Compared to dominant waveguides operating at the same frequency, coaxial lines have a lower breakdown power due to reduced separation distance between the inner and outer conductors.

4.2.3 Strip Lines

Strip lines are essentially modifications of the two wire lines and coaxial lines. These are basically planar transmission lines that are widely used at frequencies from 100 MHz to 100 GHz. Fig. 4.2 shows a cross-sectional view of the strip line structure.

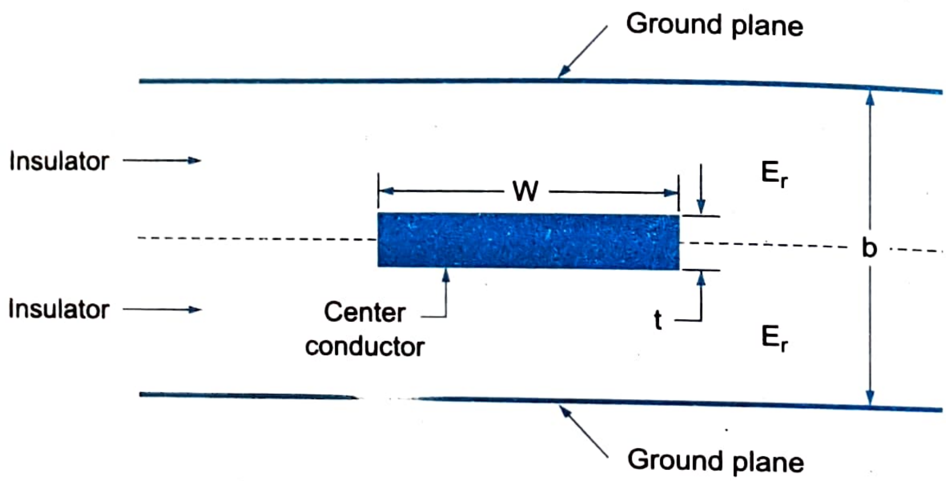


Fig. 4.2 Strip line transmission line.

As seen in Fig. 4.2, a strip line consists of a central thin conducting strip of width w which is greater than its thickness t, placed inside the low loss dielectric ($\in_r$) substrate of thickness $b/2$ between two wide ground plates. Usually the thicknesses of the metallic central conductor and the metallic ground planes are the same. The dominant mode for the strip line is a TEM mode shown in Fig. 4.3, and the fields are confined within the transmission line with no radiation losses. The width of the ground planes is atleast five times greater than the spacing between the plates there by avoiding any vertical side walls at the two transverse ends. There are practically no fringing fields after a certain distance from the edges of the centre conductor. For $b < \lambda/2$, there will be no propagation in the transverse direction.

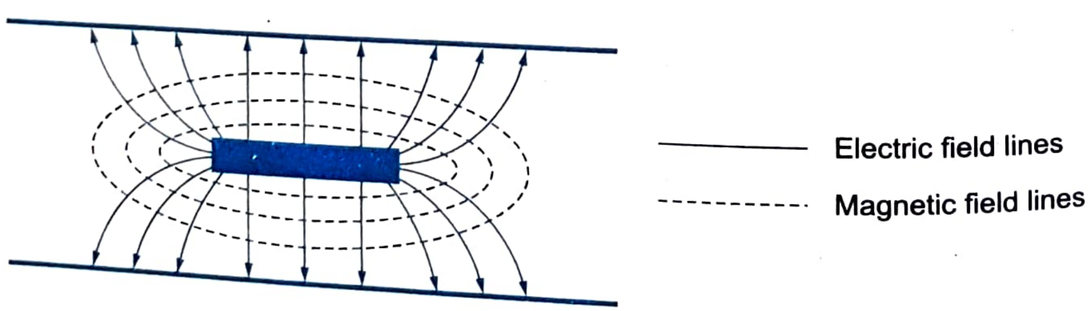


Fig. 4.3 TEM mode of strip line.

However, there are certain disadvantages of strip lines in that the circuit is not accessible during development for adjustment and tuning and also it is difficult to mount discrete and active components (like transistors, diodes, circulators, chip resistors, chip capacitors etc.).

The characteristic impedance of strip line has been analysed by a combination of analytical and empirical techniques by *H*. The design equations are divided into high-impedance region and low-impedance region determined by the ratio of w to $(b-t)$. The impedance of a strip line in inversally proportional to the ratio of the width w of the inner conductor to the distance b between the ground planes.

