CHAPTER 3

THE MODELS

In this chapter we will discuss in details about the transmission line, cavity and CAD model representation of RMSA.

Thin metalized patch mounted on a dielectric substrate with a ground plane below, are referred to as MSA. The most common configurations of MSAs are rectangular and circular and can be analyzed by using various models. The various analytical approaches, namely: (i) transmission line model, (ii) cavity model and (iii) CAD model are used for analysis of RMSAs. The transmission line and cavity model provides more physical insight than CAD model and they provide useful engineering design information. Further, they can predict the antenna performance quite accurately for thin substrate [1]. The rectangular and square patch can be analyzed by using most popular transmission line models, while cavity models can be used to analyze any arbitrary shape patches. The RMSA with fringing length extension is shown in Fig.5.

![Diagram](image)

**Fig.5:** Rectangular Microstrip Antenna with Fringing Length Extension
3.1 The Transmission Line Model

The transmission line model was used by Muson [17] for the first time to analyze a RMSA. In this technique, the interior region of the patch is modeled as a section of a transmission line [6]. The patch size and substrate parameters are chosen carefully to determine the characteristic impedance $Z_0$ and propagation constant $\beta$ of the line. The periphery of this patch is described as four walls and each pair of them are classified as radiating and non-radiating edges. Along the length, the field variations is uniform and are called radiating edge. While along the width the field is non-radiating, where there is complete cancellation of radiating power. The radiating edges are characterized by load admittance $Y$, which is the sum of conductance $G$ and susceptance $B$. The conductance is associated with radiating power from the edges, while susceptance accounts for energy stored in fringing field near the edge. The effect of fringing fields at non-radiating edges is used in the determination of phase constant $\beta$. The equivalent circuit representation of RMSA is shown in Fig.6 (a). To account for mutual coupling, the RMSA can be modeled as two slots of width $W$ and height $h$, separated by a transmission line of length $L$ as shown in Fig.6 (b).

![Fig.6 (a): Equivalent circuit of a microstrip patch element](image)
Fig. 6 (b): Two slot model of RMSA to account for mutual coupling.

3.2 The Cavity Model

Although, the transmission line model is easy to use, it has some inherent disadvantages, as it is useful for design of patches of rectangular dimension and the field variations along the radiating edges are not taken into account [1]. It can be overcome by using the cavity model. In this model, the interior region of the dielectric substrate is modeled as a waveguide cavity bounded by electric walls on the top and bottom and the other four are magnetic walls, with the assumptions that the substrates is very thin \((h \ll \lambda)\) [10]. Fig. 7 (a) shows the cavity model of the RMSA while Fig. 7 (b) shows the top view of the field and magnetic current distribution. Since the substrate is thin, the fields in the interior region do not vary much in the direction normal to the patch.

The input impedance of the patch will be imaginary and will not radiate (stored energy) if the cavity walls and the material within it is treated as lossless [1]. In order to account for radiation, effective loss tangent \(\delta_{\text{eff}}\) is chosen suitably to represent the loss mechanism of the cavity. With this consideration the dielectric loaded cavity model can be forced to behave as an antenna [1]. The \(\delta_{\text{eff}}\) is reciprocal of the antenna quality factor \(Q\) [1]. The electric field is almost normal to the surface of the patch.
If the substrate is sufficiently thin then fringing of the fields may be assumed to be negligible [1]. With this assumption that only Transverse Magnetic (TM) field configurations will be propagated within the cavity and it can be evaluated by using the vector potential approach [1].

In this model the volume below the patch is treated as a rectangular cavity filled with a dielectric material with dielectric constant $\varepsilon_r$. The fringing of the fields along the edges of the cavity is assumed to be negligible [1]. The fringing effects greatly influence the resonant frequency, antenna dimensions, input impedance, BW and radiation pattern, and it should be taken into account for accurate determination of antenna parameters.

The distribution of the tangential electric field along the side walls of the cavity determines various possible modes [1]. The MSA satisfying the conditions $L > W > h$, $h << L$ and $h << W$, the mode with the lowest frequency or the dominant mode is $\text{TM}_{010}$. The second higher order mode is the $\text{TM}_{001}$ which satisfies the conditions $L > W > L/2 > h$. While the second order mode $\text{TM}_{020}$ is excited if $L > L/2 > W > h$, and $\text{TM}_{002}$ mode is excited for $W > W/2 > L > h$ [1].

![Fig.7 (a): Cavity model representation of rectangular microstrip antenna.](image)
3.3 The CAD Model

The CAD model is the extension of cavity model, in which parameters are derived from accurate analytical approximations of exact formulas and may be utilized to describe the basic characteristics of the patch antenna [8].

The CAD formulas account for radiation into space, surface wave radiation, dielectric loss, conductor loss and can predict input radiation resistance, radiation efficiency, BW and directivity accurately. So, as long as substrate thickness is within permissible limit, baring input resistance, all other design formulas are independent of the specific feeding techniques [8]. The CAD formulas for resonant input resistance provide inaccurate results if substrate thickness does not satisfy the condition $\sqrt{\varepsilon_r} h/\lambda_0 \leq 3/100$ [8].

In the CAD model, the RMSA is modeled as a parallel RLC circuit in series with a reactance, based on cavity model theory and can be used to calculate the input impedance of the patch antenna, at any resonant frequency with the prior knowledge of resonant input resistance, resonant frequency, and BW in the desired frequency range [8].

In the next chapter of the thesis, we will discuss in details the theoretical estimation of the proposed Transmission line, Cavity and CAD models of RMSAs.