V_0}}\sin\left(\omega t_0+\frac{\theta_g}{2}\right)} \qquad (1+x)^{1/2} = 1+\frac{x}{2}+\dots$$

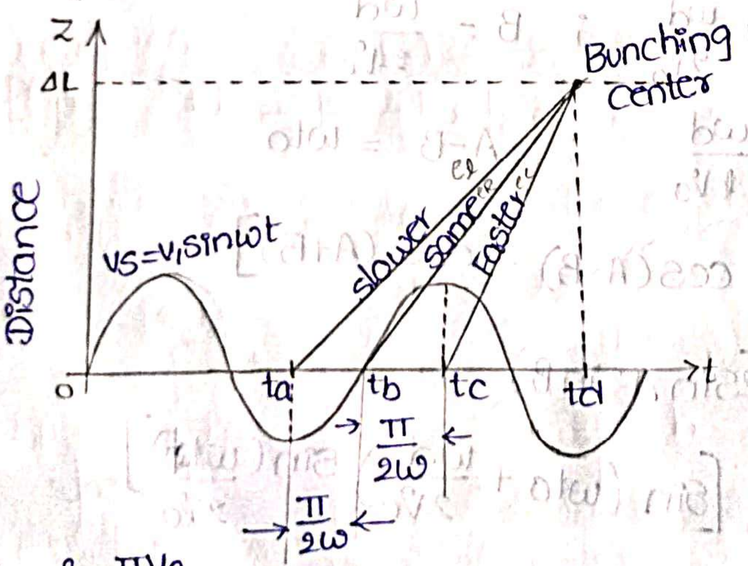
$$\boxed{v(t_1) = v_0\left(1+\frac{V_1\beta_i}{2V_0}\sin\left(\omega t_0+\frac{\theta_g}{2}\right)\right)}$$

$v(t_1)$ = exit velocity v_0 = Initial velocity

V_1 = max. Amplitude of i/p signal V_0 = voltage

θ_g = Transit angle

Bunching Process :



$$\Delta L = v_0 \frac{\pi V_0}{\omega \beta_i V_1} \longrightarrow ①$$

The Distance from the Buncher grid to the location of e^- Bunching is given as $\Delta L = v_0 \frac{\pi V_0}{\omega \beta_i V_1} \longrightarrow ①$

* The transit time for an e^- to travel a distance L is given as $T = t_2 - t_1 = \frac{L}{v(t_1)}$ $\quad \frac{\text{Distance}}{\text{velocity}}$

$$T = \frac{L}{v_0\left(1+\frac{V_1\beta_i}{2V_0}\sin\left(\omega t_0+\frac{\theta_g}{2}\right)\right)} \longrightarrow ②$$

$$\boxed{\frac{L}{v_0} = T_0}$$

$$T = T_0\left[1-\frac{V_1\beta_i}{2V_0}\sin(\omega t_0+\theta_g/2)\right]$$

$$(1-x)^{-1} = 1-x - \ldots$$

Now the time taken by the e^- to lea enter the output cavity is given as $t_2 = t_1 + T$

$$= t_1 + T_0\left[1-\frac{V_1\beta_i}{2V_0}\sin\left(\omega t_0+\frac{\theta_g}{2}\right)\right] \longrightarrow ③$$

W.K.T transit time $\tau = t_1 - t_0$

$$t_1 = \tau + t_0 \longrightarrow ④$$

eqn ④ in ③

$$t_2 = \tau + t_0 + T_0\left[1-\frac{V_1\beta_i}{2V_0}\sin\left(\omega t_0+\frac{\theta_g}{2}\right)\right] \longrightarrow ⑤$$

Differentiate the above eqn w.r.t t_0

$$dt_2 = dt_0\left[1-\frac{V_1\beta_i T_0}{2V_0}\cos\left(\omega t_0+\frac{\theta_g}{2}\right)\omega\right]$$

$$\boxed{\omega T_0 = \theta_0}$$

$$dt_2 = dt_0\left[1-\frac{V_1\beta_i\theta_0}{2V_0}\cos\left(\omega t_0+\frac{\theta_g}{2}\right)\right] \longrightarrow ⑥$$

Now consider the Bunching Parameter of input cavity

$$\boxed{X = \frac{\beta_i V_1\theta_0}{2V_0}}$$

from ⑥ $\quad dt_2 = dt_0\left[1-X\cos\left(\omega t_0+\frac{\theta_g}{2}\right)\right]$

From Principle of Conservation of charges we get,

$$\overset{\text{current at i/p}}{I_0}\,|dt_0| = i_2\,|dt_2| \quad (\text{o/p})$$

Now the current at the catcher cavity is given as

$$i_2(t_2) = \frac{I_0(dt_0)}{dt_2}$$

$$i_2(t_2) = \frac{I_0\cancel{(dt_0)}}{\cancel{dt_0}\left(1-X\cos\left(\omega t_0+\frac{\theta_g}{2}\right)\right)}$$

$$\boxed{i_2(t_2) = \frac{I_0}{1 - x\cos(\omega t_0 + \frac{\theta_g}{2})}}$$

The Bunching current $i_2(t_2)$ in the above exp. can be expanded in Fourier series which is given as.

$$i_2 = a_0 + \sum_{n=1}^{\infty}\left[a_n \cos(n\omega t_2) + b_n \sin(n\omega t_2)\right]$$

where $a_0 = I_0$; $a_n = 2I_0 J_n(nx)\cos(n\theta_g + n\theta_0)$

$b_n = 2I_0 \underbrace{J_n}_{\text{Bessel Function}}(nx)\sin(n\theta_g + n\theta_0)$

After substituting the co-efficients the induced current at the catcher cavity is given as

$$\boxed{i_2(\text{induced}) = \beta_0 2I_0 J_1(x)\cos(\omega(t_2 - \tau - t_0))}$$

Output Power and Efficiency:

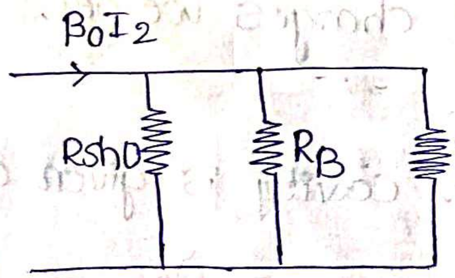
The Fundamental [Output Power and Efficiency] component of the induced current at the catcher cavity is given as

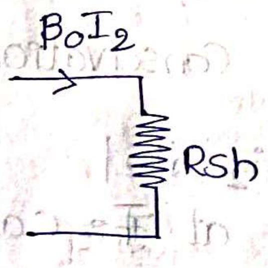
$$i_2(\text{induced}) = \beta_0 2I_0 J_1(x)\cos(\omega(t_2 - \tau - t_0))$$

Let us consider the amplitude of the induced current which is given as

$$I_2(\text{induced}) = \beta_0 2I_0 J_1(x)$$

Now consider the catcher cavity equivalent circuit





where Rsho = Resistance of the catcher cavity walls

Rsh = shunt resistance of cavity catcher

R_B = Beam load resistance

R_L = external load resistance

Now, The output power is given as

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$I_2 = \frac{\beta_0 I_2}{\sqrt{2}}$$

$$P_{out} = \left(\frac{\beta_0 I_2}{R}\right)^2 R_{sh}$$

$$P_{out} = \frac{\beta_0^2 I_2 V_2}{2} \qquad I_2 R_{sh} = V_2$$

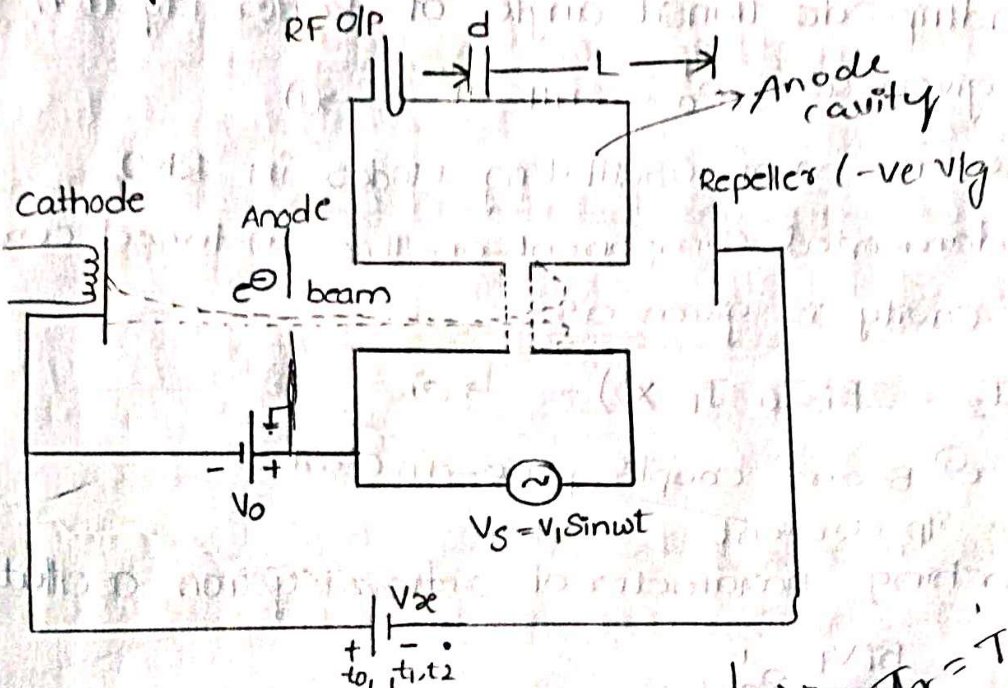
Now Efficiency of Two-cavity klystron amplifier is:

$$\eta = \frac{P_{out}}{P_{in}}$$

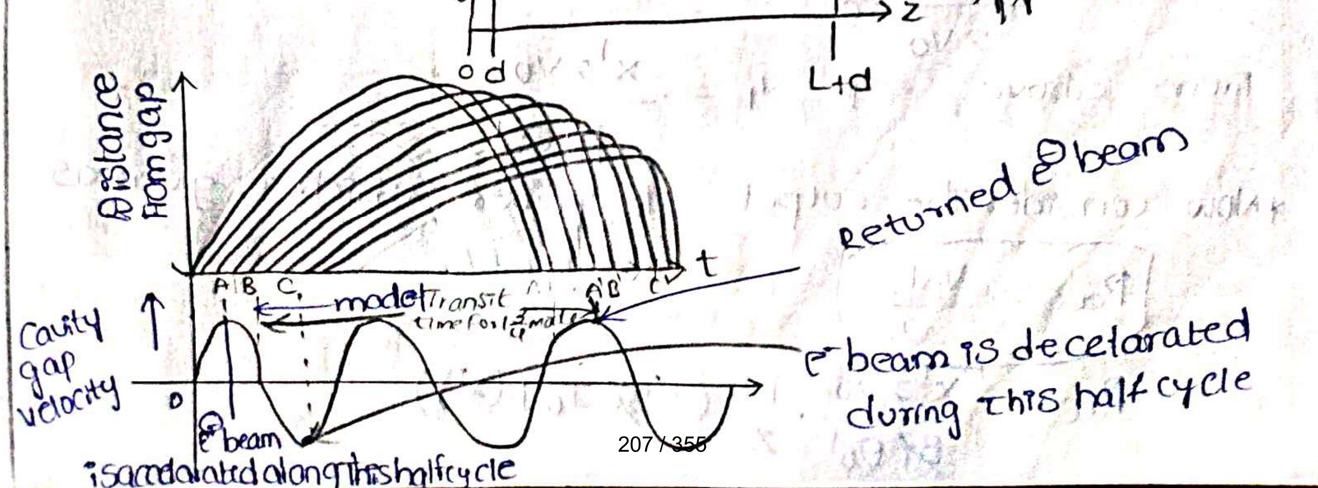
$$P_{in} = I_0 V_0$$

$$\boxed{\eta = \frac{\beta_0 I_2 V_2}{2 I_0 V_0}}$$

② Reflex Klystron Oscillator:



$$T_r = T(n + 3/4)$$



*In This Tube only A single Cavity is available for velocity Modulation Process.

*A Repeller is attatched to ~~the~~ tube which is supplied -ve voltage

*The $e^{\ominus}$ beam is first velocity Modulated by The Cavity gap vlg.

*Some of $e^{\ominus}$ are accelarated by +ve half cycle and some $e^{\ominus}$ are decelarated during -ve half and some $e^{\ominus}$ travels with an unchanged velocity.

*All the $e^{\ominus}$ turned around by The Repeller voltage when the leave The Cavity gap in Bunches That occurs Per cycle These $e^{\ominus}$ are Finally collected by walls of the Cavity.

Output Power and Efficiency:

due to -ve vlg The $\bar{e}$ are Randtrip (turning around and collect)

*The Randtrip dc transit angle of Reflex klystron oscillator is given as $\theta_0' = 2n\pi - \frac{\pi}{2} \longrightarrow$ ①

where n = no. of oscillating Modes in RKO

*The Fundamental Component of The induced current at the Cavity is given as

$$I_2 = 2\beta_i I_0 J_1(x') \longrightarrow ②$$

β_i = $e^{\ominus}$ Beam coupling co-efficient
I_0 = i/p current

*The Bunching parameter of reflex klystron oscillator is

$$x' = \frac{\beta_i V_1}{2V_0}\theta_0'$$

From above exp $V_1 = \frac{x' 2V_0}{\beta_i \theta_0'}$

*Now consider the output A/c power which is given as

$$\boxed{P_{ac} = \frac{V_1 I_2}{2}}$$

$$P_{ac} = \frac{x' 2V_0}{\cancel{\beta_i}\,\theta_0'} \cdot \frac{1}{\cancel{2}} \cdot (\cancel{2}\cancel{\beta_i}\, I_0 J_1(x'))$$

$$P_{ac} = \frac{x' 2 V_0 I_0 J_1(x')}{\theta_0'}$$

$$P_{ac} = \frac{2x' V_0 I_0 J_1(x')}{2n\pi - \frac{\pi}{2}}$$

*The efficiency of Reflex klystron Oscillator is given as

$$\eta = \frac{P_{ac}}{P_{dc}} = \frac{\text{o/p power}}{\text{i/p power}}$$

$$\eta = \frac{P_{ac}}{V_0 I_0}$$

$$\eta = \frac{2x' \cancel{V_0} I_0 J_1(x')}{(2\pi n - \pi/2) V_0 \cancel{I_0}}$$

$$\boxed{\eta = \frac{2x' J_1(x')}{2n\pi - \pi/2}}$$

Mid-1

Characteristics of RKO:

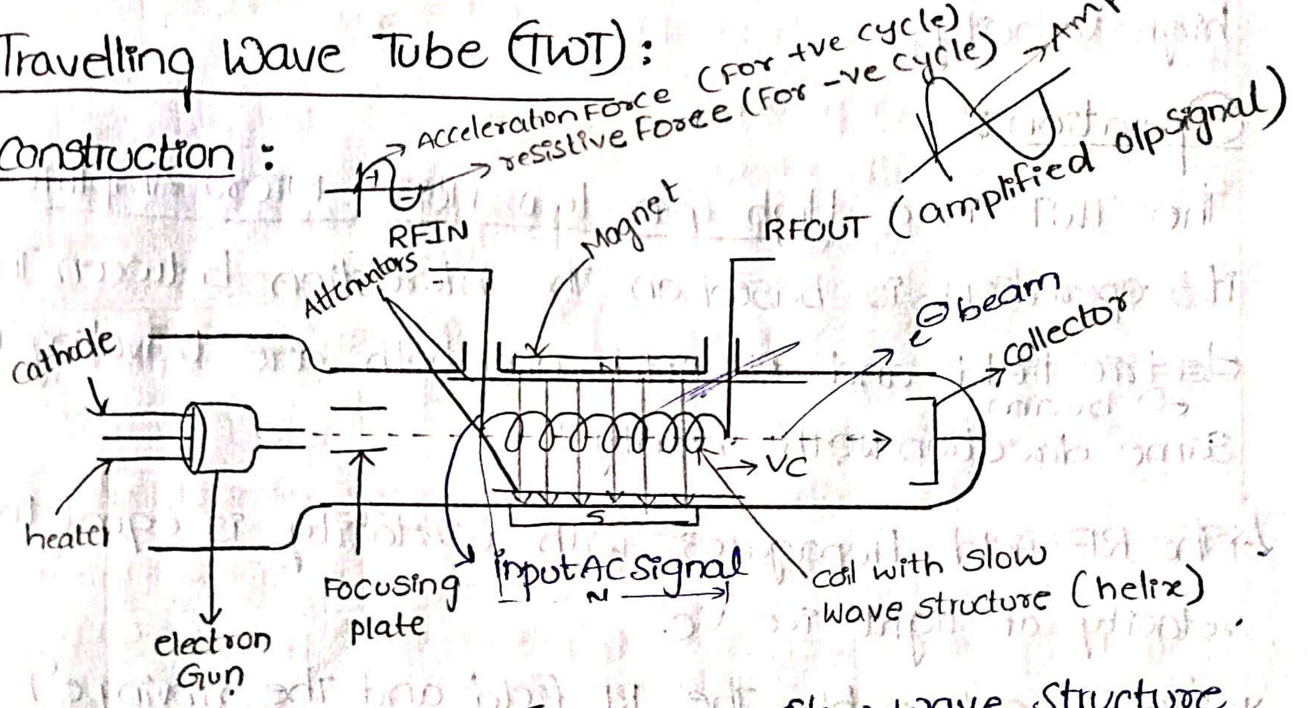
1. output power = 1mW - 2.5[illegible]W
2. Freq = 4[illegible]GHz - 200GHz
3. Efficiency = 20-30%

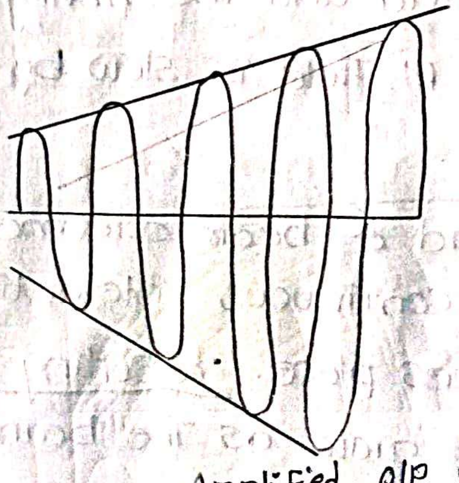
Applications:

1. used in Radar receivers
2. used in FM oscillator
3. used in Parametric amp^r

③ Travelling Wave Tube (TWT):

Construction:





Amplified o/p of TWT

∴ Slow wave structure [To reduce the velocity of The wave, so we can have maximum interaction with $e^{\ominus}$ and i/p ac signal so we get maximum current)

- working principle (Velocity Modulation Process)

Electron Gun: It Produces narrow constant velocity $e^{\ominus}$ beams.

Magnets: It used to Prevent the beam from Spreading and to guide it to the center of Helix. (to avoid Spreading)

Attenuator: It is used to isolate i/p and o/p wave

Helix (or) coil with slow wave structure: It is a wound thin conductor helical wire which acts as a slowwave struction.

RF i/p is applied at one end of helix and o/p is taken at other end of helix as shown in Fig.

Collector (Anode): It is a made +ve potential and as a result beam is attracted to collector and acquires high velocity.

Operation:

The TWT is a High Gain low Noise Micro Amplifier. its operation is based on the interaction between the ~~electric field~~ $e^{\ominus}$ beam and RF Field and both are traveling in same direction with nearly

- *The RF Field Propagates with a velocity is equal to velocity of light i.e Vc.
- *The interaction b/w the RF field and the moving $e^{\ominus}$ beam which takes place when the RF Field is slow by using slow wave structure i.e helix.
- *In TWT when RF wave and $e^{\ominus}$ beam are moving with similar velocities a continuous interaction b/w i/p wave and $e^{\ominus}$ beam takes place. resulting in $e^{\ominus}$ bunches. and these Bunches grow as the beam further the move in helix.

* The $e^{\ominus}$ gun Produces a $e^{\ominus}$ beam is travel through the center of helix without the touching the helix.

* The RF field due to RF Signal, the traveling with a velocity of light multiplied by the ratio of Helix Pitch to Helix Circumference ($2\pi R$).

The Phase velocity Vp is given as

$$V_p = \frac{V_c \times \text{Helix Pitch}}{\text{helix Circumference}}$$

V_c = velocity of light
R = Radius of helix.

* The interaction takes place b/w the $e^{\ominus}$ beam and RF field when they are travelling through the helix. and the $e^{\ominus}$ beam deliverse the energy to RF Field (wave) in helix

Differences:

Klystron	TWT
1. Two 2. one	3. No
2 i/p signal	interaction takes for total wave (length of the wave) over entire
3. No propagating wave	propagation of wave
4. Lower BW	High B.W

Characteristics:

Frequency = 1 GHz to 1000 GHz
efficiency η = 5% to 20%
output power = 20W - 250KW
tunning range = upto 40GHz
noise figure = 6db - 25db

Applications of TWT:

* Low noise RF Amplifier used in broadband Applications.
* It is used as repeater Amplifier for long distance Communication.
* It is used as a power amplifier in satellite Communication.
* It is used in radar technology.

Difference between klystron Tubes and TWT

Klystron tube	TWT
1. Interaction between $e^{\ominus}$ beam and input AC signal occur only at cavity gap.	1. Interaction between $e^{\ominus}$ beam and input AC signal occurs continuously over the entire length of circuit.
2. In Klystron tubes the cavities functions independently	2. In TWT all the devices are effectively coupled
3. In klystron the signal is not a propagating wave	3. In TWT the signal is a propagating wave
4. It have lower Bandwidth	4. More B.W and high gain.

Gain Considerations of TWT:

The output power gain of Travelling wave Tube in decibels is given as $A_p = -9.54 + 47.3NC \longrightarrow ①$

A_p = output power
N = length of ckt
C = traveling wave tube gain Parameter which is

given as $C \approx \left(\frac{I_0 Z_0}{4V_0}\right)^{1/3} \longrightarrow ②$

where $I_0 = e^{\ominus}$ beam current
Z_0 = characteristic impedence of ~~ellips~~ helix
V_0 = beam voltage

Q. A TWT operates with the following parameters beam v/g = 3kV, beam current = 30mA and characteristic impedence = 10Ω, ckt length = 50. calculate the o/p power gain in dBs

$A_p = -9.54 + 47.3NC$

given $Z_0 = 10\Omega$
$V_0 = 3kV$
$I_0 = 30mA$
$N = 50$

$$C = \left(\frac{I_0 Z_0}{4V_0}\right)^{1/3} = \left(\frac{30mA \times 10}{4 \times 3 \times 10^3}\right)^{1/3}$$

$C = 0.0292 = 29.2m$

$N = 50$

$\boxed{A_p = 59.25} = 59.518$

Expression for Amplified current of TWT ::

The current in the TWT amplifier along z- direction is given as

$$I(z) = I_0 + I_1 e^{j\omega t - \gamma z} \longrightarrow \text{①}$$

where I_0 = static current ; I_1 = amplified current

The axial electric field in TWT along the z-direction is given as

$$E(z) = E_1 e^{j\omega t - \gamma z} \longrightarrow \text{②}$$

Now the current density of direction z is given as

$$J(z) = J_0 + J_1 e^{j\omega t - \gamma z} \longrightarrow \text{③}$$

The current density (J_1) according to the "continuity eqn" is given as

$$J_1 = j\beta_e \cdot \frac{J_0}{2V_0} \cdot \frac{E_1}{(j\beta_e - \gamma)^2} \longrightarrow \text{④}$$

where β_e = phase constant $= \frac{\omega}{V_0}$

Now the amplified current of TWT is given as

$$J_1 = \frac{I_1}{A} \Longrightarrow I_1 = J_1 \cdot A$$

from ④

$$I_1 = j\beta_e \cdot \frac{J_0}{2V_0} \cdot \frac{E_1}{(j\beta_e - \gamma)^2} \cdot A$$

$$J_0 = \frac{I_0}{A} \longrightarrow \text{⑤}$$

$$I_1 = j\beta_e \frac{I_0}{\cancel{A}} \cdot \frac{1}{2V_0} \frac{E_1}{(j\beta_e - \gamma)^2} \cdot \cancel{A}$$

$$\boxed{I_1 = j\beta_e \frac{I_0}{2V_0} \cdot \frac{E_1}{(j\beta_e - \gamma)^2}}$$

The expression above is called as amplified current eqn of TWT (or) "electronic eqn of TWT".

Construction and Operation of Magnetron: (M-type Tube)

Magnetron is a M-type tube also known as "Cross Field Tubes". because the DC electric field and the DC Magnetic Field are ⊥er to each other.

* In klystron tubes the e^- beam are in contact with the input RF field at the resonant cavities only for a short duration.

* If the e^- can be made to interact with the RF field from for longer duration then high efficiency can be obtained. This can be done in TWT & Magnetrons:

⇒ There are 3 types of Magnetrons

1. Negative resistance Magnetron.
2. cyclotron Freq magnetron
3. Cavity Magnetron

1. Negative resistance Magnetron:

These Magnetron make use of -ve resistance between two segments and are only useful at low Frequencies.

2. Cyclotron Frequency Magnetron:

these Magnetron depends upon the Synchronism b/w the AC electric Field and periodic oscillations of the e^-'s parallel to the electric field, these Magnetron are useful for high Frequencies.

most useful

3. Cavity Magnetron:

This Magnetron depends upon the interaction of the e^- beam with the rotating electromagnetic Field of const. angular velocity. It provides very high power and are useful in radar applifations.

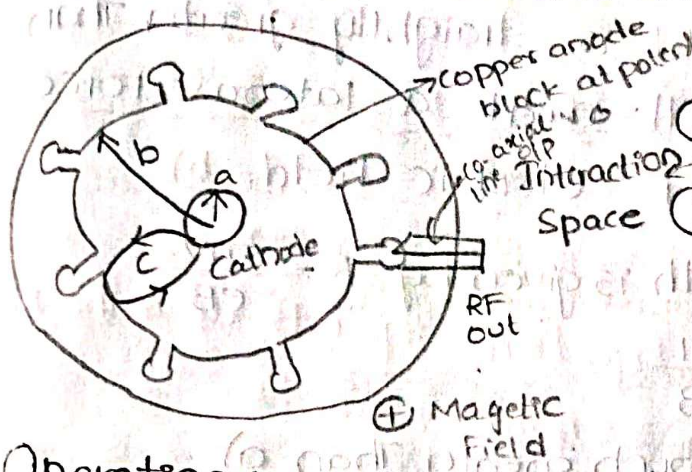
Construction of 8 Cavity Cylindrical Magnetron:

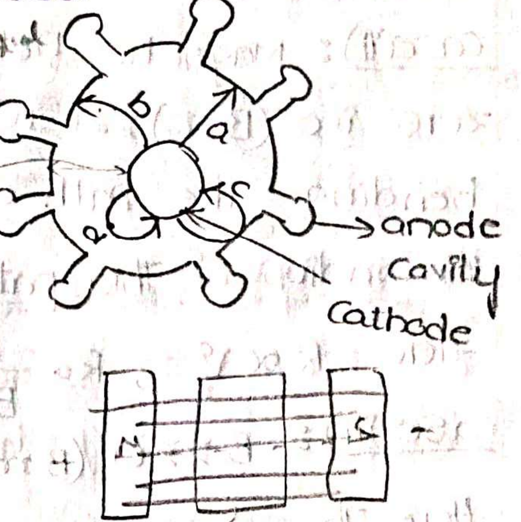
* It consist of a cylindrical configuration with thick cathode at the centre and co-axial cylindrical block of copper as an anode.

* In the anode part a no. of holes (or) slots are cuts which act as a resonant cavities.

The Space between the anode and cathode are called as "Interaction Space".

*A permanent Magnet is placed Such That The Magnetic Fields are parallel to the cathode and ⊥er to The electric Field between Cathode and anode.





Operation:

*The Cavity Magnetron has 8 Cavities That are tightly coupled system.

*In general n cavity tightly coupled system will have n modes of oprs which are uniquely characterized by phase and freq. of oscillations.

*The Phase shift between two Cavities is ϕ_v is given by $\phi_v = \frac{2\pi n}{N}$

N = no. of cavities ; $n = 0, \pm 1, \pm 2 \ldots \pm \frac{N}{2}$

*If $n = \frac{N}{2}$ we will get $\phi_v = \frac{2\pi\left(\frac{N}{2}\right)}{\frac{N}{2}} = \pi$

$$\boxed{\phi_v = \pi}$$

-Here The Magnetron Operates in π-Mode operation

*If $n=0$, then $\phi_v = 0$, Here The Magnetron operates in zero-Mode operation. which means there is NO presence of RF Field and No use of Magnetron operation.

To understand the opm of Cavity Magnetron, we should, Know The how $e^{\ominus}$ will behave in The Presence of electric Field and Magnetic Field.

*The $e^\ominus$'s will emit from cathode to anode.

<u>case(i)</u>: electric field is present, Magnetic field is zero [B=0]. The $e^\ominus$ travels straight from ~~anode~~ cath to anode (a)

<u>case(ii)</u>: Magnetic Field is straightly greater than zero i.e (B>0), It will exert a lateral Force bending the path of electric Field. (b)

The radius of this path is given by $R = \frac{mv}{eB}$

Here $R \propto v$, $R \propto \frac{1}{B}$

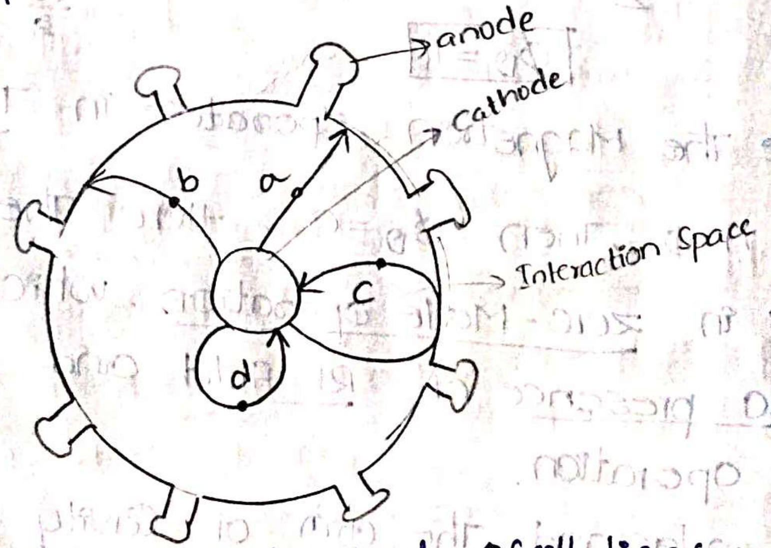
<u>case(iii)</u>: B>>0 (B much greater than 0)

Here the $e^\ominus$s are not reaches the anode cavity

The amount of Magnetic Field required for the $e^\ominus$ to return back to the cathode just by touching the anode cavity is known as critical magnetic Field (Bc). (c)

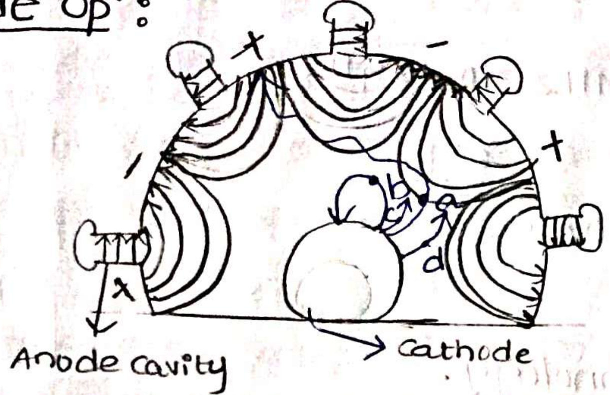
<u>case(iv)</u>: B > BC

Due to the presence of larger amout of magnetic field a greater rotational force will experience by the $e^\ominus$ and hence the $e^\ominus$ return back to the cathode very fast. (d)



In above 4 cases no RF Field oscillations present

π-Mode op^{r}:



*Let us consider the RF oscillations are present, Here the anode poles (or) cavity are π $\overset{180^\circ}{-}$ radians apart. The $e^{\ominus}$ a is seen to be slowdown in the presence of oscillations and takes longer journey from cathode to anode, This type of $e^{\ominus}$ participate in transfering the energy to the RF oscillations and are responsiple for Buching effect. these type of $e^{\ominus}$'s are called favoured $e^{\ominus}$'s.

*The electron is accelerated from the cathode instead of giving (or) impacting energy to the oscillations, it takes energy from the oscillations and increases its velocity which results it bending very sharply and return back to the cathode.

The $e^{\ominus}$ b spends very less time in the interaction space, this type of $e^{\ominus}$s are called unfavoured $e^{\ominus}$'s. and do not participate in Bunching process. These $e^{\ominus}$s are harmful because it causes "backheating."

*The $e^{\ominus}$ c tries to catch up the $e^{\ominus}$ a and $e^{\ominus}$ d will be slowdown instep with $e^{\ominus}$ a. This results all the Favoured $e^{\ominus}$'s a, c, d form a Bunch. The Magnetron when it is operated in π-Mode it gives High efficiency i.e Maximum o/p power and desired Freq.

Characteristics:

Frequency : 500MHz to 12GHz
Efficiency : 40% – 70%
power : upto 250KW

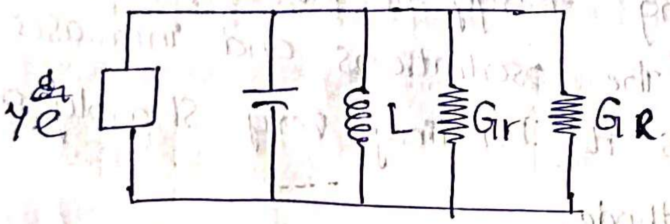
Applications:

- used radar Technology.
- used as Tunnable ckts For high Frequencies.
- used in Mitary applications.

Efficiency of The 8-cavity Magnetron:

The efficiency of the Magnetron depends upon The Two parameters namely 1. resonant structures
2. DC power supply.

Let us consider a equivalent circuit For 1-resonant Cavity of The 8-cavity Magnetron.



where Y_e = electronic admittance
G_r = conductance of the resonator
G_l = load conductance of the resonator

The ckt efficiency of Magnetron is given as

$$\boxed{\eta_c = \frac{G_l}{G_l+G_r} \Rightarrow \frac{G_l}{G_{ex}}}$$

where G_{ex} = external ckt conductance

The efficiency can be expressed interms of Quality factor which is given as:

$$\boxed{\eta_c = \frac{1}{1+\frac{Q_{ex}}{Q_{un}}}}$$

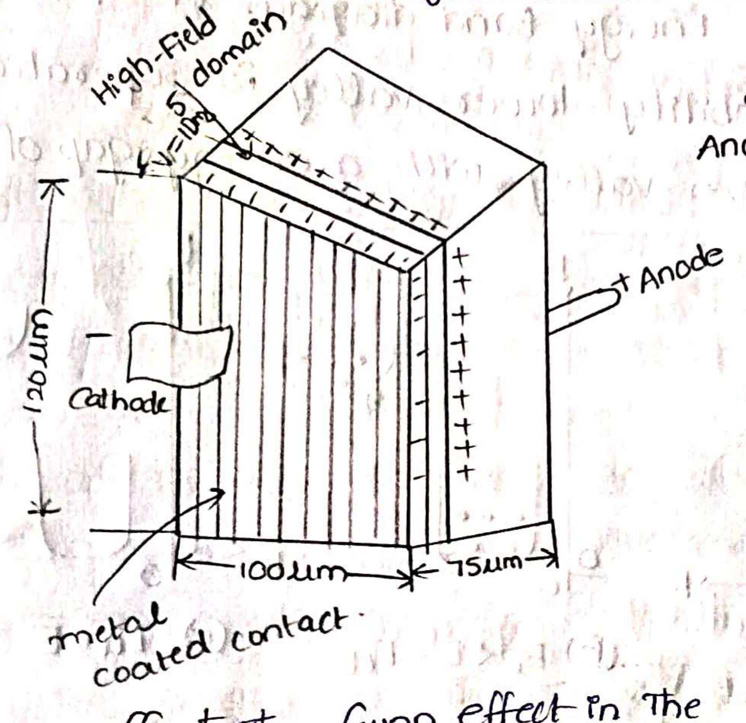
where Q_{un} = Quality Factor of unloaded cavity
Q_{ex} = external Quality Factor of load ckt

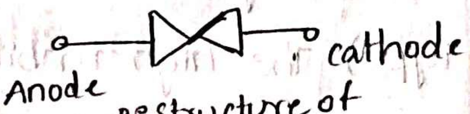
TED (Transfered Electron Device):

* The difference between microwave transistors and TED'S is that the transistors are operated with either junctions (or) gate but TED'S are Bulk devices having no-Junction (or) gate.

* Transistors are Fabricated from Semiconductors like Si, Ge, where as TED'S are Fabricated from Semiconductors like Ga, AS, In, P, Cd, Te   Ga AS ⟶ Gunndiode (or) Gallium arsanoidediode

* Gunn diodes are named after the scientist J.B. Gunn, who discovered in 1963 and observed a periodic ascillations (or) fluctuation of current passing through the Gunndiode when the applied voltage exceeds threshold.



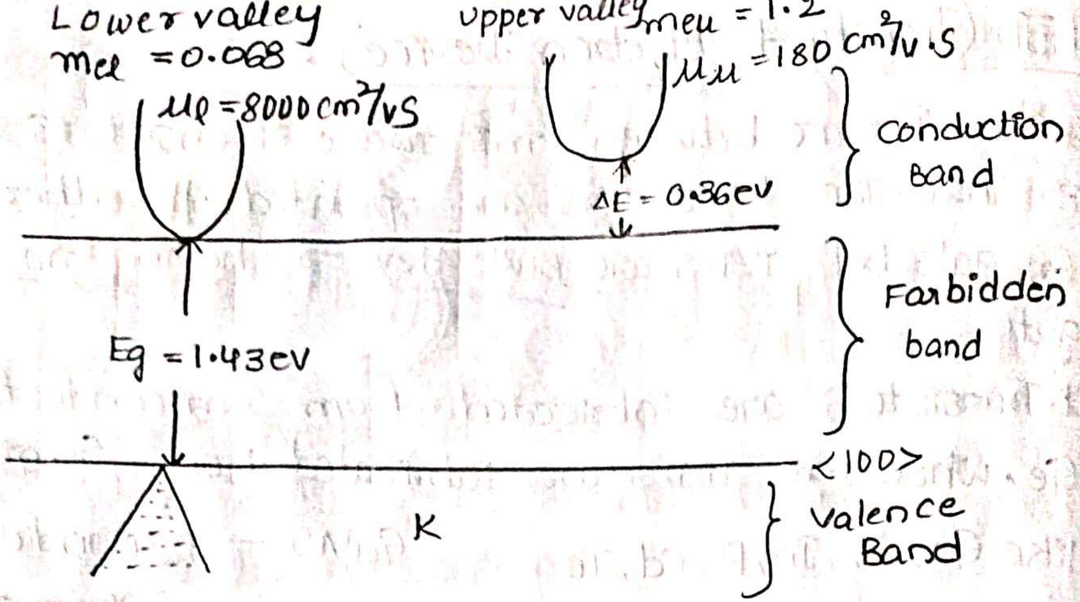


∴ Structure of Gundiode

- works on Gunn effect
- It offers -ve resistance
- used in high Freq (micro wave app.)
- GaAS

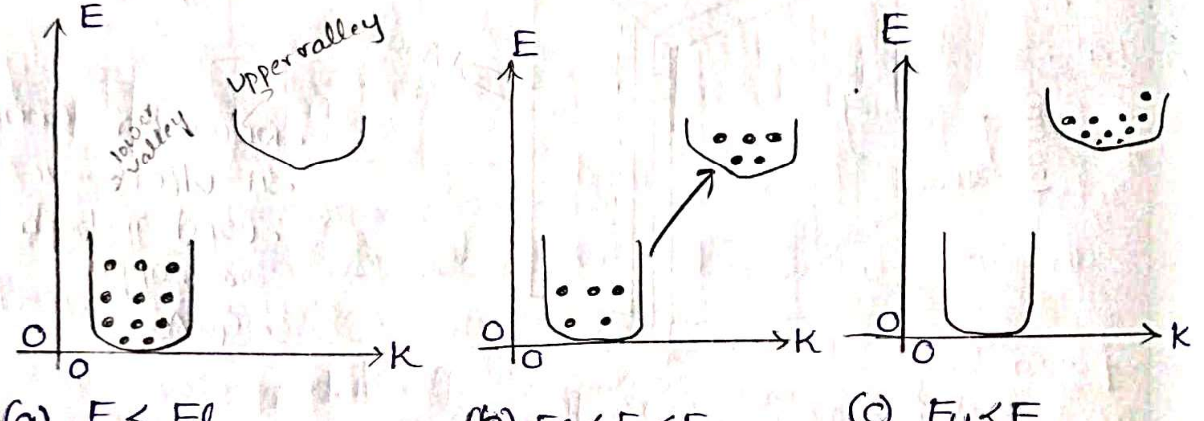
Gunn Effect: The Gunn effect in the n-type GaAs as shown in Fig. states that the carrier drift velocity of e⁻'s is linearly increased from 0 to maximum when the electric field is varied from 0 to threshold value. When the electric is beyond the threshold the drift velocity of e⁻ s decreased and the diode exibits negative resistance.

