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MEASUREMENT OF SCALED-DOWN HIGH-ALTITUDE ELECTROMAGNETIC PULSE --ETC(U)
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Measurement of Scaled-Down High-Altitude Electromagnetic Pulse (HEMP) Waveforms

by Andrew A. Duneo, Jr.
James J. Loftus

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If one desires to scale down a high-altitude electromagnetic pulse waveform to illuminate and measure the response of a physically scaled version of an Army tactical system, he is confronted with the problems of how to measure the radiated pulse, what the limitations of existing field sensors are, and what new sensors are required. This report discusses the techniques used by the Harry Diamond Laboratories to adequately describe the early time of the radiated fields in the scale modeling facility.

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FIGURES (Cont'd)

TABLE

1. INTRODUCTION

If one desires to scale down a high-altitude electromagnetic pulse (HEMP) waveform to illuminate and measure the response of a physically scaled version of an Army tactical system, he is confronted with the problem of how to measure the radiated pulse. What are the limitations of existing field sensors? What new sensors are required? While this report is not intended by any means to exhaustively discuss these questions, it discusses specific ongoing work in this area by the Harry Diamond Laboratories (HDL).

2. FABRICATION AND CALIBRATION OF D-DOT SENSOR FOR MEASURING EARLY TIME PORTION OF SCALED-DOWN HEMP

2.1 Background

Electromagnetic scale modeling of Army systems for experimentally determining external coupling features requires the generation and the measurement of extremely fast rising radiated pulses. Considerable effort in the area of pulser design and fabrication has resulted in radiated pulses with fast rise times of about 200 ps. Existing field sensors at this facility were inadequate to accurately reproduce rise times that fast. (Rise times in this report are measured from the 10- to 90-percent level unless otherwise noted.) Consequently, an effort was initiated to design and evaluate such a sensor.

Previous attempts at developing an electric field sensor resulted in a sensor of generally poor response. Subsequently, the theory of Baum[1] was used as the conceptual basis for fabricating and testing a differential D-dot sensor for this application.

2.2 Theoretical Basis for Scale Modeling

Sinclair[2] has shown that when air in the full scale system is simulated with air in the model, the following relationships are established for all media being modeled (primed macroscopic properties refer to the model media and the unprimed properties refer to the full-scale system):

$$\mu' = \mu \text{ (permeability)},$$

---

[1] *C. E. Baum, An Equivalent-Charge Method for Defining Geometries of Dipole Antennas, Air Force Weapons Laboratory, Albuquerque, NM, Electromagnetic Pulse Sensor and Simulation Note 72 (24 January 1969).*

[2] *G. Sinclair, Theory of Models of Electromagnetic Systems, Proc. IRE (November 1948), 1364-1370.*

$$\epsilon' = \epsilon \text{ (permittivity)},$$

$$\sigma' = p\sigma \text{ (conductivity)},$$

$$p = \gamma,$$

where

p = mechanical scale factor,

γ = scale factor for time.

Using these results, one sees that for $p = 100$ (that is, the model is 1/100 the size of the full scale system), the scale factor for time, γ, equals 100. This dictates a simulated electromagnetic field that has a rise time approaching 100 ps. This represents a considerable challenge in both the generation and the measurement of such rise times.

2.3 Experimental Approach

The Harry Diamond Laboratories has traditionally used time-domain sampling techniques to observe the response of scaled-down Army systems[3-5] to simulated EMP radiation. The recording instrumentation has been updated to consist of a digital processing oscilloscope controlled by a minicomputer (Tektronix WP1221 Signal Processing System). The computer's ability to signal average probe and sensor responses greatly enhances the signal-to-noise ratio of the recorded waveforms. Of significant importance is the computer's capability for mathematical manipulation of the collected waveforms. This capability includes fast Fourier transforms (FFT's), inverse fast Fourier transforms (IFFT's), and integration, as well as other processes.

An in-house effort was initiated to fabricate and characterize an electric (E-) field sensor to meet our requirements. A miniature conical monopole (CM) antenna with dimensions as shown in figure 1(a) was fed through a ground plane to the center conductor of a section of 50-Ω semirigid cable, so that it became a monopole above ground (fig. 2).

---

[3] *Andrew A. Cuneo, Jr., and James J. Loftus, Scale Modeling for the Perimeter Acquisition Radar (PAR) EMP Test, Harry Diamond Laboratories HDL-TR-1761 (September 1976).*

[4] *Andrew A. Cuneo, Jr., James J. Loftus, and Robert A. Dyckson, EMP Scale-Model Testing of an Army Brigade Signal Center, Harry Diamond Laboratories HDL-TM-77-29 (December 1977).*

[5] *Andrew A. Cuneo, Jr., and James J. Loftus, Scale Modeling for the PATRIOT Electromagnetic Pulse Test, Harry Diamond Laboratories, HDL-TM-81-16 (May 1981).*

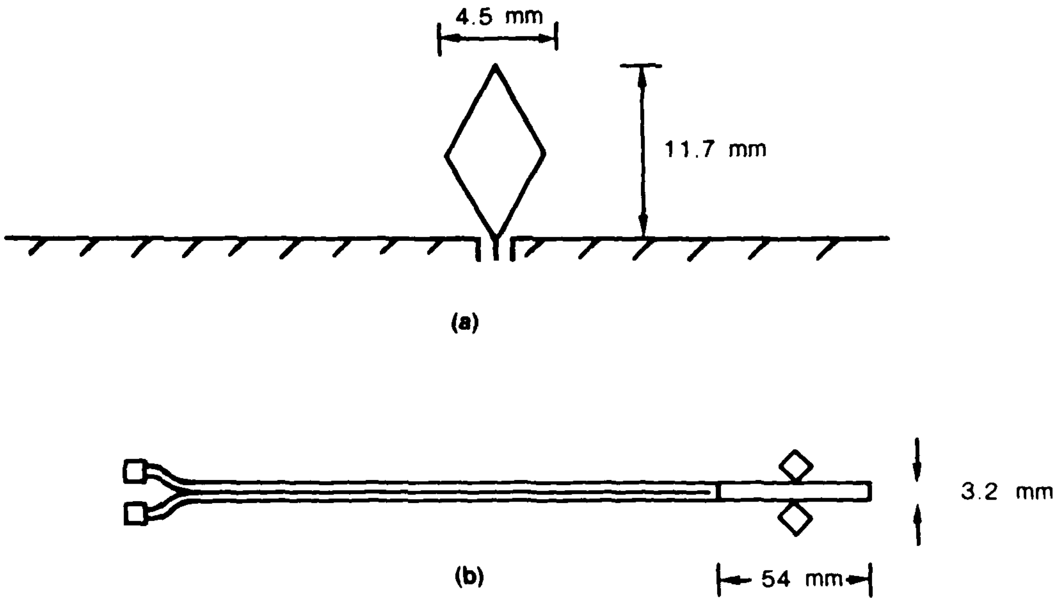

Figure 1. Test probe: (a) conical monopole and (b) conical dipole sensors.

