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SYSTEM RESPONSE AND PROPAGATION STUDIES

Ross W. Buchanan

Denver Research Institute

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FINAL TECHNICAL REPORT

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REPORT

SYSTEM RESPONSE AND PROPAGATION STUDIES

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13. ABSTRACT

This report deals with the utilization of the Denver Research Institute Pulsed Antenna System. The pulser was operated to provide a service to the community at Kirtland AFB, New Mexico and Honolulu, Hawaii (Los Alamos Scientific Laboratory). The use of the pulser as a source for an over the horizon experiment with receivers at Bangor, Maine is described. A technique for generation of "narrow" band signals using a directional antenna ~~has been~~ was developed as well as a technique for generation of two time-tied pulses from a single antenna system.

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[redacted]

APPROVED BY:

Herbert Reno

Herbert Reno
Head, Electronics Division

PREPARED BY:

Ross W Buchanan

Ross W. Buchanan, Head
Field Operations & Special Projects Laboratory
Electronics Division

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- NOTE -

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I. SUMMARY

A. An over-the-horizon experiment was conducted using the pulser at the Cherry Creek Field Site and receivers set up at the Maine Air National Guard base near Bangor, Maine. No wideband pulses that could be identified as having originated from the Cherry Creek pulser were recorded. However, the pulser was made to radiate a narrowband pulse which was received on a narrowband receiver in Bangor.

B. On December 10 and 11, 1971 the pulser was operated for the purpose of testing the Calypso II and VHF EM receiving systems. The pulser was used for similar tests on May 12 and 18, 1972 and August 9, 1972. A special report on the May and December tests is being prepared.

C. A simple double pulse system was designed and built. The system was improved by eliminating the mismatch between the pulser and the transmission line. Excellent results were achieved with the system.

D. The pulser has been used to compare the output of a monopole sensor on a flat ground plane (on top of a screen box) with the output of a loop sensor. The response of the monopole was found to be quite satisfactory for accurate recordings of the pulse. B-DOT loop sensors for the program were purchased.

E. In January the pulser was disassembled for routine maintenance. Although a number of problems were encountered, the pulser was returned to good operating order, and the work has provided valuable experience in dealing with pulser malfunctions.

F. A building was built to shelter the pulser and to provide the facilities necessary for servicing the pulser.

G. During June and July the pulser was on loan to the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico.

H. The pulser was operated for the Los Alamos Scientific Laboratory in Hawaii during Operation Picoposte. The pulser was modified to represent a conical monopole for this purpose.

II. DESCRIPTION OF WORK

A. Over-the-Horizon Experiment

1. Preparation

A receiving site was set up at the Maine Air National Guard base near Bangor, Maine, in an attempt to record pulses from the EMP simulator located at the Cherry Creek Field Site. Instrumentation was initially similar to that used during summer 1971 at Det. 433, using a multi-element loop antenna driving wideband receivers with oscilloscopes and moving film cameras as the primary recording apparatus. A typical recording channel is shown in Figure 1. Three tunable receivers were used, two of which were the new wideband receivers developed for OTH pulse monitoring, while the third was one of the fixed tuned 5 MHz bandwidth receivers used at Det. 433, modified to permit tuning to any frequency between 3 and 32 MHz. A fourth channel, consisting of a bandpass filter in the AGC system signal path was sometimes used.

A high speed digitizing channel with magnetic tape recorder was to be used to record a selected receiver output. Only one channel at a time could be digitized, so it was intended that the digitizer be connected to the channel receiving the mode with the best signal to noise ratio, or perhaps alternated between channels if more than one mode was received.

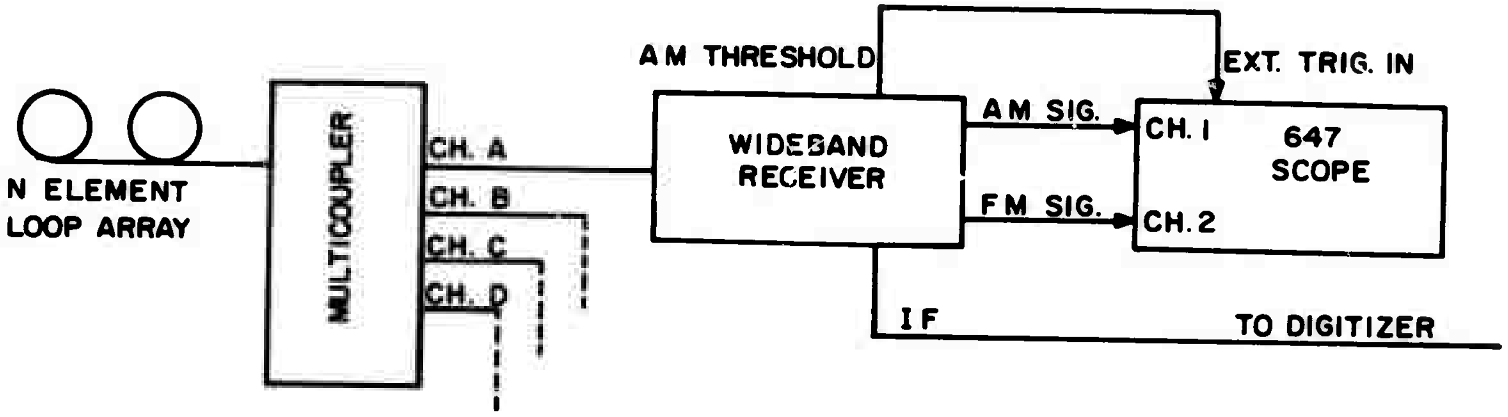
A plot, shown in Figure 2, of the median MUF for three different propagation modes was compiled from the four volume "Ionospheric Predictions" reports issued by the Office of Telecommunications, U.S. Department of Commerce. These plots are for the median value, i.e., the actual MUF will be above that shown 50 percent of the time and below 50 percent of the time. For the 1F2 mode 10 to 90% points are also shown. The lower bound is about 80-85 percent of the median value. It was then planned to set the receiver frequencies at about 80 percent of the median MUF value and change frequency from this value as necessary to avoid interfering stations.

The CCFS/Bangor, Maine path was chosen to nearly duplicate the Det. 433/1971 path. Estimates of the signal strength expected were confined to noting that the close-in vertical electric field of the pulse transmitter shows a stronger Fourier amplitude spectrum than some of the close in amplitude spectra from the events recorded successfully at Det. 433 in 1971.

2. Procedure and Modifications

The interfering noise at the Bangor site was in general lower than that at Det. 433, at least for the morning hours. A local transmitter station at Det. 433 contributed most of the interference, while at Bangor no local interference was noted. Some of the strongest interfering stations were received via ionospheric propagation, as evidenced by strong fading.

No pulses that could be identified as having originated from the Cherry Creek pulser were recorded at the chosen frequencies. Therefore the receiver frequencies were changed several times during the course of a typical test. Table 1 shows the receiver settings for the run of 17 August. Pulses were being transmitted every three minutes during the period 1815-1845 GMT. Thresholds for this run were typically 6-12 db below 1 mv/m.



RECORDING CHANNEL	FREQ.	BANDWIDTH
A	3-31.5 MHz	1,2,3 OR 4 MHz
B	3-31.5 MHz	1,2,3 OR 4 MHz
C	3-32 MHz	5 MHz
D	11.5 MHz OR 12.5 MHz	2 MHz 5 MHz

FIGURE 1

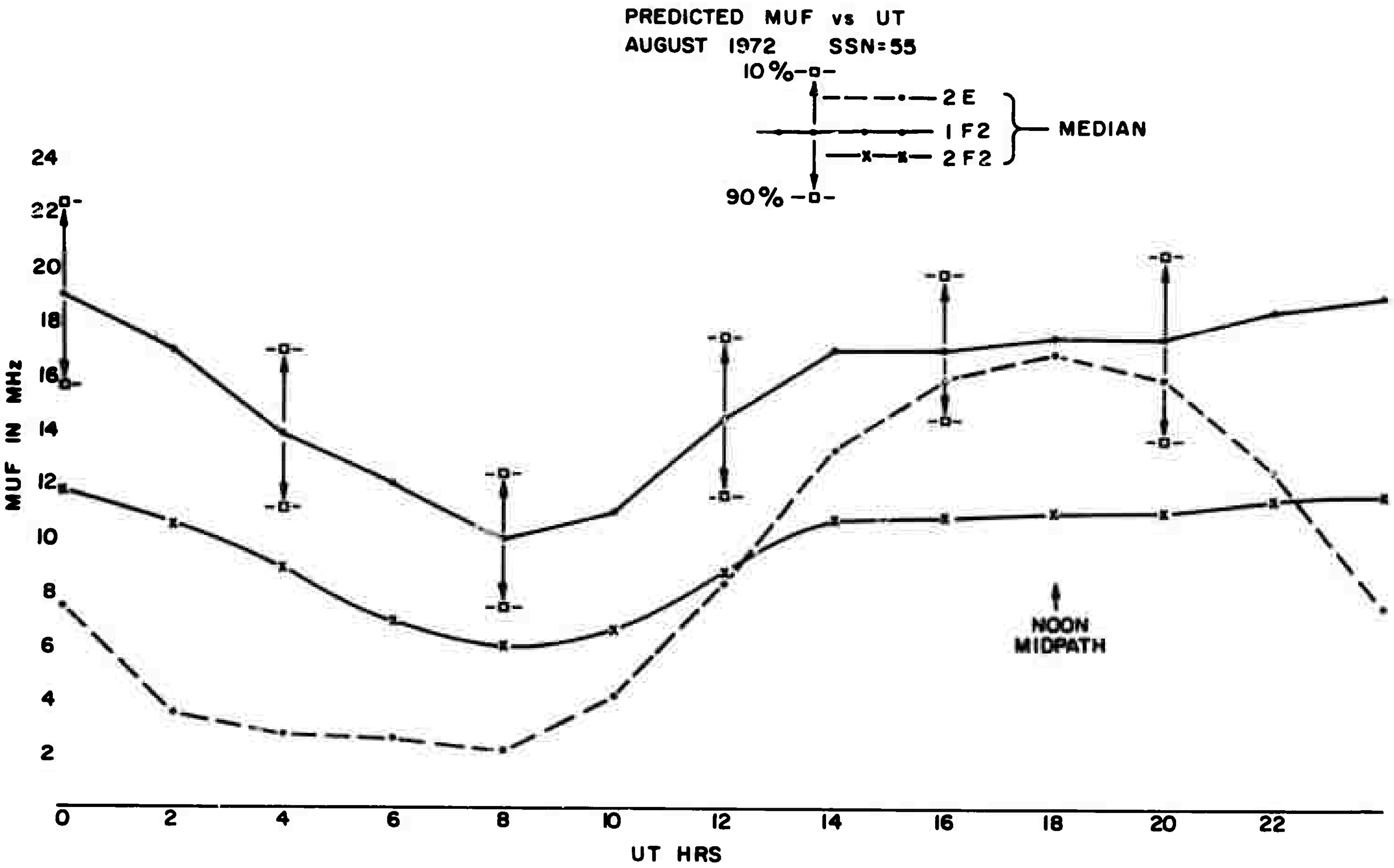

PREDICTED MUF vs UT
AUGUST 1972 SSN=55
10%
2 E
1 F2
2 F2
MEDIAN
90%
24
22
20
18
16
14
12
10
8
6
4
2
MUF IN MHz
0
2
4
6
8
10
12
14
16
18
20
22
UT HRS
NOON
MIDPATH

FIGURE 2

TABLE 1

Receiver Settings

RCVR	A		B		C		D	
	FREQ.	BW	FREQ.	BW	FREQ.	BW	FREQ.	BW
1815	12	2	14	1	11.5	5	11.5	2
1824			10	2				
1827			16	4				
1830	23	4						
1833			18	4				
1845	END RUN							

Since the pulses still were not being received, the number of loops in the receiving antenna array was increased from 8 to 17, a continuously recording tape recorder was added to the instrumentation at the receiver site, and the receiver site was moved to a different location, but all with the same negative result.

