CHAPTER III

THEORY OF MICRO-STRIP ANTENNAS

3.1 Introduction

Micro-strip antenna (MSA) are also called as printed antennas which consists of different shapes of patch as radiating elements and a ground plane in between with a dielectric substrate. Figure 3.1(a) and (b) illustrate the top view and side view of MSA. G.A. Deschamps in 1953 proposed the first micro-strip antenna. Due to several inherent defects the practicability of micro-strip antenna remained hampered (Balanis C. A. (2005)). However, the development of printed circuit board (PCB) technology, microwave techniques and various kinds of low attenuating materials made the practicability of micro-strip antennas. The patch of a micro-strip antenna may have different shapes like circular, square, rectangular, triangular and elliptical (Figure 3.2). The size and frequency of micro-strip antenna are inversely proportional. For microwave and millimeter wave frequencies the size of micro-strip antenna will be of order of 1cm and hence it is very easy to realize on soft board technology.

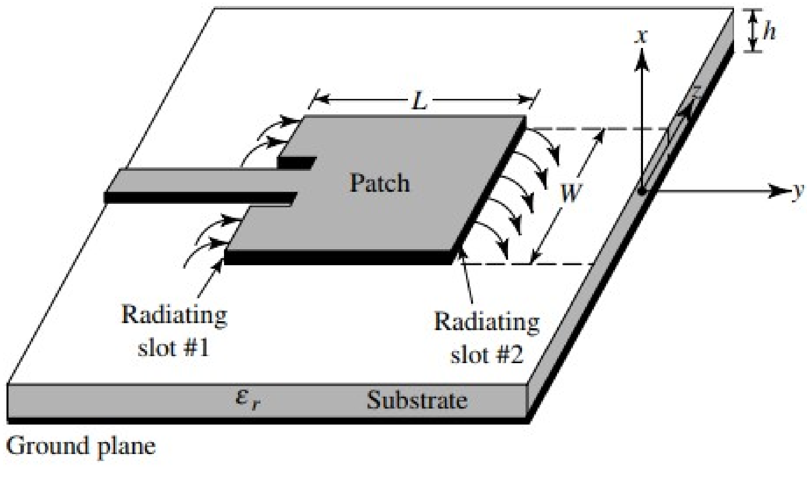


Figure 3.1(a) Micro-strip patch antenna top view (Balanis C. A. (2005))

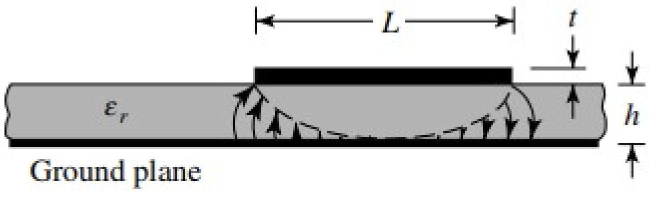


Figure 3.1(b) Micro-strip patch antenna side view (Balanis C. A. (2005))