High Impedance Region:

$$\frac{w}{b-t} \leq 0.35 \quad \text{and} \quad \frac{t}{b} \leq 0.25$$

The characteristic impedance of a strip line in the high impedance region is given by

$$z_0 = \frac{60}{\sqrt{\epsilon_r}} \ln\left(\frac{4b}{\pi d}\right) \Omega \qquad ...(4.9)$$

where d is the diameter of a circular conductor equivalent to the rectangular conductor of the strip line with width w and thickness t

$$d = \frac{w}{2}\left\{1 + \frac{t\left[1 + \ln\left(\frac{4\pi W}{t}\right) + 0.51\pi\left(\frac{t}{w}\right)^2\right]}{\pi W}\right\} \qquad ...(4.10)$$

Low Impedance Region:

$$\frac{w}{b-t} > 0.35$$

Here

$$z_0 = \frac{94.15}{\sqrt{\epsilon_r}\left(\frac{W}{bA} + B\right)} \Omega \qquad ...(4.11)$$

where $A = 1 - \frac{t}{b}$ and

$$B = \frac{1}{\pi}\left[\frac{2}{A}\ln\left(1 + \frac{1}{A}\right) - \left(\frac{1}{A} - 1\right)\ln\left(\frac{1}{A^2} - 1\right)\right]$$

The velocity of propagation for the strip line transmission line is given by

$$v = \frac{c}{\sqrt{\epsilon_r}} \text{ m/s} \qquad ...(4.12)$$

and the wavelength of the electromagnetic signal on the strip line transmission line is given by

$$\lambda = \frac{v}{f} = \frac{c}{\sqrt{\epsilon_r} f} \text{ m} \qquad ...(4.13)$$

A graph of characteristic impedance (Z_0) vs strip width ratio (w/b) is used as a design aid for determining the width of the conductor for a strip line (as a function of Z_0, ϵ_r, t/b). Nowadays, computer aided design tools are available for designing strip line circuits and transmission lines.

4.2.4 Microstrip Line

Microstrip line is an unsymmetrical strip line that is nothing but a parallel plate transmi line having dielectric substrate, the one face of which is metallised ground and the other (top) has a thin conducting strip of certain width 'w' and thickness 't'. This is shown in Fig. 4.4. Th ground plane is not present in a microstrip as compared to a strip line. Sometimes a cover pla used for shielding purposes but it is kept much farther away than the ground plane so as n affect the microstrip field lines as shown in Fig. 4.5.

There are certain advantages of microstrip lines over strip lines, coaxial lines, and wavegui

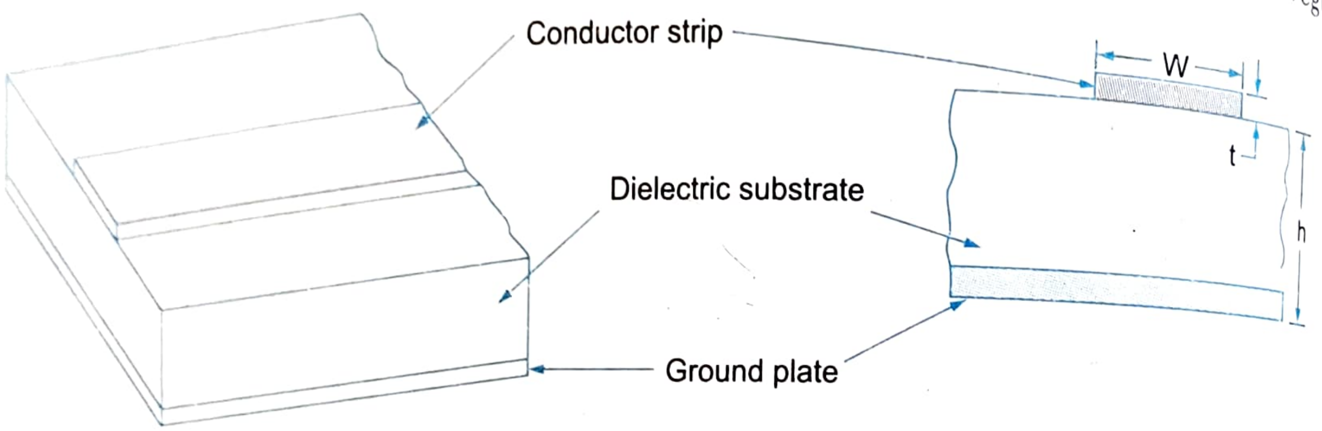


Fig. 4.4 Microstrip line.

