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THE KSU ACOUSTIC SIMULATOR FOR RADAR STUDIES

Technical Report EE-TR-1

Department of Electrical Engineering
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ABSTRACT

The analogy between acoustic and electromagnetic waves has often been used to study one type of wave in terms of the other. This report starts with a brief discussion of the basic ideas enabling the use of acoustic simulators for radar studies. This is followed by a detailed description of the acoustic simulator (or underwater acoustic facility) available in the Department of Electrical Engineering of this University.

Special attention is given to the equipment and to the instrumentation that have been developed recently for the enhancement of the measurement capabilities. These allow greater accuracy, better amplifier and transducer characteristics, provision for calibration references for obtaining quantitative rather than qualitative data, measurement of acoustic impedance of target materials, measurement of power in rapidly changing waveform-envelopes, etc. Improvements in other features like the target scanning mechanism are briefly touched upon.

In addition to its use as a "scatterometer"—i.e., a device to measure and record the scattered power received from the target—the acoustic simulator can also be operated as an "imaging" device by using the return signal to modulate the intensity of illumination of a CRO beam and photographing the trace. Detailed sub-system circuitry, system connections and operating instructions are given for both modes of operation.

Report prepared by: Report approved by:

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The acoustic simulation of radar problems has been used increasingly in recent years as a tool for radar design and for experimental verification of scattering theories. The basis for simulation is the well-known analogy between acoustic and electromagnetic waves. By considering the pressure or particle velocity of acoustic waves as the analog of the electric field intensity in the electromagnetic wave, one can obtain analogous expressions for parameters of interest in the two cases, (e.g. impedance, reflection coefficient, velocity of propagation, and so on). Thus the phenomena of propagation, reflection, refraction and scatter that are of interest in radar can be studied in the laboratory by means of an acoustic simulator. This simulation is made more convenient and economical by the proper choice of frequency and medium of propagation; ultrasonic waves in water are commonly used. It is easily shown that quantitative information (rather than merely qualitative analogy) can be gained by suitable scaling of frequency, range, impedance, or other parameters.

The acoustic simulator functions as an analog device whose output, properly interpreted, yields valuable information regarding the performance and capabilities of full-scale radar systems. Some important advantages of the acoustic simulator are: (1) the speed with which results can be obtained, (2) the economy as compared to full-scale experiments, and (3) the complete repeatability of data upon target re-runs.

A number of Universities have built acoustic simulators, which are also called Under-Water Acoustics (UWA) facilities. One such simulator was built at KSU during 1964-1965 to facilitate the study of reflection and scattering of electromagnetic waves. The acoustic simulator is designed to model both continuous and pulsed radar. Geometric shapes and rough surfaces have been constructed and are used as targets to produce backscattering effects. Changes in components and electronics are being constantly incorporated to meet the needs of new problems to be studied.

The purpose of this report is to provide the following information about the existing UWA facility:

A. Identification of the acoustic simulator's equipment and capabilities;

B. Functions of certain components of the acoustic simulator;

C. Equipment connections, settings and operating instructions.

Some of the modes in which the KSU acoustic simulator has been operated—and the problems that were studied—are listed below, but these by no means exhaust the simulator's possible applications:

I. Backscattering Measurement Mode

   A. Frequency effects on backscatter.

   B. Layer and volume backscatter.

   C. Scatter from non-homogeneous acoustic targets.

II. Imaging Mode

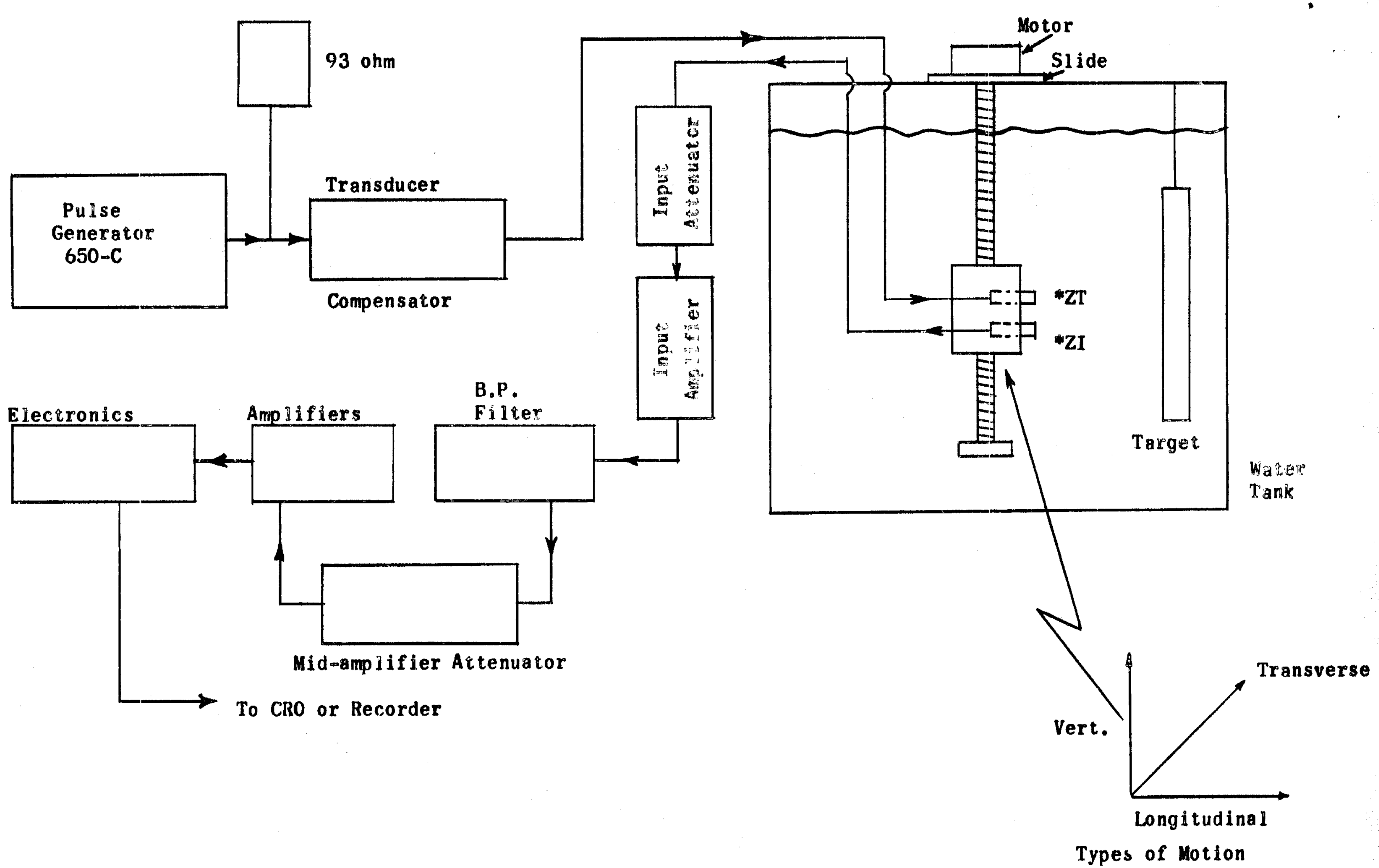
   A. Developing images at different frequencies.

   B. Simulating side-looking radar systems.

2. ACOUSTIC SIMULATOR CAPABILITIES AND MODES OF OPERATION

A typical radar experiment requires the measurement of backscattered power from a certain target for specified frequency, range and angle of incidence. In the acoustic simulator this experiment is duplicated by providing a source of acoustic power, a suitable medium of propagation, a target, and means for measuring and recording the backscattered power, as shown in the simplified diagram of Figure 1. Each of these components will be described in detail in the next section. It is sufficient to state here that the acoustic waves are generated in a large water-filled tank by means of an electro-acoustic transducer, which is driven by an electronic oscillator. The transducer is capable of being moved in three orthogonal directions relative to the target. The target is made of a suitable material whose acoustic impedance and other characteristics are analogous to those of the actual target for electromagnetic waves. It should be mentioned that the preparation of accurate acoustic analogs for better quantitative results remains one of the problem area in which much work needs to be done; however, qualitative analogs are easily made and widely used. The backscattered acoustic pressure is sensed by another transducer, converted into voltage, and read on an oscilloscope or some other indicating instrument; alternatively, it can be recorded on a graphic level indicator or a magnetic tape.

The echo signal received from a target is sometimes used to modulate the intensity of an oscilloscope beam while this



*ZT - Transmitting Transducer
*ZI - Receiving Transducer

Fig. 1. The Basic Acoustic Simulator

sweeps across the face of the oscilloscope in step with the motion of the acoustic transducers across the target. When a number of successive sweeps are photographed on film, and the film developed, an "image" of the target is obtained.

Thus the simulator can be operated in two modes, designated the "Backscatter" and the "Imaging" modes respectively, as described above. Each mode is capable of giving most of the information that can be obtained from a full-scale radar experiment, at far less expense.

A fundamental limitation of the acoustic simulator is its inability to simulate polarization. This is of course due to the fact that acoustic propagation is a scalar phenomenon whereas electromagnetic waves are in general described by vectors. As a result of this limitation, the simulator cannot be used to determine, e.g., the vertically polarized component of a reflected wave when the incident wave is horizontally polarized, or vice-versa. Apart from this drawback, however, the simulator is a versatile and economic tool for many types of problems.

3. THE ACOUSTIC SIMULATOR COMPONENTS

The simulator consists of commercial equipment except for special purpose components, as described below. A block diagram is given in Fig. 2.

A. Pulsed Oscillator - The high powered pulsed oscillator (PG 650-C, Model 2, Arenberg Ultrasonic Lab., Jamaica Plain, Mass.) is a variable frequency, pulse modulated radio frequency oscillator capable of delivering 300 volts peak-to-peak into a 93 ohm load resistor. The oscillator can deliver output pulses that vary in width from 2 μsec. to 100 μsec. over a frequency range from 0.5 Mc/sec. to 5 Mc/sec. The pulse width can be adjusted independently of frequency, except for low-frequency narrow-pulse combinations, where about 1 1/2 cycles is the minimum number of cycles per pulse. The minimum usable pulse width is determined by the bandwidth of the transducers in most cases.

The oscillator can be operated from an internal or external trigger. An external trigger source can be used to obtain a periodic operation, if desired. A PRF of 240 pulses/sec. is used for most of the experimental work. A trigger output with a variable time delay is available for synchronizing the type 555 test oscilloscope with the pulsed oscillator.

B. Transducers - All acoustic measurements are made by means of piezoelectric barium titanate transducers manufactured by Branson Instruments Mft., Standford, Connecticut. Five pairs of transducers covering the following frequency ranges are available in the laboratory: 0.7 Mc, 1.0 Mc, 1.6 Mc, 2.25 Mc, and 3.5 Mc; the measured beamwidths of these transducers are respectively 8.6°, 3.1°, 3.8° $2,8^{\circ}$ and 1.9°. Each pair of transducers consists of a transmitter and a receiver, designated by (ZT) and ZI) respectively.