Two valley model theory: The opr of the Gunn diode is explained by considering the energy band diagram of n-type GaAS as shown in Fig



m_{eu} = effective mass in upper valley
μ_u = mobility in upper valley
m_{el} = effective mass in lower valley
μ_l = mobility in lower valley

According to the Energy Band diagram of GaAs (of n-type) the high mobility lower valley is seperated from low mobility upper valley with a energy gap of 0.36eV



(a) $E < E_l$
↳ applied electric Field

(b) $E_l < E < E_u$

(c) $E_u < E$

∵ Transfer of electron densities.

E = applied electric Field
E_u = applied electric Field in upper valley
E_l = applied electric Field in lower valley

The electron densities in lower vally and upper valley remains the same under equilibrium condition when the applied electric Field is lower than the electric field of lower valley i.e $E < E_l$ then no $e^{\ominus}$ transfer to the upper valley as shown in Fig.

* When applied electric Field higher Than that of The upper valley and lower Than That of lower valley i.e. $E_u < E < E_l$ then some of $e^{\ominus}$ will begin to transfer to the upper valley as shown in Fig.

* When the applied electric Field is higher than That of The upper valley i.e $E_u < E$, Then all The $e^{\ominus}$ will transfer to The upper valley as shown in fig.

* If The $e^{\ominus}$ densities in Lower and upper valley are n_l and n_u rep. Then The conductivity of The n-type GaAs is given as $\boxed{\sigma = e(\mu_l n_l + \mu_u n_u)}$

where $e = e^{\ominus}$ charge

μ_l, μ_u = mobilities of valley

n_l, n_u = $e^{\ominus}$ densities of valley.

reverse bias

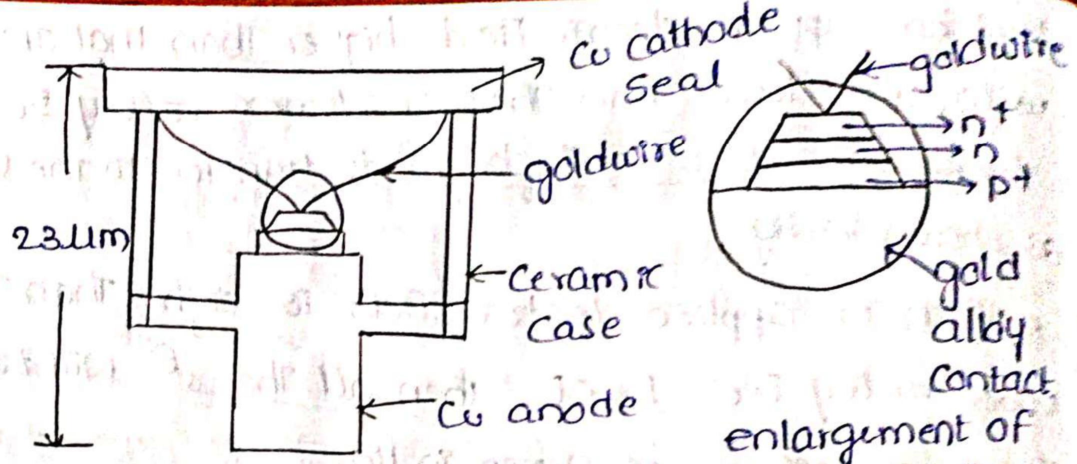
Avalanche transit time Devices:

* The Process of having delay b/w v/g and c/t in an Avalanche together with transit time to a material is said to be negative resistance.
* The devices That to help to make a diode exhibits This property is called Avalanche transit time device.
* These devices carrier Impact Ionization & drift in The high Field region of Semiconductor junction to produce -ve resistance at microwave Frequencies.
* There are 3-types, 1. IMPATT Device (read diode)

  2. TRAPATT Device
  3. BARITT Device

Construction of IMPATT Diode:

IMPATT : Impact Ionization Avalanche Transit time Diode



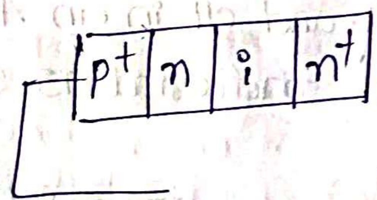
enlargement of active region

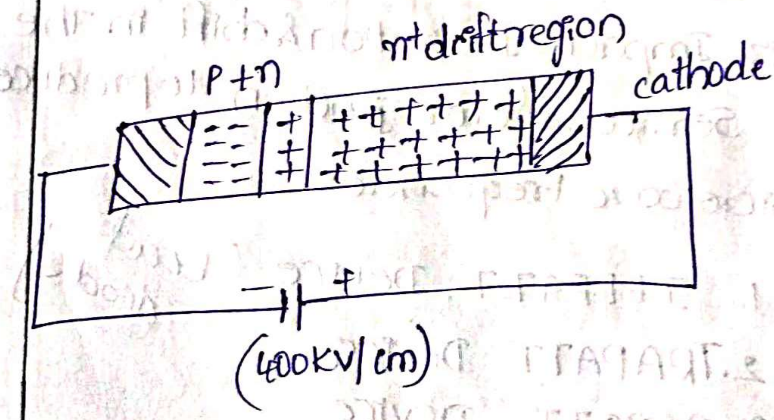
IMPATT
TRAPATT
Diodes - Ass-2

Impatt —

Impact Ionization Avalanche transit time device

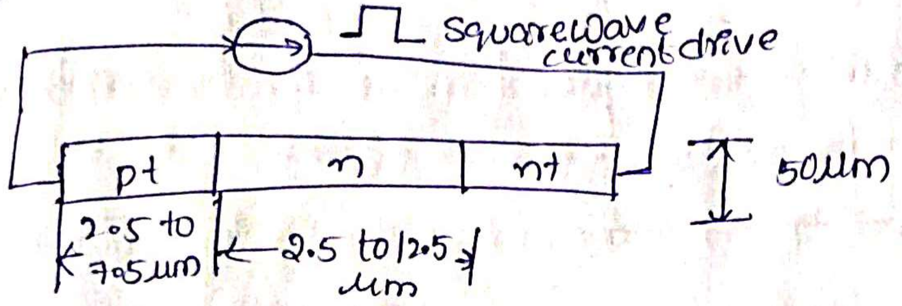
high Frequency power applications

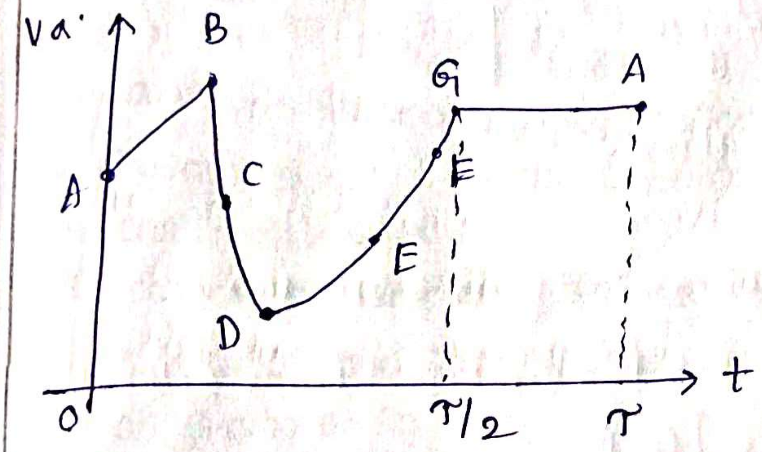




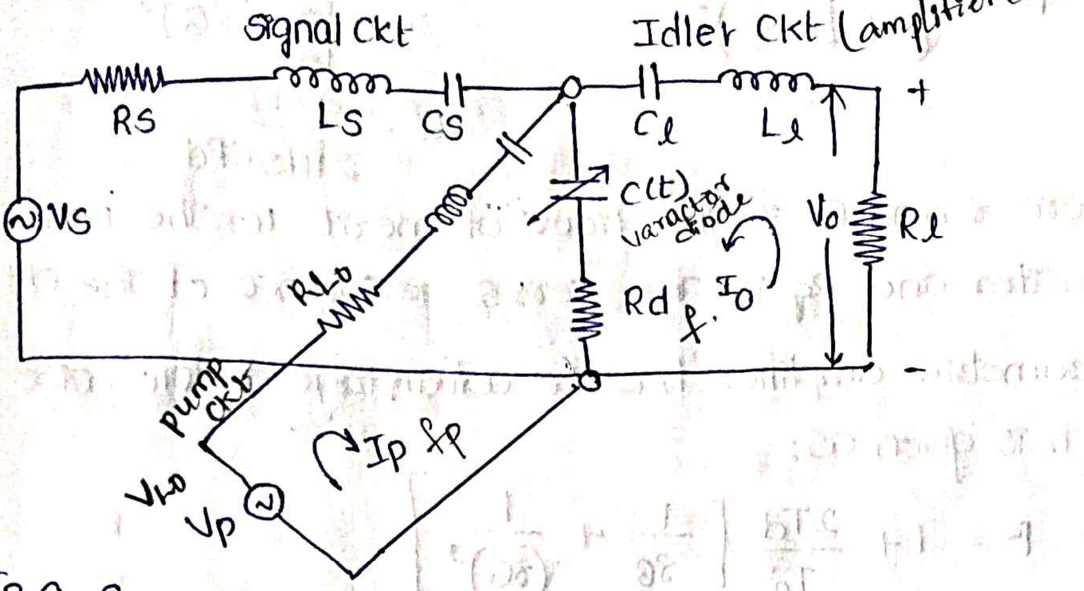
TRAPATT : Trapped Plasma Avalanche Triggered Transit diode.

(i) $n^+ - P - p^+$ (ii) $p^+ - n - n^+$





Parametric Amplifier:



*In a Superheterodyne receiver, the signal may be mixed with the sequene signal from the local oscillator to generate sum and difference frequencies.

*In parametric amplifier, the local oscillator is replaced by reflex klystron and the non-linear element is replaced by inductor as shown in fig.

*The output frequency 'fo' in the idler ckt is given as sum and difference freq. of signal frequency (fs) and pump freq. "fp".

$$\boxed{f_o = mf_p + nf_s}$$

where m and n are +ve integers.

(i) if $f_o > f_s$ then the device act as parametric upcounter.

(ii) if $f_o < f_s$ then the device act as parametric downcounter.

parametric Upcounter:

*A parametric upcounter has following properties:

1) output frequency is equal to sum of pump frequency and signal frequency. $f_o = f_p + f_s$ $\quad f_p - f_o$

2) There will no power flow in the parametric devices at frequencies other than signal, pump and output frequencies.

*When these 2 conditions are satisfied, the maximum power gain of parametric upcounter is given as:

$$\frac{f_o}{f_s} = \frac{x}{(1+\sqrt{1+x})^2}$$ where $f_o = f_p + f_s$

$$x = \frac{f_s}{f_o}(\gamma Q)^2$$

$$Q = \frac{1}{2\pi f_s C R_d}$$

Where γ and Q is the figure of merit for the non-linear Capacitor and Rq is the series resistance of the ckt.

* Parametric amplifier has the advantage of low noise figure which is given as:

$$F = 1 + \frac{2T_d}{T_o}\left[\frac{1}{\gamma Q} + \frac{1}{(\gamma Q)^2}\right]$$

where
T_d = diode temp.
T_o = 300°k temp
γQ = FOM of non-linear Capacitor.

* The Bandwidth for the Parametric Upconverter is given by $\boxed{BW = 2\gamma\sqrt{\frac{f_o}{f_s}}}$

Parametric Down Counter:

* In these mode the signal Frequency will be equal to sum and of pump Frequency and o/p Freq.

$$\boxed{f_s = f_p + f_o}$$

* The power gain of parametric downcounter is given as

$$\text{Gain} = \frac{f_s}{f_o}\,\frac{x}{(1+\sqrt{1+x})^2}$$

Unit-4

Overview of Optical Fibre Communications

Date : 15/04/23

Advantages of optical Fiber Communication:

- * Increased Bandwidth and channel capacity.
- * Low signal Attenuation.
- * Immune to noise
- * No crosstalk
- * Low Bit error rates
- * Signal security
- * electrical Isolation
- * Reduced size and weight of cables.
- * Radiation resistant & environment Friendly
- * Resistant to temp variations etc.

Applications:

* Due to its verity of advantages optical fiber Communication system has wide range of applications in different Fields namely

→ Public Network Field which Includes trunk networks, Junction networks, local access networks submerged system and Synchronous system etc.

→ Field of military Applications.

→ Civil, consumer and Industrial applications.

→ Field of computers which is the center of reasearch right now.

Historical Development:

* The Fiber optics deals with the Propagation of light through Dielectric waveguides i.e optical Fiber, which are used for Transmission of data from point to point location.

First Generation:

* The First generation of Fiber optics uses GaAS S.C layer whose specifications are given as:

(i) Bit rate : 45Mb/s

(ii) Repeater spacing : 10km

(iii) Semiconductor : GaAS

Second Generation:

(i) Bitrate : 100Mb/s to 1.7 Gb/s
(ii) Repeater spacing : 50km
(iii) Semiconductor : GaAS
(iv) wavelength : 1.3um

Third Generation:

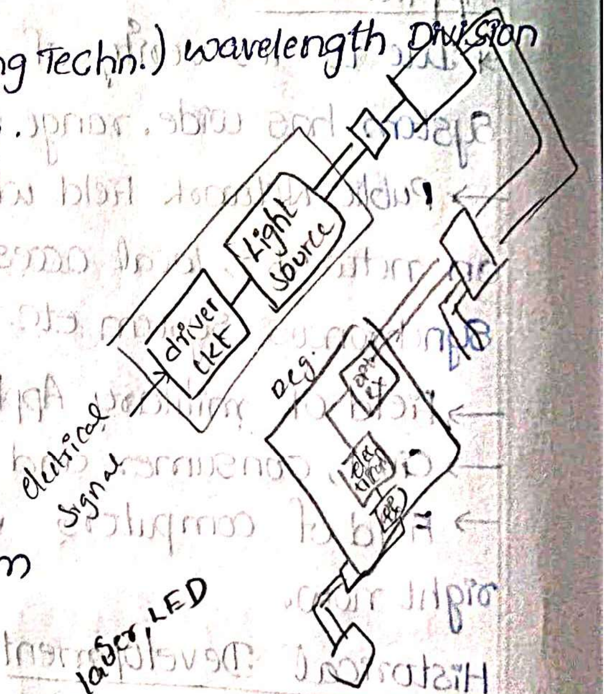
(i) Bit rate : 10 Gb/s
(ii) Repeater Spacing : 100km
(iii) Semiconductor : GaASP
(iv) wavelength : 1.55um

Fourth Generation:

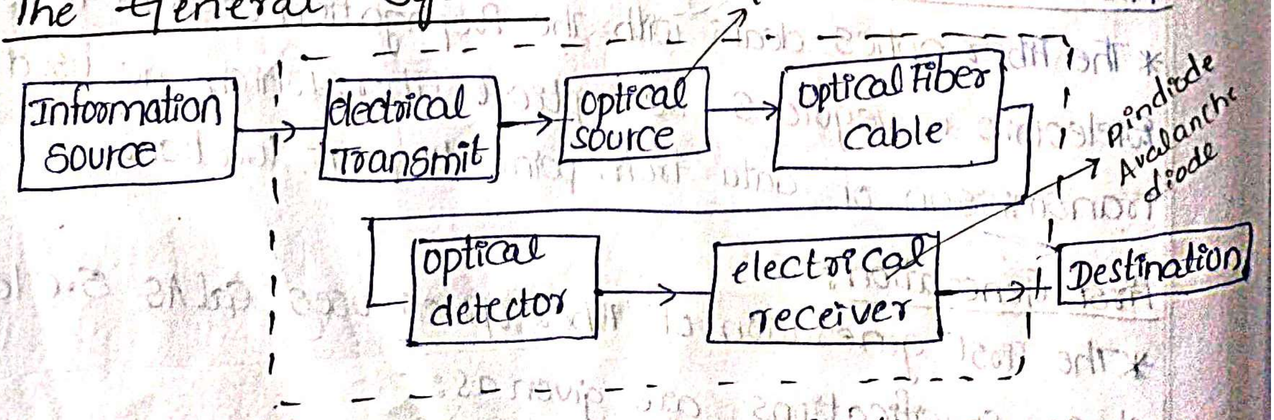
(i) Bit rate : 10 Tb/s
(ii) Repeater Spacing : 10,000km
(iii) WDM - Techique : (Multiplexing Techn.) wavelength Division Multiplexing.
(iv) wavelength = 1.62um

Fifth Generation:

(i) Bit rate : 160 Gb/s
(ii) Repeater Spacing : 35,000km
(iii) WDM Techinque
(iv) wave length : 1.53 to 1.57um



The General System:



optical Fiber communication system

Introduction to Ray Theory Transmission:

Snells law: The angle of incidence θ_1 and the angle of refraction θ_2 are related to each other, and to the refractive indices of the dielectrics by snells law of refraction:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Critical angle:

When the $\phi_2 = 90°$, the incident angle of ~~refrac~~ incidence when angle of refraction is 90° $(\phi_2 = 90°)$

$$n_1 \sin\theta_C = n_2 \sin 90°$$

$$n_1 \sin\theta_C = n_2$$

$$\sin\theta_C = \frac{n_2}{n_1} \Longrightarrow \boxed{\theta_C = \sin^{-1}\left(\frac{n_2}{n_1}\right)}$$

Total Internal reflection:

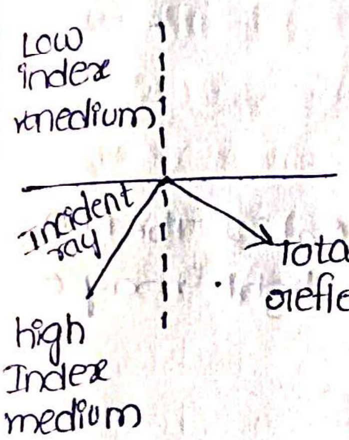


Fig: TIR

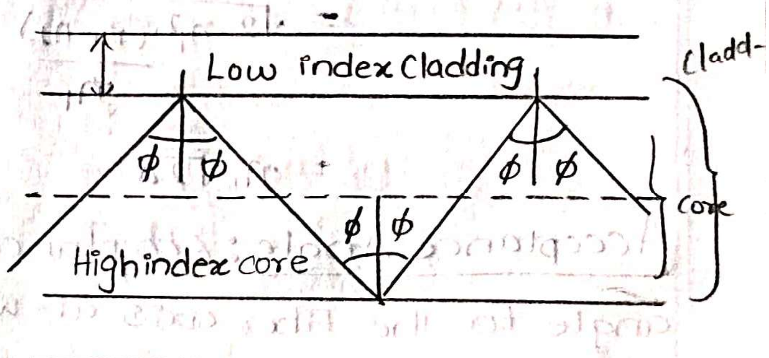


Fig: Transmission of a light ray in Perfect optical Fiber.

* In a Fiber, when the light ray is incident at the core cladding Interface, total internal Reflection (TIR) will occur, since the angle of incident at the core cladding boundary is greater than the critical angle, the gets totally reflected back to the core.

Conditions For TIR takes place:

There are 2 conditions for TIR are:

① The light should travel from higher reflex index material into lower refractive index material.

② Incident angle should be greater Than Critical angle

Numerical Aperture:

Numerical aperture gives light Gathering Capacity of Fiber (or) FOM of Fiber is given as

$$NA = \sqrt{n_1^2 - n_2^2} = n_0 \sin\theta_a$$

where θ_a = aperture angle

n_1, n_2 = refractive index of core and cladding

The refractive index (relative) difference is given by

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$NA = \sin\theta_a = \sqrt{n_1^2 - n_2^2} \qquad n_1 \simeq n_2$$

$$= \sqrt{(n_1 + n_2)(n_1 - n_2)}$$

$$= \sqrt{2n_1 \, (n_1 - n_2)}$$

$$= \sqrt{2 \, n_1^2 \frac{(n_1 - n_2)}{n_1}}$$

$$= n_1 \sqrt{2\Delta}$$

Acceptance Angle: Acceptance angle (θ_a) is The Max angle to The Fiber axis at which The light may enter The Fiber axis in order to Propagated.

Related Formula:

Refractive index (n) = c/v

Snells law ⟹ $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Critical angle $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

Acceptance angle $\theta_a = \sin^{-1}(NA)$

Numerical aperture $NA = \sqrt{n_1^2 - n_2^2} = \sin\theta_a = n_1\sqrt{2\Delta}$

Single Mode vs Multimode:

→ Differences

Meridional rays and skew ray

V-Number $\quad V = \frac{2\pi a}{\lambda} \sqrt{n_1^2 - n_2^2} \quad$ a = radius of Care

$N = 1/2 \, V^2$

②Incident angle should be greater than critical angle.

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Single Mode vs Multimode:

→ Differences

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$N = 1/2\, V^2$

Types of Fibers:

There are two types of optical Fibers:

1. Step index Fiber
2. Graded index fiber

1. Step index Fiber:

- The refractive index of core material is constant through the length of fiber.
- The refractive index Profile makes a step change at core cladding interface

Refractive index Profile:

$$n(r) = \begin{cases} n_1 \; ; & r<a \; (\text{core}) \\ n_2 \; ; & r \geq a \; (\text{cladding}) \end{cases}$$

2. Graded Index:

Refractive index of the core material is non uniform.

Refractive index profile:

$$n(r) = \begin{cases} n_1 \left(1 - 2\Delta \left(\frac{r}{a}\right)^{\alpha}\right)^{1/2} \; ; & r<a \; \text{core} \\ n_2 (1-2\Delta)^{1/2} = n_2 ; & r \geq a \; \text{cladding} \end{cases}$$

r = radical distance from ~~center~~ core axis.

Problems:

Q. Calculate the NA, acceptance angle, Critical angle of Fiber having $N_1 = 1.50$ and $N_2 = 1.45$ (always $N_1 > N_2$)

$$N.A = \sqrt{n_1^2 - n_2^2} = 0.384$$

$$\theta_a = \sin^{-1}(NA) = 22.78$$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) = 75.46.$$

Q. Calculate the refractive indices of core and cladding of fiber whose NA is 0.35, relative refractive index difference as 0.01

$NA = 0.35$

$\Delta = 0.01$

$$NA = \sqrt{2 \times \Delta} \cdot n_1$$

$$NA = \sqrt{2 \times 0.01}\, n_1$$

$$n_1 = \frac{0.35}{\sqrt{2(0.01)}} = 2.47$$

$$NA = \sqrt{n_1^2 - n_2^2}$$

$$n_1^2 - n_2^2 = (NA)^2$$

$$n_2^2 = n_1^2 - (NA)^2 = .$$

$\boxed{n_2 = 2.45}$ $\boxed{n_1 = 2.47}$

Q. In a multimode step index fiber with core diameter of 80um and relative refractive index difference of 1.5% is operating at a wavelength of 0.85um with core refractive index of 1.48 and calculate Normalized Freq and no. of modes supported by fiber.

$n_1 = 1.48$
$d = 80\mu m$
$a = 40\mu m$
$\Delta = 1.5\% = \frac{15}{100}$
$\Delta = 0.015$
$\lambda = 0.85\mu m$

$$N = \frac{V^2}{2}$$

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}$$

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$\Delta \times n_1 = n_1 - n_2$$

$$n_2 = n_1 - \Delta n_1 = 1.4578$$

$$V = \frac{2\pi\,(40 \times 10^{-6})}{0.85 \times 10^{-6}}\sqrt{(1.48)^2 - (1.457)^2}$$

$\boxed{V = 75.69}$

$$N = \frac{V^2}{2} = 2864 \text{ modes}$$ $\boxed{N = 2864 \text{ modes}}$

Q. A step index Fiber has a NA of 0.2 and a cladding refractive index of 1.59. determine the θ_a, θ_c, and also no. of modes supported by fiber operating at λ = 1300nm and 25um core radius.

$NA = 0.2$

$\Delta = 1.59$

$\theta_a = \sin^{-1}(NA) = 11.53$ $\boxed{\theta_a = 11.53}$

$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$ $NA = n_1\sqrt{2\Delta}$

$\boxed{\theta_c = 82.9}$ $n_1 = \frac{NA}{\sqrt{2\Delta}} = 0.112$

$\boxed{N = 292}$ $NA = \sqrt{n_1^2 - n_2^2}$

$n_1^2 - n_2^2 = (NA)^2$

n_2

Q. For a single mode fiber $N_1 = 1.49$, $N_2 = 1.47$, find the cutt of ~~frequenc~~ wavelength of fiber, if the core radius is 2 µm

$N_1 = 1.49$; $N_2 = 1.47$, $a = 2\,\mu m$

$V = \frac{2\pi a}{\lambda c}(NA)$

$\boxed{V = 2.405 \text{ For Single mode}}$

$\lambda c = \frac{2\pi a}{V}(NA)$

$NA = \sqrt{n_1^2 - n_2^2}$.

$\boxed{\lambda c = 1.27\,\mu m}$

MFD

Unit-5

Signal degradation in optical Fiber

Date:

Attenuation: As light travels along a fiber. It's Power decrease exponentially with distance. If P(0) is the optical Power in a fiber at the origin (at z=0) then the Power P(z) at a distance z further down the fiber is

$$P(z) = P(0)\, e^{-\alpha_p \cdot z}$$

$$\alpha_p = \frac{1}{z} \ln\left[\frac{P[0]}{P[z]}\right]$$

where α_p is the fiber attenuation co-efficient given in units of for example km^{-1}

★ **Absorption:**

*Absorption is caused by three different Mechanisms:

1. Absorption by atomic defects in the glass composition.
2. Extrinsic absorption by impurity atoms in the glass material
3. Intrinsic absorption by basic constituent atoms of the fiber material.

1. **Absorption by Atomic defects:**

*Atomic defects are imperfections in atomic structure of the fiber material like missing molecules, oxygen defects in the glass structure.

*Absorption losses arising from these defects are negligible comp° to Intrinsic and extrinsic absorption.

*They are significant if the fiber is exposed to ionizing radiation.

*The higher the radiation level, the larger Attenuation

2. **Extrinsic absorption by impurity atoms:**

*This results from Transition metal ions such as iron, Chromium, cobalt, copper and OH ions.

* The Transition metal impurities causes losses from 1 to 10 dB/km

3. <u>Intrinsic absorption</u>:

* This is associated with the basic fiber material like pure silica.

<u>Attenuation Mechanisms</u>: There are 3 Mechanisms

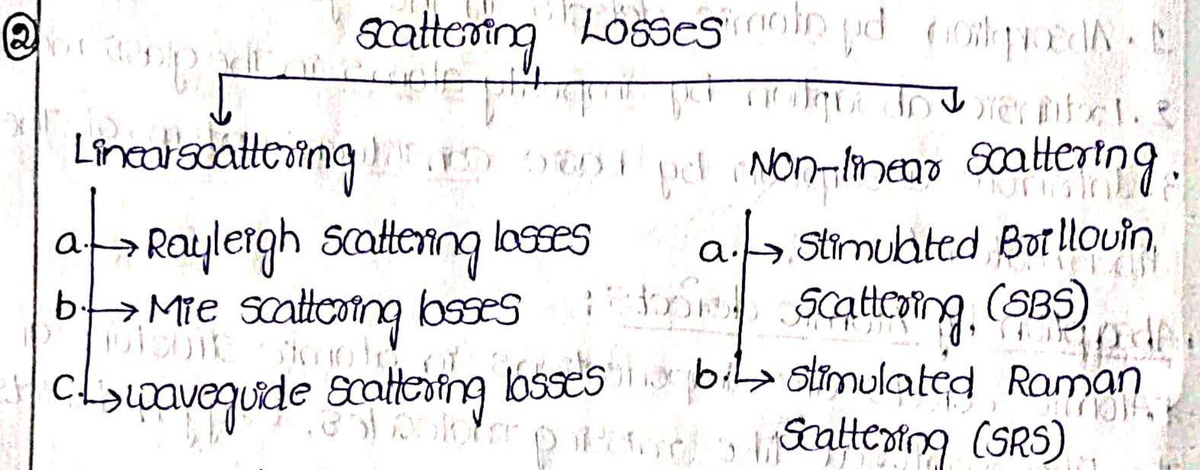
1. Absorption losses 2. Scattering losses 3. Radiation losses
4. Core and cladding losses.

<u>Scattering</u>: It is the Process in which all optical fiber are Transferred from one mode to another mode i.e guided mode to radiation mode.

<u>Causes of scattering losses</u>: exist due to

* Compositional Fluctuations
* Structural inhomogenities
* Structural defects in fiber.
* Microscopic variations in density of fiber material.

②



Scattering Losses

Linear scattering
- a. Rayleigh scattering losses
- b. Mie scattering losses
- c. waveguide scattering losses

Non-linear Scattering.
- a. Stimulated Brillouin Scattering (SBS)
- b. Stimulated Raman Scattering (SRS)

It occurs due to microscopic variations in material density, composition fluctuations...

(a) <u>Rayleigh scattering losses</u>:

* These losses are due to microscopic variation in the material of the fiber.

* Unequal distribution of molecular densities (or) atomic densities leads to RSL

For SiO_2 fiber, Rayleigh loss is given by

$$\boxed{\alpha_{scat} = \frac{8\pi^3}{3\lambda^4} n^8 p^2 \beta_c k T_F \, m^{-1}}$$

where n = Refractive index of silica

P = Photoelastic co-efficient of silica

β_c = Isothermal compressibility

T_F = Fictive temperature at which solidification of glass takes place.

(b) Mie scattering losses:

* These losses results from the compositional fluctuations, structural inhomogenitics and defects created during fiber fabrications, causes the light to scatter outside the fiber.

(c) Waveguide scattering losses:

* It is a result of variation in core diameter, imperfections of the core cladding interface, change in RI of either core (or) cladding.

② a) SBS scattering:

may regarded as the modulation of light through thermal molecule. vibrations within the fiber.

$$\boxed{P_b = 4.4 \times 10^{-3} d^2 \lambda^2 \alpha_{dB} \, v \, \text{watts}}$$

λ = operating wave length (μm)

d = Fiber core diameter (μm)

v = source B.W in (GHz)

b) SRS scattering:

Similar to SBS except that high frequency optical phonon rather than acoustic phonon is generated in scattering processes.

$$\boxed{P_R = 5.9 \times 10^{-2} d^2 \lambda \, \alpha_{dB} \text{ watts}}$$

α_R = Raman S. loss co-effi.

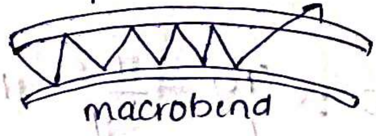
phonon: collective excitation in a periodic arrangement of atoms (or) molecules in solid.

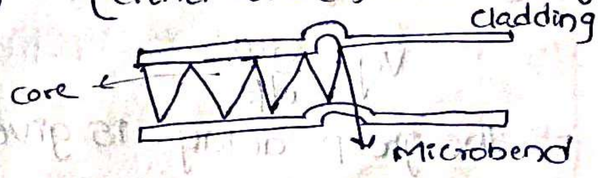
③ Bending losses (or) Radiation losses:

Bending losses (occurs when fiber undergoes excessive bending)

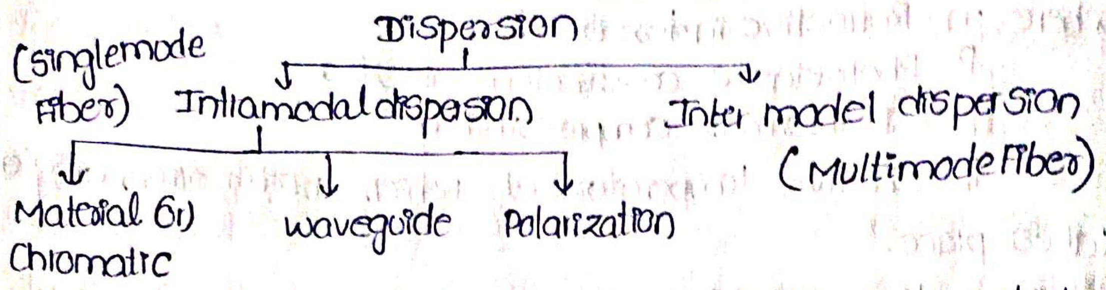
Macroscopic Bending (complete fiber undergoes)

Microscopic Bending (either core (or) cladd. undergoes)





★ Dispersion: spreading of the signal and causes pulse spreding.



polarization mode in Dispersion: when two modes that normally travel at the same speed due to fiber core geometric and stress geometry, travel at different speeds due to random imperfections that breakes symmetry.

- usually small.

Core and Cladding losses: $(n_1 > n_2)$

* Since the core and cladding have different refractive index's for a step index fiber core and cladding is given as

$$\boxed{\alpha = \alpha_1 \frac{P_{core}}{P} + \alpha_2 \frac{P_{cladding}}{P}} \longrightarrow ①$$

where α_1, α_2 are attenuation co-efficients.

For a cladded index fiber core & cladding loss at a distance r is given as

$$\boxed{\alpha(r) = \alpha_1 + (\alpha_2 - \alpha_1) \frac{n^2(0) - n^2(r)}{n^2(0) - n_2^2}}$$

$\frac{P_{core}}{P}$, $\frac{P_{cladding}}{P}$ are fractional powers in the fiber

Group delay: consider a fiber carrying the optical signal with different modes and each mode contains the spectral components in the wavelength band.. All the spectral components travel independently and time delay and group delay exist in the direction of propagation resulting in dispersion of fiber.

⇒ The velocity at which the energy in the light pulse is known as group velocity which is given as:

$$V_g = \frac{d\omega}{d\beta}$$

→ The group delay is given as : $\frac{\tau_g}{L} = \frac{1}{V_g}$ L = length of fiber

→ Now dispersion parameter of fiber is given as:

$$D = \frac{d}{d\lambda}\left(\frac{1}{V_g}\right)$$

$$\frac{1}{V_g} = \frac{d\beta}{d\omega}$$

$$\frac{1}{v_g} = \frac{d\lambda}{d\omega} \times \frac{d\beta}{d\lambda}$$

$$\frac{d\lambda}{d\omega} \Rightarrow \frac{d}{d\omega}\left(\frac{c}{f}\right) = \frac{d}{d\omega}\left(\frac{2\pi c}{2\pi f}\right) = \frac{d}{d\omega}\left(\frac{2\pi c}{\omega}\right)$$

$$\frac{d\lambda}{d\omega} = 2\pi c \cdot \frac{d}{d\omega}\left[\frac{1}{\omega}\right]$$

$$= 2\pi c \cdot \left[\frac{-1}{\omega^2}\right]$$

The phase constant in optical Fiber is given as:

$$\beta = \frac{2\pi n_1}{\lambda} \Longrightarrow \lambda = \frac{2\pi n_1}{\beta}$$

$$\beta = \frac{2\pi n_1}{c/f} \Rightarrow 2\pi n_1 \times \frac{f}{c} = \frac{\omega n_1}{c}$$

$$\omega = \frac{c\beta}{n_1}$$

$$\frac{d\lambda}{d\omega} = 2\pi c\left[\frac{-1}{\left(\frac{c\beta}{n_1}\right)^2}\right] = -2\pi c\left[\frac{n_1^2}{c^2\beta^2}\right]$$

$$\frac{d\lambda}{d\omega} = -2\pi\left[\frac{n_1^2}{c\beta^2}\right]$$

Multiply "2π" on Numr and denr

$$\frac{d\lambda}{d\omega} = \frac{-(2\pi)^2 n_1^2}{2\pi c\beta^2} = \frac{-1}{2\pi c}\left(\frac{2\pi n_1}{\beta}\right)^2$$

$$\boxed{\frac{d\lambda}{d\omega} = \frac{-\lambda^2}{2\pi c}}$$

$$D = \frac{d}{d\lambda}\left[\frac{1}{v_g}\right] ; \frac{d\lambda}{d\omega} \times \frac{d\beta}{d\lambda}$$

$$\frac{1}{v_g} = \frac{-\lambda^2}{2\pi c} \cdot \frac{d\beta}{d\lambda}$$

$$\boxed{D = \frac{d}{d\lambda}\left[\frac{-\lambda^2}{2\pi c} \cdot \frac{d\beta}{d\lambda}\right]} \longrightarrow \text{Dispersion parameter.}$$

expression for dispersion parameter, when the fiber undergoes Material dispersion: The Fiber said to have material dispersion, when the 2nd order differentiation of refractive Index of core w.r.to to wavelength is "Not equal to zero": $\frac{d^2 n_1}{d\lambda^2} \neq 0$

WKT, The phase constant in optical fiber is given as $\beta = \frac{2\pi n_1}{\lambda}$

→ The Group delay, $\frac{T_g}{L} = \frac{1}{v_g} \Rightarrow \frac{-\lambda^2}{2\pi c}\left[\frac{d\beta}{d\lambda}\right]$

Consider the material dispersion in Fiber for unit length is given as

$$\frac{\tau_{mat}}{L} = \frac{-\lambda^2}{2\pi c}\left[\frac{d}{d\lambda}\left(\frac{2\pi n_1}{\lambda}\right)\right]$$

$$\frac{\tau_{mat}}{L} = \frac{-\lambda^2}{2\pi c}\left[\frac{-2\pi n_1}{\lambda^2}+\frac{2\pi}{\lambda}\frac{dn_1}{d\lambda}\right]$$

$$\frac{\tau_{mat}}{L} = \frac{\lambda^2}{2\pi c}\frac{2\pi}{\lambda^2}\left[n_1-\lambda\frac{dn_1}{d\lambda}\right]$$

$$\frac{\tau_{mat}}{L} = \frac{1}{c}\left[n_1-\lambda\frac{dn_1}{d\lambda}\right]$$

$$\tau_{mat} = \frac{L}{c}\left[n_1-\lambda\frac{dn_1}{d\lambda}\right]$$

$$\boxed{D_{mat}(\lambda) = \frac{-\lambda}{c}\frac{d^2 n_1}{d\lambda^2}}$$

$$\sigma_{mat} = \frac{d}{d\lambda}\tau_{mat}\cdot\sigma_\lambda$$

$$\sigma_{mat} = D_{mat}(\lambda)\cdot\sigma_\lambda$$

Expression for dispersion Parameter when the Fiber undergoes Waveguide dispersion:

To evaluate the waveguide dispersion, consider group delay τ_g and normalized propagation constant $b(v)$ is given by

$$b(V) = \frac{\beta/k_0 - n_2}{n_1-n_2} \longrightarrow ①$$

W.K.T

$$\frac{\tau_g}{L} = \frac{1}{v_g} = \frac{d\beta}{d\omega}$$

$$v_g = \frac{d\omega}{d\beta}$$

from①

$$(n_1-n_2)\,b(V) = \beta/k_0 - n_2$$

$$(n_1-n_2)\,b(v) + n_2 = \frac{\beta}{k_0}$$

$$\beta = k_0[(n_1-n_2)b(V)+n_2]$$

WKT

$$k_0 = \frac{2\pi}{\lambda} = \frac{2\pi}{c/f} = \frac{2\pi f}{c}$$

$$k_0 = \frac{\omega}{c}$$

$$\beta = \frac{\omega}{c}\left[\underbrace{(n_2-n_1)b(V)}_{u}+\underbrace{n_2}_{v})\right] \longrightarrow ②$$

diff ... eqn② w.r.t ω

$$\frac{d\beta}{d\omega} = \frac{1}{c}\left[n_2+(n_1-n_2)\left[\omega\frac{db(v)}{d\omega}+b(v)\right]\right]$$

$$\frac{d\beta}{d\omega} = \frac{n_2}{c}+\frac{n_1-n_2}{c}\left[b(v)+\omega\frac{d}{d\omega}b(v)\right]$$

$$\frac{d\beta}{d\omega} = \frac{1}{c}\left[n_2+(n_1-n_2)\left[\omega\frac{d}{d\omega}b(v)+b(v)\right]\right]$$

$$\frac{d\beta}{d\omega} = \frac{n_2}{c}+\frac{1}{c}(n_1-n_2)\,b(v)+\frac{\omega}{c}(n_1-n_2).\frac{d}{d\omega}b(v)$$

$$= \frac{1}{c}\left[n_2+(n_1-n_2)b(v)+\omega(n_1-n_2)\frac{d}{d\omega}b(v)\right]$$

Multiply and divide n_2 and dv

$$\frac{d\beta}{d\omega} = \frac{1}{c}\left[n_2+\frac{n_1-n_2}{n_2}\cdot n_2\left[b(v)+\omega\frac{db(v)}{dv}\times\frac{dv}{d\omega}\right]\right]$$

dwKT

$$V = \frac{2\pi a}{\lambda}(NA)$$

$$V = \frac{2\pi a}{\lambda}(n_1\sqrt{2\Delta})$$

$$V = \frac{\omega}{c}a n_1\sqrt{2\Delta} \longrightarrow ④$$

Then

$$\frac{dv}{d\omega} = \frac{a}{c}n_1\sqrt{2\Delta} \longrightarrow ⑤$$

From④

$$\frac{a}{c}n_1\sqrt{2\Delta} = \frac{V}{\omega} \longrightarrow ⑥$$

from ⑤ and ⑥

$$\frac{dv}{d\omega} = \frac{V}{\omega} \longrightarrow ⑦$$

Sub⑦ in eqn③

$$\frac{d\beta}{d\omega} = \frac{1}{c}\left[n_2+\frac{n_1-n_2}{n_2}\cdot n_2\left[b(v)+\cancel{\omega}\frac{db(v)}{d\omega}\times\frac{V}{\cancel{\omega}}\right]\right]$$

$$\frac{d\beta}{d\omega} = \frac{n_2}{c}\left[1+\Delta\left[b(v)+V\cdot\frac{d(b(V))}{d\omega}\right]\right] \longrightarrow ⑧$$

