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Electromagnetic Implosion Using a Lens

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Abstract

This paper considers the use of dielectric lenses for concentrating a fast pulse on a target (an electromagnetic implosion). There are similarities to and differences from the prolate-spheroidal-reflector case.

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1. Introduction

Recent papers have discussed the design of a prolate-spheroidal antenna for focusing a fast transient pulse launched from one focus to concentrate to at the second focus [5-11]. This is based on reflector IRA (impulse-radiating antenna) technology in which the pulse is guided to the reflector as a spherical TEM wave by conical feed arms (typically triangular flat plates). However, a paraboloidal reflector is only one way to build an IRA. As discussed in [3] there are at least two other ways: a TEM horn feeding a dielectric lens, and a many-element array to synthesize the requisite field on an appropriate aperture.

These last two techniques can also be used to focus a pulse in the near field instead of at infinity. In this paper we consider the case of a TEM horn feeding a dielectric lens.

2. Single Refracting Surface Between Two Uniform Dielectric Media

In a previous paper [4] we have considered the transition between a spherical and a plane wave at a dielectric interface. We need to modify this to bring the wave to a second focus. In addition the TEM feed in the first dielectric medium will take the form of a TEM horn to give a linearly polarized wave on the axis, as indicated in Fig. 2.1.

In general, the surface of the lens can be found by use of the equations in [4 (Section 4)]. In that case the second wave is spherically diverging. For a converging second wave we merely need to replace ℓ_2 by $-\ell_2$ in [4 (4.9)]. This still leaves a complicated quartic surface, except in special cases. (These include $\ell_2 = \ell_1$ and $\varepsilon_1^{1/2}\ell_1 = \varepsilon_2^{1/2}\ell_2$ which give spherical surfaces).

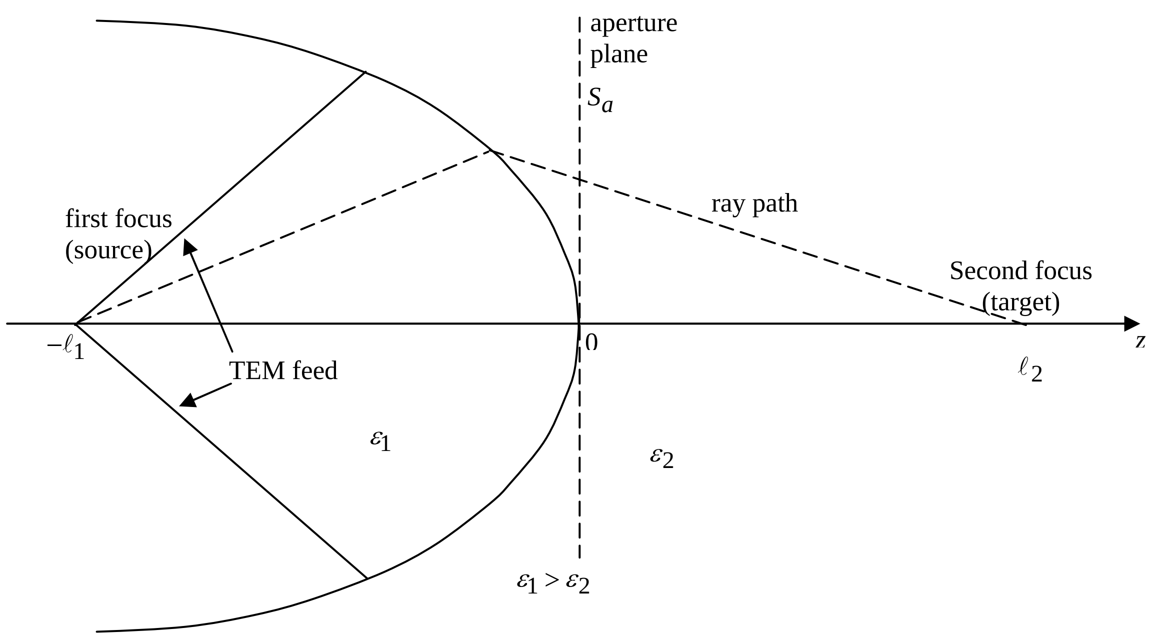

Fig. 2.1 Two-Dielectric Media Lens

3. Symmetrical Lens Between Two Identical Dielectric Media

From [4] we have the solution for matching a spherical wave to a plane wave by a hyperboloidal surface. Then, as in Fig. 3.1, we need only apply this solution twice. Considering the first (left) surface we have an equation for the lens boundary (Ψ_b, z_b) as

