Sensor and Simulation Notes
Note 454

Measurement of Prompt IRA Responses Under Different Focused Aperture Configurations

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Abstract

This article presents experimental measurements verifying the relationship between aperture shape and prompt response in an impulse radiating antenna (IRA). Various aperture configurations were realized by constructing a lens IRA with focused aperture significantly larger than the transverse electromagnetic (TEM) feed structure and then blocking portions of the aperture with metal blocks. Virtually any prompt response can be realized by suitable constuction. Experimental results agree well with predicions made by evaluating the aperture integral of the TEM mode distribution.

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1 Introduction

Impulse radiating antennas (IRAs) are a class of antennas designed to radiate short electromagnetic pulses. IRAs work by feeding a focusing optic (usually a lens or a reflector) with a non-dispersive TEM feed structure. It is known that the focused aperture radiates (in the far-field) the approximate derivative of the applied voltage signal, and the early-time portion of the radiated signal is[1]

$$E_{rad} = \frac{h_a}{2\pi r c f_g} \frac{dV}{dt}, \tag{1}$$

where $f_g = Z_{line}/\eta_0$ is the geometric impedance factor and h_a is termed the aperture height and is defined as

$$h_a = -\frac{f_g}{V_0} \iint_{S_a} E_y(x, y) dx dy. \tag{2}$$

It is assumed in (2) that the y–axis is parallel to the principal field component. When excited by a fast-rising step waveform, an antenna that obeys (1) will radiate a narrow impulse. Recently a number of studies have sought to maximize the prompt field radiated from an IRA by altering the aperture field distributions in a favorable manner.[2, 3, 4, 5, 6, 7, 8] Optimization has been in terms of a number of different parameters, but for a fixed aperture size and shape and fixed feed impedance, all optimization strategies are equivalent to maximizing h_a in (2). Baum[1, 9] first suggested that since h_a is determined by E_y everywhere in the aperture, the prompt response could be altered for a given feed structure by allowing only portions of the focused aperture to contribute to the prompt response. In this note, this supposition is verified by examining the prompt response of a lens IRA with various aperture configurations. It is found that virtually any prompt response can be realized (including negative prompt responses) if one is willing to focus a large enough area. While prompt response is easily altered, the presence of metallic aperture blocks used to trim the aperture alter the late-time response in a more complicated fashion that may not be appropriate for applications where the maximum prompt radiated signal is not the only consideration.

2 Aperture Design

Fig. 1 presents the TEM mode field distribution for a 170Ω flat-plate TEM horn feedline. Since the TEM mode is an open mode, the electric field is sometimes oriented in the $-y$–direction, sometimes in the $+y$–direction. The surface integral in (2) is carried out over the focused aperture, so it is clear that choice of S_a is instrumental in determining the prompt response of the IRA. Fig. 2 presents six apertures that use different portions of a circular aperture of radius R that encompasses the TEM feed. These apertures were synthesized experimentally, and the prompt response is discussed in the next section.

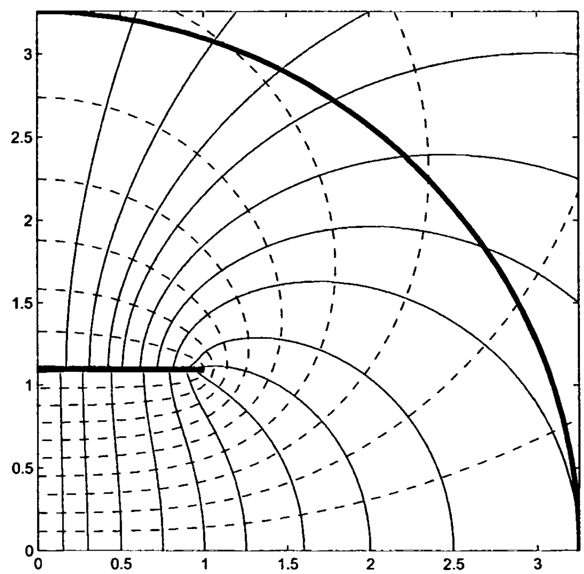

Figure 1: Electric (solid) and magnetic (dashed) field lines for the TEM mode distribution on a 170Ω, flat-plate feedline. This mode distribution is for a parallel plate TEM feed, and is only an approximation to a conical TEM feedline. The latter must be altered by a stereographic projection to get the equivalent parallel-plate feed structure. Only 1/4 of the aperture is shown due to symmetry. Eqn. (2) indicates that portions of the aperture with $E_y < 0$ contribute constructively to the prompt response while those areas with $E_y > 0$ contribute destructively (the principal field direction is in the $-y$-direction). The outer circle represents the extent of the focusing optic relative to the TEM feed.