Note:

$$b(v)+V\cdot\frac{db(v)}{d\omega} = \frac{d}{dv}(b(v)\cdot V) \longrightarrow ⑨$$

Sub⑨ in ⑧

$$\frac{\tau_g}{L} = \frac{1}{v_g} = \frac{n_2}{c}\left[1+\Delta\frac{d}{dv}[b(v)\cdot V]\right]$$

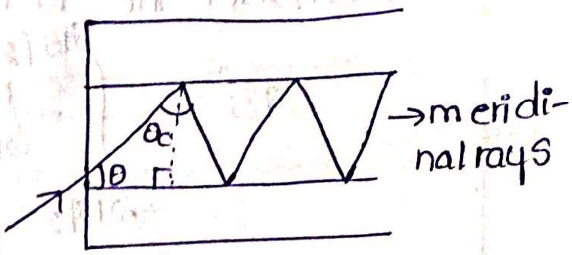
Groupdelay

$$\tau_g = \frac{n_2 L}{c}\left[1+\Delta\frac{d}{dv}(b(v)\cdot V)\right] \longrightarrow ⑩$$

$$\sigma_{wg} = \sigma_\lambda\cdot\frac{d\tau_{wg}}{d\lambda_c}$$

σ_λ = Spectral width of light source

Intermodal dispersion:



* The intermodal dispersion mostly occurs in the multimode Fibers

* The Time taken by the axial ray in the Fiber is given as:

$$n_1 = \frac{c}{v} \qquad v = \frac{c}{n_1}$$

$$\text{Axial ray} = T_{min} = \frac{L}{v}$$

$$T_{min} = \frac{L}{\frac{c}{n_1}} = \frac{Ln_1}{c}$$

* For Meridinal rays $T_{max} = \frac{L/\cos\theta}{v} = \frac{L/\cos\theta}{c/n_1}$

$$T_{max} = \frac{Ln_1}{c.\cos\theta}$$

From Fig $\theta + \theta_c + 90° = 180°$

$$\theta + \theta_c = 90°$$

$$\theta_c = 90° - \theta$$

$$\sin\theta_c = \sin(90° - \theta)$$

$$\sin\theta_c = \cos\theta$$

W.K.T $\sin\theta_c = \frac{n_2}{n_1}$

$$\sin\theta_c = \cos\theta = \frac{n_2}{n_1}$$

$$T_{max} = \frac{Ln_1}{c \cdot \frac{n_2}{n_1}} = \frac{Ln_1^2}{c.n_2}$$

$$T_{max} = \frac{Ln_1^2}{cn_2}$$

Considering the delay, the delay difference is given as:

$$\delta T_S = T_{max} - T_{min}$$

$$\delta T_S = \frac{Ln_1^2}{cn_2} - \frac{Ln_1}{c}$$

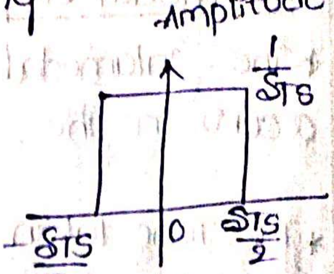
$$= \frac{Ln_1}{c}\left[\frac{n_1}{n_2} - 1\right]$$

$$= \frac{Ln_1}{c}\left[\frac{n_1 - n_2}{n_2}\right]$$

Assum

$$\delta T_S = \frac{Ln_1}{c} \cdot \Delta$$

Now consider the RMS pulse spreading



$$\sigma_s^2 = \int_{-\delta T_s/2}^{\delta T_s/2} \frac{1}{\delta T_s} t^2 \, dt$$

$$= \frac{1}{\delta T_s}\left[\frac{t^3}{3}\right]_{-\delta T_s/2}^{\delta T_s/2}$$

$$= \frac{1}{3\delta T_s}\left[\frac{\delta T_s^3}{8} + \frac{\delta T_s^3}{8}\right] = \frac{1}{3\cancel{\delta T_s}}\left[\frac{\cancel{2}\,\delta T_s^{\cancel{3}}}{\cancel{8}4}\right]$$

$$\sigma_s^2 = \frac{1}{3\cancel{\delta T_s}}\left(\frac{(\delta T_s)}{2}\right)^{\cancel{3}} = \frac{1}{3}\left(\frac{\delta T_s}{2}\right)^2$$

$$\sigma_s^2 = \frac{1}{3}\left(\frac{\delta T_s}{2}\right)^2$$

$$\sigma_s^2 = \frac{1}{3}\left(\frac{L n_1 \Delta}{2C}\right)^2$$

$$\sigma_s = \frac{1}{\sqrt{3}}\,\frac{L n_1 \Delta}{2C}$$

$$\boxed{\sigma_s = \frac{L n_1 \Delta}{2\sqrt{3}C}}$$

rms pulse spreading

UNIT- VI

Optical Sources & Optical Detectors

LED configurations classified as 2 types

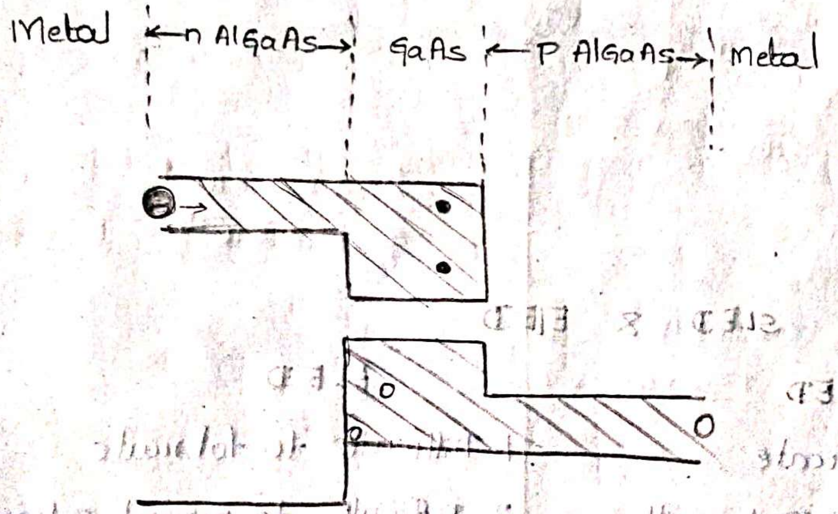
→ Surface Emitting LED
→ Edge Emitting LED

What is double hetero structure

This type of LEDs are made from two or more different types of semiconductor materials. Each having different band gap energy.

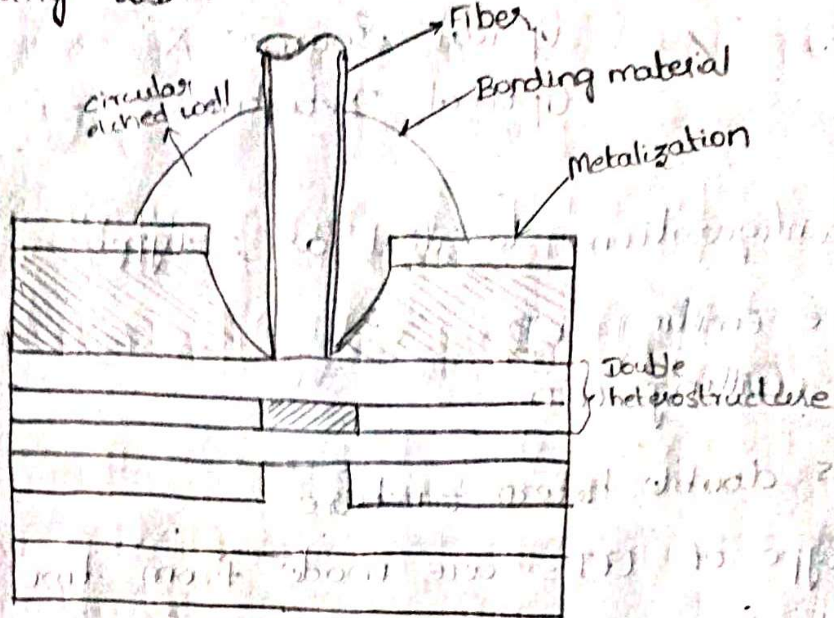
Two basic principles are involved:

1. Confinement of ē hole recombination within a highly restricted active region (carrier confinement)
2. Conduction of radiated light in 1 direction (Optical confinement)

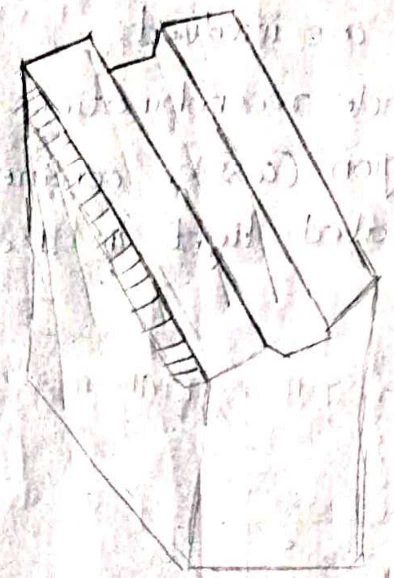


→ High radiance of light
→ High quantum efficiency

Surface Emitting LED



Edge Emitting LED



difference btw SLED & ELED

SLED	ELED
1. Easy to fabricate	1. Difficult to fabricate
2. Easy to mount & handle	2. Difficult to mount & handle
3. Requires less critical tolerance	

Quantum Efficiency & power

It is defined as the ratio of radative recombination rate to the total recombination rate.

$$\eta_{inst} = \frac{R_r}{R_r + R_{nr}}$$

Where

$R_r \Rightarrow$ radiative recombination rate
$R_{nr} \Rightarrow$ non radiative recombination rate

If n are the excess carriers, then radiative life time

$$\eta_{int} = \frac{1}{1+\frac{\tau_r}{\tau_{nr}}}$$

The recombination time of carriers in active region is τ. It is also known as bulk recombination life time.

$$\frac{1}{\tau} = \frac{1}{\tau_r} + \frac{1}{\tau_{nr}}$$

$$\eta_{int} = \frac{\tau}{\tau_r} \Rightarrow \text{Internal quantum efficiency.}$$

∴ If the c/t injected into the LED is I and q is ē charge then total no. of recombinations per second is

$$R_r + R_{nr} = \frac{I}{q}$$

$$\rightarrow \quad \eta_{int} = \frac{R_r}{I/q}$$

$$R_r = \eta_{int} \times \frac{I}{q}$$

optical power generated internally in LED

$$P_{int} = R_r \cdot h\nu \qquad h = \text{plank's const} \quad \nu = \text{freq}$$

$$= \left(\eta_{int} \times \frac{I}{q}\right) h \times \nu$$

$$= \left(\eta_{int} \times \frac{I}{q}\right) h \times \frac{c}{\lambda}$$

$$P_{int} = \eta_{int} \frac{Ihc}{q\lambda}$$

→ External quantum efficiency in LED is defined as ratio of photons emitted from LED to the ratio of photons generated internally

→ It is given as $\eta_{ext} = \frac{1}{n_1(n_1+1)^2}$

LED emitted optical power, $P = \eta_{ext} P_{int} = \frac{P_{int}}{n_1(n_1+1)^2}$

1) Double hetero structure InGaAsP LED is operating at 1310 nm as a radiative recombination rate of 30nsec & non radiative recombination rate of 100nsec if the c/t injected in the LED is 40mA calculate (i) bulb recombination life time. (ii) Internal Quantum efficiency (iii) internal power.

Given that

$\lambda = 1310\,nm$ $\quad \tau_r = 30ns$

$I = 40mA$ $\quad \tau_{nr} = 100ns$

(i) $\frac{1}{\tau} = \frac{1}{\tau_r} + \frac{1}{\tau_{nr}}$

$\Rightarrow \frac{1}{\tau} = \frac{1}{30n} + \frac{1}{100n} = 23.07\,ns$

(ii) $\eta_{int} = \frac{\tau}{\tau_r} = \frac{30}{100} = 0.769$

(iii) $P_{int} = \eta_{int} \frac{hcI}{\lambda q}$ $\quad h = 6.625 \times 10^{-34}$

$q = 1.602 \times 10^{-19}$

$P_{int} = 0.769 \times \frac{6.625 \times 10^{-34} \times 40 \times 10^{-3} \times 3 \times 10^{8}}{1310 \times 10^{-9} \times 1.602 \times 10^{-19}}$

$P_{int} = 2.9mW$

2) The radiative & non-radiative recombination life times of a double hetero structure LED are 60ns & 90ns operating at a wavelength of 870nm with drive clt of 40mA. Determine the internal optical power

Given $\lambda = 870nm$; $I = 40mA$

$\tau_r = 60ns$; $\tau_{nr} = 90ns$ $\quad \frac{1}{\tau} = \frac{1}{\tau_r} + \frac{1}{\tau_{int}} = \frac{1}{60n} + \frac{1}{90n}$

$= 36nS$

$\eta_{int} = \frac{\tau}{\tau_1} = \frac{36}{60} = 0.66\ 06$

$$P_{int} = 0.6 \times \frac{6.625\times10^{-34}\times 3\times10^{8}\times 40\times10^{-3}}{870\times10^{-9}\times 1.602\times10^{-19}}$$

$$= 34.22\ \text{mWatts}$$

Modulation of LED

→ The freq response of an LED depends on

1. Doping level in the active region
2. injected carrier lifetime

$$\text{Electrical BW} = 10\log\left[\frac{P(\omega)}{P(0)}\right] = 20\log\left[\frac{I(\omega)}{I(0)}\right]$$

P= electrical power

I= electrical c/t

$$P(\omega) = \frac{P_0}{\sqrt{1+(\omega T_i)^2}}$$

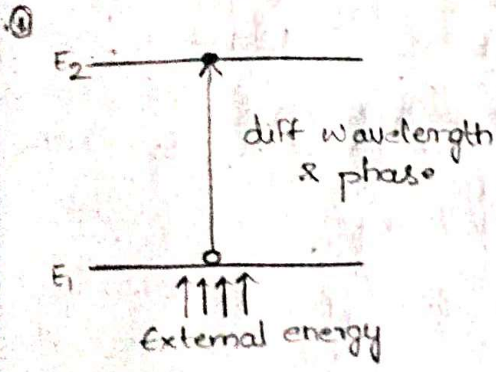
$$\text{Optical BW} = 10\log\left[\frac{P(\omega)}{P(0)}\right] = 10\log\left[\frac{I(\omega)}{I(0)}\right]$$

Laser

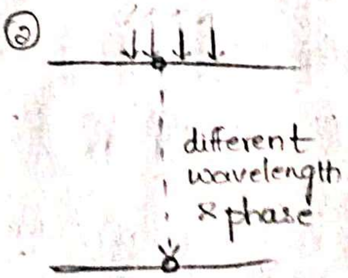
Pumped Active medium

1) Photon Absorption convert low energy to high energy state by using External Energy with diff.
2) Spontaneous Absorption convert high energy to low energy state by emiting light.
3) Stimulated Absorption

①



②



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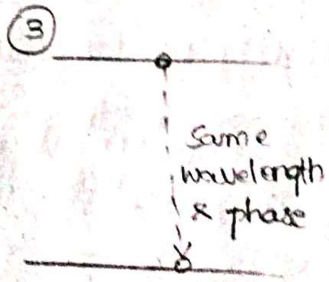
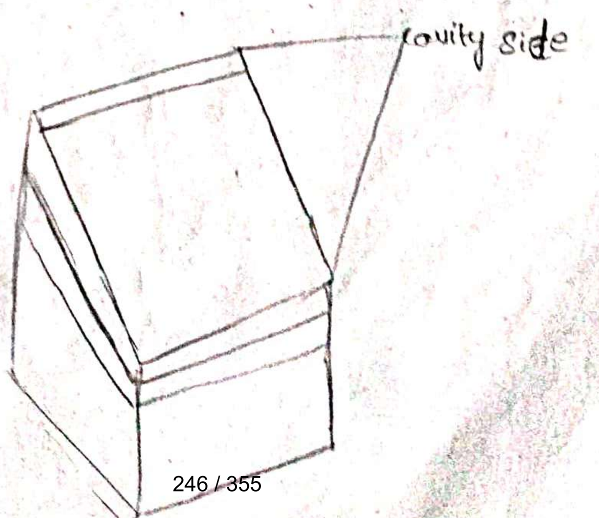


Laser diode



* Fiber connectors

connector is a temporary joint btw 2 fibers. It has wide Variety of Applications

Principle requirements

1) Low coupling losses
2) Interchangability
3) Ease of assembly
4) Ease of connections
5) Low cost
6) Reliable

Types of connectors

1) Butt joint connectors
2) Expanded Beam connectors

1) Butt joint :- used in both single & multimode fibers

Two types

1) straight sleeve connectors
2) tapered sleeve connectors

Fiber splice

Fiber splice is a permanent or semi permanent joint btw 2 fibers which are used to create long optical links or in situations where frequent connection and disconnections are not required.

Splicing techniques are

1. Fusion Splicing
2. V-groove Splicing
3. Elastic tube splicing

① → The total efficiency of an injection laser diode with GaAs is 18% the total applied voltage to the device ~~of~~ is 2.5 ~~2.8V~~ and the band gap energy for the ga' GaAs is 1.43eV Calculate the total external power efficiency of the device.

$$\eta_{exp} = \eta_T \left(\frac{E_g}{V}\right) \times 100$$

$$= 0.18 \left(\frac{1.43}{2.5}\right) \times 100$$

$$= 10.296\ \%$$

Comparison of PIN & Avalanche photo diode

Parameters	PIN Photo diode	Avalanche Photo diode
1) Sensitivity	Low	High
2) Biasing	Less reverse bias Vol (5–10V)	High reverse bias req (200–400V)
3) Wavelength region	300–1100nm	400–1000nm
4) Gain	No internal Gain	200dB gain
5) S/N ratio	poor	high
6) Detector ckt	simple	complex
7) cost	cheap	expensive
8) Support circuitary required	None	High ~~V~~ vol & temp compensation

$$\eta_{ext} = \eta_T \left(\frac{E_g}{V}\right) \times 100$$

UNIT-IV

&

UNIT-V

OVERVIEW OF OPTICAL FIBER COMMUNICATION

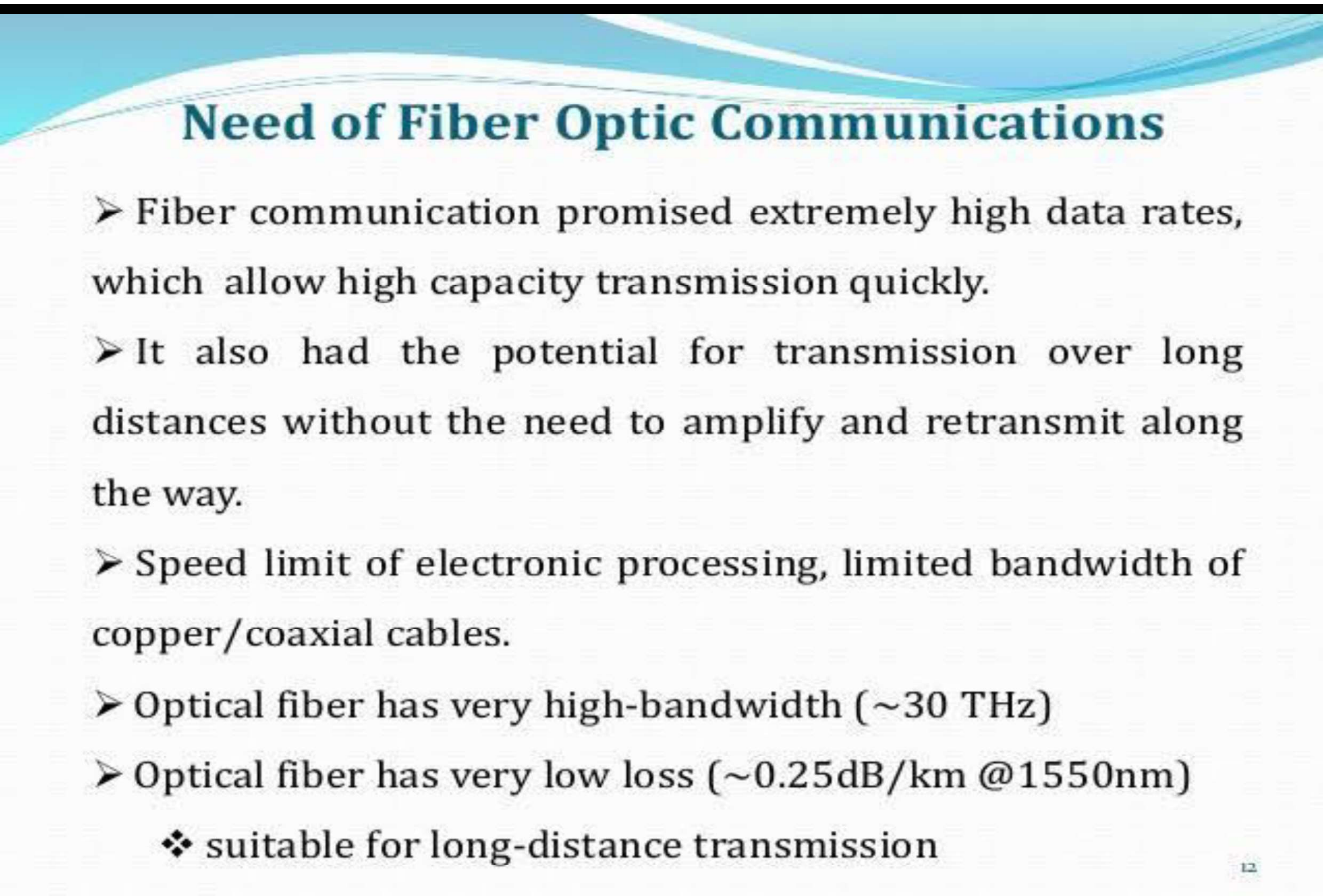
INTRODUCTION

- Fiber-optic communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information.
- **Optical Fibre -**

An optical fibre is a dielectric wave guide that operates at optical frequencies. This fibre wave guide is normally cylindrical in form.

- **Function -**

It confines electro magnetic energy in the form of light to within its surfaces and guides the light in a direction parallel to its axis.

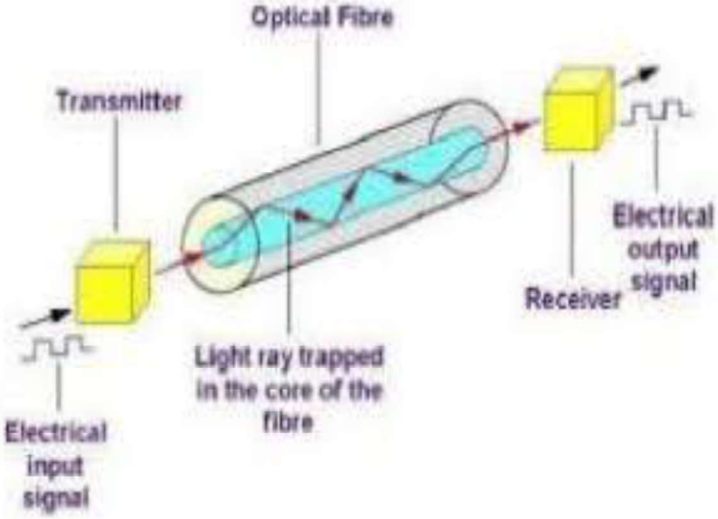


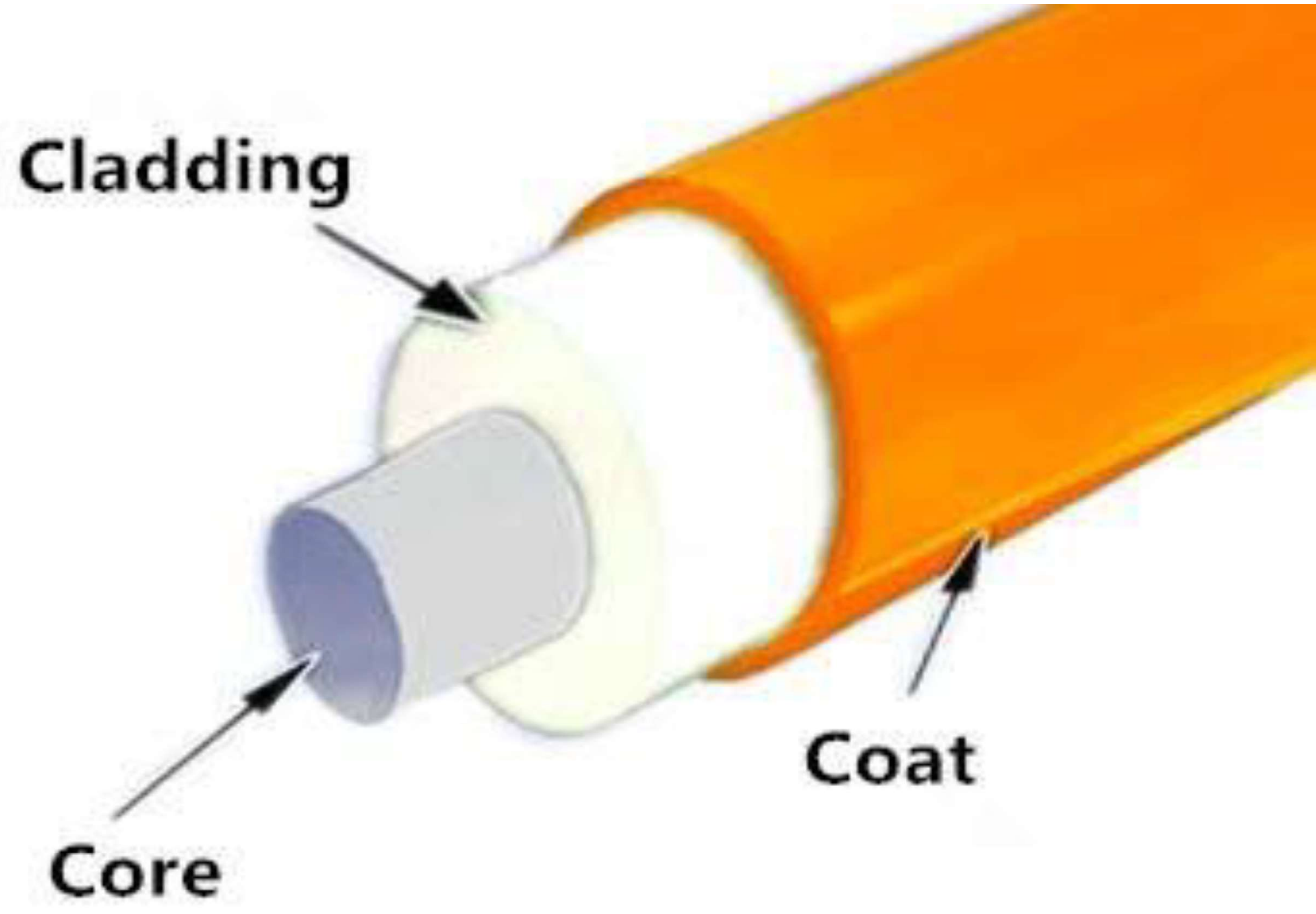
Need of Fiber Optic Communications

- ➢ Fiber communication promised extremely high data rates, which allow high capacity transmission quickly.
- ➢ It also had the potential for transmission over long distances without the need to amplify and retransmit along the way.
- ➢ Speed limit of electronic processing, limited bandwidth of copper/coaxial cables.
- ➢ Optical fiber has very high-bandwidth (~30 THz)
- ➢ Optical fiber has very low loss (~0.25dB/km @1550nm)
    - ❖ suitable for long-distance transmission

Fiber optic communication

- *Fiber optic communication is a communication technology that uses light pulses to transfer information from one point to another through an optical fiber.*
- *The light forms an electromagnetic carrier wave that is modulated to carry information.*




Cladding
Core
Coat

Advantages of optical fiber communication

- Increased Bandwidth and Channel Capacity
- Low Signal Attenuation
- Immune to Noise
- No Crosstalk
- Lower Bit Error Rates
- Signal Security
- Electrical Isolation
- Reduced Size and Weight of Cables
- Radiation Resistant and Environment Friendly
- Resistant to Temperature Variations etc.

APPLICATION

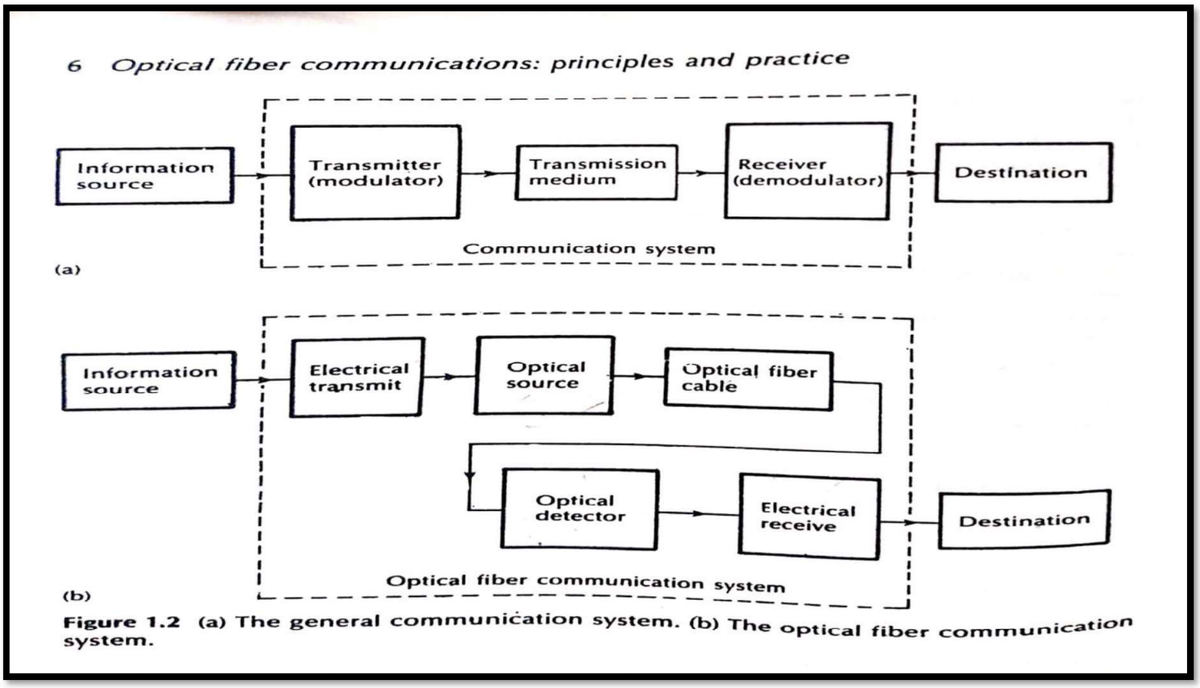
Due to its variety of advantages optical fiber communication system has a wide range of application in different fields namely:

- Public network field which includes trunk networks, junction networks, local access networks, submerged systems, synchronous systems etc.
- Field of military applications
- Civil, consumer and industrial applications
- Field of computers which is the center of research right now.

THE GENERAL SYSTEM

- An optical fiber communication system is similar to any type of communication system.
- The function of general communication system is to convey the signal from information source over the transmission medium to the destination
- The communication system consists of transmitter or modulator ,transmission medium and a receiver or demodulator at the destination point

ANALOG FORM OF FIBER OPTIC COMMUNICATION



6 *Optical fiber communications: principles and practice*

Figure 1.2 (a) The general communication system. (b) The optical fiber communication system.

- In this case the information source provides an electrical signal to a transmitter comprising an electrical stage which drives an optical source to give modulation of the light wave carrier.
- The optical source which provides the electrical to optical conversion may be a semi conductor laser or LED.
- The transmission medium consists of optical fiber cable.

- The receiver consists of an optical detector which provides the demodulation of optical carrier
- The photo diodes are utilized for the detection of optical signal and for the optical to electrical conversion.

Digital optical fiber link

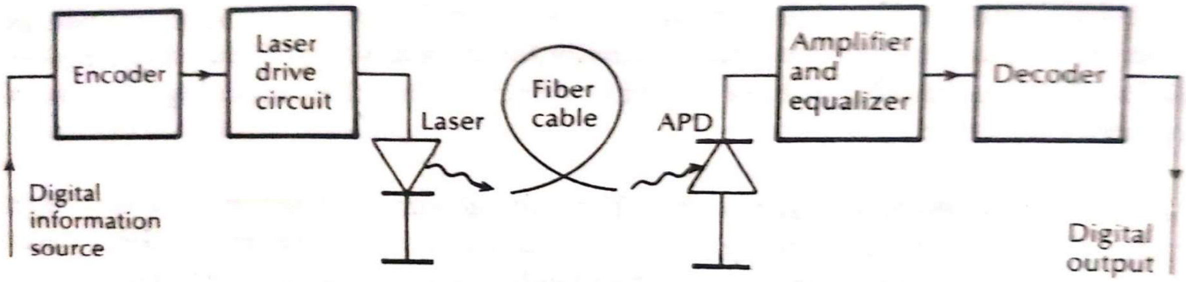


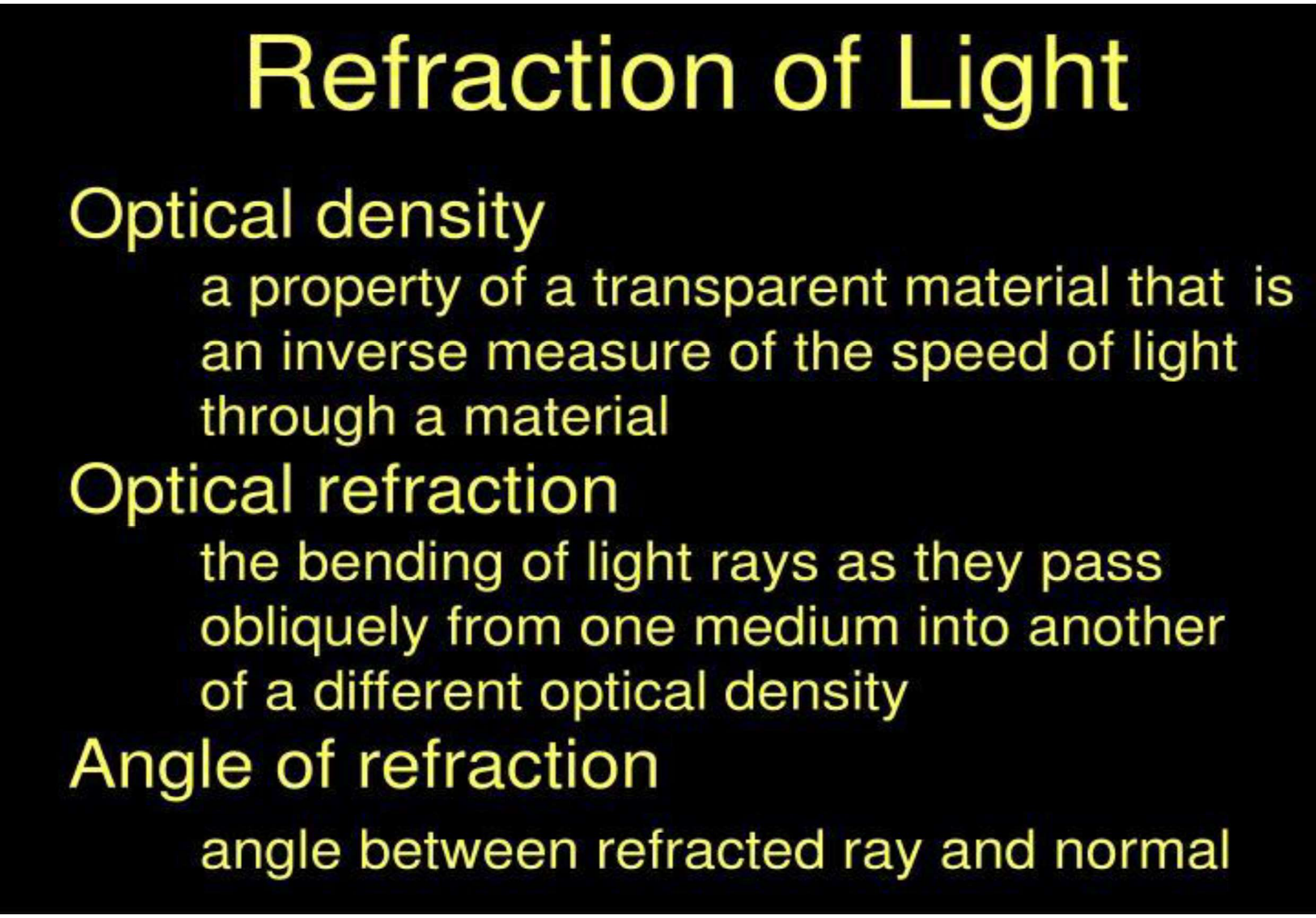
Figure 1.3 A digital optical fiber link using a semiconductor laser source and an avalanche photodiode (APD) detector.

- The input digital signal from the information source is suitably encoded for transmission.
- The laser drive circuit directly modulates the intensity of semi conductor laser with the encoded digital signal

- The input digital signal from the information source is suitably encoded for transmission.
- The laser drive circuit directly modulates the intensity of semi conductor laser with the encoded digital signal
- Hence a digital optical signal is launched into optical fiber cable.

- The APD (avalanche photodiode) detector is followed by a front end amplifier and equalizer to provide gain ,linear signal processing and noise bandwidth reduction.

Finally the signal obtained is decoded to give the original digital information.



