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Producing Large Transient Electromagnetic Fields in a Small Region: An Electromagnetic Implosion

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Abstract

One approach to producing a large, fast transient electromagnetic field in a small region consists of focusing an incoming approximately spherical wave on the position of interest. This paper discusses some of the design features involving a prolate spheroidal reflector for this purpose.

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1. Introduction

One approach to a transient electromagnetic radiator is an impulse radiating antenna (IRA) [10]. In this case an antenna aperture is focused at infinity. While there are several ways to realize an IRA (reflector, lens, array), the reflector type is very practical, especially for large ones, if electronic beam steering is not required. Basic physical considerations are discussed in [3].

What if, instead, one has a target which is relatively close to the antenna so that focusing at infinity may not be appropriate. Focusing at the target can then be used to increase the field strengths there [2, 9]. Such is the subject of the present paper.

2. Incoming Spherical Waves

Instead of thinking of a wave radiating away from a point source, let us reverse this wave (time reversal) so as to converge on some position (eventually a target). There are various ways to look at this. One way considers some surface S surrounding some volume V containing a point of interest, say $\vec{r} = \vec{r}_0$.

Imagine some transient wave propagating inward toward $\vec{r}_0$, but which has not yet reached this point. On S, there will be tangential electric $\vec{E}_S(\vec{r}_0,t)$ and magnetic $\tilde{\vec{H}}_S(\vec{r}_S,t)$ fields $(\vec{r}_S \in \text{S})$. If one then applies such fields all over S, this will produce the same inward propagating wave in V with no fields outside of V (equivalence principle). These sources can also be considered as magnetic and electric surface current densities as well. This can form the basis for an array of sources on S to approximately realize the desired fields. One can also use just one type of source, say for tangential electric field [1], but this produces waves both inside and outside of S.

As time goes along the wave reaches $\vec{r}_0$ where peculiar things may happen with the wave emerging from this region and becoming an outgoing wave propagating toward S. The details depend on the presence or absence of a target centered on $\vec{r}_0$. In the absence of a target the fields can get very large, depending on the rate of rise of the incoming wave. Now $\vec{r}_0$ is a focus of the wave which needs detailed consideration for transient pulses.

Various types of incoming waves can be considered. If S is a sphere centered on $\vec{r} = \vec{0}$, one can consider particular vector spherical harmonics for source distributions. These are boundary conditions for the spherical vector wave functions, appropriately transformed into time domain.

For IRA-like waves we think in terms of TEM waves (dispersionless) which are guided on conductors. Of course, if inside S there are no conductors, the assumed TEM fields on S will produce some other kind of wave, but still focused on $\vec{r}_0$.

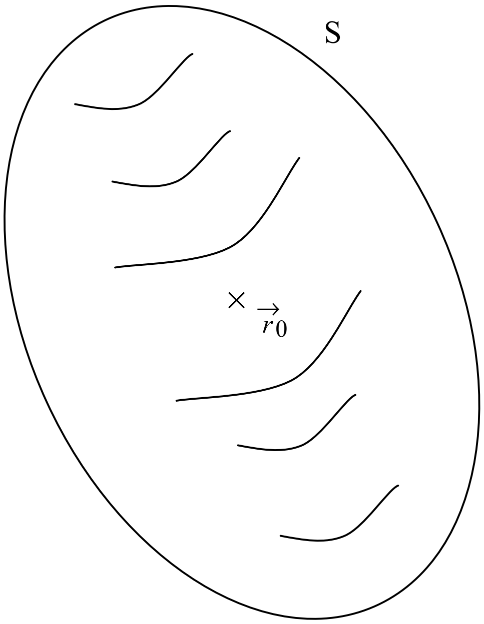

Fig. 2.1 Surface Surrounding Target Position

3. Prolate-Spheroidal Reflector

Now, instead of a paraboloidal reflector, consider a prolate-spheroidal reflector. This is based on the two foci of an ellipse. A prolate sphere S_p is a body of revolution with an equation for the surface

$$\begin{gathered}\left[\frac{\Psi}{b}\right]^2 + \left[\frac{z}{a}\right]^2 = 1 \\ a \equiv \text{major radius} \\ b \equiv \text{minor radius}\end{gathered} \tag{3.1}$$

