Sensor and Simulation Notes

Note 458

08 July 2001

Modification of TEM-Fed Reflector for Increased Efficiency

Carl E. Baum
Air Force Research Laboratory
Directed Energy Directorate

Abstract

The paper explores some concepts for increasing the efficiency of a TEM-fed paraboloidal reflector. Instead of just removing sections with unfavorable polarization, one can use uniconducting sheets (parallel conductors) to alter the polarization of the reflected fields so that they more effectively add to the aperture integral for the far field. For cases that the source has a not-too-large bandwidth one can also displace the reflector a quarter wavelength to change the phase (reverse the sign) of the field to make it add to the aperture integral.

This work was sponsored in part by the Air Force Office of Scientific Research, and in part by the Air Force Research Laboratory, Directed Energy Directorate.

1. Introduction

Much attention has been given to the design of reflectors for impulse radiating antennas (IRAs) [14]. These are important for maximizing the upper end f_u of the useful frequency response of the antenna. The lower end f_ℓ is governed by the size of the reflector and the TEM feed [4, 13]. The bandwidth is so large as to become a term of marginal utility. More useful are the terms

$$\begin{aligned} \text{bandratio} \equiv \text{brd} &= \frac{f_u}{f_\ell} \\ \text{bandratio decades} \equiv \text{brd} &\equiv \log_{10}(\text{br}) \end{aligned} \tag{1.1}$$

with typical values of 2 decades being achieved [4, 13, 14]. Let us call antennas with brd ≥ 1 as *hyperband* antennas. In addition, since IRAs have very low dispersion or *hypodispersion* and thereby have excellent fidelity for radiating/receiving pulses we can write

$$\text{hyperband} + \text{hypodispersion} = \text{impulse electromagnetics} \tag{1.2}$$

This is in contrast to more traditional narrowband sources and antennas, which for consistency we can write as

$$\text{hypoband (narrowband)} \simeq \text{single frequency} \tag{1.3}$$

For high-power applications this is discussed in detail in [12] for a source/antenna combination called a *phaser*.

More recently we have been considering other possible sources and antennas with oscillatory waveforms, but bandwidths less than IRAs but greater than phasers. With just a few cycles N to e^{-1} the *relative bandwidth* is now a more meaningful term and is given by [9, 11]]

$$\text{relative bandwidth} \simeq Q^{-1} = [\pi N]^{-1} \tag{1.4}$$

For this case let us use the term *mesoband* for consistency with

$$\text{hypoband} < \text{mesoband} < \text{hyperband} \tag{1.5}$$

This applies to the combination of the switched oscillator [9] with a TEM-fed reflector [7] which we can call an oscillator reflector antenna (ORA).

In an ORA we do not have the same high-frequency problems with which to contend as in the case of an IRA. The paraboloidal surface need not be as accurately maintained and it need not be continuous metal. Appropriate gaps in the metal with spacing small compared to a quarter wavelength can be tolerated. This opens up additional possibilities for optimizing the reflector design.

2. Placing Reflector Only Where There is an Electric-Field Component in the Desired Direction

Some work has already been done on this aspect [6]. Figure 2.1 from that paper is included here to summarize the basic ideas. It will help the reader to have this paper at hand for more of the details.

The basic idea summarized in this section is to remove portions of the reflector where the y component of the electric field is in the opposite direction to that in the center of the reflector (as in Fig. 2.1). Using complex coordinates

$$\zeta = x + jy \tag{2.1}$$

we summarize the observations in [6].

1. Eliminating regions near $\zeta = \pm ja$ from the aperture cuts top and bottom portions and allows one to increase a to fill a given $y_{\max}$.
2. The region above arm 2 (near it) and symmetrically positioned regions near the other three arms is removed from the reflector to increase the magnitude of h_{a_y} (effective aperture height).
3. Eliminate some portions of the reflector for $|y| > b \sin(\phi_0)$ between arms 1 and 2, and between arms 3 and 4.
4. Add to the reflector below arm 2 (near it) and symmetrically positioned regions near the other three arms to increase $|h_{a_y}|$.
5. Include regions for $|y| < [a^2/b]\sin(\phi_0)$ between arms 2 and 3, and between arms 4 and 1.

These observations are qualitative in nature and can be improved by detailed calculations that are in progress [8]. Note that the choice of ϕ_0 (specifying the feed-arm locations) also impacts the reflector shape. While 45° is a typical choice, larger values (e.g., 60°) are also used.