Refraction of Light

Optical density

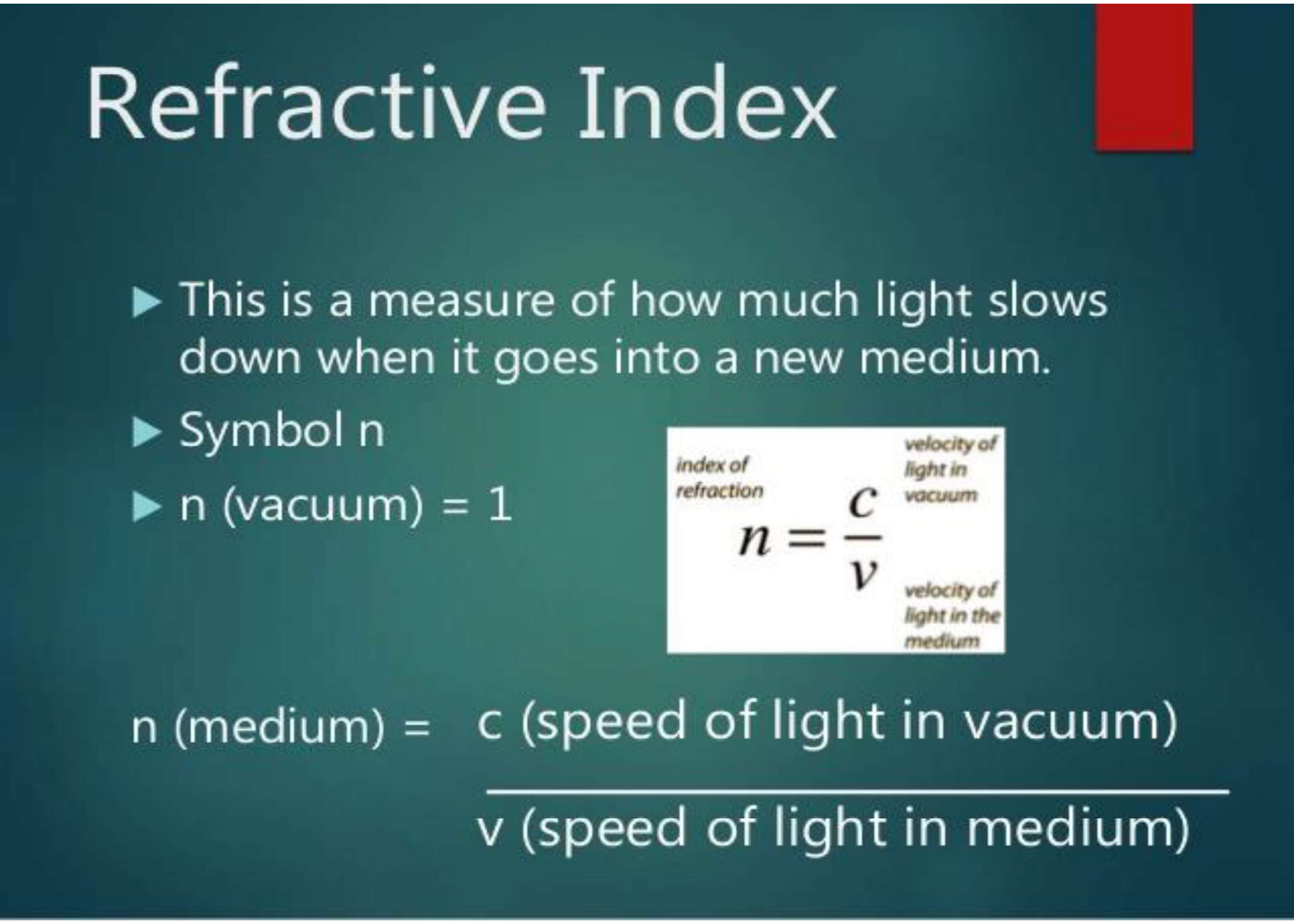
a property of a transparent material that is an inverse measure of the speed of light through a material

Optical refraction

the bending of light rays as they pass obliquely from one medium into another of a different optical density

Angle of refraction

angle between refracted ray and normal

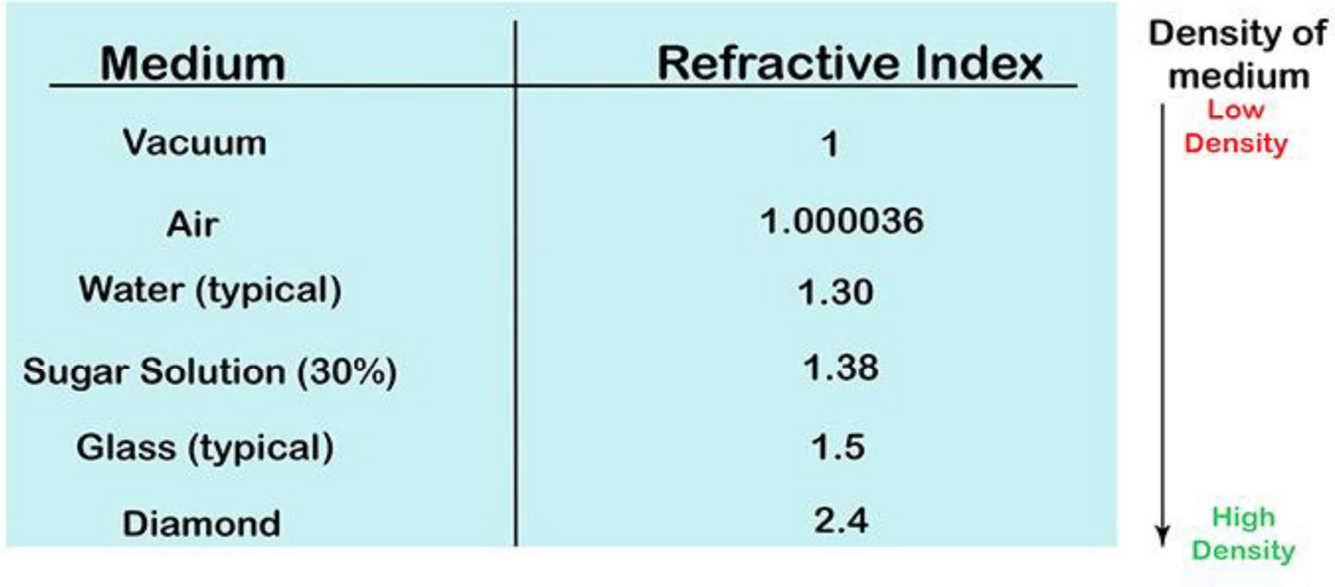


Refractive Index

- This is a measure of how much light slows down when it goes into a new medium.
- Symbol n
- n (vacuum) = 1

$$n = \frac{c}{v}$$

$$n\ (\text{medium}) = \frac{c\ (\text{speed of light in vacuum})}{v\ (\text{speed of light in medium})}$$



Medium	Refractive Index
Vacuum	1
Air	1.000036
Water (typical)	1.30
Sugar Solution (30%)	1.38
Glass (typical)	1.5
Diamond	2.4

Density of medium

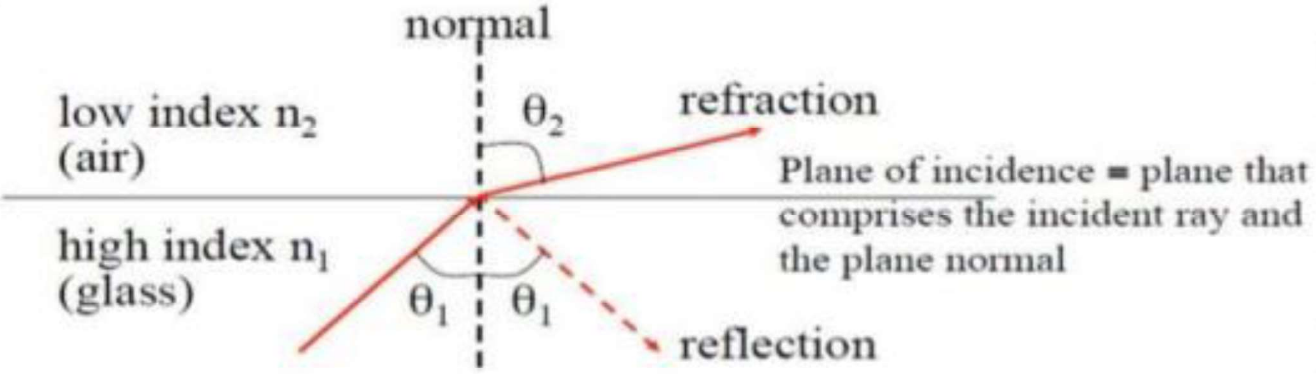
Low Density

High Density

Ray Theory Transmission

Snell's Law

When a ray is incident on the interface between two dielectrics of different refractive indices (e.g. glass-air), reflection and refraction occur.



Plane of incidence = plane that comprises the incident ray and the plane normal

The *angle of incidence* θ_1 and the *angle of refraction* θ_2 are related to each other, and to the refractive indices of the dielectrics by Snell's law of refraction:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

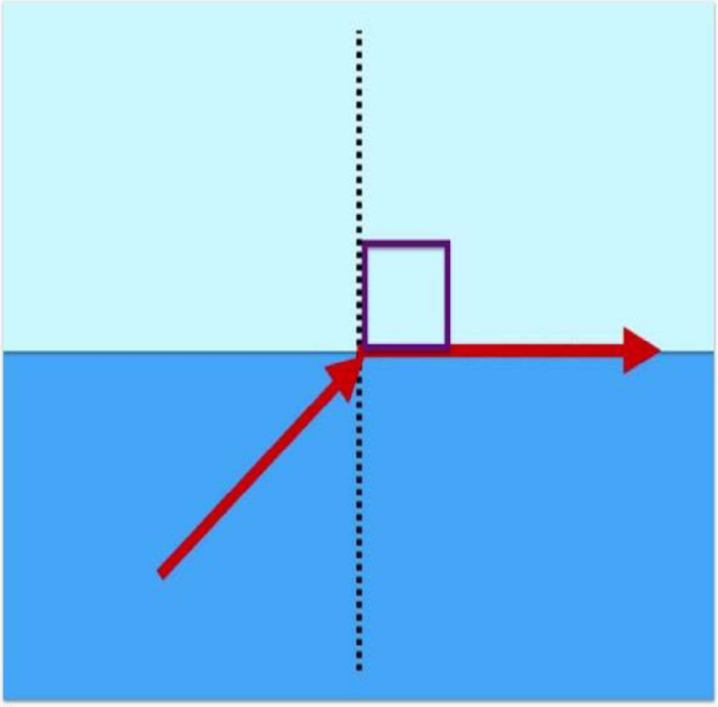
Total Internal Reflection

Recall that Snell's Law says that when light moves from material with a higher index of refraction to a material with a lower index of refraction, it is bent away from the normal.

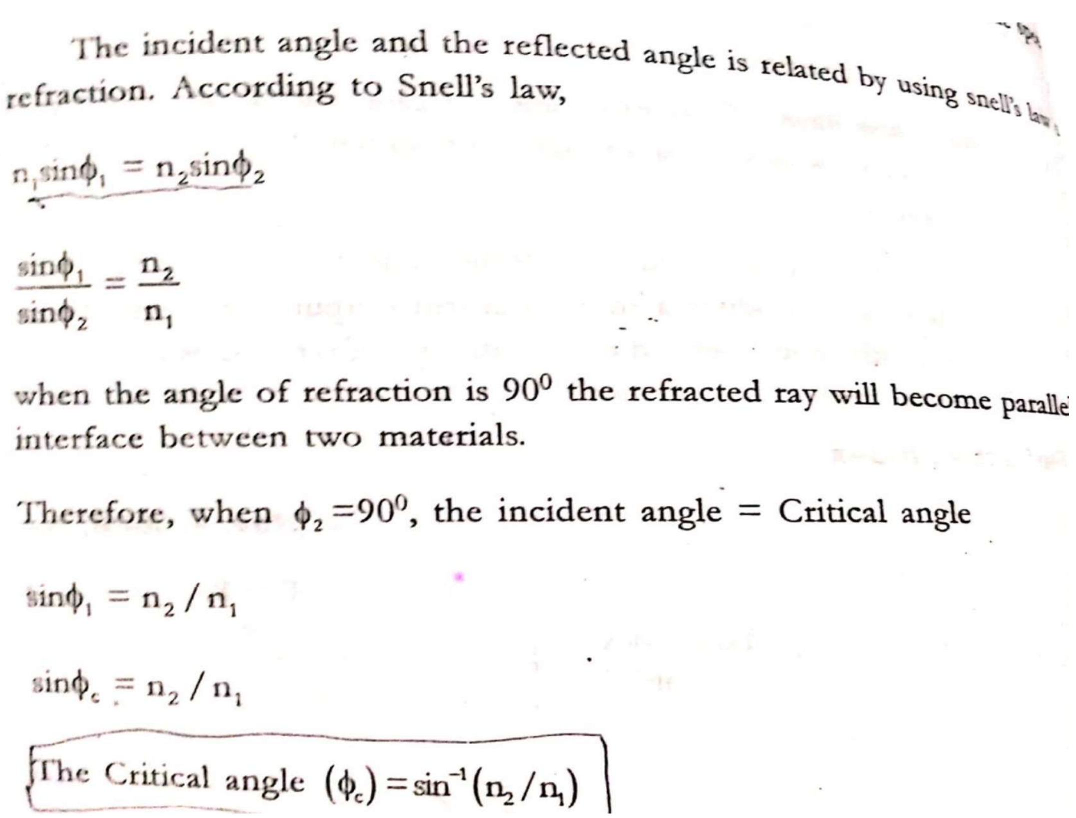
If we increase the angle of the incoming light to a certain point, we find that there is a certain angle of incoming light that causes the outgoing light to be exactly 90°. This is important, because this is the point where no light actually enters the new medium.

The critical angle θ_C is the angle of incidence that causes the angle of refraction to equal 90°.

Total internal reflection is when the angle of refraction is 90° or greater. The total light is reflected back into the original material and no light enters the new material.



CRITICAL ANGLE



The incident angle and the reflected angle is related by using snell's law, refraction. According to Snell's law,

$$n_1 \sin\phi_1 = n_2 \sin\phi_2$$

$$\frac{\sin\phi_1}{\sin\phi_2} = \frac{n_2}{n_1}$$

when the angle of refraction is 90^0 the refracted ray will become paralle interface between two materials.

Therefore, when $\phi_2 = 90^0$, the incident angle = Critical angle

$$\sin\phi_1 = n_2 / n_1$$

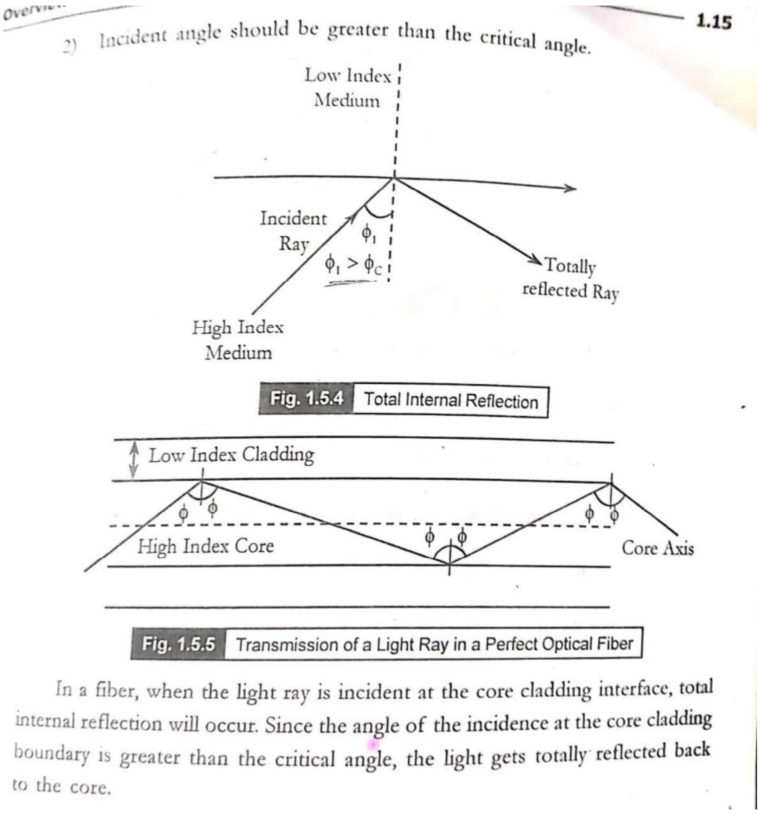
$$\sin\phi_c = n_2 / n_1$$

$$\boxed{\text{The Critical angle } (\phi_c) = \sin^{-1}(n_2 / n_1)}$$

TOTAL INTERNAL REFLECTION

- Total internal reflection is defined as the complete reflection of light into the same medium without any transmission of light into the other medium
- Conditions for total internal reflection are:
- Light should travel from higher refractive index material into lower refractive index material.
- Incident angle should be greater than critical angle

TOTAL INTERNAL REFLECTION



2) Incident angle should be greater than the critical angle.

Fig. 1.5.4 Total Internal Reflection

Fig. 1.5.5 Transmission of a Light Ray in a Perfect Optical Fiber

In a fiber, when the light ray is incident at the core cladding interface, total internal reflection will occur. Since the angle of the incidence at the core cladding boundary is greater than the critical angle, the light gets totally reflected back to the core.

ACCEPTANCE ANGLE

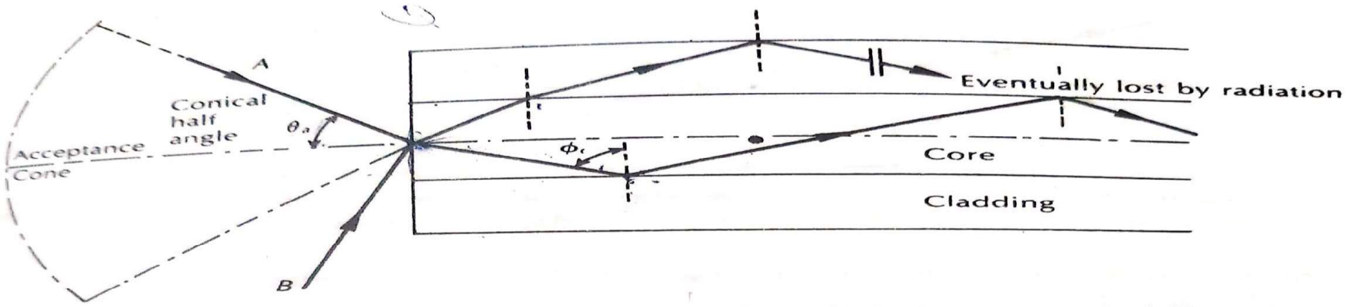
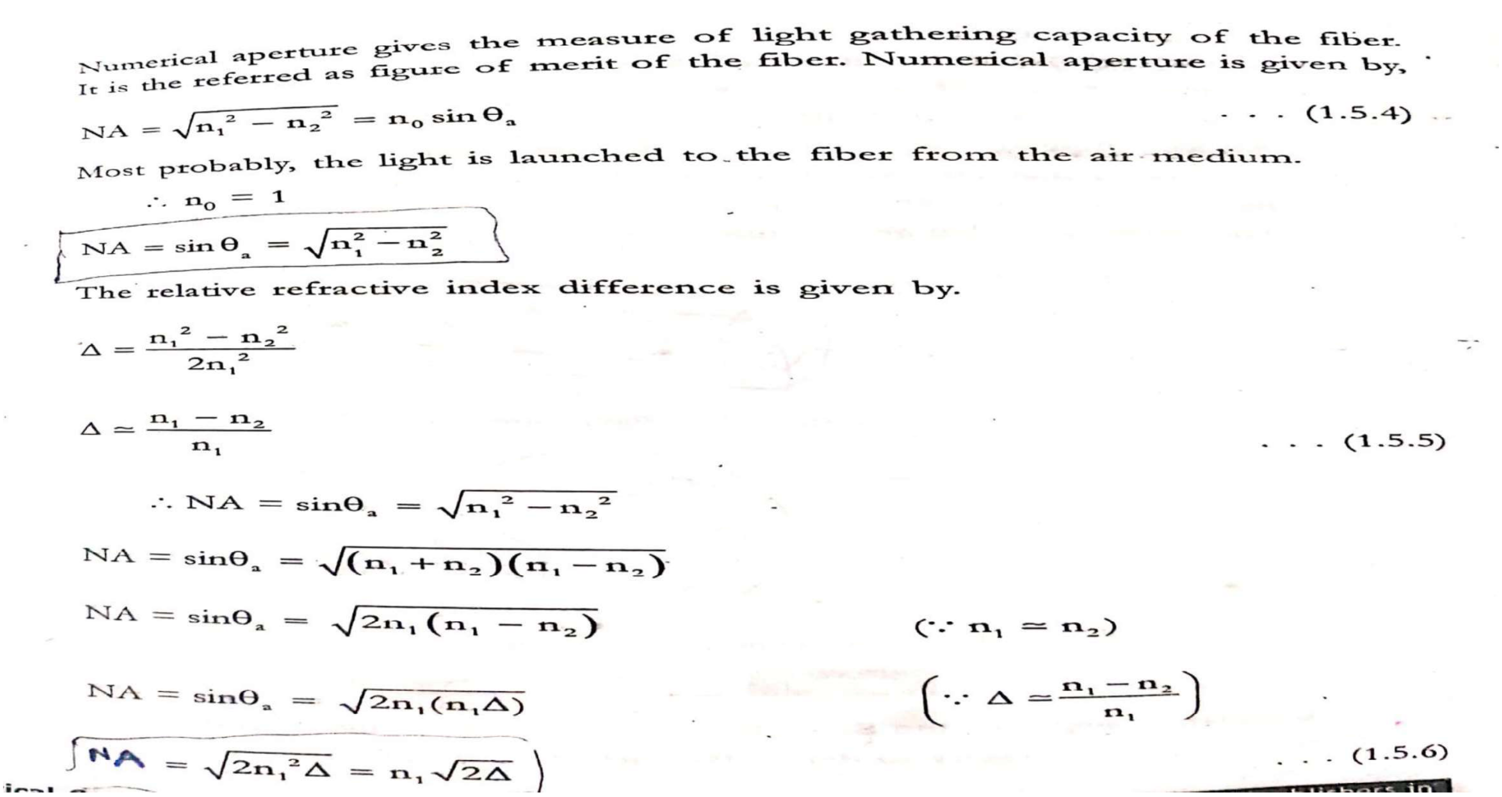


Figure 2.4 The acceptance angle θ_a when launching light into an optical fiber.

- Acceptance angle is the maximum angle to the fiber axis at which light may enter the fiber axis in order to be propagated.
- The first ray A making an angle θ_a to the fiber axis gets refracted at the air core interface and this refracted ray is getting propagated into the fiber.

Numerical Aperture



Numerical aperture gives the measure of light gathering capacity of the fiber. It is the referred as figure of merit of the fiber. Numerical aperture is given by,

$$NA = \sqrt{n_1^2 - n_2^2} = n_0 \sin \theta_a \qquad \ldots (1.5.4)$$

Most probably, the light is launched to the fiber from the air medium.

$$\therefore n_0 = 1$$

$$\boxed{NA = \sin \theta_a = \sqrt{n_1^2 - n_2^2}}$$

The relative refractive index difference is given by.

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$$

$$\Delta \simeq \frac{n_1 - n_2}{n_1} \qquad \ldots (1.5.5)$$

$$\therefore NA = \sin\theta_a = \sqrt{n_1^2 - n_2^2}$$

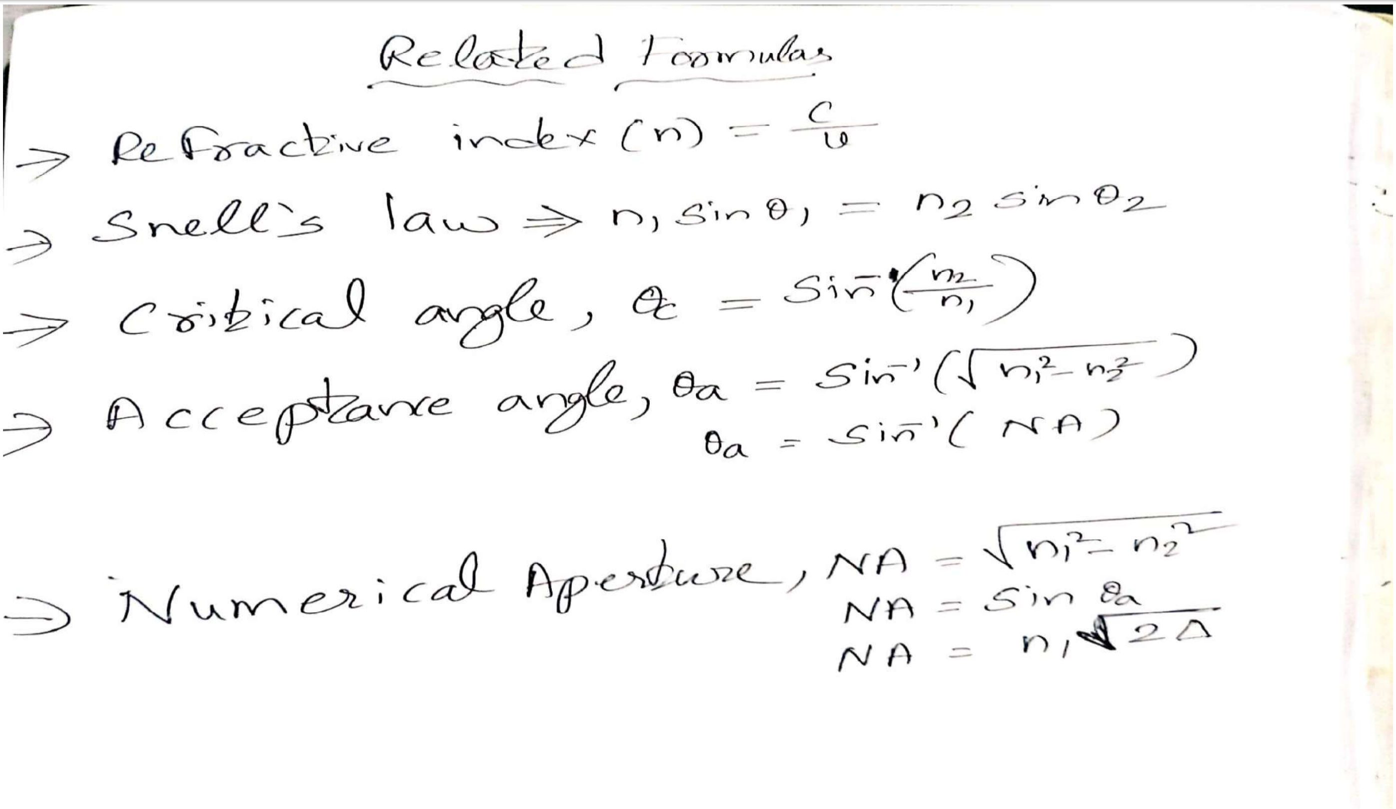
$$NA = \sin\theta_a = \sqrt{(n_1 + n_2)(n_1 - n_2)}$$

$$NA = \sin\theta_a = \sqrt{2n_1(n_1 - n_2)} \qquad (\because n_1 \simeq n_2)$$

$$NA = \sin\theta_a = \sqrt{2n_1(n_1\Delta)} \qquad \left(\because \Delta = \frac{n_1 - n_2}{n_1}\right)$$

$$\boxed{NA = \sqrt{2n_1^2\Delta} = n_1\sqrt{2\Delta}} \qquad \ldots (1.5.6)$$

Related formulae



Related Formulas

⇒ Refractive index $(n) = \frac{c}{v}$

⇒ Snell's law ⇒ $n_1 \sin\theta_1 = n_2 \sin\theta_2$

⇒ Critical angle, $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

⇒ Acceptance angle, $\theta_a = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$

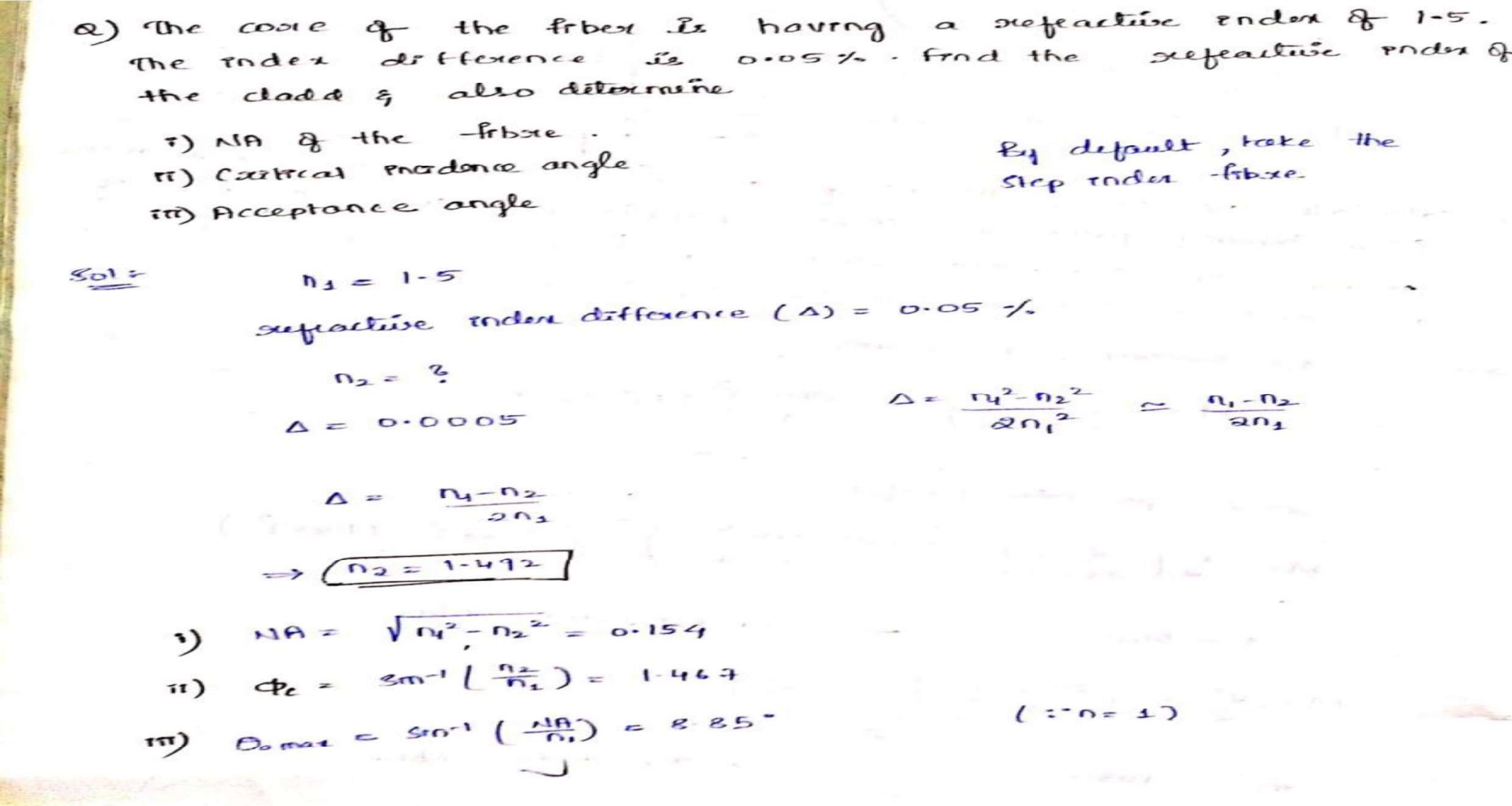
$\theta_a = \sin^{-1}(NA)$

⇒ Numerical Aperture, $NA = \sqrt{n_1^2 - n_2^2}$

$NA = \sin\theta_a$

$NA = n_1\sqrt{2\Delta}$

solution



Q) The core of the fiber is having a refractive index of 1.5. The index difference is 0.05 %. Find the refractive index of the cladd & also determine

i) NA of the fibre.

ii) Critical incidence angle

iii) Acceptance angle

By default, take the step index fibre.

Sol:- $n_1 = 1.5$

refractive index difference $(\Delta) = 0.05\ \%$

$n_2 = ?$

$\Delta = 0.0005$

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} \simeq \frac{n_1 - n_2}{2n_1}$$

$$\Delta = \frac{n_1 - n_2}{2n_1}$$

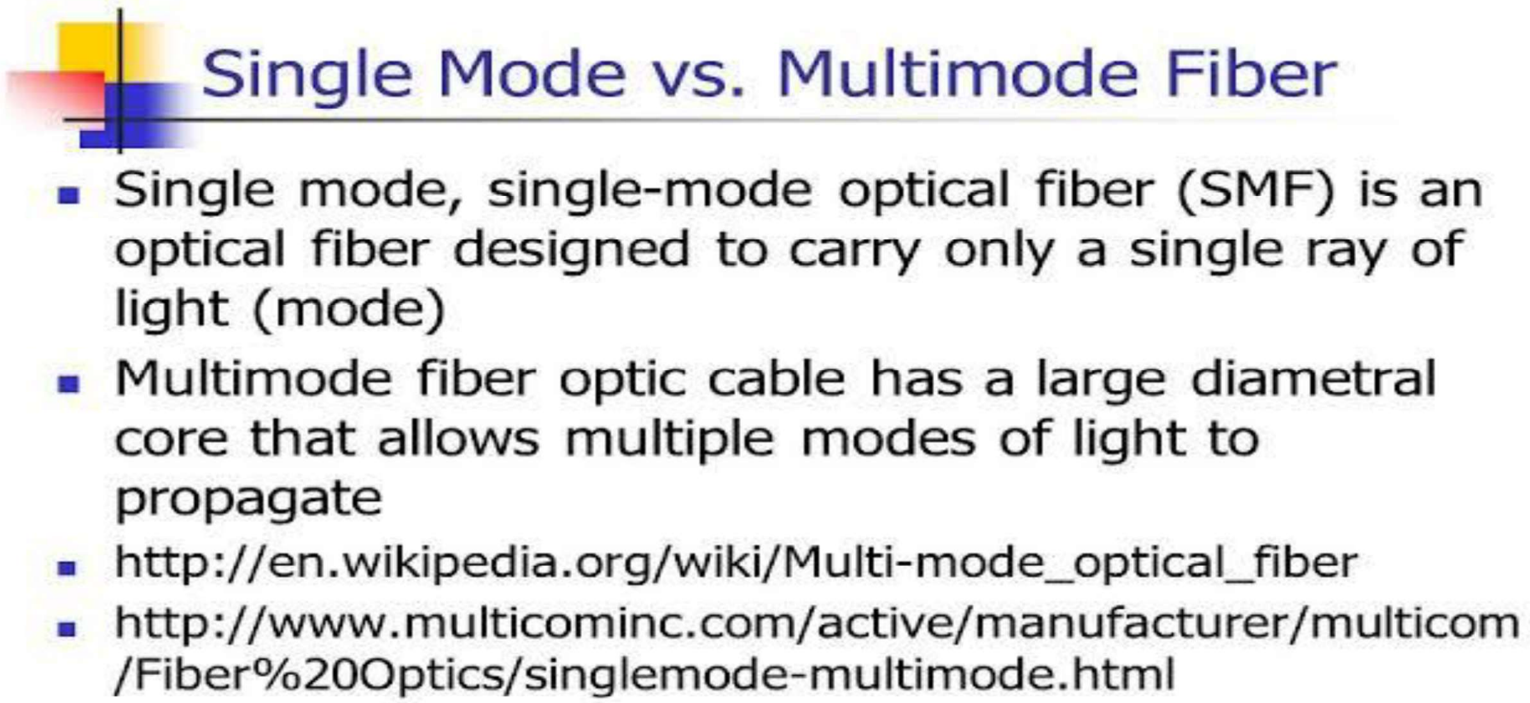
$$\Rightarrow \boxed{n_2 = 1.492}$$

i) $NA = \sqrt{n_1^2 - n_2^2} = 0.154$

ii) $\phi_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) = 1.467$

iii) $\theta_{o\,max} = \sin^{-1}\left(\frac{NA}{n_1}\right) = 8.85°$ $(\because n = 1)$

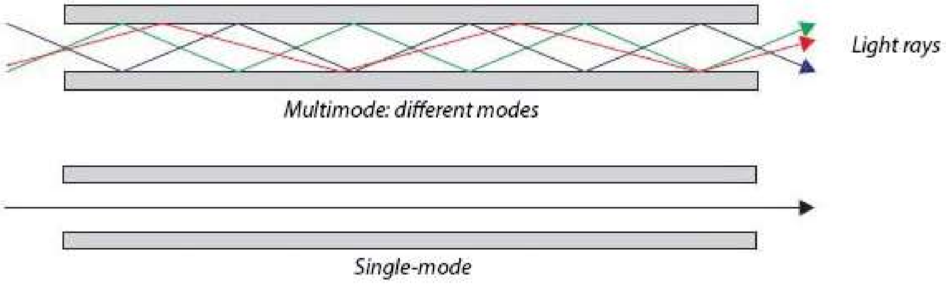
[redacted]



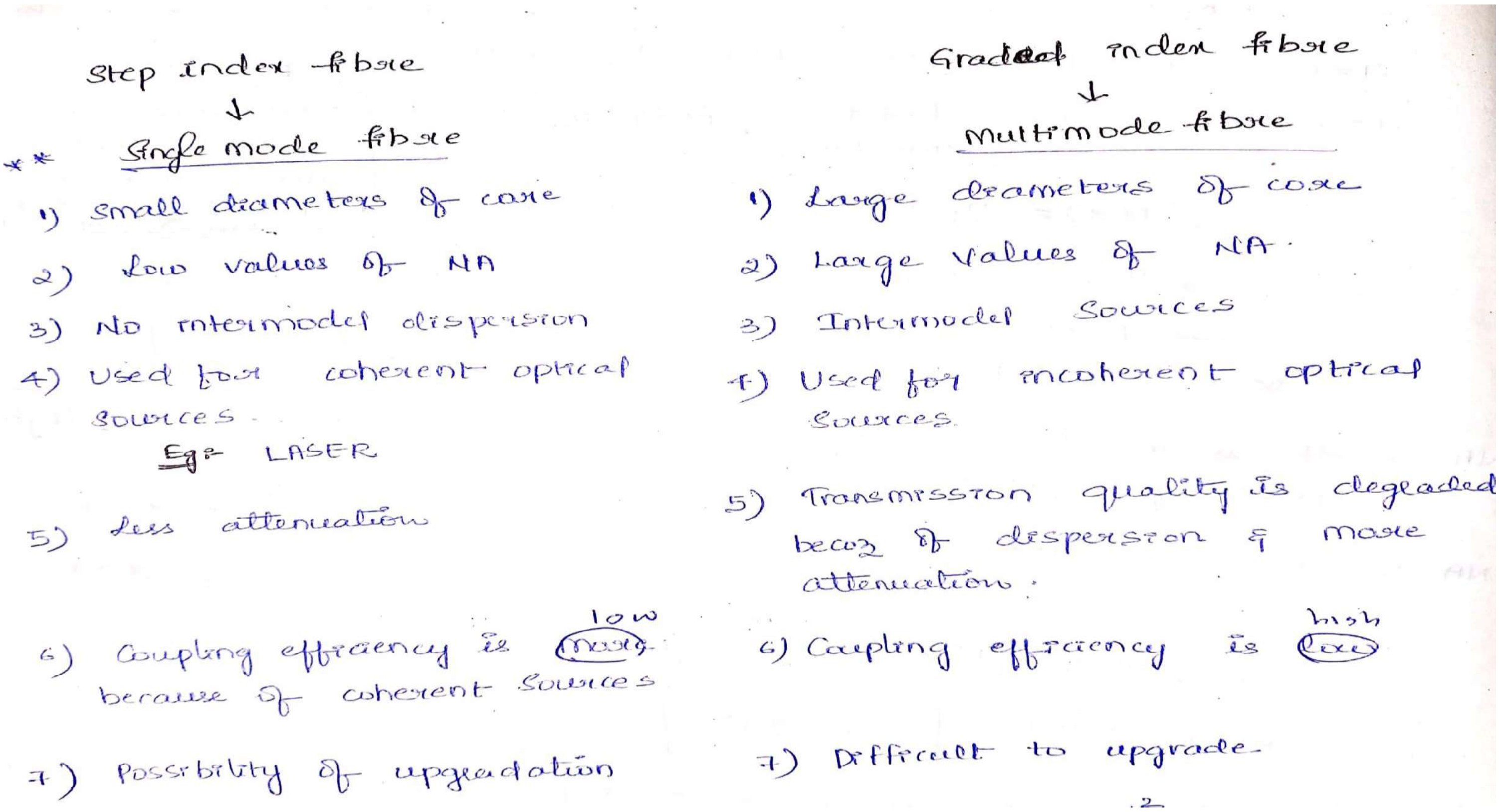
Single Mode vs. Multimode Fiber

- Single mode, single-mode optical fiber (SMF) is an optical fiber designed to carry only a single ray of light (mode)
- Multimode fiber optic cable has a large diametral core that allows multiple modes of light to propagate
- http://en.wikipedia.org/wiki/Multi-mode_optical_fiber
- http://www.multicominc.com/active/manufacturer/multicom/Fiber%20Optics/singlemode-multimode.html

Single and multimode fibers

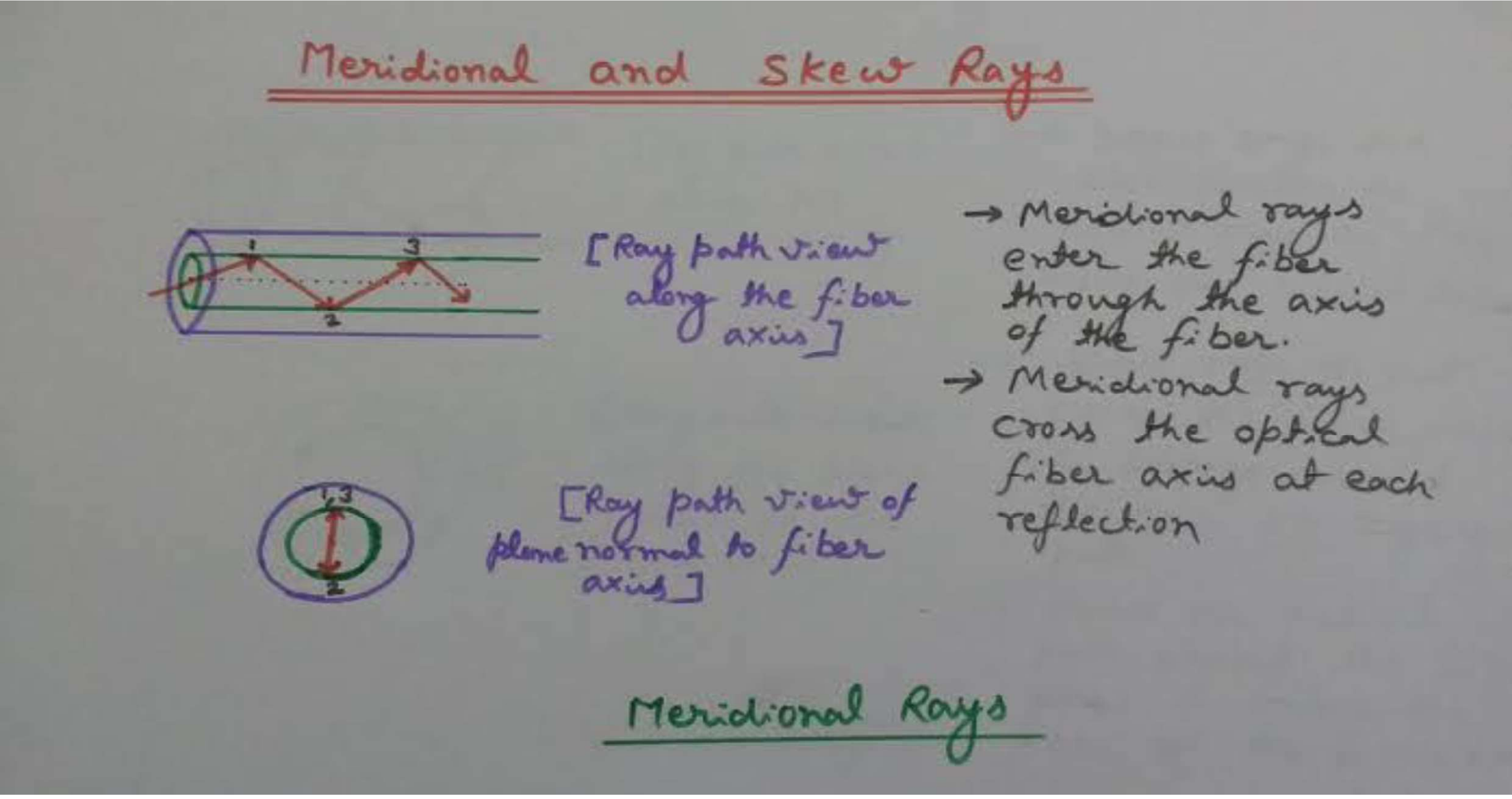


comparision



Step index fibre ↓ ** Single mode fibre	Graded index fibre ↓ Multimode fibre
1) Small diameters of core	1) Large diameters of core
2) Low values of NA	2) Large values of NA.
3) No intermodel dispersion	3) Intermodel sources
4) Used for coherent optical sources. Eg:- LASER	4) Used for incoherent optical sources.
5) Less attenuation	5) Transmission quality is degraded becoz of dispersion & more attenuation.
6) Coupling efficiency is low more because of coherent sources	6) Coupling efficiency is high low
7) Possibility of upgradation	7) Difficult to upgrade.