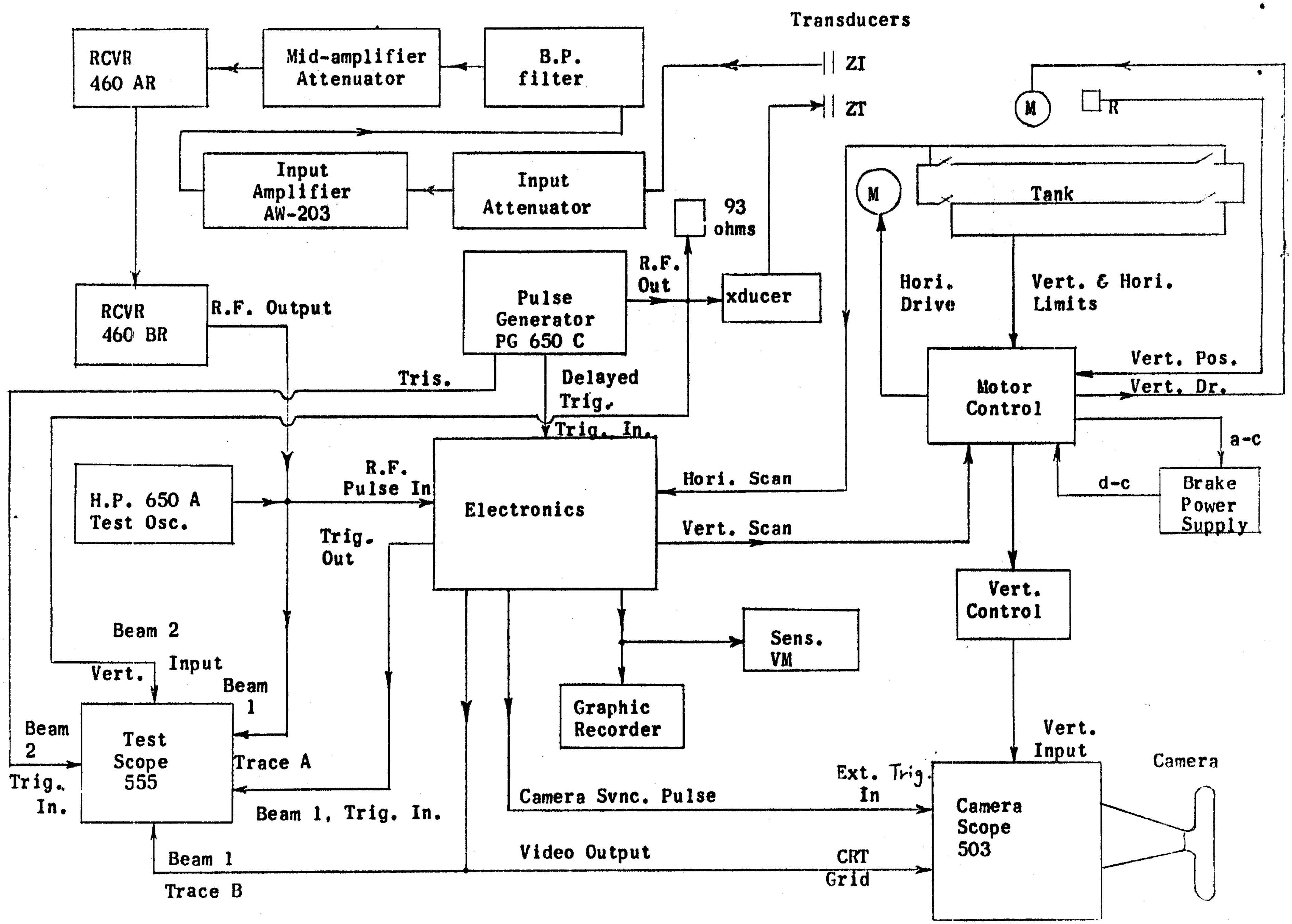


Fig. 2. The Acoustic Simulator Systems (Block Diagram)

The surface of each transducer is a simple flat disk. One surface of the disk is exposed to the water, so that the transducer acts like a piston source, while the other surface is bonded to a high impedance lossy material to reduce the mechanical Q. For relatively high frequencies, the active area of the flat disk may be several tens of wavelengths across; hence a directive antenna pattern is obtained through the interference principle.

A transducer is a pressure sensitive device; consequently, it can be employed as an integrator to determine the resultant pressure due to the plane wave components incident on its surface. Each plane wave component is weighted according to the directive gain of the transducer; the transducer, therefore, measures a partial pressure selected from a group of plane waves traveling in the directions preferred by the antenna pattern. The direction is, of course, determined by the orientation of the transducers. The transducers in the tank can now be rotated through an angle of 180° (due to improvements of the transducer mount) and can, therefore, be oriented in the "best" direction, that yields a maximum received signal.

C. <u>Transducer Compensator</u> - Functionally, the transducers operate best at mechanical and electrical resonance. Electrically the transducer appears to be a capacitor shunted by a small conductance. Electrical resonance is, therefore, achieved by adding the proper inductance in parallel to cancel the total capacitive reactance. Without such compensation, the large capacitance of the transducer cable will "pull" the oscillator frequency out of the range of frequencies marked on the oscillator coils.

A transmitting transducer compensator has been constructed to obtain this resonance, so that the ultrasonic oscillator can see at any frequency a relatively non-reactive load. An increase in maximum pulse amplitude and a better pulse shape are obtained with this compensator. Compensation is achieved by a group of variable shunt inductances connected as shown in Figure 3.

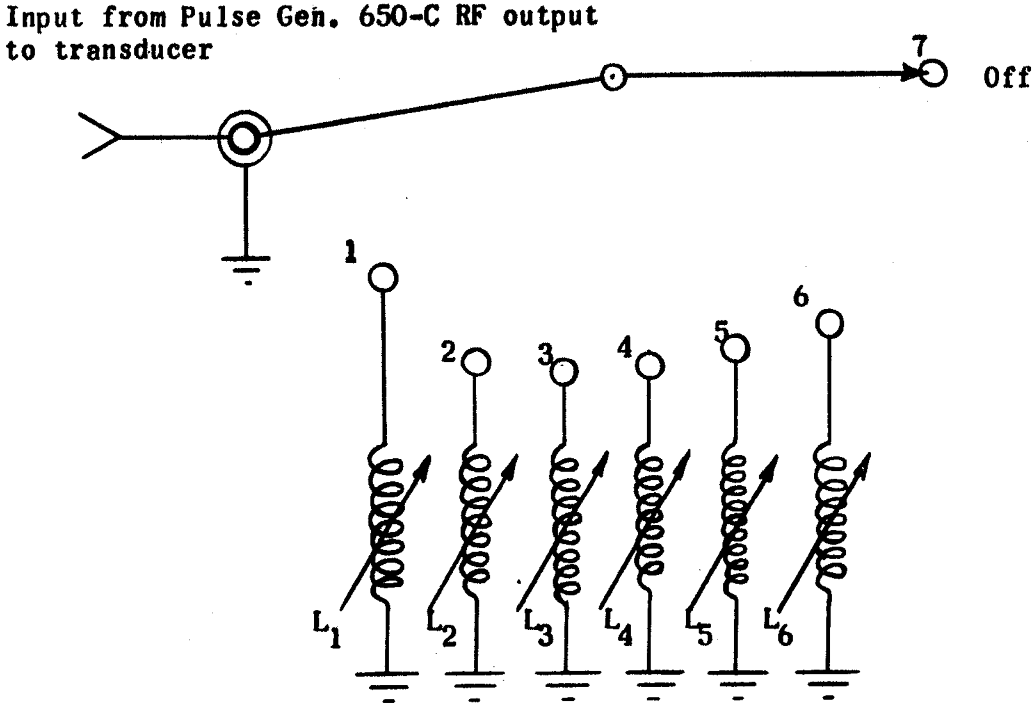
D. Receivers and Detectors - In Fig. 2 it is shown that the reflected acoustic waves are intercepted by the receiving transducer and converted there into an electrical pulse which is then transferred through an input attenuator, an input amplifier, a band-pass filter, a mid-amplifier attenuator, and two wide-band amplifiers to the block marked "electronics", a unit to be discussed in detail later.

The input attenuator can provide from 0 to 20 db of gain in steps of 1 db. A modified Electro International AW-203 amplifier is employed as the input amplifier and provides 37 db of gain; an integral part of this amplifier is an attenuator providing 40 db of attenuation in steps of 10 db.

The band-pass filters can be set to any of the five transducer frequencies; the filter's bandwidth varies from 110 Kc at the lowest frequency (700 Kc) to 300 Kc at the highest frequency (3.5 Mc). A circuit diagram for the band-pass filter is given in Figure 4.

The mid-band attenuator (L-pad structure) provides a total attenuation of 18 db in three steps of 6 db each; its circuit diagram is given in Figure 5.

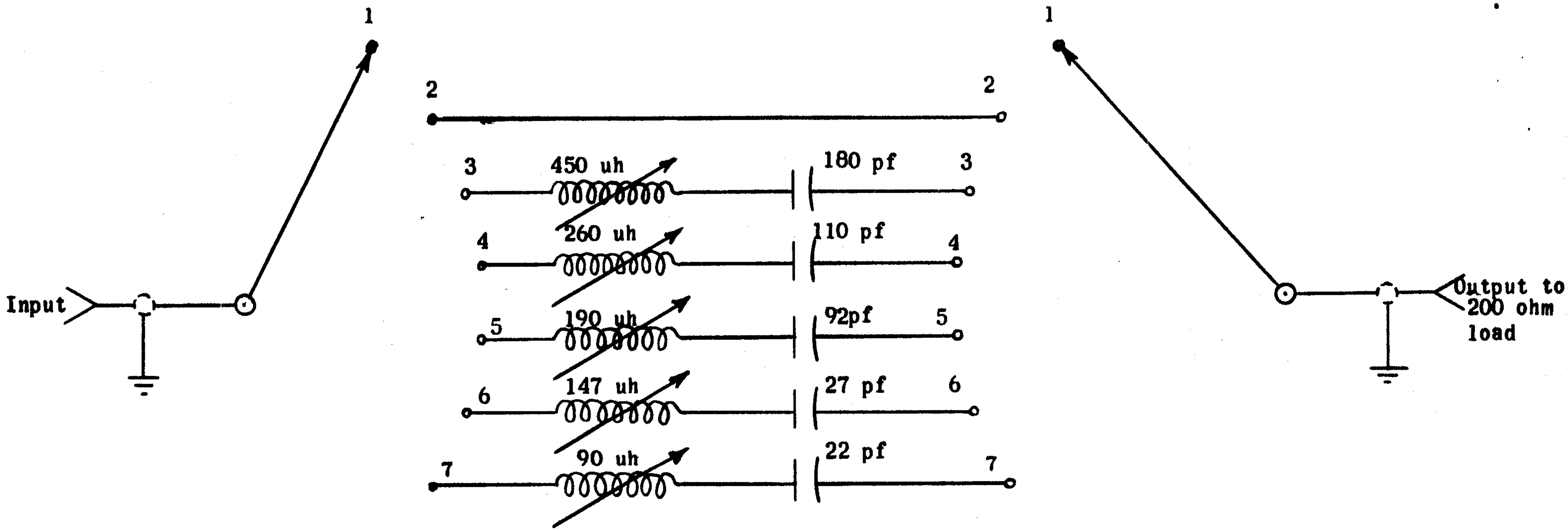
Hewlett-Packard wide-band amplifiers (460 AR and 460 BR) are used in the circuit; they can supply a gain of 20 db and 15 db, respectively, when operated into a 200 ohm load. Each



Parts List

1-1	1.5 uh-2.7 uh
L-2	2.9 uh-6.1 uh
L-3	5.8 uh-12.0 uh
L-4	12.0 uh-22 uh
L-5	22 uh-57 uh
L-6	58 uh-170 uh

Fig. 3. Transducer Compensator



Position	Description
1	Off
2	Out
3	700 kc 110 kc B. W.
4	1 Mc 200 kc B. W.
5	1.6 Mc 200 kc B. W.
6	2.25Mc 300 kc B. W.
7	3.5 Mc 300 kc B. W.
8	Off

Fig. 4. Receiving Band-Pass Filter

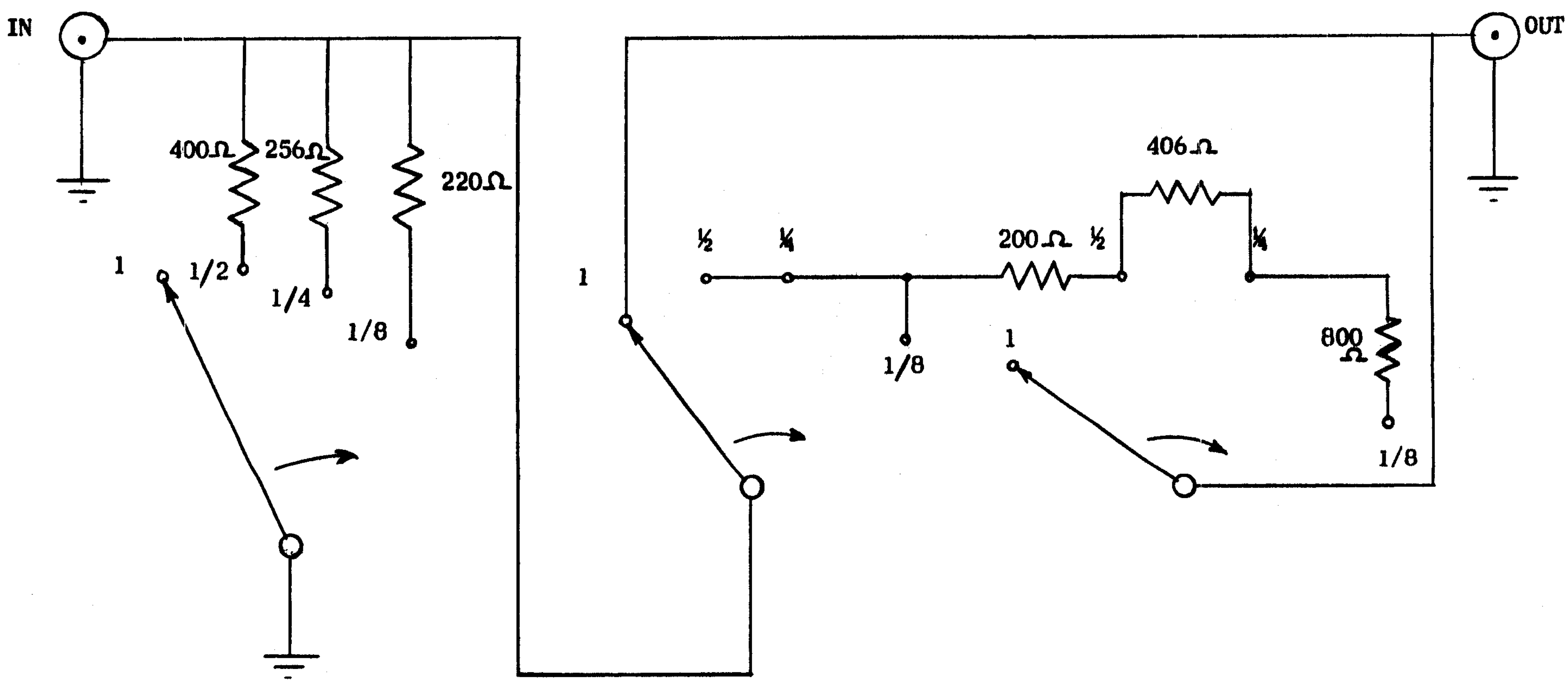


Fig. 5. Attenuator Circuit
(Mid-Amplifier)

amplifier has a frequency range of 3 Kc to 120 Mc. The 460 AR amplifier pulse output is limited to 3.5 volts peak when a positive input pulse is applied. The 460 BR amplifier pulse output is limited to 8 volts peak when terminated with a 200 ohm load and a positive input signal is applied. The gain of the 460 AR amplifier may be varied over a range of 6 db.