While these considerations have been developed for reflector IRAs, they apply to lens IRAs as well due to the complementary role of reflector regions and open regions (not blocked by conductors) of the aperture for lens IRAs [2].

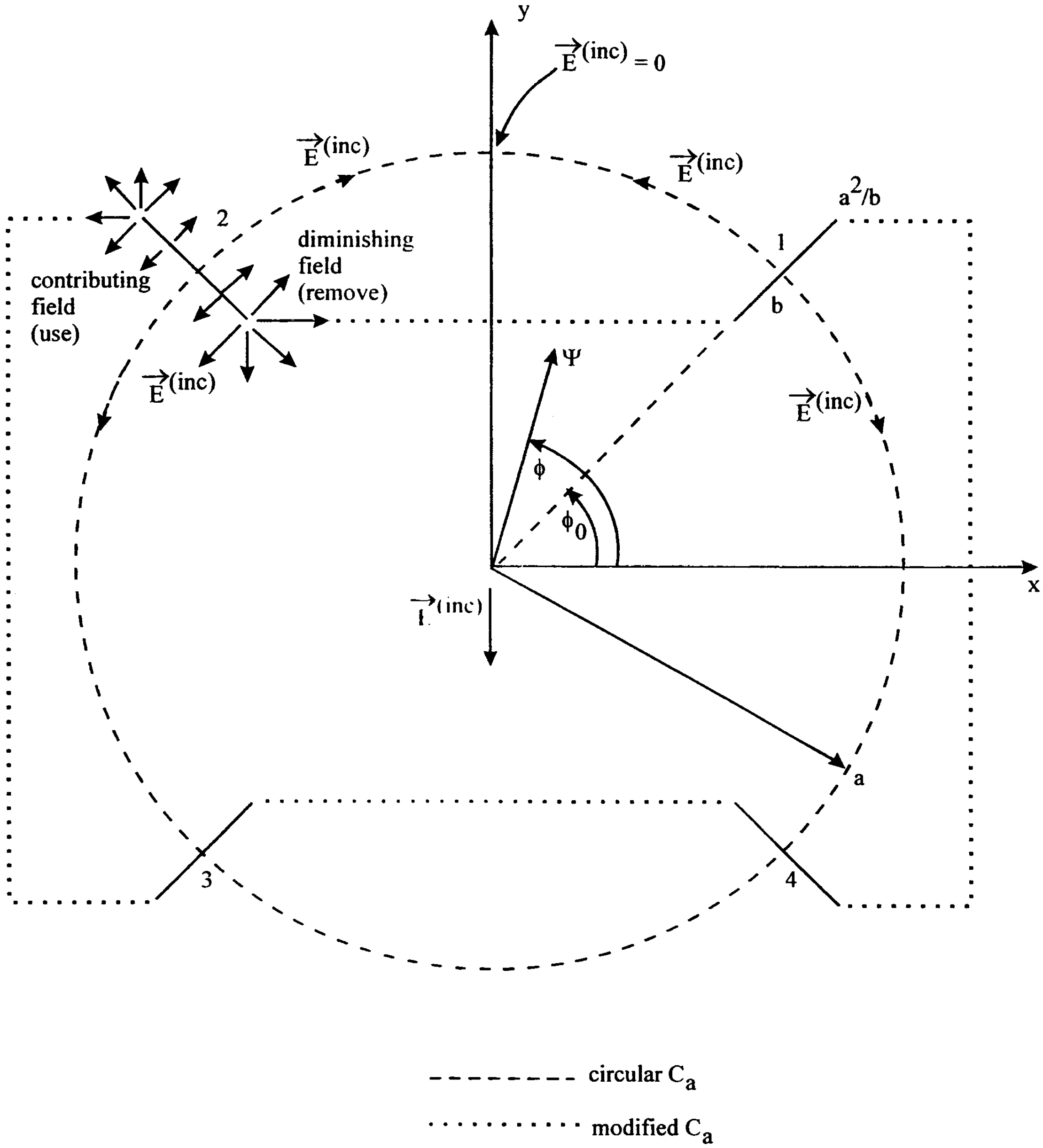


Fig. 2.1. Edge-On Four-Flat-Plate TEM Feed with Antenna Aperture.

