INSTALLATION AND OPERATION OF ELECTRONIC SFERIC DETECTION EQUIPMENT

By

PHILIP N. HESS

Bachelor of Science

North Dakota Agricultural College

Fargo, North Dakota

1949

Submitted to the Faculty of the Graduate School of
the Oklahoma Agricultural and Mechanical College
in Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

1950

INSTALLATION AND OPERATION OF ELECTRONIC

SFERIC DETECTION EQUIPMENT

PHILIP N. HESS

MASTER OF SCIENCE

1950

THESIS AND ABSTRACT APPROVED:

Herbert L. Jones
Thesis Adviser

A. Naeter
Faculty Representative

D. C. McIntosh
Dean of the Graduate School

PREFACE

Tornadoes have long been the scourge of the people in this area. For several months of the year these sudden and devastating storms are a constant threat. Tornado identification and tracking research, under the direction of Dr. Herbert L. Jones, has been in progress at the Oklahoma Institute of Technology for the past two years. Electronic equipment has been proposed to detect and locate tornadoes by means of their sferic waveforms. This thesis describes the completion, installation, testing and operation of this equipment.

ACKNOWLEDGMENT

The author wishes to express his sincere appreciation for the many suggestions and the help offered by the Oklahoma Institute of Technology staff. He is greatly indebted to Dr. Herbert L. Jones, under whose supervision this study was carried out. Special thanks are due the Research and Development Laboratory for the sferic camera modification and the construction of the light box.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF ILLUSTRATIONS

CHAPTER I

INTRODUCTION

Previous research conducted at the Oklahoma Institute of Technology has indicated the possibility that the atmospherics[1] associated with tornadoes have distinctive characteristics by which they may be identified.[2]

Electronic equipment has been developed to aid in the study of these sferics.[3,4] This equipment is designed to detect and record all pertinent characteristics of the sferic including the wave shape of the sferic itself referred to a time axis, the direction from which it arrives, and the time at which it arrives. Provision has been made to permanently record all these data on photographic film for all received sferics.

Detection Device

The detection device, developed by Mr. Harold O. Jeske, consists of a short vertical whip antenna coupled through a cathode follower to an untuned amplifier having a frequency

---

1 The term "sferic" will hereafter be applied to atmospheric electromagnetic waves originated by weather phenomena.

2 Hutchison, J. S., A Study of Tornado Identification, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1949.

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

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

response from 20 cps to 200,000 cps. The cathode follower is designed with a very high input impedance to match the high impedance of the short antenna. This impedance match is necessary to prevent attenuation and phase shift at the lower frequencies. Since it is not practical to construct an input stage with high enough impedance to result in a flat frequency response down to 20 cps, an inverse feedback compensating amplifier was included in the design. It is the purpose of this equipment to detect and amplify the electro-magnetic radiation from the lightning stroke.

The Recording Equipment

For a permanent record it was deemed advisable to use a visual indication of all received data. To achieve this, the received signal is applied to the Y-input of a cathode ray oscilloscope. The resulting trace is then photographed. In order to make this process automatic and rapid, a camera without a shutter was developed by the Research and Development Laboratory of the Institute of Technology. This camera is controlled by a solenoid which is actuated by a triggering pulse. This triggering pulse is in turn initiated by the received sferic. The triggering circuit involved also triggers the sweep of the oscilloscope into activity so that a trace of the sferic appears on the cathode ray tube, from which it is recorded on the frame of film waiting in the camera. The device then operates to advance the film one frame. During the time that the camera is advancing the film no received sferic can be seen on the oscilloscope, thus limiting the equipment to one picture per frame of film. This feature, coupled with a bias control that will allow the trigger to operate only when a relatively high intensity sferic is received, serves to conserve film. Provision has also been made to control a strob light from this trigger to illuminate the clock and date device. The direction finder cathode ray tube is also gated from this trigger circuit.

Direction Finding Equipment

Since the duration of sferics is relatively short (4-8 milliseconds), direction finding is complicated by the fact that the indication of direction must be presented instantaneously or very nearly so. This fact eliminates a rotating antenna system.

The equipment designed and constructed by Mr. Thomason consists of two directional loop antennas placed with their axis at right angles to each other. The outputs of the loop antennae are fed to two similar amplifiers. These amplifiers must be exactly the same in gain and phase shift since the relative amplitudes of the received signals on the loop antennae provides the indication of direction. The outputs of these amplifiers are fed to the deflection plates of a cathode ray tube. The loop antenna whose position will allow it to receive a maximum signal from north and south has its output coupled to the vertical deflecting plates. The east and west loop output is applied to the horizontal deflecting plates. Each amplifier also includes an LC tank circuit the output of which is a sine wave of an amplitude that is dependent upon the amplitude of the received signal. The purpose of this circuit is to apply a sine wave to the respective deflecting plates that will result in a smooth and stable trace.

Since the electron beam in the cathode ray tube is deflected by a voltage applied to the deflection plates, it is logical to suppose that the direction of deflection will be a function of the relative voltage amplitudes applied to these plates. This is quite correct as shown mathematically in Mr. Thomason's Thesis and the final result will be a trace on the cathode ray tube that will indicate the direction of the sferic.

Unfortunately loop antennae are bi-directional and, as a result, the direction indication on the scope is also bi-directional. This is not the handicap it seems, since the approximate position of conditions favorable to the formation of tornadoes will be known from weather bureau information.

Correlation of Existing Equipment

The equipment described in the preceding discussion has been constructed. The individual components have been tested in the laboratory but have not been assembled into the final, complete apparatus. They have not been tested under field conditions or on actual sferics.

It is, therefore, the purpose of the project covered in this thesis to complete the apparatus, assemble and test it, and to operate it under actual conditions. This thesis will attempt to confirm the original theory that tornado sferics have identifying characteristics. In this thesis an attempt will be made to indicate and solve some of the problems that will undoubtedly arise and to point out the direction for future research on these problems. The general topic is a problem that is of vital interest to the people of this area, where unannounced tornadoes have taken a heavy toll of life and property for many years.

CHAPTER II

ELECTRO-MAGNETIC RADIATION FROM LIGHTNING STROKES

Nature of Radiation from Lightning Discharges

Most observers agree that the great majority of lightning accompaning tornado cloud formations extends from the bottom of the cloud to the ground. The lightning strokes practically surround the funnel. However, it has been noted that the greatest number of strokes occur ahead of the direction of storm movement. Since the lightning extends from cloud to ground, the radiation of electro-magnetic energy from it is similar to that from a vertical, grounded antenna.

The detection equipment that has been developed covers the frequency range from 20 cps to 200,000 cps. At these frequencies the radiation from a vertical grounded antenna consists of a sky wave and a ground wave. Within a radius of approximately 200 miles, the great percentage of received energy travels by way of the ground wave.[1] The sky wave is reflected back to earth after only a very slight penetration of the ionosphere and with very little absorption. The reflected angle is very small and as a result very little energy reaches the ground close to the transmitting antenna. No direct wave will be transmitted from this type of antenna because of its ground termination. In other words, the ground wave and the direct wave will be coincident.

---

[1] The ground wave is considered to be that part of the radiated energy that is affected by the ground. It would account for all the received energy it if were not for the sky wave and direct wave.

The ground wave from a vertical grounded antenna is vertically polarized. This is true since any horizontal component of the electric field would be short-circuited by the conducting ground. It is of interest to note that the wave front of a vertically polarized ground wave is tilted forward in the direction of propagation. This is caused by a downward component of energy flow that is necessary to supply the losses in the ground over which the wave is being propagated. Since the ground has finite conductivity there will be a Poynting vector flow of energy into the ground at each point of the path.

Determination of Received Field Strength of Ground Wave - Sommerfeld Analysis

Since the intensity of the received tornado sferic may be one of the identifying characteristics, some indication of how the received field strength varies with distance is necessary. As already pointed out, the signal received is the ground wave of the radiated energy of the lightning discharge. A solution to this problem was first given by Sommerfeld,[1] and is included in the following analysis. The only assumption made is that the earth is considered to be flat over the range desired. An empirical formula[2] that limits this assumption is also included. For the frequency range of the sferic detection equipment

$$E_r = A \frac{El}{d}$$

---

[1] Terman, Frederick E., Radio Engineering, pp. 610-614.

[2] *Ibid.*, p. 613.

Where: E_r = Ground wave received field strength

A = Ground loss factor

E_1 = Field strength at unit distance from transmitting antenna

d = Distance from receiver to transmitter

$$R = \frac{50}{(f_{mc})^{1/3}}$$

Where: R = Flat earth range in miles

f_{mc} = Frequency in megacycles

At 20 cps this range becomes 1080 miles. At the higher frequency limit of 200,000 cps this range reduces to 231 miles. Since the usable range of the gear has been set at 200 miles, Sommerfeld's analysis will necessarily be accurate.

The factor A in Sommerfeld's equation defines ground attenuation and depends upon the conductivity and dielectric constant of the earth over which the wave is being propagated. The mathematical relationships between these constants can best be expressed by allowing A to become a function of two variables, which will be designated as P and B. P is related to the numerical distance while B is related to the phase constant of propagation. Both P and B are interrelated and their expressions contain empiricle constants.