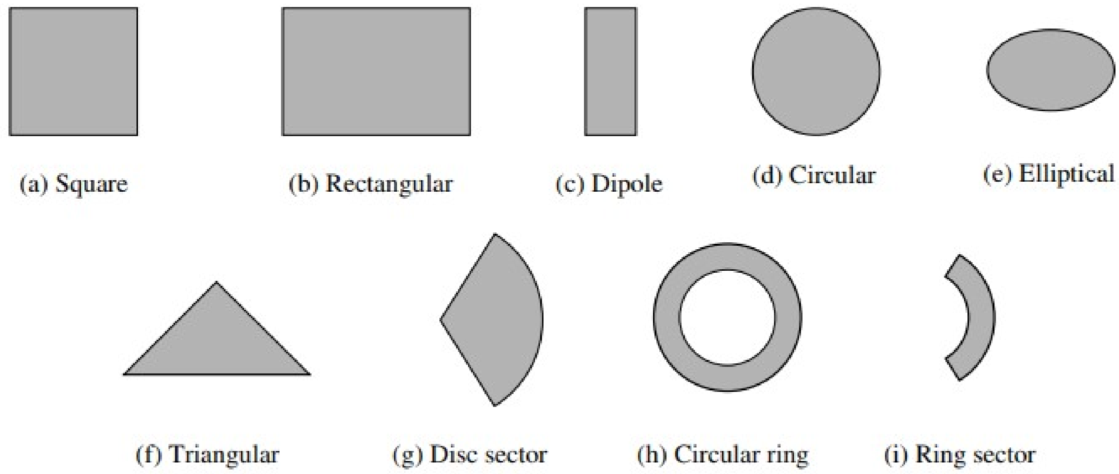


Figure 3.2 Different shapes of micro-strip patch elements (Balanis C. A. (2005))

3.2 Merits and Demerits

Micro-strip antennas have some merits and demerits as described:

Merits

- Micro-strip Antennas are of lightweight.
- They are smaller in size and lesser volume.
- Micro-strip antennas have low profile configuration and are mechanically robust and hence the conformal models can be embedded onto any desired shape without major modifications.
- The fabrication process of micro-strip antennas is compatible with optoelectronic integrated circuits (OEIC) and microwave monolithic integrated circuit (MMIC) technologies.
- Micro-strip antennas support both linear and circular polarization and are capable of operating for dual and triple frequencies.
- Formation of large arrays with half wavelength or lesser spacing is easy with micro-strip antenna.

Demerits

- Micro-strip antennas have low or narrow bandwidth.
- These are less efficient and have login with low power handling capacity.
- Micro-strip antennas are poor and fire radiators except the tapered slot antennas.

However, with the advancement in technology and extensive research in the area of micro-strip antennas the demerits are being overcome gradually. In most of the 5G and millimeter wave frequency applications the conventional antennas are expected to be replaced with micro-strip antennas.

3.3 Feeding Methods

Micro-strip patch antenna consists of radiating elements on the top layer of dielectric substrate and ground plane as the bottom layer. Micro-strip Antennas can be fed using many configurations such as:

- Micro-strip line feeding
- Coaxial probe feeding
- Aperture coupled feeding
- Proximity coupled feeding and
- Coplanar waveguide feeding

3.3.1 Micro-strip feeding

Micro-strip line feed method is easy to fabricate and simple to match by controlling the inset position, but as substrate thickness increases the spurious radiation also increases. In micro-strip line feeding technique, the edge of micro-strip patch is directly connected to a conducting strip. The width of conducting strip is usually much smaller as compared to width of patch. As represented in the Figure 3.3, in this method of feed arrangement, the feed can be etched on same substrate to provide a planar structure.

The version of micro-strip feed may be a centre feed, an offset feed, an inset feed or a quarter wave line feed (Figure 3.4). In centre feed technique, micro-strip line is in the centre of patch. In offset feed method, micro-strip line is not in the centre of patch. If a micro-strip antenna is fed in the centre of width or at an end, it is called an inset feed method. This feed method has high input impedance. The input impedance can be reduced if the patch is fed closer to centre. In quarter wave line feed method, micro-strip antenna is matched to a transmission line of characteristic impedance Z_0 by using a quarter wave section of characteristic impedance Z_1. The input impedance Z_{in} viewed from beginning of the quarter wave section is as given in Equation (3.1).

$$Z_{in} = Z_0 = \frac{Z_1^2}{Z_A} \tag{3.1}$$

Where, Z_A is the impedance of antenna.

