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Compensating Electric-Dipole-Like Radiators for Constant Input Impedance

Carl E. Baum
Air Force Research Laboratory
Directed Energy Directorate

Abstract

For hyperband application one would like an antenna input impedance which is resistive and constant with frequency. For electric-dipole-like radiators this can be approximately accomplished by the inclusion of a series inductor and resistor loading the antenna input port. The use of rotation symmetry in the antenna allows an antenna pattern, which is azimuthally uniform (two-dimensional sense) for both pulse and single-frequency operation.

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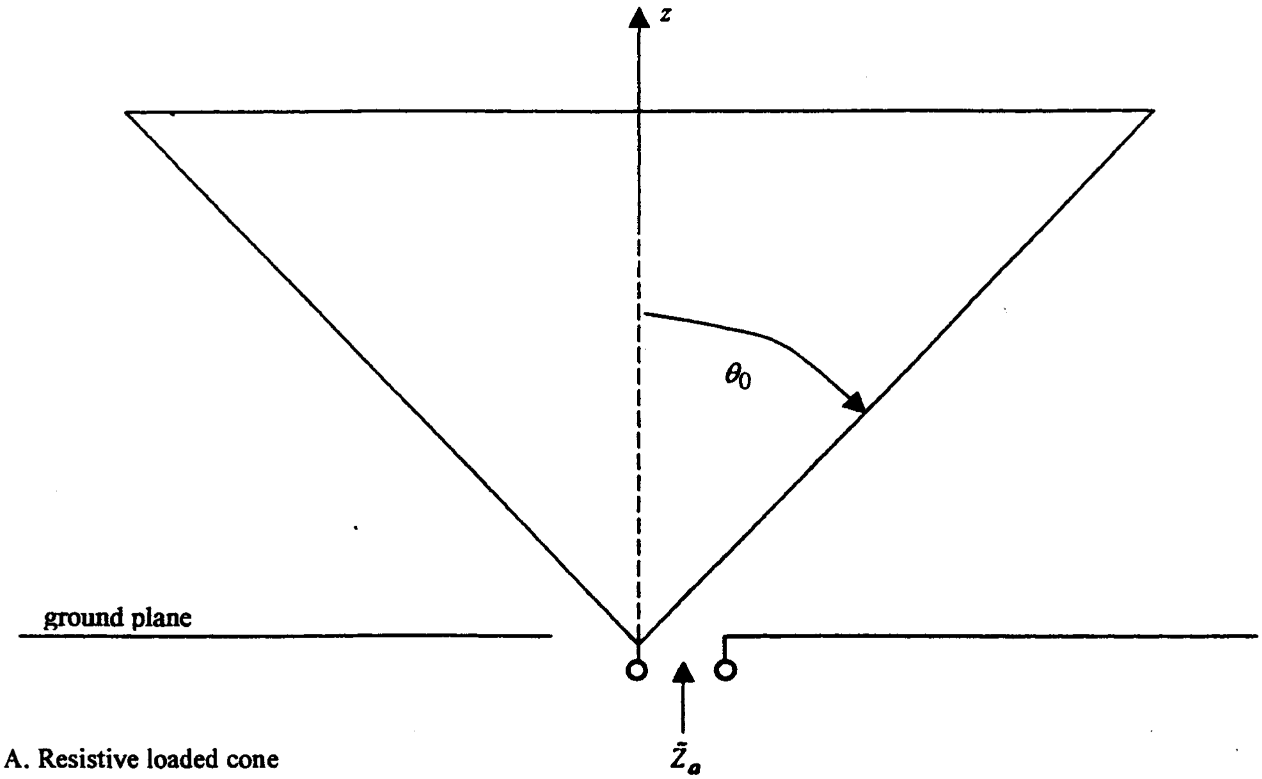
1. Introduction

