Transmission Line Model for Circular Patch Antenna

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ABSTRACT

The dominant mode resonant frequency of a circular patch antenna gives the propagation constant of its simple transmission line model. The characteristic impedance and the propagation constant of the patch antenna then contribute for the L and C of the equivalent transmission. Equating the resonant frequency of the patch antenna to that of an open circuited transmission line in resonance, the length of the transmission line is obtained. Finally, a mapping is done to map the feed-point along the radius to the proposed equivalent transmission line to calculate the impedance along the diameter of the circular patch. The results agree well with cavity model.

INTRODUCTION

The microstrip antenna technology is stabilizing very fast. The designers can now obtain commercial software like IE3D, HFSS, ADS, etc. However, for a first hand design or rule of thumb design, these are highly costly, both from computing time and economic costs. For a rectangular patch antenna, the transmission line antenna still remains the first CAD choice. The other common regular shape, the circular patch antenna, unfortunately doesn't enjoy this flexibility. This paper develops a simple transmission line model for the input impedance of circular patch antenna. In this approach, the cavity model equations of the circular patch antenna are used in establishing an analogy with the transmission line model of the rectangular patch antenna. This simple model can be used as a CAD model for a circular patch antenna design.

THEORY

The transcendental equation to determine the design parameters of a circular patch antenna is of the form [1]

$$k\left(J_1'(k)/J_1(k)\right) = -\chi \tag{1}$$

The solution for k in (1) is a complex number. The imaginary part takes care of the radiation by the antenna due to the capacitive fringing effect at its edges. The input quantity is supplied through the factor χ, in the above equation, which is given in (2) below.

$$\chi = j(\eta_0/\lambda_0)h(G + jB) \tag{2}$$

G and B in (2) are to be obtained in the form

$$G = C_1\left(\pi a/\lambda_0\right) \tag{3}$$

$$B = C_2\left(\pi a/\lambda_0\right) \tag{4}$$

In (3) and (4) C_1, and C_2 are two numerical constants to be determined from the cavity model results later. Denoting the real and imaginary parts of k as k_r and k_i, the resonant frequency and the radiation Q-factor will be given as

$$Q = 0.5\left(f_r/f_i\right) \tag{5}$$

$$f_r = \left(f_r/\alpha_0\right)f_n \tag{6}$$

In (6) above, α_0 (= 1.84118) is the first zero of the 1st order Bessel's function, and f_n is given as

$$f_n = \left[\left(c\alpha_0\right)/\left(2\pi\alpha\right)\right]/\sqrt{\varepsilon_r}$$

(7)

Transmission Line Model: The rectangular patch antenna transmission line model, assumes two conducting slots of admittance Y connected by a lossless transmission line of length slightly less than half-wave length, fed anywhere along this length. We will develop the circular patch antenna model based on this concept. In this first approach, the length of the transmission line connecting the admittance $G+jB$ is chosen to be slightly less than half wave length in complete analogy to the rectangular patch antenna. The feed-point along the radius of the patch is mapped onto this length according to the following formula.

$$l = \left(0.5r/a\right)L$$

(8)

In (8), l is the position on the equivalent transmission line of length L, corresponding to the position r along the radius a of the circular patch antenna.

Determination of C_1 and C_2: The philosophy here is that the input impedance at l on the equivalent transmission line will be equal to the input impedance at r on the circular patch antenna. There are two unknowns, C_1 and C_2. So, we need at least two equations to solve for finding the unknowns. Equating these impedances, at two different points, the constants C_1 and C_2 of (3) & (4) are found out to be 0.01731543 and 0.00798867 respectively. Thus the final equation for input impedance becomes

$$Z_{in} = 1/Y_{in}$$

(9)

$$Y_{in} = 2G\left[\cos^2(\beta l) + \left(\left(\left(G^2 + B^2\right)/Y_0^2\right)\sin^2(\beta l)\right) - \left(\left(B\sin(2\beta l)\right)/Y_0\right)\right]^{-1}$$

(10)

$$\beta = \left(2\pi\sqrt{\varepsilon_{eff}}\right)/\lambda_0$$

(11)

$$\varepsilon_{eff} = 0.5\left(\varepsilon_r + 1 + \left(\varepsilon_r - 1\right)/\left(\sqrt{\left(1 + 12h/a\right)}\right)\right)$$

(12)

RESULTS AND DISCUSSIONS

We consider a circular patch antenna of radius 6.75 cms, on a substrate of thickness 0.159 cm and dielectric constant 2.62. Figure 1 compares the theoretical and simulated VSWR at various frequencies fed at a distance of 1/3rd of the radius from its edge. The overall agreement of the curves is good.

REFERENCES

[1] J. D. Mahony, "Similarities in Design Equations for Rectangular and Circular Patches," *Antenna Designer's Note Book in IEEE Antennas Propagation Magazine*, Vol. 33, No. 5, pp. 51 – 54, Oct' 1991.

[2] K. R. Carver, and E. L. Coffey, "Theoretical Investigation of the Microstrip Antenna," *Technical Report PT – 00929*, Physical Science Laboratory, New Mexico State University, Las Cruces (New Mexico), Jan. 1979.

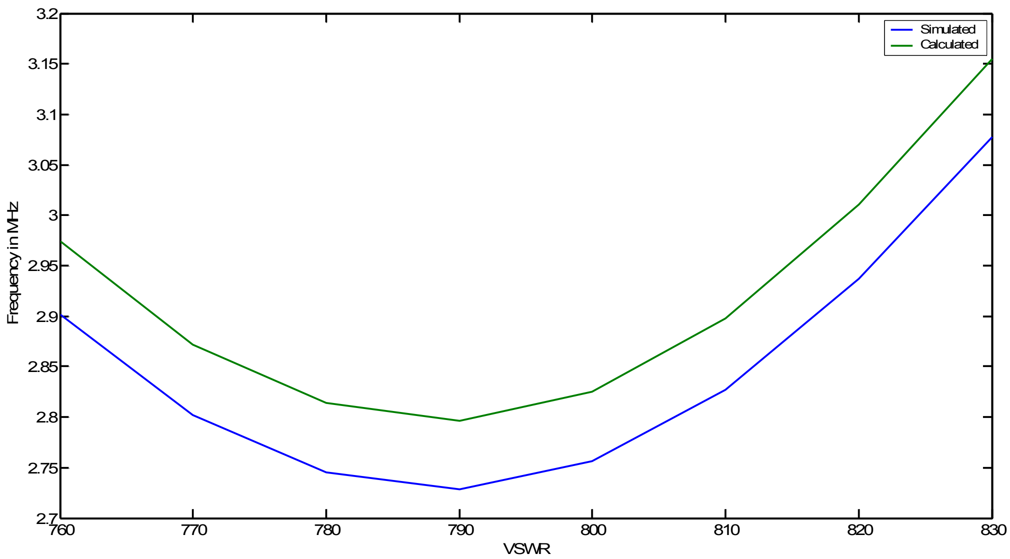

Figure 1: Comparision of Simulated and Calculated VSWR