**UNIT1:waveguides**

**Rectangular waveguide:** A hollow metallic tube with rectangular cross section. The conducting walls confine the EM fields and guide the EM wave. A number of modes or distinct field configuration can exist in it. When the waves travel longitudinally down the guide, the plane waves are reflected from wall to wall. This process results in a component of either electric or magnetic field in the direction of propagation of the resultant wave; therefore the wave is no longer a transverse electromagnetic (TEM) wave.



Fig.1 .Rectangular Waveguide

The electric and magnetic wave equations in the frequency domain are given by

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**Where** ϒ **=**α +jβ, these are called vector wave equations . the rectangular components of H or E satisfy the complex scalar wave equation or Helmoltz equation

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The equation in rectangular coordinate system is written as

 + = 4

 Z 5

 + = 6

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 = 8

= 9

 = 10

Solutions of equations 8,9 and 10 will be in the form of

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The total solution of the Helmholtz equation in rectangular coordinate system can be written a

The propagation of the wave in the guide is conventionally assumed in the + Z direction. Propagation constant in the guide differs from the intrinsic propagation constant of the dielectric where

=-16

Kc is called cutoff wave number. There are three cases for the propagation constant in the wave guide.

Case I: there will be no propagation in the guide ifand.

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Case II: The wave will propagate in the guide if and

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This means that the operating frequency must be above the cutoff frequency for the wave topropagate in the guide.

Case III: the wave will be attenuated if and

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If the operating frequency is below the cut-off frequency, the wave will decay exponentially and there will be no propagation as the propagation constant is a real quantity. Therefore the solution to the Helmholtz equation is expressed as

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**TE Modes in Rectangular wave guide :** the modes in rectangular waveguide are characterized by .and to have energy transmission in wave guide

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We substitute and in the above equations and have as

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Solving the above equations, we can have

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where

At the conducting walls of the waveguide, the tangential component of electric field will vanish out. Boundary conditions (1) at y = 0 and y = b; ,by this condition,we get constant C = 0 and and(2) at x = 0 and a; =0 by this condition, we get constant A = 0 and .

By manipulating the equations, we get

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BD = is replaced in the above equation and it becomes

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Except m=n=0,we can place m=0,1,2… and n=0,1,2…,

**TM Modes in Rectangular wave guide:** The modes in rectangular waveguide are characterized by .and to have energy transmission in wave guide

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Comparing the cofactors of both the matrices with equivalent equation coefficients, we get

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We substitute and in the above equations and have as

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Solving the above equations ,we can have

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Where

At the conducting walls of the waveguide, the tangential component of electric field will vanish out. Boundary conditions (1) at y = 0 and y = b; ,by this condition, we get constant D = 0 and and(2) at x = 0 and a; by this condition,we get constant B = 0 and .

By manipulating the equations, we get

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AC= is replaced in the above equation and it becomes

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Except m=n=0,we can place m=0,1,2… and n=0,1,2…,

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**Phase Velocity**:

It is defined as the rate at which the wave changes its phase in terms of the guide wavelength and mathematically expressed as and phase velocity is greater than the speed of light in the wave guide.

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 Where 71

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The cut off wavelength 73

Where f:Operating frequency and : Cut-off frequency

 λ:Operating frequency and : Cut-off frequency

If media is vacuum in the waveguide, then

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**Group velocity:** We know that phase constant can be defined as the rate at which wave propagates through the waveguide and mathematically expressed as .it can be derived by

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Differentiating the phase constant with reference to

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The group velocity is defined as:

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**- 79**

**GUIDE WAVE LENGTH**: The distance travelled by the wave in order to undergo a phase shift of 2π radians in the wave guide .It is related to the phase constant by the relation

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The wave length in the waveguide is different from the wavelength in free space.

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The equation is true for any mode in a wave guide of any cross section if cut-off wavelength corresponds to the mode and the cross section of the waveguide. is related with λ the operating wavelength in equation

**Wave Impedance in the transverse Electric Mode**

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**Wave Impedance in the transverse Magnetic Mode**

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**Circular wave guide:** A metallic hollow tube of circular cross-section for guided propagation of electromagnetic wave from transmitter to antenna and antenna to receiver at microwave frequency.



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 is the n th order Bessel function of the first kind, representing a standing wave of cos for ,for lossless propagation of the wave in the guide ,propagation constant .

