EC8651 TRANSMISSION LINES AND RF SYSTEM L T P C 3 0 0 3

OBJECTIVES:

- To introduce the various types of transmission lines and to discuss the losses associated.
- To give thorough understanding about impedance transformation and matching.
- To impart technical knowledge in impedance matching using smith chart
- To introduce passive filters and basic knowledge of active RF components
- To get acquaintance with RF system transceiver design

UNIT I TRANSMISSION LINE THEORY 9

General theory of Transmission lines - the transmission line - general solution - The infinite line - Wavelength, velocity of propagation - Waveform distortion - the distortion-less line - Loading and different methods of loading - Line not terminated in Z_0 - Reflection coefficient - calculation of current, voltage, power delivered and efficiency of transmission - Input and transfer impedance - Open and short circuited lines - reflection factor and reflection loss.

UNIT II HIGH FREQUENCY TRANSMISSION LINES 9

Transmission line equations at radio frequencies - Line of Zero dissipation - Voltage and current on the dissipation-less line, Standing Waves, Nodes, Standing Wave Ratio - Input impedance of the dissipation-less line - Open and short circuited lines - Power and impedance measurement on lines - Reflection losses - Measurement of VSWR and wavelength.

UNIT III IMPEDANCE MATCHING IN HIGH FREQUENCY LINES 9

Impedance matching: Quarter wave transformer - Impedance matching by stubs - Single stub and double stub matching - Smith chart - Solutions of problems using Smith chart - Single and double stub matching using Smith chart.

UNIT IV WAVEGUIDES 9

General Wave behaviour along uniform guiding structures – Transverse Electromagnetic Waves, Transverse Magnetic Waves, Transverse Electric Waves – TM and TE Waves between parallel plates. Field Equations in rectangular waveguides, TM and TE waves in rectangular waveguides, Bessel Functions, TM and TE waves in Circular waveguides.

UNIT V RF SYSTEM DESIGN CONCEPTS 9

Active RF components: Semiconductor basics in RF, bipolar junction transistors, RF field effect transistors, High electron mobility transistors Basic concepts of RF design, Mixers, Low noise amplifiers, voltage control oscillators, Power amplifiers, transducer power gain and stability considerations.

OUTCOMES:

Upon completion of the course, students will be able to:

- Explain the characteristics of transmission lines and its losses
- Write about the standing wave ratio and input impedance in high frequency transmission lines
- Analyze impedance matching by stubs using smith charts
- Analyze the characteristics of TE and TM waves
- Design a RF transceiver system for wireless communication

TEXT BOOKS

1. John D Ryder, "Networks, lines and fields", 2nd Edition, Prentice Hall India, 2010.
2. Mathew M. Radmanesh, ―Radio Frequency &Microwave Electronics‖, Pearson Education Asia, Second Edition,2002. (UNIT V)

REFERENCES

1. Reinhold Ludwig and Powel Bretchko,‖ RF Circuit Design – Theory and Applications‖, Pearson Education Asia, First Edition,2001.
2. D. K. Misra, ―Radio Frequency and Microwave Communication Circuits- Analysis and Design‖, John Wiley & Sons, 2004.
3. E.C.Jordan and K.G. Balmain, ―Electromagnetic Waves and Radiating Systems Prentice Hall of India, 2006.
4. G.S.N Raju, "Electromagnetic Field Theory and Transmission Lines Pearson Education, First edition 2005.

UNIT I -TRANSMISSION LINE THEORY

General theory of Transmission lines - the transmission line - general solution - The infinite line - Wavelength, velocity of propagation - Waveform distortion - the distortion-less line - Loading and different methods of loading - Line not terminated in Z_0 - Reflection coefficient - calculation of current,voltage, power delivered and efficiency of transmission - Input and transfer impedance - Open and short circuited lines - reflection factor and reflection loss.

PART * A

Q.No.	Questions
1.	**What is characteristic impedance? (May/June 2016)** BTL 1 a) The ratio of the voltage applied (Es) and the current flowing (Is) is the input impedance of the line. This input impedance of the line is called characteristic impedance. b) It is also known as Surge impedance. c) It is denoted by Z_0. Its unit is ohms. d) It is the impedance looking into an infinite length of line. e) Z_0=Es/Is. f) Z_0 of finite line = $Z_0=(Zoc.Zsc)^{1/2}$. [Geometric mean of open and short circuit impedances]. g) Characteristic impedance is the impedance measured at the sending end of the line. It is given by Z_0 = Z/Y, where Z = R + jωL is the series impedance Y = G + jωC is the shunt admittance.
2.	**Define Reflection loss. (May/June 2016, April/May 2018)** BTL 1 a) The reflection loss is defined as the number of nepers or decibels by which the current in the load under image matched conditions would exceed the current actually flowing in the load. b) Reflection loss is inversely proportional to reflection factor. c) Reflection loss = $10\log(P_1/P_2)$dB=$20\log(1/\lvert K\rvert)$. Where P_1-Power at receiving end due to incident wave. P_2-Power absorbed by the load. K-reflection factor. d) Reflection loss= $20\log\dfrac{Z_R + Z_0}{2\sqrt{(Z_R Z_0)}}$ Where Z_R- Terminated impedance. Z_0- Characteristic impedance.
3.	**Find the reflection coefficient of a 50 ohm transmission line. When it is terminated by a load impedance of 60+j40ohm. (Nov/Dec 2015)** BTL 3 Characteristic impedance, Z_0 =50 ohm.

	Load impedance, Z_R=60+j40 ohm. Reflection coefficient, $K=\frac{Z_R-Z_0}{Z_R+Z_0}=\frac{60+j40-50}{60+j40+50}$ =0.35<55.98^0=0.196+j0.29
4.	**What is meant by distortionless line? (Nov/Dec 2015, April/May 2018, Nov/Dec 2018, April/May 2019)** BTL 1 a) A line in which there is no phase or frequency distortion and also it is correctly terminated is called a distortionless line. b) Condition for a distortionless line. RC=LG c) For distortionless line, received signal is exact replica of the signal at the sending end, through it is delayed the signal by constant propagation time and its amplitude reduces. d) Condition for a distortionless line is identical to the condition for a minimum attenuation with L or C varied. e) The attenuation constant α should be made independent of frequency. f) The phase constant β should be made dependent of frequency g) The velocity of propagation is independent of frequency.
5.	**What are the disadvantages of telephone cables? (April/May 2015)** BTL 2 a) For Telephone cable, $\alpha=\sqrt{\frac{\omega RC}{2}}, v=\frac{\omega}{\beta}=\sqrt{\frac{2\omega}{RC}}$ b) In ordinary telephone cables, the wires are insulated with paper and twisted in pairs, therefore there will not be flux linkage between the wires, which results in negligible inductance, and conductance. If this is the case, there occurs frequency and phase distortion in the line. c) Both α and velocity,V are functions of frequency ω. Hence for high frequency there is large attenuation. d) Velocity v is also high at high frequency. e) Hence, waves travel very fast than the lower frequencies when frequency is high. f) Thus in telephone cable both phase and frequency distortions are dominant.
6.	**Define the term insertion loss. (April/May 2015, Nov/Dec 2018)** BTL 1 a) Insertion loss of a line or a network is defined as the number of nepers or decibels by which the current in the load is changed by the insertion of a line or a network in between the load and the source. b) Insertion loss= $\frac{\text{Current flowing in the load without insertion of the network}}{\text{Current flowing in the load with insertion of the network}}$ c) This loss occurs due to the insertion of a network or a line in-between the source and the load. d) Insertion loss= $20[\log\frac{1}{K_s}+\log\frac{1}{K_R}-\log\frac{1}{K_{SR}}+0.4343\alpha l]$ dB

	e) Insertion loss= $[\ln\frac{1}{K_s}+\ln\frac{1}{K_R}-\ln\frac{1}{K_{SR}}+\alpha l]$ nepers
7.	**Define Wavelength of the line. (Nov/Dec 2014)** BTL 1 a) The distance between two points along the line at which currents or voltages differ in phase by 2π radians is called wavelength. It is denoted by λ. b) It can also be defined as the distance between any point and next point along the line at which current or voltage is in the same phase. c) This distance corresponding to the phase shift of 2π radians is wavelength λ. d) In one wavelength, one electrical cycle is completed. $\lambda=\frac{2\pi}{\beta}$
8.	**What is the significance of reflection coefficient? (Nov/Dec 2014)** BTL 2 The ratio of the amplitudes of the reflected and incident voltage waves at the receiving end of the line is called the reflection coefficient. It is denoted by K. a) $K=\frac{\text{Re flectedVoltageatload}}{\text{IncidentVo ltageatload}}$ b) $Z_R=Z_0$=K=0 (No reflection). c) Z_R=0=Line is short circuited; K=-1=1<180^0. d) $Z_R=\infty$=Line is open circuited; K=1=1<0^0.
9.	**Write the need for inductance loading of telephone cables. (Nov/Dec 2013)** BTL 4 Distortionless operation can be achieved by increasing $\frac{L}{C}$ ratio. Inductance can be increased by using lumped inductors spaced at intervals along the line. This is called inductance loading.
10.	**A Transmission line has a characteristic impedance of 400 ohm and is terminated by a load impedance of (650-j475)ohm determine the reflection coefficient. (Nov/Dec 2013)** BTL 3 Z_0=400 ohm; Z_R=650-j475 ohm. Reflection coefficient= $K=\frac{Z_R-Z_0}{Z_R+Z_0}=\frac{650-j475-400}{650-j475-400}$=0.465<-37.9^0.
11.	**A Transmission line has a characteristic impedance of 600 ohm. Determine magnitude of a reflection coefficient if the receiving end impedance is (650-j475)ohm.(May/June 2014)** BTL 3 Z_0=600 ohm; Z_R=650-j475 ohm. Reflection coefficient= $K=\frac{Z_R-Z_0}{Z_R+Z_0}=\frac{650-j475-600}{650-j475-600}$=0.367<-63.09^0.

	Magnitude of reflection coefficient = |K|=0.357
12.	**Define Propagation constant of a transmission line. (May/June 2013, Nov/Dec 2018)** BTL 1 a) Propagation constant is defined as the natural logarithm of the ratio of the sending end current or voltage to the receiving end current or voltage of the line. It gives the manner in the wave is propagated along a line and specifies the variation of voltage and current in the line as a function of distance. Propagation constant is a complex quantity and is expressed as b) $\gamma = \alpha + j\beta$ The real part is called the attenuation constant α , whereas the imaginary part of propagation constant is called the phase constant β. c) γ-Propagation constant per unit length. d) $\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = \sqrt{ZY}$ e) $Z=(R+j\omega L)$=Series impedance. f) $Y=(G+j\omega C)$=Shunt admittance.
13.	**What is Phase distortion?(Nov/Dec 2009)** BTL 1 When a signal having many frequency components are transmitted along the line, all the frequencies will not have same time of transmission, some frequencies being delayed more than others. So the received end waveform will not be identical with the input waveform at the sending end because some frequency components will be delayed more than those of other frequencies. This type of distortion is called phase or delay distortion.
14.	**Define the line parameters. (Nov/Dec 2018)** BTL 1 **The parameters of a transmission line are:** Resistance (R) Inductance (L) Capacitance (C) Conductance (G). Resistance (R) is defined as the loop resistance per unit length of the wire. Its unit is ohm/Km. Inductance (L) is defined as the loop inductance per unit length of the wire. Its unit is Henry/Km. Capacitance (C) is defined as the loop capacitance per unit length of the wire. Its unit is Farad/Km. Conductance (G) is defined as the loop conductance per unit length of the wire. Its unit is mho/Km.
15.	**What are the secondary constants of a line? Why the line parameters are called distributed elements?** BTL 2 a) The secondary constants of a line are: Characteristic Impedance, Z_0 and Propagation Constant γ. b) Primary constants are Resistance R, Inductance L, Capacitance and conductance G. Since the line constants R, L, C, G are distributed through the entire length of the line, they are called as distributed elements. They are also called as primary constants.
16.	**What is a finite line? Write down the significance of this line.** BTL 2 A finite line is a line having a finite length on the line. It is a line, which is terminated, in its characteristic impedance ($Z_R=Z_0$), so the input impedance of the finite line is equal to the characteristic impedance ($Z_s=Z_0$).
17.	**What is an infinite line?** BTL 1 a) An infinite line is a line in which the length of the transmission line is infinite.

	b) A finite line, which is terminated in its characteristic impedance, is termed as infinite line. So for an infinite line, the input impedance is equivalent to the characteristic impedance. c) Infinite line is a hypothetical line. d) A finite line terminated in a load equivalent to the characteristic impedance appears to the sending end as an infinite line.
18.	**What is meant by waveform distortion?** BTL 1 If the received waveform on a transmission line is not identical with the input waveform at the sending end, it is called waveform distortion. This due to the fact that all frequencies applied on the transmission line are not equally attenuated and are not delayed equally.
19.	**What are the types of line distortions?** BTL 1 The distortions occurring in the transmission line are called waveform distortion or line distortion. Waveform distortion is of two types: a) Frequency distortion. b) Phase or Delay Distortion.
20.	**Find characteristic impedance of a line at 1600 Hz if Zoc=750<-30^0. And Zsc=600<-20^0 ohm. (April/May 2019)** BTL 3 $Z_0 = \sqrt{Z_{oc}Z_{sc}} = \sqrt{(750 \angle -30^0)(600 \angle -20^0)}$ $= \sqrt{450000 \angle -50^0}$ =670.82<-25^0 ohm
21.	**How frequency distortion occurs in a line?** BTL 4 When a signal having many frequency components are transmitted along the line, all the frequencies will not have equal attenuation and hence the received end waveform will not be identical with the input waveform at the sending end because each frequency is having different attenuation. This type of distortion is called frequency distortion.
22.	**How to avoid the frequency distortion that occurs in the line?** BTL 4 In order to reduce frequency distortion occurring in the line, a) The attenuation constant α should be made independent of frequency. b) The phase constant β should be made dependent of frequency. c) By using equalizers at the line terminals which minimize the frequency distortion. Equalisers are networks whose frequency and phase characteristics are adjusted to be inverse to those of the lines, which result in a uniform frequency response over the desired frequency band, and hence the attenuation is equal for all the frequencies. band, and hence the phase is equal for all the frequencies.
23.	**How the telephone line can be made a distortion less line?** BTL 4 For the telephone cable to be distortion less line, the inductance value should be increased by placing lumped inductors along the line.
24.	**What is Loading?** BTL 1 Loading is the process of increasing the inductance value by placing lumped inductors at specific intervals along the line, which avoids the distortion.

