Wire Equivalents of Antenna Standoffs

The paper presents an efficient technique to determine equivalents of antenna dielectric standoffs in the form of wires with distributed loadings.

Introduction

Let us consider antenna tube mounted above ground (PEC plane) using dielectric standoffs, as shown in Fig. 1. The antenna tube is capacitively coupled with the ground. The capacitive coupling of the antenna tube with the ground is characterized by capacitance per unit length (e.g. in pF/foot) of the transmission line made by the tube and the ground. Since, the capacitive coupling along the parts of the tube with standoffs is different from that along parts without standoffs, the corresponding capacitances per unit differs, too.

Influence of each dielectric standoff can be emulated by wire of properly determined radius and distributed loading. The equivalent radius and the distributed loading are determined by cross-section dimensions of the standoff and its electrical properties (relative dielectric constant). The relative dielectric constant of the standoffs can be determined according to the tube radius and capacitance per unit length in the presence of dielectric stand.

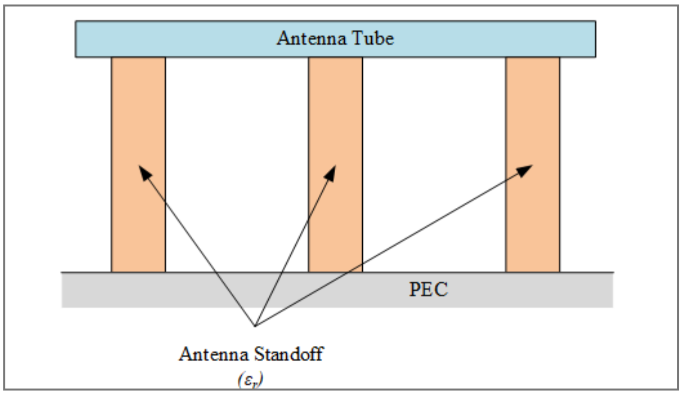

Figure 1. Antenna above PEC plane

Evaluation of Capacitance per Unit Length using WIPL-D Pro (3D EM Solver)

Capacitance per unit length of transmission line, *C*' can be expressed as:

$$C' = \frac{1}{cZ_c} \qquad (1)$$

where *c* is speed of wave propagation along the line and Z_c is its characteristic impedance. Those two parameters can be determined using WIPL-D Pro (3D EM Solver) in the following way.

Let us consider finite transmission line made of antenna tube supported by continuous dielectric standoff over the ground, as shown in Fig 2.

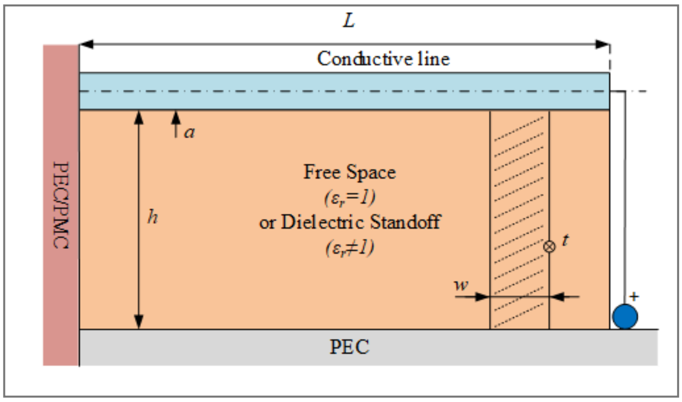

Figure 2. Sketch of transmission line made of the tube supported by dielectric standoff over the ground, excited at one side by voltage generator and short-circuited by PEC or PMC planes at another side.

On the one side the tube is excited through thin wire by delta voltage generator connected to the ground. On the other side the transmission line is shortcut by the PEC plane or by PMC plane. The PEC plane is used to model ideal short-circuited line. The PMC plane is used to model ideal open-circuited line. If length of line is $L=\lambda/8$, then the magnitude of input impedance of both, the open and the short-circuited lines, is equal to Z_c. In particular, if input impedances of both lines are determined in a range of frequencies around $L=\lambda/8$, the corresponding curves for their magnitudes mutually intersect at value equal to Z_c.