This is based on cylindrical (Ψ,ϕ,z) coordinates with

$$x = \Psi\cos(\phi) \ , \ y = \Psi\sin(\phi) \ , \ \Psi^2 = x^2 + y^2 \tag{3.2}$$

As illustrated in Fig. 3.1, there are two foci at

$$\begin{gathered}(\Psi,\phi,z) = (0,\phi,\pm z_0) = \pm\vec{r}_0 \\ z_0 = \left[a^2 - b^2\right]^{1/2}\end{gathered} \tag{3.3}$$

The distance traveled by a ray from $-\vec{r}_0$ to $\vec{r}_0$ is

$$d_1 + d_2 = 2a = 2\left[z_0^2 + b^2\right]^{1/2} \tag{3.4}$$

Independent of which direction a ray leaves from $-\vec{r}_0$. At the surface S_p the angle of incidence equals the angle of reflection.

A real reflector would consist of some sector S'_p of S_p as indicated in Fig. 3.2. As with the usual reflector IRA there could be flat-plate conical feed arms. Two are shown here, but the usual 4-arm system (with terminating resistors) would be appropriate. The wave leaving $-\vec{r}_0$ to $\vec{r}_0$ needs to be in uniform, isotropic dielectric medium (whether air or whatever), of permittivity ε (ideally lossless), extending around the target. This includes all the ray paths reflecting from S'_p. Note that one may have some special high-voltage source region around $-\vec{r}_0$ with special equipment and perhaps a lens to shape the spherical wave centered on $-\vec{r}_0$.

At later times (after first signal arrival at $\vec{r}_0$) truncation of the dielectric medium will influence the fields near $\vec{r}_0$. So some consideration of the shaping of such a boundary is appropriate. The edge of S'_p (perhaps a circle, or even a more sophisticated shape) is chosen based on feed-arm locations and the orientation of the fields incident on the reflector [7,8], so as to give the best results at $\vec{r}_0$.

In earlier papers [4-6], it was shown that the spherical TEM wave launched into paraboloidal and hyperboloidal reflectors was exactly transformed into planar and spherical TEM waves respectively. The reflectors did physically (with a minus sign) what the stereographic transformation did mathematically in transforming one type of TEM wave into another. I suspect that the same is the case with the prolate-spheroidal reflector considered here.

Also illustrated in Fig. 3.2 is an aperture plane S_a. One can take the fields incident on the plane from the left and extrapolate them to the region near $\vec{r}_0$. Some of this appears in [2]. All that is needed is the mathematic form of the early-time TEM wave incident on S_a. This can be compared to the numerical results in [9].

Here we have considered a metal (ideally perfectly conducting) reflector. If, however, $\varepsilon > \varepsilon_0$ one can utilize the positive, instead of negative, reflection with S'_p taken merely as the boundary between the dielectric ε and air ε_0.

