OPEN ACCESS
International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-5, June 2019

Analysis of Impedance Matching and Solution of Differential Partial Equation of Microstrip Antenna using Transmission Line Model

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***Abstract*: Microstrip antennas are now exclusively used in almost all wireless communication system devices, especially operating in the microwave frequencies. The high-end applications are mostly in the frequency range from 2 to 12 GHz. Owing to its light weight and integral property with integrated circuits, they are extensively used in wireless communication fields. The paper presents a simple transmission line modelling technique to find the impedance and solutions of one dimension differential equation of the rectangular microstrip antenna.**

***Index Terms:* Microstrip antenna, Microwave frequency, Impedance, Transmission Line, Differential Equation**

I. INTRODUCTION

The wireless communication system has shown a tremendous growth in the present days. Various personal applications of mobile communication, wireless computer link, wireless remote controls and wireless personal internet are on a rise in today's world. The size of electronics needed for wireless applications is shrinking drastically, where as their functionality has increased. Microstrip patch antenna fulfills most of the commercial requirements for wireless communication. The functionality of wireless devices has been increased where the size of electronic circuits is shrinking drastically. The size of the antennas being used for the most of applications is also shrinking. The very basic form of the Microstrip antenna can be constructed using a dielectric substrate [1,2] as a base material. The shape of the substrate has been taken as rectangular for simplify analysis, a radiating patch on one side of a dielectric substrate, shape of the patch is any of the simple geometrical shape or some other common shape for the simplification of the analysis and performance prediction. The simple microstrip antenna undergoes with narrow bandwidth. The low bandwidth makes it unsuitable for many applications in wireless communication. Numerous methods have been considered [3,4] and found that impedance bandwidth of the microstrip antenna can be increased, and the effects of substrate dimension could be one of them. The electromagnetic waves radiate from the antenna to the free space and the power is supplied to the antenna through the feed line [5]. Every time there may be a mismatch of impedance at the interface of feedline and antenna, it causes some of the electromagnetic waves to travel back. This results in the creation of a standing wave in the line and lowers down the performance of the antenna. a good impedance matching minimized the creation of standing wave inside the line and helps in maximum transfer of power to the antenna. The consequence would be an increase in the antenna bandwidth and its performance. Simplified models for approximate analysis of patch antennas is mainly suitable for analysis of antennas with a patch of regular geometries (such as rectangular, circular or square). Transmission line model and cavity model are suitable for analysis of microstrip patch antennas [6,7]. These two are main approaches to approximate modeling of microstrip antenna. In simple transmission line model, used for analyzing rectangular patch antenna, the interior region of the patch antenna is modeled as a section of transmission line patch antennas are narrow-band resonant devices, they can also be viewed as lossy resonant cavities. These models make some simplifying assumptions. The features of these assumptions are analytical simplicity in the form of the usage of closed-form functions and expressions for wall admittances which are less computational resource intensive. In the cavity model, the interior region of the patch is modeled as cavity bounded by electric walls on top and bottom and the magnetic wall on the periphery. This approach is more complex than the transmission line model.

In this paper, the microstrip antenna is modeled as per transmission line analysis. The characteristic impedance Z0 (or characteristic admittance Y0) and propagation constant are determined by rectangular patch dimensions (L and W) and substrate parameters Er (and loss tangent values).

Manuscript published on 30 June 2019.
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II. EQUIVALENT TRANSMISSION LINE ANALYSIS AND IMPEDANCE

Impedance matching is an important feature in high frequency circuit design. It is the proper matching of source part of an antenna to radiating part and proper matching is a must in order to achieve a maximum power transfer between the two parts.

