A STUDY OF TORNADO RESEARCH EQUIPMENT

By

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PREFACE

The purpose of this paper is to introduce the reader to the principles and theory of operation underlying the tornado research equipment. The circuits of the sferic recording equipment have been discussed at length. It should be noted at this point that no attempt has been made to discuss weather phenomenon or sferic identification. The known facts of weather and sferics have been discussed in many other papers.

The author is grateful to Dr. Herbert L. Jones, Tornado Research Director, whose interest in this paper inspired its completion. A word of thanks is also due Mr. Ruben D. Kelly who installed most of the equipment now in use at the tornado research laboratory.

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CHAPTER I

INTRODUCTION

The results of previous research at the Oklahoma Institute of Technology has indicated that the sferics associated with tornadoes have distinctive characteristics. The data collected thus far in the project have indicated that the high frequency sferics are present only when there is tornado activity.[1,2] To confirm this theory more data must be collected. It is only through comparison of sferic waveforms and known weather conditions that the project can be brought to a satisfactory conclusion.

It is the purpose of this thesis to present the theory and operating procedure of the existing recording equipment and the sferic direction finder.

Sferic Detection and Recording Equipment

The equipment built and installed by Mr. Harold O. Jeske[3] and Mr. Philip N. Hess[4] was in operation at the beginning of this study. Some modifications were made for greater circuit

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[1]John S. Hutchison, A Study of Tornado Identification, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1949.

[2]James C. Hill, Sferic Waveform Identification of Destructive Windstorms and Tornadoes, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1951.

[3]Harold O. Jeske, Electronic Apparatus for the Study of Sferic Waveforms, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1949.

[4]Philip N. Hess, Installation and Operation of Electronic Sferic Detection Equipment, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1950.

sensitivity, more stable operation, and greater flexibility.

The circuits discussed here are designed to receive the incoming sferic, apply the waveform to an oscilloscope, and record the waveform on a 35mm film. From the design viewpoint the following features were desired:

1. Omnidirectional antenna.
2. Remote antenna to eliminate local noise.
3. Frequency range from 20 cps to 500,000 cps.
4. Triggered beam control, no image between traces.
5. Positive indication of sweep time.
6. Triggered sweep for every waveform.
7. An atmospheric oscillogram on every picture frame.
8. The time and date on every picture.
9. Camera shutter open at all times.
10. Equipment that will operate unattended in order to obtain recorded samplings over long storm periods.

The sferic waveform apparatus can be divided into three major components; antenna circuit, video and trigger circuits, and the recording equipment. A new impedance matching circuit was designed and constructed by Mr. Ruben D. Kelly to replace the cathode follower that is used between the antenna and the 50 ohm coaxial transmission line. This new circuit increases the signal to the video amplifier to a gain about nine times greater than that of the original circuit.

The function of the overall equipment is shown in the block diagram, Figure 1. The incoming sferic passes through the antenna circuit to the video amplifier. The output of the video amplifier

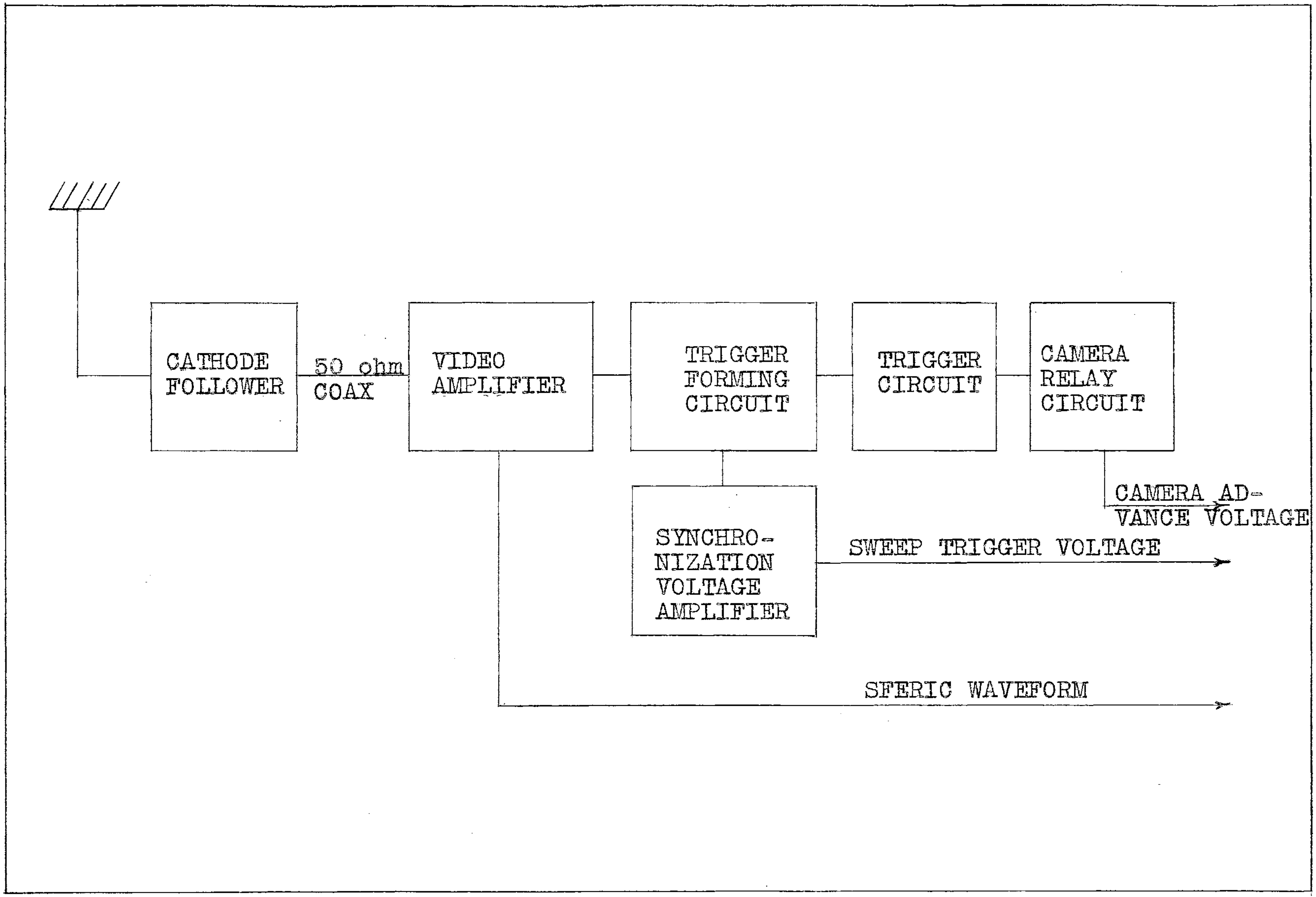

Figure 1 Sferic Detection Equipment Block Diagram

goes to the vertical deflection plates of the oscilloscope and to the trigger circuit. The pulse that actuates the camera relays is also used for the oscilloscope synchronization voltage.

Sferic Direction Finder

The direction finder now in use is the Model AN/GRD-1A. It was installed in January 1952 and has been used with gratifying results during the past six months. The indications are that, with another station similarly equipped, storm centers could easily be determined by triangulation.

The alignment procedure and operating technique have been discussed at length with the minimum of circuit theory.[5,6,7] A circuit diagram of an 180 degree ambiguity eliminator has been included and a discussion of its circuit action.

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[5]Vernon D. Wade, Development and Operation of a Crossed Loop Sferic Direction Finder, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1952.

[6]Thomas M. Holzberlein, A Study of Tornado Tracking Equipment, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1951.

[7]Thomas H. Thomason, The Development of a Sferic Direction Finder, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1949.

CHAPTER II

SFERIC DETECTION AND RECORDING EQUIPMENT THEORY

The circuits used in this equipment are in general well known, but as could be expected the manner in which they are interconnected is unique. It is desired that the equipment be designed so its operation is absolutely stable with the minimum of adjustments. The nature of the project requires the equipment be in operating condition at all times; precious time during a tornado condition should not be devoted to aligning the equipment.

The requirements of the sferic detection and recording equipment are quite rigorous but surprisingly simple. The sferic energy should be received and amplified with as little frequency distortion as possible. The system should be completely isolated and shielded from electrical disturbances other than sferics. Sferics of low energy level should be rejected. The sferic that is recorded on the photographic film should be used for triggering the film advance circuit. The system must be completely blocked while the film is being advanced. For an optimum number of recorded sferics, the equipment must be completely automatic, that is to say, the equipment should be completely restored for the next high energy sferic.

Because the circuits are quite common the design considerations are for the most part omitted, but more important the overall effect upon the system function is discussed.

Antenna to Coaxial Line Cathode Follower

A vertical whip antenna is set up 30 feet from the Tornado Research Laboratory to pick up the incoming sferics. The use of a short antenna necessitates the use of a matching circuit to couple the antenna to the 50 ohm coaxial line that is used to carry the incoming sferic into the laboratory. This circuit was designed and constructed by Mr. R. D. Kelly.[1]

The circuit shown in Figure 2 is used.[2] The input from the antenna goes through a conventional cathode follower. The total cathode resistance is 10,000 ohms which, when used with a 6AK5 tube, gives an output resistance to the next stage of 192 ohms. The senstitivity of the impedance matching circuit is varied by changing the tap on the cathode resistance. Fixed bias is maintained on the tube by the use of two one and one-half volt dry cells connected in parallel.