$$\left[\frac{\Psi_b}{\ell}\right]^2 = \left[\varepsilon_r - 1\right]\left[\left[\frac{z_b - z_{b_0}}{\ell} + \left[\varepsilon_r^{1/2} + 1\right]^{-1}\right]^2 - \left[\varepsilon_r^{1/2} + 1\right]^{-2}\right] \tag{3.1}$$

$$\varepsilon_r \equiv \frac{\varepsilon_2}{\varepsilon_1}$$

$$\ell = z_{b_0} - z_{1_0} \qquad \text{(both terms negative)}$$

Here z_{b_0} (lens boundary on $\Psi_b = 0$) is determined by setting $z_b = 0$ at the maximum of Ψ_b (lens radius). Consult [4 (Section 2)] for more details. There is a circular cone of half angle

$$\theta_c = \arctan\left(\left[\varepsilon_r - 1\right]^{1/2}\right) \tag{3.2}$$

to which the hyperboloid is asymptotic. For an example we have

$$\varepsilon_r = 2.25 \quad \text{(oil, polyethylene)}$$

$$\theta_c \simeq 48.2^\circ \tag{3.3}$$

The first lens surface converts a spherical wave into a plane wave with ray paths all parallel to the z axis. Now turn the problem around and use reciprocity. The right lens surface converts the plane wave into a spherical wave converging on

$$z_{2_0} = -z_{1_0} \tag{3.4}$$

By reflection symmetry we merely reverse the solution for z_b in (3.1). This then gives a wave propagation toward the right focus which can be calculated by using the tangential fields on the aperture plane S_a and integrating over these as in [8].