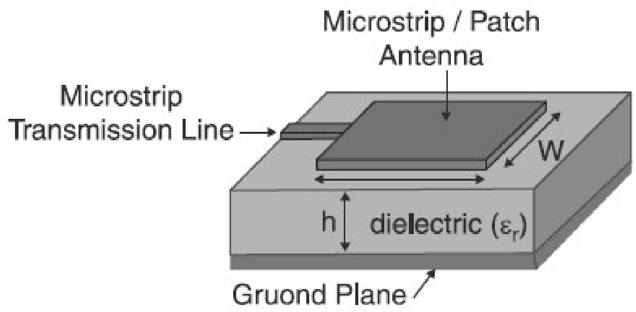
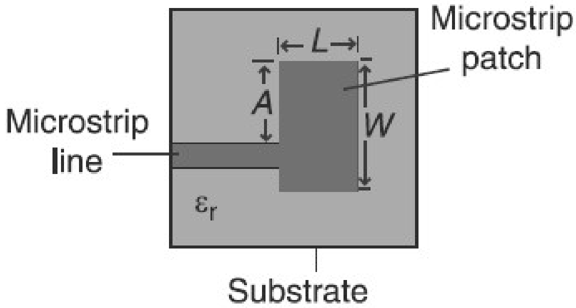
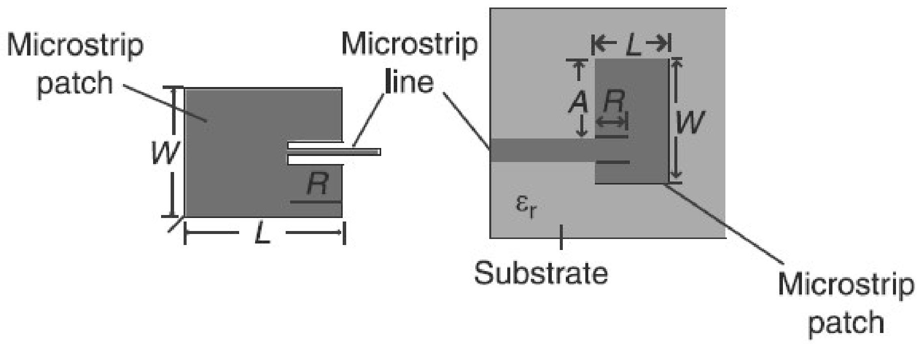


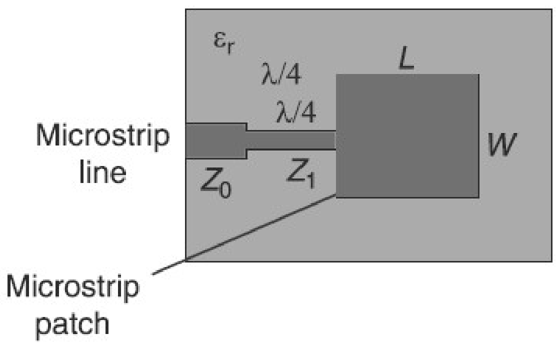
Figure 3.3 Micro-strip line feed MSA (John D Kraus et al. (2015))



(i) Offset feed



(ii) Inset feed



(iii) Quarter wave matching feed

Figure 3.4 Different kinds of micro-strip feed arrangement (John D Kraus et al. (2015))

3.3.2 Coaxial feeding

Coaxial probe feed method is also widely used. It is easy to fabricate and match, and it has low spurious radiation. As it has narrow bandwidth it is more difficult to model. In coaxial feed method, from bottom layer a coaxial connector extends through the dielectric to top layer. The inner conductor of coaxial connector is soldered to radiating patch and ground plane is connected with the outer conductor of coaxial connector. Coaxial feed type MSA is illustrated in the Figure 3.5. To match with input impedance of patch, the feed can be placed at any desired location inside patch. Coaxial feed provides narrow bandwidth and difficult to model, as a hole has to be drilled in the substrate to connect coaxial cable. If thicker substrates are to be used to widen the bandwidth then the length of the coaxial probe increases which makes the input impedance more inductive and leads to matching problems.

