SKP Engineering College

Tiruvannamalai – 606611

A Course Material

on

Transmission Lines and Waveguides

By

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Quality Certificate

This is to Certify that the Electronic Study Material

Subject Code:EC6503

Subject Name: Transmission Lines and Waveguides

Year/Sem:III/V

Being prepared by me and it meets the knowledge requirement of the University curriculum.

Signature of the Author

Name: B.Senthil Raja

Designation: Assistant Professor

This is to certify that the course material being prepared by Mr. B.Senthil Raja is of the adequate quality. He has referred more than five books and one among them is from abroad author.

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Name: Dr.V.Subramania Bharathi

Seal:

EC6503 - TRANSMISSION LINES AND WAVEGUIDES L T P C 3 1 0 4

OBJECTIVES: The student should be made to:

• To introduce the various types of transmission lines and to discuss the losses associated.
• To give through understanding about impedance transformation and matching.
• To impart knowledge on filter theories and wave guides theories.
• To use the Smith chart in problem solving.

UNIT – I TRANSMISSION LINE THEORY 9

General theory of Transmission lines – the transmission line – general solution – theinfinite line – Wavelength , velocity of propagation – Waveform distortion – the distortion – less line Loading and different methods of loading – Line not terminated in Zo –Reflection coefficient – calculation of current, voltage, power delivered d lines – reflection factor and reflection loss.

UNIT – II HIGH FREQUENCY TRANSMISSION LINES 9

Transmission line equations a 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 PASSIVE FILTERS 9

Characteristics impedance of symmetrical networks – filter fundamentals, Design of filters, constant K, Low pass, High pass, Band pass, Band Elimination, m-derived sections – low pass, high pass composite filters.

UNIT - V WAVEGUIDES AND CAVITY RESONATORS 9

General Wave behaviours along uniform, Guiding structures, transverse Electromagnetic waves, Transverse Magnetic waves, Transverse Electric waves, TM and TE wave between parallel plates, TM and TE waves in Rectangular wave guides, Bessel’s differential equation and Bessel function, TM and TE waves in Circular wave guides,Rectangular and circular cavity resonators.

TOTAL (L: 45+T: 15): 60 PERIODS

OUTCOMES:

• Upon completion of the course, students will be able to:
• Discuss the propagation of signals through transmission lines.
• Explain radio propagation in guided systems

• Analyze signal propagation at Radio Frequencies.

Text Books:

1. John D Ryder, “ Networks, lines and fields”, 2nd Edition, Prentice Hall India, 2010.

References:

1. E.C.Jordan and K.G.Balmain, “Electromagnetic waves and radiating systems”, Prentice Hall of Inda 2006

2. G.S.N. Raju, “Electromagnetic Field Theory and Transmission Lines”, Pearson Education First Edition 2005

CONTENTS

S.No	Particulars	Page
1	Unit – I	6
2	Unit – II	18
3	Unit – III	30
4	Unit – IV	42
5	Unit – V	49

Unit - I

Transmission Line Theory

Part-A

1.What is meant by distortion less line?
A line, which has neither frequency distortion nor delay distortion is called a distortion lessline.

2.Find the reflection coefficient of a 200Ω transmission line when it is terminated by aload impedance of 692∟12ºΩ.
Given: Zr=200Ω and Z0=692∟12ºΩ = 678.878-j143.87
Reflection coefficient K= (Zr-Z0)/Zr+Z0
K=200-(678.878-j143.87)/200+(678.878-j143.87)
K=(- 467.878+j143.87)/878.878-j143.87
K=(498.1∟163.21)/890.57∟-9.29
K=0.559∟172.5º

3. What are the line parameters and define it?
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 isHenry/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

4. What are the secondary constants of a line? Why the line parameters are called distributed elements?
The secondary constants of a line are: Characteristic Impedance Propagation Constant 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.

5. What is a finite line? Write down the significance of this line?
A finite line is a line having a finite length on the line. It is a line, which is terminated, in its characteristic impedance (ZR=Z0), so the input impedance of the finite line is equal to the characteristic impedance (Zs=Z0).

6. What is an infinite line?
An infinite line is a line in which the length of the transmission line is infinite. 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.

7. What is wavelength of a line?

The distance the wave travels along the line while the phase angle is changing through 2Π radians is called a wavelength.

8. What are the types of line distortions?

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.

9. How frequency distortion occurs in a line?

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.

10. How to avoid the frequency distortion that occurs in the line?

In order to reduce frequency distortion occurring in the line,

a) The attenuation constant α should be made independent of frequency. b) By using equalizers at the line terminals which minimize the frequency distortion. Equalizers 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.

11. What is delay distortion?

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.

12. How to avoid the frequency distortion that occurs in the line?

In order to reduce frequency distortion occurring in the line,

a) The phase constant β should be made dependent of frequency.

b) The velocity of propagation is independent of frequency.

c) By using equalizers at the line terminals which minimize the frequency distortion.

Equalizers 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 phase is equal for all the frequencies.

13. What is a distortion less line? What is the condition for a distortion less line?

A line, which has neither frequency distortion nor phase distortion is called a distortion less line. The condition for a distortion less line is RC=LG. Also,
a) The attenuation constant α should be made independent of frequency.
b) The phase constant β should be made dependent of frequency.
c) The velocity of propagation is independent of frequency.

14. What is the drawback of using ordinary telephone cables?
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.

15. How the telephone line can be made a distortion less line?
For the telephone cable to be distortion less line, the inductance value should be increased by placing lumped inductors along the line.

16. What is loading?
Loading is the process of increasing the inductance value by placing lumped inductors at specific intervals along the line, which avoids the distortion.

17. What are the types of loading?
a) Continuous loading b) Patch loading c) Lumped loading

18. What is continuous loading?
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.

19. What is patch loading?
It is the process of using sections of continuously loaded cables separated by sections of unloaded cables which increases the inductance value.

20. What is lumped loading?
Lumped loading is the process of increasing the inductance value by placing lumped inductors at specific intervals along the line, which avoids the distortion.

21. Define reflection coefficient
Reflection Coefficient can be defined as the ratio of the reflected voltage to the incident voltage at the receiving end of the line Reflection Coefficient K=Reflected Voltage at load /Incident voltage at the load K=Vr/Vi

22. When reflection occurs in a line?
Reflection occurs because of the following cases:
1) when the load end is open circuited
2) when the load end is short-circuited

3) 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 all the 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.

23. What are the conditions for a perfect line? What is a smooth line?
For a perfect line, the resistance and the leakage conductance value were neglected. The conditions for a perfect line are R=G=0.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.

24. Define reflection loss
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

25. Define the term insertion loss
The insertion loss of a line or network is defined as the number of nepers or decibels by which the current in the load is changed by the insertion . Insertion loss=Current flowing in the load without insertion of the network**/**Current flowing in the load with insertion of the network

<u>Part-B</u>

1. Explain in detail about wave-form distortion and also derive the condition for distortion less line.
Waveform Distortion: Signal transmitted over lines are normally complex and consists of many frequency components. For ideal transmission, the waveform at the line-receiving end must be the same as the waveform of the original input signal. The condition requires that all frequencies have the same attenuation and the same delay caused by a finite phase velocity or velocity of propagation.
When these conditions are not satisfied, distortion exists. 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.

a) Frequency distortion:
In general, the attenuation function is a function of frequency. Attenuation function specifies the attenuation or loss incurred in the line while the signal is propagating. 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. That is, when the attenuation constant is not a function of frequency, frequency distortion does not exist on transmission lines.
In order to reduce frequency distortion occurring in the line,
a) The attenuation constant should be made independent of frequency.
b) By using equalizers at the line terminals which minimize the frequency distortion.

Equalizers 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.

b) Delay distortion:
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.
It is that type of distortion in which the time required to transmit the various frequency components over the line and the consequent delay is not a constant.
This is, when velocity is independent of frequency, delay distortion does not exist on the lines.
In general, the phase function is a function of frequency. Since v= ω / β, it will be independent of frequency only when β is equal to a constant multiplied by ω
In order to reduce frequency distortion occurring in the line,
a) The phase constant _ should be made dependent of frequency.
b) The velocity of propagation is independent of frequency.
c) By using equalizers at the line terminals which minimize the frequency distortion.
Therefore, we conclude that a transmission line will have neither delay nor frequency distortion only if α is independent of frequency and β should be a function of frequency.
The value of the attenuation constant α has been determined that

$$\alpha = \sqrt{\frac{RG - \omega^2 LC + \sqrt{(RG - \omega^2 LC)^2 + \omega^2 (LG + CR)}}{2}}$$

In general α is a function of frequency. All the frequencies transmitted on a line will then not be attenuated equally. A complex applied voltage, such as voice voltage containing many frequencies, will not have all frequencies transmitted with equal attenuation, and the received for will be identical with the input waveform at the sending end. This variation ic=s known as frequency distortion.

Phase Distortion
All the frequencies applied to a transmission line will not have the same time of transmission, some frequencies delayed more than the others. For an applied voice voltage waves the received waves will not be identical with the input wave form at the

receiving end, since some components will be delayed more than those of the other frequencies. This phenomenon is known as **delay or phase distortion**.

It is apparent that ω and β do not both involve frequency in same manner and that the velocity of propagation will in general be some function of frequency.

Frequency distortion is reduced in the transmission of high quality radio broadcast programs over wire line by use of equalizers at line terminals These circuits are networks whose frequency and phase characteristics are adjusted to be inverse to those of the lines, resulting in an overall uniform frequency response over the desired frequency band. Delay distortion is relatively minor importance to voice and music transmission because of the characteristics of ear. It can be very series in circuits intended for picture transmission, and applications of the co axial cable have been made to over come the difficulty. In such cables the internal inductance is low at high frequencies because of skinn effect, the resistance small because of the large conductors, and capacitance and leakance are small because of the use of air dielectric with a minimum spacers. The velocity of propagation is raised and made more nearly equal for all frequencies.

THE DISTORTION LESS LINE

It is desirable, however to know the condition on the line parameters that allows propagation without distortion. The line having parameters satisfy this condition is termed as a distortion less line.

The condition for a distortion less line was first investigated by Oliver Heaviside. Distortion less condition can help in designing new lines or modifying old ones to minimize distortion.

A line, which has neither frequency distortion nor phase distortion is called a distortion less line.

Condition for a distortion less line

The condition for a distortion less line is RC=LG. Also,

a) The attenuation constant _ should be made independent of frequency. α = RG

b) The phase constant _ should be made dependent of frequency. β = ω LC

c) The velocity of propagation is independent of frequency. V=1 / LC

For the telephone cable to be distortion less line, the inductance value should be increased by placing lumped inductors along the line.

For a perfect line, the resistance and the leakage conductance value were neglected. The conditions for a perfect line are R=G=0. 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.

The distortion Less line

If a line is to have neither frequency nor delay distortion, then attenuation constant and velocity of propagation cannot be function of frequency. Then the phase constant be a direct fuction of frequency

$$\beta = \sqrt{\frac{\omega^2 LC - RG + \sqrt{(RG - \omega^2 LC) + \omega^2 (LG + CR)}}{2}}$$

The above equation shows that if the the term under the second radical be reduced to equal

$$(RG + \omega^2 LC)^2$$

Then the required condition for ß is obtained.
Expanding the term under the internal radical and forcing the equality gives

$$R^2G^2 - 2\omega^2 LCRG + \omega^4 L^2C^2 + \omega^2 L^2G^2 + 2\omega^2 LCRG + \omega^2 C^2 R^2 = (RG + \omega^2 LC)^2$$

This reduces to

$$2\omega^2 LCRG + \omega^2 L^2 G^2 + \omega^2 C^2 R^2 = 0$$

$$(LG - CR)^2 = 0$$

Therefore the condition that will make phase constant a direct form is *LG* = *CR*
A hypothetical line might be built to fulfill this condition. The line would then have a value of ß obtained by use of the above equation.