The mathematical expressions for P and B for vertically polarized waves is as follows:

$$P = \frac{\pi d}{XL} \cos B \qquad B = \tan^{-1} \frac{e + 1}{X}$$

Where: $\frac{d}{L}$ = distance in wave-lengths

$$X = \frac{1.7973 \cdot 10^{15}\ s}{f_{mc}}$$

s = earth conductivity in emu

e = earth dielectric constant, with air as unity

The conductivity and dielectric constant of the earth vary according to locale and season. As a consequence, an average must be taken. For the type of soil found in this section of Oklahoma, the average conductivity is 3×10^{-14} emu while the average dielectric constant is approximately 11.[3]

Because the sferic receiving equipment is an untuned device, and also since both P and B in the preceding expressions are functions of frequency, it is necessary to calculate the received field strength at both the upper and lower frequency limits of the equipment. It is also desirable to calculate the strength at various distances from the lightning stroke. The empiracle formula relating P and B to the ground loss constant A is taken as[4]

$$A = \frac{2 + .3P}{2 + P + .6P^2} - \sqrt{\frac{P}{2}}\ e^{-\frac{5}{8}P} \ \sin B$$

Figure 2-1 is a plot of ground loss factor A versus distance from the radiating element.

---

[3] Standards of Good Engineering Practise Concerning Standard Broadcast Stations, Federal Register, (8 July, 1939), p. 2862.

[4] Terman, Fredrick E., Radio Engineering Handbook, p. 677.

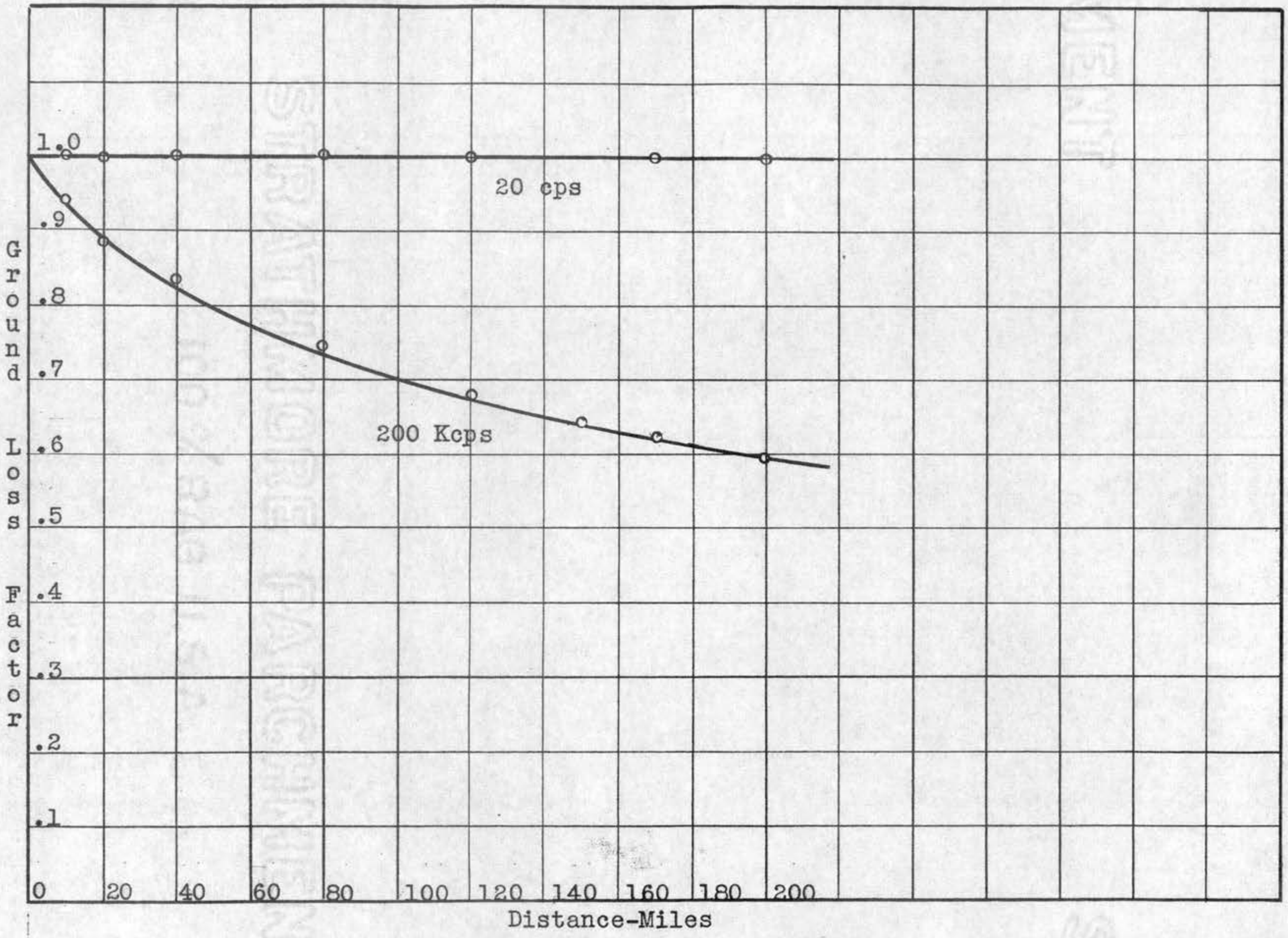


Figure 2-1 Ground Loss vs. Distance

Several conclusions can be drawn from this analysis. Much study and time was devoted to the development of an amplifier that would accurately reproduce all signals impinging on the antenna over the complete frequency range of the equipment. This was done to assure a true reproduction of the sferic waveform on the recording oscilloscope. Because of the varying rates of attenuation of the different frequency components of the sferic as it travels outward from the lightning stroke, the waveform of the sferic as it reaches the antenna will not be an accurate reproduction of the current flow or potential gradient existing in the lightning stroke. Hence the compensation amplifiers are not necessary. This is not a serious matter, since the project is interested in the relative difference in lightnings and all kinds will be subject to this frequency distortion.

It was hoped that the relative amplitude of the tornado sferic would be an identifying characteristic. Unfortunately, unless the exact difference in amplitude is known, and the exact distance to the storm noted, this method of identification is impossible. This is true because, as shown in the preceding analysis, the sferic amplitude is inversely proportional to the first power of the distance at the lower frequency limit and approximately inversely proportional to the second power of the distance at the upper frequency limit. Thus, it would be difficult to differentiate between a distant tornado and a close thunderstorm.

More will be said about the above conclusions in a later chapter.

CHAPTER III

COMPLETION OF SFERIC DETECTION AND RECORDING EQUIPMENT

In order to correctly actuate the chain of events necessary to detect and record sferic data, it was necessary to make some changes in the existing equipment. In addition to these changes it was also necessary to construct the inter-connecting cables and junction boxes. Although the details of these inter-connecting cables is of a trivial nature, and although their construction was routine, both the construction details and the cabling diagram will be included in this chapter for the convenience of those who will continue the sferic research.

Sferic Detection Equipment Modification

The sferic detection equipment as originally designed consisted of a vertical whip antenna, an antenna cathode follower and a series of compensation amplifiers.[1] It was the purpose of the cathode follower to match the high impedance of the relatively short antenna, while the compensation amplifiers were used to obtain a flat response to the signals on the antenna within the frequency limits of the equipment. It was the purpose of these amplifiers to accurately reproduce the waveform of the signal on the antenna at their respective outputs.

As pointed out in the preceding chapter, the radiation of electro-magnetic energy from a lightning discharge will have its

---

[1] Jeske, loc. cit.

various frequency components attenuated at different rates as it travels outward from the source. Thus, the waveform of the sferic when it reaches the receiving antenna will not be the true waveform of the radiation from the lightning stroke. For this reason it was not deemed necessary to use the compensation amplifiers. It was decided to replace the compensation amplifiers with a single-stage video amplifier. This amplifier would be free from the spurious oscillations which were encountered in the compensation amplifiers, it would have higher gain and would have a frequency response to several megacycles. It was believed that this type of amplifier would result in greater energy pick-up from the lightning stroke because of its wider frequency response and that for this reason would give a more complete picture of the sferic.

Since the sferic research project is primarily concerned with the <u>difference</u> in waveforms of ordinary lightning and lightning emanating from tornado clouds, the distortion due to ground attenuation and the distortion introduced by uncompensated amplifiers will make little or no difference.

Design of the Video Amplifier

The video amplifier decided upon was of the conventional shunt-compensated type. In this type of compensation, the shunting effect of stray capacitance together with tube capacitance is cancelled by an inductance placed in series with the plate load resistance. This topic will not be covered in this exposition because the design equations of such an amplifier are simple and well known.[2] It is felt that a compilation of the operating constants will be sufficient. The amplifier was designed to have a linear frequency response for a band of 50 to 2,500,000 cps, and a calculated gain at mid-band of 15.

Also included in the amplifier design was a coupling cathode-follower. This unit was incorporated in the design to match the impedance of the coaxial cable used to transmit the signal from the amplifier to the oscilloscope and trigger circuit, and to provide a volume control independent of the video amplifier. The schematic diagram of the video amplifier and cathode follower is shown in Figure 3-1 while the response curve of the unit is shown in Figure 3-2.

Trigger Circuit Modification

As originally designed, the trigger circuit consisted of an R-C coupled phase-inverter, a rectifier, two stages of R-C coupled amplification, a multivibrator and a relay tube.[3] The phase inverter was incorporated in the design because it was not known what the polarity of the arriving sferic would be and it was desired that the trigger circuit operate on either a positive or a negative signal. The rectifier unit was used to produce a pulse of constant polarity, regardless of the polarity of the entering signal. This rectified pulse was amplified through the

---

[2] Sarbacher, R. I. and Edson, W. A., Hyper and Ultrahigh Frequency Engineering, pp. 469-482.

