

PETTY LABORATORIES, INC.

San Antonio, Texas

GENERAL APPROACH

TO

INITIAL FIELD EXPERIMENTS

Development of

Sonic Archaeological Probe

GENERAL APPROACH  
TO  
INITIAL FIELD EXPERIMENTS  
Development of  
Sonic Archaeological Probe

I. Object

The object of this development program is to provide a sonic probing or exploration system capable of locating and outlining, from the surface of the earth, archaeological ruins and objects buried under shallow alluvium. Location of stone and masonry artifacts having a minimum dimension of four feet, as well as larger ruins of considerable horizontal extent, is desired. Maximum depth of burial is considered to be about thirty feet. Assuming development of a satisfactory technique, design of the final instrumentation should satisfy requirements for maximum portability, simplicity of operation and minimum required interpretation of data.

II. Basic Considerations

Although the desired depth of penetration for the sonic probe is quite modest, by comparison with commercial geophysical exploration, the relatively small size of the objects and the resulting requirement for high sensitivity and resolving power result in major problems. For example, an object 4 feet in diameter at a depth of 30 feet subtends an angle of only 7 degrees, as viewed at the surface, so that the energy intercepted from a rather wide-beam source at the surface is relatively small. Again, on a wavelength basis the object also would represent a rather small target. If the velocity in the alluvium cover is 1000 feet per second, the 4 foot object would represent an obstacle of only 2 wavelengths dimension at 500 cycles

per second. For purposes of adequate resolution, frequencies of the order of 500 cps or higher probably would be necessary to result in useful reflections or other signal indications with any practical amount of sonic power at the source. Choice of this frequency range implies rather high propagation losses and probable use of peak power techniques.

Selection of the most suitable frequency definitely will require compromise between various factors. So far as resolution and target area are concerned, the frequency should be as high as practical; with regard to propagation loss, a much lower frequency is preferable. From the practical aspect of portability, a higher frequency and consequently shorter wavelength should result in smaller and lighter transducers. Referring to Figure 1, the possible range of operation can be explained briefly. Assuming alluvium overburden, the longitudinal sonic velocities most probably will be in the range of 550-5500 feet per second. If a minimum target dimension of one wavelength is assumed as necessary to meet energy and resolution requirements, probe operation should be in the range 130-2500 cps, with the higher velocity subsurface materials necessitating use of higher frequencies. Consideration of the attenuation and propagation loss, which is much greater at the higher frequencies, probably would necessitate an upper limit between 500 and 1000 cps.

### III. Proposed Field Measurements

Experimental investigation of the propagation parameters is necessary to provide a sound basis for design of the sonic instrumentation. Initially, measurements should be made to determine the maximum useable frequency for penetration to a depth of about 30 feet, using a practical power level at the source. Secondly, it is desirable to determine if reflections or other useful indications can be obtained from buried objects under the specified conditions.

A series of measurements in a typical subsurface are proposed to determine these propagation factors and the general possibilities of the method. For determination of the signal level decay as the sonic wave progresses into the earth, a series of closely spaced holes will be drilled to different depths so as to include a depth range of about 5 to 24 feet (Figure 2). In each hole a sonic detector will be "planted" carefully so as to insure efficient coupling to the earth. Near the surface, and in line with the spaced detectors, a source of sonic energy will be installed in a somewhat larger hole so that the distance to the closest detector is only several feet. This first detector will have a relatively large signal output which can serve as reference level for the measurements.

The source device will be coupled to the earth through a liquid in the hole, with the walls of the hole made impermeable by coating with plastic, paraffin or other material of suitable characteristics. A simulated target object will be prepared, in line with the detector arrangement, by pouring one or two cubic yards of concrete into a hole 4 feet or so in diameter and 30 feet deep. A detector will be installed on the upper surface of this object while the concrete is wet so as to insure good coupling. Finally the large hole will be filled with the removed material and restored so far as practical to the original conditions.

By measuring the signal outputs of the spaced detectors, for different source frequencies and power levels, the following information should be obtained rather directly:

- (1) the decay in signal level as a function of distance, for different frequencies, in the particular subsurface;
- (2) an indication of the useful penetration which can be obtained with available energy sources, from which the amount of energy required in the final system can be

predicted; and

- (3) data on the coupling efficiency between the source and the earth, which can be investigated concurrently with the other measurements.

After one-way transmission of a useful signal is achieved, attempts will be made to obtain indications of reflections or other signal return from the target object. If the initial attempts are only partially successful, it will be desirable to have shallower objects on which tests can proceed. For this purpose other simulated target objects of the same size, but buried at depths of 8 and 15 feet, will be included in the field arrangement (Figure 3). Successful probing indications on these shallower targets would field information needed for possible modification of the technique to achieve the maximum depth.

It is planned to locate this arrangement of test holes and simulated targets in a suitable area near San Antonio, Texas. The proposed test site is located between a river and creek which are about one mile apart. The surface is sandy loam and subsurface is known to be soft clay and sandy clay. Longitudinal sonic velocity in the subsurface down to 30 feet is about 1900 feet per second, so that a transmission frequency of 500 cps would result in a wavelength of about 3.8 feet. The velocity contrast between the earth and a concrete target, with a velocity of perhaps 10,000 ft/second, should be sufficient to insure a good reflection factor; thus, reflected energy would be dependent largely on the target area. This locality is believed to be sufficiently representative of the desired type of subsurface, at least for the initial experiments.

The general arrangement of instrumentation for the propagation tests is indicated in Figure 4. A power transducer will be driven from a power source controlled by a variable frequency oscillator, so that measurements can be

made over the wide frequency range. Detectors most probably will be of the acceleration-responsive type which is more effective at higher frequencies. A preamplifier will be used to couple the accelerometer to the surface amplifier and to provide improved signal-to-noise operation. In the surface measuring equipment, a tuned amplifier will be used to exclude interfering signals and greatly improve the detection capabilities of the system. Direct meter measurements will be made of the received and amplified signal, particularly for continuous transmissions, and provisions will be made for oscillographic recording which will be most useful with impulsive signals.

#### IV. Present Status of Preparations

Measuring instrumentation for the field propagation tests has been assembled in a truck for use at the test site. A small number of acceleration detectors are available for the initial tests and the necessary preamplifiers are being constructed. Some velocity type detectors also have been assembled with cables for comparison purposes in the initial work. In the final arrangement for deep planting or burial, the preamplifiers will be housed with the acceleration-responsive unit in a single protective casing.

Initial propagation tests are underway at the laboratory with a separation of a few feet between source and detector. Although this location is not suitable for deeper tests because of noise and subsurface limitations, experimental work can proceed on source coupling to earth and related instrumental problems.

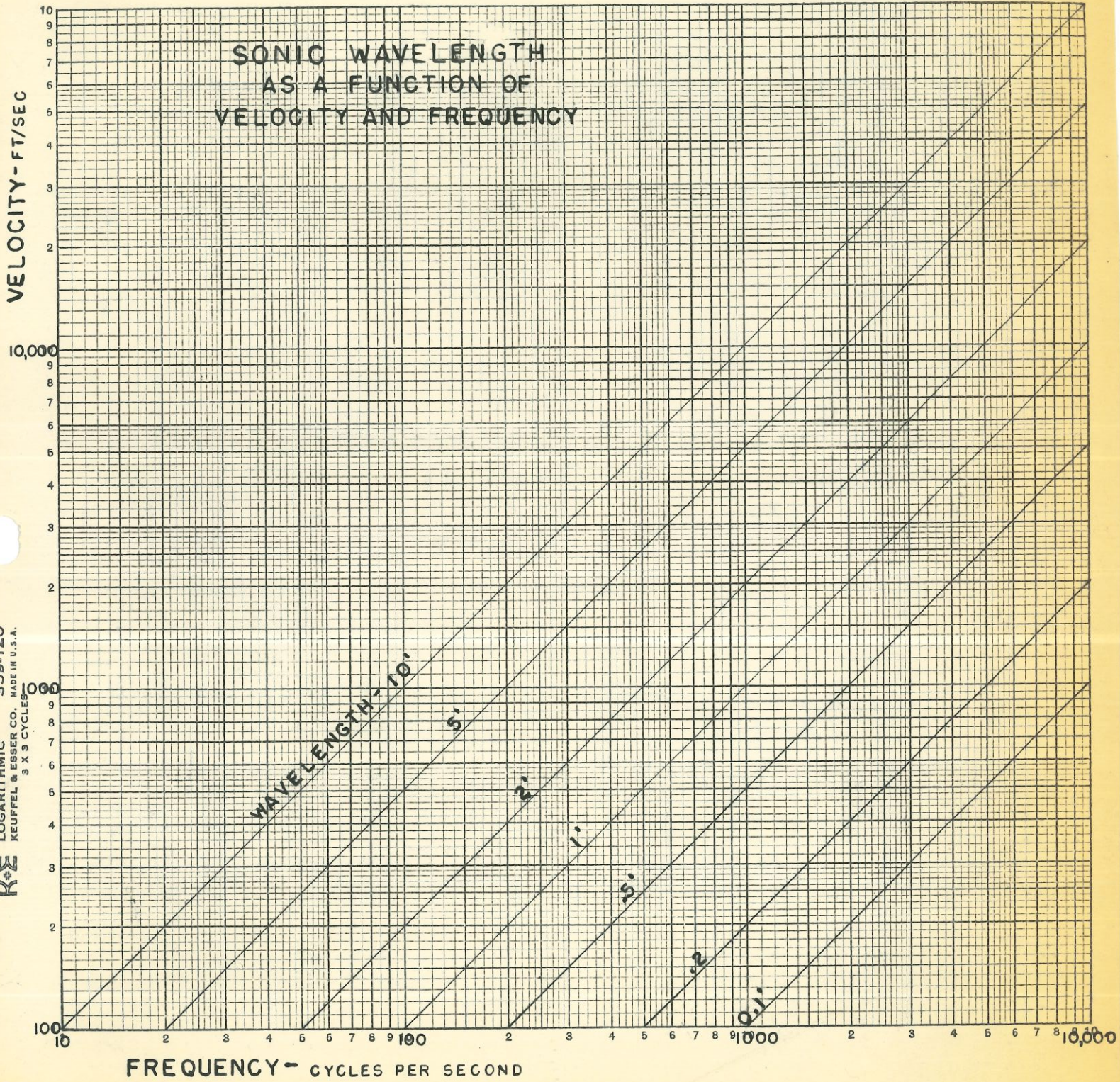
Arrangements are in progress for the full scale tests, down to 30 feet, at a rural site about 18 miles from Laboratory. Necessary power and other facilities are being installed and preliminary determinations are being made of related factors such as ambient noise level, noise frequencies etc.

#### IV. Conclusion

As a result of the field propagation measurements, the possibilities and requirements of the method will be determined. Either successful operation will have been achieved or the major necessary requirements for a successful design will be known on the basis of experimental data. From this basis it is believed that any necessary additional development work could continue, and design of the instrumentation could proceed concurrently.

Figure 1

SONIC WAVELENGTH  
AS A FUNCTION OF  
VELOCITY AND FREQUENCY

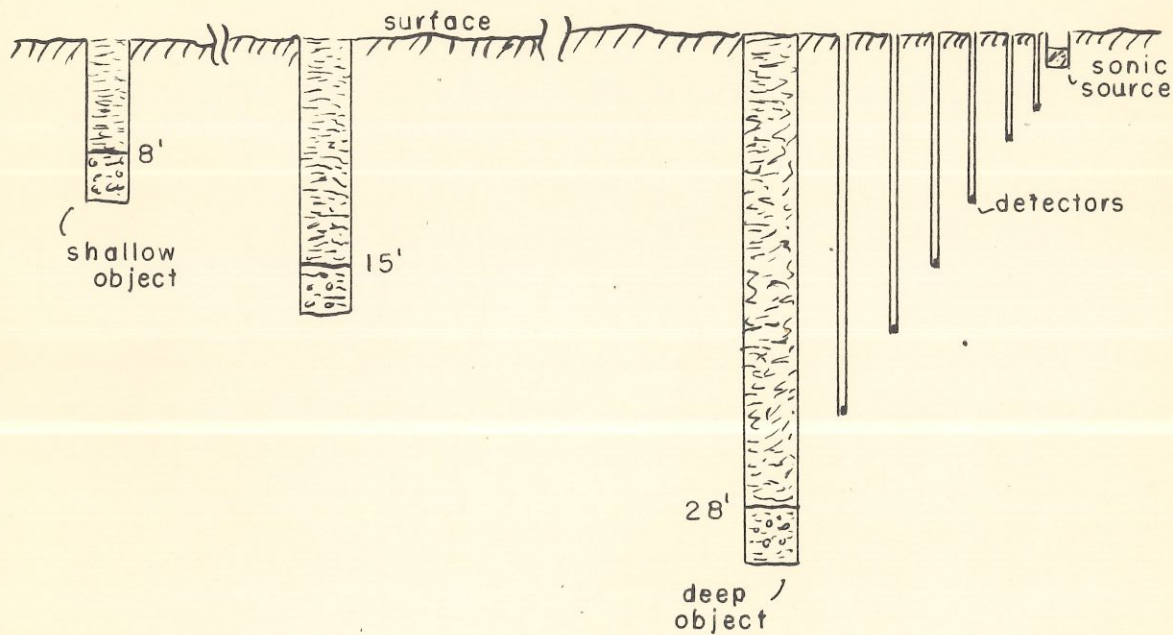


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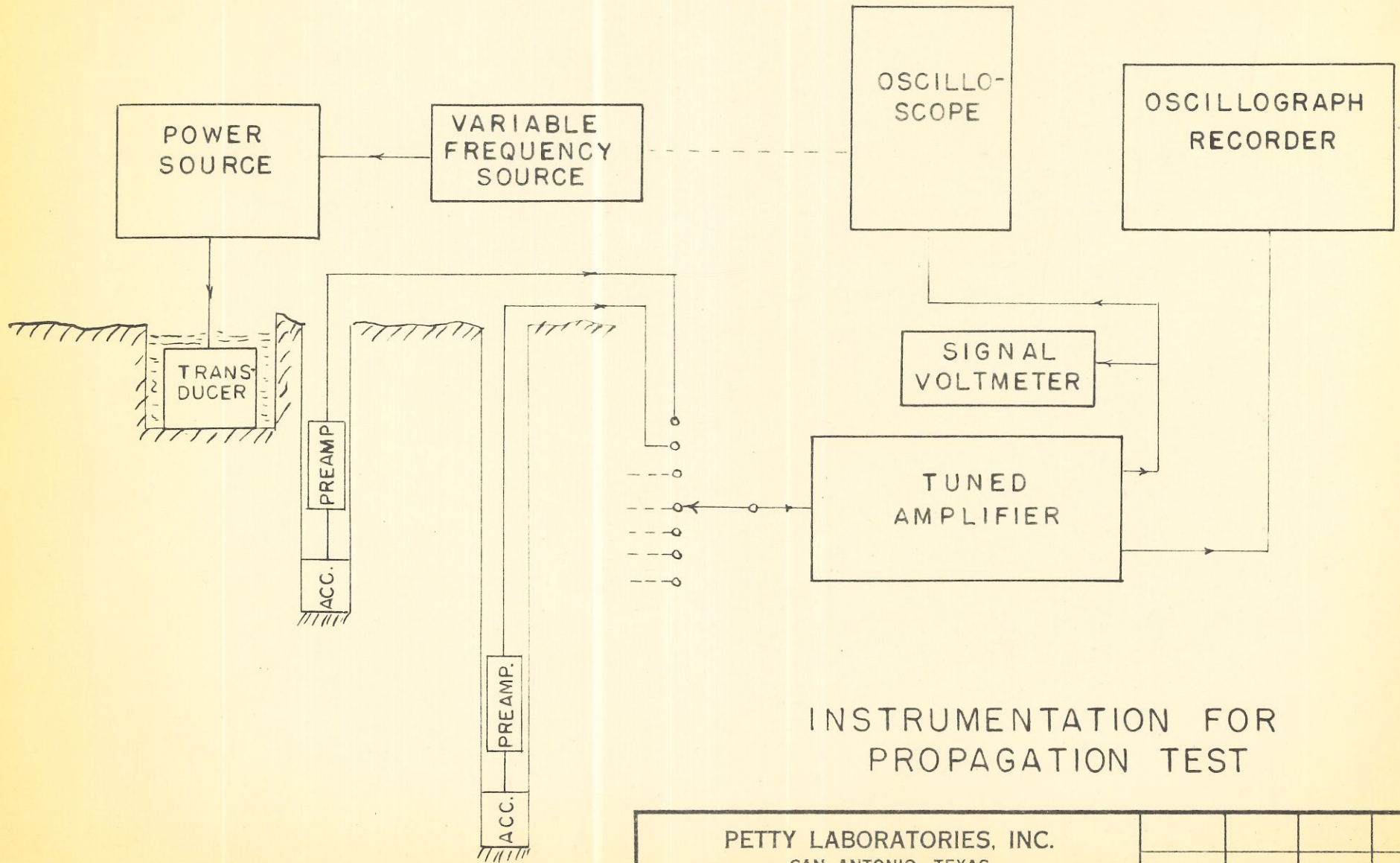


# SUBSURFACE ARRANGEMENT

## LOCAL FIELD TEST SITE



PETTY LABORATORIES, INC. SAN ANTONIO, TEXAS						
ARCHAEOLOGICAL PROBE DEVELOPMENT FOR UNIVERSITY MUSEUM	MAT. FFH	REQ'D	SCALE 3-18-62	CKD.	PART NO.	



### INSTRUMENTATION FOR PROPAGATION TEST

PETTY LABORATORIES, INC. SAN ANTONIO, TEXAS				
ARCHAEOLOGICAL PROBE DEVELOPMENT FOR UNIVERSITY MUSEUM	MAT.	REQ'D	SCALE	
	FFH		3-17-62	
	DRAWN	CKD.	PART No.	

Figure 1



P. O. DRAWER 2061 • SAN ANTONIO 6, TEXAS

512 CAPITOL 6-1393 • CABLE: PETTYCO

INCORPORATED 1932

Sonic Archaeological Probe

Development

PROPAGATION MEASUREMENTS  
IN TYPICAL EARTH

Interim Technical Report

No. 1

Prepared By:

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Petty Laboratories Inc.  
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Sonic Archaeological Probe Dev.  
Propagation Measurements in Typical Earth  
Interim Report No. 1 10/1/62  
SUMMARY

Propagation measurements have been made at various frequencies in the range 200 to 1600 cycles per second. A vertical spread of seven acceleration type detectors, planted from three feet to a depth of fifteen feet, was used in conjunction with a symmetrically-located driver one foot deep. Detectors were planted with moist earth and allowed to set or dry before use.

Measurements were made with a low power continuous-wave driver coupled to the earth through an oil medium. Earth at the site consists of a sandy-clay soil having seismic velocity of about 1900 feet per second to a depth of thirty feet. Good signal to noise ratios were obtained for frequencies up to 600 cycles per second and distances up to fourteen feet. Additional measurements using impulse operation of the driver are presently underway.

The investigation thus far indicates that an operating frequency of no higher than about 600 cycles per second should be used for the sonic probe. Driver powers of some hundreds of watts probably will be required for fully reliable measurements to 25 or 30 feet on a continuous-wave basis.

# Sonic Archaeological Probe

## Development

### PROPAGATION MEASUREMENTS IN TYPICAL EARTH

#### I. INTRODUCTION

In previous reports an experimental investigation of the propagation conditions in typical earth has been indicated as necessary to provide a sound basis for design of the sonic instrumentation. The purpose of the present work was to carry out the initial phase of this investigation and make at least preliminary conclusions as to the most desirable frequency range to be used and the sonic power requirements.

Continuous-wave signals have been used in all measurements in the presently described investigation. Although signals traveling along indirect paths may result in some confusion when the continuous-wave technique is employed, observation and evaluation of the received waveforms on an oscilloscope permit differentiation of the desired signal and the undesired signals and noise. The resulting data are believed to be quite representative of the actual signal conditions.

## II. DISCUSSION

### A. Measuring Arrangement

#### 1. General Instrumentation

Instrumentation for measurement of the sonic signal decay in earth follows the general arrangement as outlined in previous reports. Major elements of the sonic driver and signal measuring systems are shown in Figure 1 of the illustrations.

The driver system consists essentially of a 25 watt power source adjustable over a wide frequency range and an underwater type speaker unit which is coupled to the earth through a fluid medium. Monitoring equipment is provided for maintaining the electrical power at the desired level.

In the measuring system acceleration type detectors are used with a high gain wide-band amplifier which has calibrated attenuators and provision for plug-in filters of various types. Amplified signal output is measured on a precision AC voltmeter and the received waveform is viewed on a cathode-ray oscilloscope.

The acceleration type detectors, designed especially for this work, and the arrangement for coupling the driver output to the earth have proven of major interest in the instrumentation.

#### 2. Acceleration Detectors

Although several small velocity type moving coil detectors were tried early in the work at the site, these proved quite inferior at the higher frequencies (400 cps and above). To take advantage of the characteristic of an accelerometer which increases in motion sensitivity with increasing frequency, a special detector has been designed.

The detector assembly consists of a ceramic crystal with mass directly coupled to an emitter-follower amplifier of high input and low output impedance. As illustrated in Figure 2, these two units are combined in an aluminum case 2-7/8 inches long by 1-5/8 diameter which is completely sealed by "O" rings against the elements. Both signal output and operating power for the unit are transmitted over a two conductor shielded cable from the surface. Required power is about .5 ma at 12 volts direct current.

During the development various changes in the detector resulted in great improvements in the signal to noise ratio; i.e., one type transistor change resulted in a 25:1 signal to noise improvement and about 20% increased performance has been achieved in later units. These improvements in design have resulted in an increase of about six feet in the usable distance at higher frequencies.

Four of the detectors have been used in the measurements at the site and eight additional units have been completed for future use. All of the detectors have been calibrated for motion sensitivity at the laboratory.

### 3. Driver Coupling To Earth

In the course of the investigation attempts were made to provide an optimum coupling medium between the driver and the earth, water, starch solution and oil were tried. As reported previously, the starch solution can be varied widely in viscosity but the tendency to thicken as the water evaporates makes the medium unstable. Consequently SAE 140 lubricating oil was used in all of the later tests. Fluid viscosity of this oil is quite stable and the coupling was improved by 3 db over water.

Various types of drivers have been tried. Horn type units required an air column between diaphragm and oil resulting in very poor impedance

match. Finally an underwater speaker type of driver has been used; maximum sine wave power capability is 25 watts and a larger diaphragm is in direct contact with the oil, resulting in greatly increased coupling efficiency.

At the time of the present report the coupling problem has been resolved with a driver hole 11 inches in diameter by one foot deep, lined with a thin plastic material (to prevent loss of fluid) and filled with six gallons of SAE 140 oil. Vertical position of the driver (University Model MM2FUW underwater speaker) was varied until the best coupling was achieved. Best position for the driver is against the bottom of the hole, with all air purged from the unit.

#### B. Propagation Measurements

In the arrangement for propagation measurements the driver and detector were arranged in the configuration shown in Figure 3. The driver was located at the center of a circle of eighteen inches diameter with the detectors planted in four holes of various depths on the circle. A stepped diameter hole was used with a 2-1/2 inch diameter section, at the bottom, in which the detector was planted, packed firmly with moist earth and allowed to dry. This arrangement resulted in minimum disturbance of the earth.

Plants in the three, five and seven foot holes were allowed to remain undisturbed throughout the measurements. In the fourth hole plants of the same detector were made successively at depths of nine, eleven, twelve and fifteen feet for measurements at these depths. In this work the driver to detector distance was the hypotenuse of a triangle formed by the base of eighteen inches and depth of the detector.

Numerous measurements were made at each depth with twenty five watts of continuous-wave power applied to the driver. Narrow passband filters

were used in the main amplifier, for all measurements utilized in this report, so as provide improved signal to noise conditions. For each measurement the noise level was determined so as permit correction of the signal data. The points plotted in Figure 4, showing the signal decay as a function of distance (for various frequencies) are well-established average-value measurements.

Signal decay (measured in acceleration units) for various frequencies is as follows, with the determination effective over the depth interval 4 feet to 10 feet:

200 cps	-	3.5 db per ft.
400 cps	-	4.1 db per ft.
600 cps	-	2.9 db per ft.
800 cps	-	5.1 db per ft.
1000 cps	-	11.1 db per ft.
1600 cps	-	28.6 db per ft.

The crossover and variation in slope in the 200 and 400 cps curves is possibly due to interfering waves reflected from the surface or otherwise. Also, the driver has a low frequency cutoff of 350 cycles per second, and therefore at a 25 watt driving level will not produce as much motion at 200 as at 400 cps. The apparently lower decay in the 600 cps curve is believed due to harmonic interference in the signal output which could not be allowed for in the data reduction; from various measurements it is believed that the 600 cps curve should follow more closely the 800 cps plot.

Rapid deterioration in the 1600 cps curve is partially due to the bandpass filter which has a voltage gain of only 1/2 as compared to a gain of 2 for the other filters. Therefore the response curve suffers from an initial disadvantage of lower signal to noise ratio.

The signal decay curves as plotted for different frequencies are not directly related in that they do not have a common zero reference; but the curves do show, in general, the decay of acceleration versus distance and frequency.

Location of the site for the measurements is in south Bexar County, Texas about 18 miles from San Antonio. Photographs of the site are shown in Figure 5. The earth section is a relatively uniform sandy clay with a variation in color from dark brown at the surface to light brown at fifteen feet.

### C. Additional Propagation Measurements

A measurements program using pulsed sinewave signals is being planned and will be carried out in the near future. Plans call for the use of the present driver equipment and oscillographic type recording for the signal decay measurements. Additional deeper holes will be drilled, along with planting of targets below the surface for reflection work.

## III. CONCLUSIONS AND RECOMMENDATIONS

Tests on propagation of sonic energy in earth have produced information which permits preliminary estimates as to frequency and power requirements for a sonic probe. The relatively low attenuation of signals at the higher frequencies, up to 600 or 800 cycles per second, is very encouraging, particularly in view of the resolution required in probing for rather small archaeological objects.

Based on present results and maximum desired penetration of higher frequency energy to thirty feet, considerably more driver power probably will be required for measurements deeper than the fifteen feet covered thus

far. Some hundreds of watts may be necessary for reliable signal decay measurements using continuous-wave transmissions; kilowatts probably will be necessary to obtain reflections from buried objects as deep as thirty feet.

