THE DEVELOPMENT OF AN IMPROVED 150 KILOCYCLE INSTANTANEOUS SFERIC DIRECTION FINDER

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THE DEVELOPMENT OF AN IMPROVED 150 KILOCYCLE

INSTANTANEOUS SFERIC DIRECTION FINDER

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PREFACE

As Project Engineer for the Atmospherics Laboratory at Oklahoma State University, I have been responsible for the development of electronic equipment which is associated with atmospherics research. One of the most interesting projects associated with this endeavor was the development of an improved version of the 150 kilocycle direction finding equipment. Past experience with the 150 kilocycle direction finder has proven the value of this instrument in the field of tornado identification and tracking. It is my hope that the improved version will be even more valuable to the research program of the Atmospherics Laboratory.

I am indebted to the many persons who have helped with this project for it was only through their participation that completion of the project was possible. Particular mention should be made for the fine work of Anthony Flowers, Bob Caswell, and Harvard Tomlinson who did all of the construction work, and Barbara Adams who has so patiently taken the time to transform my handwritten copy into a professionally typed thesis. Thanks are also due to fellow engineers, Felix Boudreaux and George Lucky who have made many suggestions on the design of the equipment, and to Ivan Hurst who did most of the internal design of the preamplifier and notch filter units. And especially thanks to Dr. H. L. Jones, Director of the Atmospherics Laboratory, who has developed the tornado tracking art to its present state and has provided the funds and inspiration so necessary to such an undertaking.

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CHAPTER I

INTRODUCTION

System engineering is a term which has recently been applied to the ancient art of integrating all of the various aspects of a project into one complete and workable assembly. It has received much attention in the last few years because engineering projects have become very vast and complex and require an increased amount of effort in organizing the overall plan. Nowhere has the need for this phase of engineering been as prevalent as in the development of missiles; however, a new emphasis on system design principles has been discernible in all fields of engineering.

The development of an improved high frequency direction finder has been an interesting experiment in system engineering. This instrument is an assembly of 17 units and 6 power supplies. A total plan for the entire complex had to be formulated and specifications for each unit tentatively decided upon before the internal design of any unit could begin. Each unit had to be compatible not only with the improved high frequency direction finder assembly but also with the original direction finder because it was desirable to make the transition from old to new one unit at a time so that a working direction finder would be available at all times. The improved direction finder also had to be compatible to the Q-3, an instrument for the analysis of sferics, because the cathode-ray tubes and photographic equipment of the Q-3 are used to make permanent records of the high frequency direction finder information.

The 150 kilocycle direction finding system is basically divided into four different sets of units. Each set handles the information at a distinctly different level. The antennas, which are the primary signal source, handle the signal at the lowest level. A preamp is used to amplify the antenna output for use by the receivers. The calibration of the system is also done at this second level. A third level of processing of the signal is done by the receivers which select the 150 kilocycle component of the sferic waveform and prepare it for presentation on the indicators. The output of the receivers is used for distribution of the signal to the various indicators, but the amplitude of the output of the receivers is not sufficient to operate the indicators. The deflection amplifiers and intensification units are used to provide the necessary amplification to operate the indicators. A set of these units is placed near each indicator.

Both system and circuit problems were involved in the design of the improved high frequency direction finder. The circuit problems generally reduce to undergraduate design problems after the requirements of the circuit have been specified by the system design considerations. Therefore, the major emphasis of this thesis is the discussion of the system engineering problems related to the development of the high frequency direction finder. Consequently, very little space is devoted to the design of the individual circuits.

CHAPTER II

THE ORIGINAL HIGH FREQUENCY DIRECTION FINDING SYSTEM

In 1956 Mr. Ruben Kelly put into operation the original high frequency direction finder which will be referred to here as the HFDF-1. This was an instantaneous direction finder tuned to operate on the 150 kilocycle component of the sferic waveform. The purpose of the present design was to develop a system of essentially the same type as the HFDF-1, but with greater sensitivity and increased versatility and reliability.

The work involved was greatly simplified by the fact that a system of this type had already been built and was operating. The accomplishments of the HFDF-1 in the field of tornado tracking are truly remarkable and have lent assurance as to the value of developing an improved version of this same system. (1, 2). On the other hand, the fact that the HFDF-1 was in operation demanded certain development procedures that might have been by-passed if one were developing a totally new system. In particular it was desired to place certain parts of the new system into operation at the earliest possible date while the design and development of the rest of the system continued. Therefore, each unit of the new system had to be entirely compatible with the HFDF-1. In order to fully understand the development of the new system, it is necessary first to discuss the characteristics of the HFDF-1.

Antenna System of HFDF-1

The antenna assembly of the HFDF-1 consisted of two mutually perpendicular loop antennas and a whip. Each loop antenna was a coaxial cable mounted on a frame in such a way that the entire loop was in one plane, called the plane of the loop, and the total enclosed area was approximately 440 square feet. At one end of the coaxial cable the shield and center conductor were connected to ground. At the other end the shield was left floating and the center conductor was connected to the input of the receiver via another coaxial cable. In order that the impedance of the antenna match the coaxial transmission cable, a 50 ohm resistor was placed across the output of the antenna. It should be mentioned that the floating shield was intended to shield the antenna against electrostatic effects. Extreme care was exercised when installing the loop antennas to see that the area of both of the loops were the same. This was necessary for calibration purposes since the output signal is a function of the loop area and the amplitude of the wave.

The direction finding ability of the loops is derived from the fact that the output signal is also a function of the angle (θ) between the plane of the loop and a line drawn between the station and the location of the origin of the signal. In particular

$$V_{out}(t) = E(t) \cos \theta$$

where

V_{out} is the output voltage of the loops

$E(t)$ is the amplitude of the vertically polarized portion of the incoming wave.

Thus for two loops which are mutually perpendicular, the outputs will be proportional to the sine and cosine of the angle of the incoming signal. These outputs are then utilized by the HFDF-1 receiver to produce the desired display as will be explained in another section.

A whip antenna was used to produce a sensing signal. The sense signal requirement is that a signal be produced which is proportional to the vertical polarized portion of the incoming wave and is independent of the direction of arrival. Thus a signal from a whip antenna mounted centrally within the loop arrangement was transmitted via coaxial cable to the sensing portion of the HFDF-1 receiver.

The HFDF-1 Receivers

The purpose of the HFDF-1 receivers was to convert the sferic signals received on the antenna system into signals suitable for presentation on the cathode-ray tube indicator. A block diagram of an HFDF-1 receiver is shown in Figure 1. The 1/10 step attenuator serves the dual purpose of a termination to match the 50 ohm transmission line from the loop antennas and as an attenuator to reduce the signals at the front end of the receiver so that large signals may be studied without overloading the receiver circuits. It can be set for gain ratios of 1, 0.9, 0.8, etc. to and including 0.1. A cathode follower is used at the input to drive a video amplifier whose plate circuit contains the 1/2 gain step attenuator that can be set for gain ratios of 1, 1/2, 1/4, and 1/8. A cathode follower is used to drive the tuned amplifier which in turn drives the output cathode follower. Phase distortion is a very critical problem in the design of this type of equipment because a slight relative phase shift between the two receiver channels will cause an elliptical presentation. Therefore, cathode followers are used in the HFDF-1 to isolate

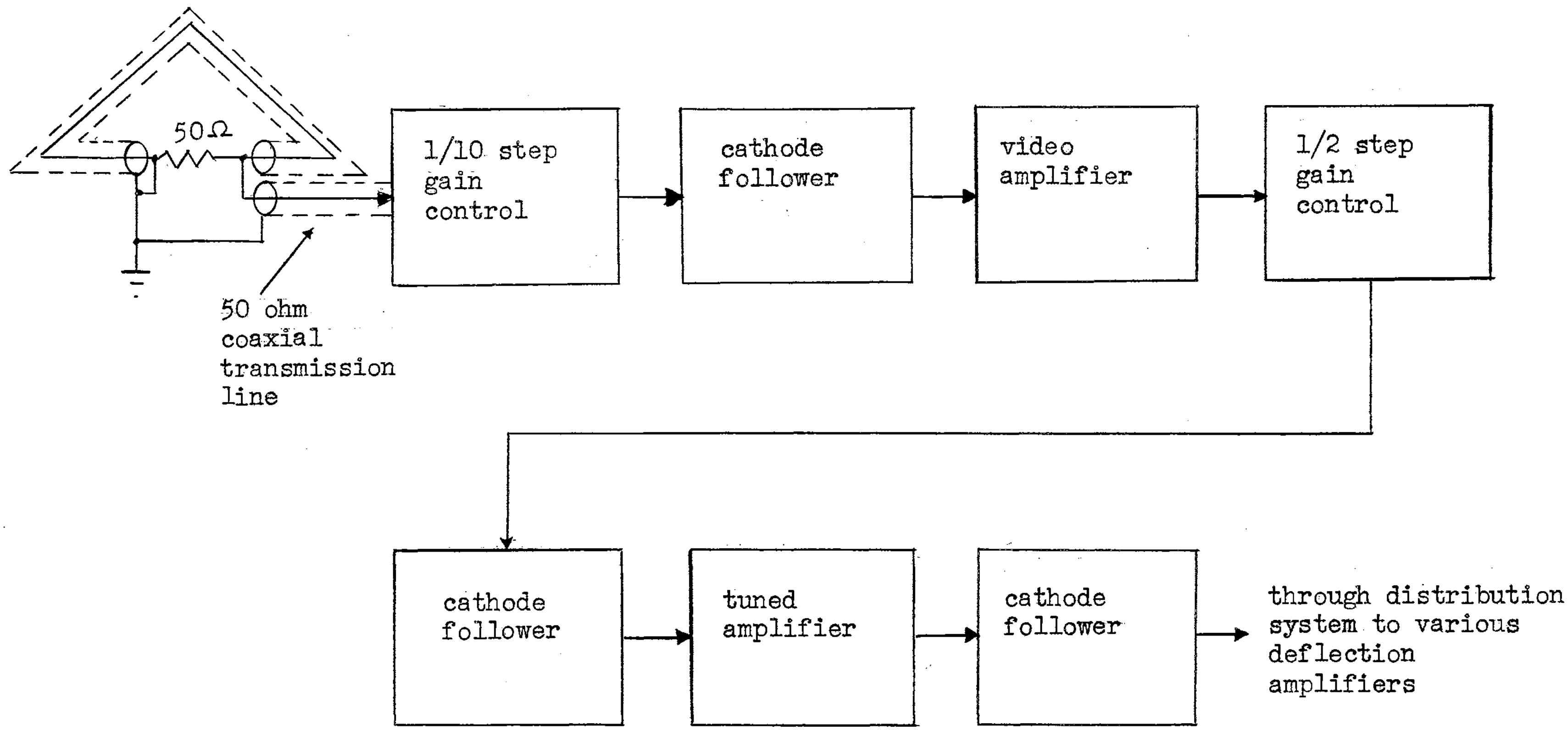


Figure 1. Block Diagram of HFDF-1 Receiver

each stage in an effort to minimize the detrimental effect of Miller capacitance on the phase shift of the amplifiers at the high frequencies involved.

The tuned amplifier is the only frequency sensitive portion of the entire system and as such is one of the most critical circuits. It consists of a pentode amplifier with a tank tuned to 150 kilocycles in the plate circuit. A variable resistance across the tank permits adjustment of the bandwidth or damping factor, and a variable resistance in the cathode circuit permits adjustment of the degeneration so that a gain balance can be effected between the two receivers.

A third receiver of similar design is used to create a sense signal. The sense signal is required to be a signal of similar characteristics to the output of the DF receivers, except that it is independent of the direction of arrival of the sferic. Thus a receiver of the same design is used, except that three additional stages of amplification are added to the output of the receiver in order to have a signal of sufficient amplitude to operate the intensification circuits of the indicators.

The resonant circuits in the receivers are excited by the sferic pulse and ring with a maximum amplitude proportional to the 150 kilocycle energy contained in the input signal. The 150 kilocycle energy in the input signal is proportional to the 150 kilocycle energy in the sferic and the sine or cosine of the angle of arrival, depending on the antenna which received it. Thus

$$V_{ns} = K\, W_s \cos\theta \sin wt\, e^{-\alpha t}$$

$$V_{ew} = K\, W_s \sin\theta \sin wt\, e^{-\alpha t}$$

where

V_{ns} is the output voltage of the NS receiver

V_{ew} is the output voltage of the EW receiver

K is a constant of the system

θ is the angle of arrival of the sferic with north = 0° as a reference

W_s is the 150 kilocycle energy content of the sferic

W is 2π f or $2\pi \times 150 \times 10^3$

α is a constant depending on the damping factor of the tank circuit.