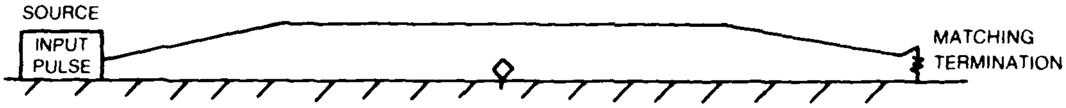

Figure 2. Conical monopole sensor mounted in ground plane of transmission line.

The transmission line was driven by a fast-rising step function generator (rise time $\lesssim$250 ps), and the output of the monopole was recorded via the digital processing oscilloscope. The E-field within the transmission line, assuming a transverse electromagnetic (TEM) mode, can be computed by using the formula $E = V/h$, where V is the voltage between the plates and h is the plate spacing.

It was reasoned that the calibration factor for a CM would be twice that for a conical dipole (CD) (fig. 1b) having identical monopole element dimensions. This difference is because the two theoretically identical outputs of a CD are added with a polarity reversal of one side to account for the opposite polarity of the two sides. The total output of the CD, the sum of the outputs for sides one and two, is then twice that for the CM when the CD and the CM are immersed in a field of the same intensity. The CD is called a balanced sensor and is used to cancel out the common-mode ambient noise induced on the radio frequency (rf) semirigid coaxial cables attached to both sides of the sensor.

The results of this effort yielded a calibration factor for the CM of 8.3×10^{12} V/m/V•s. The field is in volts per meter and the computer integrated output yields the units of volt•second. It was intended that this sensor would be used to measure only the peak field strength.

A CD was fabricated by forming, in effect, two transmission line monopoles back to back on a small circular ground plane (fig. 1b). This yielded a dipole. This dipole was exposed to the horizontally polarized free field radiation of a scale-model radiating source (fig. 3, 4) with its axis oriented for maximum response. It was located

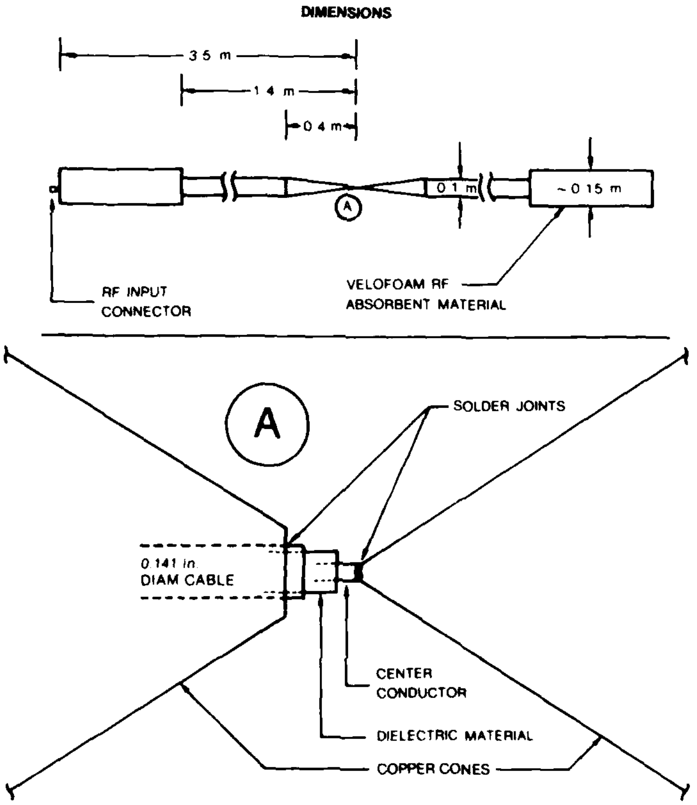

Figure 3. Loaded dipole antenna.

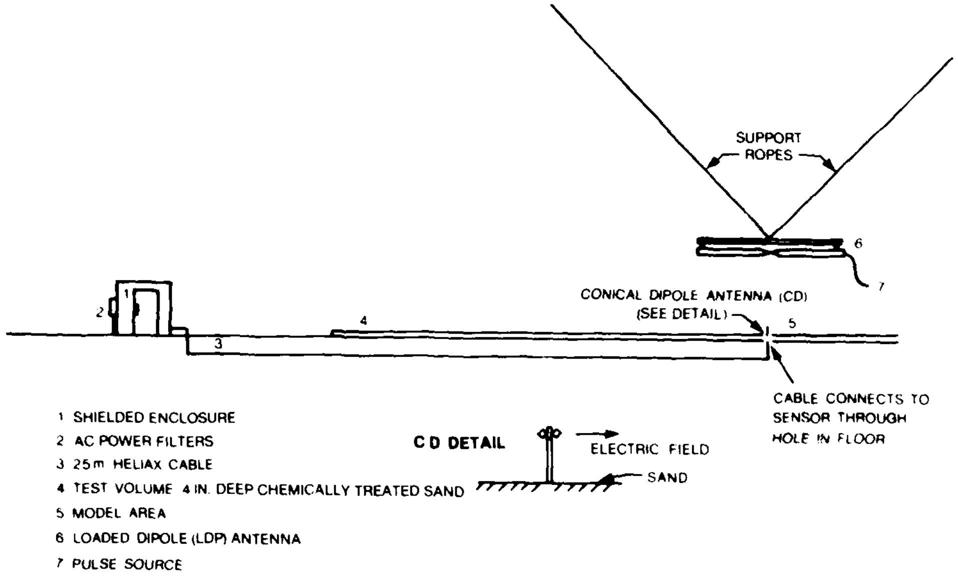

Figure 4. Test volume and instrumentation enclosure.

high enough aboveground so that the peak amplitude of the pulse could be observed before the ground reflected wave interfered with the incident wave. While the response of one side of the CD was sampled and stored on a magnetic disc, the other side was terminated in 50 Ω. This procedure was then reversed, with care taken so as not to disturb the physical positioning of the CD relative to the radiation source or the oscilloscope trigger signal antenna. It was then a simple matter in the computer to reverse the polarity of the waveform representing the response of one side of the CD and add it to the other. In this way, the common-mode rejection characteristic of the balanced sensor was maintained. The resultant integrated output is shown in figure 5.