Meridional rays



Meridional and Skew Rays

[Ray path view along the fiber axis]

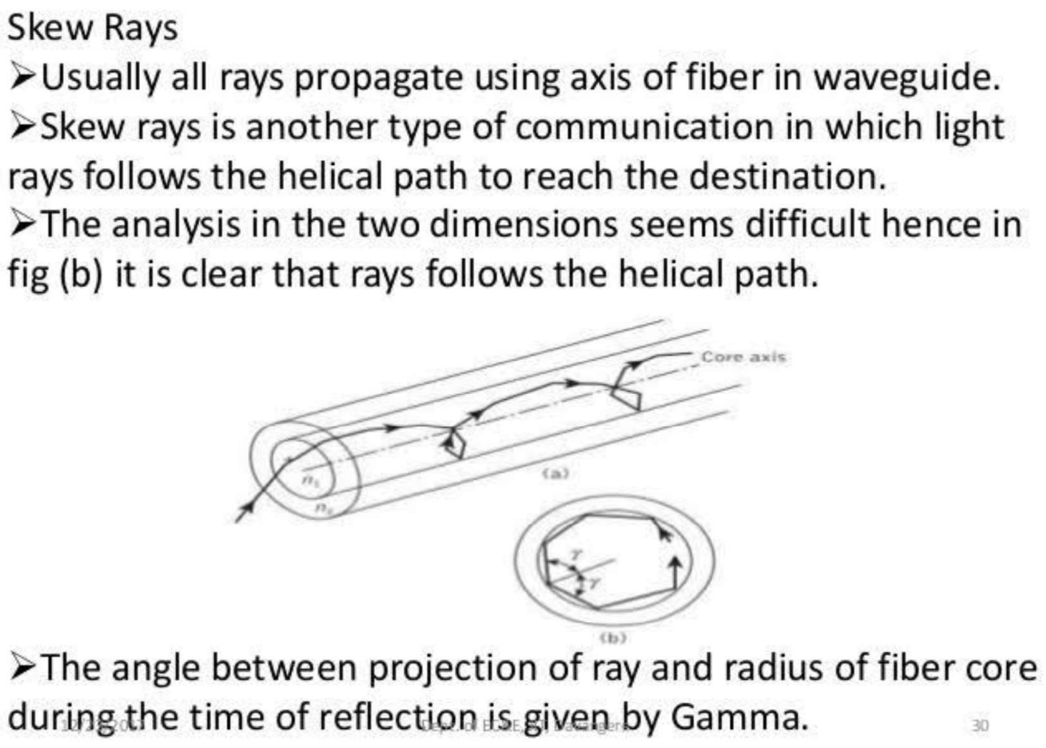
→ Meridional rays enter the fiber through the axis of the fiber.

→ Meridional rays cross the optical fiber axis at each reflection

[Ray path view of plane normal to fiber axis]

Meridional Rays

Skew rays

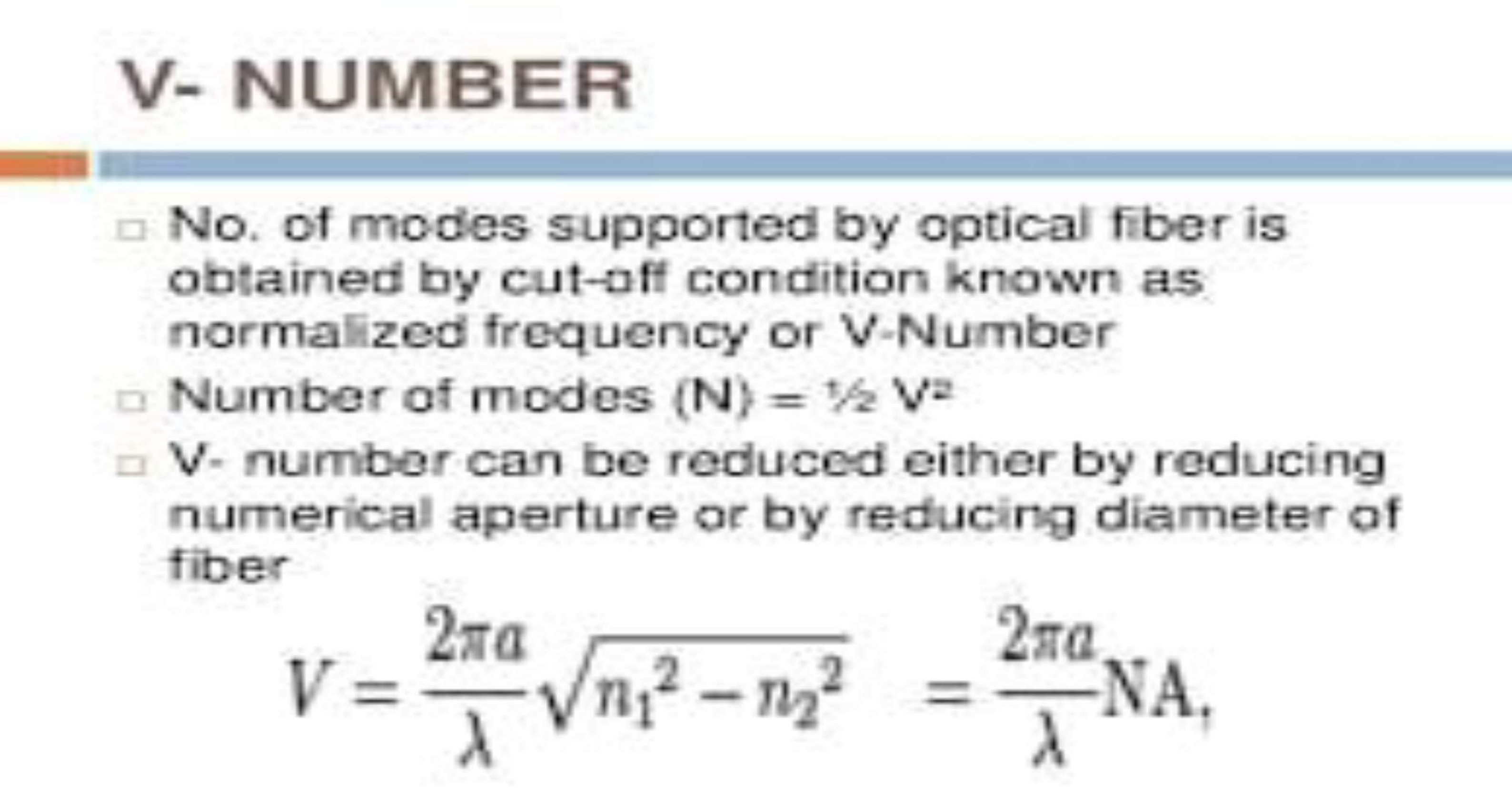


Skew Rays

- ➢Usually all rays propagate using axis of fiber in waveguide.
- ➢Skew rays is another type of communication in which light rays follows the helical path to reach the destination.
- ➢The analysis in the two dimensions seems difficult hence in fig (b) it is clear that rays follows the helical path.

- ➢The angle between projection of ray and radius of fiber core during the time of reflection is given by Gamma.

V-NUMBER

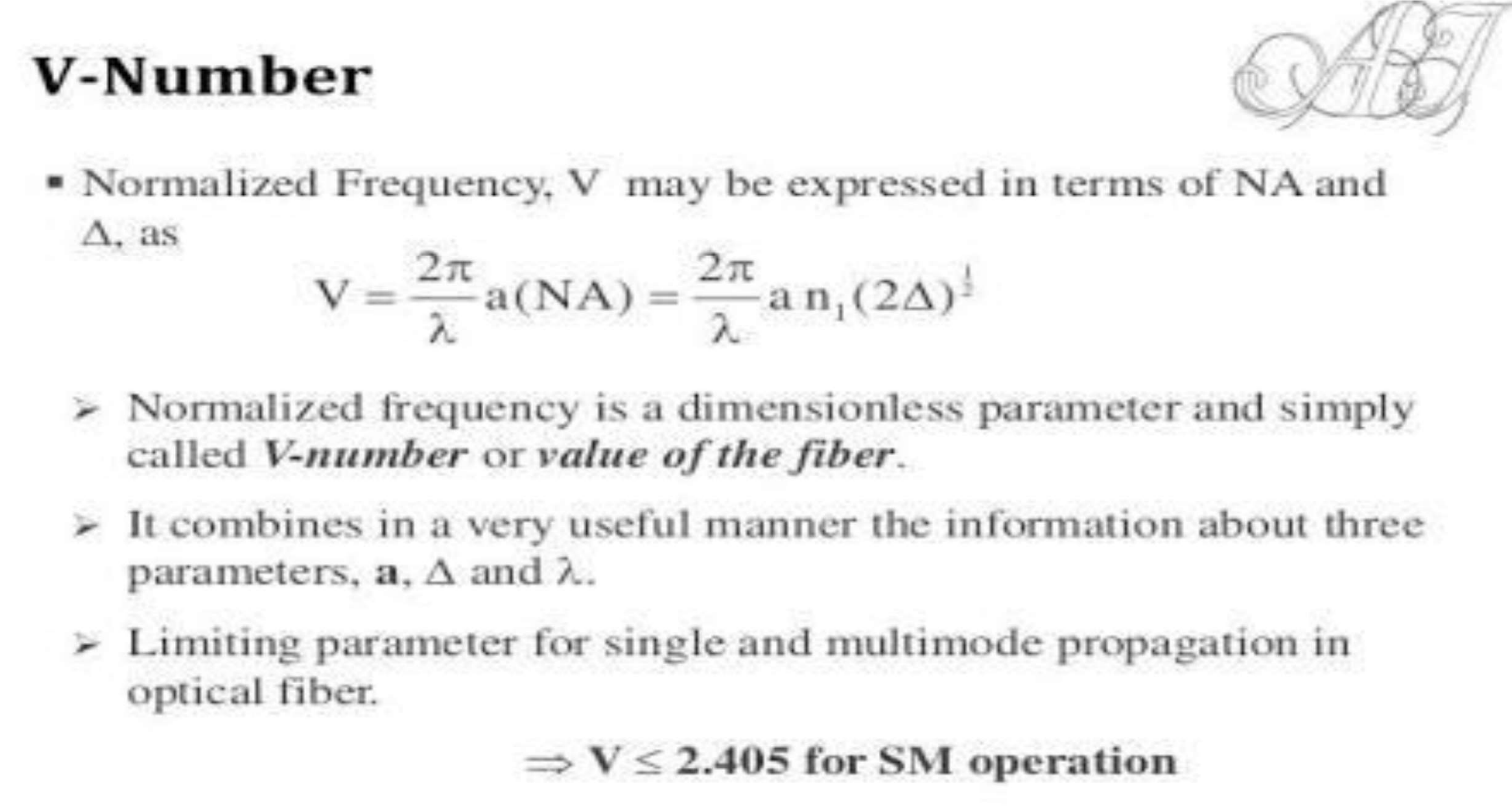


V- NUMBER

- ☐ No. of modes supported by optical fiber is obtained by cut-off condition known as normalized frequency or V-Number
- ☐ Number of modes (N) = ½ V^2
- ☐ V- number can be reduced either by reducing numerical aperture or by reducing diameter of fiber

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2} \quad = \frac{2\pi a}{\lambda}\mathrm{NA},$$

V-NUMBER



V-Number

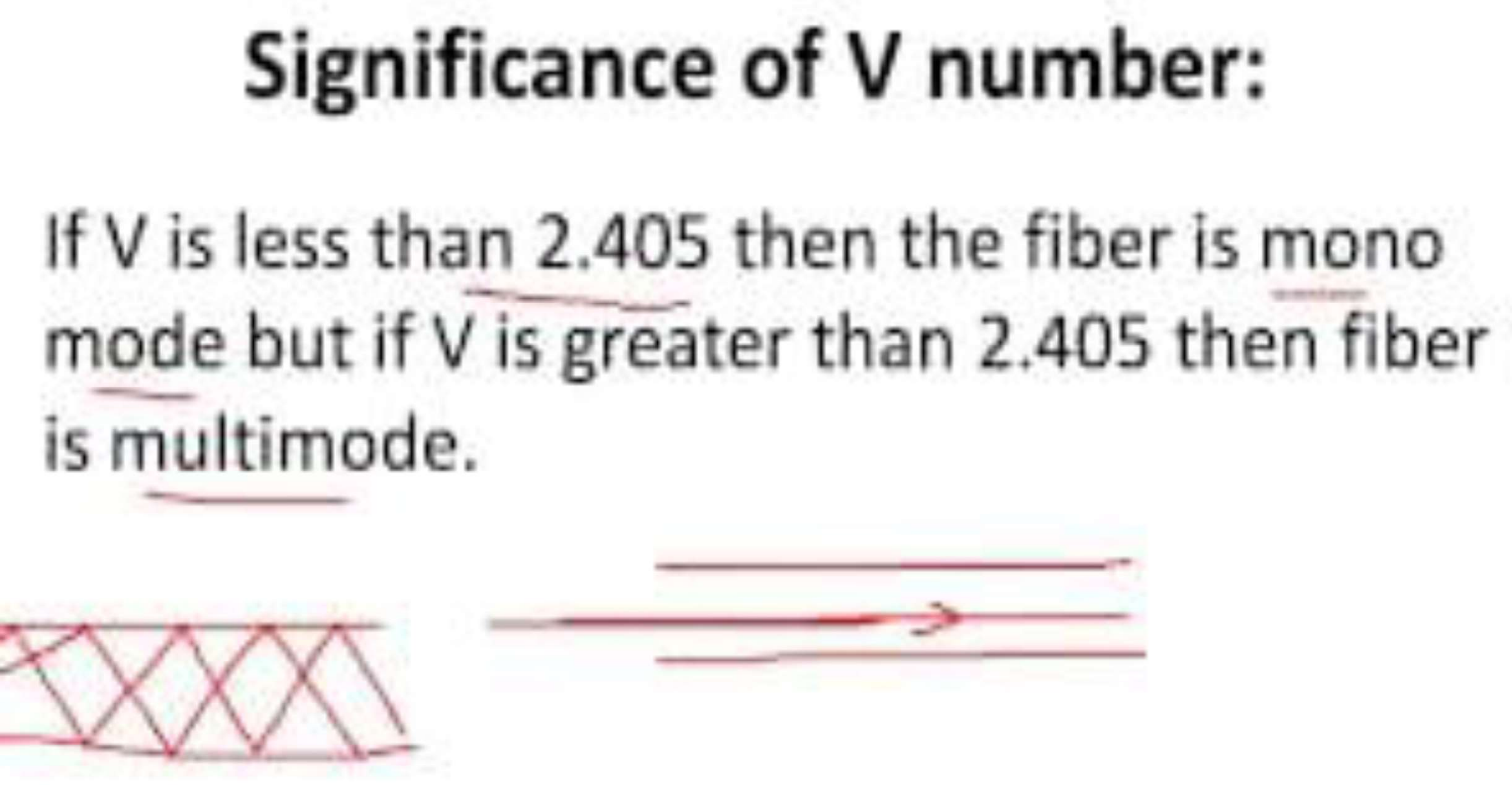
- Normalized Frequency, V may be expressed in terms of NA and Δ, as

$$V = \frac{2\pi}{\lambda} a(\mathrm{NA}) = \frac{2\pi}{\lambda} a\, n_1 (2\Delta)^{\frac{1}{2}}$$

  - Normalized frequency is a dimensionless parameter and simply called ***V-number*** or ***value of the fiber***.
  - It combines in a very useful manner the information about three parameters, **a**, Δ and λ.
  - Limiting parameter for single and multimode propagation in optical fiber.

$$\Rightarrow \mathbf{V \le 2.405 \text{ for SM operation}}$$

V-NUMBER

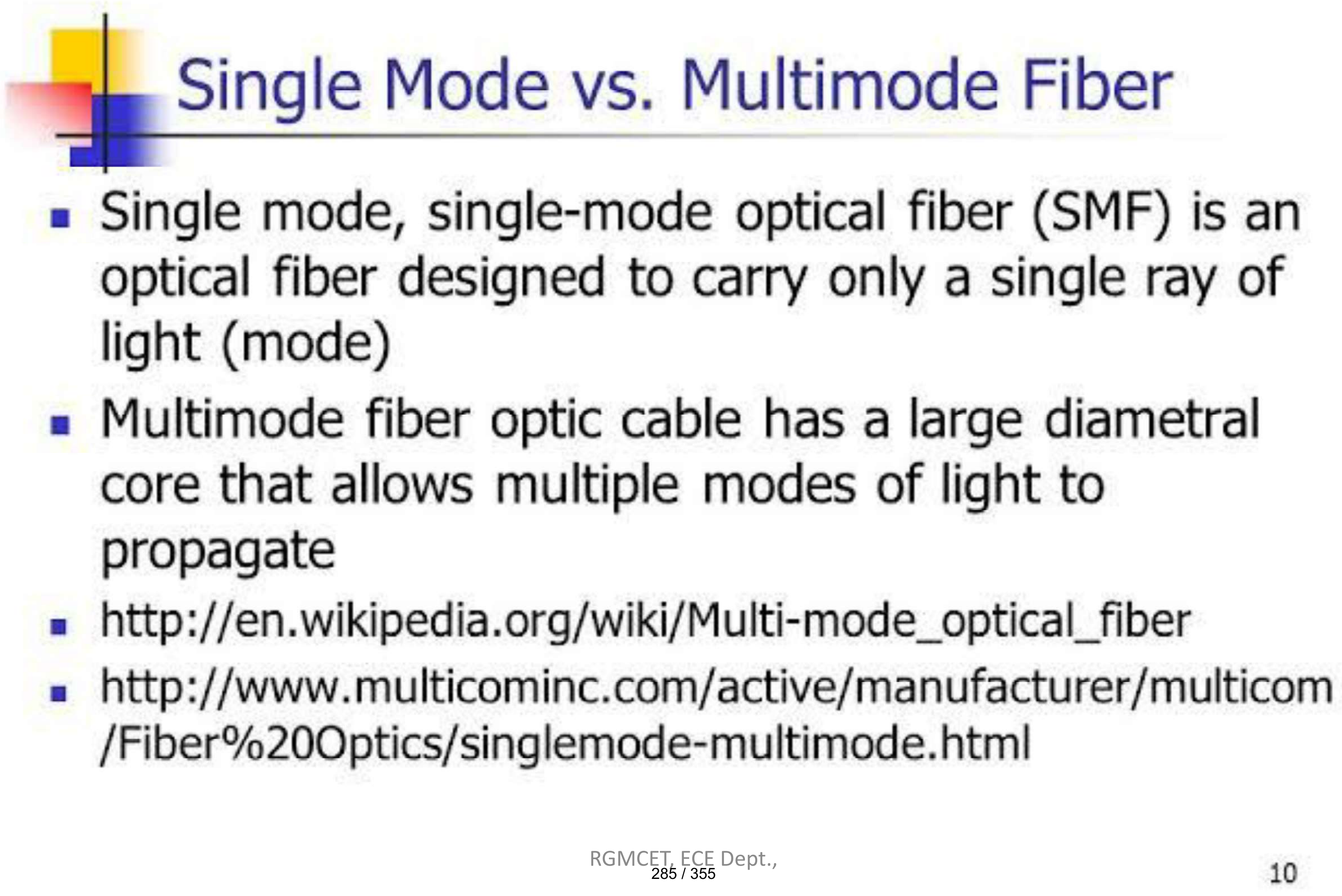


Significance of V number:

If V is less than 2.405 then the fiber is mono mode but if V is greater than 2.405 then fiber is multimode.

Step and Graded index fibers

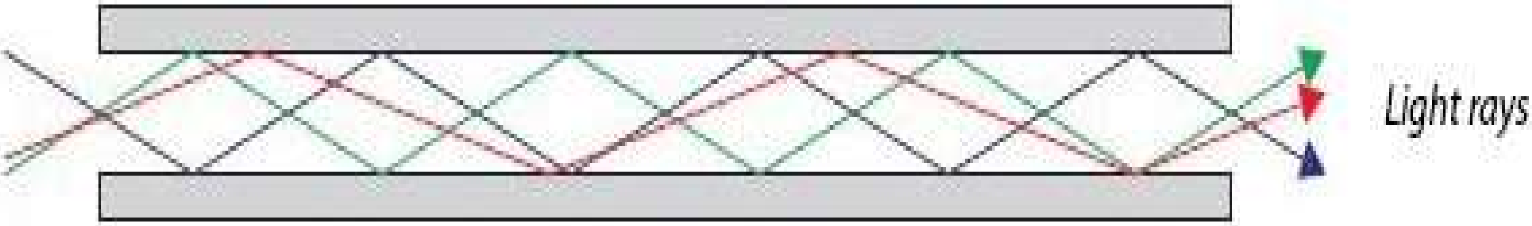
Classification of Fibers



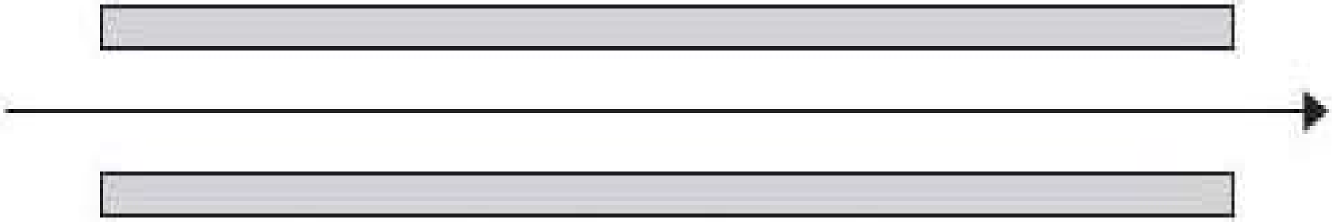
Single Mode vs. Multimode Fiber

- Single mode, single-mode optical fiber (SMF) is an optical fiber designed to carry only a single ray of light (mode)
- Multimode fiber optic cable has a large diametral core that allows multiple modes of light to propagate
- http://en.wikipedia.org/wiki/Multi-mode_optical_fiber
- http://www.multicominc.com/active/manufacturer/multicom/Fiber%20Optics/singlemode-multimode.html

SINGLE MODE AND MULTI MODE FIBERS



Multimode: different modes



Single-mode

Step index fiber- Single mode and Multimode

- Step index fiber- Single mode and Multimode The refractive index of the core material is constant throughout the length and diameter and an abrupt change occurs in step at the core cladding boundary .
- n(r)=n1 for r<a (core)
- n(r)=n2 for r>a (cladding)

Step Index / Graded Index

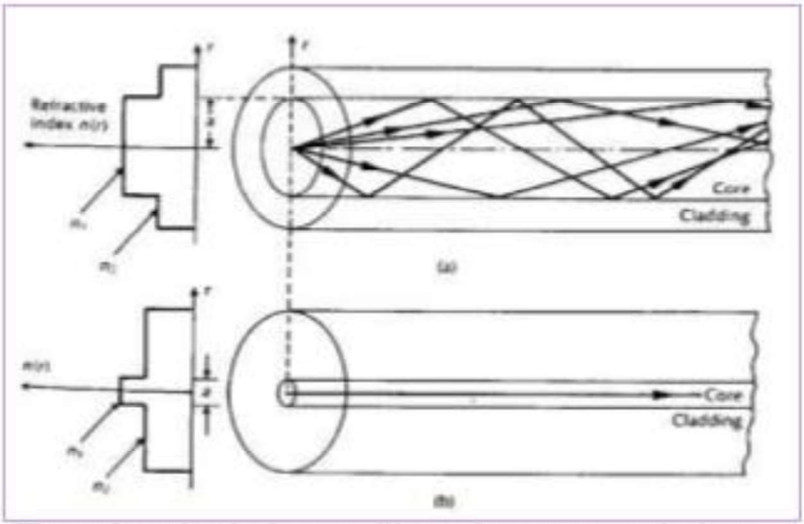
Fiber with a core of constant refractive index n_1 and a cladding of slightly lower refractive index n_2 .

- ➢ Refractive index profile makes a step change at the core-cladding interface

Refractive index profile

$$n(r) = \begin{cases} n_1 & ; \quad r<a \quad \text{(core)} \\ n_2 & ; \quad r \geq a \quad \text{(cladding)} \end{cases}$$

- Multimode Step Index
- Single mode Step Index



The refractive index profile and ray transmission in step index fibers: (a) multimode step index fiber: (b) single-mode step index fiber.

- The single mode fiber allows only transmission of mono mode light which is called fundamental mode(TEM00)
- It is used for long haul communication
- No of modes=N=V2 /2 V= normalized frequency

Advantages Single mode fibers

- The wavelength of operation is from 300 nm to 2000 nm
- The attenuation is around 0.15 dB/km
- The bandwidth capacity is from 1 to 100 Tb/km
- More than 3,00,000 voice channels are possible
- The cable is capable to tolerate higher temperature and has good mechanical strength

Disadvantages of Single mode step index fiber

- It is difficult to couple light into and out of fiber
- A highly directive light source(laser) is required to couple light
- They are expensive and difficult to manufacture

Advantages & disadvantages of Multimode step-index fiber

Advantages:

- They are relatively inexpensive and simple to manufacture
- It is easier to couple light into and out

Disadvantages:

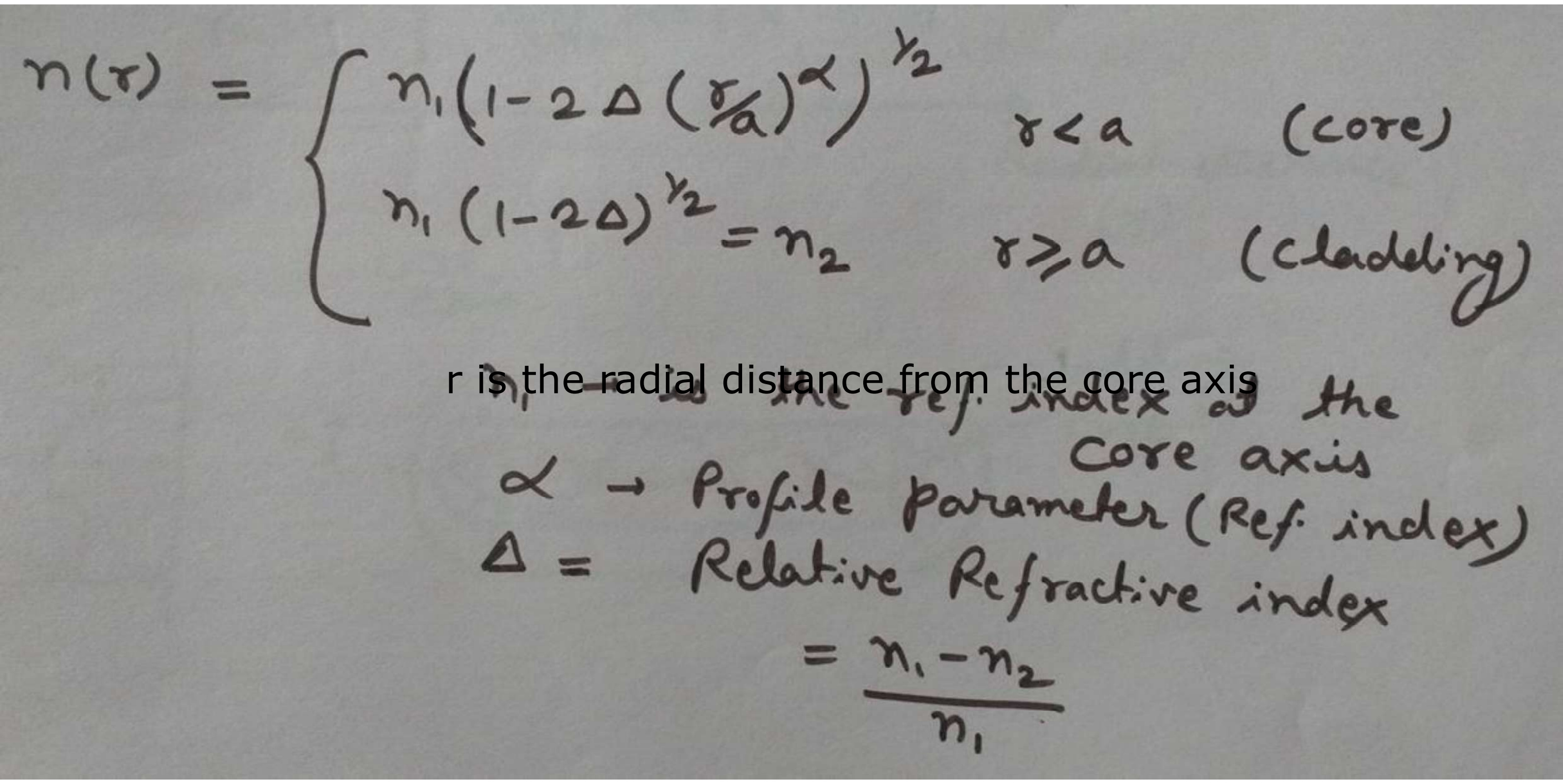
Light rays take many different paths down the fiber which results in large differences in propagation times(distortion)

- The bandwidths and rate of information rates possible with this type of fiber are less

Graded Index Fiber

- **Definition**: Graded Index fiber is another type of optical fiber in which the refractive index of the core is non-uniform. This non-uniformity is present because the refractive index is higher at the axis of the core and continuously reduces with the radial movement away from the axis.

REFRACTIVE INDEX PROFILE OF GRADED INDEX FIBER



$$n(r) = \begin{cases} n_1\left(1-2\Delta\left(\frac{r}{a}\right)^{\alpha}\right)^{1/2} & r<a \quad \text{(core)} \\ n_1(1-2\Delta)^{1/2} = n_2 & r \geq a \quad \text{(cladding)} \end{cases}$$

r is the radial distance from the core axis

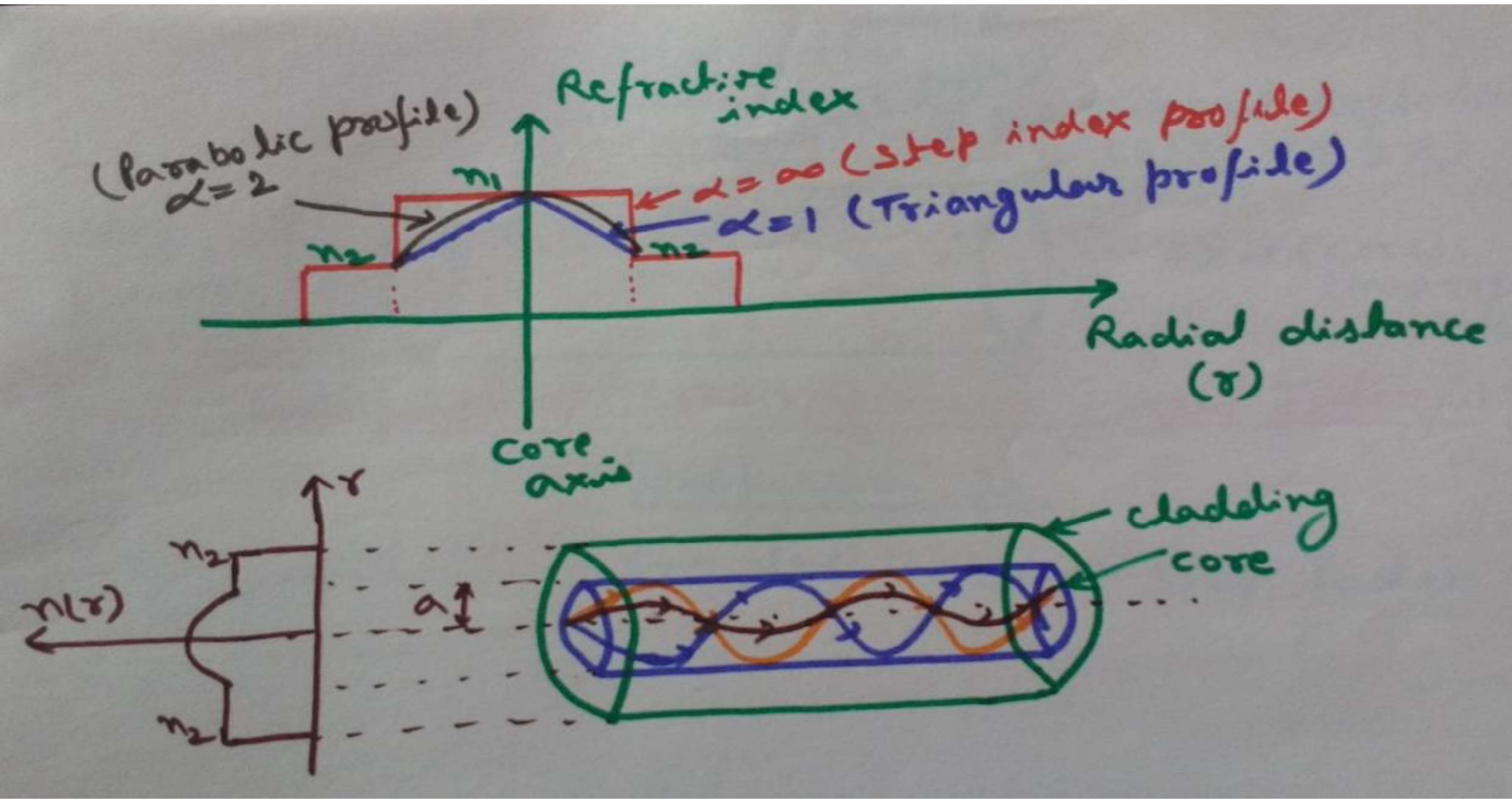
n_1 is the ref. index at the core axis

$\alpha \rightarrow$ Profile parameter (Ref. index)

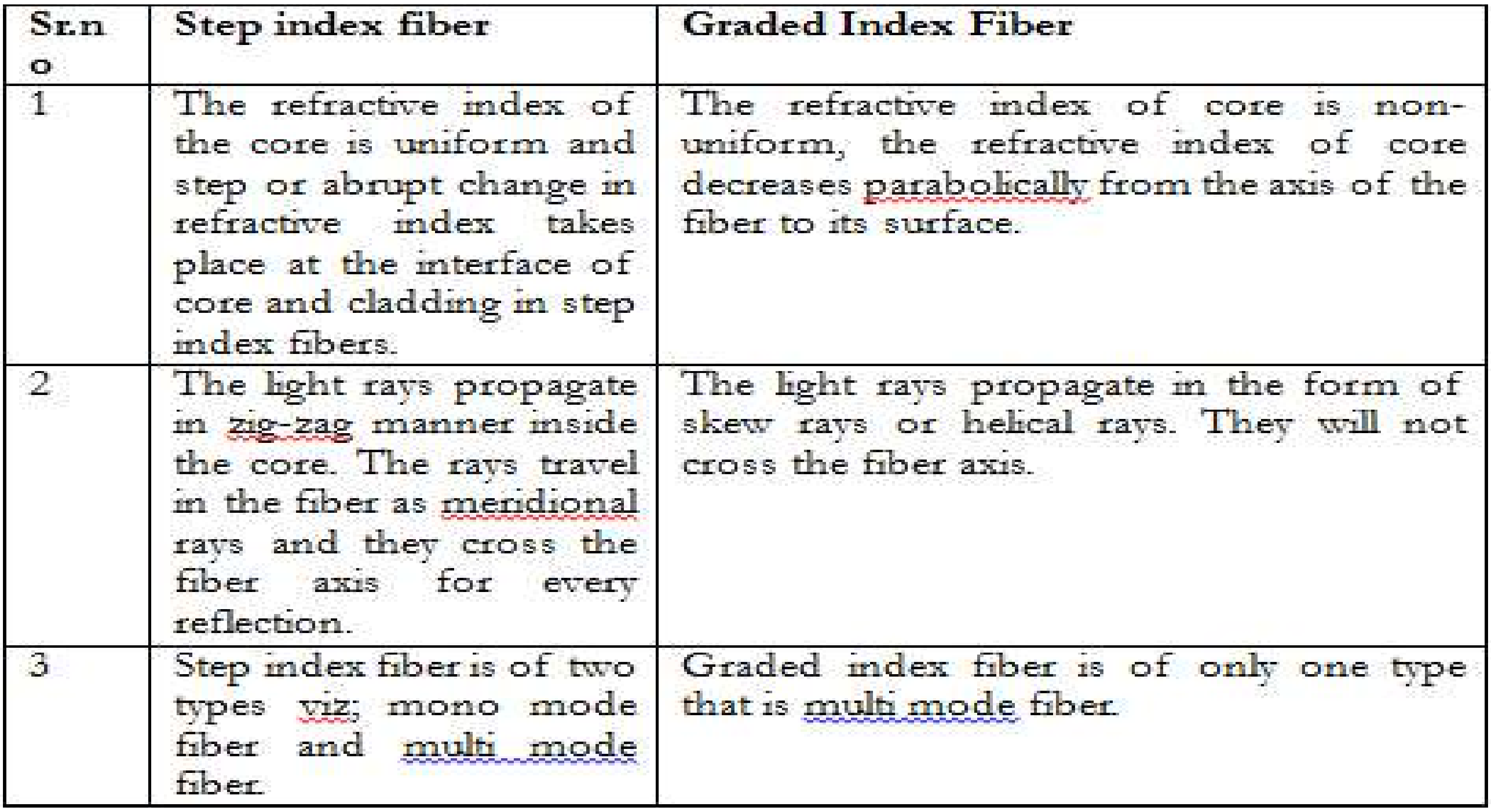
$\Delta =$ Relative Refractive index

$$= \frac{n_1 - n_2}{n_1}$$

MULTIMODE GRADED INDEX FIBER

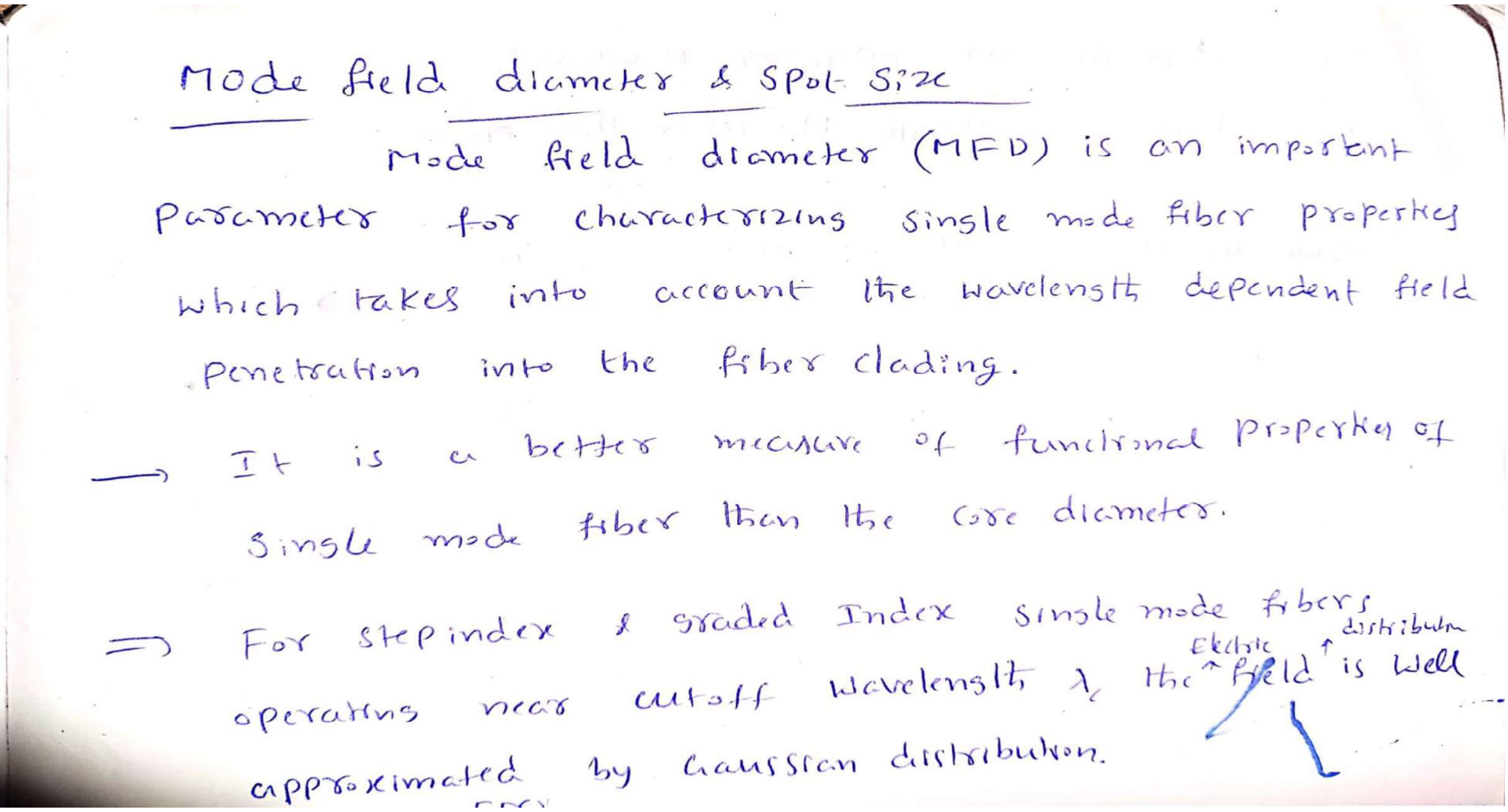


COMPARISION



Sr.no	Step index fiber	Graded Index Fiber
1	The refractive index of the core is uniform and step or abrupt change in refractive index takes place at the interface of core and cladding in step index fibers.	The refractive index of core is non-uniform, the refractive index of core decreases parabolically from the axis of the fiber to its surface.
2	The light rays propagate in zig-zag manner inside the core. The rays travel in the fiber as meridional rays and they cross the fiber axis for every reflection.	The light rays propagate in the form of skew rays or helical rays. They will not cross the fiber axis.
3	Step index fiber is of two types viz; mono mode fiber and multi mode fiber.	Graded index fiber is of only one type that is multi mode fiber.