[3] Jeske, loc. cit.

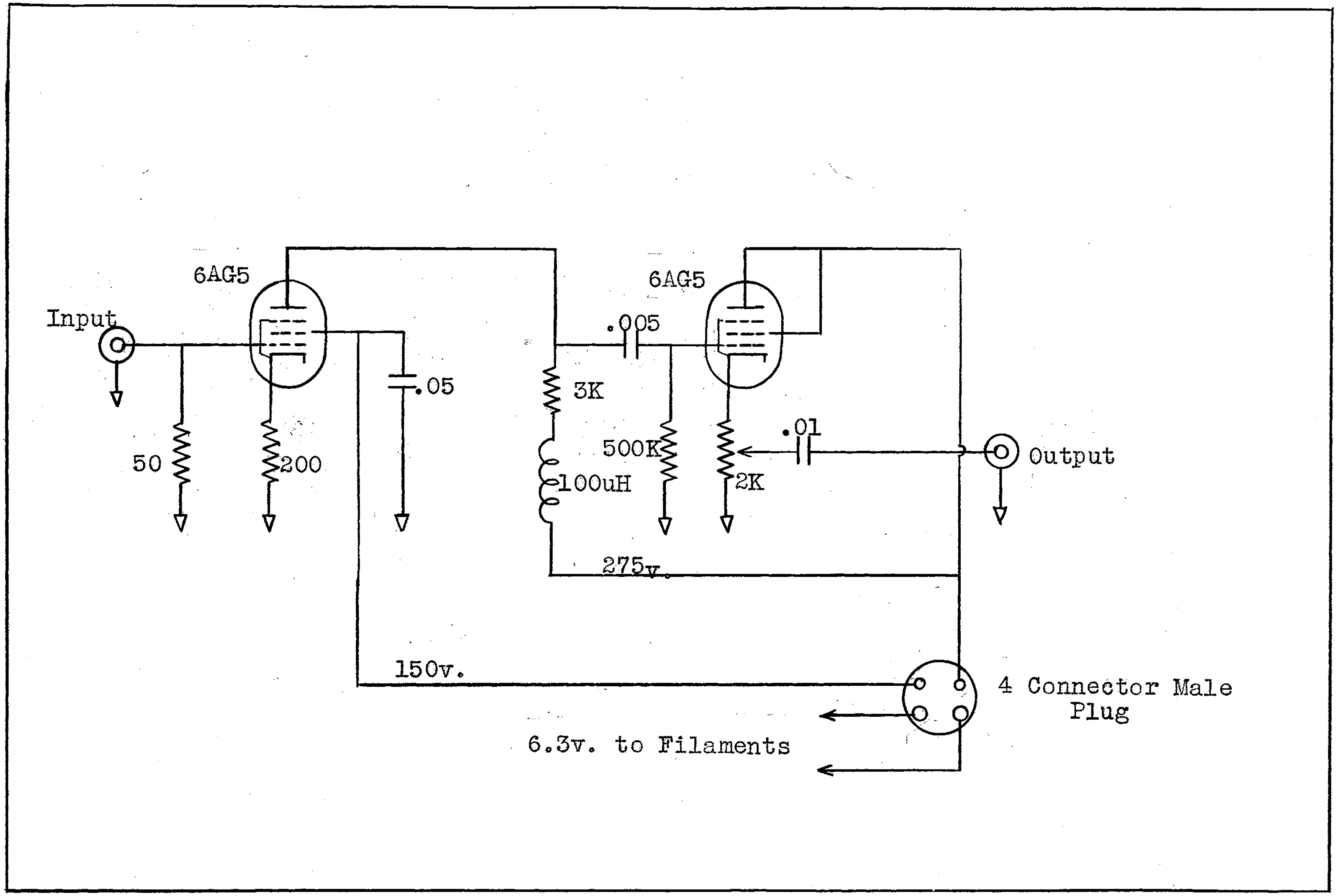


Figure 3-1 Video Amplifier

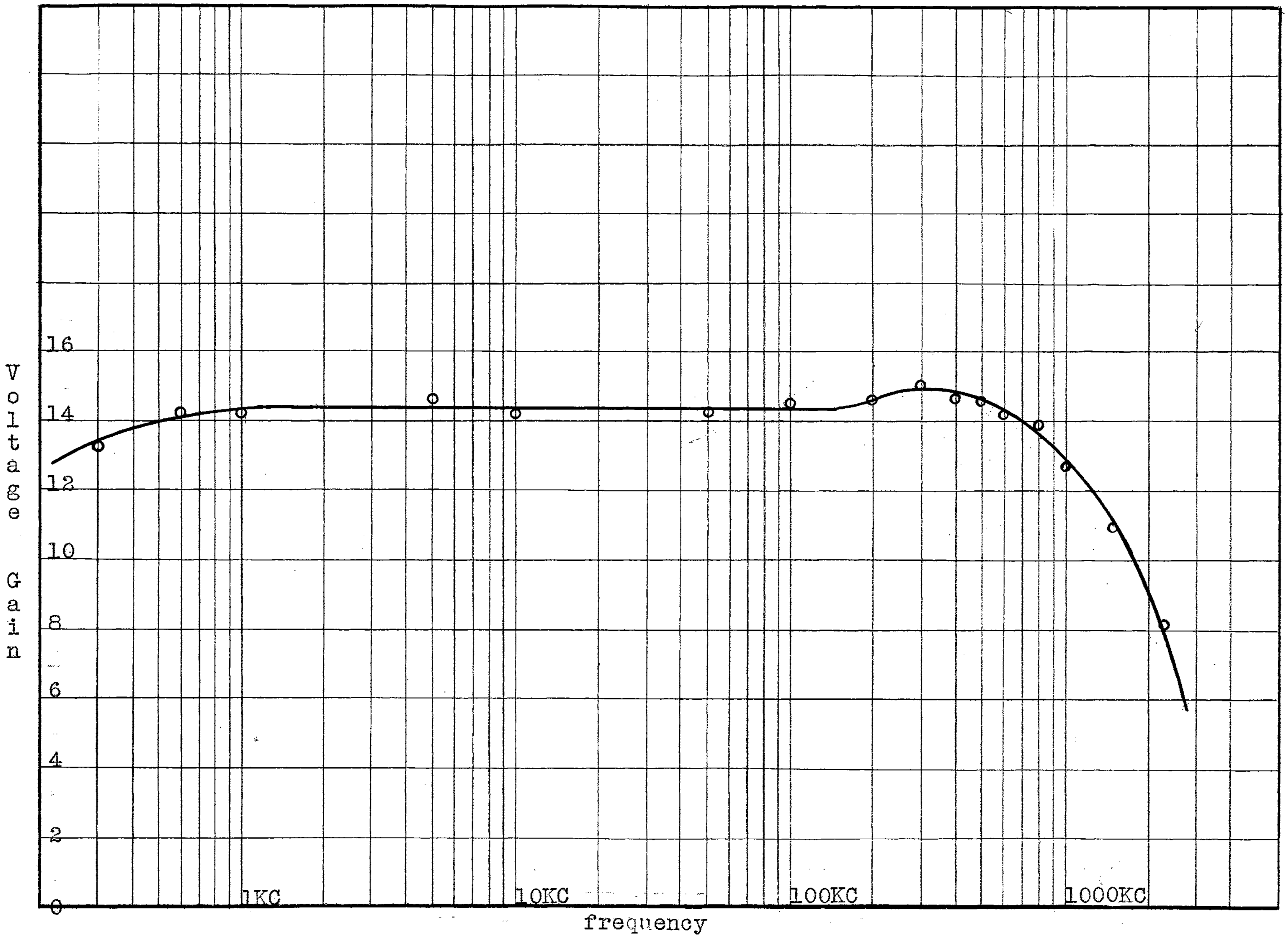


Figure 3-2 Video Amplifier Response

two stages of amplification and used to trigger a multivibrator, which in turn actuated the relay tube, operating the camera solenoid and strob light. This piece of equipment was designed and built before the camera and light box had been completed and tested by the Research and Development Laboratory. As a result, no data as to relay closure time, relay holding time or strob light time was available. In addition to this, because of the many stages of R-C amplification and coupling, the trigger circuit was very susceptible to spurious oscillations. It was decided to redesign the gear to provide for sufficient relay closing time and to rid the equipment of the oscillations which made it impossible to operate. The sequence of events as outlined above were kept in the new design, but several changes in the individual circuits were incorporated in the new equipment.

Redesigned Trigger Circuit

The original trigger circuit needed a high gain because of the very low gain of the compensation amplifiers. Since the compensation amplifiers had been superceded by a higher gain video amplifier, the overall gain of the trigger circuit was greatly reduced by removing one stage of R-C coupled amplification. To further reduce the possibility of oscillation, the R-C coupled phase inverter was replaced by a transformer input push-pull amplifier which functioned in the same manner. The exclusion of one stage of amplification necessitated the inversion of the rectifier tube in order to produce a pulse of the correct polarity to trigger the multivibrator.

Tests on the completed camera revealed the fact that a reasonably long duration pulse had to be applied to the rotary solenoid to complete a full cycle and advance the film one complete frame. The multivibrator originally incorporated in the trigger circuit was found to have much too short a pulse duration to accomplish this cycle. This multivibrator was replaced by a reliable common cathode one-shot multivibrator with a pulse duration of approximately 450 msec. This was found to be sufficient to complete a full cycle under load.