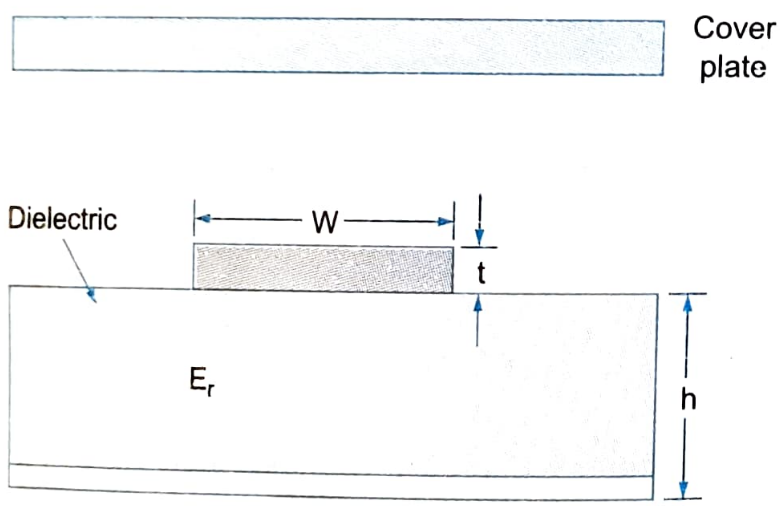


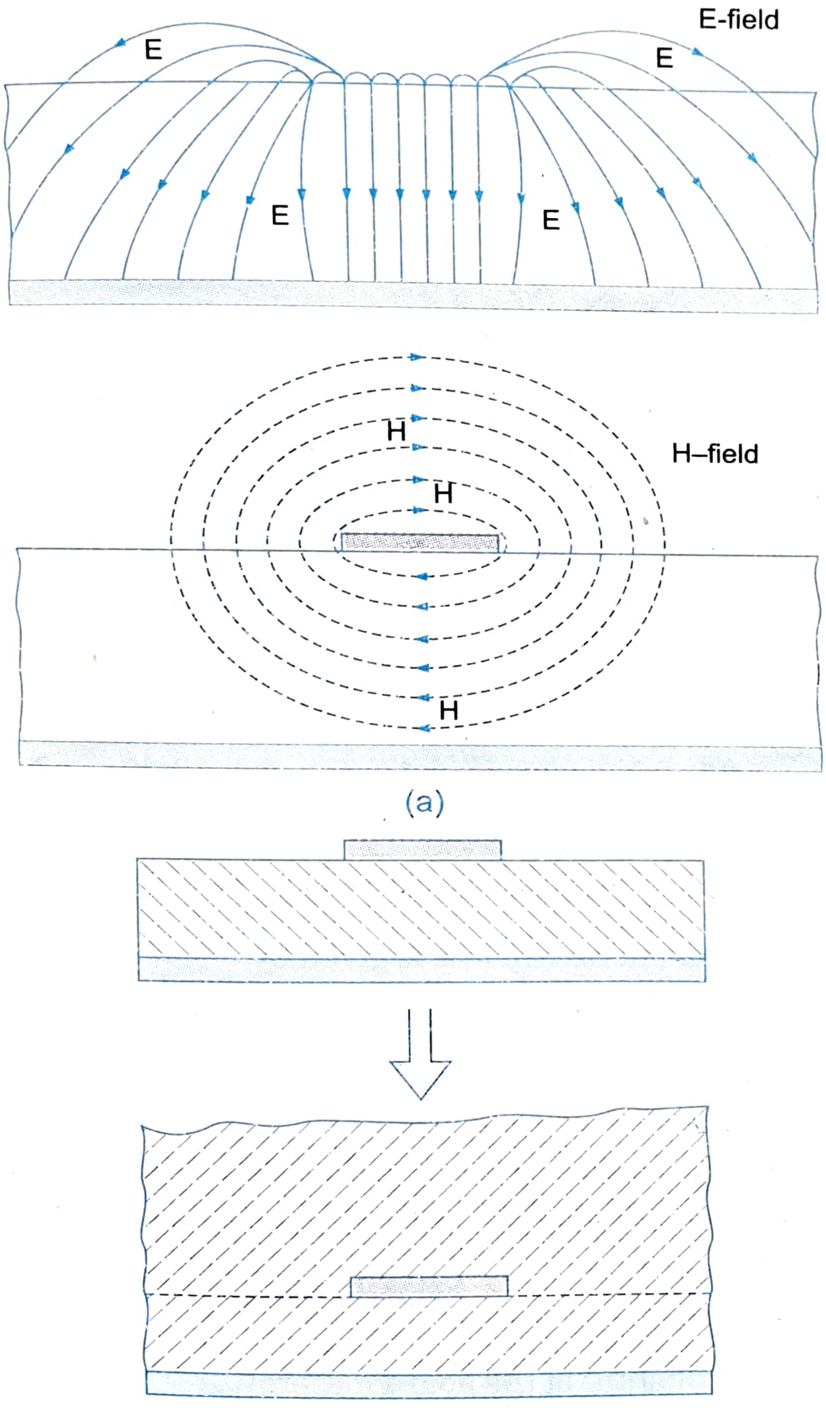
Fig. 4.5 Microstrip line with a cover plate.