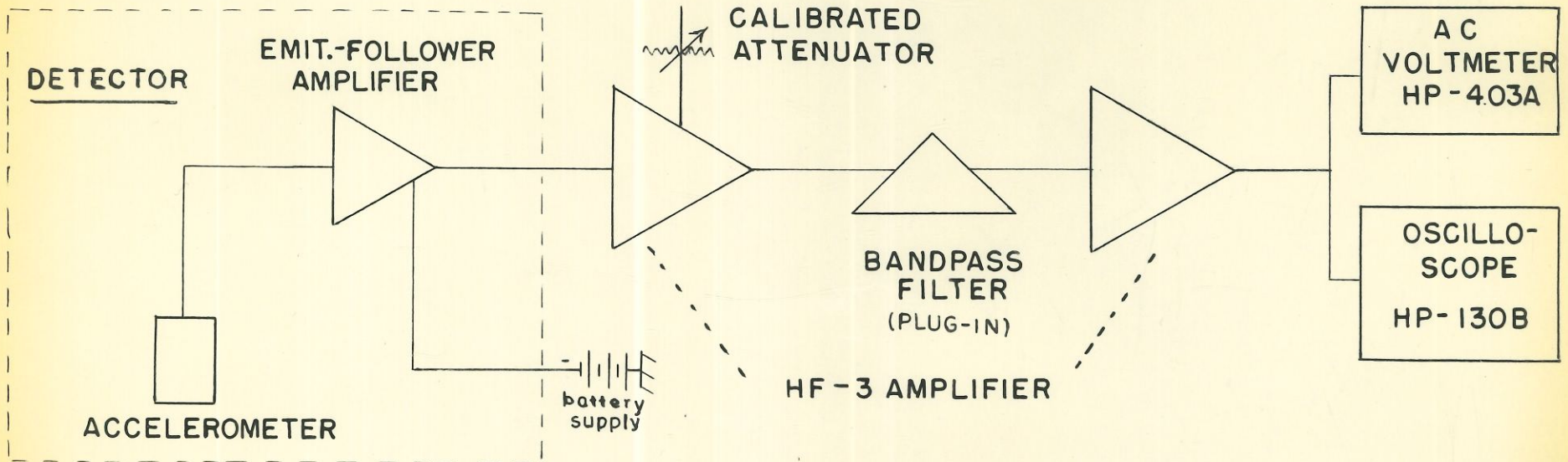
From the present results it appears that the frequency of the probe should be no higher than about 600 cycles per second. Somewhat higher frequencies might be desirable for increased resolution, but the required driver power would become excessive.

It is recommended that additional measurements be restricted to frequencies of 1000 cycles per second and below.

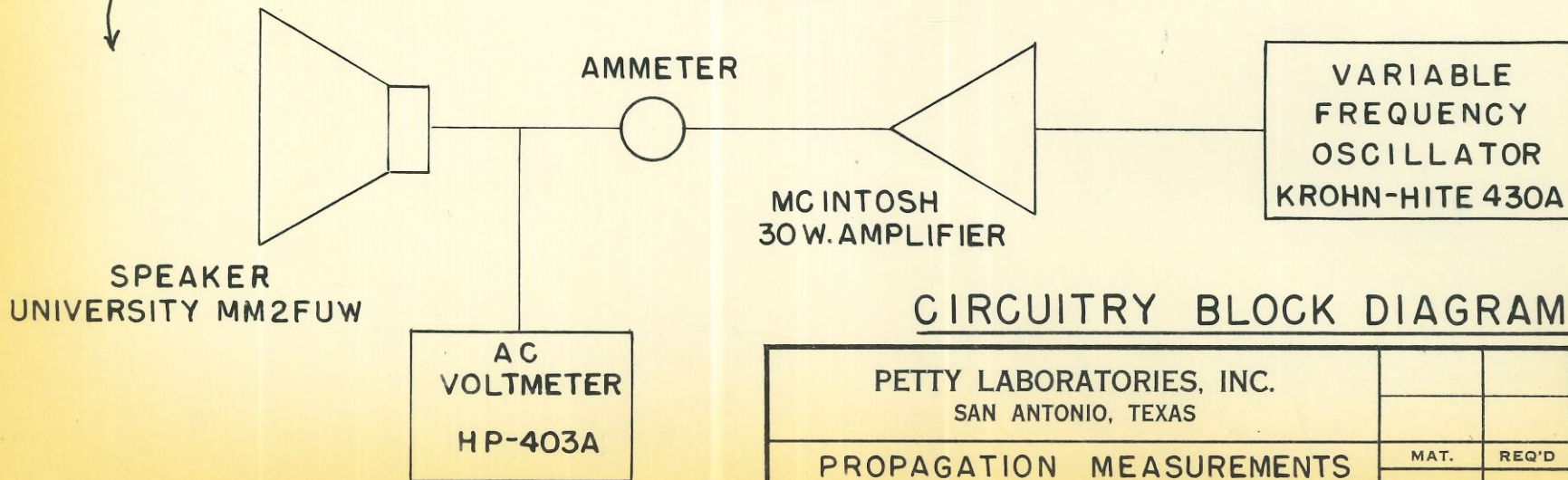
#### IV. ILLUSTRATIONS

- Figure 1 - Circuitry Block Diagrams
- 2 - Sketch of Detector
- 3 - Driver and Detector Plants - Hole Configuration
- 4 - Signal Decay - Detector Motion vs Distance
- 5 - Photographs of Site Location

MEASURING EQUIPMENT



DRIVER EQUIPMENT

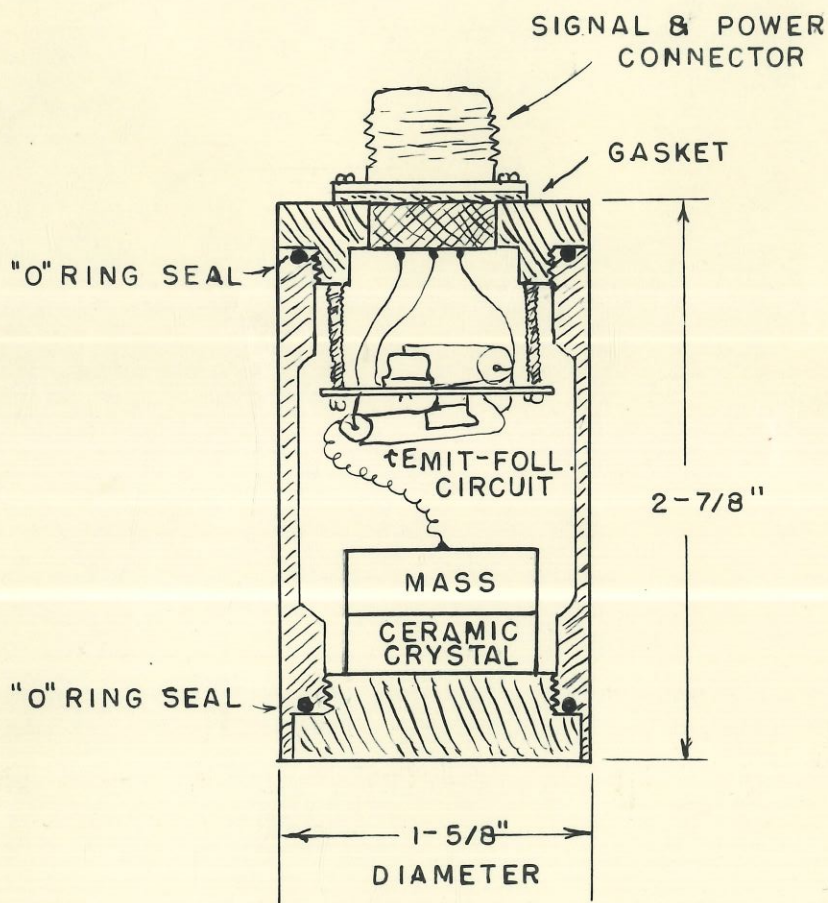


CIRCUITRY BLOCK DIAGRAMS

PETTY LABORATORIES, INC. SAN ANTONIO, TEXAS			
PROPAGATION MEASUREMENTS SONIC ARCHAEOLOGICAL PROBE			
MAT.	REQ'D	SCALE	
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DRAWN	CKD.	PART No.	
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Figure 1

SKETCH OF DETECTOR

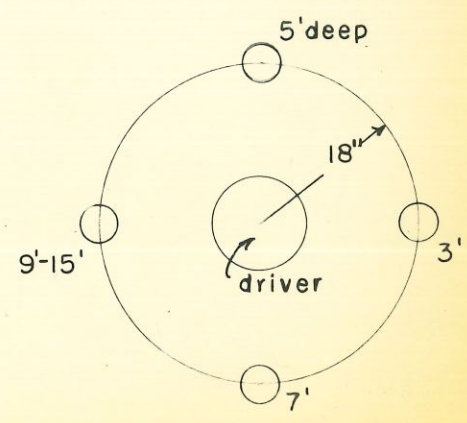
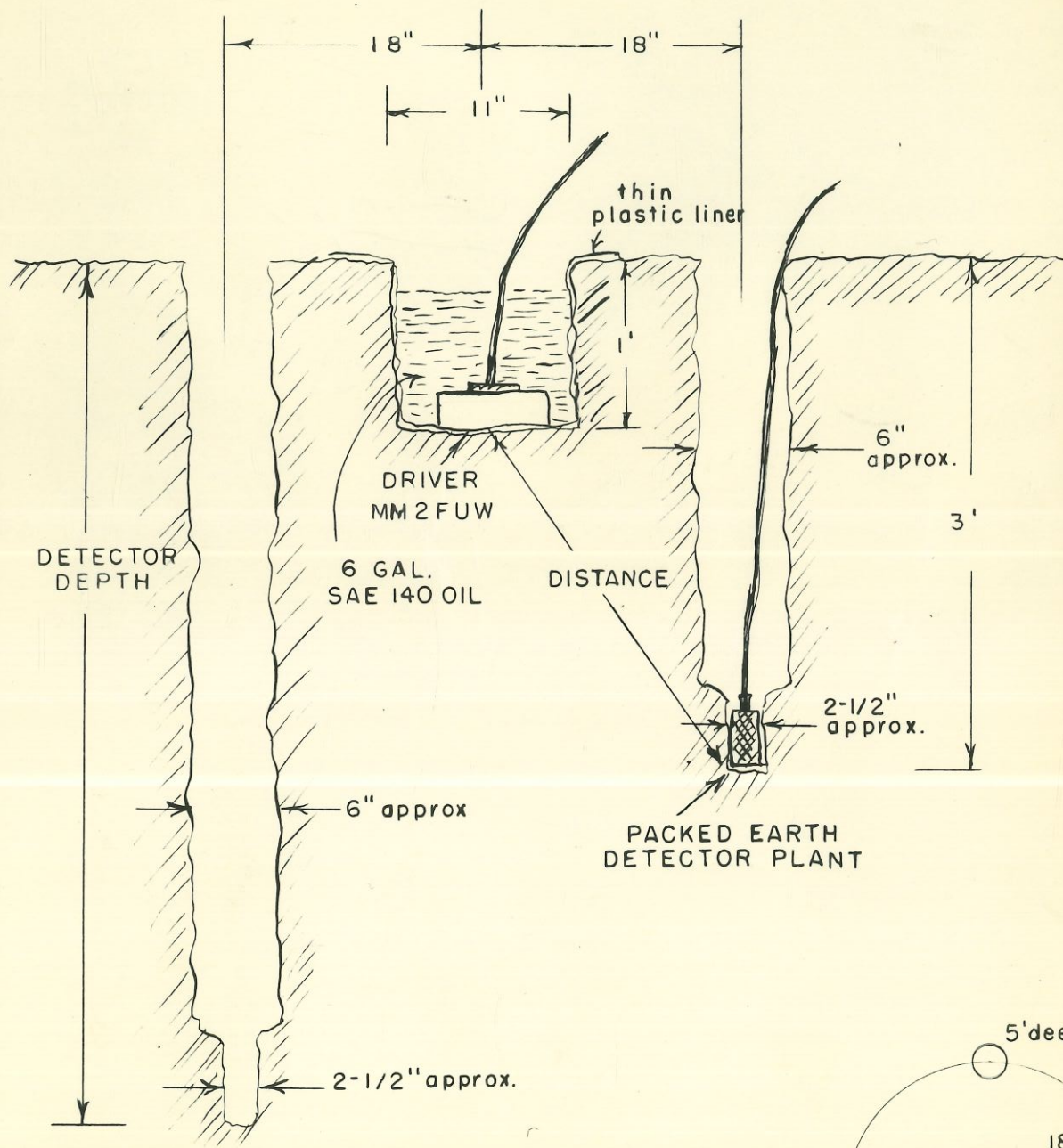


PETTY LABORATORIES, INC.  
SAN ANTONIO, TEXAS

PROPAGATION MEASUREMENTS  
SONIC  
ARCHAEOLOGICAL PROBE

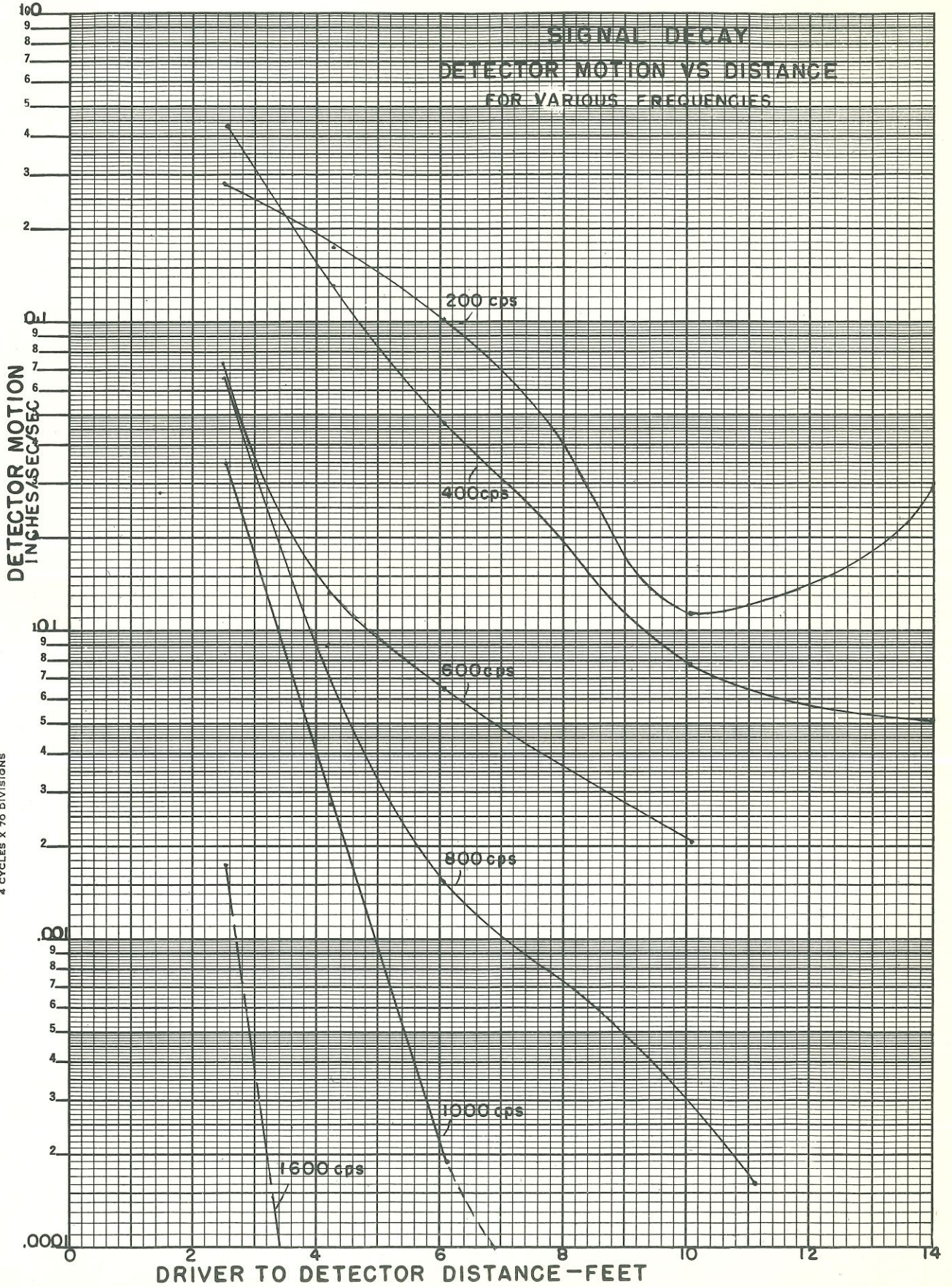
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	ACB.	

# DRIVER AND DETECTOR PLANTS



HOLE CONFIGURATION

			REQ'D	SCALE			PART No.
			MAT.	10-1-62			
			DRAWN	A.S.P.			
PETTY LABORATORIES, INC. SAN ANTONIO, TEXAS				PROPAGATION MEASUREMENTS SONIC ARCHAEOLOGICAL PROBE			



**K&E** SEMI-LOGARITHMIC 359-81  
 KEUFFEL & ESSER CO. MADE IN U.S.A.  
 4 CYCLES X 70 DIVISIONS

OCT 62



View of Test Site

OCT 62



Driver-Detector Arrangement  
At Test Site

Sonic Archaeological Probe

EXPERIMENTAL TESTS WITH THE EDGERTON, GERMESHAUSEN AND GRIER, INC.

"1000 WS AND 500 WS BOOMER SYSTEM"

Interim Technical Report

No. 2

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## SUMMARY

Various tests with the "Boomer System were made initially in a brown sandy-clay soil with buried objects simulated by buried three foot diameter concrete targets.

Vertical spreads of detector plants, from three to thirty feet, were used to measure seismic signal amplitude and frequency produced by the Boomer transducers in water filled driver holes at the surface. Recordings of the signals indicate frequencies lower than 600 cycles predominate, however, the signals were readily detected to a depth of thirty feet, one way path, and the Boomer System proved to be an excellent high power sonic source.

In another test, an attempt was made to obtain reflected seismic signals from a three foot concrete target buried twenty feet deep in the brown sandy-clay soil. The soil directly above the target has a lower velocity than is normal for this location indicating an unconsolidated condition exists. Horizontal spreads of detectors were used in conjunction with horizontal movement of the transducer along a line. Again frequencies lower than 600 cps predominated and this probably accounted for the absence of any measurable reflected signals from the fractional wavelength target.

Since lower frequency signals were recorded, an attempt was made to produce an exploration tool of limited utility for the Museum. The test location was changed to a site that had larger buried objects in the form of limestone beds at depths of eighteen feet and deeper. Portable reflections were obtained from these targets, but the experiments were terminated by the University Museum, because such larger objects are not of sufficient archaeological interest.

Sonic Archaeological Probe

EXPERIMENTAL TESTS WITH THE EDGERTON, GERMESHAUSEN AND GRIER, INC.

1000 WS AND 500 WS BOOMER SYSTEM

I. INTRODUCTION

The purpose of this project is to conduct a study of the feasibility of detecting objects with a minimum dimension of three feet buried at depths of up to thirty feet in alluvium deposits.

Various methods of producing 600 cycles or higher frequency sonic energy in the earth have been tried as discussed in previous reports. The lower frequency limit of 600 cps is dictated by the minimum size of the objects, whereas higher frequencies suffer more severe attenuation through the earth medium.

Through arrangements by Miss Ralph of the University Museum, Dr. Edgerton furnished a "Boomer System" with transducers of 1000 WS and 500 WS power to the Sonic Archaeological project for evaluation in this application.

This report sets forth briefly, the results of these tests with the "Boomer System" and recordings of the seismic signal amplitudes and frequencies so obtained.

## II. DISCUSSION

### A. General Instrumentation

Equipment for the project is truck mounted with provision for recording up to twelve inputs for simultaneous recording.

Acceleration type detectors are used to measure the seismic signals. A pre-amplifier is included in the detector case to furnish low impedance output to the truck mounted amplifiers. Power for the detector pre-amplifiers is provided from the surface.

The "Boomer System" transducers consisted of a 1000 WS and two 500 WS experimental units. Short wooden legs were bolted to the 1000 WS transducer to hold it off the bottom, while the 500 WS transducers were suspended in the driver holes. The driver or transducer holes were lined with a thin plastic material to prevent loss of the water coupling medium. A multiple system of wire grounds were used and equipment cabling was buried to reduce the capacitive discharge pulse coupling to the detection and recording equipment.

An oscilloscope and precision AC voltmeter are provided for direct viewing and measurements as well as a high speed oscillograph recorder.

The amplifiers are Petty Model HF-3 with calibrated attenuators of 0 to 90 db in 10 db steps and 0 to 10 db in 2 db steps. High or low impedance input is provided with a low impedance gain of  $5.3 \times 10^5$ . The amplifiers provide a normal -3 db cut at 1 kcps, and plug in type filter arrangements are available for other responses.

### B. Propagation Measurements

Initial tests with the "Boomer System" were made in a brown sandy-clay soil having an average velocity of 1900 feet per second. Seismic signals were recorded using acceleration type detectors carefully planted in earth.

Two vertical spreads of detectors, Sketch 1, were used with plants in separate holes of 3, 5, 7 and 15 foot depths arranged on an 18 inch radius about the source transducer hole. The other deep spread had detectors planted in holes of 16, 21, 26, and 31 foot depths. Previous driver holes in the centers of the spreads were used for the smaller 500 WS transducers. Holes were dug as near as practical to the shallow and deep vertical detector spreads for the 1000 WS transducer.

The 1000 WS and 500 WS transducers proved to be excellent sources of high sonic power and seismic signals were readily detected to a distance of 30 feet through the earth, as shown in Figures 1 through 4. Frequencies below 600 cps largely predominate, so apparently the pulse from the transducer is either altered or suffers severe high frequency attenuation through the earth. Previous results of impulsed continuous wave seismic recording, see Figure 5, indicated a gradual buildup of the 600 cps signal through about 3 or 4 cycles.

In another test, detector plants were spaced horizontally at intervals across a concrete target which is 3 feet in diameter and 24 feet deep, as shown in Sketch 2 and Figure 6. The 1000 WS transducer was moved from one hole to another along a line of driver holes spaced at intervals of 0, 5, 10 and 15 feet with the "0" hole directly above the target.

No definite reflections were recorded with any of the above methods described. The absence of 600 cps or higher frequency signal probably accounts for the absence of measurable reflections from this target of fractional wavelength.

### C. Additional Propagation Measurements

In order to determine the feasibility of recording seismic signal reflections from larger buried objects, another test site was chosen. This area is characterized by chalk and limestone series immediately beneath a thin layer of soil. Hard sections are present below 18 feet and hard limestone at 48 feet. Also, the chalk is a good high frequency transmission medium in comparison to

the sandy-clay soil of the initial location. Four transducer holes were dug 6 feet apart along a horizontal line, Sketch 3, with holes drilled to a 2 foot depth on either side of the transducer holes for detector plants. Recordings were made using the HF-3 amplifier with high-pass 400 cps, high pass 200 cps and high-pass - 3 db at 1 kcps filters. Results indicate possible seismic signal reflections, see Figure 7, from the 24 foot and deeper limestone beds. No further work was performed on this chalk-limestone location. Information was received from Miss Ralph that the largest buried objects of interest have been walls no more than one meter thick, with no pavement in association. Therefore; continued experiments to improve results of reflections from large buried objects were discontinued.

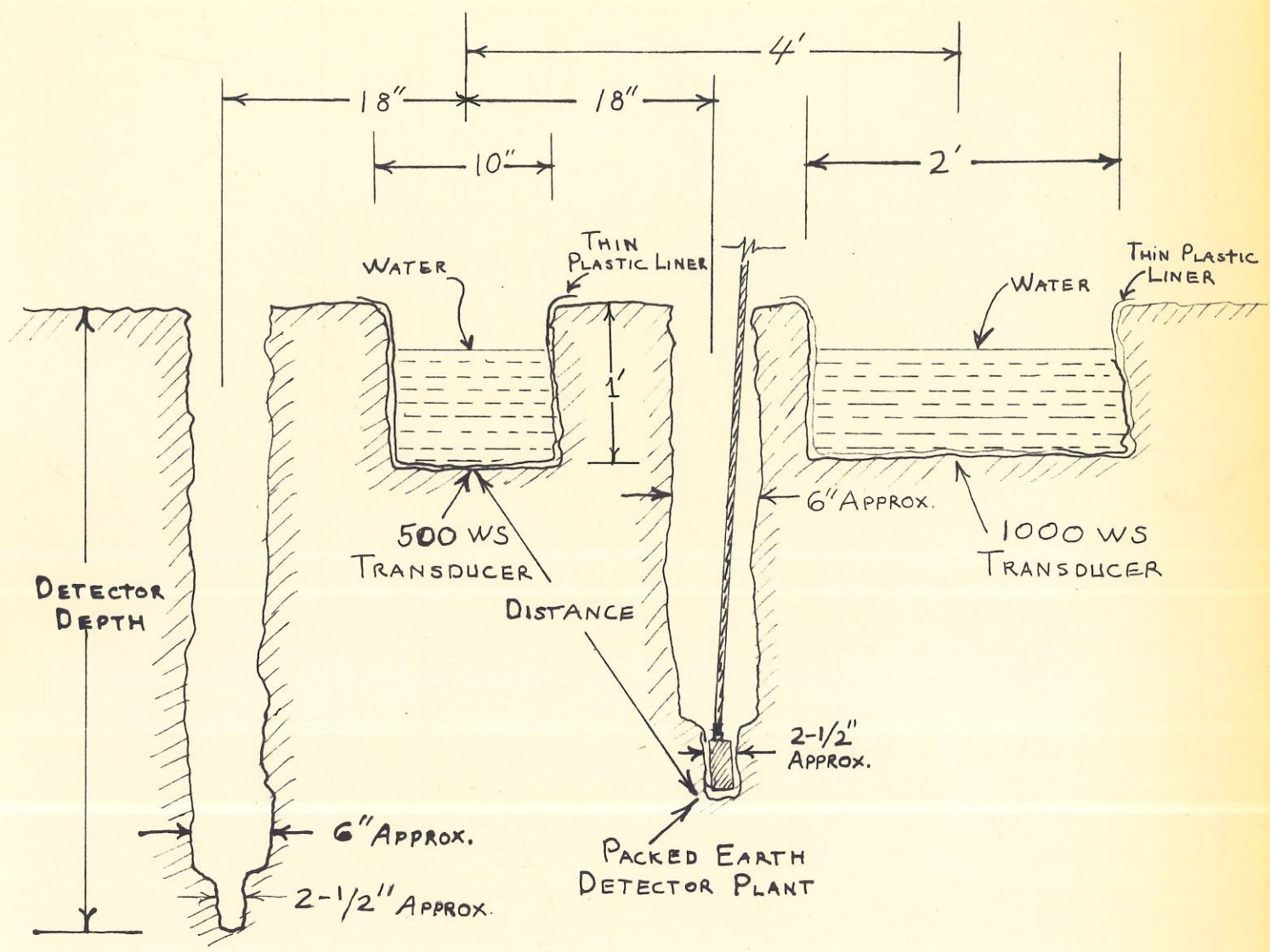
### III. CONCLUSIONS

Based on results to date, it is thought that a high power discrete frequency source of sonic power is necessary for possible detection of small objects buried in alluvium deposits to depths of up to thirty feet. As mentioned previously in this report, the lack of 600 cps and higher frequencies probably accounts for the lack of reflected seismic signals from an object that is only a fraction of a wavelength at the observed frequencies. Transducers of the order of power of the "Boomer System" will be required at the 600 cps frequency, and perhaps some record enhancement techniques will also be required to obtain satisfactory results in this application.

#### IV. Illustrations

- Sketch 1 - Illustration of shallow and deep vertical detector spreads and transducer holes.
- Sketch 2 - Illustration of 24 foot target and detector arrangement.
- Sketch 3 - Illustration of detector-transducer arrangement for detection of large buried objects.
- Figure 1 - 500 WS transducer, shallow spread recording.
- Figure 2 - 500 WS transducer, deep spread recording.
- Figure 3 - 1000 WS transducer, shallow spread recording.
- Figure 4 - 1000 WS transducer, deep spread recording.
- Figure 5 - Pulsed continuous wave recording with MM2FUW underwater speaker.
- Figure 6 - 1000 WS transducer and 24 foot target recording.
- Figure 7 - 1000 WS transducer at other location for large buried object detection. Recording of probable reflection.

