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A MEASUREMENT TECHNIQUE FOR DETERMINING THE TIME-DOMAIN VOLTAGE--ETC(U)
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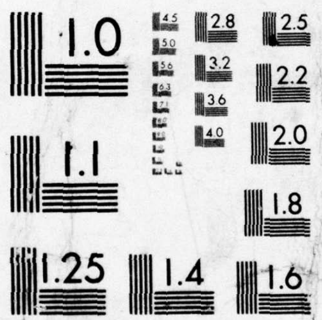

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

A laboratory time-domain measurement technique is being developed that will provide research, development, testing, and evaluation laboratories with the capability to determine quickly and economically the transient response of vhf and uhf antennas. The procedure uses a transverse electromagnetic (TEM) horn radiator to illuminate the test antenna with a short pulse of electromagnetic energy. The transient voltage generated at the

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 SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) output of the antenna by this incident field is approximately the impulse response of the antenna and can be used to obtain the approximate response of the antenna to an arbitrary incident field. In some cases, especially where the response to a nuclear EMP is desired, it may be necessary to process the data in order to compensate for the nonideal waveform that illuminates the test antenna. Analysis of the test equipment indicates that the sampling oscilloscope and x-y recorder used in the experiment provide an accurate means of obtaining data. The wide-bandwidth radiation properties and small physical size of the TEM horn antenna are well suited to laboratory measurements, and a wire model antenna could be designed for field tests.

CONTENTS

FIGURES

FIGURES (Cont'd)

1. INTRODUCTION

In recent years, considerable interest has developed in the effect of transient electromagnetic signals on communication systems. Of particular concern is the disruption or damage caused to sensitive electronic components by a transient voltage or current. Since the character of the disruption depends on the shape of the transient waveform, an important part of any failure analysis is an estimate of the voltages or currents coupled into the system from the electromagnetic signal. In uhf and vhf communication systems, the antenna provides a major coupling path into the system for a nuclear EMP. It is, therefore, important to develop methods for predicting an antenna's response to EMP transient signals.

Analytical techniques have been shown to be useful for many simple antennas, but complicated antenna structures often have anomalies that are overlooked in the analytical model. Experimental techniques utilizing simulators have been developed and used to test systems at low levels and at threat levels. These techniques provide much useful information, but the simulator facilities are usually large and expensive to build, operate and maintain. It is, therefore, advantageous to develop techniques that permit economical evaluation of an antenna's coupling to an EMP. Since communication antennas are generally linear devices, low-level testing is appropriate.

The Harry Diamond Laboratories (HDL) has recently been engaged in the development of a simple, low-cost, easily implemented technique to obtain the time-domain impulse response of uhf and vhf antennas. The objective is to provide research, development, testing and evaluation (RDT&E) laboratories with a reliable means to evaluate EMP coupling to the antennas. Throughout the program emphasis has been placed on the use of equipment normally found in or available to an RDT&E antenna facility. The results presented in section 4 demonstrate that a sampling oscilloscope and x-y recorder provide an accurate means of obtaining wide-bandwidth data on antenna transient response. Also, the transverse electromagnetic (TEM) horn is shown to be an excellent transient radiator for the laboratory tests. The TEM horn is much smaller than a biconic or dipole antenna capable of radiating a comparable bandwidth pulse.

This report describes the equipment and procedures used to test antennas. Some sources of error are identified and discussed, and an error analysis is performed on the test equipment. Experimental results demonstrating the usefulness of the technique are presented. The necessity of data processing to obtain accurate low-frequency information also is illustrated. The response of an antenna to a hypothetical EMP is computed from the measured data.

2. BASIC CONCEPTS FOR THE METHOD

It is well known that the response of a linear, time-invariant network to an arbitrary excitation can be easily calculated if the response of the network to a unit impulse is known. This concept provides the basis for the experimental method that has been developed. The quantity to be measured is the time-domain receive transfer function, $h_R(t)$, of the antenna being tested. Ideally $h_R(t)$ is the transient voltage generated at the terminated output of the antenna by the reception of a unit electric-field impulse, $E_o \delta(t)$, where E_o is 1 V/m. Although any experimentally determined $h_R(t)$ will be only an approximate impulse response, it can be used to predict the response of the antenna to an EMP if it correctly describes the antenna's response over the bandwidth where significant coupling between the antenna and the pulse occurs. The most difficult problem to be overcome in developing a laboratory measurement technique is that of obtaining accurate data for the lower frequencies (below 50 MHz) of the EMP spectrum. However, coupling of low-frequency signals to many of the communications antennas decreases significantly with decreasing frequency so that an asymptotic approximation to the low-frequency response can be employed. Then the response to an arbitrary incident pulse can be computed, and useful estimates of peak power levels and total energy can be obtained.

The response of the antenna to an illuminating field is computed by using the convolution integral

$$v(t) = \int_{-\infty}^{\infty} e(t')\, h_R(t - t')\, dt'$$

where $v(t)$ is the voltage response and $e(t)$ is the illuminating waveform. The transfer function, $h_R(t)$, is characteristic of the antenna and is, in general, dependent upon the angle of incidence.

An important, fundamental property of antennas, the time-domain reciprocity relationship, should be mentioned here since it is not well known, but is very useful in simplifying the measurement techniques being developed. The well-known and widely used reciprocity relationship for antennas states that the radiation pattern shape measured in the transmit mode is the same as that measured when the antenna is used to receive. What this relationship does not give is any information on how the magnitudes of the receive and transmit radiation patterns change as function of frequency. Through the Fourier transform, this change .ves information on the time-domain relationship.

The time-domain interpretation of the Carson-Rayleigh reciprocity theorem was given by Schmitt[1] and demonstrated qualitatively by Mayo.[2] Susman and Lamensdorf[3] demonstrated its application in their experiments on picosecond pulse antenna techniques.

It turns out that the relative magnitudes of the receive and transmit radiation patterns are related by a multiplicative factor of ω, the angular frequency of the signal. Fourier transforming to the time domain leads to a reciprocity relationship between the receive transfer function, $h_R(t)$, and the transmit transfer function, $h_T(t)$, given here in the form of a proportionality,

$$h_T(t) \propto \frac{d}{dt} h_R(t)$$

or

$$h_R(t) \propto \int_0^t h_T(t')dt'$$

By proper use of this characteristic, time-domain measurements and analysis can be made with the antenna operating in either the receive or transmit mode, and the transfer function in the other mode can be easily derived.

The measurement schemes presented here were developed specifically for assessing the EMP vulnerability of uhf communication antennas. However, the techniques are general and can be used for other types of antennas.

3. THE MEASUREMENT TECHNIQUE

3.1 Procedure and Equipment

The method selected for measuring $h_R(t)$ is depicted in figure 1 and is referred to as the TEM horn method. This method was chosen because (1) it does not require a large expensive waveguide structure (e.g., parallel plates) in which the test antenna must be placed, (2) the TEM horn radiator provides the required wide-bandwidth illumination from a relatively small antenna, and (3) the necessary equipment is readily available to an RDT&E laboratory.