Finally it was decided to try a narrowband approach. A five-element, monopole, Yagi transmitting array was built with a nominal center frequency of 12.5 MHz. The array is sketched in Figure 3. The pulser acting as the driven element in the array was somewhat short for 12.5 MHz. It was not lengthened because the spectrum of the pulser by itself was known to peak at just under 12.5 MHz.

The Yagi array was very effective in concentrating the energy in a narrow frequency band. Figure 4 shows the pulse recorded at 100 meters from the pulser in the direction of maximum gain. The spectrum of this pulse is plotted in Figure 5 along with a comparison spectrum of the unmodified pulse. The spectrum peaks at 11.8 MHz with half power points at 11.2 MHz and 12.4 MHz. The peak level is 9.2 db above the level of the unmodified pulse spectrum.

These pulses were received at Bangor on a narrowband receiver having a 3 db bandwidth of 8 kHz. The signal strength was equivalent to a CW signal of about 42 microvolts RMS at the receiver input. Using a conservative figure of 10 meters for the antenna height, the field was thus roughly equivalent to 4.2 microvolts per meter rms, or 6 microvolts per meter, peak.

3. Analysis - Narrowband Receiver

The narrowband signal can be used to estimate a point on the receiver pulse amplitude spectrum. For an ideal receiver of 8 kHz bandwidth the spectral amplitude at 11.8 MHz should be $A(\omega) = \frac{6 \times 10^{-6}}{2 \times 8 \times 10^{3}} = 3.8 \times 10$