1. Complete conductor pattern may be deposited and processed on a single dielectric substra which is supported by a single metal ground plane. Thus fabrication costs would b substantially lower than strip line, coaxial or waveguide circuits.
2. Due to the planar nature of the microstrip structure, both packaged and unpackage semiconductor chips can be conveniently attached to the microstrip element.
3. Also there is an easy access to the top surface making it easy to mount passive or acti discrete devices and also for making minor adjustments after the circuit has been fabricate This also allows access for probing and measurement purposes.

However, microstrips have some limitations too.

1. Due to the openness of the microstrip structure, they have higher radiation losses or interference due to nearby conductors. These can be reduced by choosing thin substrates with high dielectric constants.
2. Because of the proximity of the air-dielectric air interface with the microstrip conductor at the interface, a discontinuity in the electric and magnetic fields is generated. This results in a microstrip configuration that becomes a mixed dielectric transmission structure with unpure TEM modes propagating. This makes the analysis complicated.

The approximate distribution of electric and magnetic field is shown in Fig. 4.6.



(b)

Fig. 4.6 Approximate electric and magnetic field in a microstrip line.

We can see that there is a concentration of fields below the microstrip element. The electric flux crossing the air dielectric boundary is small and although a pure TEM mode cannot exist, a small deviation from TEM mode does exist which can be neglected.

The characteristic impedance of a microstrip is a function of the strip line width (w), thickness (t) and the distance between the line and the ground plane (h). In fact, the variation of characteristic impedance in terms of w/h ratio is shown in Fig. 4.7.

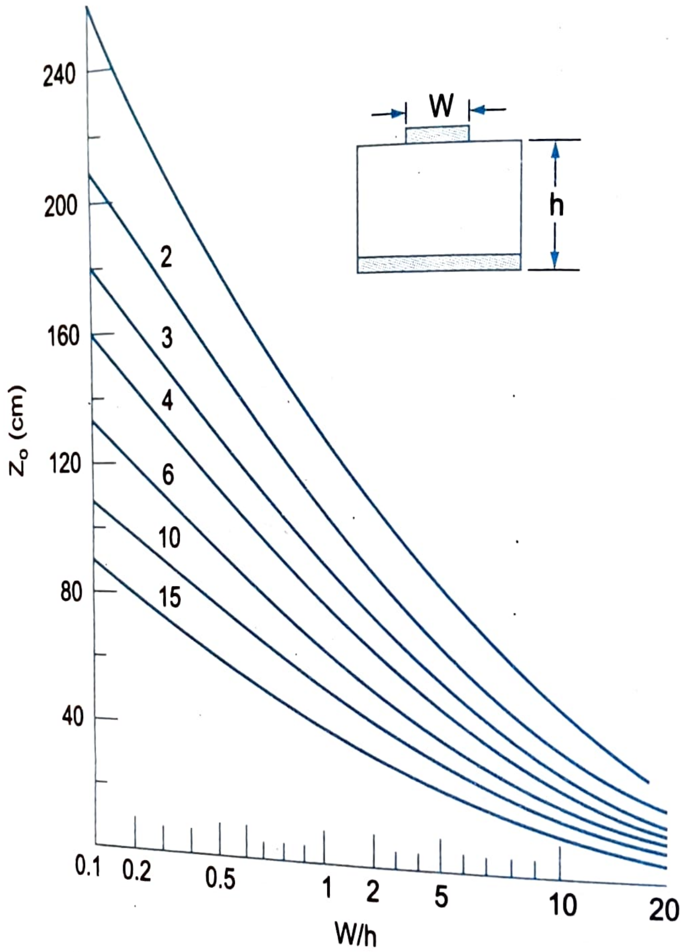


Fig. 4.7 Z_0 vs w/h ratios.

Empirical relation for Z_o for a microstrip line is given by

$$Z_o = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(\frac{4h}{d}\right) \text{for } h >> d \quad ...(4.14)$$

where, ε_r = dielectric constant of the dielectric medium

h = distance between the microstrip line and the ground plane

d = diameter of the wire (wire over ground transmission line).