25.	**What are the types of loading?** BTL 1 a) Continuous loading. b) Patch loading. c) Lumped loading.
26.	**What is continuous loading?** BTL 1 Continuous loading is the process of increasing the inductance value by placing a iron core or a magnetic tape over the conductor of the line.
27.	**What is patch loading?** BTL 1 It is the process of using sections of continuously loaded cables separated by sections of unloaded cables which increases the inductance value.
28.	**What is lumped loading?** BTL 1 Lumped loading is the process of increasing the inductance value by placing lumped inductors at specific intervals along the line, which avoids the distortion.
29.	**What is Impedance matching?** BTL 1 If the load impedance is not equal to the source impedance, then all the power that are transmitted from the source will not reach the load end and hence some power is wasted. This is called impedance mismatch condition. So for proper maximum power transfer, the impedances in the sending and receiving end are matched. This is called impedance matching.
30.	**When reflection occurs in a line?** BTL 2 **Reflection occurs because of the following cases:** a) When the load end is open circuited. b) When the load end is short-circuited. c) When the line is not terminated in its characteristic impedance. When the line is either open or short circuited, then there is not resistance at the receiving end to absorb all the power transmitted from the source end. Hence the entire power incident on the load gets completely reflected back to the source causing reflections in the line. When the line is terminated in its characteristic impedance, the load will absorb some power and some will be reflected back thus producing reflections.
31.	**What are the conditions for a perfect line? What is a smooth line?** BTL 1 a) For a perfect line, the resistance and the leakage conductance value were neglected. The conditions for a perfect line are R=G=0. b) A smooth line is one in which the load is terminated by its characteristic impedance and no reflections occur in such a line. It is also called as flat line.
	PART * B
1.	**Explain in detail about the reflection on a line not terminated by its characteristic impedance Z_0. (13 M) (Nov/Dec 2016, April/May 2019)** BTL 2 **Answer: Page: 256-260 - John D. Ryder** **Equations**: Voltages and currents measurement (3 M) a) $E = \frac{E_R(Z_R + Z_0)}{2Z_0}\left[e^{\gamma s} + \left(\frac{Z_R - Z_0}{Z_R + Z_0}\right)e^{-\gamma s}\right]$

	b) $I=\frac{I_R(Z_R+Z_0)}{2Z_0}\left[e^{\gamma s}-\left(\frac{Z_R-Z_0}{Z_R+Z_0}\right)e^{-\gamma s}\right]$ **Equations:** Component varying with $e^{\gamma s}$ = incident wave, Component varying with $e^{-\gamma s}$ = reflected wave (1 M) **Diagram**: Rotating voltage phasor systems incident - reflected waves-open circuited lines.(3M) **Diagram**: Curves - incident - reflected current waves- open circuited lines**.** (3 M) **Smooth line**: Line terminated in Z_0. Energy absorbed, no reflections. (1 M) **Energy equation** (2 M) a) $W_e=\frac{CE^2}{2}\text{ joules}/m^3$ b) $W_m=\frac{LI^2}{2}\text{ joules}/m^3$
2.	**Derive the condition for minimum attenuation in a distortionless line. (13 M) (Nov/Dec 2016)** BTL 5 **Answer: Page: 249-251- John D. Ryder** **Distortionless line:** Neither frequency nor delay distortion, α - velocity not function - frequency. (3 M) **Condition:** for distortionless line RC=LG (3 M) a) The **attenuation** constant - independent frequency. $\alpha=\sqrt{\frac{RG-\omega^2LC+\sqrt{(RG-\omega^2LC)^2+\omega^2(LG+CR)^2}}{2}}$ (3 M) b) The **phase** constant - dependent frequency. $\beta=\sqrt{\frac{\omega^2LC-RG+\sqrt{(RG-\omega^2LC)^2+\omega^2(LG+CR)^2}}{2}}$ (3 M) c) The **velocity** of propagation- independent frequency. $V=\frac{1}{\sqrt{LC}}$ (1 M)
3.	**Derive the transmission line equation and hence obtain expression for voltage and current on a transmission line. (13 M) (April/May 2017, Nov/Dec 2017, May/June 2016, May/June 2015, Nov/Dec 2013, April/May 2018, April/May 2019)** BTL 5 **Answer: Page: 236-240 - John D. Ryder** **Diagram**: A long line -infinitesimal sections (2 M) **Notations**: R, L, C, G, ωL, Z=R+j ωL, ωC, Y=G+j ωC, s, I, E, l. (2 M) a) dE=IZds (1 M) b) dI=EYds (1 M) c) $E=E_R\text{Cosh}\sqrt{zy}s+I_RZ_0\text{Snh}\sqrt{zy}s$ (4 M) d) $I=I_R\text{Cosh}\sqrt{zy}s+\frac{E_R}{Z_0}\text{Snh}\sqrt{zy}s$ (3 M)

4.	**Prove that an infinite line equal to finite line terminated in its characteristic impedance. (13 M) (May/June 2016)** BTL 5 **Answer: Page: 240-245- John D. Ryder** **Physical significance:** I_s and Z_s. (2 M) Unity-lumped constants, distributed constant-circuit performance - Z_0 and γ. (2 M) **Infinite Line**: finite length - terminated - load equivalent -characteristic impedance (3 M) **Equation:** derivation $Zs=Z_0$. (3 M) **Diagram:** Voltage phasor diagram. (2 M) **Diagram:** Voltage along an infinite line. (1 M)
5.	**Explain in detail about the waveform distortion, its types and also derive the condition for distortionless line. (13 M) (Nov/Dec 2015), (Nov/Dec 2013)** BTL 2 **Answer: Page: 249-251 - John D. Ryder** **Waveform distortion is of two types:** (4 M) a) **Frequency** distortion: signal, many frequencies, all frequencies – no equal attenuation. b) **Phase** or **Delay** Distortion: Applied voice voltage, received wave- not identical - input at sending end, components delayed more - frequencies. **To reduce frequency distortion occurring in the line,** a) Attenuation constant, independent of frequency. (1 M) b) Equalizers minimize frequency distortion. (1 M) c) Co-axial Cable-Phase distortion **Distortionless** line: condition RC=LG. (4 M) d) Attenuation constant independent - frequency. $\alpha=\sqrt{\frac{RG-\omega^2LC+\sqrt{(RG-\omega^2LC)^2+\omega^2(LG+CR)^2}}{2}}$ e) Phase constants dependent - frequency. $\beta=\sqrt{\frac{\omega^2LC-RG+\sqrt{(RG-\omega^2LC)^2+\omega^2(LG+CR)^2}}{2}}$ velocity of propagation - independent frequency. $V=1/(LC)^{(1/2)}$. (3 M)
6.	**Derive the expressions for input impedance of open and short circuited lines. (13 M) (Nov/Dec 2015, Nov/Dec2018)** BTL 5 **Answer: Page: 264-267 - John D Ryder** $Z_s = Z_0 \frac{Z_R \text{Cosh}\gamma l + Z_0 \text{Sinh}\gamma l}{Z_0 \text{Cosh}\gamma l + Z_R \text{Sinh}\gamma l}$ (3 M)

	$Z_{sc}=Z_0\tanh\gamma l$; $Z_R=0$ (3 M) $Z_{oc}=Z_0\coth\gamma l$; $Z_R=\infty$ (3 M) $Z_0=\sqrt{Z_{oc}.Z_{sc}}$ (2 M) $\tanh\gamma l=\sqrt{\frac{Z_{sc}}{Z_{oc}}}$ (1 M) $\gamma l=\tanh^{-1}\sqrt{\frac{Z_{sc}}{Z_{oc}}}$ (1 M)
7.	**Explain about different type of transmission line. (13M) (May/June 2015)** BTL 2 **Answer: Page: 233-236 - John D Ryder** **Transmission line parameters**: small series resistance, series inductance, shunt conductance, shunt capacitance: (5 M) **Open wire line**: parallel conductors (2 M) **Cables:** Underground lines, oil impregnated paper, solid dielectric (2 M) **Co-axial cable**: co-axially placed, high voltage levels (2 M) **Waveguides:** Electrical waves, microwave frequency, hollow conducting tubes (2 M)
8.	**Discuss the following: Reflection Factor, Reflection Loss and return loss.(13M) (May/June 2015)** BTL 2 **Answer: Page: 265-267 - John D. Ryder** **Diagram**: Generator of impedance Z_1 connected to load Z_2. (1 M) **Image matching:** Insertion of ideal transformer (1 M) **Theory of ideal transformer:** $\frac{I_1}{I_2}=\sqrt{\frac{Z_2}{Z_1}}$ $\text{REFLECTION LOSS}=\ln\left\lvert\frac{Z_1+Z_2}{2\sqrt{Z_1Z_2}}\right\rvert,\text{nepers}$ (2 M) $\text{REFLECTION LOSS}=20\log\left\lvert\frac{Z_1+Z_2}{2\sqrt{Z_1Z_2}}\right\rvert,\text{db}$ (2 M) **Reflection Factor:** Term K - change in current - load - reflection - mismatched junction. (2 M) $K=\frac{\lvert 2\sqrt{Z_1Z_2}\rvert}{\lvert Z_1+Z_2\rvert}$ (2 M) **Reflection Loss:** Number of nepers or decibels - current in load - image matched conditions -exceed - current - flowing in load. (2 M) **Insertion Loss:** Number of nepers or decibels - the current in the load- changed - insertion. (1 M)
9.	**Explain wavelength and velocity of propagation. (13 M)** BTL 2 **Answer: Page: 245-247 - John D. Ryder**

	Wave propagation: -Any of the ways -waves travel. Direction oscillation - relative propagation direction (2 M) **Wavelength:** Distance wave travels - along line - phase angle - 2Π radians **λ =2π/ ß** (2 M) Change 2π in time-occurs in a distance one wavelength, **λ= v/f** **Velocity** (1 M) **V= f λ** **V=ω/ ß** Change - phase angle - line, Measured in miles/second - ß in radians per meter. (1 M) $\gamma = \sqrt{RG - \omega^2 LC + j\omega(LG + CR)}$ (2 M) $\alpha = \sqrt{\frac{RG - \omega^2 LC + \sqrt{(RG - \omega^2 LC)^2 + \omega^2 (LG + CR)^2}}{2}}$ (2 M) $\beta = \sqrt{\frac{\omega^2 LC - RG + \sqrt{(RG - \omega^2 LC)^2 + \omega^2 (LG + CR)^2}}{2}}$ (2 M) $V = \frac{1}{\sqrt{\mu_V \varepsilon_V}}$ m/sec (1 M)
10.	**Describe reflection coefficient. (13 M)** BTL 2 **Answer: Page: 260-261- John D. Ryder** **The reflection coefficient:** Amplitude or intensity - reflected wave relative - incident wave, related - transmission coefficient. (3 M) **Reflection occurs because of the following cases** (4 M) a) Load end - open circuited b) Load end - short-circuited c) Line - not terminated - characteristic impedance. $K = \frac{\text{Reflected Voltage at Load}}{\text{Incident Voltage at Load}} = \frac{Z_R - Z_0}{Z_R + Z_0}$ (2 M) **Definition:** Ratio of amplitudes - reflected - incident voltage waves - receiving end (2 M) Sign of K - polarity - reflected wave - on angles and magnitudes of Z_R and Z_0. (1M) Z_0 termination, reflection Zero. (1 M)
11.	**Derive expression for the attenuation and phase constant of transmission line in constant R, L, G and C. (13 M) (Nov/Dec 2018)** BTL 5 **Answer Page: 245-247 - John D Ryder** **Derivation**:

	$\alpha = \sqrt{\frac{RG-\omega^2LC+\sqrt{(RG-\omega^2LC)^2+\omega^2(LG+CR)^2}}{2}}$ (7 M) **Derivation:** $\beta = \sqrt{\frac{\omega^2LC-RG+\sqrt{(RG-\omega^2LC)^2+\omega^2(LG+CR)^2}}{2}}$ (6 M)
12.	**Derive the expression for input and transfer impedance of the transmission line. (13 M), or Derive input impedance from transmission line equation and also find voltage reflection ratio at the load. (Nov/Dec 2017)** BTL 5 **Answer: Page: 263-264 - John D. Ryder** **Derivation**: Input impedance - line, in terms of exponentials - derivation equation of E_s. (7 M) **Derivation** : Transfer Impedance (6 M) $Z_T=Z_R\cosh\gamma l+Z_0\sinh\gamma l$ Voltage reflection ratio K= $\frac{\text{Reflected Voltage at Load}}{\text{Incident Voltage at Load}} = \frac{Z_L - Z_s}{Z_L + Z_s}$
13.	**Discuss in detail about lumped loading and derive the Campbell's equation. (13 M) (April/May 2017)** BTL 2 **Answer: Page: 252-256 - John D. Ryder** **Telephone cable**: Wires insulated-paper - twisted – pairs **Derivation**: $\gamma=\sqrt{RG-\omega^2LC+j\omega(LG+CR)}$ and v= $\frac{\omega}{\beta}$. (2 M) **Inductance loading of telephone cables**:Assumptions G=0, ωL large with respect to R.(3 M) **Diagram**: Equivalent T section for part line - 2 lumped loading coils of impedance. (4 M) Inductors-introduced in lumps – uniform distance – both limbs – line balanced – loading coils. **Disadvantages lumped loading:** Z_2 Capacitive – LPF, below f_c – attenuation reduced – above- attenuation rises. **Advantages**: **a)** No limit – inductance increased **b)** Small cost **c)** Lines modified **Graph**: Attenuation frequency characteristics **Campbells** equation derivation: $\sinh N\gamma = \frac{Z_0}{Z_2}$

	$\text{Cosh}N\gamma = 1 + \frac{Z_1}{2Z_2}$ $Z_1^{'} = \frac{Z_c}{2} + \frac{Z_1}{2}$ $\text{Cosh}N\gamma - 1 = \frac{Z_1}{2Z_2}$ $\frac{Z_1}{2} = Z_2\left[\text{Cosh}N\gamma - 1\right]$ $\frac{Z_1}{2} = \frac{Z_0}{\text{Sinh}N\gamma}\left[\text{Cosh}N\gamma - 1\right]$ $\frac{Z_1^{'}}{2} = \frac{Z_c}{2} + \frac{Z_0}{\text{Sinh}(N\gamma)}\left[\text{Cosh}(N\gamma) - 1\right]$ $\text{Cosh}(N\gamma^1) = 1 + \frac{Z_1^1}{2Z_2} = 1 + \frac{\frac{Z_1^1}{2}}{Z_2}$ $= 1\frac{\left[\frac{Z_c}{2} + \frac{Z_0}{\text{Sinh}N\gamma}\left[\text{Cosh}N\gamma - 1\right]\right]}{\frac{Z_0}{\text{Sinh}N\gamma}}$ $= 1 = \frac{\text{Sinh}N\gamma}{2Z_0}\left[Z_c + \frac{2Z_0}{\text{Sinh}N\gamma}\left[\text{Cosh}N\gamma - 1\right]\right]$ $\text{Cosh}N\gamma^{'} = 1 + \frac{Z_c\text{Sinh}N\gamma}{2Z_0} + \text{Cosh}N\gamma - 1$ $$\text{Cosh}N\gamma^{'} = \frac{Z_c}{2Z_0}\text{Sinh}N\lambda + \text{Cosh}N\lambda$$ **Campbell's** equation, (4 M)
	PART*C
1.	**A Communication line has L=3.67mH/km, G=0.8x10^{-6} mhos/Km, C=0.0083µF/Km and R=10.4 ohms/Km. Determine the characteristic impedance, propagation constant, phase constant, velocity of propagation, sending and receiving end current for given frequency f=1000Hz, sending end voltage is 1 volt and transmission line length is 100 Km. (15 M) (April/May: 2017, Nov/Dec 2016, May/June 2016, April/May 2018)** BTL 6 **Answer: Page: 261-263- John D.Ryder and lecture notes Page: 130** $Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} = 694.32\angle -11.703^0\,\Omega$ (2 M) $\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = 0.007928 + j0.03553$ (2 M) α=0.007928 nepers/Km (1 M) β=0.03553 rad/Km. (1 M)

$\lambda = \frac{2\pi}{\beta} = 176.841\text{Km}$

(2 M)

$V=\omega/\beta=176.84\text{x}10^3\text{Km/s}$ (1 M)

$I_s=E_s/Z_0=1.4402\text{x}10^{-3}<11.703^0$ (2 M)

$I_R=I_S e^{-\alpha l}<-\beta l=6.516\text{x}10^{-4}<-191.86^0$. (2 M)

$E_R=I_R Z_0=0.4524<-203.56^0$. (1 M)

$P_R=E_R I_R \text{Cos}\theta=288\text{x}10^{-6}\text{W}$. (1 M)

2. **A parallel-wire transmission line is having the following line parameters at 5 KHz. Series resistance ($R=2.59\text{x}10^{-3}$ ohm/m). Series inductance (L=2µH/m), Shunt conductance (G=0mho/m) and capacitance between conductors (C=5.56 nF/m). Find the characteristic impedance, attenuation constant, phase shift constant, velocity of propagation and wavelength. (15 M) (Nov/Dec 2015, April/May 2016, April/May 2019)** BTL 6

Answer: Page: 261-263- John D Ryder and lecture notes Page: 131

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} = 18.97\angle -1.18^0 \Omega$$

(3 M)

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = 6.825\text{x}10^{-5} + j3.313\text{x}10^{-3}$$

(3 M)

$\alpha=68.25\text{x}10^{-6}$ nepers/Km (2 M)

$\beta=3.313\text{x}10^{-3}$ rad/Km. (2 M)

$\lambda = \frac{2\pi}{\beta} = 1896.52\text{m}$

(2 M)

$V=\omega/\beta=9.48\text{x}10^6\text{m/s}$ (3 M)

3. **A 2 m long transmission line with characteristic impedance of 60+j40 ohm is operating at $\omega=10^6$ rad/sec has attenuation constant of 0rad/m. If the line is terminated by a load of 20+j50 ohm, determine the input impedance of this line. (15 M) (April/May 2017, Nov/Dec 2015)** BTL 6