If V_{ns} is applied to the vertical input of an oscilloscope and V_{ew} is applied to the horizontal input, a deflection will result such that

$$Y = K_1 W_s \cos\theta \sin wt \, e^{-\alpha t}$$

$$X = K_1 W_s \sin\theta \sin wt \, e^{-\alpha t}$$

where

Y is the vertical deflection

X is the horizontal deflection

K_1 is a constant

These equations may be converted to polar coordinates by standard trigonometric formulas:

$$r = \sqrt{x^2 + y^2} = \sqrt{(K_1 W_s \sin wt \, e^{-\alpha t})^2 (\cos^2\theta + \sin^2\theta)}$$

$$r = K_1 W_s \sin wt \, e^{-\alpha t}$$

and

$$\theta = \tan^{-1}\left[\frac{K_1 W_s \cos\theta \sin wt \, e^{-\alpha t}}{K_1 W_s \sin\theta \sin wt \, e^{-\alpha t}}\right]$$

$$= \tan^{-1} \frac{\cos \theta}{\sin \theta} = 90^{\circ} - \theta$$

It is evident that the maximum length of deflection, r_{max}, is directly proportional to the 150 kilocycle energy content, and the position of the dot is always along a line inclined $90^{\circ} - \theta$ with respect to the X axis, which causes it to deflect in the direction of the origin of the sferic if north is taken up and east to the right as is done on most maps. The expression for r shows that r can be positive or negative depending on the half cycle of the ringing of the tank and a 180° ambiguity exists. This ambiguity may be eliminated by blanking the oscilloscope beam during every other half cycle. The signal from the sense receiver is applied to the intensification circuit of the oscilloscope and the beam is thus intensified during one half cycle and blanked during the next half cycle so that a single strobe appears on the oscilloscope screen in the direction of the origin of the sferic.

The Distribution System

A block diagram of the distribution of signals from the three receivers is shown in Figure 2. Deflection amplifiers were required at the location of each indicator because the necessarily high output impedance of the deflection amplifiers does not permit the use of long lengths of cable to the indicators. The HFDF-1 receivers connect directly to the visual indicator amplifiers and the counter CRT because it is desirable to always have north up on these scopes. However, a 90° azimuth rotation device is inserted in the deflection amplifier signal path for the camera scope in order that north up or north left can be selected at will. It merely switches the N-S and E-W signal leads. The sense receiver

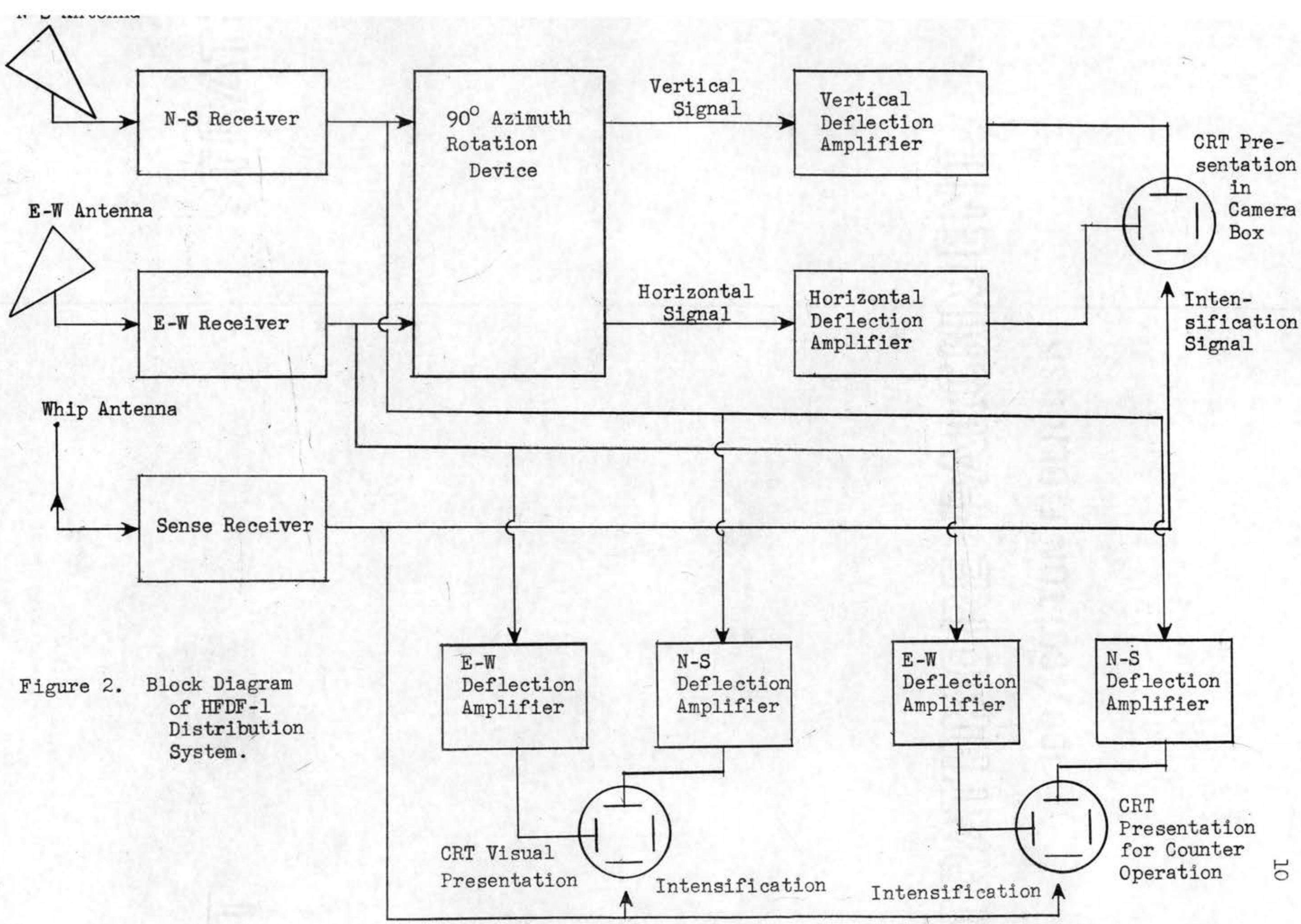


Figure 2. Block Diagram of HFDF-1 Distribution System.

distribution is a direct connection from the receiver to the various cathodes or grids of the indicator scopes. Due to the additional amplification in the sense receiver, the signal level is sufficient.

Possible Improvements on the HFDF-1

The HFDF-1 system as described above worked very satisfactorily. It might be considered a prototype or breadboard of the new design and as such was a masterwork of electronic design. However, in the course of operation of the HFDF-1 several possible improvements appeared. First and most important was reliability and ease of maintenance. The original system had been developed in the course of several years and very little planning could possibly have gone into the overall system design. Thus many circuits were virtually inaccessible and as parts burned out and needed replacement, maintenance became a major problem. Second, the sensitivity of the system was not as great as would be desired. Therefore, one of the important features of an improved version should be greater sensitivity. This creates a real problem since radio stations in the vicinity of the laboratory were riding in on the receivers and creating interference problems. To increase the total sensitivity would be to increase this interference problem in direct proportion. Third, the original system provided for the calibration of the system only with regard to azimuth. In the new system it is desired to be able to calibrate the presentation with regard to energy content as well as azimuth. Fourth, the deflection amplifiers of the HFDF-1 did not have a sufficient output level to utilize the full dynamic range that was available on the indicators. Thus an improved version of the system would include the development of deflection amplifiers of greater dynamic range. In the HFDF-1, the sensing amplifier was required to supply all the indicators with a sense signal. This meant that the amplifier was loaded not only with the three indicators but also with the capacitance of the connecting cable. This resulted in a considerable phase shift and its associated "tailing" in the presentation. Consequently, the development of intensification units which have no inherent phase shift was necessary in the improved version in order that the tailing would be reduced to a minimum.

CHAPTER III

ASSOCIATED EQUIPMENT

It is necessary that the improved version of the HFDF be compatible with associated equipment. The most important unit in this regard is the Q-3, an instrument designed to receive sferic electromagnetic radiation at various frequencies between 3 kilocycles and 10 megacycles and to photographically record data on the sferics received. In the HFDF-1 equipment the primary sferic display was recorded on 35 millimeter photographic film by moving the film at a constant rate through a camera focused on the HFDF indicator display. A light-tight box had been constructed to house the indicator and a strip film camera supplied by the United States Signal Corps was used to record the data. The Sferics Laboratory added the Q-3 to its compilment of equipment in 1959. The Q-3 has its own light-tight box and a Dumont oscillographic recording strip film camera. It was therefore desirable to use this facility for recording the HFDF information.

The Q-3 Waveform Section

The purpose of this section is to receive the waveform of a sferic and record it on film. The waveform is received on a vertical 12 foot whip antenna and is amplified for presentation on the cathode ray oscillograph. The amplifiers for this purpose have a frequency response from 3 to 300 kilocycles and additional filters may be used to attenuate the high frequencies at a rate of 72 db per octave from a breakpoint of 150, 200, 250, or 300 kilocycles. There is a delay of 50 microseconds introduced in the signal path to enable the very first part of the waveform to appear in the presentation.

The waveform is presented on the cathode-ray tube by means of a linear sweep. This sweep is initiated by a trigger circuit which must of necessity trigger only on sferics of greater than a certain amplitude. Thus there are always sferics which are not presented in this section because of their amplitude.

A raster presentation is used to separate closely spaced waveforms. The sweep has ten different positions along the ordinate and is given the next position after each waveform has been presented. This makes possible a presentation of a greatly increased number of waveforms for a given film speed.

The Q-3 Frequency Sampling Section

The waveform section of the Q-3 presents all of the information about the energy content of the sferic between 3 and 300 kilocycles, in the form of an amplitude versus time plot. The Fourier Integral is a mathematical method for converting this time function into a frequency function. In practice, however, the arithmetic is too involved without the aid of an electronic computer. Therefore the Q-3 has three beams of a four-beam cathode-ray tube devoted to spot checks of the energy content of the sferic at frequencies of 20 and 75 kilocycles and 10 megacycles. In essence these are merely tuned tank circuits connected to the deflection plates of the cathode-ray tubes through amplifiers. The tank circuits will ring at their natural resonant frequency and the amplitude of the ringing will be proportional to the energy at the particular frequency involved. Thus the amplitude of the presentation will be directly proportional to the energy content at that frequency.

The Q-3 Direction Finding System

The Q-3 has a direction finding system which is very similar in principle to the HFDF-1 described in Chapter II, except that it operates on the 10 kilocycle component of the sferic rather than the 150 kilocycle component. It uses two orthogonally oriented loop antennas of 400 turns each as the primary signal source in conjunction with a vertical whip as the source of a sensing signal. The presentation may be either of two types called RF operation and DET operation. In RF operation the output of the tank circuits is connected directly through the deflection amplifiers to the deflection plates of the cathode-ray tube. In DET operation the signals are first rectified by a phase-sensitive rectifier so that the presentation is only one strobe which is in the direction of the sferic. Since this system utilizes the 10 kilocycle component of the sferic, it also gives an indication of the energy content of the sferic at this frequency and may be considered as part of the frequency sampling section as well.

The Q-3 Timing System

The Q-3 has a very elaborate timing system which permits the timing of the sferic to within a few milliseconds. A 100 kilocycle crystal oscillator is used as the basic standard. Transistor frequency dividers reduce the 100 kilocycle signal to a 100 cycle power source to drive a digital clock. Further dividers reduce this to one and six-second pulses which operate lights in the camera box for accurate timing. The entire timing system is periodically calibrated with the National Bureau of Standards uniform time signal, WWV.

Other Equipment

The HFDF-1 operated two other indicators in addition to the one used for film recording. One was a visual indicator used to accurately determine the angle of highly active storm cells. This unit was a cathode ray display with a pointer and azimuth ring mounted so that the pointer could be positioned over the active sferic display and the angle of the display read directly from the azimuth ring.