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 is the n th order Bessel function of the first kind, representing a standing wave of cosfor and is the n th order Bessel function of the second kind, representing a standing wave of sin for .At , ,so,it means that at on z-axis,the field must be finite.

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Where and tan

More conveniently, the equation can be written for +z direction propagation as

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TEnp –mode in circular waveguide: The modes in circular waveguide are characterized by and to have energy transmission in wave guide.

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At r=a,

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here the prime denotes the differentiation with respect to at r=a

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 The root of this equation is denoted by

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Table 1.1 pth zeroes of for TEnp -modes

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| P | n=0 | 1 | 2 | 3 | 4 |
| 1 | 3.832 | 1.841 | 3.054 | 4.201 | 5.317 |
| 2 | 7.016 | 5.331 | 6.706 | 8.015 | 9.282 |
| 3 | 10.173 | 8.536 | 9.969 | 11.170 | 12.682 |
| 4 | 13.324 | 11.706 | 13.170 |  |  |

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We substitute and in the above equations and have as

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 109 113

110 114

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Solving the above equations ,we can have

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where

Replacing andin all the equations

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 TMnp –mode in circular waveguide: The modes in circular waveguide are characterized by and to have energy transmission in wave guide.

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 is an oscillating function having infinite roots.

By applying the boundary condition; at r=a,the electric field component in z-direction Ez becomes zero

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The root of this equation is denoted by

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Table 1.1 pth roots of for TMnp -modes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| p | n=0 | 1 | 2 | 3 |
| 1 | 2.405 | 3.832 | 5.136 | 6.380 |
| 2 | 5.520 | 7.106 | 8.417 | 9.761 |
| 3 | 8.645 | 10.173 | 11.620 | 13.015 |
| 4 | 11.792 | 13.32 | 14.796 |  |

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We substitute and in the above equations and have as

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Solving the above equations ,we can have

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where

Replacing and in all the equations

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MICROWAVE CAVITIES:

cavity resonator is a metallic enclosure that confines the electromagnetic energy within it .the electric and magnetic energies inside the cavity determine its equivalent inductance and capacitance . The energy dissipated by the finite conductivity of the cavity walls determines its equivalent resistance . In practice ,the rectangular cavity resonator and reentrant –cavity resonator are commonly used in microwave applications .

Theoretically a given resonator has an infinite number of resonant modes ,and each mode corresponds to a definite resonant frequency .when the frequency of an impressed signal is equal to a resonant frequency ,maximum amplitude of the standing wave occurs ,and the peak energies stored in the electric and magnetic fields are equal. The mode having the lowest resonant frequency is known as the dominant mode.

**Rectangular cavity resonator:**

The electromagnetic field inside the cavity should satisfy the maxwell’s equations .subject to the boundary conditions that the electric field tangential to and the magnetic field normal to the metal walls must vanish. The wave equations in rectangular resonator should satisfy the boundary conditions of the zero tangential E at four walls .the fieldequation in rectangular wave guide is given by

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n =0,1,2,3… number of half wave periodicity in the x-direction

m =0,1,2,3… number of half wave periodicity in the y-direction

p = 1,2,3… number of half wave periodicity in the z-direction

 159

n =1,2,3… number of half wave periodicity in the x-direction

m =1,2,3… number of half wave periodicity in the y-direction

p =0, 1,2,3… number of half wave periodicity in the z-direction

 The separation equation for both TE and TM mode is given by

 160

In general , a straight wire probe inserted at the position of maximum electric intensity is used to excite a desired mode , and the loop coupling placed at the position of maximum magnetic intensity is utilized to launch a specific mode .

**Circular cavity resonator:**

 A circular cavity resonator is a circular waveguide closed at both the ends .

, 161 (forTEnpq)

n =0,1,2,3… number of the periodicity in the -direction

p =1,2,3… number of zeros of field in the radial direction

q =0, 1,2,3… number of half wave periodicity in the axial-direction

 162 ( for TMnpq)

n =0,1,2,3… number of the periodicity in the -direction

p =1,2,3… number of zeros of field in the radial direction

q =0, 1,2,3… number of half wave periodicity in the axial-direction

,the resonant frequency is given by

 for TE modes

 ` 163

 For TM modes

 164

**A semi circular cavity resonator**

A semi circular cavity resonator is a half circular waveguide closed at both the ends .