MODE FIELD DIAMETER AND SPOT SIZE



Mode field diameter & Spot Size

Mode field diameter (MFD) is an important parameter for characterizing single mode fiber properties which takes into account the wavelength dependent field penetration into the fiber cladding.

→ It is a better measure of functional properties of single mode fiber than the core diameter.

⇒ For step index & graded Index single mode fibers operating near cutoff wavelength λ_c the Electric field distribution is well approximated by Gaussian distribution.

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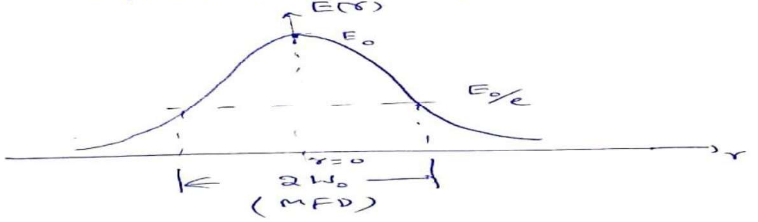
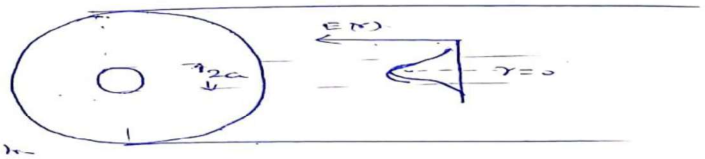


$$E(r) = E_0 \exp\left(\frac{-r^2}{W_0^2}\right)$$

⇒ MFD is defined as the distance between the two opposite end points of field amplitude distribution



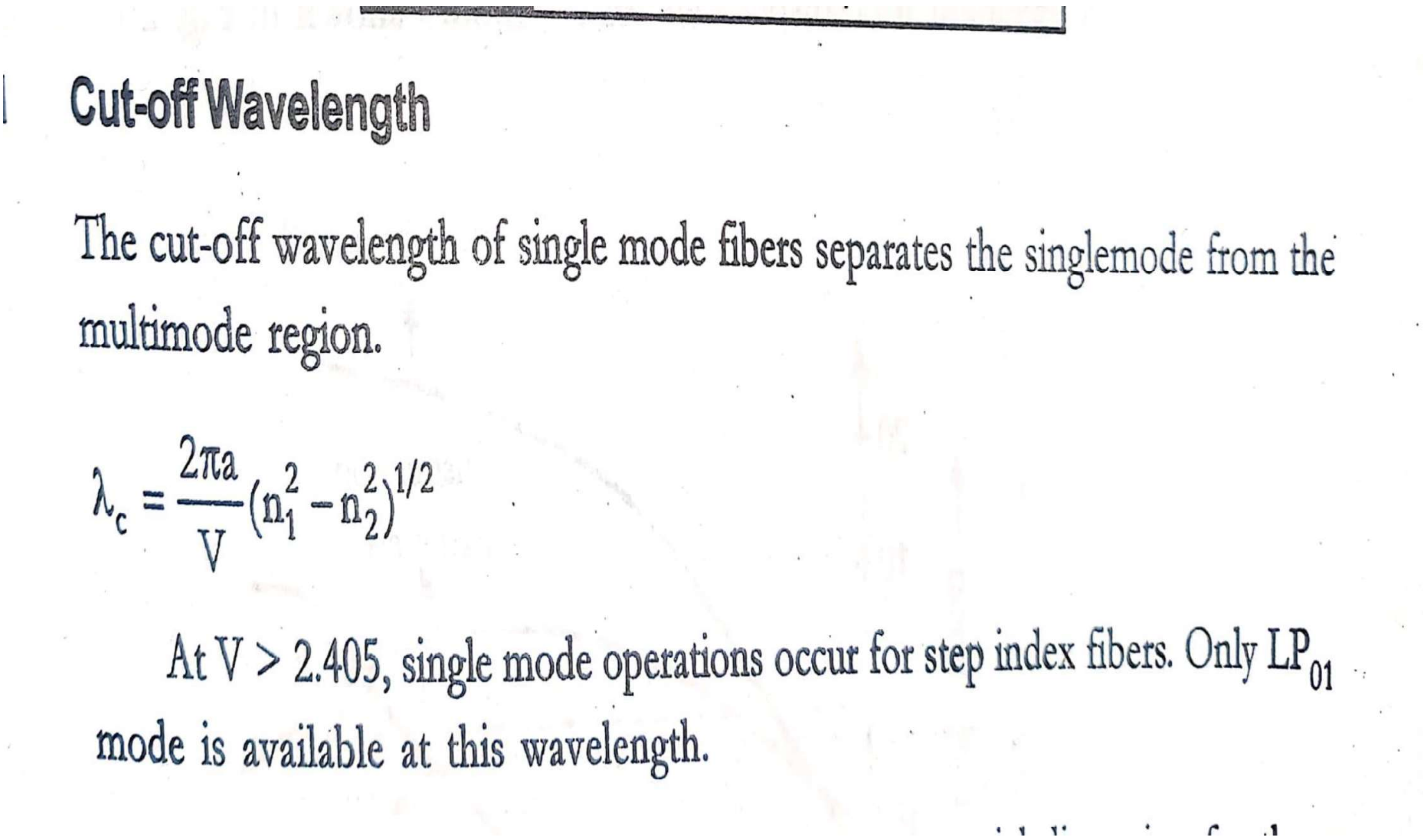
where Electric field is $\frac{1}{e} = 0.367$ times field along fiber axis (or) $\frac{1}{e^2} = 0.135$ times power along fiber axis.

⇒ Another parameter related to mode field diameter is spot size (or) mode field radius (W_0)

Mode field diameter MFD = 2 × spot size
= $2 \times W_0$

⇒ Mode field diameter is analogous to core diameter in multimode fibers

CUT OFF WAVELENGTH



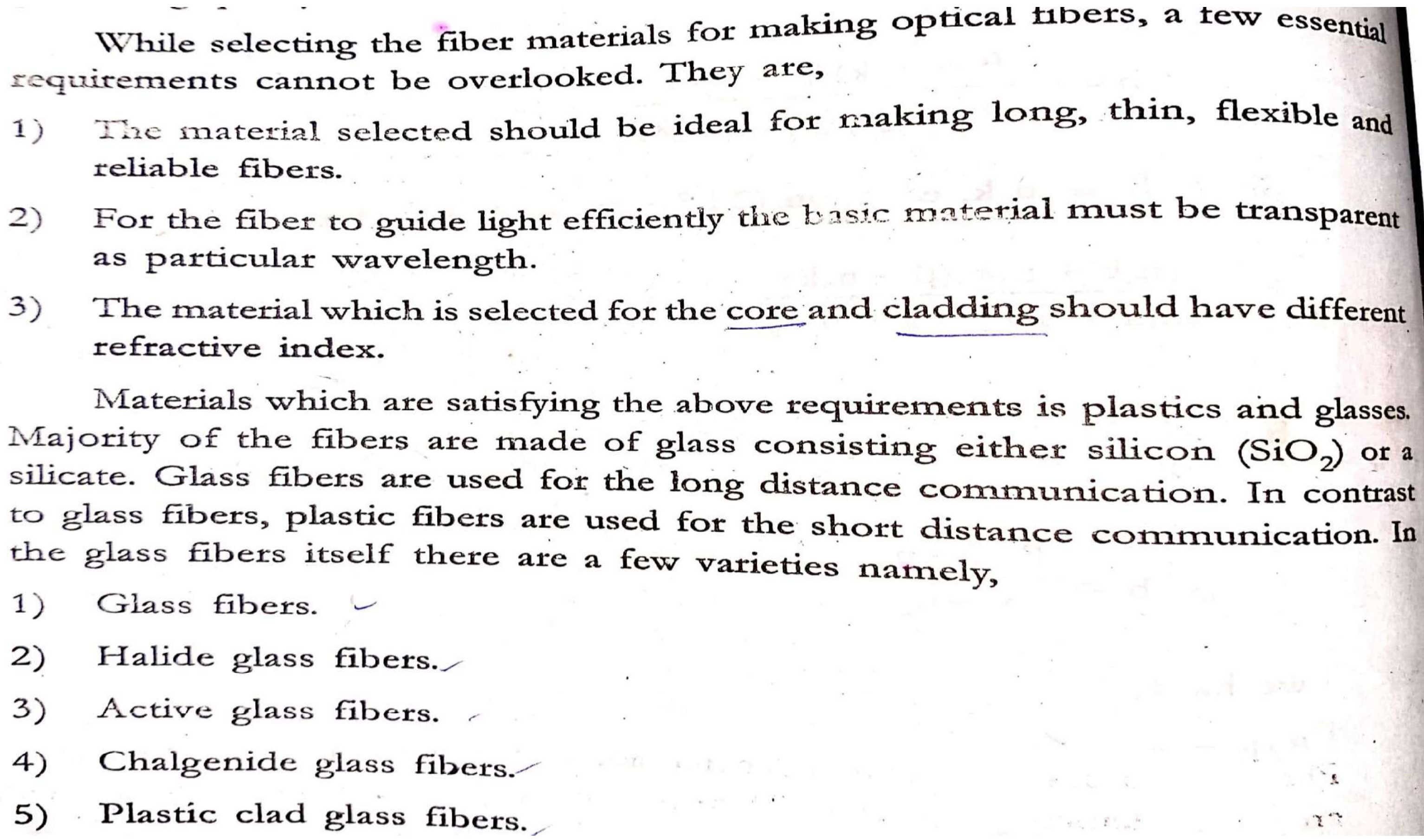
Cut-off Wavelength

The cut-off wavelength of single mode fibers separates the singlemode from the multimode region.

$$\lambda_c = \frac{2\pi a}{V}(n_1^2 - n_2^2)^{1/2}$$

At V > 2.405, single mode operations occur for step index fibers. Only LP_{01} mode is available at this wavelength.

FIBER MATERIALS



While selecting the fiber materials for making optical fibers, a few essential requirements cannot be overlooked. They are,

1) The material selected should be ideal for making long, thin, flexible and reliable fibers.

2) For the fiber to guide light efficiently the basic material must be transparent as particular wavelength.

3) The material which is selected for the core and cladding should have different refractive index.

Materials which are satisfying the above requirements is plastics and glasses. Majority of the fibers are made of glass consisting either silicon (SiO_2) or a silicate. Glass fibers are used for the long distance communication. In contrast to glass fibers, plastic fibers are used for the short distance communication. In the glass fibers itself there are a few varieties namely,

1) Glass fibers.

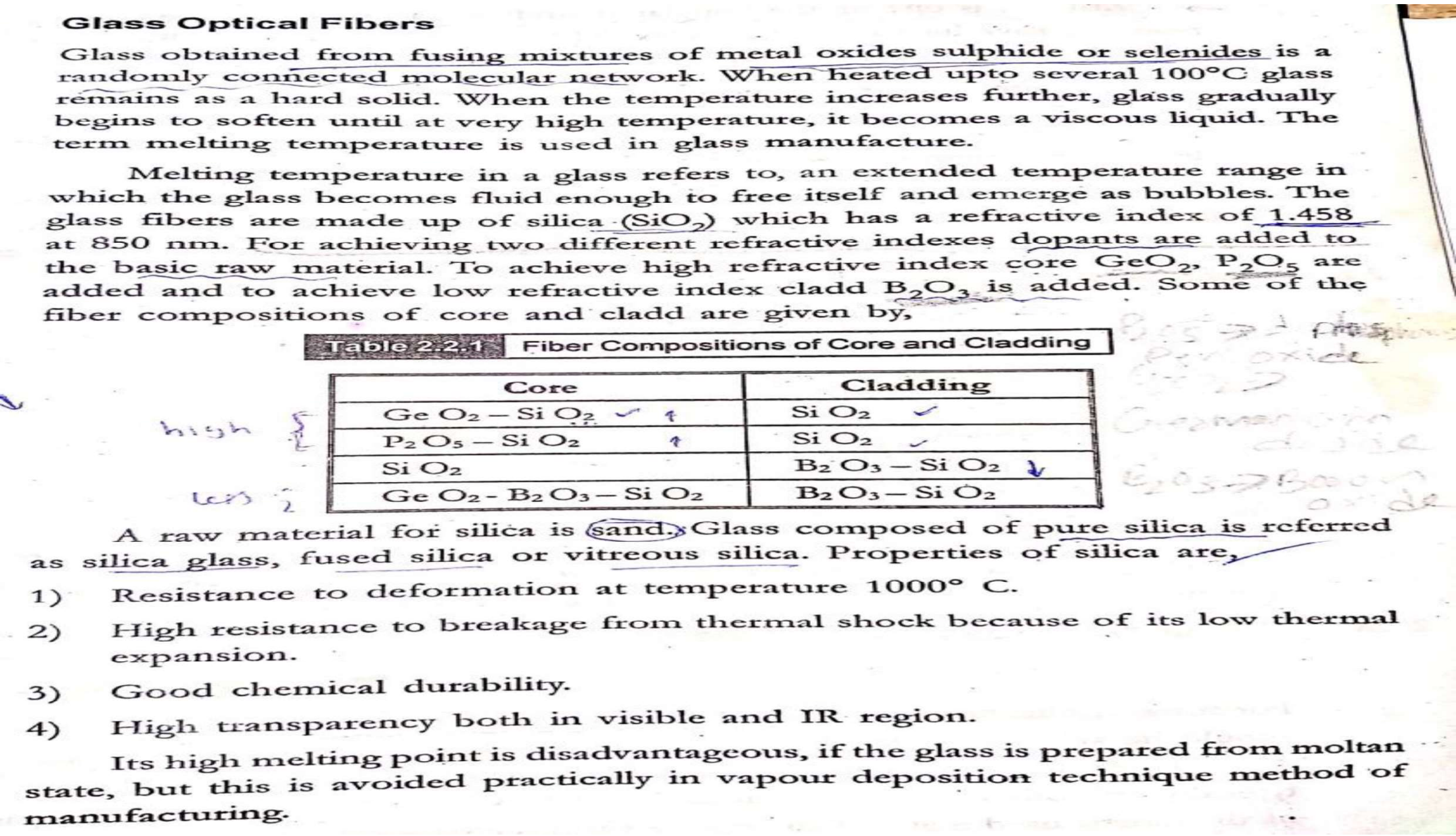
2) Halide glass fibers.

3) Active glass fibers.

4) Chalgenide glass fibers.

5) Plastic clad glass fibers.

1.GLASS FIBERS



Glass Optical Fibers

Glass obtained from fusing mixtures of metal oxides sulphide or selenides is a randomly connected molecular network. When heated upto several 100°C glass remains as a hard solid. When the temperature increases further, glass gradually begins to soften until at very high temperature, it becomes a viscous liquid. The term melting temperature is used in glass manufacture.

Melting temperature in a glass refers to, an extended temperature range in which the glass becomes fluid enough to free itself and emerge as bubbles. The glass fibers are made up of silica (SiO_2) which has a refractive index of 1.458 at 850 nm. For achieving two different refractive indexes dopants are added to the basic raw material. To achieve high refractive index core GeO_2, P_2O_5 are added and to achieve low refractive index cladd B_2O_3 is added. Some of the fiber compositions of core and cladd are given by,

Table 2.2.1 Fiber Compositions of Core and Cladding

P_2O_5 → phos... pent oxide

GeO_2 → Germanium dioxide

B_2O_3 → Boron oxide

high {

less }

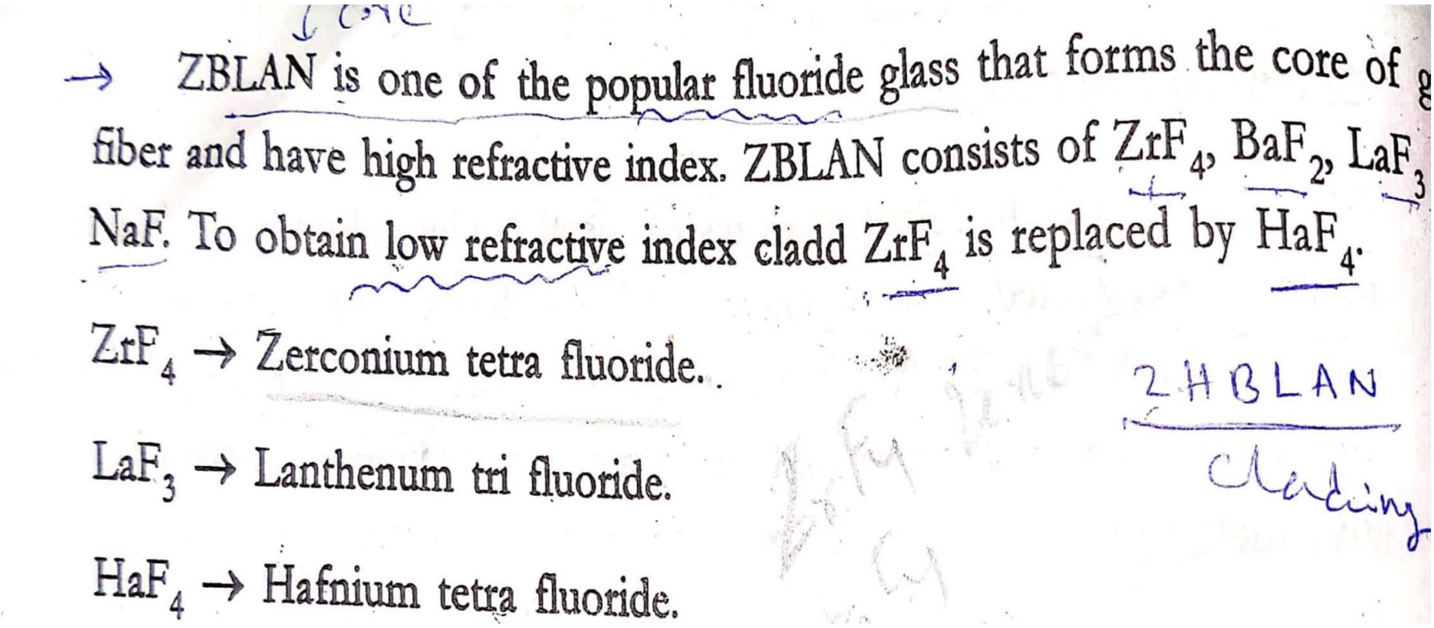
Core	Cladding
$GeO_2 - SiO_2$ ✓ ↑	SiO_2 ✓
$P_2O_5 - SiO_2$ ↑	SiO_2 ✓
SiO_2	$B_2O_3 - SiO_2$ ↓
$GeO_2 - B_2O_3 - SiO_2$	$B_2O_3 - SiO_2$

A raw material for silica is sand. Glass composed of pure silica is referred as silica glass, fused silica or vitreous silica. Properties of silica are,

1) Resistance to deformation at temperature 1000° C.
2) High resistance to breakage from thermal shock because of its low thermal expansion.
3) Good chemical durability.
4) High transparency both in visible and IR region.

Its high melting point is disadvantageous, if the glass is prepared from moltan state, but this is avoided practically in vapour deposition technique method of manufacturing.

HALIDE GLASS FIBERS



core

→ ZBLAN is one of the popular fluoride glass that forms the core of g fiber and have high refractive index. ZBLAN consists of ZrF_4, BaF_2, LaF_3 NaF. To obtain low refractive index cladd ZrF_4 is replaced by HaF_4.

ZrF_4 → Zerconium tetra fluoride.

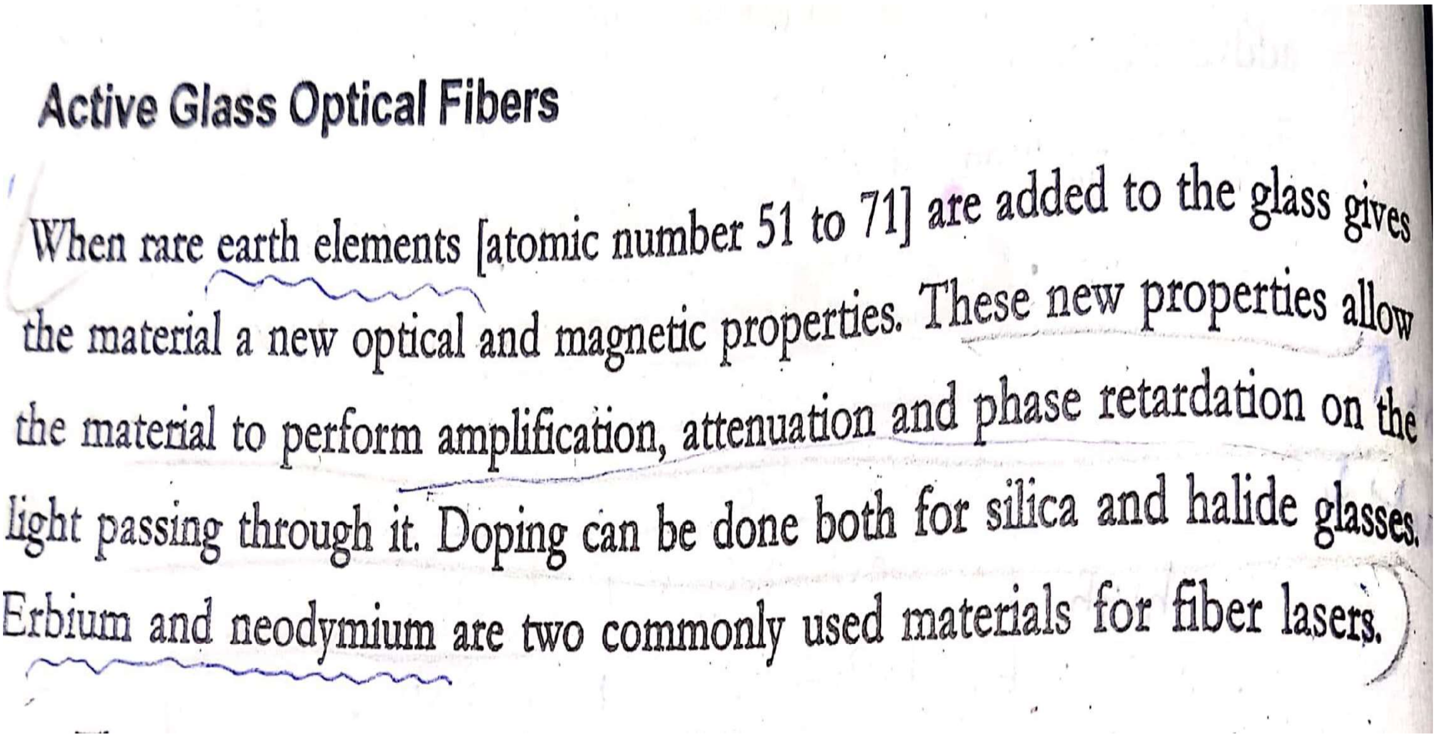
LaF_3 → Lanthenum tri fluoride.

HaF_4 → Hafnium tetra fluoride.

ZHBLAN

cladding

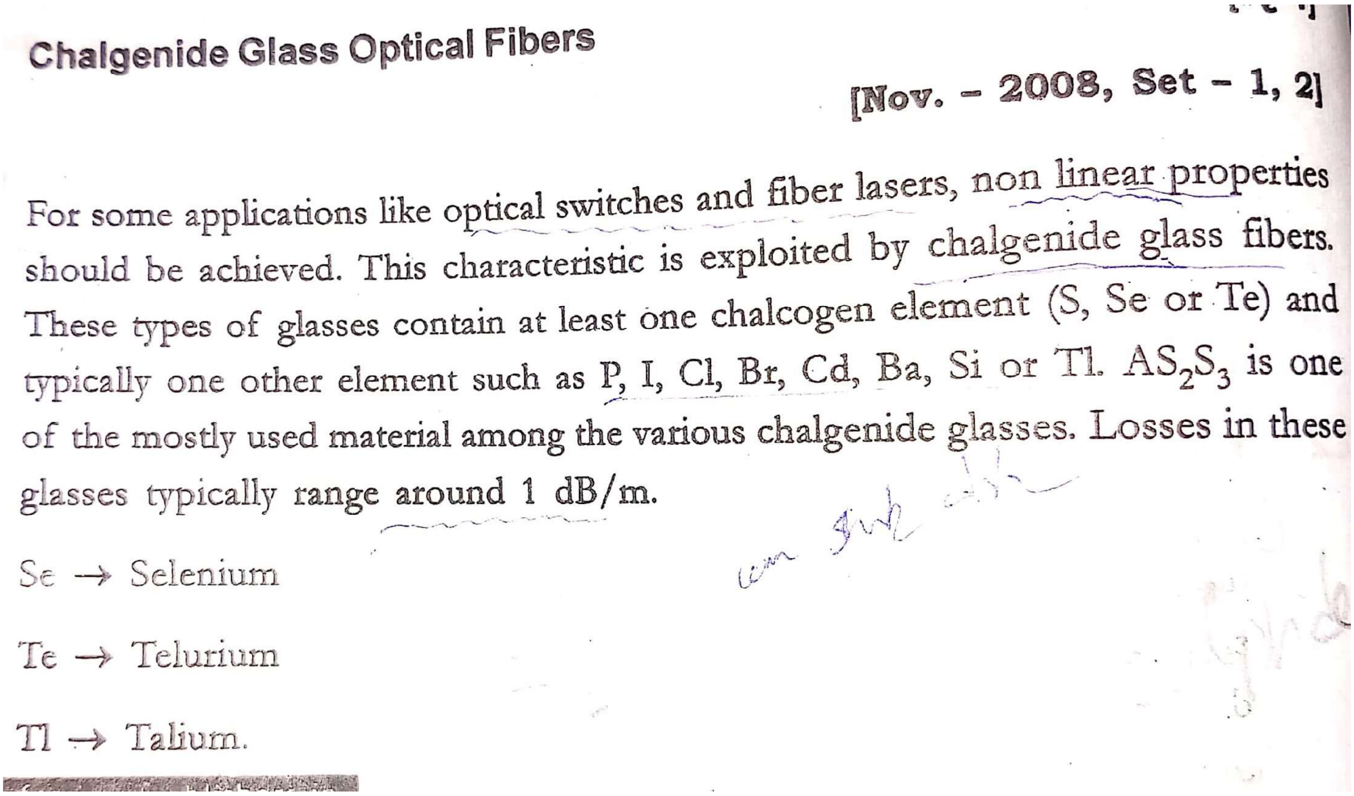
ACTIVE GLASS FIBERS



Active Glass Optical Fibers

When rare earth elements [atomic number 51 to 71] are added to the glass gives the material a new optical and magnetic properties. These new properties allow the material to perform amplification, attenuation and phase retardation on the light passing through it. Doping can be done both for silica and halide glasses. Erbium and neodymium are two commonly used materials for fiber lasers.

CHALGENIDE GLASS FIBER



Chalgenide Glass Optical Fibers

[Nov. – 2008, Set – 1, 2]

For some applications like optical switches and fiber lasers, non linear properties should be achieved. This characteristic is exploited by chalgenide glass fibers. These types of glasses contain at least one chalcogen element (S, Se or Te) and typically one other element such as P, I, Cl, Br, Cd, Ba, Si or Tl. AS_2S_3 is one of the mostly used material among the various chalgenide glasses. Losses in these glasses typically range around 1 dB/m.

Se → Selenium

Te → Telurium

Tl → Talium.

PLASTIC FIBERS

- For long distance communication where very low losses are achievable, optical fibers with glass cores and glass cladding are very important.
- For short distance communication where high losses are tolerable, less expensive plastic fibers are used.
- Plastic fibers are of two types namely:
- Plastic clad glass fiber
- Plastic fibers

Plastic clad glass fiber

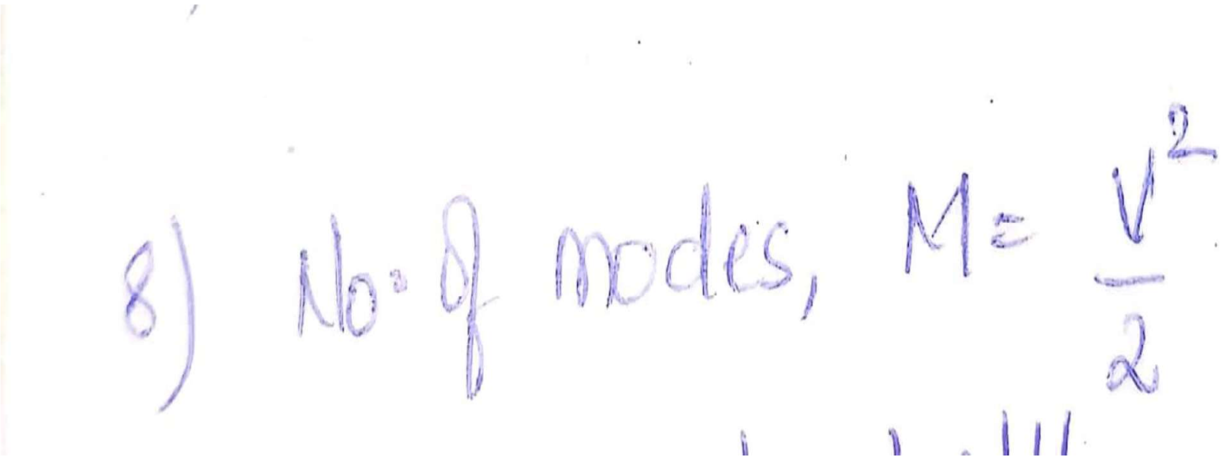
- These fibers are composed of silica cores with low refractive index.
- These fibers are also referred as PCS fibers.
- High purity natural quartz is a common material source for the silica core.
- Cladding material is a silicone resin having a refractive index of 1.405 at 850nm.

Plastic fibers

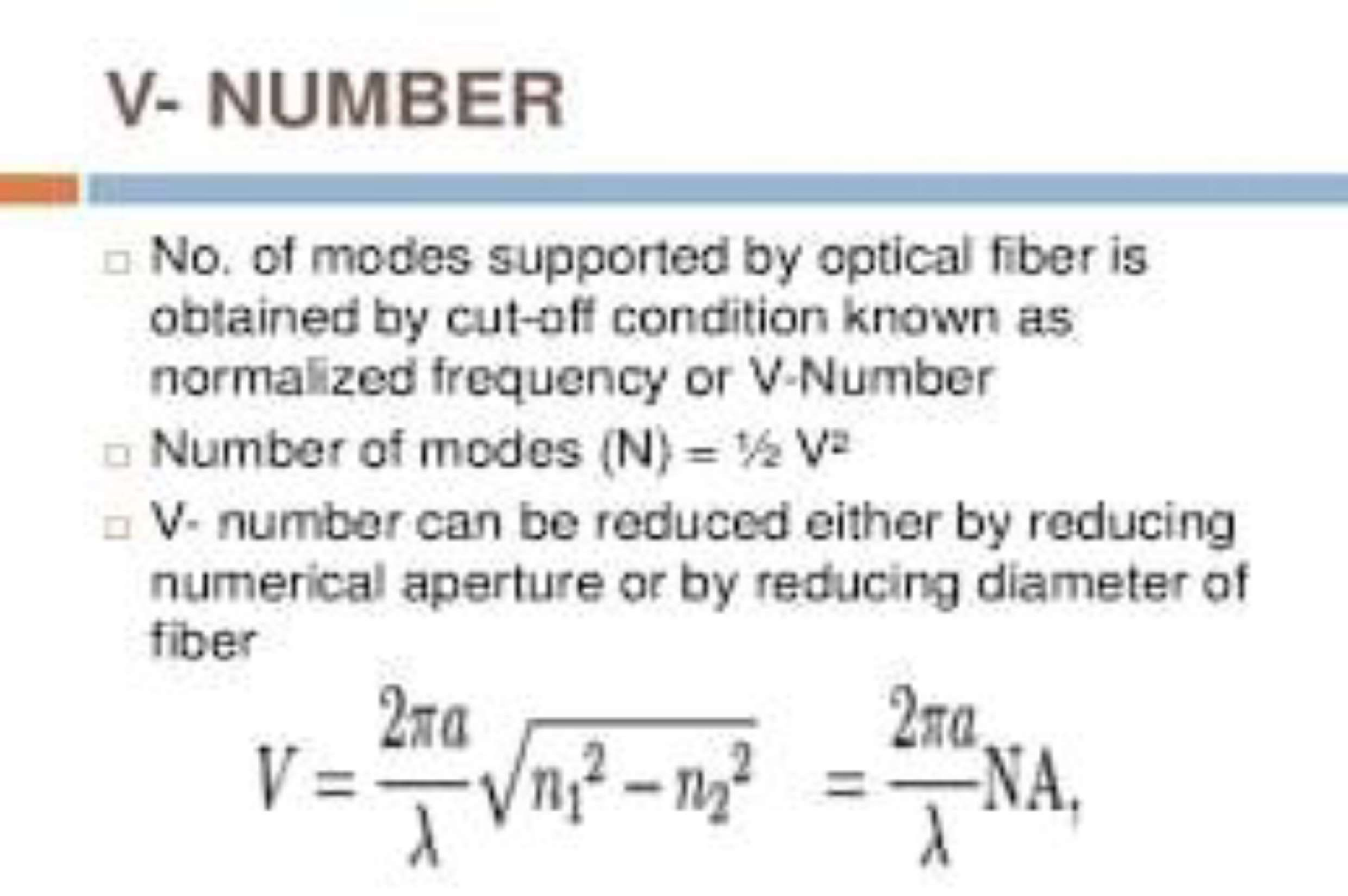
- For short distance all plastic multimode step index fibers are used for communication.
- The toughness and durability of plastic allow these fibers to have great optical signal attenuation.
- This type of fiber is having numerical aperture 0.6 and large acceptance angle of up to 70.

NUMERICALS

- The number of modes supported by step index fiber is given by



8) No. of modes, $M = \frac{V^2}{2}$



V- NUMBER

- No. of modes supported by optical fiber is obtained by cut-off condition known as normalized frequency or V-Number
- Number of modes (N) = ½ V^2
- V- number can be reduced either by reducing numerical aperture or by reducing diameter of fiber

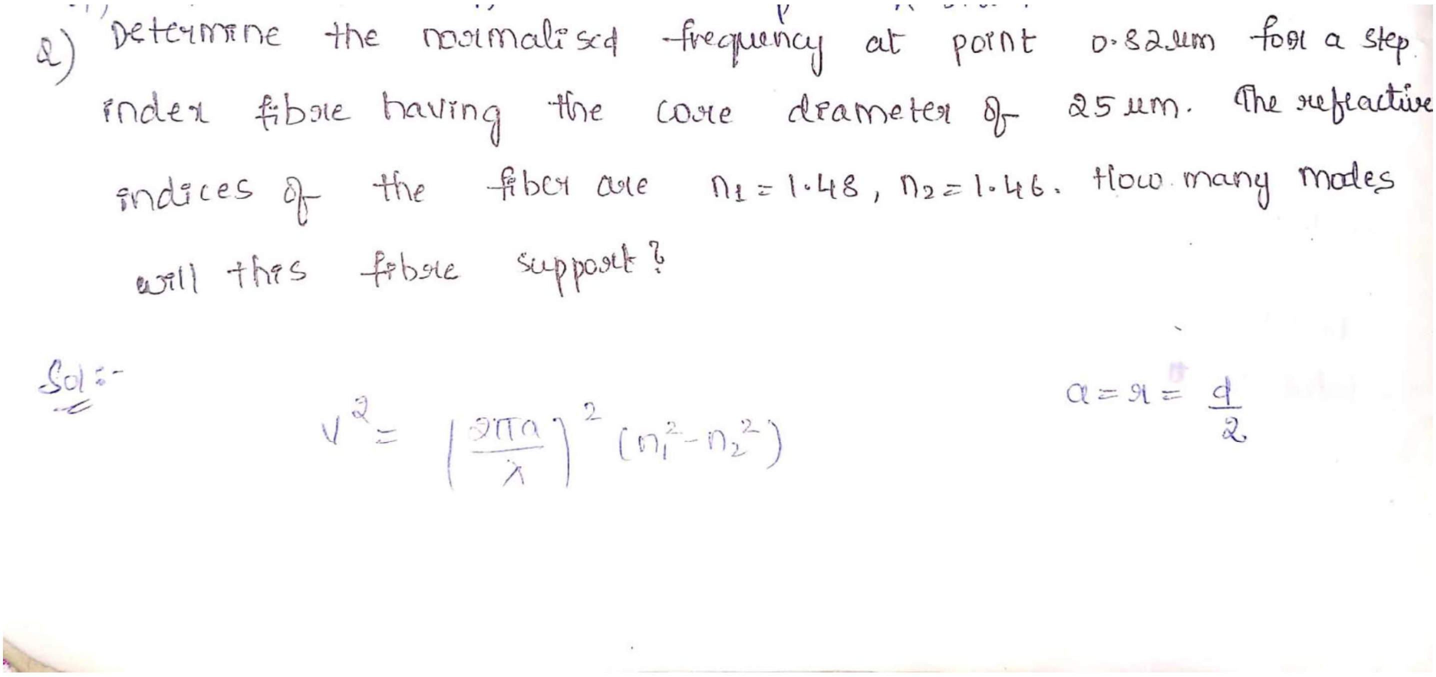
$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2} \quad = \frac{2\pi a}{\lambda}\mathrm{NA},$$

NUMERICALS

- The number of modes supported by graded index fiber is given by

8) $$M = \left(\frac{\alpha}{\alpha+2}\right) \cdot \frac{V^2}{2}$$

NUMERICALS



2) Determine the normalised frequency at point 0.82μm for a step index fibre having the core diameter of 25μm. The refractive indices of the fiber are $n_1 = 1.48$, $n_2 = 1.46$. How many modes will this fibre support?