Answer: Page: 261-263- John D Ryder and lecture notes Page: 132

$\beta=2\pi/\lambda=3.33\text{x}10^{-3}$ rad/m (5 M)

	$K=0.342<117.59^0$. (5 M) $Z_s= Z_0 \dfrac{e^{\gamma l}+Ke^{-\gamma l}}{e^{\gamma l}-Ke^{-\lambda l}} = 54.32\angle 68.33^0 = 20.053 + j50.486$ (5 M)
4.	**Find the characteristic impedance of a line at 1600 Hz, if the following measurements have been made on the line at 1600Hz, $Z_{oc}=750<-30^0$ ohm and $Z_{sc}=600<-20^0$ ohm on the line at 1600 Hz. (7 M) (Nov/Dec 2016),** BTL 6 **Answer: Page: 261-Pg.263 -John D Ryder and lecture notes Page: 133** $Z_0 = \sqrt{Z_{sc}.Z_{oc}} = 670.82\angle -25^0\,\Omega$ (7 M)
5.	**For an open wire overhead line β=0.04 rad/Km. Find the wavelength and velocity at a frequency of 1600 Hz. Hence calculate time taken by the wave to travel 90 km. (15 M)** BTL 3 **Answer: Page: 261-263 -John D Ryder and lecture notes Page: 133** $v = \dfrac{\omega}{\beta} = 2.5132x10^5\,Km/s$ (8 M) $t=3.581x10^{-4}s$ (7 M)
6.	**A line 20 Km long has following constants $Z_0=600<0^0$ ohm, α=0.1 nepers/Km, β=0.05 rad/Km. Find the received current when 20mA are sent into one end and receiving end is short circuited. (15 M)** BTL 3 **Answer: Page: 261-Pg.263 -John D Ryder and lecture notes Page: 133** $\dfrac{E_s}{I_s} = Z_0 \tanh(\gamma l)$ (10 M) $I = \dfrac{I_s}{Cosh(\gamma l)} = 5.45\angle -56.33^0\,mA$ (5 M)

	UNIT II - HIGH FREQUENCY TRANSMISSION LINES
	Transmission line equations at radio frequencies - Line of Zero dissipation - Voltage and current on the- Input impedance of the dissipation-less line - Open and short circuited lines - Power and impedance measurement on lines - Reflection losses - Measurement of VSWR and wavelength.
	PART * A
Q.No.	**Questions**
1.	**State the assumptions for the analysis of the performance of the radio frequency line. (May/June 2016, April/May 2018)** BTL 1 a) Due to the skin effect, the currents are assumed to flow on the surface of the conductor. The internal inductance is zero. b) The resistance R increases with $\sqrt{f}$ while inductance L increases with f. Hence, wL>>R. **c)** The line at radio frequency is constructed in such a way that the leakage conductance G is zero.
2.	**Write the expression for standing wave ratio in terms of reflection coefficient. (Nov/Dec 2015, April/May 2019)** BTL 1 $S=\frac{(1+\|K\|)}{(1-\|K\|)}$ $\|K\|=\frac{(S-1)}{(S+1)}$
3.	**A lossless transmission line has a shunt capacitance of 100pF/m and a series inductance of 4µH/m. Determine the characteristic impedance. (Nov/Dec 2015)**BTL 3 C=100pF/m L=4µH/m Characteristic impedance, $Z_0=R_0=\sqrt{\frac{L}{C}}=\sqrt{\frac{4x10^{-6}}{100x10^{-12}}}$ =200ohm
4.	**For a line of zero dissipation, what will be the values of attenuation constant and characteristic impedance? (Nov/Dec 2016)** BTL 2 For the dissipation less line, the Z_0 is purely resistive and given by, $Z_0=R_0=\sqrt{\frac{L}{C}}$ ohm Attenuation constant, $\alpha = 0;$
5.	**How will you make standing wave measurements on coaxial lines?(April/May 2015)** BTL 4 For coaxial lines it is necessary to use a length of line in which a longitudinal slot, one half wavelength or more long has been cut. A wire probe is inserted into the air dielectric of the line as a pickup device, a vacuum tube voltmeter or other detector being connected between probe and sheath as an indicator. If the meter provides linear indications, S is readily determined. If the indicator is non linear, corrections must be applied to the readings obtained.

6.	**A line having characteristic impedance of 50ohm is terminated by load impedance (75+j75)ohm. Determine reflection coefficient. (Nov/Dec 2014)** BTL 3 Z_0=50 ohm; Z_R=75+j75 ohm Reflection coefficient= $K = \frac{Z_R - Z_0}{Z_R + Z_0} = \frac{75 + j75 - 50}{75 + j75 + 50}$ =0.5423<-40.6^0. VSWR $S = \frac{1+\|K\|}{1-\|K\|} = \frac{1+0.5423}{1-0.5423} = 3.369$
7.	**Write the conditions to be satisfied by dissipation less line. (May/June 2014)** BTL 1 For dissipation less line, R=G=0.
8.	**Give the equations for the characteristic impedance and propagation constant of dissipation less line. (May/June 2014)** BTL 1 a) Characteristic impedance, $Z_0=R_0 = \sqrt{\frac{L}{C}}$ ohm b) Propagation constant, $\gamma = j\omega\sqrt{LC}$ c) Attenuation Constant, $\alpha = 0$ d) Phase constant, $\beta = \omega\sqrt{LC}$ rad/m e) Velocity of propagation, $v = \frac{1}{\sqrt{LC}}$ m/s f) Wavelength, $\lambda = \frac{2\pi}{\omega\sqrt{LC}}$ m
9.	**Define SWR. (May/June 2013)** BTL 1 a) The ratio of the maximum to minimum magnitudes of voltage or current on a line having standing waves called standing waves ratio. b) It is denoted by S c) $S = \frac{\|E_{max}\|}{\|E_{min}\|} = \frac{\|I_{max}\|}{\|I_{min}\|}$ d) Measured by RF voltmeter across the line at a point.
10.	**Calculate standing wave ratio and reflection coefficient on a line having characteristic impedance Z_0=300 ohm and terminating impedance in Z_R=300+j400 ohm. (Nov/Dec 2016)** BTL 3 Z_0=300 ohm; Z_R=300+j400 ohm Reflection coefficient= $K = \frac{Z_R - Z_0}{Z_R + Z_0} = \frac{300 + j400 - 300}{300 + j400 + 300}$ =0.5547<56.31^0. VSWR $S = \frac{1+\|K\|}{1-\|K\|} = \frac{1+0.5547}{1-0.5547} = 3.49$
11.	**Give the input impedance of open and short circuited lines. (Nov/Dec 2016, April/May**

	2018) BTL 1 The input impedance of open and short circuited lines are given by, Zsc = jRo tan βs Zoc=-jR_0Cotβs
12.	**Determine the values of VSWR in the case of Z_R=0 and Z_R=Z_0.** BTL 4 a) Z_R=0, |K|=1 and S=∞ b) Z_R=Z_0; |K|=0 and S=1
13.	**Give the minimum and maximum value of SWR and reflection coefficient.** BTL 1 **1<SWR<**∞ Minimum value of SWR is 1 Maximum value of SWR is ∞ **0<K<1** Minimum value of reflection coefficient is 0 Maximum value of reflection coefficient is 1.
14.	**State the expressions for inductance L of a open wire line and coaxial line.** BTL 1 For open wire line , L=9.21*10^{-7}(μ/μr +4ln d/a)=10^{-7}(μr+9.21log d/a) H/m For coaxial line, L = 4.60*10^{-7}[log b/a]H/m
15.	**State the expressions for the capacitance of an open wire line.** BTL 1 For open wire line , C=(12.07)/(ln d/a)μμf/m
16.	**What is dissipation less line?** BTL 1 A line for which the effect of resistance R is completely neglected is called dissipation less line.
17.	**State the values of α and β for the dissipation less line.** BTL 1 $\alpha = 0; \ \beta = \omega\sqrt{LC}$ **rad/m**
18.	**What are nodes and antinodes on a line? (April/May 2019)** BTL 1 The points along the line where magnitude of voltage or current is zero are called nodes while the points along the lines where magnitude of voltage or current first maximum are called antinodes or loops.
19.	**What is the range of values of standing wave ratio?** BTL 2 The range of values of standing wave ratio is theoretically 1 to infinity.
20.	**What are standing waves?** BTL 1 If the transmission is not terminated in its characteristic impedance, then there will be two waves traveling along the line which gives rise to standing waves having fixed maxima and fixed minima.
21.	**Give the maximum and minimum input impedance of the dissipationless line.** BTL 1 Maximum input impedance, R max = R0 $[\frac{(1+K)}{(1-K)}]$ = SR_o

	Minimum input impedance, R min = $\dfrac{R_0}{[\frac{(1+K)}{(1-K)}]} = \dfrac{R_0}{S}$
22.	**Why the point of voltage minimum is measured rather than voltage maximum?** BTL 4 The point of a voltage minimum is measured rather than a voltage maximum because it is usually possible to determine the exact point of minimum voltage with greater accuracy.
23.	**What is the input impendence equation of dissipation less line?** BTL 1 The input impendence equation of a dissipation less line is given by Zs=Ro= $\dfrac{(1+\lvert K\rvert(\phi-2\beta s))}{(1-\lvert K\rvert(\phi-2\beta s))}$
24.	**Give the properties of an infinite line.** BTL 1 a) Due to infinite line, no waves will reach the receiving end and hence there is no reflection at the receiving end. b) Thus no reflected waves to sending end. c) Complete power applied at sending end is absorbed by the line. d) As the reflected waves are absent, Z_0 at sending end will decide the current flowing, when a voltage is applied to the sending end. e) It is hypothetical line which has input impedance equal to the characteristic impedance. f) A finite line terminated in a load equivalent to the characteristic impedance appears to the sending end as an infinite line.
	PART * B
1.	**Derive an expression for the input impedance of a dissipation less line and also find the input impedance is maximum and minimum at a distance 's'. (13 M) (Nov/Dec 2016, April/May 2018, April/May 2019)** BTL 5 **Answer: Page: 295- 297 - John D. Ryder** a) **Phasor diagram** (2 M) b) **Derivation: Zs=** $R_0\left(\dfrac{1+\lvert K\rvert\angle(\phi-2\beta S)}{1-\lvert K\rvert\angle(\phi-2\beta S)}\right)$ (5 M) c) **Derivation:** $R_{max}=SR_0$ (3 M) d) **Derivation :** $R_{min}=R_0/S$ (3 M)
2.	**Describe an experimental setup for the determination of VSWR of an RF transmission. (13 M) (Nov/Dec 2016,April/May 2018)** BTL 2

	Answer: Page: 291- 294 - John D. Ryder a) **S=** $\frac{\lvert E_{max}\rvert}{\lvert E_{min}\rvert} = \frac{\lvert I_{max}\rvert}{\lvert I_{min}\rvert}$ (2 M) b) **Calculate** values -K and S - maximum - minimum voltages - currents. (1 M) c) **SWR** measured on **open-wire** lines. (1 M) d) **Co-axial line** – longitudinal slot, one-half wavelength, Wire probes - air dielectric - pick up device, vacuum tube voltmeter - sheath - indicator. (2 M) e) **Measure wavelength**: distance between successive voltage or current maxima or minima - half wavelength - **Lecher measurements**. (2 M) f) **Diagram** - slotted line section, probe voltmeter - co-axial line measurements (3 M) **Directional coupler** : measure standing waves (2 M)
3.	**Briefly explain standing waves, and Reflection Loss. (13 M) (Nov/Dec 2016, April/May 2018, April/May 2019)** BTL 2 **Answer: Page: 291 - 302 - John D. Ryder** **Standing Waves:** Resultant voltage - stands still on line, oscillating magnitude, time - fixed positions – maxima, minima. (2 M) a) **Nodes:** points of Zero voltage, current (1 M) b) **Antinodes or loops:** points - maximum - voltage - current. (1 M) c) **S=** $\frac{\lvert E_{max}\rvert}{\lvert E_{min}\rvert} = \frac{\lvert I_{max}\rvert}{\lvert I_{min}\rvert}$ (2 M) **Reflection losses:** (3 M) a) **Reflection losses** - function of SWR. b) Ratio - power delivered load - power transmitted - incident wave. c) $\frac{P}{P_i} = 1 - \frac{\lvert E_r\rvert^2}{\lvert E_i\rvert^2} = 1 - \lvert K\rvert^2 = \frac{4s}{(s+1)^2}$ (2 M) **Insertion loss:** (2 M) Figure of merit - Ratio - signal level - test configuration without the filter - (V1) - signal level with the filter installed (V2). Ratio - dB
4.	**Derive the line constants of a zero dissipation less line. (13 M) (May/June 2016, April/May 2017, April/May 2018)** BTL 5**.** **Answer: Page: 282- 290 - John D. Ryder** a) **(Graph):** Variation of R_0 with d/a ratio for an open wire line.

	b) $Z_0 = R_0 = \sqrt{\frac{L}{C}}$ ohms (2 M) c) $R_0 = 120\ln\left(\frac{d}{a}\right)$ ohms (2 M) d) $R_0 = 270\log\left(\frac{d}{a}\right)$ ohms (2 M) e) **Graph:** Variation of R_0 with d/a ratio - co-axial line. f) $R_0 = \frac{60}{\sqrt{\varepsilon_r}}\ln\left(\frac{b}{a}\right)$ ohms (2 M) g) $R_0 = \frac{138}{\sqrt{\varepsilon_r}}\log\left(\frac{b}{a}\right)$ ohms (2 M) h) Characteristic impedance - ohms (Ω). Resistance per unit length -coaxial cables, capacitance per unit length (C) - inductance per unit length (L). Determined Parameters ratio - inner (d) - outer (D) diameters - dielectric constant (ε). (3 M)
5.	**Discuss in detail about the variation of input impedance along open and short circuit lines with relevant graphs. Or draw the input impedance pattern for a lossless line when short circuited and open circuited. (13 M) (May/June 2016, Nov/Dec 2017, April/May 2018, April/May 2019)** BTL 5 **Answer: Page: 297- 299 - John D. Ryder** **Input impedance of a transmission line:** (3 M) Transmission line – lossless- propagation constant - purely imaginary. If Z=0 - terminals - load – antenna – then ratio - voltage - current – at location Z=-L: a) **Input impedance,** $Z_s = R_0\left(\frac{Z_R + jR_0\tan\beta s}{R_0 + jZ_R\tan\beta s}\right)$ (3 M) b) **Short circuited line, Z_{SC}=** $jR_0\tan\left(\frac{2\pi s}{\lambda}\right)$ (3 M) c) **Open circuited line, Z_{OC}= -**$jR_0\mathrm{Cot}\left(\frac{2\pi s}{\lambda}\right)$ (3 M) d) **Graph**: Variation - input impedance – dissipation less line - function - length, -Short circuited line - open-circuited line. (1 M)
6.	**Discuss the various parameters of open wire and co-axial lines at radio frequencies. (13 M) (Nov/Dec 2015, Nov/Dec 2018)** BTL 2 **Answer: Page: 278- 282 - John D. Ryder** **Two forms of line at high frequency** (2 M)

a) Open wire line

b) Coaxial line

c) **Assumption:** At Radio frequency (4 M)

d) **Skin effect:** Current flowing - conductor surface, internal inductance - Zero.