The camera solenoid was carefully tested under conditions approximating actual operating conditions. This was done by applying a sharp pulse to the amplifier circuit and tracing it through the amplifier circuit and trigger circuit. It was found that under these conditions it was possible to complete a full cycle of operation in approximately 500 msec. Since incoming signals which would arrive immediately after a triggering pulse was received would interfere with the normal operation of the trigger circuit, some method of blocking the equipment during the camera solenoid cycle was necessary. It was finally decided to utilize a spare set of contacts on the relay tube plate relay to disconnect the grid of the multivibrator tube after the cycle had started. This was tried and was very successful in accomplishing the desired blocking action. In addition to the above changes, a volume control was incorporated in the design in order that the triggering pulse intensity could be controlled. This was necessary since without it, distant sferics would trigger the equipment and film would be wasted. The project is interested only in sferics which originate within a 200 mile radius of Stillwater. It is not felt that distant sferics, whether tornado sferics or ordinary thunderstorm sferics, could be differentiated. A schematic diagram of the redesigned trigger circuit appears in Figure 3-3.

The Relay Circuits

Three relays are incorporated in the sferic detection and recording equipment. Two are of the conventional direct current type, while the third is a direct current rotary solenoid which actuates the camera, advancing the film one frame each time the system is triggered by a sferic. This rotary solenoid is actuated from a relay located on the trigger circuit chassis and connected to the camera mechanism by a three conductor cable. Because of the relatively high direct current drawn by the rotary solenoid, this relay had to be equipped with heavy-duty contacts. No relay with a coil suitable for plate circuit operation and equipped with these type of contacts was available, necessitating the inclusion of a second relay to control the relay that operates the camera solenoid. This plate circuit control relay is a precision relay with a 12,000 ohm coil. It is located in the plate circuit of the relay tube in the trigger circuit. The relay is double-pole double-throw contacted. One set of contacts controls the blocking action and the strob light while the other set operates the relay that controls the camera solenoid. This system has the added advantage of delaying the camera advancement while the strob light illuminates the clock and date device and

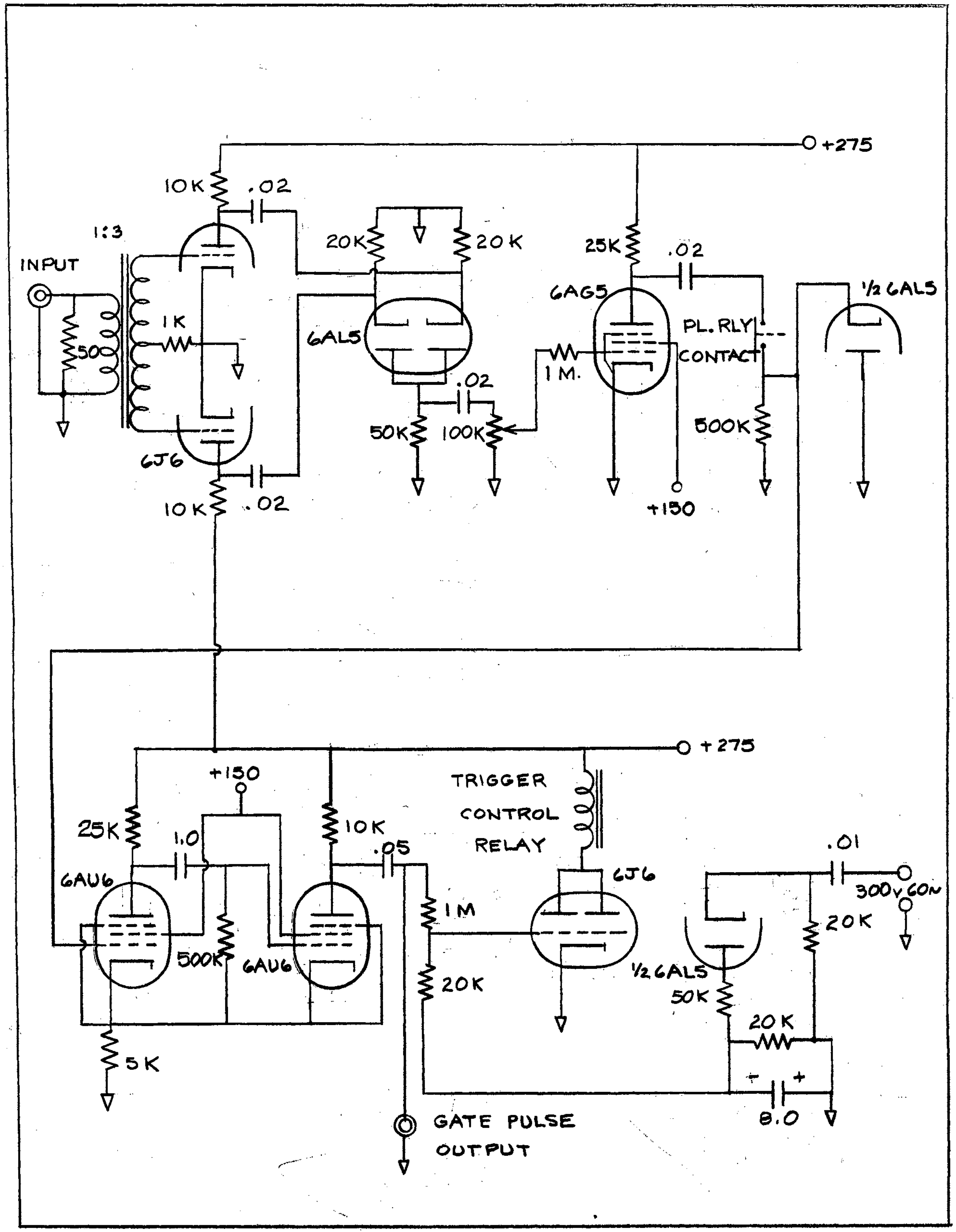


Figure 3-3 Trigger Circuit

the trace appears on the oscilloscope. This prevents blurring of the photographic record, due to film movement before the strob light flash is extinguished.

The camera rotary solenoid operates from a 110 volt direct current source. It draws approximately 2 amperes current under intermittent operation. To provide this direct current source, a bridge-type, full-wave rectifier especially designed by the makers of the rotary solenoid was purchased and installed in the trigger circuit chassis. It is of the selenium type and also provides power for the strob light and the heavy-duty solenoid control relay. A schematic diagram of the relay circuits and associated power supplies is shown in Figure 3-4.

Inter-connection of Component Units

To facilitate further use of the sferic detection and recording equipment, it was decided to include in this chapter an explanation of the inter-connections of the various units. It is hoped that such an addition will serve to simplify the work of those who will continue the tornado detection project.

Because the equipment is an untuned device whose frequency ranges extend down below power frequencies, it was decided to completely shield all cables to minimize 60 cps pick-up from power lines in and around the site of operations. As far as was possible, all cables carrying the signal were coaxial cable with a characteristic impedance of 52 ohms. Unfortunately the cathode follower case must remain ungrounded to achieve the high input impedance necessary to match the short antenna. For this reason

