

Optimization of a Resistively-Loaded Horn for Mine Detection

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Abstract

Five basic versions of an U.S. Army Research Laboratory (ARL) built Synchronous Impulse Reconstruction (SIRE) radar antenna were modeled using the method of moments (MOM) algorithm in FEKO computational electromagnetics software with the goal of improving the antenna performance. The antennas consist of two-sided, open horns where horizontal, resistively loaded parallel plates were attached at the radiating end of the horn. Three of the models featured cylindrical flares attached to the end of the parallel plates. Each of the five versions was optimized over a small range of geometry and resistance parameters. The computations predicted that the design using resistive sheets in the parallel line structure with no flare had the best performance because of its combination of favorably low S11 parameters and forward-directed vertical electric far field.

I. Introduction

One technology the U.S. Army Research Laboratory (ARL) is exploring for detecting and locating landmines is a ground based broad-band radar system called Synchronous Impulse Reconstruction or SIRE. This vehicle mounted radar is intended to detect and locate landmines far enough in advance to be avoided or rendered harmless before reaching them.

From the radar returns, synthetic aperture radar (SAR) images are generated and show the presence and location of landmines. SAR imaging is most effective when the signal to noise ratio is high and the clutter from non relevant objects is low, therefore, the design of the radar system must be one in which its own signal to noise ratio is maximized.

The ARL SIRE radar antennas transmit radar pulses towards a target field of some depth and then receive target returns by means of a series of 16 approximately collocated Vivaldi notch antennas. With current SIRE antennas, echo-like images of actual targets appear so that the actual object image can be confused with multiple echo images leading to uncertainty in the true target location. The echoes may also cover or obscure other objects hidden beneath them. The time separations between the echoes correspond to round-trip distances within the radar system suggesting an internal antenna reflection back to the transmitter. When this reflected pulse hits the transmitter it is again reflected so that most of this secondary pulse will also reach the target. Therefore, the primary goal was to reduce internal antenna reflections. Since another possible source of erroneous returns are reflections of the transmitted pulses off of the support structure, in this case a vehicle, minimizing rearward emissions from the transmit antenna was a second goal of this investigation.

In order to reduce the apparent echoes we sought to improve the original SIRE transmit antenna by optimizing its S11 parameter and its radiation pattern. To do this we used FEKO¹ computational electromagnetics software (method of moments algorithm) to examine these characteristics for models of several variations of the antenna when their geometric and resistance parameters were adjusted². A major constraint on these variations was the need to maintain an antenna characteristic impedance that matched the balun impedance of 200 Ω .

II. Transmitting Antenna Variations

The original SIRE antenna consists of a two-plate horn that is open lengthwise on two of its four sides, and attached at its emitting end is a short, resistively-loaded parallel plate transmission line. Figure 1 shows a facet model of the original 80 cm long antenna that includes rows of 8 strip resistors separating metal plates in the parallel section. The

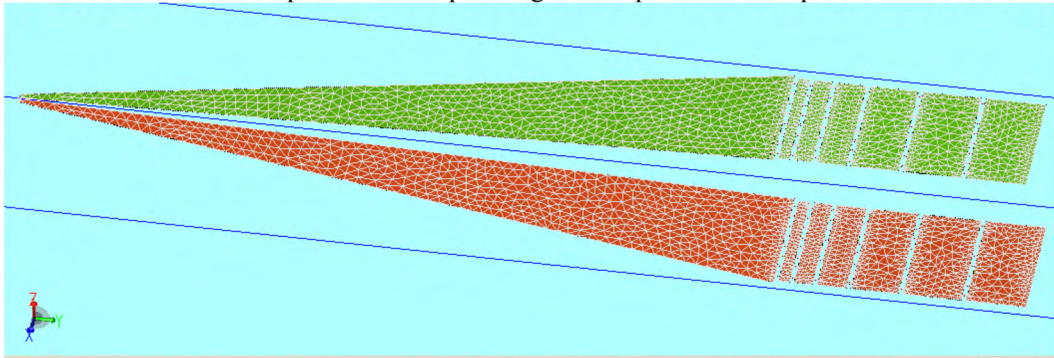


Figure 1. A FEKO triangular facet model for the original ARL TEM Impulse Transmitting Antenna (design 1).

model variations had the same base dimensions. The individual resistances increase from 37.4 to 374 Ω from the inner row to the outer row in the original design. The feed end of each model is cut short of a perfect point so that it is electrically divided and the drive wires can be separately attached to the top and bottom of the feed. A balun connects the radar transmitter to the antenna in the physical model, but not in the computer model. In addition to adjusting or optimizing certain geometric and resistance parameters of this model, four other variants of this design were also explored as alternates.

