APERTURE DESIGN FOR IMPULSE RADIATING ANTENNAS

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ABSTRACT

Impulse radiating antennas (IRAs) suffer from relatively low aperture efficiency due to the open mode propagating on the TEM transmission line feed section. The low efficiency results from two mechanisms: some of the energy passes outside the IRA aperture (spillover), and 2) the TEM mode distribution is not uniform in the aperture plane. A number of recent advances have been made that increase the prompt radiated fields from impulse radiating antennas (IRAs), including repositioning of the feed structure to maximize field uniformity and concentration, reshaping the aperture to eliminate improperly oriented fields, and reshaping the field distribution using uniaxial conducting materials.

INTRODUCTION

IRAs are a class of focused aperture antenna that use a non-dispersive transverse electromagnetic (TEM) conical transmission line to feed a focusing optic, usually a lens or a reflector. The optic converts the spherical wave on the transmission line into a plane wave in the near field, and diffraction effects cause the antenna to radiate the derivative of the applied voltage in the early time. When excited by a fast-rising step waveform, IRAs emit an extremely short pulse of electromagnetic energy. It is a well known property of IRAs that the radiated far-field on boresight is given by a surface integral of the electric field vector in the aperture of the antenna in retarded time. Because of the symmetry inherent in the transverse electromagnetic (TEM) feed transmission lines of IRAs, the principal polarization is typically taken to be vertical. To create a field pattern that will radiate effectively, the TEM feed is usually a conically-symmetric balanced transmission line. These structures are non-dispersive, but support modes that are defined over the entire sphere of space surrounding the feed point. After stereographic projection, this corresponds to a longitudinal mode that is defined over the entire aperture plane. Ideally, one would want all of the energy from the feed structure to impinge on the focused aperture with uniform amplitude and polarization. Such a configuration would maximize the prompt radiated fields for a given input power. Such a scenario is not physically possible, since TEM transmission lines have open modes. There are two distinct loss mechanisms that must be dealt with: 1) energy in the TEM mode that passes outside the aperture and 2) non-uniformity of the TEM mode in amplitude and polarization. For typical reflector IRAs, as much as 50% of the mode energy passes outside the aperture. Even if the aperture were extended to encompass this additional area, much of the field is oriented in the wrong direction and would contribute destructively to the integral. Figure 1 presents a model for the feed structure and focusing optic of a reflector IRA.

IRA IMPROVEMENTS

This review talk will focus on the following developments. First, a discussion of IRA optimization metrics will describe the concepts of power and voltage normalized gain, prompt aperture efficiency, and impedance normalized gain. These metrics will be defined, and their relative regimes of utility will be discussed. Prompt aperture efficiencies of popular lens and reflector IRA configurations will be presented and discussed.

Second, the recent improvements in prompt aperture efficiency for reflector IRAs will be discussed. These improvements have focused on two areas: 1) modifying the size and shape of the TEM feed electrodes to improve the mode uniformity; and 2) altering the size and shape of the aperture to maximize the prompt radiated field for a given feed structure and aperture space.

Reflector IRAs are usually constructed with crossed-coplanar feed arms forming a conical transmission line with a 200-Ohm input impedance. The two pairs of feed arms are typically oriented orthogonally to eliminate coupling and allow for exact determination of the aperture fields. The coplanar plates form a self-reciprocal transmission line, and the circle of symmetry is usually used as the outer perimeter of a circular reflector. Studies have demonstrated that by moving the feed arms from their traditional angle of 45 degrees from the vertical towards the vertical improves the aperture height, prompt aperture efficiency, and other time domain metrics. By moving the feed arms from 45 degrees to 30 degrees, the radiated electric field was demonstrated experimentally to increase by 19% (a 40% increase in radiated power) for the same input impedance and power. Detailed results allow the feed structure to be optimized for any feed arm angle or for any input impedance, with an overall optimum at approximately 250 Ohms, with feed arms oriented at 20 degrees from the vertical.

Almost invariably, reflector IRAs have had circular-cross-sectioned reflectors that focus all of the fields inside the circle of symmetry for the TEM mode on the feed line. Such reflectors invariable capture fields in the aperture that are oriented in the wrong direction and actually detract from the prompt radiated fields. Once the TEM mode fields are known, it is a trivial task to locate the contour where the vertical component of the field changes sign. By projecting a given aperture shape onto this "ideal contour" and removing the portions of the aperture where the fields are oriented in the wrong direction, the prompt aperture efficiency can be made to increase. For feed arms located at 45 degrees from the vertical, the improvement can be more than 10%. For feed arms located closer to the vertical, the improvement is less, but still not insignificant. Preliminary experimental results from a time-domain antenna range verify the numerical predictions.

Finally, it has been shown that the prompt radiated fields can be further enhanced by actually making the feed arms smaller with respect to the aperture of the optic and trimming the resulting aperture accordingly. The amount of decrease is dependent on the exact geometry. This counter-intuitive result is actually due to a redistribution of the fields inside the aperture.

Other mechanisms for the improvement of prompt aperture efficiency will be addressed, including time-domain arrays, isorefractive materials, and the choice of lens or reflectors for particular applications.