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[1] *H. J. Schmitt, Transients in Cylindrical Antenna, IEE Monograph 377E (April 1960), 292.*

[2] *B. R. Mayo, Generalized Linear Radar Analysis, Microwave Journal, 4 (1961), 79.*

[3] *L. Susman and D. Lamensdorf, Picosecond Pulse Antenna Techniques, Rome Air Development Center Technical Report RADC-TR-71-64 (May 1971).*

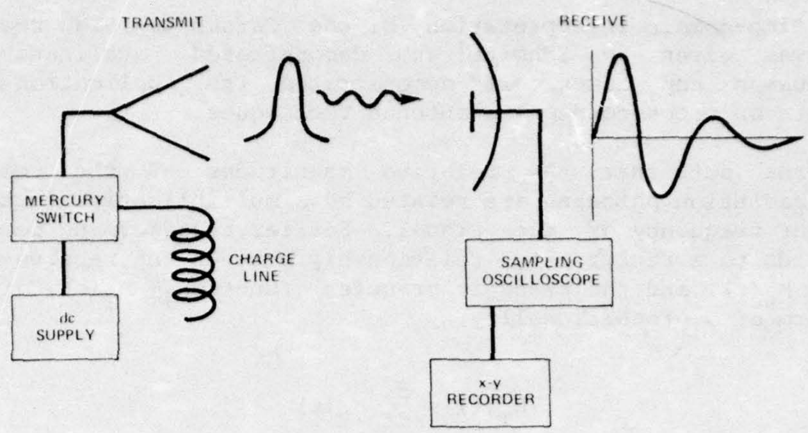

Figure 1. The TEM horn measurement method using equipment readily available to research, development, testing, and evaluation laboratories.

The measurements can be performed inside an anechoic chamber, on an outdoor antenna range or any place that is free of reflecting obstacles. (The objective here is to obtain the response of the antenna in a free-space environment. The effect of the ground or other obstacles is included in the calculations as a modification of the incident field.) The TEM horn (fig. 1) is excited by a fast rise-time pulse of duration 2L/v generated by discharging a low-loss, low-dispersion coaxial line of length L and velocity of propagation v. The discharge occurs through a mercury switch, which provides very good pulse-to-pulse reproducibility. The TEM horn radiates an electric field that is approximately the derivative of the exciting current (see sect. 3.2) so that the test antenna is illuminated by a short pulse followed by 2L/v seconds of very little incident field and then by a negative pulse. By using a sufficiently long charge line, a time window long enough to observe the antenna's complete transient response is obtained. The voltage delivered to the test antenna's load is detected by using a sampling oscilloscope and is recorded on an x-y recorder.

3.2 Characteristics of the TEM Horn

Since the TEM horn is a key element of the measurement, its characteristics will be discussed. Susman and Lamensdorf[3] have reported their results on transient antenna measurements using an unbalanced TEM

[3] *L. Susman and D. Lamensdorf, Picosecond Pulse Antenna Techniques, Rome Air Development Center Technical Report RADC-TR-71-64 (May 1971).*

horn over a ground screen. A balanced TEM horn fed from a single coaxial line has been designed and constructed (fig. 2) at HDL. This antenna has a constant 50-ohm characteristic impedance and supports only a TEM mode for the frequencies of interest in this experiment. An improved version of the balanced TEM horn employing two coaxial feed lines was designed and constructed.

The two methods of feeding the antenna are shown in figure 3. The two-coaxial-line feed provides a better balanced transition, which results in much less current flowing on the exterior of the feed lines and, therefore, less unwanted radiation and conduction coupling from them. Both methods can be readily implemented by using commercially available pulse switches, but the two-feed-line approach requires the pulse created by closing the switch to travel through transmission lines before reaching the radiator. The dispersion of these lines causes a slight broadening of the radiated pulse, which is not significant for EMP frequencies but may be for other applications. In the receive mode, the two-feed-line antenna requires a means of providing the algebraic difference of the inputs.

The radiation characteristics of the TEM horn can be qualitatively studied by considering the radiation from accelerating charges[4] at the leading edge of the exciting current step. Figure 4 depicts the situation at several instances in time. The current traveling on the antenna is depicted on the left side, and the radiated field is depicted on the right. Since the horn has a small flare angle, radiation from the bend at the feed point is small and is ignored in this analysis. The current wave traveling out the antenna radiates strongly in the forward direction. The energy radiated during the L/v seconds that the current wave is traveling toward the observer arrives in the far field during only $(1 - \cos \theta)L/v$ seconds, where θ is the angle between the conductor carrying the current and the direction of observation. After being reflected from the aperture, the current is traveling away from the observer and does not radiate as strongly in the observer's direction. Furthermore, the energy radiated during L/v seconds arrives in the far field during $(1 + \cos \theta)L/v$ seconds. Since the antenna is matched to the feed line, the returning current wave reenters the transmission line and radiation ceases. The resulting radiated waveform is a short, high-amplitude pulse followed by a long, low-level undershoot.

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[4] *M. Handlesman, Time Domain Impulse Antenna Study, Rome Air Development Center Technical Report RADC-TR-72-105 (May 1972).*

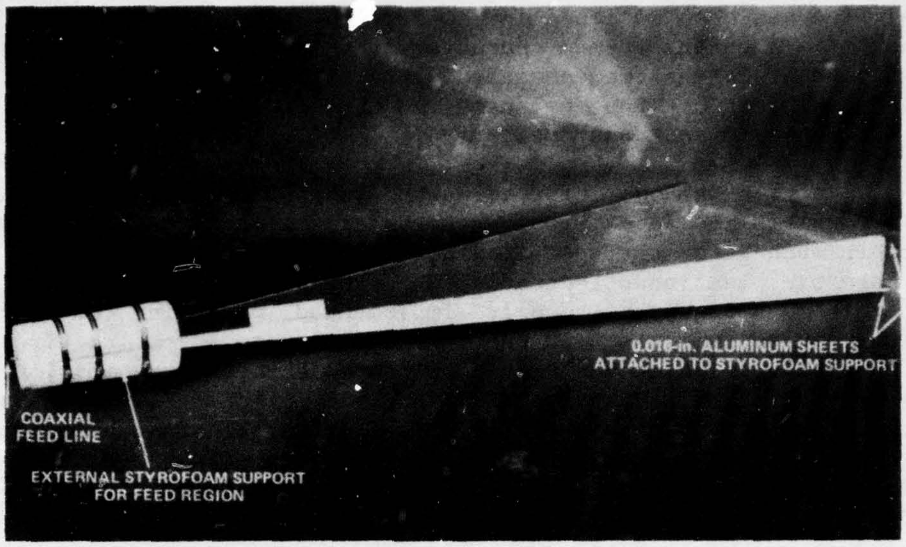

Figure 2. Two-meter-long TEM horn antenna.