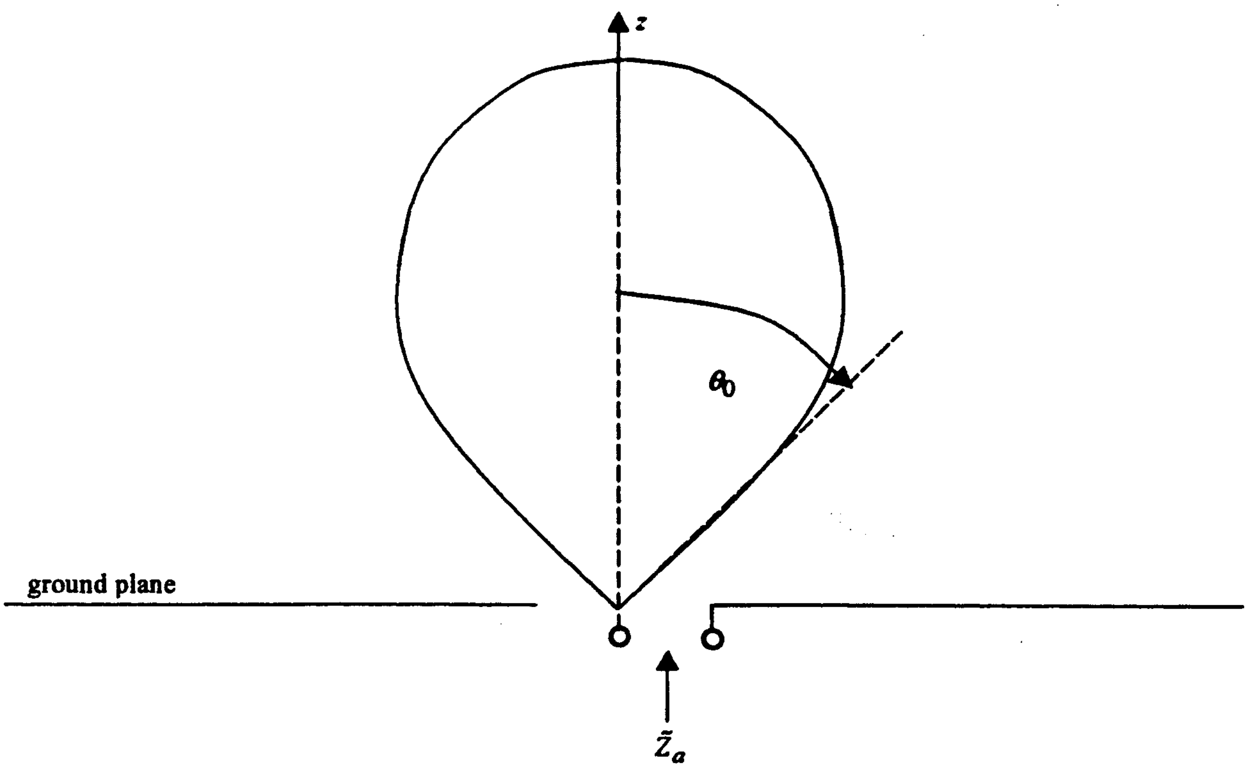
In the design of antennas for radiating pulses, or multiple frequencies over a large frequency band, one may want the antenna to represent an approximately constant-resistance load (say 50 Ω) over the entire frequency band. This is accomplished, for example, in the reflector IRA through the terminating resistors connecting the feed arms to the reflector [7]. Such an antenna has been designed for maximum narrow-beam performance. In the present paper let us consider a broad-beam antenna, specifically one which is a uniform radiator in a rotationally-symmetric sense, behaving like an electric dipole in the electrically small regime.

There are various possible candidates for the geometry of such an antenna with $C_{\infty a}(= O_2)$ symmetry, i.e., continuous two-dimensional rotation symmetry (about an axis we can take as the z axis) with all axial planes as symmetry planes. These include circular cones with various truncations or caps (flat, spherical), as well as other rotational shapes, and may include impedance loading as well.

For present purposes we may consider two commonly used antennas indicated in Fig. 1.1. The first (Fig. 1.1A) is a resistively loaded cone, which has been commonly used as an EMP simulator [2]. Its design, including the resistance loading function, is summarized in [3] with many references for the details, which will not be repeated here. The second (Fig. 1.1B) is based on the common asymptotic-conical-dipole (ACD) electric-field sensor [8]. This latter has not been optimized as a radiator (in contrast to the former) but improvements could be made by the similar inclusion of resistive loading in the antenna element. Here we have shown ground-plane versions (single ended) but differential versions with a transverse symmetry plane are simple extensions of the present results.



A. Resistive loaded cone



B. Asymptotic conical dipole (ACD),
perhaps with resistive loading

Fig. 1.1 Candidate Antennas

2. Low-Frequency Antenna Model

All antennas of the general form in Fig. 1.1 behave as electric dipoles at low frequencies. Thus the antenna (input) impedance behaves as [8]

$$\tilde{Z}_a(s) \to \frac{1}{sC_a} \quad \text{as } s \to 0$$

$$\begin{aligned} C_a &\equiv \text{antenna capacitance} \\ &> 0 \\ \sim &\equiv \text{two-sided Laplace transform} \\ s &\equiv \Omega + j\omega \equiv \text{Laplace-transform variable or complex frequency} \end{aligned} \tag{2.1}$$

