EFFICENT ANALYSIS OF A THIN-WIRE ANTENNA ATTACHED TO A BODY

John C. Young[1] **and Chalmers M. Butler**[2]

[1] *Holcombe Department of Electrical and Computer Engineering*
336 Fluor Daniel EIB
Clemson University, Clemson, SC 29634-0915 USA
johny@ces.clemson.edu

[2] *As (1) above, but E-mail: cbutler@ces.clemson.edu*

ABSTRACT

The determination of the current on a thin-wire antenna mounted on a conducting body is of great interest. If the structure lacks proper symmetry, calculating the antenna current is difficult because the currents on the body vary rapidly near the wire-body junction. When the antenna is attached to a planar surface of the body, the difficulties associated with the junction may be mitigated by the utilization of the equivalence principle. Numerical results are obtained and verified with measurements.

INTRODUCTION

The determination of the input characteristics of a wire antenna mounted on a circumferentially invariant conducting body is of great interest and the coupling between thin-wire antennas and general bodies of revolution (BOR) has been studied by numerous researchers. Because the junction between the wire and conducting body presents computational difficulty, an efficient method to calculate the wire current that obviates these difficulties is highly desirable. If the wire is attached to a planar surface of the BOR, then the difficulties associated with the junction may be mitigated. In this case, the structure may be divided into two regions by the choice of an appropriate surface. With this (artificial) boundary surface properly defined, the original problem is divided into two equivalent problems or models. One model is chosen so that image theory may be used to remove the planar surface to which the wire is attached. Integral equations are formulated in such a way that the two models are coupled through the surface introduced. By solving these equations, one determines the currents on the antenna. Because the surfaces in the equivalent problems are circumferentially invariant, BOR theory may be used to efficiently solve the integral equations.

THEORY

Consider an axisymmetric, perfect electric conductor (pec) body with a planar surface to which a thin-wire antenna is attached as suggested in Fig. 1. The radius of the wire antenna is assumed to be much much smaller than the operating wavelength, so it may be treated as thin. The wire antenna is outside the body and may be in a medium characterized by (μ_e, ε_e) or it may be embedded in a dielectric medium characterized by (μ_i, ε_i) that is also axisymmetric and that terminates at the edge of the planar surface. Let S_a denote the portion of the surface of the dielectric material that is not in contact with the conducting body and let S_b denote the entire surface of the conducting body. S_b comprises two sub-surfaces: S_{b2} is the planar surface of the conducting body to which the wire antenna is attached and S_{b1} is the remaining portion of the conducting body surface. The surface S_a separates the two dielectric media but, if there is no dielectric body present, then $(\mu_i, \varepsilon_i) = (\mu_e, \varepsilon_e)$ and S_a is a surface introduced for convenience. The circle at $t_c = (\rho_c, z_c)$ denotes the location where the edge of the conducting body meets S_a. One notes that, in the vicinity of t_c, the ϕ-directed electric field E_ϕ is very small and vanishes as the point of observation approaches the pec.

Three regions of the original structure are identified: the region interior to the surface $S_a + S_{b2}$ is designated region I, that exterior to the surface $S_a + S_{b1}$ is designated region II, and that interior to S_b is designated region III. A model Ω_{I} (Fig. 2) is constructed so that the field in region I is identical to the field in region I of the original problem. Let the material (μ_i, ε_i), the antenna, and any sources in region I of the original problem be retained in region I of model Ω_{I}. Furthermore, let the region exterior to $S_a + S_{b2}$ in model Ω_{I} be filled with a material (μ_i, ε_i) and let the planar pec surface S_{b2} extended to infinity, i.e., this surface becomes an image plane. The field of model Ω_{I} is constrained to be the same as that of the original problem in region I only, so the electromagnetic environment in model Ω_{I} outside region I is of no moment. The electric field tangential to a pec surface is zero at the surface, and, hence, the tangential electric field on S_{b2} in region I of model Ω_{I} is identical to the tangential electric field on S_{b2} in region I of the original problem. To support the original region I field in the model Ω_{I}, a magnetic surface current $\mathbf{M}^i$ is placed on the surface S_a. If this surface current is adjusted so that the region I field on and tangential to $S_a + S_{b2}$ is identical to the *original* region I field on and tangential to $S_a + S_{b2}$, then the uniqueness theorem guarantees that the region I field in model Ω_{I} is identical to the *original* region I field.