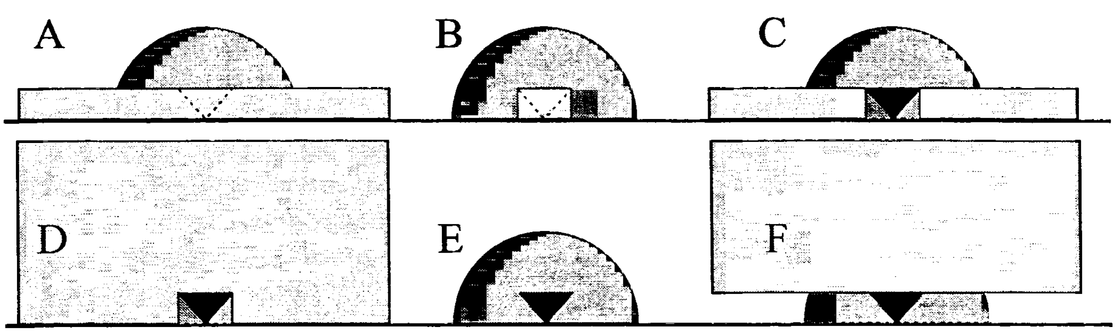

Figure 2: Six apertures considered in this paper. A. .Horizontal Block B. Aperture Blocked. C. Blocking strip. D. Natural Aperture. E. "Infinite" aperture. F. Strip aperture.

3 Experiment

The experiments described here were performed on an ultra-wideband (UWB) ground-plane antenna range that is described elsewhere.[10] The range had a 4-ns clear time with a 4-ns monocone reference antenna. The monocone (over the ground plane) radiated a replica of the applied signal until the transit time of the antenna. The monocone was excited by a Picosecond Pulse Labs 4050B 47-ps risetime, 10-V, 10-ns duration step generator. The antenna under test was located approximately 13 m down-range from the monocone. The antenna was tested on receive, and reciprocity dictates that the transmit step response is equivalent to the derivative of the receive step response.[1] The responses were measured with a Tektronix CSA803A Digital Sampling Oscilloscope with a SD-24 TDR sampling head. There were 512 points in each record with an effective sampling interval of 10 ps. Sixty-four records were averaged for each waveform. The nominal risetime of the entire system was approximately 50 ps.[10] The antenna was configured as a lens half-IRA with a 85Ω flat-plate TEM feed made of 0.8-mm thick aluminum. The width of the feed aperture was 18.7 cm and the height was 10.2 cm. The focusing optic was a 30.5-cm radius polyethylene lens with a 71-cm focal length. The focused aperture was larger than the TEM horn aperture, making it possible to synthesize apertures much larger than typical lens IRAs. The apertures presented in fig. 2 were constucted by blocking portions of the lens with aluminum foil. The presence of the foil prevented signals from the blocked portions of the aperture from contributing to the prompt signal. The aperture blocks did alter the late-time response of the antenna, and that might not be acceptable for all applications. These experiments were conducted with a lens IRA, but are directly applicable to reflector IRAs.[1, 8] In a reflector IRA, the blockage would be achieved by eliminating portions of the reflector in areas that are not to be included in the prompt response. Such an antennas has not yet been fabricated, but might be expected to have less of an effect on the late-time response of the antenna.

Fig. 3 presents the step and impulse receive responses of the IRA with the aperture blocks from fig. 2. The step transmit responses are equivalent to the impulse receive responses. The impulse responses were obtained by differentiation, as described in the figure caption. The data clearly demonstrate that a particular feed impedance can be made to produce almost any prompt response. By including portions of the aperture that contribute constructively, a prompt response of up to twice the mean charge separation is possible.[4]