e) **ωL>>R, R** increases with $\sqrt{f}$

f) **G=0.**

g) **Parameters of open-wire line at high frequencies**. (3 M)

h) $$L = \frac{\mu_0}{2\pi}\ln\frac{d}{a} = 4x10^{-7}\ln\frac{d}{a}\,\text{henrys}/\text{m} = 9.21x10^{-7}\log\frac{d}{a}\,\text{henrys}/\text{m}$$

i) $$C = \frac{\pi\varepsilon_v}{\ln\frac{d}{a}}\,\text{farads}/\text{m} = \frac{12.07}{\ln\frac{d}{a}}\,\mu\mu f/\text{m}$$

j) $$\delta = \frac{1}{\sqrt{\pi f\mu\sigma}}\,\text{meters}$$

k) $$R_{dc} = \frac{K}{\pi a^2}$$

l) $$R_{ac} = \frac{8.33x10^{-8}\sqrt{f}}{a}\,\text{ohms}/\text{m}$$

m) **Parameters of co-axial line at high frequencies.** (4 M)

n) $$L = \frac{\mu_0}{2\pi}\ln\frac{b}{a} = 2x10^{-7}\ln\frac{b}{a}\,\text{henrys}/\text{m} = 4.60x10^{-7}\log\frac{b}{a}\,\text{henrys}/\text{m}$$

o) $$C = \frac{2\pi\varepsilon}{\ln\frac{b}{a}}\,\text{farads}/\text{m} = \frac{24.14\varepsilon_r}{\log\frac{b}{a}}\,\mu\mu f/\text{m}$$

p) $$R_{ac} = 4.16x10^{-8}\sqrt{f}\left(\frac{1}{b}+\frac{1}{a}\right)\text{ohms}/\text{m}$$

7\. **Derive an expression that permit the easy measurement of power flow on a line of negligible losses. (13 M) (April/May 2017, Nov/Dec 2015, April/May 2019)** BTL 5

Answer: Page: 299- 302 - John D. Ryder

a) **Dissipation less** line: Voltage and current (1 M)

a. $$E = \frac{I_R\left(Z_R + R_0\right)}{2}\left(1 + |K|\angle(\phi - 2\beta S)\right)$$

(3 M)

b. $$I = \frac{I_R\left(Z_R + R_0\right)}{2}\left(1 - |K|\angle(\phi - 2\beta S)\right)$$

(3 M)

b) **Diagram:** illustrating voltage and current. (3 M)

c) $$\frac{E_{max}}{E_{max}} = \frac{E_{min}}{I_{min}} = R_0$$

d) $$\frac{E_{max}}{I_{min}} = SR_0 = R_{max}$$

e) $$\frac{E_{min}}{I_{max}} = \frac{R_0}{S} = R_{min}$$

f) $$P = \frac{E_{max}^2}{R_{max}} = \frac{E_{min}^2}{R_{min}} = \frac{|E_{max}||E_{min}|}{R_0} = \left(|I_{max}||I_{min}|\right)R_0$$

(3 M)

g) Impedance, $$Z_R = R_0\left[\frac{1 - jS\tan\left(\frac{2\pi s'}{\lambda}\right)}{S - j\tan\left(\frac{2\pi s'}{\lambda}\right)}\right]$$

8. **Briefly explain standing waves, Nodes, Antinodes and Standing Wave Ratio. (13 M) (April/May 2018)** BTL 1

Answer: Page: 291- 294 - John D. Ryder

Standing Waves: Transmission - terminated - characteristic impedance - two waves - fixed maxima - fixedminima. (3 M)

a) Resultant voltage - stands still on line, oscillating magnitude, time - fixed positions – maxima, minima.

b) **Nodes-**points - zero voltage - current**.** (3 M)

c) **Antinodes or loops:** points - maximum voltage - current. (3 M)

d) **S=** $$\frac{|E_{max}|}{|E_{min}|} = \frac{|I_{max}|}{|I_{min}|}$$

(4 M)

Standing wave ratio S- maximum - minimum magnitudes - current - voltage - standing wave

9.	**Derive the Voltages and currents on the dissipation less line. (13 M) (April/May 2015, April /May 2017)** BTL 5 **Answer: Page: 285- 290 - John D. Ryder** **Graph**: Incident and reflected voltage - wave phasors and values along dissipation less line - successive instants of time. (3 M) a) **Graph:** Waves of superposed. b) **Graph:** Voltage values as read on line c) **Graph:** Voltage and current on open-circuited dissipation less line. d) **Open circuited, I_R=0**. (1 M) $E_{OC} = E_R \text{Cos} \frac{2\pi s}{\lambda}$ (2 M) $I_{OC} = \frac{jE_R}{R_0} \text{Sin} \frac{2\pi s}{\lambda}$ (2 M) e) **Short circuited, E_R=0** (1 M) $E_{SC} = jI_R R_0 \text{Sin} \frac{2\pi s}{\lambda}$ (2 M) $I_{SC} = I_R \text{Cos} \frac{2\pi s}{\lambda}$ (2 M)
10.	**Derive an expression for reflection loss and discuss in detail about the wavelength measurement. (13 M) (April/May 2018)** BTL 5 **Answer: Page: 302- 304 - John D Ryder** a) Reflection losses - unmatched line (1 M) b) Derivation: Reflection losses – function of SWR. (1 M) c) Graph: SWR: Ratio - power absorbed - load - power transmitted. (1 M) Ratio - power delivered - load - power transmitted - incident wave. (1 M) $\frac{P}{P_i} = 1 - \frac{\lvert E_r \rvert^2}{\lvert E_i \rvert^2} = 1 - \lvert K \rvert^2 = \frac{4s}{(s+1)^2}$ **Insertion loss:** (2 M) Figure of merit - data - with filter. Ratio - signal level - without the filter - (V1) - with the filter - (V2). Ratio - dB **Measurement of Wavelength:** **Diagram:** slotted line section - probe voltmeter - co-axial line measurements. (3 M) **Distance:** successive voltage or current maxima or minima - equal - half wavelength. (3 M) **Lecher:** measurements (1 M)

11.	**Calculate the average input power at a distance from the load 'l' and find the impedance when the load is short circuited, open circuited and for a matched line. (13 M)** BTL 5 (**Nov/Dec 2017)** **Refer** Answers 5 and 7.
	PART * C
1.	**A line with Zero dissipation has** **R = 0.006 ohm per m; C = 4.45pF per m and L = 2.5 μH per m** **If the line is operated at 10 MHz find R_0, α, β, λ , v. (15 M) (May/June 2016)** BTL 6 **Answer: Page: 283 - John D.Ryder and lecture notes Page: 134** a) $Z_0 = \sqrt{\frac{L}{C}} = 749.53\Omega$ (3 M) b) $\alpha=0$ (2 M) c) $\beta= \omega\sqrt{LC} = 0.2095 rad/m$ (2 M) d) $\gamma=\alpha+j\beta=0+j0.2095$ per m (2 M) e) $v= \frac{1}{\sqrt{LC}} = 2.998X10^8 m/s$ (3 M) f) $\lambda= \frac{2\pi}{\beta} = 29.9913m$ (3 M)
2.	**A lossless line has a standing wave ratio of 4. The R_0 is 150Ω and the maximum voltage measured in the line is 135 V. Find the power delivered to the load. (15 M) (May/June 2016)** BTL 6 **Answer: Page: 292 - John D Ryder and lecture notes Page: 134** a) $R_{max}=SR_0$. (7 M) b) $P= \frac{E^2_{max}}{R_{max}} = 30.375W$ (8 M)
3.	**A lossless line in air having a characteristic impedance of 300 ohm is terminated in unknown impedance. The first voltage minimum is located at 15cm from the load. The Standing wave ratio is 3.3. Calculate the wavelength and terminated impedance. (15 M) (Nov/Dec 2015)** BTL 5 **Answer: Page: 282 - John D Ryder and lecture notes Page:134**

	a) $\lvert K\rvert = \frac{S-1}{S+1} = 0.5348$ (4 M) b) $\Phi=180^0$ (3 M) c) K=-0.5348 (4 M) d) $Z_R = Z_0\left[\frac{1-\lvert K\rvert}{1+\lvert K\rvert}\right] = 90.93\Omega$ (4 M)
4.	**Find the primary and secondary constants of line 50 Km long when Z_{oc} measured by a bridge at 700Hz is 286<-40^0 ohms and Z_{sc} is 1520<16^0 ohms.(15 M) (Nov/Dec 2014, April/May 2017)** BTL 6 **Answer: Page: 279 - John D Ryder and lecture notes Page: 136** a) $\tanh(\gamma l) = \sqrt{\frac{Z_{sc}}{Z_{oc}}} = 2.0354 + j1.0822$ (3 M) b) $\gamma = 0.0076 + j13.355^0.$ (2 M) c) α=0.00766 (2 M) d) β=0.0267rad/Km (2 M) e) $Z_0 = \sqrt{Z_{sc}.Z_{oc}} = 659.33\angle -12^0$ (2 M) f) L=3.6805mH/Km (2 M) g) C=9.563x10^{-9}F/Km (2 M)
5.	**A transmission line has L=10mH/m, C=10^{-7} F/m, R=20ohm/m and G=10^{-5} mhos/m. Find input impedance at a frequency of [500/2π] Hz, if the line is very long. The Standing wave ratio is 3.3. Calculate the wavelength and terminated impedance. (15 M) (Nov/Dec 2013, May/June 2016)** BTL 5 **Answer: Page: 282 - John D Ryder and lecture notes Page: 137** a) Z=R+jωL=20+j50Ω (5 M) b) Y=G+jωC=10^{-5}+j5x10^{-4}mho (5 M) c) $Z_0 = \sqrt{\frac{Z}{Y}} = 328.17\angle -10.4\Omega$ (5 M)

6.	**Find the sending end line impedance for a HF line having characteristic impedance of 50 ohm. Line is of length (1.185 λ) and is terminated in a load of (110+j80) ohm. (15 M) (Nov/Dec 2016)** BTL 5 **Answer: Page: 283 - John D Ryder and lecture notes Page: 138** a) $K = \frac{Z_R - Z_0}{Z_R + Z_0} = 0.559\angle 26.57^0$ (5 M) b) $S = \frac{1+\lvert K\rvert}{1-\lvert K\rvert} = 3.535$ (5 M) c) $Z_{smax}=R_0S=176.757\Omega$ (3 M) d) $Z_{smin}=R_0/S=14.144\Omega$ (2 M)

UNIT III - IMPEDANCE MATCHING IN HIGH FREQUNCY TRANSMISSION LINES

Impedance matching: Quarter wave transformer - Impedance matching by stubs - Single stub and double stub matching - Smith chart - Solutions of problems using Smith chart - Single and double stub matching using Smith chart.

PART * A

Q.No.	Questions

1. Why is a quarter wave line called as impendence inverter?(May/June 2016) BTL 3

a) A quarter wave line may be considered as an impendence inverter because it can transform a low impendence in to a high impendence and vice versa.

b) Open circuited $\frac{\lambda}{4}$ line gives zero input impedance

c) Short circuited $\frac{\lambda}{4}$ line gives infinite input impedance

d) Thus a short circuit quarter wave line behaves as an open circuit at the other end

e) Open circuit quarter wave line behaves as a short circuit at the other end.

2. What is a Stub? Why it is used in between transmission lines? (May/June 2016)BTL 4

a) A stub is a impedance matching sections between the line and the load, such that the load appears as a resistance R_0 to the line.

b) It can be used as open or closed stub lines.

c) In this method, a stub of suitable length is connected in parallel with the line at a certain distance from the load.

d) Due to stub, anti-resonance is achieved providing impedance at resonance equal to R_0.

3. What is the application of the quarter wave matching section? (Nov/Dec 2015, Nov/Dec 2018) BTL1

a) Quarter wave line can be used as transformer for impedance matching $R_0 = \sqrt{Z_R Z_{in}}$

b) Impedance inverter: Transform low impedance into a high impedance and vice versa.

c) An important application of the quarter wave matching section is to a couple a transmission lines to a resistive load such as an antenna. $R'_0 = \sqrt{R_0 R_A}$

d) The quarter–wave matching section must be designed to have a characteristic impendence Ro, chosen such that the antenna resistance Ra is transformed to a value equal to the characteristic impendence Ra of the transmission line.

e) When quarter wave line is shorted to ground then input impedance is very high and the line acts as copper insulator.

4. Distinguish between single stub and double stub matching. (Nov/Dec 2015, April/May 2019) BTL 4

Single stub Matching	Double stub Matching
It requires one stub for matching.	It requires 2 stubs for matching.

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<tr><td>It is suitable for fixed frequency only. As frequency changes location of stub has to be changed and length is also varied.</td><td>Only the length of the stub is altered.</td></tr>
<tr><td>Stub have to be placed at a definite place on the line</td><td>Location of stub is arbitrary.</td></tr>
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List the applications of the smith chart.(April/May 2015, Nov/Dec 2018) BTL 1

The applications of the smith chart

a) It is used to find the input impendence and input admittance of the line.
b) It is used to measure VSWR.
c) Measurement of reflection coefficient K, magnitude and phase.
d) Impedance to admittance conversion.
e) Location of voltage maximum and minimum.
f) It helps to find the length and location of the stub.
g) The smith chart may also be used for lossy lines and the locus of points on a line then follows a spiral path towards the chart center, due to attenuation.
h) Single stub matching.

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What are the difficulties in single stub matching? (May/June 2014) BTL1

a) Single stub matching is suitable for fixed frequency only.
b) As frequency changes, location and length of the stub have to be changed.
c) Single stub impedance matching requires the stub to be located at a definite point on the line. This requirement frequently calls for placement of the stub at an undesirable place from a mechanical view point.
d) For a coaxial line, it is not possible to determine the location of a voltage minimum without a slotted line section, so that placement of a stub at the exact required point is difficult.
e) In the case of the single stub it was mentioned that two adjustments were required, these being location and length of the stub. To adjust for final position along the line, stub has to be moved or repositioned.

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Design a quarter wave transformer to match a load of 200 ohm to a source resistance 500 ohm. The operating frequency is 200MHz. (May/June 2013) BTL 6

Z_R=200 ohm,
Z_S=500ohm,
F=200MHz

$R_0=\sqrt{Z_S Z_R} = \sqrt{(500)(200)} = 316.22$ ohm

Wavelength, $\lambda = \frac{c}{f} = \frac{3x10^8}{200x10^6} = 1.5m$

Length of the quarter wave line = $\frac{\lambda}{4} = S = \frac{1.5}{4} = 0.375m$

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8.	**What is the use of eighth wave line?(Nov/Dec 2009)** BTL 1 a) An eighth wave line is used to transform any resistance to an impendence with a magnitude equal to Roof the line b) To obtain a magnitude match between a resistance of any value and a source of Ro internal resistance.
9.	**What are constant-S circles?** BTL 1 The input impedance equation for dissipation less line if expressed in terms of standing wave ratio S, results in the form of a circle. The circles are called as constant-S circle. Since, the maximum value of S is unity, S-circles surround the (1,0) point.
10.	**How the smith chart can be used as the admittance chart?** BTL 2 The smith chart may be used as an admittance chart, the r and x axis becomes g and b axis with a usual implication when capacitive susceptance is positive above and inductive susceptance is below the V or real axis. The point at the left of the conductance of g-axis then represents Zero conductance or an open circuit, while the point at extreme right represent infinite conductance or a short circuit.
11.	**Write down the expression to determine the length of the stub.** BTL 1 Lt= $\frac{\lambda}{2\pi}\tan^{-1}\frac{\sqrt{1-\|K\|^2}}{2\|K\|}$ Lt= $\frac{\lambda}{2\pi}\tan^{-1}[-\frac{\sqrt{1-\|K\|^2}}{2\|K\|}]$ Lt= $\frac{\lambda}{2\pi}\tan^{-1}\frac{\sqrt{Z_R Z_0}}{(Z_R - Z_0)}$ Where, K is the reflection coefficient. λ is the wavelength Z_R is the load impedance Z_0 is the characteristic impedance.
12.	**Write down the expression to determine the position of the stub**. BTL 1 S_1= $\frac{\phi+\pi-\cos^{-1}(\|K\|)}{\pi}\frac{\lambda}{4}$ S'_1= $\frac{\phi+\pi+\cos^{-1}(\|K\|)}{\pi}\frac{\lambda}{4}$ S= $\frac{\lambda}{2\pi}\tan^{-1}\sqrt{\frac{Z_R}{Z_0}}$ Where φ is the angle of reflection coefficient |K| is the magnitude of reflection coefficient λ is the wavelength Z_R is the load impedance Z_0 is the characteristic impedance
13.	**Give the input impendence of eighth wave line terminated in a pure resistance R_R.** BTL 1

	The input impendence of eighth wave line terminated in a pure resistance R_R. Is given by Zs = (Z_R+jR_o/R_o+jZ_R) From the above equation it is seen that ½Zs½ = Ro.
14.	**What do you mean by copper insulators?** BTL 2 An application of the short circuited quarter wave line is an insulator to support an open wire line or the center conductor of a coaxial line .This application makes se of the fact that the input impendence of a quarter –wave shorted line is very high, such lines are sometimes referred to as copper insulators.
15.	**Give the significance of a half wavelength line**. BTL 1 A half wavelength line may be considered as a one- to – one transformer. It has its greatest utility in connecting load to a source in cases where the load source cannot be made adjacent.
16.	**Give some of the impendence–matching devices.** BTL 1 The quarter – wave line or transformer and the tapered line are some of the impendence – matching devices.
17.	**What is impendence matching using stub? (April/May 2018)** BTL 2 In the method of impendence matching using stub, an open or closed stub line of suitable length is used as a reactance shunted across the transmission line at a designated distance from the load, to tune the length of the line and the load to resonance with an anti-resonant resistance equal to Ro.
18.	**Give reasons for preferring a short- circuited stub when compared to an open circuited stub.** BTL 2 A short circuited stub is preferred to an open circuited stub because of greater ease in constructions. The inability to maintain high enough insulation resistance at the open–circuit point ensures that the stub is really open circuited. A shorted stub also has a lower loss of energy due to radiation, since the short–circuit can be definitely established with a large metal plate, effectively stopping all field propagation.
19.	**What are the two independent measurements that must be made to find the location and length of the stub?** BTL 2 The standing wave ratio S and the position of a voltage minimum are the independent measurements that must be made to find the location and length of the stub.
20.	**What is the use of a circle diagram?** BTL 2 The circle diagram may be used to find the input impendence of a line m of any chosen length.
21.	**How is the circle diagram useful to find the input impendence of short and open circuited lines?** BTL 4 An open circuited line has s = a, the correspondent circle appearing as the vertical axis. The input impendence is the pure reactance with the value for various electrical lengths determined by the intersections of the corresponding β_s circles with the vertical axis. A short circuited line may be solved by determining its admittance. The S circle is again the vertical axis, and susceptance values may be read off at appropriate intersection of the β_s circles with the vertical axis.

