

APPROXIMATION OF THE EQUIVALENT SLOT CAPACITANCE IN A SLOTTED BOW-TIE
ANTENNA

A. A. Lestari, R. Pugliese, A.G. Yarovoy, L.P. Ligthart
International Research Centre for Telecommunications-transmission and Radar (IRCTR)
Delft University of Technology
Mekelweg 4, 2628 CD Delft, The Netherlands
a.lestari@irctr.tudelft.nl

1. Introduction

In our previous publications we have introduced a method for applying a combination of resistive (R) and capacitive (C) loading on a circular-end bow-tie antenna to considerably improve the antenna bandwidth [1] – [4]. The application of the RC loading allows the antenna to transmit ultra-wideband pulses with relatively high radiation efficiency and very small late-time ringing, suitable for impulse ground penetrating radars for detection of small shallowly-buried objects. While the resistive loading is realized by attaching volumetric absorbers on the antenna surface, the capacitive loading is realized by constructing concentric slots on the antenna body for which the amount of the loading is determined by the widths of the slots. In Fig. 1 the experimental slotted bow-tie antenna is shown. The antenna consists of an array of concentric slots with increasing widths towards the antenna ends for realizing a certain loading profile. Unfortunately, as there is no easy way to precisely determine the capacitance across the slots, the optimal slot widths are difficult to find. In this paper a numerical technique for approximating the equivalent capacitance across a concentric slot on a bow-tie structure is presented. This technique is useful for optimizing the dimensions and distribution of the slots in the antenna to improve the antenna's performance.

2. Approximation for the equivalent slot capacitance

In this paper we wish to find an approximate expression for the equivalent capacitance across a concentric slot on a bow-tie structure with geometry shown in Fig. 2. The geometry consists of a circular-end bow-tie body and a bow-shaped strip separated by a concentric narrow slot. The length of the bow-tie body, the strip width and the slot width are given by l_0 , l_1 , and Δ , respectively. The flare angle of the bow tie is 90° .

Since the slot width is small in terms of the smallest wavelength of interest, we may assume constant electric fields across the slot in the radial direction, or

$$E_\rho(\varphi, z = 0) = \text{constant}, \quad l_0 < \rho < l_0 + \Delta. \quad (1)$$

To simplify the derivation we further assume that E_ρ is constant for all values of φ covering the flare angle, although we realize that this is not true as currents concentrate more at the straight edges of the bow tie. The displacement current across the slot is the result of the electric flux density variation in time over the area of $2\pi(l_0 + \Delta/2)/4$ (parallel to the z -axis). Hence it can be written as

$$J_\rho = \frac{\pi}{2}(l_0 + \Delta/2)\epsilon_0 \int_{-\infty}^{+\infty} \frac{dE_\rho}{dt} dz, \quad (2)$$

where ϵ_0 is the free-space permittivity. Accumulation of electric charges along the edge of the slot causes a potential difference across the slot, which in the monochromatic case is given by

$$U = J_{\rho} / (j\omega C_{\text{eff}}), \quad (3)$$

where C_{eff} is the effective capacitance across the slot. Using Eq. (3) and the time-harmonic counterpart of Eq. (2) and by noting that across the slot $U = E_{\rho}\Delta$, the effective capacitance is obtained as

$$C_{\text{eff}} = \frac{\frac{\pi}{2}(l_0 + \Delta/2)\epsilon_0 \int_{-\infty}^{+\infty} E_{\rho} dz}{E_{\rho}(z=0)\Delta}. \quad (4)$$

3. Discussions

In this paper we consider the geometry in Fig. 2 with $l_0 = 8$ mm, $l_1 = 10$ mm, and $\Delta = 1$ mm, and 5-GHz time-harmonic excitations. Due to the constant-field assumption given by Eq. (1) the electric field in Eq. (4) may be evaluated at the middle of the slot ($z = 0$, $\rho = l_0 + \Delta/2$). The evaluation of the electric field has been performed numerically using the commercial code FEKO. The computed x -component of the electric field along a line parallel to the z -axis and intersecting the middle of the slot at $y = 0$ is plotted in Fig. 3 and inserted into Eq. (4). The computed values of C_{eff} as functions of frequency, slot width, strip width and body length are presented in Fig. 4. Note that since the problem considered is a radiating rather than an electrostatic problem, the obtained values of C_{eff} are complex.

Fig. 4(a) shows dependence of C_{eff} on the frequency. We observe that the real part is nearly constant while the imaginary part has a negative slope, meaning that as expected losses in C_{eff} increase with frequency since the antenna becomes electrically smaller. At low frequencies, the imaginary part of C_{eff} goes to zero as the problem approaches an electrostatic condition. Fig. 4(b) gives the values of C_{eff} for different slot widths at 5 GHz. It can be seen that in analogy with cylindrical DC capacitors, the real part of C_{eff} decays logarithmically as the slot width increases. Furthermore, Fig. 4(c) shows that C_{eff} is nearly independent on the strip length. This result is important for designing a bow-tie antenna with many slots such as the one shown in Fig. 1, because it reveals that spacing between slots may be freely chosen. In addition, dependence of C_{eff} with the body length is plotted in Fig. 4(d), where it is shown that C_{eff} increases almost linearly with the body length.