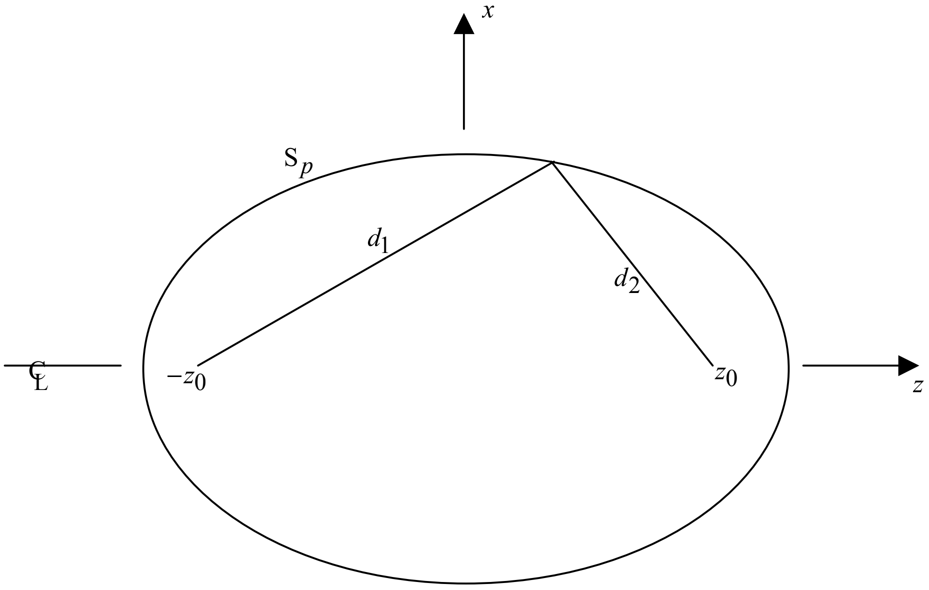

Fig. 3.1 Prolate-Spheroid Cross Section (Ellipse)

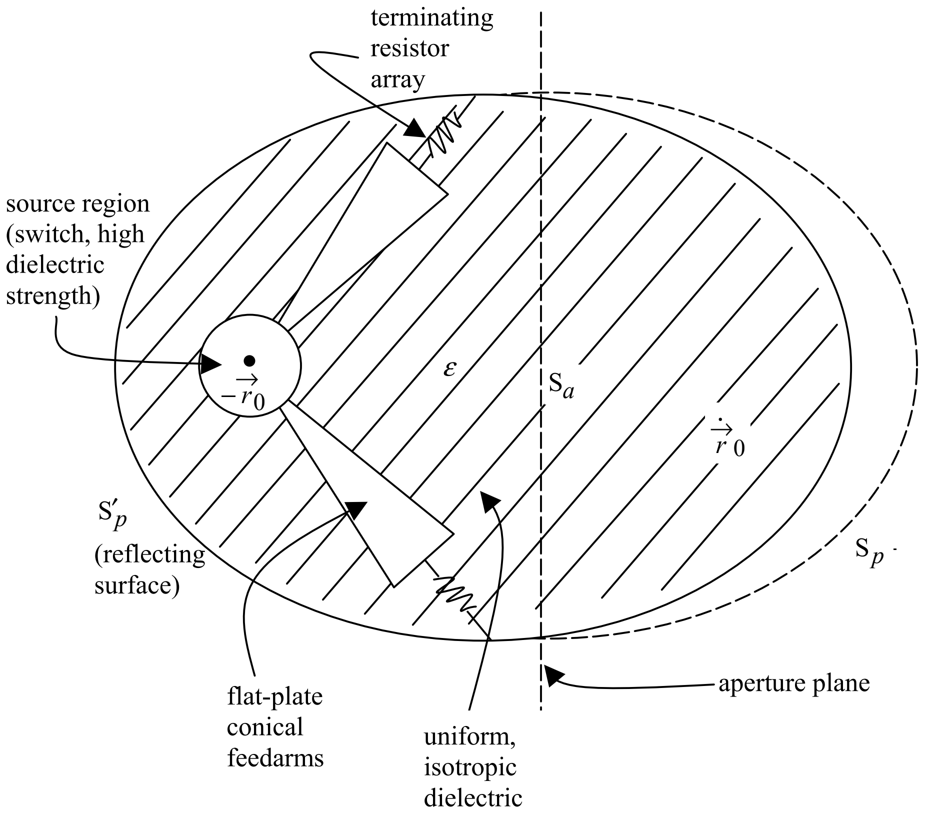

Fig. 3.2 Focused IRA

4. Concluding Remarks

The basic concept is fairly simple. The practical implementation, however, involves many details. There are both theoretical and construction questions to be addressed.

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