At this point, a program was written to compensate for the high-frequency loss of the coupling cable and the delay line (app A). The resultant waveform (fig. 6) is more than twice the amplitude of the waveform in figure 5 because of the 6-dB loss of the sampling system delay line in addition to the cable loss. Comparing waveforms before and after the high-frequency loss compensation shows that the rise time improved by 46 ps (~8 percent).

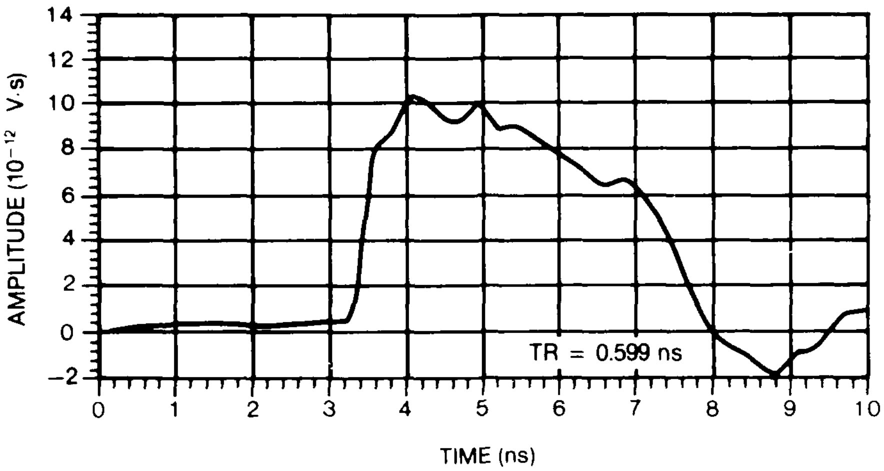

Figure 5. Integrated output of conical dipole sensor.

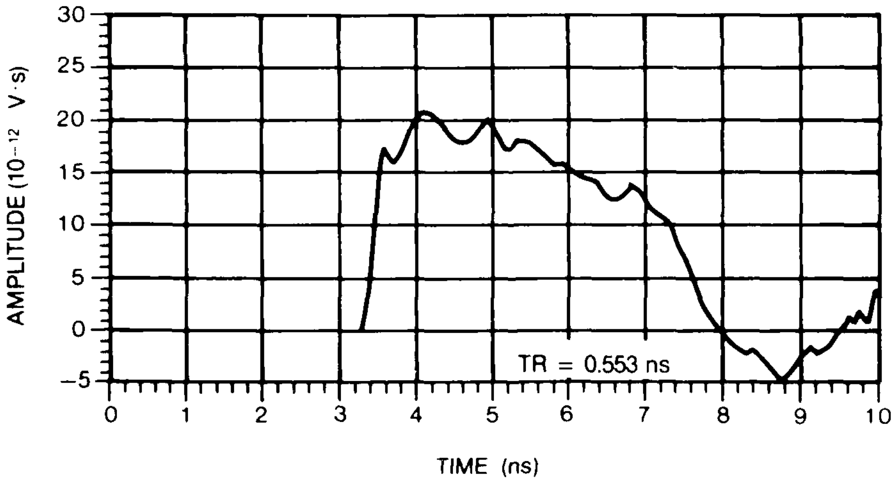

Figure 6. Integrated output of conical dipole sensor with compensation for cable and delay line loss; computer calculated rise time using 10- to 90-percent amplitudes.

2.4 Results

The rise time of figure 6 (~553 ps) was calculated by the computer using the 10- to 90-percent amplitudes of the leading edge. Figure 7 shows the result of instructing the computer to calculate the rise time using the 10- to 80-percent leading edge amplitudes. This yields a rise time of approximately 206 ps. This value scaled up by a factor of 50 would represent a real world HEMP rise time of 10 ns. This value is believed to be a more accurate estimate of the rise time of the field. To demonstrate this accuracy, the D-dot response peak amplitude was normalized to a value of 1 (fig. 8) and transformed into the frequency domain (fig. 9). Next, the original time-domain waveform was manipulated by the computer so that it rose directly to a value of 1 (fig. 10). This waveform was then transformed into the frequency domain (fig. 11). A comparison of the amplitude changes in the frequency domain shows very little, if any, increase in the higher frequencies.

There is reason to believe that the radiated field may be rising even faster than these measurements indicate. Currently, other CD sensors are being fabricated to investigate the possibility.

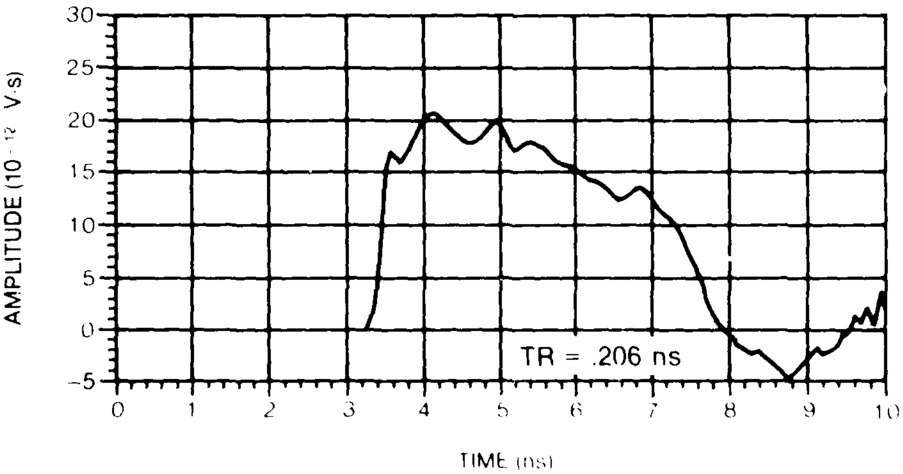

Figure 7. Integrated output of conical dipole sensor with compensation for cable and delay line loss; computer calculated rise time using 10- to 80-percent amplitudes.