Since the output of the first stage is not matched to the transmission line, the second circuit, V2 and V3, were added for the exact match. This circuit can be analyzed by considering V2 and V3 as a two stage resistance-coupled amplifier, with 100 per cent feedback from the plate of V3 to the cathode of V2. Analysis of the equivalent circuit gives the ratio of output to input voltages as

$$\frac{E_{out}}{E_{in}} = \frac{\mu^2 + \mu + \left(\frac{r_p}{R}\right)}{(\mu^2+\mu+1)+(\mu+2)(r_p/R)}$$

and the output conductance is

$$G_{out} = \frac{1}{R_{out}} = \frac{\mu + 1}{r_p + R} + \frac{1 + \frac{\mu(\mu+1)}{(r_p/R)+1}}{r_p}$$

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[1]Herbert L. Jones, Research on Tornado Identification, Second Quarterly Progress Report, File Number 11587-PH-52-91, Signal Corps Research.

[2]Calvin M. Hammack, "Cathode Follower", Report 469, Radiation Laboratory, M.I.T., Cambridge, Mass.

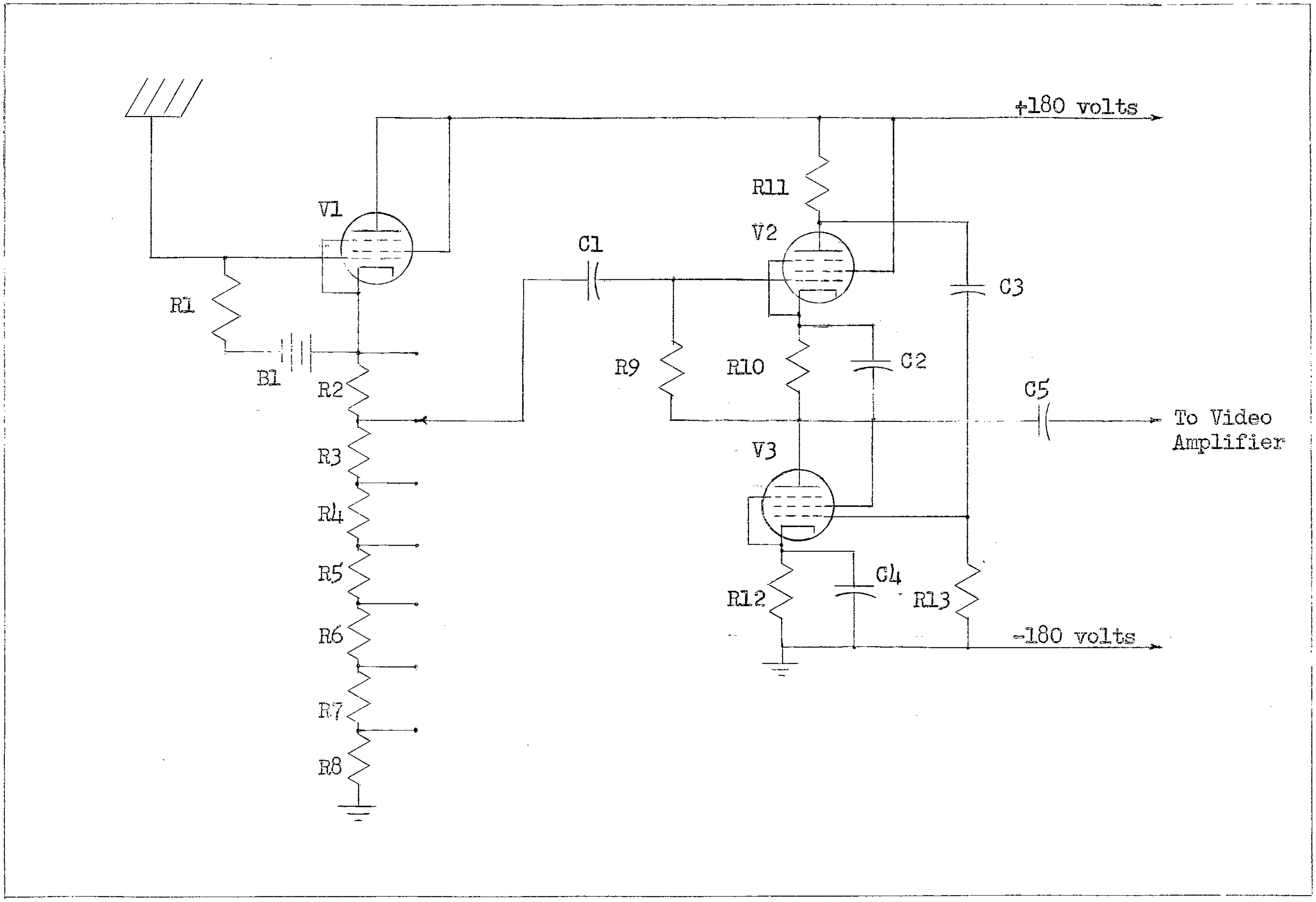

Figure 2. Antenna Cathode Follower Circuit.

When R is large compared to r_p, the first term of the conductance equation becomes negligible and the equation approaches

$$G_{out} = (\mu^2 + \mu + 1)/r_p$$
$$\approx \mu \, gm$$

The power supply for the matching circuits consists of two 90 volt dry cells connected in series for the plate supply and a 6 volt "Hot Shot" battery. By using this type of power supply the possibility of 60 cycle pickup is entirely eliminated. The power switch for the cathode follower is located at the matching circuit.

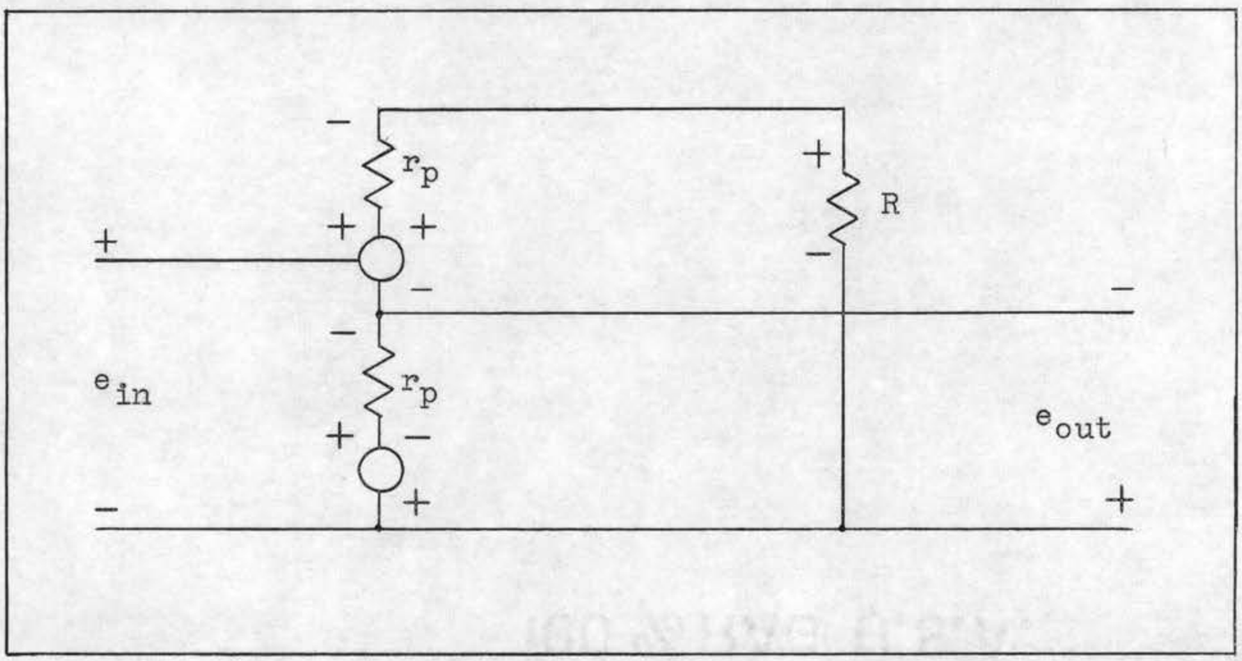

Figure 3. Equivalent Circuit for the Antenna Matching Network

Video Amplifier

The video amplifier used in this installation is the shunt peaking type,[3] Figure 6. The amplifier is designed for a

[3]Fredrick E. Terman, Radio Engineering, p. 250-268.

Figure 4. Remote installation of the antenna to coaxial line cathode follower.

Figure 5. Antenna to coaxial line cathode follower with power supply.

