Sensor and Simulation Notes

Note 553

2 February 2011

Modifications to a Commercial Impulse Radiating Antenna (IRA) for Accurate Mono-static Impulse Radar Application

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Abstract

In this note, we outline the modifications made to a reflector type of IRA we procured from Farr Research, Inc., (FRI) located in Albuquerque, NM (URL: www.farr-research.com). This antenna system was procured, modified and used in our mono-static short pulse radar measurements.

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1. Description of the 18 inch IRA

The model number for this antenna supplied by Farr Research, Inc is FRI-IRA-3M and a photograph of the antenna as received from FRI is shown in Figure 1.

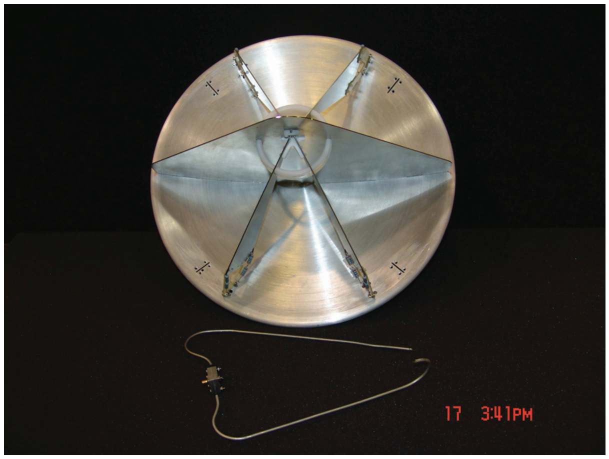


Figure 1. FRI-IRA-3M → 46 cm diameter full IRA that we procured

Geometrical and electrical features (from the manufacturer's data sheet) are summarized below:

- Diameter D = 46 cm
- Focal length F = 23 cm → (F/D) = 0.5
- Feed arms ($\pm$ 30 degrees from the vertical) → reducing gain and cross pol
- Ground plane in the symmetry plane to reduce cross pol and add to ruggedness
- 50 Ohm to 200 Ohm transmission line Balun
- Input connector is SMA (50 Ohms)
- Frequency band (250 MHz to 20 GHz)
- Midband effective height 6.3 cm
- Peak gain of 26 dB at 17 GHz
- Weight 2.3 kg or 5 lbs

2. Rationale and Description of the Modifications Made

We observed that this commercial IRA is built for ruggedness and ease of transportation and use. It is a commercial product which quite often results in engineering compromises.

For example:

- One of the 100 Ohm transmission lines from the Balun punctured the reflector near the termination, rather than going over the reflector and away from the terminating resistors.

- The terminating resistors are rather “lumpy” with two series resistors per chain and two parallel chains, with a net of 200 Ohm at the end of each of the 4 arms. We decided to attempt implementing a somewhat more of a distributed resistive termination in all four feed arms.

- The SMA connector may limit the application. We decided to change the SMA connector to N or HN connector. We tried both, but had to settle for the N type connector for the new Balun, because of the poor quality of the HN connector.

- Closed-form analytical solutions exist for on-axis near, intermediate and far fields for the case of $\pm$ 45 degree arms and for our application (short pulse radar), it was not important to get the extra (10 - 15%) on axis radiation by going to the $\pm$ 30 degree feed arms. It was also believed that the $\pm$ 45 degree arms, resulting in orthogonal conical line feeds would have no mutual interaction and would ultimately result in a “spectrally cleaner” radiation. In the $\pm$ 30 degree case, the conical feed line will couple to each other, helping in some ways with the cross pol, increased radiation on axis, but with an “unknown” price to pay. We are not using this as a hyperband weapon (where enhanced on-axis radiation is useful), but as hyperband radar where spectral cleanliness is useful, if we get improvements in TDR.