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This in turns minimizes the reflected waves and enhances performance. Impedance matching is an emerging arena of research in almost every aspect of technology viz. communication, electronics, electrical, sound, optical etc. In communication area for the transmission of different types of the signal; proper termination is important to reduce reflections and to preserve signal integrity with a higher throughput of absolute data. As impedance mismatch in radio frequency network causes power to be reflected back to the source from the impedance mismatch boundary [8]. This reflection creates a standing wave, which leads storage of power instead of transmitting it to the load. Hence, there will be less power delivered from the input to the load or other parts of the system. Along with this, standing waves may damage and overheat the device because of increased peak power level. Other advantages of proper termination of load are a reduction in amplitude and phase error, reduction in power loss and improvement in the signal to noise ratio. Impedance matching is a challenging step in the antenna design to achieve optimum performance parameters like return loss, efficiency, gain, etc. Impedance matching also helps in tuning the antenna frequency with a much easier and faster way than modifying the antenna geometry. Proper impedance matching also helps in improving the bandwidth of antenna because of impedance matching circuits add some additional resonances. Impedance matching circuits also allow incorporating last-minute design change by allowing freedom in choosing the values of discrete components independently.

Transmission Line Model [9] is the simplest method of analysis the microstrip antenna. In this model of analysis, the rectangular patch is represented as a parallel-plate transmission line connecting two radiating slots or apertures of width W and height h, as shown in figure 1. Submit your manuscript electronically for review.

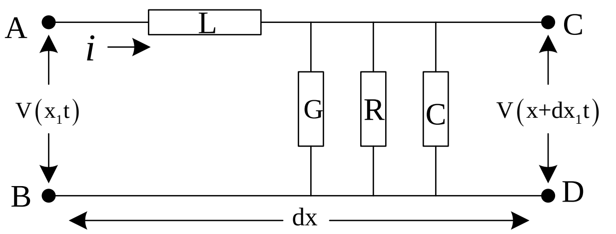

Fig 1: Equivalent Model diagram of microstrip antenna.

The equivalent circuit representing the antenna and the feedline includes the two radiating slots as parallel R-C circuits. The characteristics of the feedline are considered in the same way as those of a microstrip antenna as both are coupled to each other. Though this model lacks versatility, it presents a relatively fair insight into the nature of the patch antenna and the field distribution for all modes. The two radiating slots act as an open circuit and are represented by high-impedance terminations from both of its sides. This makes the structure to be highly resonant characteristics along the direction of propagation i.e z-axis. The field of TM mode does not depend on the x and y coordinates, but it strongly depends on the z-coordinate.

The width, W, is given as:

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad \text{- (1)}$$

This makes the width, W, equal to about half a wavelength and results in an effective radiation within the acceptable dimensions. Also this presents the antenna as a continuous planer source consisting of infinite number of infinitesimally small half wavelength dipoles.

The fringing occurs alongside the effective length of the patch Leff, and it eventually resultsin greater length than the physical length L. i.e. *Leff>L* .Therefore. The resonance condition $\beta=n\pi/2$ depends on *Leff* and not *L*, and effective length is known as the resonating length [10]. The fringing contributes the physical length L lesser than λ/2.

The effective length of patch L_{eff} is given as:

$$L = \frac{c}{2f}\left(\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\sqrt{\left[1+12\frac{h}{W}\right]}\right)^{\frac{-1}{2}} - 2\Delta L \quad \text{– (2)}$$

Effectively, $L_{eff} = \frac{\lambda_0}{2} = \frac{c}{2L_{eff}}$ and is responsible for resonant frequency.

Table 1 shows the value of length and width of the microstrip antenna in the microwave frequency range of 2-12 GHz. This is the frequency range where this type of antenna finds maximum application.

Table I: Antenna Dimension at Microwave Frequency

Frequency (in GHz)	Length (in cm)	Width (in mm)	Frequency (in GHz)	Length (in cm)	Width (in mm)
3	2.49	3.04	8	0.97	1.14
4	1.88	2.28	9	0.86	1.02
5	1.52	1.82	10	0.78	0.91
6	1.28	1.52	11	0.72	0.83
7	1.11	1.31	12	0.65	0.76

In the equivalent circuit of the antenna in terms of conductance G and susceptance B is shown in figure 2.

