Subtraction of Discontinuity Susceptance for WIPL-D Source Modeling

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Abstract- WIPL-D does not include a provision for a direct specification of a coaxial line excitation of patch antennas in terms of the incident dominant TEM mode. Instead, such an excitation is approximated by a voltage generator in series with a thin wire, one end of which is connected to the inner conductor of the coax and the other end to a flat shorting cap joined to the outer conductor. The transition from the diameter of the inner conductor to the diameter of the wire gives rise to a spurious capacitive shunt susceptance leading to an error in the calculated antenna input impedance. It is shown that this susceptance can have a significant effect on the WIPL-D calculations of the return loss of narrow band patch antennas. A computational technique is presented for neutralizing this modeling deficiency.

Index Terms- WIPL-D, narrow band patch antennas, return loss.

I. INTRODUCTION

WIPL-D is a program that allows modeling and analysis of metallic and/or dielectric/magnetic structures (antennas, scatterers, passive microwave circuits, etc.) [1]. We have used WIPL-D to design the coaxially fed patch antenna illustrated in Figure 1 (a). The cross section of the coax feed and patch antenna is shown in Figure 1(b). One peculiarity of WIPL –D is that it does not allow a direct coaxial line feed (e.g., a magnetic current sheet corresponding to the TEM coax mode electric field). Instead, auxiliary structures are employed at the input end to facilitate the injection of a voltage source. These are illustrated in Fig. 1 (c). One arrangement, shown in the upper portion of Fig.1(c), employs a thin short wire (length $r_0/4$, with r_0 is the radius of the inner conductor of the coax) that connects the inner conductor to the conducing back plate terminating the coax. An ideal voltage source is applied in series with the wire. We refer to this type of arrangement as an edge excitation. Alternatively, to provide a smoother transition from the coax inner conductor to the thin wire at the voltage source, several wires may be used, each connecting the voltage source with a wire to a side of a regular polygon approximating the cross section of the inner conductor of the coax. In WIPL-D at most 12 wire - to -plate junctions can be defined, which limits the modeling of the cross-section of a circular cylinder to a polygon with 12 sides. This second form of excitation is illustrated schematically in the lower portion of Fig. 1c).We shall refer to it as cone excitation.

As a result of the transition of the coax inner conductor to the voltage source both the edge and the cone excitations give rise to a shunt discontinuity susceptance. This susceptance is an artifact of the feed structure used to facilitate numerical calculations and would normally not be present when a real physical coaxial feed is employed. Using WIPL calculations for the input impedance of a patch antenna we investigate the effect of this susceptance and present a technique for neutralizing the resulting error.

Referring to the geometry of a single-layer patch antenna shown in Figure 1(a), the length of the patch L is 51.22 mm, the width is W, thickness of 35μm, and a substrate height h of 0.062 inches. The coaxial line feed point is located at x_r and y_r. A finite ground plane (dimensions u and v) is assumed. The dimensions and parameters of this design were chosen to obtain a patch antenna radiator in the 1895-1910 MHz band [2]. The specific parameter values are L= 51.22 mm, W=