The Fourier transform of the ideal waveform corresponding to a 1-m-long TEM horn is shown in figure 5 along with the spectrum of the three-impulse signal radiated by a bicone of 1-m half-length. These spectra assume that zero rise-time signals excite the antennas. The finite rise-time of the actual signals modify the high-frequency portion of the radiated waveform, as can be seen in the data of figure 6. The 0-deg waveform has the basic shape depicted in figure 4. The positive pulse is broadened and rounded because of the finite rise-time of the current step. The ripples in the undershoot are the result of ripples on the current step. Off boresight the radiation changes in a manner that can be predicted by an analysis similar to that of figure 4. The increase in amplitude of the positive pulse at 30-deg is due to improved radiation at angles further off the axis of current flow. The waveform radiated to the rear--180 deg--is approximately the mirror image of the forward waveform. However, the waveform is lower in amplitude and more spread out due to the radiation of much of the high-frequency energy in the forward direction and to some recapture of backward-traveling energy.

The TEM horn used in the tests has two drawbacks. First, the antenna feed must be well matched and balanced to prevent unwanted reflections and radiation. The two-feed-line method described above minimizes this problem. Second, the TEM horn differentiates the exciting current waveform, which means that the source must supply a step function that is high in energy content in order to radiate a short pulse that is low in energy.

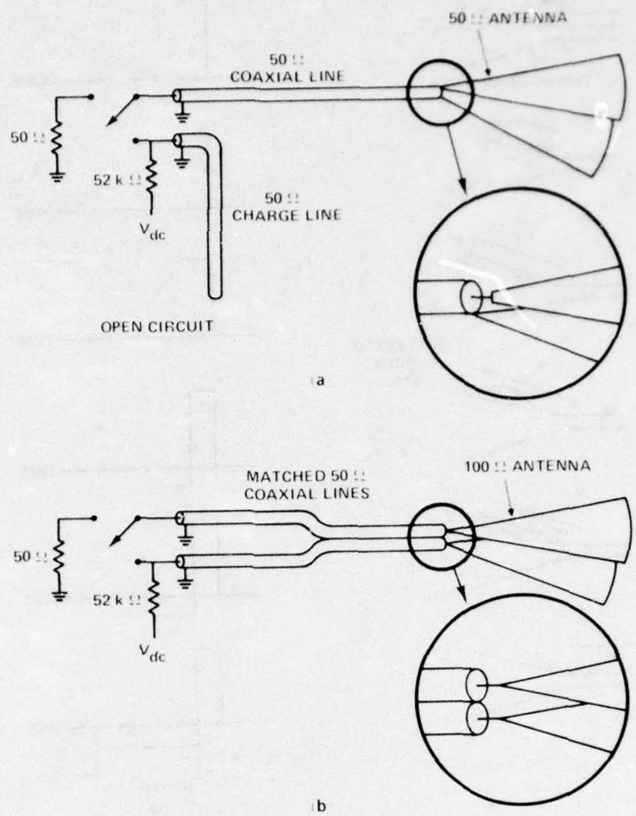

Figure 3. Two techniques for *feeding* the TEM horn radiator: (a) single-feed-line antenna and (b) two-feed-line antenna.

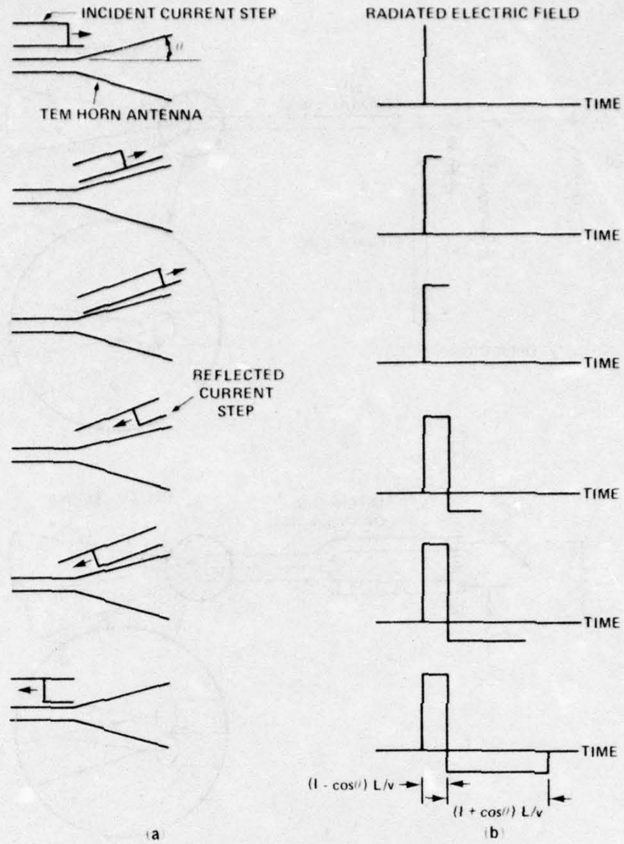

Figure 4. Radiation from a TEM horn: (a) current flowing on antenna and (b) radiated field.

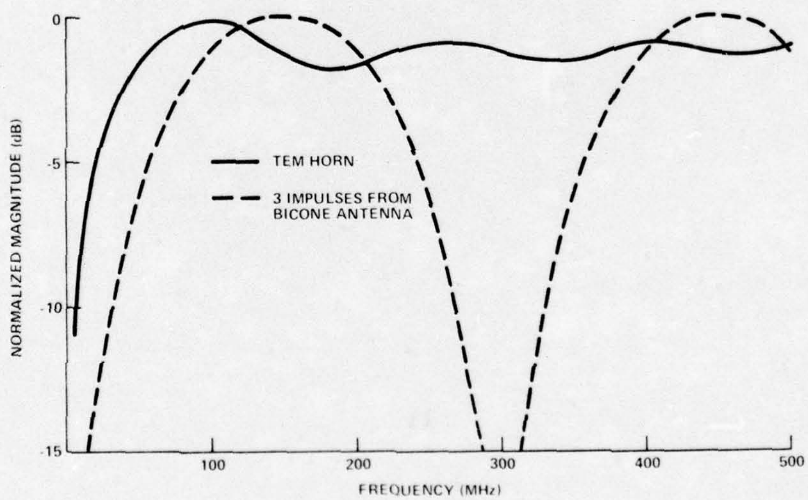

Figure 5. Normalized amplitude spectra of ideal pulses radiated by a 1-m-long, 50-ohm TEM horn and a biconic antenna of 1-m half-length.

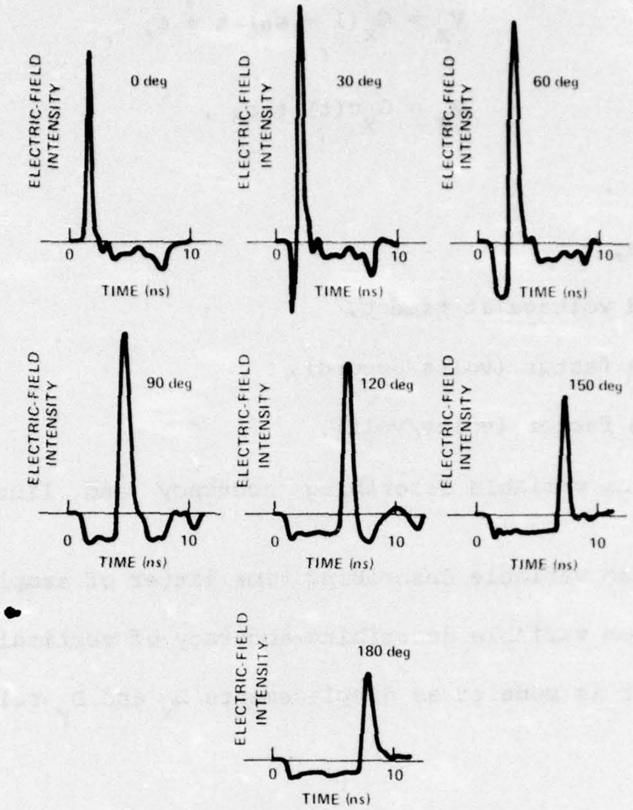

Figure 6. Actual signal radiated by TEM horn at several angles in E-plane.