, 165 (for TEnpq)

n =0,1,2,3… number of the periodicity in the -direction

p =1,2,3… number of zeros of field in the radial direction

q = 1,2,3… number of half wave periodicity in the axial-direction

 166 ( forTMnpq)

n =0,1,2,3… number of the periodicity in the -direction

p =1,2,3… number of zeros of field in the radial direction

q = 1,2,3… number of half wave periodicity in the axial-direction

,the resonant frequency is given by

 for TE modes

 167

 For TM modes

 168

TE111-mode is dominant if d≥a, TM110-mode is dominant if a≥d

Q-factor:

The Q-factor is a measure of the frequency selectivity of a resonator or antiresonant circuit , and it is defined as

 where we can define

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**Power losses in wave guide :**

There two types of losses in wave guide

1. Losses in the dielectric

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1. Losses in waveguide walls

 watt/ unit length 174

 175

**Micro strip lines**

 ***INTRODUCTION***

Prior to 1965 nearly all microwave equipment utilized coaxial, waveguide, or parallel

strip-line circuits. In recent years-with the introduction of monolithic microwave

integrated circuits (MMICs)-microstrip lines and coplanar strip lines have

been used extensively, because they provide one free and accessible surface on which

solid-state devices can be placed. In this chapter parallel, coplanar, and shielded strip lines and microstrip lines will be studied.l

Electrical and electronic devices with high-power output commonly use conventional

lines, such as coaxial lines or waveguides, for power transmission. However, the microwave

solid-state device is usually fabricated as a semiconducting chip with a volume

on the order of 0.008-0.08 mm3.• The method of applying signals to the chips

and extracting output power from them is entirely different from that used for

vacuum-tube devices. Microwave integrated circuits with microstrip lines are commonly

used with the chips.The microstrip line is also called an *open-strip line.* In

engineering applications.

Modes on microstrip line are only quasi-transverse electric and magnetic

(TEM). Thus the theory of TEM-coupled lines applies only approximately.

 Radiation loss in microstrip lines is a problem, particularly at such discontinuities as shortcircuit posts, corners, and so on. However, the use of thin, high-dielectric materials

considerably reduces the radiation loss of the open strip. A microstrip line has an advantage

over the balanced-strip line because the open strip has better interconnection

features and easier fabrication.



1. Micro strip line pictorial view (b) Field radiation from the microstrip line

**Characteristic Impedance of Microstrip lines**:

 Microstrip lines are used extensively to interconnect high-speed logic circuits in digital

computers because they can be fabricated by automated techniques and they provide the required uniform signal paths.



Fig2. cross sections of (a) micro strip line (b) wire over ground

 Microstripline is a function of the strip-line width, the strip-line thickness, the distance between the line and the ground plane, and the homogeneous dielectric constant of the

board material.The well-known equation of the characteristic impedance of a wire-over-ground transmission line is indited as

 176

where = dielectric constant of the ambient medium

*h* = the height from the center of the wire to the ground plane

*d* = diameter of the wire

If the effective or equivalent values of the relative dielectric constant of the ambient

medium and the diameter *d* of the wire can be determined for the microstrip line, the characteristic impedance of the microstrip line can be calculated. The equivalent relation ship is established by the following formulae for cross sections of microstrip line and the wire over ground shown in figure 2.

= 0.475 + 0.67 177

*d* = 0.67w (o.8 + ) 178

replacing the equations 177 and 178 in equation 176,the following relation is received.

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Most microstrip lines are made from boards of copper with a thickness of 1.4 or 2.8 mils (1 or 2 ounces of copper per square foot). The narrowest widths of lines in production are about 0.005-0.010 in.Line widths are usually less than 0.020 in.; consequently, ratios of thickness to

width of less than 0.1 are uncommon. The straight-line approximation from Eq177 is an accurate value of characteristic impedance, or the ratio of thickness to width between 0.1 and 0.8. The dielectric constant of the materials used does not vary excessively

with frequency, the dielectric constant of a microstrip line can be considered independent

of frequency. The validity of Eq. 179 is doubtful for values of dielectric thickness *h* that are greater than 80% of the line width *w.* Typical values for the characteristic impedance of a microstrip line vary from 50 n to 150 n, if the values of the parameters vary from = 5.23, *t* = 2.8 mils, *w* = 10 mils, and *h* = 8 mils to = 2.9, *t* = 2.8 mils, *w* = 10 mils, and *h* = 67 mils