To prove the concept, let us consider first the case with air-filled standoff, i.e. tube without support, as shown by WIPL-D model in Fig. 3.

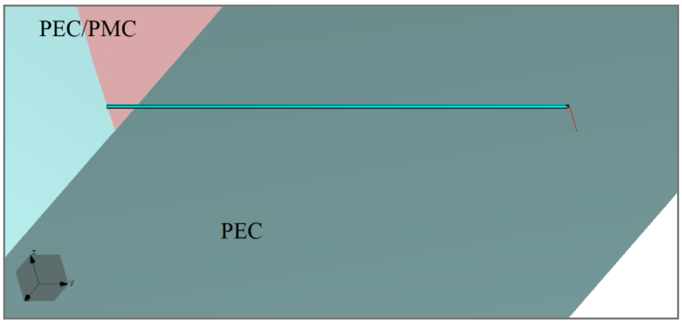

Figure 3. WIPL-D model of system in free space

Theoretically, capacitance per unit length of the line in free space can be determined in closed form as:

$$C' = \frac{2\pi\varepsilon_0}{\ln\frac{2h}{a}} \qquad (2)$$

For h = 203.2 *mm* (~8") and a = 25.4 *mm* (~1"), formula (2) gives C' = 16.33 pF/m, while WIPL-D curves obtained by PEC and PMC shortcut intersects at Z_c = 205.3 *Ω*.

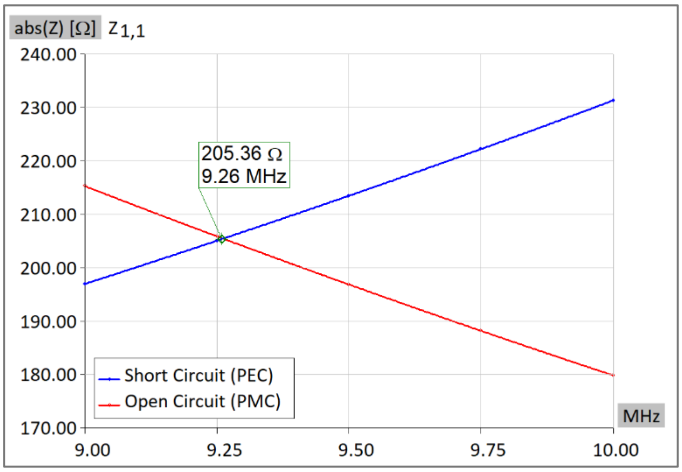

Figure 4. Magnitude of Z versus frequency for PEC and PMC projects mutually intersect at value of Zc in free space

Using $c = c_0$, where c_0 = 299,792,458 *m/s* is speed of TEM waves in vacuum, in formula (1) gives C' = 16.23 pF/m. All these results are summarized in Tab. 1

Table 1. Capacitance per unit length in free space (WIPL-D results are compared with theoretical results).

Theoretical result	Result by WIPL-D
C' = 16.33 pF/m	Z_c = 205.36 Ω
	$c = c_0$ = 299,792,458 m/s
	C' = 16.23 pF/m

It is seen that results obtained using WIPL-D are very close to the theoretical result, which proves the concept.

In the next step let us consider the case with dielectric standoff of t = 12.7 *mm* (~0.5") and $\varepsilon_r = 16$. (WIPL-D model in Fig. 5.)

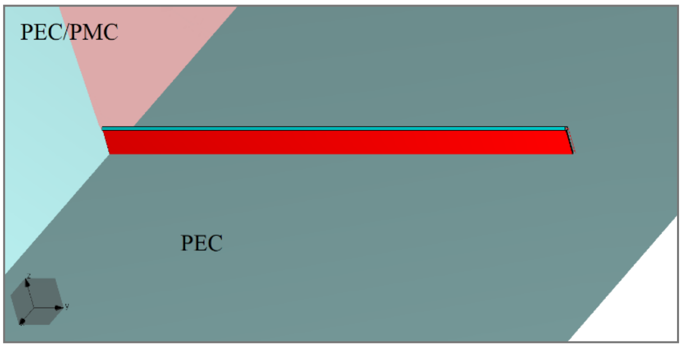

Figure 5. WIPL-D model of system with dielectric standoff

After running the PEC and PMC projects, the results for magnitude of input impedance are intersected at Z_c = 161.40 *Ω*, as shown in Fig. 6.