The modifications that were made can be summarized as follows:

1) Reroute one of the 100 Ohm cable from the balun to go over the reflector and away from the termination rather than thru the reflector and close to the termination

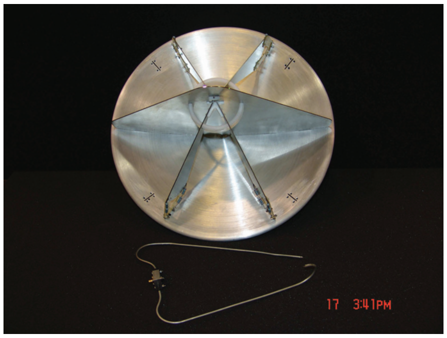
2) Change the $\pm$ 30 degree feed arms to $\pm$ 45 degree feed arms

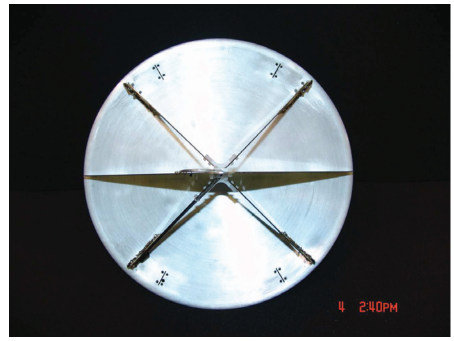
3) We also eliminated some dielectric supports near the feed which are required for a commercial item in the interest of ruggedness, but not required in a laboratory device. Dielectric material in the feed region tends to slow the wave as it passes over.

4) Change the SMA- connector Balun to N-connector Balun

5) Somewhat more distributed terminations in all four arms

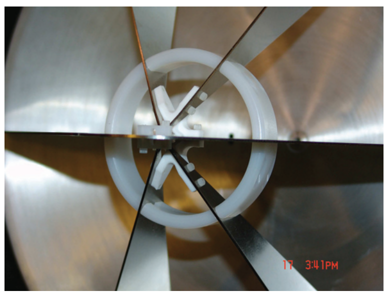
Some “before and after” photographs showing the modifications are shown in Figure 3.

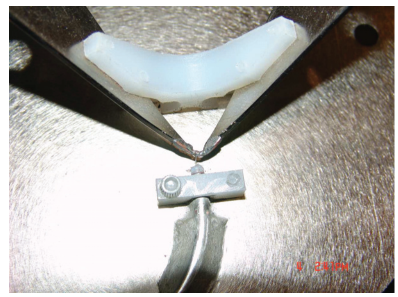




$\pm$ 30 degree feed arms (before)

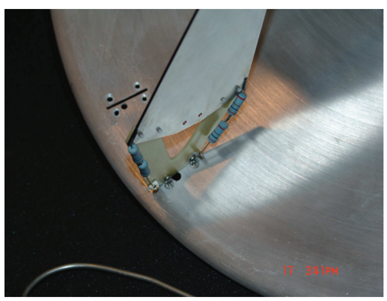
$\pm$ 45 degree feed arms (after)





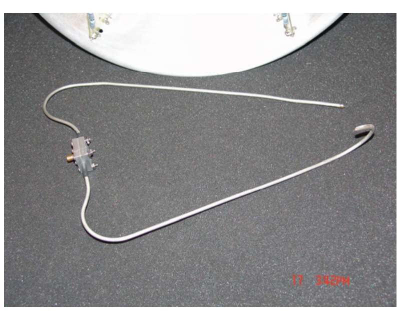
Feed point details (before)

Reduced dielectric material (after)



Termination (before)

Termination (after)



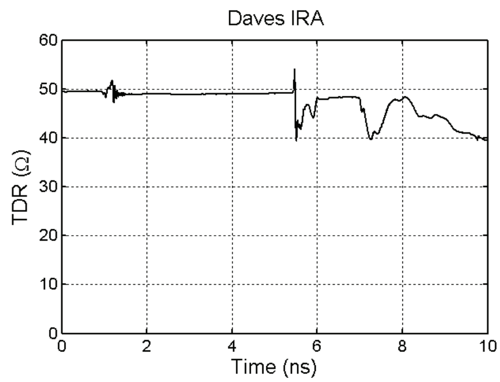
Balun with an SMA connector (before)

Balun with an N-connector (after)

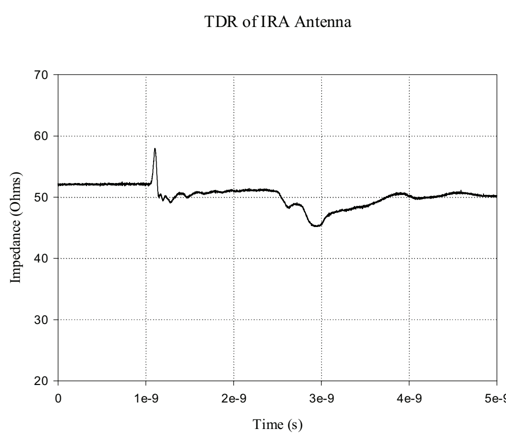
Figure 2. Photographs showing the various modifications made

One of our objectives in making the modifications to this commercial IRA was to improve the TDR data at the feed point. The directional couplers (or Transmit/Receive switch for a mono-static impulse radar) are designed to work into a 50 Ohm antenna and it is important to maintain this input impedance of the IRA close to 50 Ohms. We decided to use the TDR data as the bench mark test to demonstrate the improvement.