22.	**What is double stub matching?** BTL 1 Another possible method of impedance matching is to use two stubs in which the locations of the stub are arbitrary, the two stub lengths furnishing the required adjustments. The spacing is frequently made $\lambda/4$. This is called double stub matching.
23.	**Give reason for an open line not frequently employed for impedance matching.** BTL 4 An open line is rarely used for impedance matching because of radiation losses from the open end, and capacitance effects and the difficulty of a smooth adjustment of length.
24.	**State the use of half wave line.** BTL 1 a) The expression for the input impendence of the line is given by Zs = Zr b) Thus the line repeats is terminating impedance .Hence it is operated as one to one transformer .Its application is to connect load to a source where they cannot be made adjacent.
25.	**Why Double stub matching is preferred over single stub matching?** BTL 4 Double stub matching is preferred over single stub due to following disadvantages of single stub. a) Single stub matching is useful for a fixed frequency. So as frequency changes the location of single stub will have to be changed. b) The single stub matching system is based on the measurement of voltage minimum .Hence for coaxial line it is very difficult to get such voltage minimum, without using slotted line section.
26.	**Give the names of circles of Smith chart.** BTL 1 The names of circles on Smith chart are a) Constant-R circles b) Constant X circles
	PART * B
1	**Explain the operation of quarter wave transformer and mention its important applications. (13 M) (Nov/Dec 2016, May/June 2016, April/May 2017, Nov/Dec 2018, April/May 2019)** BTL 2 **Answer: Page: 305 -306 - John D. Ryder** **Input impedance:** Dissipationless line (2 M) a) $Zs = R_0 \left[\dfrac{\dfrac{Z_R}{\tan\left(\frac{2\pi s}{\lambda}\right)} + jR_0}{\dfrac{R_0}{\tan\left(\frac{2\pi s}{\lambda}\right)} + jZ_R} \right]$ b) Quarter wave, $s = \frac{\lambda}{4}$ (2 M)

	c) Zs= $\frac{R_0^2}{Z_R}$ (2 M) **Applications:** **a) Quarter-Wave Transformer** (2 M) b) $R_0' = \left\|\sqrt{Z_s Z_R}\right\|$ c) Quarter wave line- impendence inverter - transform a low impendence in to a high impendence, vice versa. (2 M) d) To couple a transmission line to a resistive load such as an antenna. $R_0' = \sqrt{R_A.R_0}$ (1 M) e) Quarter wavelines as insulators (1 M) f) Load - not pure in resistance (1 M) g) For step down in impedance, $R_0' = R_0\sqrt{\frac{1}{s}}$ This technique - patch antennas. Circuits are printed. A 50 Ohm microstrip transmission line - matched - a patch antenna (impedance typically 200 Ohms or more) - via a quarter-wavelength microstrip transmission line - characteristic impedance - to match the load
2.	**Explain the significance of Smith chart and its application in a transmission lines.(13M) (Nov/Dec 2016, April/May 2018)** BTL 2 **Answer: Page: 327 -331- John D.Ryder** Smith Chart - tool - impedance of a transmission line, antenna system - to increase understanding of transmission lines - helpful for impedance matching - To display a real antenna's impedance - on a Vector Network Analyzer (VNA). (6 M) **Applications of smith Chart:** a) Plotting an impedance (1 M) b) Measurement of VSWR (1 M) c) Measurement of reflection coefficient (magnitude and phase) (1 M) d) Measurement of input impedance of the line (1 M) e) To find the input impendence, input admittance of the line. (1 M) f) Lossy lines, the locus of points on a line - follows a spiral path towards chart center - due to attenuation. (1 M) g) Single stub matching. (1 M)

3.	**Explain the technique of Double stub matching with neat diagram. (13 M) (Nov/Dec 2015)** BTL 2 **Answer: Page: 333-337 - John D. Ryder** **Difficulties of single stub matching** (3 M) a) Single stub impedance matching - stub located - definite point on line. Stub at an undesirable place - mechanical view point. b) A coaxial line - not possible to determine location - voltage minimum without a slotted line section – difficulty in stub placement at exact point. c) Single stub - two adjustments - location, length of the stub. Double stub impedance matching $Y_s = \frac{y_R(1+\tan^2\beta s)}{1+y_R^2\tan^2\beta s} + \frac{(1-y_R)^2\tan\beta s}{1+y_R^2\tan^2\beta s}$ (4 M) Quarter wavelength spacing between 2 stubs (3 M) Three-eighth wavelength spacing between 2 stubs. (3 M)
4.	**Discuss in detail about the impedance matching by stubs. (13 M)** BTL 2 **Answer: Page: 312-317 - John D. Ryder** **Single stub impedance matching:** a) Load – matches characteristic impedance - power - transmitted from generator to load for radio - frequency power transmission. (2 M) b) Lines – matches reflections from mismatched load, junctions – echoes distort information - carrying signal. (3 M) c) Short-circuited (instead of open-circuited) stubs - for impedance matching on transmission lines. d) Single-stub method for impedance matching: Arbitrary load impedance - matched to a transmission line - a single short-circuited stub in parallel with line - suitable location. (1 M) **Difficulties of single stub matching** (2 M) a) Single stub impedance matching - located at definite point on the line - mechanical issues in an undesirable place. b) For a coaxial line- not possible to determine location - voltage minimum without a slotted line section, stub - exact point - difficult. c) Single stub - two adjustments - location, length of stub. a) Double stub impedance matching (3 M) $Y_s = \frac{y_R(1+\tan^2\beta s)}{1+y_R^2\tan^2\beta s} + \frac{(1-y_R)^2\tan\beta s}{1+y_R^2\tan^2\beta s}$ b) c) Quarter wavelength spacing between 2 stubs (1 M) d) Three-eighth wavelength spacing between 2 stubs (1 M)
5.	**Discuss the principle of single stub matching with neat diagram. (13 M) (Nov/Dec 2018)** BTL 2

Answer: Page: 312-317 - John D. Ryder

a) Location of single stub for impedance matching (1 M)

b) Input admittance, $Y_s = \frac{1}{R_0}\left(\frac{1-|K|\angle(\phi-2\beta s)}{1+|K|\angle(\phi-2\beta s)}\right)$

(3 M)

$$s_1 = \frac{\phi + \pi - \cos^{-1}|K|}{2\beta}$$

$$s_2 = \frac{\phi + \pi}{2\beta}$$

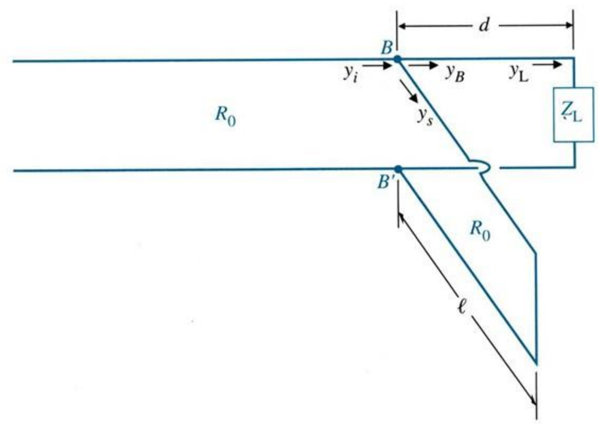
(3 M)

$$d = \frac{\cos^{-1}|K|}{2\beta}$$

$$L = \frac{\lambda}{2\pi}\tan^{-1}\frac{\sqrt{s}}{s-1}$$

(3 M)

$$L^1 = \frac{\lambda}{2} - L$$



Impedance matching by single-stub method.

Admittance conditions on a line indicating proper location of stub for $|K| = 0.5$ (3 M)

6. **Discuss in detail the construction of Smith chart and derive the relevant equations. (13 M) (Nov/Dec 2018)** BTL 5

Answer: Page: 324-327 - John D. Ryder

Construction of smith chart (2 M)

Constant resistance circle (2 M)

Radius of circles, $r = \dfrac{1}{1 + r_i}$

Centre= $\left[\dfrac{r_i}{1 + r_i}, 0\right]$

Family of constant r-circles

Family of constant X-circles

Basic of Smith circle diagram

Constant reactance circle (3 M)

a) Radius of circles, $r = \dfrac{1}{x_{ii}}$

b) Centre= $\left[1, \dfrac{1}{x_i}\right]$

c) Constant S-circles

d) **Properties of Smith chart**: Refer Part-B 7th question. (3 M)

e) **Applications of Smith chart**: Refer Part-B 2nd question. (3 M)

Smith Chart - complex reflection coefficient, in polar form, arbitrary impedance. In plotting - complex reflection coefficient, along real and imaginary axis. Center - Smith Chart - point - reflection coefficient - zero. No power - reflected - load impedance.

Outer ring - Smith Chart - magnitude equal to 1. Along this curve, all of the power - reflected by the load impedance.

7. **Explain the properties of Smith chart.** **(13 M)** BTL 2

Answer: Page: 326-327 - John D. Ryder

a) Impedance and admittance (1 M)

b) r_i circle and x_i circle (1 M)

c) $|K|$ is unity (1 M)

d) Impedance is real at any point on S circle (1 M)

e) Horizontal line represents real axis or r_i axis, for impedance, g_i axis for admittance. Extreme left-Short circuit condition, extreme right –Open circuit condition. (2 M)

f) Outer rim - scaled in degrees or wavelength (1 M)

g) Clockwise – Travel towards generator from load, Anti-clockwise – Travel towards load from generator. (2 M)

h) 3 scales (1 M)

i) Extreme left of gi axis – zero conductance or open circuit, extreme right of gi axis-infinite conductance or short circuit (2 M)

	j) Volt maxima= $Z_{in(max)}$, voltage minima $Z_{in(min)}$. (1 M)
8.	**Discuss in detail about the single stub matching using Smith chart. (13 M)** BTL 2 **Answer: Page:331-333 - John D Ryder** a) Locate normalized impedance point (2 M) b) Draw constant S-circle – SWR value (2 M) c) Locate a normalized load admittance (2 M) d) Line conductance - unity. (1 M) e) Measure distance of stub location. (2 M) f) Susceptance of line at point of stub connection. (2 M) g) Input admittance of short circuited stub line. (1 M) h) Length of short circuited stub. (1 M)
9.	**Discuss in detail about the double stub matching using Smith chart. (13 M)** BTL 2 **Answer: Page: 333-337 - John D. Ryder** **Double stub matching:** (6 M) Double stub matching - preferred over single stub **Disadvantages of single stub**. a) Single stub matching - for a fixed frequency. Changes in frequency - location of single stub changes. b) Single stub matching system - measurement of voltage minimum. Coaxial line - very difficult - voltage minimum, without using slotted line section. **Steps** (7 M) a) Calculate Normalized load impedance b) Locate normalized admittance c) Circle-A - constant R circle, circle B: circle A displaced by $\lambda/4$. d) Quarter wave line transforms admittance e) Stub length should cancel imaginary part of admittance. **f)** Locate length of stub.
10.	**Explain in detail about the Smith circle diagram and derive the necessary equations with neat diagrams.(13 M)** BTL 2 **Answer: Page: 317-327 - John D. Ryder** a) Reactance curve (3 M) b) Resistance curve (3 M) c) Open circuit (3 M)

	d) Short circuit (4 M)
	PART * C
1.	**Determine length and location of a single short circuited stub to produce an impedance match on a transmission line with characteristic impedance of 600 ohm and terminated in 1800 ohm. (15 M) (Nov/Dec 2016)** BTL 5 **Answer: Page: 331 - John D. Ryder and lecture notes Page: 147** a) $K = \frac{Z_R - Z_0}{Z_R + Z_0} = 0.5\angle 0^0$ (2 M) b) **Case 1: s_1=** $\frac{\phi + \pi - \cos^{-1}(\lvert K \rvert)}{2\beta} = 0.1666\lambda$ (2 M) **L=** $\frac{\lambda}{2\pi}\tan^{-1}\left[\frac{\sqrt{1-\lvert K \rvert^2}}{2\lvert K \rvert}\right] = 0.1135\lambda$ (2 M) c) **Case 2: s_1=** $\frac{\phi + \pi - \cos^{-1}(\lvert K \rvert)}{4\pi} = 0.333\lambda$ (2 M) **L=** $\frac{\lambda}{2\pi}\tan^{-1}\left[\frac{\sqrt{1-\lvert K \rvert^2}}{2\lvert K \rvert}\right] = 0.386\lambda$ (2 M) **Smith chart:** (5 M)
2.	**Design a quarter wave transformer to match a load of 200 ohm to a source resistance of 500 ohm. Operating frequency is 200 Mhz. (15 M) (May/June 2016, April/May 2017, April/May 2018)** BTL 6 **Answer: Page: 305 - John D Ryder and lecture notes Page: 140** a) $R_0 = \sqrt{Z_S Z_R} = 316.22\Omega$ (5 M) b) $\lambda = \frac{c}{f} = 1.5m$ (5 M)

	c) $s = \frac{\lambda}{4} = 0.3755\text{m}$ (5 M)
3.	**A load (50-j100) ohms is connected across a 50 ohms line. Design a short circuited stub to provide matching between the two at a signal frequency of 30Mhz using smith chart. (15 M) (May/June 2016, April/May 2018)** BTL 6 **Answer: Page: 331 - John D Ryder and lecture notes Page: 137** a) Normalized load admittance $\frac{Y_R}{G_0} = \frac{Z_0}{Z_R} = (0.2 + j0.4)$ (3 M) b) Normalized load impedance $Z_R' = \frac{Z_R}{Z_0} = (1 - j2)\Omega$ (3 M) c) Distance of stub from load, S=0.128λ (from smith chart) (3 M) d) Wavelength= $\lambda = \frac{c}{f} = 10\text{m}$, (2 M) e) Distance of stub from load=1.28 m (2 M) f) Length of stub, L=0.76 m. (2 M)
4.	**A 75 ohm lossless transmission line is to be matched with a 100-j80 ohm load using single stub. Calculate the stub length and its distance from the load corresponding to the frequency of 30 Mhz using Smith chart. (15 M) (Nov/Dec 2015, April/May 2019)** BTL 5 **Answer: Page: 331 - John D Ryder and lecture notes Page:** a) Normalized Load impedance= $Z_L^1 = \frac{Z_L}{Z_0} = 1.33 - j1.06\Omega$ (3 M) b) Normalized Load admittance= $Y_L^1 = \frac{1}{Z_L^1} = 0.459 + j0.366\text{mho}$ (3 M) c) $\lambda = \frac{c}{f} = 10\text{m}$ (2 M) d) S=0.9m from Smith chart (4 M) e) L=1.32m from Smith chart (3 M)

5.	**A 300 ohm transmission line is connected to a load impedance of (450-j600)ohm at 10 Mhz. Find the position and length of a short circuited stub required to match the line using Smith chart. (15 M) (April/May 2017, Nov/Dec 2015)** BTL 5 **Answer: Page:331 - John D Ryder and lecture notes Page: 141** a) Normalized Load impedance= $Z_L^1 = \frac{Z_L}{Z_0} = 1.5 - j2\Omega$ (3 M) b) Normalized Load admittance= $Y_L^1 = \frac{1}{Z_L^1} = 0.3 + j0.35\text{mho}$ (3 M) c) $\lambda = \frac{c}{f} = 30\text{m}$ (3 M) d) S=3.75m from Smith chart (3 M) e) L=2.64m from Smith chart (3 M)

UNIT IV –WAVEGUIDES

General Wave behaviors along uniform Guiding structures, Transverse Electromagnetic waves, Transverse Magnetic waves, Transverse Electric waves, TM and TE waves between parallel plates. Field equation in Rectangular Waveguide, TM and TE waves in Rectangular wave guides, Bessel function, TM and TE waves in Circular wave guides.