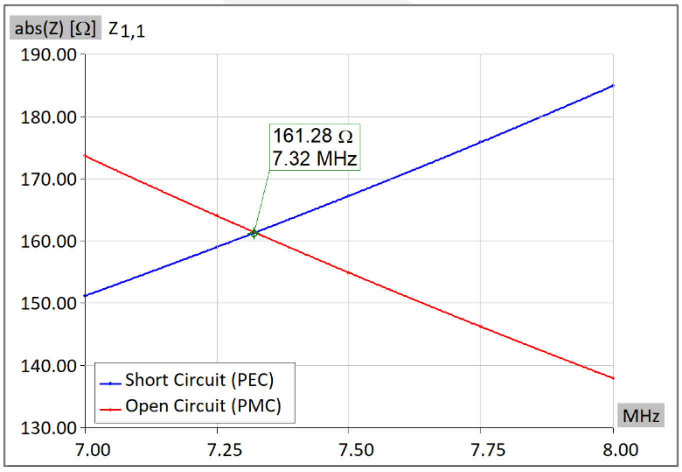

Figure 6. Results of PEC/PMC simulation with dielectric standoff

Comparing these results with those at Fig. 4, it is seen that frequency, at which $L=\lambda/8$, is shifted from f_0 = 9.26 MHz to f = 7.32 MHz. Having this in mind, it is possible to evaluate the effective electric constant of equivalent transmission line immersed in homogeneous environment, using simple formula

$$\varepsilon_{ef} = \varepsilon_0 \left(\frac{f_0}{f} \right)^2 \qquad (3)$$

resulting in ε_{ef} = 1.60. Further, the speed of corresponding TEM wave can be calculated as

$$c = c_0 \frac{f}{f_0} . \qquad (4)$$

resulting in c = 237,149,028 *m/s*. Finally, after applying formula (1) the value for capacitance per unit length is obtained, C' = 26.12 pF/m (~8 pF/foot). All these results are summarized in Table 2.

Table 2. Capacitance per unit length with dielectric standoff

Parameters	Values
Z_c – with dielectric standoff	161.40 Ω
f_0 – in free space	9.26 MHz
f – with dielectric standoff	7.32 MHz
c – with dielectric standoff	237,149,028 m/s
C'	**26.12 pF/m**

Wire Equivalents of Dielectric Standoffs

Part of the dielectric standoff of rectangular cross-section can be emulated by wire with distributed loadings under two conditions:

- Surface area of the wire cross section should be equal to the surface area of the standoff cross section, i.e. the radius of the wire is calculated as

$$R = \sqrt{\frac{w \cdot t}{\pi}} \qquad (5)$$

where $w = 107.14\ mm$ is width of the standoff cross-section and $t = 12.7\ mm$ is its thickness. (Dimensions w and t corresponds to real dimensions of the standoff given by the antenna manufacturer.)

- Surface capacitance of the wire is related to dielectric constant of the standoff $\varepsilon_r = 16$, as:

$$C_s = \frac{\varepsilon_0 (\varepsilon_r - 1) \cdot R}{2} \qquad (6)$$

Thus, we obtained the parameters of the equivalent wire with distributed loading: $R = 20.81\ mm$, $C_s = 1.38\ pF$

To prove this equivalence let us present the continuous standoff given in Figs. 2 and 5, as array of standoffs. The equivalent wire model in WIPL-D is shown in Fig. 7.