VERTICAL SPREAD  
TRANSDUCER AND DETECTOR PLANTS

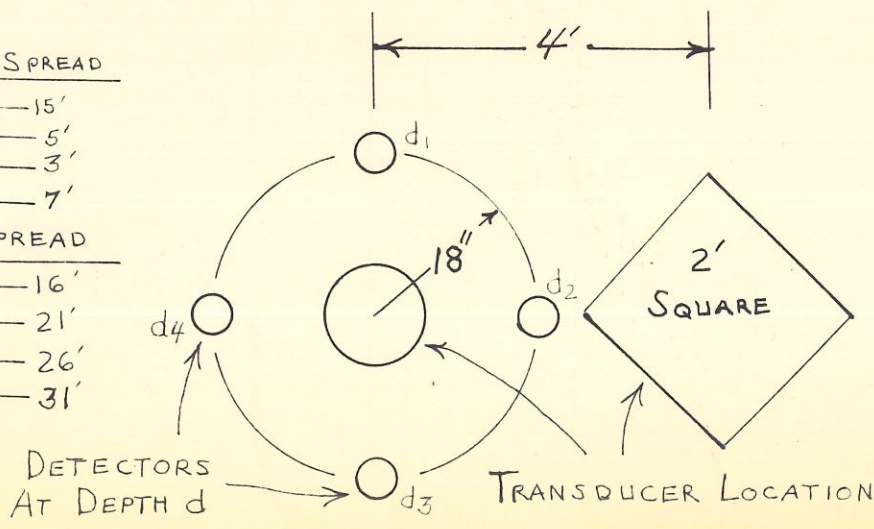


SHALLOW SPREAD

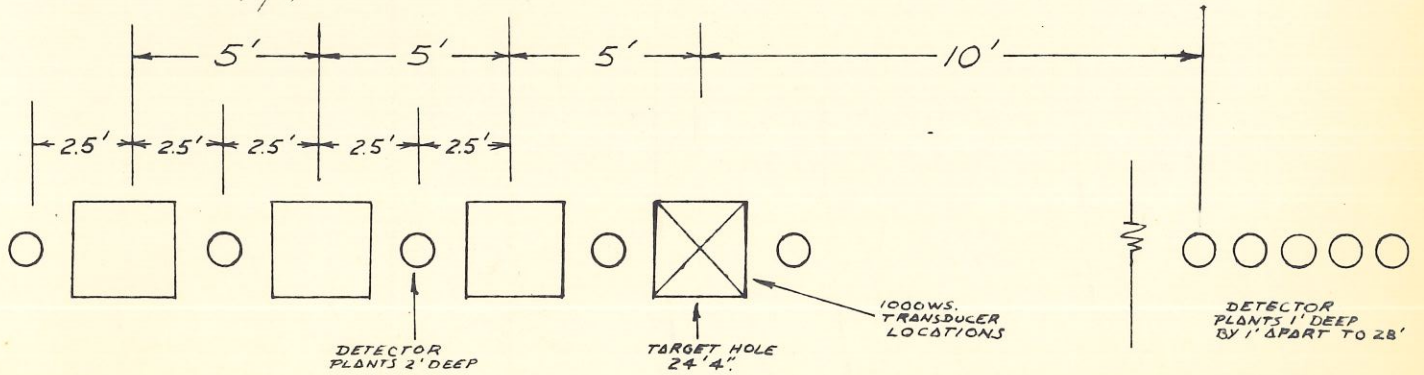
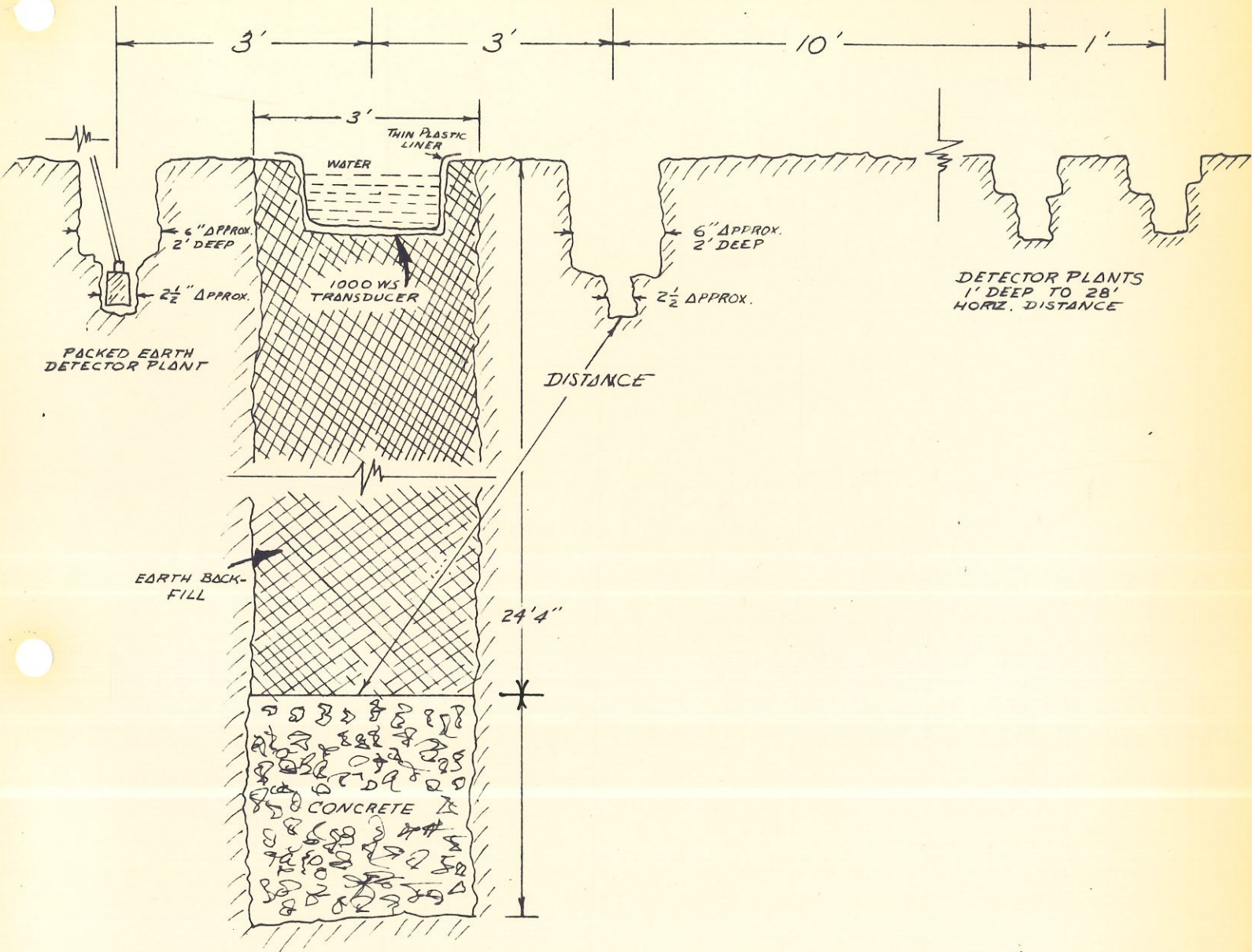
- d<sub>1</sub> — 15'
- d<sub>2</sub> — 5'
- d<sub>3</sub> — 3'
- d<sub>4</sub> — 7'

DEEP SPREAD

- d<sub>1</sub> — 16'
- d<sub>2</sub> — 21'
- d<sub>3</sub> — 26'
- d<sub>4</sub> — 31'

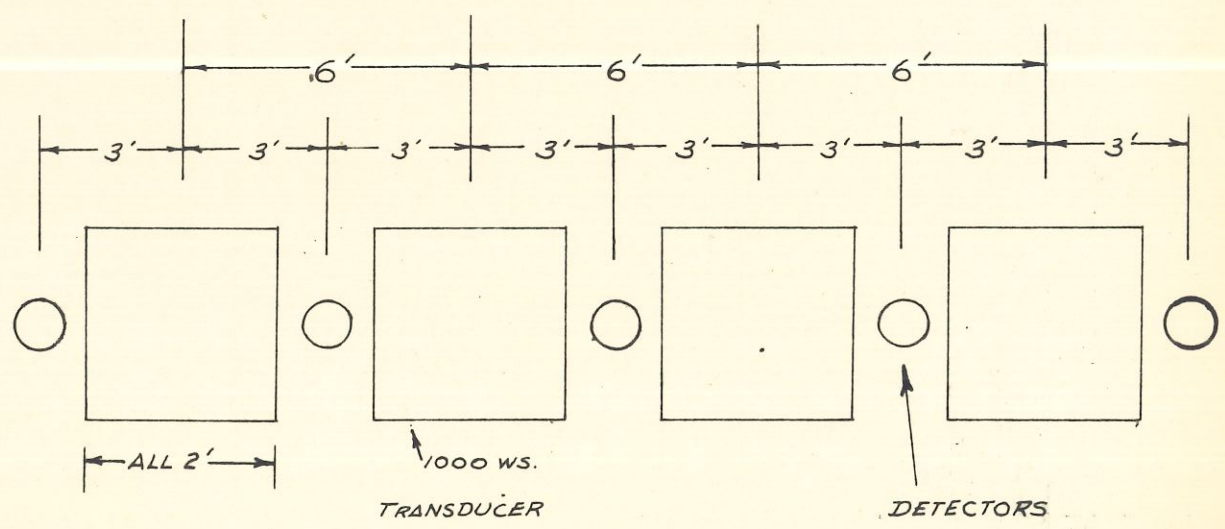
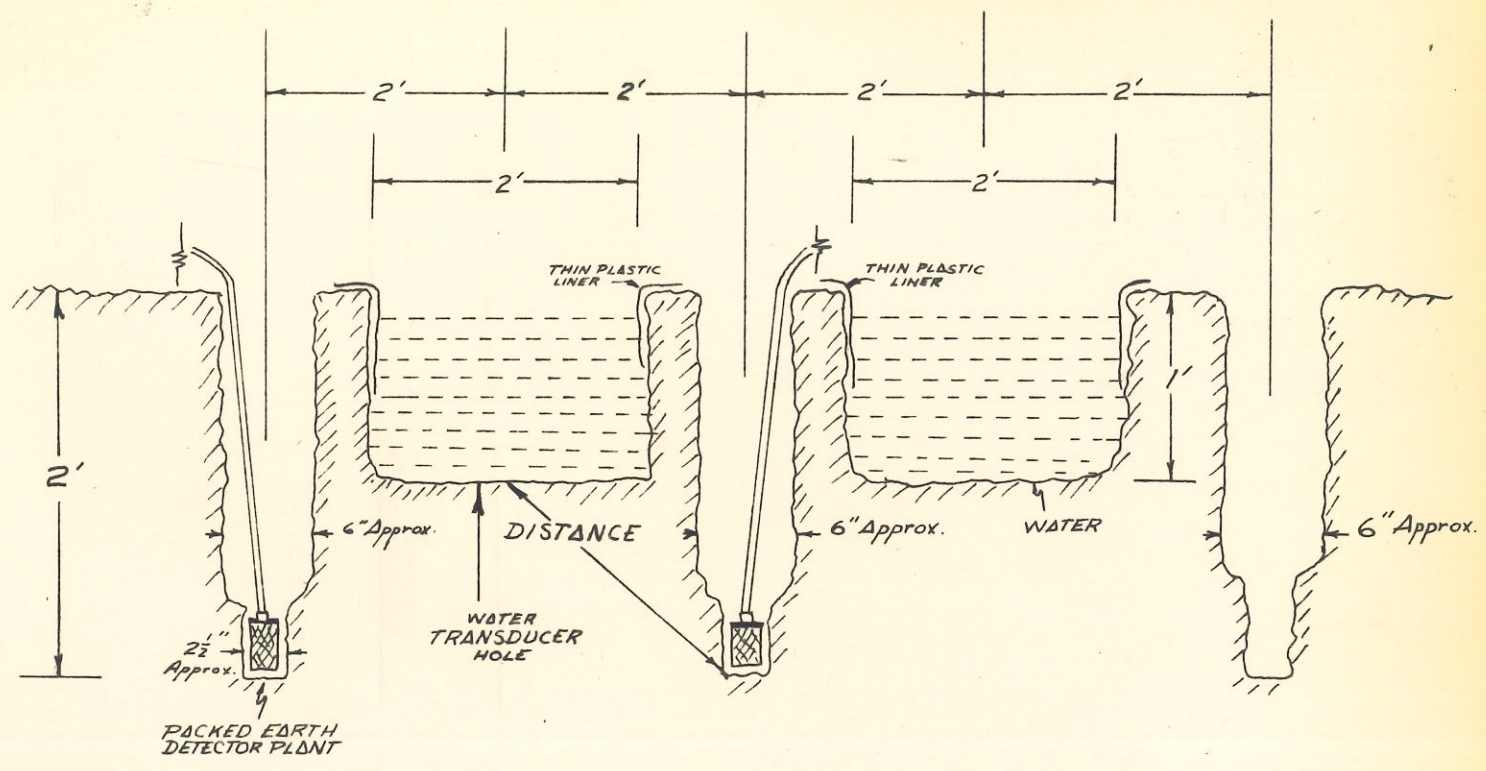


HOLE CONFIGURATION



HOLE CONFIGURATION

- Not to Scale -



HOLE CONFIGURATION

5-16-63 Evans

SHALLOW VERTICAL DETECTOR SPREAD

500 WS "Boomer" System

Firing Pulse

HF-3 Amplifier with high-pass  
filter -3 db at 1 kcps.

Amplifier gain  $5.3 \times 10^5$

Detector 3 feet below surface in  
packed earth plant.  
Distance 2.5 feet.  
Ampl. attenuation -86 db.

Detector 5 feet below surface in  
packed earth plant.  
Distance 4.3 feet.  
Ampl. attenuation -82 db.

Detector 7 feet below surface in  
packed earth plant.  
Distance 6.2 feet.  
Ampl. attenuation -70 db.

Detector 15 feet below surface in  
packed earth plant.  
Distance 14 feet.  
Ampl. attenuation -70 db.

Millisecond Timing Lines

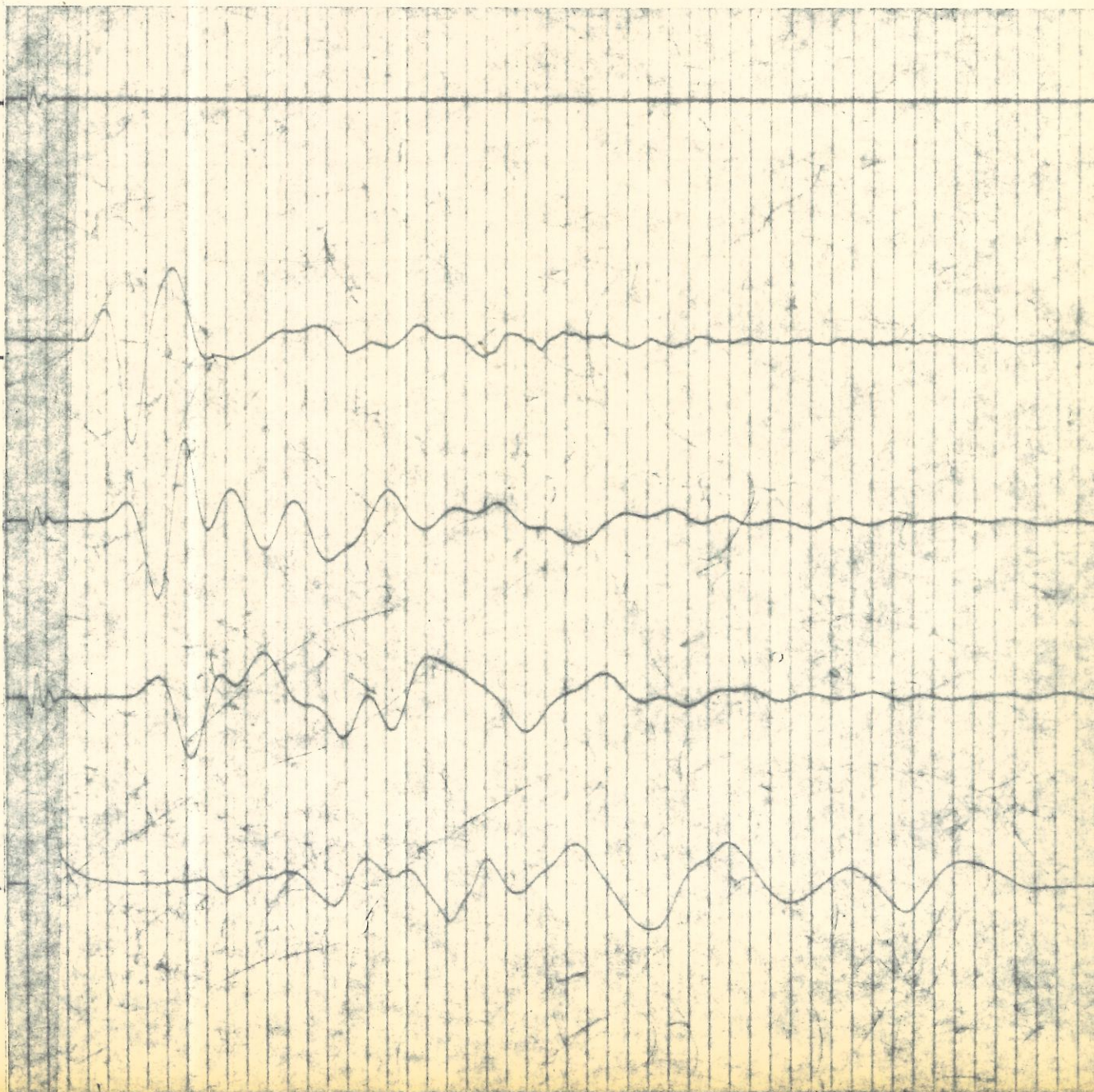


FIGURE 1

5-13-63 Evans

DEEP VERTICAL DETECTOR SPREAD

500 WS "Boomer" System

Firing Pulse

HF-3 Amplifier with high-pass  
filter -3 db at 1 kcps.

Amplifier gain  $5.3 \times 10^5$

Detector 16 feet below surface in  
packed earth plant.  
Distance 15 feet.  
Ampl. attenuation -70 db.

Detector 21 feet below surface in  
packed earth plant.  
Distance 20 feet.  
Ampl. attenuation -70 db.

Detector 26 feet below surface in  
packed earth plant.  
Distance 25 feet.  
Ampl. attenuation -54 db.

Detector 31 feet below surface in  
packed earth plant.  
Distance 30 feet.  
Ampl. attenuation -46 db.

Millisecond Timing Lines

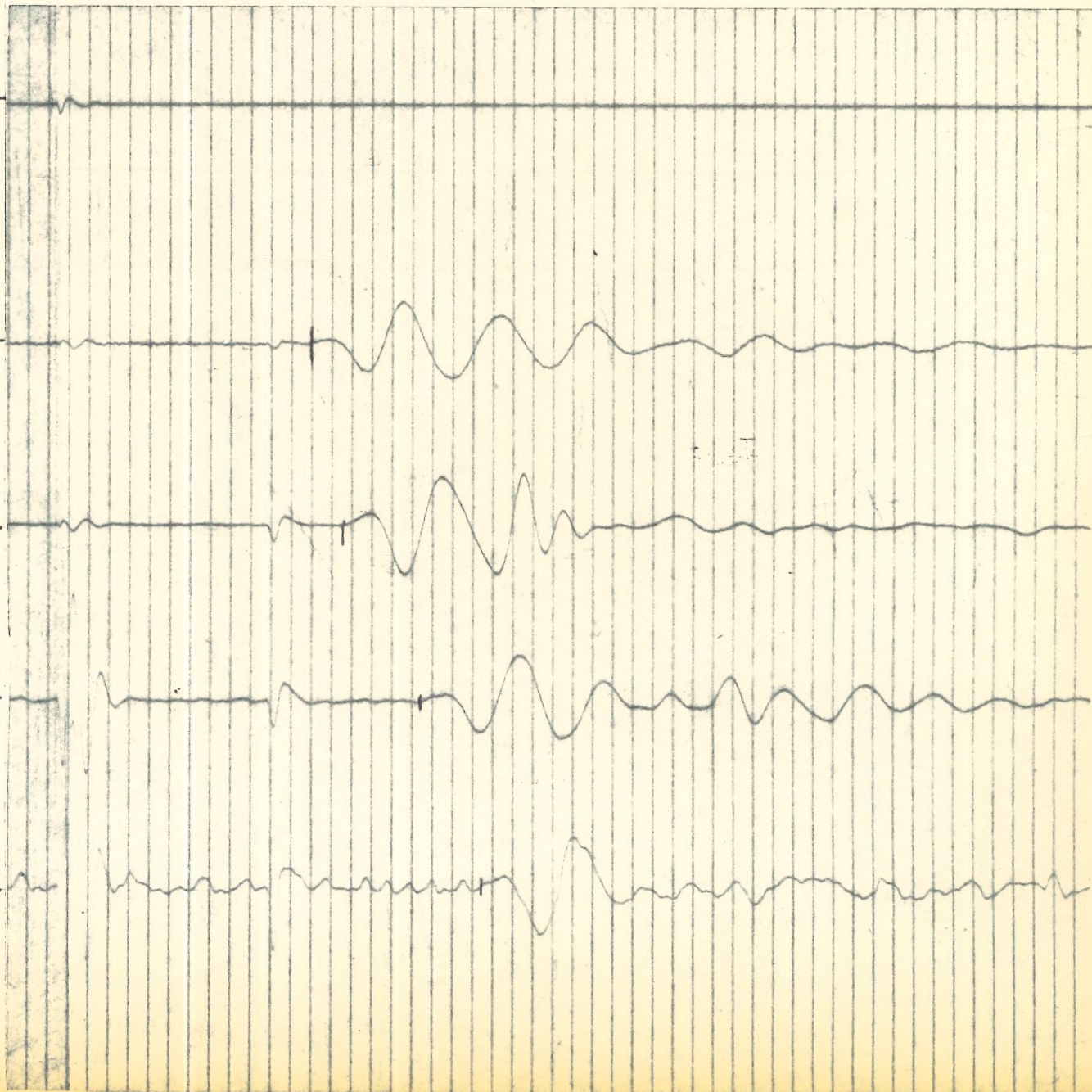


FIGURE 2

SHALLOW VERTICAL DETECTOR SPREAD

1000 WS "Boomer" System

Firing Pulse---

HF-3 Amplifier with high-pass filter -3 db at 1 kcps.

Amplifier gain  $5.3 \times 10^5$

Detector 3 feet below surface in packed earth plant.  
Distance 6.3 feet.  
Ampl. attenuation -70 db.

7.5 ms

Detector 5 feet below surface in packed earth plant.  
Distance 5 feet.  
Ampl. attenuation -94 db.

6.3 ms

Detector 7 feet below surface in packed earth plant.  
Distance 8.5 feet.  
Ampl. Attenuation -74 db.

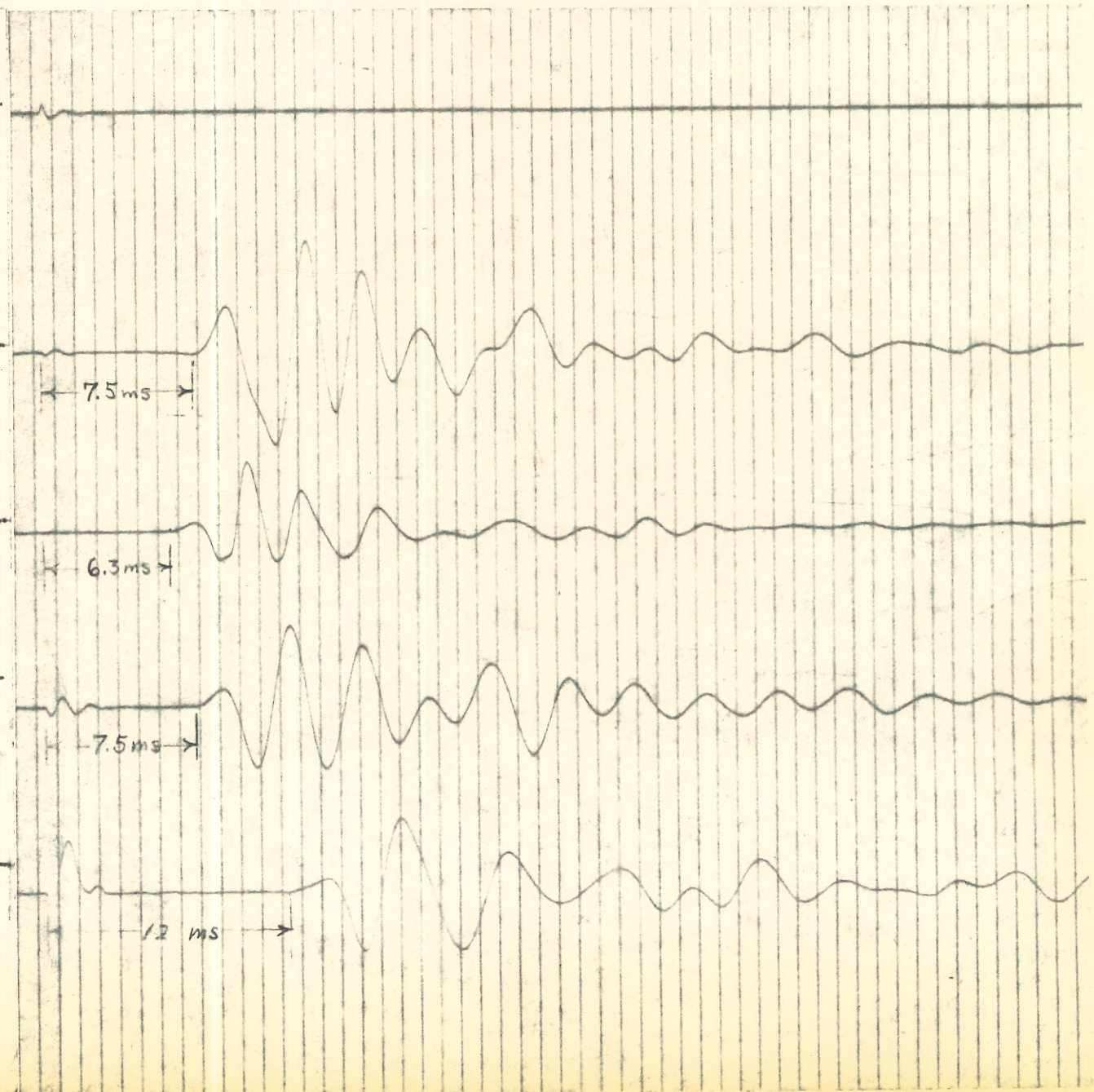
7.5 ms

Detector 15 feet below surface in packed earth plant.  
Distance 15.3 feet.  
Ampl. attenuation -70 db.

12 ms

Millisecond Timing Lines

FIGURE 3



DEEP VERTICAL DETECTOR SPREAD  
1000 WS "Boomer" System

Firing Pulse-

HF-3 Amplifier with high-pass  
filter -3 db at 1 kcps.

Amplifier gain  $5.3 \times 10^5$

Detector 15 feet below surface in  
packed earth plant.  
Distance 16.8 feet.  
Ampl. attenuation -66 db.

Detector 21 feet below surface in  
packed earth plant.  
Distance 21 feet.  
Ampl. attenuation -72 db.

Detector 26 feet below surface in  
packed earth plant.  
Distance 26.2 feet.  
Ampl. attenuation -60 db.

Detector 31 feet below surface in  
packed earth plant.  
Distance 31.8 feet.  
Ampl. attenuation -50 db.