The variants chiefly differed either by the presence of a cylindrical flare on the radiating end or by the use of three resistive sheets. Two of four variations on the original design replaced the parallel line section containing embedded rows of chip resistors with three sheet resistors following a resistance sheet design by Shlager, et al³. That their design was for a 50 Ω antenna suggests room for further optimization in the case of our 200 Ω antenna. Three of four had 6 cm radius, 170° cylindrical flares attached to the radiating end as shown in the facet file of figure 2. One of the flared designs used only conductive sheets in the parallel line section. Although the designs with attached flares were a little larger, the choices considered were not greatly larger than the original SIRE antenna.

Since the original design was a variant of a larger antenna optimized by NIST, the approach was to use this as a starting point. Following a study by Lee and Smith,⁴ the ratio of the horizontal to vertical divergence angles of the horn was held constant to maintain a 200 Ω characteristic impedance.

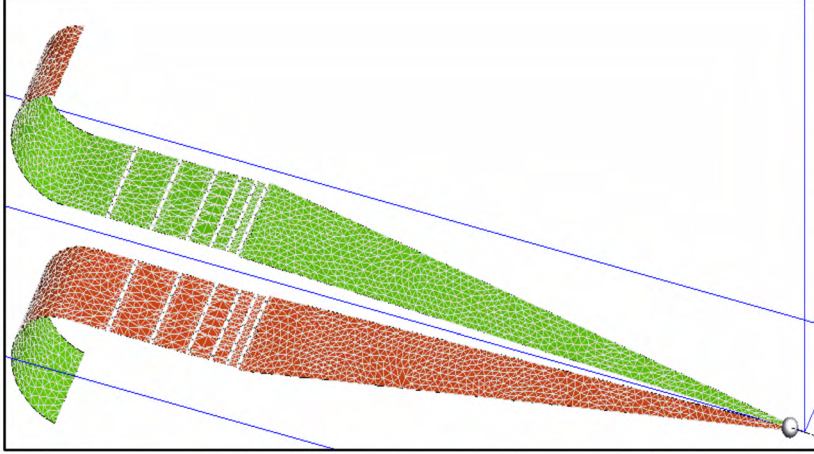


Figure 2. A FEKO triangular facet file for a flared antenna design.

III. Optimized Models

FEKO computations indicated what changes and models produced the lowest S11 and best radiation pattern across the 300 MHz to 3 GHz spectrum of the SIRE transmitting antenna. Various changes in the resistances as a whole or for sections of the antennas did not have a strong effect. When the resistances were boosted by a large factor, S11 tended to drop, but this would be at the expense of transmitter power and therefore undesirable. However, the use of conductive sheets in place of the strip resistors had a very favorable effect on the S11. Flares also dropped the S11. Figure 3 summarizes the S11 for the

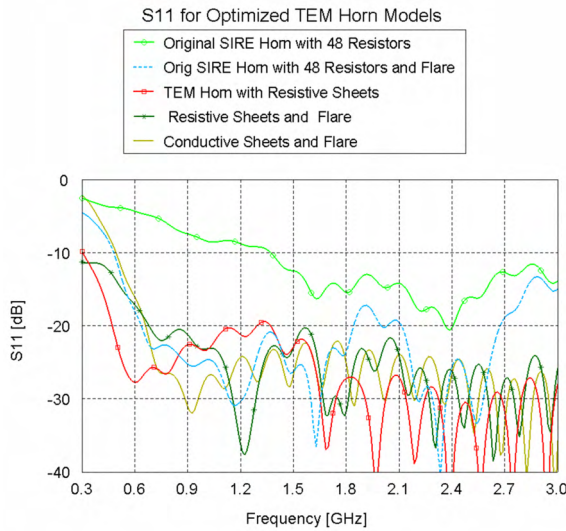


Figure 3. S11 for Optimized Horn Models.

four optimized models, suggesting considerable improvement by the alternates over the original antenna, especially at the lower frequencies.