Sol:-

$$V^2 = \left(\frac{2\pi a}{\lambda}\right)^2 (n_1^2 - n_2^2)$$

$a = r = \frac{d}{2}$

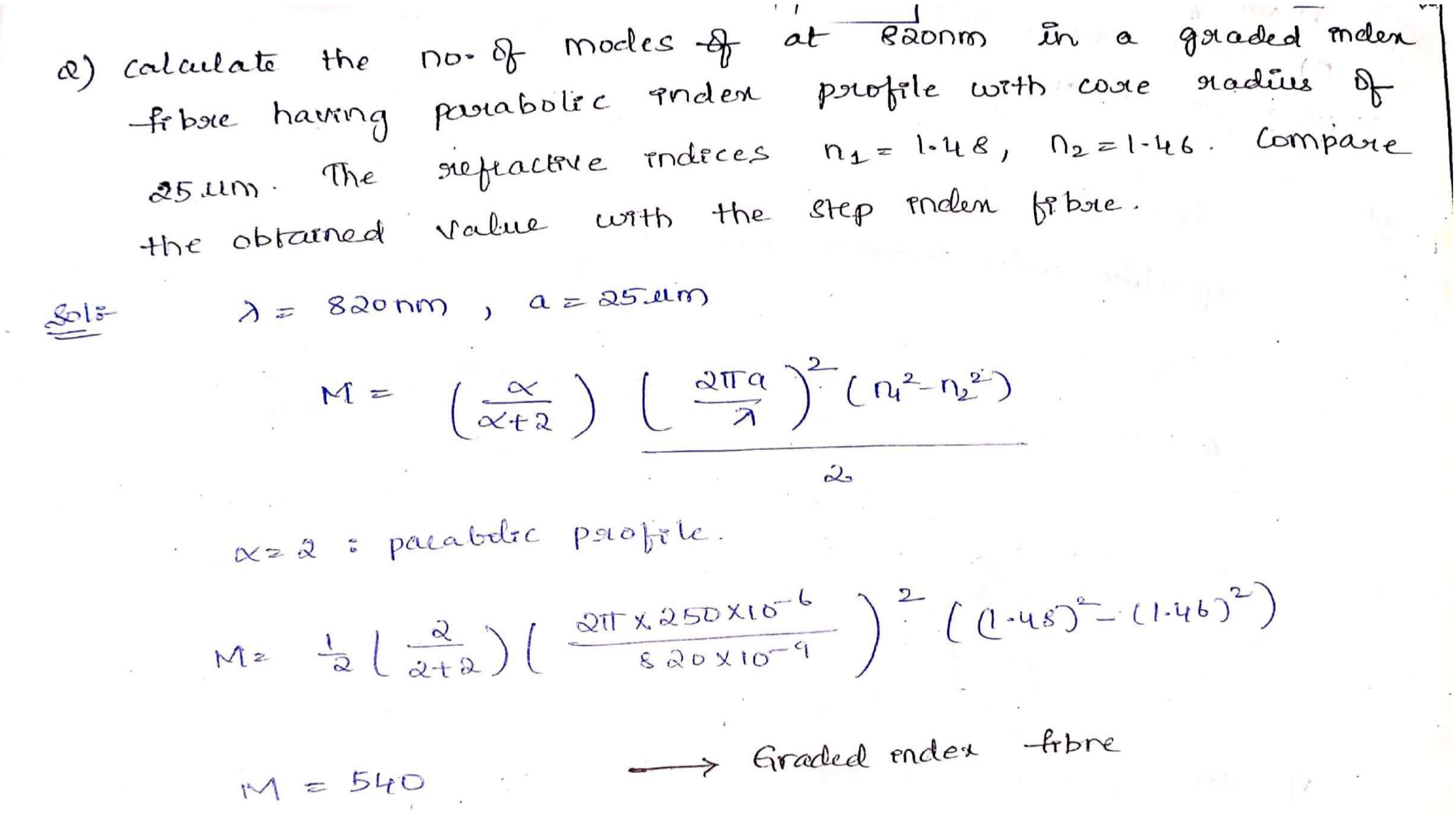
NUMERICALS

$$= \left(\frac{2\pi(12.5 \times 10^{-6})}{0.82 \times 10^{-6}} \right)^2$$

$$= 539.42 \simeq \underline{\underline{540}}$$

$$M = \frac{V^2}{2} = \frac{540}{2} = 270.$$

NUMERICALS



Q) Calculate the no. of modes of at 820nm in a graded index fibre having parabolic index profile with core radius of 25 μm. The refractive indices $n_1 = 1.48$, $n_2 = 1.46$. Compare the obtained value with the step index fibre.

Sol:- $\lambda = 820\,nm$, $a = 25\,\mu m$

$$M = \frac{\left(\frac{\alpha}{\alpha+2}\right)\left(\frac{2\pi a}{\lambda}\right)^2 (n_1^2 - n_2^2)}{2}$$

$\alpha = 2$: parabolic profile.

$$M = \frac{1}{2}\left(\frac{2}{2+2}\right)\left(\frac{2\pi \times 250 \times 10^{-6}}{820 \times 10^{-9}}\right)^2 \left((1.48)^2 - (1.46)^2\right)$$

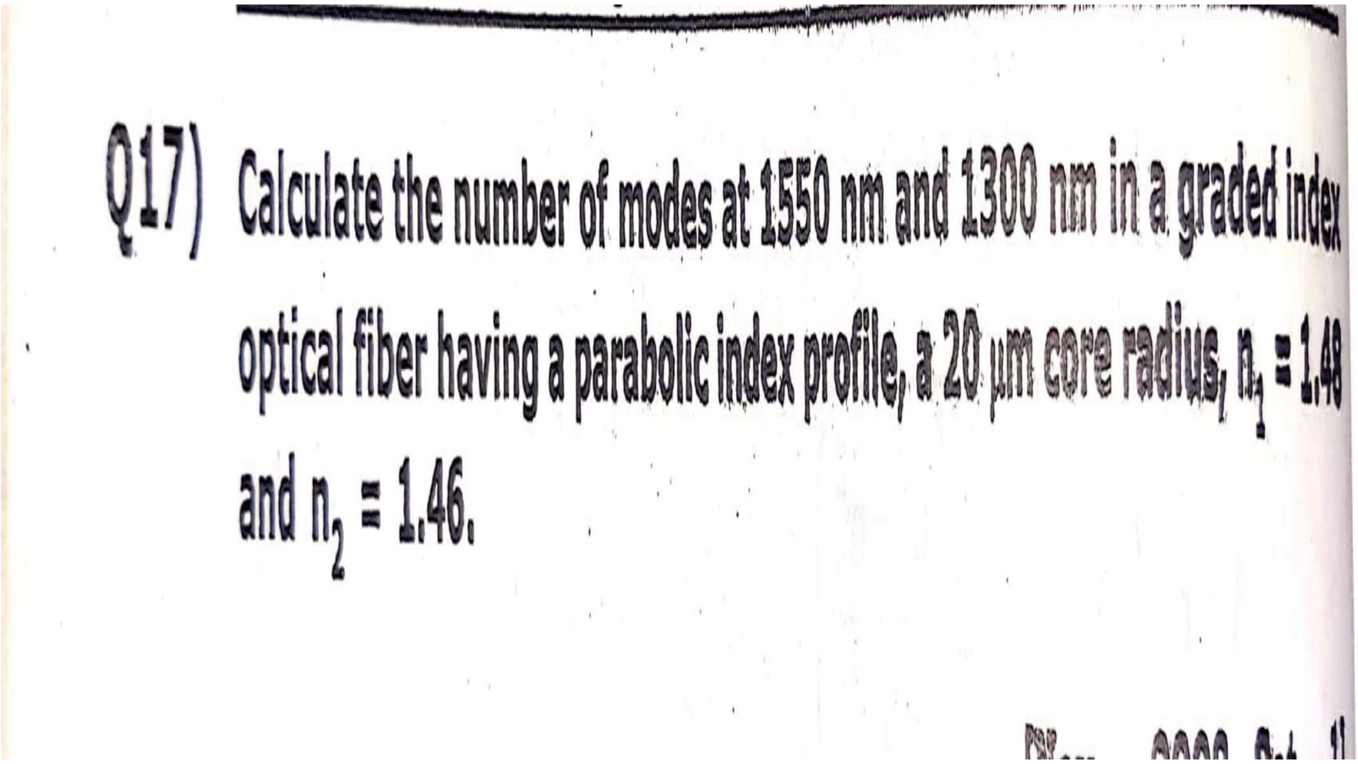
$M = 540$ $\longrightarrow$ Graded index fibre

NUMERICALS

$$M = \frac{V^2}{2} = \frac{\left(\frac{2\pi a}{\lambda}\right)^2 \left(n_1^2 - n_2^2\right)}{2}$$

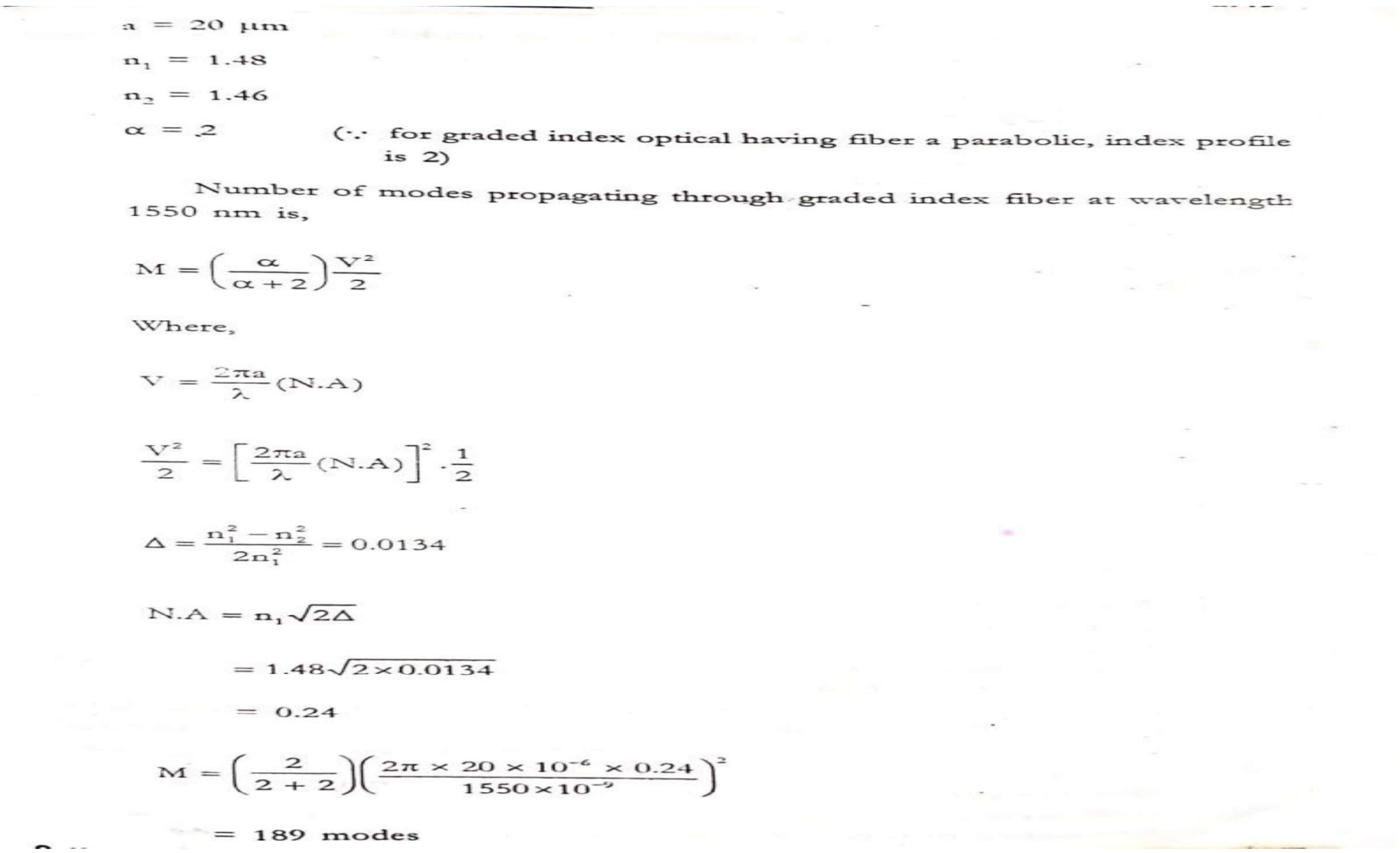
$m = 1080$ → step index fibre.

NUMERICALS



Q17) Calculate the number of modes at 1550 nm and 1300 nm in a graded index optical fiber having a parabolic index profile, a 20 μm core radius, $n_1 = 1.48$ and $n_2 = 1.46$.

solution



$a = 20\ \mu m$

$n_1 = 1.48$

$n_2 = 1.46$

$\alpha = 2$ (∵ for graded index optical having fiber a parabolic, index profile is 2)

Number of modes propagating through graded index fiber at wavelength 1550 nm is,

$$M = \left(\frac{\alpha}{\alpha + 2}\right)\frac{V^2}{2}$$

Where,

$$V = \frac{2\pi a}{\lambda}(N.A)$$

$$\frac{V^2}{2} = \left[\frac{2\pi a}{\lambda}(N.A)\right]^2 \cdot \frac{1}{2}$$

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} = 0.0134$$

$$N.A = n_1\sqrt{2\Delta}$$

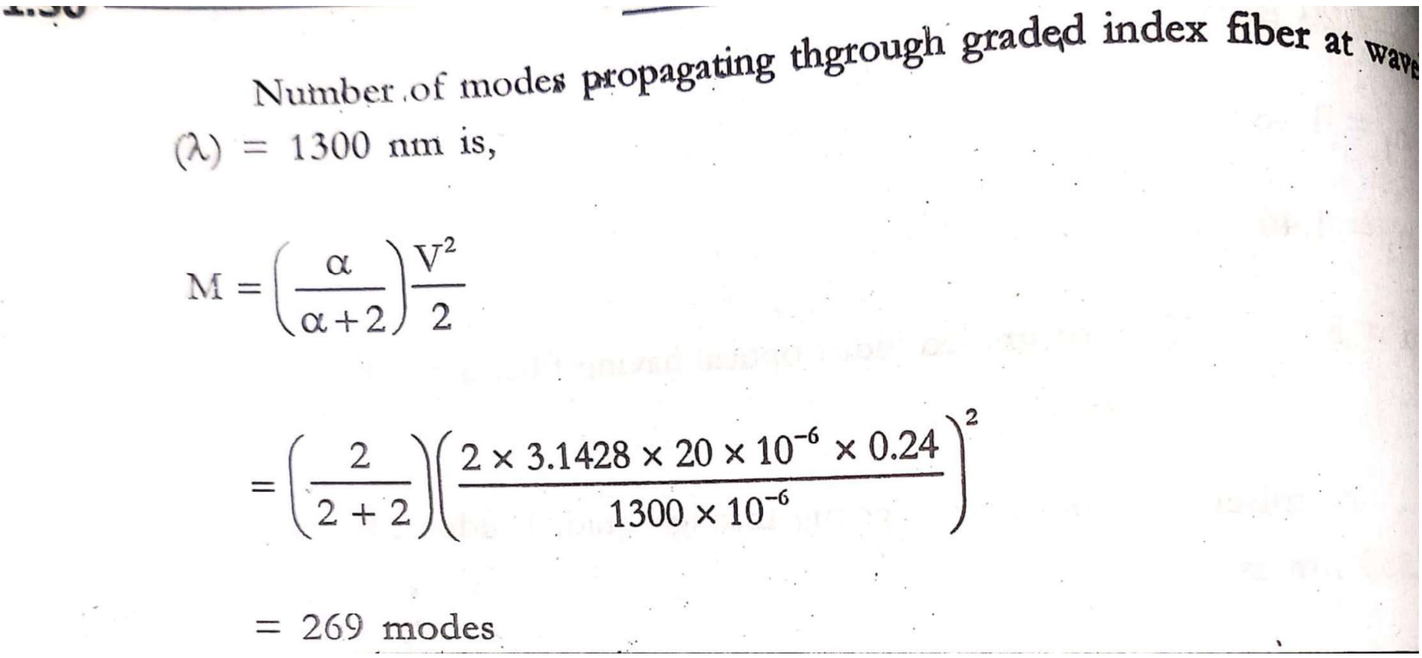
$$= 1.48\sqrt{2 \times 0.0134}$$

$$= 0.24$$

$$M = \left(\frac{2}{2+2}\right)\left(\frac{2\pi \times 20 \times 10^{-6} \times 0.24}{1550 \times 10^{-9}}\right)^2$$

$$= 189 \text{ modes}$$

solution



Number of modes propagating thgrough graded index fiber at wave

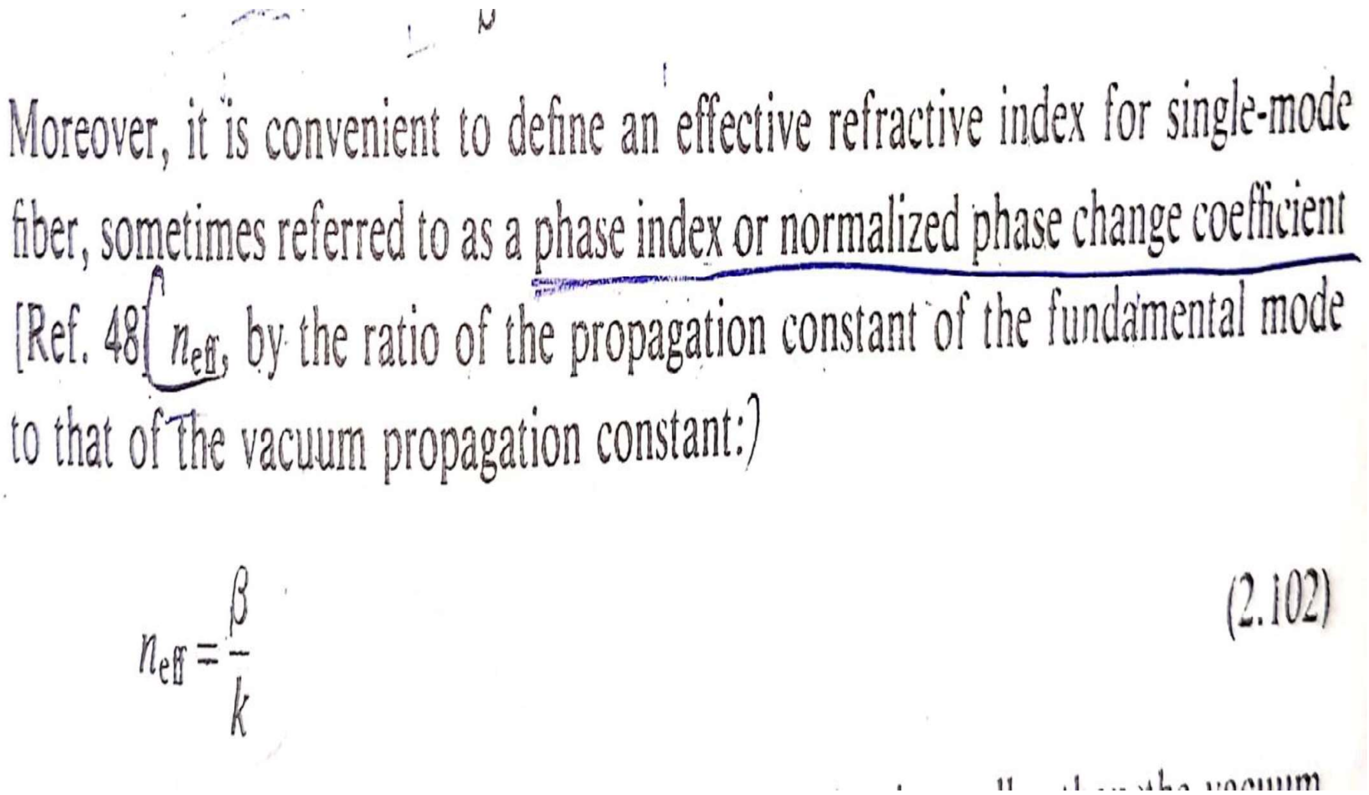
(λ) = 1300 nm is,

$$M = \left(\frac{\alpha}{\alpha+2}\right)\frac{V^2}{2}$$

$$= \left(\frac{2}{2+2}\right)\left(\frac{2 \times 3.1428 \times 20 \times 10^{-6} \times 0.24}{1300 \times 10^{-6}}\right)^2$$

= 269 modes

EFFECTIVE REFRCTIVE INDEX



Moreover, it is convenient to define an effective refractive index for single-mode fiber, sometimes referred to as a phase index or normalized phase change coefficient [Ref. 48] n_{eff}, by the ratio of the propagation constant of the fundamental mode to that of the vacuum propagation constant:

$$n_{\text{eff}} = \frac{\beta}{k} \tag{2.102}$$

In this case the propagation constant β will be approximately equal to n_2k (i.e. the cladding wavenumber) and the effective index will be similar to the refractive index of the cladding n_2. Physically, most of the power is transmitted in the cladding material. At short wavelengths, however, the field is concentrated in the core region and the propagation constant β approximates to the maximum wave-number n_1k. Following this discussion, and as indicated previously in Eq. (2.62), then the propagation constant in single-mode fiber varies over the interval $n_2k < \beta < n_1k$. Hence, the effective refractive index will vary over the range $n_2 < n_{\text{eff}} < n_1$.

In addition, a relationship between the effective refractive index and the normalized propagation constant b defined in Eq. (2.71) as:

$$b = \frac{(\beta/k)^2 - n_2^2}{n_1^2 - n_2^2} = \frac{\beta^2 - n_2^2k^2}{n_1^2k^2 - n_2^2k^2} \tag{2.104}$$

may be obtained. Making use of the mathematical relation, $A^2 - B^2 = (A + B)(A - B)$, Eq. (2.104) can be written in the form:

$$b = \frac{(\beta + n_2k)(\beta - n_2k)}{(n_1k + n_2k)(n_1k - n_2k)} \tag{2.105}$$

However, taking regard of the fact that $\beta \simeq n_1k$, then Eq. (2.105) becomes:

$$b \simeq \frac{\beta - n_2k}{n_1k - n_2k} = \frac{\beta/k - n_2}{n_1 - n_2}$$

Finally, in Eq. (2.102) n_{eff} is equal to β/k, therefore:

$$b = \frac{n_{\text{eff}} - n_2}{n_1 - n_2} \tag{2.106}$$

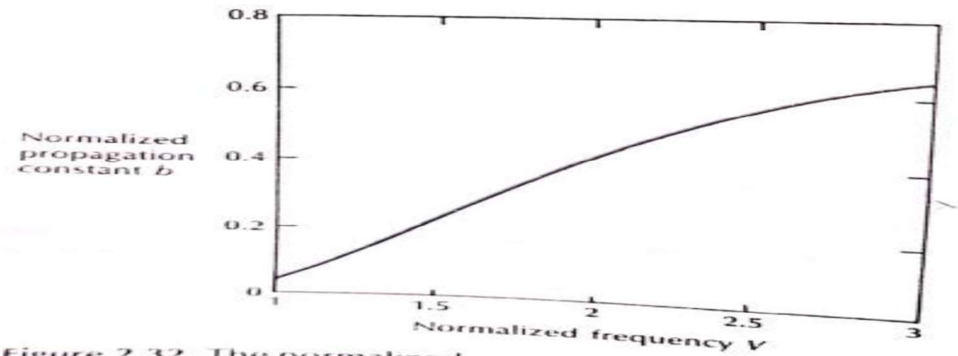


Figure 2.32 The normalized propagation constant (b) of the fundamental mode in a step index fiber shown as a function of the normalized frequency (V).

SIGNAL DISTORTION IN OPTICAL FIBERS

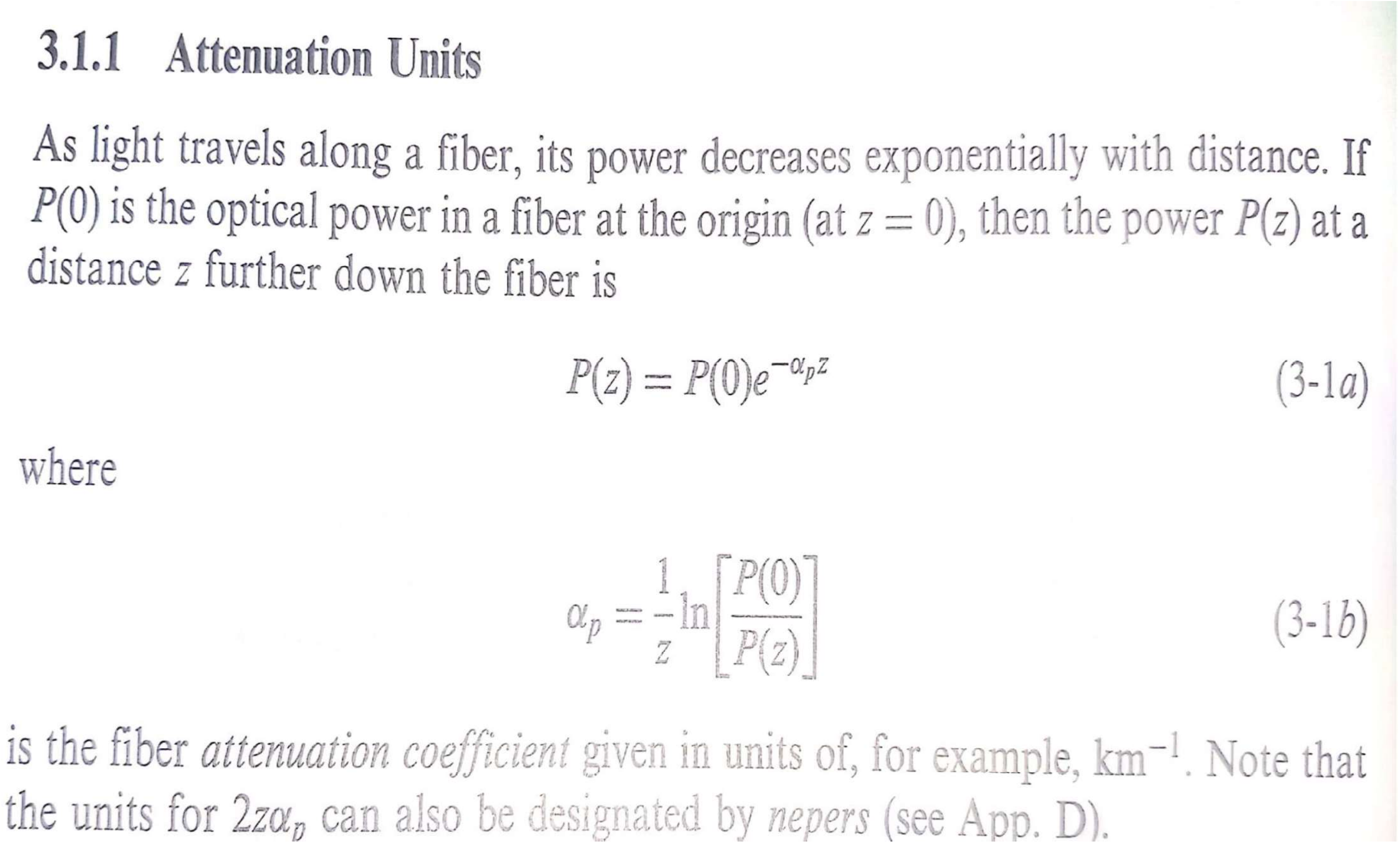
ATTENUATION

- Attenuation of a light signal as it propagates along a fiber is an important consideration in the design of optical communication system.
- Since it plays a major role in determining the maximum transmission distance between transmitter and receiver
- The basic attenuation mechanisms in a fiber core are absorption,scaterring,and radiative losses of optical energy.

ATTENUATION

- Absorption is related to fiber material, where as scattering is related both with fiber material and structural imperfections in the optical waveguide.
- Attenuation owing to radiative effects originates from imperfections of fiber geometry

ATTENUATION



3.1.1 Attenuation Units

As light travels along a fiber, its power decreases exponentially with distance. If $P(0)$ is the optical power in a fiber at the origin (at $z = 0$), then the power $P(z)$ at a distance z further down the fiber is

$$P(z) = P(0)e^{-\alpha_p z} \tag{3-1a}$$

where

$$\alpha_p = \frac{1}{z}\ln\left[\frac{P(0)}{P(z)}\right] \tag{3-1b}$$

is the fiber *attenuation coefficient* given in units of, for example, km^{-1}. Note that the units for $2z\alpha_p$ can also be designated by *nepers* (see App. D).

Absorption

- Absorption is caused by three different mechanisms :

1.Absorption by atomic defects in the glass composition.

2.Extrinsic absorption by impurity atoms in the glass material.

3.Intrinsic absorption by the basic constituent atoms of the fiber material.

Absorption by atomic defects

- Atomic defects are imperfections in the atomic structure of the fiber materials like missing molecules, oxygen defects in the glass structure.
- Absorption losses arising from these defects are negligible compared with Intrinsic and Extrinsic absorption.
- They can be significant if the fiber is exposed to ionizing radiation.
- The higher the radiation level, the larger the attenuation.

Extrinsic absorption by impurity atoms

- Extrinsic absorption results from transition metal ions such as iron, chromium, cobalt, copper and OH(water) ions.
- The transition metal impurities causes losses from 1 to 10 dB/km.

Intrinsic absorption

- Intrinsic absorption is associated with the basic fiber material pure silica.
- It occurs when the material is in perfect state with no density variation, impurities, material in homogeneities.
- Intrinsic absorption thus sets the fundamental lower limit on absorption for any particular material.

For, SiO_2 fiber, Rayleigh loss is given by,

$$\alpha_{scat} = \frac{8\pi^3}{3\lambda^4} n^8 \, p^2 \beta_c \, k \, T_F \; m^{-1}$$

where,

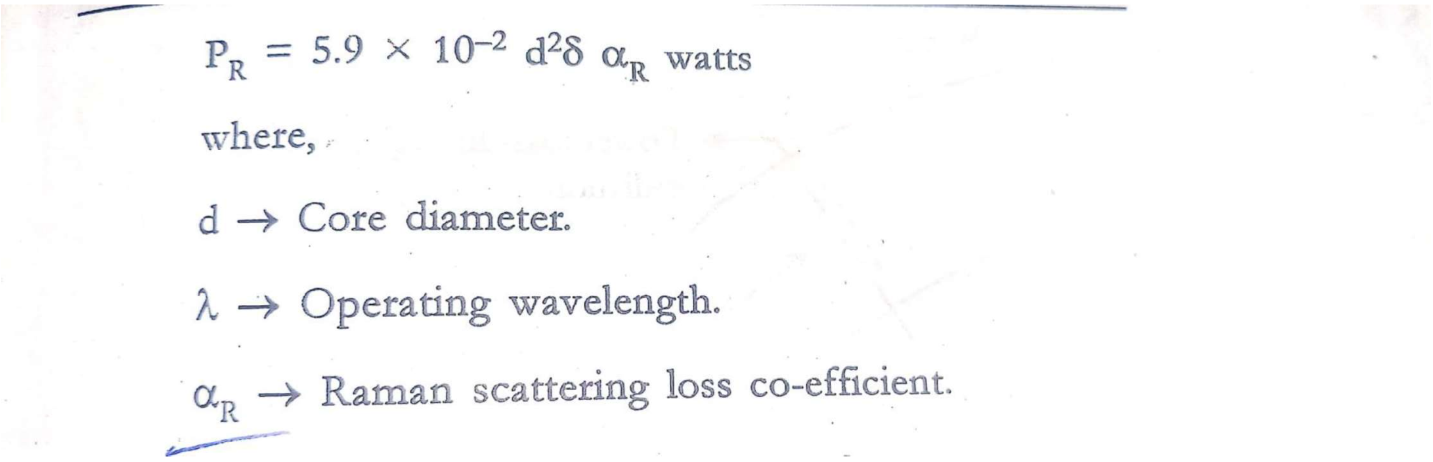
n → Refractive index of silica.

p → Photoelastic co-efficient of silica.

β_c → Isothermal compressibility.

T_F → Fictive temperature at which solidification of glass takes place or simply annealing temperature

SRS SCATTERING LOSS



$P_R = 5.9 \times 10^{-2} d^2\delta \alpha_R$ watts

where,

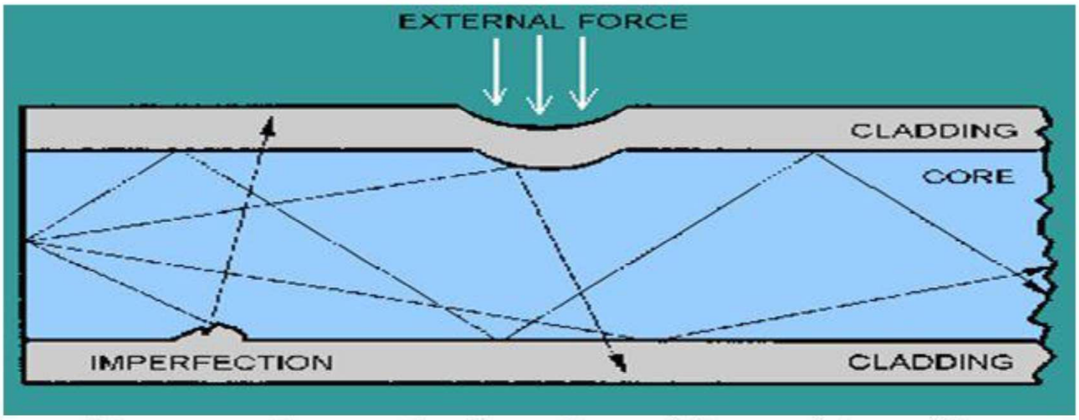
d → Core diameter.

λ → Operating wavelength.

α_R → Raman scattering loss co-efficient.

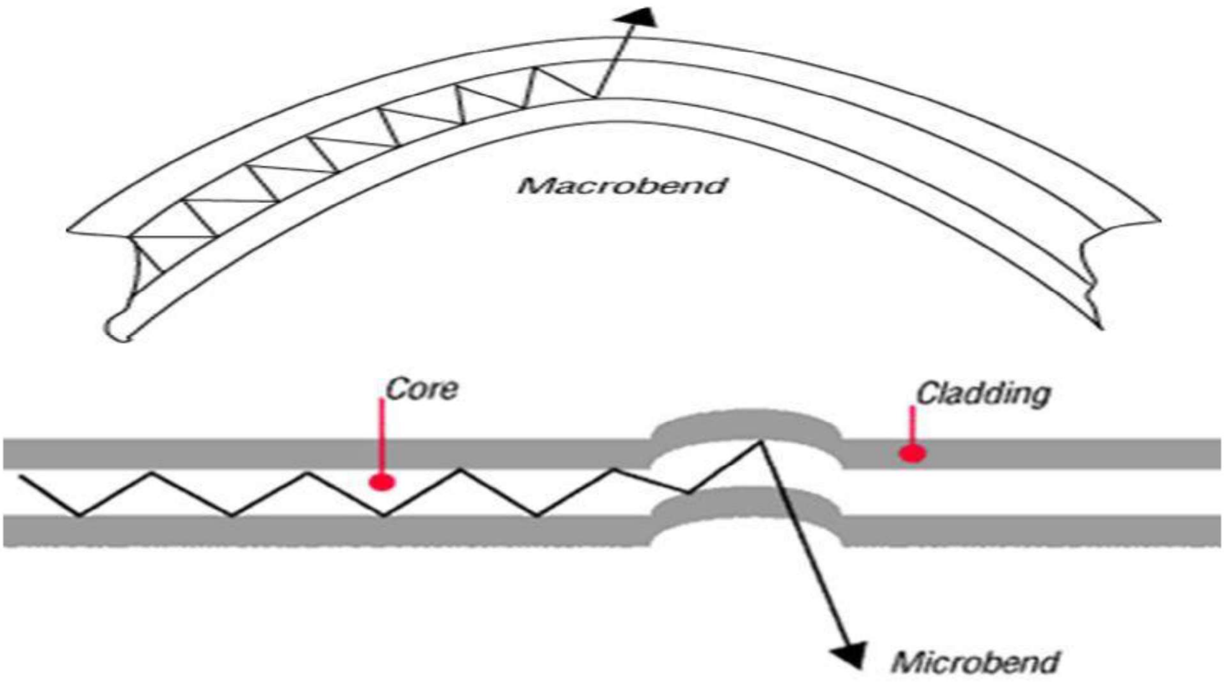
Bending losses

- These losses occurs due to imperfections and deformations present in the fiber structure.Micro bending and macro bending losses are two types of bending losses.
- **Microbend losses** occurs when the core surface has small variation in shape.These variation change the angle at which light strikes the core cladding interface and can cause the light to refract into the cladding rather than refract into core. Microbend loss shown in fig.



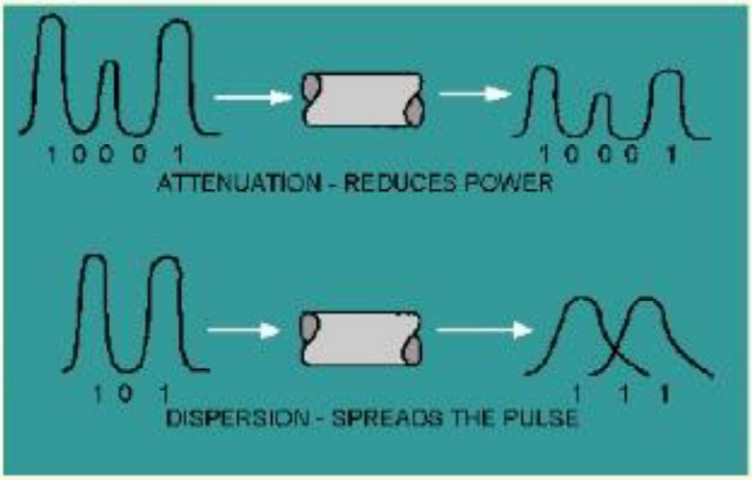
- **Macrobend losses**: Excessive bending of the cable or fiber may result in loss known as macroband loss. The fiber is sharply bent so the light traveling through the fiber cannot make the turn and is lost in the cladding as shown in fig.

Macro- & Micro-bending Loss



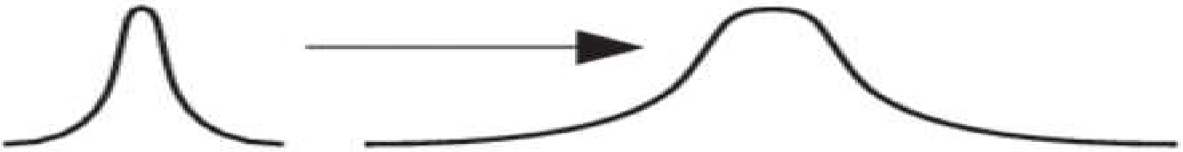
Attenuation & Dispersion

- Fiber optics properties that affect performance are:
  - Attenuation
  - Dispersion
- **Attenuation** is a result of:
  - Light absorption
  - Light scattering
  - Bending losses
- If the signal **strength** is reduced below a specific point, the receiver is unable to detect it.

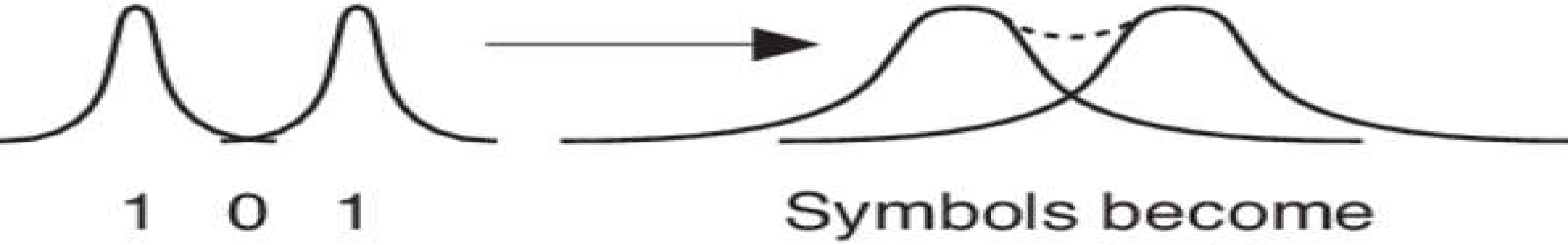


Dispersion is the spreading of the signal. The **spreading** limits how fast data can be transmitted along the fiber.
The receiver is unable to distinguish between input pulses caused by the spreading of each pulse.

Dispersion



As a pulse travels down a fiber, dispersion causes pulse spreading. This limits the distance and the bit rate of data on an optical fiber.



Symbols become unrecognizable

Types of Dispersion

1) Intra modal dispersion.
    - i) Material (or) Chromatic dispersion.
    - ii) Wave guide dispersion.
    - iii) Polarization-mode dispersion
2) Inter modal dispersion.

Factors causing distortion in optical fibers.