Effective dielectric constant, (ε_{re}) also has an empirical relation given by (due to Digiacomo)

$$\varepsilon_{re} = 0.475\, \varepsilon_r + 0.67 \quad ...(4.15)$$

where, ε_r = relative dielectric constant of the board material.

ε_{re} = effective relative dielectric constant for a microstrip line.

Since the cross-section of microstrip line is rectangular, diameter (d) also has an empirical relation given by (due to Springfield),

$$d = 0.67\, w\left(0.8 + \frac{t}{w}\right) \qquad ...(4.16)$$

where symbols have their usual significance.

The phase velocity of a microstrip line is given by

$$V_p = V_c / \sqrt{\varepsilon_{re}} \qquad ...(4.17)$$

where, V_c = velocity of electromagnetic waves.

ε_{re} is given by an empirical relation (due to Schmeiter)

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10h}{w}\right)^{-1/2} \qquad ...(4.18)$$

Hence design of microstrip is quite complex as it has to take care of so many factors discussed above like w, h, ε_r, ε_{re}, ε_{eff} etc.

Taking into account the relationships for ε_{re} and d (from Eqs. 4.15 and 4.16), Z_o can be written as,

$$Z_o = \frac{87}{\sqrt{\varepsilon_r + 1.41}} \ln\left[\frac{5.98h}{0.8w + t}\right] \text{ for } h < 0.8\, w \qquad ...(4.19)$$

If $w >> h$, *i.e.*, for a wide microstrip line, Z_o is given by (as per Assadourian)

$$Z_o = \frac{377}{\sqrt{\varepsilon_r}} \cdot \frac{h}{w} \qquad ...(4.20)$$

The microstrip lines have a power handling capacity of a few watts which is quite adequate for most microwave circuits. Microstrip lines offer advantage of miniaturization but for long transmission lengths, they suffer from excessive attenuation per unit length. The attenuation of a microstrip depends upon the electric properties of the substrate and the conductors and also on the frequency. The attenuation constant α, is given by

$$\alpha = \alpha_d + \alpha_c \qquad ...(4.21)$$

where, α_d = dielectric attenuation constant (due to dielectric in substrate)

α_c = ohmic attenuation constant (due to ohmic skin losses in conductor and the ground plane)

Radiation loss of a microstrip line depends on the substrate thickness and dielectric constant as well as its geometry.

The quality factor Q of a microstrip line is very high which may be the requirement for high quality resonant MICs. It is however limited by the radiation losses of the substrate and with low dielectric constant. The Q of a microstrip line is given by

$$Q_d = \frac{1}{\tan\theta} \qquad ...(4.22)$$

where, θ = dielectric loss tangent.

4.2.5 Types of Microstrip Lines

There are many varieties of microstrip lines that have been used in practice such as embedded microstrip, standard inverted microstrip, suspended microstrip and slotted transmission line. The cross-sectional views of these are shown in Fig. 4.8. In addition to all these lines, some other TEM lines such as parallel strip lines, coplanar strip lines also have been used for MIC's.