Let us do a side-by-side comparison of the TDR before and after the modifications made here. This comparison is shown in Figure 3 below.



a) TDR of the FRI-IRA-3M (before)



(b) TDR of the modified IRA (after)

Figure 3. Comparison of TDR (before and after modifications)

We see a 10 Ohm variation in the original IRA, whereas a 7 Ohm variation in the modified IRA. Also, the late time behavior of the modified IRA appears to be improved as well, because of the improvements in the termination.

Dr. Farr has indicated (private communication) that the IRA-1B shown in Figure 4-9 of Sensor and Simulation Note 499 or the identical IRA-1 shown in Figure 2.1 of Sensor and Simulation Note 463 comes closest to what we have built here, after modifying the FRI-IRA-3M. This IRA is shown in Figure 4. Since the IRA -1B shown in Figure 3 is closer to our modified IRA; we can do a side-by-side comparison of our modified IRA with the TDR of IRA-1B of Figure 3. This is done in the following Figure 5.

Figure 4. IRA – 1B {SSN 499} or the IRA-1 (SSN 463) which is closest to our modified IRA

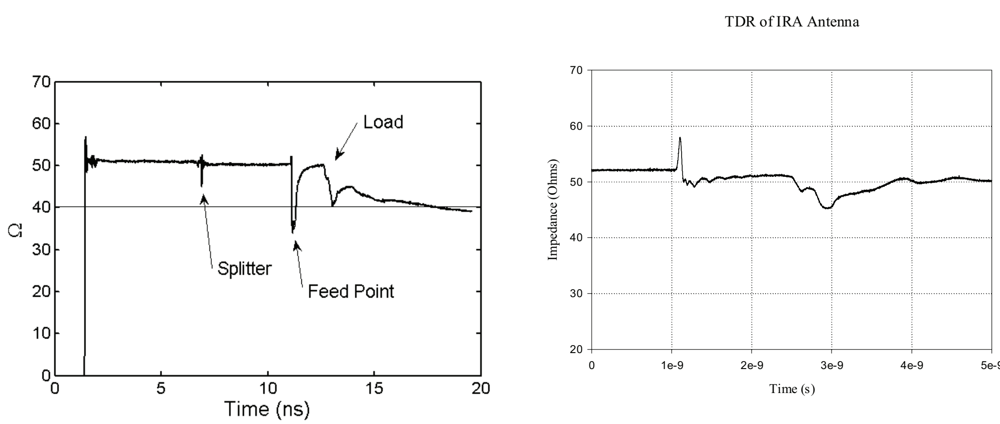


Figure 5. Side-by-side comparison of the TDR of IRA-1B with our modified IRA

The following comments are in order.

- The two IRAs (our modified and the IRA-1B) are similar except that we used Allen Bradley resistors, while the IRA -1B used generic carbon comp and metal-film resistors and found no appreciable difference. Maybe the Allen Bradley resistors are the key to the improvement seen above.

- We have seen a similar improvement in the TDR of the Swiss Half IRA (1.4m diameter; 100 Ohms; no Balun needed) by replacing Ohmite ceramic resistors with Allen Bradley resistors, all other parameters being equal. The late-time behavior improved as well. The final data with Allen Bradley resistors resulted in 100 ± 6 Ohm variation in the TDR or ± 6% from the nominal 100 Ohm value. It could perhaps be improved some more, but was deemed to be acceptable.

- Once gain, we see that our TDR variation is 7 Ohms (45 to 52 Ohms in the figure on the right of Figure 4) while the variation is 10 Ohms (40 to 50 Ohms) in Farr's results. This is a modest improvement.

- It appears as though, the late time value is better with the modified IRA, although this may or may not be critical depending on the application.

- It is also realized that some of the modifications we have made are not necessarily practical for a commercial IRA, but are acceptable for a laboratory IRA for a specific application. It is not our intention to suggest that commercial IRA be made following the modifications that we have attempted. Basically, we made the modifications to suit our present needs.