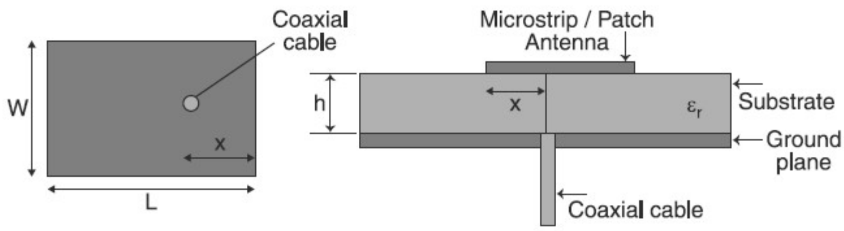


Figure 3.5 Coaxial feed MSA (John D Kraus et al. (2015))

Micro-strip line and coaxial probe feeding methods are contacting type feed methods. In these feeding methods, cross polarized radiation is produced by the generation of higher order modes in micro-strip antennas due to inherent asymmetries. To overcome the problems in contacting type feeding methods, non contacting aperture coupling feed methods like aperture coupling and proximity coupling are introduced.

3.3.3 Aperture coupled feeding

Aperture coupling field method has narrow bandwidth and the most difficult to fabricate. However, it is the model that has moderate spurious radiation. A micro-strip feed line is present on bottom side of lower substrate and its energy is coupled to patch through a slot on the ground plane separating two substrates as shown in Figure 3.6. In general, a high dielectric material is used for bottom substrate and low dielectric constant material is used for top substrate.

This feed method is also known as electromagnetic coupling scheme. The shape of aperture, its size and location determine the amount of energy coupled between field and patch. As the patch and feed line are separated by ground plane, the spurious radiations are low in aperture coupling. In aperture coupling feed method due to increase in the thickness of micro-strip patch antenna, the bandwidth gets widen. However, fabrication of aperture coupled micro-strip patch antenna is difficult as the micro-strip line needs proper alignment between the two dielectric layers.

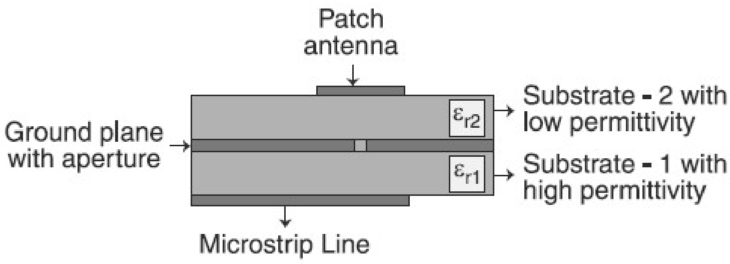


Figure 3.6 Aperture coupled feed MSA (John D Kraus et al. (2015))

3.3.4 Proximity-coupled feeding

Proximity coupling field method has the largest bandwidth and it is the model which has low spurious radiation. However, fabrication of proximity coupling fed micro-strip antenna is more difficult. Proximity coupled feed is also called as indirect feed. In proximity coupled feed technique gap exist between micro-strip line and patch of micro-strip antenna. Capacitance is introduced by the gap into the feed and this capacitance can cancel out the inductance added due to probe feed. The arrangement of proximity coupled feed technique is shown in Figure 3.7.

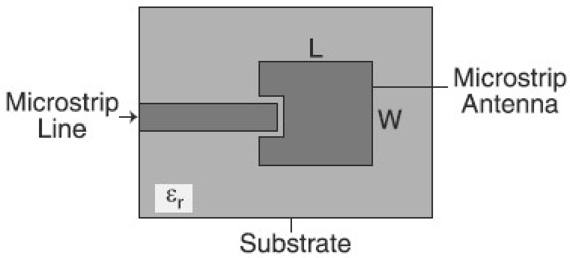


Figure 3.7 Proximity coupled MSA (John D Kraus et al. (2015))

3.3.5 Co-Planar waveguide feeding

Coplanar waveguide (CPW) feeding is a planar micro-strip line feeding method. Such type of feeding is the most preferable for MMIC designs. In this feeding method, the impedance can be tuned by varying the width of the signal trace and gap between the conducting plane and ground. The spurious radiation is less as it operates in odd mode in which the feed radiation is negligible due to cancellation of equivalent magnetic currents on CPW slots. CPW fed MSA is as presented in Figure 3.8.