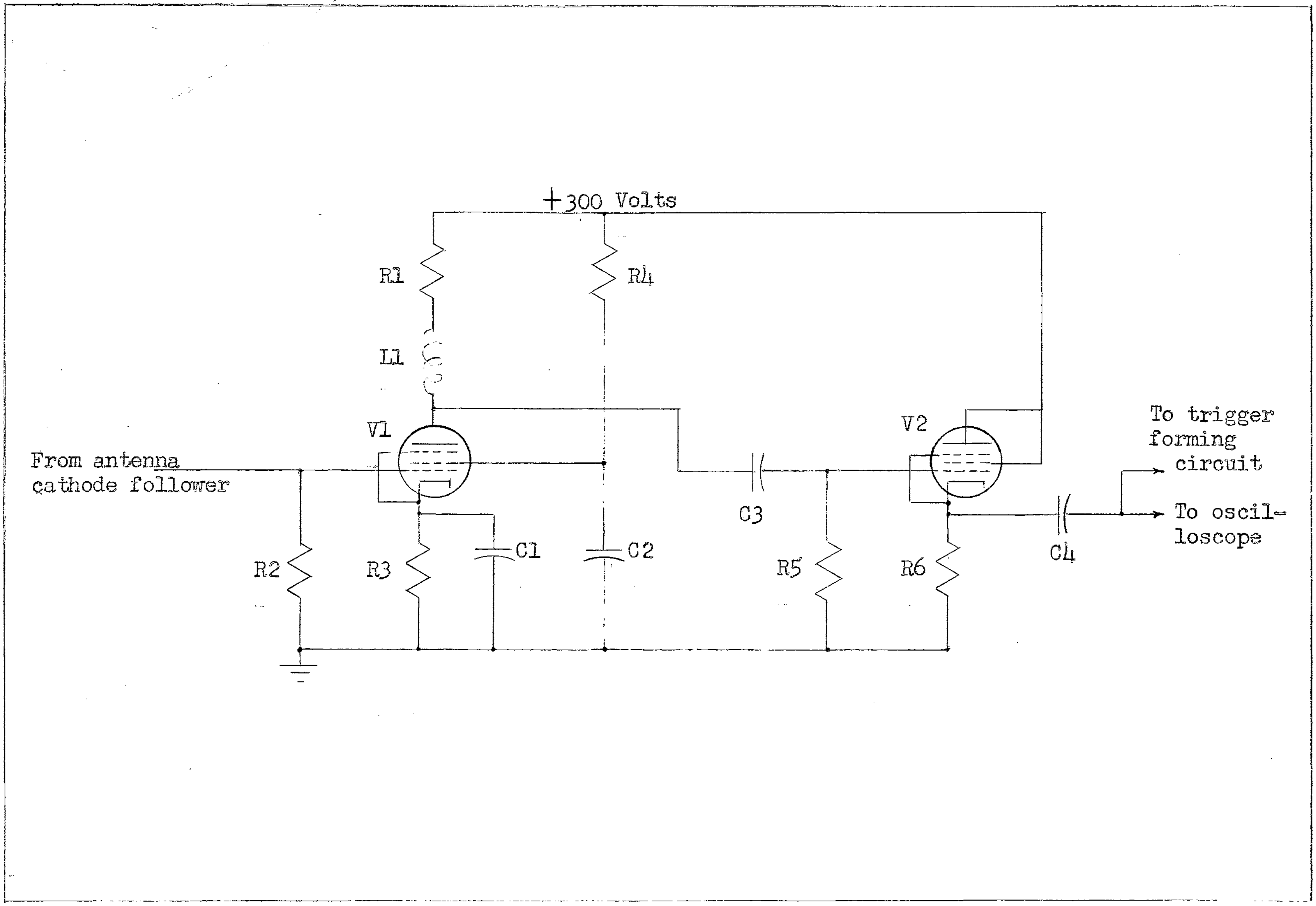

Figure 6. Video Amplifier Circuit.

frequency response that is flat from 50 cps to 2.5 mcs. The mid-band gain is fifteen. The video amplifier is coupled directly to a cathode follower circuit, which serves as an isolation stage for the video amplifier. Signals coming from the cathode follower are coupled through a 50 ohm coaxial line to the oscilloscope deflection circuits, and directly to the trigger forming circuits.

Trigger Forming Circuits

A positive pulse of 12 volts magnitude is needed to trigger the multivibrator in the trigger circuit. It is the purpose of the trigger forming circuit to provide this pulse. The first stage in the trigger forming circuit, Figure 7, is a conventional RC-coupled amplifier.

Since the trigger circuit must operate on both negative and positive pulses, a phase inverter[4] is built into the trigger forming circuit. The phase-inverting arrangement has better frequency response and more gain than the transformer method of phase inversion. Phase inversion in this circuit is provided by triode V2B. The output voltage of V2A is applied to the plate of V3A. A portion of the output voltage of V2A is also applied through the resistors R9 and R10 to the grid of V2B. The output voltage of V2B is applied to the plate of V3B. When the output voltage of V2A swings in the positive direction, the plate current of V2B increases. This action increases the voltage drop across the plate

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[4] E.E. Staff, M. I. T., Applied Electronics, 1949, p. 489.

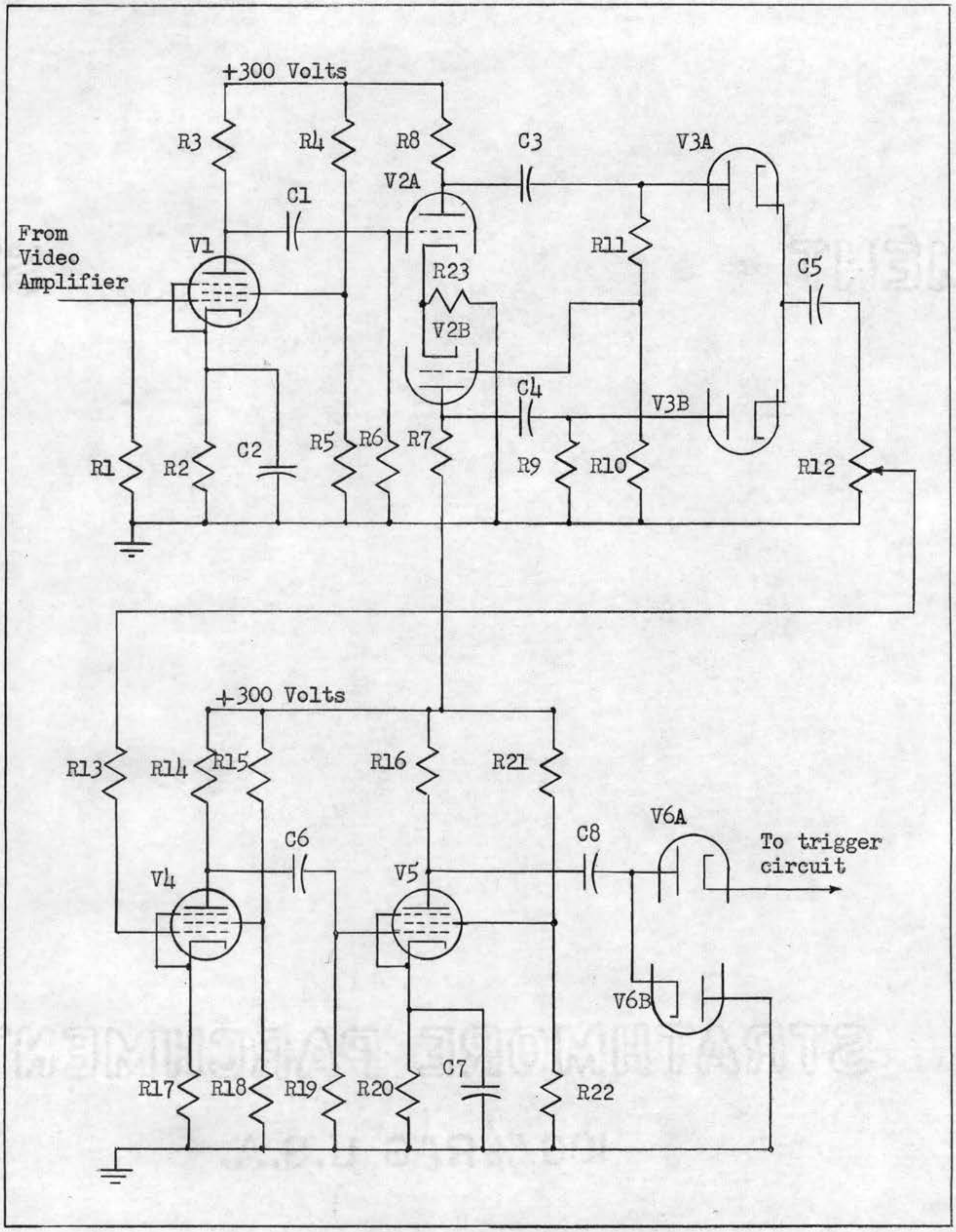

Figure 7. Trigger Forming Circuit.

resistor R7 and swings the plate of V2B in the negative direction. Thus, when the output voltage of V2A swings positive, the output voltage of V2B swings negative. The circuits of V2A and V2B are designed as conventional RC-coupled amplifiers with the input of V2B coming from the voltage divider network of R9 and R10. In order to obtain equal output voltages, the quantity $\frac{R9 + R10}{R10}$ should be equal to the voltage gain of V2B.

The diode V3 is used to couple the output of the phase inverter to the next stage of amplification. It is the function of V3 to pass the positive signals and reject the negative pulses. From the previous discussion of circuit action it is evident that the output of V3 will always be a positive pulse regardless of the polarity of the incoming signal.

In order to keep the trigger circuit from triggering on small distant sferics, the gain gontrol, R12, was added to the circuit. V4 and V5 are trigger pulse amplifiers. Since the multivibrator input grid is subject to wide variations of voltage when disturbed, it is necessary to couple the trigger pulse through a unidirectional coupling device, V6. This assures that there will be no loading back from the multivibrator to the pulse amplifier.

Trigger Circuits

The trigger circuits furnish the oscilloscope synchronization voltage and the camera circuit energizing voltage. It is desired to add to the circuit a device to vary the time required by the trigger circuit to restore itself. By this means the equipment operator will be enabled to vary the rate at which the sferics are recorded.

The trigger circuits consist of an Eccles-Jordan circuit and three vacuum tube controlled relays as shown in Figure 8. The circuit operation is explained in the sequence of the effects upon the circuit action.

It will be assumed that tube V1A is not conducting. This is the usual condition which will exist before a sferic triggers the circuit, as will be demonstrated subsequently. When a positive pulse is applied to the grid of V1A, this tube will begin to conduct. This conduction will cause the plate potential of V1A to drop. This drop in plate potential will be coupled to the grid of V1B to bias it below cutoff. As V1B is cut off, the potential of its plate will rise to the value of the plate potential, E_{bb}. This rise of potential is coupled through the voltage divider R9 and R10. Tube V2 is normally not conducting due to the positive potential placed on the cathode by the voltage divider R11 and R12 which is connected to a positive 300 volts. When V2 conducts, relay CR1 is energized. Relay CR1 is equipped with double-pole double-throw contacts to control the action of both V3 and V4.