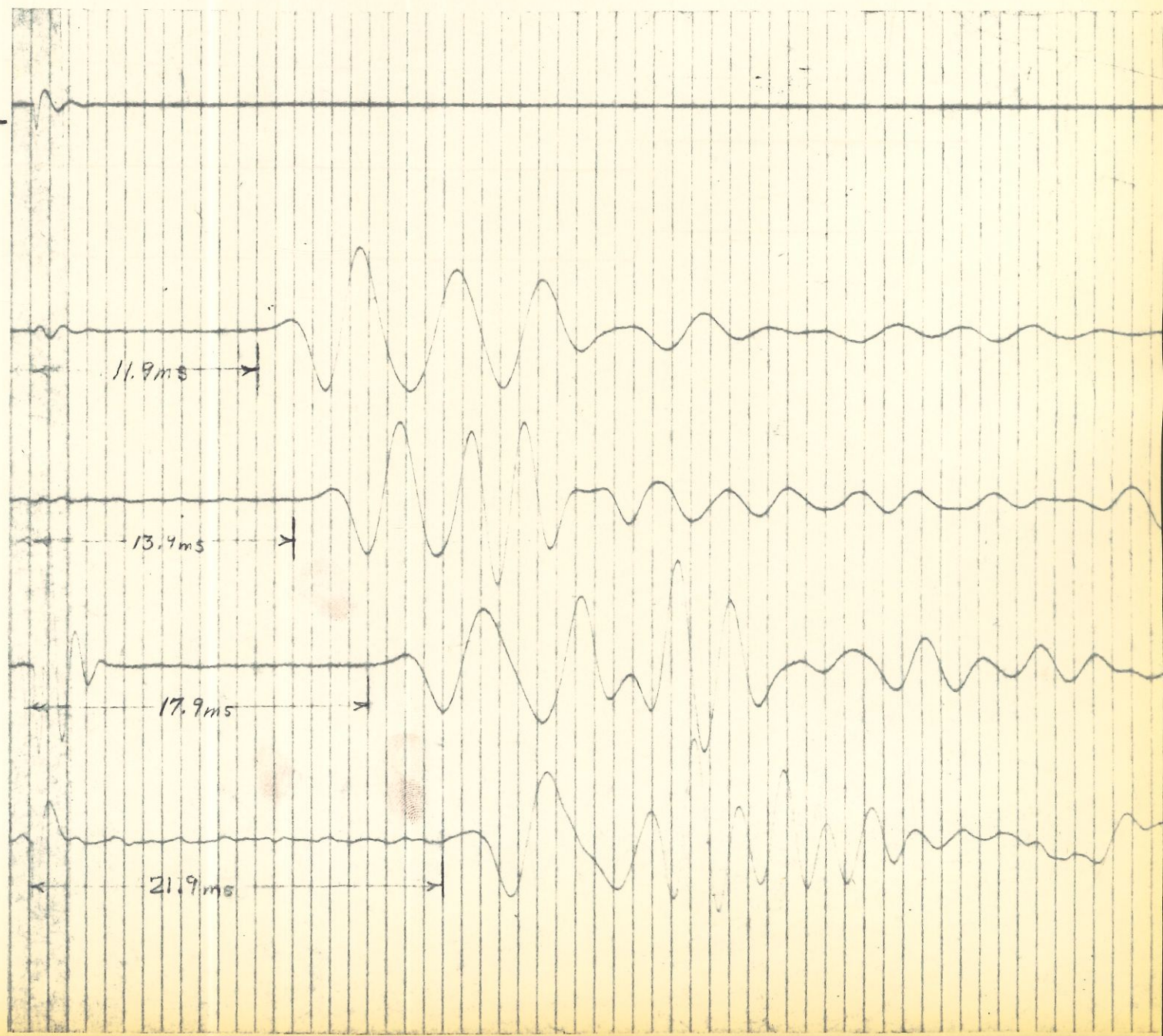


FIGURE 4

Millisecond Timing Lines

PULSED CONTINUOUS WAVE

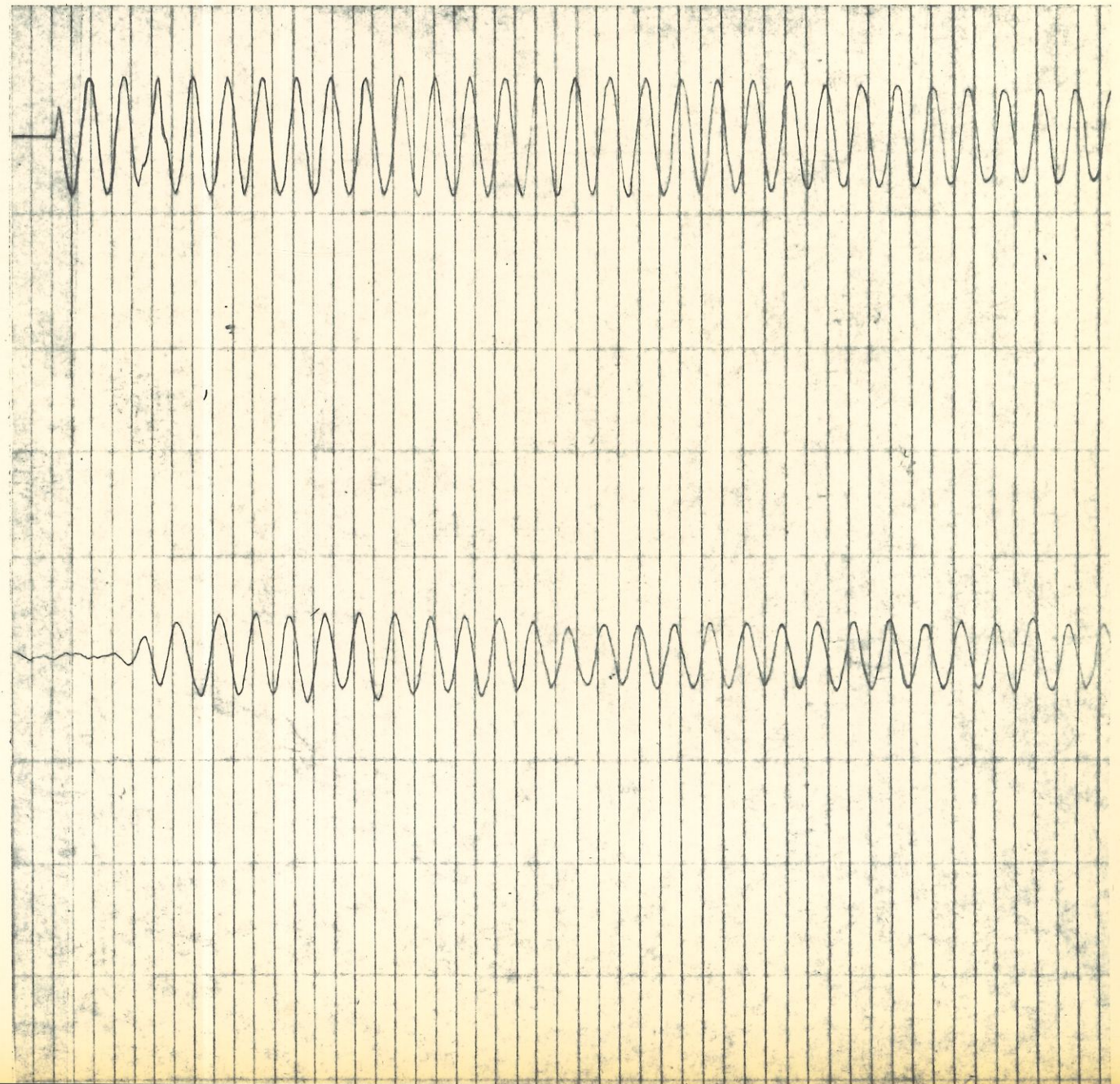
University MM2FUW underwater  
speaker in oil filled driver hole

Monitor of speaker input, 600 cps  
at 15 watts

HF-3 Amplifier with high-pass  
filter -3 db at 1 kcps

Amplifier gain  $5.3 \times 10^5$   
attenuation -50 db.

Detector 3 feet below surface in  
packed earth plant.  
Distance 2.5 feet.



Millisecond Timing Lines

FIGURE 5

24 FOOT TARGET LOCATION

1000WS "Boomer" System

Lower velocity disturbed soil at target location.

Firing Pulse---

HF-3 Amplifier with high-pass filter of -3 db at 1 kcps.

Amplifier gain  $5.3 \times 10^5$

Detector 2 feet below surface in packed earth plant.

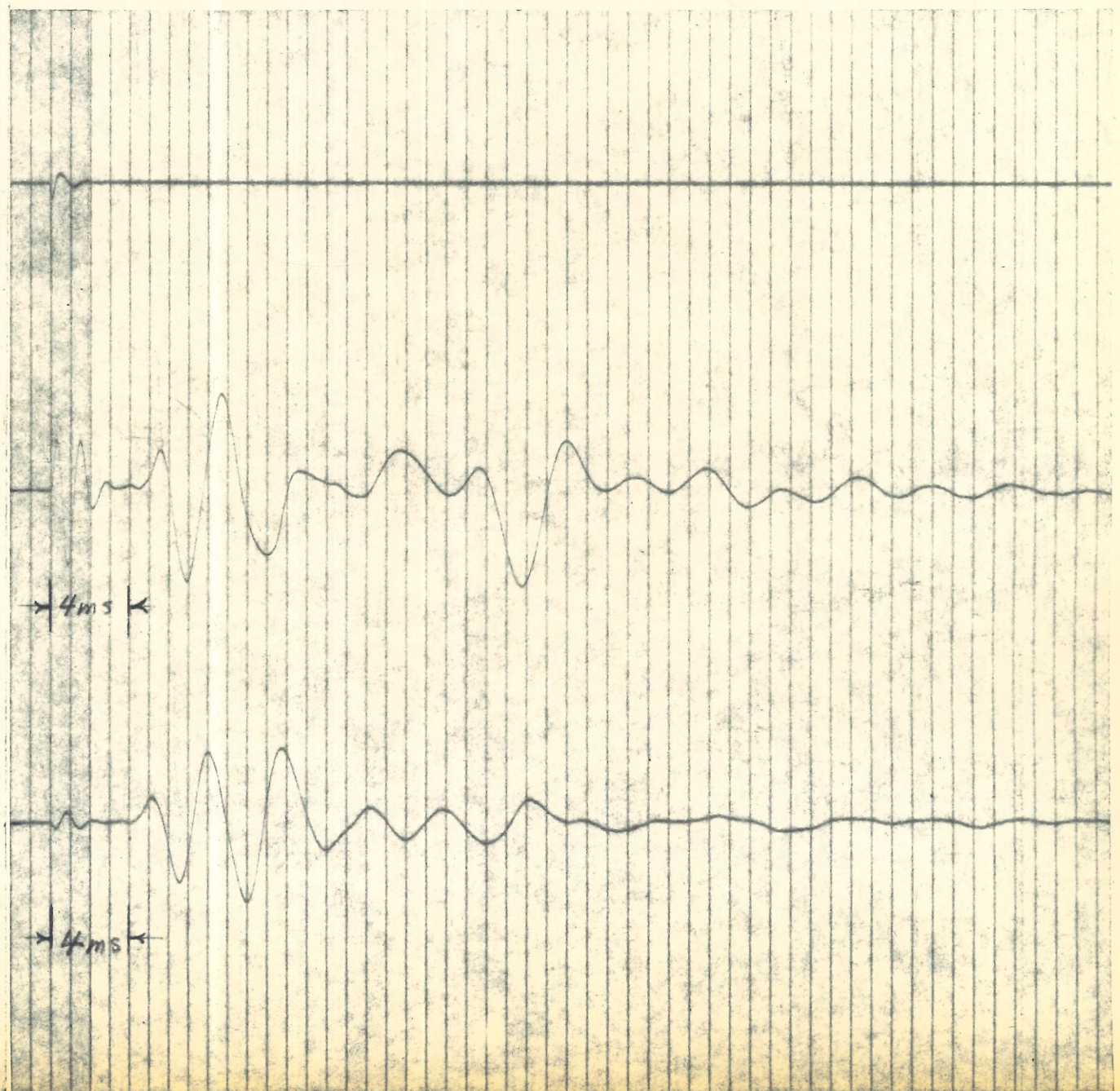
Distance 2.2 feet.

ampl. attenuation -70 db.

Detector 2 feet below surface in packed earth plant.

Distance 2.2 feet.

ampl. attenuation -80 db.



4ms

4ms

Millisecond Timing Lines

LARGE BURIED OBJECT DETECTION

1000 WS "Boomer" System

Chalk subsurface with limestone  
bed at approximately 26 feet.

Firing Pulse

HF-3 Amplifier with high-pass 400  
cps filter HPLA -40 db/ octave

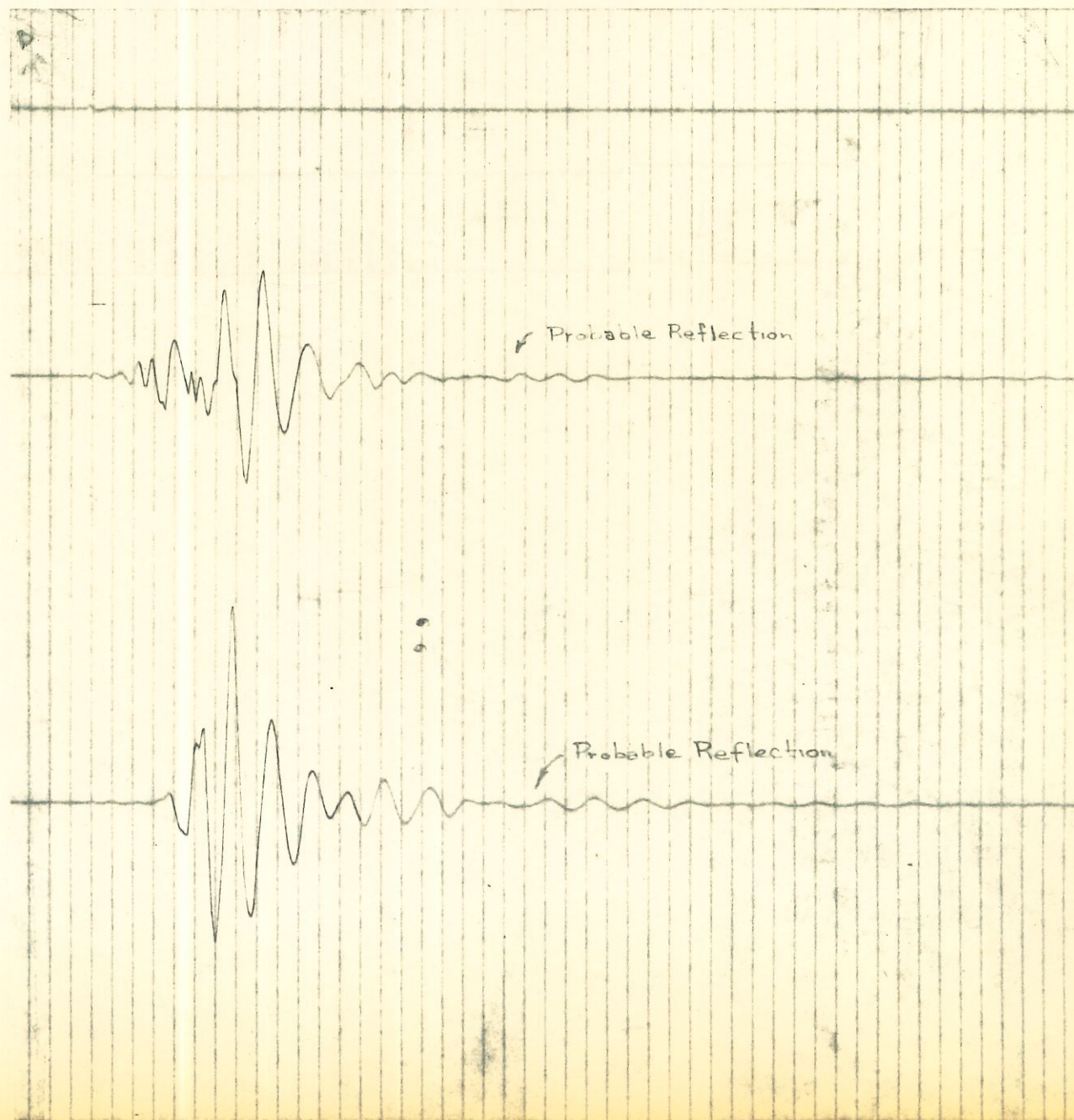
Amplifier gain  $5.3 \times 10^5$

Detector 2 feet below surface in  
packed earth plant.

Distance 2.2 feet.  
ampl. attenuation -90 db

Detector 2 feet below surface in  
packed earth plant.

Distance 2.2 feet.  
ampl. attenuation -84 db.



Millisecond Timing Lines

FINAL FIELD EXPERIMENTS AND GENERAL REVIEW  
of the  
Development of the Sonic Archaeological Probe

FINAL REPORT

Prepared by:

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Date: October 28, 1963

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## SUMMARY

The first phase of the field tests was concerned with soil attenuation measurements of the sonic signal versus frequency and amplitude. The most suitable frequency, considering the minimum size of the buried objects and signal decay, was 600 cycles per second with an attenuation of approximately - 3 db per foot of earth.

Transducer coupling to the earth was investigated and required numerous experiments. Within the limits of the fluids tried, the fluid with the highest viscosity was the most efficient coupling medium. Various driver or transducer units were tried in an attempt to increase sonic power output.

While no entirely successful instrumentation has been forthcoming, the numerous experiments have yielded pertinent information necessary to outline the instrumentation needs of the project, attenuation of sonic energy versus frequency, power requirements of transducers, and filtering and record enhancement techniques.

Detection of larger buried objects, such as floors or walls, is apparently feasible using the Edgerton, Germeshausen and Grier, Inc. "Boomer" system, or dynamite caps as an energy source. The exploration system should also include maximum filtering throughout and magnetic recording with stacking techniques.

Sonic Archaeological Probe  
Development

FINAL FIELD EXPERIMENTS AND GENERAL REVIEW

I. INTRODUCTION

The object of this project was to provide a feasibility study and design of final instrumentation for a sonic probing or exploration system capable of locating archaeological ruins and artifacts from a few feet to tens of feet in extent and buried up to a depth of thirty feet in alluvium.

The purpose of this final report is to outline the various experiments performed, and the results obtained, using various methods and instrumentation in an attempt to produce high power sonic energy at frequencies needed to detect, by use of recorded reflected energy, small buried objects. Since a minimum object size of three feet was determined, the most suitable frequency, considering soil velocity, wave length and attenuation, was approximately 600 cps. The major project problem encountered has been, and remains, the production of a transducer and earth coupling system suitable for portable or semi-portable operation, and capable of sufficient power output.

## II. DISCUSSION

### A. Measuring Arrangement

#### 1. General Instrumentation

Instrumentation used for the measurement of sonic signal amplitudes and waveform followed the general arrangement as presented in previous technical reports. Essentially the system consisted of truck mounted power amplifiers, power supplies, calibrated signal amplifiers, visual monitoring and a photo-recorder and the related auxiliary equipment.

The driver or transducer supply for the electromagnetic systems utilized a thirty watt power source adjustable over a wide frequency range with suitable monitoring equipment such as detectors, amplifiers and a recorder, as described in Interim Technical Report No. 1.

Acceleration type detectors utilizing a barium-titanate transducer and emitter-follower pre-amplifier, as described in detail in Interim Technical Report No. 1, were used. Sonic signals from the detector were then recorded through an amplifier-filter system and a high speed photopaper recorder.

#### 2. Special Equipment

Special power supplies for the "pinger" and the Boomer" systems were furnished by Dr. Edgerton. The high voltage pulse power supplies used in evaluating the ceramic transducers were provided by Petty Laboratories with the addition of a thirty thousand volt MacLaughlin pulse power supply as provided by The University Museum.

Hall Sears HS-1 calibrated velocity detectors were also used to help determine the plant characteristics of the steel and aluminum plates.

### 3. Driver or Transducer Coupling to Earth

The electromagnetic transducers were fluid coupled to earth by plastic lined, oil filled holes and is treated in Interim Technical Report No. 1. The coupling of Edgerton's "Boomer" system with plastic lined water filled holes is described in Interim Technical Report No. 2. The "Pinger" system was coupled to earth in a water filled driver hole for tests at the laboratory and later in an oil filled hole in the center of the shallow vertical detector spread located at the brown sandy-clay soil test site (Evans Lease).

#### B. Propagation Measurements

A twelve watt Atlas and sixty watt University drivers were the first transducers evaluated using pulsed continuous sine wave operation. These drivers had a throat restriction of three fourths of an inch diameter and required an air to fluid seal. This condition resulted in a very poor impedance match of at least 1000 : 1 air to water, and inefficient coupling to the earth.

The next transducer unit tested was the MM2FUW University underwater speaker. This unit had a two and one half inch diameter diaphragm, in direct contact with the oil, which resulted in the highest coupling efficiency, of the transducers tested, in a fluid medium. This driver was used with a pulsed continuous sine wave to establish attenuation curves of signal decay versus frequency and thus establish, somewhat, the power level requirements for a transducer. Figure 1B shows a plot of signal decay as a function of distance for various frequencies. These are well established average value measurements.

Numerous measurements at each depth were made with twenty five watts of

continuous-wave power applied to the driver. Narrow passband filters were used in the amplifier to improve signal to noise ratios. Noise level was determined for each measurement and used to correct signal data.

The crossover and variations in slope of the 200 and 400 cps curves is possibly due to interfering waves reflected from the surface or otherwise. The MM2FUW driver has a low frequency cutoff of 350 cycles per second, and therefore at a 25 watt driving level will not produce as much motion at 200 as at 400 cps. The lower signal decay at 600 cps is due to harmonic interference which could not be allowed for in the data reduction. Based on various measurements it is believed that the 600 cps curve should follow more closely the 800 cps plot. Rapid deterioration of the 1600 cps curve is partially due to the bandpass filter gain of only  $\frac{1}{2}$  as compared to a gain of 2 for the other filters. Therefore the response curve suffers from an initial disadvantage of lower signal to noise ratio.

The signal decay curves as plotted for the different frequencies are not directly related in that they have no common zero reference; but the curves do show, in general, the decay of acceleration versus distance and frequency.

The propagation measurement arrangement was at the shallow vertical detector spread. The driver or transducer was located at the center of an eighteen inch radius circle in an oil filled hole with the detectors planted in four holes of various depths on the circle.

The underwater speaker had a 125 cycle resonance, see Figure 3, when it was DC pulsed. The resonance of the speaker was adjusted to 600 cps, Figure 4, by stiffening the diaphragm surround, however; this resulted in a decrease in power from twenty five watts to three watts maximum power. The sonic signal produced by the 600 cycle pulse was detected to a distance of

twelve feet, one way travel, Figure 1A. Figures 1 and 2 are examples of an attempt to obtain reflected signals from the seven foot target with inconclusive indication of reflected signals from the buried target.

Arrangements were made by The University Museum with Dr. Edgerton, for a loan of the "Pinger" system to be followed later with the "Boomer" system. The "Pinger" is a magnetostrictive transducer resonant at 9 kcps. It was placed in an oil filled hole, see Sketch 1 Note, in the center of the shallow vertical detector spread. Sonic signals were detected to a maximum distance of three feet with the signal about plus 6 db above the noise. A recorded sample of the sonic signal is illustrated by Figure 5. Only direct viewing of the signal on an oscilloscope was used at the test site.

The following field experiments concerned the evaluation of the Edgerton, Germeshausen and Grier, Inc. "Boomer" system as described in Interim Technical Report No. 2. An additional record No. 6, included in this report, shows the signal amplitude and wave shape of a horizontal detector spread at the large object test site (530 Area). Some indication of possible reflections are indicated on the record. Essentially the unit consisted of an electromagnetic repulsion type transducer which would repel a restricted movement plate when pulsed, and the associated power supplies. The frequency of the sonic signal produced by this device was approximately 3 cycles of a 4 kcps damped wave in a water medium. 1000 watt second and 500 watt second transducers were tested with the latter producing less signal amplitude, but similar wave shape, as compared to the 1000 WS transducer. Although sonic signals of lower than 600 cps were recorded, this energy was readily detected to a depth of thirty feet. A brief attempt was made to evaluate the "Boomer" as a limited utility exploration tool for detection of larger buried objects, but was abandoned for lack of immediate interest to the client.

At the site of the limestone ledges, or large simulated buried objects, (530 Area) dynamite caps were fired in the water filled driver holes at the same approximate location as the 1000 WS "Boomer" transducer. Results, see Sketch 2 and Figures 7,8 and 9, indicate a wave shape very similar to that produced by the "Boomer" transducer, but of a higher order of power. With more suitable coupling and damping, it is reasonable to assume that the sonic energy transmission through the earth would be greatly increased using a dynamite cap, but with poor frequency and pulse time characteristics as compared to a discrete frequency source. Figures 10 and 11 show the results of a dynamite cap planted in earth and fired above the 24 foot target at the brown sandy-clay location.

Next a five inch diameter by one half inch thick ceramic transducer loaded to a resonance of 12 kcps, was tested as a possible sonic power source. The transducer was pulsed with 2 to 6 cycles of a 600 cps power source at about three thousand volts. Both a mud and an oil coupling medium were tried in the center of the shallow detector spread, see Sketch 1 and Figure 12. The oil medium was the more efficient coupling medium and the maximum distance for a detectable sonic signal was approximately five feet, one way travel. This transducer served as an indicator of the possibilities of a good discrete sonic frequency source if one could be constructed with sufficient power capabilities and be coupled efficiently to the earth.

Following the above experiments, a steel plate one inch thick by thirty inches in diameter was fabricated. The natural resonance of this plate was approximately 600 cps as determined from laboratory tests of different plates. Acceleration type detectors were planted at a 2 and a 7 foot interval directly below the plant in previously undisturbed soil, as illustrated in Sketch 3. Also an HS-1 calibrated velocity detector and an acceleration type detector

were cemented to the top of the plate for impact time and plant resonance. Balls from 16 to 93 grams weight were dropped from a height of three feet onto the plate and signal amplitudes and waveform from the detectors were recorded. Such a mechanical system is a good source of sonic energy, as indicated on the records, Figures 13 through 17, but is relatively uncontrollable as to its output frequency time length. The sonic signal was readily detected to the seven foot distance with the 16 gram ball dropped from a three foot height.

The last test consisted of a stack of eight ceramic rings under a compression load produced by a one inch bolt through the center of two plates, Sketch 4, one aluminum and one steel, and both one inch thick by thirty inches in diameter and were placed on either side of the ceramic ring assembly. The same detector plant arrangement of 2 and 7 foot intervals as discussed in the paragraph on ball drop tests was used. The plate was coupled to the brown sandy-clay surface with a mud slurry and allowed to set. High voltage pulses were applied to the ceramic assembly, first with the Petty supply at 14 thousand volts and then the MacLaughlin 30 thousand volt supply. Detectable sonic signals to the two foot detector were recorded, while a signal at the seven foot detector was just barely discernable above the noise, see Figures 18 and 19. The maximum sonic energy occurred with the steel plate in contact with the earth. While the ceramic-plate transducer produced 600 cps sonic signal at the two foot detector, the overall power output of this system is too low to be useful.

### III. CONCLUSIONS AND RECOMMENDATIONS

At present the difficulty of transmission of 600 cycle sonic energy with pulse duration control through the earth appears to be a scientific rather than an engineering problem. Extension of the 'Geophysical Art' seems to be

necessary in the investigation of discrete frequency high power sonic sources, earth coupling of the transducer source, and improvement in the detection system. The problem is not beyond solution, but would probably require the expenditure of a considerable sum of money and time.