3. Calculated Fields from the Modified IRA

The pulser used to energize the modified IRA is a PBG 1 high-voltage pulse source built by Kentech Instruments Ltd. The peak amplitude is typically 7 kV into a 50 Ω load, and the output waveform consists of a fast rising edge followed by an exponential decay. The full-width to half-max (FWHM) time of the pulse is about 3 ns and the 10-90% rise time is about 100 ps. Figures 6 and 7 show the input pulse.

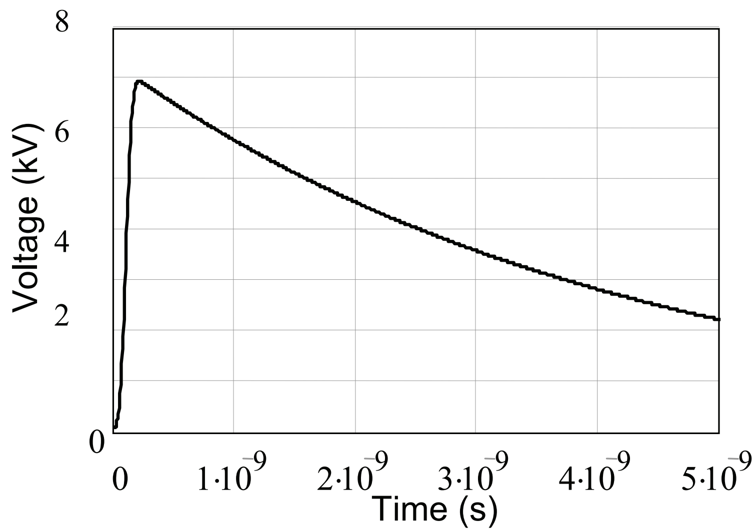


Figure 6. Analytical representation of the PBG-1 pulser waveform

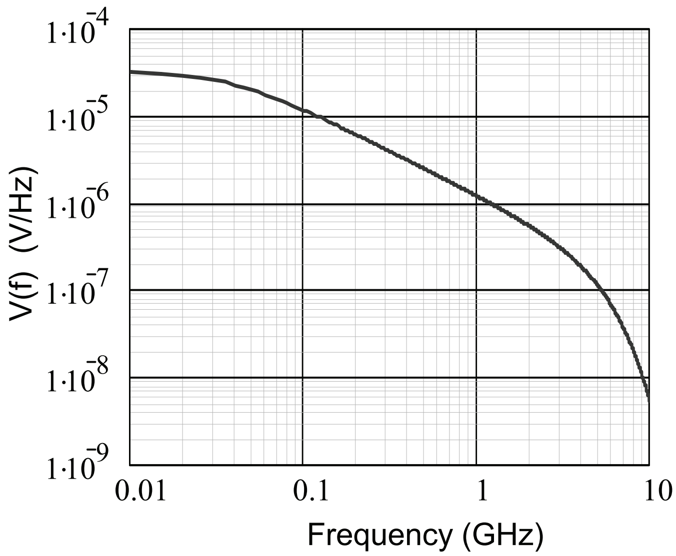


Figure 7. Plot of the spectral magnitude of the excitation voltage

The calculated fields are shown in Figure 8(a) and 8(b).

The peak electric field as a function of the range is shown in Figure 9 and the (rE/V) as a function of the range in Figure 10.

The spectral magnitudes of the transfer function $|T_{IRA}| = |rE^{rad}(f)/V_o(f)|$ for the on-axis field for different ranges from the IRA are shown in Figure 11.