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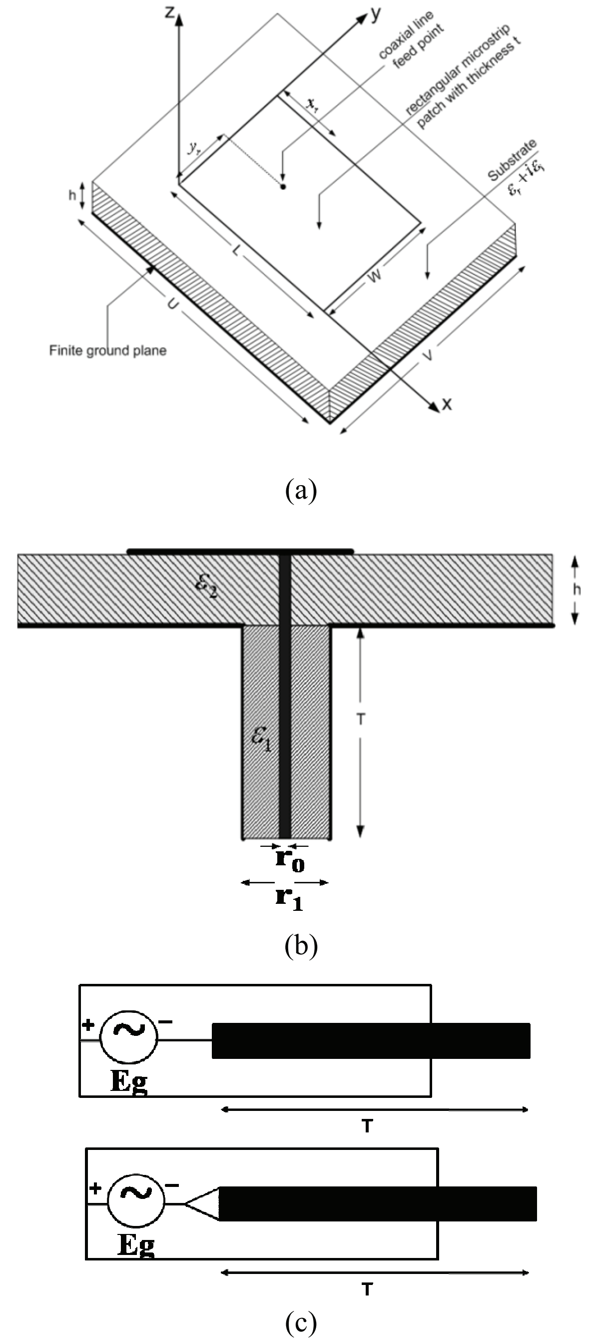
60 mm, h=1.5748 mm, $\varepsilon_2 = 2.2(1 - i0.0004)$, x_r=0.35L, and y_r=W/2. The transmission line parameters are Length=2cm, r_0=0.635mm, r_1=2.0574mm, ε_1=2.07, and a ground plane size=(L+40h)*(W+40h) mm^2.



(a)

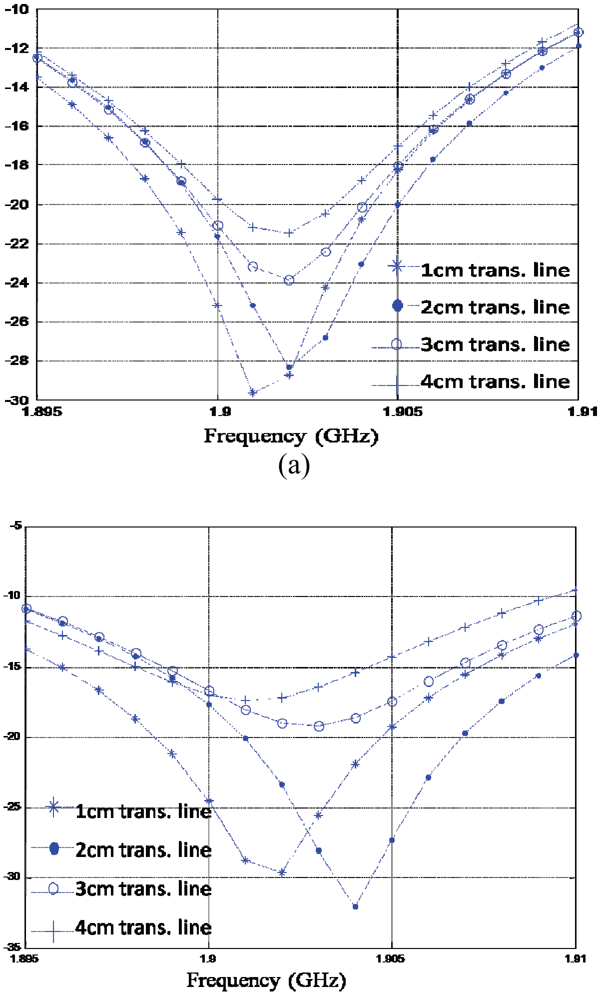
(b)

(c)

Fig. 1. Rectangular microstrip patch antenna (a), cut through the coax feed (b), and auxiliary feed structures (c).

II. CALCULATIONS OF RETURN LOSS WITH WIPL-D FOR DIFFERENT LENGTHS OF TRANSMISSION FEED LINE

In the following we present results of return loss calculations for the patch antenna in Fig. 1 for the cone and edge excitation options in WIPL-D described in the preceding.