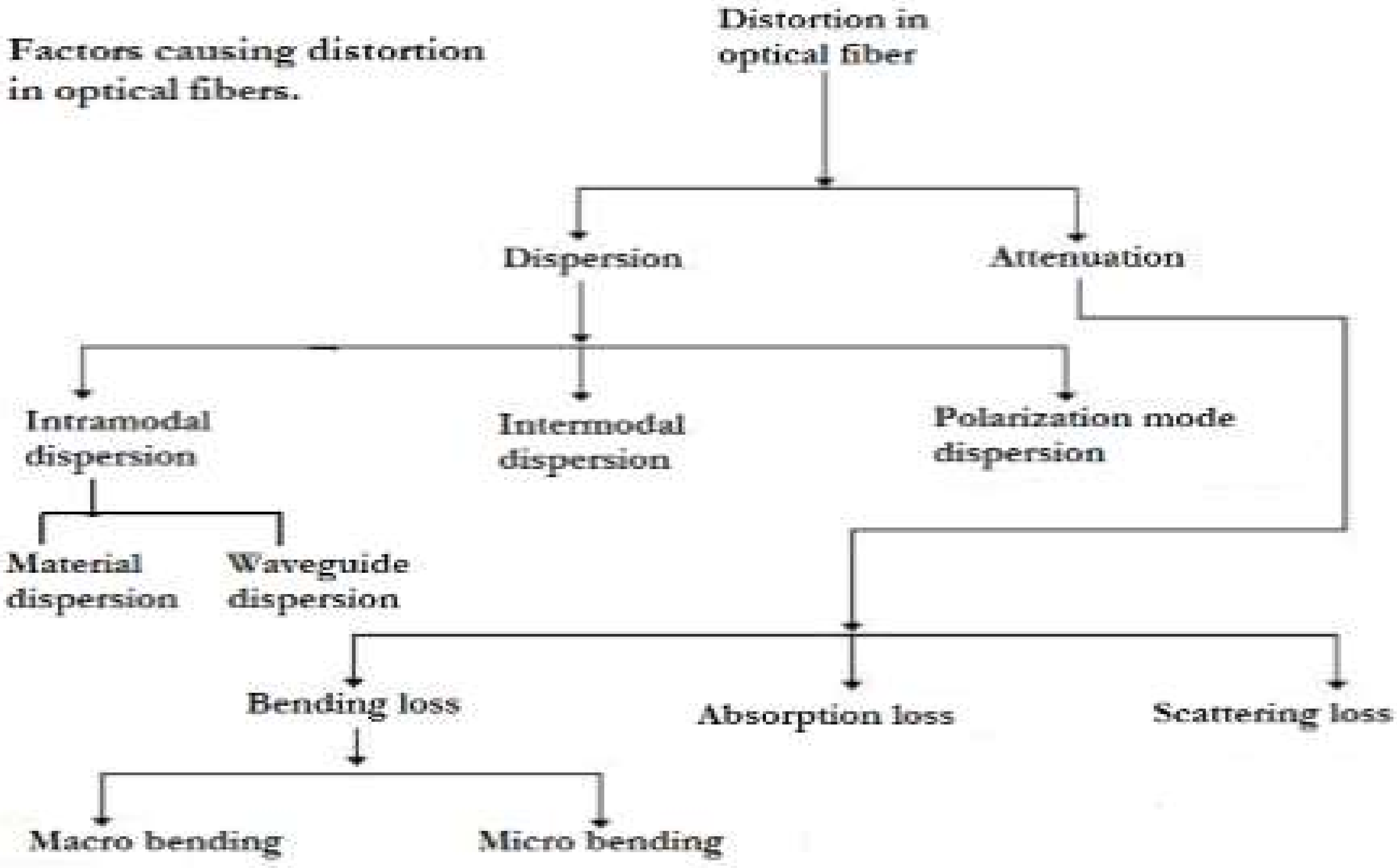


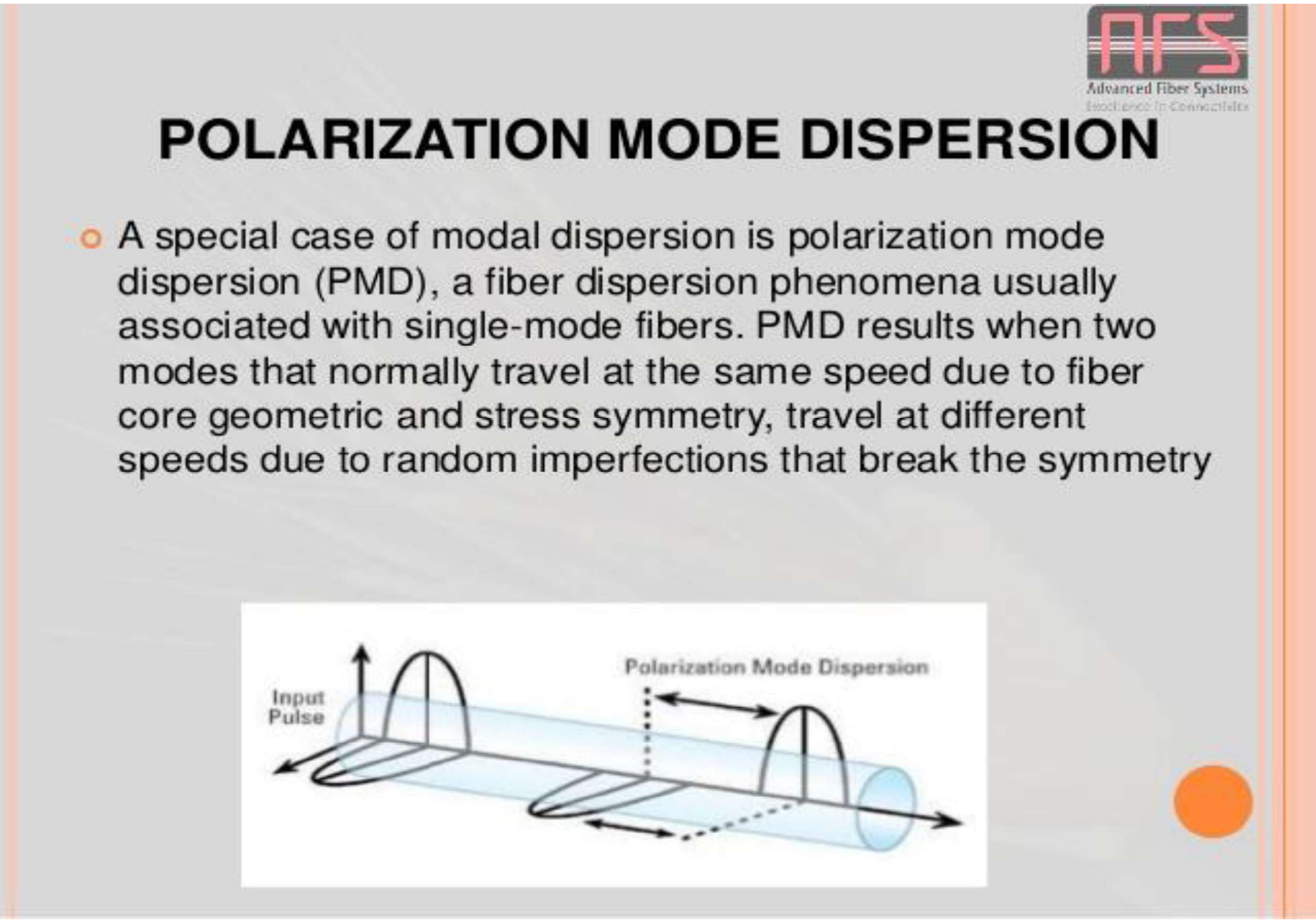
Figure 2.2

2. Material Dispersion

- In a **single mode**, step-index fibre, there is no intermodal dispersion of an input light pulse.
  - But there will still be dispersion due to the variation of the core refractive index, n_1 , with wavelength of light coupled into the fibre.
- Therefore, the propagation velocity of the guided wave depends on the wavelength.
  - The dispersion due to the wavelength dependence of the material properties of the guide is called **material dispersion**.
- No practical light source is perfectly monochromatic

Waveguide Dispersion

- Arises because a Single Mode Fiber confines only 80% of the optical power to the core
- The other 20% tends to travel through the cladding and hence travels faster
- This results in spreading of the light pulses
- The amount of dispersion depends on the fiber design and the size of the fiber core relative to the wavelength of operation
- In multimode fibers, waveguide dispersion and material dispersion are basically separate properties.
- Multimode waveguide dispersion is generally small compared to material dispersion and is usually neglected.

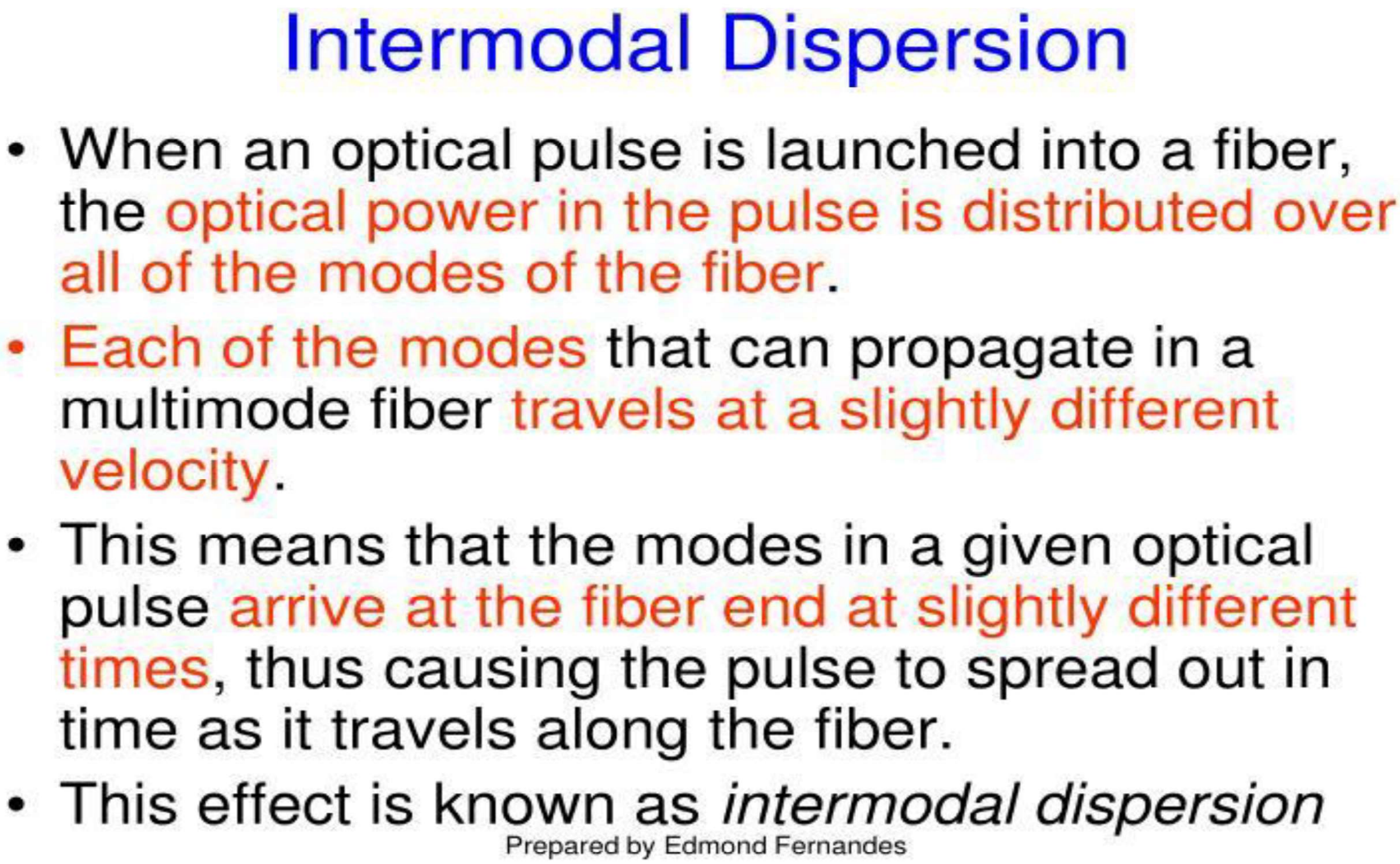


POLARIZATION MODE DISPERSION

- A special case of modal dispersion is polarization mode dispersion (PMD), a fiber dispersion phenomena usually associated with single-mode fibers. PMD results when two modes that normally travel at the same speed due to fiber core geometric and stress symmetry, travel at different speeds due to random imperfections that break the symmetry

Polarization Mode Dispersion

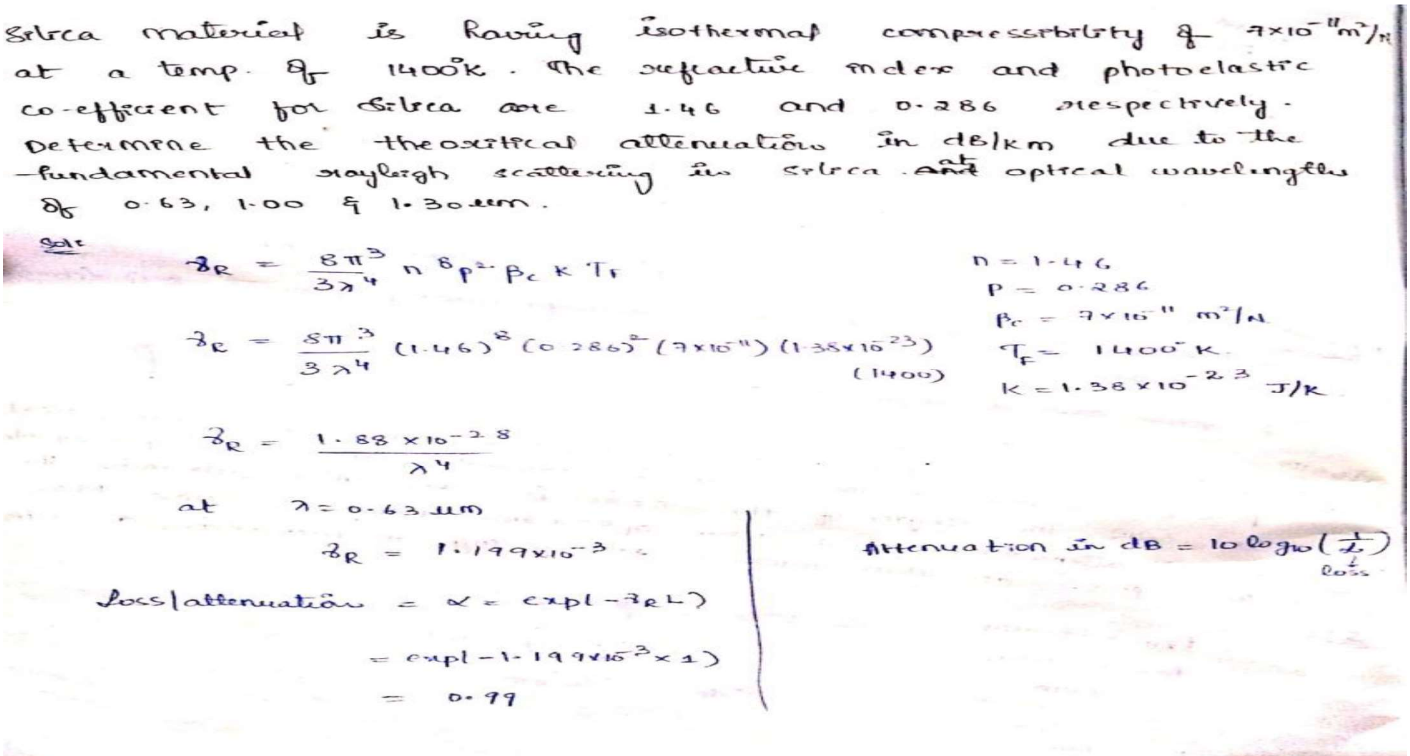
- Due to differently polarized light traveling at slightly different velocity
- Usually small
- Significant if all other dispersion mechanisms are small



Intermodal Dispersion

- When an optical pulse is launched into a fiber, the optical power in the pulse is distributed over all of the modes of the fiber.
- Each of the modes that can propagate in a multimode fiber travels at a slightly different velocity.
- This means that the modes in a given optical pulse arrive at the fiber end at slightly different times, thus causing the pulse to spread out in time as it travels along the fiber.
- This effect is known as *intermodal dispersion*

NUMERICALS



Silica material is having isothermal compressibility of $7\times10^{-11}\,m^2/N$ at a temp. of 1400°K. The refractive index and photoelastic co-efficient for silica are 1.46 and 0.286 respectively. Determine the theoretical attenuation in dB/km due to the fundamental rayleigh scattering in silica. ~~And~~ at optical wavelengths of 0.63, 1.00 & 1.30 µm.

Sol:

$$\gamma_R = \frac{8\pi^3}{3\lambda^4} n^8 p^2 \beta_c K T_F$$

$n = 1.46$
$P = 0.286$
$\beta_c = 7\times10^{-11}\ m^2/N$
$T_F = 1400\ K$
$K = 1.38\times10^{-23}\ J/K$

$$\gamma_R = \frac{8\pi^3}{3\lambda^4}(1.46)^8(0.286)^2(7\times10^{-11})(1.38\times10^{-23})(1400)$$

$$\gamma_R = \frac{1.88\times10^{-28}}{\lambda^4}$$

at $\lambda = 0.63\ \mu m$

$$\gamma_R = 1.199\times10^{-3}$$

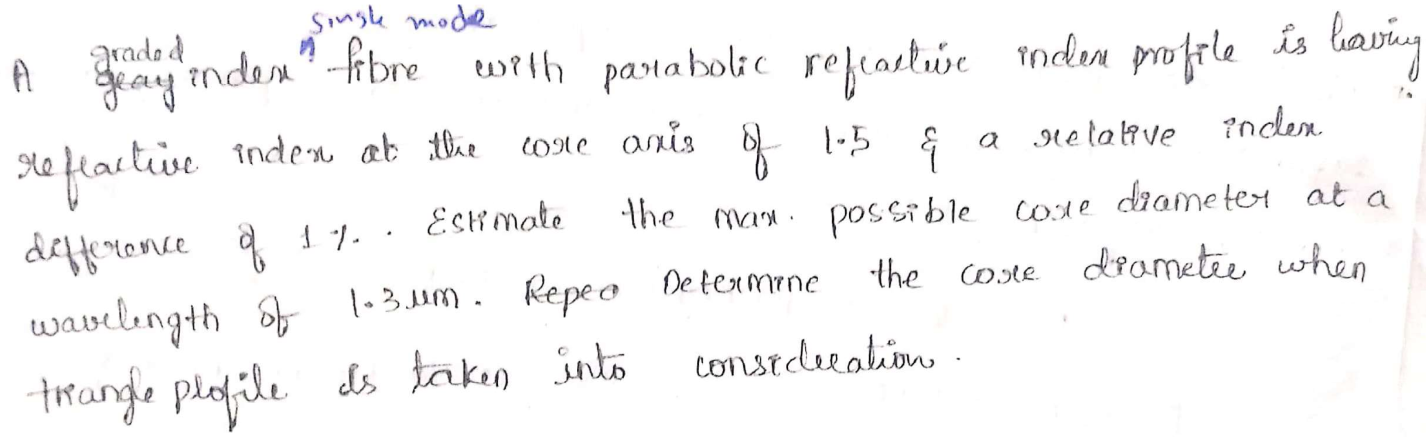
loss/attenuation $= \alpha = \exp(-\gamma_R L)$

$= \exp(-1.199\times10^{-3}\times1)$

$= 0.99$

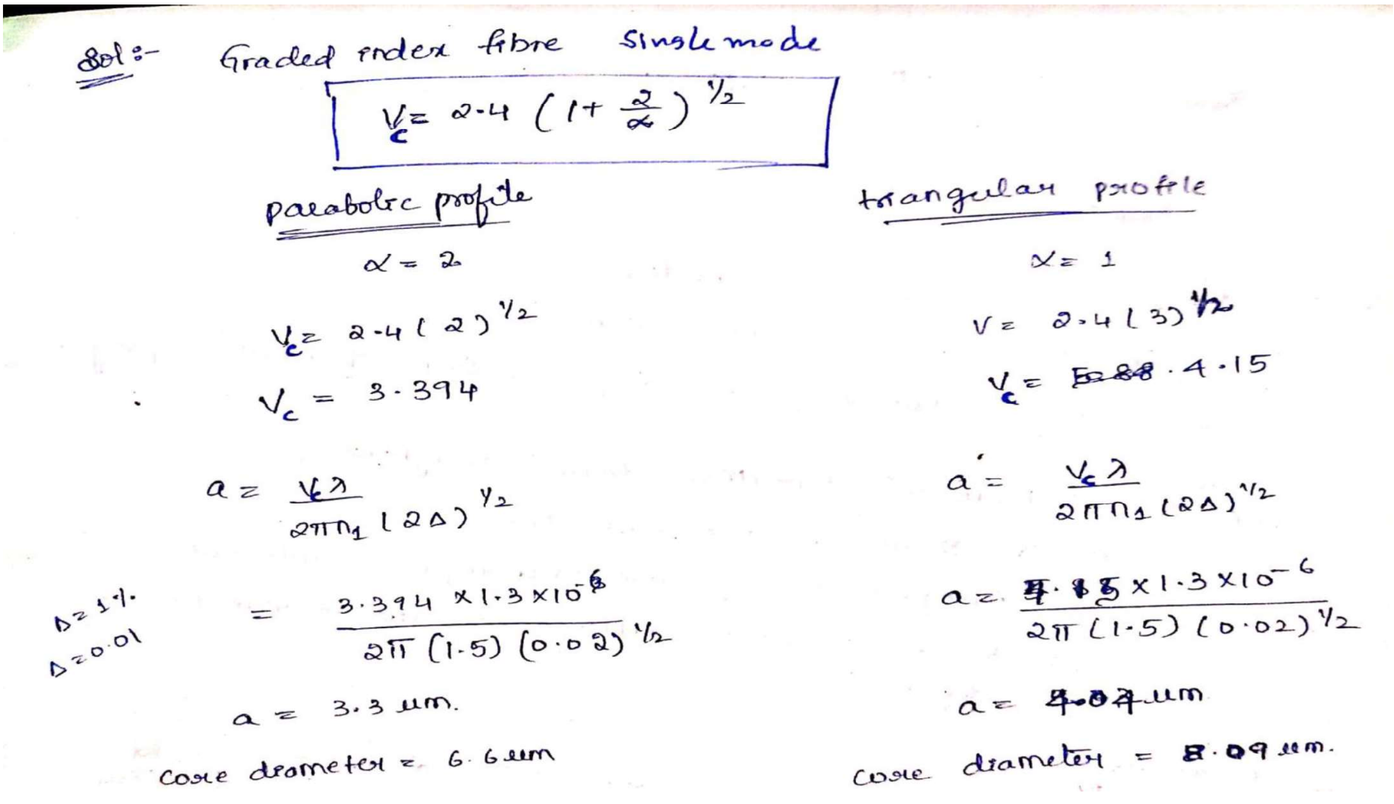
Attenuation in dB $= 10\log_{10}\left(\frac{1}{\alpha}\right)$ loss

NUMERICALS



A gray graded index single mode fibre with parabolic refractive index profile is having refractive index at the core axis of 1.5 & a relative index difference of 1%. Estimate the max. possible core diameter at a wavelength of 1.3 μm. Repeo Determine the core diameter when triangle profile is taken into consideration.

NUMERICALS



Sol:- Graded index fibre single mode

$$\boxed{V_c = 2.4\left(1+\frac{2}{\alpha}\right)^{1/2}}$$

parabolic profile

$\alpha = 2$

$V_c = 2.4(2)^{1/2}$

$V_c = 3.394$

$a = \frac{V_c \lambda}{2\pi n_1 (2\Delta)^{1/2}}$

$\Delta = 1\%$

$\Delta = 0.01$

$= \frac{3.394 \times 1.3 \times 10^{-6}}{2\pi (1.5)(0.02)^{1/2}}$

$a = 3.3\ \mu m.$

core diameter = $6.6\ \mu m$

triangular profile

$\alpha = 1$

$V = 2.4(3)^{1/2}$

$V_c =$ ~~2.88~~ 4.15

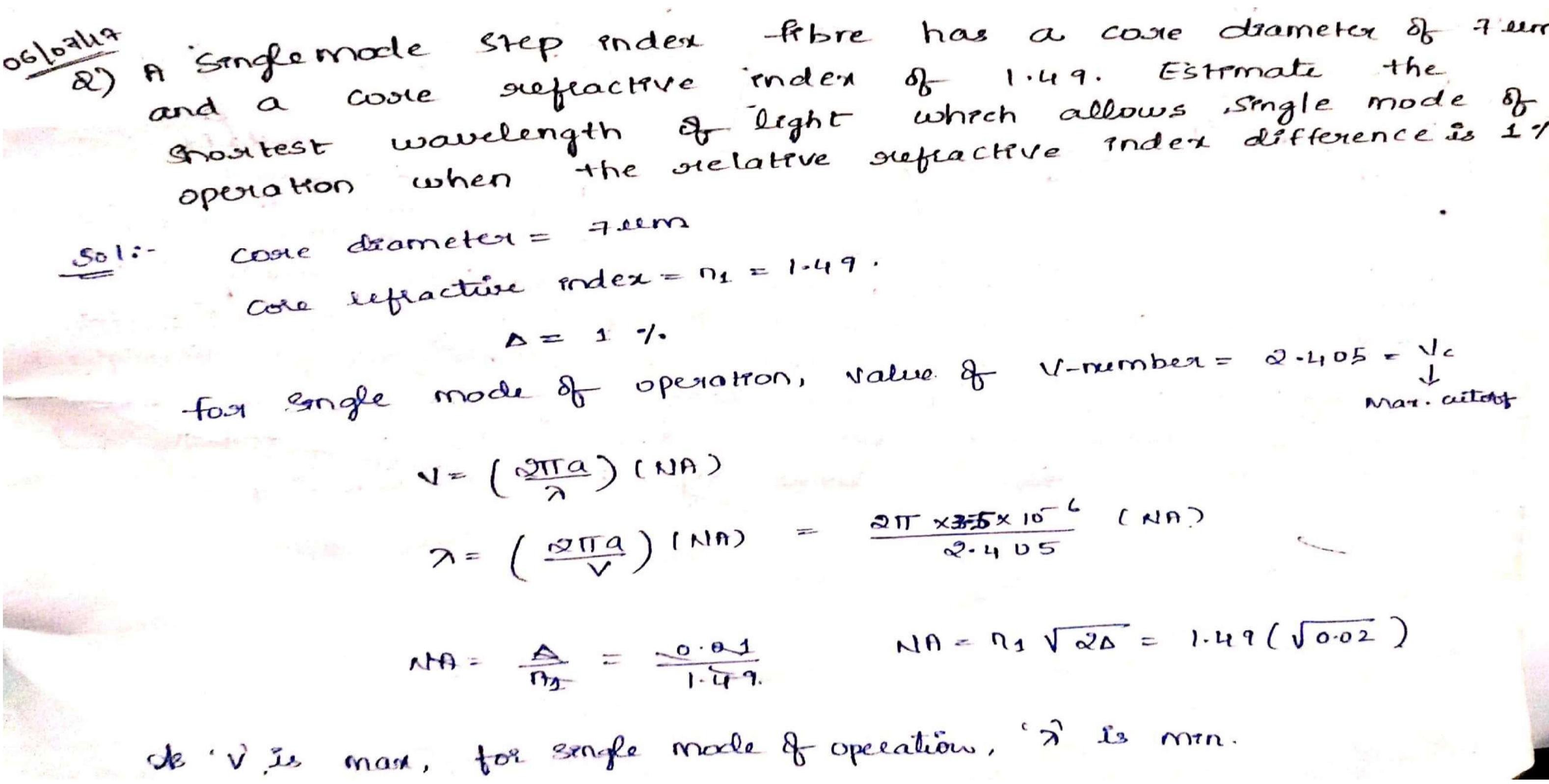
$a = \frac{V_c \lambda}{2\pi n_1 (2\Delta)^{1/2}}$

$a = \frac{4.15 \times 1.3 \times 10^{-6}}{2\pi (1.5)(0.02)^{1/2}}$

$a = 4.04\ \mu m$

core diameter = $8.09\ \mu m.$

NUMERICALS



06/07/17

Q) A single mode step index fibre has a core diameter of 7 μm and a core refractive index of 1.49. Estimate the shortest wavelength of light which allows single mode of operation when the relative refractive index difference is 1%

Sol:- core diameter = 7 μm

core refractive index = n_1 = 1.49.

$\Delta = 1\ \%$.

for single mode of operation, value of V-number = $2.405 = \underset{\text{Max. cutoff}}{\underset{\downarrow}{V_c}}$

$$V = \left(\frac{2\pi a}{\lambda}\right)(NA)$$

$$\lambda = \left(\frac{2\pi a}{V}\right)(NA) = \frac{2\pi \times 3.5 \times 10^{-6}}{2.405}(NA)$$

$$NA = \frac{\Delta}{n_1} = \frac{0.01}{1.49}. \qquad NA = n_1\sqrt{2\Delta} = 1.49(\sqrt{0.02})$$

As 'V' is max, for single mode of operation, 'λ' is min.

Backward Wave Oscillator

Topics covered beyond syllabus

Backward Wave Oscillator

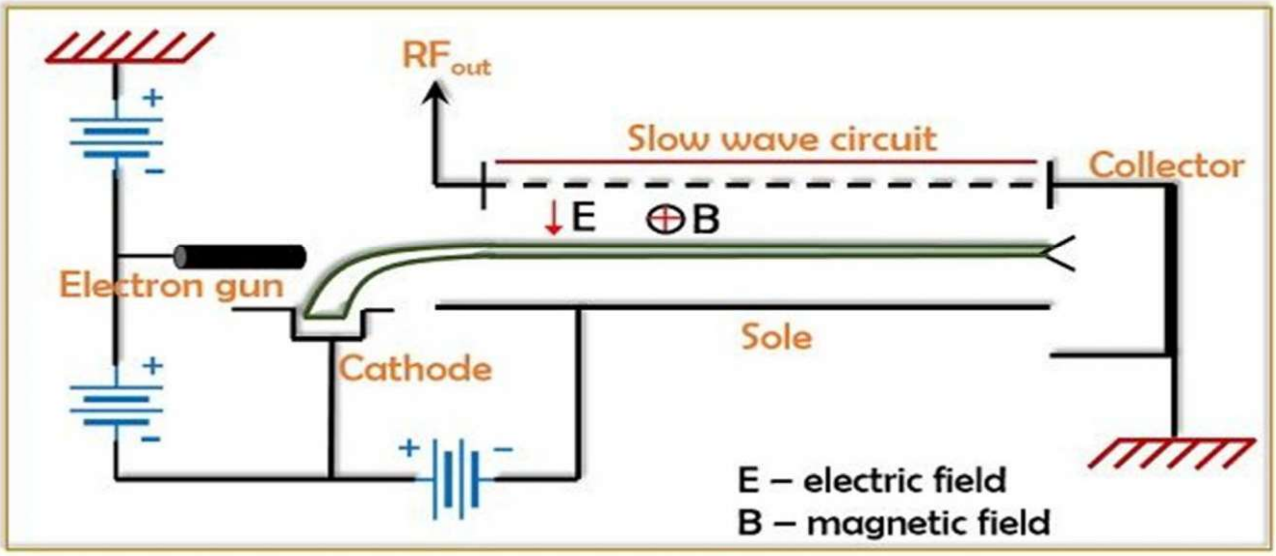
- **BWO** is an abbreviation used for **B**ackward **W**ave **O**scillator. It is a special type of vacuum tube used to produce microwave signals in the range of **Terahertz** (**THz**). Backward wave oscillator belongs to the group of Travelling Wave Tubes that generates oscillations at microwave frequencies.
- Backward wave oscillators are also known as **Carcinotrons**.

Operating Principle

- The principle of operation of BWO is such that in order to sustain the oscillations inside the tube, a back-reflected wave from an imperfectly terminated collector is utilized that has a direction opposite to the direction of emergence of the electron beam.
- It uses the principle of **velocity modulation** in order to build oscillations inside the vacuum tube.

Construction

The figure shown here represents the structure of backward wave oscillator:



Schematic representation of Backward Wave Oscillator

Electronics Desk

OPERATION

- As we can see that the structure is quite different from that of TWT. To generate the electron beam, an electron gun is used that is composed of a heating element and cathode. The cathode generates the electron beam inside the tube. A slow-wave structure is present inside the tube that is responsible for velocity modulation.
- We have already discussed the need for slow-wave structure in our previous article of TWT. So, if you want to know more about it then you can refer the same.
- The opposite end of the electron gun consists of a collector region from where the forward wave gets reflected back towards the cathode side and received at the output.

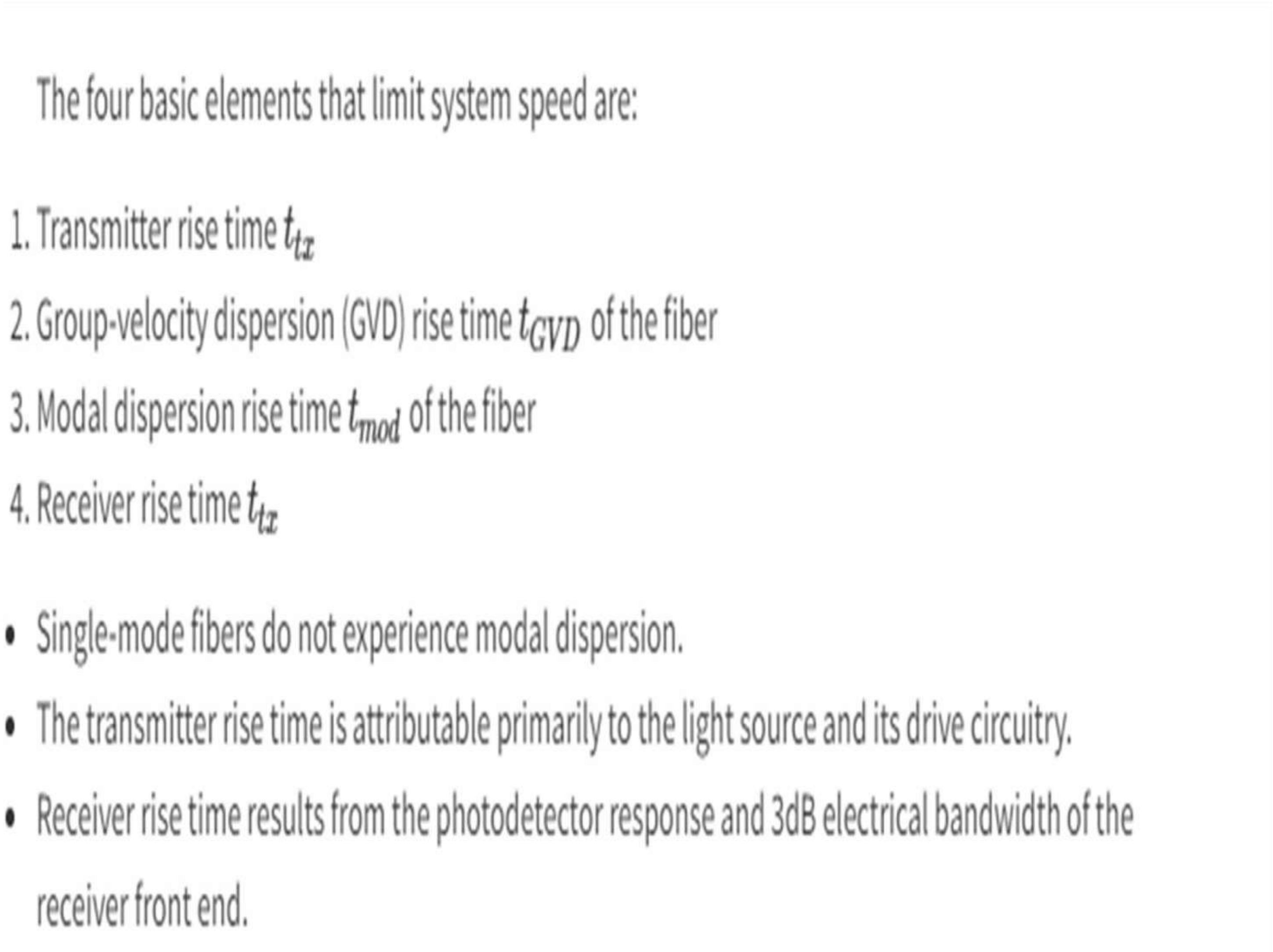
Advantages &Disadvantages

- BWO provides wide range of tunability by the variation in collector voltage.
- It generates oscillations that shows high-frequency stability.
- It holds the ability to produce sharp desired signal at the output.
- It is less efficient in comparison to TWTs and klystrons.
- The fixed spacing between the helical ring of the slow-wave structure leads to cause a limiting factor over the bandwidth.

Rise Time Budget:

- Rise-time budget analysis is a convenient method for determining the dispersion limitation of an optical fiber link, useful for digital systems.
- The total rise time tsys of the link is the root sum square of the rise times from each contribution t_i, to the pulse rise-time degradation.

$$t_{sys} = \left(\sum_{i=1}^{N} t_i^2 \right)^{1/2}$$



The four basic elements that limit system speed are:

1. Transmitter rise time t_{tx}
2. Group-velocity dispersion (GVD) rise time t_{GVD} of the fiber
3. Modal dispersion rise time t_{mod} of the fiber
4. Receiver rise time t_{tx}

- Single-mode fibers do not experience modal dispersion.
- The transmitter rise time is attributable primarily to the light source and its drive circuitry.
- Receiver rise time results from the photodetector response and 3dB electrical bandwidth of the receiver front end.

Rajeev Gandhi Memorial College of Engineering & Technology

Autonomous

NANDYAL-518501

Department of Electronics & Communication Engineering

Academic Year: 2022 - 23

Subject: Microwave Engineering and Optical Communications

Class: III B.Tech, II SEM

Faculty member taught earlier: Dr. V.N.V.Satya Prakash

Suggestions:

As per the course structure of the UG (R20), Microwave Engineering and Optical Communications subject is completely based on the understanding of microwave waveguides, passive & active devices, microwave tubes and network analysis. It is also based on the study of optical fiber communication systems and their basic applications in wireless communications. So, this subject covers theory along with derivations and numerical problem solving. Hence, following suggestions are made by subject experts:

1. As the subject comprises of theory and quantitative analysis derivations, earlier overall pass percentage was 85%. So, it is decided to solve more numerical problems to improve overall percentage further.
2. To improve the subject knowledge, students are demonstrated the microwave engineering concepts with experiments in the laboratory.
3. To improve the results, it is decide to take care of slow learners by taking extra classes and make them to practice more numerical problems from previous year question papers as assignments.
4. Regular counseling and motivation should be given to the students to follow the lacking in the subject knowledge.
5. The environment of the class should be interactive with respect to the subject discussion so that students can understand elaborately and may ask more questions.

Signature of the subject expert

(Dr. V.N.V.Satya Prakash.)

Assessment

Rajeev Gandhi Memorial College of Engineering & Technology

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S.No.	Year (Batch)	Section	Subject	Branch	Registered	Appeared	Failed	Pass(%)	Highest
1	III B.Tech. II Sem. & 2020	A	M&OC Lab	ECE	65	64	0	100.00	10
2	III B.Tech. II Sem. & 2020	D	ME&OC	ECE	63	58	14	75.86	8
3	III B.Tech. II Sem. & 2020	A	ME&OC	ECE	65	64	0	100.00	10
4	IV B.Tech. I Sem. & 2019	C	MOC LAB	ECE	69	69	1	98.55	10
5	III B.Tech. I Sem. & 2020	C	AWP	ECE	61	59	0	100.00	9
6	III B.Tech. I Sem. & 2020	B	AWP	ECE	65	65	0	100.00	10
7	II B.Tech. II Sem. & 2020	D	ECAD Lab	ECE	61	61	2	96.72	10
8	II B.Tech. II Sem. & 2020	C	ARMP Lab	ECE	62	62	2	96.77	10
9	IV B.Tech. II Sem. & 2018	D	WCN	ECE	59	53	9	83.02	8
10	IV B.Tech. II Sem. & 2018	A	WCN	ECE	67	67	0	100.00	9
11	IV B.Tech. I Sem. & 2018	A	M&OC Lab	ECE	67	67	0	100.00	10
12	IV B.Tech. I Sem. & 2018	D	OC	ECE	60	56	17	69.64	8
13	IV B.Tech. I Sem. & 2018	A	OC	ECE	67	67	0	100.00	9
14	IV B.Tech. II Sem. & 2017	D	SEM	ECE	51	49	0	100.00	10
15	IV B.Tech. II Sem. & 2017	C	SEM	ECE	52	52	0	100.00	10
16	IV B.Tech. II Sem. & 2017	B	WCN	ECE	57	56	0	100.00	9
17	IV B.Tech. II Sem. & 2017	A	WCN	ECE	57	57	0	100.00	9
18	IV B.Tech. I Sem. & 2017	D	M&OC Lab	ECE	51	50	11	78.00	9
19	IV B.Tech. I Sem. & 2017	A	M&OC Lab	ECE	57	57	0	100.00	10
20	IV B.Tech. I Sem. & 2017	D	OC	ECE	51	51	5	90.20	9
21	IV B.Tech. I Sem. & 2017	A	OC	ECE	57	57	0	100.00	10
22	III B.Tech. II Sem. & 2017	D	MWE	ECE	52	51	5	90.20	8

S.No.	Year (Batch)	Section	Subject	Branch	Registered	Appeared	Failed	Pass(%)	Highest
23	IV B.Tech. I Sem. & 2016	B	M&OC Lab	ECE	55	53	0	100.00	10
24	IV B.Tech. I Sem. & 2016	A	M&OC Lab	ECE	56	54	1	98.15	10
25	III B.Tech. I Sem. & 2017	C	AWP	ECE	55	52	7	86.54	9
26	IV B.Tech. I Sem. & 2016	B	OC	ECE	55	54	1	98.15	9
27	IV B.Tech. I Sem. & 2016	A	OC	ECE	56	56	2	96.43	9
28	IV B.Tech. II Sem. & 2015	D	SEM	ECE	59	59	0	100.00	10
29	IV B.Tech. II Sem. & 2015	D	WCN	ECE	59	59	5	91.53	9
30	IV B.Tech. II Sem. & 2015	A	WCN	ECE	63	62	7	88.71	9
31	IV B.Tech. I Sem. & 2015	D	M&OC Lab	ECE	59	58	0	100.00	10
32	III B.Tech. I Sem. & 2016	B	AWP	ECE	56	53	4	92.45	10
33	III B.Tech. I Sem. & 2016	A	AWP	ECE	57	56	6	89.29	9
34	III B.Tech. II Sem. & 2015	B	ECDT Lab	ECE	60	59	0	100.00	10
35	III B.Tech. II Sem. & 2015	D	MWE	ECE	59	59	0	100.00	9
36	III B.Tech. I Sem. & 2015	D	AWP	ECE	60	59	5	91.53	10
37	III B.Tech. I Sem. & 2015	C	AWP	ECE	62	62	2	96.77	10
38	III B.Tech. II Sem. & 2014	C	MVE	ECE	66	65	7	89.23	93
39	III B.Tech. II Sem. & 2014	B	MVE	ECE	69	68	5	92.65	92
40	III B.Tech. I Sem. & 2014	C	AC	ECE	67	66	4	93.94	92
41	III B.Tech. I Sem. & 2014	B	AWP	ECE	69	67	10	85.07	88

Developed by Suresh Babu J