Before examining the characteristics of the block marked "Electronics" on Figure 2, a quick look at its basic design and a description of "how it works" are perhaps in order. As shown in Figure 6, the "electronics" is composed of the following: (1) recycle gate generator, (2) amplifier gate generator, (3) gated amplifier, (4) detector, (5) video amplifier, (6) box car circuit, (7) relay logic circuitry (scale of four), (8) video gate relay, (9) horizontal sweep univibrator, (10) vertical carriage step univibrator, (11) a vertical scan relay circuit, and (12) video squarer and integrator.

The recycle gate generator (1) receives a delayed trigger from the pulsed oscillator approximately 90 microseconds to 240 microseconds before the received R.F. pulse. The output of the recycle gate generator is a 40 microsecond pulse, whose differentiated trailing edge triggers the amplifier gate generator (2) and also gets the boxcar circuit (6) ready for the reception of the next received r.f. pulse by discharging a capacitor in the boxcar circuit. The amplifier gate generator establishes a positive gate pulse variable in length from 100 microseconds to 400 microseconds (this longer gate length being required for the larger angles of incidence during backscattering measurements) that triggers the gated amplifier just before it receives the

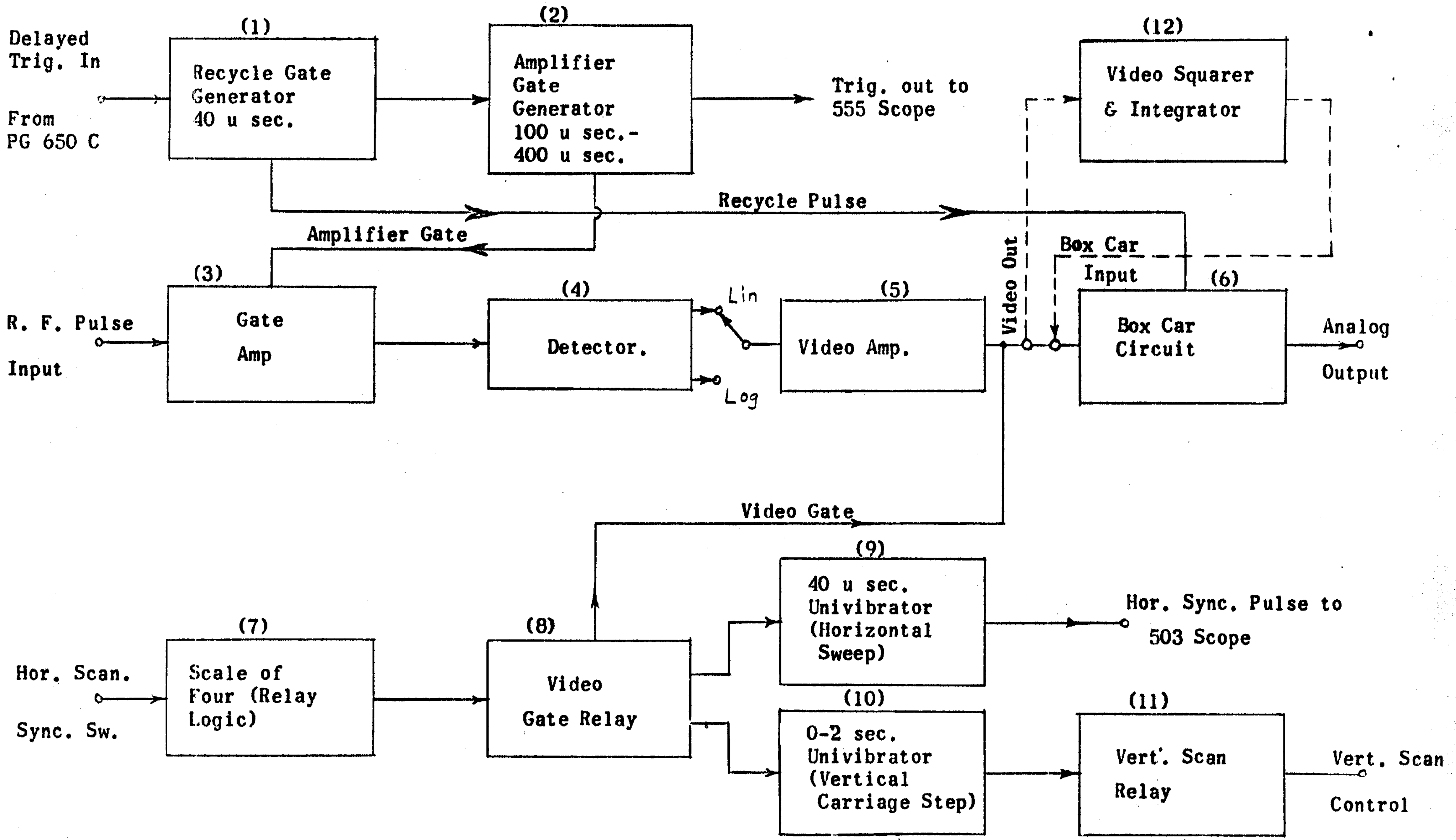


Fig. 6. Electronics Block Diagram

R.F. output pulse from the RCVR 460 BR amplifier; the differentiated leading edge of the negative gate pulse is used to trigger beam 1 of the 555 oscilloscope. Circuits for these two units (recycle gate generator and amplifier gate generator) are shown in Figure 7. Also, Figure 8 shows the time sequence of these triggering pulses in the "electronics" unit.

Referring again to Figure 6, it can be seen that the echo (R.F. input) is amplified by the gated amplifier (3) and then demodulated by the detector (4). Detailed circuits for these are shown in Figure 9. The demodulated pulse is then amplified again in the video amplifier (5) and inverted, as shown in Figures 6 and 9. This video signal drives a cathode follower which in turn drives a video output jack. For imagery experiments the video output is used to intensity modulate the beam of the camera oscilloscope. For some backscattering experiments the video output can be applied directly to the input of the boxcar circuit (6) in order to produce an analog voltage proportional to the peak value of the received acoustic pulse. For other backscattering experiments the video output is applied to a video squarer and integrator circuit (12); the output of this latter circuit then drives the boxcar circuit (6) to produce an analog voltage proportional to the mean square value of the received acoustic pulses. The circuit of the video squarer and integrator is shown in Figure 10.

A holding capacitor of the boxcar circuit (6) samples the peak amplitude of the video pulse and stays charged until it is discharged by the next recycle gate pulse. The analog output of this part of the system is used to drive the graphic level recorder. Details of the boxcar circuit are given in Figure 11.