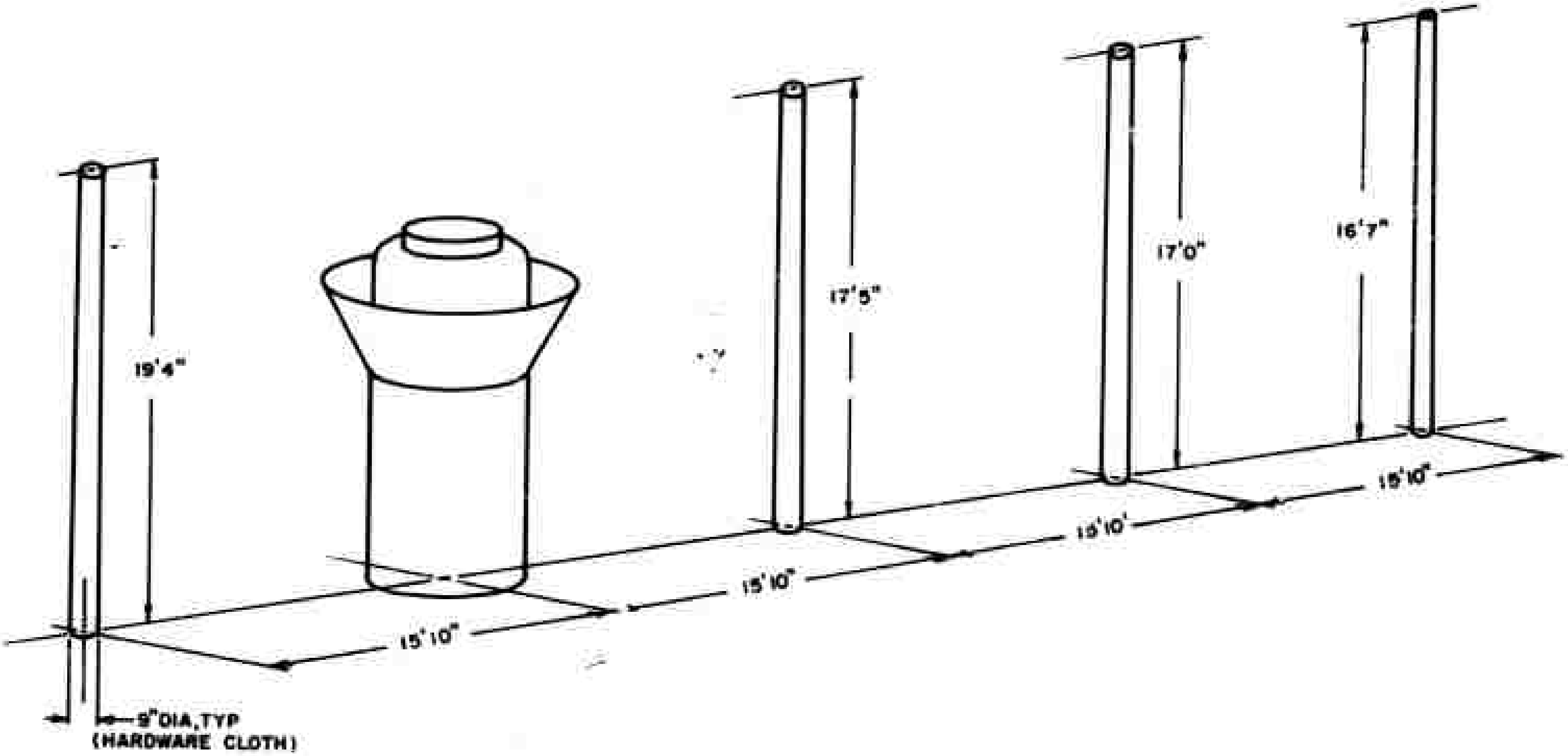


FIGURE 3 , YAGI TRANSMITTING ARRAY

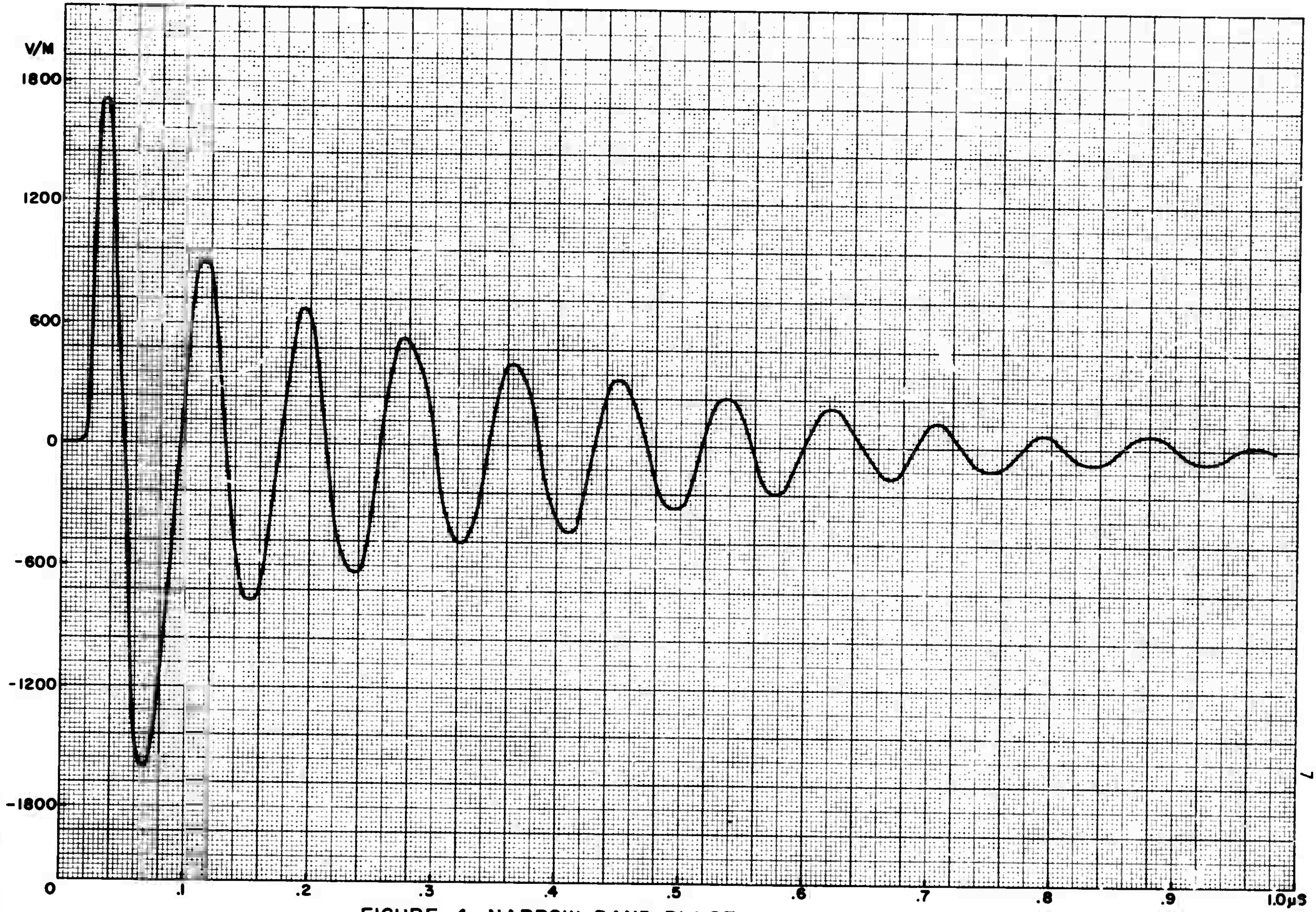


FIGURE 4, NARROW BAND PULSE

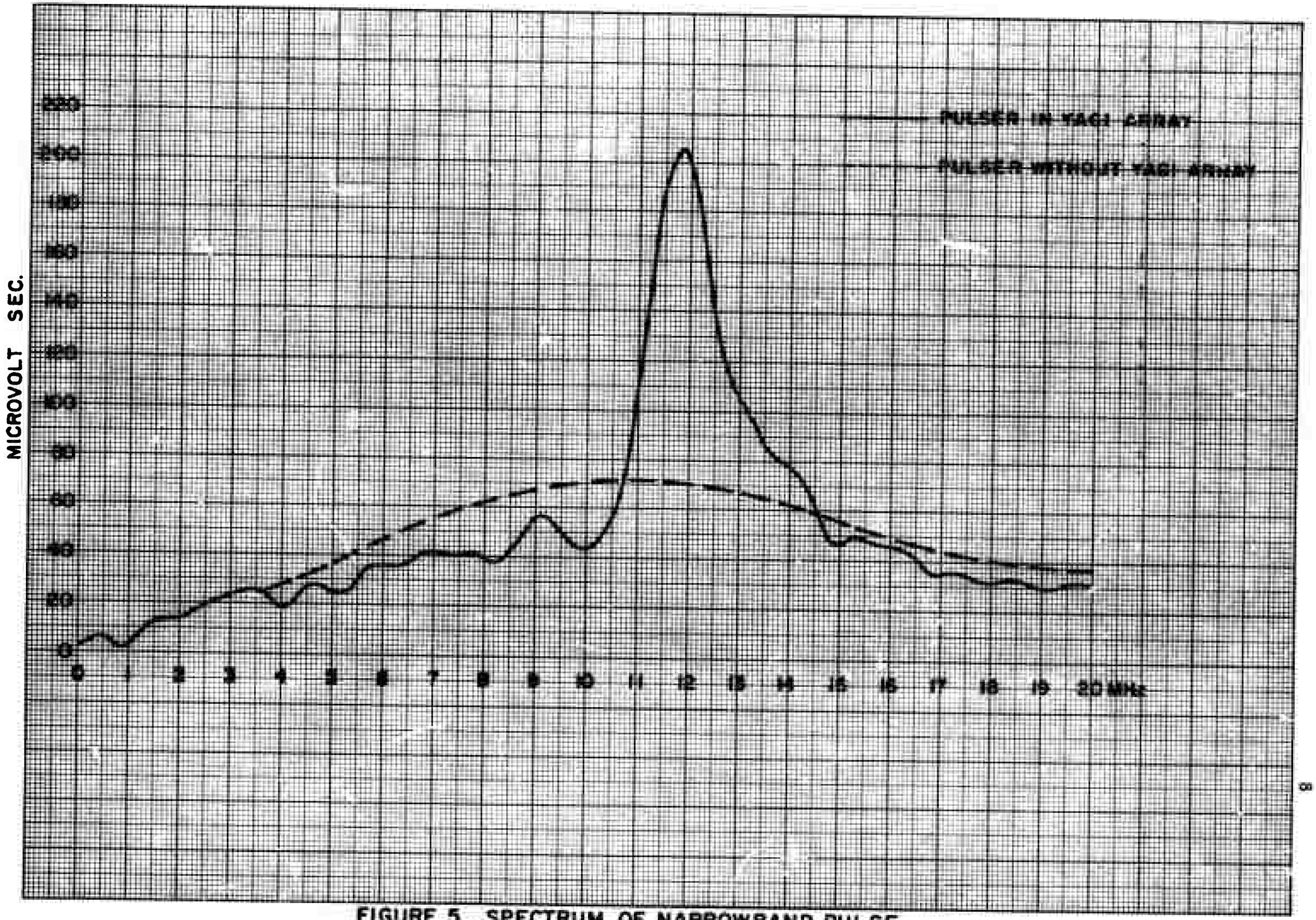


FIGURE 5 . SPECTRUM OF NARROWBAND PULSE

volts-seconds per meter. A second method of calibrating the narrowband receiver produced essentially the same results. A swept-frequency calibration of 3.8 millivolts peak, at 3 μs/MHz sweep rate, produced the same receiver output as the received pulses. This gives $A(\omega) = \sqrt{3} \times 10^{-3} \times 3.8 \times 10^{-6}/2 = 3.3 \times 10^{-9}$ volt-seconds, or 3.3×10^{-10} vs/m, using 10 m for the antenna effective height. This value is probably more nearly correct than the value of 3.8×10^{-10}, since it is not necessary to assume an ideal receiver for the second method of calibration. Using a $\frac{1}{d}$ approximation to translate the value of $A(\omega)$ back to a point 100 meters from the source gives $A(\omega) = \frac{3.3 \times 10^{-10} \times 3 \times 10^{6}}{100} = 10 \times 10^{-6}$ volts-seconds per meter with no attenuation, or about 158×10^{-6} if one assumes 24 db of attenuation. The value actually measured was 200×10^{-6} at 100 meters. However, the measured value of 200×10^{-6} was taken from a measurement by a loop about 3 meters above the ground and is predominantly surface wave. Calculations show that the radiated component at a launch angle of about 5 degrees would be about a factor of two lower than the loop measurement.

4. Analysis-Wideband Receivers

Using the measured field from the Cherry Creek pulser at a launch angle of 6.5 degrees and 2.75 KM distance, an estimate can be made of the expected field strength at the Bangor location. The time domain signal amplitude is approximately equal to the Fourier amplitude spectrum divided by twice the square root of dispersion, or $E(t) = \frac{A(\omega)}{2\sqrt{D}}$. The value for $A(\omega)$ was calculated for the close-in pulse (at 2.75 KM) using about 1.45 microvolt seconds per meter, so the field at 3000 KM, using 5 microseconds/MHz for the dispersion* and ignoring ionospheric attenuation is

$$E(t) = \frac{1.45 \times 10^{-6}}{\sqrt{20 \times 10^{-12}}} \times \frac{2.75}{3 \times 10^{+3}} = .297 \times 10^{-3}$$

With a few db of attenuation, the signal would be lost in the wideband noise. Figure 6 shows a typical plot of noise vs frequency at the Bangor site. The plot is roughly consistent with operator observations that the threshold was of the order of 0.5 mv/m. After the directional tuned antenna array was erected at the Cherry Creek site, the value of $A(\omega)$ was 100×10^{-6} volt-seconds per meter at a 100 meter distance and would have been 31.6×10^{-10} at Bangor with no attenuation in the ionosphere. Using the same approximation as above, $E(t) = A(\omega)/\ 4D$, one can estimate the maximum dispersion which would give a field of 0.5 mv/m at the Bangor site. The values are given in Table 2 for various values of attenuation.

TABLE 2
Maximum Allowable Dispersion for 0.5 mv/m Threshold

ATTENUATION, db	0	3	6
MAX DISPERSION, μs/MHz	10	5	2.5

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* The 5 microsecond/MHz dispersion coefficient was deduced from the Det. 433 data recorded over a similar path during the CREW DRIVER '71 experiments.

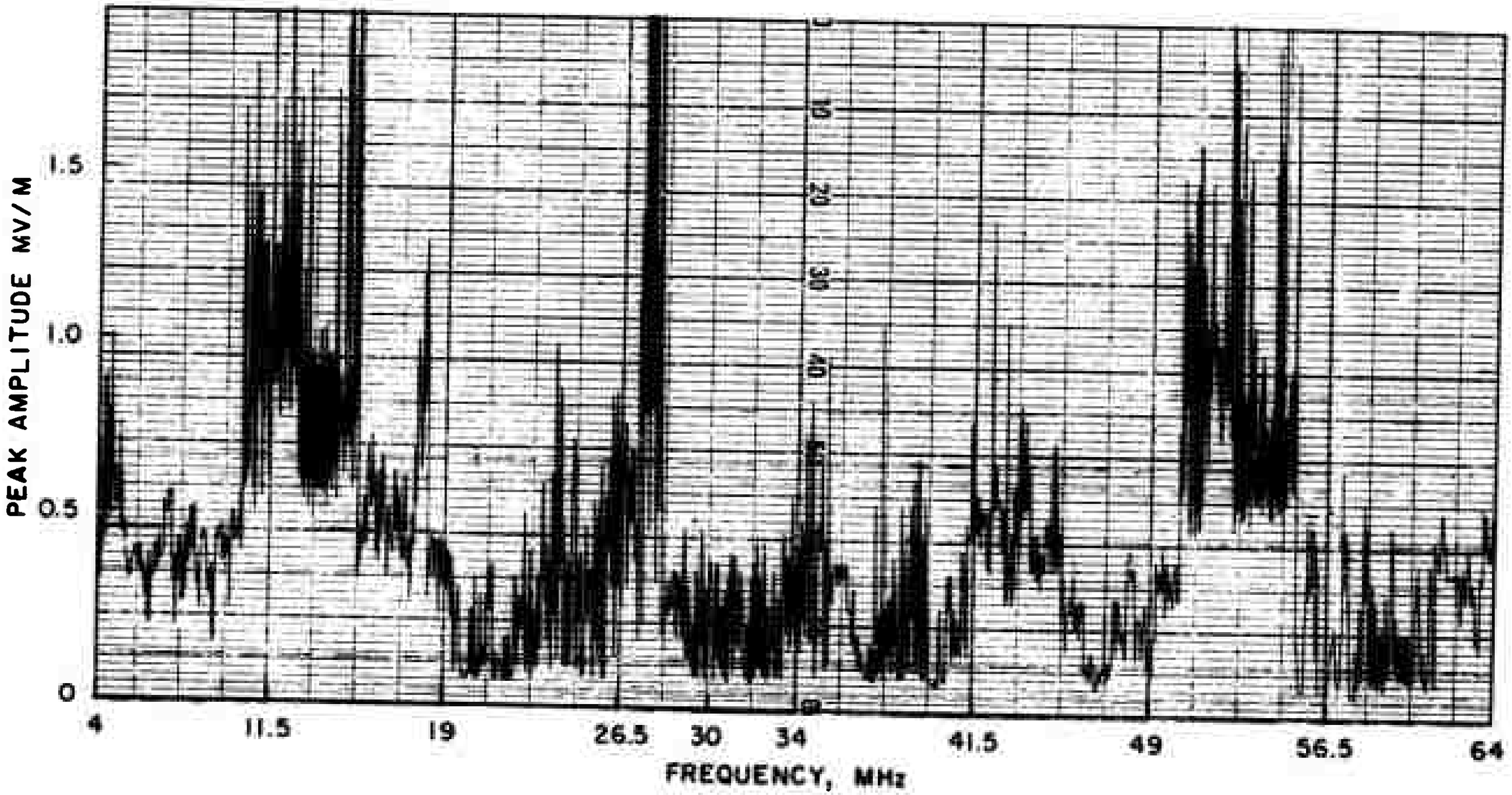


FIGURE 6. CW NOISE RECORD 1 MHz BANDWIDTH
17 AUGUST 1972, BANGOR MAINE

These values are meaningful in that absorption decreases with increasing frequency, while dispersion increases. Thus, if the receiver is tuned well below the MUF, where one might expect a dispersion as low as 2.5 μs/MHz, the absorption would be expected to exceed 6 db. The same calculations, however, can be applied to the close-in signals from the pulses recorded at Det. 433, with essentially the same conclusion, that some of the ionospherically propagated signals arriving at Det. 433 should have been lost in noise. Two possible conclusions are that:

1. The sensitivity of the receiving antennas was greater at 433 than at Bangor, due perhaps to local environment.

2. The sources of the pulses received at 433 radiated more energy in the HF band than can be deduced from close-in measurements of the vertical electric field.

During the period when the narrowband signals were being recorded, WWV reception at both 10 and 15 MHz was good. WWV transmits from Ft. Collins so that the paths were nearly the same for WWV and the CCFS pulses. However, WWV may have been received via some higher order mode, with higher launch and reception angles, and higher dispersion than the CCFS pulses. The reception of the 2E and 1F2 modes would be expected to be poor due to ground reflections in front of the antenna at the low angles of arrival. For a poorly conducting soil, with $E = 10$ and $\sigma = 2 \times 10^{-3}$ mhos/meter, the reflection coefficient is about 0.45 at a phase angle of -175 degrees, so that the signal arriving at the antenna has been reduced by a factor of nearly two. For the 433 location, the reflection should have occurred over seawater, with a reflection coefficient of nearly unity at an angle close to zero degrees, so that the arriving signal was nearly doubled. Thus the antenna sensitivity at Bangor was probably a factor of four less than at 433 for the low reception angles. This, of course, changes the observations concerning noise at the two sites. If the apparent noise levels were comparable, but the antenna sensitivity was less by a factor of four, then the effective noise was four times as great at the Bangor site.

In addition, the sources of the Det. 433 signals radiated efficiently in the horizontal mode, although this should not have increased the received signal strength by as much as a factor of two over that calculated from the close-in vertical field.

B. Other Field Tests

The pulser has served as an essential component for several test programs. On December 10 and 11, 1971 the pulser was operated for the purpose of testing the CALYPSO II and VHF EM receiving systems. For the December 10 test, the conical late time antenna was installed. This configuration and its radiated pulse have been described in DRI Quarterly Technical Report #2578. On December 11, the pulser was operated in the double pulse configuration, which is described in this report.

During these tests the pulser operated reliably, except for two problems that were easily corrected. On the first day, the pulser would occasionally prefire; this was corrected by purging the Marx gaps and refilling them with sulfur hexaflouride. On the second day, an unbalanced condition was indicated several times. This was due to a static charge on the face of the unbalance meter, and the problem was eliminated by cleaning the meter.

On May 12, 1972 the pulser was operated to test EMP monitoring equipment for the Los Alamos Scientific Laboratory. A similar test was conducted on May 18, 1972 to test the AFTAC Calypso II and modified VHF systems. (After the tests on December 10, and 11, 1971, the VHF system was modified to increase its low frequency response). The data from the May tests as well as the December tests has been received and is being analyzed; a special report is being written.

On August 9, 1972 the pulser was operated as part of the post operation calibration flight of aircraft 369. During the first half of the test, the pulser was suspended in its horizontal configuration. The pulser was then repositioned in its vertical configuration for the second half of the test. However, a bubble had developed in one of the main charging resistors, which prevented the Marx generator from charging. Quick recognition of the problem permitted opening the Marx housing and repairing the resistor with only two hours delay in the test. The pulser performed reliably for the remainder of the test.

The pulser was also used for the initial calibration of a new E field sensor developed by DRI. The sensor has its own self contained recording equipment and will be used as a standard for the determination of effective height of various aircraft antennas.

C. Double Pulse Technique

Several techniques for generating a double pulse were studied. Since all of these involved a delay line, it was decided to build a simple double pulse system to test the feasibility of propagating the high energy pulse on a practical transmission line.