Already we know that the formula for the phase constant *β* = _ *LC*

Then the velocity of propagation will be *v* = 1/ *LC*

This is the same for the all frequencies, thus eliminating the delay distortion.
May be made independent of frequency if the term under the internal radical is forced to reduce to

(*RG* +_ *LC*)2

Analysis shows that the condition for the distortion less line *LG* = *CR* , will produce the desired result, so that it is possible to make attenuation constant and velocity independent of frequency simultaneously. Applying the condition LG= RC to the expression for the attenuation gives

α = *RG*

This is the independent of frequency, thus eliminating frequency distortion on a line. To achieve

LG = *CR L* = *R*
C G

Require a very large value of L, since G is small. If G is intentionally increased, attenuation are increased, resulting in poor line efficiency.

To reduce R raises the size and cost of the conductors above economic limits, so that the hypothetical results cannot be achieved.

Propagation constant is 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 γ= α + j β.

The real part is called the attenuation constant, whereas the imaginary part of propagation constant is called the phase constant.

2. Define loading and explain different types of loading?

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.

Quarter wave length

For the case where the length of the line is one quarter wavelength long, or an odd multiple of a quarter wavelength long, the input impedance becomes

$$Z_{in} = \frac{Z_0^2}{Z_r}$$

Matched load

Another special case is when the load impedance is equal to the characteristic impedance of the line (i.e. the line is matched), in which case the impedance reduces to the characteristic impedance of the line so that

$$Z_{in} = Z_r = Z_0$$

For all l and all λ.

Short : For the case of a shorted load (i.e. ZL = 0), the input impedance is purely imaginary and a periodic function of position and wavelength (frequency)

$$Z_{in}(l) = jZ_0 \tan(\beta l)$$

Open: For the case of an open load (i.e), the input impedance is once again imaginary and periodic

$$Z_{in}(l) = -jZ_0 \cot(\beta l)$$

3. Explain the line not terminated in Z0.

The insertion loss of a line or network is defined as the number of nepers or decibels by which the current in the load is changed by the insertion . Insertion loss=Current flowing in the load without insertion of the Network Current flowing in the load with insertion of the network.

Coaxial cable

Coaxial lines confine the electromagnetic wave to the area inside the cable, between the center conductor and the shield. The transmission of energy in the line occurs totally through the dielectric inside the cable between the conductors. Coaxial lines can therefore be bent and twisted (subject to limits) without negative effects, and they can be strapped to conductive supports without inducing unwanted currents in them.

In radio-frequency applications up to a few gigahertz, the wave propagates in the transverse electric and magnetic mode (TEM) only, which means that the electric and magnetic fields are both perpendicular to the direction of propagation (the electric field is radial, and the magnetic field is circumferential). However, at frequencies for which the wavelength (in the dielectric) is significantly shorter than the circumference of the cable, transverse electric (TE) and transverse magnetic (TM) waveguide modes can also propagate.

When more than one mode can exist, bends and other irregularities in the cable geometry can cause power to be transferred from one mode to another.
T
he most common use for coaxial cables is for television and other signals with bandwidth of multiple megahertz. In the middle 20th century they carried long distance telephone connections.

Microstrip
A microstrip circuit uses a thin flat conductor which is parallel to a ground plane.
Microstrip can be made by having a strip of copper on one side of a printed circuit board (PCB) or ceramic substrate while the other side is a continuous ground plane. The width of the strip, the thickness of the insulating layer (PCB or ceramic) and the dielectric constant of the insulating layer determine the characteristic impedance. Microstrip is an open structure whereas coaxial cable is a closed structure.

Stripline
A stripline circuit uses a flat strip of metal which is sandwiched between two parallel ground planes. The insulating material of the substrate forms a dielectric. The width of the strip, the thickness of the substrate and the relative permittivity of the substrate determine the characteristic impedance of the strip which is a transmission line.

Balanced lines
A balanced line is a transmission line consisting of two conductors of the same type, and equal impedance to ground and other circuits. There are many formats of balanced lines, amongst the most common are twisted pair, star quad and twin-lead.
Twisted pair
Twisted pairs are commonly used for terrestrial telephone communications. In such cables, many pairs are grouped together in a single cable, from two to several thousand.

The format is also used for data network distribution inside buildings, but in this case the cable used is more expensive with much tighter controlled parameters and either two or four pairs per cable.

Single-wire line

Unbalanced lines were formerly much used for telegraph transmission, but this form of communication has now fallen into disuse. Cables are similar to twisted pair in that many cores are bundled into the same cable but only one conductor is provided per circuit and there is no twisting. All the circuits on the same route use a common path for the return current (earth return). There is a power transmission version of single-wire earth return in use in many locations.

Waveguide

Waveguides are rectangular or circular metallic tubes inside which an electromagnetic wave is propagated and is confined by the tube. Waveguides are not capable of transmitting the transverse electromagnetic mode found in copper lines and must use some other mode. Consequently, they cannot be directly connected to cable and a mechanism for launching the waveguide mode must be provided at the interface.

4. Explain in detail about wavelength, velocity and propagation of the infinite line?

Wavelength:

The distance the wave travels along the line while the phase angle is changed through 2Πradians is called wavelength.

$\lambda = 2\pi / \beta$

The change of 2π in phase angle represents one cycle in time and occurs in a distance of one wavelength,

$\lambda = v/f$

Velocity:

$V = f\lambda$

$V = \omega / \beta$

This is the velocity of propagation along the line based on the observation of the change in the phase angle along the line. It is measured in miles/second if ß is in radians per meter.

Propagation:

We know that

$Z = R + j\omega L$

$Y = G + j\omega C$

Then

$\gamma = \alpha + j\beta = \sqrt{(ZY)}$

$\gamma = \sqrt{(RG - \omega^2 LC + j\omega(LG + CR))}$

Squaring on both sides

$\alpha^2 + 2j\alpha\beta - \beta^2 = RG - \omega^2 LC + j\omega(LG + RC)$

Equating real parts and imaginary parts we get α and β values

In a perfect line R=0 and G = 0 , Then the above equation would be

$\beta = \omega \sqrt{(LC)}$
And the velocity of propagation for such an ideal line is given by
$\gamma = \omega\sqrt{\beta}$
Thus the above equation showing that the line parameter values fix the velocity of propagation.

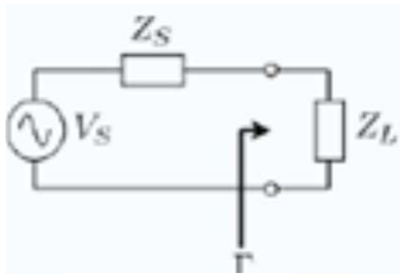
5. Derive the expression for Reflection coefficient?
Reflection coefficient:
The reflection coefficient is used in physics and electrical engineering when wave propagation in a medium containing discontinuities is considered. A reflection coefficient describes either the amplitude or the intensity of a reflected wave relative to an incident wave. The reflection coefficient is closely related to the transmission coefficient.

Reflection occurs because of the following cases:
1) When the load end is open circuited
2) When the load end is short-circuited
3) 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 all the 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. Reflection Coefficient can be defined as the ratio of the reflected voltage to the incident voltage at the receiving end of the line Reflection Coefficient K=Reflected Voltage at load /Incident voltage at the load.
$K = V_r/V_i$
Telecommunications In telecommunications, the reflection coefficient is the ratio of the amplitude of the reflected wave to the amplitude of the incident wave. In particular, at a discontinuity in a transmission line, it is he complex ratio of the electric field strength of the reflected wave (E^-) to that of the incident wave (E^+). This is typically represented with a Γ (capital gamma) and can be written as

$$\Gamma = \frac{E^-}{E^+}$$

The reflection coefficient may also be established using other field or circuit quantities. The reflection coefficient can be given by the equations below, where ZS is the impedance toward the source, ZL is the impedance toward the load:



$$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S}$$

Simple circuit configuration showing measurement location of reflection coefficient.

Notice that a negative reflection coefficient means that the reflected wave receives a 180°, or π, phase shift.

The absolute magnitude (designated by vertical bars) of the reflection coefficient can be calculated from the standing wave ratio,

SWR: $$|\Gamma| = \frac{SWR - 1}{SWR + 1}$$

Unit - II

High Frequency Transmission Line

Part-A

1. For the line of zero dissipation, what will be the values of attenuation constant and characteristic impedance?

Attenuation constant: $\alpha=0$,
Phase constant: $\beta=\omega\sqrt{(LC)}$
Characteristic impedance: $Z0=\sqrt{(L/C)}$

2. State the assumptions for the analysis of the performance of the radio frequency line.

i).Due to the skin effect ,the currents are assumed to flow on the surface of the conductor. The internal inductance is zero.
ii).The resistance R increases with Ö f while inductance L increases with f . Hence wL>>R.
iii).The leakage conductance G is zero

3. State the expressions for inductance L of a open wire line and coaxial line.

i) For open wire line,
L=9.21*10-7(μ/μr +4ln d/a)=10-7(μr+9.21log d/a) H/m
ii) For coaxial line,
L = 4.60*10-7[log b/a]H/m

4. State the expressions for the capacitance of a open wire line

For open wire line,
C=(12.07)/(ln d/a)μμf/m

5. What is dissipationless line?

A line for which the effect of resistance R is completely neglected is called dissipationless line

6. What is the nature and value of Z0 for the dissipation less line?

For the dissipation less line, the Z0 is purley resistive and given by, Z0=R0 = Ö L/c

7. State the values of a **and** b **for the dissipation less line.**

Answer:
a=0 and b=w ÖLC

8. What are nodes and antinodes on a line?

The points along the line where magnitude of voltage or current is zero are called nodes while the the points along the lines where magnitude of voltage or current first maximum are called antinodes or loops.

9. What is standing wave ratio?
The ratio of the maximum to minimum magnitudes of voltage or current on a line having standing waves called standing waves ratio.
½Emax½ ½Imin½ S = ¾¾ = ¾¾ ½Emin½ ½Imin½

10. What is the range of values of standing wave ratio?
The range of values of standing wave ratio is theoretically 1 to infinity.

11. What are standing waves?
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.

12. What is called standing wave ratio?
The ratio of the maximum to minimum magnitudes of current or voltage on a line having standing wave is called the standing-wave ratio S. That is,
S= E max = I max Emin I min

13. State the relation between standing were ratio S and reflection co-efficient k.
The relation between standing wave ratio S and reflection co-efficient k is,
1+ k S = 1- k S-1 Also k = S+1

14. How will you make standing wave measurements on coaxial lines?
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.

15. Give the input impedance of a dissipationless line.
The input impedance of a dissipationless line is given by,
Z s = Es = R0 1+ k < f **-2**b**s I s 1- k <**f **-2**b**s**

16. Give the maximum and minimum input impedance of the dissipationless line.
Maximum input impedance,R max = R0 1+ k
1- k= SRo
Minimum input impedance, R min = Ro 1+ k
1- k = Ro S

17. Give the input impedance of open and short circuited lines.
The input impedance of open aned short circuited lines are given by, Zsc = jRo tan 2 ps

18. Why the point of voltage minimum is measured rather than voltage maximum?
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.

19. What is the use of eighth wave line?
An eighth wave line is used to transform any resistance to an impendence with a magnitude equal to Roof the line or to obtain a magnitude match between a resistance of any value and a source of Ro internal resistance.

20. Give the input impendence of eighth wave line terminated in a pure resistance Rr.
The input impendence of eighth wave line terminated in a pure resistance Rr. Is given by
Zs = (ZR+jRo/Ro+jZR)
From the above equation it is seen that ½Zs½ = Ro.