PART * A

Q.No.	Questions
1.	**Define dominant mode. What is the dominant mode for the rectangular waveguide? (May/June 2016, April/May 2018)** BTL 1 a) The wave which has the lowest cut-off frequency is called dominant mode. b) The lowest mode for TE wave is TE10 (m=1 , n=0) whereas the lowest mode for TM wave is TM11(m=1 , n=1). The TE10 wave have the lowest cut off frequency compared to the TM11 mode. Hence the TE10 (m=1 , n=0) is the dominant mode of a rectangular waveguide. Because the TE10 mode has the lowest attenuation of all modes in a rectangular waveguide and its electric field is definitely polarized in one direction everywhere. c) $\lambda_{cmn} = \frac{2ab}{\sqrt{m^2b^2 + n^2a^2}}$ d) $\lambda_{cmn} = 2a[\max imum]$
2.	**Define the terms phase velocity and group velocity. (April/May 2015)** BTL 1 **Phase Velocity** is defined as he rate at which the wave changes its phase with respect to the guide wavelength λ_g. The phase velocity is given by $V_p = \frac{\lambda_g}{t} = \frac{c}{\sqrt{1-(\frac{f_c}{f})^2}}$ **Group velocity** of the wave is defined as the rate at which the wave actually propagates. It is denoted by v_g. $\mathbf{V_g} = \frac{d\omega}{\beta} = c\sqrt{1-(\frac{\lambda_0}{\lambda_c})^2}$
3.	**What are the characteristics of TEM wave? (April/May 2015, April/May 2017)** BTL 1 a) Fields are entirely transverse b) Along the direction normal to the direction of propagation, the amplitude of field components are constant, c) The velocity of propagation is given by $v = \frac{1}{\sqrt{\mu_0\varepsilon_0}} = c.$ d) Thus, velocity of TEM wave is independent of frequency unlike TE and TM waves.

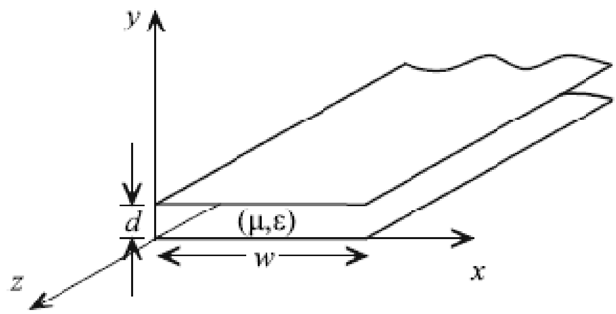
	e) The cut-off frequency of wave is zero, indicating all frequency down to zero can propagate along the guide. f) The ratio of amplitudes of E and H between parallel planes is defined as intrinsic impedance, $\eta = \left\|\frac{E_x}{H_y}\right\| = \sqrt{\frac{\mu}{\varepsilon}}$
4.	**Why TEM mode is not possible in a rectangular waveguide? (Nov/Dec 2014, April/May 2019)** BTL 4 a) If TEM wave is to exist in a waveguide the field lines of B and H would form closed loops in a transverse plane. b) But the ampere's circuital law requires that the line integral of magnetic field around any closed loop in the transverse plane must equal the sum of longitudinal conduction and displacement currents through the loop. c) TEM wave does not have any longitudinal current d) Thus there can be no closed loops of H-field in any transverse plane. e) Since TEM wave do not have axial component of either E or H ,it cannot propagate within a single conductor waveguide
5.	**What are the advantages and mention the applications of circular waveguide? (May/June 2016)** BTL 1 a) A circular waveguide is a cylindrical hollow metallic pipe with uniform cross section of finite radius 'a'. It is also called as cylindrical waveguide. Applications a) Circular waveguides are used as attenuators and phase-shifters. **b)** It is also used in long low loss communication links.
6.	**Mention the different types of guide termination. (May/June 2014)** BTL 1 a) A horn antenna connected to the waveguide. b) Dissipative loads or non-reflecting termination. c) Matched terminations either with the single taper or double taper.
7.	**What are the disadvantages of circular waveguides? (Nov/Dec 2009)** BTL 1 a) Frequency distortion between the lowest frequency on dominant mode and the next mode is smaller than in a rectangular waveguide with $\frac{b}{a} = 0.5$ b) Circular symmetry of the waveguide may reflect on the possibility of the wave not maintaining its polarization throughout the length of guide. c) For the same operating frequency, circular waveguide is bigger than a rectangular waveguide.
8.	**Why is circular or rectangular form used as waveguide?** BTL 4 Waveguides usually take the form of rectangular or circular cylinders because of its simpler forms in use and less expensive to manufacture.
9.	**What is an evanescent mode?** BTL 1 When the operating frequency is lower than the cut-off frequency, the propagation constant becomes real The wave cannot be propagated. This non- propagating mode is

	known as evanescent mode.
10.	**What is the dominant mode for the TE waves in the rectangular waveguide? (April/May 2018)** BTL 1 The lowest mode for TE wave is TE10 (m=1 , n=0)
11.	**What is the dominant mode for the TM waves in the rectangular waveguide?** BTL 1 The lowest mode for TM wave is TM11(m=1 , n=1)
12.	**Which are the non-zero field components for the for the TE10 mode in a rectangular waveguide?** BTL 1 Hx, Hz and Ey
13.	**Which are the non-zero field components for the for the TM11 mode in a rectangular waveguide?** BTL 1 Hx, Hy, Ey and Ez.
14.	**Define characteristic impedance in a waveguide.** BTL 1 The characteristic impedance Zo can be defined in terms of the voltage-current ratio or in terms of power transmitted for a given voltage or a given current. Zo (V,I) = V/I
15.	**Why TM01 and TM10 modes in a rectangular waveguide do not exist? (April/May 2019)** BTL 2 For TM modes in rectangular waveguides, neither m nor n can be zero because all the field equations vanish (i.e., Hx, Hy, Ey and Ez=0). If m=0, n=1 or m=1, n=0 no fields are present. Hence TM01 and TM10 modes in a rectangular waveguide do not exist.
16.	**What are degenerate modes in a rectangular waveguide? (Nov/Dec 2018)** BTL 1 Some of the higher order modes, having the same cut off frequency, are called degenerate modes. In a rectangular waveguide, TEmn and TMmn modes (both m=0 and n=0) are always degenerate.
17.	**What is a circular waveguide?** BTL 1 A circular waveguide is a hollow metallic tube with circular cross section for propagating the electromagnetic waves by continuous reflections from the surfaces or walls of the guide
18.	**Why circular waveguides are not preferred over rectangular waveguides?** BTL 4 **The circular waveguides are avoided because of the following reasons:** a) The frequency difference between the lowest frequency on the dominant mode and the next mode is smaller than in a rectangular waveguide, with b/a= 0.5 b) The circular symmetry of the waveguide may reflect on the possibility of the wave not maintaining its polarization throughout the length of the guide. c) For the same operating frequency, circular waveguide is bigger in size than a rectangular waveguide.
19.	**Which mode in a circular waveguide has attenuation effect decreasing with increase in frequency?** BTL 3 TE01
20.	**What are the possible modes for TM waves in a circular waveguide?** BTL 1 The possible TM modes in a circular waveguide are : TM01 , TM02 , TM11, TM12
21.	**What are the root values for the TM modes?** BTL 1 The root values for the TM modes are: (ha)01 = 2.405 for TM01

	(ha)02 = 5.53 for TM02 (ha)11 = 3.85 for TM11 (ha)12 = 7.02 for TM12
22.	**Define dominant mode for a circular waveguide.** BTL 1 The dominant mode for a circular waveguide is defined as the lowest order mode having the lowest root value.
23.	**What are the possible modes for TE waves in a circular waveguide?** BTL 1 The possible TE modes in a circular waveguide are : TE01 , TE02 , TE11, TE12
24.	**What are the root values for the TE modes?** BTL 1 The root values for the TE modes are: (ha)01 = 3.85 for TE01 (ha)02 = 7.02 for TE02 (ha)11 = 1.841 for TE11 (ha)12 = 5.53 for TE12
25.	**What is the dominant mode for TE waves in a circular waveguide**? BTL 1 The dominant mode for TE waves in a circular waveguide is the TE11 because it has the lowest root value of 1.841
26.	**What is the dominant mode for TM waves in a circular waveguide?** BTL 1 The dominant mode for TM waves in a circular waveguide is the TM01 because it has the lowest root value of 2.405.
27.	**What is the dominant mode in a circular waveguide?** BTL 1 The dominant mode for TM waves in a circular waveguide is the TM01 because it has the root value of 2.405. The dominant mode for TE waves in a circular waveguide is the TE11 because it has the root value of 1.841. Since the root value of TE11 is lower than TM01, TE11 is the dominant or the lowest order mode for a circular waveguide.
28.	**Mention the dominant modes in rectangular and circular waveguides**. BTL 1 For a rectangular waveguide, the dominant mode is TE01 For a circular waveguide, the dominant mode is TE11
29.	**Why is TM01 mode preferred to the TE01 mode in a circular waveguide?** BTL 4 TM01 mode is preferred to the TE01 mode in a circular waveguide, since it requires a smaller diameter for the same cut off wavelength.
	PART * B
1.	**Derive an expression for the transmission of TE waves between parallel perfectly conducting planes for the field components. (13 M) (Nov/Dec 2016, April/May 2019)** BTL 5 **Answer: Page: 479-480 - John D. Ryder** a) The transverse fields of TE modes - found by simplifying - general guided wave equations. (3 M) b) Ez = 0. The resulting transverse fields for TE modes c) $Ex=E_z=H_y=0$ (3 M) d) $E_y = C_1 \mathrm{Sin}\left(\frac{m\pi}{a}\right) x e^{-j\beta Z}$ (3 M)

	e) $H_x = -\frac{\beta}{\omega\mu} C_1 Sin\left(\frac{m\pi}{a}\right) xe^{-j\beta Z}$ (3 M) f) $H_Z = -\frac{1}{j\omega\mu}\left(\frac{m\pi}{a}\right) C_1 Cos\left(\frac{m\pi}{a}\right) xe^{-j\beta Z}$ g) Electric and Magnetic fields for TE_{10} wave. (1 M)
2.	**Derive the field component of a transverse Electric wave in Rectangular waveguides. (13 M) (April/May 2017, Nov/Dec 2017, May/June 2016, Nov/Dec 2018)** BTL 5 **Answer: Page: 504-510 - John D. Ryder** $E_x = \frac{j\omega\mu}{h^2} ACCosBxSinAye^{-j\beta Z}$ (3 M) $E_y = -\frac{j\omega\mu}{h^2} CASinBxCosAye^{-j\beta Z}$ (3 M) $E_Z=0$ $H_x = \frac{j\beta}{h^2} CBSinBxCosAye^{-j\beta Z}$ (3 M) $H_y = \frac{j\beta}{h^2} CACosBxSinAye^{-j\beta Z}$ (2 M) $H_z = CCosBxCosAye^{-j\beta Z}$ (2 M)
3.	**Using Bessel function, derive the TE wave components in circular waveguides. (13 M) (Nov/Dec 2015, Nov/Dec 2018)** BTL 5 **Answer: Page: 510-528 - John D.Ryder** Bessel's differential equation Bessel function & TM and TE waves in Circular wave guides Circular waveguide - hollow metallic tube with circular cross section - propagates electromagnetic waves - continuous reflections from surfaces or walls of guide. (1 M) Circular waveguides - avoided because of following reasons: (1 M) a) Frequency difference between - lowest frequency on dominant mode, next mode - smaller than in a rectangular waveguide- b/a= 0.5 b) Circular symmetry - waveguide reflects wave not maintaining polarization throughout guide length. c) Circular waveguide - bigger than rectangular waveguide. Circular waveguide's equations: (4 M)

	TE Waves in Circular waveguide a) $E_\rho = -\frac{j\omega\mu}{h^2\rho} nC_n J_n(h\rho)\text{Sin}(n\phi)e^{-j\beta Z}$ (1 M) b) $E_\phi = \frac{j\omega\mu}{h} C_n J_n(h\rho)\text{Cos}(n\phi)e^{-j\beta Z}$ (1 M) c) $E_Z=0$ (2 M) d) $H_\rho = -\frac{j\beta}{h} C_n J_n^1(h\rho)\text{Cos}(n\phi)e^{-j\beta Z}$ (1 M) e) $H_\phi = \frac{j\beta}{\rho h^2} nC_n J_n(h\rho)\text{Sin}(n\phi)e^{-j\beta Z}$ (1 M) f) $H_Z = J_n(\rho h)C_n\text{Cos}(n\phi)e^{-j\beta Z}$ (1 M)
4.	**Discuss the characteristics of TE an TM waves and also derive the cut-off frequency and phase velocity from the propagation constant. (13 M) (May/June 2015, April/May 2018)** BTL 5 **Answer: Page: 473-474 - John D.Ryder** a) $\gamma = \sqrt{\left(\frac{m\pi}{a}\right)^2 - \omega^2\mu\varepsilon}$ (4 M) b) $f_c = \frac{m}{2a\sqrt{\mu\varepsilon}}$ (4 M) c) $v_p = \frac{v}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$ (5 M)
5.	**Derive the expression of wave impedance of TE, TM and TEM wave between a pair of perfectly conducting planes. (13 M) (May/June 2015, April/May 2018)** BTL 5 **Answer: Page: 473-474 - John D Ryder** TM and TE wave between parallel plates Parallel Plate Waveguide



(2 M)

Parallel plate waveguide - two conducting plates - width *w* separated by a distance. Waveguide - TEM, TE, TM modes.

Assumptions - various modes on parallel plate waveguide (3 M)

a) Waveguide - infinite in length (no reflections).

b) Waveguide conductors - PEC's, dielectric lossless.

c) Plate width - much larger than plate separation ($w >> d$), variation of fields with respect to x - neglected.