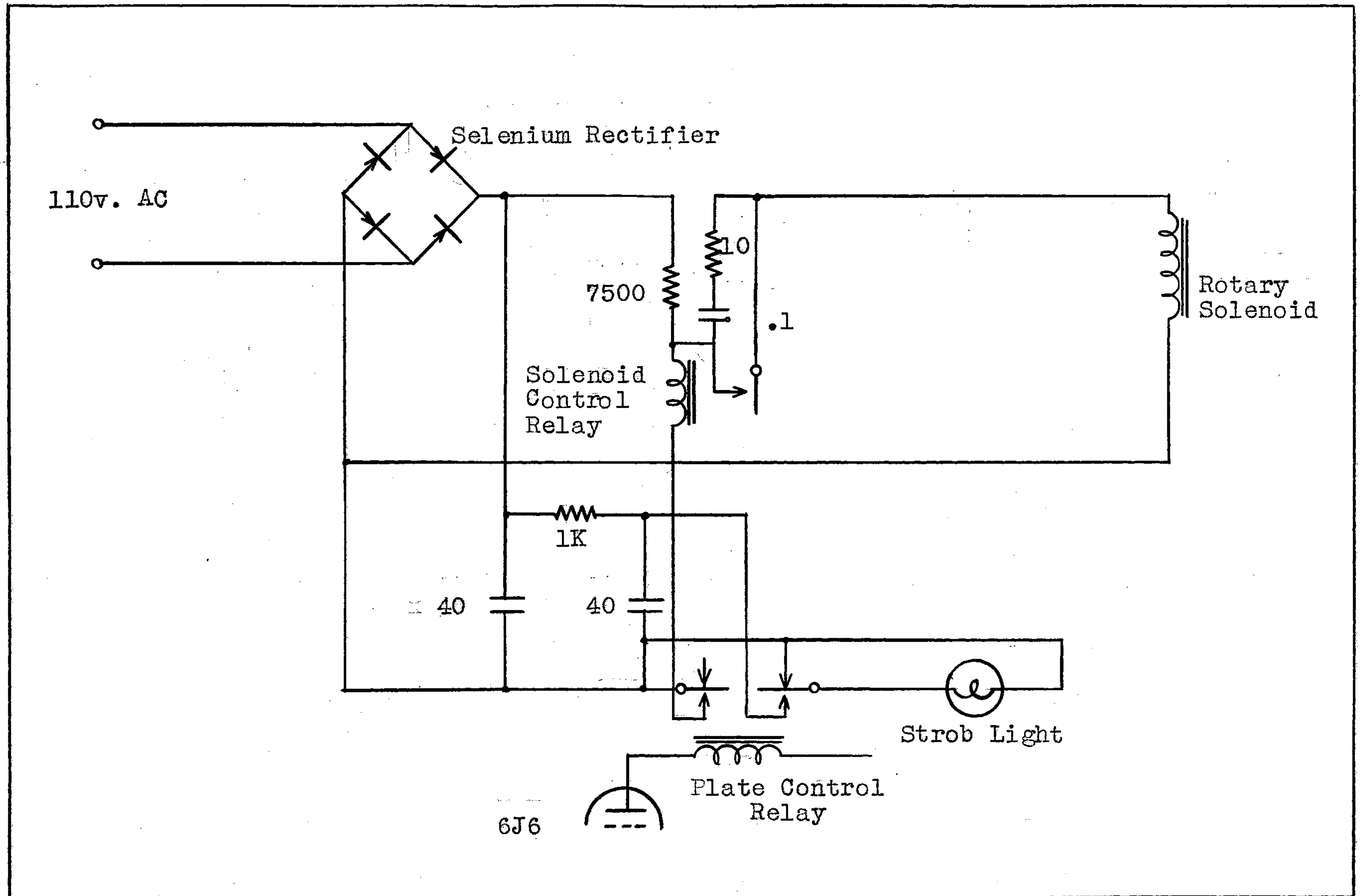


Figure 3-4 Relay Circuit

coax cable could not be used from this unit to the amplifiers because no special coax connectors were available. The above mentioned cathode follower was designed to operate directly under the antenna and as close to it as possible. Since the antenna was located some distance from the amplifier, it was thought best to provide a junction box in close proximity to the cathode follower for the express purpose of providing a standard coax cable connector so that coax cable could be used from the vicinity of the antenna to the amplifiers. This became doubly important when it was discovered that to avoid stray power frequency pick-up on the antenna it would have to be located at some distance from the amplifier and recording apparatus. This junction box also houses the coupling capacitance between the cathode follower and the amplifier. The cable connecting the cathode follower and the junction box is of the shielded pair type as is the cathode follower battery cable. A cabling diagram appears in Figure 3-5.

Camera, Light-tight Box and Oscilloscope

The camera used in the recording apparatus is a modified 35 mm motion picture camera. The film advancement is now operated by the afore mentioned rotary solenoid and only advances one frame per cycle instead of the usual continuous operation. It is mounted with its lens inside a light tight box which has at its other end the oscilloscope, clock, data device and direction-finder cathode ray tube. The clock and the date device are illuminated by a strob light located inside the box while the two cathode ray tubes are triggered and remain dark until a sferic

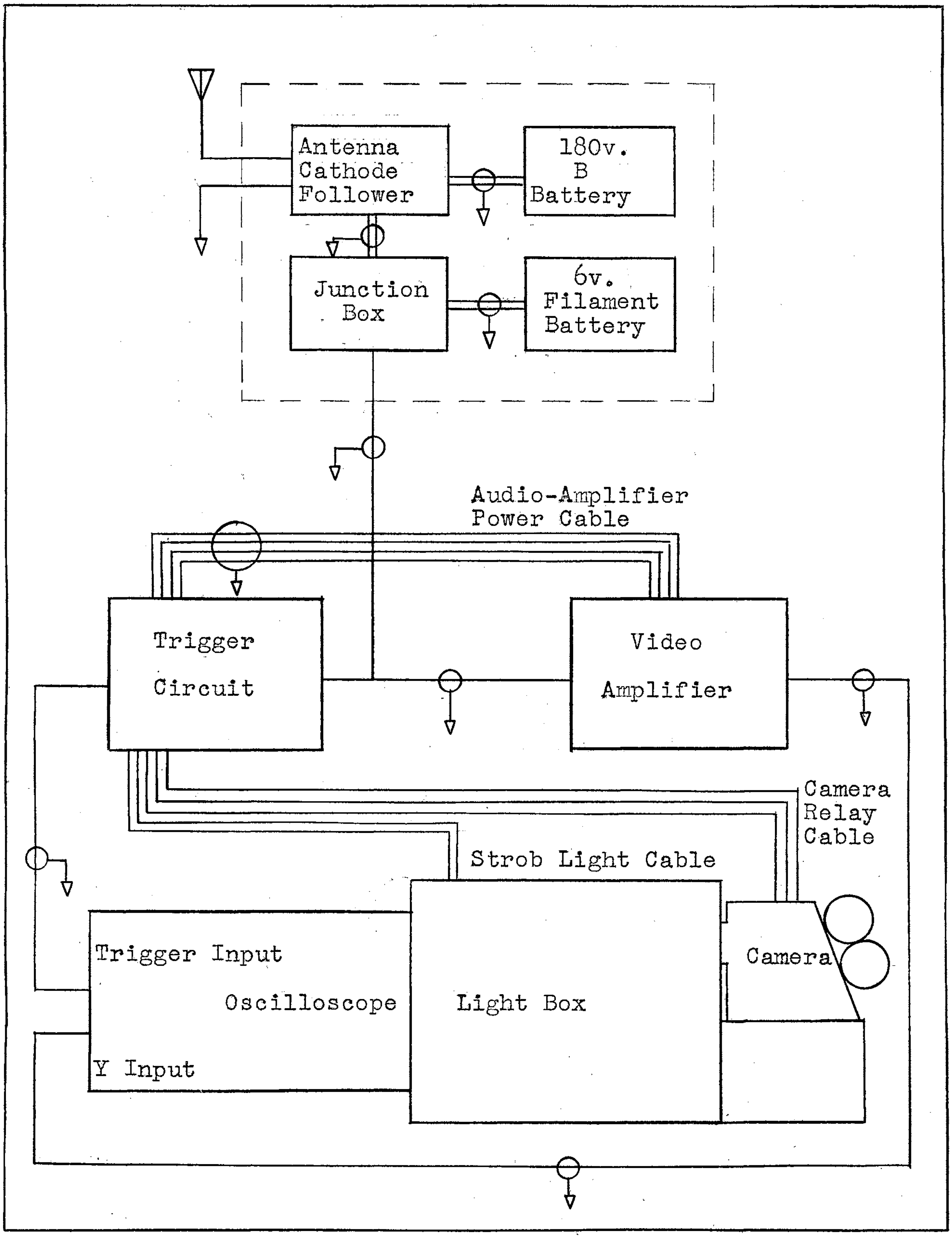


Figure 3-5 Cabling Diagram

is received. For these reasons, the camera can operate without a shutter, no light being produced in the box until a sferic arrives to trigger the cycle of events.

The camera was modified and the light box constructed by Mr. Alex Woods working under the auspices of the Research and Development Laboratory. Mr. Woods also assisted in testing the camera circuit with the sferic trigger circuit.

CHAPTER IV

INSTALLATION OF SFERIC DETECTION EQUIPMENT

Location of Sferic Detection and Direction Finding Equipment

It was decided that in order to obtain the best possible results the sferic detection device and direction finder should be located in an isolated region. This region should be free from man-made static such as cars, electric razors, rotating electric machinery and all other sources of interference that might cause spurious triggering of the equipment. In addition to this, the direction finding equipment had to be installed in a region relatively free from power lines and metal buildings which would influence the accuracy of the crossed loop antenna system. For economic reasons, the location had to be on College owned or leased land, fairly close to a source of power. A location that meets these qualifications was found, after much search, adjacent to the southeast corner of the Stillwater airport, which is leased and operated by Oklahoma A and M College. The location is several hundred yards from the nearest buildings and roads and is on relatively high ground.

The problem of suitable housing for the equipment was solved rather easily when it became known that the college was disposing of a number of temporary housing units. These units are of wood construction, 16' x 16', with a peaked roof and are admirably suited for our purpose. The radar gear that will eventually work in conjunction with the sferic equipment and the magnetic detection device designed and built by Professor Johnson[1] should be in an isolated region. For this reason it was decided that two huts should be installed on the site. These structures are placed approximately 100' apart.

Electrical power is supplied to the hutments from the Stillwater Municipal power plant transmission line supplying the Stillwater Airport buildings. It was necessary to have a several hundred yard feeder line constructed from the point on the transmission line nearest the operating site to the hutments. A transformer was mounted on the receiving end of this feeder line, making available to the hutments either 110 or 220 volts A.C.

In addition to the feeder transmission line, the inside of the hutments had to be wired to provide lights and electrical outlets for the power supplies of the various equipments. Standard Romax cable was used for this wiring throughout each hutment.

Installation of Equipment

The vertical antenna was mounted on the peak of the roof of the hutment with its feed-through connector extending through the roof of the ceiling of the hutment. The cathode follower was mounted directly under the antenna connector on the ceiling. Also mounted in this location was a gap type lightning arrestor.

---

[1] Johnson, David L., An Electronic Magnetometer, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1950.

This arrestor was necessary to protect both the equipment and the hutment from lightning strokes which might strike the antenna. Because of the location of the hutment, the vertical antenna extends considerably higher than any neighboring object. A gap type arrestor was used because it was felt that this type of arrestor would have less effect on the antenna impedance than would a common resistance type.

The remainder of the equipment was mounted on a shelf extending along one side of the hutment and on a long table set directly below this shelf.