21. What do you mean by copper insulators?
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.

22. What is the input impendence equation of dissipation less line?
The input impendence equation of dissipation less line is given by
(Zs/Ro)=(1+|K|(-2_s)/ (1-|K|(-2_s)

<u>Part-B</u>

1. Discuss the various parameters of open-wire and co-axial lines at radio frequency
There are two main forms of line at high frequency
i) Open wire line
ii) Co-axial line

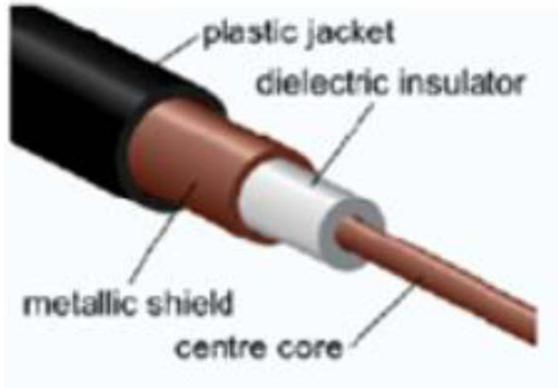
When a line, either open wire or coaxial, is used at radio frequencies of a megacycle or more, it is found that certain approximations may be employed leading to simplified analysis of line performance. The assumptions usually made are:
1. Very considerable skin effect, so that currents may be assumed as flowing on a conductor surfaces, internal inductance then being zero.
2. That ω L>>R when computing Z. This assumption is justifiable because it is found

that the resistance increases because of skin effect with $\sqrt{f}$ while the line resistance increases directly with f.
3. The lines are well enough constructed that G may be considered zero

Open-wire line:
Open wire transmission lines have the property that the electromagnetic wave propagating down the line extends into the space surrounding the parallel wires. These lines have low loss, but also have undesirable characteristics. They cannot be bent, twisted or otherwise shaped without changing their characteristic impedance, causing reflection of the signal back toward the source. They also cannot be run along or attached to anything conductive, as the extended fields will induce currents in the nearby conductors causing unwanted radiation and detuning of the line. Coaxial lines solve this problem by confining the electromagnetic wave to the area inside the cable, between the center conductor and the shield.

The transmission of energy in the line occurs totally through the dielectric inside the cable between the conductors. Coaxial lines can therefore be bent and moderately twisted without negative effects, and they can be strapped to conductive supports without inducing unwanted currents in them. In radio-frequency applications up to a few gigahertz, the wave propagates primarily in the transverse electric magnetic (TEM) mode, which means that the electric and magnetic fields are both perpendicular to the direction of propagation. However,above a certain cutoff frequency, transverse electric (TE) and/or transverse magnetic (TM) modes can also propagate, as they do in a waveguide. It is usually undesirable to transmit signals above the cutoff frequency, since it may cause multiple modes with different phase velocities to propagate, interfering with each other. The outer diameter is roughly inversely proportional to the cutoff frequency.
A propagating surface-wave mode that does not involve or require the outer shield but only a single central conductor also exists in coax but this mode is effectively suppressed in coax of conventional geometry and common impedance. Electric field lines for this TM mode have a longitudinal component and require line lengths of a half wavelength or longer.

Coaxial line:
Coaxial cable is used as a transmission line for radio frequency signals, in applications such as connecting radio transmitters and receivers with their antennas, computer network (Internet) connections, and distributing cable television signals. One advantage of coax over other types of transmission line is that in an ideal coaxial cable the electromagnetic field carrying the signal exists only in the space between the inner and outer conductors. This allows coaxial cable runs to be installed next to metal objects such as gutters without the power losses that occur in other transmission lines, and provides protection of the signal from external electromagnetic interference.



Coaxial cable differs from other shielded cable used for carrying lower frequency signals such as audio signals, in that the dimensions of the cable are controlled to produce a repeatable and predictable conductor spacing needed to function efficiently as a radio frequency transmission line.

Like any electrical power cord, coaxial cable conducts AC electric current between locations. Like these other cables, it has two conductors, the central wire and the tubular shield. At any moment the current is traveling outward from the source in one of the conductors, and returning in the other. However, since it is alternating current, the current reverses direction many times a second. Coaxial cable differs from other cable because it is designed to carry radio frequency current. This has a frequency much higher than the 50 or 60 Hz used in mains (electric power) cables, reversing direction millions to billions of times per second. Like other types of radio transmission line, this requires special construction to prevent power losses:

If an ordinary wire is used to carry high frequency currents, the wire acts as an antenna, and the high frequency currents radiate off the wire as radio waves, causing power losses. To prevent this, in coaxial cable one of the conductors is formed into a tube and encloses the other conductor. This confines the radio waves from the central conductor to the space inside the tube. To prevent the outer conductor, or shield, from radiating, it is connected to electrical ground, keeping it at a constant potential.

The dimensions and spacing of the conductors must be uniform. Any abrupt change in the spacing of the two conductors along the cable tends to reflect radio frequency power back toward the source, causing a condition called standing waves. This acts as a bottleneck, reducing the amount of power reaching the destination end of the cable. To hold the shield at a uniform distance from the central conductor, the space between the two is filled with a semirigid plastic dielectric. Manufacturers specify a minimum bend radius[2] to prevent kinks that would cause reflections. The connectors used with coax are designed to hold the correct spacing through the body of the connector.

Each type of coaxial cable has a characteristic impedance depending on its dimensions and materials used, which is the ratio of the voltage to the current in the cable. In order to prevent reflections at the destination end of the cable from causing standing waves, any equipment the cable is attached to must present an impedance equal to the characteristic impedance (called 'matching'). Thus the equipment "appears" electrically similar to a continuation of the cable, preventing reflections. Common values of characteristic impedance for coaxial cable are 50 and 75 ohms.

Description

Coaxial cable design choices affect physical size, frequency performance, attenuation, power handling capabilities, flexibility, strength and cost. The inner conductor might be solid or stranded; stranded is more flexible. To get better high-frequency performance, the inner conductor may be silver plated. Sometimes copper-plated iron wire is used as an inner conductor.

The insulator surrounding the inner conductor may be solid plastic, a foam plastic, or may be air with spacers supporting the inner wire. The properties of dielectric control some electrical properties of the cable. A common choice is a solid polyethylene (PE) insulator, used in lower-loss cables. Solid Teflon (PTFE) is also used as an insulator. Some coaxial lines use air (or some other gas) and have spacers to keep the inner conductor from touching the shield. Many conventional coaxial cables use braided copper wire forming the shield.

This allows the cable to be flexible, but it also means there are gaps in the shield layer, and the inner dimension of the shield varies slightly because the braid cannot be flat. Sometimes the braid is silver plated. For better shield performance, some cables have a double-layer shield. The shield might be just two braids, but it is more common now to have a thin foil shield covered by a wire braid. Some cables may invest in more than two shield layers, such as "quad-shield" which uses four alternating layers of foil and braid. Other shield designs sacrifice flexibility for better performance; some shields are a solid metal tube. Those cables cannot take sharp bends, as the shield will kink, causing losses in the cable. For high power radio-frequency transmission up to about 1 GHz coaxial cable with a solid copper outer conductor is available in sizes of 0.25 inch upwards. The outer conductor is rippled like a bellows to permit flexibility and the inner conductor is held in position by a plastic spiral to approximate an air dielectric.

Coaxial cables require an internal structure of an insulating (dielectric) material to maintain the spacing between the center conductor and shield. The dielectric losses increase in this order: Ideal dielectric (no loss), vacuum, air, Polytetrafluoroethylene (PTFE), polyethylene foam, and solid polyethylene. A low relative permittivity allows for higher frequency usage. An inhomogeneous dielectric needs to be compensated by a non-circular conductor to avoid current hot-spots.

Most cables have a solid dielectric; others have a foam dielectric which contains as much air as possible to reduce the losses. Foam coax will have about 15% less attenuation but can absorb moisture—especially at its many surfaces—in humid environments, increasing the loss. Stars or spokes are even better but more expensive. Still more expensive were the air spaced coaxials used for some inter-city communications in the middle 20th Century. The center conductor was suspended by polyethylene discs every few centimeters. In a miniature coaxial cable such as an RG-62 type, the inner conductor is supported by a spiral strand of polyethylene, so that an air space exists between most of the conductor and the inside of the jacket. The lower dielectric constant of air allows for a greater inner diameter at the same impedance and a greater outer diameter at the same cutoff frequency, lowering ohmic losses.

Inner conductors are sometimes silver plated to smooth the surface and reduce losses due to skin effect. A rough surface prolongs the path for the current and concentrates the current at peaks and thus increases ohmic losses.

The insulating jacket can be made from many materials. A common choice is PVC, but some applications may require fire-resistant materials. Outdoor applications may require the jacket to resist ultraviolet light and oxidation. For internal chassis connections the insulating jacket may be omitted.

The ends of coaxial cables are usually made with RF connectors.

2. Explain reflection losses in detail?

Insertion loss:

Insertion loss is a figure of merit for an electronic filter and this data is generally specified with a filter. Insertion loss is defined as a ratio of the signal level in a test configuration without the filter installed (V1) to the signal level with the filter installed (V2). This ratio is described in dB by the following equation:

$$\text{Insertion loss (dB)} = 10\log_{10}\frac{V_1^2}{V_2^2} = 20\log_{10}\frac{V_1}{V_2}$$

Filters are sensitive to source and load impedances so the exact performance of a filter in a circuit is difficult to precisely predict. Comparisons, however, of filter performance are possible if the insertion loss measurements are made with fixed source and load impedances, and 50 Ω is the typical impedance to do this. This data is specified as common-mode or differential-mode. Common-mode is a measure of the filter performance on signals that originate between the power lines and chassis ground, whereas differential-mode is a measure of the filter performance on signals that originate between the two power lines.

Link with Scattering parameters

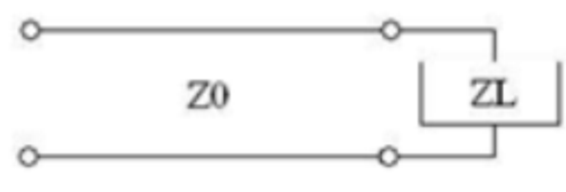
Insertion Loss (IL) is defined as follows:

$$IL = 10\log_{10}\frac{|S_{21}|^2}{1-|S_{11}|^2}\,\mathrm{dB}$$

This definition results in a negative value for insertion loss, that is, it is really defining a gain, and a gain less than unity (i.e., a loss) will be negative when expressed in dBs.

However, it is conventional to drop the minus sign so that an increasing loss is represented by an increasing positive number as would be intuitively expected

Reflection Coefficient:
The characteristic impedance of a transmission line, and that the tx line gives rise to forward and backward travelling voltage and current waves. We will use this information to determine the voltage reflection coefficient, which relates the amplitude of the forward travelling wave to the amplitude of the backward travelling wave. To begin, consider the transmission line with characteristic impedance Z0 attached to a load with impedance ZL:



$$ZL = RL + jXL$$

At the terminals where the transmission line is connected to the load, the overall voltage must be given by:

$$\frac{V}{I} = Z_L$$

$$V(z,t) = V^{+}e^{(j\omega t - \gamma z)} + V^{-}e^{(j\omega t + \gamma z)}$$

$$I(z,t) = I^{+}e^{(j\omega t - \gamma z)} + I^{-}e^{(j\omega t + \gamma z)}$$

If we plug this into equation [1] (note that z is fixed, because we are evaluating this at a specific point, the end of the transmission line), we obtain:

$$\frac{V^{+} + V^{-}}{I^{+} - I^{-}} = \frac{V^{+} + V^{-}}{V^{+} - V^{-}} Z_0 = Z_L$$

The ratio of the reflected voltage amplitude to that of the forward voltage amplitude is the voltage reflection coefficient. This can be solved for via the above equation:

$$\Gamma = \frac{V^{-}}{V^{+}} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

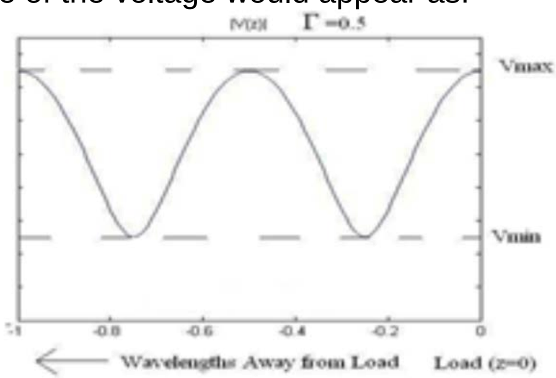
The reflection coefficient is usually denoted by the symbol gamma. Note that the magnitude of the reflection coefficient does not depend on the length of the line, only the load impedance and the impedance of the transmission line. Also, note that if ZL=Z0, then the line is "matched". In this case, there is no mismatch loss and all power is transferred to the load. At this point, you should begin to understand the importance of impedance matching: grossly mismatched impedances will lead to most of the power reflected away from the load.