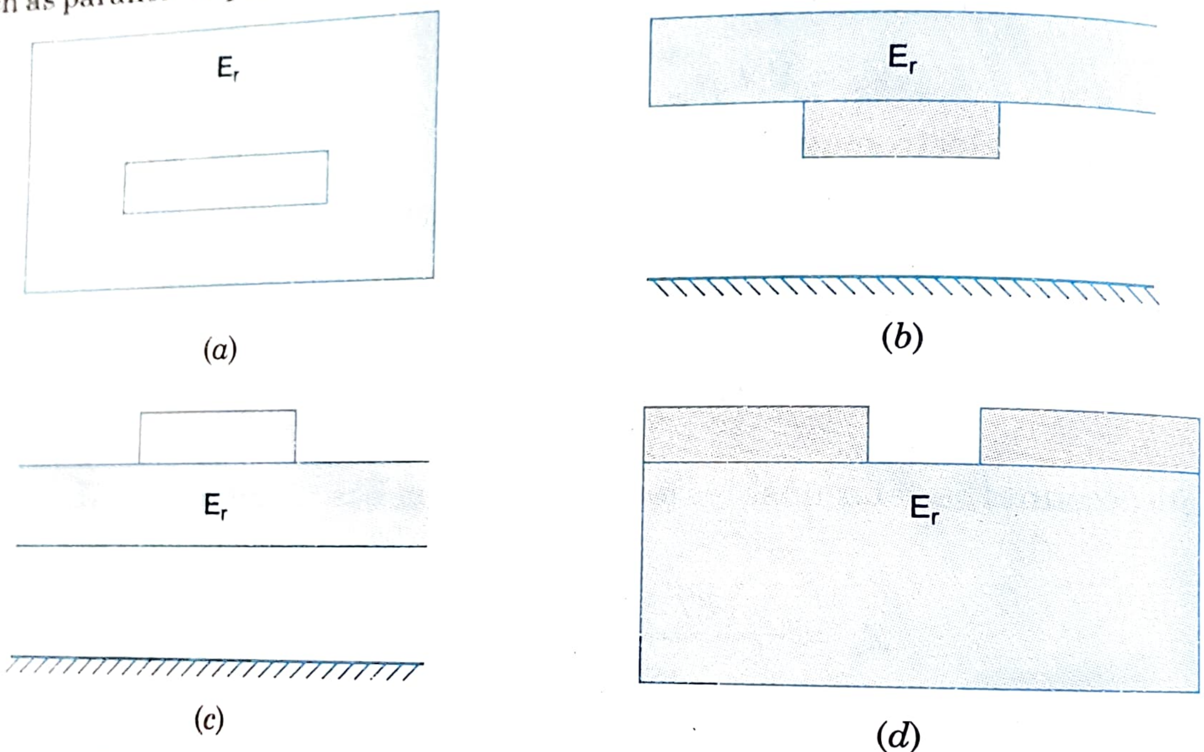


Fig. 4.8 Various types of microstrip lines (a) embedded microstrip, (b) inverted Microstrip (c) suspended microstrip, and (d) slotted microstrip.

Parallel Strip Lines

A parallel strip line consists of two perfect dielectric slabs of uniform thickness, as shown in Fig. 4.9.

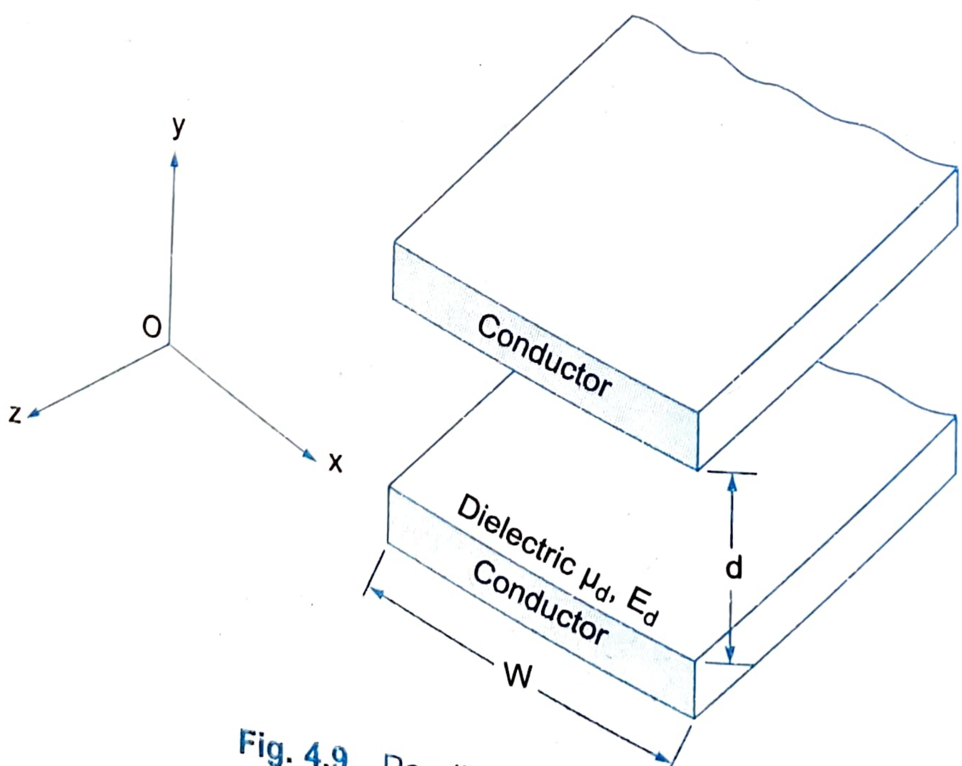


Fig. 4.9 Parallel strip line.

The parallel strip line is similar to a two conductor transmission line, with the result it can support a quasi TEM mode.

Coplanar Strip Lines

A coplanar strip line consists of two conducting strips on one substrate surface with one strip grounded as shown in Fig. 4.10.