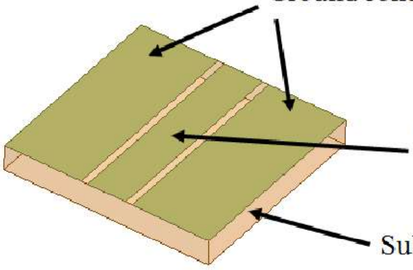


Figure 3.8 CPW feed MSA

The comparison of various feeding methods of micro-strip patch antenna is tabulated in Table 3.1 in terms of impedance matching, ease of fabrication, reliability, spurious radiation, polarization and impedance bandwidth.

Table 3.1 Comparison of micro-strip antennas feeding methods

Characteristics	Coaxial/Probe Feed	Proximity Coupling	Micro-strip line feed	Aperture Coupling	CPW Feed
Impedance bandwidth	2-5%	13%	2-5%	21%	3%
Purity in Polarization	Poor	Poor	Poor	Excellent	Good
Reliability	Poor due to soldering	Good	Better	Good	Good
Ease of fabrication	Drilling required	Alignment necessary	Easy	Alignment necessary	Easy
Spurious radiation	More	More	More	More	Less
Impedance Matching	Easy	Easy	Easy	Easy	Easy

3.4 Performance Parameters

The important parameters for analyzing the performance of micro-strip antennas are impedance bandwidth, return loss, radiation pattern, directivity, gain, efficiency, polarization and VSWR.

3.4.1 Radiation pattern

Radiation pattern of an antenna is defined as a mathematical function or graphical representation of the radiation properties of antenna as a function of space coordinates. Radiation pattern is a far field characteristic of antenna. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization. A typical radiation pattern of an antenna is as shown in the Figure 3.9. The parameters that can be studied from radiation pattern are: 3dB bandwidth, major lobe, minor lobe, side lobe, back lobe, half power beam-width and first null beam-width.

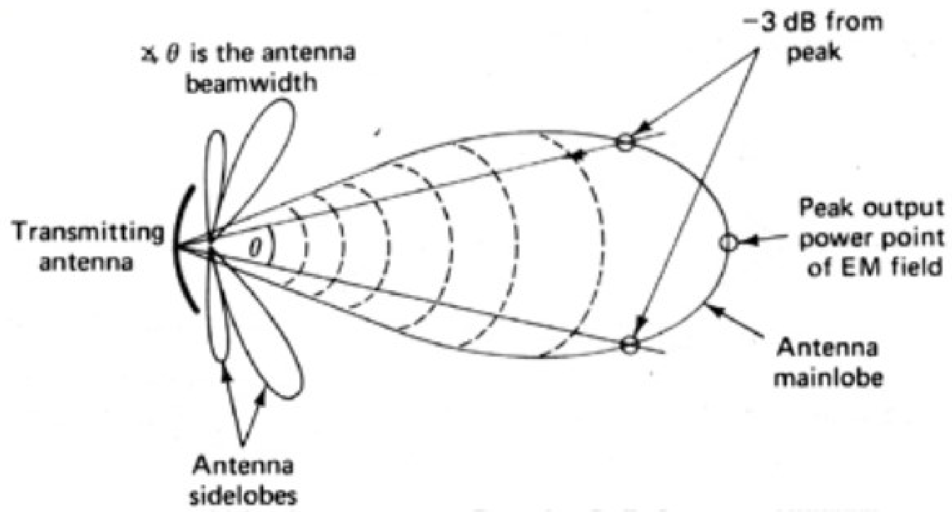


Figure 3.9 Radiation pattern of antenna

3.4.2. Gain

One of the important parameters that describe the performance of a micro-strip antenna is gain. Gain is defined as the ratio of intensity in a given direction to radiation intensity that would be obtained if power accepted by antenna were radiated isotropically.