Based on the archaeological probe work to date, considerable knowledge and appreciation of the difficulty of propagation of sonic energy through the earth has been established. While the transmission of high frequency sonic signals with the required power through the earth has not been achieved, results do indicate an apparent ability to provide detection of larger objects buried in alluvium. This condition would require a lower order of resolution and hence lower frequencies which appear to be feasible from the results to date.

If the limited utility of a large object detection system is of sufficient interest, certain equipment refinements should be made such as : a magnetic recording enhancement system, a decision on the type of sonic power transducer to be used (based on results of the work so far), and maximum permissible filtering throughout the system. The equipment should include frequency flexibility in order to be useful in the event a suitable transducer is developed.

#### IV. ILLUSTRATIONS

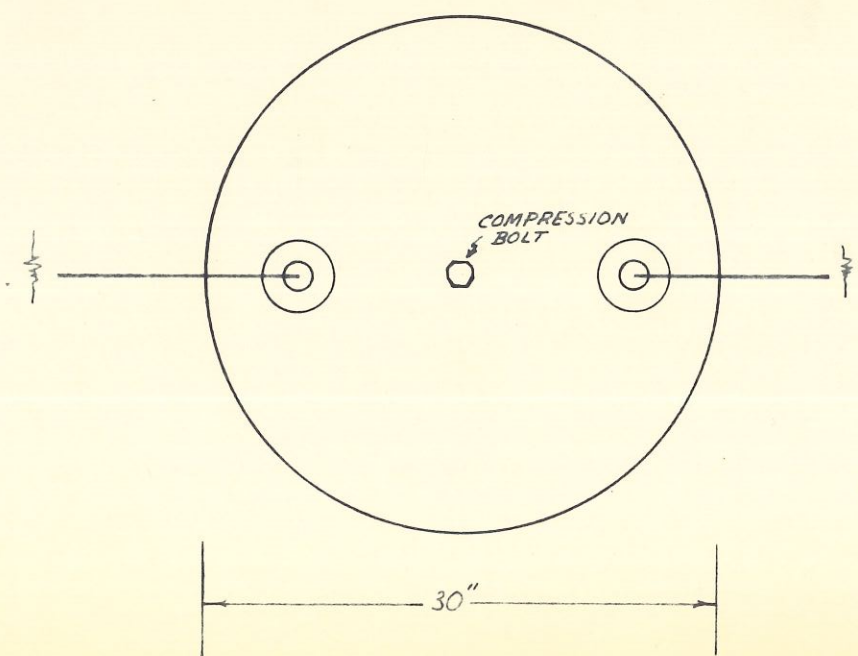
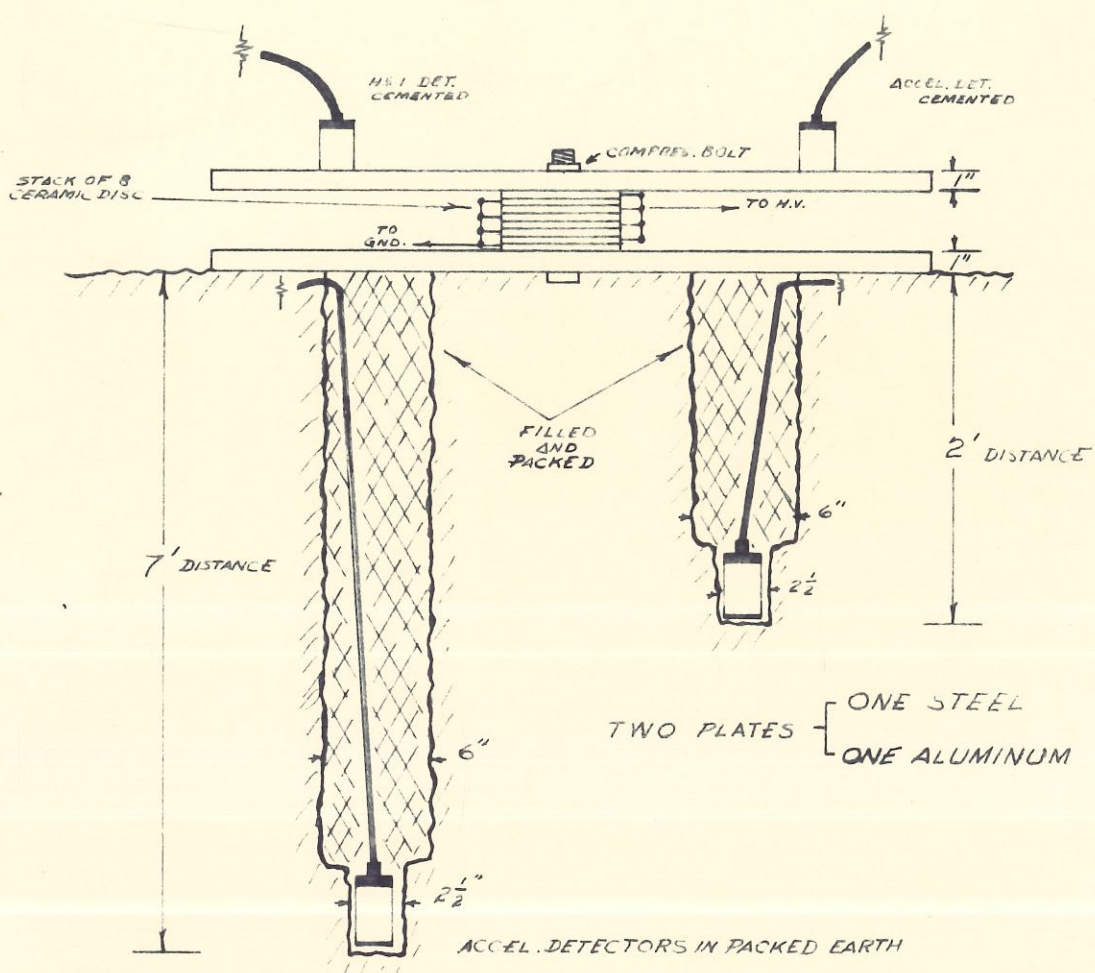
- Sketch 1 - Ceramic transducer-detector plant arrangement and "Pinger" plant.
- Sketch 2 - Dynamite cap transducer.
- Sketch 3 - Ball drop tests on steel plate transducer.
- Sketch 4 - Plate-ceramic disc assembly.
- Figure 1 - MM2FUW speaker transducer and 7 foot target.
- 1A- MM2FUW speaker transducer and shallow vertical detector spread.
- 1B- Signal decay, detector motion versus distance.
- 2 - MM2FUW speaker transducer and 7 foot target.
- 3 - Resonant frequency response of MM2FUW speaker in water.
- 4 - Resonant frequency of adjusted MM2FUW speaker in water.
- 5 - "Pinger" system.
- 6 - 1000 watt second "Boomer" system, large buried object detection.
- 7 - Dynamite cap transducer for large buried object detection.
- 8 - Similar to No. 7.
- 9 - Similar to No. 7.
- 10 - Dynamite cap fired in shallow vertical detector spread.
- 11 - Dynamite cap and 24 foot concrete target.
- 12 - Ceramic transducer and shallow vertical detector spread.
- 13 - Ball drop tests on steel plate.
- 14 - Ball drop tests on steel plate
- 15 - Ball drop tests on steel plate
- 16 - Ball drop tests on steel plate
- 17 - Ball drop tests on steel plate. 7 foot target location.
- 18 - Ceramic stack assembly-plate transducer with PLI power supply.
- 19 - Ceramic stack assembly-plate transducer with MacLaughlin power supply.







SKETCH OF 30" PLATES AND CERAMIC DISC ASSEMBLY



ONE STEEL	NONE	REQ'D	SCALE	PART No.
ONE ALUMINUM				
MAT.		REQ'D	SCALE	CKD.
PETTY LABORATORIES, INC. SAN ANTONIO, TEXAS		ABB		
PROPAGATION MEASUREMENTS				
SONIC				
ARCHAEOLOGICAL PROBE				

University Underwater Speaker

MMOFUN At 7 foot Target Hole

Transducer in oil filled 1 foot deep driver hole.

Pulse

IE-3 Amplifier with high-pass filter -3 db at 1 kcps.

Amplifier gain  $5.3 \times 10^5$  Lo-Z

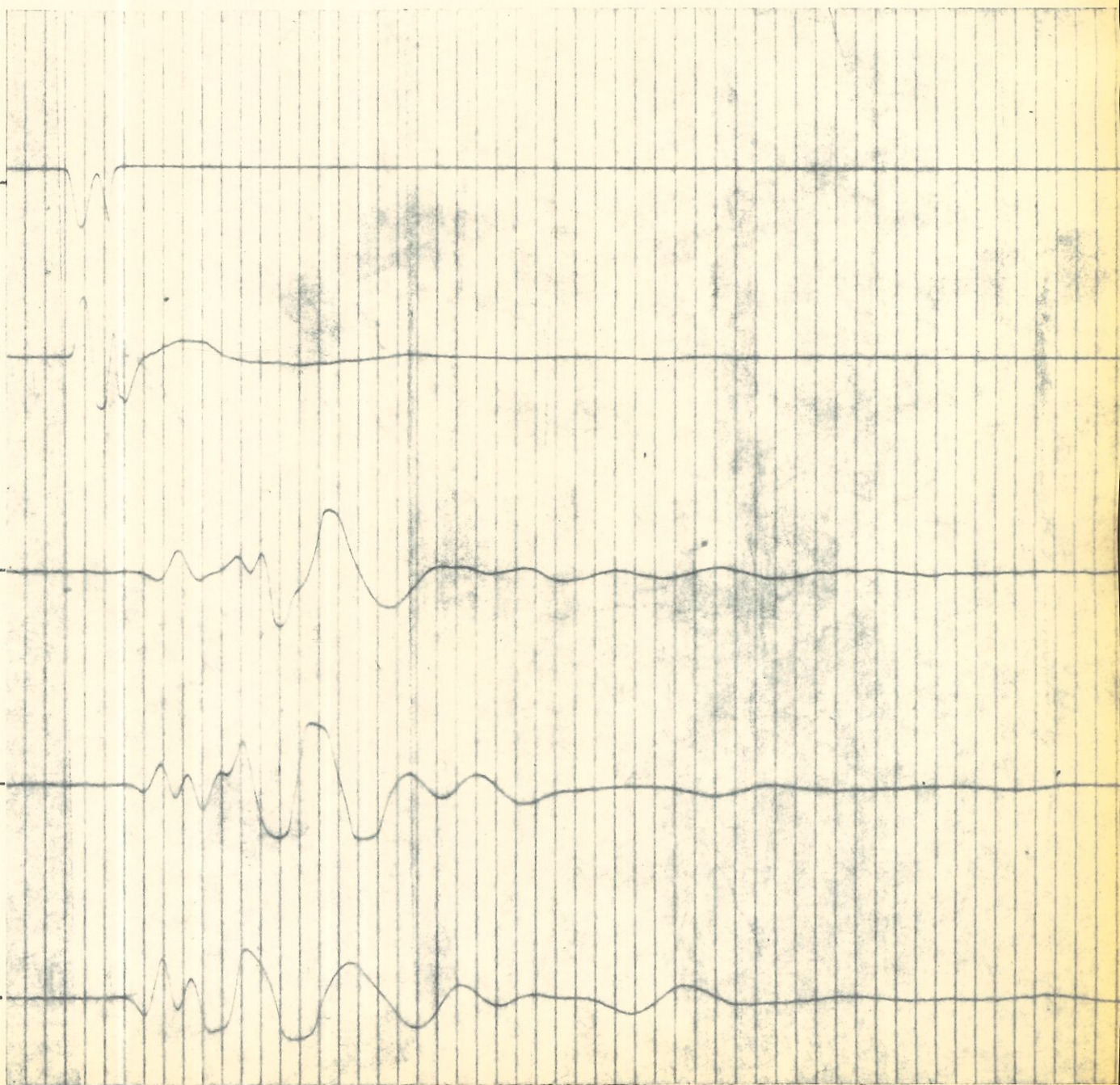
Detector in oil with transducer - Attenuation - 70 db.

Following three detectors connected in parallel and planted on an 18 inch radius about the driver hole.

Detector planted in 2 foot deep hole. Distance 1.8 feet. Attenuation -58 db.

Detector planted 2 feet deep. Distance 1.8 feet. Attenuation -60 db.

Detector planted 2 feet deep. Distance 1.8 feet. Attenuation -56 db.



Millisecond Timing Lines

Evans 7-18-63

MM2FUW Underwater Speaker

Transducer With Shallow Detector

Spread

Adjusted resonance speaker in oil filled center hole of spread of detectors, planted at various depths on an 18 inch radius.

600 cycle Pulse Input

HF-3 Amplifier with high-pass filter HP6A-400 cycles.

Amplifier gain  $5.3 \times 10^5$  Lo-Z

Detector planted 3 feet deep.  
Distance 2.5 feet.  
Attenuation -50 db.

Detector planted 5 feet deep.  
Distance 4.3 feet.  
Attenuation -40 db.

Detector planted 7 feet deep.  
Distance 6.2 feet.  
Attenuation -30 db.

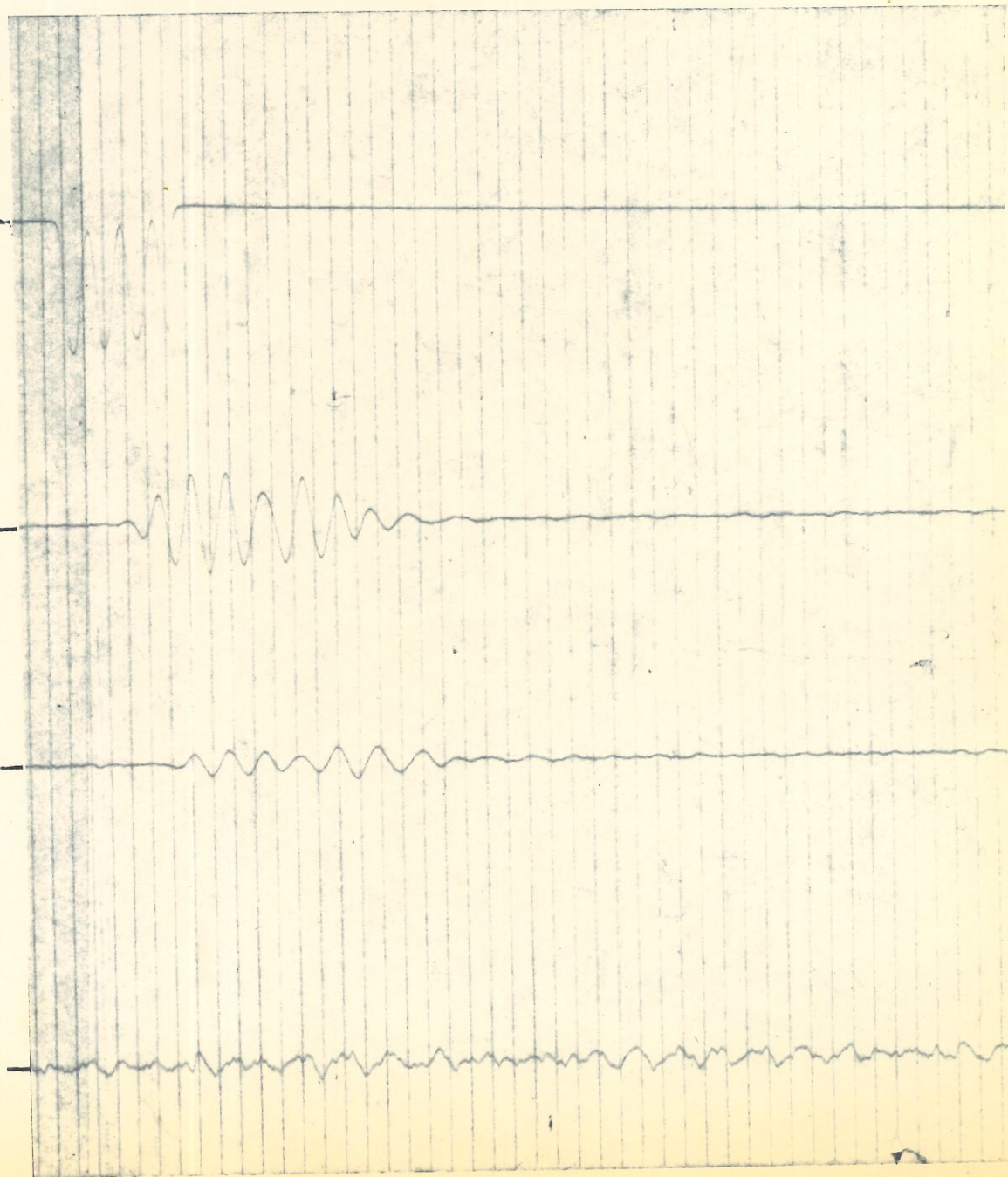


Figure 1A

Millisecond Timing Lines

**KE** SEMI-LOGARITHMIC 359-81  
 KEUFFEL & ESSER CO. MADE IN U.S.A.  
 4 CYCLES X 70 DIVISIONS

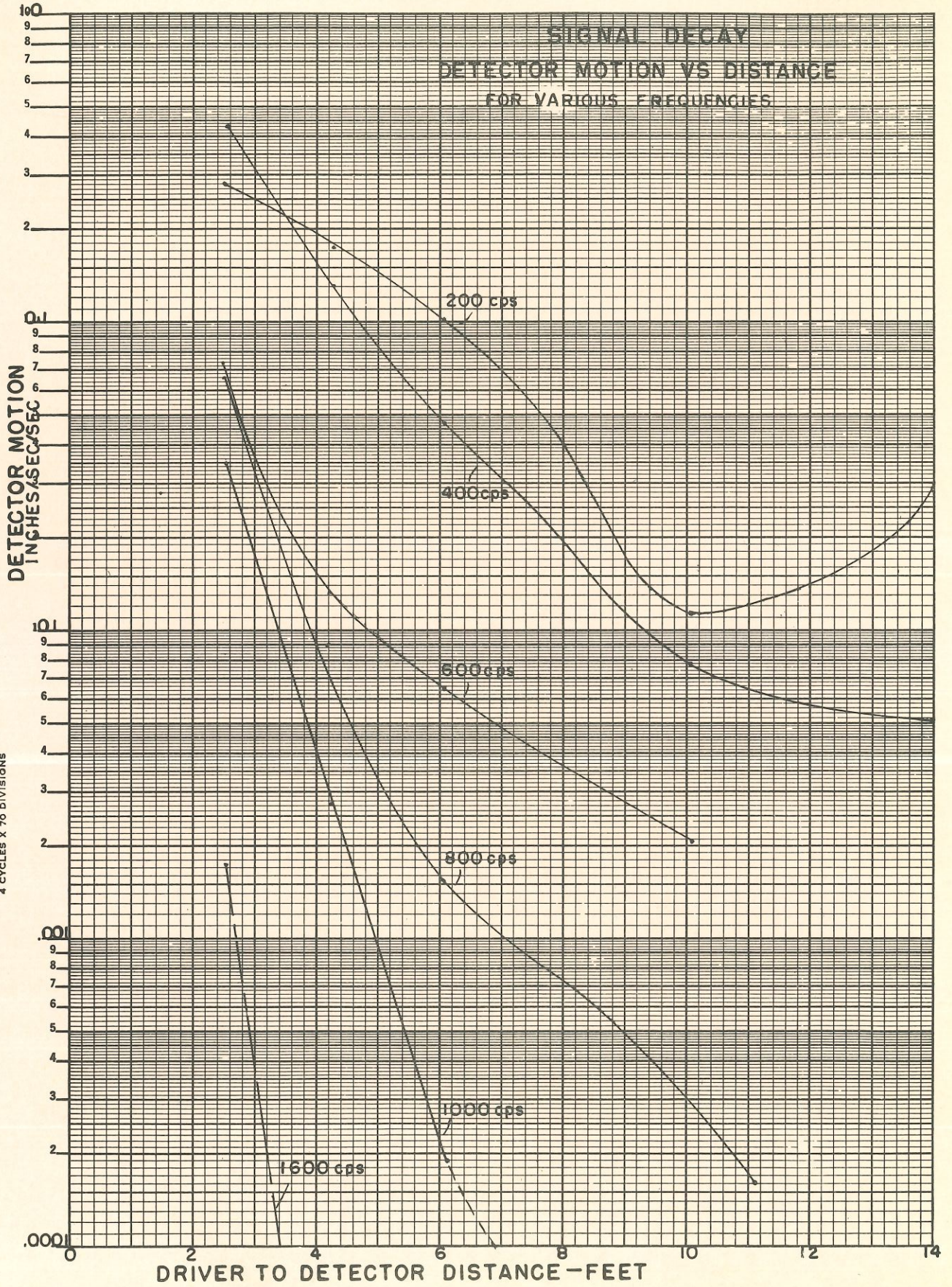


Figure 1B

University M2FW Underwater

Speaker In Oil Filled Driver

Hole Above 7 foot Target

600 cycle pulse operation  
of transducer.

Input Pulse

HF-3 Amplifier with high-pass  
filter HP6A 400 cps -40 db per  
octave.

Detector in oil with transducer  
Attenuation -60 db.

Detector planted 1 foot deep on  
18 inch radius. Distance 1.5 ft.  
Attenuation -40 db.

Detector planted 2 feet deep on  
18 inch radius. Distance 1.3 ft.  
Attenuation -40 db.

Millisecond Timing Lines

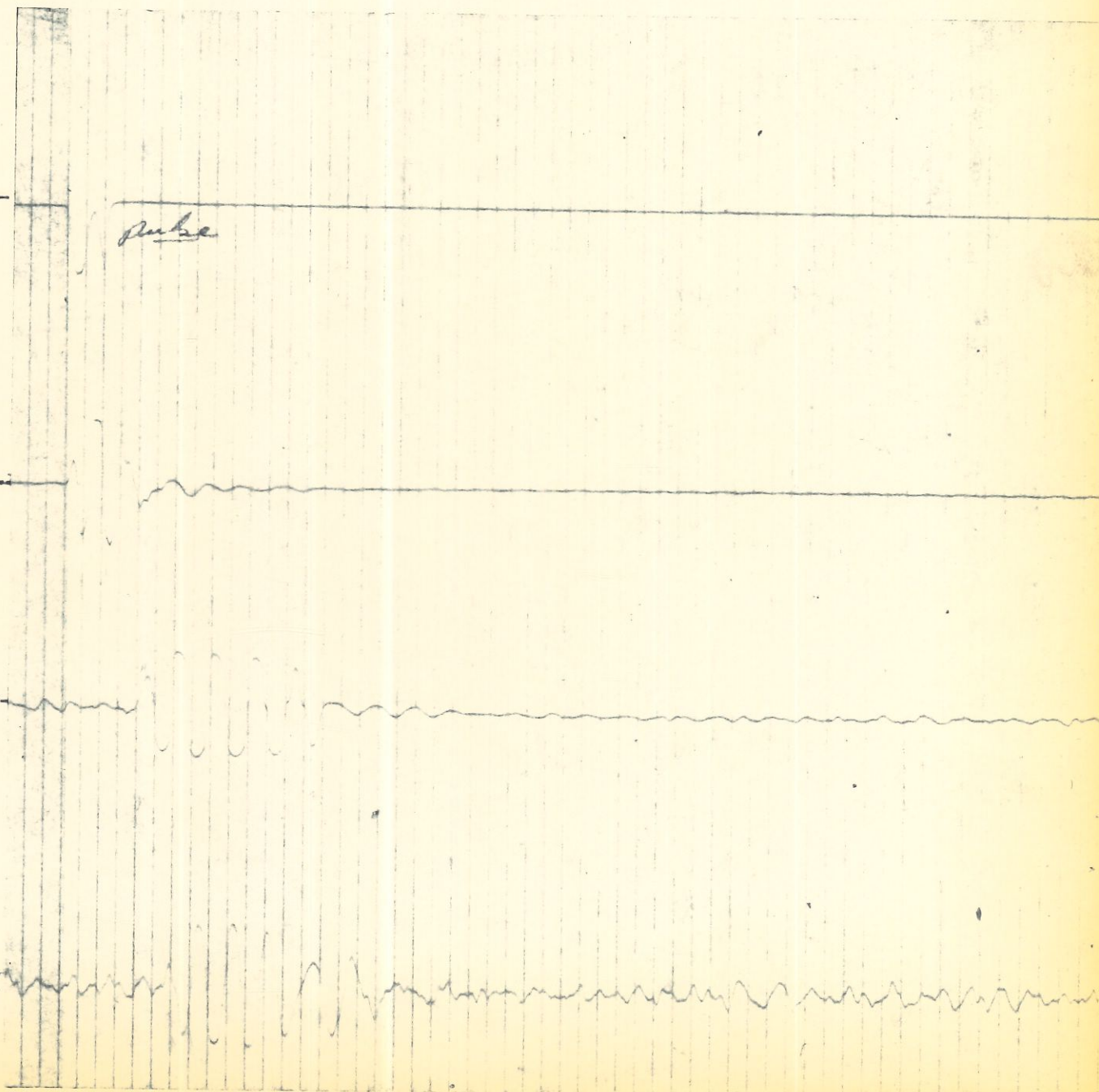


Figure 2

Lab. 1-30-63

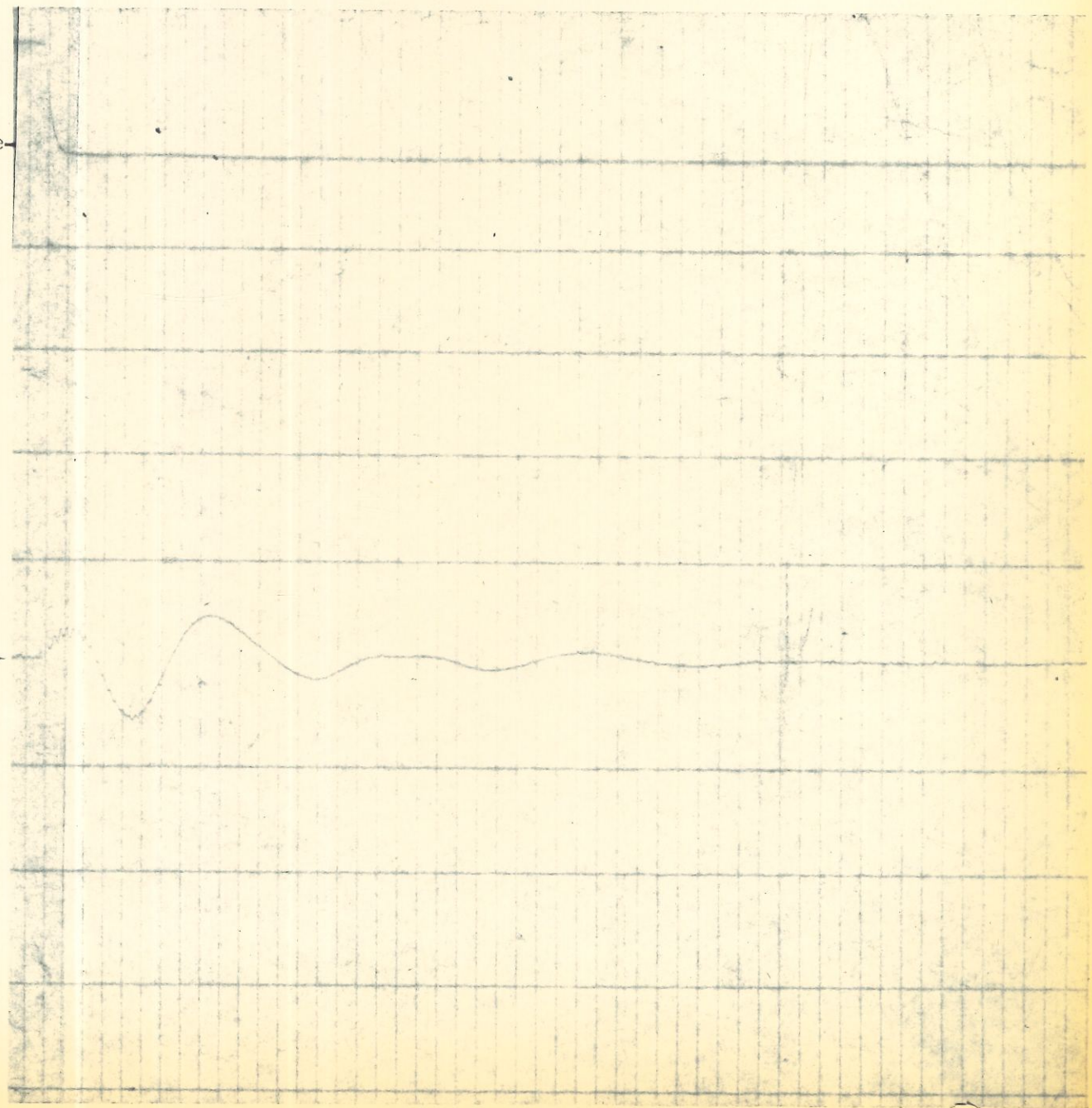
Resonant Frequency Response Of  
Underwater Speaker M12FW In  
Water

12 volt DC Pulse

HF-3 Amplifier with high-pass  
filter -3 db at 1 kcps

Amplifier gain  $5.3 \times 10^5$  Lo-Z

Detector in water with speaker  
Amplifier attenuation -60 db.