To compare these experimental results with the theoretical prediction, the surface integral in (2) was cast into a contour integral of the complex potential function used to derive the TEM electric field.[1, 9] Using Matlab (ver. 5.3), the contour integrals were evaluated numerically using a potential distribution calculated using a 2-dimensional, static-potential, method of moments technique. The value of this contour integral is proportional to h_a, and the values for the various apertures studied here (normalized to the value for the "natural" aperture (case D)) are tabulated in table 1. These values compare favorable with the measured values of h_a (again normalized) that are also presented in the table. The error in all cases is less than 10% of the prompt response of the natural aperture. Possible sources of error include incomplete and imperfect aperture blockage and the fact that the TEM mode

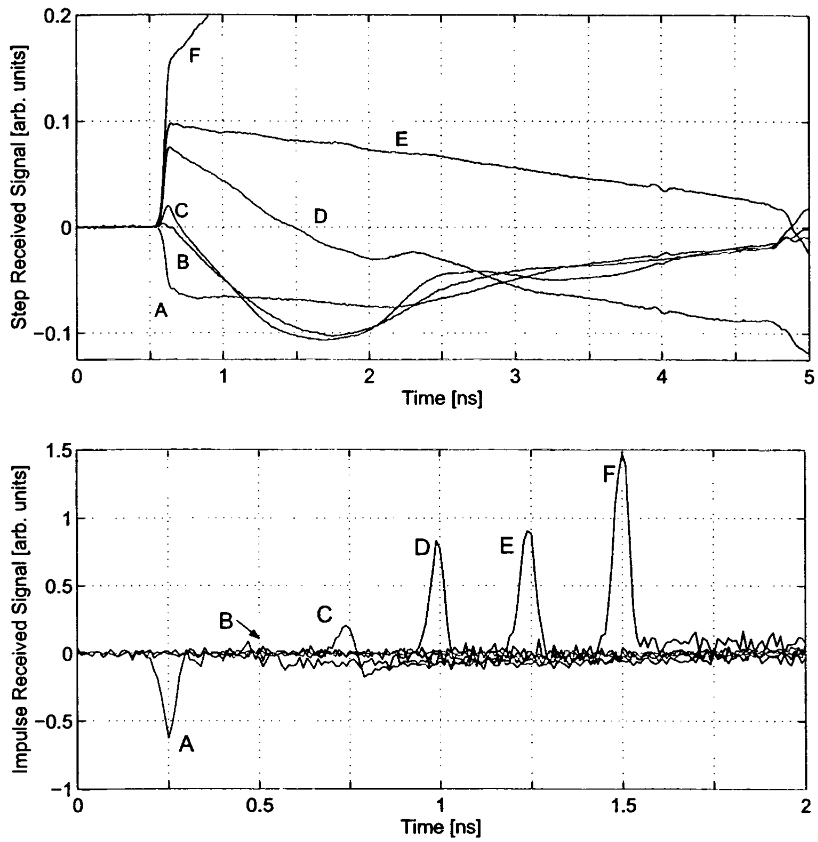

Figure 3: Prompt receive step and impulse responses of the lens IRA with the six aperture configurations depicted in fig. 2. The aperture height h_a is proportional to the magnitude of the initial rise of the step responses or the magnitude of the impulse responses. The step radiated response is equivalent to the impulse receive response. The risetime of all six measured signals was between 50 and 55 ps. The impulse responses were obtained by numerical differentiation of the step responses. A Gaussian low-pass filter (σ = 8ps) was used to eliminate numerical noise. The impulse responses are offset on the time axis for clarity.

Aperture	A	B	C	D	E	F
Measured h_a	-0.73	0.14	0.26	1.00	1.16	1.86
Predicted h_a	-0.64	0.10	0.36	1.00	1.10	1.74

Table 1: Measured and predicted values of h_a. Values are normalized to the "natural aperture", aperture D in fig. 2.

distribution in fig. 1 must be modified by use of a stereographic projection to completely predict the mode distribution of the TEM feed.[11]

4 Conclusions

Experimental measurement of the prompt response of a lens IRA with different aperture configurations are shown here to agree with theoretical predictions. Consideration of only the aperture fields allows prediction of the magnitude of the radiated field from an IRA. These results indicate that recent optimization studies [5, 8] that seek to further improve prompt response by aperture shaping are well founded. The aperture blocks as implemented here alter the late-time response, but in several cases, this alteration is difficult to detect in the time-domain impulse response, and might be deconvolved if necessary. These results indicate that the antenna designer has a new degree of freedom in designing an IRA to fit into a constrained space, allowing for improvement of the prompt radiated signal.

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