3. Determine the expression for measurement of VSWR and wavelength.
Standing Waves:
Standing waves on the transmission line. Assuming the propagation constant is purely imaginary (lossless line), We can re-write the voltage and current waves as:

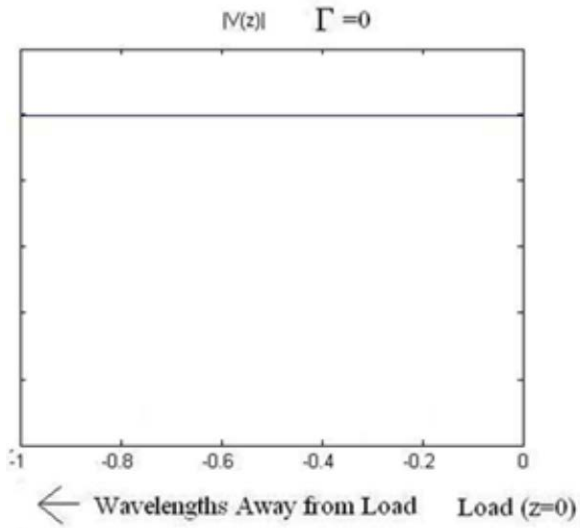
$$V(z) = V^{+}\left(e^{-j\beta z} + \Gamma e^{j\beta z}\right)$$

$$I(z) = \frac{V^{+}}{Z_0}\left(e^{-j\beta z} - \Gamma e^{j\beta z}\right)$$

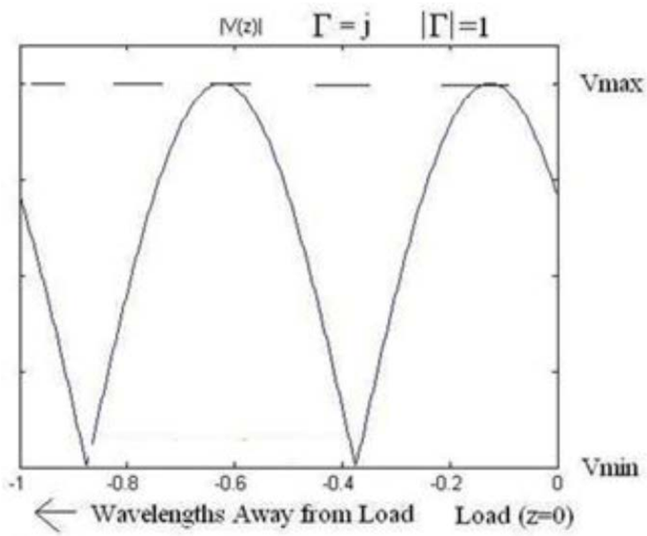
If we plot the voltage along the transmission line, we observe a series of peaks and minimums, which repeat a full cycle every half-wavelength. If gamma equals 0.5 (purely real), then the magnitude of the voltage would appear as:



Similarly, if gamma equals zero (no mismatch loss) the magnitude of the voltage would appear as:



Finally, if gamma has a magnitude of 1 (this occurs, for instance, if the load is entirely reactive while the transmission line has a Z0 that is real), then the magnitude of the voltage would appear as:

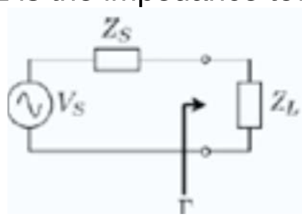


One thing that becomes obvious is that the ratio of Vmax to Vmin becomes larger as the reflection coefficient increases. That is, if the ratio of Vmax to Vmin is one, then there are no standing waves, and the impedance of the line is perfectly matched to the load. If the ratio of Vmax to Vmin is infinite, then the magnitude of the reflection coefficient is 1, so that all power is reflected. Hence, this ratio, known as the Voltage Standing Wave Ratio (VSWR) or standing wave ratio is a measure of how well matched a transmission line is to a load. It is defined as:

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

The reflection coefficient may also be established using other field or circuit quantities.

The reflection coefficient can be given by the equations below, where ZS is the impedance toward the source, ZL is the impedance toward the load:



Simple circuit configuration showing measurement location of reflection coefficient.

$$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S}$$

Notice that a negative reflection coefficient means that the reflected wave receives a 180°, or π, phase shift.

SWR: $$|\Gamma| = \frac{SWR - 1}{SWR + 1}$$

Thus the absolute magnitude (designated by vertical bars) of the reflection coefficient can be calculated from the standing wave ratio.

4. Explain line of zero dissipation in detail?

Fundamental electrical parameters

Shunt capacitance per unit length, in farads per metre.

$$C = \frac{2\pi\epsilon}{\ln(D/d)} = \frac{2\pi\epsilon_0\epsilon_r}{\ln(D/d)}$$

Series inductance per unit length, in henrys per metre.

$$L = \frac{\mu}{2\pi}\ln(D/d) = \frac{\mu_0\mu_r}{2\pi}\ln(D/d)$$

Series resistance per unit length, in ohms per metre. The resistance per unit length is just the resistance of inner conductor and the shield at low frequencies. At higher frequencies, skin effect increases the effective resistance by confining the conduction to a thin layer of each conductor.

Shunt conductance per unit length, in siemens per metre. The shunt conductance is usually very small because insulators with good dielectric properties are used (a very low loss tangent). At high frequencies, a dielectric can have a significant resistive loss.

Derived electrical parameters

Characteristic impedance in ohms (Ω). Neglecting resistance per unit length for most coaxial cables, the characteristic impedance is determined from the capacitance per unit length (C) and the inductance per unit length (L). Those parameters are determined from the ratio of the inner (d) and outer (D) diameters and the dielectric constant (ε). The characteristic impedance is given by

$$Z_0 = \frac{1}{2\pi}\sqrt{\frac{\mu}{\epsilon}}\ln\frac{D}{d} \approx \frac{138\Omega}{\sqrt{\epsilon_r}}\log_{10}\frac{D}{d}$$

Assuming the dielectric properties of the material inside the cable do not vary appreciably over the operating range of the cable, this impedance is frequency independent above about five times the shield cutoff frequency. For typical coaxial cables, the shield cutoff frequency is 600 (RG-6A) to 2,000 Hz (RG-58C)

Attenuation (loss) per unit length, in decibels per meter. This is dependent on the loss in the dielectric material filling the cable, and resistive losses in the center conductor and outer shield. These losses are frequency dependent, the losses becoming higher as the frequency increases. Skin effect losses in the conductors can be reduced by increasing the diameter of the cable.

A cable with twice the diameter will have half the skin effect resistance. Ignoring dielectric and other losses, the larger cable would halve the dB/meter loss. In designing a system, engineers consider not only the loss in the cable, but also the loss in the connectors. Velocity of propagation, in meters per second. The velocity of propagation depends on the dielectric constant and permeability (which is usually 1).

$$v = \frac{1}{\sqrt{\epsilon\mu}} = \frac{c}{\sqrt{\epsilon_r\mu_r}}$$

Cutoff frequency is determined by the possibility of exciting other propagation modes in the coaxial cable. The average circumference of the insulator is π(D + d) / 2. Make that length equal to 1 wavelength in the dielectric. The TE01 cutoff frequency is therefore

$$f_c = \frac{1}{\pi\left(\frac{D+d}{2}\right)\sqrt{\mu\epsilon}} = \frac{c}{\pi\left(\frac{D+d}{2}\right)\sqrt{\mu_r\epsilon_r}}$$

Unit - III

Impedance Matching In High Frequency Lines

Part-A

1. What is Impedance matching?
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.

2.Distinguish between single stub and double stub matching.
Single stub matching Double stub matching
i) It has one stub to match the transmission line impedance
It requires two stubs for impedance matching
ii) Stub should be placed on a definite place on a line Location of stub is arbitrary.
iii) It necessities both length and location of stub to be altered for matching.
It alter the length of stubs for matching

3. Why is a quarter wave line called as impendence inverter?
A quater wave line may be considered as an impendence inverter because it can transform a low impendence in to ahigh impendence and vice versa.

4. List the application of the quarter wave line ?
☐ An important application of the quarter wave matching section is to a couple a transmission line to a resistive load such as an antenna.
☐ The quarter–wave matching section then must be designed to have a characteristic impendence Ro so chosen that the antenna resistance Ra is transformed to a value equal to the characteristic impendence Ra of the transmission line.
☐ The characteristic impendence Ro of the matching section should be Ro' = Ö RaRo

5. Explain impendence matching using stub.
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.

6. Give reasons for preferring a short- circuited stub when compared to an open – circuited stub.
A short circuited stub is preferred to an open circuited stub because of greater ease in constructions and because of the inability to maintain high enough insulation resistance at the

open –circuit point to ensure that the stub is really opencircuited .A shorted stub also has a lower loss of energy due to radiation, since the short – circuit can be definitely established witha large metal plate ,effectively stopping all field propagation.

7. What are the two independent measurements that must be made to find the locationand length of the stub.

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.

8. Give the formula to calculate the distance of the point from the load at which the stub is to be connected.

The formula to calculate the distance of the point from the load at which the stub is to be connected is, S1 = (f +_-cos-1|K|)/(2_)

9. Give the formula to calculate the distance d from the voltage minimum to the point stub be connection.

The formula to calculate the distance d from the voltage minimum to the point of stub be connection is, d= cos-1|K| / (2_)

10. Give the formula to calculate the length of the short circuited stub.

The formula to calculate the length of the short circuited stub is,
L=_/2_ tan-1(s/(s-1))
This is the length of the short – circuited stub to be placed d meters towards the load from a point at which a voltage minimum existed before attachment of the stub.

11. Give reason for an open line not frequently employed for impedance matching.

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.

12. State the use of half wave line.

The expression for the input impendence of the line is given by Zs = Zr. 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.

13. Why Double stub matching is preferred over single stub matching.

Double stub matching is preferred over single stub due to following disadvantages of single stub.

1. Single stub matching is useful for a fixed frequency. So as frequency changes the location of single stub will have to be changed.
2. The single stub matching system is based on the measurement of voltage minimum .Hence for coxial line it is very difficult to get such voltage minimum, without using slotted line section

14. List the applications of the smith chart.
The applications of the smith chart are,
(i) It is used to find the input impendence and input admittance of the line.
(ii) 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.
(iii) In single stub matching

15. Give reason for an open line not frequently employed for impedance matching.
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.

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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.

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An important application of the quarter wave matching section is to a couple a transmission line to a resistive load such as an antenna .The quarter –wave matching section then must be designed to have a characteristic impendence Ro so chosen that the antenna resistance Ra is transformed to a value equal to the characteristic impendence Ra of the transmission line. The characteristic impendence Ro of the matching section then should be Ro’ = Ö RaRo

20. What are the difficulties in single stub matching?
The difficulties of the smith chart are
(i) 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.

(ii) 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.
(iii) In the case of the single stub it was mentioned that two adjustments were required, these being location and length of the stub.

21. What is double stub matching?
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 ʎ/4.This is called double stub matching.
22. Give the equation for the radius of a circle diagram.
The equation for the radius of a circle diagram is R=(S2-1)/2S and C = (S2+1)/2S Where C is the shift of the center of the circle on the positive Ra axis.

23. What is the use of a circle diagram?
The circle diagram may be used to find the input impendence of a line mof any chosen length.

24. How is the circle diagram useful to find the input impendence of short and opencircuited lines?
An open circuited line has s = a ,the correspondent circle appearing as the vertical axis .The input impendence is then pure reactance , with the value for various electrical lengths determined by the intersections of the corresponding bs 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 bs circles with the vertical axis.

Part-B

1. Explain Quarter wave line in detail?

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

Quarter-Wave Transformer
The input impedance of a transmission line of length L with characteristic impedance Z0 and connected to a load with impedance ZA:

$$Z_{in}(-L) = Z_0\left[\frac{Z_A + jZ_0\tan(\beta L)}{Z_0 + jZ_A\tan(\beta L)}\right]$$

An interesting thing happens when the length of the line is a quarter of a wavelength:

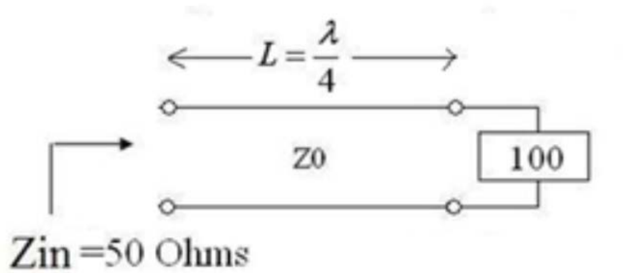
$$Z_{in}\left(L=\frac{\lambda}{4}\right) = Z_0\left[\frac{Z_A + jZ_0 \tan\left(\frac{2\pi}{\lambda}\frac{\lambda}{4}\right)}{Z_0 + jZ_A \tan\left(\frac{2\pi}{\lambda}\frac{\lambda}{4}\right)}\right] \quad (\tan \to \infty)$$

$$\boxed{Z_{in}\left(L=\frac{\lambda}{4}\right) = \frac{Z_0^2}{Z_A}}$$

The above equation is important: it states that by using a quarter-wavelength of transmission line, the impedance of the load (ZA) can be transformed via the above equation.