In addition the radiation properties are described by the electric-dipole moment $\vec{\tilde{p}}(s)$ which will normally take the form [5]

$$\begin{aligned} \vec{\tilde{p}}(s) &= \tilde{p}(s)\,\vec{1}_z \\ \tilde{p}(s) &\to \tilde{V}(s)\,C_a\,h_{eq} \quad \text{as } s \to 0 \\ \vec{\tilde{h}}_e(s) &= \tilde{h}_e(s)\,\vec{1}_z \to h_{eq}\,\vec{1}_z \quad \text{as } s \to 0 \\ h_{eq} &> 0 \end{aligned} \tag{2.2}$$

3. Simplified All-Band Approximation

In general the antenna impedance can be a rather complicated function of frequency. A reasonable approximation for the resistive-loaded cone [3] takes the form

$$\tilde{Z}_a(s) = Z_\infty + \frac{1}{sC_a} \quad , \quad Z_\infty > 0 \tag{3.1}$$

The resistive term Z_∞ is just the pulse impedance of the circular cone with respect to the ground plane as

$$\begin{aligned} Z_\infty &= f_g \, Z_0 \\ Z_0 &= \left[\frac{\mu_0}{\varepsilon_0}\right] \equiv \text{wave impedance of free space} \\ &\simeq 376.73 \\ f_g &= \frac{1}{2\pi} \ell n \left[\cot\left(\frac{\theta_0}{2}\right)\right] \equiv \text{geometric impedance factor} \end{aligned} \tag{3.2}$$

For 50 Ω we have $\theta_0 \simeq 47.0^\circ$.

The ACD in Fig. 1.1B also has the property that as $s \to \infty$ (in the right half s-plane), $\tilde{Z}_a(s) \to Z_\infty$ with the half-cone angle θ_0 describing the geometry near the input port at $\vec{r} = \vec{0}$. For intermediate frequencies the behavior can be rather different from (3.1), but by resistively loading the antenna surface one may be able to approach this behavior. In addition there is more than one variant of the ACD design [4], allowing one some flexibility here. So, for present purposes let us take (3.1) as one special canonical form for the antenna impedance.

4. Compensating Network

Let us now add a terminating impedance $\tilde{Z}_t(s)$ across the antenna input port as indicated in Fig. 4.1. Furthermore, let it consist of a series combination of a resistance and an inductance as

$$\tilde{Z}_t(s) = Z_\infty + sL_t \tag{4.1}$$

with the resistive part equal to the high-frequency antenna impedance. Constraining

$$\tau \equiv Z_\infty \, C_a \equiv \frac{L_t}{Z_\infty} \quad , \quad L_t = C_a \, Z_\infty^2 \tag{4.2}$$

we have the special case where the combined impedance at the antenna port is just the parallel combination of impedances as

$$\tilde{Z}_a(s) // \tilde{Z}_t(s) = \left[\left[Z_\infty + \frac{1}{sC_a} \right]^{-1} + \left[Z_\infty + sL_t \right]^{-1} \right]^{-1} = Z_\infty \tag{4.3}$$

This is the well-known result for what is called an all pass network.

We now have, within the limits of our approximations, a frequency-independent resistance Z_∞ as the load to be driven by our source. This allows our selection of Z_∞ to match the characteristic impedance, say 50 Ω, of a cable from the source to the antenna.