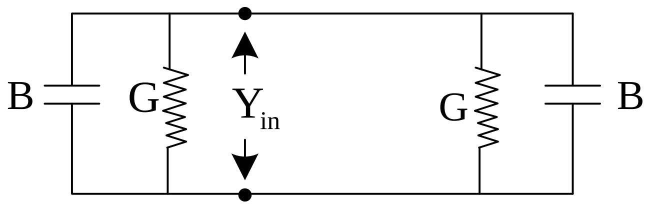

Fig 2: Equivalent circuit diagram of microstrip antenna.

Here, the width, W, and height h, are associated with conductance G and susceptance B as:

$$G = \frac{W}{120\lambda_0}\left\{1-\frac{1}{24}\left(\frac{2\pi h}{\lambda_0}\right)^2\right\} \quad \text{- (3)}$$

$$B = \frac{W}{120\lambda_0}\left\{1-0.64\ ln\left(\frac{2\pi h}{\lambda_0}\right)^2\right\} \quad \text{- (4)}$$

The conductance (G = 1/R) represents the radiation loss and the susceptance (B = jωC) represents the capacitance of each slot respectively.

A plot of absolute value of G and B over the microwave frequency is plotted in figure 3. The plot reveals that the two values are almost identical after 5 GHz of frequency.

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Whereas the variation of the absolute values of these two parameters per unit length is shown in figure 4. This plot indicates that the effect of G and B over length is minimum, and no variation is exhibited. The nature of the plots in figure 3 and 4 are identical.

At the point of power source, the impedance poised by is transferred to the corresponding transmission line as represented by the antenna [5,6].

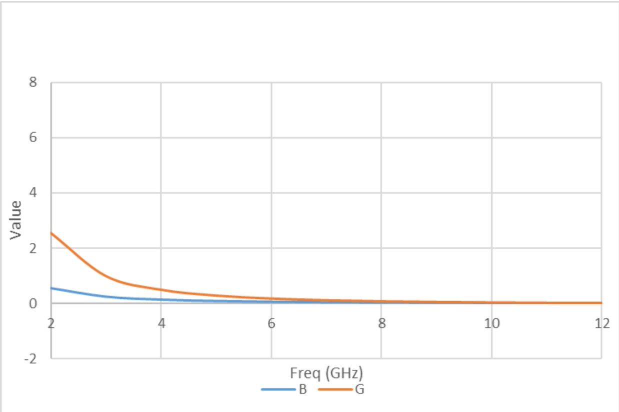

Fig 3: Variation of B and G over Microwave frequency

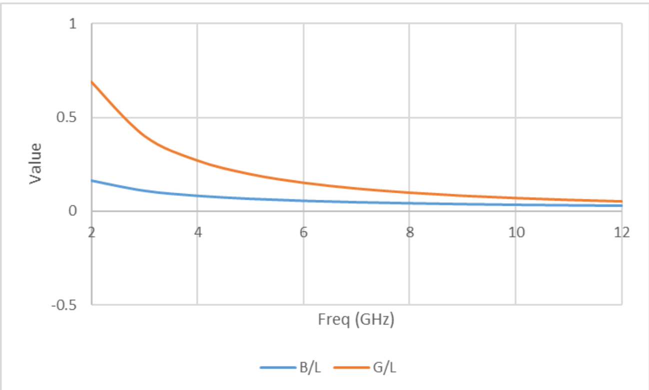

Fig 4: Variation of B and G per unit length of antenna over Microwave frequency

The susceptance of each of the two both slots cancel out at the source feed point during the resonant condition of the antenna. This gives the value of the input admittance Y_{in} always real. The position of input admittance is shown in figure 2. The input admittance Z_{in} is related to the input admittance Y_{in} as:

$$Z_{in} = \frac{1}{Y_{in}} = R_{in} \quad \text{-(5)}$$

The value of the antenna input admittance is given as:

$$Y_{in} = \frac{Y_c^2 + Y_s^2 - Y_m^2 + 2Y_sY_c\coth(\gamma L) - 2Y_mY_c\,cshh(\gamma L)}{Y_s + Y_c\coth(\gamma L)} \text{-} \quad (6)$$

Taking into account the parasitic effect of the feed line,

$$Y_{in} = \left(1 - \frac{W_m}{W}\right)Y_s + \frac{Y_c^2 - Y_m^2 + 2Y_sY_c\coth(\gamma L) - 2Y_mY_c\,cshh(\gamma L)}{Y_s + Y_c\coth(\gamma L)} \quad \text{---} \quad (7)$$