A third indicator was used for an electronic sferic incidence azimuth integrator. This device records a time-averaged integration of the number of sferics per second occurring at any particular angle.

CHAPTER IV

SYSTEM ORGANIZATION

The development of an improved version of the HFDF-1 (referred to hereafter as the HFDF-2) required an overall plan of organization. The plan had to incorporate all of the desired improvements as set forth in Chapter II as well as to be made compatible both with the existing HFDF-1 and with the new Q-3.

At the beginning of this project a new underground concrete laboratory was built to house the new equipment. Since the antennas were semi-permanent structures, it was decided that they be constructed in their final form at the new site. A balanced line and balanced shielding were considered to be one of the necessary improvements. However, the HFDF-1 receiver inputs were single ended. This required that either the receivers be modified for balanced input or that an intervening preamp be developed which would permit driving a single-ended input with a balanced line. The latter alternative was taken because the logical design of the final system indicated that a common preamp driving individual receivers would be the best design. The calibration functions were also included in the preamp. Thus the development of a final unit of the HFDF-2 could commence and the unit would be compatible with the HFDF-1. The unit was designed to provide additional amplification to increase the sensitivity of the HFDF-1. It included the calibration circuitry so that it could serve as a calibrator for the HFDF-1 as well as the HFDF-2.

Physical arrangement was important in the design of the HFDF-2. Relay rack mounting was used for the HFDF-2 because it provides the ease of maintenance and flexibility of modification so necessary to satisfactory operation of such equipment. The Q-3 is also relay rack mounted equipment and much of the completed HFDF-2 is mounted in the Q-3 cabinets.

The original HFDF-1 deflection amplifiers were unsatisfactory for use with the cathode-ray tubes in the Q-3 because of the considerably lower sensitivity of these tubes. In order to have a completed system at the earliest possible time, the deflection amplifiers of the HFDF-2 were designed and built concurrently with the preamp. These amplifiers, also built on a relay rack chassis, are required to amplify the HFDF receiver signal with minimum phase shift and distortion and produce a maximum peak output voltage of over 200 volts. They are connected to the deflection plates through a special junction box which permits access to any of the deflection plates on the 4-beam cathode-ray tube in the Q-3 camera box. This junction box also includes a switch which permits interconnecting of the plates on the fourth beam of the 4-beam cathode-ray tube, so that the presentation of this beam may be rotated 0°, 90°, 180°, or 270°. Azimuth rotation is accomplished by this method.

The sense channel of the HFDF-1 required an input from a vertical whip antenna. In the original operation of the new system a cathode follower and whip antenna used for the 10 megacycle frequency sampling section of the Q-3 were used to excite the sense channel. In later development this was replaced with a whip antenna and preamp designed expressly for the HFDF-2.

It was found that the sense channel for the HFDF-1 did not provide sufficient output voltage for proper operation of the intensification circuits of the Q-3. Therefore, a small amplifier was hurriedly built for intensification purposes and the HFDF-1 receivers were successfully adapted to the Q-3 presentation so that experiments could again be run with the HFDF.

Further development included the design and construction of two HFDF-2 intensification units. One of these was designed to be used with the Q-3 indicator and the other with the counter indicator.

Operation of the system in this manner became difficult because of continued maintenance requirements of the HFDF-1 receivers, and it was decided to build the new receivers for the HFDF-2. The design of the receivers includes the same basic functions as the HFDF-1 receivers but uses considerably different circuitry. The input stage is a grounded grid type and includes a ten-step attenuator to reduce the signal level at the input to prevent overloading of the receiver on high signal levels. The receiver also has the 1/2 step gain control which was used on the HFDF-1. The output stage of the receiver was designed to have an output impedance of 100 ohms so that several deflection amplifiers and associated cabling could be used without appreciably loading the receivers. The sense receiver was originally designed with a high-impedance grounded cathode input circuit, but later design of a sense preamp enabled use of the same unit as is used for the loop receivers.

Due to the higher sensitivity of the HFDF-2 receivers, more difficulty was experienced with interference from radio stations than had been encountered before. Notch filters were designed to attenuate the particular frequencies that were causing interference and were installed between the HFDF-2 preamp and HFDF-2 receivers.

To complete the system, two more deflection amplifiers were built to be used with the counter indicator. The line amplifiers from the HFDF-1 were found to work satisfactorily with a Dumont 304 oscilloscope when used as a visual indicator, and a small amplifier, which was already built, was found to be satisfactory as a sense amplifier for the visual indicator.

Calibration was a problem with the original sense arrangement because of uncertainties in the Q-3 whip antenna and cathode follower circuit. Therefore, a sense antenna and a preamp were build to provide a standard signal for calibration purposes. One feature of the new preamp is that the sense receiver can be of the same design as the other two receivers because of the low output impedance of the sense preamp. This is an advantage in servicing because a spare receiver can be kept which will replace any one of the receivers in case of malfunction of that receiver.

New Lambda 32M regulated power supplies were purchased for operation of the various equipments of the HFDF-2. All of the HFDF-2 units were designed to operate from standard voltages of +300 volts and -300 volts for the direct current supply and 6.3 v.a.c. for the filament supply. This permits considerable flexibility in allotment of power supplies; however, crosstalk can be reduced if a single power supply does not supply units which operate at different signal levels.

CHAPTER V

THE ANTENNAS

As the primary signal source for the HFDF-2, the antenna assembly is one of the simplest and one of the most critical units of the entire HFDF-2 system. The antenna assembly has two distinct parts, the loop antennas and the vertical whip antenna.

The Loop Antennas

The theory of the loop antenna can be best described in terms of the square loop shown in Figure 3.

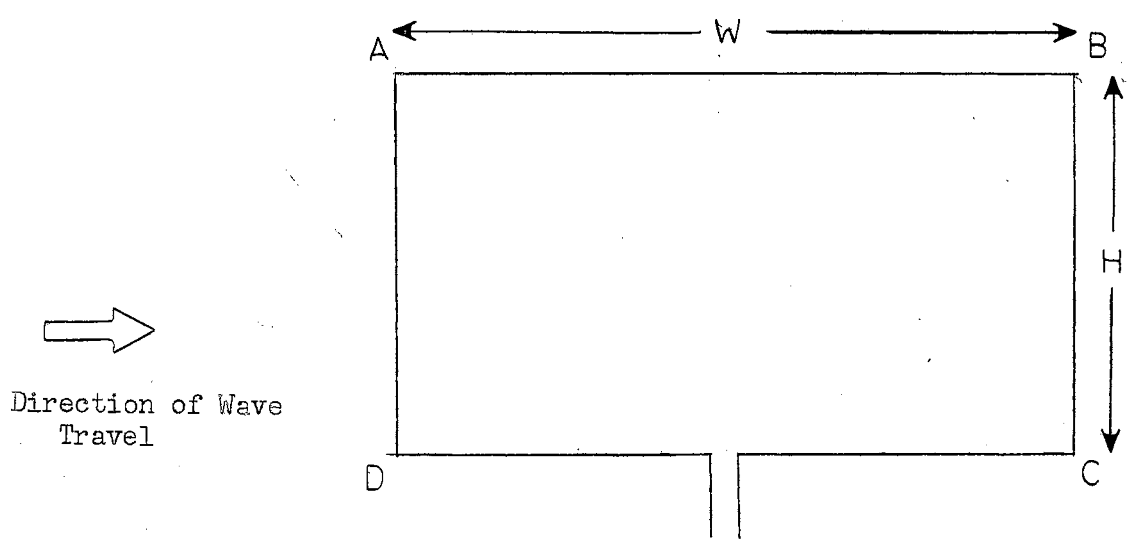


Figure 3. Loop Antenna for Theory Discussion

First, consider the plane of the loop to be parallel to the direction of travel of the EM wave. A voltage will be induced in side AD which is proportional to the electric field along AD, and a voltage will be induced in side BC which will be proportional to the electric field along BC. There will be no voltage induced in sides AB or DC because the electric field of the EM wave is everywhere perpendicular to these sides. If the induced voltages in sides AD and BC were exactly the same, there would be no terminal voltage since these voltages are series subtracting around the loop. However, there is a slight phase difference between the two voltages caused by the time it takes the wave to travel from one side of the loop to the other. This angle is very small for the HFDF antennas, since the dimensions of the antennas are very small compared to the wavelength of a 150 kilocycle EM wave. Figure 4 is a vector diagram of the voltage relationships in a loop antenna. The resultant voltage at the antenna terminals is 90° out of phase with the electric field at the antennas.

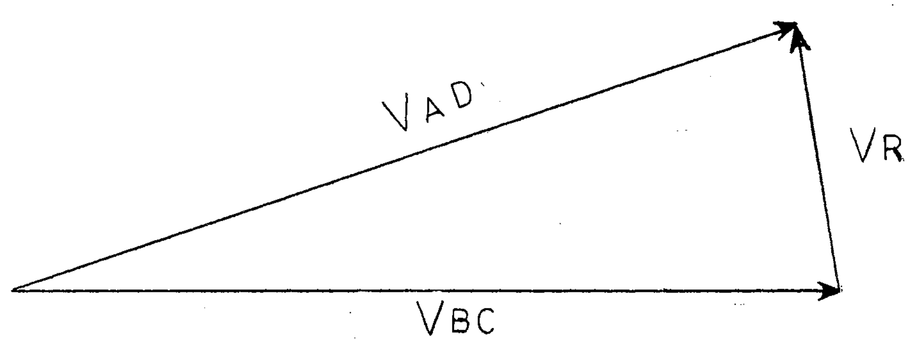


Figure 4. Vector Diagram of Voltage Relationships in a Loop Antenna

The preceding discussion has been concerned only with a square loop, but it is found that the relationships are essentially the same for a loop of any geometry as long as the plane of the loop is vertical and the dimensions of the loop are small compared to the wavelength. Two loops will have essentially the same characteristics if they both enclose the same area, and loops of different areas will have output voltages proportional to their areas.

The directional effect of a loop antenna may be thought of as a change in the effective area of the loop. Figure 5a shows the case which has already been discussed where the plane of the loop is in the direction of wave travel. In this case the total area of the loop is the effective area also. Figure 5b shows the case where the plane of the loop is perpendicular to the direction of wave travel. In this case the component of width parallel to the direction of wave travel is zero, and thus the effective area is zero and no signal is received. Figure 5c shows the case where the plane of the loop is inclined at some angle θ with respect to the direction of wave travel. In this case the component of width, W_e, parallel to the direction of wave travel is