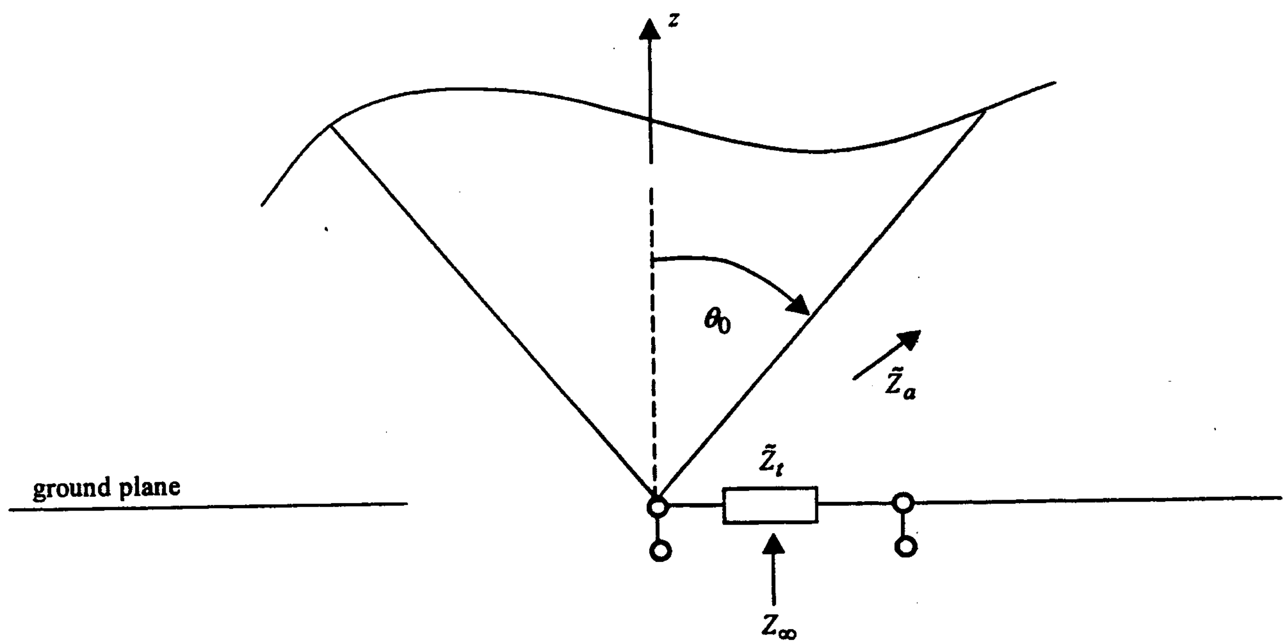


Fig. 4.1 Compensating Network at Antenna Port

5. Symmetry in Geometry of Compensating Network

The compensating network is not merely a mathematical object occupying a point in space. It occupies some volume and the current follows some path(s). One can minimize the size to reduce radiation from the circuit elements. The geometry can be arranged to keep the currents close to the plane of the ground plane. Furthermore, one can use multiple networks (N) as indicated in Fig. 5.1 to have currents flowing in opposite directions to minimize radiation from the resulting loops. Of course, the coax connecting to the source can be flared at the antenna base to encompass the bottom side of these networks.

The inductors can also be made in a way which produces no net magnetic dipole moment. One technique for such is the bisolenoidal inductor [6].

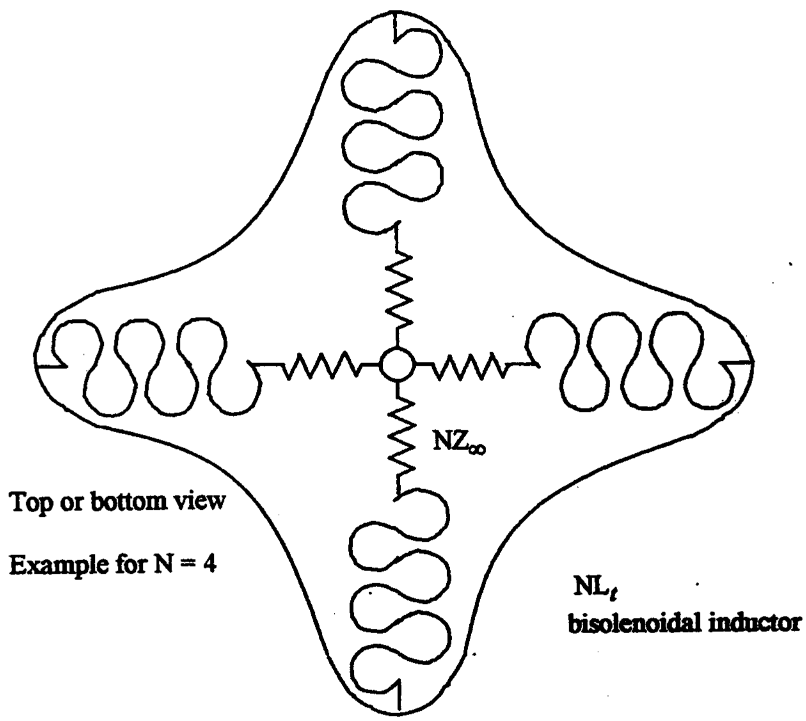


Fig. 5.1 Geometry of Compensating Network

6. Concluding Remarks

One form of compensating network is the series LR form discussed here. This is similar in some respects to that used for distributed terminators in simulators for the nuclear electromagnetic pulse (EMP) [1, 9]. If one has a more accurate model of the intermediate-frequency region of the antenna, the compensating network can be modified to give a net impedance which still approximates Z_∞ to some degree.

Another approach to the intermediate-frequency region is the synthesis of appropriate resistive loading on the antenna to make $\tilde{Z}_a$ more closely approximate $Z_\infty + 1/[sC_a]$. In addition to the antenna impedance such loading damps the antenna, affecting the radiated fields, including pulse shape and associated frequency spectrum.

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