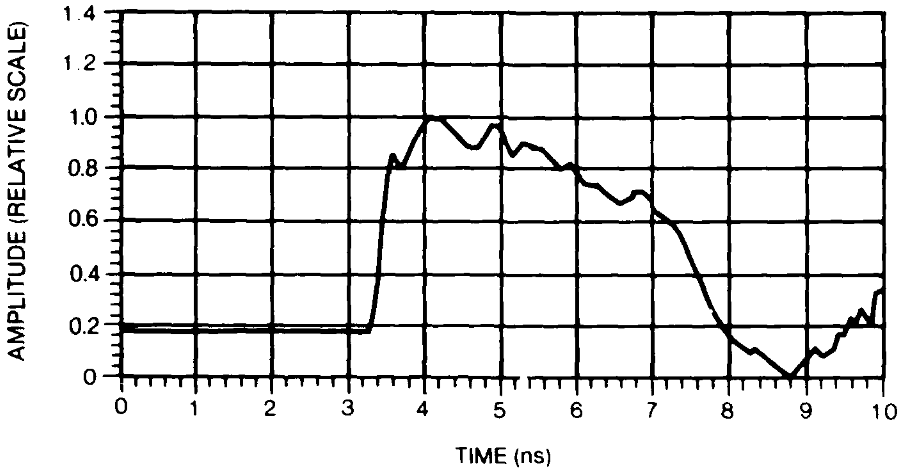

Figure 8. Integrated output of conical dipole sensor with compensation for cable and delay line loss; peak amplitude normalized to 1.

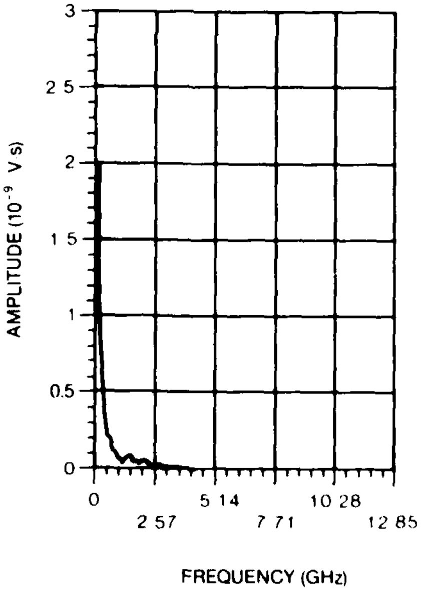

Figure 9. Fast Fourier transform of output shown in figure 8.

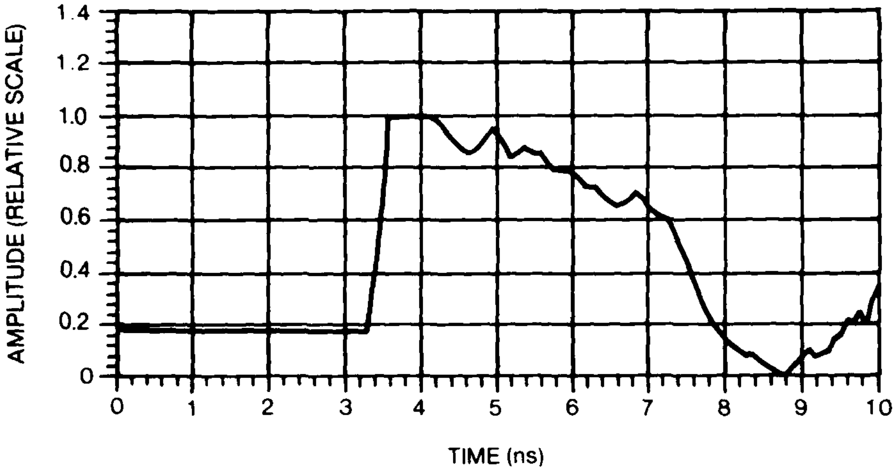

Figure 10. Waveform of figure 8 changed to rise directly to value of 1.

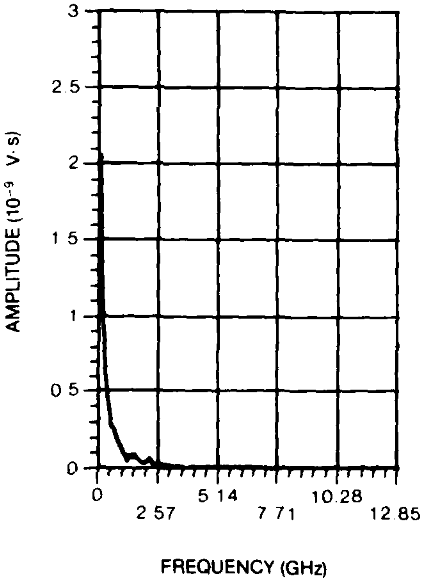

Figure 11. Fast Fourier transform of output shown in figure 10.

The CD waveform peak amplitude (fig. 7) was next multiplied by

$$\frac{\text{calibration factor of CM}}{2} = \frac{8.3 \times 10^{12}\ \text{V/m/V}\cdot\text{s}}{2}$$

$$= 4.15 \times 10^{12}\ \text{V/m/V}\cdot\text{s} \quad .$$

The result shows a peak value of 87 V/m at a radial distance of 3.1 m from the source.

The peak E-field generated for this experiment was calculated by measuring the incident and reflected voltages (fig. 12) associated with the model radiator. From this information, one computes the voltage driving the bicone. Using the following formula,[6] one calculates the peak radiated E-field:

$$E_{pk}^{inc} = \frac{60V_o}{rZ_k} \quad ,$$

where

inc = incident,

pk = peak,

V_o = driving voltage,

r = radial distance,

Z_k = bicone impedance,

so that

$$E_{pk}^{inc} = \frac{60(1461\ \text{V})}{(3.1\ \text{m})(300\ \Omega)}$$

$$= 94\ \text{V/m} \quad .$$

The CD measured value of 87 V/m is within 8 percent of the calculated value.

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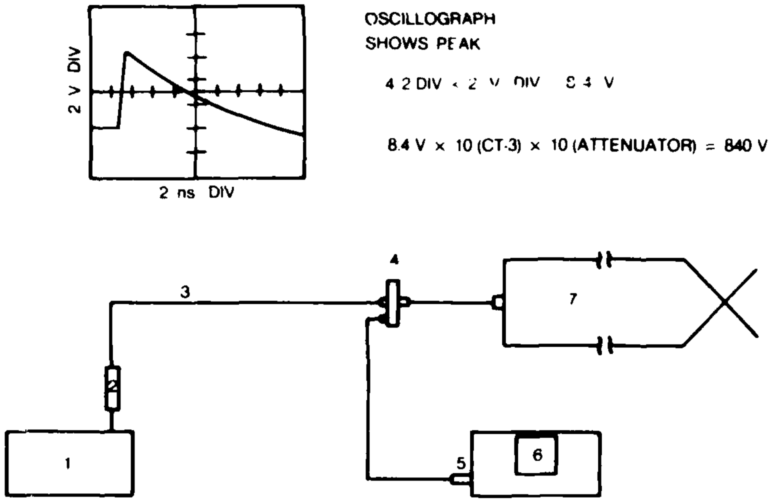
[6] *J. Krause, Antennas, McGraw-Hill Book Co., New York (1950), 221.*