The function of the system (shown in Figure 7) is to let some energy radiate from the pulser while another portion of energy travels down a strip line to be radiated by a conical monopole. The latter radiation will then be delayed a certain length of time depending on the length of the strip line and the direction from the pulser to the recording equipment.

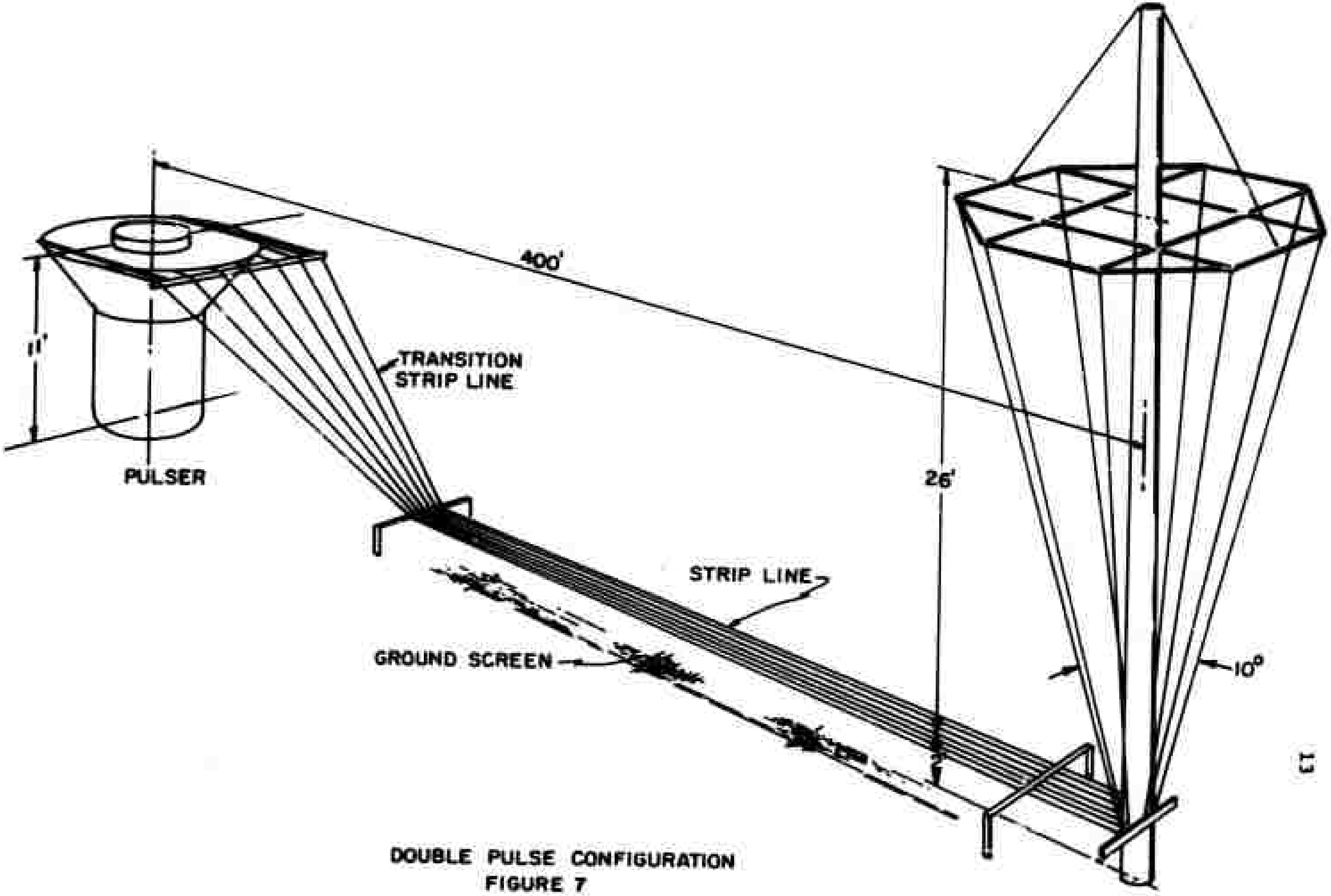
Although the dimensions of the pulser are large so that it radiates significant amounts of energy, it is in fact a transmission line. It is a biconic transmission line for which the characteristic impedance is given by the equation,

$$Z_0 = \sqrt{\frac{\mu}{\epsilon}}\,\frac{1}{\pi}\ln\left(\cot\frac{\theta_0}{2}\right)$$

where θ_0 is the angle from the axis of the cone to the surface of the cone. The pulser has a θ_0 equal to 30°, but the effective θ_0 is more like 34° due to irregularities at the apexes of the conic sections. The impedance of the pulser operating in air is then

$$Z_0 = \sqrt{\frac{1.26\times10^{-6}}{8.85\times10^{-12}}}\,\frac{1}{\pi}\ln\left(\cot 17^\circ\right)$$

$$Z_0 = 120\ln(3.27) = 142\,\Omega$$



DOUBLE PULSE CONFIGURATION
FIGURE 7

The objective now is to guide some of the pulse energy away from the pulser on a transmission line that matches the impedance of the pulser. A strip line with air dielectric was chosen for this purpose in order to minimize the cost. The height of the strip line is determined by voltage breakdown considerations. The peak potential on the strip line was estimated at 10^6 volts. Air breaks down at approximately 7.5×10^4 volts per inch; that is, 10^6 volts would arc across 13.3 inches of air. A safety factor of 1.8 was used to allow for the concentration of electric field near the strip conductor. Thus the height of the strip line was set at 24 inches. This is still marginal, of course, but increasing the height would permit undesirable radiation from the strip line.

An approximation of the width of the strip line can be obtained from the formula

$$Z_o \simeq \frac{138}{\sqrt{\epsilon'}} \log \frac{8h}{w}$$

where Z_o = 142 ohms, h = 24 inches, ϵ' = 1 for air, and w is the unknown width.

$$142 \simeq 138 \log \frac{192}{w}$$

$$w \simeq 18 \text{ inches}$$

The width was increased to 19.5 inches to allow for the error in the approximation and the error in replacing the strip conductor with seven parallel wires.

The transition from the biconic transmission line (pulser) to the strip line was a tapered strip line. The height to width ratio was held constant to maintain the 142 ohm impedance. At the far end of the strip line, a 142 ohm conical monopole was connected.

The initial system was built in November, and preliminary double pulse data were presented without analysis at the PRIME ARGUS meeting in December, 1971. The system has a 400' strip line so that at an angle of 159.5° true from the simulator, the time separation between pulses is 800 nanoseconds. However, the pulses were monitored at 69.5° true in order to correctly measure the relative amplitudes of the two pulses. The resulting 400 nanosecond delay is apparent in the recorded pulses shown in Figure 8.

In order to increase the amplitude of the secondary pulse, a time domain reflectometer was used to find mismatches in the system. Figure 9 shows the response of the reflectometer connected to the last 28 feet of transmission line which is terminated by the secondary radiator. It is apparent that the antenna matches the transmission line, but there is a small capacitive mismatch at the base of the antenna. The mismatch was nearly eliminated by moving the antenna wires to form more of a point at the apex of the antenna. See Figure 10.

Another mismatch was discovered at the connection of the strip line to the pulser as shown in Figure 11. It was thought that this condition might be corrected by removing the upper conical extension and reconnecting the strip line at the lower end of the Marx housing. This would not only eliminate some capacitance but would also reduce the size of the