Parallel Plate Waveguide TEM Mode (2 M)

Transverse fields - TEM mode on general wave guiding structure - equal to corresponding static fields of structure. Electrostatic field of parallel plate waveguide ($w >> d$) - equivalent to that found in ideal parallel plate capacitor.

a) **Transverse electric (TE) modes** - electric field - transverse to direction of propagation (no longitudinal electric field component, magnetic field has both transverse, longitudinal components [$Ez = 0$, Hz . 0]. (3 M)

b) **Transverse magnetic (TM) modes** - magnetic field - transverse to direction of propagation (no longitudinal magnetic field component) electric field has both transverse, longitudinal components [$Hz = 0$, Ez . 0]. (3 M)

6. **Derive field component of the wave propagation between parallel plates**. **(13 M)** **(May/June 2015)** BTL 5

Answer: Page :469-474 - John D. Ryder

a) Derivation of E-field and H-field components. (1 M)

b) $$Ex = \frac{\beta_m}{2\omega\varepsilon_1} B_1 e^{-j\beta m Z}\left[\mathrm{Cos}\left(\omega t - \frac{m\pi x}{a}\right) - \mathrm{Cos}\left(\omega t + \frac{m\pi x}{a}\right)\right]$$ (4 M)

c) $$E_Z = \frac{-m\pi}{2a\omega\varepsilon_1} B_1 e^{-j\beta m Z}\left[\mathrm{Cos}\left(\omega t - \frac{m\pi x}{a}\right) + \mathrm{Cos}\left(\omega t + \frac{m\pi x}{a}\right)\right]$$ (4 M)

	d) $H_y = \frac{1}{2}B_1 e^{-j\beta m Z}\left[\cos\left(\omega t - \frac{m\pi x}{a}\right) - \cos\left(\omega t + \frac{m\pi x}{a}\right)\right]$ (4 M)
7.	**Explain about excitation modes in rectangular waveguides. (13 M) (May/June 2015)** BTL 2 **Answer: Page: 498 - John D. Ryder** a) TE_{10}, TE_{20}, TM_{11} and TM_{21} modes (3 M) b) Rods coincide – excite at position of maximum electric field intensity. (3 M) c) Current loops – excites - phase of loop made normal to magnetic field- loop located at a point of maximum field intensity. (4 M) d) Proper guide dimensions excite only desired wave above cut-off frequency. (3 M)
8.	**Discuss the transmission of TM waves between parallel perfectly conducting planes with necessary expressions for the field components. Discuss briefly the manner how the wave travels and phase and group velocities between the two parallel planes. (13 M) (Nov/Dec 2013)** BTL 5 **Answer: Page: 474-478 - John D. Ryder** a) Transverse magnetic (TM) modes - magnetic field transverse to direction of propagation (no longitudinal magnetic field component) electric field has both transverse and longitudinal components [*Hz* = 0, *Ez*≠0]. (1 M) b) $E_x = -\frac{\gamma}{j\omega\varepsilon} C_4 \cos\left(\frac{m\pi}{a}\right) x e^{-\gamma Z}$ (2 M) c) $E_y=0$ (2 M) d) $E_Z = -\frac{1}{j\omega\varepsilon}\left[\frac{m\pi}{a}\right] C_4 \sin\left(\frac{m\pi}{a}\right) x e^{-\gamma Z}$ (2 M) e) $H_x=0$ (2 M) f) $H_y = C_4 \cos\left(\frac{m\pi}{a}\right) x e^{-\gamma Z}$ (2 M) g) $H_Z=0$ (2 M)
9.	**Discuss briefly the attenuation of TE and TM waves between parallel plane. (13 M) (Nov/Dec 2013)** BTL 5 **Answer: Page: 494-495 - John D. Ryder**

	a) $\alpha_{TE} = \dfrac{2m^2\pi^2\sqrt{\dfrac{\omega\mu}{2\sigma}}}{\beta\omega\mu a^3}$ (6 M) b) $\alpha_{TM} = \dfrac{2\omega\varepsilon R_s}{\beta a}$ Nepers/m (7 M)
10.	**Give a brief note on the transmission of TEM waves between parallel plane. (13 M) (Nov/Dec 2013)** BTL 5 **Answer: Page : 481-494** - John D.Ryder a) Both electrical, magnetic component are transverse - Transverse Electromagnetic wave or principal waves. (1 M) b) $\gamma = j\omega\sqrt{\mu\varepsilon}$; α=0; $\beta = \omega\sqrt{\mu\varepsilon}$ (2 M) c) $\lambda_g = \dfrac{2\pi}{\omega\sqrt{\mu_0\varepsilon_0}}$ (2 M) d) $v = \dfrac{1}{\sqrt{\mu_0\varepsilon_0}}$ (2 M) e) $f_c = \dfrac{m}{2a\sqrt{\mu_0\varepsilon_0}}$ (2 M) f) $\eta = \sqrt{\dfrac{\mu_0}{\varepsilon_0}}$ (1 M) g) $E_x = \eta H_y$ (1 M) h) $P = \dfrac{1}{2}\eta H_y^2$ watts/meterofwidth (2 M)
11.	**Describe the propagation of TM waves in a rectangular waveguide with necessary expressions for the field component. (13 M) (Nov/Dec 2013, Nov/Dec 2018)** BTL 2 **Answer: Page: 500-504 - John D.Ryder** a) $E_x = -\dfrac{j\beta}{h^2} BCCosBxSinAye^{-j\beta Z}$ (2 M) b) $E_y = -\dfrac{j\beta}{h^2} ACSinBxCosAye^{-j\beta Z}$ (2 M) c) $E_Z = C\sin BxSinye^{-j\beta Z}$ (2 M)

	d) $H_x = \frac{j\omega\varepsilon}{h^2} ACSinBxCosAye^{-j\beta Z}$ (2 M) e) $H_y = -\frac{j\omega\varepsilon}{h^2} BCCosBxSinAye^{-j\beta Z}$ (2 M) f) $H_Z=0$ (3 M)
12.	**Explain briefly the propagation of TM waves in a circular waveguide with necessary expressions for the field component. (13 M) (Nov/Dec 2013, Nov/Dec 2018)** BTL 2 **Answer: Page :510-528 - John D. Ryder** a) $E_\rho = -\frac{j\beta}{h} J_n(\rho h) A_n Cosn\phi e^{-j\beta Z}$ (2 M) b) $E_\phi = \frac{j\beta}{\rho h^2} J_n(\rho h) A_n Sinn\phi e^{-j\beta Z}$ (2 M) c) $E_Z = J_n(\rho h) A_n Cosn\phi e^{-j\beta Z}$ (2 M) d) $H_\rho = -\frac{j\omega\varepsilon}{\rho h^2} nA_n J_n(\rho h) Sinn\phi e^{-j\beta Z}$ (2 M) e) $H_\phi = -\frac{j\omega\varepsilon}{h} nA_n J_n^1(\rho h) Cosn\phi e^{-j\beta Z}$ (2 M) f) $H_Z=0$ (3 M)
	PART * C
1.	**A TE_{11} wave is propagating through a circular waveguide. The diameter of the guide is 10 cm and the guide is air-filled. Given X_{11}=1.842. (15 M) (Nov/Dec 2016)** BTL 5 **Find the cut-off frequency.** **Find the wavelength λ_g in the guide for a frequency of 3 GHz** **Determine the wave impedance in the guide.** **Answer: Page: 510 - John D Ryder and lecture notes Page: 159** a) $f_c = \frac{\chi_{11} C}{2\pi a} = 8.7949x10^8 Hz$ (5 M) $\beta = \sqrt{\omega^2\mu\varepsilon - h^2} = 60.11 rad/m$ b) $\lambda_g = \frac{2\pi}{\beta} = 0.1045m$ (5 M) c) $Z_{TE} = \frac{\omega\mu}{\beta} = 394.06\Omega$ (5 M)
2.	**For a frequency of 10 Ghz and plane separation of 5cm in air, find the cut off frequency, phase velocity and group velocity of the wave. (15 M) (May/June 2016, April/May**

	2017) BTL 5 **Answer: Page: 469 - John D Ryder and lecture notes Page: 157** a) $\lambda_c = \frac{2a}{m} = 10\text{cm}$ (5 M) b) $f_c = \frac{m}{2a\sqrt{\mu\varepsilon}} = 3\text{GHz}$ (5 M) c) $v_p = \frac{v}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}} = 3.1448\text{x}10^8\,\text{m/s}$ (3 M) d) $v_g = v\sqrt{1-\left(\frac{f_c}{f}\right)^2} = 2.861\text{x}10^8\,\text{m/s}$ (2 M)
3.	**A rectangular air-filled copper waveguide with dimension 0.9inchx0.4inch cross section and 12 inch length is operated at 9.2Ghz with a dominant mode. Find cut-off frequency, guide wavelength, phase velocity, characteristic impedance and the loss. (15 M) (Nov/Dec 2015, Nov/Dec 2018)** BTL 5 **Answer: Page: 498 - John D Ryder and lecture notes Page: 158** a) $f_c = \frac{c}{2a} = 6.579\text{GHz}$ (3 M) b) $\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}} = 4.664\text{cm}$ (3 M) c) $v_p = \frac{c}{\sqrt{1-\left(\frac{f_c}{f}\right)}} = 4.29\text{x}10^8\,\text{m/s}$ (3 M) d) $Z_0 = \frac{377}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}} = 539.3\Omega$ (3 M) e) α=0.036dB (3 M)

UNIT V – RF SYSTEM DESIGN CONCEPT	
Active RF components: Semiconductor basics in RF, bipolar junction transistors, RF field effect transistors, High electron mobility transistors Basic concepts of RF design, Mixers, Low noise amplifiers, voltage control oscillators, Power amplifiers, transducer power gain and stability considerations.	
PART * A	
Q.No.	**Questions**
1.	**Write the function of matching networks? [Nov/dec-15, Nov/dec-11] BTL1** Matching networks can help stabilize the amplifier by keeping the source and load impedances in the appropriate range. Impedance matching (or tuning) is an important issue for - Maximum power is delivered when load is matched to line (assuming the generator is matched) - Power loss is minimized. S/N- ratio of receiver components is increased. - Amplitude and phase errors are reduced.
2.	**What is function of input and output matching networks? BTL1** Input and output matching networks are needed to reduce undesired reflections and improve the power flow capabilities.
3.	**What are the parameters used to evaluate the performance of an amplifier? [Nov/dec-15] BTL1** Key parameters of amplifier, to evaluate the performance are i. Gain and gain flatness(in dB) ii. Operating frequency and bandwidth (in Hz) iii. Output power (in dB) iv. Power supply requirements (in V and A) v. Input and output reflection coefficients (VSWR) vi. Noise figure (in dB)
4.	**Define transducer power gain.[Nov/dec-13, April/May 2017] BTL1** Transducer power gain is nothing but the gain of the amplifier when placed between source and load. G_T= Power delivered to the load/Available power from the source. GT=PL/Pavg
5.	**Write a short note on feedback of RF circuit. BTL1** (1)If |T|>1, then the magnitude of the return voltage wave increases called positive feedback, which causes instability (oscillator). **(2)If |T|<1, then the return voltage wave is totally avoided (amplifier). It is called as negative feedback.**
6.	**Define power gain of amplifier in terms of S- parameter and reflection coefficient. [Nov/Dec-12, Nov/Dec13] BTL1** **Transducer Power Gain** Transducer Power Gain is nothing but the gain of the amplifier when placed between source and load

$$G_T = \frac{(1-|i|^2)|S21|^2(1-|s|^2)}{|1-s_{in}|^2|1-S22_L|^2}$$

The Operating power gain is defined as the ratio of power delivered to the load to the power supplied to the amplifier.

$$G_T = \frac{(1-|i|^2)|S21|^2}{|1-s_{in}|^2|1-S22_L|^2}$$

7. **What are the considerations in selecting a matching network? [Nov/Dec12] BTL1**

(i) Complexity of the system
(ii) Bandwidth requirement
(iii) Adjustability
(iv) Implementation
(v) Maximum power delivery
(vi) Optimal efficiency.

8. **Define Stability. [May/June-14] BTL1**

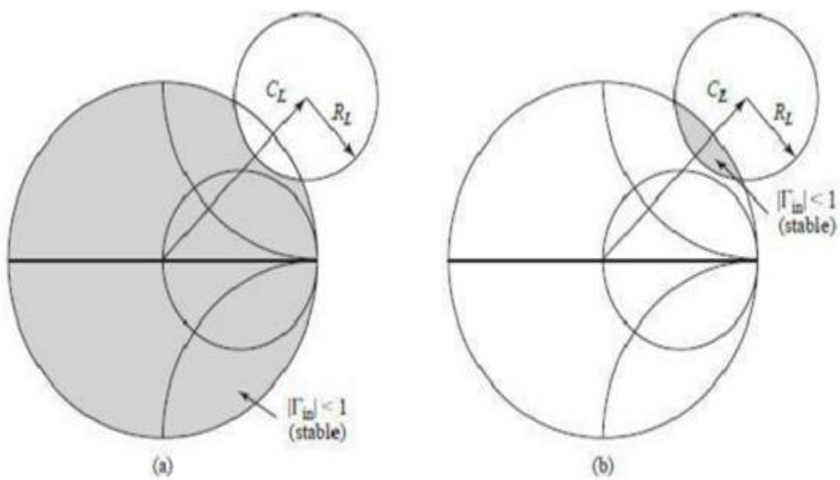
Stability refers to the situation where the amplifier remains stable for any passive source and load at the selected frequency and bias condition.

PART * B

1. **Write mathematical analysis of amplifier stability. (16)[Nov/Dec2011,April/May 2015, May/June 2016,Nov/Dec 2018] BTL4**

Ans:

1) Conditional stability (6M)
2) Unconditional stability (6M)
3) Stability circles (4M)



PART*C

1. **Microwave amplifier is characterized by its s parameters. Derive equations for power gain, available gain and transducer gain. (16) [Nov/Dec-11, Nov/Dec 12, May/June 2013,May/June 2016,April/May 2015] BTL4**

Ans:

Transducer power gain:

It is nothing but the gain of the amplifier when placed between source and load.

G_T= Power delivered to the load/Available power from the source.

$G_T=P_L/P_{avg}$

Unilateral Power gain:

It is the amplifier power gain, when feedback effect of amplifier is neglected i.e.S12=0.

$$G_{TU} = \frac{|S_{21}|^2 (1-|\Gamma_S|^2)(1-|\Gamma_L|^2)}{(1-\Gamma_S \Gamma_{in})^2 (1-S_{22}\Gamma_L)^2}$$

Available power gain:

The available power gain for load side matching (TL = T*Out) is given as,

G_A= Power available from the network/power available from the source

a) $\mathbf{G_A= P_N/P_A}$

OBJECTIVE TYPE QUESTIONS

UNIT I - TRANSMISSION LINE THEORY

1) What is the phase variation range for reflection coefficient in the transmission lines?

a. 0° to 90°
b. 90° to 150°
c. 0° to 180°
d. 90° to 360°

ANSWER: 0° to 180°

2) For a transmission line with propagation constant γ = 0.650 + j 2.55, what will be the value of phase velocity for 1 kHz frequency?
a. 1.18 x 10^3 km/sec
b. 1.50 x 10^3 km/sec
c. 2.46 x 10^3 km/sec
d. 4.58 x 10^3 km/sec
ANSWER: 2.46 x 10^3 km/sec

3) Which primary constant of transmission line is exhibits its dependency of value on the cross-sectional area of conductors?
a. Resistance (R)
b. Inductance (I)
c. Conductance (G)
d. Capacitance (C)
ANSWER: Resistance (R)

4) Which type of transmission line/s exhibit/s less capacitance in comparison to underground cables?
a. Open-wire
b. Co-axial cables
c. Waveguides
d. All of the above
ANSWER: Open-wire

5) Which among the following is also regarded as Twin-lead transmission line?
a. Open-wire
b. Underground cable
c. Co-axial cable
d. Waveguide
ANSWER: Open-wire

6) Which among the following represents a scalar quantity?
a. Velocity
b. Momentum
c. Force
d. Potential
ANSWER: Potential

7) Which nature of applied voltage results in the flow of conduction current in the displacement current concept?

a. Constant
b. Variable
c. Both a and b
d. None of the above

ANSWER: Variable

8) What is the value of cross product for two similar unit vectors?
a. Zero
b. Infinity
c. Third unit vector
d. Negative vector

ANSWER: Zero

9) **A load impedance, (200 + j0) Ω is to be matched to a 50 Ω lossless transmission line by using a quarter wave line transformer (QWT). The characteristic impedance of the QWT required is ________**

Soln. For Quarter wave line transformer

$Z0\ 2 = Zin.$

$ZL\ Z0\ 2 = 50 \times 200$

$Z_0 = 100\ \Omega$

10) A transmission line of 50 Ω characteristic impedance, is terminated with a 100 Ω resistance. The minimum impedance measured on the line is equal to

(a) 0 Ω (b)25 Ω (c) 50 Ω (d)100 Ω [GATE 1997: 1 Mark]

ANSWER: 25 Ω

11) The magnitudes of the open – circuit and short – circuit input impedances of a transmission line are 100 Ω and 25 Ω respectively. The characteristic impedance of the line is.