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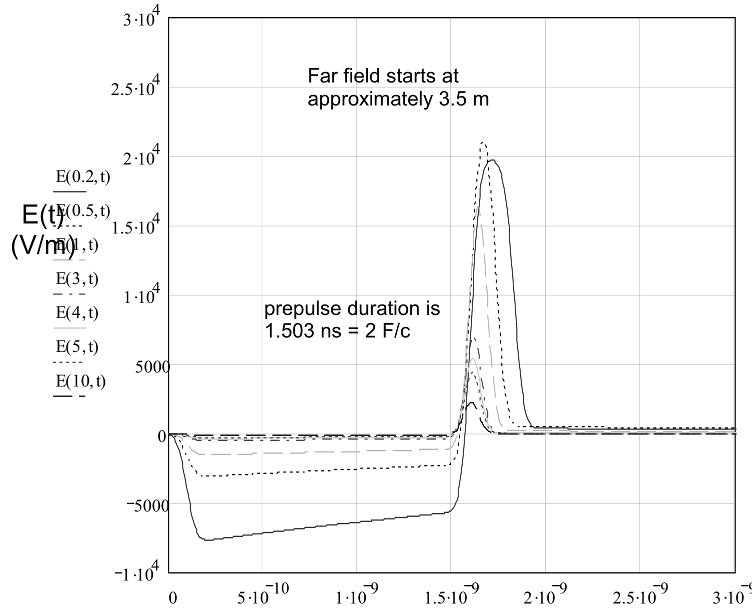
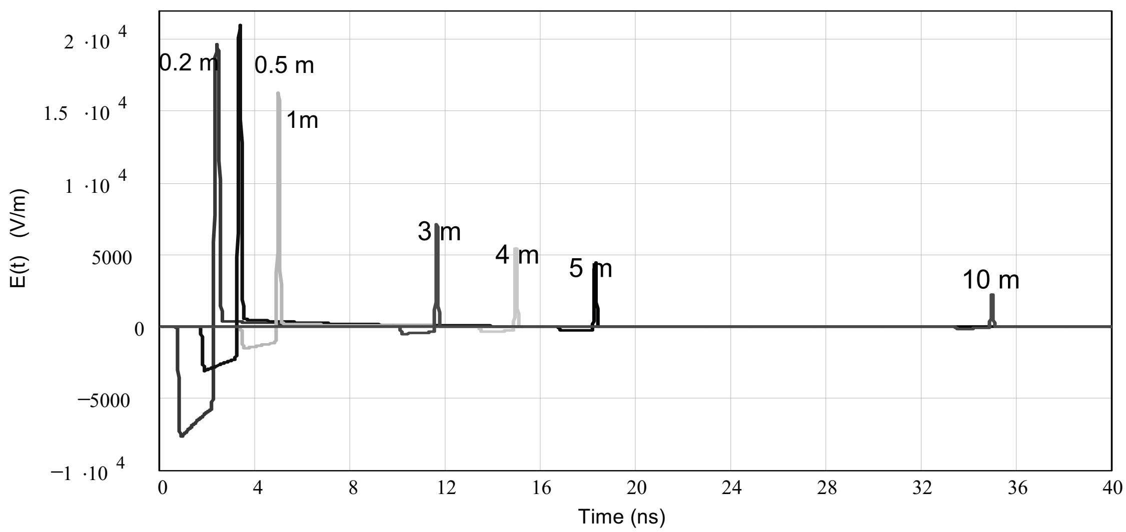


(a) Detailed E-fields as a function of retarded time



(b) Temporal boresight fields

Figure 8. Plots of the on-axis transient E-field for different ranges *r* from the antenna.

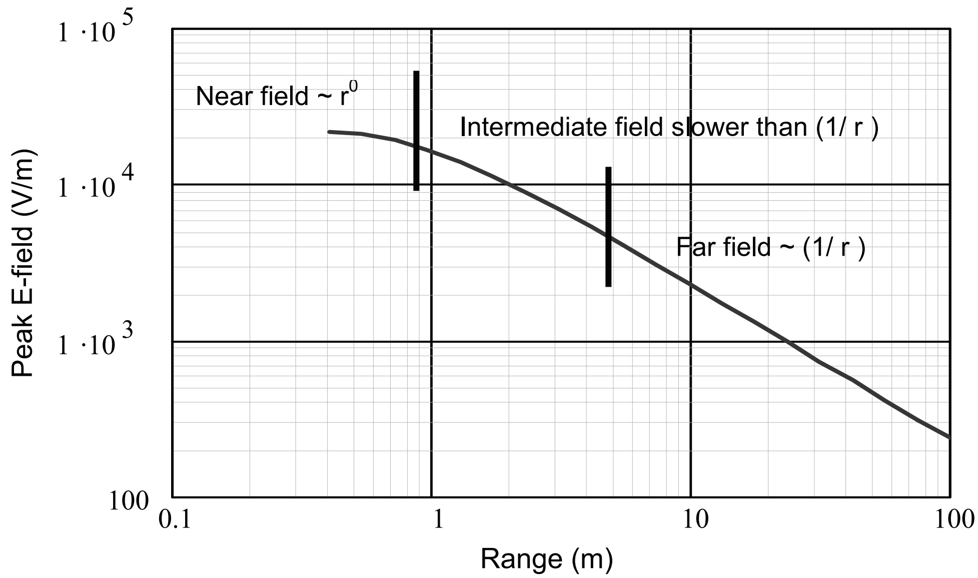


Figure 9. Plot of the peak E-field as a function of range *r* from the IRA.