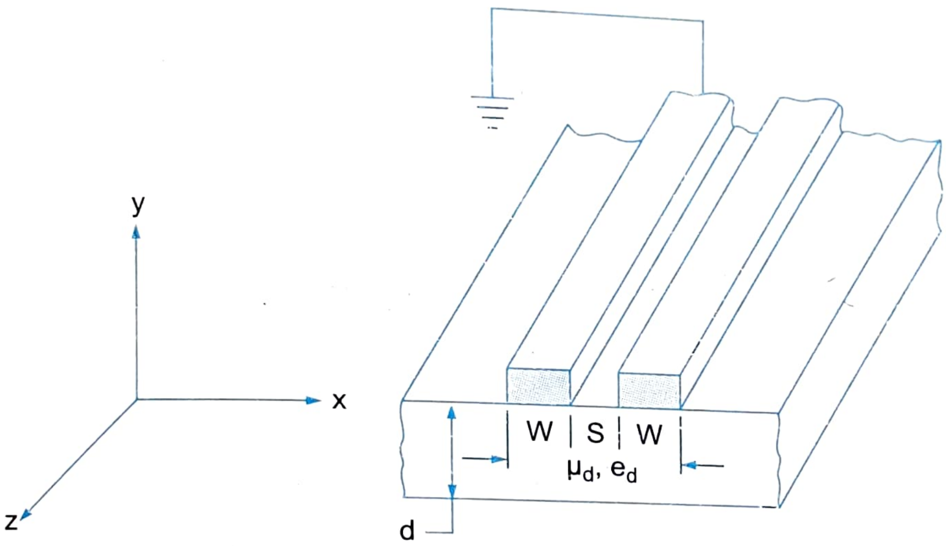


Fig. 4.10 Coplanar strip line.

The coplanar strip line has advantages over the conventional parallel strip line because its two strips are on the same substrate surface for convenient connections.

Slot Line and Coplanar Waveguide

Two other types of transmission lines are used in MICs. These are known as slot line and coplanar wave guide.

As shown in Fig. 4.11*a*, a slot line consists of a slot or gap in a conducting coating on a dielectric substrate. The fabrication process is identical to that of microstrip lines.

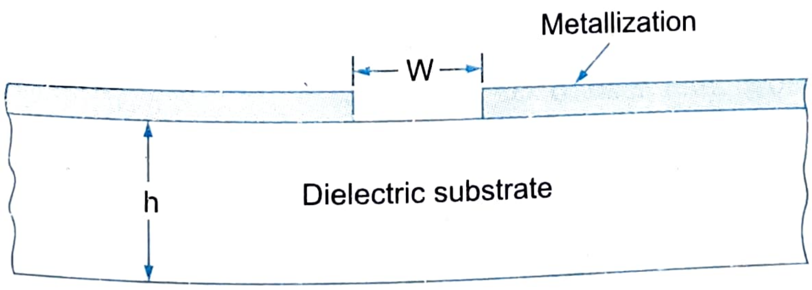


Fig. 4.11 (a) Slot line

As shown in Fig. 4.11*b* a coplanar wave guide consists of a strip of thin metallic film deposited on the surface of a dielectric slab with two ground electrodes running adjacent and parallel to the strip on the same surface.