$$W_e = W \cos \theta$$

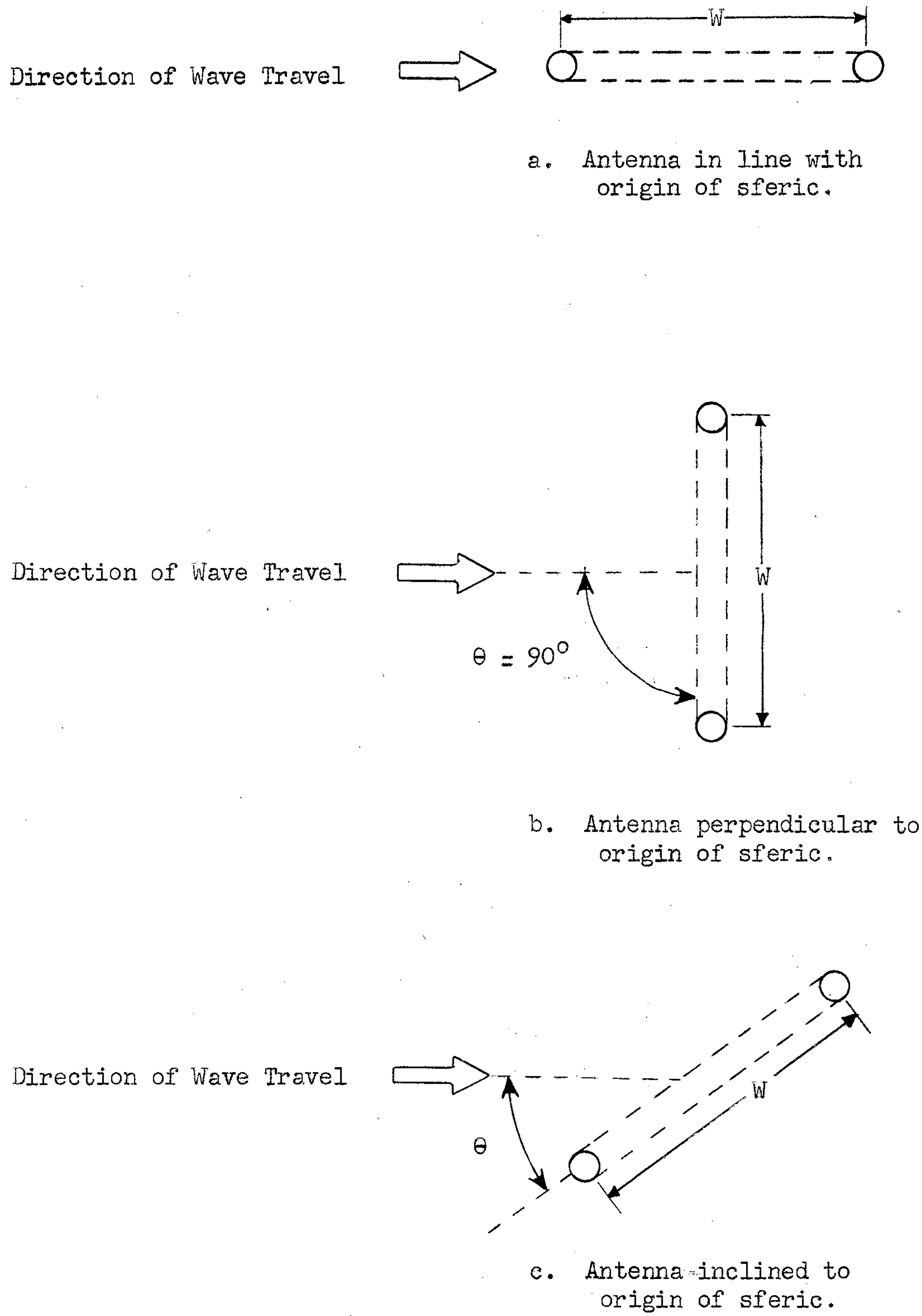
and the effective area, A_e, of the loop is

$$A_e = W_e h = W h \cos \theta$$

and the signal is thus proportional to $\cos \theta$ in the general case.

If a second loop antenna is placed perpendicular to the first one, it will produce a signal proportional to $\cos (90^\circ - \theta)$ or $\sin \theta$, and the required signal sources are thus available.

The preceding discussion has assumed that the loops are entirely free from external effects. This is never true in practice. Any metallic



a. Antenna in line with origin of sferic.

b. Antenna perpendicular to origin of sferic.

c. Antenna inclined to origin of sferic.

Figure 5. Effect of Angle of Arrival on Loop Effective Area.

object in the area will act as an antenna for the EM wave, i.e., a voltage will be set up in the object, and this voltage will cause a current to flow so that the wave will be reradiated. Due to the fact that conductors very much shorter than 1/2 wavelength are very inefficient radiators of energy, it was not anticipated that much difficulty would be experienced with this phenomenon. However, one precaution was taken to guard against trouble of this nature. Near the location of the laboratory, there are several barbed wire fences which are many times the length of any other conductors in the area except the power lines. In order that the long barbed wires would not act as reradiators, they were cut at intervals along the fence and joined by insulators. Of course, this could not be done with the power lines, and it is hoped that they do not have too detrimental an effect upon the loop characteristics.

Another external effect is caused by unbalanced capacitance to the loop from objects near the loop. If an object is near one side of the loop, it will cause an additional capacitance to that side of the loop which will cause additional currents to flow in the loop and cause additional signals at the loop terminals. This effect may be minimized by enclosing the loop in a shield which is grounded on both sides at the loop terminals and is opened at the center top of the loop. It is necessary to open the shield at the center top in order that the shield does not act as a short-circuited transformer turn and short out the signal. By grounding both sides of the shield at the loop terminals, the capacitance to ground is made equal at all points on the loop, and the unbalanced capacitance effect is minimized. Shielding the loop in this manner also eliminates any signals which may be caused by electrostatic effects such as charged dust or rain particles hitting the loops.

The HFDF-2 loop antennas were designed to take the considerations discussed above into account. Each of the antennas is a single turn loop of RG-11U coaxial cable mounted on a frame which holds the top center of the loop 22 feet in the air and the corners of the base 20 feet each side of the center so that each loop forms an isosceles triangle whose area is 440 square feet. The loops are mounted so that the plane of one loop is parallel to a north-south line, and the plane of the other loop is parallel to an east-west line. These are called the north-south loop and the east-west loop, respectively.

The loops are shielded by connecting each end of the shield of the coaxial cable to ground at the terminal box and breaking the same shield at the top center of the loop. It should be noted that an earth ground is not used at the antenna's site because it has been found that severe ground currents exist near the laboratory. Thus all the laboratory equipment is grounded at one point which has been chosen to be the Q-3 whip antenna location.

Each of the loops is loaded with a 95 ohm resistor and connected to a 95 ohm balanced twinax transmission line which feeds the HFDF-2 preamp.

The Vertical Whip Antenna

The sense receiver of the HFDF requires a signal from a vertical whip antenna. In early stages of development of the HFDF-2, a whip antenna and associated cathode follower from the Q-3 were used to serve this purpose. However, these proved unsatisfactory because their characteristics were not stable enough at 150 kilocycles for accurate calibration of the equipment. Therefore, a separate whip for HFDF-2 use only was constructed.

Theory of a whip antenna will not be discussed because it is covered in many standard texts. The whip used for the HFDF-2 is eight feet high, which is very small compared to a wavelength at 150 kilocycles. Therefore, it may be assumed to have an effective height of 1/2 its physical height and input capacitance equal to the measured low frequency capacitance of the antenna. If the input circuitry does not load the whip significantly, the output voltage of the loop will be in phase with the electric field of the EM wave.

The Whip Antenna Preamplifier

The whip antenna preamp was required to have a high input impedance so that it would not load the whip; an output impedance of 75 ohms to match the RG-11U coaxial leadin cable; and produce a 90° phase shift (either lead or lag) in order that the sense signal would be in phase with the loop signals, which are inherently 90° leading the electric field. The preamp shown in Figure 6 was designed using 1/2 a 12AU7 as a cathode follower for a high input impedance and the other half of the 12AU7 as a phase shifter and amplifier to secure the desired 90° phase shift. A 12 db per octave low pass filter was used to shift the phase because it would also serve to attenuate the higher frequencies and thus eliminate much of the interference from radio stations in the broadcast band. The output of the preamp is a totem pole amplifier designed to have an output impedance of 75 ohms. This entire unit is mounted inside a weather-proof case and fastened next to the whip on the roof of the laboratory.

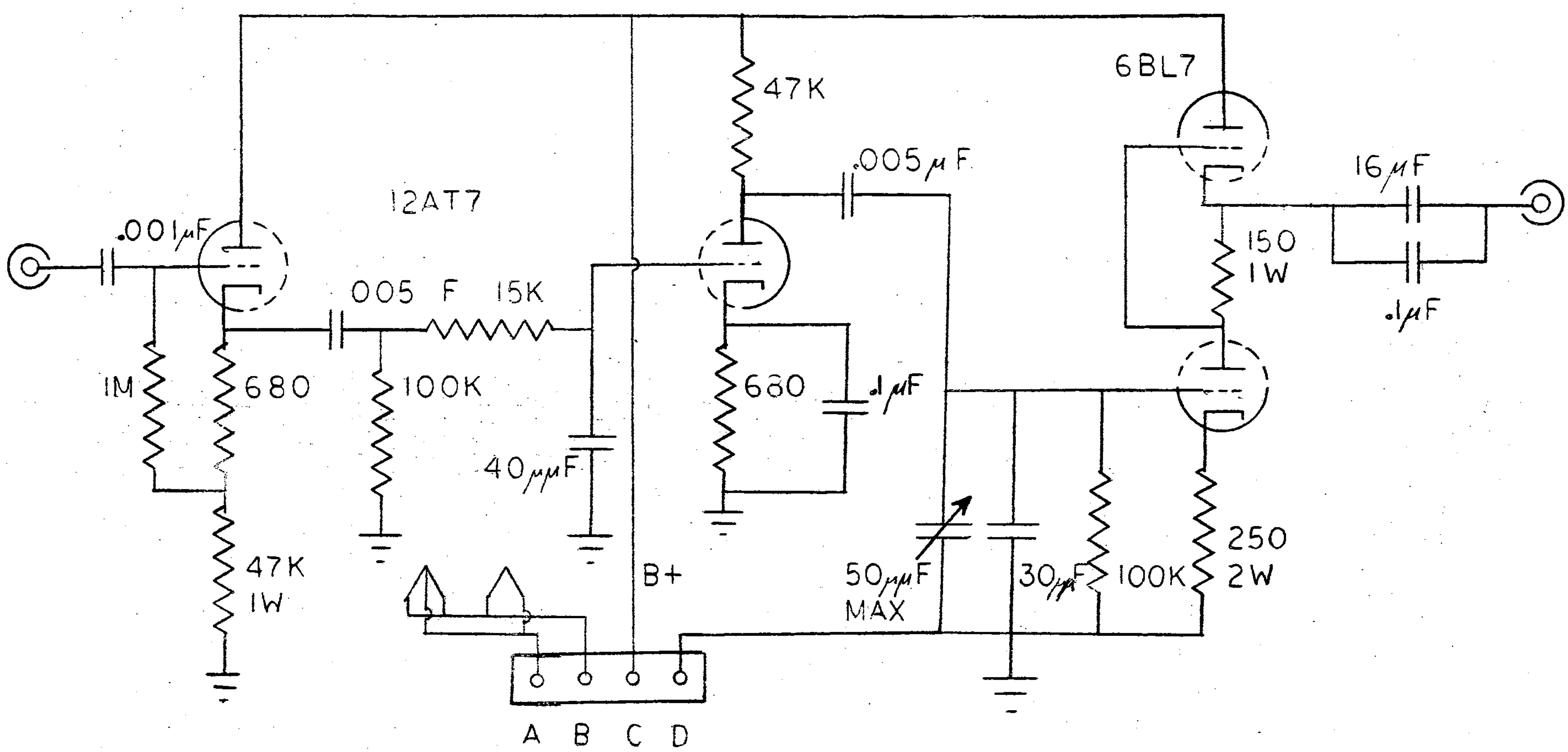


Figure 6. Whip Antenna Preamplifier

CHAPTER VI

THE HFDF-2 PREAMP AND CALIBRATOR

The HFDF-2 preamp and calibrator is designed to match the output of the balanced line from the loop antennas to the single ended input of the receivers and provide the calibration functions necessary for accurate calibration of the entire HFDF-2 system. The HFDF-2 preamp originally had to be compatible with the HFDF-1 receivers, and thus had to be capable of driving the low impedance load of the HFDF-1 receiver input. It was also desired that the preamp have some gain in order that the sensitivity of the system could be increased.

The Preamplifier Section

The input of the preamp is a balanced grounded-grid amplifier. The grounded grid configuration is used because the antennas represent a low impedance driving source, and the higher gain and lower noise level of this configuration can be used to advantage in the input circuit. The 250 ohm potentiometer in the plate circuit permits adjustment of the relative gain of the two amplifiers in the input circuit so that they may be balanced.

A differential paraphase amplifier is used to convert the balanced output of the first stage to a single ended output. The 1,000 ohm potentiometer in the cathode of the differential amplifier adjusts the bias on the separate sections of the amplifier in order to secure the best common mode rejection ratio. A common mode rejection ratio of about 70 is possible. The output stage of the preamp is a totem pole amplifier designed to match the 47 ohm input of the HFDF-1 receivers. The HFDF-2 receivers could have been designed for a high impedance input, but the low impedance terminations permit more flexibility in physical arrangement of the HFDF-2 system, since the preamp and receiver may be physically separated by any desired distance. The two channels shown in Figure 7 comprise the amplifying section of the preamp. One of the channels is used for the N-S loop and the other for the E-W loop.