3. Anisotropic (Uniconducting) Reflector

The next technique expands on a paragraph in [2 (Section V)]. The reflector, or portions of it, can be replaced by uniconducting sheets which reflect or transmit desired components of the electric field incident on it. A uniconducting sheet is approximated by a grid of parallel wires (conducting tubes, strips, etc.) without conducting cross connections. The spacing of these conductors should be small compared to a quarter wavelength, so that for the desired electric field component the grid behaves as a conducting sheet. The conductor spacing makes the equivalent conducting sheet behind the grid a distance proportional to the conductor spacing. This distance can be estimated by the formulae in [1]. (This inductance is in parallel with the wave impedance of free space (wave propagating through the reflector) for an equivalent impedance.) Essentially the magnetic field penetrating between the conductors implies an extra inductance to account for these fields. Correspondingly the grid can be placed in front of the ideal paraboloidal surface to allow for this.

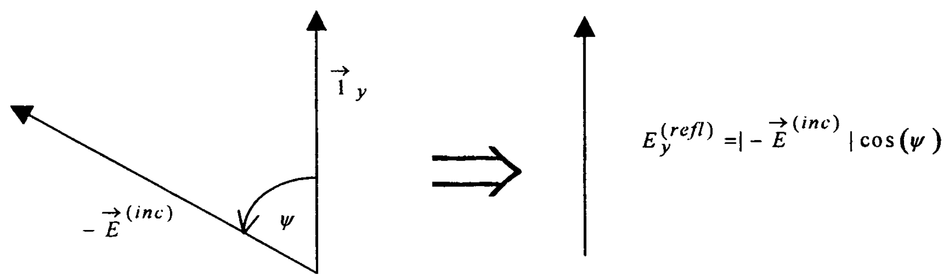
The design problem for a uniconducting sheet is to optimally orient the conduction direction. In Fig. 2.1 the reflected component of interest of the electric field is in the $+\vec{1}_y$ direction (opposite that of the incident electric field). For simplicity consider a long feed so that the reflector is almost a flat plane. Then as in Fig. 3.1A let us consider the reflection of $\vec{E}^{(inc)}$ as $-\vec{E}^{(inc)}$ at an angle ψ with respect to the y axis. For a perfectly conducting reflector we have

$$\eta_c = \frac{E_y^{(refl)}}{|-\vec{E}^{(inc)}|} \tag{3.1}$$

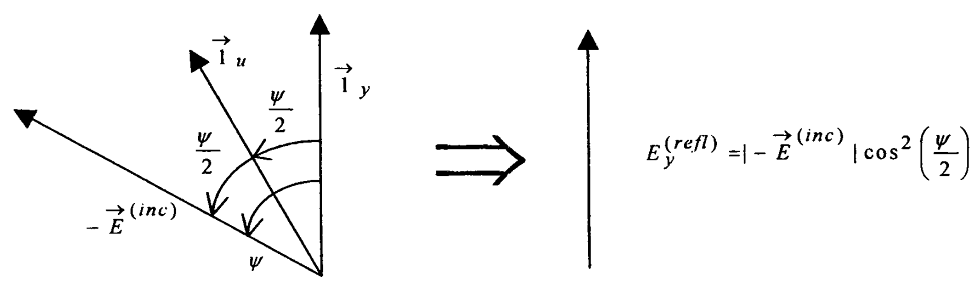
as an efficiency in converting the incident electric field into a reflected y component which contributes to the aperture integral for the boresight radiated electric field. Note that for $\pi/2 < \psi < \pi$, this is negative, leading to the considerations in Section 2.

By comparison let there be a uniconducting sheet characterized by conduction direction $\vec{1}_u$ as in Fig. 3.1B. With $\vec{1}_u$ chosen to bisect the angle ψ between $\vec{1}_y$ and $-\vec{E}^{(inc)}$ we have

$$\eta_u = \frac{E_y^{(refl)}}{|-\vec{E}^{(inc)}|} = \frac{\vec{1}_u \cdot [-\vec{E}^{(inc)}]}{|-\vec{E}^{(inc)}|} \vec{1}_u \cdot \vec{1}_y = \cos^2\left(\frac{\psi}{2}\right) \tag{3.2}$$



B. *y* component of reflection from conducting sheet



B. *y* component of reflection from uniconducting sheets

Fig. 3.1 Efficiencies of Conducting and Uniconducting Reflectors

Basically, the current induced on the uniconducting sheet is proportional $\cos(\pi/2)$. This in turn radiates an electric field with a y component proportional to $\cos(\pi/2)$. This bisection of ψ is optimal from symmetry considerations (e.g., reciprocity on interchange of roles of incident and scattered fields). Note that for all ψ in $0 \le \psi < \pi$ this efficiency η_u is positive. For an x directed incident electric field $\eta_u = 0.5$ while $\eta_c = 0$.