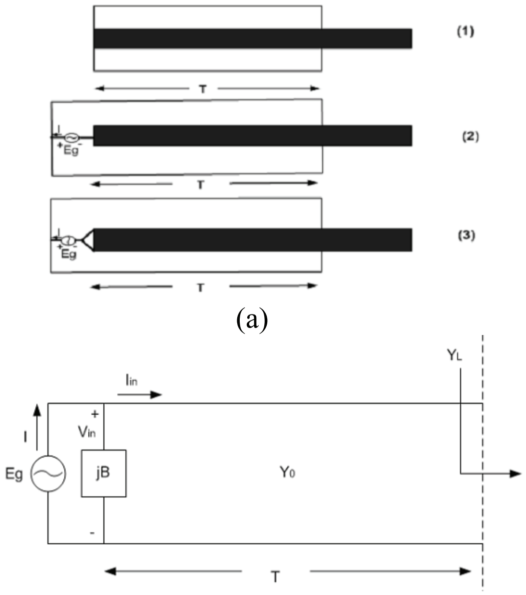
(a)

(b)

Fig. 2. Return loss (dB) of patch antenna for different transmission line lengths using cone-excitation (a), edge excitation (b).

Figure 2(a) shows plots of the magnitude of the input reflection coefficient as a function of frequency for the cone excitation for four different lengths of the input feed line. These large differences among the return loss response curves and changes of the effective resonance frequency are incompatible with the model of a transmission line excited by an ideal voltage source, since in such a model different lengths of lossless feed lines can affect only the phase of the input reflection coefficient and not its magnitude. Similar effects are observed when an edge excitation is employed, as shown in Fig. 2(b). The reason for the variation of the return loss with the length of the feed line can be traced to the discontinuity susceptance introduced by the change of the inner conductor of the coax at the feed point, as discussed in following section.

III. SUBTRACTION OF DISCONTINUITY SUSCEPTANCE FOR WIPL SOURCE MODELING



(a)

(b)

Fig. 3. The coaxial line feed models (a), equivalent circuit of a coaxial line feed in WIPL (b).

Despite the imperfection in modeling the coaxial line feed in WIPL-D, it is possible to correct the calculated input reflection coefficient by taking into account the effect of the shunt susceptance introduced by the wire excitation at the end of the coaxial line. Indeed, as discussed in the sequel, the correction technique generalizes to the S matrix of an array of patch antennas. Figure 3(a) shows three sketches of a coaxial line. The top is the ideal coaxial line that we would like to simulate, wherein an ideal voltage generator could be modeled exactly by a sheet of magnetic current inserted between the inner and outer conductor, representing the E field of the coaxial TEM mode. The two lower configurations represent excitations used in WIPL-D: the edge excitation, and the cone excitation. Because of the change in the diameter of the inner conductor both WIPL-D excitations deviate from an ideal voltage source. To a first approximation, the effect of the change in the diameter can be modeled as a capacitive shunt susceptance in which case the circuit representation of the coaxial transmission line feed assumes the form shown in Fig. 3(b). Although the magnitude of this susceptance could be obtained from a separate numerical calculation, it is simpler and of greater utility to be able to infer it directly from WIPL-D. Thus the input admittance Y computed by WIPL-D is the ratio

$$Y = \frac{I}{E_g} \qquad (1)$$

with I the E_g defined in Figure 3, whereas the actual input admittance is given by

$$Y_{in} = \frac{I_{in}}{E_g} \qquad (2)$$

or, equivalently, by

$$Y_{in} = Y - jB \qquad (3)$$

The parasitic discontinuity susceptance B can be determined by running WIPL-D for two or more transmission line lengths as shown in the following development.

Using normalized quantities y_{in}, b, y , and y_L with Y_0 the characteristic impedance of the coax,

$$y_{in} = \frac{Y_{in}}{Y_0}, \quad y = \frac{Y}{Y_0}, \quad y_L = \frac{Y_L}{Y_0}, \quad b = \frac{B}{Y_0}, \qquad (4)$$

$$y_{in} = y - jb \qquad (5)$$

the normalized input admittance y_{inq} to the coaxial line with electrical length θ_q becomes

$$y_{inq} = \frac{y_L + j\tan\theta_q}{1 + jy_L \tan\theta_q} \qquad (6)$$

where y_L is the normalized input admittance at a fixed reference plane, and $q = 1, 2, \ldots N$ refers to different choices of the length the coaxial line. For example, with $N = 2$

$$y_{in1} = \frac{y_L + j\tan\theta_1}{1 + jy_L\tan\theta_1} \tag{7}$$

$$y_{in2} = \frac{y_L + j\tan\theta_2}{1 + jy_L\tan\theta_2} \tag{8}$$

where

$$\theta_1 = \frac{2\pi f\sqrt{\varepsilon_r}}{c}T_1, \quad \theta_2 = \frac{\theta_1}{T_1}T_2 \tag{9}$$