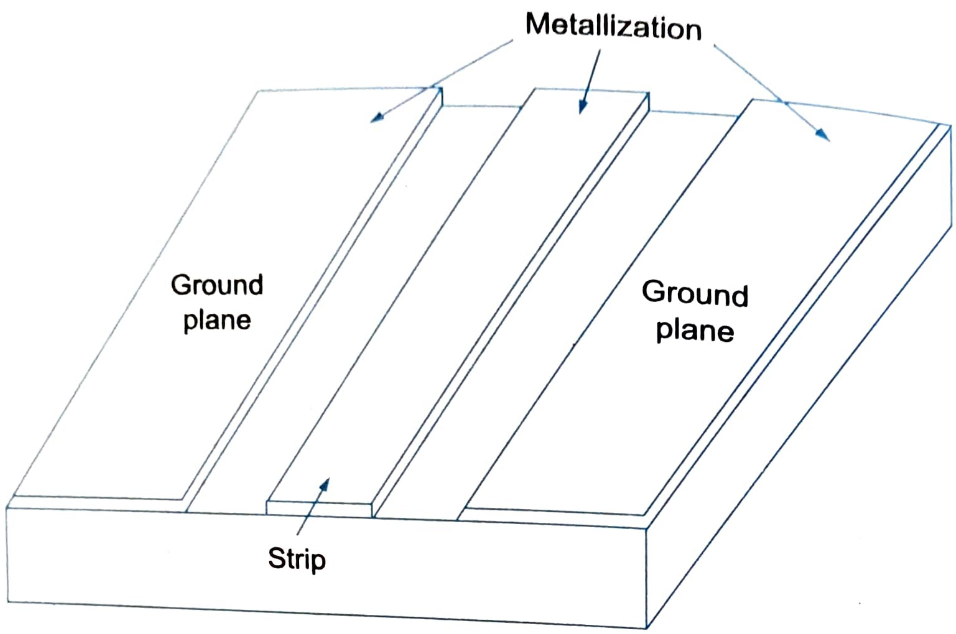


Fig. 4.11 (b) Coplanar waveguide.

4.2.6 Microwave Components using Strip Lines

It is possible to design/construct most of the microwave components using strip lines as the strip line particularly lends itself to satisfactory fabrication processes. The dielectrics used for development of components include polystyrene and laminated phenolic plastics. Fibrous sheet materials impregnated with a thermosetting resign have had their use limited to guide wavelength studies only due to their excessive attenuation. The products are available commercially in sheet form with either or both sides coated with cooper and have been used with the mechanical stripping, photo engraving and etching processes. In case of polystyrene, cementing of metal conductors to the surface gives good performance without introducing appreciable dissipation. Preformed shapes of line conductor can thus be cemented on place to form a particular configuration. Sandwich type construction is readily accomplished by cementing under pressure.

Microwave components have been successfully fabricated/operated in several frequency bands such as 1 GHz, 5 GHz and 10 GHz. Some of them include

1. **Transitions:** Strip to coaxial transition equivalent to coaxial to waveguide transmission with VSWR's as low as 1.2 at 5 GHz.
   — Waveguide to strip line or crossbar feed waveguide to coaxial transitions.
2. **Crystal Modulators:** A coaxial transition with the crystal holder as an integral part of the coaxial with VSWR's less than 1.5 in the 4.4 to 5 GHz band.
3. **Magic Tees:** With extremely low VSWR's balanced crystal response and negligible radiation.
4. **Attenuator Pads and Loads:** Microstrip line coated with a lossy dielectric or graphited paint of appropriate characteristics. The lossy dielectric can be tapered to get proper matching.

— Attenuators with a range of 0 to 15 dB similar to flap attenuator. Variation of attenuation is obtained by rotation of the flap which adjusts the length of the dielectric run with respect to the strip line.

5. Directional couplers, filter elements and antennas can also be fabricated.
6. Microwave receivers with noise figures better than 16 dB and very little conversion losses can be fabricated in one price.

Microstrip Lines Advantages and Disadvantages

The microstrip lines can be used at microwaves particularly in those applications where the more bulky and expensive to manufacture conventional plumbing is at a disadvantage.

However there are a number of limitations to microstrips.

1. Open structure of microstrip leads to a somewhat greater coupling between side-by-side configurations as compared to waveguide or coaxial system. The absolute value of coupling is however small.
2. Higher attenuation compared to waveguide structures. Hence cannot be used in systems where extremely low loss is the requirement. For example, in microwave receivers where line length are smaller, the insertion loss can be made negligible compared to other losses.
3. Low resonant impedance is inherent in microstrip structures which limit the magnitude of the obtainable Q.

A practical compromise between the extremes of maximum in electrical performance and optimum physical realisation can be made.

Design Considerations of a Microstrip Line

The design parameters are

1. Characteristic impedance

$$Z = Z_o / \sqrt{\varepsilon_{eff}}$$

2. Guide wavelength

$$\lambda = \lambda_o / \sqrt{\varepsilon_{eff}}$$

3. Effective dielectric component is a function of w/h, ε_r and frequency. (Refer Fig. 4.12).

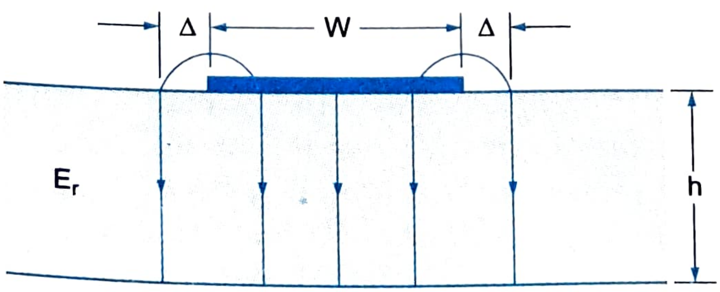


Fig. 4.12 Designing microstrip line.