The utility of this operation can be seen via an example.

Example. Match a load with impedance ZA=100 Ohms to be 50 Ohms using a quarter-wave transformer, as shown below.



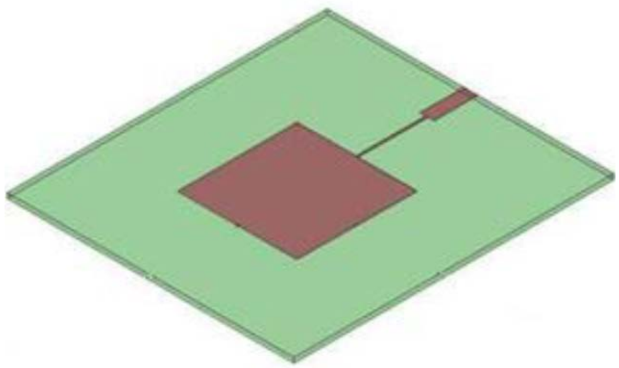
Solution: The problem is to determine Z0 (the characteristic impedance of our quarter-wavelength transmission line) such that the 100 Ohm load is matched to 50 Ohms. By applying the above equation, the problem is simple:

$$Z_{in}(L = \frac{\lambda}{4}) = \frac{Z_0^2}{Z_A}$$

$$50 = \frac{Z_0^2}{100} \Rightarrow Z_0 = \sqrt{(50)(100)} = 70.71\ \Omega$$

Hence, by using a transmission line with a characteristic impedance of 70.71 Ohms, the 100 Ohm load is matched to 50 Ohms. Hence, if a transmitter has an impedance of 50 Ohms and is trying to deliver power to the load (antenna), no power will be reflected back to the transmitter.
In general, impedance matching is very important in RF/microwave circuit design. It is relatively simple at a single frequency, but becomes very difficult if wideband impedance matching is desired.

This technique is commonly employed with patch antennas. Circuits are printed as



shown in the following figure. A 50 Ohm microstrip transmission line is matched to a patch antenna (impedance typically 200 Ohms or more) via a quarter-wavelength microstrip transmission line with the characteristic impedance chosen to match the load

Because the quarter-wavelength transmission line is only a quarter-wavelength at a single frequency, this is a narrow-band matching technique

An important application of the quarter wave matching section is to a couple a transmission line to a resistive load such as an antenna .The quarter –wave matching section then must be designed to have a characteristic impendence Ro so chosen that the antenna resistance Ra is transformed to a value equal to the characteristic impendence Ra of the transmission line.

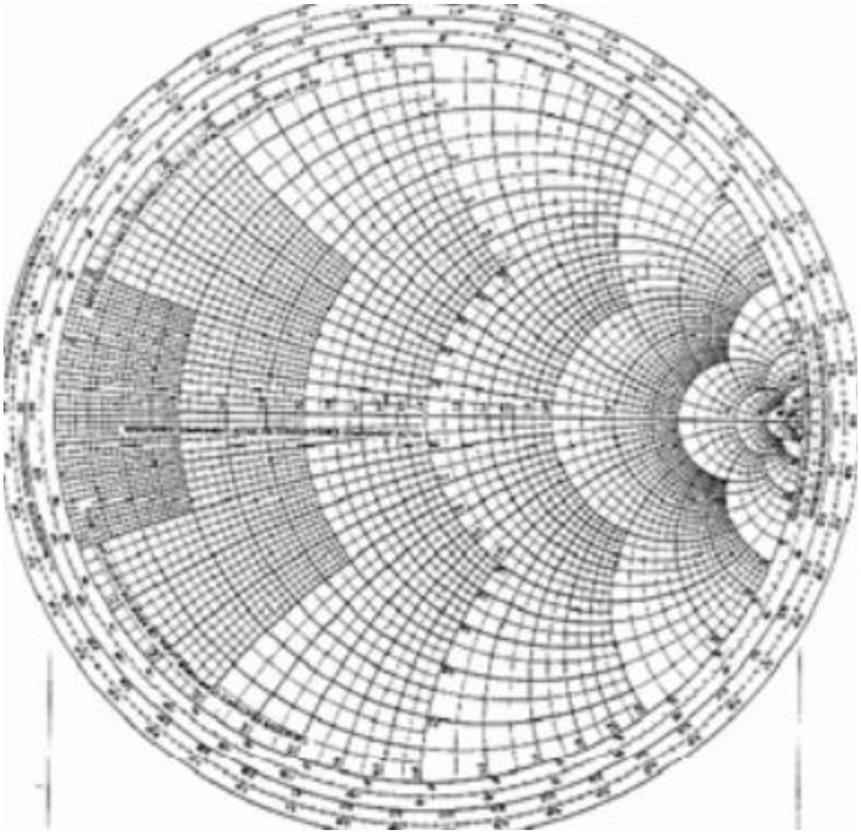
2. Determine the length and the distance of the stub from the load. Given that a complex load ZL= 50-j100 is to be matched to a 75 ohm transmission line using a short circuited stub.

Given

Characteristic impedance of the transmission line Z0= 75ohm
Length of the stub from the load

Solution:

1. The normalized impedance is determined by dividing the load impedance by the characteristic impedance of the transmission line.
ZL =Z
L=50 - *j*1= 0.667 - *j*1.33
2. The normalized impedance, ZL is plotted on the smith chart by determining the point of intersection between the constant R circle with R = 0.667 and constant X circle with X=1.33. T
he impedance circle is drawn. Because the stubs are connected in parallel with the load, admittances can be much easily used rather than impedances to simplify the calculations.
3. The normalized admittance is determined from the smith chart by simply rotating the impedance plot, by 180degree. This is simply done by drawing a line from point A through the center of the chart to the opposite side of the circle, point B.
4. The admittance point is rotated clockwise to a point on the impedance circle where it intersects the characteristic impedance *Z*0. At the point C. The real component of the input impedance at this point is equal to the characteristic impedance *Z*0. At this point C, the admittance is y=1+j1.7.
5. The distance from point B to point C, in terms of the wavelength is how far from load the stub must be placed, The stub must have a zero resistive component impedance and susceptance that has the opposite polarity.
6. To determine the length of the shorted stub that has an opposite reactive component to the input admittance, the outside of the Smith chart (R=0) is moved around with the starting point at D {since at point D t= 0 and hence $y = \infty$ }, until an admittance y= 1.7 is found.
7. The distance between point D and E is the length of the stub from the smith chart.



3. The 0.1λ length line shown has a characteristic impedance of 50 and is terminated with a load impedance of ZL = 5+j25. Determine the impedance and VSWR measurements using smith chart.
Solution:

(a) Locate zL = ZL/Z0 = 0.1 + j0.5 on the Smith chart.

(b) What is the impedance at l = 0:1λ?
Since we want to move away from the load (i.e., toward the generator), read 0.074 λ on the wavelengths toward generator scale and add l = 0.1 λ to obtain 0.174 λ on the wavelengths toward generator scale.

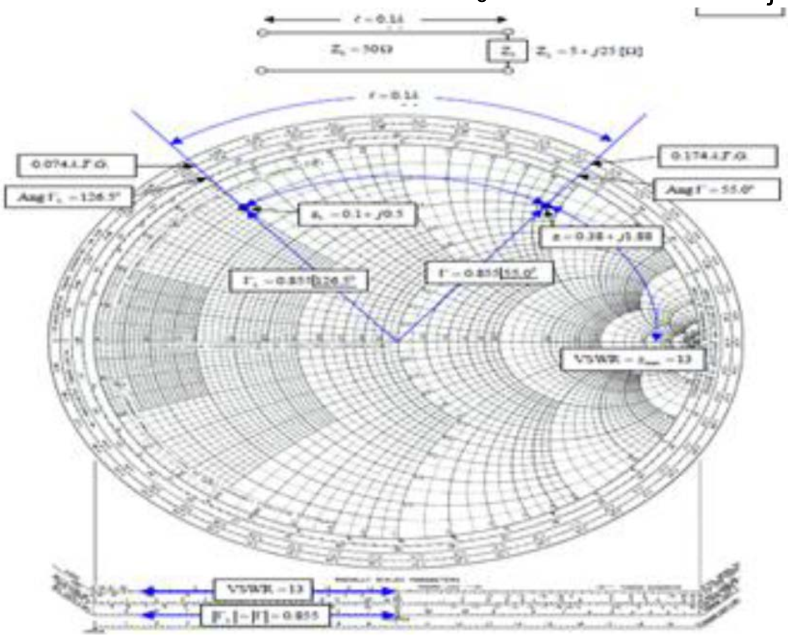
A radial line from the center of the chart intersects the constant reflection Co-efficient magnitude circle at z = 0.38 + j1.88. Hence Z = zZ0 = 50(0.38 + j1.88) = 19 +94Ω.

(c) What is the VSWR on the line?
Find VSWR = Zmax = 13 on the horizontal line to the rightof the chart's center or use the SWR scale on the chart.

(d) What is ΓL?

From the reflection coefficient scale below the chart Find |ΓL| = 0.855. From the angle of reflection coefficient scale on the perimeter of the chart, Find the angle of ΓL=126.5$_o$.Hence ΓL=0.855e j126.5$_o$.

(e) What is Γ at l = 0.1λ from the load?
Note that |Γ| =|ΓL|=0.855.Read the angle of the reflection coefficient from the angle of reflection coefficient scale as 55.0$_o$. Hence ΓL=0.855e j126.5$_o$.

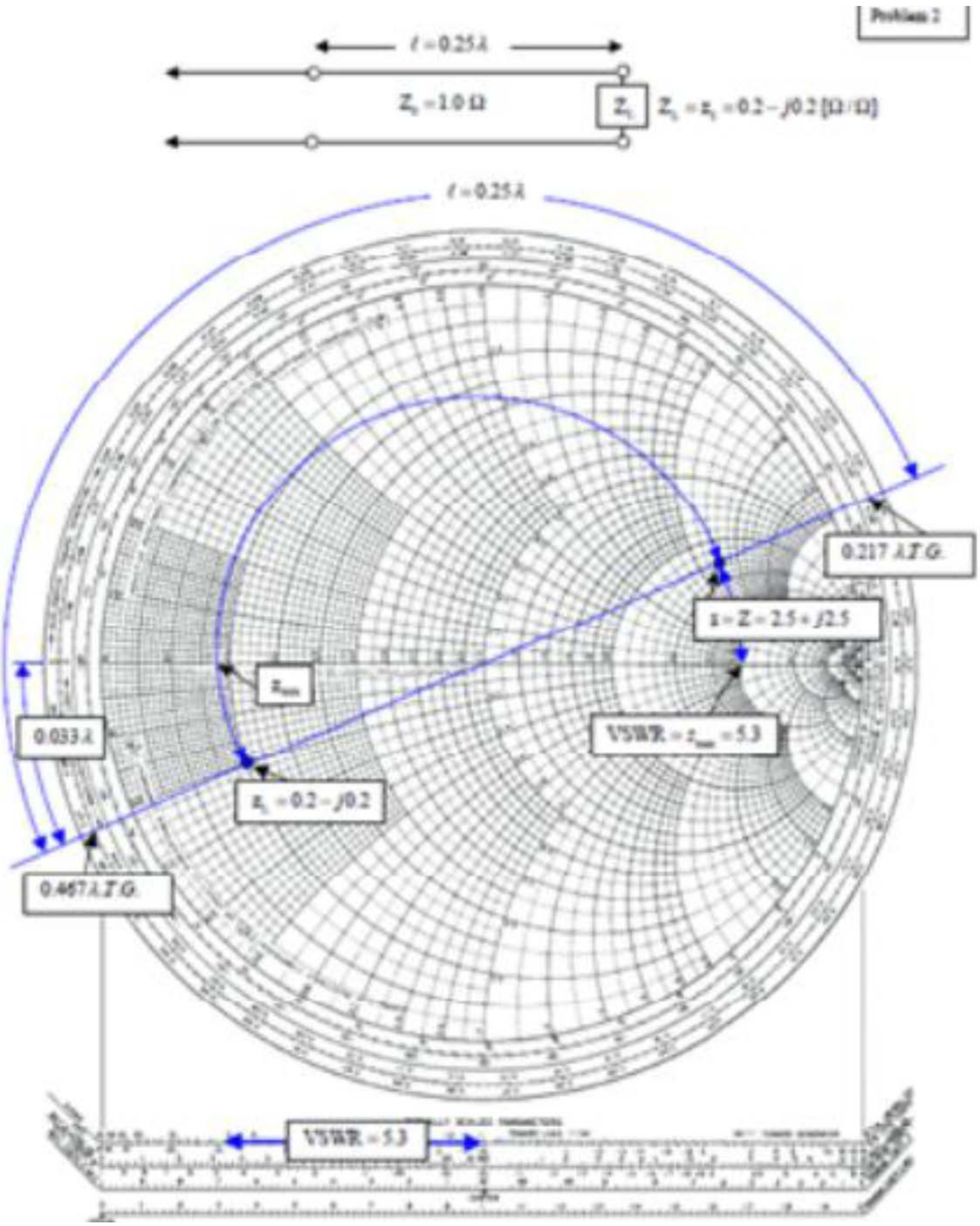


4. A transmission line has Z0 = 1.0, ZL = 0.2- j0.2Ω. Find the VSWR voltage minimum and voltage maxima using smith chart.