1 PULSER # 2, 1 kV OUTPUT (INTO 50 Ω), 50 ns INTERNAL CHARGE LINE
2 GENERAL RADIO INSERTION LINE WITH 68 pF SERIES CAPACITOR, 560 Ω RESISTOR TO GROUND
3 RG-213 CABLE, 12 FT LENGTH
4 TEKTRONIX CT-3 PICKOFF UNIT (OUTPUT = × 10 INPUT)
5 ATTENUATOR (× 10)
6 TEKTRONIX 485 OSCILLOSCOPE, TEKTRONIX C-32 CAMERA
7 LOADED DIPOLE ANTENNA (LDP)

Figure 12. Measurement of incident and reflected voltages.

3. USE OF B-DOT AND D-DOT SENSORS TO CHARACTERIZE RADIATED FIELD FROM ADVANCED DESIGN PULSE GENERATOR

3.1 Discussion

A new pulse generator was designed by HDL to improve the very early time characteristics of the radiated waveform. The pulse from this source was applied to the same radiator used in section 2. An EG&G B-dot sensor, model MGL-7, and an HDL D-dot sensor were located directly under the radiator (fig. 13). The B-dot sensor was mounted on a 12 × 12 ft (3.6 × 3.6 m) metal ground screen. The D-dot sensor was elevated sufficiently above the model facility sand to allow the peak amplitude of the incident field to be observed uncorrupted by the ground reflection.

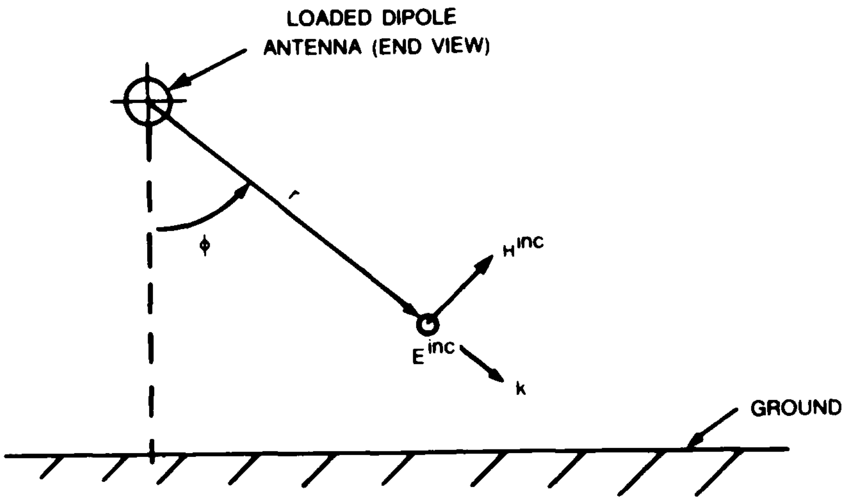


Figure 13. Physical relationship of field quantities to antenna and ground (k = propagation vector).

3.2 Results

The results of the experiment to determine the value of E_{pk}^{inc} from both calculation and measurement are shown in table 1. The incident E-field is related to the measured magnetic (H-) field by the relationship

$$E_{pk}^{inc} = \frac{377H_{pk}^{meas}}{2} ,$$

where we have assumed a perfect ground plane.

The recorded early time D-dot waveform (range is 1.3 m) is presented in figure 14. We see that the rise time (10 to 90 percent) is 337 ps. There is a generally improved shape to the waveform when compared with that in section 2. By using the B-dot sensor at 2.9 m, the rise time (10 to 90 percent) measured is 428 ps (fig. 15). These waveforms have not been compensated for cable and delay line loss because the existing compensation does not extend high enough in the frequency domain.

TABLE 1. DETERMINATION OF E_{pk}^{inc}

Range (m)	E_{pk}^{inc} of B-dot sensor* (V/m)	E_{pk}^{inc} of D-dot sensor (V/m)	E_{pk}^{inc} (calc)† (V/m)	$\frac{\text{calc - meas}}{\text{calc}}$
0.915	263	-	323	0.19
1.3	-	232	229	-0.02
1.83	128	-	162	0.21
2.9	79	-	102	0.23

*$E_{pk}^{inc} = 377 H_{pk}^{meas}/2 \cos \phi$, where H_{pk}^{meas} = measured value of peak magnetic field and $\phi = 0$.

†$E_{pk}^{inc} = \frac{60(1470 \text{ V})}{r(300 \ \Omega)}$, where r = range from antenna to observation point.

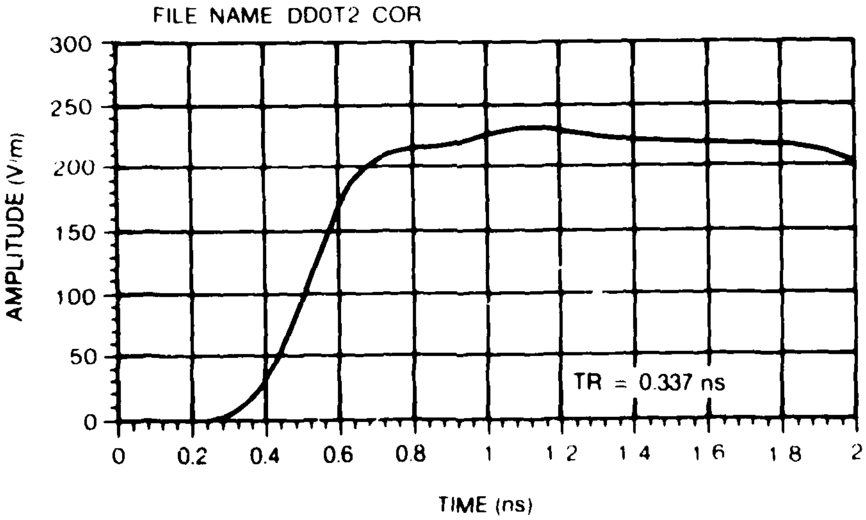


Figure 14. D-dot response range = 1.3 m.