The ideal reflecting surface is a paraboloid, so the directions in Fig. 3.1 should be considered as projections on the aperture plane (a plane of constant z). It has previously been shown [3 (Appendix A)] that the conversion of the incident spherical TEM wave (guided by the feed arms from the paraboloidal focus) to the reflected TEM wave is exact (before truncation scattering) and follows the stereographic transformation formula. The tangential electric fields exactly match (cancel) on the paraboloidal reflector for arbitrary focal lengths.

Figure 3.2 shows what such an anisotropic reflector might look like. Certain regions for which the incident electric field is approximately optimally polarized might be a solid or dense mesh region of the reflector. This includes the regions near the x axis and near the y axis for $|y| < a$. The remainder of the reflector consists of conductors following contours roughly as indicated and positioned slightly in front of the ideal paraboloidal surface. Note that these conductors (some of them) connect to the feed arm through some termination impedance to be selected. The reflector being truncated at some outer edge, the conductors can be connected together there as desired.

Our considerations have been based on a local approximation of a uniconducting sheet with constant conduction direction $\vec{1}_u$. Depending on the wavelength of the incident field this may or may not be a good approximation at the various positions on the reflector. There is also the issue of the length of these conductors in wavelength units due to possible resonance effects. More detailed quantitative calculations are needed to optimize the design of such a uniconducting reflector.

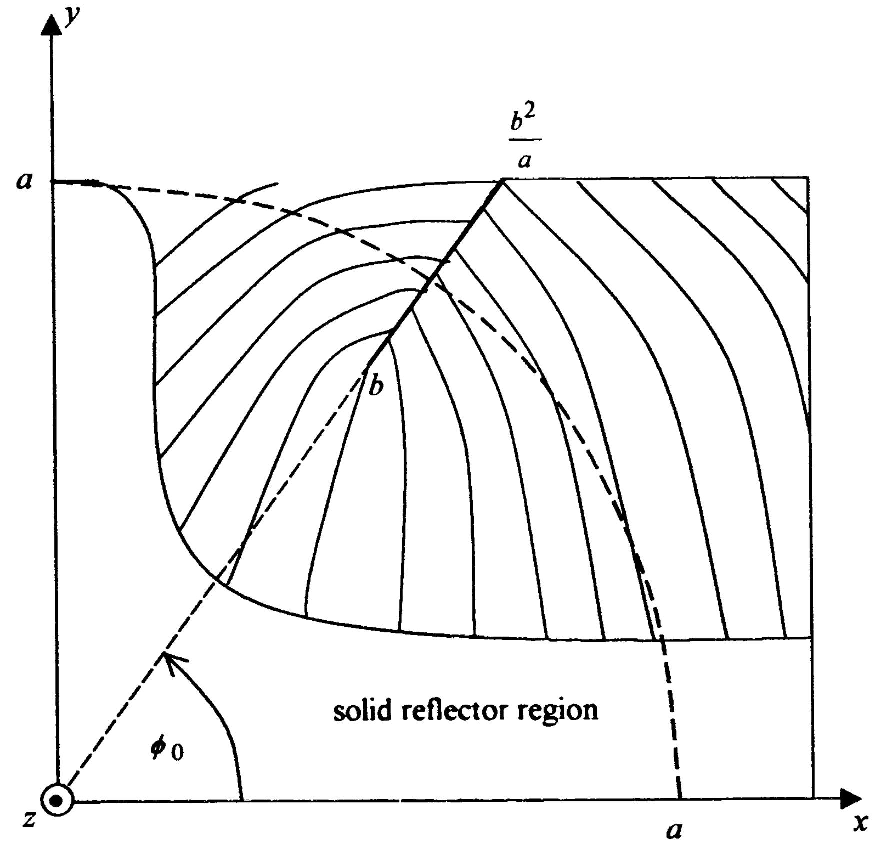


Fig. 3.2 Uniconducting Reflector: One Quadrant, Qualitative

4. Displacing Portions of Reflector by Quarter Wavelength

Yet another technique for improving aperture efficiency of the reflector involves displacing the reflector by a quarter wavelength $\lambda/4$ (either back or forward) in regions where the vertical component of the incident electric field has the undesired polarity. (See Fig. 2.1 and items 2 and 3 in the summary in Section 2.) Instead of eliminating the reflector in these regions, the quarter-wave displacement gives a round-trip of a half wavelength which is a 180° phase shift, and thereby a sign reversal on the y component so that it now increases $|h_{a_y}|$. Note that this technique only applies to a wave with not-too-large bandwidth so that $\lambda/2$ is does not appreciably vary over the frequency band of interest (hypoband and perhaps mesoband).