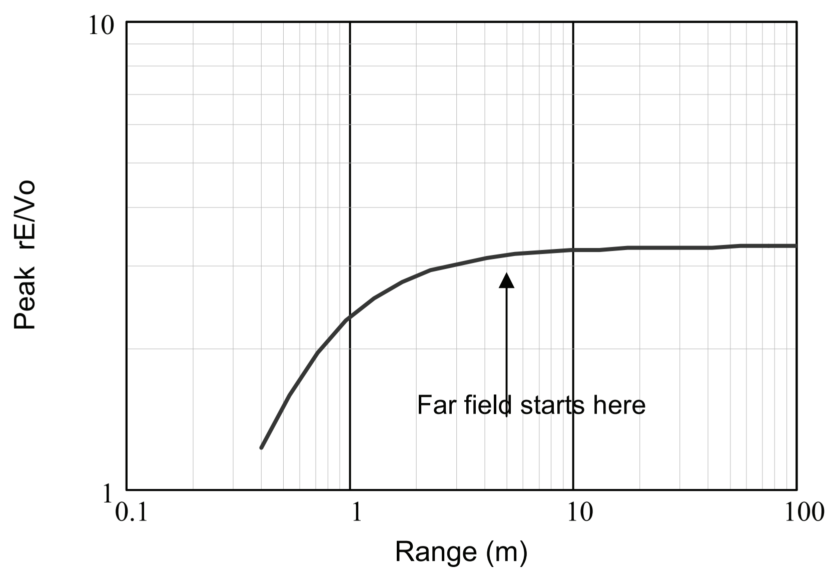


Figure 10. Plot of the peak normalized E-field rE/V_o as a function of range *r*

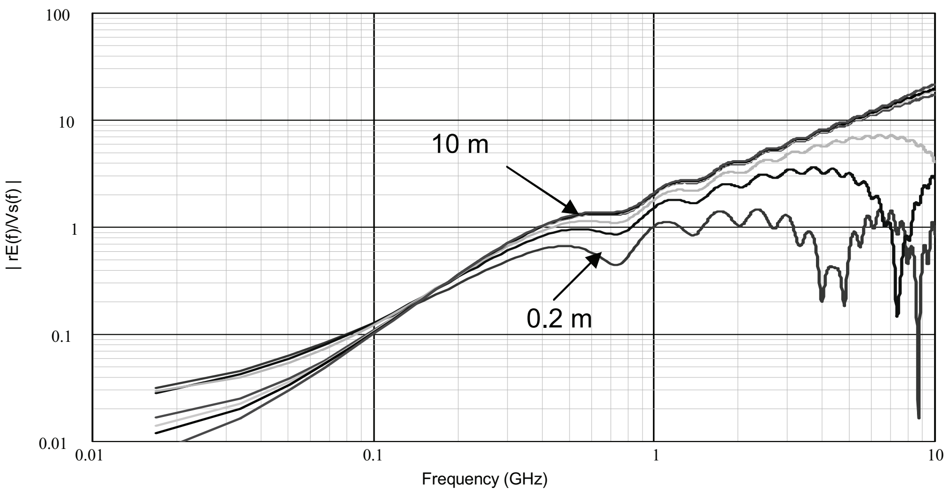


Figure 11. Plots of the transfer function magnitudes $|T_{IRA}| = |rE^{rad}(f)/V_o(f)|$ for the on-axis field for different ranges from the IRA

4. Measured Pulser Voltage and Electric Fields from the Modified IRA

The antenna drive pulse is shown in Figure 12 and the dish sensor field measurement in Figure 13.