3.3 Sources of Error in the Data

Data obtained by using the TEM horn method are expected to be useful for estimating peak voltages and total energy delivered to the antenna's load, but are expected also to be subject to certain errors. Some of the errors are due to the accuracy of the test equipment, and some of them are due to the constraints placed on the method by the laboratory environment. Field testing would not, however, be a panacea, because new sources of error (e.g., signal-to-noise ratio) would be introduced.

The errors introduced by the test equipment have been estimated by assuming a simple model for the system. In this model, the field illuminating the antenna under test is assumed to be identical from pulse to pulse. The oscilloscope is modeled as having two voltage outputs, V_x and V_y, given by

$$V_x = G_x(1 + \varepsilon_0)\ t + \varepsilon_1 \quad (1)$$

$$V_y = G_y v(t) + \varepsilon_3\ , \quad (2)$$

where

t = time,

$v(t)$ = load voltage at time t,

G_x = gain factor (volts/second),

G_y = gain factor (volts/volt),

ε_0 = random variable describing accuracy and linearity of time base

ε_1 = random variable describing time jitter of sampling circuit,

ε_3 = random variable describing accuracy of vertical amplifiers.

The x-y recorder is modeled as displacements D_x and D_y related to V_x and V_y by

$$D_x = g_x V_x + \varepsilon_2, \quad (3)$$

$$D_y = g_y V_y + \varepsilon_4, \quad (4)$$

where

g_x = gain factor (inches/volt),

g_y = gain factor (inches/volt),

$\varepsilon_2, \varepsilon_4$ = random variables describing accuracy of pen displacements.

Linearity errors of the recorder are not siginificant here. Using equations (1) to (4), we can express D_y as

$$D_y = g_y G_y v \left[\frac{D_x}{g_x G_x (1 + \varepsilon_0)} - \frac{\varepsilon_2}{g_x G_x (1 + \varepsilon_0)} - \frac{\varepsilon_1}{G_x (1 + \varepsilon_0)} \right]$$

$$+ g_y \varepsilon_3 + \varepsilon_4 \ . \qquad (5)$$

The random variables are assumed to be normally distributed, so the variance σ_y^2 of D_y is easily obtained[5] from equation (5).

$$\sigma_y{}^2 = \sum_{i=0}^{4} \left(\frac{\partial D_y}{\partial \varepsilon_i} \right)^2 \sigma_i{}^2 \ , \qquad (6)$$

where σ_i^2 is the variance of ε_i.

The derivatives can be evaluated from equation (5) to obtain

$$\sigma_y^2 = g_y^2 G_y^2 \left(\frac{dv}{dt} \right)^2 \left(\frac{D_x^2}{g_x^2 G_x^2} \sigma_0^2 + \frac{\sigma_1^2}{G_x^2} + \frac{\sigma_2^2}{g_x^2 G_x^2} \right)$$

$$+ g_y^2 \sigma_3^2 + \sigma_4^2 \ . \qquad (7)$$

As an example of the use of equation (7), consider the case of a 100-MHz sine wave of amplitude 0.5 V detected and recorded on equipment having the following typical characteristics:

$$G_y = 10 \text{ V/V}$$

$$G_x = 0.32 \times 10^9 \text{ V/s}$$

$$g_y = 0.5 \text{ in./V}$$

$$g_x = 0.62 \text{ in./V}$$

[5] *H. D. Young, Statistical Treatment of Experimental Data, McGraw-Hill Book Co., New York (1962), 98.*

$$\sigma_0 = 0.01$$

$$\sigma_1 = 0.016 \text{ V}$$

$$\sigma_2 = 0.014 \text{ in.}$$

$$\sigma_3 = 0.16 \text{ V}$$

$$\sigma_4 = 0.02 \text{ in.}$$

These standard deviations were obtained by using the manufacturer's specifications as the 3σ values (99-percent confidence). By using the maximum value of dv/dt, equation (7) yields

$$\sigma_y \leq 0.8 \text{ in.}$$

This maximum standard deviation should be observed only at points of maximum slope. The peak values of the recorded waveform are dominated by the accuracy of the vertical amplifiers and should be about 10 times better, i.e., $\sigma_y \approx 0.08$ in. That is, peak values should be accurate to within 2 or 3 percent.

The errors introduced by the laboratory environment and the experimental setup are of two types: (1) loss of low-frequency information due to limited physical size and (2) coupling by means of cables in the setup. The latter problem can be overcome by proper placement and connection of the test equipment. The ac power supply for the receive equipment is isolated from that for the transmit equipment by use of the filtered supply that is part of the shielded anechoic chamber. Whenever possible, horizontal polarization is used so that vertically hanging cables are orthogonal to the electric field. In general, it has been found that minimizing the scattering cross section of the test equipment results in test data that is insensitive to changes in the position of the equipment.

The low-frequency limitations of the TEM horn method are directly related to size limitations of the anechoic chamber. The anechoic chamber is used as a test environment because it is shielded to provide a very good signal-to-noise ratio and because the absorbing walls simulate a free-space environment. The shielding effectiveness of the absorbing walls is, however, dependent upon the thickness in wavelengths of the absorber, and low frequencies tend to be reflected.

The data in section 4 were obtained inside an anechoic chamber whose walls attenuate the reflected signal by more than 30 dB at 200 MHz and above. The chamber provides at least 10 dB of attenuation at 50 MHz.

A less severe limitation on the low-frequency data is imposed by the size of the TEM horn. As shown in figure 5, a 1-m-long horn can radiate a pulse with significant frequency content down to about 35 MHz. A 2-m horn extends this range down to about 17 MHz. Improving the accuracy of low-frequency information through data processing is an area that needs further investigation.

4. EXPERIMENTAL RESULTS

4.1 General

The data presented were all taken in HDL's anechoic chamber by using the TEM horn method shown in figure 1. The charge line was semirigid 50-ohm coaxial cable, and the mercury switch had a rise time of 400 ps and a pulse repetition rate of approximately 300 Hz. The sampling oscilloscope had a 350-ps rise time and was modified to provide nearly 100,000 samples of the waveform during a single sweep of the oscilloscope (1000 samples is standard for this unit). With this modification, the scan rate is slow enough to permit high-resolution recording of the data directly on an x-y recorder. The x signal comes from the sweep output of the time base, and the y signal comes from the output of the vertical amplifier. In order to minimize the length of cables carrying rf signals, the mercury switch, dc supply, charge lines and oscilloscope were all inside the anechoic chamber. The x-y recorder was placed in a shielded control room adjacent to the chamber.