When the equipment had been installed and tested, it was found that a large amplitude 60 cps signal was being induced on the antenna by the power lines and inside wiring, both of which were relatively close to the antenna. This induced voltage was, of course, being amplified through the video amplifier and fed to the oscilloscope. It was of such an amplitude so as to completely override any sferic that might be induced on the antenna. Complete grounding of all cables and chassis to a well-constructed earth ground was tried in an effort to alleviate this condition. It was not successful. There remained two possibilities; a high pass filter could be employed between the antenna and the amplifier or the antenna and associated equipment could be moved to a remote region. The first mentioned method would be the easier, but would result in a decrease in energy pick-up due to the large attentuation of the low frequency component. Because of this reason, it was decided to move the antenna and associated equipment to a region near the hutment, but far enough away to reduce the power frequency pick-up to a minimum.

It was, as mentioned above, also necessary to move the antenna cathode follower, the junction box and the cathode follower power supply batteries along with the antenna. This would allow a single inter-connecting coaxial cable between antenna and hutment. To house this equipment and provide a base for the antenna, a plywood box was constructed. The antenna was mounted on the hinged top of the box, while the other equipment mentioned was placed in the box. Also included was a switch for the cathode follower batteries and the lightning arrestor already described. It was felt that the lightning arrestor was still necessary to protect the equipment in the box and to prevent the lightning stroke from traveling along the inter-connection coaxial cable to the hutment.

The antenna box was placed approximately 300' from the hutment, at right angles to the incoming feeder transmission line. It was found that such an arrangement completely eliminated the 60 cps stray pickup on the antenna.

It was found by test that the antenna box could be placed nearer the hutment without excessive pickup. The box was moved closer to the hutment in small increments while the amount of pickup was checked. A final distance of approximately 35' was decided upon. This distance was great enough to eliminate objectionable amounts of 60 cps pickup but short enough so that transmission line attenuation was not excessive.

As a final check on the total installation, a square wave generator was connected at the cathode follower input terminals and the resultant waveform checked at the oscilloscope. It was found that small changes were necessary to prevent distortion of the square wave and oscillation in the trigger circuit. These changes were made and the resultant waveform was an accurate replica of the input waveform. The gear was then considered ready for operation.

Figures 4-1 through 4-6 are photographs of the hutment, equipment location and antenna box.

Figure 4-1 Operational site of sferic equipment

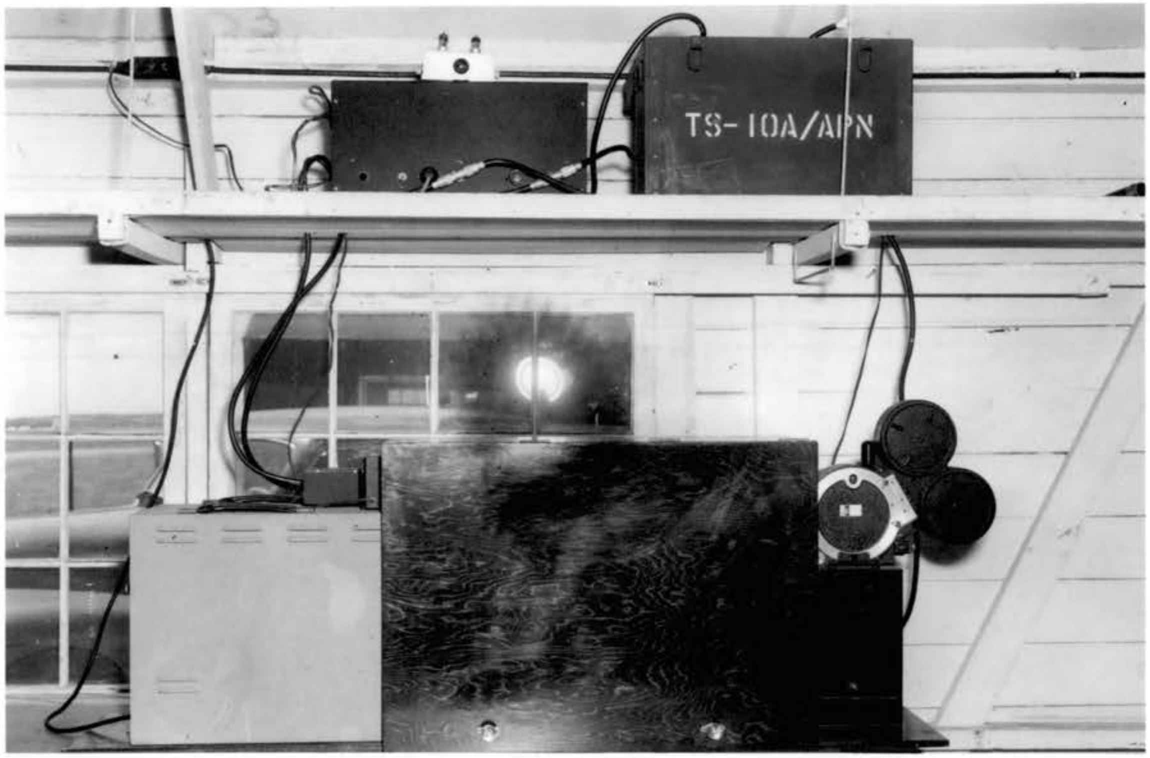


Figure 4-2 Interior of hutment showing video amplifier, trigger circuit chassis, oscilloscope, light box and camera.

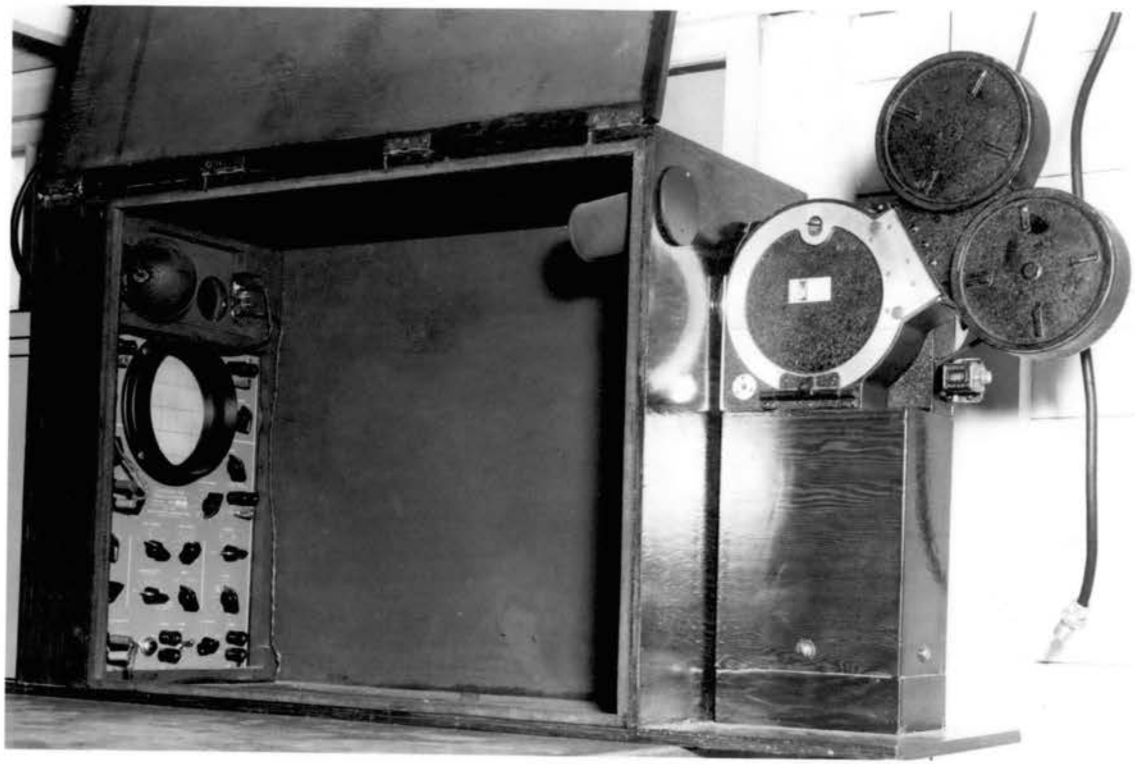


Figure 4-3 Interior of light box. Note strob light and oscilloscope controls.

Figure 4-4 Antenna and antenna box.

Figure 4-5 Location of antenna with respect to the hutment.