Using the corresponding admittance calculated by WIPL-D y_1 and y_2 the input admittances (7) and (8) are

$$y_{in1} = y_1 - jb \tag{10a}$$

$$y_{in2} = y_2 - jb \tag{10b}$$

Subtracting, one obtains

$$\Delta y = y_{in1} - y_{in2} \quad = y_1 - y_2 \tag{11}$$

so that Δy is fixed from two WIPL-D calculations. Thus subtracting (7) and (8) and using (11) yields the following quadratic equation for $\mathrm{y_L}$:

$$\alpha y_L^2 + \beta y_L + \gamma = 0 \tag{12}$$

where

$$\alpha = \tan\theta_2 - \tan\theta_1 - j\Delta y\tan\theta_1\tan\theta_2$$

$$\beta = -\Delta y(\tan\theta_1 + \tan\theta_2) \tag{13}$$

$$\gamma = \tan\theta_1 - \tan\theta_2 + i\Delta y$$

Only the root with the positive real part corresponds to the correct solution, which, upon substitution in (5), yields the susceptance *b*. Ideally, this should yield a purely real positive number since the susceptance is capacitive. However numerical errors will generally cause the answer to be complex. If the real part is positive and much larger than the imaginary part the imaginary part may be discarded. The accuracy can be improved by using $N > 2$ and solving an overdetermined system using least squares.

IV. RETURN LOSS FOR THE CORRECTED EDGE AND CONE EXCITATIONS

The preceding correction procedure was applied to both cone and sharp-edge excitations. Figure 4 shows plots of the return loss for three different lengths of the feed line. Comparing these plots with Fig. 2 we see that variation of return loss with changes in lengths has been reduced to less than 2dB. Note that the correction gives essentially the same results for the sharp-edge and cone excitations. Hence, the cone excitation offers no advantages over the sharp edge excitation.

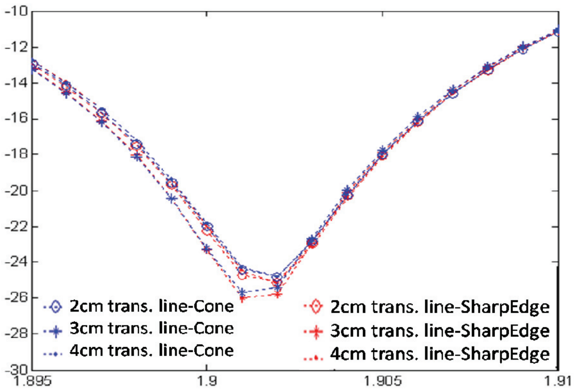


Fig. 4. Corrected return loss for both edge and cone excitations.

V. CONCLUSIONS

The WIPL-D source model for coaxial line feeds for patch antennas introduces a spurious discontinuity susceptance which can give rise to significant errors in the return loss calculations of narrow band patch antennas. A technique for subtracting this susceptance has been presented and illustrated by numerical examples.

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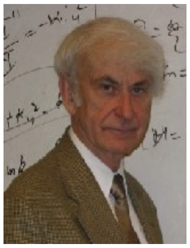

Wasyl Wasylkiwskyj (F'97) received his BEE degree from the City University of New York in 1957 and the MS and Ph.D. degrees in electrical engineering from the Polytechnic University in 1965 and 1968, respectively. His past research and industrial experience covers a broad spectrum of electromagnetics, including microwave components and techniques, phased array antennas, propagation and scattering, radar cross-section modeling as well as modeling of geophysical and oceanographic electromagnetic phenomena. In addition, he has extensive experience in ocean and structural acoustics with applications to active SONAR. Since 1985 Dr. Wasylkiwskyj has held the position of Professor of Engineering and Applied Science at the George Washington University, Washington, DC. His current research activities are primarily in numerical electromagnetics and array antennas for direction –of- arrival estimation.