4.2 A 480-MHz Antenna

The TEM horn method was used to obtain $h_R(t)$ for a 480-MHz antenna consisting of two crossed dipoles, a reflector and a phasing network (the antenna is designed for circular polarization). The time-domain transfer function of this antenna is shown in figure 7. This transfer function was obtained by dividing the load voltage measured using the TEM horn method by the area (expressed in volt-seconds/meter) of the positive pulse exciting the antenna (see fig. 8). The transfer function, $h_R(t)$, may be thought of as the effective height of the antenna per unit time, which is consistent with the dimensions of meters/second in figure 7. Since this antenna has no significant response to frequencies below 50 MHz, no correction is

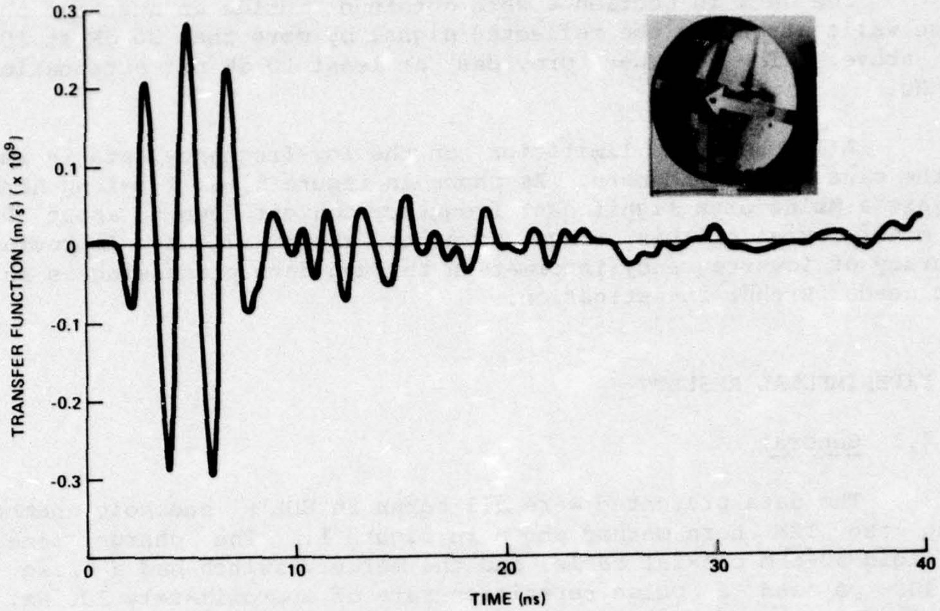

Figure 7. Measured time-domain transfer function of 480-MHz antenna obtained by using TEM horn method.

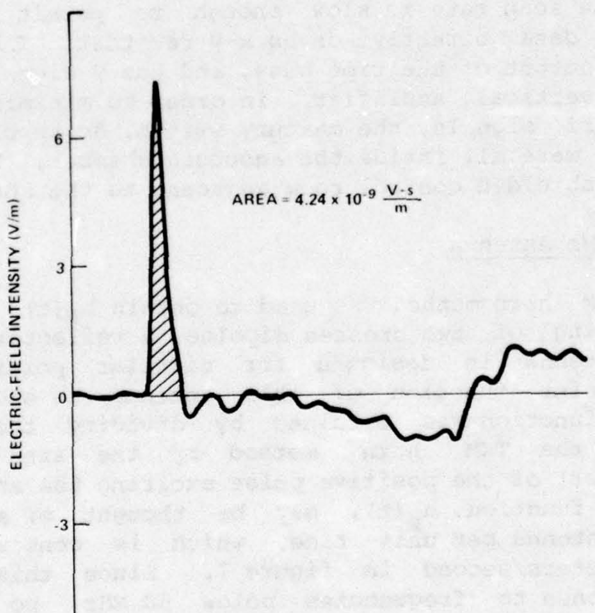

Figure 8. Waveform incident on 480-MHz test antenna.

needed to compensate for the low-frequency roll-off of the TEM horn. For some antennas, it may be necessary to process the measured data to obtain a better estimate of low-frequency coupling. Although no data are available for comparison, the transfer function of figure 7 is believed to provide estimates of induced voltage within a factor of two, which is at least as good as other techniques.

4.3 A Wire Model TEM Horn

If the TEM horn method were to be used for testing antennas that respond significantly to signals below 5 MHz, the TEM horn radiator would have to be several meters long. In that case, the tests would probably be performed out of doors and could be part of a transportable testing facility. A model of the TEM horn consisting of wires or cables stretched between dielectric supports would be much easier to transport and would encounter much less wind loading than the structure of figure 2. To test the radiation properties of a wire antenna, the model shown in figure 9 was constructed. This antenna has the same overall dimensions as the one in figure 2, and the radiated waveform (fig. 9) is basically the same as for the original antenna (fig. 8). There are two differences, both attributable to the impedance of the wire horn shown in figure 10. Because the wire horn is not matched to the feed line, approximately one-half of the incident current wave is reflected at the feed point so that the radiated signal is lower in amplitude. Also, a portion of the current wave returning from the aperture reflects from the feed point and radiates a negative pulse about 13 ns after the original pulse. Proper design of the wire model, perhaps including solid conductors near the feed, could minimize the impedance discontinuities and lead to a radiated waveform very similar to that of figure 8.

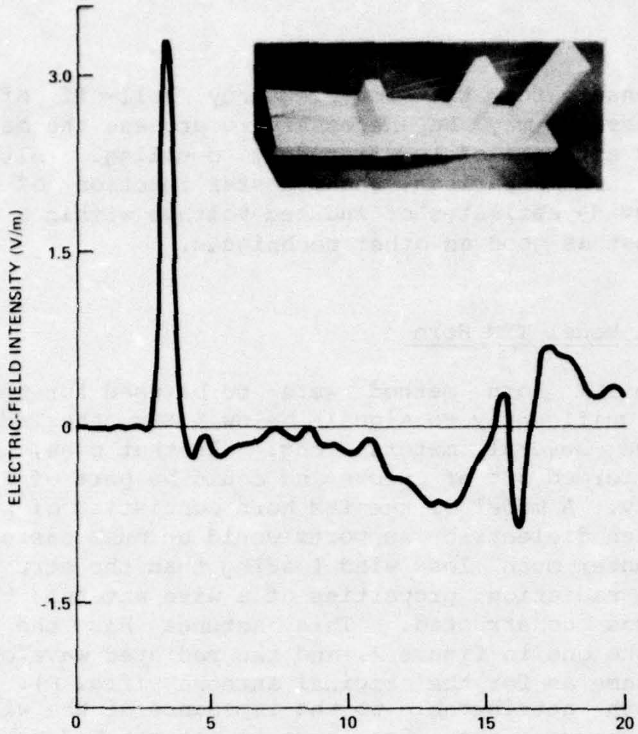

Figure 9. Electric field radiated by four-wire model of 2-m, 50-ohm TEM horn.