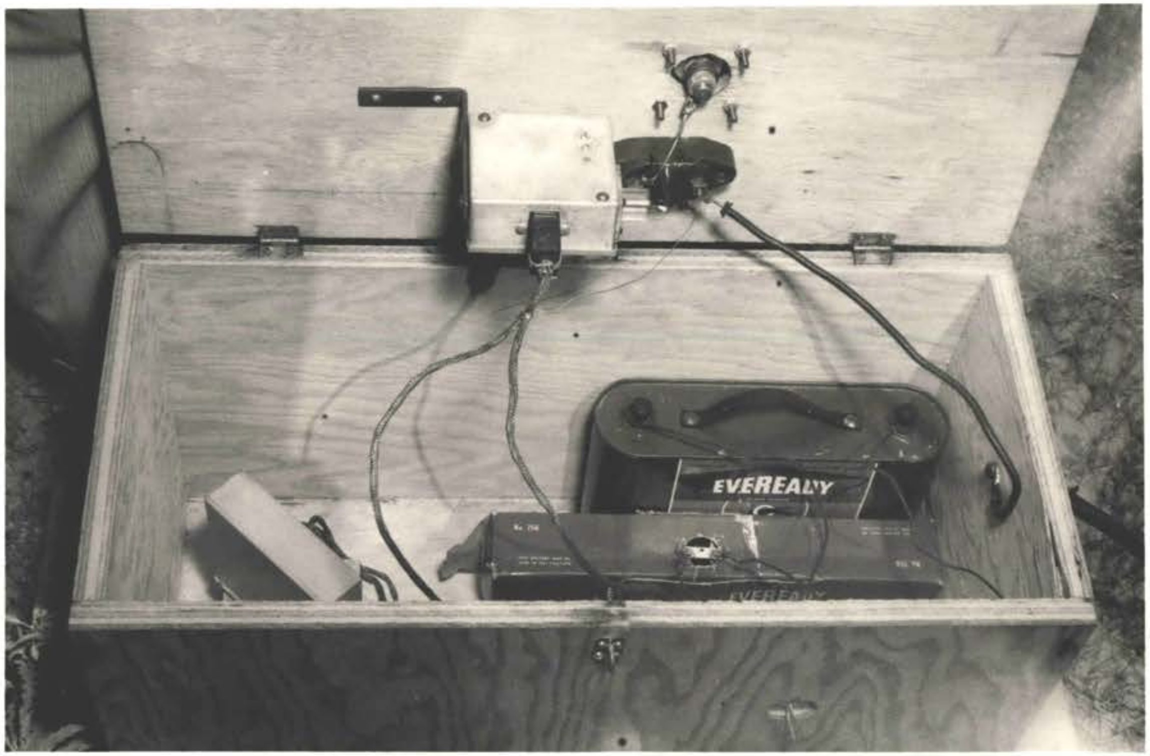


Figure 4-6 Interior of antenna box showing antenna cathode follower, lightning arrestor, junction box and power supply batteries.

CHAPTER V

OPERATION OF EQUIPMENT

The sferic detection equipment was first operated on 1 June, 1950. At that time all equipment except the sferic direction finder was completed and installed. The sferic direction finder was found to have several questionable characteristics that indicated the need for further research. As a result, this project was turned over to Mr. W. Wade, a graduate student at Oklahoma A and M.

Although the sferic detector is capable of long range operation it was decided to limit its operation to those times when a known storm was within the arbitrary range of 200 miles. To limit the equipment in this way, the volume control on the trigger circuit was set at such a value that the equipment would not trigger on the far distant storms.

Used in conjunction with the sferic equipment was a log book. This book was so arranged that pertinent information as to the oscilloscope settings, date, weather conditions and known weather data could be recorded. This log was necessary in order to correlate the waveforms obtained with other waveforms taken at different sweep speeds, different gains, etc. It was found to be an invaluable aid while reviewing the pictures taken and while attempting to group pictures as to the type of storm they represented. A sample log sheet is shown in Figure 5-1.

Several storms occurred between the time the sferic detection equipment was installed and the writing of this thesis. During this time one tornado was reported within the operating range and at least one incipient tornado was observed. While this amount of evidence is not sufficient for a formal proof of the original theory, it does indicate that a difference in lightning waveforms does exist. It is believed, however, that considerably more evidence will be necessary to establish the complete nature of this difference. Of particular importance is the inclusion of the direction finder at the earliest possible date. Until this is done and the direction of the sferic recorded, no final positive proof can be claimed.

All of the storms that occurred after the sferic detection equipment was put into operation were recorded. In all, some 250' of 35mm film was exposed. It would be impossible to present all of the photographic evidence in this thesis. For that reason it was decided to include only a few enlargements of the waveform pictures, including representative ones from each type of storm that occurred. The conclusions that will be drawn in a later chapter are not based upon these few waveforms but upon the total amount of film exposed and developed at the time of this writing.

Storm of 9 June, 1950

On this date a cold front moved over the area from the northwest. Conditions were such that thunderstorms were occuring ahead of the front. At approximately 6:20 p.m. a tornado funnel was reported about 60 miles west of Stillwater. During this time the sferic detection equipment was in operation. It was noted that the triggering of the equipment was very rapid and almost continuous although the trigger volume control was set at a low value. Representative waveforms of this storm taken before, during and after are shown in Figure 5-2 and 5-3. The time of occurrence can be noted on the picture. It was noted that these waveforms contained a large amount of high frequency components.

At approximately midnight of the same day a local thunderstorm of relatively low intensity occurred. The sferic equipment was operated since it was desired to obtain all kinds of lightning waveforms. It was noted that this storm, which was in the immediate vicinity, triggered the gear at about the same rate as the tornado storm had earlier. The waveforms of this disturbance are shown in Figure 5-4. It was noted that these waveforms did not have the preponderance of high frequency components.

Storm of 10 June, 1950

Early in the afternoon of the above date, notification was received from the weather bureau that another critical area existed. It was a condition similar to the storm of the day before. The sferic equipment was put into operation. Triggering intensity and frequency were once again high. Several tornado clouds were reported to the west of Stillwater although no funnels were reported. At 3:20 p.m. the clouds overhead began to boil and momentarily started a slow rotation. It was the opinion of Professor Hardy, meteorologist at Oklahoma A & M, that the phenomena witnessed was an incipient tornado. Professor Hardy was present at the site during this period. Figures 5-5, 5-6 and 5-7 show representative pictures taken during this time. They include waveforms taken before, during, and after the incipient tornado was observed. A large amount of high frequency components was again noticed.

The high frequency components can be recognized in the pictures presented in this chapter by the fact that the waveforms appear very close together. In the extreme cases the waveforms appear hazy, due to the fact that there are many of them on the trace. For all of the pictures presented the sweep rate of the oscilloscope was held constant.

It should be noted at this time that the sferic equipment is still being operated. Every storm occurring in the vicinity is being recorded. Because of the time element involved, it was necessary to limit the material covered in this chapter to the already mentioned storms.

Clock No.	Date	Scope Amp.	Y Atten.	Y Gain	Coarse Sweep	Fine Sweep	Time	Remarks

Figure 5-1 Sferic Log Sheet

Coarse Sweep - 20K
Fine Sweep - 0
Y Attenuation - 1:1

Y Gain - 100
Amplifier - D. C.

Figure 5-2 Storm of 9 June, 1950

Coarse Sweep - 20K
Fine Sweep - 0
Y Attenuation - 1:1
Y Gain - 100
Amplifier - D. C.

Figure 5-3 Storm of 9 June, 1950

Coarse Sweep - 20K
Fine Sweep - 0
Y Attenuation - 1:1

Y Gain - 100
Amplifier - D. C.

Figure 5-4 Thunderstorm of 9 June, 1950


Coarse Sweep - 20K
Fine Sweep - 0
Y Attenuation - 1:1

Y Gain - 100
Amplifier - D. C.

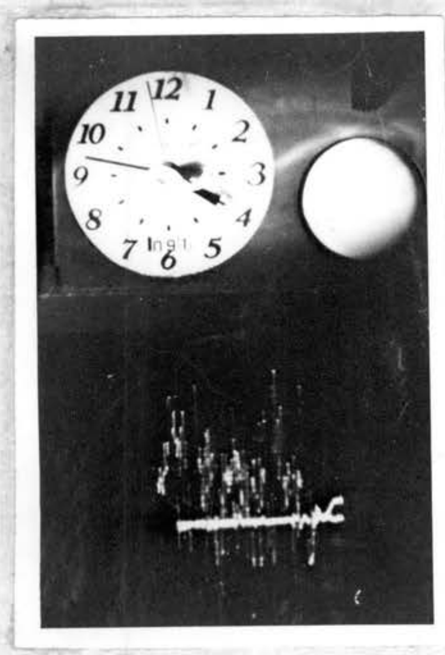
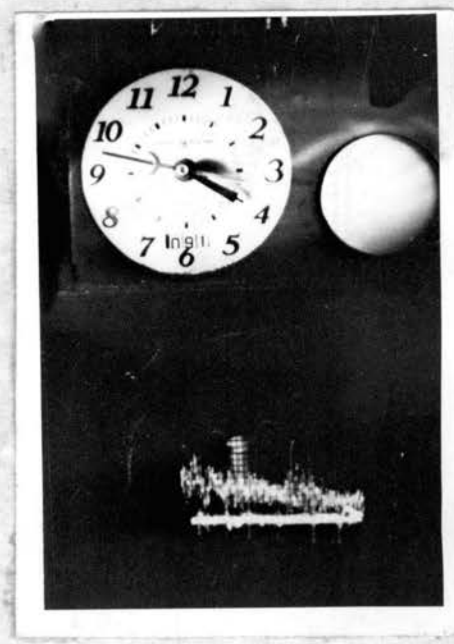
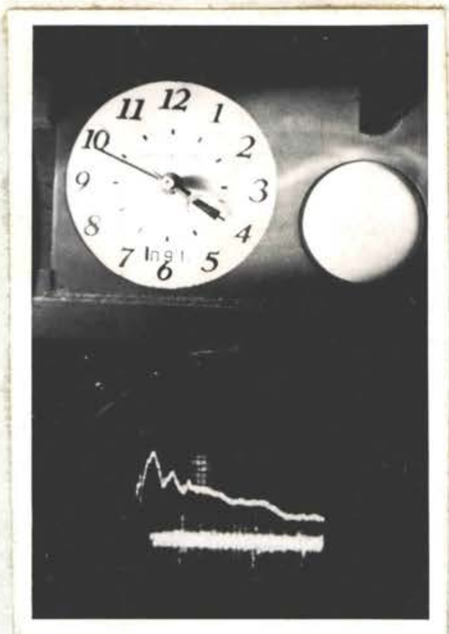



Figure 5-5 Storm of 10 June, 1950

Coarse Sweep - 20K
Fine Sweep - 0
Y Attenuation - 1:1

Y Gain - 100
Amplifier - D. C.