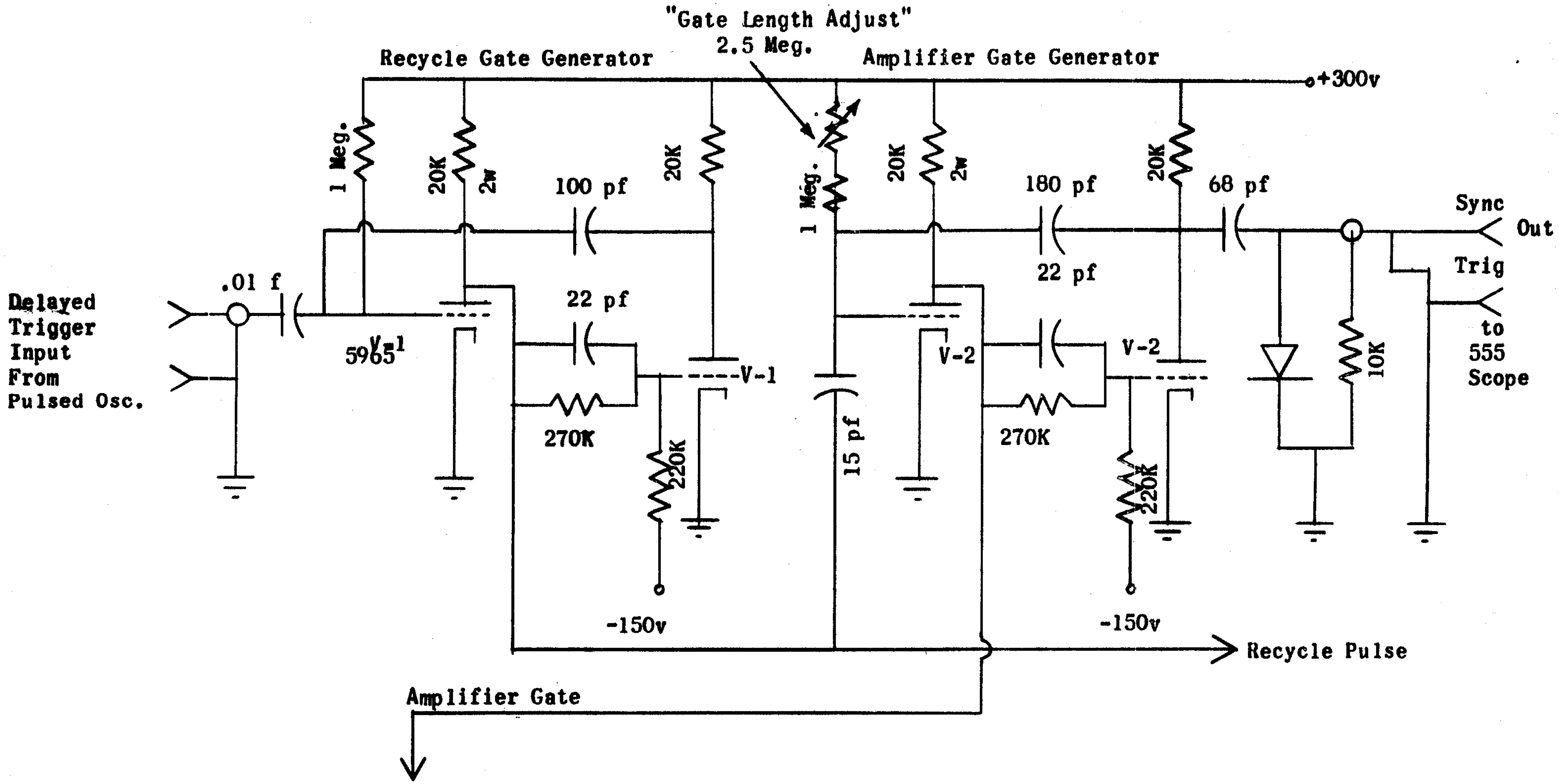


Fig. 7. Recycle Gate and Amplifier Gate Generators

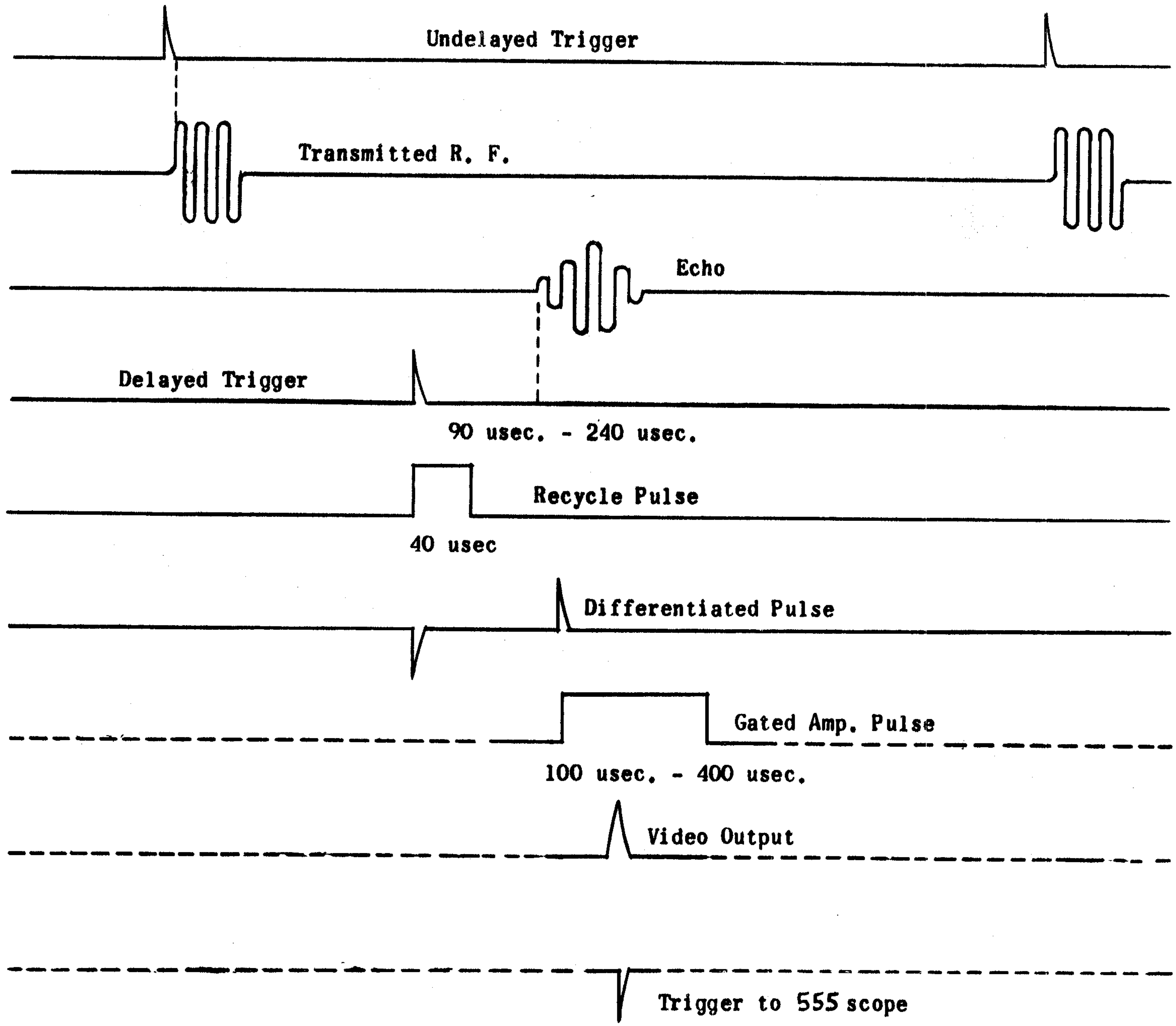


Fig. 8. Time Sequence of Pulses

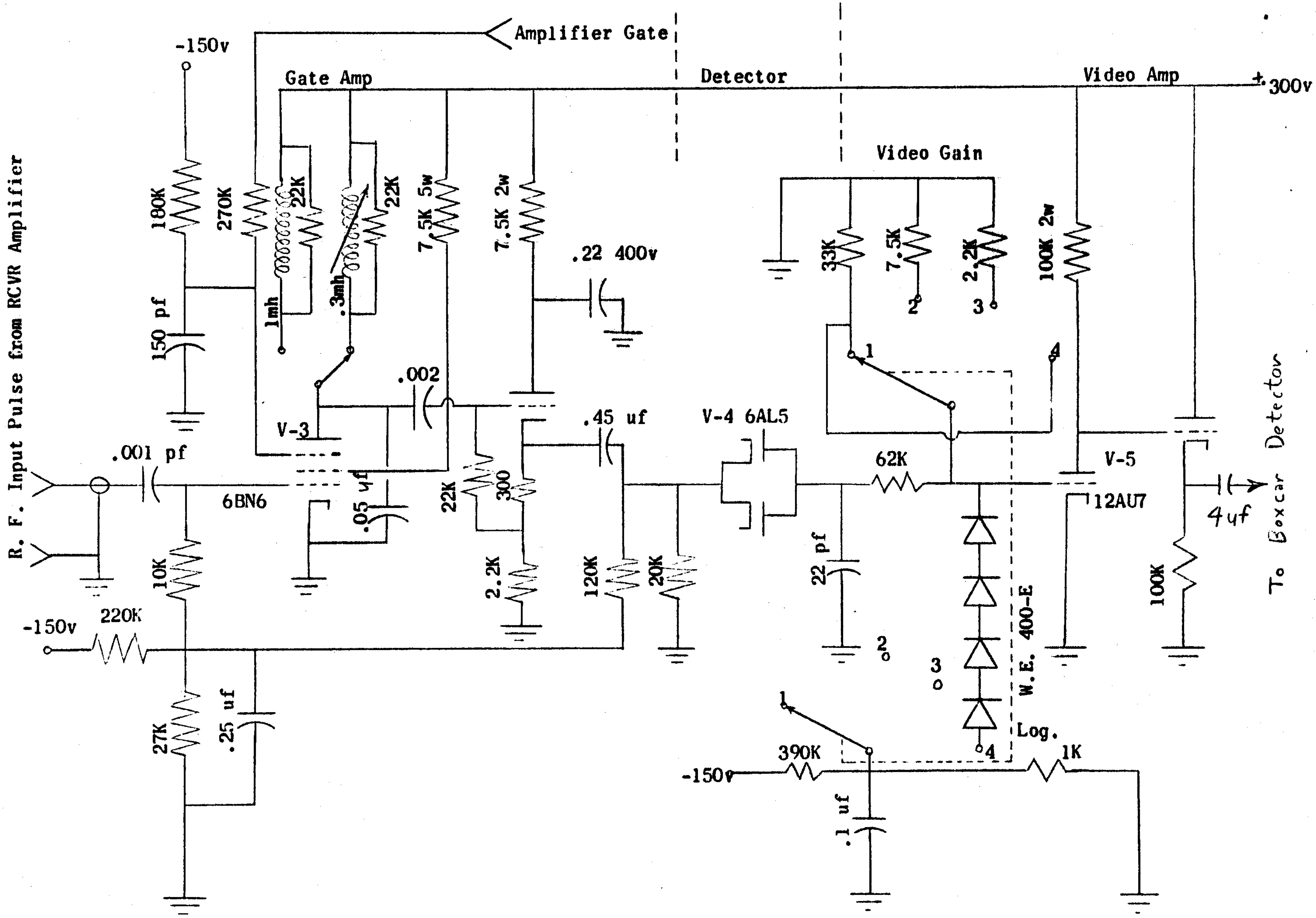


Fig. 9. Gated Amplifier, Detector and Video Amplifier

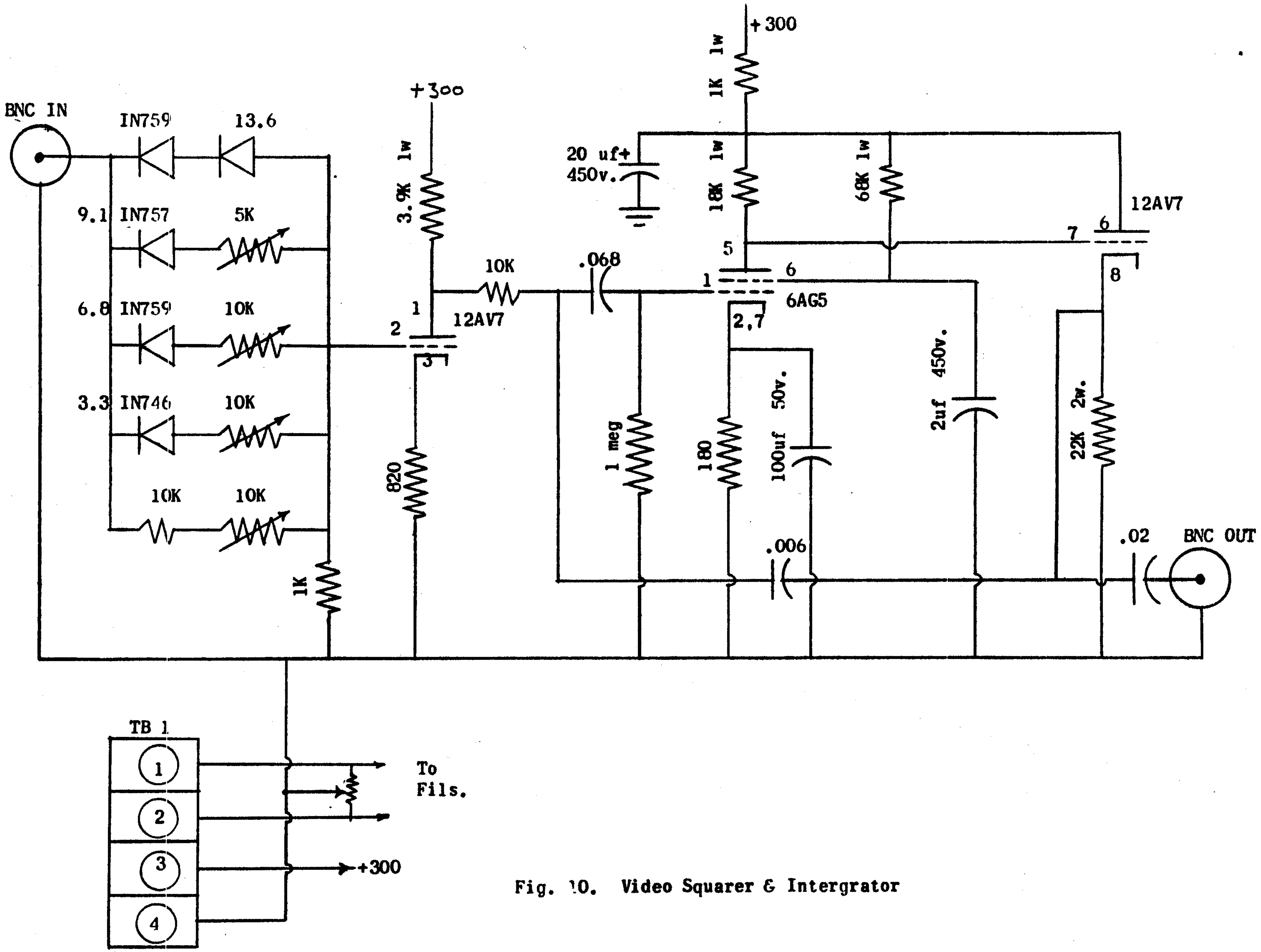


Fig. 10. Video Squarer & Intergrator

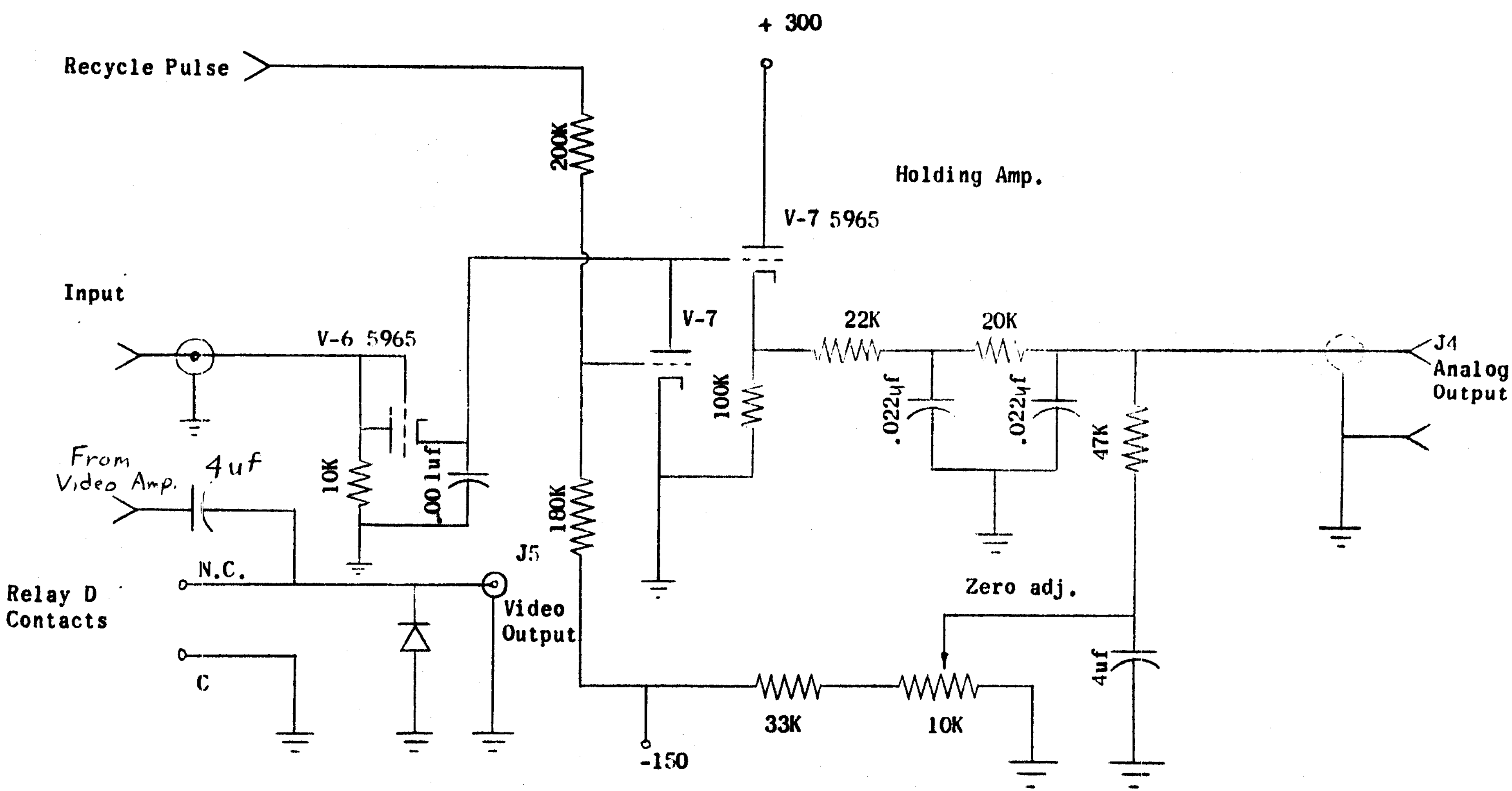


Fig. 11. Boxcar Circuit

At the start of the forward motion (East to West) the horizontal carriage closes the East-end micro-switch in the relay logic circuit (7). This action energizes the video gate relay D, (8), which unblanks the oscilloscope by removing a short from the video output jack; the energized video gate relay also triggers the horizontal sweep univibrator (9). A differentiated output pulse from this univibrator triggers the horizontal sweep of the camera scope. At the end of its westward motion the horizontal carriage closes the West-end logic micro-switch; the video gate relay then de-energizes to blank the oscilloscope during the carriage return and to trigger the vertical carriage step univibrator (10). This actuates the vertical scan relay (11), thus lowering the transducer carriage for the next horizontal traverse. See Figures 12 and 13 for detailed circuitry for these units.

For most backscattering experiments the action of the video gate relay D can be defeated by throwing the relay D switch on the electronics chassis to the "energized" position.

The above description has shown in a basic manner how the "electronics" functions as a receiver and detector package. It was designed, built and tested in the KSU Electrical Engineering laboratory.

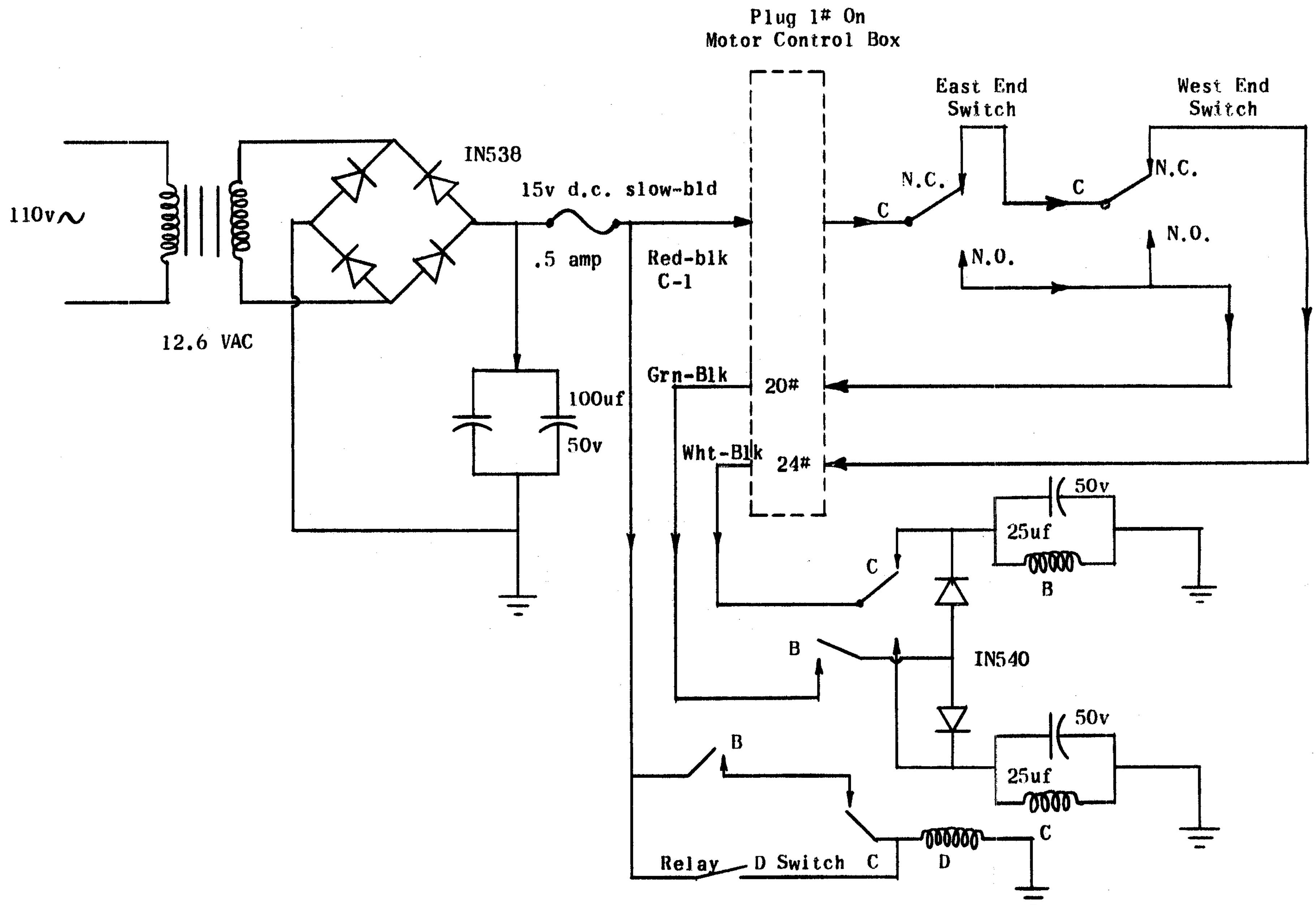


Fig. 12. Relay Logic and Video Gate Relay D.

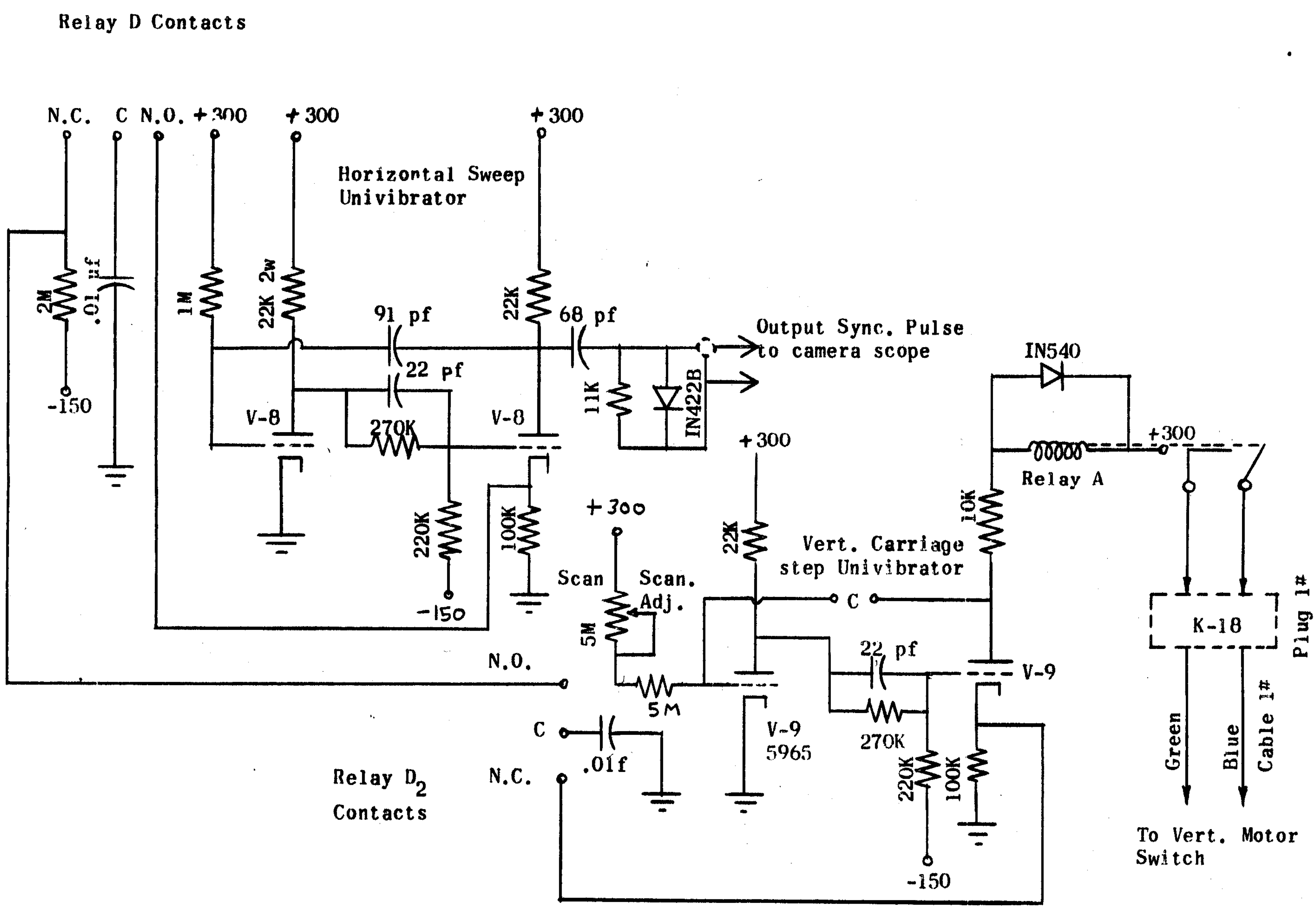