The reader may note some similarity of this concept to the stepped reflector in the COBRA antenna designs [5, 10]. In that case, corrections were derived to allow for the fact that the incident wave on the TEM feed propagates at some angle (not generally zero) with respect to the z axis. The same applies here.

5. Concluding Remarks

The techniques discussed in this paper need not be used separately, but can be combined in various ways for each portion of the paraboloidal reflector. For example, the $\lambda/4$ displacement of the reflector can be combined with the uniconducting reflector. While the discussion here has been in terms of a reflector, similar considerations can be used for lens-focused apertures. These are complementary as discussed in [2 (Section III)]. Note that in the case of a uniconducting sheet the lens case involves a rotation of $\vec{1}_u$ by $\pi/2$ to give the complementary sheet for transmitting instead of reflecting the field.

For a mesoband ORA we can also revisit the feed structure. The TEM feed from focus to reflector is most appropriate for the dispersionless hyperband application as in an IRA. For hypoband application a common wave launcher toward a reflector is a microwave horn operating in some waveguide mode (not TEM). For sufficiently high frequencies such that the horn aperture is small compared to the reflector aperture, such a design is quite appropriate. As one lowers the frequency so that the reflector aperture is only a few wavelengths across, such a microwave horn may become unacceptably large. One may then prefer a TEM feed, or perhaps an offset feed from a microwave horn. Perhaps one can begin the launch as a TEM structure near the focal point, and transition to some other kind of non-TEM structure as one approaches the reflector to give some kind of hybrid.

References

1. C. E. Baum, "Impedances and Field Distributions for Parallel Plate Transmission Line Similators," Sensor and Simulation Note 21, June 1966.

2. C. E. Baum, "Aperture Efficiencies for IRAs," Sensor and Simulation Note 328, June 1991.

3. E. G. Farr and C. E. Baum, "Prepulse Associated with the TEM Feed of an Impulse Radiating Antenna," Sensor and Simulation Note 337, March 1992.

4. D. V. Giri, "Radiated Spectra of Impulse Radiating Antennas (IRAs)," Sensor and Simulation Note 386, November 1995.

5. C. C. Courtney and C. E. Baum, "Coaxial Beam-Rotating Antenna (COBRA) Concepts," Sensor and Simulation Note 395, April 1996.

6. C. E. Baum, "Optimization of Reflector IRA Aperture for Filling a Rectangle," Sensor and Simulation Note 439, September 1999.

7. C. E. Baum, "Antennas for the Switched-Oscillator Source," Sensor and Simulation Note 455, March 2001.

8. J. S. Tyo, private communication, July 2001.

9. C. E. Baum, "Switched Oscillators," Circuit and Electromagnetic System Design Note 45, September 2000.

10. C. C. Courtney and C. E. Baum, "The Coaxial Beam-Rotating Antenna (COBRA): Theory of Operation and Measured Performance," IEEE Trans. Antennas and Propagation, 2000, pp. 299-309.

11. M. E. Van Valkenburg, *Network Analysis, 3rd Edition*, Prentice-Hall, 1974.

12. C. D. Taylor, *High-Power Microwave Systems and Effects*, Taylor & Francis, 1994.

13. D. V. Giri and C. E. Baum, "Temporal and Spectral Radiation on Boresight of a Reflector Type of Impulse Radiating Antenna," pp. 65-80, in C. E. Baum, L. Carin, and A. P. Stone (eds.), *Ultra-Wadeband, Short-Pulse Electromagnetics 3*, Plenum press, 1997.

14. C. E. Baum, E. G. Farr, and D. V. Giri, "Review of Impulse-Radiating Antennas," ch. 16, pp. 403-439, in W. R. Stone (ed.), Review of Radio Science 1996-1999, Oxford U. Press, 1999.