Tube V3 is normally cut off by the positive potential of the cathode. During the cut off period, condenser C1 has been charged to the cathode potential. When CR1 is energized, the normally closed contact of CR1 in the grid circuit will open to place the negative potential of C1 on the grid. After C1 has discharged sufficiently through resistor R13, tube V3 will conduct and as a result rely CR2 will be energized. When relay CR2 is energized, the normally closed contacts in the Eccles-Jordan circuit open to cause the right side of the circuit to conduct. This conduction is coupled back to the grid of V2. This cuts

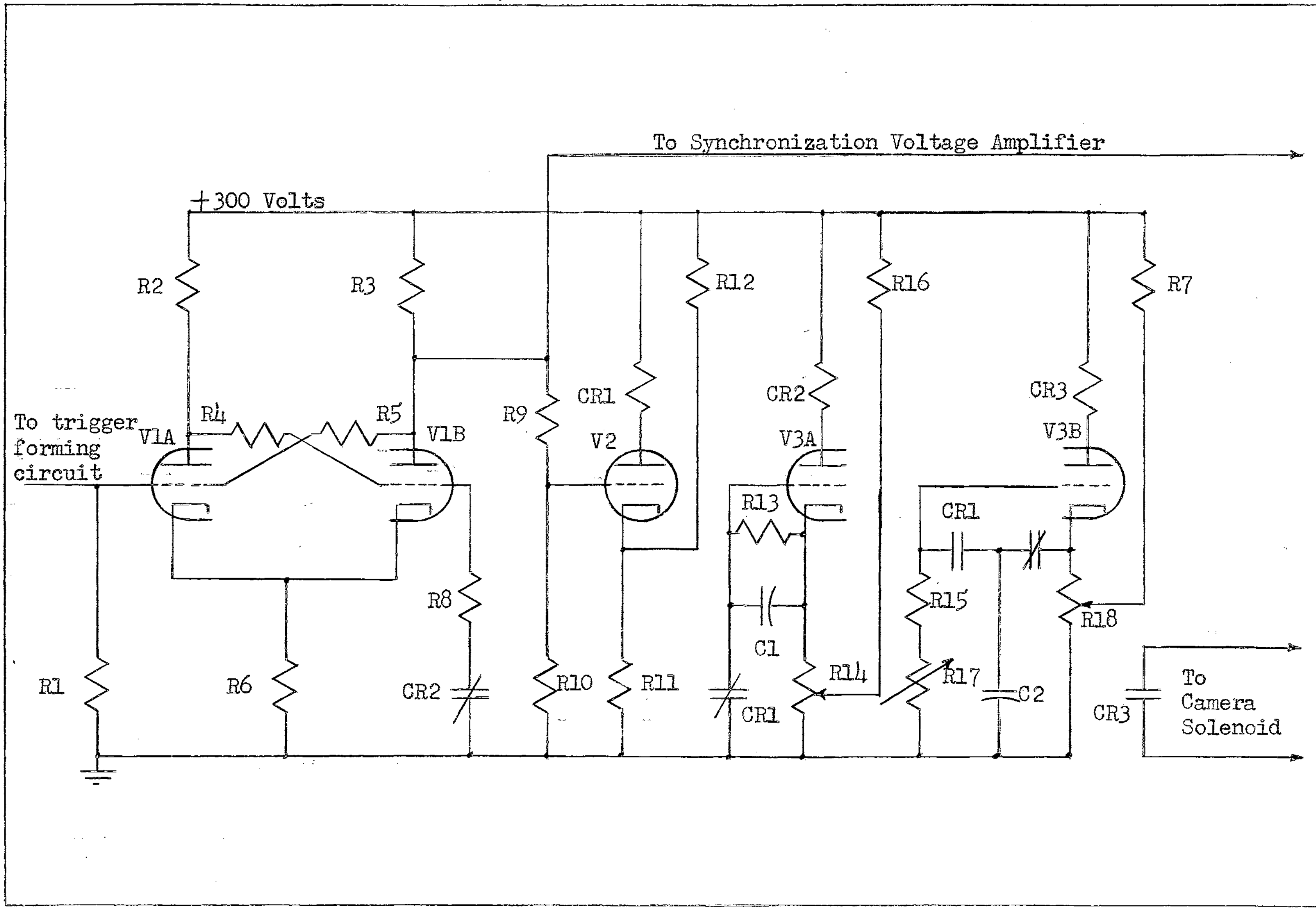

Figure 8. Trigger Circuit.

off tube V2 which in turn closes the contacts in the grid circuit of V3. Tube V3 is then restored to its non-conducting state.

Through the interaction of V1 and V3, tube V1B will always be in a conducting condition before a sferic triggers the circuit. If tube V1B had been initially not conducting, the circuit action would have been such that relay CR2 would have opened the grid circuit on the right side of V1 and as a result tube V1B would conduct. From the previous discussion it can be seen that the reset time for the trigger circuits is established by the values of R13, C1 and the bias on V3.

The next consideration is the circuit that triggers the camera relay. In its quiescent state tube V4 is inoperative due to the positive cathode potential. Condenser C2 is charged to the cathode potential. When relay CR1 is energized, the contacts in the grid circuit of V4 will place the positive potential of C2 on the grid of V4. This will cause V4 to conduct and to energize CR3 which controls the camera relay. The time that tube V4 conducts is determined by the RC time of R15, R17, and C2. Potentiometer R18 is set to cut off conduction of V4.

The values of the RC products in the grid circuits of V3 and V4 and the grid bias of V3 are selected so that tube V4 is returned to its steady state condition before V3 starts to conduct. The adjustments for the trigger circuits are discussed in the chapter on equipment operation.

The synchronization signal is taken from the plate of V1B. This positive square wave is coupled to the synchronization voltage amplifier.

Synchronization Voltage Amplifier

Design considerations dictate that the same sferic that triggers the sweep must also actuate the camera solenoid. The signal is easily obtained by taking the synchronization pulse from the plate of V1B of the trigger circuit. This positive square wave is coupled through a cathode follower, which acts as a buffer stage, to a RC-coupled amplifier as shown in Figure 9. The components C2 and R4 act as a differentiator circuit to form a short time duration pulse. The amplifier V2 is biased to cut-off by the voltage divider R7 and R5. The output of V2 is coupled through a coaxial line to the external synchronization jack on the oscilloscope.

Camera Relay Circuit

The camera relay circuit, Figure 10, is mounted on a separate chassis from the rest of the recording equipment. This layout is necessary because the unit requires its own power supply and heavy transient currents are drawn by the camera solenoid.

A direct current rotary solenoid actuates the camera to advance the film one frame each time the system is triggered by a sferic. This rotary solenoid is energized by a relay located on the camera relay circuit chassis and is connected to the camera mechanism by a three conductor cable. Because of the relatively high direct current drawn by the rotary solenoid, this relay is equipped with heavy-duty contacts. Since relays with coils suitable for plate circuit operation are not usually equipped with these heavy-duty contacts, a second relay with high current contacts is included to control the relay that operates the camera

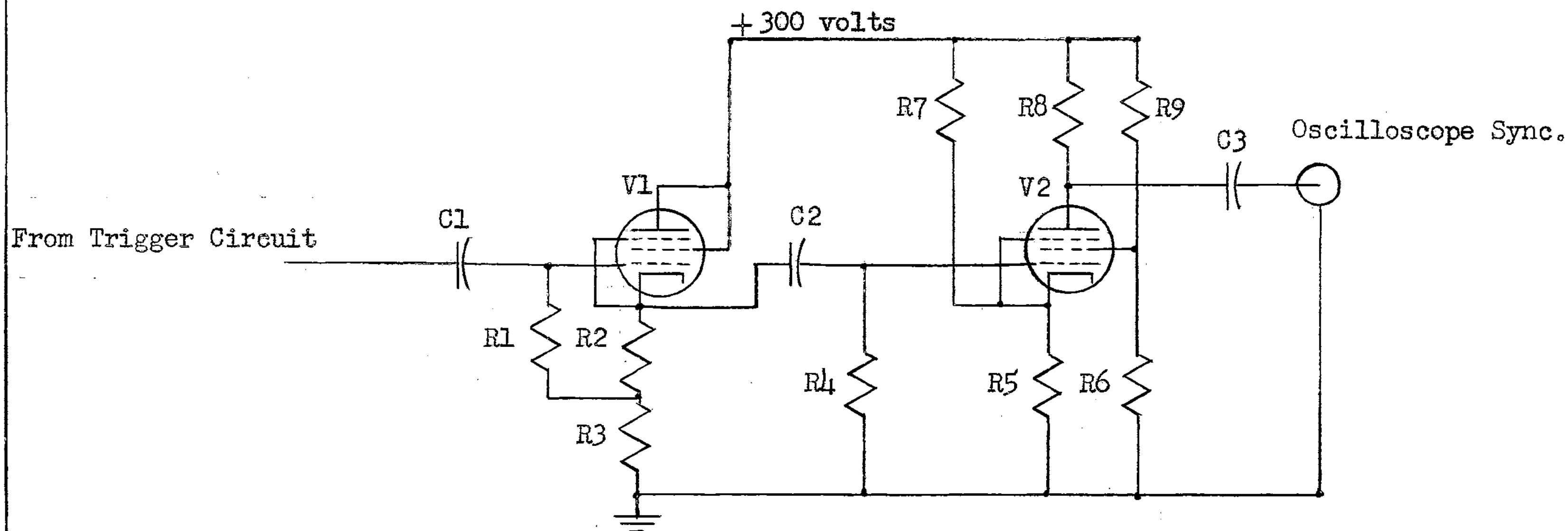

Figure 9. Synchronization Voltage Amplifier Circuit.