(a) 25 Ω (b)50 Ω (c) 75 Ω (d)100 Ω

ANSWER: 50 Ω

12) A transmission line is distortion less if

(a) $RL = 1\ RC$ (b)$RL = GC$ (c) LG = RC (d)$RL = LC$

ANSWER: LG = RC

13) A transmission line has a characteristic impedance of 50Ω and a resistance of 0.1 Ω/m. If the line is distortion less, the attenuation constant (in Np/m) is

(a) 500 (b)5 (c) 0.014 (d)0.002 [GATE 2010: 1 Mark]

ANSWER: **0.002**

14) A transmission line of characteristic impedance 50Ω is terminated by a 50Ω load. When excited by a sinusoidal voltage source at 10 GHz, the phase difference between two points spaced 2 mm apart on the line is found to be π/4 radians. The phase velocity of the wave along the line is

(a) 0.8 × 108 m/s (b)1.2 × 108 m/s (c) 1.6 × 108 m/s (d)3 × 108 m/s

ANSWER: 1.6 × 108 m/s

15)A transmission line whose characteristic impedance is a pure resistance

(a) Must be a lossless line (b)Must be a distortion less line (c) May not be a lossless line (d)May not be a distortion less line

ANSWER: A loss less line is always a distortion less line

16) In a twin – wire transmission line in air, the adjacent voltage maximum are at 12.5cm and

27.5cm. The operating frequency is
(a) 300 MHz (b) 1 GHz (c) 2 GHz (d) 6.28 GHz
ANSWER: 1 GHz
17) In air, a lossless transmission line of length 50 cm with $L = 10\mu H/m$, $C = 40PF/m$ is operated at 25 MHz. It's electrical path length is
(a) 0.5 meters (b) λ meters (c) π /2 radians (d) 180 degrees
ANSWER: **π /2 radians**

18) Characteristic impedance of a transmission line is 50Ω. Input impedance of the open circuited line is $Z0C$ = 100 + j 150Ω. When the transmission line is short circuited then the value of the input impedance will be

(a) 50Ω (b) 100 + j 50Ω (c) 7.69 + j 11.54Ω (d) 7.69 − j 11.54Ω

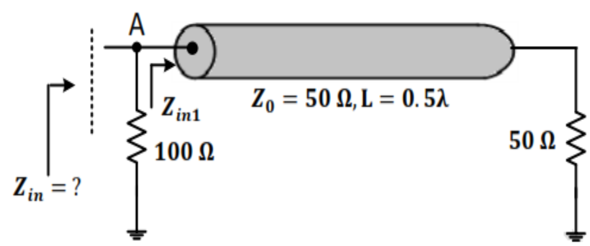
ANSWER: 7.69 − j 11.54Ω

19. One end of a lossless transmission line having the characteristic impedance of 75 and length of 1 cm is short circuited. At 3 GHz, the input impedance at the other end of the transmission line is

(a) 0 (b) Resistive (c) Capacitive (d) Inductive

ANSWER: Inductive

20) In the transmission line shown the impedance Zin between node A and the ground is



ANSWER:33.3Ω

UNIT II - HIGH FREQUENCY TRANSMISSION LINES

1) Which lossless element is inserted between source and load in addition to an ideal transformer in order to reduce the effect of reflection loss phenomenon by image matching?

a. Amplitude shifter
b. Phase shifter
c. Frequency divider
d. Voltage divider

ANSWER: Phase shifter

2) What would be the depth of penetration for copper at 2 MHz frequency with σ = 5.8 x 10^7?

a. 46.72 μm
b. 56.90 μm
c. 66.08 μm
d. 76.34 μm

ANSWER: 46.72 μm

3) Which parameter is much larger than the resistance at radio frequencies in RF circuits?

a. Inductive reactance
b. Capacitive susceptance
c. Shunt conductance
d. Series admittance

ANSWER: Inductive reactance

4) If the rate of attenuation is high for good conductors at radio frequency, where does an input wave get reduced to?

a. Zero
b. Infinity
c. Minor proportion of its initial strength value
d. Major proportion of its final strength value

ANSWER: Minor proportion of its initial strength value

5) What would be the Standing Wave Ratio (SWR) for a line with reflection coefficient equal to 0.49?

a. 0.01
b. 2.12
c. 2.921
d. 3.545

ANSWER: 2.921

6) Which operation is performed over the in phase incident and reflected waves in order to obtain maximum voltage of SWR?

a. Addition
b. Subtraction
c. Differentiation
d. Integration

ANSWER: Addition

7) Which parameter is much larger than the resistance at radio frequencies in RF circuits?

a. Inductive reactance
b. Capacitive susceptance
c. Shunt conductance
d. Series admittance

ANSWER: Inductive reactance

8) If the rate of attenuation is high for good conductors at radio frequency, where does an input wave get reduced to?

a. Zero

b. Infinity
c. Minor proportion of its initial strength value
d. Major proportion of its final strength value

ANSWER: Minor proportion of its initial strength value

9) What does the line showing termination at R_0 with an absence of standing wave and node/anti-node, known as?

a. Smooth line
b. Rough line
c. Load line
d. Point line

ANSWER: Smooth line

10) Which points have maximum magnitude along the line?

a. Nodes
b. Antinodes
c. Both a and b
d. None of the above

ANSWER: Antinodes

11) How does the short-circuited line behave for the first λ/4 distance if input impedance is purely reactive?

a. As an inductance
b. As a resistance
c. As a capacitance
d. As a conductance

ANSWER: As an inductance

12) If the medium is different than air, then what would be the equation of capacitance for a co-axial cable capacitor?

a. C = ε0 εr A / d
b. C = 4π ε0 εr [ab / a - b]
c. C = 2π ε0 εr L / ln (b/a)
d. C = 2π ε0 εr R

ANSWER: $C = 2\pi \varepsilon_0 \varepsilon_r L / \ln (b/a)$

13) A lossless transmission line having 50 Ω characteristic impedance and length λ/4 is short circuited at one end and connected to an ideal voltage source of 1V at the other end. The current drawn from the voltage sources is

(a) 0
(b)0.02 A
(c) ∞
(d)None of the these [GATE 1996: 1 Mark]

ANSWER: 0.

14) The capacitance per unit length and the characteristic impedance of a lossless transmission line are C and Z0 respectively. The velocity of a travelling wave on the transmission line is

(a) Z0C (b)1/(Z0C) (c) Z0/C (d)C/Z0

ANSWER: **1/(Z0C)**

15)The VSWR can have any value between
(a) 0 and 1 (b)– 1 and + 1 (c) 0 and ∞ (d)1 and ∞ [

ANSWER: **1 and ∞**

16) The return loss of a device is found to be 20 dB. The voltage standing wave ratio (VSWR) and magnitude of reflection coefficient are respectively
(a) 1.22 and 0.1 (b)0.81 and 0.1 (c) – 1.22 and 0.1 (d)2.44 and 0.2

ANSWER: 1.22 and 0.1

17) A transmission line of pure resistive characteristic impedance is terminated with an unknown load. The measured value of VSWR on the line is equal to 2 and a voltage minimum point is found to be at the load. The load impedance is then
(a) Complex (b)Purely capacitive (c) Purely resistive (d)Purely inductive

ANSWER: **Purely resistive**

18) A 50 ohm lossless transmission line has a pure reactance of (j 100) ohms as its load. The VSWR in the line is
(a) 1/2 (b)2 (c) 4 (d)(infinity)

ANSWER: **(infinity)**

19) Consider a transmission line of characteristic impedance 50 ohms. Let it be terminated at one end by (+ j50) ohm. The VSWR produced by it in the transmission line will be
(a) + 1 (b)0 (c) ∞ (d)+ j

ANSWER: ∞

UNIT III - IMPEDANCE MATCHING IN HIGH FREQUNCY TRANSMISSION LINES

1)The constant x-circles of Smith chart becomes smaller due to increase in the value of 'x' from ______

a. 0 to π

b. 0 to 2π

c. 0 to π /2

d. 0 to ∞

ANSWER: 0 to ∞

2) According to Smith diagram, where should be the position of reflection coefficient value for a unity circle with unity radius?
a. On or inside the circle
b. Outside the circle
c. Both a and b
d. None of the above

ANSWER: On or inside the circle

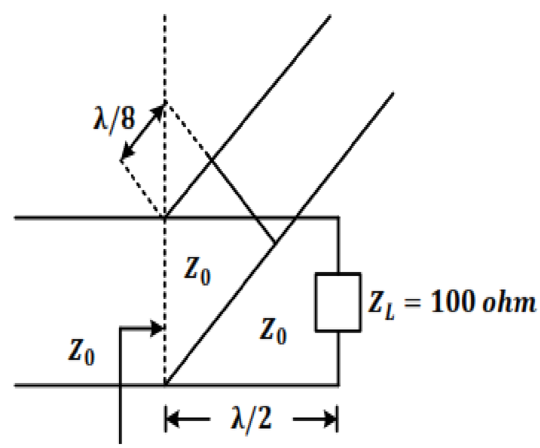
3) If the quarter line is short-circuited, then it acts as _______
a. Conductor
b. Insulator
c. Semiconductor
d. Power regulator

ANSWER: Insulator

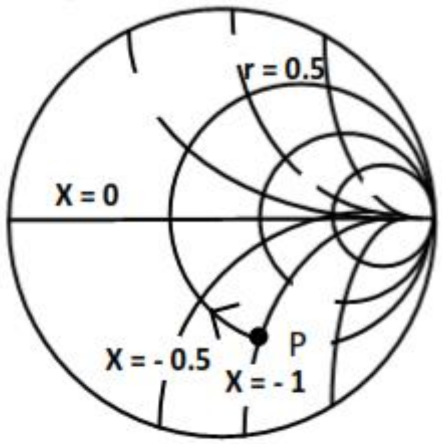
4) After what wavelength does the nature of graph get reversed for the input impedance of open-circuited line?
a. λ/2
b. λ/4
c. λ/8
d. λ/16

ANSWER: λ/4

5)**The input impedance of a short circuited lossless transmission line quarter wave long is**
(a) Purely reactive (b)Purely resistive (c) Infinite (d)Dependent on the characteristic impedance of the line
ANSWER : **Infinite**
6) A short circuited stub is shunt connected to a transmission line as shown in figure. If 50Ω, the admittance Y seen at the junction of the stub and transmission line is



(a) (0.01 – j 0.02) mho (b) (0.02 – j 0.01) mho (c) (0.04 + j 0.02) mho (d) (0.02 + j 0) mho
ANSWER : **(0.01 – j 0.02) mho**
7) Consider impedance marked with point P in an impedance smith chart as shown in figure. The movement from point P along a constant resistance circle in the clockwise direction by an angle 450 is equivalent

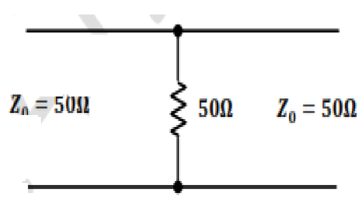


(a) Adding an inductance in series with Z (b) Adding a capacitance in series with Z (c) Adding an inductance in shunt across Z (d) Adding a capacitance in shunt across Z

ANSWER : **Adding an inductance in series with Z**

UNIT IV - PASSIVE FILTERS

1) A load of 50Ω is connected in shunt in a 2 – wire transmission line of Z_0 = 50Ω as shown in the figure. The 2 – port scattering parameter (s – matrix) of the shunt element is



(a) $\begin{bmatrix} -\frac{1}{2} & \frac{1}{2} \\ \frac{1}{2} & -\frac{1}{2} \end{bmatrix}$

(b) $\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$

(c) $\begin{bmatrix} -\frac{1}{3} & \frac{2}{3} \\ \frac{2}{3} & -\frac{1}{3} \end{bmatrix}$

(d) $\begin{bmatrix} \frac{1}{4} & -\frac{3}{4} \\ \frac{1}{2} & \frac{1}{4} \end{bmatrix}$

ANSWER: option (b)

2) **It is possible to overcome the drawback of m-derived filter by connecting number of sections in addition to prototype & m-derived sections with terminating __________**

a. One-fourth sections

b. Half sections

c. Square of three-fourth sections

d. Full sections

ANSWER: Half sections

3) In band elimination filter, the frequency of resonance of individual arms is geometric _________

a. Mean of two cut-off frequencies

b. Difference of two cut-off frequencies

c. Product of two cut-off frequencies

d. Division of two cut-off frequencies

ANSWER: Mean of two cut-off frequencies

4) What do the high pass filters generally comprise of?
A. Capacitive series arm
B. Capacitive shunt arm
C. Inductive series arm
D. Inductive shunt arm

a. A & D

b. A & C

c. B & C

d. B & D

ANSWER: A & D

UNIT V - WAVEGUIDES AND RESONATORS

1) By which phenomenon does the energy transmission take place between the walls of the tube in waveguides?

a. Reflection
b. Refraction
c. Dispersion
d. Absorption

ANSWER: Reflection

2) The ratio of magnitudes of electric field intensity to the magnetic field intensity is regarded as ________

a. Intrinsic Impedance
b. Characteristic Impedance
c. Both a and b
d. None of the above

ANSWER: Both a and b

3) How is the relation between energy transfer and the electric and magnetic fields specified?

a. By Poynting theorem

b. By Stoke's theorem
c. By Helmholtz theorem
d. By Lagrange's theorem

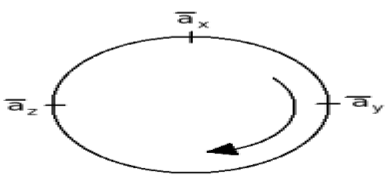
ANSWER: By Poynting theorem

4) According to Maxwell's first equation in a point form for the static field, the electric flux per unit volume by leaving a small value is equal to __________

a. Zero
b. Current density
c. Volume charge density
d. Magnetic field intensity

ANSWER: Volume charge density

5) If a conductor with length of 5m is located along z-direction with a current of about 3A in az direction & B = 0.04 ax (T), then what would be the value of force experienced by conductor?



a. 0.6ax N
b. 0.6ay N
c. 0.6az N
d. None of the above

ANSWER: 0.6a$_y$ N

6) Consider the assertions given below. Which of them represent/s the precise condition/s of Ampere's circuital law for the evaluation of magnetic field intensity?

A. If H is tangential to the path, then its value must be different at all the points
B. At each point on closed path, H is either tangential or normal to the path

a. A is true and B is false
b. A is false and B is true
c. Both A & B are true
d. Both A & B are false

ANSWER: A is false and B is true

7) Which type of capacitor possesses magnitude of flux density equivalent to its surface charge density?

a. Parallel Plate capacitor
b. Spherical Capacitor
c. Co-axial cable capacitor
d. None of the above

ANSWER: Parallel Plate capacitor

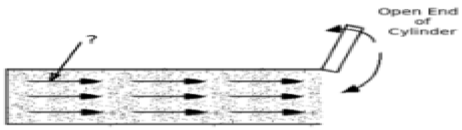
8) Basically, the flux lines which are represented by the lines of force are regarded as _________

a. Branch lines
b. Node lines

c. Stream lines
d. Loop lines

ANSWER: Stream lines

9) What does an arrow indicate in the diagram shown below?



a. Displacement Vector
b. Velocity Vector
c. Viscocity Vector
d. Acceleration Vector

ANSWER: Velocity Vector

10) What kind of function is an electric field intensity with respect to the value of charge?
a. Linear
b. Angular
c. Delta
d. Sinc

ANSWER: Linear

11) At which point it becomes necessary to determine the electric field intensity?
a. Field Point
b. Source Point
c. Sink Point
d. Static Point

ANSWER: Field Point

12) An electric field exhibits variation corresponding to _________
a. Position
b. Time
c. Both a and b
d. None of the above

ANSWER: Both a and b

13) Which co-ordinate/s serve/s to be a function of magnitude of magnetic field intensity due to infinite long straight filament?
a. 0
b. Φ
c. z
d. r

ANSWER: r

14) If the material is isotropic and linear, what would be the direction of electric field

intensity and the polarization at each point?
a. Parallel
b. Perpendicular
c. Both a and b
d. None of the above

ANSWER: Parallel

15) Which conceptual notion introduced by Maxwell, indicates the generation of magnetic field in an empty free space?
a. Displacement current
b. Velocity Vector current
c. Acceleration current
d. Projectile current

ANSWER: Displacement current