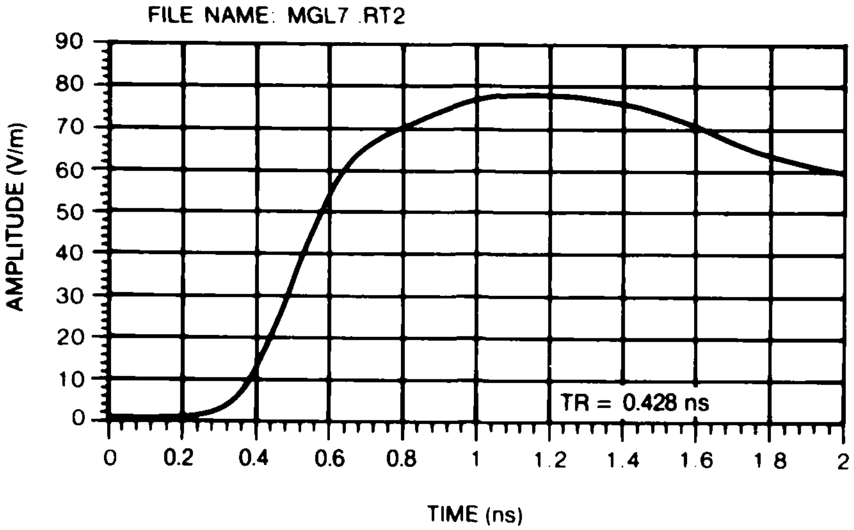


Figure 15. B-dot response range = 2.9 m.

4. COMMENTS

The accurate measurement of the radiated fields in an EMP scale-modeling facility requires techniques and equipment quite different from those used in full-scale experimental efforts. Frequencies in the gigahertz regime experience significant losses even in the best cable. Consequently, these losses must be taken into account to faithfully reproduce the temporal waveforms.

The need for very small sensors to achieve the proper frequency response introduces the attendant problem of low sensitivity. In many cases, the signals are too small to "see" unless they are averaged 100 times or more until the signal-to-noise ratio is adequate. Signal averaging is a very vital tool in scale-modeling work.

APPENDIX A.--A BASIC LANGUAGE PROGRAM TO COMPENSATE FOR THE HIGH-FREQUENCY LOSSES IN PASSIVE COMPONENTS

The Harry Diamond Laboratories has a computer controlled digitizing oscilloscope using time-domain sampling (TDS) techniques to observe the subnanosecond responses of model systems. While TDS allows the equivalent recording of picosecond regime events, the system requires a delay line that causes rise time degradation. Further loss of high-frequency content is caused by the radio frequency (rf) cable that couples the model response to the facility shielded enclosure. Fortunately, the computer with its capacity for forward and inverse fast Fourier transforms (FFT's) allows for data compensation. In fact, when the loss versus frequency through any passive component is known, its effect can be removed.

The HELIAX 25-m-long cable and the Tektronix 7M11 delay line were frequency swept from 0.1 to 6.5 GHz, and their loss versus frequency was recorded. This information is stored on a magnetic disc in the same format as the FFT of a datum. The figure after listing A-1 shows the loss of the cable that has been normalized to 1. Waveforms collected through this cable can be transformed into the frequency domain by the computer and then divided by the frequency response of the cable. The resulting frequency-domain waveform is then inverse transformed yielding a time-domain waveform with the high-frequency cable loss replaced. This procedure is then repeated for the delay line.

Listings A-1 and A-2 present the basic language program to compensate for the high-frequency losses in passive components.

APPENDIX A

LISTING A-1. PROGRAM 'CBLADD.MOD'

```
10 REM    PROGRAM NAME: 'CBLADD.MOD' ........ 13 APRIL, 1979 . JJL
20 REM         RENAMED FROM: 'CABLE.ADD' ..... JJL/OCT.80
30 REM   PURPOSE: RETRIEVE DATA FROM DX1 AND COMPENSATE FOR LOSS
40 REM   DUE TO CABLE #1. (80' ANDREWS HELIAX)
50 PAGE\LET W$=" "
60 WAVEFORM A IS AA(511),SA,HA$,VA$
70 PRINT "PROGRAM NAME: 'CBLADD.MOD'
80 PRINT "RETRIVES DATA AND COMPENSATES FOR CABLE #1 LOSSES "
90 PRINT "INPUT FILE NAME  "
100 INPUT FN$
110 PAGE
120 CLOSE #1\OPEN #1 AS DX1:FN$ FOR READ
130 EOF #1 GOTO 190
140 READ #1,FN$,A,MA,NA,PP,RT
150 READ #1,SU$,PU$,PL$,CP$,CB$,AN$
160 READ #1,PO$,SR$,SF$,DL$,TB$
170 READ #1,V$,CT$,DA$,W$
180 IF W$="CABLE COMPENSATED" THEN GOSUB 1030
190 CLOSE #1
200 LET M=MAX(A)
210 LET T=CRS(A,.1*M)
220 LET N=CRS(A,.9*M)
230 LET T=N-T
240 LET T=T*SA
250 VIEWPORT 100,900,300,700
260 SETGR VIEW
270 GRAPH A
280 IF W$="CABLE COMPENSATED" THEN SMOVE 500,700
290 PRINT W$
300 LET P=MAX(A)
310 IF W$<>" " THEN LET CT$=CT$&"  **  "&W$
320 SMOVE 600,655
330 PRINT "MAX= ",MA
340 LET BO=CRS(A,.1*MA)
```

LISTING A-1. (Cont'd)