Self-admittance of slots (*Ys*) and mutual admittance (*Ym*) are directed by a series of equations [8-10]. Putting these values in equation (7), a generalized solution of getting the input admittance (Z_{in}) is obtained. The input admittance is given as:

$$Z_{in} = Z_c\left|\frac{Y_c + jY_L\tan(\beta L)}{Y_L + jY_c\tan(\beta L)}\right| \quad \text{--} \ (8)$$

For a normalized value of $\beta L = \pi$, $Z_{in} = Z_c$. Z_c is the characteristic impedance of the antenna.

The enhancement of the performance of the antenna is very much dependent on the impedance matching of it.

III. DIFFERENTIAL EQUATION OF THE MICROSTRIP ANTENNA

With reference to figure 1, the equivalent circuit of the microstrip antenna, the symbols L, G, R and C donate the inductance, conductance, admittance and capacitance [11]. The symbol v and i refer to the voltage and current, whereas x and t are the distance and time respectively.

Let v (x,t) is the voltage between terminals A and B, whereas at a distance dx from this terminal the voltage drop is v(x+dx,t), whereas i is the current along the microstrip antenna.

The voltage across the inductor is given by

$$v = -\frac{di}{dt} \quad \text{- (9)}$$

The voltage across the capacitor is given as

$$v = -\frac{1}{c}\int i\,dt \qquad (10)$$

The voltage at terminal CD is the difference in voltage at terminal AB and voltage along the terminals. Therefore, it is written as:

$$v(x + dx, t) - v(x, t) = -(-Ldx)\frac{di}{dt}(11)$$

Apply partial differentiation w.r.t x, we get on equation no (9), we have

$$\frac{dv}{dx} = L\frac{di}{dt} \quad \text{- (12)}$$

Differentiating Eq. (4) with respect to x, we get

$$\frac{\partial^2 v}{\partial x^2} = L\frac{\partial^2 i}{\partial x \partial t} \text{ or}$$

$$\frac{\partial^2 i}{\partial x \partial t} = \frac{1}{L}\frac{\partial^2 v}{\partial x^2} \quad \text{- (13)}$$

Similarly, the current at terminal CD is the difference in current at terminal AB and current flow across the terminal, and from this we get

$$\frac{di}{dx} = -Gv - I_L - I_C \qquad (14)$$

The current across the capacitor is given as

$$I_C = C\frac{dv}{dt} \qquad (15)$$

The current across the inductor is given by

$$v = -L\frac{dI_L}{dt} \qquad (16)$$

From Eq. (16), we get

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$$v = -\frac{1}{G}\frac{di}{dx} - \frac{1}{G}I_L - \frac{1}{G}I_C. \qquad (17)$$

Now differentiating Eq. (17) partially with respect to t, we have

$$\frac{dv}{dt} = -\frac{1}{G}\frac{d^2 i}{dxdt} - \frac{1}{G}\frac{di_L}{dt} - \frac{1}{G}\frac{di_C}{dt} \qquad (18)$$

Now using Eq. (14) and (17) in Eq. (18), we have

$$\frac{dv}{dt} = -\frac{1}{GL}\frac{d^2 v}{dx^2} - \frac{C}{G}\frac{d^2 v}{dt^2} + \frac{v}{LG}$$
$$\Rightarrow \frac{1}{GL}\frac{d^2 v}{dx^2} = \frac{C}{G}\frac{d^2 v}{dt^2} - \frac{dv}{dt} + \frac{v}{LG}$$
$$\Rightarrow \frac{d^2 v}{dx^2} = LC\frac{d^2 v}{dt^2} - GL\frac{dv}{dt} + v \qquad (19)$$

This is the required partial differential of dimension one equation for microstrip antenna.

IV. CONCLUSION

Approximate models for patch antenna analysis and their applications are discussed. Formulae used for the design of microstrip patch antenna based on the transmission line model and differential equation are presented in this paper.

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