Millisecond Timing Lines

3 04174

Lab. 2-12-63

Resonant Frequency Of Adjusted

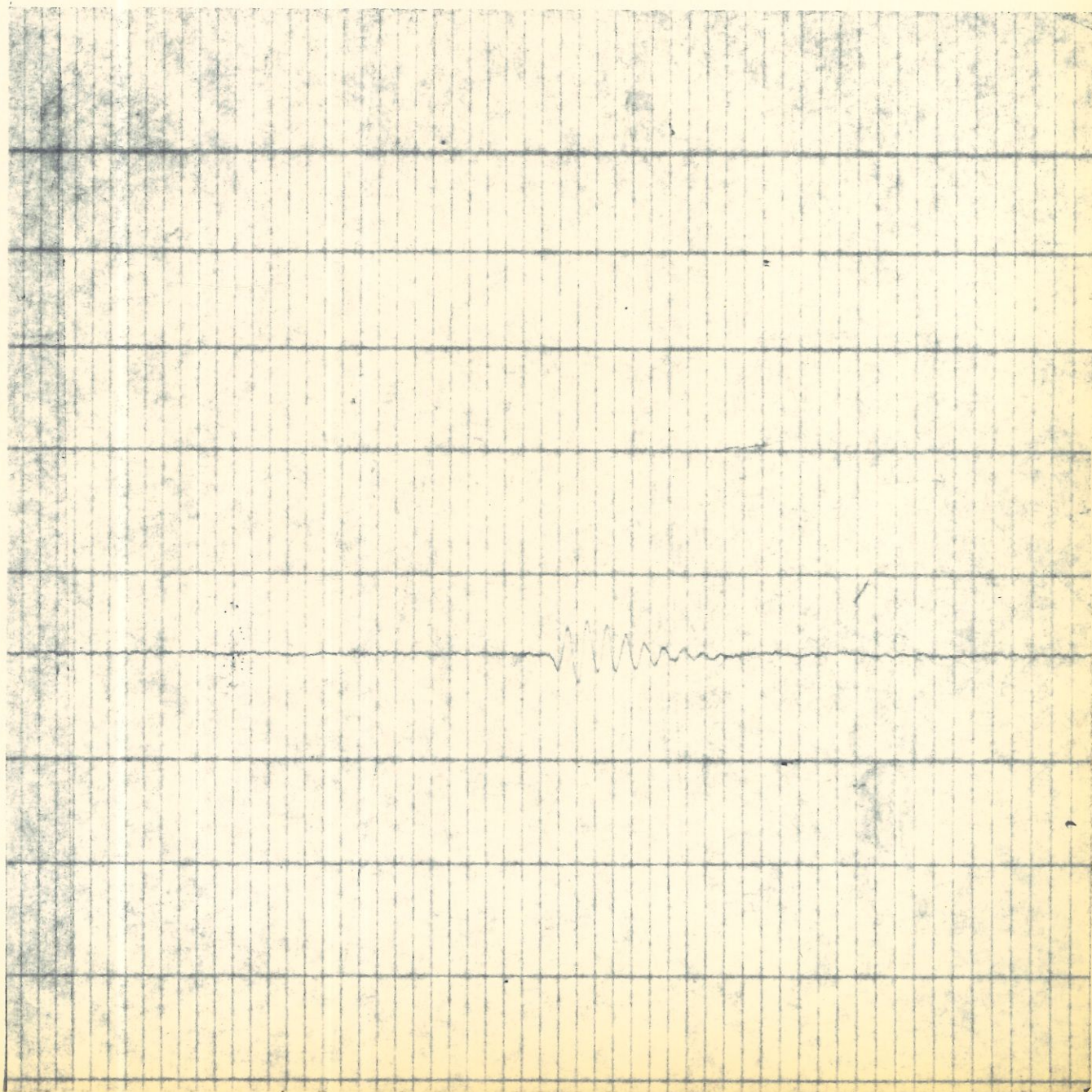
Underwater Speaker MF2FU.

Weldwood glue applied to  
diaphragm surround.

HF-3 Amplifier with high-pass  
filter -3 db at 1 kcps.

Amplifier gain  $5.3 \times 10^5$  Lo-Z

Detector in water with speaker  
Amplifier attenuation -60 db.



4 000 14

Millisecond Timing Lines

Edgerton, Germeshausen & Grier, Inc.

9 kcps Pinger System

Magnetostrictive transducer placed first in water and then suspended in air above the water.

The first record segment illustrates the sonic signal through 1.6 feet of soil.

The second record segment is acoustic coupling thru the air to the buried detector.

The detector is planted 1 foot away and 16 inches deep.

HF-3 Amplifier with no filter.

Amplifier gain  $5.3 \times 10^5$  Lo-Z

Attenuation -40 db.

Small arrow denotes limit of initial firing pulse.

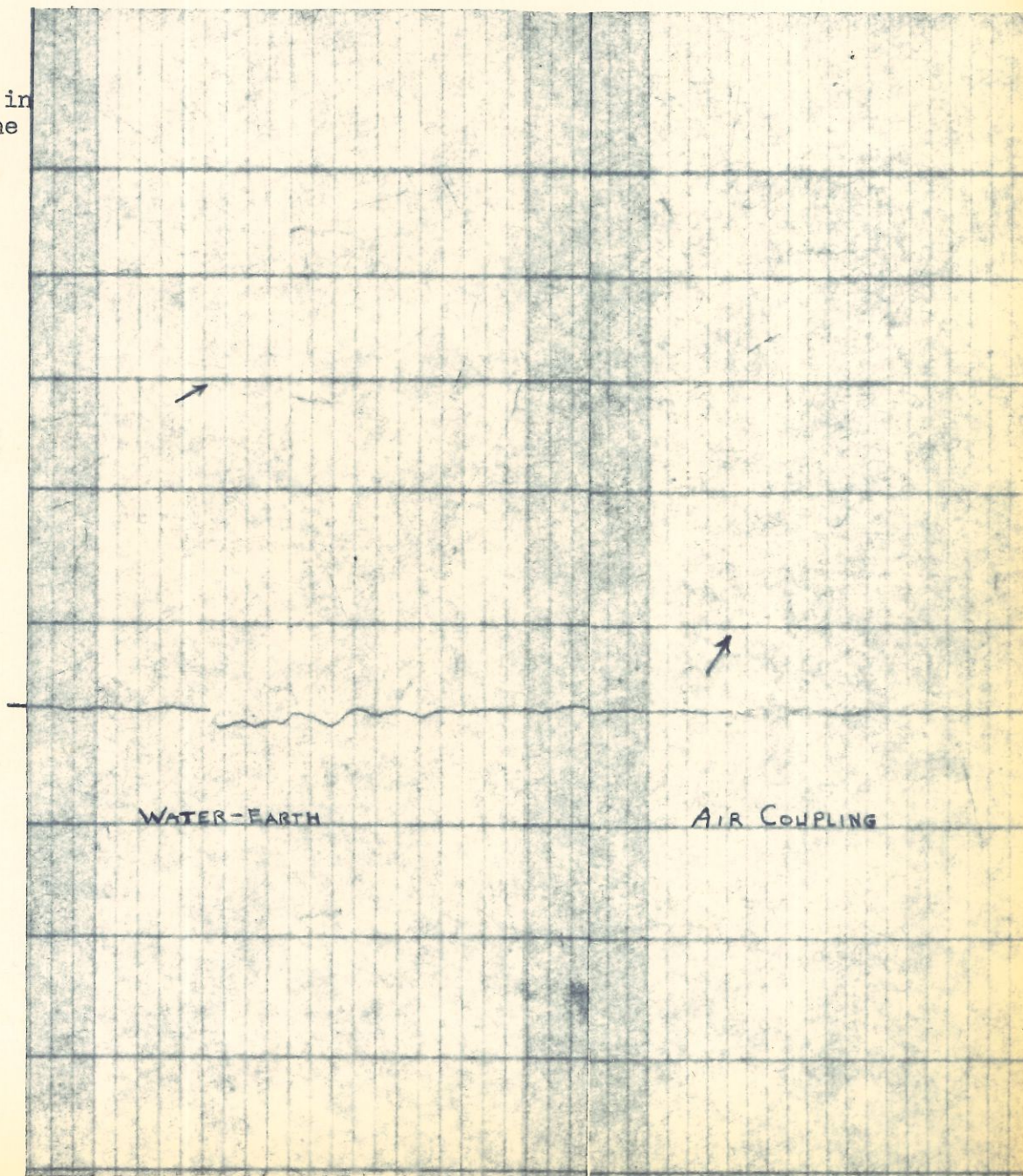


Figure 5

Millisecond Timing Lines

530 Area 4-30-63

1000 WS Boomer Transducer

Large Object Detection

Area of limestone ledges  
simulating large buried objects.

Detectors all planted two feet  
deep at the given distances.  
HF-3 Amplifier with high-pass  
filter HP6A-400 cycles.

Amplifier gain  $5.3 \times 10^5$  Pulse  
Lo-Z

Detector distance 3.15 feet  
Attenuation -70 db.

Detector distance 6.07 feet.  
Attenuation -70 db.

Detector distance 9.1 feet.  
Attenuation -70 db.

Detector distance 12 feet.  
Attenuation -64 db.

Detector distance 15 feet.  
Attenuation -54 db.

Detector distance 18 feet.  
Attenuation -66 db.

Detector distance 21 feet.  
Attenuation -56 db.

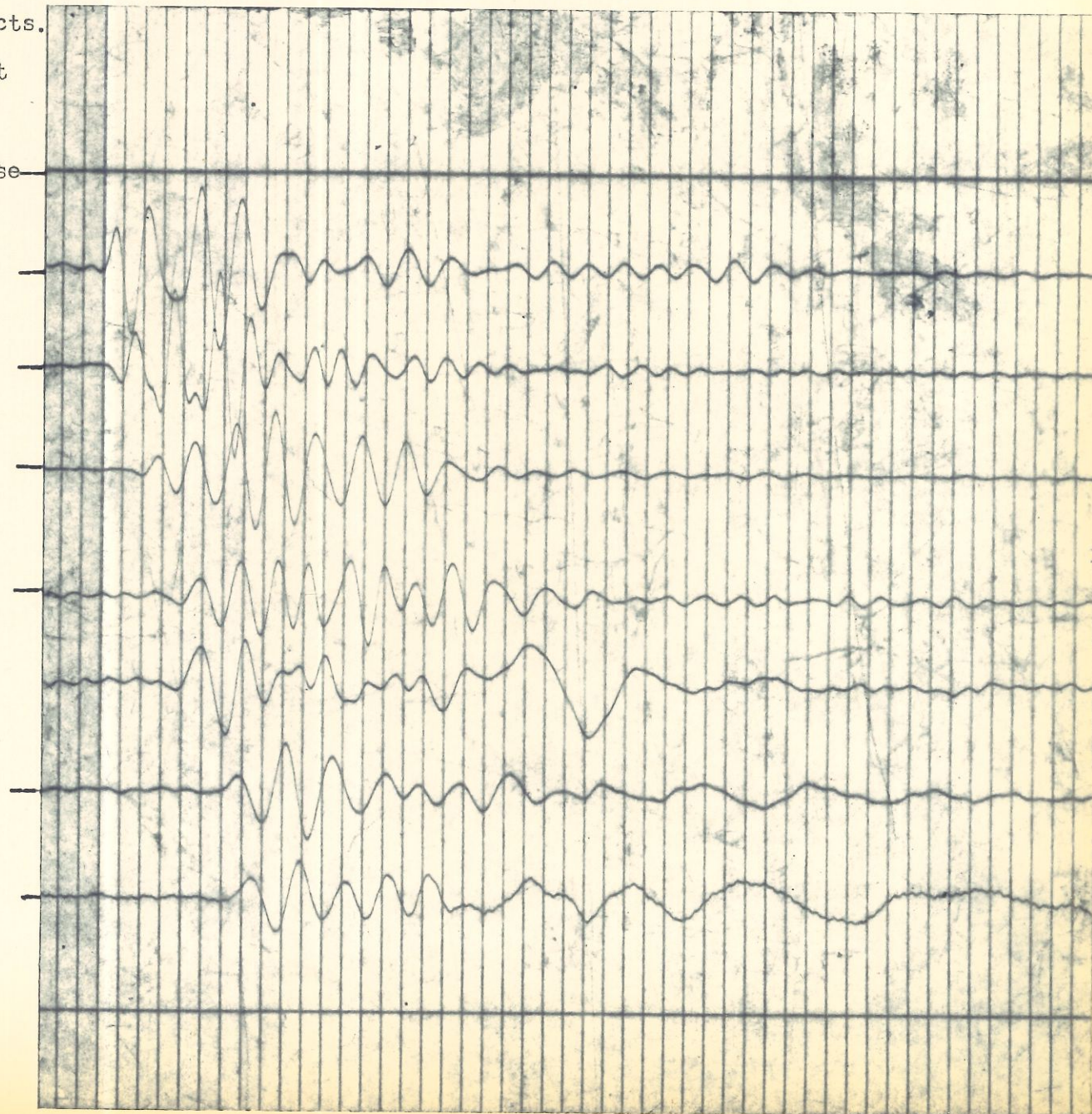


FIGURE 6

Millisecond Timing Lines

Dynamite Cap Transducer For  
Large Object Detection

Dynamite cap fired in water  
filled transducer hole No.1 at  
the limestone ledge area. SHOT.

HF-3 Amplifier with high-pass  
filter -3 db at 1 kcps.

Amplifier gain  $5.3 \times 10^5$  Lo-Z

Detector planted 2 feet deep and  
distance of 2.2 feet from  
transducer.  
Attenuation -22 db.

Detector planted 2 feet deep and  
distance of 2.2 feet from  
the transducer.  
Attenuation -22 db.

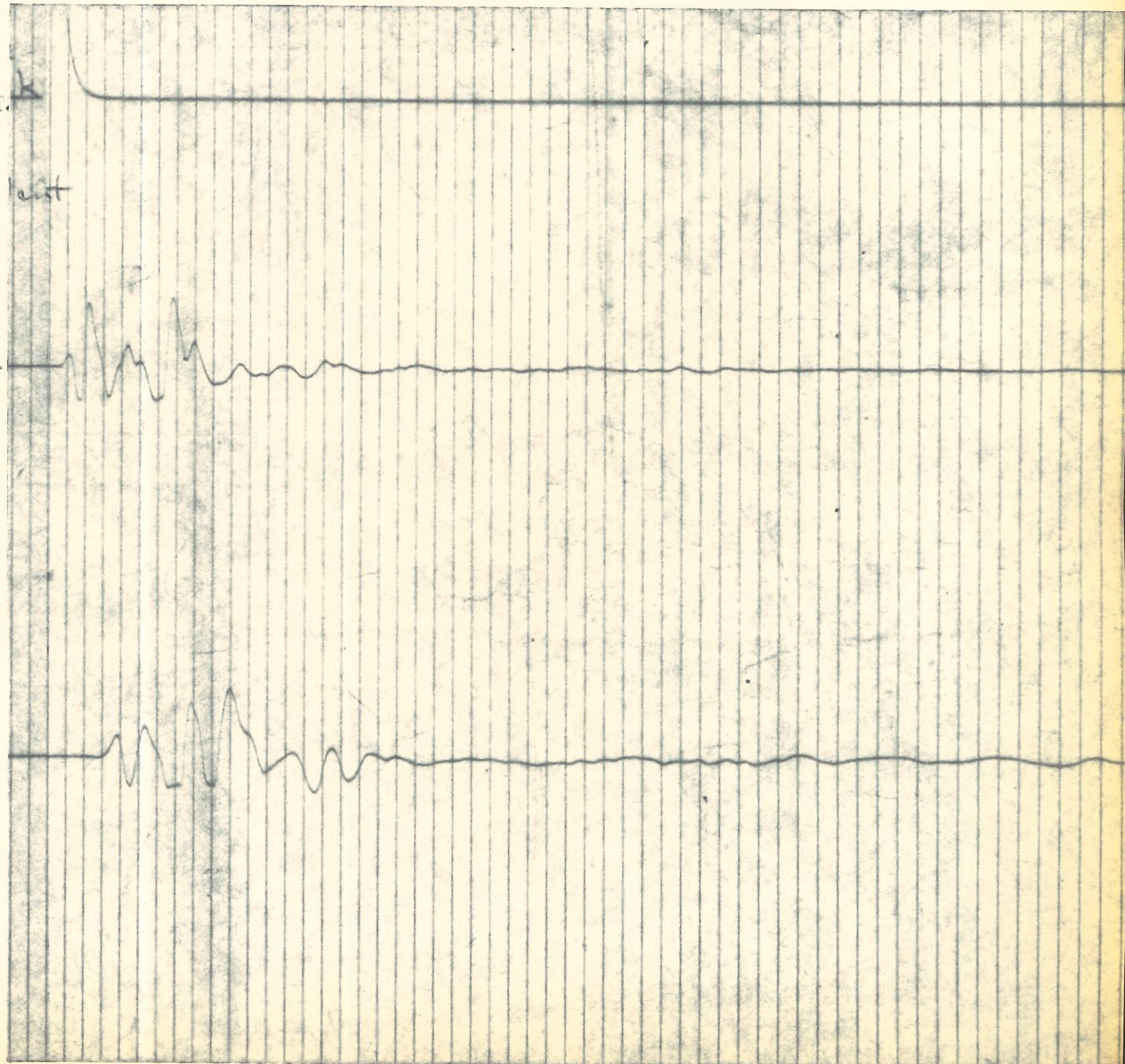


Figure 7

Millisecond Timing Lines

530 Area 5-7-63

Dynamite Cap Transducer

Large Object Detection

Limestone ledges below the surface.

Cap Fired--

Dynamite cap in one foot of water in center of 1000 WS transducer hole.

HF-3 Amplifier with high-pass filter HP6A-200 cycles.

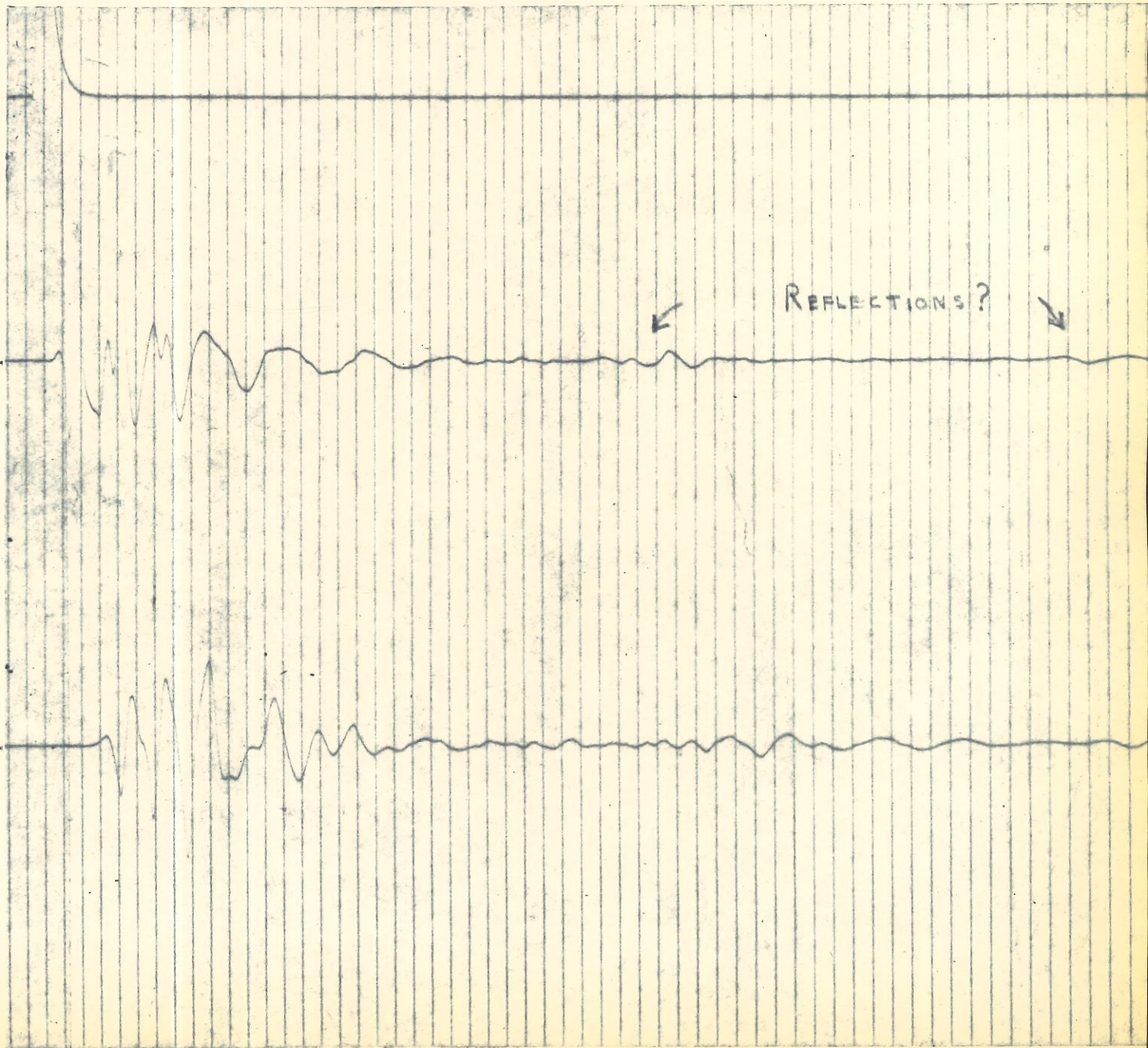
Amplifier gain  $5.3 \times 10^5$  Lo-Z

Detector planted 2 feet deep at side of transducer hole.

Distance 2.2 feet.  
Attenuation -88 db.

Detector planted 2 feet deep at side of transducer hole.

Distance 2.2 feet.  
Attenuation -88 db.



Millisecond Timing Lines

530 Area 5-7-63

Dynamite Cap Transducer

Large Object Detection

Limestone ledges below the surface.

Cap Fired---

Dynamite cap in one foot of water in the center of the 1000 WS transducer hole.

HF-3 Amplifier with high-pass filter HP6A- 400 cycles.

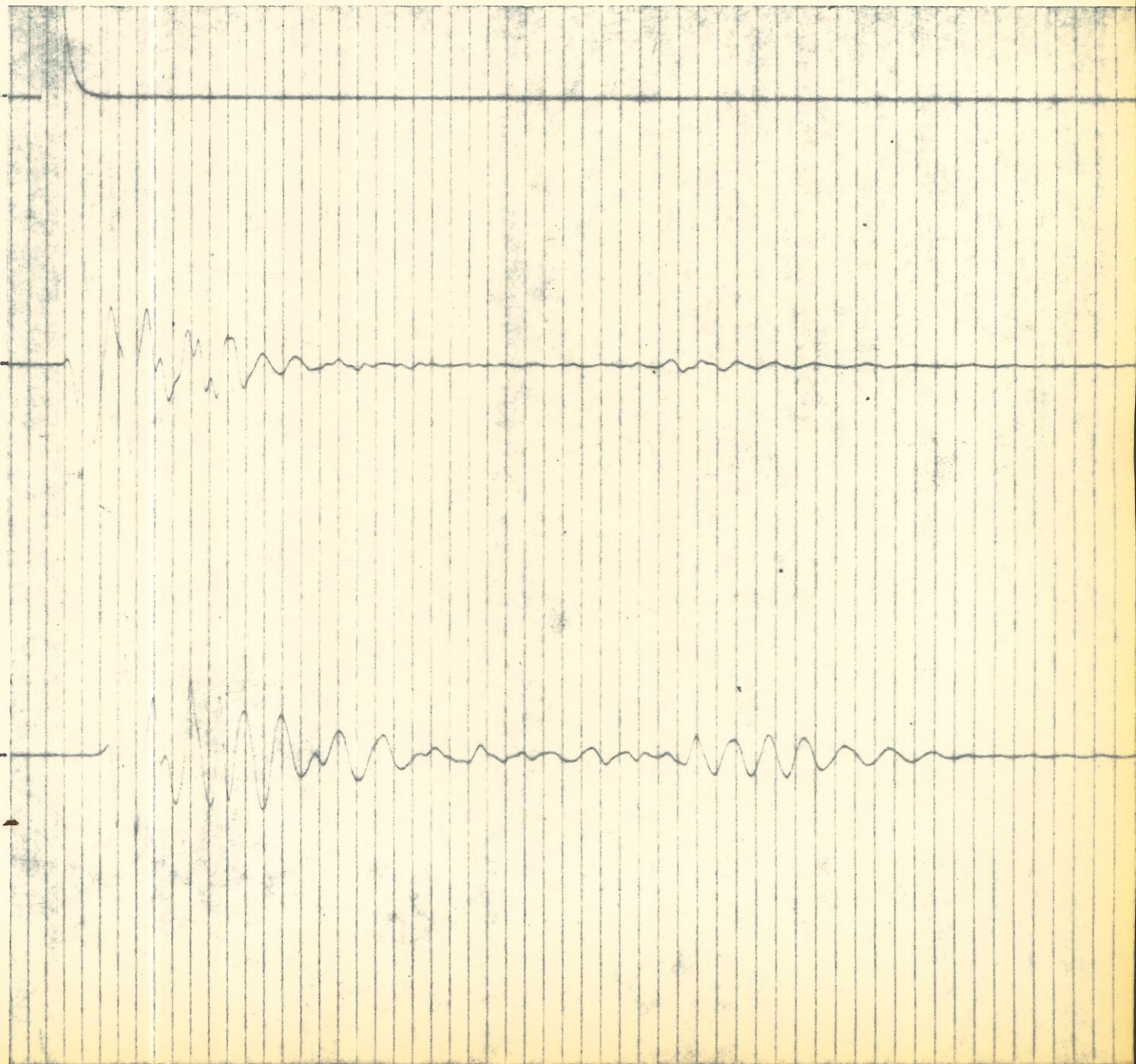
Amplifier gain  $5.3 \times 10^5$  Lo-Z

Detector planted 2 feet deep at side of transducer hole.---

Distance 2.2 feet.  
Attenuation -84 db.