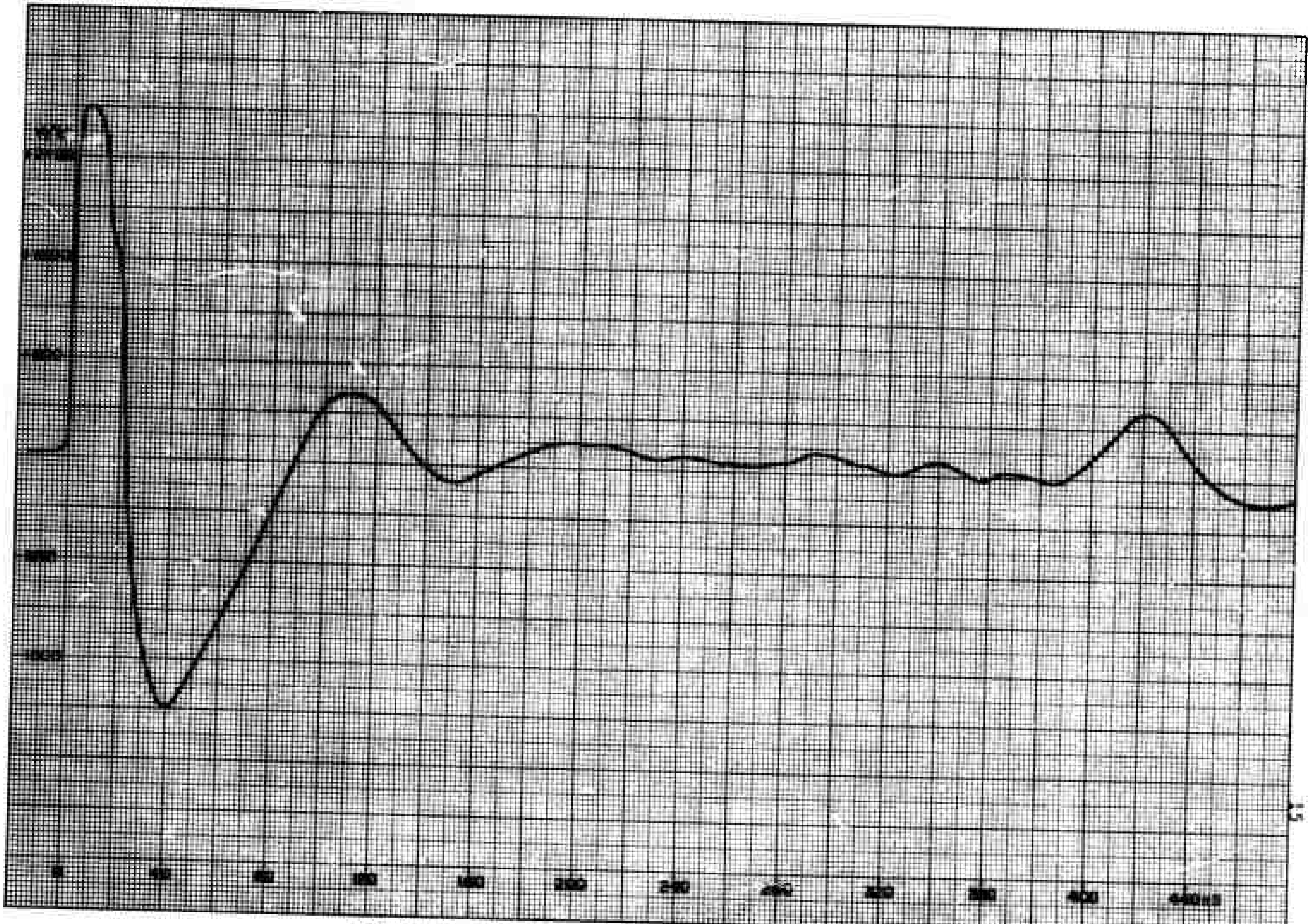


FIGURE 8, ORIGINAL DOUBLE PULSE

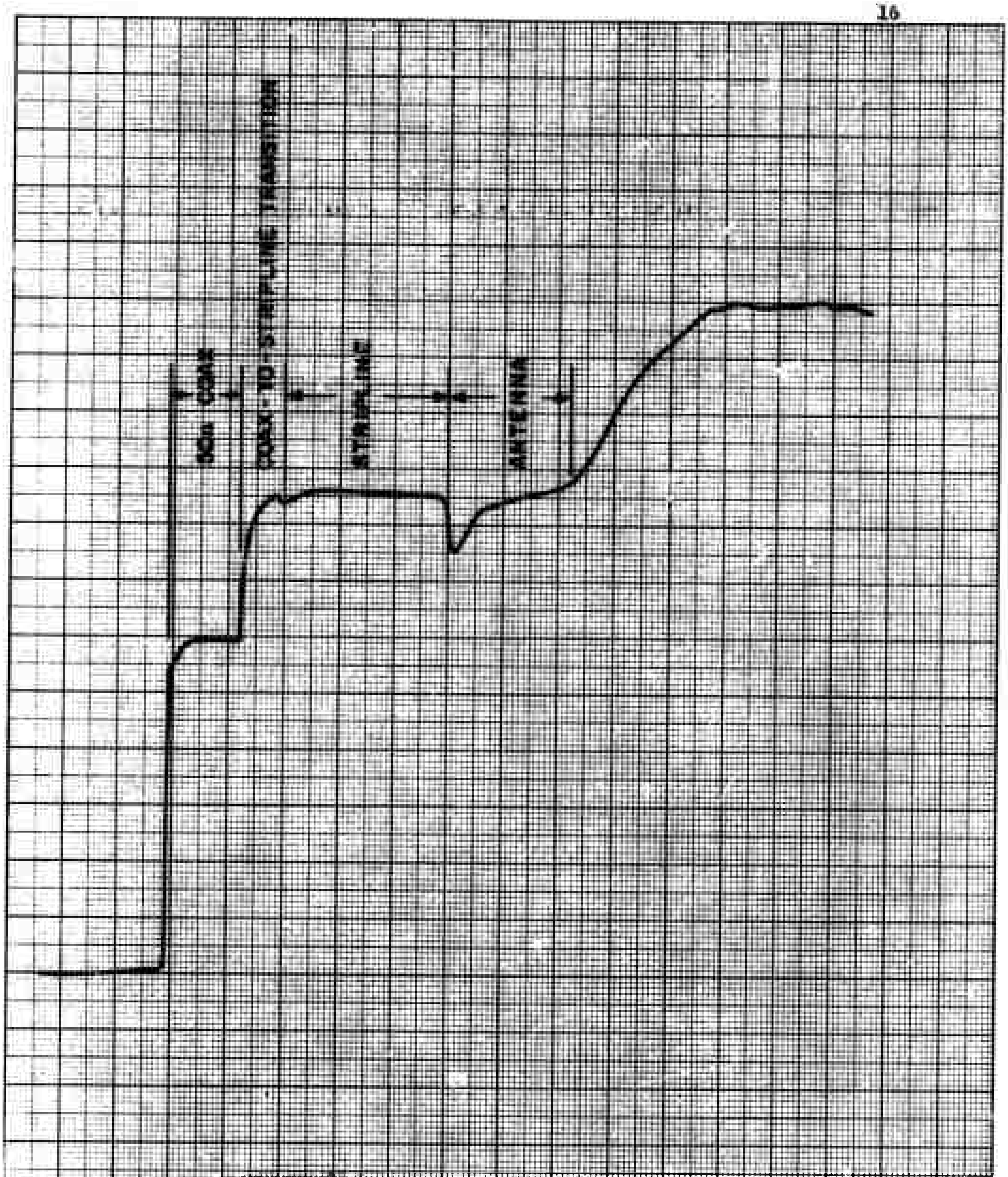


FIGURE 9. TIME DOMAIN REFLECTOMETER PLOT OF SECONDARY ANTENNA WITH 10" OF STRIPLINE

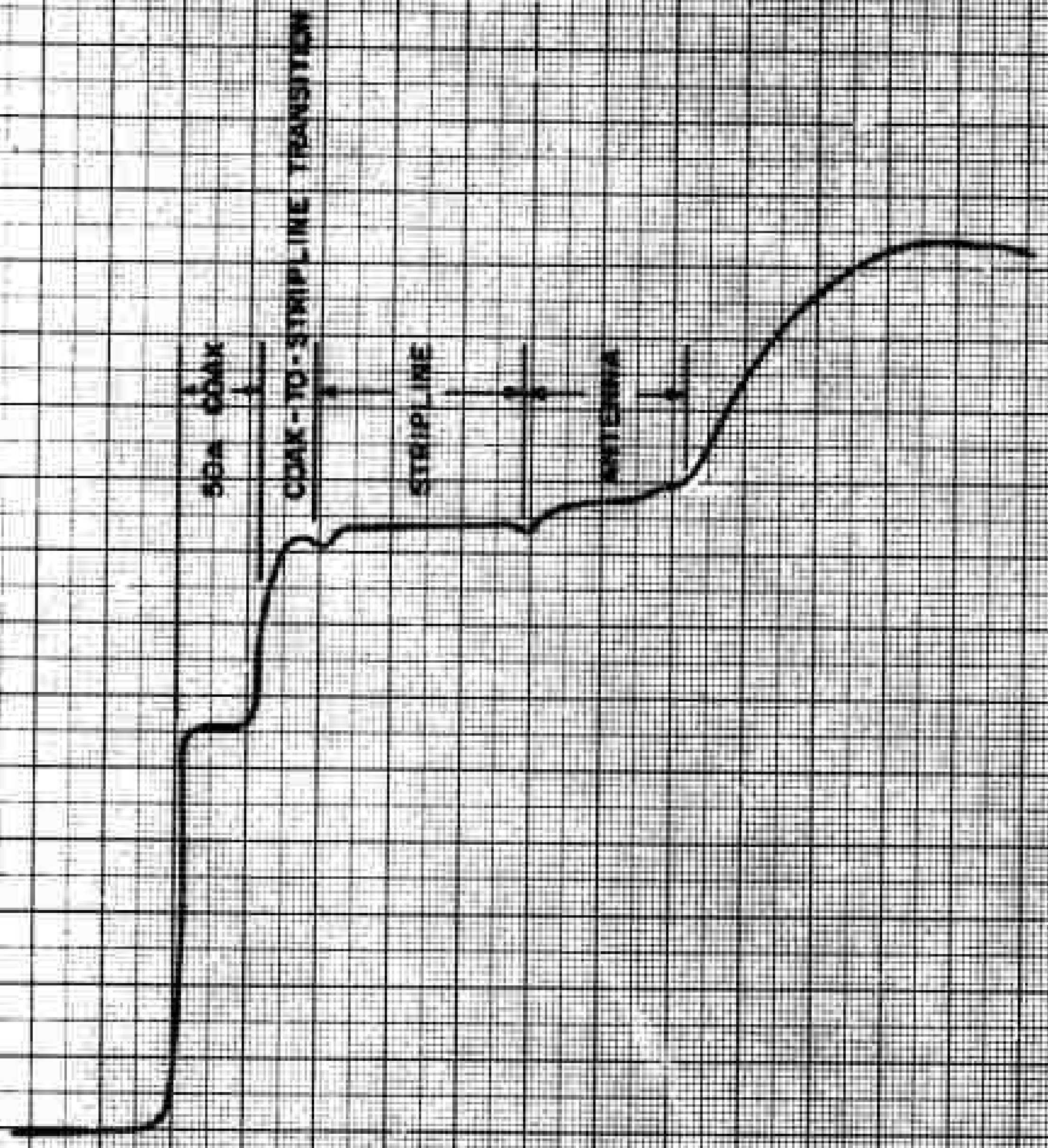


FIGURE 10. TIME DOMAIN REFLECTOMETER PLOT OF SECONDARY ANTENNA AFTER REMOVING EXCESSIVE CAPACITANCE

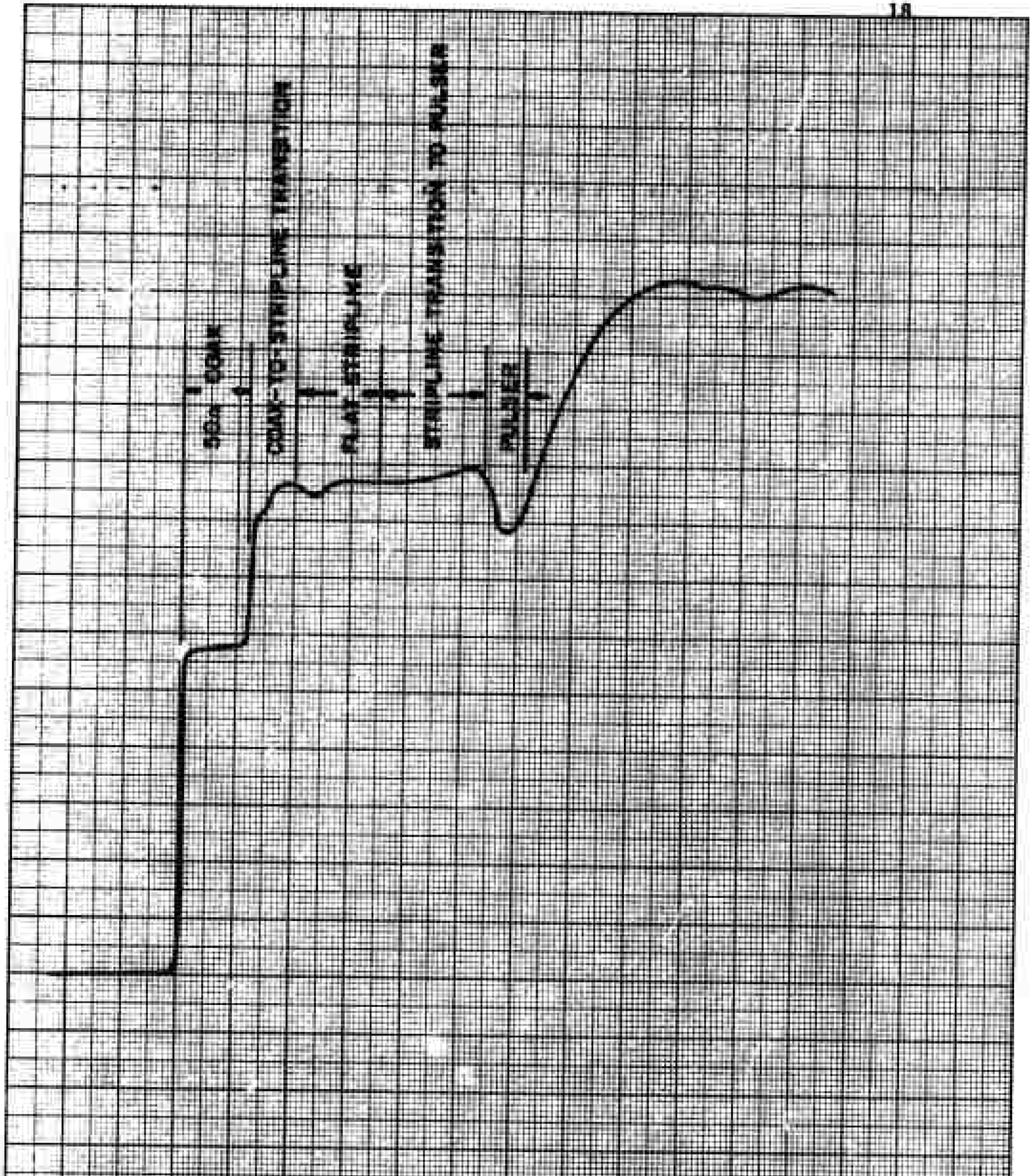


FIGURE 11. TIME DOMAIN REFLECTOMETER PLOT SHOWING MISMATCH AT PULSER

primary radiating structure so that more of the total energy would be propagated on the strip line. Unfortunately this did little to correct the mismatch, but the conical extension was left off to take advantage of the additional energy on the strip line. It became apparent that the impedance of the pulser was lower than had been estimated, and the strip line would have to be modified to match the pulser. The straight section of the transmission line was widened from 20" to 36", and the transition section was widened proportionately. The improvement is apparent in comparing TDR recordings, before the modification (Figure 11) and after the modification (Figure 12). The double pulse system with the modifications is sketched in Figure 13.

With the impedance of the strip line reduced, the impedance of the secondary radiator was made too high. This remains to be corrected. Another problem that requires work is the possibility of voltage breakdown on the strip line. The system should be observed at night to determine the extent of any voltage breakdown. Also it may become desirable to increase the height of the secondary radiator.

