# Analysis of Microstrip Patch Antenna using Transmission Line Model: Survey

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*Abstract*- **Microstrip antennas have been one of the most innovative topics in recent years. They have numerous advantages over conventional microwave antennas such as their small size, low weight, low cost, ease of installation, polarization diversity and compatibility with microwave integrated circuits. These antennas are low profile and can be fabricated using the modern printed circuit technology. Microstrip antennas are finding application in a wide range of modern wireless communication system. This paper gives a brief overview of the basic characteristics of microstrip antenna, different types of feeding techniques and theoretical analysis using transmission line model.**

***Keywords*-Microstrip Patch Antenna, Feeding Techniques, Fringing, Transmission line model**

## I. INTRODUCTION

Antennas play a very important role in the field of wireless communications. Some of them are parabolic reflectors, patch antennas, slot antennas, and folded dipole antennas with each type having their own properties, usage, advantages and disadvantages. The development in the antenna design is the driving force behind the advances in wireless communication technology.

Microstrip antenna technology began its rapid development in the late 1970s. By the early 1980s basic microstrip antenna elements and arrays were fairly well establish in term of design and modeling. They provide some significant advantages over other radiating systems, which include: light weightiness, reduced size, low cost, conformability and the ease of integration with active device. But suffer from the disadvantages such as narrow bandwidth, poor polarization purity, low power, spurious feed radiation etc [1]. Microstrip antenna have been widely used in modern wireless communication systems, for example, GSM, GPS, Bluetooth, WLAN, Satellites, Radars etc.

## II. MICROSTRIP PATCH ANTENNA

Microstrip antennas are also known as patch antennas. It consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side as shown in figure 1. The radiating element and feed line is usually photo etched on the dielectric substrate [1]. The patch is a very thin ($t<<\lambda_o$, where $\lambda_o$ is the free space wavelength) and its length 'L' is usually $\lambda_o/2$. The patch is normally made of copper or gold and it can assume different geometries such as square, rectangle, circle, dipole, triangle or any other configuration. Rectangular and circular patch are mostly used.

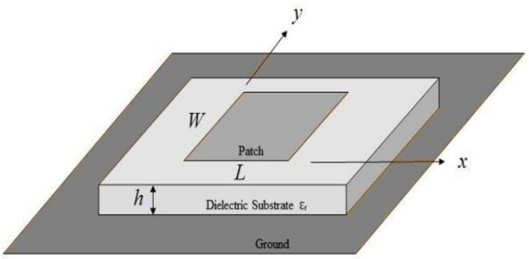

Fig 1: Structure of rectangular microstrip patch antenna

The Substrate provides proper spacing and mechanical support between the patch and its ground plane. Its thickness is usually $h\leq 0.05$ of free-space wavelength ($\lambda_o$). Dielectric constant '$\varepsilon_r$' of substrate varies from 1.17 to about 25 and loss tangents vary from 0.0001 to 0.004. Thicker substrate with low dielectric constant increase the radiated power, reduce conductor loss, improve impedance bandwidth and increase the fringing fields but at the expense of increased weight and larger element size [2]. Thin substrates reduce the element size but they suffer from greater losses and provide smaller bandwidths. A trade-off exists between antenna size and bandwidth.

## III. FEEDING TECHNIQUES

A feedline is used to excite the patch to radiate by direct or indirect contact. The most important thing to be considered is the maximum transfer of power between the radiating patch and feed structure that is impedance matching between the two. There are many methods of feeding a microstrip antenna. The most popular methods are the microstrip line, coaxial probe, aperture coupling, and proximity coupling [3][7].

Coaxial probe feed is the simplest feed for microstrip antennas. In this, an inner conductor of coaxial line is attached to the radiating patch while outer conductor is connected to ground plane. The structure of coaxial probe feed is shown in figure 2. Coaxial probe feed is very easy to fabricate, directly compatible with the coaxial cables, easy to obtain input match by adjusting feed position and it has low spurious radiation. However it has narrow bandwidth and is difficult to model for thicker substrates.

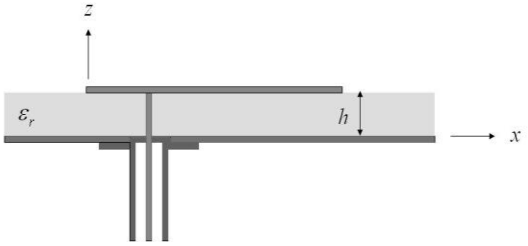

Fig 2: Coaxial probe feed Patch Antenna

Microstrip line feed is connected directly to the radiating patch as shown in figure 3. The location of the feed line may affect a small shift in resonant frequency, due to the change in coupling between the feed line and the antenna. It is simple to model, easy to fabricate and provide good polarization. However as substrate thickness increases, surface wave and spurious feed radiation increases which limit the bandwidth. Spurious radiation will increase sidelobes on the radiating pattern.