**Losses in microstrip lines**:

The attenuation constant of the dominant microstrip mode depends on geometric factors, electrical properties of the substrate and conductors, and on the frequency. For a nonmagnetic dielectric substrate, two types of losses occur in the dominant microstrip mode: (1) dielectric loss in the substrate and (2) ohmic skin loss in the strip conductor and the ground plane. The sum of these two losses may be expressed as losses per unit length in terms of an attenuation factor *α.*

 **Dielectric losses**:

 when the conductivity of a dielectric cannot be neglected, the electric and magnetic fields in the dielectric are no longer in time phase. In that case the dielectric attenuation constant is expressed as

 Np/cm 181

 Np/cm 182

where

 183

 *q* denotes the dielectric filling factor,

 **Ohmic losses:**

In a microstrip line over a low-loss dielectric substrate, the predominant sources of losses at microwave frequencies are the non perfect conductors.

The current density in the conductors of a microstrip line is concentrated in a sheet that is approximately a skin depth thick inside the conductor surface and exposed to the electric field. Both the strip conductor thickness and the ground plane ,thickness are assumed to be at least three or four skin depths thick. The current density in the strip conductor and the ground conductor is not uniform in the transverse plane. The microstrip conductor contributes the major part of the ohmic loss which can be expressed as

 dB/cm for 184

 **Radiation Loss**:

 In addition to the conductor and dielectric losses, microstrip line also has radiation losses. The radiation loss depends on the substrate's thickness and dielectric constant, as well as its geometry. the radiation loss for several discontinuities using the following approximations is calculated:

1**.** TEM transmission

2. Uniform dielectric in the neighborhood of the strip, equal in magnitude to an

effective value

3. Neglect of radiation from the transverse electric (TE) field component parallel

to the strip

4**.** Substrate thickness much less than the free-space wavelength

The ratio of radiated power to total dissipated power for an open-circuited micro strip line is expressed as

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The radiation factor decreases with increasing substrate dielectric constant.. The radiation loss decreases as the characteristic impedance increases. For lower dielectric-constant, Radiation is significant at higher impedance levels. For higher dielectric constant substrates, radiation becomes significant until very low impedance levels are reached.

**Q-factor:**

Many microwave integrated circuits require very high quality resonant circuits. The

quality factor *Q* of a microstrip line is very high, but it is limited by the radiation

losses of the substrates and with low dielectric constant.

Finally, the quality factor *Qc* of a wide microstrip line is given by

 187

Quality factor is related to the dielectric attenuation constant

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for the dielectric attenuation constant of a microstrip line is approximately the reciprocal of the dielectric loss tangent and is relatively constant with frequency.

***PARALLEL STRIP LINES***

A parallel strip line consists of two perfectly parallel strips separated by a perfect

dielectric slab of uniform thickness, as shown in the following figure. The plate width is *w,*

the separation distance is *d,* and the relative dielectric constant of the slab is ***εrd***



***figure***

***Distributed Parameters***

In a microwave integrated circuit a strip line can be easily fabricated on a dielectric

substrate by using printed-circuit techniques. A parallel stripline is similar to a

two-conductor transmission line, so it can support a quasi-TEM mode. Consider a

TEM-mode wave propagating in the positive *z* direction in a lossless strip line

*(R* = G = O). The electric field is in the y direction, and the magnetic field is in the

*x* direction. If the width *w* is much larger than the separation distance d, the fringing

capacitance is negligible. Thus the equation for the inductance along the two conducting

strips can be written as

 H/m

where *µ* is the permeability of the conductor. The capacitance between the two

conducting strips can be expressed as

 F/m

)

where *ε* is the permittivity of the dielectric slab.If the two parallel strips have some surface resistance and the dielectric substrate has some shunt conductance, however, the parallel stripline would have some losses. The series resistance for both strips is given by

where *Rs* is the conductor surface resistance . where *σ* is the conductivity of the dielectric substrate.

***11 ·2·2 Characteristic Impedance***

The characteristic impedance of a lossless parallel strip line is

***Attenuation Losses***

The propagation constant of a parallel strip line at microwave frequencies can be expressed

By

for *R*  *wL* and *G*  *wC*

Thus the attenuation and phase constants are

Np/m and

 rad/m

**Shielded strip lines**

A partially shielded strip line has its strip conductor embedded in a dielectric

medium, and its top and bottom ground planes have no connection, as



Figure.3. The shielded strip line

The characteristic impedance for a wide strip *(w/d* ~ 0.35)

*t* = the strip thickness

*d* = the distance between the two ground planes

 **C= ;**being the fringing capacitance