Although no further improvements were made the modified system has been operated several times, and the pulses have been recorded. Figure 14 shows the pulses recorded in a manner similar to that of Figure 8. The amplitude of the second pulse has apparently been increased. When the spectrum of the double pulse was computed, an additional 400 nanoseconds of delay was inserted to make the total delay 800 nanoseconds. A log plot of the spectrum is shown in Figure 15. It is interesting to compare Figure 15 with Figure 16, which is the spectrum of a pulse similar to the primary pulse without the secondary pulse.

D. EMP Sensors

There has been a continuing effort to determine what sensors will accurately record the electromagnetic pulse. The EG&G Model MGL-2 loop sensor has been used as a standard for most tests. Two of these loops have been purchased and are used frequently.

The requirement for placing the loop in a location approximating free space is often inconvenient or impossible to satisfy. However, a monopole is not limited in this way and has the advantage of a simpler design. To compare the performance of a monopole with that of the loop, the electromagnetic pulse was recorded using each sensor at 100 meters from the pulser. The monopole was mounted on a 4' foot square ground plane which was the lid of the screen box housing the recording equipment. The monopole was on the ground, and the loop was ten feet in the air, but the results were quite similar as shown in Figure 17. It is apparent that for distances of 100 meters or more the electric field pulse and the magnetic field pulse are almost identical. The monopole can be used with good confidence whenever it is required.

E. Community Service

During the month of October the pulser was operated in Hawaii for the Los Alamos Scientific Laboratory in support of Operation Picoposte. For these tests the lower bicone was removed and a new ground was added to make the pulser appear to be a vertical monopole. This modification resulted in the radiation field as a function of elevation having a much more uniform real time wave shape.

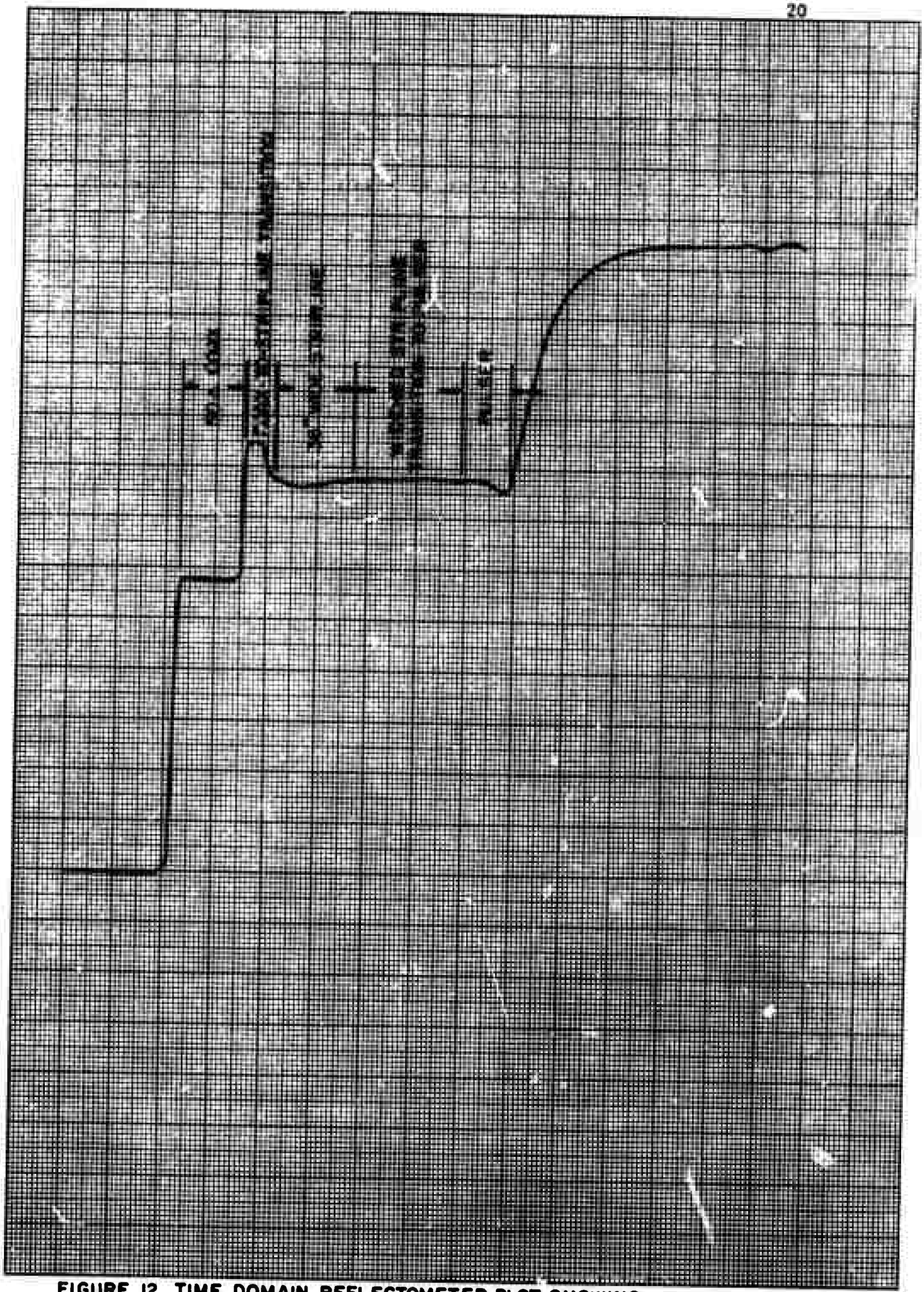
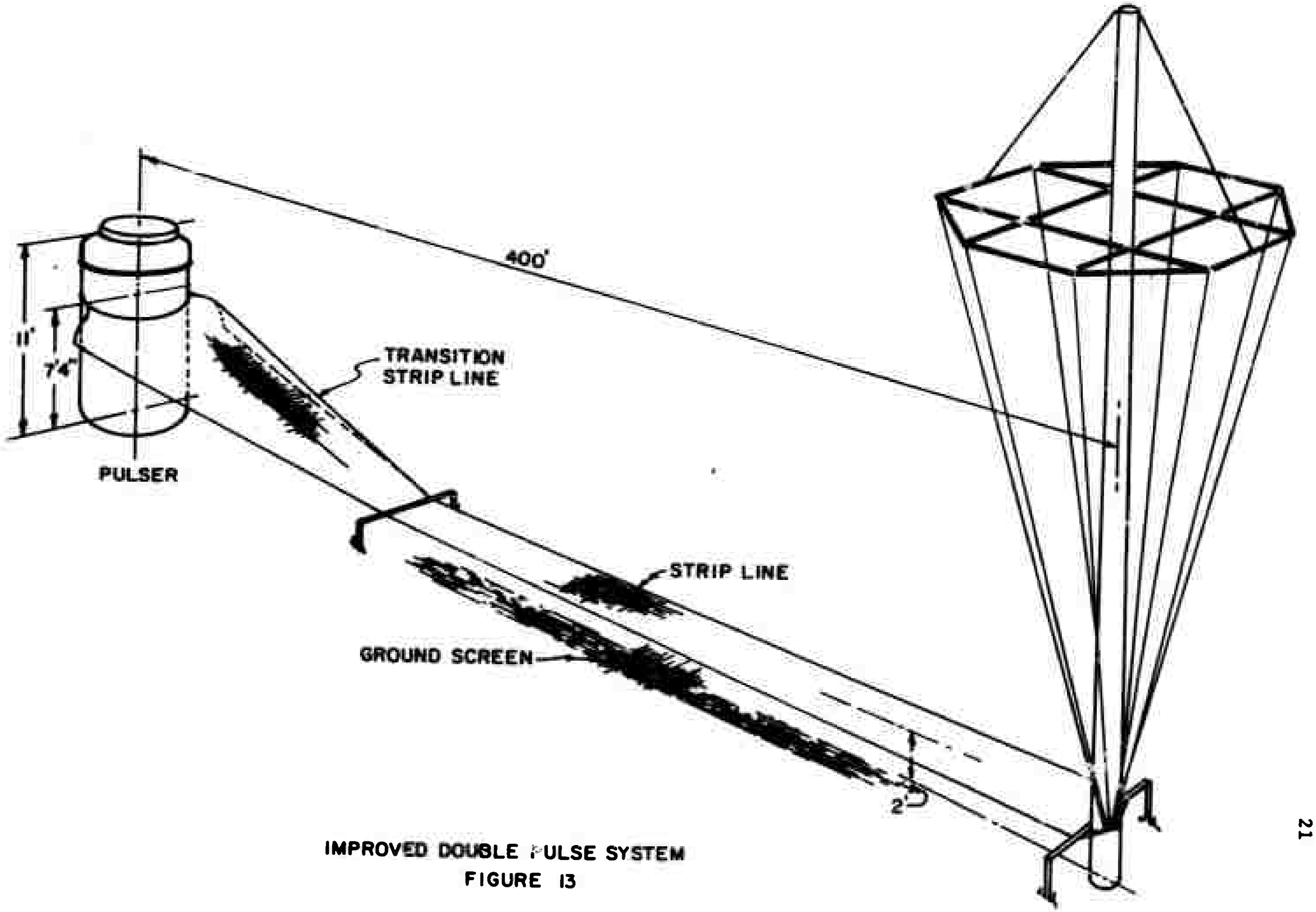


FIGURE 12, TIME DOMAIN REFLECTOMETER PLOT SHOWING REDUCED MISMATCH AT PULSER.