Fig. 13. Vertical Carriage Step Univibrator and Horizontal Sweep Univibrator

E. <u>Recording Devices</u> - The acoustic return (echo) data is usually recorded by two methods, corresponding to the two "modes" of operation. The first method is by use of an oscilloscope and oscilloscope camera. The second method is by the use of a graphic level recorder.

In the first method, ("imaging" mode), detected return signals are applied to the external cathode ray tube (CRT) input of the Tektronix type 503 oscilloscope for intensity modulation. As already explained in the section on electronics, the video gate relay D blanks the oscilloscope except during the forward motion of the carriage from East to West. The forward horizontal motion of the carriage also starts the horizontal oscilloscope sweep. At the end of each horizontal scan, the transudcer mount is automatically lowered a preset distance by the vertical scan univibrator and vertical scan relay. A vertical position helipot is coupled to the vertical motion by a gearbox which rotates the helipot shaft through 13 turns per inch during the vertical motion of the transducer mount. This shaft rotation establishes vertical separation between traces on the 503 oscilloscope by applying a d-c voltage to the vertical input of the oscilloscope.

A polaroid camera loaded with 46-L film photographs each trace, thereby producing a positive slide with the image of the target. A series of runs at 0.8 Mc and 1.6 Mc have been performed on certain targets with reasonable results, but the recordings lack sufficient resolution and contrast. Improvements in beam intensity adjustment, modulation depth, film, and camera are under consideration. To make photographic recordings, refer to the equipment connections and settings section of this report.