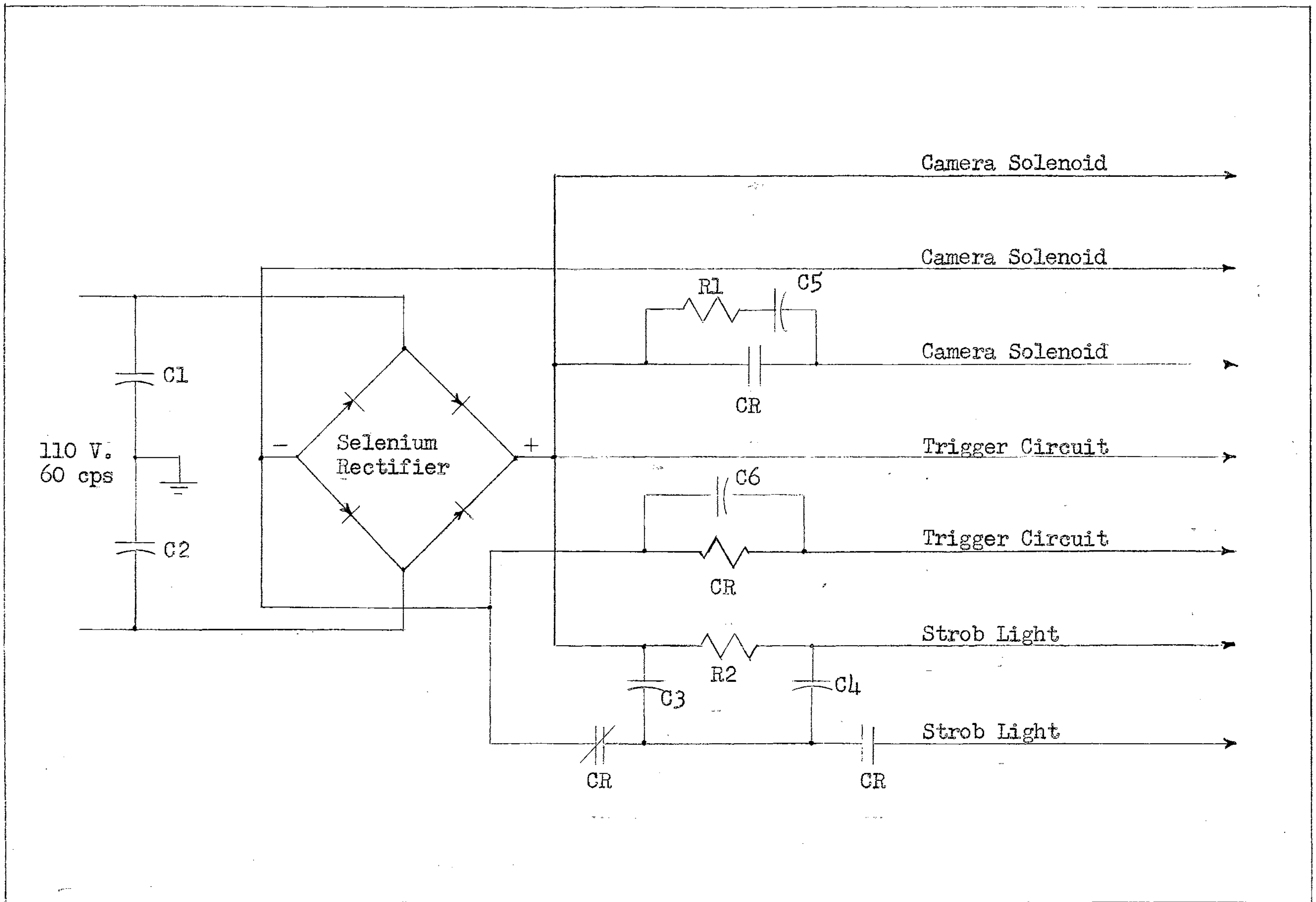

Figure 10. Camera Relay Circuit.

solenoid. The control relay circuit is designated as CR3 in the trigger circuit.

It is noted in the discussion of the trigger circuit that a control potentiometer was installed to control the length of time that CR3 is energized. This potentiometer indirectly controls the time that relay CR of the camera relay circuit is energized. Such an adjustment is deemed necessary because a long duration pulse is needed for the camera solenoid to complete its cycle.

The camera solenoid operates from a 110 volt direct current source. It draws approximately 2 amperes current under intermittent operation. To provide the direct current, a bridge type, full-wave rectifier, especially designed by the makers of the rotary solenoid, is installed in the camera relay circuit chassis. It is of the selenium type and also provides power for the strob light and the heavy-duty solenoid control relay.

The necessity of time and date data on each picture is solved by the installation of a clock above the oscilloscope. When a sferic is recorded a strob light illuminates the clock face. The strob light is controlled from the camera relay circuit. It can be seen from the circuit diagram that the power for the strob light is furnished by the energy stored in the capicators C3 and C4.

Camera and Oscilloscope

The camera, a modified 35 mm motion picture camera, was developed by the Oklahoma Institute of Technology Engineering Research and Development Laboratory. Its location with respect to the oscilloscope can best be understood by referring to Figure

11. A direct current rotary solenoid actuates the camera to advance the film one frame each time the system is triggered by a high energy sferic.

The desired sferic waveforms are displayed on the screen of a Type 250 Dumont oscilloscope. Frequency response of this oscilloscope is flat to 200 kcps.

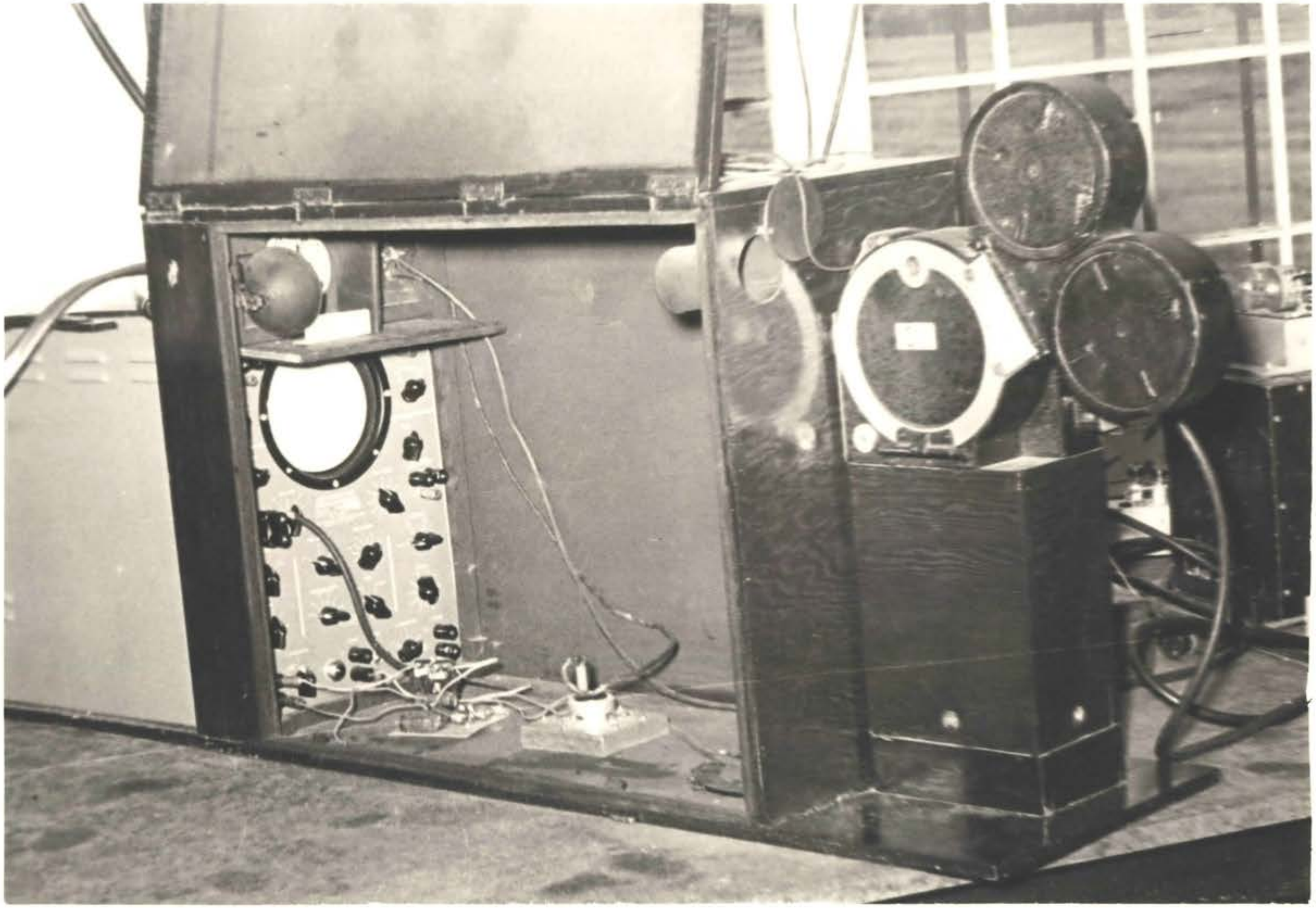

Figure 11. Sferic recording equipment.

CHAPTER III

SFERIC DETECTION AND RECORDING EQUIPMENT OPERATION

There are certain preliminary steps that should be made before the equipment is put into operation. The clock in the light box should be set to the correct time. A Signal Corps communications receiver capable of receiving WWV time data has been installed in the Tornado Research Laboratory. The date should be written on a small white card and mounted directly below the clock.

A very necessary part of collecting data is an accurate log book. This book should be so arranged that pertinent information such as the oscilloscope settings, date, known weather conditions, and any unusual circumstances are recorded. The log is necessary in order to correlate the waveforms obtained with other waveforms taken at different sweep speeds, different gains, and other locations. This information is an invaluable aid while reviewing the pictures and while attempting to group pictures as to the type of storm represented.