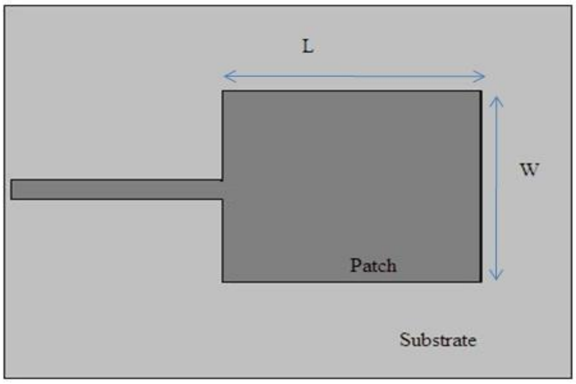

Fig 3: Microstrip line feed Patch Antenna

Proximity coupled feed uses two substrate $\varepsilon_{r1}$ and $\varepsilon_{r2}$. The patch will be on the top, the ground plane in the bottom and a microstrip feed line is connected to the power source and lying between the two substrates as shown in the figure 4. It is also known as “electromagnetically coupled microstrip feed”. Coupling between the patch and feedline is capacitive in nature. It is easy to model, has low spurious radiation and it provide large bandwidth. However its fabrication is difficult because of multilayer geometry and requirement for accurate alignment between the patch and feed.

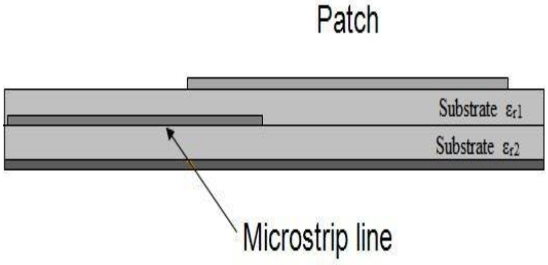

Fig 4: Proximity coupled micro strip patch antenna

Aperture coupled feed consist of two different substrate separated by a common ground plane. Microstrip feed line on the bottom side of lower substrate is electromagnetically coupled to the patch through a slot aperture on the ground plane separating two substrates. The amount of coupling depends on the size, shape and also the location of the aperture. The thickness and dielectric constants of the two substrates are chosen to optimize the feed and radiation separately. It is difficult to fabricate as this has got multiple layers, due to this the thickness of the antenna increases.

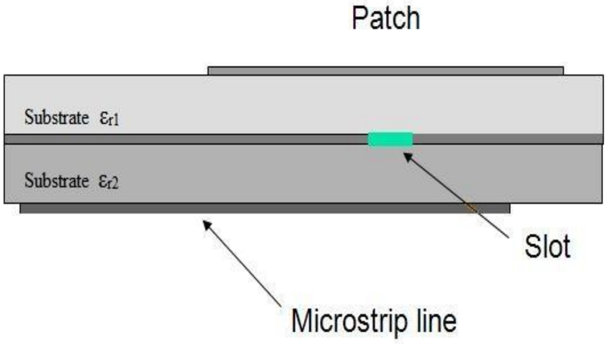

Fig 5: Aperture coupled feed patch antenna

Comparison of the different feed techniques and their characteristics [3] is given in Table 1.

TABLE 1

| **Characteristics** | **Co-axial Probe Feed** | **Microstrip line feed** | **Proximity Coupled** | **Aperture Coupled** |
|---|---|---|---|---|
| **Configuration** | Non Planar | Coplanar | Planar | Planar |
| **Spurious Feed Radiation** | More | More | More | More |
| **Polarization Purity** | Poor | Good | Poor | Excellent |
| **Ease of fabrication** | Soldering and drilling needed | Easy | Alignment required | Alignment required |
| **Reliability** | Poor due to soldering | Better | Good | Good |
| **Impedance Matching** | Easy | Easy | Easy | Easy |
| **Bandwidth** | 2-5% | 2-5% | 12% | 21% |

## IV. DESIGN AND ANALYSIS

Microstrip antennas are generally analyzed by three different models. These are transmission line model, cavity model and full-wave numerical methods such as Method of Moments. In the transmission line method, microstrip antenna is represented by an equivalent circuit and characteristic impedance and propagation constant are expressed in closed form. Cavity model is a modal solution and it gives field distributions in the cavity between microstrip patch and the ground plane surrounded by magnetic walls. Application of these two methods is limited due to approximations made. To obtain more accurate results full-wave numerical methods, such as Method of Moments, Finite Element, Finite Difference Time Domain, are preferred [4] [8]-[10]. Each of these techniques has certain advantages and disadvantages.

The simplest and the least accurate method to analyze a rectangular microstrip patch is the transmission line method. It basically represents the antenna by two parallel radiating slots separated by a transmission line of length ‘L’, which is equal to the length of the patch, and characteristic impedance ‘$Z_c$’. Transmission line representation of a microstrip patch antenna is shown in Figure 6(b). The slot length is equal to the width of the patch and the slot width is equal to the thickness of the substrate.