The Calibration Section

The calibration section of the preamp is shown in Figure 8. A pulse transformer is used to convert the single ended pulse from the Hewlett-Packard model 212-A pulse generator into a balanced output, which is suitable as a test input into the preamp. A resistance divider network provides a very low impedance output which is necessary to prevent the preamp from loading the calibrator. A flexible switching arrangement permits the connection of the calibrator to the preamp in any possible arrangement. Switch S_2 connects the calibration pulses to both HFDF loop receivers or to either one individually. Switch S_1 causes an apparent rotation of the calibration display by 0°, 90°, 180°, or 270° and also switches the loop amplifiers to the loop antennas in the operation position and to ground for special maintenance tests. If S_1 is in the 0° calibrate position and S_2 is in the both receivers position, a calibrate pulse will excite both receivers by exactly the same amount in the positive direction, and the indicator display should be a strobe at 45°. If, however, S_2 is in the N-S receiver position only, that receiver will

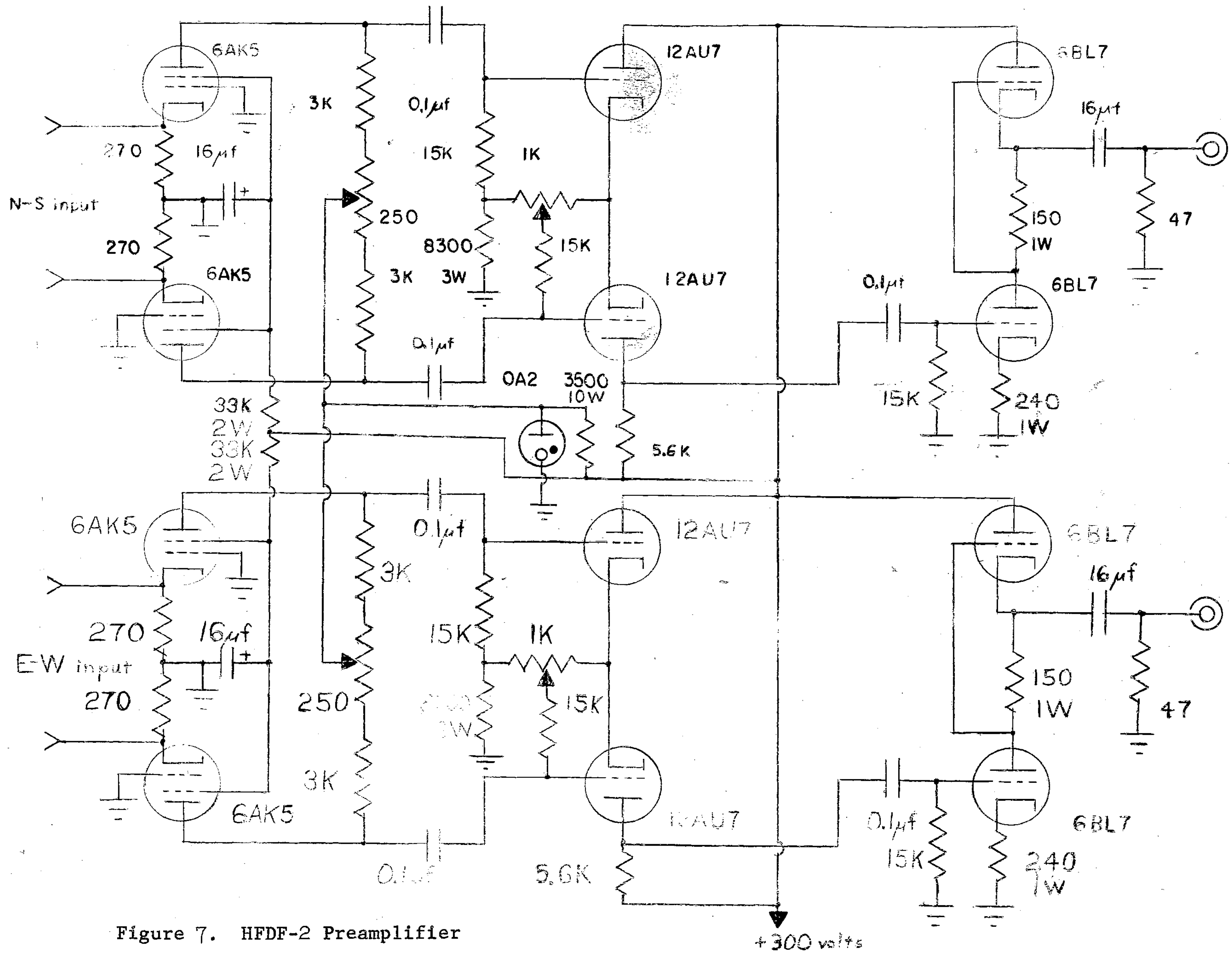


Figure 7. HFDF-2 Preamplifier

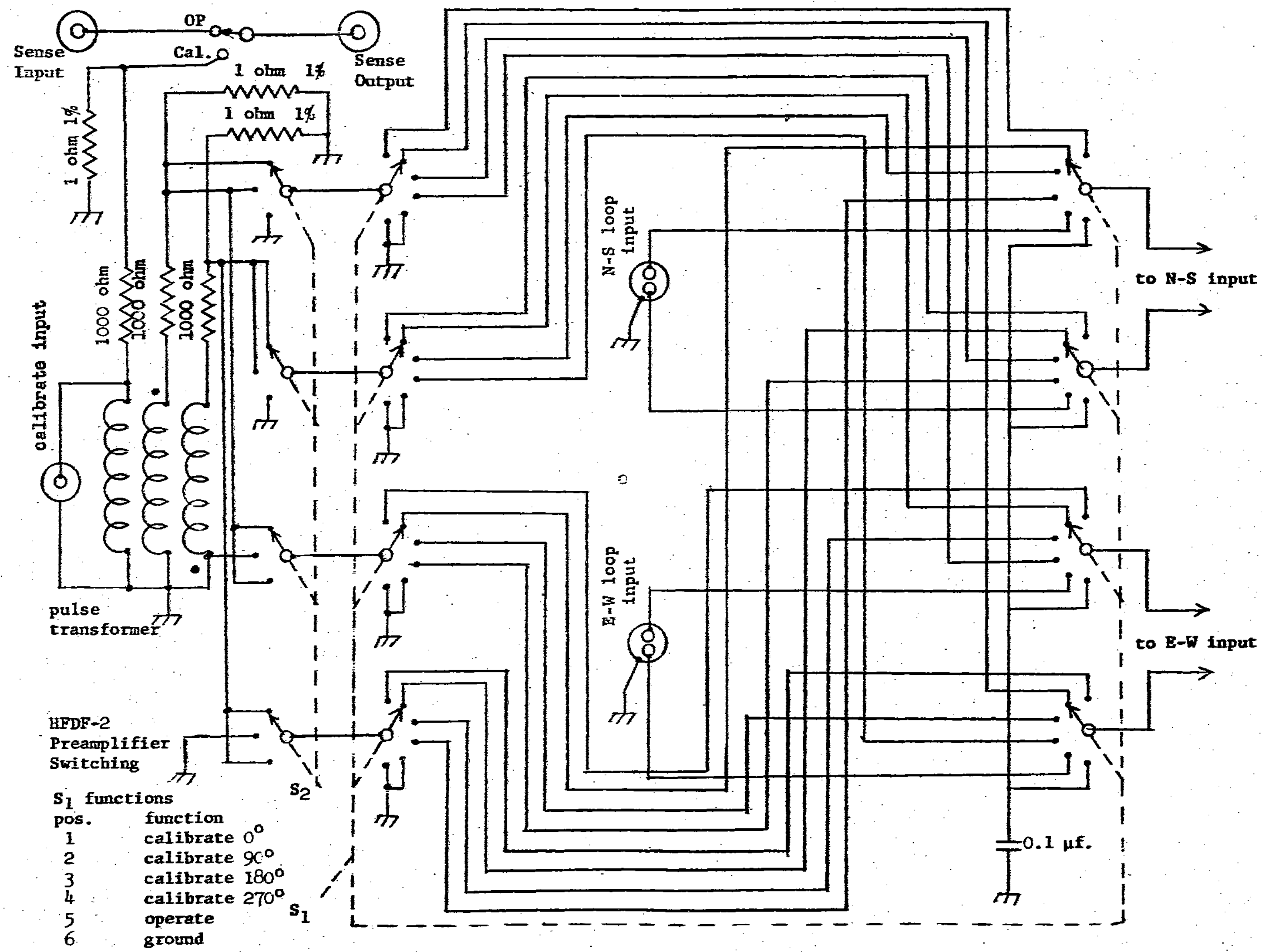


Figure 8. Calibrator Unit

receive the calibration pulse and the indicator display will be a strobe at 0°. Likewise if S_2 is in the E-W receiver position, the strobe will be at 90°. If S_1 is switched to 90°, 180°, or 270°, an apparent rotation of that amount will be indicated in the strobe position. This flexible switching arrangement permits calibration of the indicators for azimuth, calibration of the strobe length for energy content, and calibration of the azimuth markers on the sferic incidence azimuth integrator. The method of calibration will be discussed in Chapter IX.

The completed preamp and calibrator is mounted in a five inch panel chassis and is powered by a Lambda 32M power supply, which also powers the sense preamp. This power supply should not be used to supply other equipment because of the high sensitivity of the preamplifiers.

CHAPTER VII

THE HFDF-2 RECEIVERS AND NOTCH FILTERS

In the present form of the HFDF-2 system all three of the receivers are identical. They are driven by a low impedance single ended preamp and feed the deflection or intensification units from a low impedance source. Each receiver has a 1/10 step gain control at the input so that large signals may be attenuated before amplification to prevent overloading of the circuit and a 1/2 step gain control to accommodate a further dynamic range of signal strength. Also included are a damping factor control to vary the ring time of the tank circuit and a gain balance control to vary the total gain of a channel and thus permit adjustment of the balance between the two receiver channels.

Figure 9 is a diagram of an HFDF-2 receiver. The input is a series of ten 10 ohm resistors connected by a switch to a grounded cathode amplifier so that gains of 1 to 1/10 may be selected. A grounded cathode amplifier is used because a low impedance driver is available, and it is desired to have as high an impedance as possible to drive the tank circuit. A grounded cathode configuration also permits a higher gain per stage than any other configuration. A pentode is used because of the desirability of high output impedance and high gain in the first stage. The plate of the 6AU6 input pentode is connected directly to the tank circuit, which is tuned to 150 kilocycles by the variable capacitor.