Similarly, model Ω_{II}, suggested in Fig. 3, is constructed so that the field in region II of model Ω_{II} is equal to the field in region II of the original problem. In model Ω_{II}, the conducting body, dielectric, and antenna are removed. Material characterized by (μ_e, ε_e) resides everywhere in space and magnetic surface currents $\mathbf{M}^a$ and $\mathbf{M}^b$ are placed on S_a and S_b, respectively. To produce the original region II field, surface currents are required only on the surfaces S_a and S_{b1}, but advantages are gained if $\mathbf{M}^b$ is placed on the complete surface S_b. Again, if these currents are adjusted so that the field tangential to the surfaces S_a and S_{b1} in region II satisfies the original boundary conditions, then the field in II of model Ω_{II} is identical to that of the original problem in region II. The boundary condition on S_{b1} is that the component of the electric field tangential to S_{b1} in region II be zero. Because the surface S_{b2} is not contained in region II, some freedom is available in the choice of the boundary condition on this portion of S_b. As is explained below, a convenient choice for the boundary condition on S_{b2}, insofar as model Ω_{II} is concerned, is to require that the component of the electric field tangential to the surface S_{b2} in region I be zero.

The surfaces S_a and S_b can be formed by rotating the generating arcs depicted in Fig. 4 about the z axis. The vector $\hat{\mathbf{t}}(t)$ is the unit vector tangent to the generating arc at t in the direction of increasing t and the surface currents are decomposed into $\mathbf{M} = M_t \hat{\mathbf{t}} + M_\phi \hat{\boldsymbol{\phi}}$. For model Ω_I, the electric field tangential to the infinite ground plane vanishes as the observation point approaches the pec. In particular, E_ϕ vanishes at the ground plane and, because E_ϕ must jump by M_t^i across S_a, M_t^i must also vanish as $t \to 0$ on S_a. Since the ground plane is infinite in extent, image theory is used to remove the ground plane in model Ω_{I}, which removes the difficulties associated with modeling the electric current near the wire-body confluence. Furthermore, in model Ω_{II}, the choice of boundary conditions on the surface S_b results in the same conclusion that M_t^a vanish as $t \to 0$ on S_a. If a magnetic surface current were placed only on S_{b1} and not on S_{b2} and if it were not required that the electric field tangential to the exterior side of S_b be zero, then the conclusion that M_t^a vanishes as $t \to 0$ on S_a would not hold. The vanishing of M_t^i and M_t^a as $t \to 0$ is advantageous in a computer solution of the integral equation since no basis function is required to represent the current at this location. The addition of a basis function to represent a nonzero current at $t = 0$ on S_a causes a variety of difficulties in the computational solution of the problem. If only electric currents were used, then J_t would not approach zero as $t \to 0$ on S_a in either equivalent model. Another way to avoid this problem would be an appropriate combination of both electric and magnetic currents, but this results in increased complexity in the testing of the integral equations. Therefore, the use of only one type of equivalent current on the surfaces S_a and S_b is highly desirable. One disadvantage that occurs when a magnetic current is placed on the closed surface S_b and the tangential electric field is enforced to be zero is that fictitious resonances are introduced into the solution.

Because the conducting body and dielectric are ϕ symmetric, BOR theory is employed to solve for the equivalent currents. To solve for the antenna current, a numerical Green's function as described in [1] is used in conjunction with the equivalent models described above. The numerical Green's function technique is convenient because the wire may be treated with normal thin-wire techniques and because the Fourier modes of the BOR analysis are decoupled.

RESULTS

To corroborate the computations, measurements were performed. The experimental structure consists of a brass cylinder with a flat top cap and a thin, straight-wire antenna mounted on the top cap as pictured in Fig. 5. The wire antenna is of height L and wire radius c, and the distance from the cylinder axis to the wire antenna axis is ρ_o. The antenna was mounted on the top cap by feeding the center conductor of a coax through the bottom of the top cap. The height of the cylinder is h_c and the cylinder radius is ρ_c. Because the conducting cylinder is mounted on a ground plane, image theory is used to remove the ground plane and the theory is modified to account for the image terms. No dielectric body is present, so the material in regions I and II is that of free space (μ_o, ε_o). The fictitious surface S_a is arbitrarily chosen to be a cylinder of height L topped by a hemisphere of radius ρ_c. The input admittance of the antenna was measured with a network analyzer in the range 100 MHz to 2 GHz.