Relative gain is defined as the ratio of power gain in a given direction to power gain of a reference antenna in its reference direction. Usually gain is given in terms of decibels instead of the dimensional quantity.

3.4.3 Directivity

Directivity of antenna is defined as the ratio of radiation intensity in a given direction from antenna to radiation intensity averaged over all directions. The average radiation intensity is equal to total power radiated by antenna divided by 4π.

3.4.4 Efficiency

Efficiency (η) of antenna is defined as the ratio of power delivered (P_d) to power radiated (P_r).

$$\eta = \frac{P_d}{P_r} \tag{3.2}$$

3.4.5 Impedance bandwidth

Bandwidth of an antenna is defined as the range of frequencies within which the performance of antenna with respect to some characteristic conforms to a specified standard (Balanis C. A. (2005)). The expressions for broadband and narrowband are given in Equation (3.3)

$$BW_{broad} = \frac{f_H}{f_L} \quad , \quad BW_{narrow} = \left[\frac{f_H - f_L}{f_C}\right] \tag{3.3}$$

where, f_H = upper frequency, f_L = lower frequency and f_C = center frequency.

3.4.6 Return loss

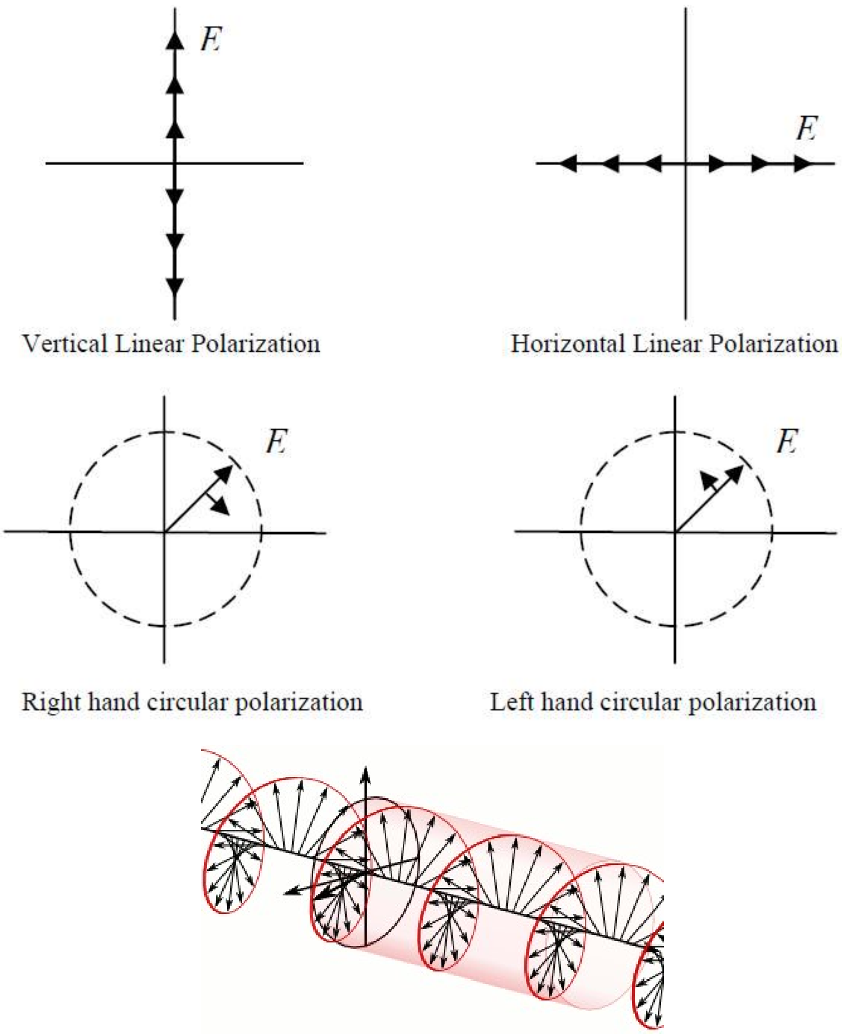
Return loss is the measure of effectiveness of power delivery from an antenna to a load (Trevor S. Bird, (2009)). It gives the measure of degree of mismatch between the incident and reflected power of an antenna usually return loss (RL) is expressed in dB and is given in Equation (3.4).

