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CHARACTERISTICS OF A HORIZONTAL LOOP ANTENNA OVER A DISSIPATIVE HALF-SPACE

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The loop antenna to be analyzed consists of a circular ring of perfectly-conducting wire, and is located in free-space over a homogeneous, non-magnetic dissipative half-space. When the antenna is electrically small, current is known to be predominantly due to that of a uniform-mode, and the antenna is analogue to a magnetic Hertzian dipole. When the antenna length is comparable to the free-space wavelength (λ), the dipole-mode current, becomes dominant and the analogy is no longer valid. Since the broadside radiation of an isolated antenna is known to be enhanced by the dipole-mode, the change in antenna characteristics due to the presence of the half-space is expected to be more pronounced.

In formulating the problem, it is assumed that the antenna is driven by a delta-function voltage generator of amplitude V_0 at $\phi = 0$. The radius of the loop is b , and that of the wire a . The center of the loop is located along the z -axis of coordinate system (ρ, ϕ, z) , at a distance $z = d$ above a dissipative half-space, having a conductivity σ , relative dielectric constant ϵ_r and refractive index $n = \epsilon_r + i\sigma/\omega\epsilon_0$. A suppressed time-factor, $\exp(-i\omega t)$, and a thin-wire approximation $a \ll \lambda$ and $a^2 \ll b^2$ are assumed. By matching the electric field E_ϕ on the antenna surface, an integral equation for the current distribution I_ϕ , is obtained. This equation is then solved by the Fourier-series expansion.

$$I_\phi(\phi) = \sum_{m=0}^{\infty} \epsilon_m I_m \cos m\phi$$

$$I_m = iV_0 / \{\pi \zeta_0 (a_m^p + a_m^s)\}$$

where $\epsilon_m = 1$ for $m=0$, and 2, otherwise. For a thin-wire loop, analytical expression for a_m^p is given by King¹, while a_m^s can be shown as

$$a_m^s = 0.5(kb)^2 \{ (\Omega_{m+1,2} + \Omega_{m-1,2}) - m^2 \{ \Omega_{m,1}/n^2 - (1-1/n^2)\Omega_{m,3} \} \}$$

$$\Omega_{m,j} = i \int_0^1 T_j^! \{ (1-s^2)^{j/2} \} \exp(i2kzs) ds + \int_0^\infty T_j^! \{ (1+s^2)^{j/2} \} \exp(-2kzs) ds$$

for $m=1,2,3,\dots$ and $j=1,2,3$ and

$$T_j^!(w) = T_j(w) J_m^2(kbw),$$

$$T_1(w) = (n^2 t - t_n) / (n^2 t + t_n),$$

$$T_2(w) = (t - t_n) / (t + t_n), \quad T_3(w) = 1;$$

where $t = (w^2 - 1)^{1/2} = -i(1 - w^2)^{1/2}$, and $t_n = (w^2 - n^2)^{1/2} = -i(n^2 - w^2)^{1/2}$. J_m^n is the Bessel function of order m . Thus, the associated admittance of the loop, $Y = Y^p + Y^s$, is simply given by I_ϕ/V_0 at $\phi=0$. If the infinite sum is replaced by a finite one, say $m=20$, then the approximate formula, thus obtained, gives a good measure of the admittance for use with a physically realizable voltage source, provided that a proper terminal-zone is included. For a half-space corresponding to a typical earth ($\epsilon_r=10$, $\sigma=10^{-2}$ mho/m), the refractive index is $3.17+i0.28$ at

	a_0^P	a_1^P	a_2^P
	1.488 + i0.136	-0.154 + i0.224	-3.500 + i0.039
h/λ	a_0^S	a_1^S	a_2^S
0.1	(-96.21 - i12.73) $\times 10^{-3}$	(98.74 - i42.17) $\times 10^{-3}$	(65.42 + i17.63) $\times 10^{-3}$
0.2	(-10.80 - i32.68) $\times 10^{-3}$	(78.00 + i15.71) $\times 10^{-3}$	(10.26 - i15.37) $\times 10^{-3}$
0.3	(12.82 - i10.81) $\times 10^{-3}$	(21.33 + i57.76) $\times 10^{-3}$	(5.992 + i1.686) $\times 10^{-3}$
0.5	(-1.118 + i6.269) $\times 10^{-3}$	(-36.76 - i14.61) $\times 10^{-3}$	(-1.879 + i2.161) $\times 10^{-3}$
0.8	(1.757 + i1.835) $\times 10^{-3}$	(16.08 + i19.81) $\times 10^{-3}$	(1.087 - i0.563) $\times 10^{-3}$
1.25	(0.115 - i1.044) $\times 10^{-3}$	(16.24 + i3.109) $\times 10^{-3}$	(0.162 - i0.493) $\times 10^{-3}$

100 MHz. The table gives the change in model currents (a_m^S), from an isolated antenna (i.e. a_m^P), as a function of height for the first three modes. The antenna is assumed to have a radius $kb=1$ and $\Lambda=2 \ln 2 b/a=12$. Thus, it appears that only the dipole-mode ($m=1$) is greatly affected by the presence of the earth. The admittance is plotted as a function of height in Fig. 1. As expected, both the conductance and susceptance are oscillatory with a decaying envelope. On the other hand, the change in admittance of the same antenna at height $z = 0.1\lambda$ is plotted in Fig. 2, as a function of the earth parameters. The value of admittance changes from $17.2+i1.2$ mhos for the case of sea-water to $5.18-i4.2$ mhos. In this regard, the resonant loop is useful in probing the electrical property of an unknown earth. Comparison between the characteristics of the loop, in the presence of a homogeneous earth, with that of a layered earth will also be discussed.

¹Antenna Theory, pt. I, (ed. Collin and Zucker), p. 463, McGraw-Hill, New York, 1969.