It should be noted that the results given in Fig. 4 are approximations that are useful only for a qualitative study of the problem. In the above results we do not take into account: 1) the radial variation of the field along the slot (assumption of constant fields across the slot), 2) the fringing effects (here we assume the field outside the coverage of the flare angle vanishes), and 3) the dependence of the field inside the slot on φ (current concentration within the body is assumed to be uniform). The expression for C_{eff} would be extremely difficult to derive if the mentioned factors are to be taken into account. Nevertheless, the given simplified expression in Eq. (4) should provide a useful tool for the antenna designer to estimate the equivalent capacitance of the slots in a slotted bow-tie antenna, important for determining the optimal slot dimensions and antenna's capacitive loading profile.

4. Conclusions

In this paper we present an approximate expression for the equivalent capacitance of a concentric slot in a slotted bow-tie antenna. Such an antenna has been introduced in previous publications, in which the slots were utilized to create a tapered capacitive loading in the antenna for bandwidth improvement which made the antenna suitable for transmitting ultra-wideband pulses with relatively high radiation efficiency. However, in previous publications the values of the equivalent capacitance of the slots have been determined intuitively, as there is no easy way to precisely determine them. The approximate expression for the equivalent slot capacitance presented here is thus an important alternative to qualitatively evaluate the equivalent capacitance of the slots in the antenna. The expression should provide a useful tool for the antenna designer to determine the optimal slot dimensions and antenna's capacitive loading profile for improving the antenna's performance.

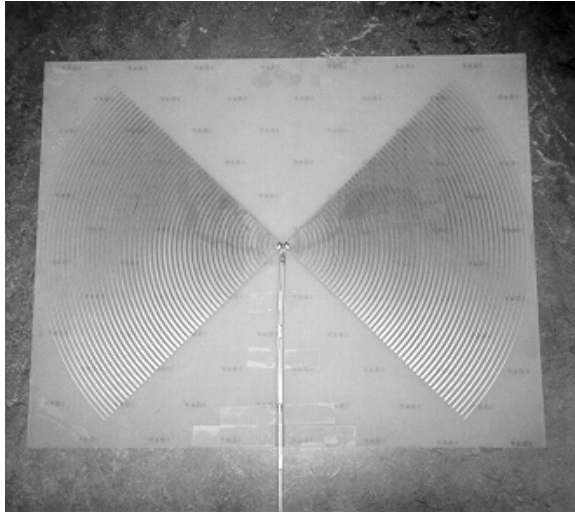


Fig. 1. Capacitively loaded bow-tie antenna. The capacitive loading is realized by narrow slots.

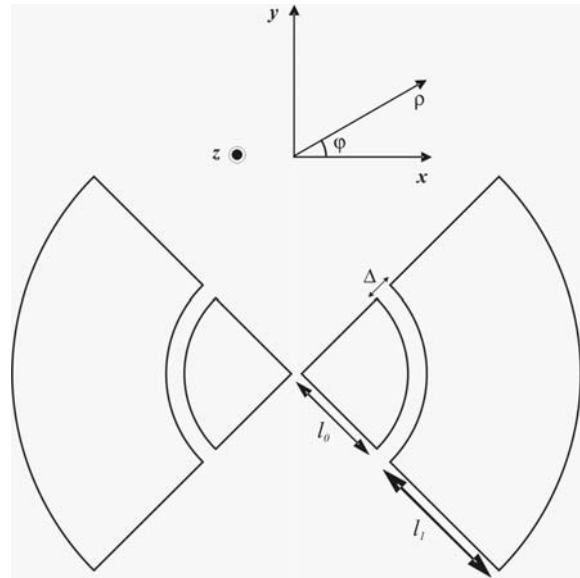


Fig. 2. Geometry of the problem. The flare angle is 90° .