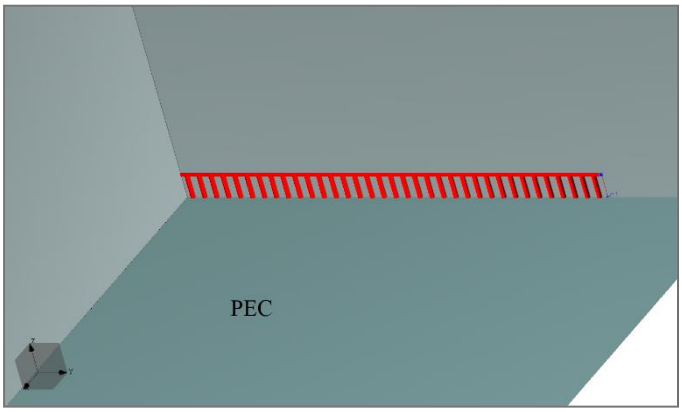

Figure 7. Wire model of system in WIPL-D

The results for original and equivalent model are shown in Fig. 8. It can be seen that results for characteristic impedance Z_c and frequency at which $L=\lambda/8$, mutually differs for ~2% when compared with original results.

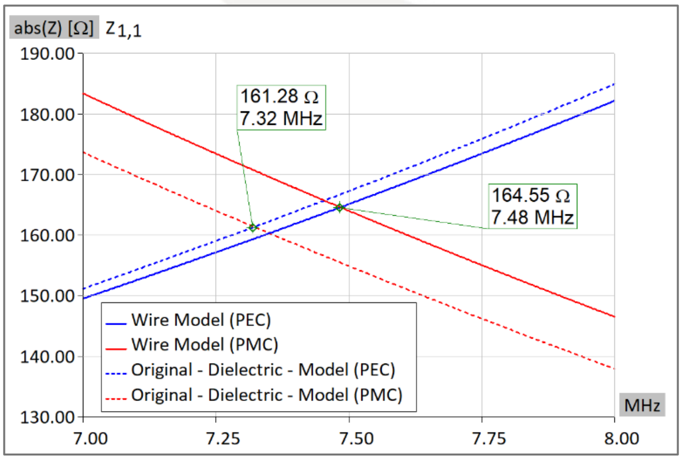

Figure 8. Results of the wire model

In particular, surface reactance can be tuned manually in order to obtain better matching with original model. Fig. 9 shows results for wire model with $C_s = 1.55\ pF$.

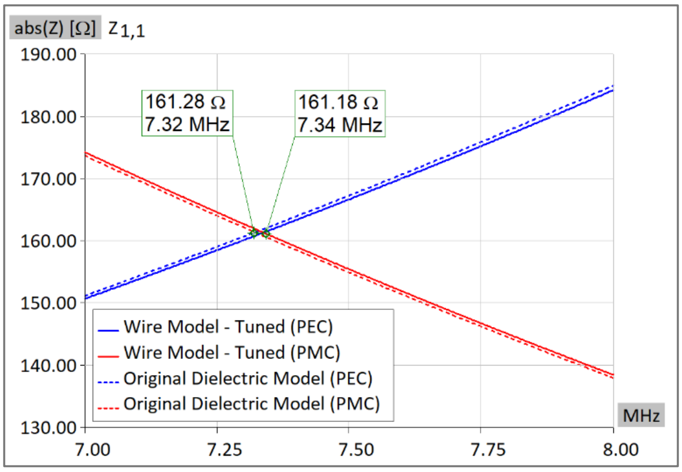

Figure 9. Results of the wire model obtained by tuning surface reactance

Conclusion

This paper presents how to determine basic parameters of the line in WIPL-D, as well as equivalency of the dielectric antenna standoff with wires with distributed loadings. Determining of characteristic impedance of arbitrary line, its effective dielectric permittivity and, at the end, its capacity per unit length are presented. Using reverse engineering, dielectric constant can be emulated if the capacity per unit length is known.

If simple and fast model are required for fast simulation and optimization, replacement of the dielectric standoff with wires with distributed loadings is the right approach. In this paper, through the simple example, this approach and its results are presented.