IMPROVED DOUBLE PULSE SYSTEM
FIGURE 13

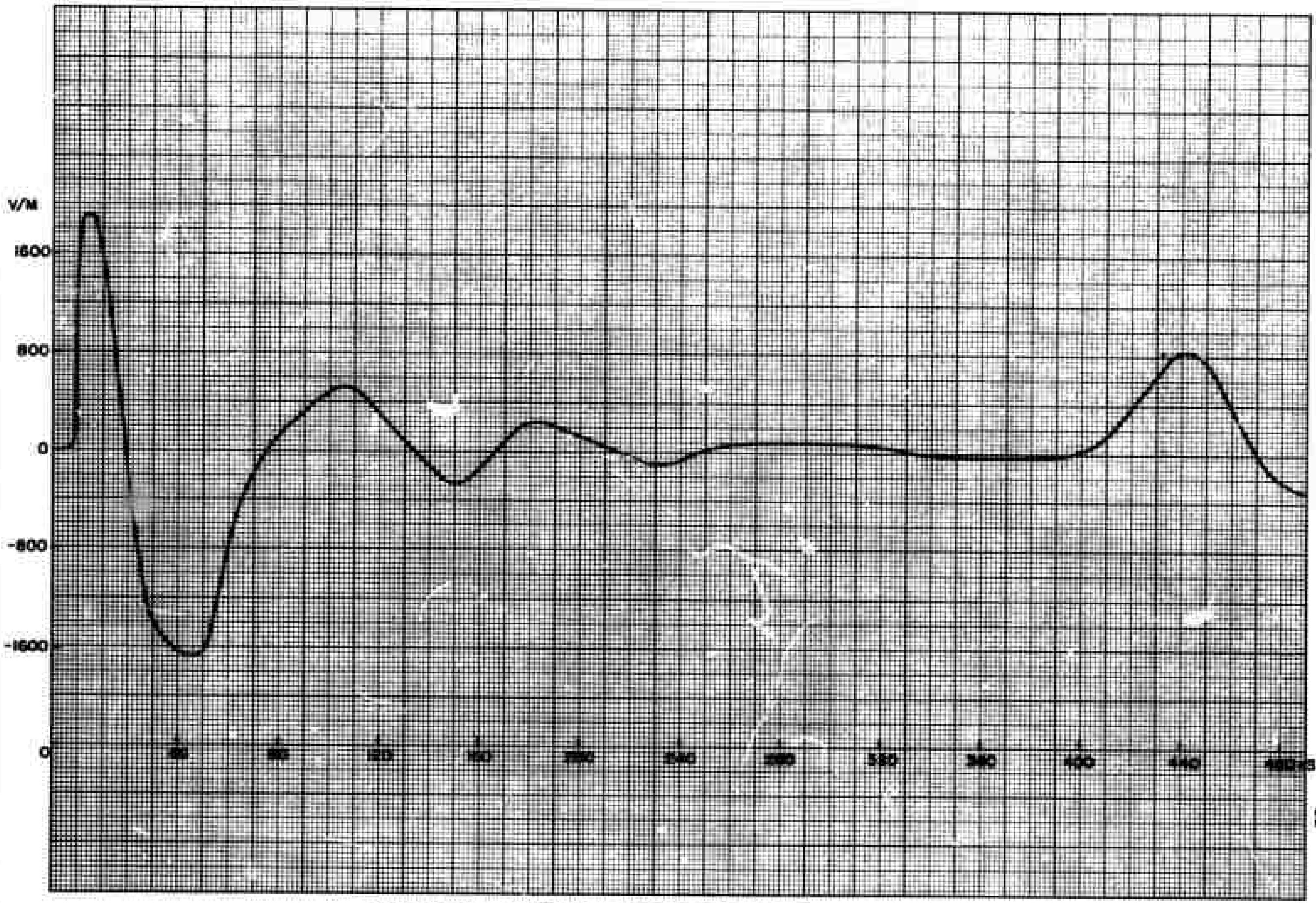


FIGURE 14, IMPROVED DOUBLE PULSE

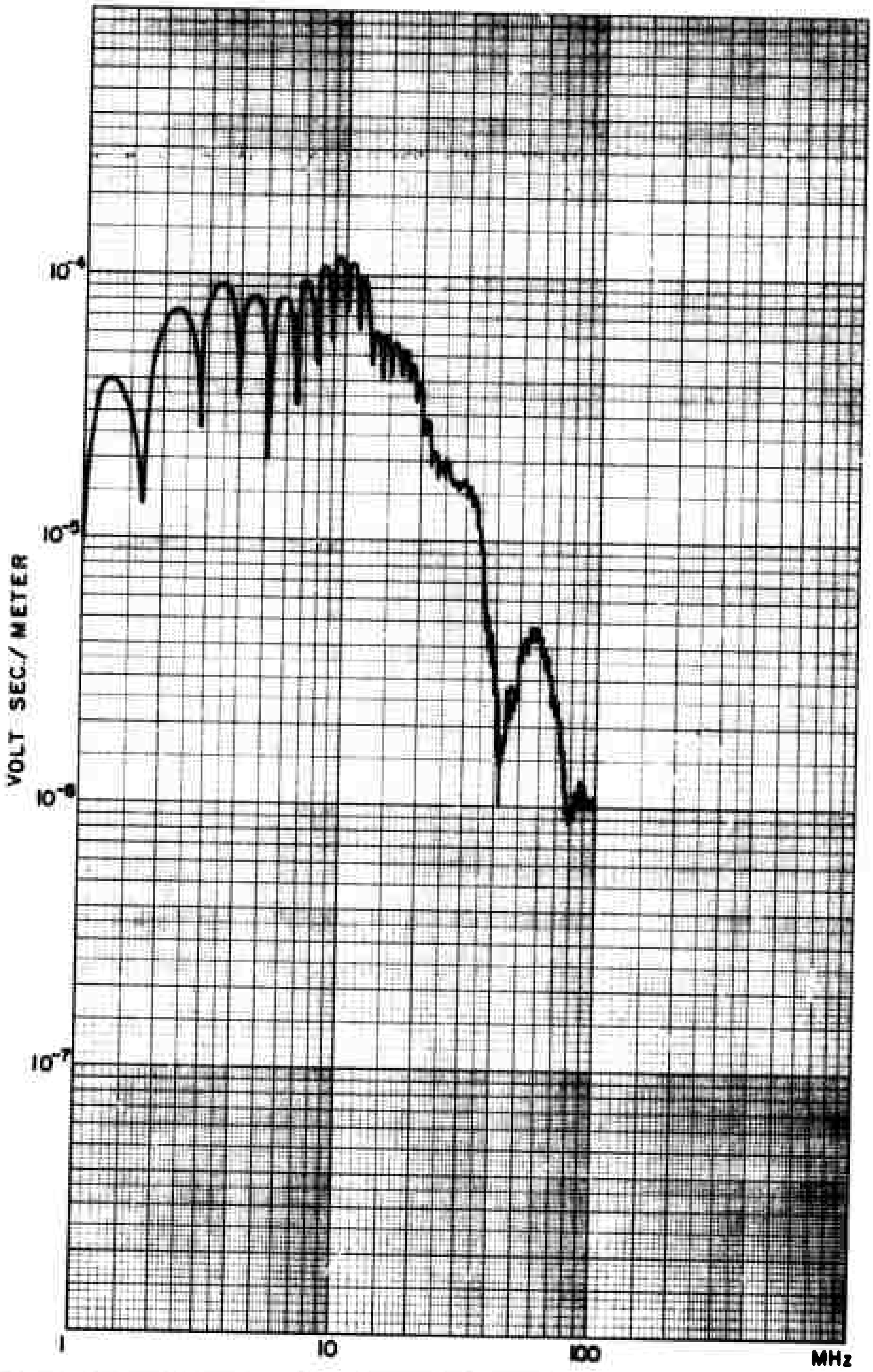
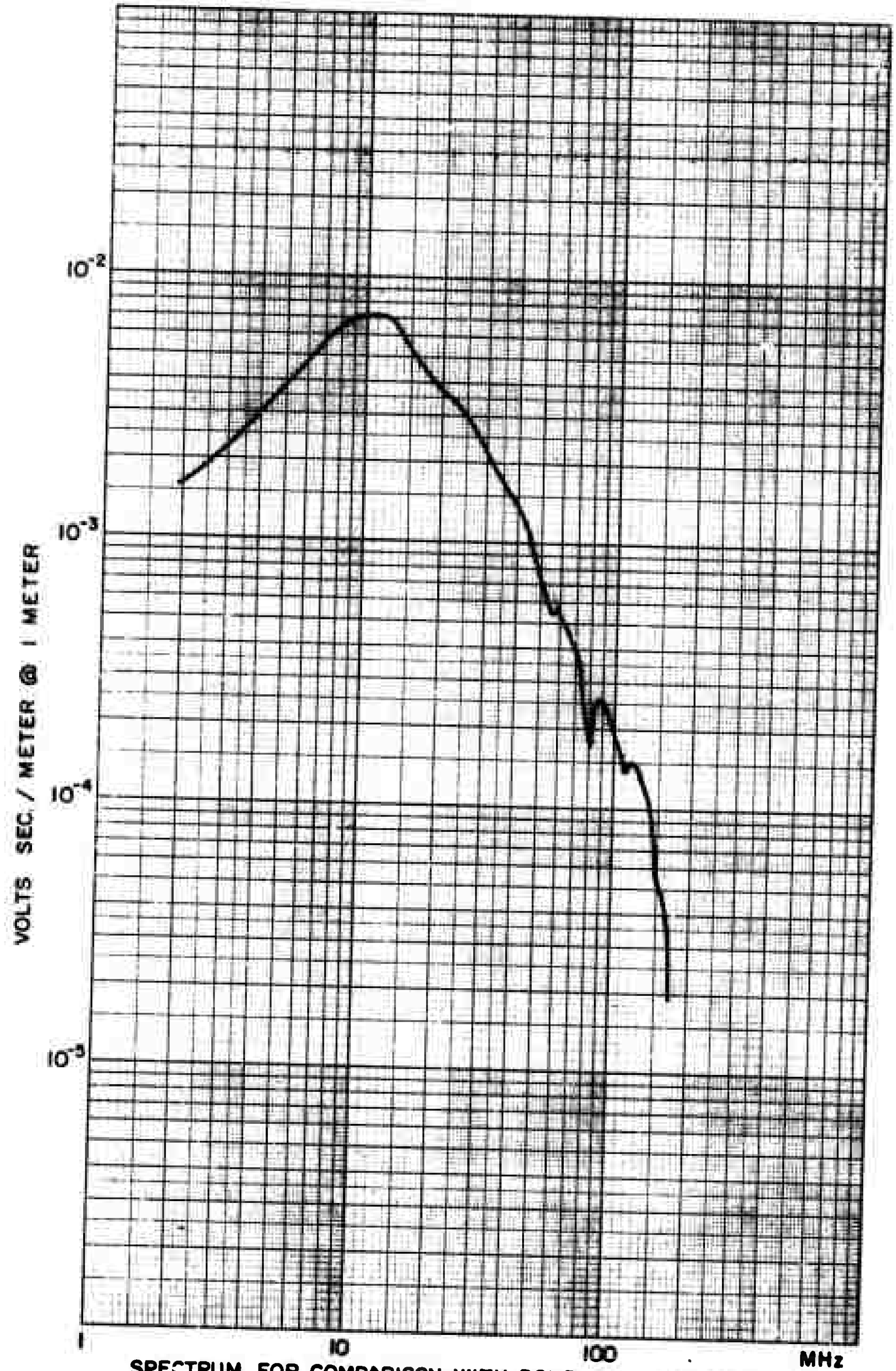
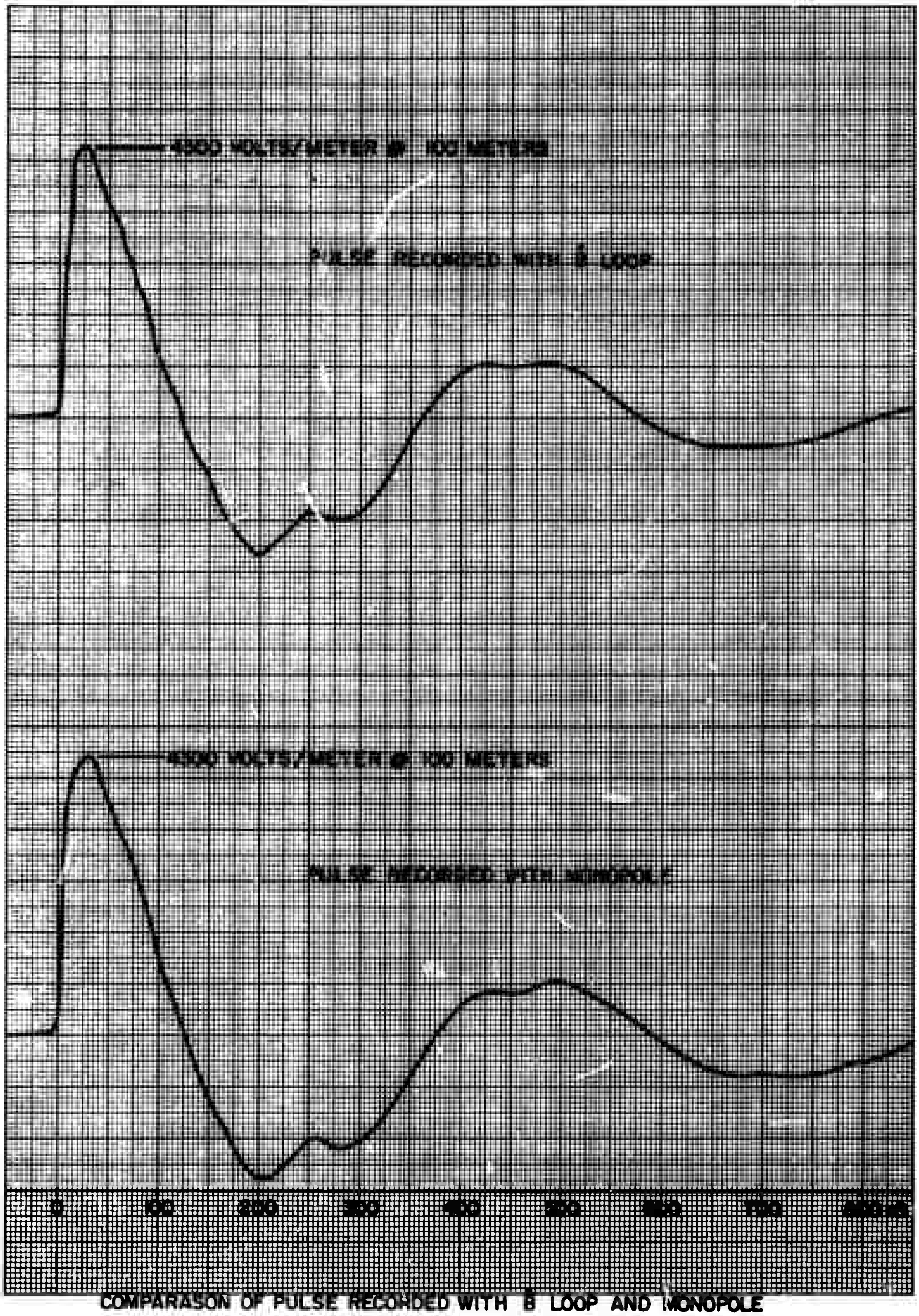


FIGURE 15, SPECTRUM OF IMPROVED DOUBLE PULSE



SPECTRUM FOR COMPARISON WITH DOUBLE PULSE SPECTRUM

FIGURE 16



COMPARASON OF PULSE RECORDED WITH $\dot{B}$ LOOP AND MONOPOLE

FIGURE 17

The azimuthal and elevation radiation patterns of the pulser were mapped. The importance of a ground plane around the pulser was clearly demonstrated by these tests. A vertical E field sensor on a spherical ground plane was used for the field mapping. The spherical dipole shown in Figure 18 is similar to the sensor used in Hawaii.