In Fig. 6 and Fig. 7 are presented the measured and computed input admittance for two straight-wire antennas mounted on two different cylinders. The radii of both wires was $c = 0.456$ mm. A straight-wire antenna of length $L = 22.38$ cm was attached to a brass cylinder of height $h_c = 28.02$ cm and a straight-wire antenna of length $L = 11.47$ cm was attached to a cylinder of height $h_c = 17.5$ cm. The two brass cylinders both were of radius $\rho_c = 6.5$ cm. The antennas were mounted near the edges of the cylinders and converged results for the input admittance were obtained by only taking the first three Fourier modes. The agreement is excellent at lower frequencies for both the real and imaginary parts of the input admittance. At higher frequencies, the agreement in the real parts of the input admittance is still good but the imaginary parts begin to diverge slightly. Failures are seen in the computed data at frequencies corresponding to the interior resonances of the volumes defined by the equivalent surfaces.

REFERENCES

[1] A.W. Glisson and C.M. Butler, " Analysis of a wire in the presence of a body of revolution," *IEEE Trans. Antennas and Propagat.*, Vol. AP-28, pp. 604-609, Sept, 1980.

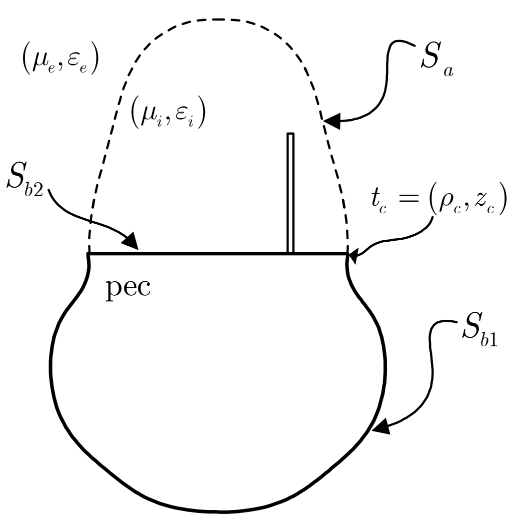

Fig. 1: Antenna attached to a conducting body

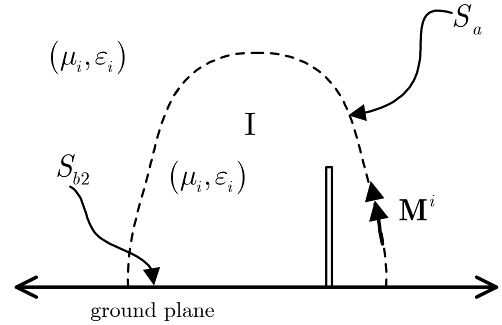

Fig. 2: Ω_I equivalent model

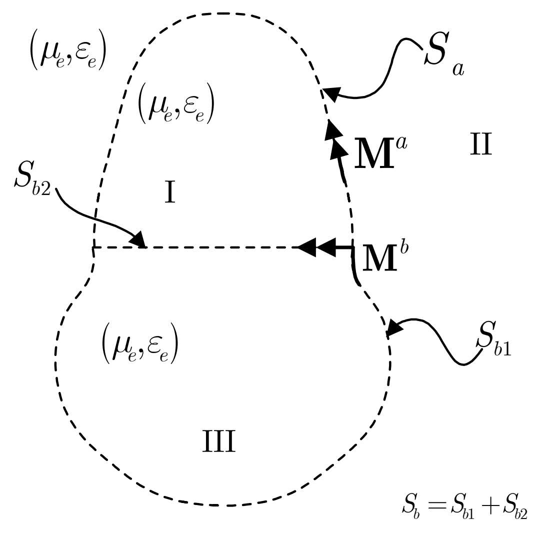

Fig. 3: Ω_{II} equivalent model

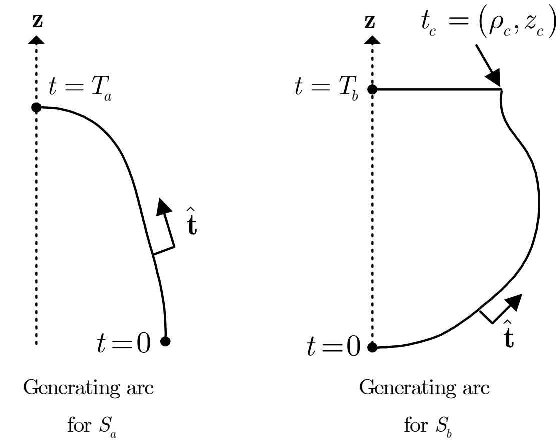

Fig. 4: Generating arcs for equivalent surfaces

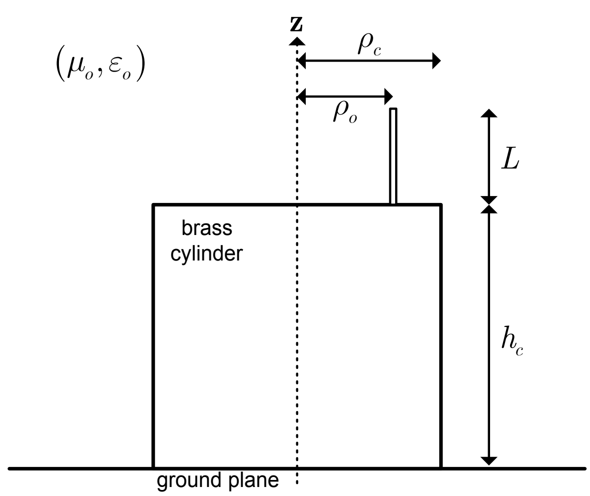

Fig. 5: Experimental structure

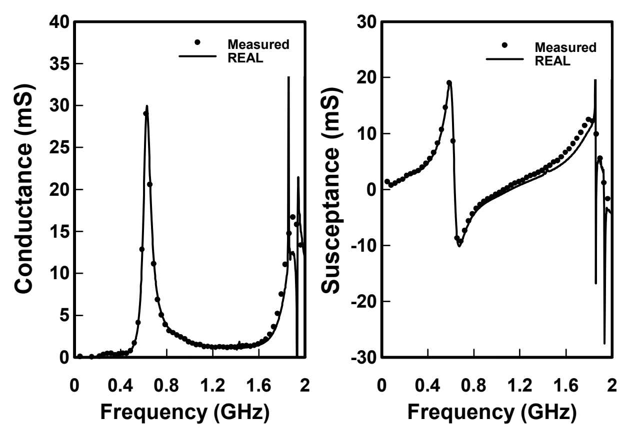

Fig. 6: Input admittance for $\rho_c = 6.5\,\text{cm}$, $L = 11.47\,\text{cm}$, $h_c = 17.5\,\text{cm}$, $\rho_o = 4.915\,\text{cm}$

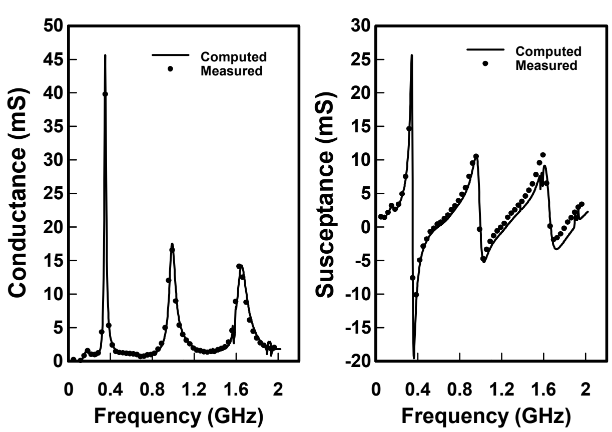

Fig. 7: Input admittance for $\rho_c = 6.5\,\text{cm}$, $L = 22.38\,\text{cm}$, $h_c = 28.02\,\text{cm}$, $\rho_o = 4.915\,\text{cm}$