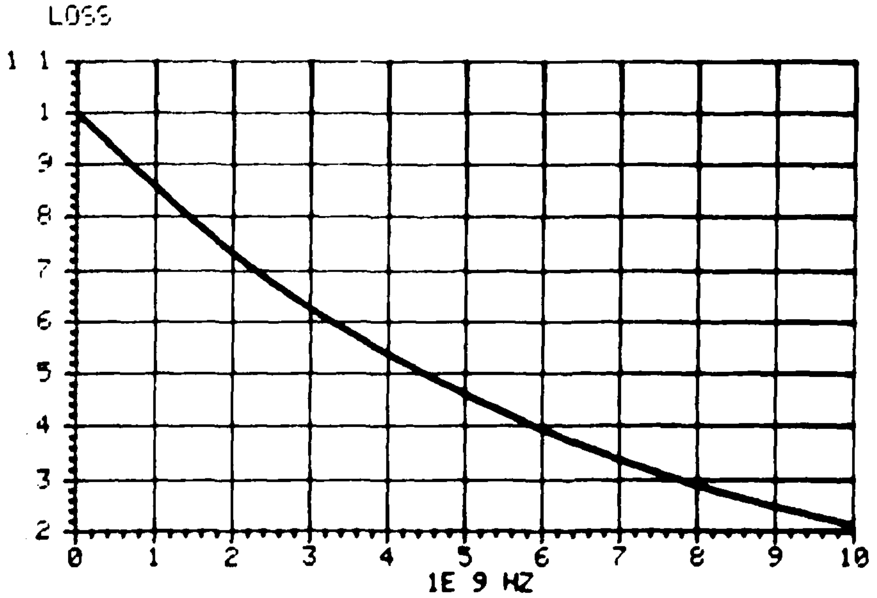
```
350 LET TP=CRS(A,.9*MA)
360 LET RT=(TP-BO)*SA
370 LET RT=RT/9.999994E-10
380 LET RT=RT*1000\LET RT=ITP(RT)\LET RT=RT/1000
390 SMOVE 600,630
400 LET NA=NA*(-1)
410 PRINT "MIN= ";NA
420 SMOVE 600,610
430 PRINT "P/P= ";PP
440 SMOVE 150,720
450 PRINT "FILE NAME  ",FN$;"                    DATE  ",DA$
460 SMOVE 600,320
470 PRINT "RT= ",RT," NS"
480 SMOVE 150,200
490 PRINT SU$
500 PRINT PU$,PL$,CP$
510 PRINT CB$,"  ",AN$;"  ",PO$
520 PRINT SR$,SF$,DL$
530 PRINT TB$,U$
540 PRINT CT$
550 IF W$="CABLE COMPENSATED" THEN GOSUB 1050
560 WAIT
570 REM  GIVES FFT OF PREVIOUS DATA
580 WAVEFORM B IS BB(256),SB,HB$,VB$
590 WAVEFORM C IS CC(256),SC,HC$,VC$
600 DELETE DD,EE
610 DIM DD(256)\DIM EE(256)
620 LET A=A-MEA(A)
630 REM ...ABOVE REMOVES DC COMPONENT FROM TIME DOMAIN WAVEFORM.
640 RFFT A,B,C
650 REM ABOVE TRANSFORMS TIME INTO FREQUENCY DOMAIN
660 POLAR B,C
670 REM AMPLITUDE VS FREQ IS NOW IN 'B'  .PHASE VS FREQ. IN 'C'.
680 PAGE\GRAPH B
690 SMOVE 300,720
```

LISTING A-1. (Cont'd)

```
700 PRINT "FFT OF DATA  ",FN$
710 WAIT\PAGE\PRINT "DO YOU WISH TO CABLE COMPENSATE THIS DATA ?"
720 INPUT R$
730 IF R$="Y" THEN IF W$=" " THEN GOTO 760
740 IF R$="Y" THEN IF W$="CABLE COMPENSATED" THEN GOSUB 1030
750 IF R$="N" THEN END
760 OPEN #1 AS DX0 "CABLE1 LOS" FOR READ
770 WAVEFORM % IS XX(1023),S%,HX$,V%$
780 READ #1,E$,%
790 CLOSE #1
800 REM        WAVEFORM '%' IS THE LOSS OF THE CABLE VS  FREQUENCY
810 REM        THAT IS, A NUMBER VS FREQUENCY
820 PAGE
830 SMOVE 100,200\PRINT E$
840 VIEWPORT 100,800,300,700\SETGR VIEW GRAPH %
850 FOR N=0 TO 256
860 LET FB=SB*N
870 LET BB(N)=BB(N)/((%(FB/SX)))
880 IF FB=1E+10 THEN GOTO 900
890 NEXT N
900 PAGE GRAPH B
910 SMOVE 250,700\PRINT "THIS IS FFT OF ",FN$;" WITH CABLE LOSSES ADDED
920 FOR N=0 TO 256
930 LET DD=BB
940 LET EE=CC
950 LET BB(N)=DD(N)*COS(EE(N))
960 LET CC(N)=DD(N)*SIN(EE(N))
970 NEXT N
980 RFFT A,B,C,"INV"
990 PAGE
1000 LET AA=AA-MEA(AA(0 20))
1010 LET W$="CABLE COMPENSATED"
1020 GOTO 190
1030 PRINT "MY INFORMATION IS THAT CABLE COMPENSATION ALREADY DONE."
1040 END
```

```
1050 PRINT "DO YOU WISH TO STORE THIS COMPENSATED DATA ?"
1060 PRINT "BEFORE COMPENSATION, FILE NAME WAS  ";FN$
1070 INPUT L$
1080 IF L$<>"Y" THEN IF L$<>"N" THEN GOTO 1050
1090 IF L$="N" THEN END
1100 IF L$="Y" THEN PRINT "INPUT NEW FILE NAME."
1110 IF L$="Y" THEN INPUT FN$
1120 IF L$="Y" THEN OPEN #1 AS DX1 FN$ FOR WRITE
1130 WRITE #1,FN$,A,MA,NA,P,RT
1140 WRITE #1,SU$,PU$,PL$,CP$,CB$,AN$
1150 WRITE #1,PO$,SR$,SF$,DL$,TB$
1160 WRITE #1,U$,CT$,DA$,W$
1170 CLOSE #1
1180 PAGE\DIR DX1 FN$
1190 END

READY
*
```



CABLE #1 LOSS VS FREQUENCY, TAKEN FROM DB GRAPH WHICH WAS STRAIGHT LINE APPROXIMATION (QUESTIONABLE BEYOND 6.5GHZ DATA TAKEN VIA SWEEPER & SPEC. ANALYZER ON 10 APRIL, 79 (JJL)

LISTING A-2. PROGRAM 'DLYADD.MOD'

```
10 REM    PROGRAM NAME: 'DLYADD.MOD'          13 APRIL, 1979    JJL
20 REM            RENAMED IN OCT.1980 FROM: 'DELAY.ADD'      JJL
30 REM   PURPOSE: RETRIEVE DATA FROM DX1 AND COMPENSATE FOR LOSS
40 REM   DUE TO DELAY #148
50 PAGE\LET W$=" "
60 WAVEFORM A IS AA(511),SA,HA$,VA$
70 PRINT "PROGRAM NAME: 'DLYADD.MOD'
80 PRINT "RETRIVES DATA AND COMPENSATES FOR DELAY #148 LOSSES."
90 PRINT "INPUT FILE NAME: "
100 INPUT FN$
110 PAGE
120 CLOSE #1\OPEN #1 AS DX1 FN$ FOR READ
130 EOF #1 GOTO 110
140 READ #1,CM$,A
150 CLOSE #1
160 LET M=MAX(A)
170 LET T=CRS(A, 1*M)
180 LET N=CRS(A, 8*M)
190 LET T=N-T
200 LET T=T*SA
210 VIEWPORT 100,900,300,700
220 SETGR VIEW
230 GRAPH A
240 IF W$="DELAY COMPENSATED" THEN SMOVE 500,700
250 PRINT W$
260 LET P=MAX(A)
270 SMOVE 200,670
280 PRINT "TR (10 TO 80%)= ",T;HA$
290 SMOVE 500,730
300 LET P=P*1000
310 PRINT "MAX= ";P;" MILLIVOLTS"
320 SMOVE 100,200
330 IF W$<>" " THEN LET CM$=CM$&"  **  "&W$
340 PRINT CM$\WAIT
```