(a) What is z at l =λ/4=0.25 λ?
From the chart, read 0:467λfrom the wavelengths to-ward generator scale. Add 0.25λ to obtain 0.717 λ on the wavelengths toward generator scale. This is not on the chart, but since it repeats every half wavelength, it is the same as 0.717 λ – 0.500 λ = 0.217 λ. Drawing a radial line from the center of the chart, we find an intersection with the constant reflection coefficient magnitude circle at z = Z = 2.5 + j2.5.

(b) What is the VSWR on the line?
From the intersection of the constant reflection coefficient circle with the right hand side of the horizontal axis, read VSWR= zmax = 5.3.

(c) How far from the load is the first voltage minimum?
The voltage minimum occurs at zmin which is at a distance of 0.500λ-0.467λ =0:033λ from the load. Or read this distance directly on the wavelengths toward load scale. The current minimum occurs at zmax which is a quarter of a wavelength farther down the line or at 0.033λ+0.25λ = 0.283λ from the load.


Problem 2
ℓ = 0.25λ
Z0 = 1.0 Ω
ZL
ZL = zL = 0.2 − j0.2 [Ω/Ω]
ℓ = 0.25λ
0.217 λ T.G.
z = Z = 2.5 + j2.5
zmin
VSWR = zmax = 5.3
0.033 λ
zL = 0.2 − j0.2
0.467 λ T.G.
VSWR = 5.3

5. Using Double stub matching, match a complex Load of ZL = 18.75+j56.25 to a Line with characteristic impedance Z0 = 75ohm. Determine the stub Lengths, assuming a quarter wavelength spacing are maintained between the two short circuited stubs.

Solution:
A spacing of $\lambda / 4$ is maintained between the stubs, stub2 and stub1. For smooth line operation of the transmission line the input impedance looking into the terminals 2,2 of the line should be,

$$Y2,2 = 1/ Z0$$

The stub at 1,1 must be capable to transform the admittance at the terminating impedance end to the circle B which is displaced from the circle A; R=1 by ' $\lambda / 4$ '. The quarter wavelength line will further transform the admittance into a value at 2,2 which plot on the circle A. Thus the line to load distance between position 2,2 is not required to be determined.

ZT

Terminating impedance

The normalized load impedance

$ZL = (18.75 + j56.25)/75$

$ZL = 0.25 + j0.75$

Plotting the normalized impedance on the Smith chart, the impedance circle is drawn with distance between the point (1,0) and the point of the normalized impedance as the radius {distance, OA}

1. Moving by 180 degree (0.25 λ) on the impedance circle , that is at a diametrically opposite point to the point A, i.e., point B will give the normalized admittance. From the smith chart YL= 0.4-j1.2

2. Circle A is the constant R circle for R = 1. Circle B is the locus of all the points on the circle A is displaced by λ /4, quarter wavelength. The stub 1 adds a suscepatance of all the points on the circle B.Since stub 1 cannot alter the conductance , to a point on the circle B, point C, Y(at point C)= 0.4-j0.5

3. Transferring the point C to the point D on the circle A, since the line between 1,1 and2,2 is a quarter wave line that transforms the admittance at 1,1 to 2,2 such that the conductance equals the characteristic conductance, 1/ Z0.
Y(At point D) = 1.0+j1.2

4. The stub length at 2,2 should cancel the imaginary part of the above admittance of the stub at 2,2 must be -1.2.

5. To find the length of the stub with an admittance ,
(a) +j0.7 and
(b) –j1.2

The outside circle of the smith chart (the circle, R=0), is moved around having a reference at a point P, until
An admittance y= -1.2 is found at point E and
An admittance y= +0.7 is found at point F.

6. From the smith chart,
Length of the stub 1= distance between P and F Ls1=0.348 λ
Length of the stub 2= distance between P and F Ls2=0.11 λ

Unit IV

Passive Filters

Part-A

1. Define Characteristic impedance

Characteristic impedance is the impedance measured at the sending end of the line. It is given by

$Z0 = Z/Y$, where $Z = R + j\omega L$ is the series impedance $Y = G + j\omega C$ is the shunt admittance.

2. Define Propagation constant

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 $\gamma = \alpha + j\, \beta$.

The real part is called the attenuation constant α whereas the imaginary part of propagation constant is called the phase constant β.

3. What is symmetrical network?

A network is said to be symmetrical if the two series arms of a T network or shunt arms of a Π network are equal.

4. If the short circuit impedance is 100Ω and open circuit impedance 400Ω, What is the characteristic impedance of symmetrical network.

Given: Zsc=100Ω and Zoc=400Ω

$Z0=\sqrt{(Zsc.Zoc)} =\sqrt{(100*400)}=200\Omega$

5. Define cut-off frequency of a filter.

The frequency at which the network changes from a pass band to a stop band or vice-versa is called cut-off frequency.

6. What are the disadvantages of constant K prototype filters?

i) Attenuation does not increase rapidly beyond cut-off frequencies ii) Characteristic impedance varies widely in the pass band from its desired value.

7. What is the condition for occurrence of cut-off frequency of a filter?

i) $Z1/(4\ Z2)=0$ i.e, $Z1=0$

ii) $Z1/(4\ Z2)= -1$ i.e $Z1= -4\ Z2$

8. Mention the advantages of m-derived filters.
i) Attenuation rises near cut-off frequency and its slope is adjustable by varying f ∞.
ii) The characteristic impedance will be uniform in the pass band when m-derived half section having m=0.6 is connected at the ends.

9. What are composite filters?
A Composite filter is a combination of constant K filters, m-derived filters and m-derived half section.

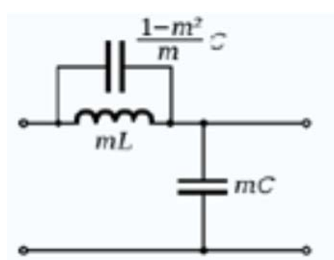
10. What is low pass filter?
Low pass filter is a network which allows only low frequencies at below cut-off frequency and attenuates high frequencies.

Part –B

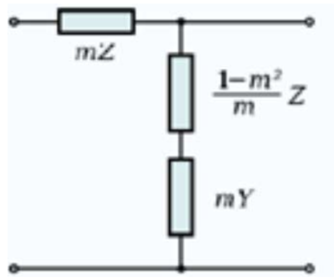
1. Derive and draw the m-derived T and Π section for low pass and high pass filter.

m-derived filter:
m-derived filters or m-type filters are a type of electronic filter designed using the image method. They were invented by Otto Zobel in the early 1920s.[1] This filter type was originally intended for use with telephone multiplexing and was an improvement on the existing constant k type filter.[2] The main problem being addressed was the need to achieve a better match of the filter into the terminating impedances. In general, all filters designed by the image method fail to give an exact match, but the m-type filter is a big improvement with suitable choice of the parameter m. The m-type filter section has a further advantage in that there is a rapid transition from the cut-off frequency of the pass band to a pole of attenuation just inside the stop band. Despite these advantages, there is a drawback with m-type filters; at frequencies past the pole of attenuation, the response starts to rise again, and m-types have poor stop band rejection. For this reason, filters designed using m-type sections are often designed as composite filters with a mixture of k-type and m-type sections and different values of m at different points to get the optimum performance from both types.

Derivation



m-derived series general filter half section



m-derived shunt low-pass filter half section.

$$C = \frac{L}{R_0^2}$$

The building block of m-derived filters, as with all image impedance filters, is the "L" network, called a half-section and composed of a series impedance Z, and a shunt admittance Y. The m-derived filter is a derivative of the constant k filter. The starting point of the design is the values of Z and Y derived from the constant k prototype and are given by

$$k^2 = \frac{Z}{Y}$$

where k is the nominal impedance of the filter, or R0.

The designer now multiplies Z and Y by an arbitrary constant m (0 < m < 1). There are two different kinds of m-derived section; series and shunt. To obtain the m-derived series half section, the designer determines the impedance that must be added to 1/mY to make the image impedance ZiT the same as the image impedance of the original constant k section. From the general formula for image impedance, the additional impedance required can be shown to be

$$\frac{1-m^2}{m}Z.$$

To obtain the m-derived shunt half section, an admittance is added to 1/mZ to make the image impedance ZiΠ the same as the image impedance of the original half section. The additional admittance required can be shown to be

$$\frac{1-m^2}{m}Y.$$

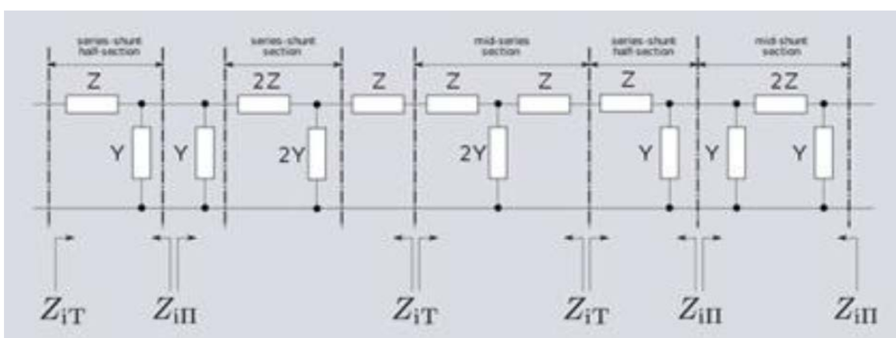
The general arrangements of these circuits are shown in the diagrams to the right along with a specific example of a low pass section.
A consequence of this design is that the m-derived half section will match a k-type section on one side only. Also, an m-type section of one value of m will not match another m-type section of another value of m except on the sides which offer the Zi of the k-type.

Operating frequency
For the low-pass half section shown, the cut-off frequency of the m-type is the same as the ktype and is given by

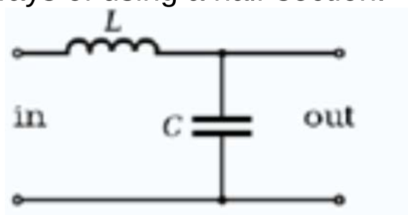
$$\omega_c = \frac{1}{\sqrt{LC}}.$$

2. Derive the Characteristics impedance of symmetrical networks, Constant K, Low pass, High pass, Band pass filter..
1. Constant k filter:
Constant k filters, also k-type filters, are a type of electronic filter designed using the image method. They are the original and simplest filters produced by this methodology and consist of a ladder network of identical sections of passive components. Historically, they are the first filters that could approach the ideal filter frequency response to within any prescribed limit with the addition of a sufficient number of sections. However, they are rarely considered for a modern design, the principles behind them having been superseded by ot er methodologies which are more accurate in their prediction of filter response.