The Tornado Research Laboratory has a gasoline motor driven generator for an emergency power source. This motor generator set supplies sufficient 60 cps 110 volt power to operate all of the sferic detection equipment and the sferic direction finder. The fuel tank of this unit should be refilled as soon as possible after it has been operated.

The batteries in the antenna cathode follower box should be checked before each new period of tornado conditions. The condition of the batteries can be indicated by keeping a log of the time the batteries are in use.

Operating Procedure for Viewing Sferic Waveforms

After the video amplifier and trigger circuit power has been turned on, the power switch in the antenna cathode follower box should also be turned on. The power for the camera relay has a separate switch and should be left in the "off" position. The approximate oscilloscope adjustments are as follows:

NAME	CONTROL SETTINGS
Y selector	A. C. Amplifier
Y gain	60
Y attenuation	10:1
X selector	Sweep
X gain	100
X attenuation	1:1
Sweep	Driven
Sweep range	20,000 cps
Sync selector	External
External sync	Input for sync voltage amplifier
Sync gain	$\pm$ 10

The positioning, intensity, and focus controls should be set to give a trace that is satisfactory for photographic purposes.

The trigger voltage gain control, R12 of the trigger forming circuits, should be set so that only the high intensity sferics are passed as indicated on the oscilloscope screen. The trigger rate control, R14 of the trigger circuit, should be adjusted to the "Fast" position. It will then be possible to view the sferics through the opening in the rear of the light box. The simplicity of operation is evidenced by the fact that only two circuit controls are used.

Operating Procedure for Recording Sferic Waveforms

The equipment should be adjusted as indicated in the preceding paragraph. The trigger rate control can then be adjusted to the rate at which the photographs are desired. This rate of recording can be varied from approximately three recordings per second to one every three seconds.

Control R18 of the trigger circuit is adjusted until the relay CR3 closes with its most positive action. When the camera relay power is turned on, the camera should begin immediately to operate. If the camera action is sluggish or if it tends to "stutter", control R17 should be adjusted until the action is smooth. It should be noted at this point that controls R17 and R18 will need very little adjustment at any time after the initial installation.

CHAPTER IV

SFERIC DIRECTION FINDER

The purpose of the sferic direction finder is to detect, amplify, and visually indicate the direction of arrival of the incoming sferics. The equipment must be capable of indicating the direction of approach of the incoming sferic whose duration is such that time is not available to use any electro-mechanical system of direction finding. When the energy of a sferic is detected by the antennas, it is amplified and instantaneously indicated on the cathode-ray screen of the indicator. The direction of the sferic can then be read on an azimuth scale.

Theory of Operation

Loop antennas form the directional element of the equipment. One loop antenna is located with its plane vertical to the north-south direction and the other with its plane vertical to the east-west direction. The output voltage of a loop antenna is directly proportional to the strength of the signal and to the direction of approach of the signal. A signal arriving at the loop in the same direction as the plane of the loop produces a maximum response, while the one at right angles to the plane of the loop produces no response. If two loops are mounted so that one has its plane vertical in the north-south direction and the other has its plane vertical in the east-west direction, the signals arriving along the ground will produce voltages in each loop whose value is determined by the azimuth angle of the source of the signal. The output voltage of each loop is coupled to identical but separate amplifiers. These high-gain amplifiers are designed to pro-

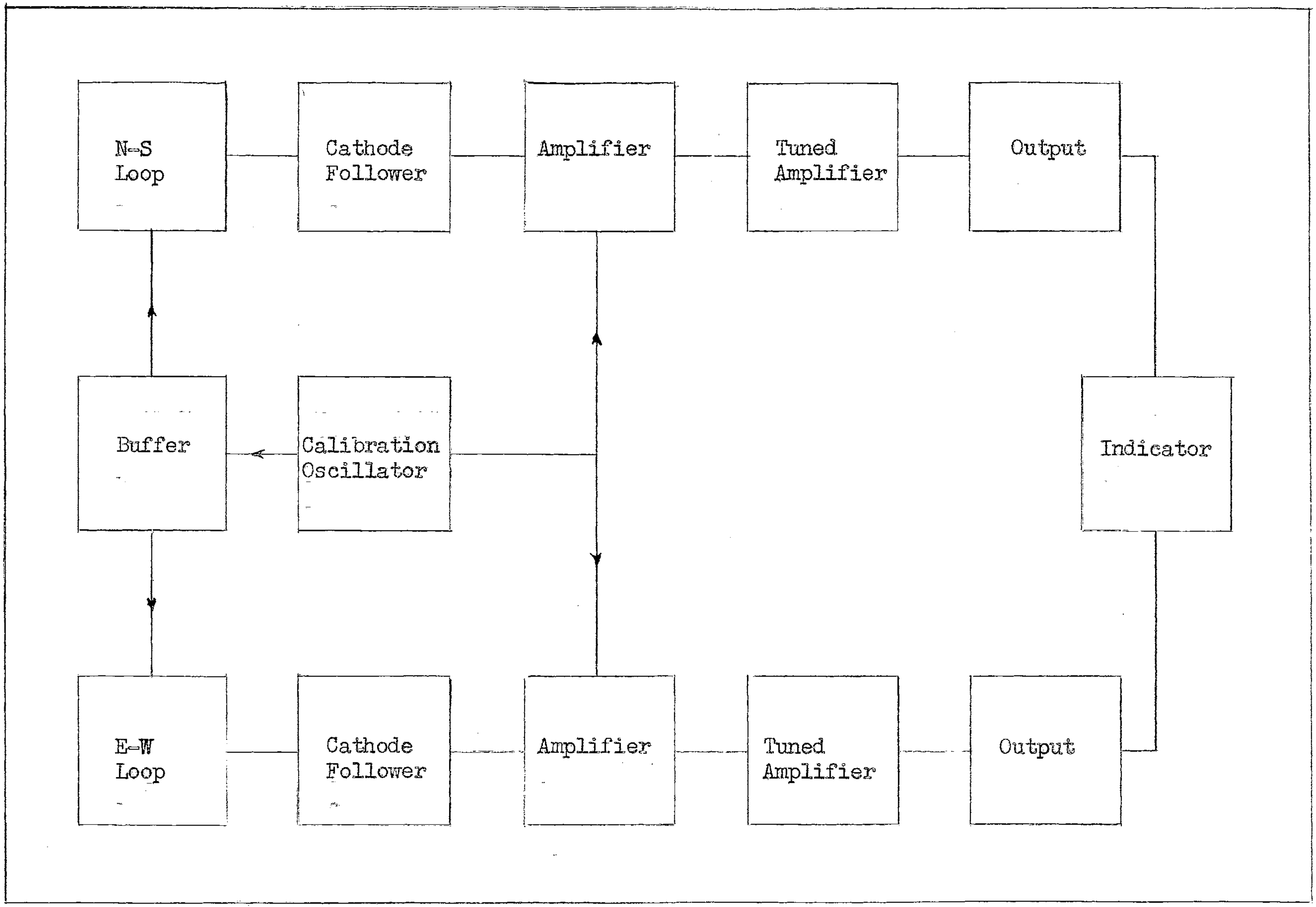

Figure 12. Sferic Direction Finder Block Diagram.

duce identical output voltages. The output voltages of the amplifiers are coupled to the deflection plates of the cathode-ray tube.

The antenna system of the AN/GRD-1A consists of two loops, each consisting of two 200-turn coils of wire. The overall dimensions of the loop antenna are 54 inches in height and 50 inches in length.

With the exception of the loop antennas, the entire sferic direction finder is built in one compact unit as shown in Figure 13. The unit at the bottom of the cabinet is the rectifier-oscillator unit. The calibration oscillator is continuously variable from 3.6 kcps to 17.5 kcps. Power for the entire system is provided by the rectifier section.

The center section of the equipment contains the amplifiers for the system with the associated amplifer controls mounted on the front panel. The amplifiers have been designed to have identical amplification characteristics, thus producing output voltages that are identical both in relative magnitude and phase. Because of manufacturing tolerances in the construction of electrical parts, variable circuit components are included at various points so that the amplification characteristics of each amplifier can be synchronized with the other.

Sferic direction is indicated by the cathode ray tube at the top of the unit. The indicator section includes the intensity, focus, and centering controls.

<u>Ambiguity Eliminator</u>

A serious limitation is imposed upon the crossed loop direction finder system by the possibility of a 180 degree ambiguity

Figure 13. Front view of the sferic direction finder and ambiguity eliminator.