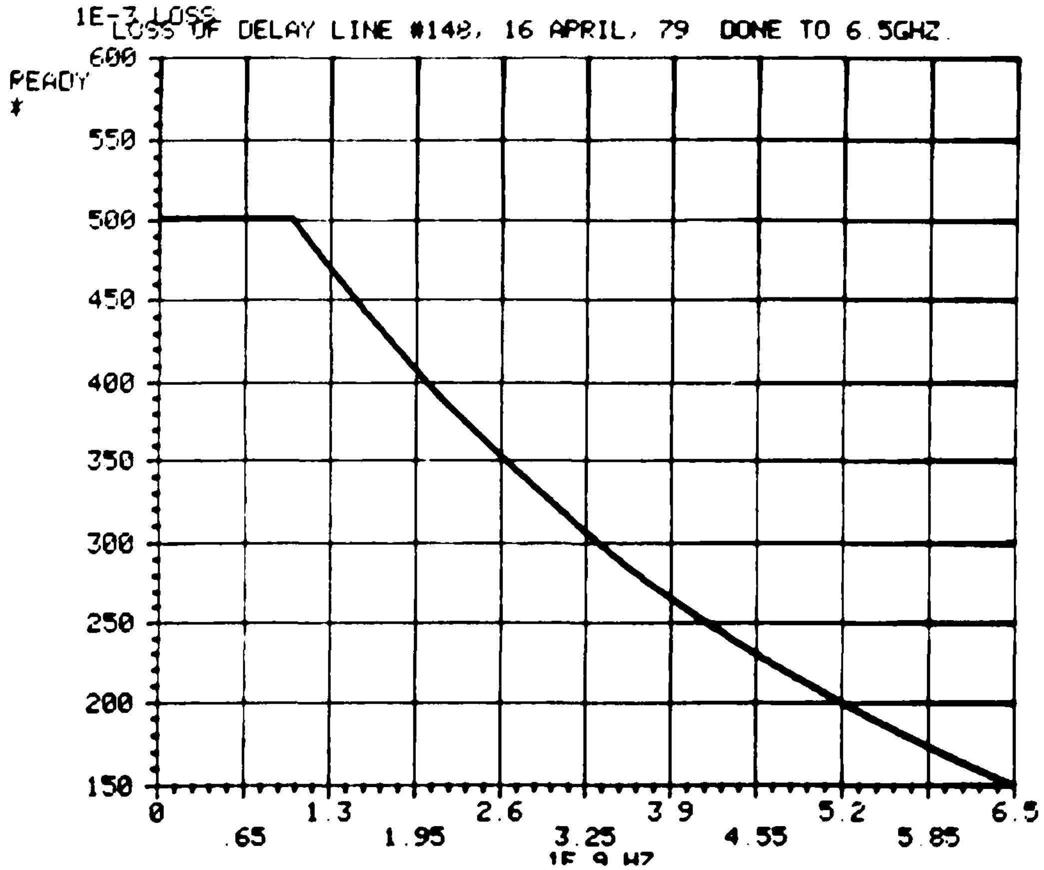
LISTING A-2. (Cont'd)

```
350 IF W$="DELAY COMPENSATED" THEN GOSUB 760
360 REM  GIVES FFT OF PREVIOUS DATA
370 WAVEFORM B IS BB(256),SB,HB$,VB$
380 DELETE DD,EE
390 DIM DD(256)\DIM EE(256)
400 WAVEFORM C IS CC(256),SC,HC$,VC$
410 LET A=A-MEA(A)
420 RFFT A,B,C
430 POLAR B,C
440 PAGE\GRAPH B
450 SMOVE 300,720
460 PRINT "FFT OF DATA  ",FN$
470 WAIT PAGE
480 PRINT "DO YOU WISH TO DELAY COMPENSATE THIS DATA ?"
490 INPUT R$
500 IF R$="Y" THEN IF W$=" " THEN GOTO 530
510 IF R$="Y" THEN IF W$="DELAY COMPENSATED" THEN GOSUB 740
520 IF R$="N" THEN END
530 OPEN #1 AS DX0 "DELAY LOS" FOR READ
540 WAVEFORM X IS XX(511),SX,HX$,VX$
550 READ #1,E$,X
560 CLOSE #1
570 FOR N=0 TO 256
580 LET FB=SB*N
590 IF FB>=6.5E+09 THEN GOTO 620
600 LET BB(N)=BB(N)/((XX(FB/SX)))
610 NEXT N
620 PAGE\GRAPH B
630 FOR N=0 TO 256
640 LET DD=BB
650 LET EE=CC
660 LET BB(N)=DD(N)*COS(EE(N))
670 LET CC(N)=DD(N)*SIN(EE(N))
680 NEXT N
690 RFFT A,B,C,"INV"
```

LISTING A-2. (Cont'd)

```
700 PAGE
710 LET AA=AA-MEA(AA(0 20))
720 LET W$="DELAY COMPENSATED"
730 GOTO 150
740 PRINT "MY INFORMATION IS THAT DELAY COMPENSATION ALREADY DONE "
750 END
760 PRINT "DO YOU WISH TO STORE THIS COMPENSATED DATA ?"
770 PRINT "BEFORE COMPENSATION, FILE NAME WAS  ".FN$
780 INPUT L$
790 IF L$<>"Y" THEN IF L$<>"N" THEN GOTO 760
800 IF L$="N" THEN END
810 IF L$="Y" THEN PRINT "INPUT NEW FILE NAME "
820 IF L$="Y" THEN INPUT FN$
830 IF L$="Y" THEN OPEN #1 AS DX1 FN$ FOR WRITE
840 WRITE #1.CM$.A
850 CLOSE #1
860 PAGE DIR DX1 FN$
870 END

READY
*
```



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