F. Maintenance

In January 1972 the pulser was disassembled for routine maintenance. In addition to cleaning and inspecting all parts, it was necessary to increase the percentage of ethylene glycol in the water capacitor. Almost two gallons of the old solution was drained and replaced with pure ethylene glycol. Every precaution was taken to prevent air from entering with the ethylene glycol, but after two days bubbles were apparent along the walls of the tygon tubing.

A similar problem was discovered in the copper sulfate charging resistors. Large bubbles were found in the resistors when the pulser was disassembled. Attempts to refill the resistors resulted in more bubbles within one or two days. It was becoming doubtful that the bubbles were actually air, and therefore the gas was analyzed on the DRI mass spectrometer and gas chromatograph. Both instruments showed strong concentrations of Freon 12 with a somewhat smaller amount of sulphur-hexafluoride. Although the source of the Freon 12 could not be immediately determined, the sulphur-hexafluoride was obviously from the sulphur-hexafluoride contained in the Marx housing. Further investigation revealed that Freon 12 was in fact leaking into the Marx housing from the pressure vessel. The leak was stopped, but it was still necessary to deal with the apparent problem of gases migrating through the walls of the tygon tubing. Even after the tubing had been out of the sulphur-hexafluoride for three weeks, there was still sufficient gas in the walls of the tubing to cause the observed bubbles. This fact was substantiated by the occurrence of bubbles in the H_2O system as well as the resistors.

It was decided to replace the tygon tubing with a less permeable tubing. Polyurethane tubing is hopefully much better for this application. Coincidentally it was discovered that polyurethane had been specified (but not installed) for all tubing connected to the water capacitor. All polyurethane tubing was used when the pulser was reassembled.

Close examination of the water capacitor revealed another problem. The lucite top of the capacitor had been damaged by high voltage tracking. However, the damage was minor compared to that described in Quarterly Technical Report #2566. There were only two tracks, and these were sanded and polished out by hand.

In addition it was found that the Marx gap enclosures had become contaminated so that a resistance of less than ten megohms appeared across the gaps. This loaded the high voltage power supply and limited its output to about one kilovolt. Efforts to clean the gaps without further disassembly were unsuccessful. It was decided to completely rebuild the gaps using new lucite parts, and this solved the problem.

Still another problem was discovered after the pulser had been reassembled and fired several times. There was one place where two copper

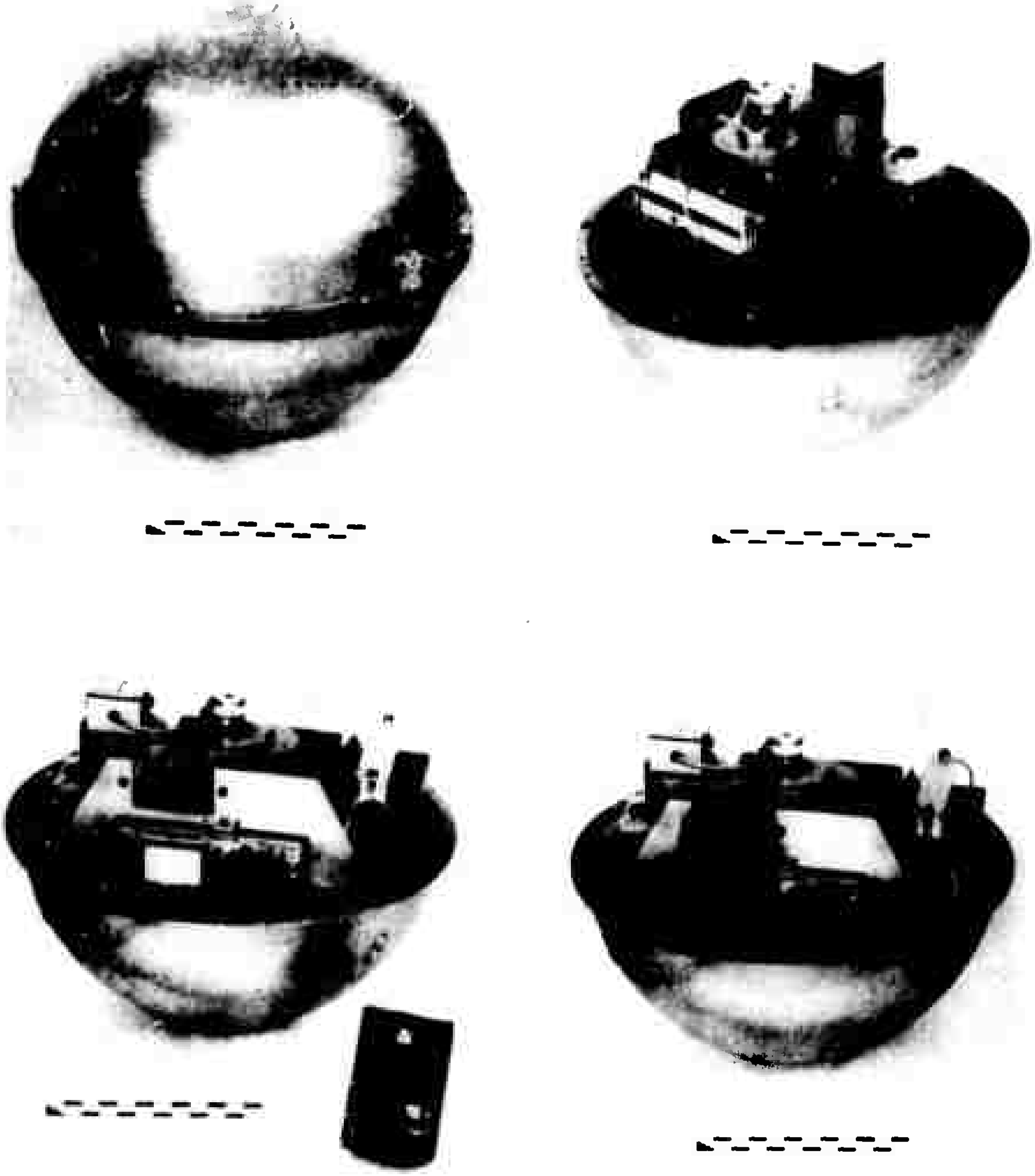


FIGURE 18

SPHERICAL DIPOLE: Designed and fabricated by the Denver Research Institute, this self-contained recording sensor is used to map E-fields in the vicinity of the EMP Simulator and to provide signal intensity measurements at distances up to 10 km for calibrating aircraft antennas at frequencies up to 75 MHz.

sulphate resistors touched each other. The walls of the polyurethane tubing broke down under the high voltage and sprayed copper sulphate all over the Marx housing. The entire Marx housing had to be disassembled and cleaned with alcohol and freon. The two resistors were rebuilt and repositioned so that there was a space of at least one half inch between all resistors. The pulser was returned to good working order.

G. Shelter for EMP Simulator

On 4 April 1972 the contract was amended (P00001) to provide for an increase in funding, and the statement of work was modified by the addition of item No. 3, "Construct a building on Government owned land provided as referred to in Section J.5 hereof to house the EMP simulator in accordance with the Contractor's Drawings ED-100-11510, Sheets 1 through 4, and Contractor's letter (DRI Proposal E7118A - Amendment) dated 12 August 1971."

Following receipt of the amendment, candidate sub-contractor's were asked to submit final quotations for the erection of a pre-fabricated temporary-type steel shelter which would satisfy the drawings referred to above at minimal cost. The intent of the shelter is to protect the simulator, particularly during repair procedures when it might be necessary to remove the covers from the high-voltage discharge areas. It is important that these internal areas of the pulser be kept immaculately clean to prevent premature and uncontrolled discharges which can damage the instruments and result in excessive repair costs.

The shelter was designed with two functional areas. An ante-room, 20' x 40' x 24' high with a 22' overhead door is included for bringing the EMP simulator into the shelter with a crane. Provisions are included for an overhead crane, built into the ceiling of this portion of the building to lift off segments of the pulser during dismantling procedures and, of course, to replace these segments after maintenance has been accomplished.

Another part of the shelter, 40' x 40' x 12' high is included for actual repair work on sub-assemblies of the pulser, for maintenance equipment and for test equipment. During tests of the pulser indoors, it is necessary to have several yards of distance between the operators and maintenance personnel and the pulser. Also, it is necessary to have considerable space around the pulser free of conducting materials lest the discharges be uncontrollable. Safety considerations were largely responsible for the size and shape of the structure, added to the fact that it is necessary to use heavy-materials handling equipment in manipulating the EMP simulator and its sub-assemblies.

The successful bidder, Bickle Construction Company, was granted a sub-contract in July 1972 and the shelter was completed on 5 October 1972.

H. Pulser Operation at Kirtland Air Force Base

During June and July the pulser was on loan to the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico. DRI personnel disassembled the pulser, packed it for shipment, and assisted in making it operational at Kirtland. The pulser was fired 846 times during the two months. A minor problem of arcing from the charging resistors was corrected by AFWL personnel. After being returned, the pulser was re-assembled and found to be in good working order.

III. CONCLUSIONS

Wideband radiation from the Cherry Creek Field Site Pulse Generator is insufficient for ranges of the order of 3000 KM, at least for receiver bandwidths of the order of 1 MHz. A directional, tuned radiating antenna, as was used in the latter stages of the testing, perhaps with grounding radials, might permit wideband reception at ranges of the order of 1500 KM. Such testing should await completion of the instrumentation currently being developed for the OTH program.

The pulser is a reliable and useful tool for testing EMP receiving systems.

The feasibility of using a transmission delay line to produce a delayed second pulse has been demonstrated. Some improvements have been made to increase the amplitude of the secondary pulse. Further improvement can be made by reducing the mismatch at the secondary antenna and by eliminating corona breakdown on the transmission line.

The monopole sensor mounted on the screen box can be used with good confidence whenever it is required.

A number of problems were discovered during the maintenance operation but were corrected before any major damage was done. The maintenance work has provided valueable experience in dealing with pulser malfunctions. Tygon should not be used in the Marx housing; it is probable that polyurethane will be a much better material. Only a long term test can determine this.

The new building provides a good shelter for the pulser and will significantly improve the efficiency of servicing the pulser.

The pulser can be utilized quite effectively to provide services to the EMP community at a reasonable cost. The operation of the unit in Hawaii was satisfactory in all respects.

IV. FUTURE WORK

Much remains to be done to improve the radiation efficiency of the simulator. Effective ground plane design is one important area that should be investigated. In addition the Cherry Creek Field Site installation should be modified to take advantage of the pulser modification made for the AEC/Hawaii tests. The field of the pulser must be mapped and the double pulse technique should be pursued to provide more accurate source data for airborne equipment calibration.