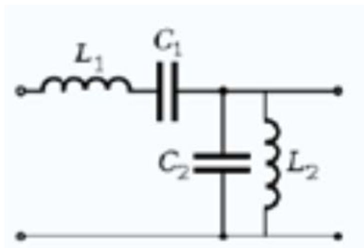
Terminology: Some of the impedance terms and section terms used in this article are pictured in the diagram below. Image theory defines quantities in terms of an infinite cascade of two-port sections, and in the case of the filters being discussed, an infinite ladder network of L-sections. Here "L" should not be confused with the inductance L – in electronic filter topology, "L" refers to the specific filter shape which resembles inverted letter "L".



The sections of the hypothetical infinite filter are made of series elements having impedance 2Z and shunt elements with admittance 2Y. The factor of two is introduced for mathematical convenience, since it is usual to work in terms of half-sections where it disappears. The image impedance of the input and output port of a section will generally not be the same. However, for a mid-series section (that is, a section from halfway through a series element to halfway through the next series element) will have the same image impedance on both ports due to symmetry. This image impedance is designated ZiT due to the "T" topology of a mid series section. Likewise, the image impedance of a mid-shunt section is designated ZiΠ due to the "Π" topology. Half of such a "T" or "Π" section is called a half-section, which is also an L-section but with half the element values of the full L-section. The image impedance of the half-section is dissimilar on the input and output ports: on the side presenting the series element it is equal to the mid-series ZiT, but on the side presenting the shunt element it is equal to the mid-shunt ZiΠ . There are thus two variant ways of using a half-section.



Constant k low-pass filter half section. Here inductance L is equal Ck2



Constant k band-pass filter half section. L1 = C2k2 and L2 = C1k2

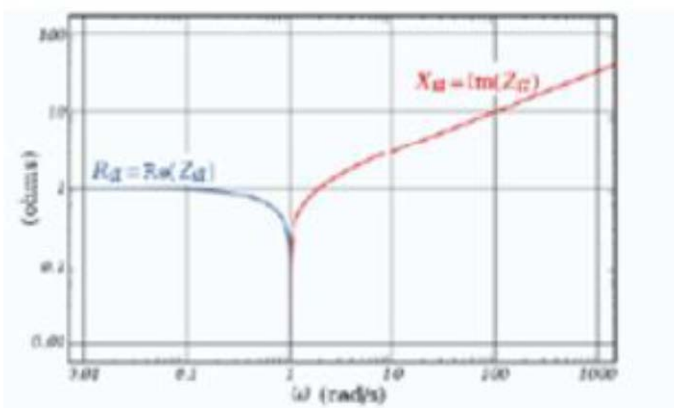


Image impedance ZiT of a constant k prototype low-pass filter is plotted vs. frequency ω. The impedance is purely resistive (real) below ωc, and purely reactive (imaginary) above ωc.

The building block of constant k filters is the half-section "L" network, composed of a series impedance Z, and a shunt admittance Y.

Thus, k will have units of impedance, that is, ohms. It is readily apparent that in order for k to be constant, Y must be the dual impedance of Z. A physical interpretation of k can be given by observing that k is the limiting value of Zi as the size of the section (in terms of values of its components, such as inductances, capacitances, etc.) approaches zero, while keeping k at its initial value. Thus, k is the characteristic impedance, Z0, of the transmission line that would be formed by these infinitesimally small sections. It is also the image impedance of the section at resonance, in the case of band-pass filters, or at ω = 0 in the case of low-pass filters.[7] For example, the pictured low-pass half-section has

$$k = \sqrt{\frac{i\omega L}{i\omega C}} = \sqrt{\frac{L}{C}}$$

Elements L and C can be made arbitrarily small while retaining the same value of k. Z and Y however, are both approaching zero, and from the formulae (below) for image impedances

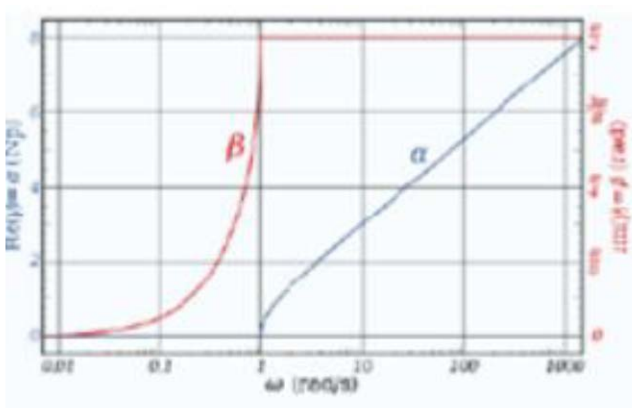
$$\lim_{Z.Y \to 0} Z_i = k$$

The image impedances of the section are given by

$$Z_{iT}{}^2 = Z^2 + k^2$$

Provided that the filter does not contain any resistive elements, the image impedance in the pass band of the filter is purely real and in the stop band it is purely imaginary. For example, for the pictured low-pass half-section.

Transmission parameters



The transfer function of a constant k prototype low-pass filter for a single half-section showing attenuation in nepers and phase change in radians.

The transmission parameters for a general constant k half-section are given by

$$\gamma = \sinh^{-1} \frac{Z}{k}$$

There are four types of filter that can be defined. Each different type rejects or accepts signals in a different way, and by using the correct type of RF filter it is possible to accept the required signals and reject those that are not wanted. The four basic types of RF filter are:

- ☐ Low pass filter
- ☐ High pass filter
- ☐ Band pass filter

☐ Band stop filter

As the names of these types of RF filter indicate, a low pass filter only allows frequencies below what is termed the cut off frequency through. This can also be thought of as a high reject filter as it rejects high frequencies. Similarly a high pass filter only allows signals through above the cut off frequency and rejects those below the cut off frequency. A band pass filter allows frequencies through within a given pass band. Finally the band reject filter rejects signals within a certain band. It can be particularly useful for rejecting a particular unwanted signal or set of signals falling within a given bandwidth.

Filter frequencies

A filter allows signals through in what is termed the pass band. This is the band of frequencies below the cut off frequency for the filter. The cut off frequency of the filter is defined as the point at which the output level from the filter falls to 50% (-3 dB) of the in band level, assuming a constant input level. The cut off frequency is sometimes referred to as the half power or -3 dB frequency. The stop band of the filter is essentially the band of frequencies that is rejected by the filter. It is taken as starting at the point where the filter reaches its required level of rejection.

Unit V

Waveguides and Cavity Resonators

Part-A

1. What are guided waves? Give examples
The electromagnetic waves that are guided along or over conducting or dielectric surface are called guided waves.
Examples: Parallel wire, transmission lines

2. What is TE wave or H wave?
Transverse electric (TE) wave is a wave in which the electric field strength E is entirely transverse. It has a magnetic field strength Hz in the direction of propagation and no component of electric field Ez in the same direction

3. Why is circular or rectangular form used as waveguide?
Waveguides usually take the form of rectangular or circular cylinders because of its simpler forms in use and less expensive to manufacture.

4. What is an evanescent mode?
When the operating frequency is lower than the cut-off frequency, the propagation constant becomes real i.e. The wave cannot be propagated. This non- propagating mode is known as evanescent mode.

5. What is the dominant mode for the TE waves in the rectangular waveguide?
The lowest mode for TE wave is TE10 (m=1 , n=0)

6. What is the dominant mode for the TM waves in the rectangular waveguide?
The lowest mode for TM wave is TM11(m=1 , n=1)

7. What is the dominant mode for the rectangular waveguide?
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.

8. Which are the non-zero field components for the for the TM11 mode in a rectangular waveguide?
Hx, Hy ,Ey. and Ez

9. Define characteristic impedance in a waveguide
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

10. Why TEM mode is not possible in a rectangular waveguide?
Since TEM wave do not have axial component of either E or H ,it cannot propagate within a single conductor waveguide

11. Explain why TM01 and TM10 modes in a rectangular waveguide do not exist.
For TM modes in rectangular waveguides, neither m or 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.

12. What are degenerate modes in a rectangular waveguide?
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.

13. What is TH wave or E wave?
Transverse magnetic (TM) wave is a wave in which the magnetic field strength H is entirely transverse. It has a electric field strength Ez in the direction of propagation and no component of magnetic field Hz in the same direction

14. What is a TEM wave or principal wave?
TEM wave is a special type of TM wave in which an electric field E along the direction of propagation is also zero. The TEM waves are waves in which both electric and magnetic fields are transverse entirely but have no components of Ez and Hz .it is also referred to as the principal wave.

15. What is a dominant mode?
The modes that have the lowest cut off frequency is called the dominant mode.

16. Give the dominant mode for TE and TM waves
Dominant mode: TE10 and TM10

17. What is cut off frequency?
The frequency at which the wave motion ceases is called cut-off frequency of the waveguide.

18. What is cut-off wavelength?
It is the wavelength below which there is wave propagation and above which there is no wave propagation.

19. Write down the expression for cut off frequency when the wave is propagated inbetween two parallel plates.
The cut-off frequency, fc = m/ (2a (μE)1/2)

20. Mention the characteristics of TEM waves.
a) It is a special type of TM wave
b) It doesn't have either e or H component
c) Its velocity is independent of frequency
d) Its cutoff frequency is zero.

21. Define attenuation factor
Attenuation factor = (Power lost/ unit length)/(2 x power transmitted)

22. Give the relation between the attenuation factor for TE waves and TM waves
aTE = aTM (fc/f)2

23. Define wave impedance
Wave impedance is defined as the ratio of electric to magnetic field strength Zxy= Ex/ Hy in the positive direction
Zxy= -Ex/ Hy in the negative direction

24. What is a parallel plate wave guide?
Parallel plate wave guide consists of two conducting sheets separated by a dielectric material.

25. Why are rectangular wave-guides preferred over circular wave-guides?
Rectangular wave-guides preferred over circular wave guides because of the following reasons.
a) Rectangular wave guide is smaller in size than a circular wave guide of the same operating frequency
b) It does not maintain its polarization through the circular wave guide c) The frequency difference between the lowest frequency on dominant mode and the next mode of a rectangular wave-guide is bigger than in a circular wave guide.

26.Mention the applications of wave guides
The wave guides are employed for transmission of energy at very high frequencies where the attenuation caused by wave guide is smaller. Waveguides are used in microwave transmission.Circular waveguides are used as attenuators and phase shifters

27.What is a circular waveguide?
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

28. Why circular waveguides are not preferred over rectangular waveguides?
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.

29. Mention the applications of circular waveguide.
Circular waveguides are used as attenuators and phase-shifters

30. What are the possible modes for TM waves in a circular waveguide?
The possible TM modes in a circular waveguide are : TM01 , TM02 , TM11, TM12

31. What are the root values for the TM modes?
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

32. Define dominant mode for a circular waveguide.
The dominant mode for a circular waveguide is defined as the lowest order mode having the lowest root value.

33. What are the possible modes for TE waves in a circular waveguide?
The possible TE modes in a circular waveguide are: TE01, TE02, TE11and TE12.

34. What are the root values for the TE modes?
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

35. What is the dominant mode for TE waves in a circular waveguide.
The dominant mode for TE waves in a circular waveguide is the TE11 because it has the lowest root value of 1.841

36. What is the dominant mode for TM waves in a circular waveguide
The dominant mode for TM waves in a circular waveguide is the TM01 because it has the lowest root value of 2.405.

37. What is the dominant mode in a circular waveguide

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.

38. Mention the dominant modes in rectangular and circular waveguides

For a rectangular waveguide,the dominant mode is TE01 For a circular waveguide, the dominant mode is TE11

39. Why is TM01 mode preferred to the TE01 mode in a circular waveguide?

TM01 mode is preferred to the TE01 mode in a circular waveguide, since it requires a smaller diameter for the same cut off wavelength.

40. Define quality factor of a resonator.

The quality factor Q is a measure of frequency selectivity of the resonator. It is defined as Q =2 _ x Maximum energy stored / Energy dissipated per cycle = _ W/ P Where W is the maximum stored energy P is the average power loss

41. What is a resonator?

Resonator is a tuned circuit which resonates at a particular frequency at which the energy stored in the electric field is equal to the energy stored in the magnetic field.