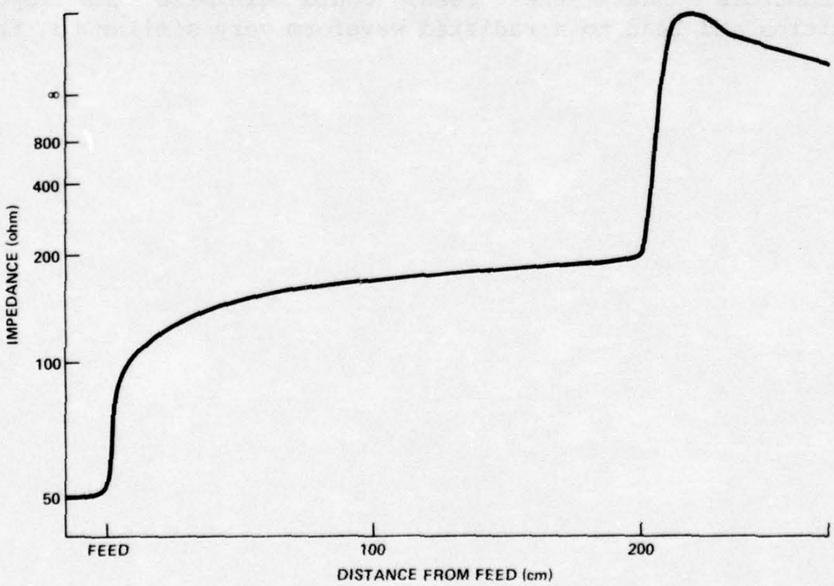

Figure 10. Impedance of 2-m wire model TEM horn measured by using time-domain reflectometer.

4.4 The AS-1852 Antenna

The Army's AS-1852/GRC, a dipole antenna with a corner reflector (fig. 11), is used with the Army's AN/TRC-145 communication van and is designed to operate from 220 to 404.5 MHz. An AS-1852 antenna has been tested without its conducting mast, and the results have been compared with measurements taken by using an EMP simulator. The transfer function of this antenna was obtained by using the TEM horn method and is shown in figure 11. This transfer function was convolved with an EMP of the form

$$E(t) = E_o\left[e^{-at} - e^{-bt} - A\left(e^{-ct} - e^{-dt}\right)\right] , \qquad (8)$$

where

E_o = amplitude factor (V/m),

$a = 0.15 \times 10^7\ s^{-1}$,

$b = 0.26 \times 10^9\ s^{-1}$,

$c = 0.20 \times 10^6\ s^{-1}$,

$d = 0.50 \times 10^6\ s^{-1}$,

$A = 0.22$.

The result in figure 12 was obtained. The response attains a peak of 3 V, but it has a very strong response at about 90 MHz. This low-frequency response showed up again when $h_R(t)$ was convolved with an analytical estimate of the pulse radiated from an EMP simulator (fig. 13). This result is shown in figure 14.

The spectrum of $h_R(t)$ shown in figure 15 has a significant peak in the vicinity of 90 MHz. This peak is caused by a secondary excitation of the AS-1852 antenna by the pulse reflected from the anechoic chamber walls. The reflection greatly enhances the 90-MHz portion of the incident spectrum (fig. 16). Therefore, the 90-MHz response of the AS-1852 antenna is the result of the incident field and not characteristic of the antenna.

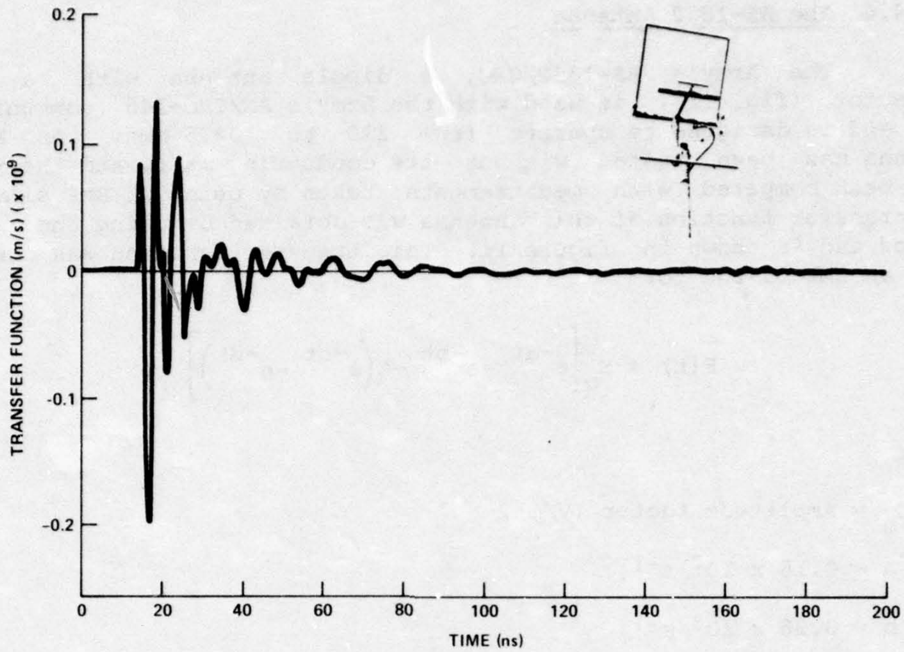

Figure 11. Measured boresight impulse response of AS-1852 antenna.

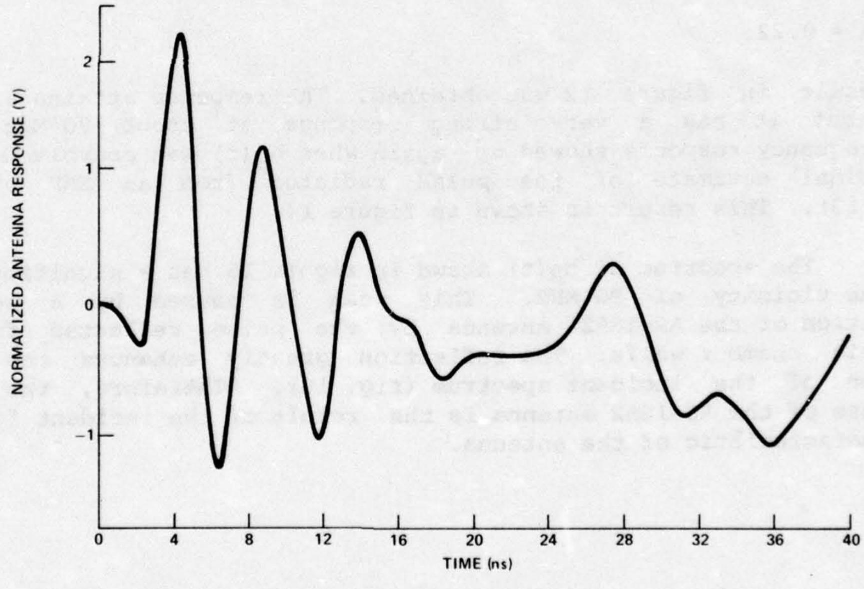

Figure 12. Normalized response of AS-1852 antenna to EMP incident from boresight direction computed by using $h_R(t)$ in figure 11.