Fields at the edge of the patch, both for the length and the width, undergo fringing as a result of the finite dimension of the patch. Besides the dimensions, height and dielectric constant of the substrate also affect the amount of fringing. Because of fringing, patch looks wider then its physical dimensions. In order to take into account this effect, an effective dielectric constant ‘$\varepsilon_{reff}$’ is calculated as [1]

$W/h > 1$

$$\varepsilon_r^{eff} = \frac{\varepsilon_r + 1}{2} + \left(\frac{\varepsilon_r - 1}{2}\right)\left[1 + 12\left(\frac{h}{W}\right)\right]^{-1/2} \qquad (1)$$

Where ‘*W*’ is the patch width, ‘*h*’ is the height of substrate and ‘$\varepsilon_r$’ is the dielectric constant of the substrate. Similarly effective patch length can be written in terms of effective dielectric constant as:

$$\Delta L/h = 0.412\left[\frac{(\varepsilon_r + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_r - 0.258)\left(\frac{W}{h} + 0.8\right)}\right] \qquad (2)$$

$$L_e = L + 2\Delta L$$

Without fringing resonant frequency of the antenna is formulated as

$$f_r = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0 \varepsilon_0}} = \frac{v_0}{2L\sqrt{\varepsilon_r}} \qquad (3)$$

Where ‘$v_0$’ is speed of light in free space. In order to take into account fringing, effective patch length and effective dielectric constant are used to formulate resonant frequency.

$$f_{rc} = \frac{1}{2L_{eff}\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} = \frac{1}{2(L+2\Delta L)\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}}$$

$$f_{rc} = q\frac{1}{2L\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} = q\frac{v_0}{2L\sqrt{\varepsilon_r}} \qquad (4)$$

*'q'* in (4) is called the fringing factor and it calculated by measuring '$f_r$' for a rectangular patch on a given substrate . The fringe factor determines the accuracy of the resonant frequency.

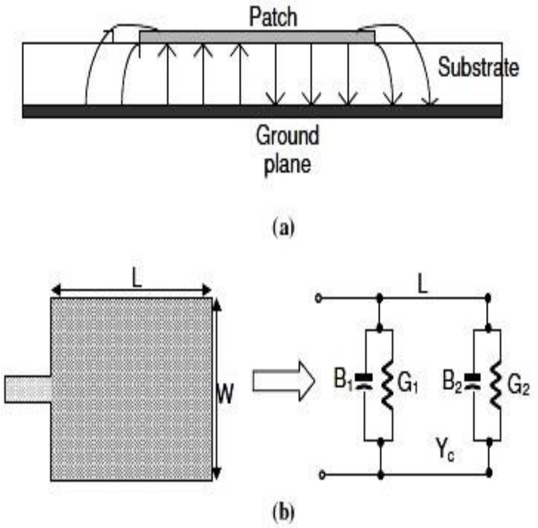

Fig 6: (a) Fringing effect (b) Transmission line model of rectangular microstrip antenna [1].

As mentioned earlier, equivalent circuit of radiating slots used to represent microstrip patch consists of equivalent parallel admittance *Y* with conductance *G* and susceptance *B.* Related circuit and fringing is shown in Figure 6. *Y* can be written as [1] [4].

$$Y = G_1 + jB_1$$

$$G_1 = \frac{W}{120\lambda_0}\left[1 - \frac{1}{24}(k_0 h)^2\right] \quad \frac{h}{\lambda_0} < \frac{1}{10} \qquad (5)$$

$$B_1 = \frac{W}{120\lambda_0}\left[1 - 0.636\ln(k_0 h)^2\right] \quad \frac{h}{\lambda_0} < \frac{1}{10}$$

Where '$\lambda_0$' is free space wavelength and $k_0 = 2\pi/\lambda_0$ is the free space wave number. Since the slots are identical, (5) is valid for both of the slots.

Ideally, $\lambda/2$ separation between slots provides $180^0$ phase difference, where $\lambda$ is the wavelength in the substrate, but because of fringing, separation between the slots is slightly less than $\lambda/2$. So L is chosen properly in the range $0.48\lambda < L < 0.49\lambda$ which results the admittance in slot 2 as

$$\begin{aligned}\tilde{Y}_2 &= \tilde{G}_2 + j\tilde{B}_2 = G_1 - jB_1 \\ \tilde{G}_2 &= G_1 \\ \tilde{B}_2 &= -B_1\end{aligned} \qquad (6)$$

So the total admittance at resonance becomes

$$\begin{aligned}Y_{in} &= G_1 + jB_1 + \tilde{G}_2 + j\tilde{B}_2 \\ &= G_1 + jB_1 + G_1 - jB_1 \\ &= 2G_1\end{aligned} \qquad (7)$$

The transmission line model provides less accuracy, but its advantage lies in its simplicity i.e., calculation of resonant frequency and input admittance of a microstrip antenna is simple by this method. Detailed explanation about transmission line model is provided in [3] [4] [6].

## V. CONCLUSION

Microstrip antennas have made great progress in recent years and this trend is likely to continue. The performance of the antenna can be improved by varying the size and shape of the patch, by choosing the appropriate dielectric substrate, varying the height of the substrate, by choosing the appropriate feeding technique. By using linear or planar array configuration low gain and low power handling capacity can be overcome. Different analysis techniques can be used to obtain the more accurate results.

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