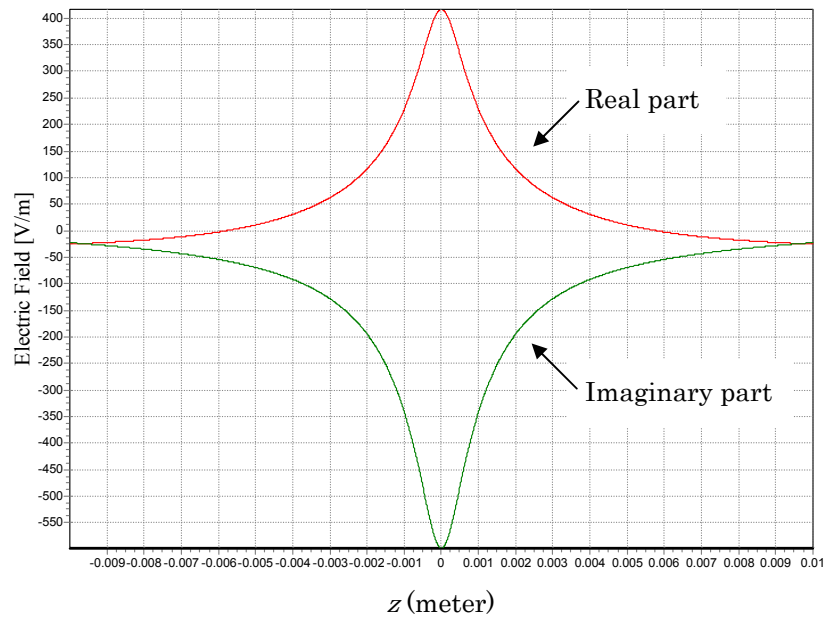


Fig. 3. Computed x -component of the electric field along a line parallel to the z -axis and intersecting the middle of the slot at $y = 0$.

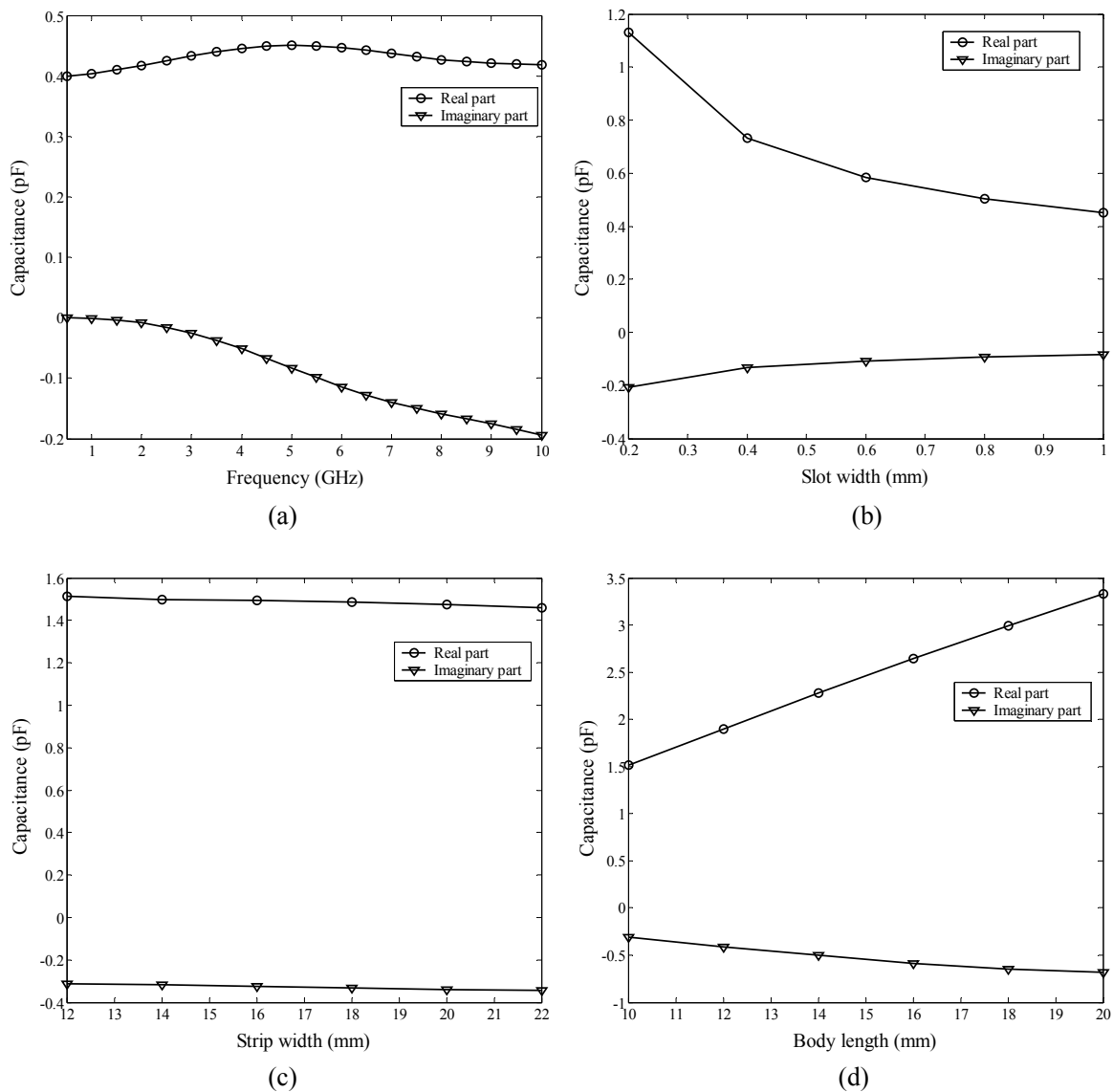


Fig. 4. Computed equivalent capacitance across the slot as functions of (a) frequency, (b) slot width at 5 GHz, (c) strip width at 5 GHz (body length = 10 mm, slot width = 0.2mm), (d) body length (l_0) at 5 GHz (slot width = 0.2 mm, strip width = 10 mm).

References

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