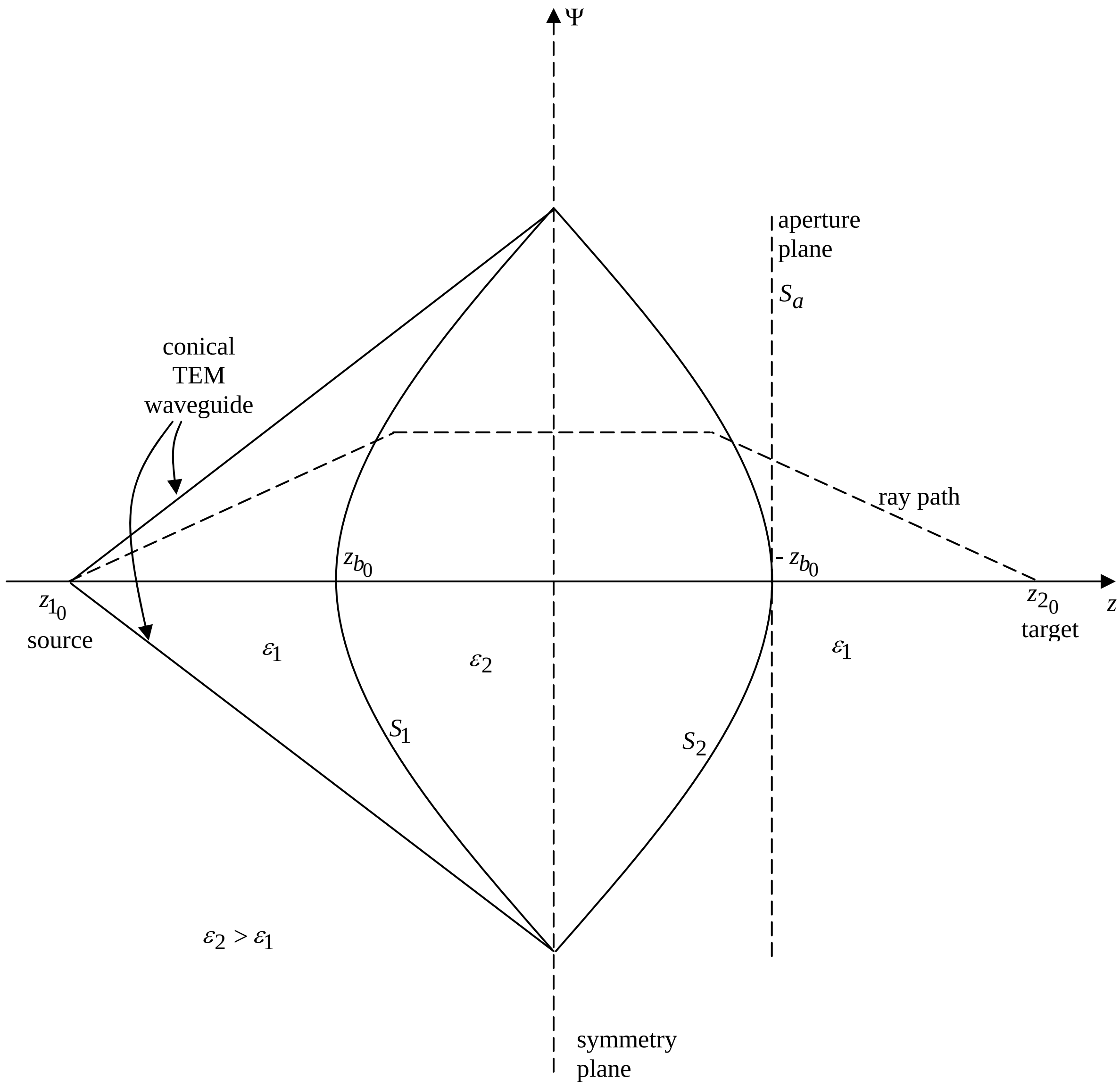

Fig. 3.1 Symmetrical Lens With Two Hyperboloidal Surfaces

On the left side (z negative) there is also a TEM horn guiding the TEM wave toward the lens. The conical conductors can have various cross-section shapes, such as flat plates. Another interesting (and self reciprocal [12]) shape has the conductor cross section as circles centered on the z axis. As discussed in [2] this can give a very uniform field on axis when each curved plate subtends an angle of 90° with respect to the z axis.

Now there will be some reflections at both lens surface, so the wave transmitted through the lens will not be perfectly TEM. However, for ε_r not too far from unity, the error will not be large. Note that the reflections are of opposite sign when passing through the two lens surfaces. For comparison to another lens of similar type in the context of an EMP simulator, see [1].

Other solutions of such a lens are possible. The present solution is easily extended if we maintain rays parallel to the z axis in the lens. In this case z_{2_0} need not be $-z_{1_0}$. The lens portion for $z > 0$ need not be the mirror of that for $z < 0$, and (3.1) can be separately applied to each side. One can also have different permittivities on both sides of the lens as long as the permittivities are both less than the lens permittivity. One can also add spherical dielectric boundaries centered on the respective focal points without changing the ray paths. (This may be useful in the case of very large fields.) If the rays in the lens are not parallel to the z axis, the solution is more complicated.

4. Concluding Remarks

Such lens systems are another approach to focusing a pulse (electromagnetic implosion). The aperture integrals for the focal waveform are much the same as for the prolate-spheroidal-reflector case. A disadvantage of the lens approach concerns the mass of a large lens (say meter size) to get good focusing of 100 ps pulses. Otherwise the two approaches are similar.

Other features such as a lens concentrating the beam near the second focus [9] are common to both approaches. High fields launched near the first focus will also need to be considered in the design in both cases.

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