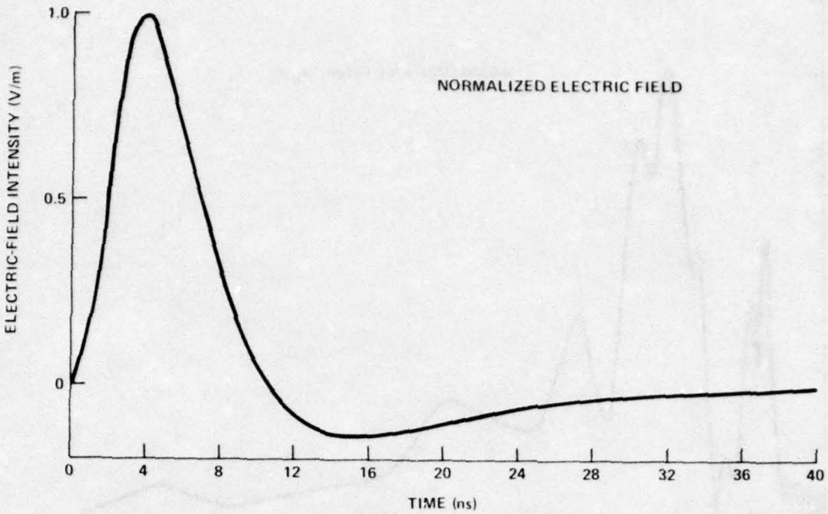

Figure 13. Idealized waveform of pulse incident from EMP simulator.

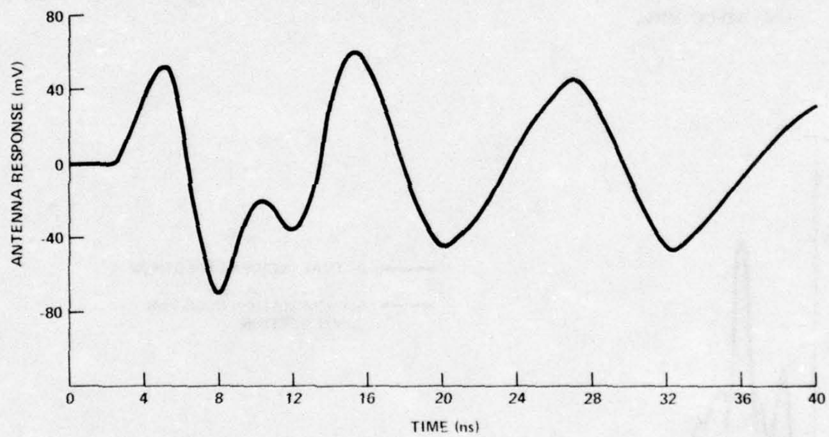

Figure 14. Computed response of AS-1852 antenna to pulse of figure 13.

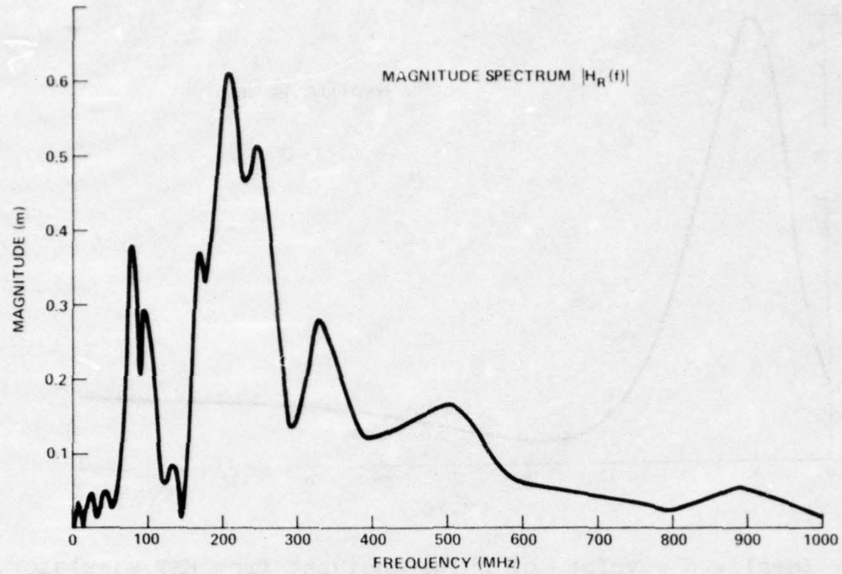

Figure 15. Amplitude spectrum of $h_R(t)$ in figure 11; dimensions (meters) of $H_R(f)$ indicate that this is effective height of antenna.

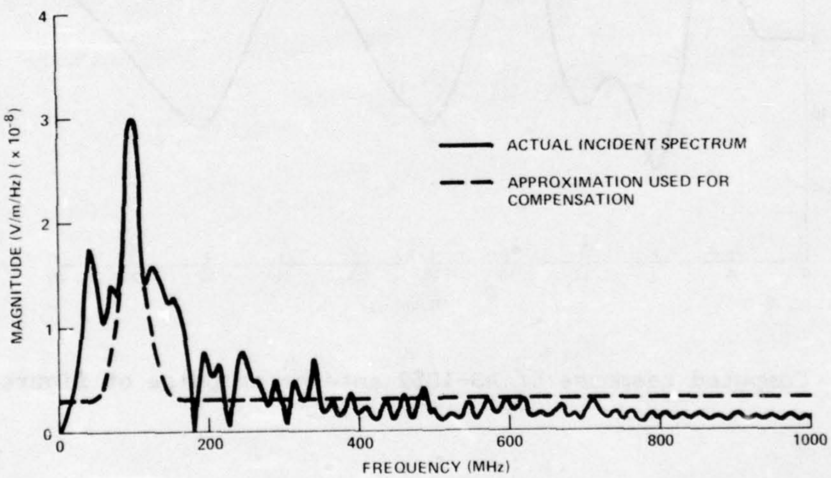

Figure 16. Magnitude spectrum of electric field that illuminated AS-1852 antenna to produce response of figure 11.

A simple correction was applied to the spectrum of $h_R(t)$ to compensate for the spectrum of the incident field. The spectrum $H_R(f)$ was divided by a spectrum (fig. 16) that approximated the incident spectrum and accounted for the major peak at 100 MHz. The resulting spectrum corresponds to the transfer function shown in figure 17, which is not significantly different in appearance from the original $h_R(t)$. However, when convolved with the simulator pulse waveform (fig. 18), the modified transfer function gives a waveform very similar to that measured by Werner J. Stark (HDL, unpublished) and shown in figure 19. The amplitude discrepancy is probably due in part to uncertainties in the pulse shape and amplitude during Stark's experiment.

The response of the AS-1852 antenna to the EMP was computed by using the modified transfer function and is shown in figure 20.

This experiment indicates a need to process the measured data in order to compensate for the nonideal pulse that illuminates the antenna.