The second method of recording data, necessary when making backscattering measurements, is by use of the General Radio type 1521-A graphic level recorder. This recorder has an input resistance of 1000 ohms and is driven by a d-c analog voltage from the boxcar detector. The voltage normally ranges from 0 to 0.8 volts, providing a maximum stylus deflection of four inches on the chart.

F. Motor Control - All control of the scanning mechanism is normally done from a remote motor control box. Approximately 4.0 amperes of d-c current from an EICo (Model 1064) power supply unit are applied to the "start" and "run" windings of each of the two a-c split phase motors to provide electrodynamic braking. This allows more accurate positioning of the transducers on target areas to be examined. Circuit diagrams for the motor control box are shown in Figures 14 and 15.

Referring to Figure 14, it can be seen that the horizontal run switch on the main motor control panel is open. Upon closing this switch, 110 volts is applied to relay K-2 to energize the relay. The contacts of relay K-2 are shown on Figure 15 of the motor control relay circuitry. Thus closing the horizontal run switch allows the "run" and "start" contacts of relay K-2 to be released from their braking position and to make contact with the 110 volt line for operation of the run and start windings of the split phase a-c motor. This same horizontal run switch can also be actuated from the remote motor control box.

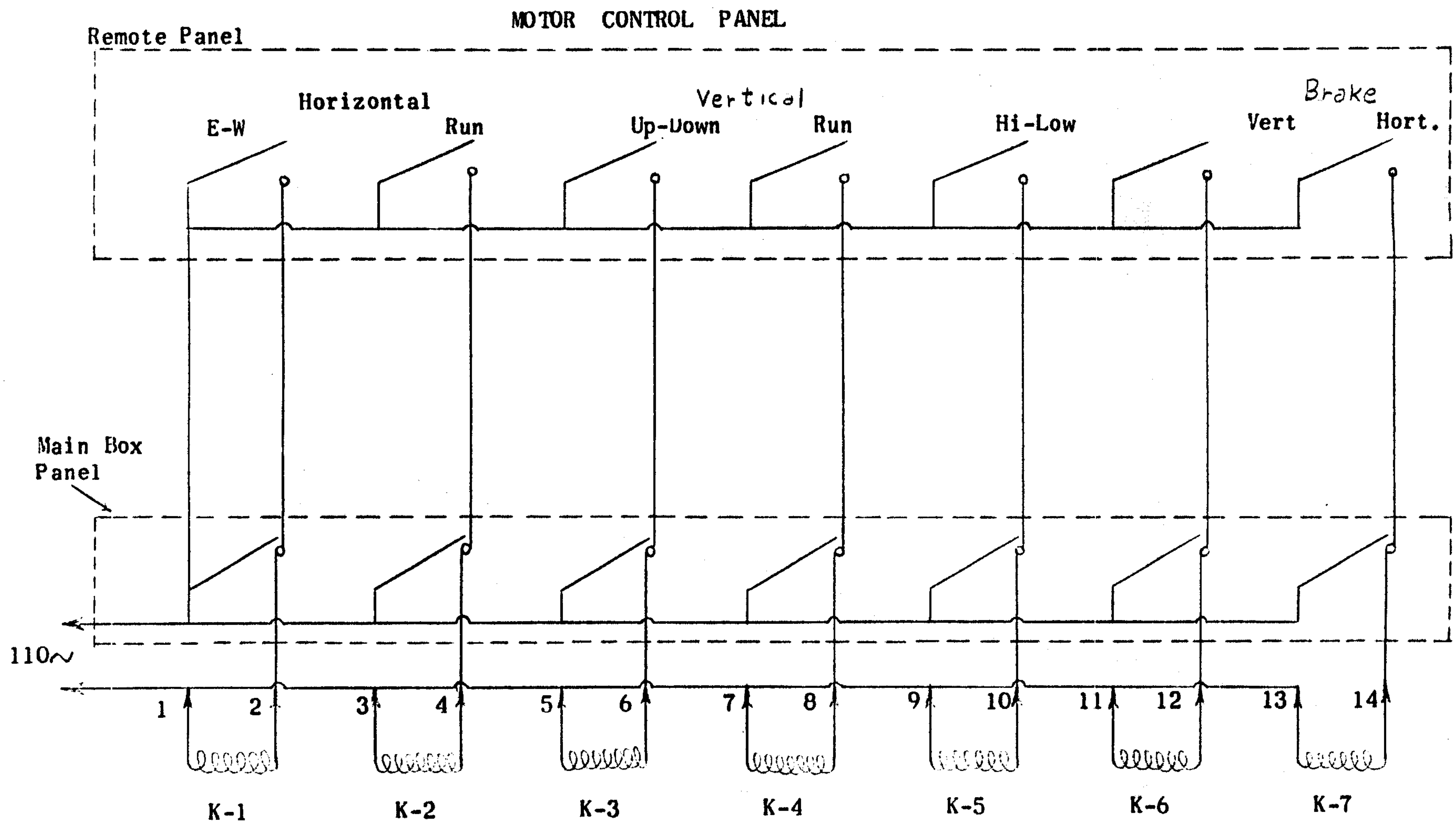


Fig. 14. Motor Control Panel

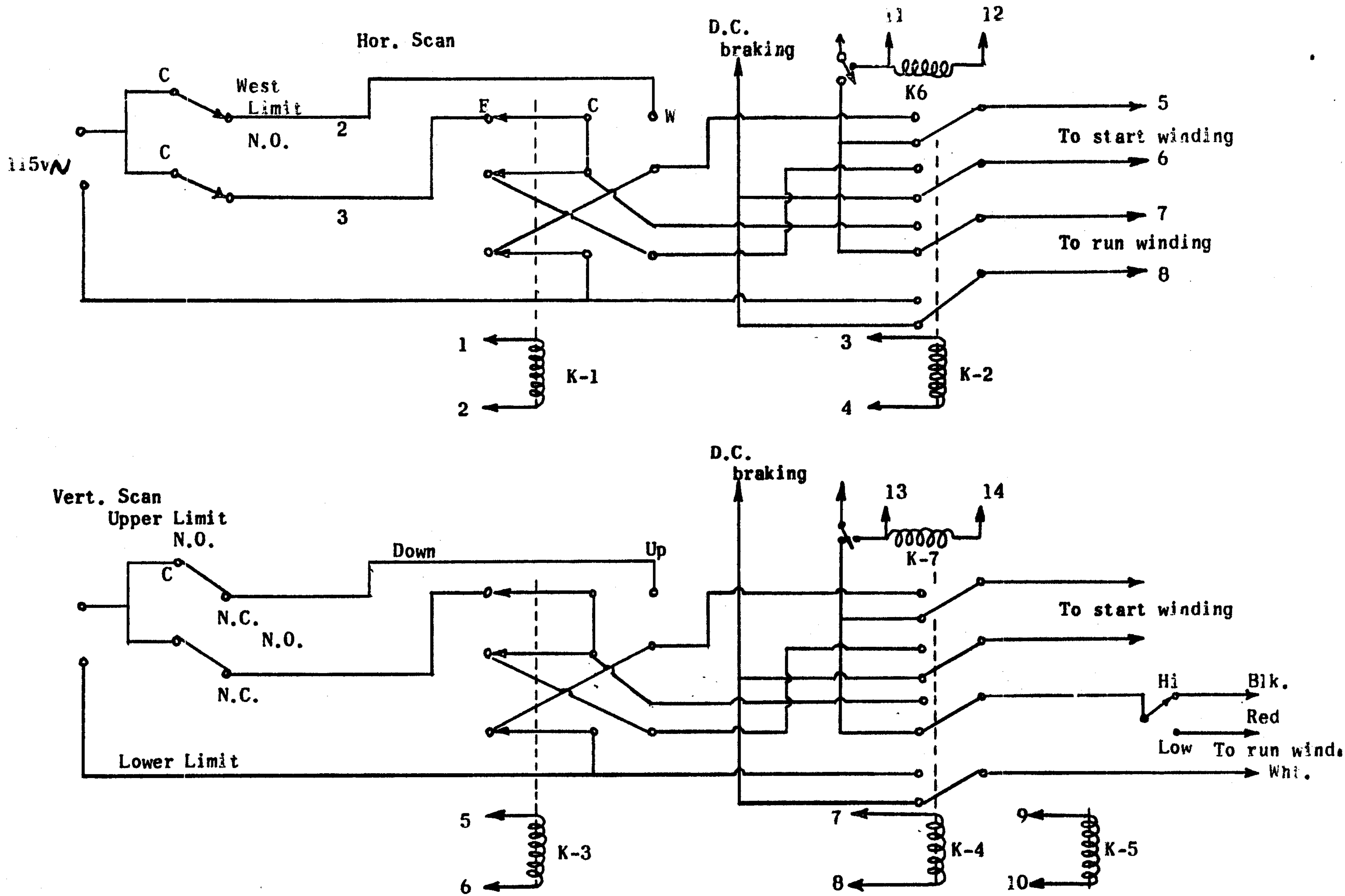


Fig. 15. Motor Control Relay Circuitry

The East-West (E-W) switch controls the direction of motion of the horizontal carriage. As shown in Figure 14, it is in the East position. When it makes contact with terminals 2 of relay K-1 it is in the West position.

A similiar arrangement is used for the operation of the vertical scan motor, except that a "high-low" speed switch energizes relay K-5 for change of the vertical scan speed. Limit switches are placed on both the horizontal and vertical scan systems to prevent the transducers or the scanning carriage from being driven into the sides or bottom of the tank.

G. <u>The Tank</u> - The tank is 5 feet wide, 6 feet long, and 5 feet deep. It is constructed of 1/8 inch galvanized steel sheets. The tank has been painted with aluminum paint to prevent rusting, and all corners and joints have been sealed with pitch to prevent water leakage. The approximate filling time of the tank is 35 minutes and the drain time is nearly 50 minutes. During periods of experimenting, the water is usually left in the tank for three days to allow for the dispersion of some of the air bubbles, which would otherwise cause possible errors.

H. <u>Scanning Mechanism</u> - The tank scanning mechanism (see Fig. 1) is built on a steel slide which is supported by wheels mounted on two parallel angle iron rails at the top of the tank. Thus the tank scanning mechanism can be placed at any desired distance from the target up to a maximum distance of 44 in.

The scanning carriage is mounted upon the steel slide so that east-west motion is given to the scanning carriage by an a-c split phase motor which is fixed to one end of the slide. Vertical motion of the transducers is obtained through another a-c split phase motor (rated like the first motor at 1/4 h.p., 115 volts and 5.4 amps.) supported by the carriage and driving a vertical screw shaft. On this shaft ride the transducer mount, transducer vertical scan assembly, and a helipot box.

Two mechanical digital counters are installed on the scanning mechanism to indicate the position of the vertical and horizontal scan motions. An electrically operated digital counter driven by the vertical motor run winding indicates the number of scans made across the target during an imagery experiment. The circuit of this counter is shown in Fig. 16.

I. Targets - The targets used in the tank usually range in sizes from 9" X 8" X 1/32" to 48" X 48" X 3/4". They are made from different materials and in different shapes, as required for particular experiments.