$$RL = 10\log_{10}\left[\frac{P_{in}}{P_r}\right] = -20\log_{10}|\Gamma| \tag{3.4}$$

Where, Γ is reflection coefficient, P_{in} is incident power and P_r is reflected power.

3.4.7 Polarization

Polarization of an antenna in a given direction is defined as polarization of the wave transmitted or radiated by antenna. Polarization of a radiated wave is defined as "that property of an electromagnetic wave describing the time varying direction and relative magnitude of the electric field vector specifically, the figure traced as a function of time by the extremity of the vector at a fixed location in space and the sense in which it is traced, as observed along the direction of propagation" (Balanis C. A. (2005)). Fundamentally there are three types of polarizations: linear, circular and elliptical polarization. Linear and circular polarizations are as illustrated in the Figure 3.10. In linear polarization the polarization may be either vertical or horizontal, in circular polarization the polarization may be clockwise or counter clockwise and right hand polarization or left hand polarization. Axial ratio defines the type of polarization of antenna.



3D Circular polarization

Figure 3.10 Linear and circular polarizations of an antenna

3.4.8 Voltage standing wave ratio (VSWR)

VSWR is a measure of impedance mismatch between the transmitter and antenna. VSWR ranges between 1 to ∞. For a perfect match between the transmitter and antenna, VSWR value is 1. Expression for VSWR is given in the Equation (3.5).

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{3.5}$$

Where, Γ is reflection coefficient, $\Gamma = \frac{V_r}{V_i}$

V_{max} is maximum voltage

V_{min} is minimum voltage

V_r is reflected voltage

V_i is incident voltage

3.5 Methods of Micro-strip Antenna Analysis

Micro-strip Antennas (MSA) can be analyzed using many models and the most popular models include the transmission-line model analysis, the cavity model analysis and the full wave model analysis. Other than these some other models used for MSA analysis are: Multiport Network Model (MNM), Method of Moments (MoM), Spectral Domain Technique (SDT) and Finite Element Method (FEM).

3.5.1 Transmission-line model

Transmission line model is the least accurate and the simplest of all models. Though this model is easy in implementation, it has some inherent disadvantages. It is specifically useful for rectangular shape patches and not for circular or arbitrary shaped geometries. In this model the micro-strip antenna is analyzed by two slots of width 'W' and height 'H' separated by a transmission line of length 'L'. The radiating edges of patch located at the end opposite to feed end are modeled as a pair of Transmission lines excited 180 degrees out of phase. The model neglects variations along radiating edges and effect of feed. It requires an empirically determined correction factor for accounting fringing field at the edges (John D Kraus et al. (2015)).

3.5.2 Cavity model

Cavity model analysis overcomes the limitations of transmission line model. In the cavity model analysis, interior region of dielectric substrate is modeled as a resonant cavity bounded by electric walls on top and bottom. Fields in micro-strip antenna are derived from the solution of $TM_{m,n}$ mode in cavity. This model works well for simple cavity shapes such as rectangular and circular. For arbitrarily shaped cavities, the derivation for $TM_{m,n}$ mode is often complex and numerical techniques are to be employed to solve integral equations. The commonly adopted methods include the finite difference time domain method and the method of moment. The cavity model is more rigorous and hence more accurate, but it is complex in nature (John D Kraus et al. (2015)).

3.5.3 Full wave model

The full wave models involve integral equations/moment methods. These models are extremely accurate, versatile and can treat equally single elements, stacked elements, arbitrary shaped elements, finite and infinite arrays. The full wave models however are far more complex in nature (John D Kraus et al. (2015)).