Detector planted 2 feet deep at side of transducer hole.---

Distance 2.2 feet.  
Attenuation -84 db.



Millisecond Timing Lines

Dynamite Cap Fired In 1000 WS  
Driver Hole At Shallow Spread  
In One Foot Of Water

Cap Fired-

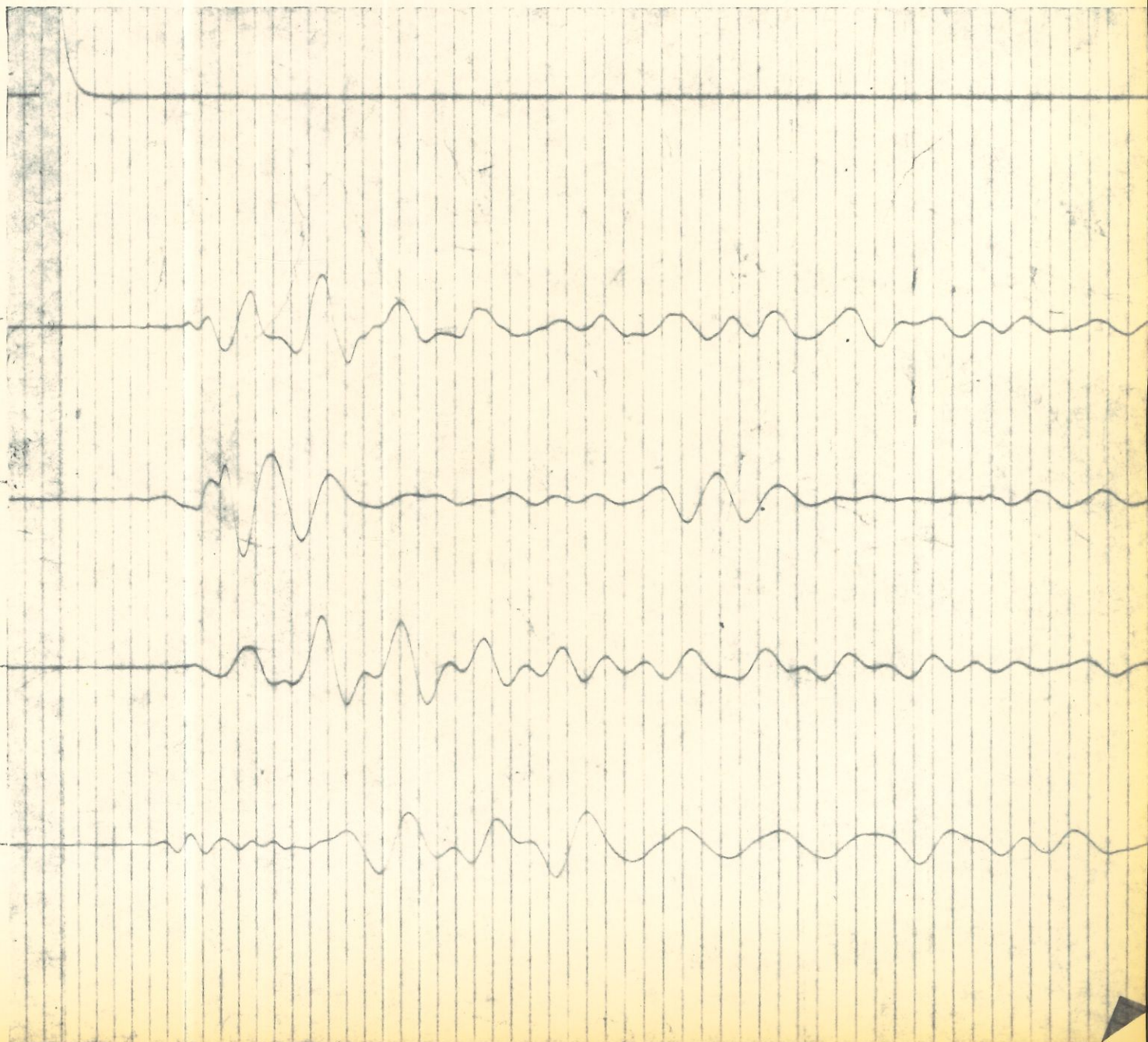
HF-3 Amplifier with high-pass  
filter -40 db per octave.  
HP6A-200 cycles  
Amplifier gain  $5.3 \times 10^5$  Lo-Z

Detector planted 3 feet deep  
distance 6.3 feet.  
Attenuation -80 db.

Detector planted 5 feet deep  
distance 5 feet.  
Attenuation -96 db.

Detector planted 7 feet deep  
distance 8.5 feet.  
Attenuation -78 db.

Detector planted 15 feet deep  
distance 15.3 feet.  
Attenuation -76 db.



Millisecond Timing Lines

Evans 10-30-62

Dynamite Can Fired Above

Concrete Target (24 feet)

Firing Pulse—

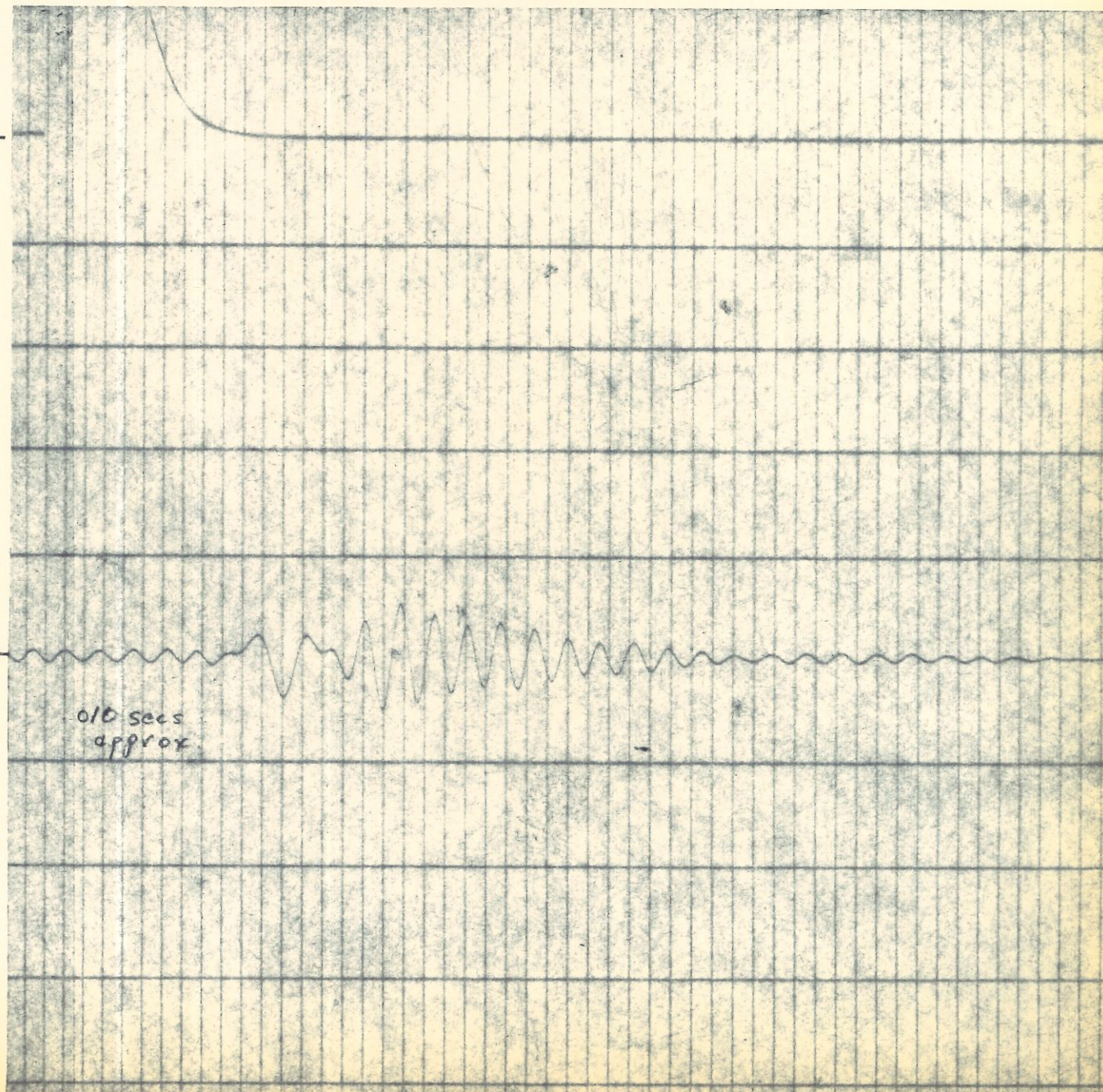
MF-3 Amplifier with high-pass  
HP6A 600 cycles filter.

Amplifier gain  $5.3 \times 10^5$  Lo-Z

Unconsolidated soil above  
concrete target. Dynamite can  
fired in earth.

Detector planted 1 foot deep  
above target.  
Distance 24.4 feet.  
Amplifier attenuation -40 db.

Note filter ringing. Lumped  
filter of -40 db per octave.



Evans 7-16-63

BaTi Transducer With Shallow

Spread

Transducer in oil filled center hole.

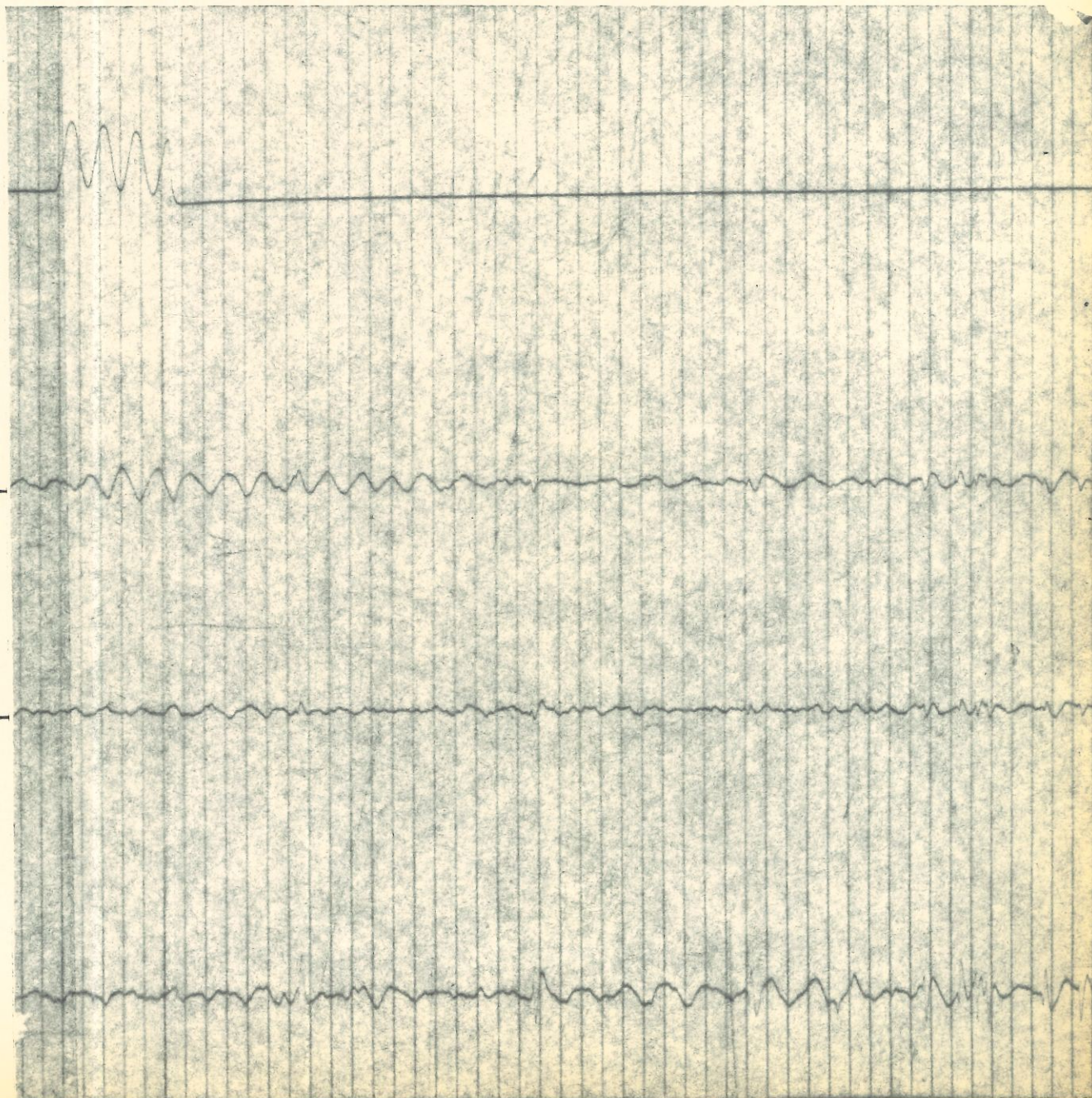
HF-3 Amplifier with high-pass filter HP6A-400 cycles.

Amplifier gain  $5.3 \times 10^5$  Lo-Z  
3 kv 600 cycle Pulse ---

Detector planted 3 feet deep on  
18 inch radius from transducer ---  
Attenuation -30 db.  
Distance 2.5 feet.

Detector planted 5 feet deep on  
18 inch radius from transducer ---  
Attenuation -30 db.  
Distance 4.3 feet.

Detector planted 7 feet deep on  
18 inch radius from transducer  
Attenuation -30 db.  
Distance 6.2 feet.



Millisecond Timing Lines

ans 8-27-63

Ball Drop On Steel Plate

Previously undisturbed soil  
location.

1 X 30 inch steel plate surface  
planted with mud slurry.

16.1 gram ball dropped from a 3  
foot height.

HF-3 Amplifier with high-pass  
filter -3 db at 1 kcps.

Amplifier gain  $5.3 \times 10^5$  Lo-Z

Detector cemented to plate  
Attenuation -82 db.

Detector planted 2 feet in  
packed hole under plate  
Attenuation -68 db.

Detector planted 7 feet in  
packed hole under plate  
Attenuation -48 db.

Detector planted 42 inches away  
and 3 feet deep. Distance 3.6 ft.  
Attenuation -50 db.

Millisecond Timing Lines

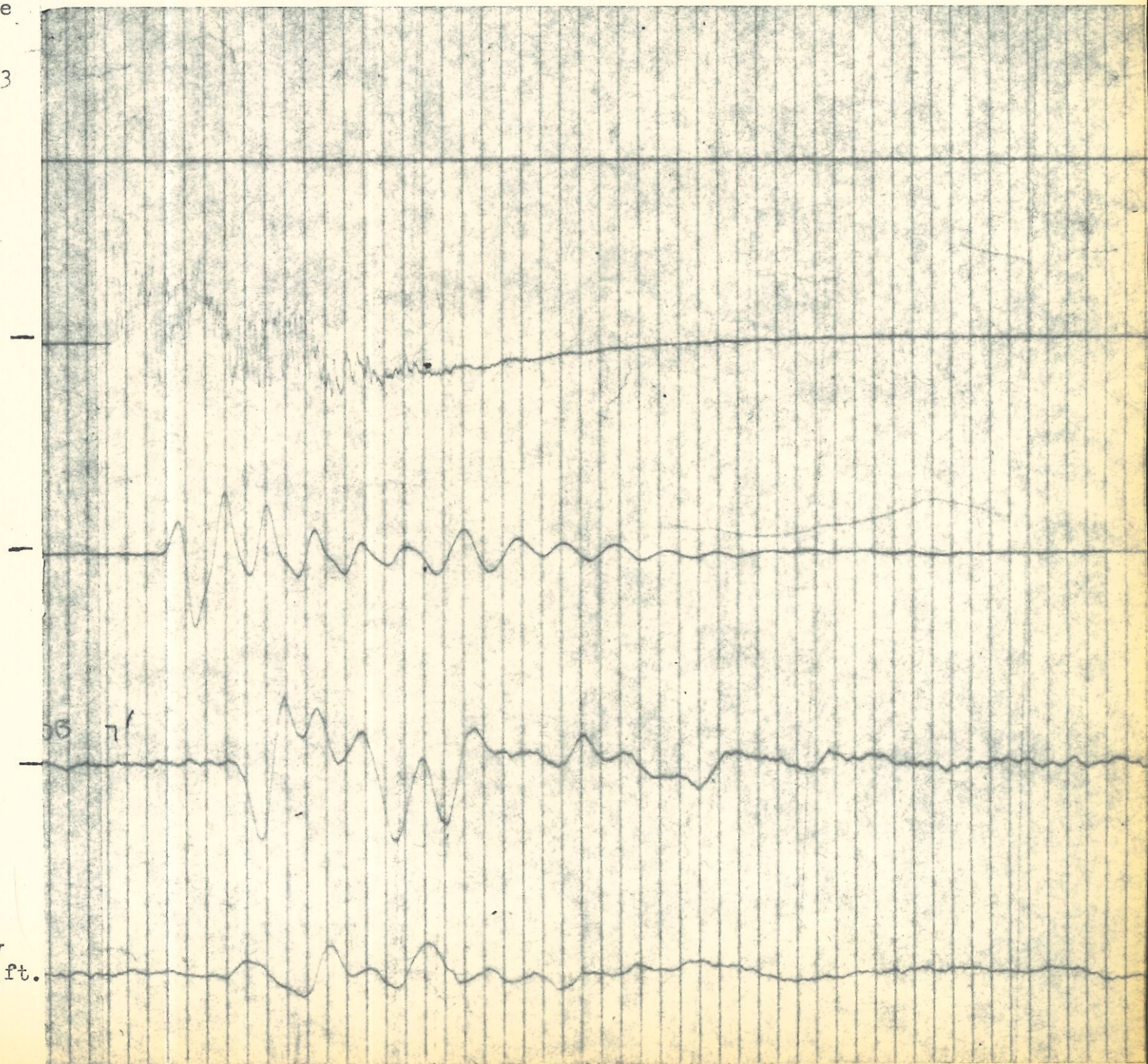


Figure 13

Ball Drop On Steel Plate

Previously undisturbed soil  
location.

1 X 30 inch steel plate surface  
planted with mud slurry.

21.7 gram ball dropped from a 3  
foot height.

HF-3 Amplifier with high-pass  
filter -3 db at 1 kcps.

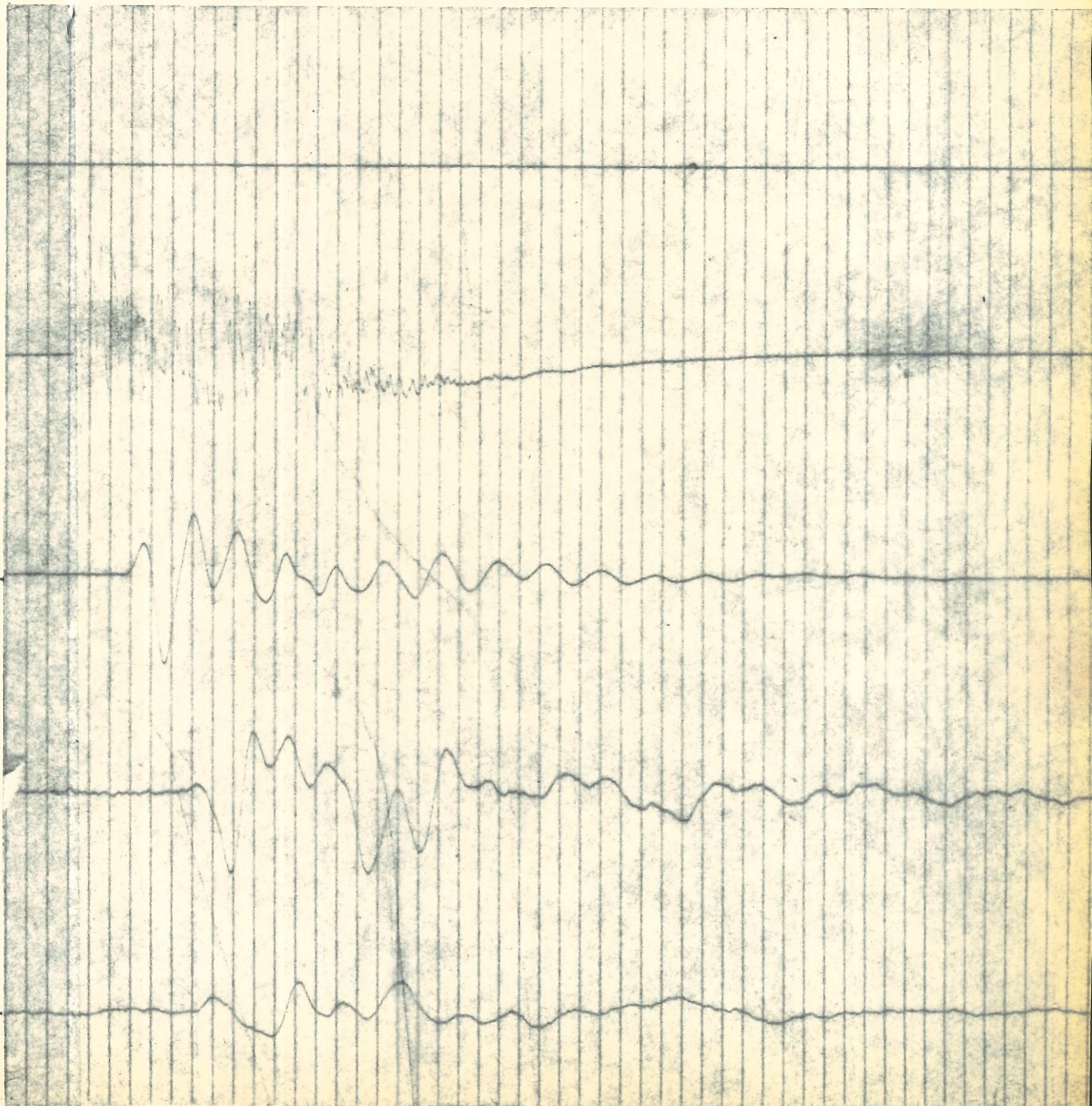
Amplifier gain  $5.3 \times 10^5$  Lo-Z

Detector cemented to plate.  
Attenuation -82 db.

Detector planted 2 feet in  
packed hole under plate.  
Attenuation -70 db.

Detector planted 7 feet in  
packed hole under plate.  
Attenuation -50 db.

Detector planted 1/2 inches away  
and 3 feet deep. Distance 3.6 ft.  
Attenuation -52 db.



Millisecond Timing Lines

Figure 11

Ball Drop On Steel Plate

Previously undisturbed soil  
location.

1 X 30 inch steel plate surface  
planted with mud slurry.

35.7 gram ball dropped from a 3  
foot height.

HF-3 Amplifier with high-pass  
filter -3 db at 1 kcps.

Amplifier gain  $5.3 \times 10^5$  Lo-Z

Detector cemented to plate  
Attenuation -84 db.

Detector planted 2 feet in  
packed hole under plate.  
Attenuation -70 db.

Detector planted 7 feet under  
plate in packed hole  
Attenuation -52 db.

Detector planted 1/2 inches away  
and 3 feet deep. Distance 3.6 ft.

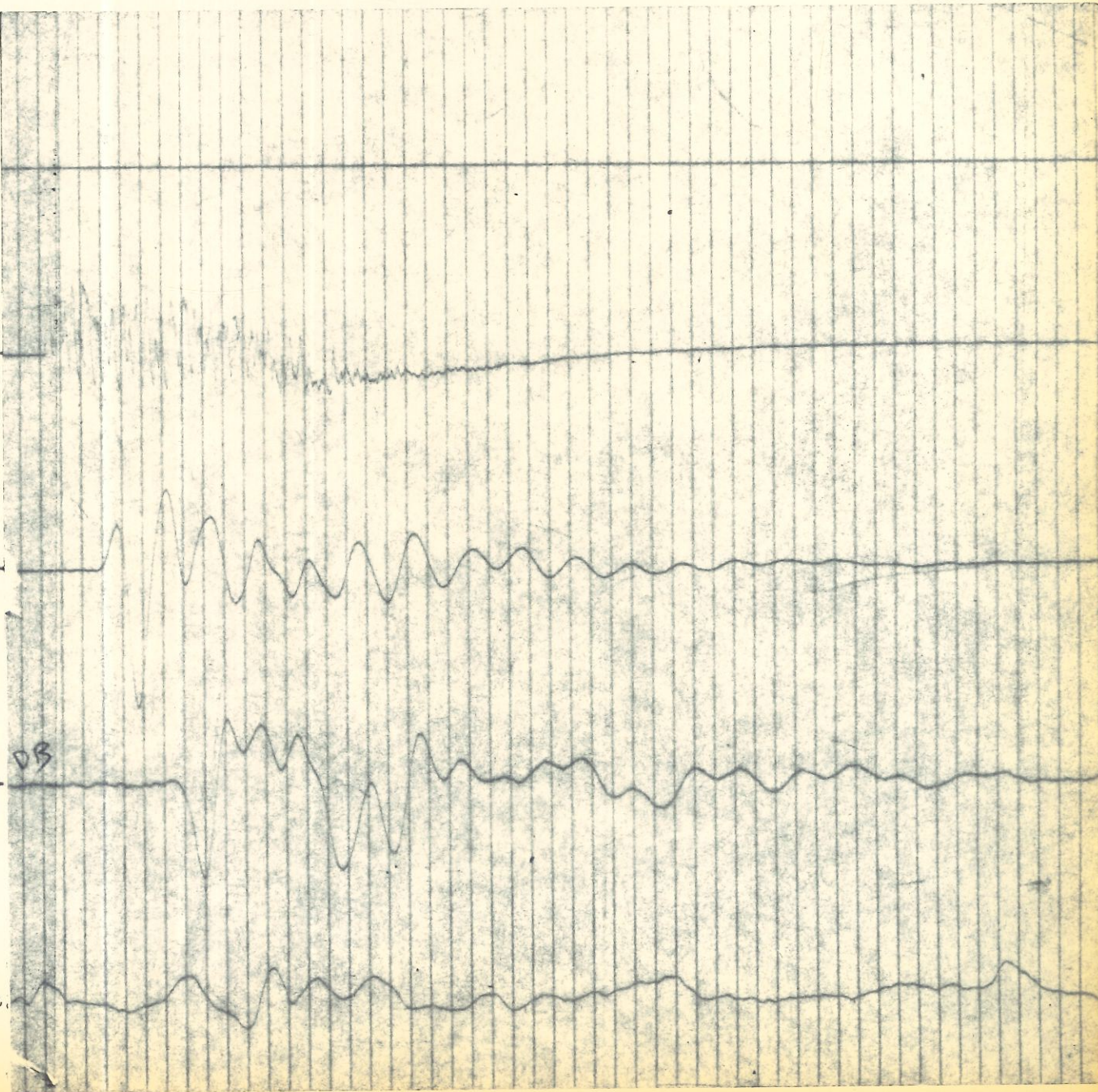


Figure 15

Millisecond Timing Lines

Ball Drop On A Steel Plate

Previously undisturbed soil location.

1 X 30 inch steel plate surface planted with mud slurry.

93.5 gram ball dropped from a 3' height.

IF-3 Amplifier with high-pass filter -3 db at 1 kcps.