The acoustic simulator has often been used to study the backscatter from rough surfaces. The rough surface is usually obtained by combining samples of sand, rock and gravel that have been sifted through U. S. standard sieves of the following sizes:

	Mesh Opening	Mesh No.
1.	74 microns or 0.0029 inches	200
2.	149 microns or 0.0059 inches	100
3.	297 microns or 0.0117 inches	50
4.	595 microns or 0.0234 inches	30
5.	1.19 mm or 0.0469 inches	16
6.	2.38 mm or 0.0937 inches	8
7.	4.76 mm or 0.187 inches	4
8.	9.51 mm or 3/8 inches	-
9.	19.0 mm or 3/4 inches	-

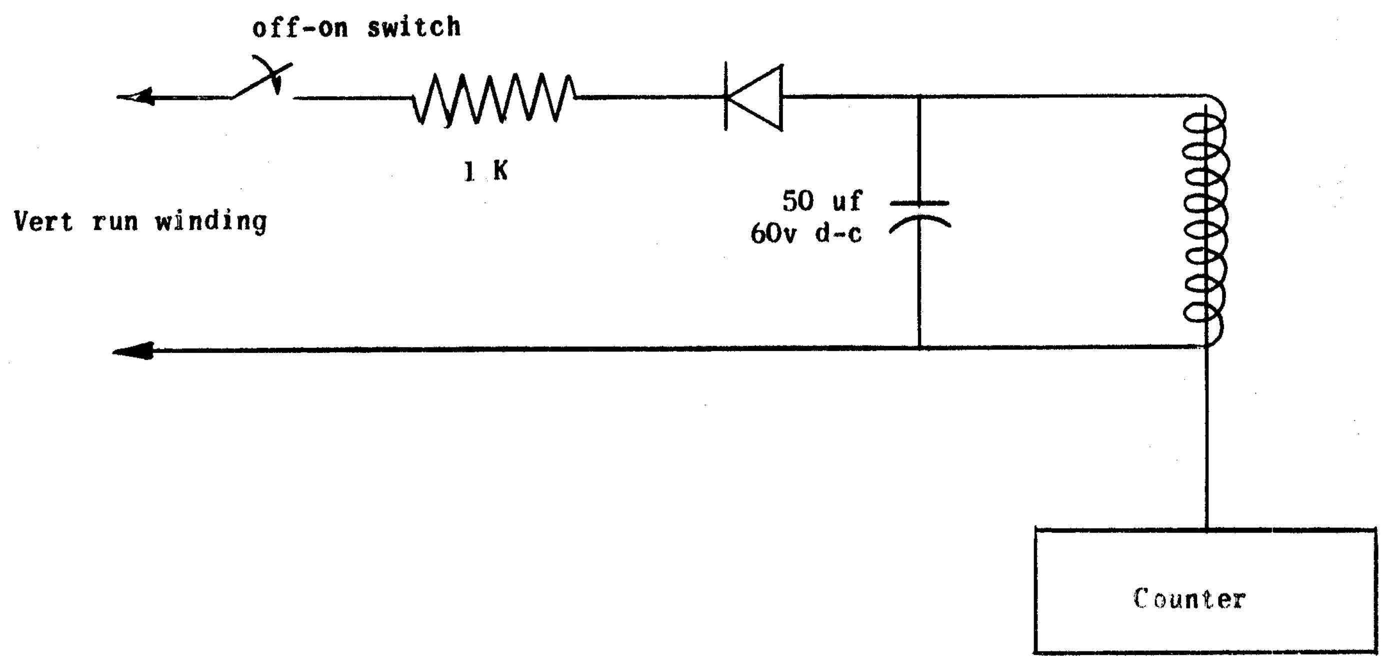


Fig. 16. Vertical Scan Counter

Other materials used to provide rough surfaces are wood and bombarded aluminum sheets. An inverted "Y" made of linoleum and mounted on a polished aluminum sheet has been used to provide a simple geometric target for imagery experiments.

The above materials are usually applied to a plywood base, by using Weldweed waterproof resorcinol glue. Because of loss of maximum return signal due to warping of the wooden targets, all targets have now been supported by an aluminum sheet of 1/8 inch thickness. These experimental targets are suspended by hooks from a one inch diameter steel pipe that hangs across the top of the tank. At present there are no other means built in the tank to support the targets and keep them from vibrating.

The air-water interface is used as a target for calibrating purposes. Due to the great difference in the acoustic impedance of air and water, this interface acts as a plane surface with a reflection coefficient of nearly unity.

4. EQUIPMENT CHECKLIST

For backscattering measurements the following equipment must be turned on:

A. Model 650A Test Oscillator

B. Model PG 650-C Pulsed Oscillator

C. Wide Band Amplifier AW-203

D. Wide Band Amplifiers 460AR and 460BR

E. Type 555 Oscilloscope With 53/54C and L Plug-in Units

F. Electronics Power Supply PP-1386

G. Brake Power Supply, EICo 1064 Power Supply

H. Motor Control Box

I. Graphic Level Recorder

J. Sensitive D. C. Meter Model 95A

For imagery experiments the following equipment must be turned on:

A. Model 650A Test Oscillator

B. Model PG 650-C Pulsed Oscillator

C. Wide Band Amplifier AW-203

D. Wide Band Amplifiers 460AR and 460BR

E. Type 555 Oscilloscope with 53/54C and L Plug-in Units

F. Electronics Power Supply PP-1386

G. Brake Power Supply, EICo 1064 Power Supply

H. Motor Control Box

I. Type 503 Oscilloscope

J. Polaroid F 284 Camera mounted on Type 503 Oscilloscope

K. Helipot Box

5. EQUIPMENT CONNECTIONS AND SETTINGS

I. Connections and Settings for Imaging Mode.

A. Model 650-A Test Oscillator (Hewlett-Packard)

1. BNC cable to R.F. pulse input jack, electronics chassis. A 600 ohm load is required at the test oscillator.
2. Output attenuator: 1.0 volt-0 db position.
3. Frequency: As required by the experiment.

B. Type 503 Oscilloscope (Tektronix)

1. BNC cable, "external trig.-in" to "camera sync." jack of electronics.
2. BNC cable, CRT external input to video output in electronics.
3. Two banana plugs from + vertical input (d.c.) to helipot box (red lead to ground).
4. Vertical sensitivity: 1 volt/cm, calibrated.
5. Power: On but fully cw.
6. Focus: Adjust for smallest spot.
7. Intensity: Set at scribed mark. (A photocell system for more precise adjustment of intensity will be developed later.)
8. Vertical Position: Trace should be approximately one inch from the top of the screen when the transducer scans the upper edge of the target.
9. Horizontal Position: Trace should start approximately 1/4 inch from the left edge of camera scope mask.
10. Horizontal Display: Sweep normal (X, 1).
11. Sweep time: 1 sec/cm and sweep time variable control (red knob) turned approximately 30° from full cw position.

12. Trigger level: Turned approximately 30° ccw from 0 (zero) level (negative trigger pulses accepted).
13. Trigger slope: Negative.
14. Trigger coupling: A-C.
15. Trigger source: External.

C. Polaroid F-284 Scope Camera

1. Shutter: T (time).
2. Diaphragm (lens settings): f/16.

D. Model PG 650-C Pulsed Oscillator

1. BNC cable, delayed triggers jack to "trig. in." jack, rear panel of electronics.
2. R.F. Output: 93 ohm load; VHF cable to transducer compensator. (Presently, the 93 ohm load is connected as a 100: 1 attenuator, so that the output pulses of the pulse generator may be viewed, if necessary, on beam 2 (type L plug-in unit) of the 555 oscilloscope.)
3. Trigger: INT.
4. Delay μsec: 1100.
5. PRF: 80 (240p/s).
6. R.F. Delay: Out.
7. Delay: adjust to receive return echo pulse within amplifier gate.
8. High Voltage Adjustment: Adjust for experiment requirements.
9. Pulse Length: Adjust for experiment requirements.
10. Frequency: Adjust for experiment requirements.
11. Coil: Determined by the frequency used.
12. R.F. Output Switch: OFF.

E. Wide-Band Amplifiers (HP 460AR & 460BR)

1. 200 ohm cable, input 460AR amplifier to output mid-amplifier attenuator.
2. 200 ohm cable, output 460AR to input 460BR.
3. 200 ohm cable, output 460BR to R.F. pulse input of electronics.
4. Gain Control 460AR: Adjust for experiment requirements.
5. Amplification 460BR: Linear.

F. Dual Beam Oscilloscope (Tektronix Type 555)

1. BNC cable, Channel A input of type 53/54C plug-in unit to R.F. pulse input jack electronics chassis.
2. BNC cable, Channel B input of type 53/54C plug-in unit to video output jack electronics chassis.
3. Scope probe, input of Type L plug-in unit to 93 ohm attenuator load on PG 540-C pulsed oscillator.
4. BNC cable, trigger input on type 21 time-base unit to trigger output jack at rear of electronics chassis.
5. BNC cable, trigger input on type 22 time-base unit to trigger jack of PG 650-C pulsed oscillator.
6. Horizontal Display Beam 1: Time-Base A X 1.
   Horizontal Display Beam 2: Time-Base B X 1.
7. Control Settings of Type 53/54C plug-in unit:
   a. Mode: Alternate
   b. Channel A volts/cm: 2 volts/cm
   c. Channel A: a-c coupling
   d. Channel A polarity: normal
   e. Channel B volts/cm: 10 volts/cm
   f. Channel B: a-c coupling
   g. Channel B polarity: normal

8. Control Settings of Type L plug-in unit:

    a. A-C coupling

    b. Volts/cm: .05 volts/cm

9. Control Settings of Time-Base A:

    1. Trigger source: external

    2. Trigger coupling: a-c

    3. Trigger slope: negative

    4. Trigger level: negative

    5. Sweep function: normal

    6. Time/cm: 20 μsec/cm

10. Control Settings of Time-Base B: Identical to the settings for Time-Base A.

G. Mid-amplifier Attenuator

1. BNC cable from input jack to output jack of Band Pass Filter.

2. Adjust control as required by the experiment.

H. Band-Pass Filter.

1. BNC cable from input jack to output jack AW-203 input amplifier.

2. Set frequency as required by the experiment.

I. Input Amplifier (Electro-International AW-203)

1. BNC cable from input jack to 72 ohm to 50 ohm adapter on output of input attenuator.

2. Control Settings

    a. Low Frequency cutoff 25 Kc

    b. Attenuation: as required by the experiment

    c. Gain: fully clockwise

J. Input Attenuator

1. 72 ohm to 50 ohm adapter connected on output of attenuator.

2. BNC cable from receiving transducer to input of attenuator.

3. Adjust attenuation as required by experiment.

K. Transducer Compensator

1. Connect the r.f. output of the pulsed oscillator through a T-Connector on the transducer compensator to the transmitting transducer BNC cable.

2. Set compensator to obtain maximum acoustic pulse return with desired pulse waveform.

L. Electronics

1. Relay D switch: De-energized.

2. Hi-Lo Switch: Hi position for frequencies above 1.2 Mc; Lo position for frequencies below 1.2 Mc.

3. Video Gain: Log position.

4. Transducer carriage should be fully eastward when electronics power is first applied.

M. Brake Power Supply

1. Cable with banana plugs to output of power supply.

2. Adjust voltage control for 4.0 amperes of braking current per motor when motors are at rest.

<u>Don't apply braking current for extended periods of time.</u>

N. Motor Control Box

1. 8-pin Amphenol connector to electronics chassis.

2. 10-pin Jones plug to horizontal motor.

3. 10-pin Jones plug to vertical motor.

4. 2-pin shielded connector to brake power supply.

5. 8-pin Amphenol connector to remote motor control box.

6. For remote control of motors, all panel switches on Motor Control Box should be off. For control at the

Motor Control Box, all switches at Remote Motor Control Panel should be off.

O. Helipot Box (See Section B3).

P. Remote Motor Control Panel (See Section N6).

II. Connections and Settings For Backscattering Mode.

A. Model 650-A Test Oscillator (Refer to Section IA).

B. Graphic Level Recorder

1. BNC cable from input to boxcar detector output of electronics.

2. Control settings:

a. Attenuation: 0 db.

b. Writing speed: 20 in/sec.

c. Chart drive: as required by experiment.

C. Sensitive D.C. Motor (Boonton Type 95A)

1. Connected at input of graphic level recorder.

2. Range setting: 1 volt full scale.

D. Model PG 650-C Pulsed Oscillator (Refer to Section I-D).

E. Wide Band Amplifiers (HP 460AR & 460BR): Settings Identical to Section I-E except:

4. Gain control 460AR: fully clockwise

F. Dual Beam Oscilloscope (Tektronix Type 555): (Refer to Section I-F).

G. Mid-amplifier Attenuator (Refer to Section I-G).

H. Band Pass Filter (Refer to Section I-H).

I. Input Amplifier (Electo-International AW-203): (Refer to Section I-I).

J. Input Attenuator (Refer to Section I-J).

K. Transducer Compensator (Refer to Section I-K).

L. Electronics

1. Relay D Switch: energized
2. Hi-Lo Switch: Hi position for frequencies above 1.2 Mc; Lo position for frequencies below 1.2 Mc.
3. Video Gain: 0 db, -10 db, -20 db (as required by the experiment).
4. BNC jumper cable from video output jack to box car detector input for an analog signal proportional to peak received pulse.
5. BNC cable from video output to video squarer and integrator input, and BNC cable from box car detector input to video squarer and integrator output for an analog signal proportional to the mean square of the received pulse.

M. Brake Power Supply (Refer to Section I-M).

N. Motor Control Box (Refer to Section I-N).

O. Video Squarer and Integrator (See Section L-5 Above).

P. Remote Motor Control Panel (Refer to Section I-N6).

6. OPERATING PROCEDURE

I. Imaging Mode

A. Turn R. F. output switch of pulse generator on, and set band-pass filter to appropriate frequency.

B. Set high voltage control and transmitter transducer compensator to values in Table I. Set pulse length control on pulsed oscillator PG 650-C for desired length of output pulse; length of the pulse can be observed directly on beam #2 of the 555 oscilloscope.