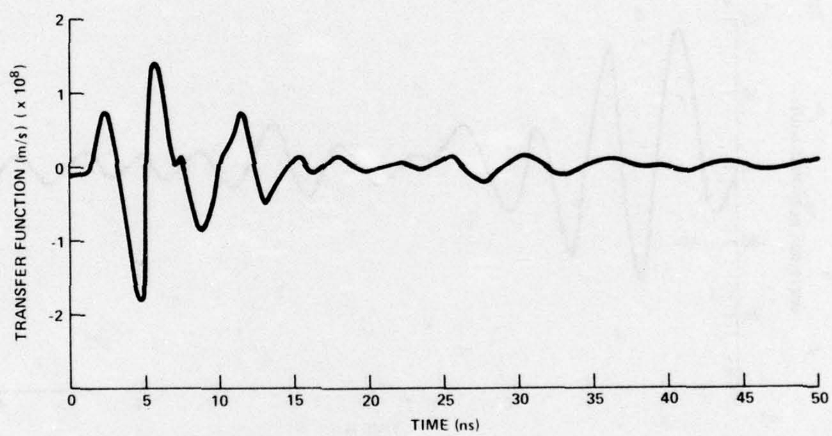

Figure 17. Impulse response of AS-1852 antenna obtained after modifying measured data to account for large low-frequency content in incident field.

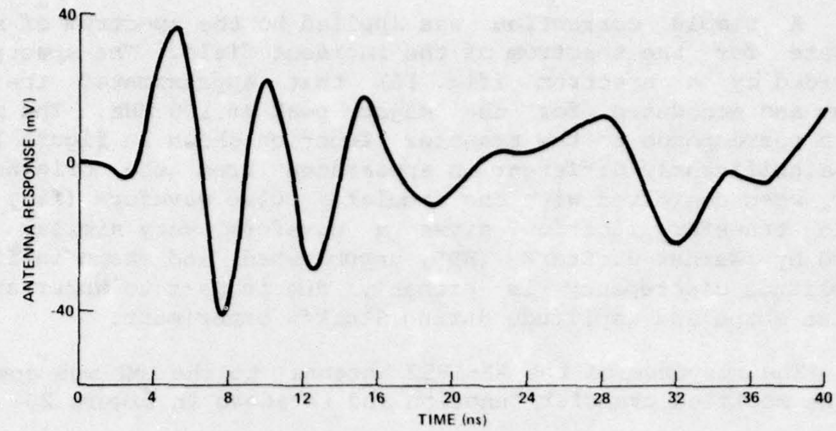

Figure 18. Response of AS-1852 antenna to EMP simulator pulse computed by using corrected $h_R(t)$ of figure 17.

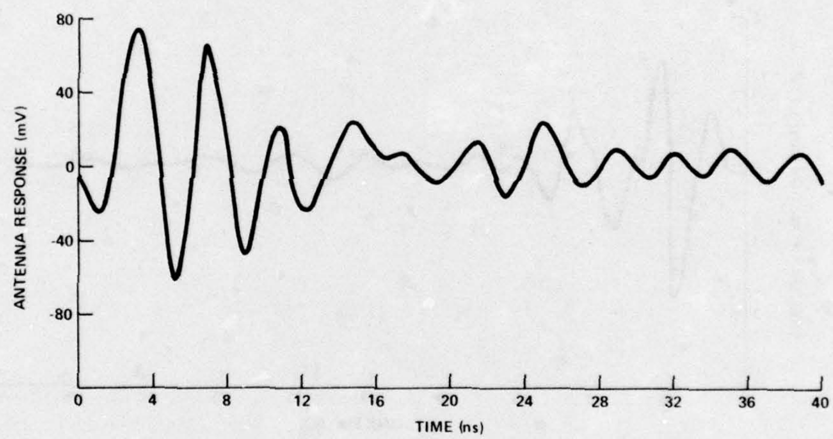

Figure 19. Measured data of the AS-1852 antenna response to actual simulator pulse (Werner J. Stark, HDL, unpublished).

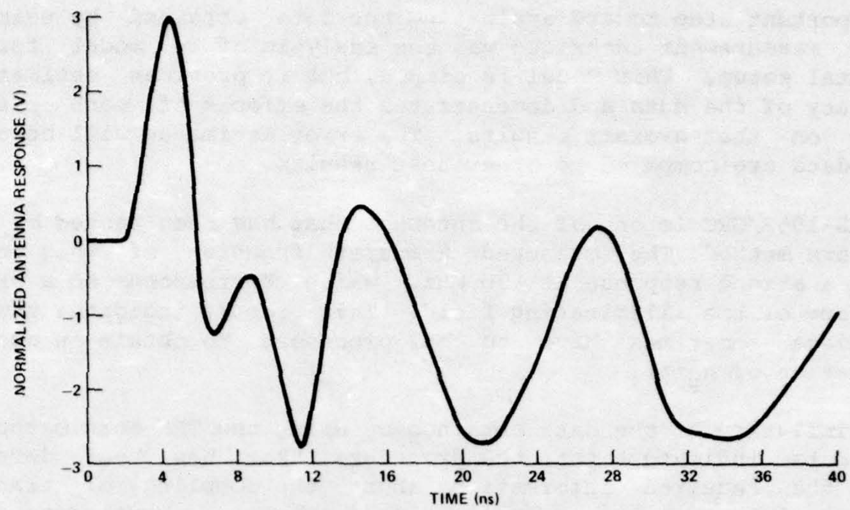

Figure 20. Normalized response of AS-1852 antenna to EMP computed by using corrected $h_R(t)$ of figure 17.

5. CONCLUSIONS

The objective of this project was to develop a time-domain laboratory measurement technique that can be readily implemented by RDT&E laboratories to obtain EMP susceptibility information on communication antennas. Several techniques were considered. However, the TEM horn method was selected as the most promising based on ease of implementation, compactness of equipment and ability to provide the necessary information. Considerable effort has gone into developing the test procedure in a way that makes it easy for laboratory personnel not thoroughly familar with time-domain measurements to perform the tests and obtain meaningful data.

Two important results related to the TEM horn antenna were obtained. First, a four-wire model of the 2-m horn was constructed and shown to radiate a pulse very similar to that radiated by the horn constructed from solid sheets. This means that good TEM horn radiators can be built that are easily disassembled for transporting and that have little wind loading in a field-test environment. Second, a TEM horn with a balanced, two-coaxial-line feed has been developed. This antenna has the advantage that the antenna currents flow only onto the inner conductors of the feed lines so that unwanted coupling from these cables is minimized.

An important step toward evaluating the data obtained by using the TEM horn measurement technique was the analysis of a model for the experimental setup. This model is simple, but it provides estimates of the accuracy of the data and demonstrates the effects of each piece of equipment on the overall results. The error estimates will be useful when the data are compared to other test results.

The AS-1852/GRC is one of the antennas that has been tested by using the TEM horn method. The measured transfer function of this antenna contained a strong response at 90 MHz, which corresponds to a peak in the spectrum of the illuminating field. This result indicates that the measured data sometimes have to be processed to obtain an accurate representation of $h_R(t)$.

The similarity of the data obtained by using the TEM horn method and Stark's data indicates that the procedure that has been developed provides the required information about the coupling of transient electromagnetic energy to communication antennas. Furthermore, the accuracy of the data (after proper processing) should be at least as good as that obtained from large-simulator experiments.

The method is not intended to supplant simulator test facilities that can illuminate very large areas with threat-level or low-level fields. The method will, however, provide any RDT&E laboratory with the capability to assess the out-of-band and transient behavior of a large class of antennas.

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