A cathode follower is used to isolate the input stage from the rest

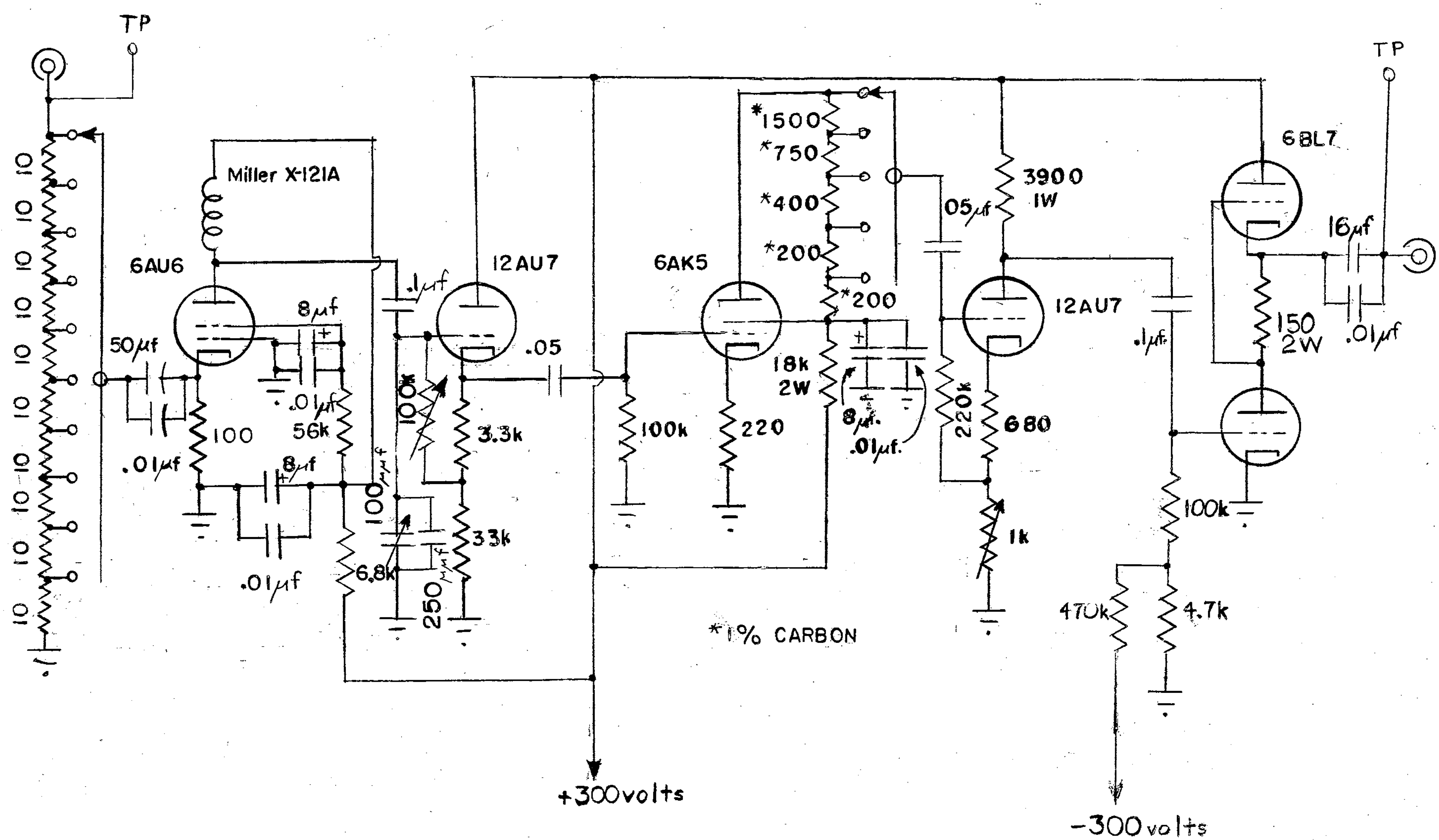


Figure 9. HFDF-2 Receiver

of the circuit. The 100 K variable resistor in the grid circuit of the cathode follower varies the resistive loading of the cathode follower on the tank circuit, and thus varies the damping factor (or bandwidth) of the resonant condition.

Two video amplifiers are used to amplify the resulting output waveform of the tank circuit. Video amplifiers are required because even small phase shifts at 150 kilocycles cannot be tolerated. The first amplifier, a 6AK5 pentode, has a nominal gain of 8, which may be reduced to 4, 2, 1, or 1/2 by means of the 1/2 step gain in the plate circuit. The second video amplifier is the other half of the 12AU7 used for the cathode follower and has a maximum gain of 2.5. Its major purpose is to permit adjustment of the overall gain of the unit so that the two units of the loop system may be matched identically. A variable resistor in the cathode of this stage permits adjustment of the gain of the stage without detrimentally affecting the frequency response or phase characteristics of the amplifier.

A 6BL7 totem pole amplifier is used in the output stage to provide a low output impedance of about 100 ohms. No effort is made to match the amplifier to the coaxial connecting cables, because three cables are connected to each receiver and would load the amplifier with a prohibitively small resistance if matched to the output amplifier. Therefore, the output impedance is made small enough so that the reactance of the shunt capacitance of the connecting cables is large in comparison. This is possible because the connecting cables are relatively short.

The entire receiver is mounted on a standard 3 1/2 inch panel rack chassis, and the three receivers are powered by one Lambda 32M power supply with the exception of the -300 volts, which is supplied by the

-300 volt power supply on the Q-3.

The Notch Filters

Due to the increased snesitivity of the HFDF-2 over the HFDF-1, considerable trouble was expected and experienced with interference from local radio stations which broadcast in the lower frequency section of the broadcast band. In particular the Stillwater radio station KSPI on 780 kilocycles, and the Tulsa radio station KRMG on 740 kilocycles caused considerable interference with the presentation of the HFDF-2. Since these are the only radio stations which caused interference, it was decided to design notch filters to attenuate their particular frequencies. After a rather exhaustive study of possible filters, it was decided to build a parallel resonant circuit in series with the connection between the preamp and the receivers. This is a low impedance circuit and the impedance of the resonant circuit had to be very low at 150 kilocycles to prevent an undesirable phase shift through the notch filter. It was found that a coil of 3.5 millihenries in parallel with the correct capacitance to resonant at the radio station frequencies would produce about 4° phase shift in the signal at 150 kilocycles. This is absolute phase shift and the relative phase shift is very much smaller, so that such a value is permissible. The notch filters were designed with two such resonant circuits in each loop receiver line, i.e., one for KSPI and one for KRMG. The sense channel did not require a notch filter since it already has a 12 db per octave low pass filter built into the preamp which will eliminate radio station interference. The total notch filter (two sets of two resonant circuits) is mounted on a 3 1/2 inch panel rack chassis and is connected into the signal path by coaxial connectors. A diagram of it is shown in Figure 10.

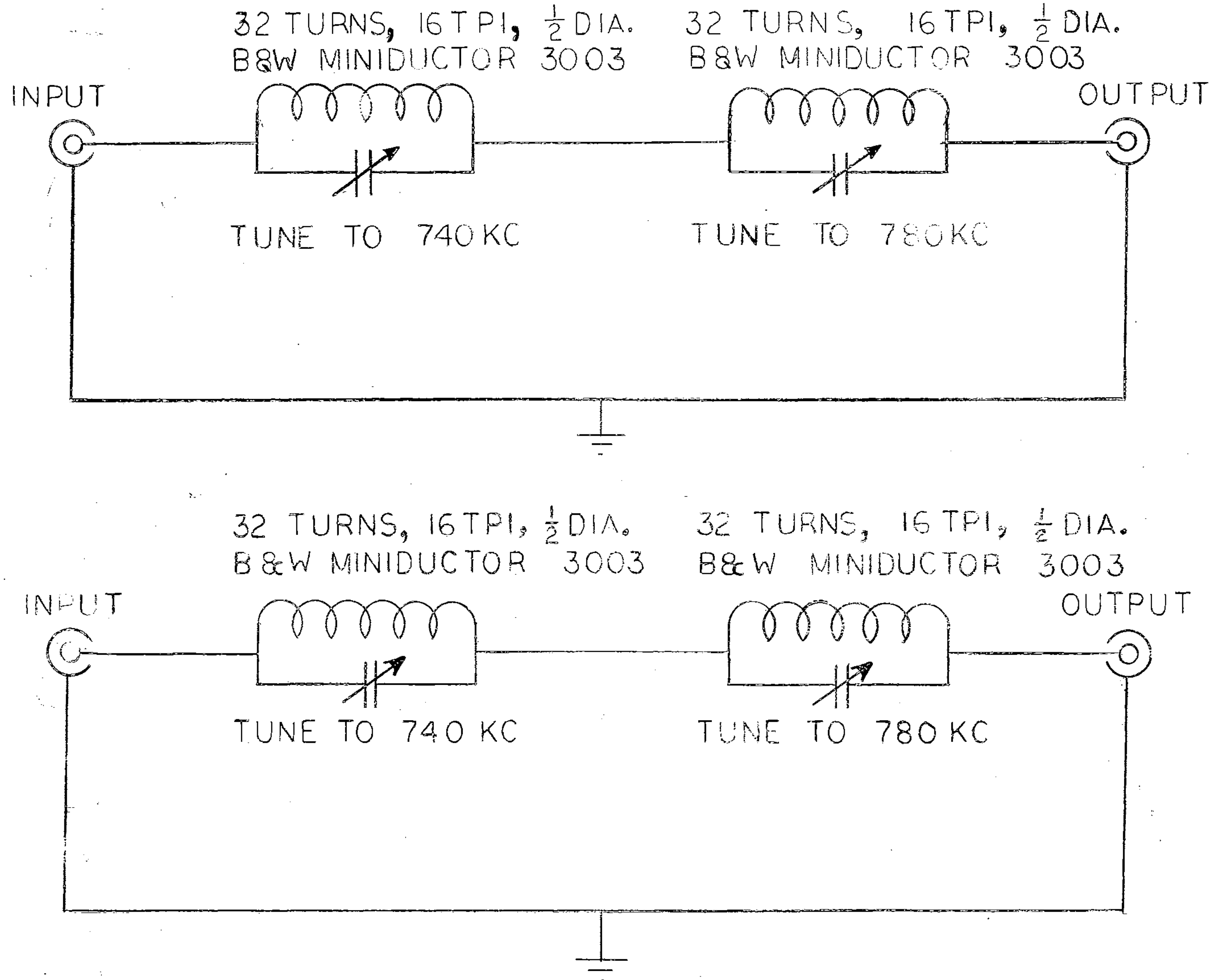


Figure 10. HFDF-2 Notch Filter

CHAPTER VIII

THE HFDF-2 DEFLECTION AMPLIFIERS AND INTENSIFICATION UNITS

The output level of the HFDF-2 receivers is relatively low, but a very high voltage level is required for the deflection plates of the cathode-ray tubes, which are used as indicators. Therefore, additional amplification is required in order to have a useful signal level. The high signal levels required by the deflection plates dictate a high impedance output from the deflection amplifiers. At the frequencies involved it is impossible to faithfully transmit the signal over any appreciable distance from a high impedance source. Thus the deflection amplifiers must be located very close to the indicators. The distribution of the signal is at the low impedance level from the HFDF-2 receivers, and deflection amplifiers are placed very near the indicators. The line amplifiers which were built for the HFDF-1 are used for the deflection amplifiers of the visual indicator in the HFDF-2 system. A diagram of these units is shown in Figure 11. The Q-3 indicator and the sferic incidence azimuth integrator indicator, however, require deflection amplifiers of greater gain and higher maximum output voltage.

The Deflection Amplifiers

Figure 12 is a diagram of the deflection amplifier which was designed for the HFDF-2. The amplifier is of conventional design but is