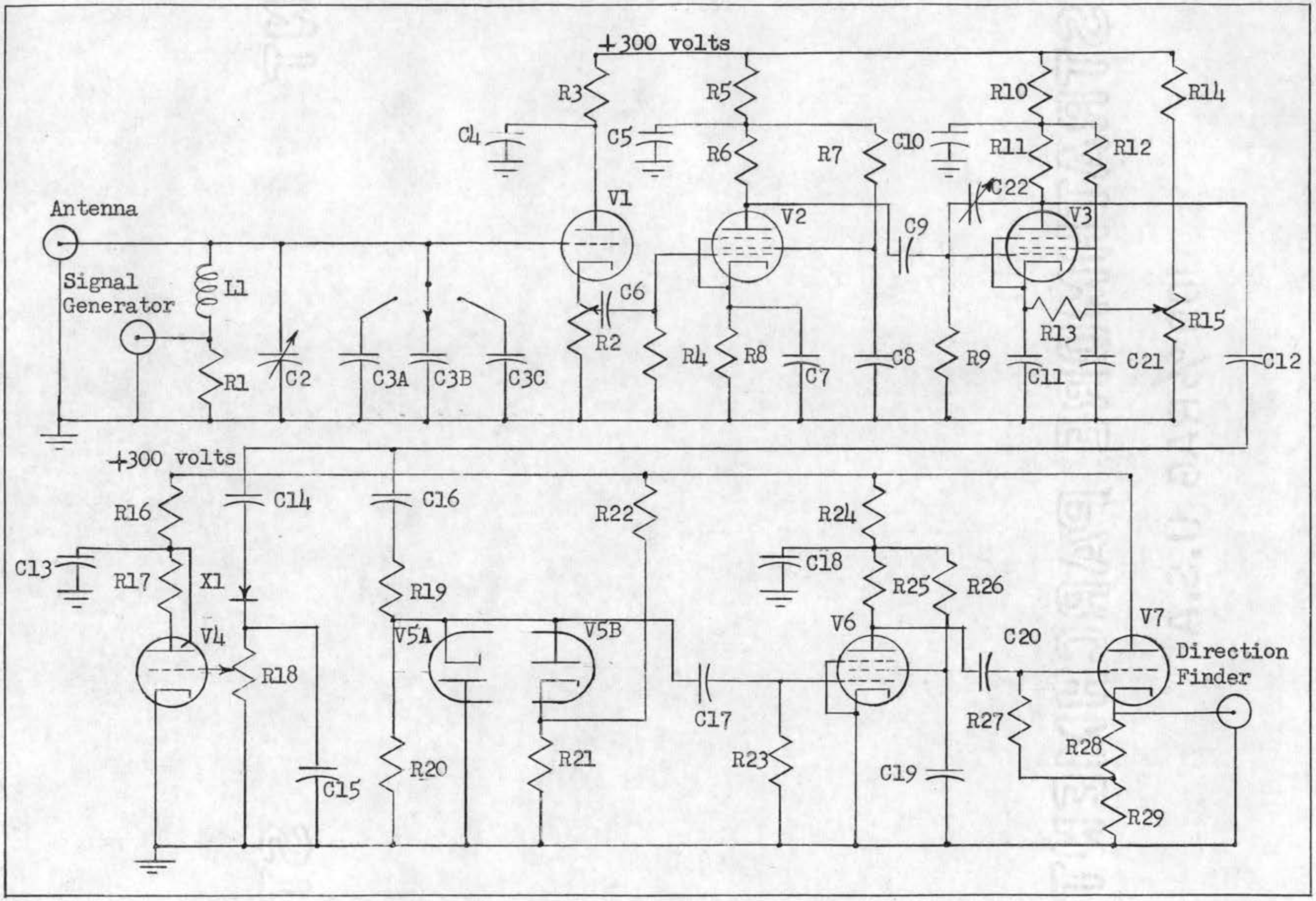

Figure 14. Ambiguity Eliminator Circuit.

error. The ambiguity eliminator, R-333/GRD-1A, was developed to nullify these false indications of direction. This unit is placed on top of the direction finder as shown in Figure 13. Suitable cables are connected to the calibration oscillator and the direction finder cathode ray grid circuit.

The ambiguity is due to the characteristics of the loop antennas. It is obvious that the side of the antenna which is first encountered by the field of the wave will experience the initial induced voltage. This voltage will be in the direction of the vector component, $\overline{E}$, of the incident wave. The voltage of this half of the antenna will predominate as long as the wave front continues to increase. When the wave ceases to increase, both halves of the antenna will have the same induced voltage and they will exactly cancel each other. As the field decreases, even with the same polarity as before, the output voltage is reversed because the opposite section of the antenna now has the maximum induced voltage. As a result of this action it follows that an all-positive wave can give both a positive and a negative indication on the cathode ray screen. By reversing the direction of incidence the reverse indication would appear on the indicator screen.

The ambiguity is removed by differentiating the signal from a vertical whip antenna and using the differentiated signal to intensity modulate the cathode ray tube. The ambiguity eliminator amplifiers must have the same phase shift characteristics as the amplifiers in the direction finder. If the input field is such a polarity as to give a correct direction, the signal will appear on the cathode ray screen. When the polarity is reversed, the ambiguity eliminator applies a negative gate to the cathode ray tube grid to eliminate the ambiguous indication.

The ambiguity eliminator is aligned by applying a signal voltage from the direction finder calibration oscillator to the input circuit. Either of three frequencies may be used, 8 kcps, 9 kcps, or 10 kcps. The fine tuning control, C2, is used to resonate the input circuit; the resonant condition is indicated by minimum shadow on the tuning eye tube, V4. The phasing control, C10, is used to compensate for the difference in the phase shift between the ambiguity eliminator amplifier and the amplifiers of the sferic direction finder.

Alignment Procedure

When the signals from the loops are not amplified indentical distortion, the sharp line of direction becomes poorly defined and assumes the shape of an ellipse. It thus becomes very difficult to determine the direction that the pattern is supposed to represent and for this reason the equipment must be tuned with great care. Since the action of the ambiguity eliminator is so closely integrated with the function of the direction finder, it is necessary to include the alignment procedure for this instrument with the instructions for tuning the direction finder. The step by step procedure is as follows.

1. Turn the power switches of the calibration oscillator, indicator, and amplifier to the "On" position.
2. To align the amplifier output transformers, turn the Operate-Sync-Parallel switch to "Operate." Set the frequency of the calibration oscillator to 10 kcps.

Rotate the alignment switch to position "5" and adjust the transformer phasing control on the left of the front panel until a maximum vertical trace is obtained. Place the alignment switch in position "7" and the Operate-Sync-Parallel switch to the "Parallel" position and adjust the transformer phasing control on the right of the front panel until all indications of ellipticity are removed from the trace.

3. Return the Operate-Sync-Parallel switch to the "Operate" position and with both amplifier gain controls set at position "5", place the alignment switch on position "6" and adjust the horizontal amplifier tuning control to produce a horizontal line of maximum length on the screen. Repeat the procedure for alignment position "5" and the vertical amplifier tuning control.

4. By turning the alignment switch to position "7", the oscillator signal will be applied to both amplifiers similtaneously. The resultant trace should be a straight line at a 45 degree angle. If the trace is not at a 45 degree angle, adjust either amplifier gain control until this is the case. By "rocking" the calibrating oscillator frequency through 10 kcps and observing the trace, indications of misalignment may be seen. If the trace becomes elliptical, correction may be made by either the phasing control or the amplifier tuning control. The tuning controls should be adjusted first. Faulty tuning may be determined by noting the change of

slope of the trace as the frequency of the calibration oscillator is varied. Should the angle of the trace go both above and below the 45 degree position, adjust either amplifier tuning control until the trace remains fixed. With one of the phasing controls set at zero, adjust the other until all ellipticity disappears.

5. If the trace on the screen of the cathode-ray tube is a straight line when the amplifiers are at resonance with the frequency of the calibration oscillator, but becomes elliptical at frequencies well off resonance, and if the slope deviates in only one direction from 45 degrees on either side of resonance, it is an indication that the Q's of the tuned circuits in the amplifiers are not identical. The Q controls should be adjusted with one control rotated fully counterclockwise while the adjustment is made with the other. While continuously varying the calibrating oscillator frequency, the Q should be adjusted until the trace does not deviate from the straight line at 45 degrees.

6. The next step is to align the loop circuits. With the alignment switch at position "4" and the calibration oscillator frequency tuned to 10 kcps, the horizontal loop coupling is adjusted until the maximum length of the horizontal trace is obtained on the cathode ray tube. The loop Q's are adjusted as instructed in step five. Using position "3" of the alignment switch, repeat the procedure for the vertical loop. If the vertical trace

is not the same length as the horizontal trace, adjust with the amplifier gain controls.

7. With the alignment switch in position "1" or "2", a straight line trace at 45 degrees should be obtained on the cathode ray screen. Switch back and forth between positions "1" and "2". The patterns should be identical in shape and position. If the two traces do not coincide, adjust the loop coupling controls. If the trace is elliptical, adjust the loop tuning controls until the ellipse disappears and does not reappear when the calibration oscillator frequency is varied. If the trace is not at 45 degrees as indicated on the cathode ray tube, adjust the amplifier gain controls.

8. After the preceding steps have been completed, the ambiguity eliminator can be aligned. With the power switch turned to the "On" position and the attenuator switch on position "8", turn the frequency selector switch to 9 kcps. Rotate the calibration oscillator tuning control to the left and right of the frequency selected on the ambiguity eliminator. When the tuned section of the ambiguity eliminator is properly adjusted, the indicator eye will close. If the eye does not close completely, adjust the calibration oscillator attenuator for a closed position. The fine tuning control can now be used for the final closure of the indicator eye. <u>The oscillator tuning control should not be rotated during</u>

<u>the remainder of the alignment of the direction finder.</u>

9. Detune the horizontal loop tuning until a slight semi-ellipse appears on the cathode ray tube screen. If the ends of the elliptical trace are not even, adjust the phasing control on the ambiguity eliminator until the ends match. Readjust the horizontal loop tuning control until a straight line appears on the screen of the cathode ray tube.

10. Turn the power switch of the calibration oscillator to the "Off" position. The intensity control sould be adjusted until the spot in the center of the cathode ray screen is just extinguished. With the alignment switch on position "2" the intensity control can be adjusted for the desired brilliance of the traces.

11. If the sensitivity of the direction finder is not satisfactory, turn on the calibration oscillator and turn the alignment switch to position "7". The gain controls can be adjusted to the desired value of sensitivity while the trace is maintained at a 45 degree angle. The final adjustment can be checked by switching the alignment switch back and between positions "1" and "2". The lines should coincide. The procedure of step ten should now be followed.

When the alignment switch is on position "2", the azimuth calibration is east, south, west, and north, starting at the top of the indicator screen and tracing clockwise.