Figure 5-6 Storm of 10 June, 1950



Coarse Sweep - 20K
Fine Sweep - 0
Y Attenuation - 1:1
Y Gain - 100
Amplifier - D.C.

Figure 5-7 Storm of 10 June, 1950

CHAPTER VI

CONCLUSIONS

The results obtained from operation of the equipment are still insufficient to prove definitely that tornadoes may be identified by their sferic waveforms. More data will have to be obtained through operation of the equipment. It is also of vital importance to include a record of the direction from which the sferic is arriving. Without this indication the data cannot be correlated with weather bureau information as to the type and position of any given storm. This is of importance because thunderstorms of the ordinary type are generally present in the general area of a tornado. A statistical method of grouping data is also needed. It is felt that no other method would result in positive proof.

As pointed out in Chapter II, it will be impossible to rely on amplitude of the sferic as an identifying characteristic. There remain three possibilities for identification; the duration of the sferic, the waveshape, and the frequency components. All of these possibilities were considered while examining the small amount of film already exposed. It was immediately apparent that the most obvious difference was in the frequency components of the various waveforms. It was noted that the majority of the waveforms recorded during violent storms and reported tornadoes contained a large amount of higher frequency components. This was especially evident when these waveforms were compared with the waveforms recorded during ordinary local thunderstorms. This phenomena cannot be identified with the distance to the disturbance, for the higher frequencies will be attenuated more in their travel over the ground than will the lower frequencies. It can be explained by the mechanism of the lightning discharge, whereby the velocity of the charge flow in the stepped leaders is dependent upon the intensity of the electric field existing between cloud and ground or cloud and cloud, depending upon the type of discharge. The more intense the electric field, the greater will be the velocity of the charge flow. The velocity of the charge flow can, in turn, be identified with the frequency of electro-magnetic radiation since it approximates the current flow in an antenna. This is only one consideration, since the lightning stroke itself is a complex series of events, all of which are not completely explained or proven. A more intense field will be present under tornado conditions due to greater charge accumulations.

Complete examination of the waveform pictures revealed that both low frequency and high frequency waveforms were present in local thunderstorms, reported tornadoes, and incipient tornadoes. However, ordinary thunderstorms resulted in few high frequency sferics while tornadoes and incipient torandoes showed a large majority of high frequency sferics.

These results suggest a statistical compilation of pictures based upon this difference, although it is felt that the other two mentioned possibilities should not be neglected.

The Incipient Tornado

It is the opinion of most meteorologists in this area that many tornadoes occur that are not reported because they never hit the ground. These observers also believe that a great many tornado clouds start to form funnels which dissipate in a short time. These are the so-called incipient tornadoes. Because this type of disturbance is very nearly a tornado, the indication on the sferic equipment will suggest that a tornado is in progress. This is an important problem that must be faced if a warning system is to be set up for a given area. The warning system will not be acceptable to the general public unless it is fool-proof. People are not interested in what might have happened; they will demand warning only in the case of a well-developed tornado heading in their direction.

In order for a tornado to form, energy relationships in the atmosphere must be of a certain level. The reason incipient tornadoes form and dissipate is because these energy levels are not present. It has been stated that the frequencies contained in the sferic might be a function of the energy level of the storm. If this conclusion is correct, it will provide a means of differentiating between tornadoes and incipient tornadoes as well as between tornadoes and ordinary thunderstorms. Unfortunately the energy necessary to precipitate a tornado is of a critical level. The difference between the energy necessary to support a tornado and the energy necessary to form an incipient tornado is probably relatively small. This will make detection by this method very difficult.

Before the sferic equipment was installed, a tornado was witnessed by the author. It occurred late in the evening due west of Stillwater. Estimation of distance was difficult at that time, but it appeared to be at a distance of 15 to 25 miles. It was not plotted by the weather bureau since it occurred in open country and did no damage. The storm was observed by the author during its entire existence, a period of approximately 40 minutes. During this time many lightning strokes occurred around the funnel to ground. These strokes were very bright and seemed to be of longer duration than the strokes occurring at a distance from the funnel. The strokes were also observed to be an orange color, very decidedly different from the other strokes. This suggests that a difference will be found between the sferic associated with a true, formed tornado and the incipient variety. Proof of this theory will have to wait until sferics are recorded from a true tornado. They can then be compared with the sferics already recorded from the incipient type of tornado.

It should be noted here that these observations of an actual tornado were substantiated by several observers who were on the scene with the author. No definite statement as to duration and color can be made since the human eye with its retentative sensivity to bright light, makes any definite statement impossible. It is possible that the duration appeared longer than ordinary due to the increased brilliance of the stroke. This can be determined one way or the other by sferic recordings of actual tornadoes, which will undoubtably be taken within the next year.

Suggestions for Future Research

Of primary importance for future operation of the sferic equipment is the inclusion of a direction indication on the sferic recording. Until this is included no definite proof can be advanced. No correlation with weather bureau data as to location of the storms can be made. At the present time, a direction finder study is being made by a graduate student, Mr. W. Wade. Plans as now formulated call for the completion and installation of direction finding equipment by the beginning of the next tornado season, that is, the early spring of 1951.

While operating the equipment it was noted that the beginning of each waveform was being lost. This was due to the closure time of the relays that provided triggering of the oscilloscope. The only solution to this problem that is available at this time is the inclusion of a delay line between the video amplifier and the oscilloscope. It was found by test that a delay line sufficient to include all of the waveform attenuated the signal to a great extent. It is suggested that more stages be incorporated in the video amplifier to make up for this attenuation. It is highly desirable to obtain all of the waveform if studies are to be made on waveshape and duration. Additions of this type to the video amplifier would be relatively simple because of the new techniques and circuits developed during the last decade pertaining to this type of amplifier.

A statistical grouping of sferic pictures will have to be made if proof of the original theory is to be presented. This grouping should consist of three separate studies; comparing frequency components against type of storm, comparing sferic duration against type of storm, and comparing waveforms of the sferics against type of storm. A statistical study of this type is the only way to handle the large amounts of data that will be available for study as more and more pictures are taken. Such a study will have to wait until tornadoes, incipient tornadoes and ordinary thunderstorms have occurred in sufficient numbers to permit the collection of the necessary amount of data. From the results gained in the short time the equipment has been in operation it seems logical to suppose that such a study will be successful in determining the difference in the sferics from these three types of storms. When this difference has been determined, a warning network can be set up. Used in conjunction with the other methods of detection; radar, magnetometers, and high frequency radio, this development of a warning network should be possible.

BIBLIOGRAPHY

Beck, Edward. "Lightning Strokes Prefer Tall Structures." Westinghouse Engineer, (July, 1949).

Byers, Horace R. "The Thunderstorm." United States Department of Commerce Bulletin, Washington, D. C. (1949).

"Direction Finding and Ranging on Atmospherics." Department of Electrical and Industrial Experiment Station, University of Florida, Gainsville, Florida, (1948).

Harrison, L. P. "Lightning Discharges to Aircraft and Associated Meteorological Conditions." National Advisory Committee for Aeronautics, Technical Note No. 1001, Washington, D.C. (1946).

Hutchinson, John Stanley. "A Study of Tornado Tracking." Unpublished Master's thesis. Stillwater, Oklahoma: Oklahoma A & M College, (1949).

Jeske, Harold O. "Electronic Apparatus for the Study of Sferic Waveforms." Unpublished Master's thesis. Stillwater, Oklahoma: Oklahoma A & M College, (1950).

Johnson, David L. "An Electronic Magnetometer." Unpublished Master's thesis. Stillwater, Oklahoma: Oklahoma A & M College, (1950).

Miller, C. W. "A Proposed Method of Identifying and Tracking Tornadoes." Unpublished Master's thesis. Stillwater, Oklahoma: Oklahoma A & M College, (1948).

Sarbacher, R. I. and Edson, W. A. Hyper and Ultrahigh Frequency Engineering, First Edition. New York: McGraw-Hill Book Company, Inc., 1948.

"Standards of Good Engineering Practises Concerning Standard Broadcast Stations." Federal Register, (8 July, 1939).

Terman, Frederick E. Radio Engineering Handbook. New York: McGraw-Hill Book Company, Inc., 1939.

Terman, Frederick E. Radio Engineering, Third Edition. New York: McGraw-Hill Book Company, Inc., 1947.

Thomason, Thomas H. "The Development of A Sferic Direction Finder." Unpublished Master's thesis. Stillwater, Oklahoma: Oklahoma A & M College, 1949.

Weil, J. and Mason, W. "The Locating of Tropical Storms by Means of Associated Static." _University of Florida, Engineering Experiment Station_, Bulletin Number 3, (October, 1936).

Workman, E. J. and Reynolds, S. E. "Thunderstorm Electricity." _Research and Development Division, New Mexico School of Mines_. Final Report, Signal Corps Research, 1948.

THESIS TITLE: INSTALLATION AND OPERATION OF ELECTRONIC SFERIC DETECTION EQUIPMENT

NAME OF AUTHOR: PHILIP N. HESS

THESIS ADVISER: HERBERT L. JONES

The content and form have been checked and approved by the author and thesis adviser. "Instructions for Typing and Arranging the Thesis" are available in the Graduate School office. Changes or corrections in the Thesis are not made by the Graduate School office or by any committee. The copies are sent to the bindery just as they are approved by the author and faculty adviser.

NAME OF TYPIST: PATTY McAFFREY HOWELL