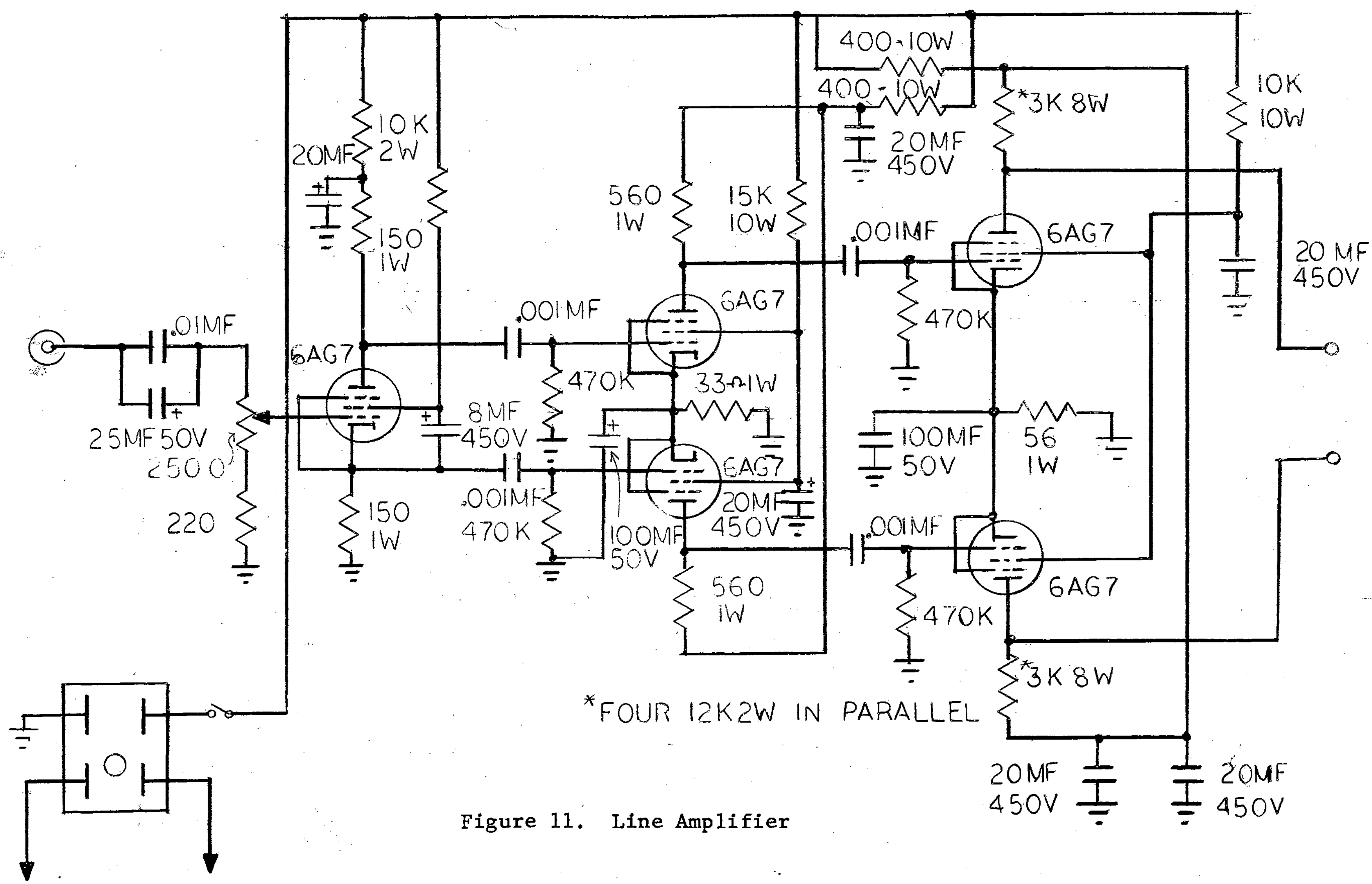


Figure 11. Line Amplifier

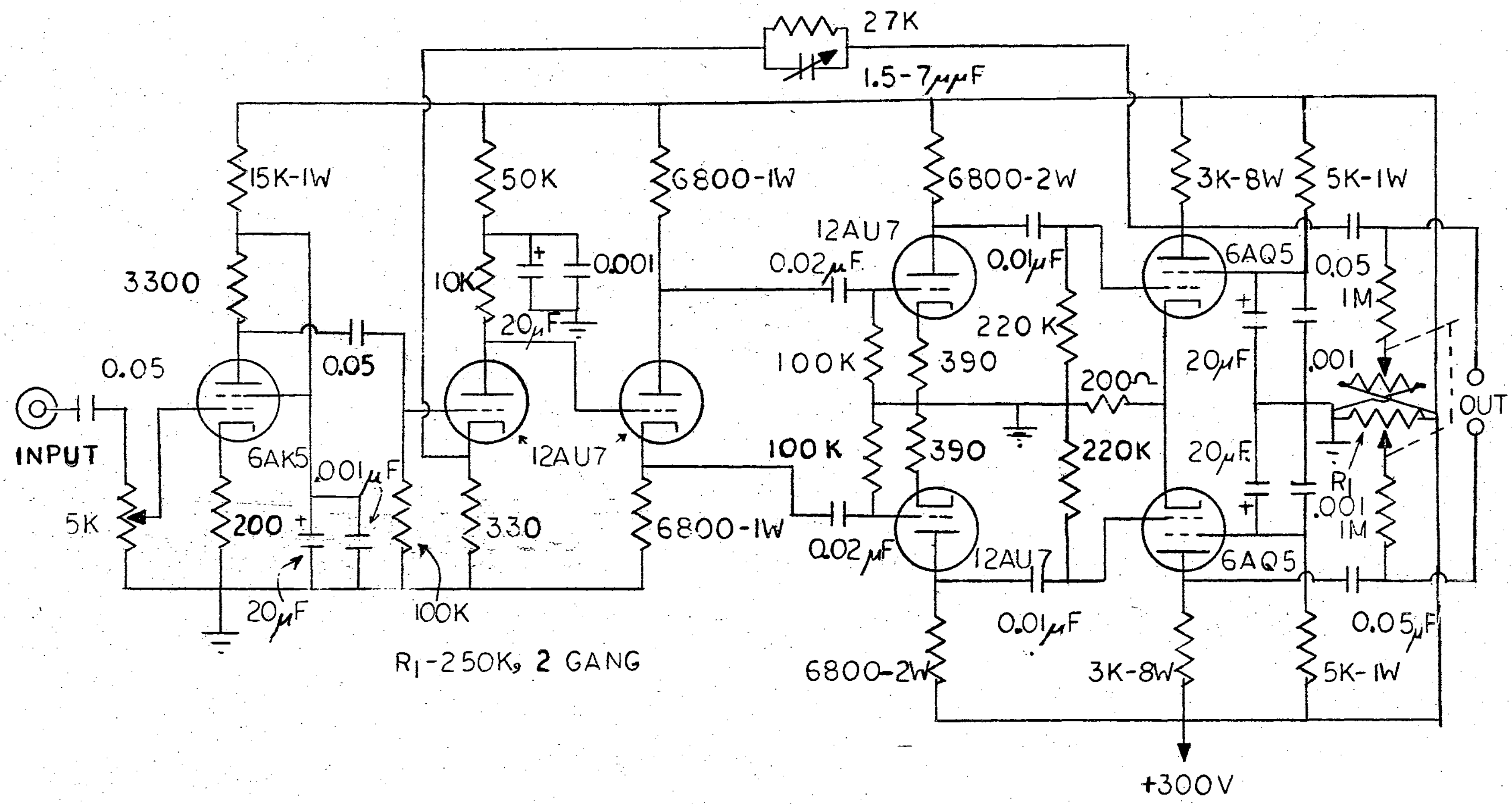


Figure 12. Deflection Amplifier

carefully designed and constructed to eliminate all possible phase shift at 150 kilocycles. A gain control at the input is used to compensate for the variance of deflection plate sensitivities in the cathode-ray tubes, and may also be used to increase the dynamic range of the system by lowering the gain of the deflection amplifiers. The first two stages comprise a conventional single ended video amplifier using a 6AK5 and 1/2 of a 12AU7 tube. The other half of the 12AU7 is used as a phase inverter which feeds a 12AU7 in a push-pull driver stage. The output uses two 6AQ5 beam power output tubes to drive the deflection plates. A dual potentiometer in the output circuit biases the deflection plates so that the electron beam may be positioned to any location on the indicator screen. The overall amplifier has a frequency response which is flat to 400 kilocycles. Two such deflection amplifiers are used for each indicator, i.e., one for the vertical deflection plates and one for the horizontal deflection plates. A Lambda 32M power supply is used for each set of two deflection amplifiers.

The Intensification Units

The output of the HFDF-2 sense receiver is a low level, low impedance source identical to the loop receiver outputs. The voltage and impedance levels are ideal for signal distribution, but are not high enough for proper operation of the intensification grids of the cathode-ray tubes. Intensification amplifiers were designed and built to be placed near the indicators and provide the necessary amplification. A diagram of these units is shown in Figure 13. The first three stages comprise a conventional video amplifier which is used to increase the sense amplifier's signal level. The last stage uses a 6AQ5 in a double clipping output

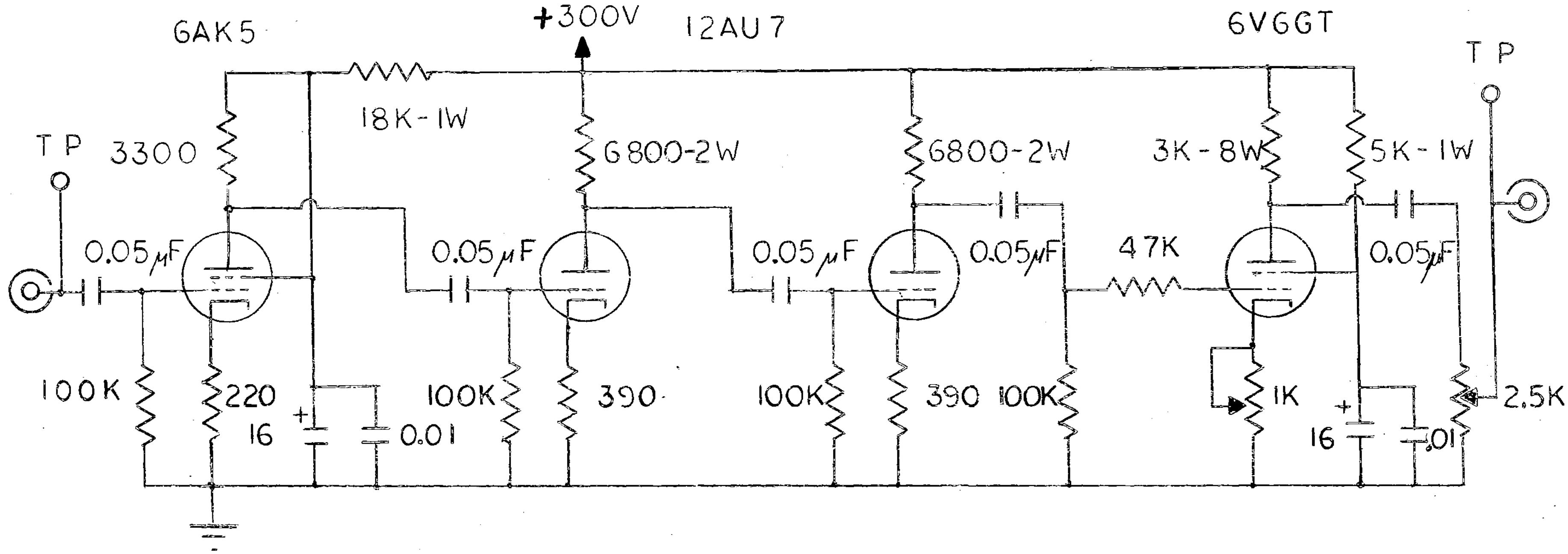


Figure 13. HFDF-2 Intensification Unit

stage. The grid is allowed to go below cutoff of the 6AQ5 and to clamp on positive grid current. This causes the output to be a pseudo square wave, which produces cleaner sensing than the conventional sine wave intensity modulation. The 100 ohm variable resistor in the cathode circuit of the 6AQ5 controls the symmetry of clipping. It may be adjusted by applying a simulated sferic to the sense input with the calibrator and observing the output of the intensification unit. The resistor is adjusted for symmetrical clipping of the sferic. A potentiometer is used in the output circuit to vary the amount of intensification. It is set by visually observing the indicator and adjusting the potentiometer for good intensification.

An amplifier which had been built some time ago is used for the intensification unit on the visual indicator. The visual indicator, a Dumont 304 oscilloscope, does not require as great a voltage for intensity modulation as does the other indicators, and the small amplifier works fine as an intensification unit. A diagram of the visual indicator intensification unit is shown in Figure 14. The unit is a simple three-stage video amplifier with a gain of 100 and response to about 1 megacycle.

A Lambda 32M power supply is used to power all three intensification units. Each unit is mounted on a 3 1/2 inch panel rack chassis.