42.How the resonator is constructed at low frequencies?

At low frequencies upto VHF (300 MHz) , the resonator is made up of the reactive elements or the lumped elements like the capacitance and the inductance.

43. What are the disadvantages if the resonator is made using lumped elements at high frequencies?

1) The inductance and the capacitance values are too small as the frequency is increased beyond the VHF range and hence difficult to realize .

44. What are the methods used for constructing a resonator?

The resonators are built by

a) using lumped elements like L and C

b) using distributed elements like sections of coaxial lines

c) using rectangular or circular waveguide

Part-B

1. Give a brief note on the transmission of TEM waves between parallel plates.

Using the general equations for the transverse fields of guided waves [Equation (3)], we see that the transverse fields of a TEM mode (defined by *Ez* = *Hz* = 0) are non-zero only when *kc* = 0. When the cutoff wavenumber of the TEM mode is zero, an indeterminant form of (0/0) results for each of the transverse field equations

$$E_x = \frac{-j}{k_c^2}\left(\beta\frac{\partial E_z}{\partial x} + \omega\mu\frac{\partial H_z}{\partial y}\right) \qquad \text{(3a)}$$

$$E_y = \frac{j}{k_c^2}\left(-\beta\frac{\partial E_z}{\partial y} + \omega\mu\frac{\partial H_z}{\partial x}\right) \qquad \text{(3b)}$$

$$H_x = \frac{j}{k_c^2}\left(\omega\varepsilon\frac{\partial E_z}{\partial y} - \beta\frac{\partial H_z}{\partial x}\right) \qquad \text{(3c)}$$

$$H_y = \frac{-j}{k_c^2}\left(\omega\varepsilon\frac{\partial E_z}{\partial x} + \beta\frac{\partial H_z}{\partial y}\right) \qquad \text{(3d)}$$

A zero-valued cutoff wave number yields the following

$$k_c^2 = k^2 - \beta^2 = 0 \quad \rightarrow \quad \beta = k = \omega\sqrt{\mu\varepsilon}$$

$$k_c = \omega_c\sqrt{\mu\varepsilon} = 2\pi f_c\sqrt{\mu\varepsilon} = 0 \quad \rightarrow \quad f_c = 0$$

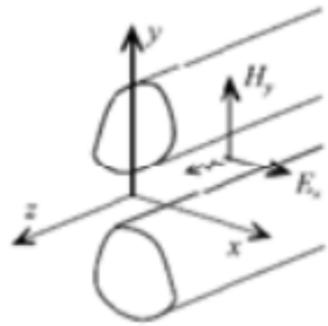
The first equation above shows that the phase constant â of the TEM mode on a guiding structure is equivalent to the phase constant of a plane wave propagating in a region characterized by the same medium between the conductors of the guiding structure. The second equation shows that the cutoff frequency of a TEM mode is 0 Hz. This means that TEM modes can be propagated at any non-zero frequency assuming the guiding structure can support a TEM mode.

Relationships between the transverse fields of the TEM mode can be determined by returning to the source-free Maxwell's equation results for guided waves [Equations (1) and(2)] and setting *Ez* = *Hz* = 0 and â = *k*.

$$E_x = \frac{k}{\omega\varepsilon} H_y$$

$$E_y = -\frac{k}{\omega\varepsilon} H_x$$

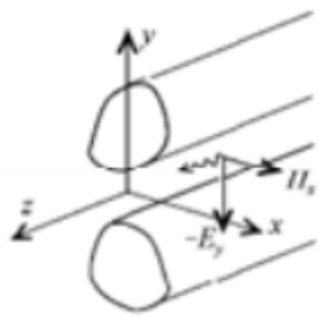
$$\frac{\partial H_y}{\partial x} = \frac{\partial H_x}{\partial y}$$



$$H_x = -\frac{k}{\omega\mu} E_y$$

$$H_y = \frac{k}{\omega\mu} E_x$$

$$\frac{\partial E_y}{\partial x} = \frac{\partial E_x}{\partial y}$$



Note that the ratios of the TEM electric and magnetic field components define wave impedances which are equal to those of equivalent plane waves.

$$\frac{E_x}{H_y} = \frac{k}{\omega\varepsilon} = \frac{\omega\mu}{k} = \sqrt{\frac{\mu}{\varepsilon}} = \eta = Z_{TEM} \quad \rightarrow \quad E_x = Z_{TEM} H_y$$

$$\frac{-E_y}{H_x} = \frac{k}{\omega\varepsilon} = \frac{\omega\mu}{k} = \sqrt{\frac{\mu}{\varepsilon}} = \eta = Z_{TEM} \quad \rightarrow \quad E_y = -Z_{TEM} H_x$$

According to the previous result, the transverse fields of the TEM mode must satisfy Laplace's equation with boundary conditions defined by the conductor geometry of the guiding structure, just like the static fields which would exist on the guiding structure for $f = 0$. Thus, the TEM transverse field vectors ***e***(x,y) and ***h***(x,y) are identical to the static fields for the transmission line. This allows us to solve for the static fields of a given guiding structure geometry (Laplace's equation) to determine the fields of the TEM mode.

2. Give a brief note on the transmission of TE waves between parallel plates.

The transverse fields of TE modes are found by simplifying the general guided wave equations in (3) with $E_z = 0$. The resulting transverse fields for TE modes are

$$E_x = \frac{-j\omega\mu}{k_c^2}\frac{\partial H_z}{\partial y} \qquad (4a)$$

$$E_y = \frac{j\omega\mu}{k_c^2}\frac{\partial H_z}{\partial x} \qquad (4b)$$

$$H_x = \frac{-j\beta}{k_c^2}\frac{\partial H_z}{\partial x} \qquad (4c)$$

$$H_y = \frac{-j\beta}{k_c^2}\frac{\partial H_z}{\partial y} \qquad (4d)$$

The cutoff wave number *kc* must be non-zero to yield bounded solutions for the transverse field components of TE modes. This means that we must operate the guiding structure above the corresponding cutoff frequency for the particular TE mode to propagate.Note that all of the transverse field components of the TE modes can be determined once the single longitudinal component (*Hz*) is found. The longitudinal field component *Hz* must satisfy the wave equation so that

$$\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + \frac{\partial^2 H_z}{\partial z^2} + k^2 H_z = 0$$

$$\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} - \beta^2 H_z + k^2 H_z = 0$$

$$\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + k_c^2 H_z = 0$$

Given the basic form of the guided wave magnetic field

$$\boldsymbol{H}(x,y,z) = [\boldsymbol{h}(x,y) + h_z(x,y)\boldsymbol{a}_z]\, e^{-j\beta z}$$

$$H_z(x,y,z) = h_z(x,y)\, e^{-j\beta z}$$

We write

$$\frac{\partial^2 h_z(x,y)}{\partial x^2} + \frac{\partial^2 h_z(x,y)}{\partial y^2} + k_c^2 h_z(x,y) = 0$$

The equation above represents a reduced Helmholtz equation which can be solved for *hz*(*x,y*) based on the boundary conditions of the guiding structure geometry. Once *hz*(*x,y*) is found, the longitudinal magnetic field is known, and all of the transverse field components are found by evaluating the derivatives in Equation (4).

The wave impedance for TE modes is found from Equation (4):

$$Z_{TE} = \frac{E_x}{H_y} = \frac{-E_y}{H_x} = \frac{\omega\mu}{\beta} = \frac{k\eta}{\beta}$$

Note that the TE wave impedance is a function of frequency.

3. Give a brief note on the transmission of TM waves between parallel plates.

The transverse fields of TM modes are found by simplifying the general guided wave equations in (3) with *Hz* = 0. The resulting transverse fields for TM modes are

$$E_x = \frac{-j\beta}{k_c^2}\frac{\partial E_z}{\partial x} \qquad (5a)$$

$$E_y = \frac{-j\beta}{k_c^2}\frac{\partial E_z}{\partial y} \qquad (5b)$$

$$H_x = \frac{j\omega\varepsilon}{k_c^2}\frac{\partial E_z}{\partial y} \qquad (5c)$$

$$H_y = \frac{-j\omega\varepsilon}{k_c^2}\frac{\partial E_z}{\partial x} \qquad (5d)$$

The cutoff wavenumber *kc* must also be non-zero to yield bounded solutions for the transverse field components of TM modes so that we must operate the guiding structure above the corresponding cutoff frequency for the particular TMmode to propagate. Note that all of the transverse field components of the TMmodes can be determined once the single longitudinal component (*Ez*) is found. The longitudinal field component *Ez* must satisfy the wave equation so that

$$\frac{\partial^2 E_z}{\partial x^2} + \frac{\partial^2 E_z}{\partial y^2} + \frac{\partial^2 E_z}{\partial z^2} + k^2 E_z = 0$$

$$\frac{\partial^2 E_z}{\partial x^2} + \frac{\partial^2 E_z}{\partial y^2} - \beta^2 E_z + k^2 E_z = 0$$

$$\frac{\partial^2 E_z}{\partial x^2} + \frac{\partial^2 E_z}{\partial y^2} + k_c^2 E_z = 0$$

Given the basic form of the guided wave electric field

$$\boldsymbol{E}(x,y,z) = [\boldsymbol{e}(x,y) + e_z(x,y)\boldsymbol{a}_z]\, e^{-j\beta z}$$

$$E_z(x,y,z) = e_z(x,y)\, e^{-j\beta z}$$

We may write

$$\frac{\partial^2 e_z(x,y)}{\partial x^2} + \frac{\partial^2 e_z(x,y)}{\partial y^2} + k_c^2 e_z(x,y) = 0$$

The equation above represents a reduced Helmholtz equation which can be solved for *ez*(*x,y*) based on the boundary conditions of the guiding structure geometry. Once *ez*(*x,y*) is found, the longitudinal magnetic field is known, and all of the transverse field components are found by evaluating the derivatives in Equation.

4. Explain resonator and its types in detail.

Resonator is a tuned circuit which resonates at a particular frequency at which the energy stored in the electric field is equal to the energy stored in the magnetic field.

Resonant frequency of microwave resonator is the frequency at which the energy in the resonator attains maximum value. i.e., twice the electric energy or magnetic energy.

At low frequencies upto VHF (300 MHz), the resonator is made up of the reactive elements or the lumped elements like the capacitance and the inductance.

The inductance and the capacitance values are too small as the frequency is increased beyond the VHF range and hence difficult to realize.

Transmission line resonator can be built using distributed elements like sections of coaxial lines. The coaxial lines are either opened or shunted at the end sections thus confining the electromagnetic energy within the section and acts as the resonant circuit having a natural resonant frequency.

At very high frequencies transmission line resonator does not give very high quality factor Q due to skin effect and radiation loss. So, transmission line resonator is not used as microwave resonator.
The performance parameters of microwave resonator are:
(i) Resonant frequency
(ii) Quality factor
(iii) Input impedance

Quality Factor of a Resonator.:
• The quality factor Q is a measure of frequency selectivity of the resonator.
• It is defined as Q = 2 x Maximum energy stored / Energy dissipated per cycle = W / P
Where,
W is the maximum stored energy
P is the average power loss

The methods used for constructing a resonator:
The resonators are built by
a) Using lumped elements like L and C
b) Using distributed elements like sections of coaxial lines
c) Using rectangular or circular waveguide
There are two types of cavity resonators.
a) Rectangular cavity resonator
b) Circular cavity resonator

5. Explain the rectangular cavity resonator in detail.
Rectangular or circular cavities can be used as microwave resonators because they have natural resonant frequency and behave like a LCR circuit.

Cavity resonator can be represented by a LCR circuit as:

The electromagnetic energy is stored in the entire volume of the cavity in the form of electric and magnetic fields.

The presence of electric field gives rise to a capacitance value and the presence of magnetic field gives rise to a inductance value and the finite conductivity in the walls gives rise to loss along the walls giving rise to a resistance value.

Thus the cavity resonator can be represented by a equivalent LCR circuit and have a natural resonant frequency.

Cavity resonators are formed by placing the perfectly conducting sheets on the rectangular or circular waveguide on the two end sections and hence all the sides are surrounded by the conducting walls thus forming a cavity.