CHAPTER V

CONCLUSIONS

As the research in tornado identification and tracking progresses, there will be a need for new equipment and modifications of the equipment discussed in this paper. In general the sferic waveform recording equipment is operating satisfactorily. Two successive frames of a low intensity sferic waveform are shown in Figure 16.

The high intensity sferic waveforms pictured in Figure 15 show a double trace for each frame. This is due to the high intensity waveform coupling through the plate circuits of the Eccles-Jordan circuit to the synchronization voltage amplifier. This triggered the sweep before the film had advanced. Tests on the trigger circuit show that a positive pulse of 12 to 50 volts from the trigger forming circuit will trigger the Eccles-Jordan circuit, and that pulses of 25 volts from the trigger forming circuit can trigger the sweep by coupling through the Eccles-Jordan plate circuits. These tests indicate that a positive limiter should be incorporated into the trigger forming circuits to eliminate this double trace. The trigger forming circuit gain control could be used to reduce the occurrence of the double trace, but in reducing the sensitivity of these circuits the possibility of not recording all the high frequency sferics would be greatly increased.

The sferic direction finder has been tested thoroughly during the past seven months, and its operation has been completely satisfactory. A remote direction indicator is installed in the sferic waveform recording light box. This new installation has not been completely tested.

Figure 15. High Intensity Sferic Waveform.

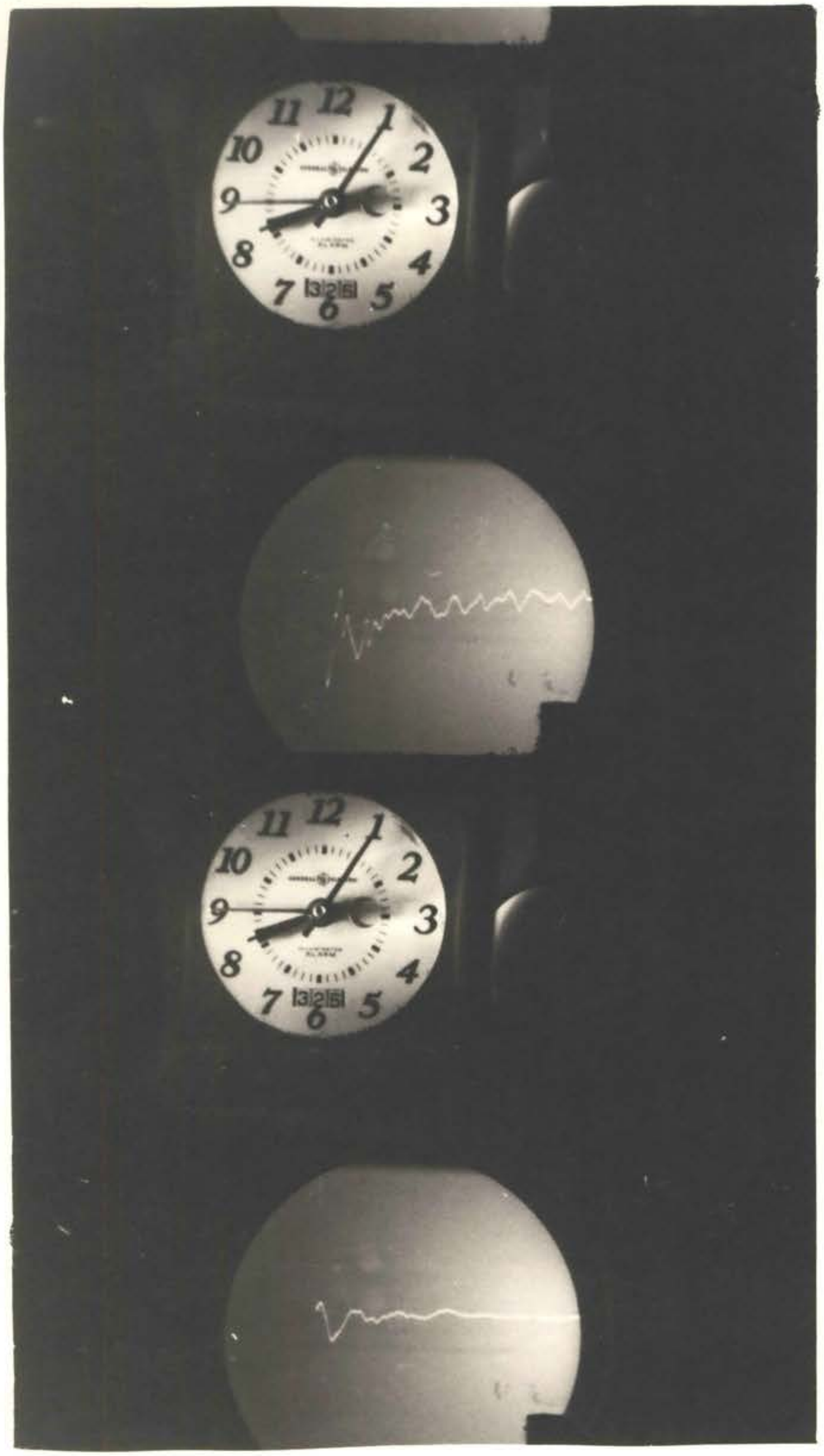

Figure 16. Low Intensity Sferic Waveform.

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APPENDIX

List of Circuit Components

Antenna Cathode Follower

R1	Resistor	20 Meg
R2	"	2 K
R3	"	1 K
R4	"	2 K
R5	"	1 K
R6	"	2 K
R7	"	1 K
R8	"	1 K
R9	"	1 Meg
R10	"	200
R11	"	300
R12	"	200
R13	"	1 Meg
C1	Condenser	.1 uf
C2	"	25 uf
C3	"	.1 uf
C4	"	25 uf
C5	"	150 uf
V1	Vacuum Tube	6AK5
V2	" "	6AK5
V3	" "	6AK5

Video Amplifier

R1	Resistor	3 K
R2	"	50
R3	"	200
R4	"	85 K
R5	"	.5 Meg
R6	"	2 K
C1	Condenser	25 uf
C2	"	.05 uf
C3	"	.005 uf
C4	"	.01 uf
L1	Choke	100 uh
V1	Vacuum Tube	6AG5
V2	" "	6AG5

Trigger Forming Circuit

R1	Resistor	20 K
R2	"	100 K
R3	"	300
R4	"	50 K
R5	"	15 K
R6	"	.5 Meg

R7	Resistor	50 K
R8	"	50 K
R9	"	120 K
R10	"	20 K
R11	"	.1 Meg
R12	"	.5 Meg
R13	"	1 Meg
R14	"	20 K
R15	"	50 K
R16	"	20 K
R17	"	100
R18	"	15 K
R19	"	.5 Meg
R20	"	300
R21	"	50 K
R22	"	15 K
R23	"	600
C1	Condenser	.05 uf
C2	"	25 uf
C3	"	.02 uf
C4	"	.02 uf
C5	"	.02 uf
C6	"	.1 uf
C7	"	25 uf
C8	"	.5 uf
V1	Vacuum Tube	6AG5
V2	" "	6J6
V3	" "	6AL5
V4	" "	6AG5
V5	" "	6AK5
V6	" "	6AL5

Trigger Circuit

R1	Resistor	100 K
R2	"	20 K
R3	"	20 K
R4	"	.5 Meg
R5	"	.5 Meg
R6	"	7.5 K
R7	"	20 K
R8	"	100 K
R9	"	5 Meg
R10	"	1 Meg
R11	"	2.5 K
R12	"	20 K
R13	"	1 Meg
R14	"	20 K
R15	"	250 K
R16	"	20 K
R17	"	20 K
R18	"	20 K
C1	Condenser	.1 uf

C2	Condenser	.1 uf
V1	Vacuum Tube	6J6
V2	" "	6J6
V3	" "	6SN7

Synchronization Voltage Amplifier

R1	Resistor	1 Meg
R2	"	200
R3	"	10 K
R4	"	20 K
R5	"	3.5 K
R6	"	10 K
R7	"	150 K
R8	"	20 K
R9	"	50 K
C1	Condenser	.1 uf
C2	"	.02 uf
C3	"	.02 uf
V1	Vacuum Tube	6AG5
V2	" "	6AG5

Ambiguity Eliminator

R1	Resistor	10
R2	"	5 K
R3	"	4.7 K
R4	"	100 K
R5	"	4.7 K
R6	"	22 K
R7	"	75 K
R8	"	300
R9	"	100 K
R10	"	4.7 K
R11	"	22 K
R12	"	75 K
R13	"	300
R14	"	220 K
R15	"	250 K
R16	"	15 K
R17	"	1 Meg
R18	"	1 Meg
R19	"	47 K
R20	"	240 K
R21	"	15 K
R22	"	47 K
R23	"	100 K
R25	"	22 K
R26	"	56 K
R27	"	47 K
R28	"	820
R29	"	6.8 K
C1	Condenser	.1 uf

C2	Condenser	210 uuf
C3A	"	2550 uuf
C3B	"	1350 uuf
C3C	"	750 uuf
C4	"	.25 uf
C5	"	2 uf
C6	"	.01 uf
C7	"	.25 uf
C8	"	.25 uf
C9	"	.01 uf
C10	"	.5 uf
C11	"	.25 uf
C12	"	.01 uf
C13	"	.25 uf
C14	"	.001 uf
C15	"	.001 uf
C16	"	.01 uf
C17	"	.1 uf
C18	"	.5 uf
C19	"	.5 uf
C20	"	.1 uf
C21	"	.25 uf
C22	"	4.0-23 uuf
L1	Choke	90 mh
V1	Vacuum Tube	6C4
V2	" "	6AG5
V3	" "	6BA6
V4	" "	6E5
V5	" "	6AL5
V6	" "	6AG5
V7	" "	6C4
X1	Crystal	1N43

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