C. The delay control of the PG 650-C pulsed oscillator and the three receiver attenuators—input, input amplifier, and mid-amplifier—should be adjusted to give the acoustic return echo from the reference target, usually the back-wall of the tank, on channel A of beam #1 of the 555 oscilloscope. (Throughout the experiment check occasionally the input amplifier and the two wide-band amplifiers for overloading. Maximum output of the AW-203 input amplifier should not exceed 1.0 volt peak; maximum output of the H-P 460-BR amplifier should not exceed 2.0 volts peak.) Increase the setting of the output attenuator on the 650A test oscillator until a series of lines or sinusoidal patterns appear on top of the video pulse as seen on channel B, beam #1 of the 555 oscilloscope. (It may be necessary to temporarily increase the pulse length at this point, as well as to switch the "electronics" video gain control from 'log' position). When the test oscillator frequency matches the frequency of the pulsed oscillator, the lines riding on the top of the video pulse will be horizontal and parallel to one another. Upon obtaining the correct frequency, reduce the output of the test oscillator to zero and return both the pulsed oscillator pulse length control and the "electronics" video gain control to their former settings.

D. Run the transducer carriage across the target and stop at a point of maximum acoustic return.

E. Adjust the attenuation controls in the receiving amplifier system to obtain a video pulse of 15 volts.

F. Run the transducer carriage across the target and check that points of minimum acoustic return produce video pulses of at least 5 volts. If not, adjust the receiver attenuation controls so that a point of minimum return produces a 5 volt video pulse.

G. On the 503 oscilloscope, switch the trigger level to "auto" position and the sweep time to 5 milliseconds/cm. With a video pulse of 5 volts applied to the CRT grid, adjust the intensity to obtain a pattern that resembles a string of beads. (It should be noted at this point that, because of the time constant of the R-C network coupling the video pulse to the CRT grid, video pulses with lengths in excess of 10 microseconds are ineffectual in modulating the CRT beam.) As a check on the intensity setting, the r.f. input signal can be increased in steps of 6 db up to a total of 18 db by switching the mid-amplifier attenuator; this increase of signal should produce but little "blooming" or defocusing of the spots.

H. Return the scope trigger level and time/cm controls as well as the mid-amplifier attenuator settings back to the positions held prior to step G.

I. Scanning operation is now ready to begin. The transducer carriage should be directed at the uppermost portion of the target. Set the vertical carriage step univibrator scan adjust control, located at the rear edge of the electronics chassis, to give the desired vertical scan interval. The vertical control switch on the motor control box should be set to "down" position.

J. Begin operation by opening camera shutter. Cycle the horizontal carriage from east to west, west to east, etc., starting from the easternmost position. Continue this horizontal cycling until the desired count is reached on the vertical position indicator.

K. Open shutter and develop picture.

II. Backscattering Mode.

A. Refer to step A for imaging mode

B. Refer to step B for imaging mode

C. The delay control of the PG 650-C pulsed oscillator and the three receiver attenuators—input, input amplifier, and mid-amplifier—should be adjusted to give, on channel A of beam #1 of the 555 oscilloscope, an acoustic return echo from a plane target such as the back wall of the target. (Throughout the experiment all amplifiers should be held within their linear range of operation. At no time should the output of the AW-202 input amplifier exceed 1.0 volt peak, the output of the H-P 460BR amplifier exceed 2.0 volts peak, or the video pulse exceed 40 volts with 0 db video gain.) Increase the setting of the output attenuator on the 650A test oscillator until a series of lines or sinusoidal patterns appears on top of the video pulse displayed on channel B, beam #1, of the 555 oscilloscope. (It may be necessary to temporarily increase the pulse length at this point.) When the test oscillator frequency matches the frequency of the pulsed oscillator, the lines riding on top of the video pulse will be horizontal and parallel to one another. Upon obtaining the correct frequency, reduce the output of the test oscillator to zero and return the pulsed oscillator pulse length control to its former setting. Under no circumstances should the pulse length or the setting of the high voltage control on the pulsed oscillator be altered during a series of measurements at the particular frequency just set. An occasional recheck of the frequency should be made every two or three hours of operation.

D. Check the physical alignment of the transducers by directing the transducer beam perpendicularly to a plane surface, such as the back wall of the tank. Adjust the three adjustment screws on each transducer mount for a maximum return echo at the distance "d" at which the backscattering measurements will be made, the distance "d" being measured always from the front face of the transducers to the target surface. The occurence of maximum return echo is best observed as a maximum reading on the Boonton Type 95A sensitive d.c. voltmeter.

E. If the experiment involves measurements made at various angles of incidence, a table of relative beam return attenuation factors vs. distance to target must be experimentally determined at this time for the particular frequency and transducers. When the backscattering measurements are made at a distance "d" from the target, then as the angle of incidence θ changes the distance to the target will be given by $d/\cos\theta$. Using a plane surface such as the back wall of the tank as a target, measure the return on the d-c meter at target distances $d/\cos\theta$ for all θ employed at this frequency; convert these returns to relative beam attenuation factors by dividing them by the return for the distance "d" at 0° incidence.

F. All backscattering return data should be measured relative to the return from a perfectly reflecting plane surface such as the air-water interface at the water surface. The transducer swivel head is now rotated 90° so the acoustic beam is normal to the air-water interface; the front face of the transducers should be at a distance "d" (as defined in Section D) from the air-water interface. Allow several minutes for the water surface to return to an undisturbed state, then adjust the three receiver attenuators for a deflection of 0.5V-0.6V on the graphic level recorder, taking care that none of the amplifiers are overloaded. (See Section C). Record the settings of the three receiver attenuators and the deflection of the graphic level recorder. Note the position of the video gain control; this control should not be disturbed during the series of measurements taken at this particular frequency. Be certain that both the graphic level recorder and the sensitive d-c voltmeter are properly zeroed; this should be checked from time to time by switching the band-pass filter to the off position and observing whether the deflections of the two instruments fall to zero. If there is a residual deflection, re-adjust the zero-adjust control on the electronics chassis.

G. Rotate the transducer swivel head to the angle of incidence θ desired for the measurement, and position the transducer carriage so the front face of the transducer is at the required distance from the target. Scan the target once to obtain a setting of the three receiver attenuators that gives an average deflection of 0.2V-0.3V on the graphic level recorder and permits no off scale recorder deflections during the scan. Record the new settings of the three receiver attenuators and make the recording of the backscattering data by turning on the chart speed drive switch. For horizontal scanning a chart speed of 300 div/min is satisfactory; for vertical scanning chart speeds of 30 div/min for low speed scan and 100 div/min for high speed scan are satisfactory.

H. Repeat step G for all angles of incidence θ required at this frequency. For measurements at other frequencies repeat all steps starting at step A.

I. If the video squarer and integrator circuit is used to obtain output voltages proportional to the mean square of the received signal, the video pulse driving this circuit should not exceed 25 volts.

J. In calculating the appropriate scale factos to be used on each record taken of backscattering data, the recorder attenuation settings should be converted to actual attenuation values as given in Table I. Let A_o be the reading in chart divisions of the return for normal incidence from the air-water interface. Let G_o be the actual attenuation value in db within the receiving amplifier system for normal incidence from the air-water interface. Let $G(\theta)$ be the actual attenuation value in db for the return at an angle of incidence θ from the target. Let DG be defined as

$$DG = G_o - G(\theta).$$

Then the voltage gain ratio $K(\theta)$ is given by

$$K(\theta) = \log_{10}^{-1}(DG/20)$$

or the power gain ratio $K'(\theta)$ is given by

$$K'(\theta) = \log_{10}^{-1}(DG/10).$$

Let $T(\theta)$ be the relative beam return attenuation factor as determined in step E. If the backscattering results are being recorded in terms of the peak value of the received acoustic pulse (direct connection between video output and boxcar detector input of electronics), then $A(\underline{\theta})$, the chart scale factor in chart divisions for unity reflection coefficient, R, will be:

$$A(\theta) = A_o K(\theta)\ T(\theta).$$

If the backscattering results are being recorded in terms of the mean-squared value of the received acoustic pulse (video pulse fed to video squarer and integrator and thence to input of boxcar detector), then $A'(\theta)$, the chart scale factor in chart divisions for unity value of the square of the reflection coefficient, R^2, will be

$$A'(\theta) = A_o K'(\theta)\ T^2(\theta).$$

7. CONCLUDING REMARKS

The acoustic simulator has been used to perform numerous experiments resulting in much useful information on backscattering and imaging problems. However, many aspects of its performance need to be improved, and certain additional capabilities as discussed below need to be incorporated.

Imaging Mode: A series of runs at 0.8 Mc, 1.2 Mc and 1.6 Mc have been carried out in the simulation of multi-frequency radar, and the resulting slides were sent to CRES, University of Kansas, for use in their polychromatic projector.

The slides suffered from two defects. First, the initial few sweeps at the top of the photographs were slightly displaced to the right because of irregularities in the horizontal carriage speed. This trouble has been eliminated by proper lubrication of the carriage. Second, the exposure latitude of the 46-L film used is not sufficient to cover the dynamic range of the received acoustic pulses. On the light areas (reflection from bare metal) the film is fully exposed, but on the dark areas (reflection from either crushed rock or linoleum) the film shows very little exposure. Consideration is now being given to matching the response of the video amplifier to that of regular 4" x 5" cut film which has a wider exposure latitude than Polaroid film. The use of regular film will have the additional advantage that the negative produced can be directly used in the CRES flying spot scanner without going through an intermediate process of converting the Polaroid print to a larger negative with the consequent loss of detail and resolution.

Backscattering Mode: In the early experiments, the receiver amplifiers were found to possess non-linearities. Thus, the gain was not constant but depended on the frequency, and also on the amplitude, of the received (echo) signal. These defects have now been removed.

The warping of target back-up material (plywood) caused a fluctuation of the received signal, a situation now avoided by using stronger re-inforcements and metal-plate mountings.

General: Tables listing the settings for the high voltage control on the pulsed oscillator have been completed (see Table II). The table will aid the acoustic simulator operator to obtain with reasonable accuracy the desired frequency (as checked with the test oscillator) and the optimum output pulse shape of the transmitter.

Design and development of an apparatus to measure the velocity of propagation of acoustic waves in solids and liquids have been completed. The method consists of using acoustic transducers to launch and receive a wave, and measuring the difference in times taken to travel a certain distance through water and through the medium in question, respectively. Knowing the velocity of propagation and the material's density, one can calculate its acoustic impedance.

It is felt that the existing capabilities, along with the modifications and improvements currently underway, make the acoustic simulator a versatile and useful tool for the study of electromagnetic as well as acoustic problems.

TABLE I. RECEIVER ATTENUATOR CALIBRATION

INPUT ATTENU-ATOR POSITION	AW 203 ATTENUATOR POSITION					MID-AMPLIFIER ATTENUATOR
	0	10	20	30	40	
0	0.0	10.96	20.64	31.26	41.32	0.0
1	0.96	11.96	21.64	32.26	42.34	
2	1.98	12.96	22.62	33.32	43.36	
3	3.00	14.00	23.68	34.34	44.38	
4	3.96	14.98	24.70	35.32	45.42	
5	4.94	15.98	25.68	36.34	46.42	
6	5.96	16.98	26.70	37.34	47.42	6.0
7	6.98	17.98	27.66	38.34	48.44	
8	7.94	19.00	28.68	39.38	49.42	
9	8.96	20.02	29.71	40.36	50.46	
10	9.98	21.02	30.68	41.36	51.44	
11	10.96	22.02	31.68	42.36	52.44	
12	11.96	23.02	32.70	43.40	53.46	12.44
13	12.98	24.04	33.70	44.42	54.48	
14	13.98	25.04	34.72	45.42	55.44	
15	14.98	26.04	35.72	46.38	56.46	
16	16.00	27.06	36.74	47.38	57.46	
17	17.00	28.06	37.72	48.40	58.46	
18	17.98	29.04	38.74	49.42	59.46	
19	19.00	30.06	39.74	50.42	60.48	18.42
20	20.00	31.04	40.76	51.42	61.46	

TABLE II. PULSED OSCILLATOR HIGH VOLTAGE CONTROL SETTINGS (PRF=240 CPS)

Receiving Transducer	Transmitting Transducer	Operating Frequency	Coil	Freq. Dial Setting	High Voltage Control Setting	Transducer Compensator
700KC	700KC	720KC	#7	0.0	72	#6, SLUG COMPLETELY IN
1MC	1MC	1MC	#7	90.0	56	#4, 1/8" OUT
1.6MC	1.6MC	1.6MC	#9	37.0	62	#4, 1/8" OUT
2.25MC	2.25MC	2.25MC	#9	80.0	100	#3 SLUG COMPLETELY OUT
3.5MC	3.5MC	3.5MC	#11	5.5	94	#3 SLUG COMPLETELY OUT