Amplifier gain  $5.3 \times 10^5$  Lo- Z

Detector cemented to plate. Attenuation -90 db.

Detector planted 2 feet in packed hole under plate. Attenuation -76 db.

Detector planted 7 feet in packed hole under plate. Attenuation -60 db.

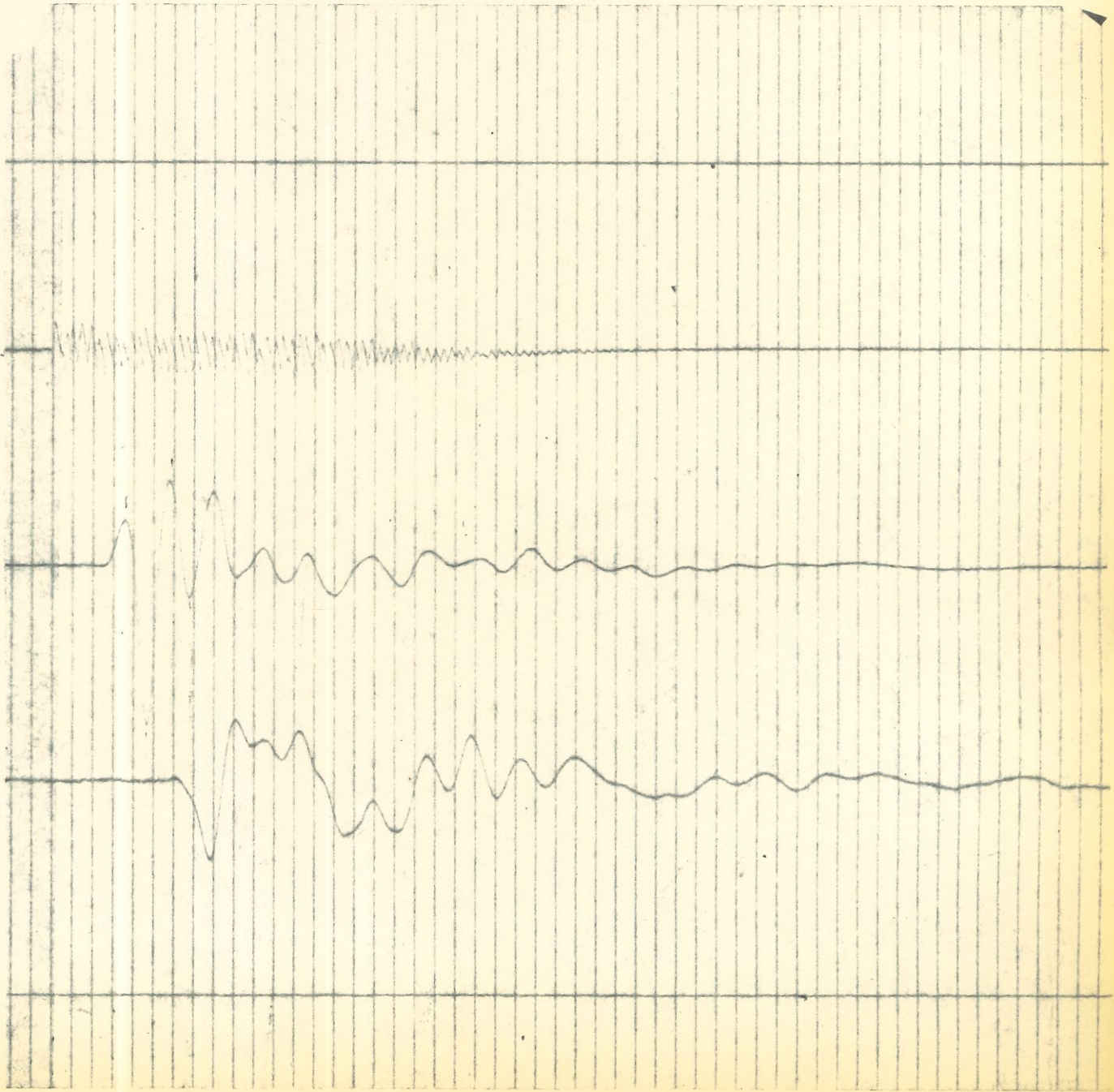


Figure 16

Millisecond Timing Lines

Evans 8-27-63

Ball Drop On Plate At

7 Foot Target Location

Plate 1 X 30 inches, surface  
plated with mud slurry.

Ball weight 23.5 grams dropped  
from a 3 foot height.

Detector cemented to plate. Impact  
Attenuation -74 db.

Detector in packed hole 2 feet  
under plate.  
Attenuation -74 db.

Detector planted 3 feet away and  
2 feet deep. Distance 3.6 feet.  
Attenuation -60 db.

Detector in packed hole 6.5 feet  
under plate.  
Attenuation -76 db.

Millisecond Timing Lines

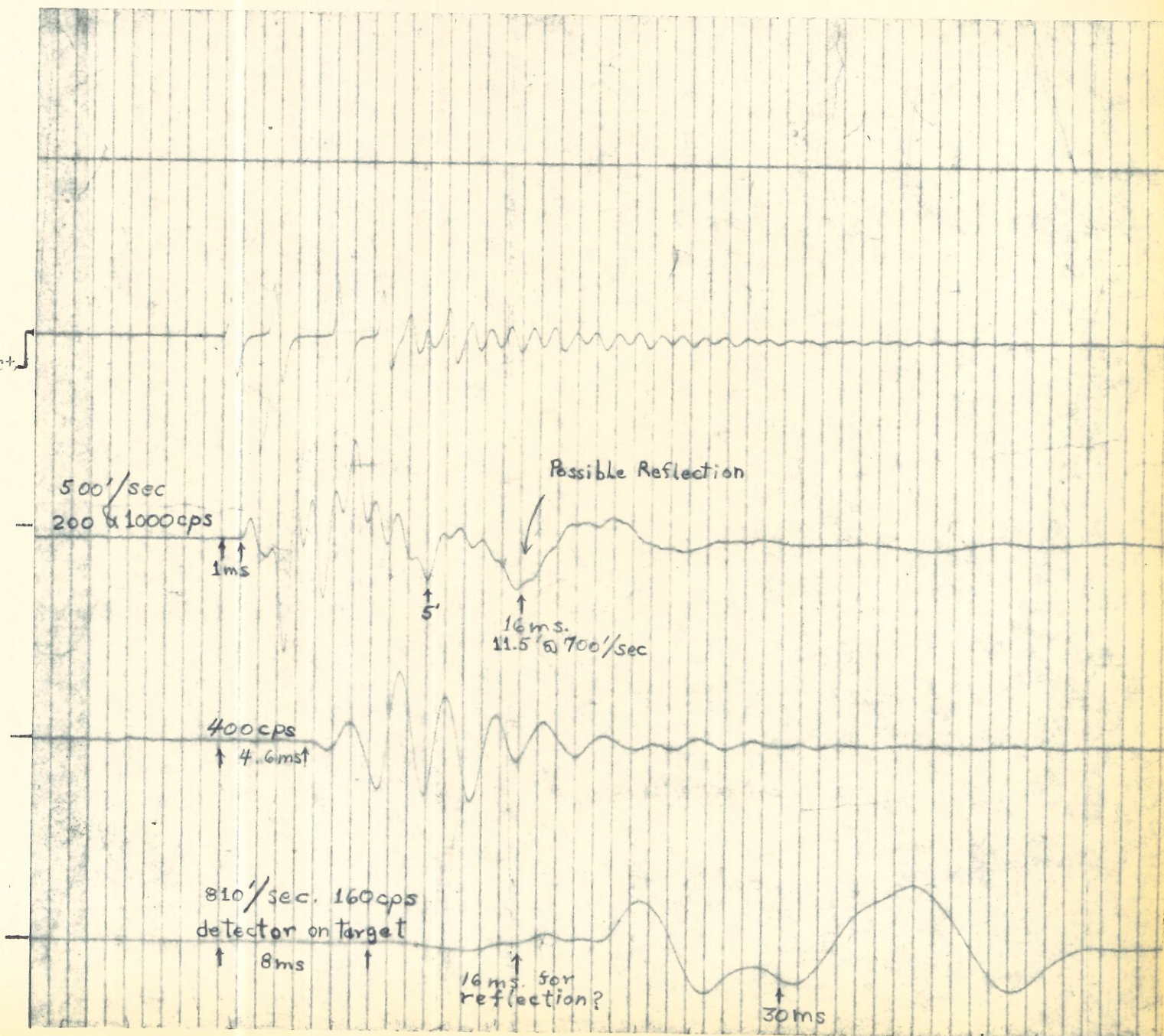


Figure 17

Evans 10-1-63

Plates-Ceramic Stack Transducer

With PLI 14 KV Pulse Power

Supply

30 inch aluminum plate over 30 inch steel plate with ceramic rings in the middle under compression load.

Steel plate in contact with soil and coupled with mud slurry.

HF-3 Amplifier with high-pass filter -3 db at 1 kcps.  
Amplifier gain  $5.3 \times 10^5$  Lo-Z

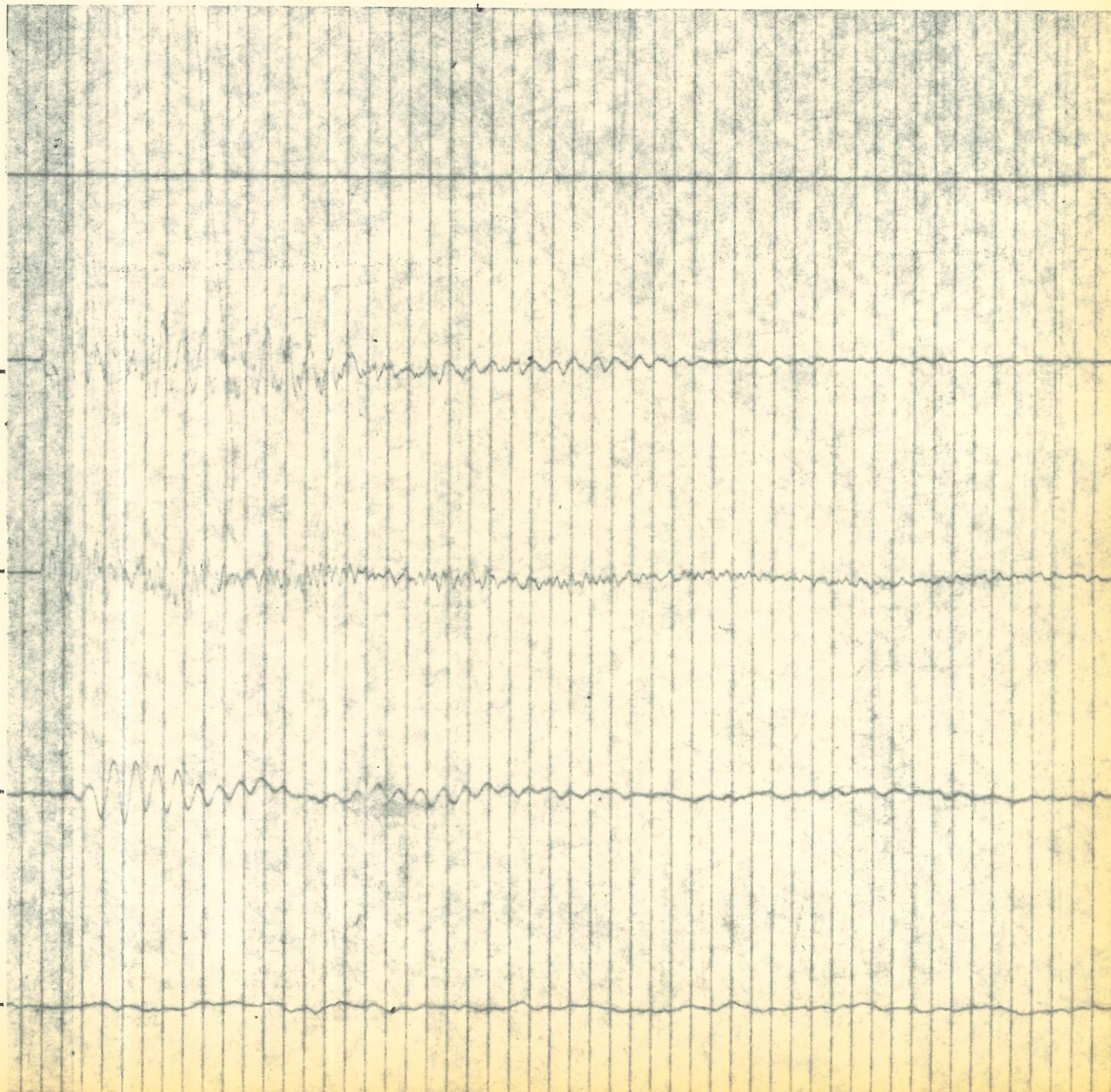
Detector cemented to plate.  
Attenuation - 84 db.

Detector HS-1, Velocity Type,  
cemented to plate.  
Attenuation -34 db.

Detector planted 2 feet under  
steel plate in packed hole.  
Attenuation -50 db.

Detector planted 7 feet under  
steel plate in packed hole.  
Attenuation -50 db.

Millisecond Timing Lines



Plates-Ceramic Stack Transducer

With MacLaughlin 30 kv Power

Supply

30 inch aluminum plate on top  
with steel plate in contact  
with the earth. Ceramic stack  
between under compression load.

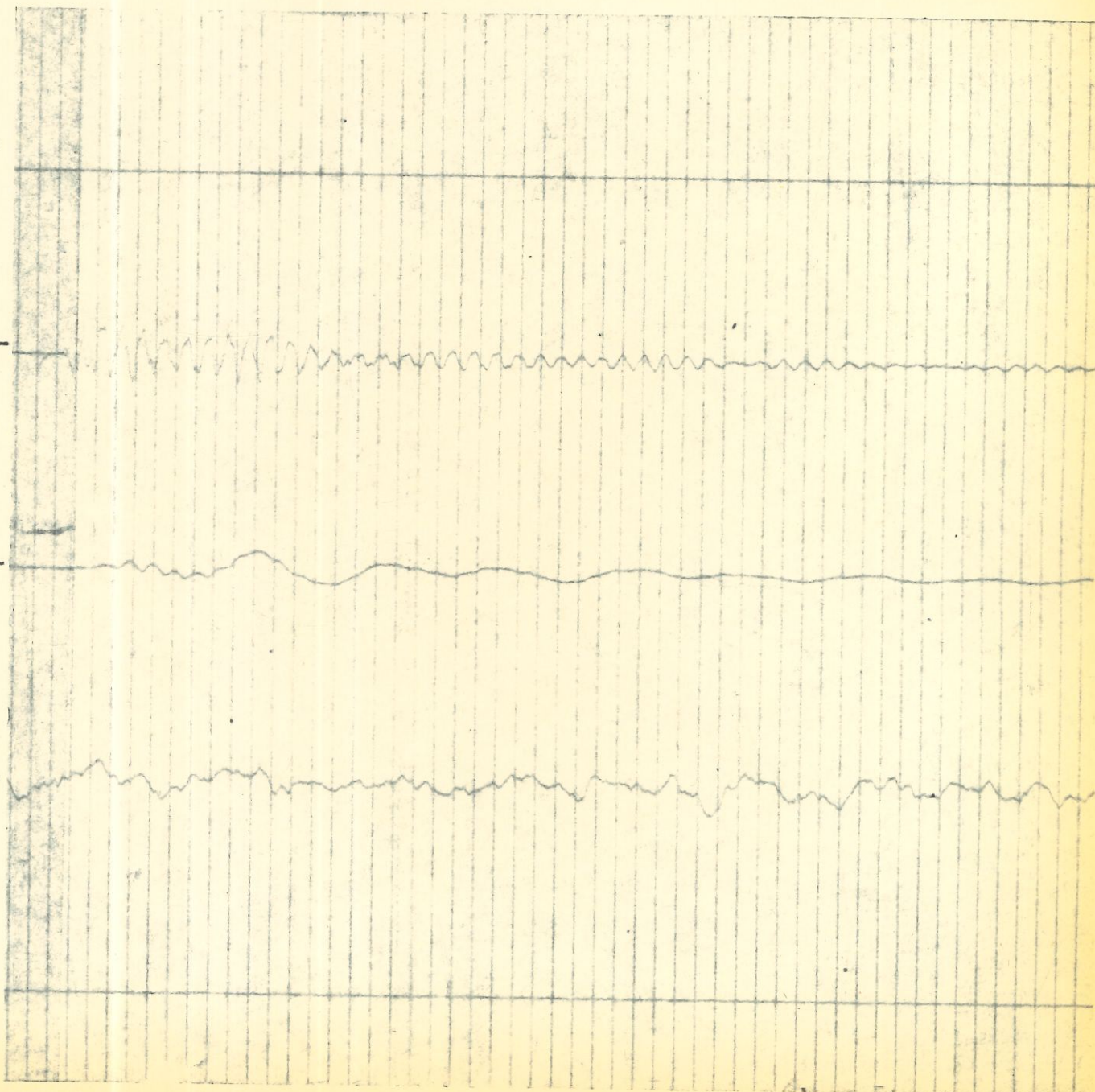
HF-3 Amplifier with high-pass  
filter -3 db at 1 kcps.

Amplifier gain  $5.3 \times 10^5$  Lo-Z

Detector cemented to plate.  
Attenuation -84 db.

Detector 2 feet under plate in  
packed earth.  
Attenuation -34 db.

Detector 7 feet under plate in  
packed earth.  
Attenuation -50 db.

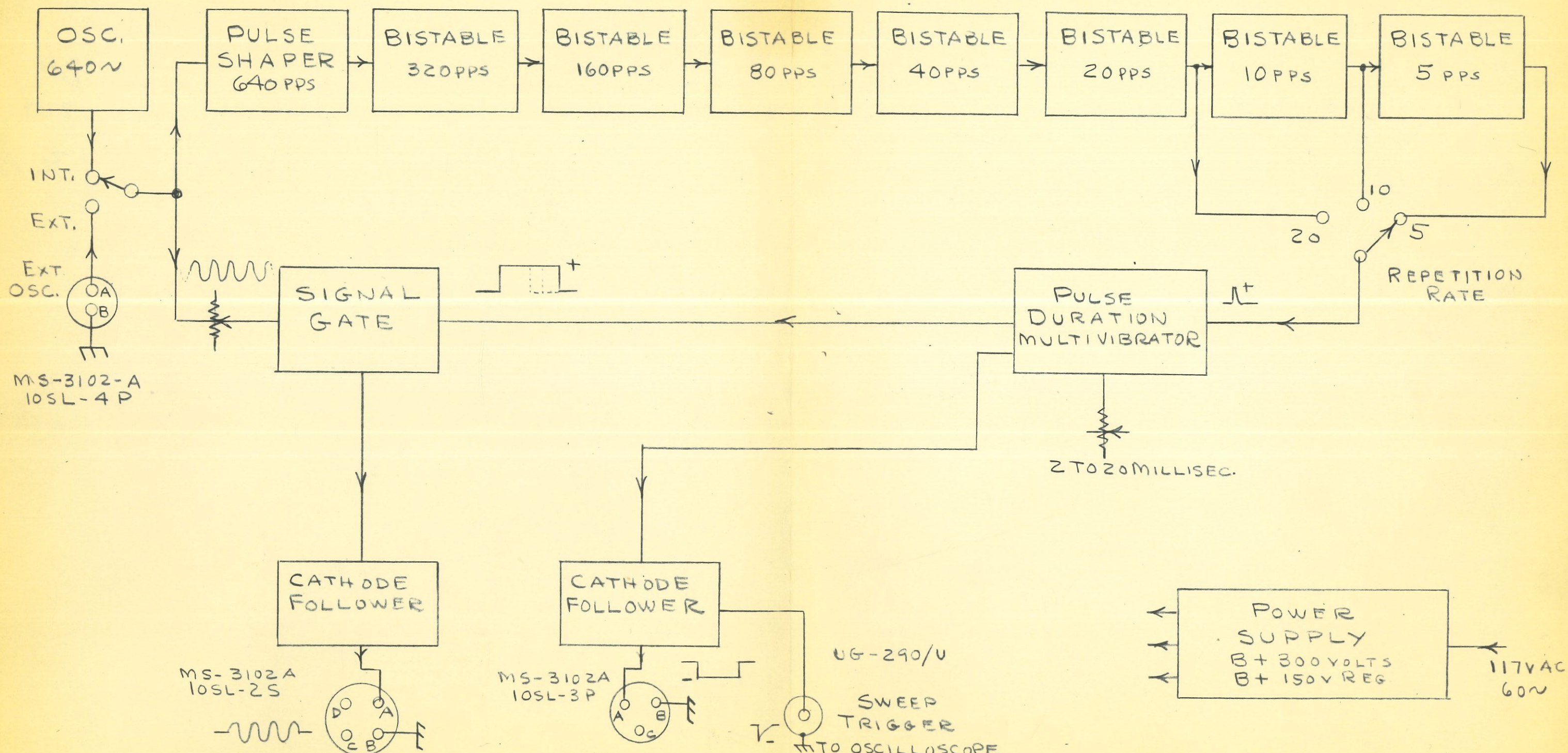


Millisecond Timing Lines

8294

2744

36 pms



MS-3102A  
10SL-2S

PULSE OUTPUT  
TO  
POWER AMPLIFIER

MS-3102A  
10SL-3P

SUPPRESSION GATE  
TO  
SIGNAL AMPLIFIER

UG-290/U

SWEEP  
TRIGGER  
TO OSCILLOSCOPE

2 TO 20 MILLISEC.

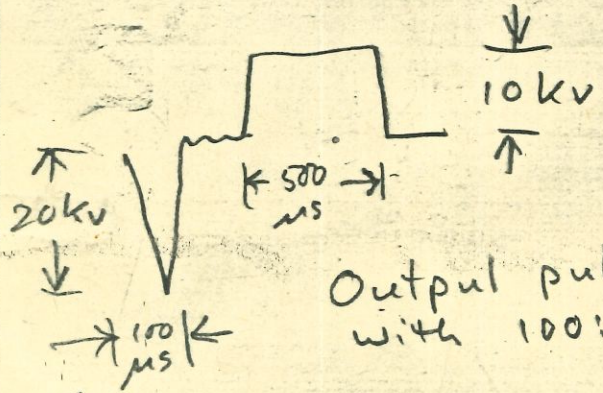
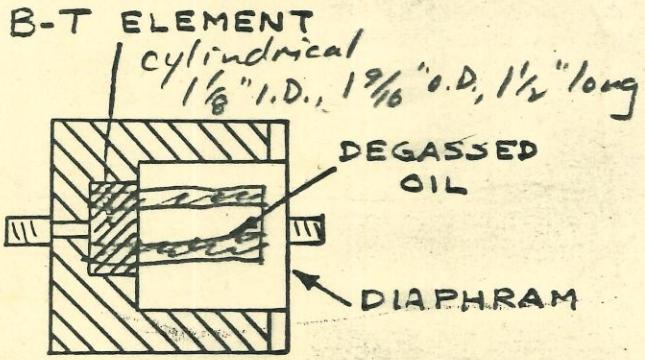
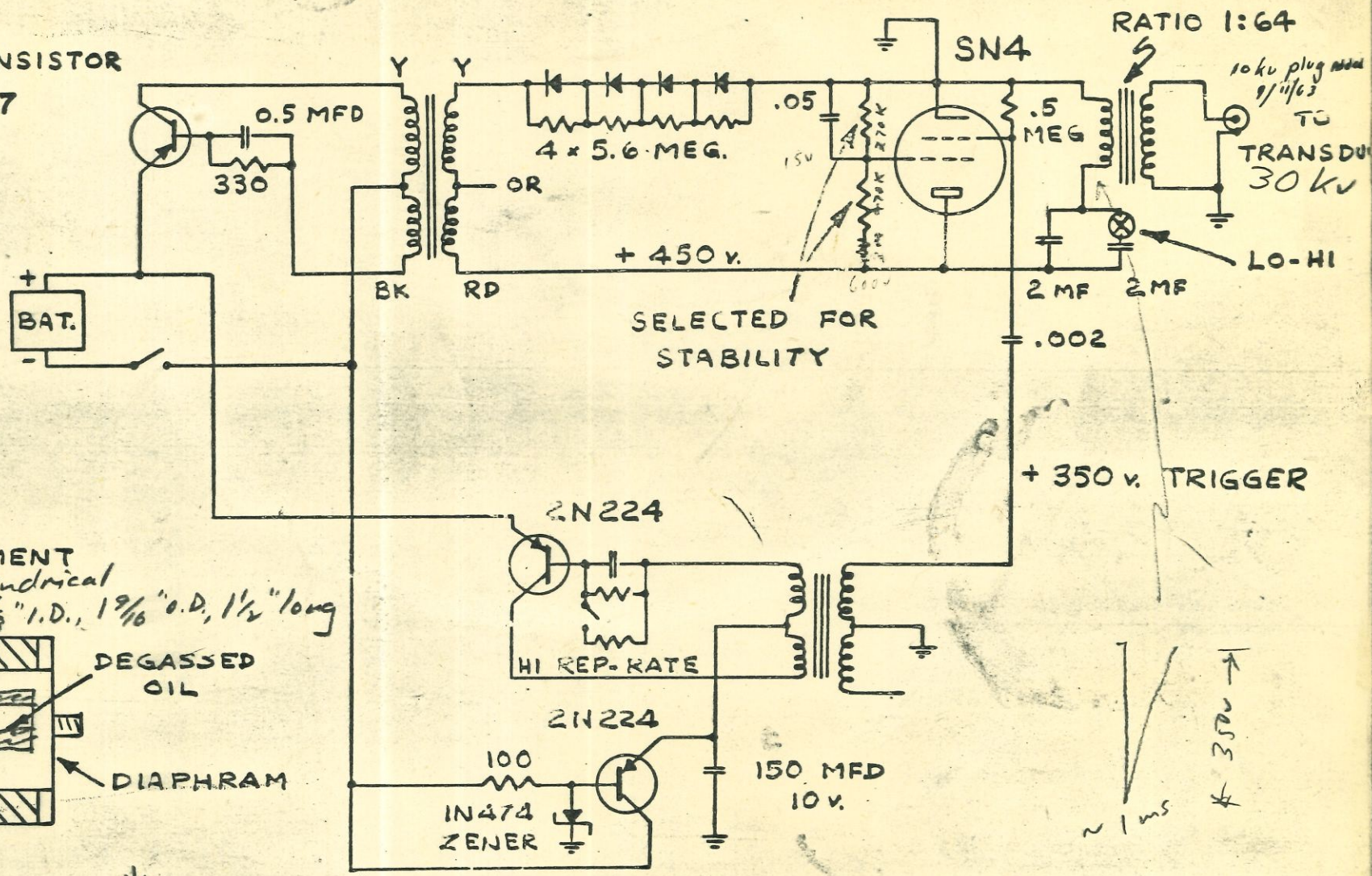
POWER  
SUPPLY  
B+ 300 VOLTS  
B+ 150V REG  
117VAC  
60N

PETTY LABORATORIES INC. SAN ANTONIO, TEXAS.			
MAT.	REQ'D	SCALE	
12-10-62	1/3/63		
FFH	AO-B		
DRAWN	CKD.	PART NO.	

REVISED 1-7-62

15 AMP TRANSISTOR  
ET-7

9 v. MAX.  
5 v. MIN.



Output pulse viewed  
with 100:1 meg bleeder.

Repetition Rates:  
Slow: ~ 3 cps  
Fast: ~ 5 cps

9/24/63

ONE-PULSE TRANSDUCER  
& DRIVER CIRCUIT  
A-0207M

GM 8-15-63  
TR. 8-27-63 R