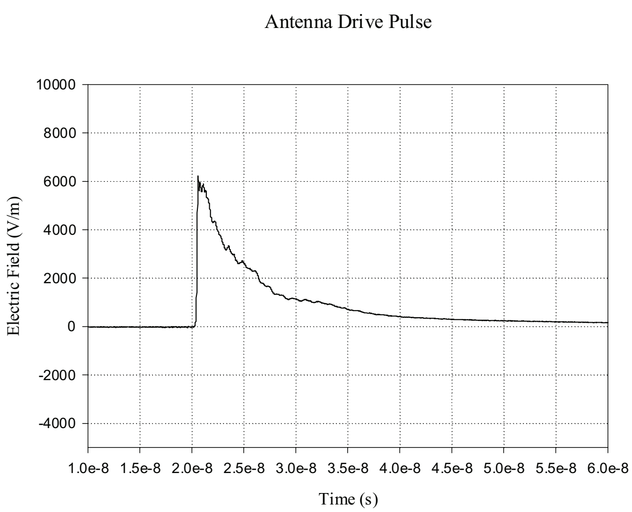


Figure 12. Measured voltage pulse into 50 Ohms (NOTE: The peak is 6 kV and not 7 kV as assumed in the theoretical calculations)

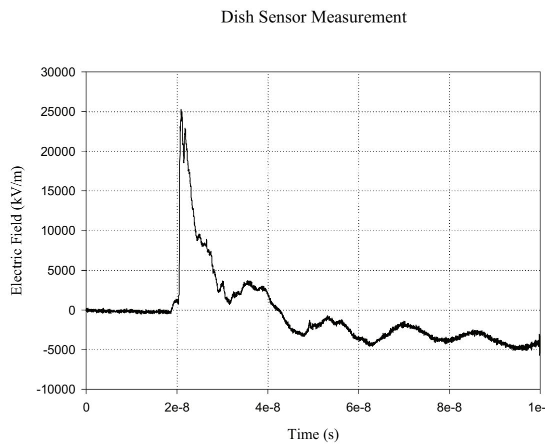


Figure 13. Dish sensor measurement which is ~ same as near field and compares well with the calculated values at ranges of 0.2 and 0.5 m in Figure 8

The measured transient electric fields at two different ranges are shown in Figure 14.

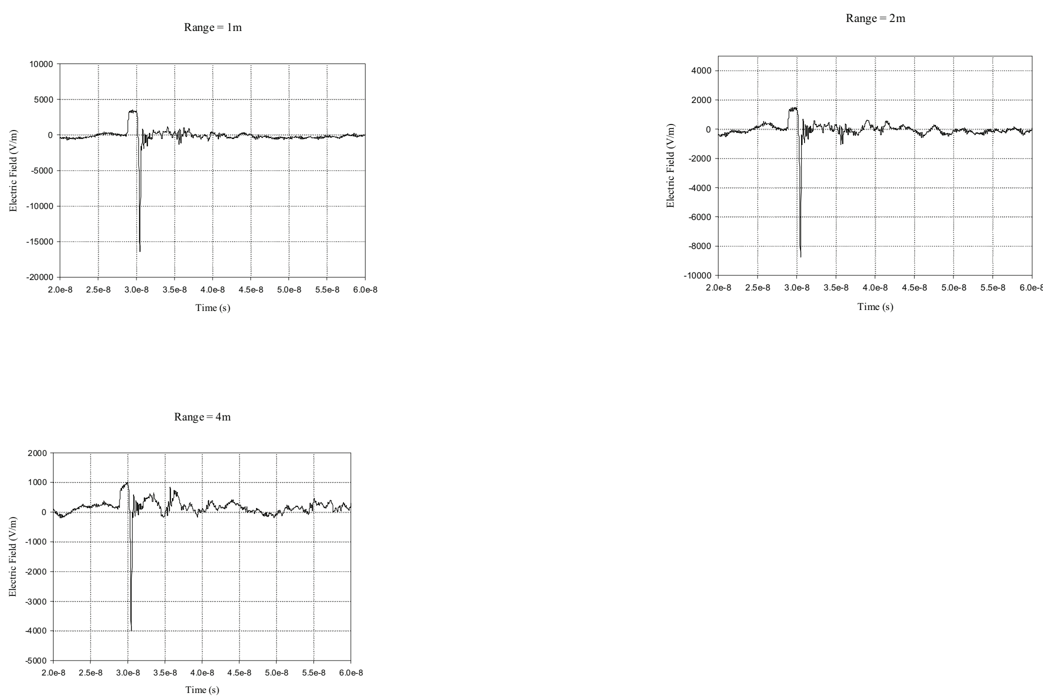


Figure 14. Measured electric field on axis at 1, 2 and 3 m.

After scaling the calculations for the 6 kV amplitude instead of the assumed 7 kV, the calculated field quantities agree well with the measured results.