Radiation patterns varied significantly among the models as shown in figure 4 where 90° lies at the mouth of the antenna. The electric far field slice in figure 4 was taken at 1 GHz near the transmitter's peak frequency. Horizontal slices through the antenna axis (and parallel to the parallel plate section) showed similar qualitative differences between the patterns. In particular, flares improved the field pattern, but the resistive sheets did even more according to the calculations.

IV. Conclusions

Most of the optimized variants had reasonably low S11, especially in the 600 to 1800 MHz range where most of the transmitter power lies. However, the models with resistive sheets had strongly improved radiation patterns. Table 1 summarizes the results and points to design 3 with resistive sheets and no flare as the most promising design overall.

Vertical Electric Far Field (dB) for TEM Horn Models

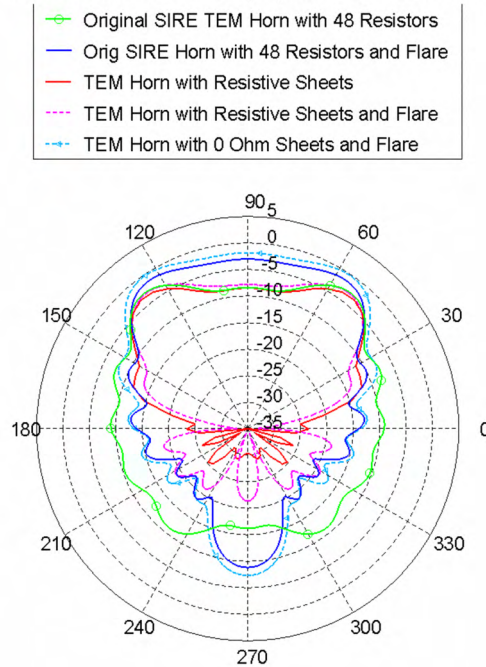


Figure 4. Vertical Electric field vertically sliced through antenna axis at 1 GHz.

When rotated 90° about the antenna axis, all of the antenna designs radiate a horizontally polarized electric field uniform within ± 2.5 dB over more than a 60° span. This coverage shows promise for forward radar coverage including side zones.

Modeling greatly helped to optimize the flares and the feed end. More complete modeling including the physical presence of the balun near the feed may be needed to better characterize the performance of the antenna as a whole. However, the ability to optimize the S11 and radiations patterns gives us more designs with which to improve our radar.

Table 1. Performances of optimized SIRE radar antenna models.

Model	Resistance Type	End Flare	S11	Radiation Pattern
1	6 rows, 8/row	None	Very poor especially at low frequencies.	Very poor
2	6 rows, 8/row	6 cm radius, 170° span	Very good at middle frequencies.	Middle
3	3 resistive sheets	None	Very good at low, moderate at mid, and good at high frequencies.	Very good; Rearward very low
4	3 resistive sheets	6 cm radius, 170° span	Good at mid frequencies.	Good
5	0 Ω sheets	6 cm radius, 170° span	Very good at mid-range and high frequencies.	Middle

¹ FEKO Comprehensive EM Solutions Site. <http://www.feko.info/FEKO-at-a-glance> (accessed January 2009).

² Christopher S. Kenyon, "Optimization of a Resistively-Loaded Antenna Using FEKO Software," Tech. Report ARL-TR-4633, Nov. 2008, Distribution Limited to U.S. Government Agencies and their Contractors.

³ Shlager, Kurt L.; Smith, Glenn S.; Maloney, James G., "TEM Horn Antenna For Pulse Radiation, an Improved Design," *Microwave and Optical Technical Letters* vol. 12, no. 2, pp. 23-26, June 5, 1996.

⁴ Lee, R. Todd; Smith, Glenn S. "A Design Study for the Basic TEM Horn Antenna," *IEEE AP Magazine*, vol. 46, no. 1, pp. 86-92, February 2004.