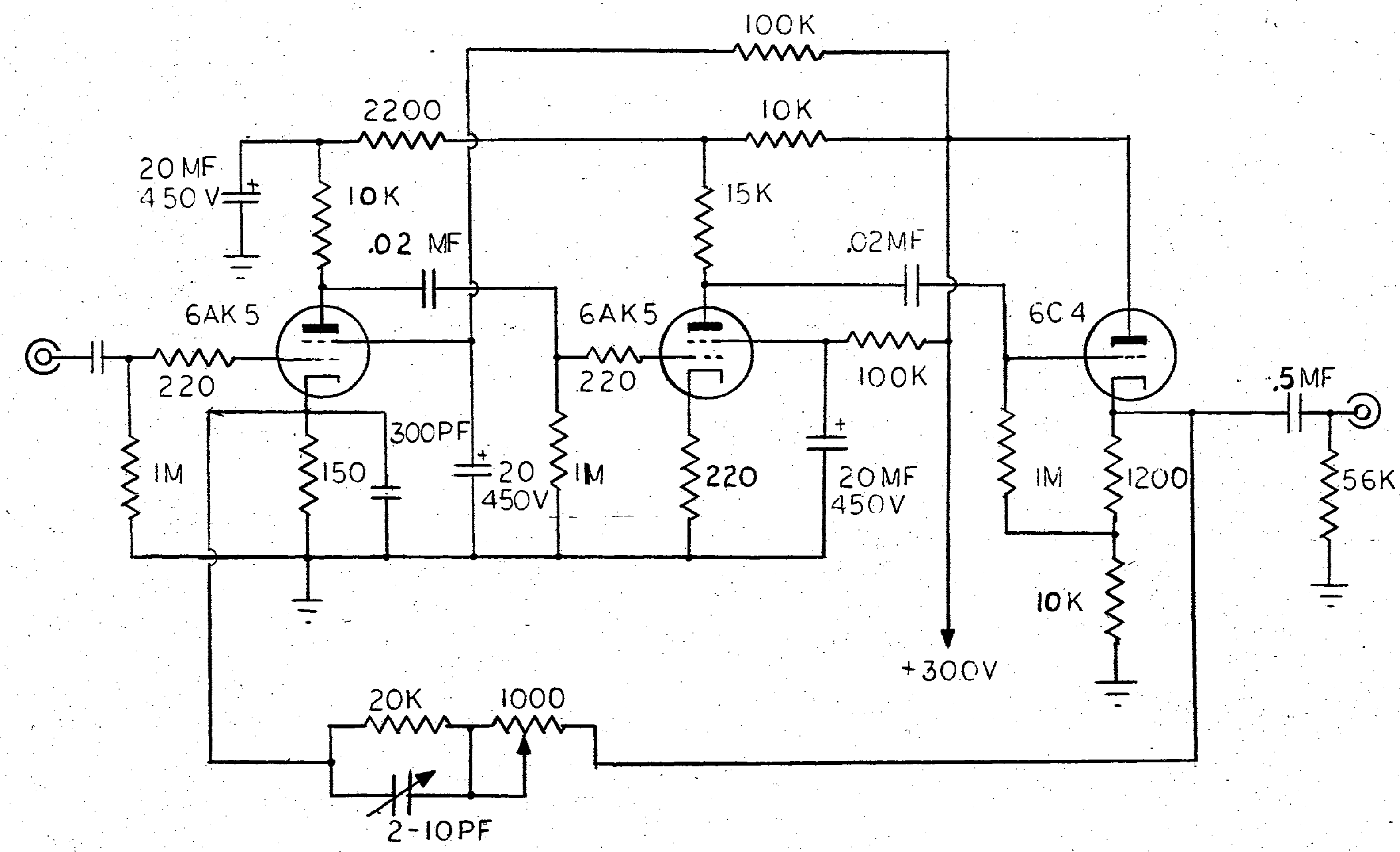


Figure 14. Visual Indicator Intensification Unit

CHAPTER IX

CALIBRATION AND TUNING

A flexible switching arrangement permits accurate calibration and tuning of the HFDF-2 and associated equipment.

Tuning and Calibration of Azimuth

The first step in tuning the HFDF-2 system is to tune one receiver. The Hewlett-Packard model 650 test oscillator is connected to the calibrate input on the preamp. The Tektronix model 502 oscilloscope is connected to a receiver output and the waveform is observed. The amplitude of the waveform should reach a maximum as the test oscillator is tuned to 150 kilocycles, and if it does not, the receiver must be tuned to 150 kilocycles. If it is desired to have a certain bandwidth, the bandwidth control of the particular receiver under test should be adjusted and checked at this time. The tuning and bandwidth controls of this receiver should not be adjusted after the above settings have been made.

The next step in the tuning procedure is to tune the other receiver and the sense receiver to identically the same frequency and bandwidth as the first. To accomplish this, a pulse tuning technique developed by R. D. Kelly for the HFDF-1 is used. The Hewlett-Packard model 212A is connected to the calibration input of the preamp, and a 1 microsecond pulse is used to excite the receivers. Switch S_1 is set to the calibrate 0^o position and S_2 to the both receivers position. The sense calibrate-operate switch should be in operate position to prevent feed through to the loop receivers. The 1/10 step gain of all receivers should be in the maximum gain position, and the 1/2 step gain controls in the minimum gain position. The Tektronix 502 oscilloscope is set for X-Y plotting at 100 microvolts per centimeter, and one input is connected to the output of the receiver, which has already been tuned, while the other input is connected to the other loop receiver. The X-Y plot should be a straight line inclined at 45° as shown in Figure 15. If the plot is a series of ellipses, as shown in Figure 16, the receivers are not tuned to the same frequency, and the tuning control of the yet untuned receiver should be adjusted. If the plot is fan shaped, as shown in Figure 17, the bandwidth of the two receivers is not the same, and the bandwidth control of the second receiver should be adjusted. If the plot is not inclined at 45°, as shown in Figure 18, the gains of the two receivers are not identical, and the gain balance of one of the receivers should be adjusted.

The sense receiver is tuned in exactly the same manner, except that the gain balance control of the sense receiver is set for maximum gain, and no effort is made to check the relative gain of the sense receiver with respect to the other receivers.

After the receivers have been properly tuned, the deflection amplifier gains may be set. The pulse generator is connected in the same manner as for the tuning procedure, and the settings of the HFDF-2 controls remain the same with the possible exception that the gain of the sense amplifier may need to be changed to secure proper intensification. A straight line should appear on the three indicators similar to the X-Y plot on

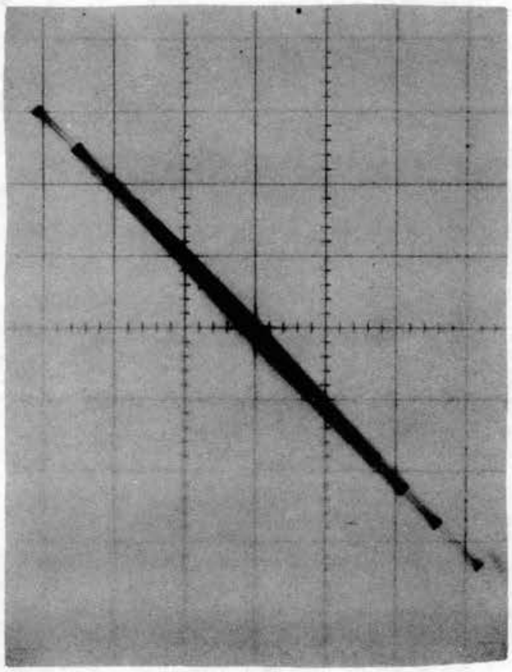


Figure 15. Properly Tuned Calibration Pattern.

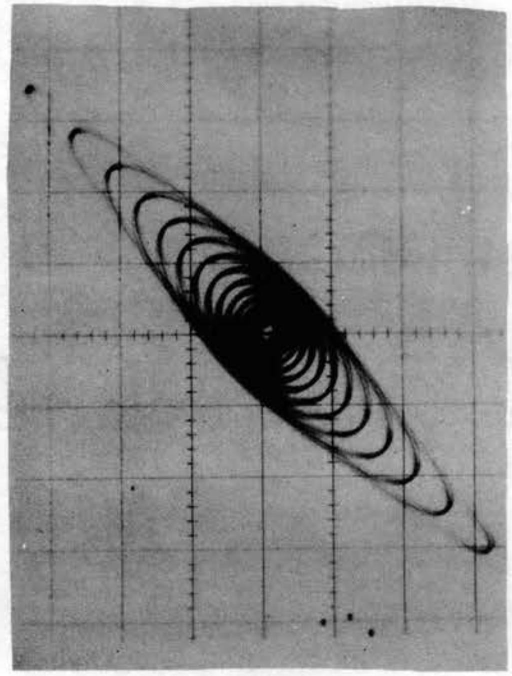


Figure 16. Tuning Control Incorrectly Adjusted.

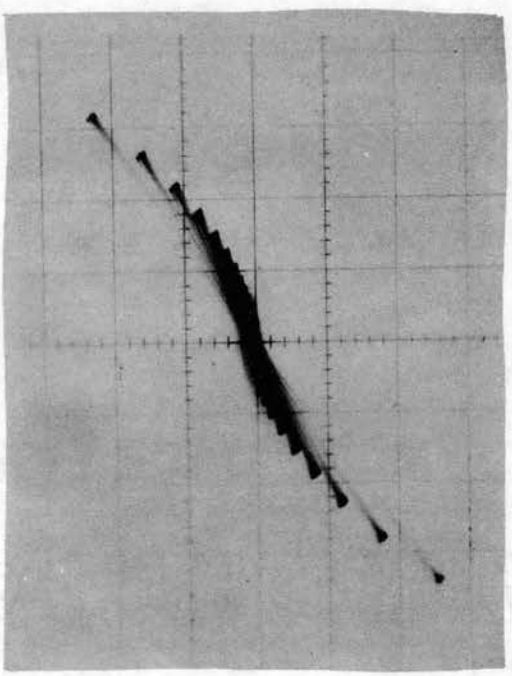


Figure 17. Bandwidth Control Incorrectly Adjusted.

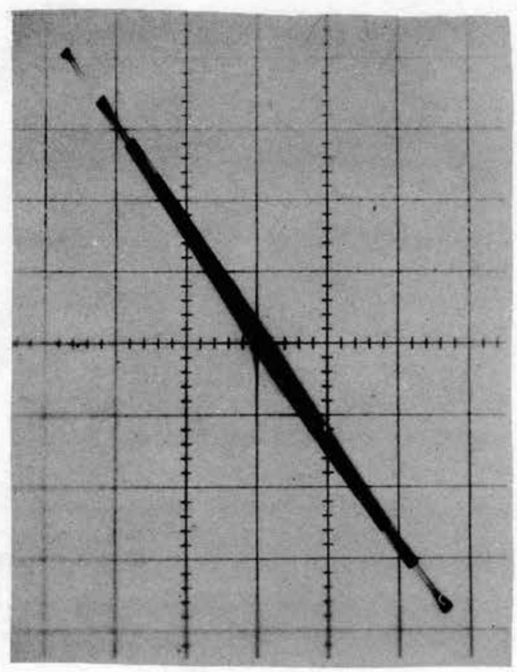


Figure 18. Gain Balance Control Incorrectly Adjusted.

the 502 scope, except that it will be sensed, i.e., only half of the line will be visible. The gains of the deflection amplifiers should be adjusted so that the strobe is at an incline of 45° on each indicator, and the gain of the intensification units should be set for proper intensification. The calibrate rotation switch should be switched to each of the four calibrate positions and the indicators checked. If the strobe appears in the correct position, the HFDF-2 system is correctly tuned and aligned.

The above tuning setup may also be used for calibrating the azimuth measuring equipment on the sferic incidence azimuth integrator. Simulated sferics at 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315° are possible by use of switches S_1 and S_2. These angles may be used to check the azimuth indications on the integrator.

Calibration for Energy Content

Calibration of the HFDF-2 for energy content is accomplished by measuring the actual 150 kilocycle component of a sferic by means of a calibrated sense channel connected to an auxiliary deflection system in the Q-3 recording camera box and comparing it with the observed deflection of the direction finding trace for the same sferic. In this way the true total gain of the direction finding system may be determined.

It is first necessary to calibrate the sense channel. This is possible with existing equipment, because the characteristics of the whip antenna used for sensing may be very closely approximated by assuming its effective height to be 1/2 its physical height, which is a good assumption whenever the height of the antenna is very much less than one half the wavelength. The physical height of the HFDF-2 sense antenna is

2.44 meters. Thus the effective height is 1/2(2.44) or 1.22 meters. The input capacitance may be determined by measuring the capacitance of the antenna in its mounting and then subtracting the measured capacitance of the mounting alone. The capacitance was measured and found to be 27 μμf. The vertical whip antenna may be represented by the equivalent circuit shown in Figure 19.

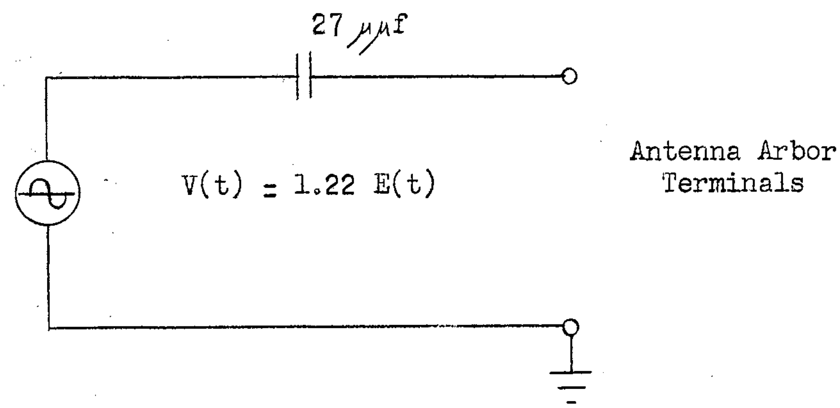


Figure 19. Equivalent Circuit of HFDF-2 Sense Antenna

In order to simulate this antenna, a dummy antenna was built consisting of a 27 μμf condenser in series with a signal source as shown in Figure 20.

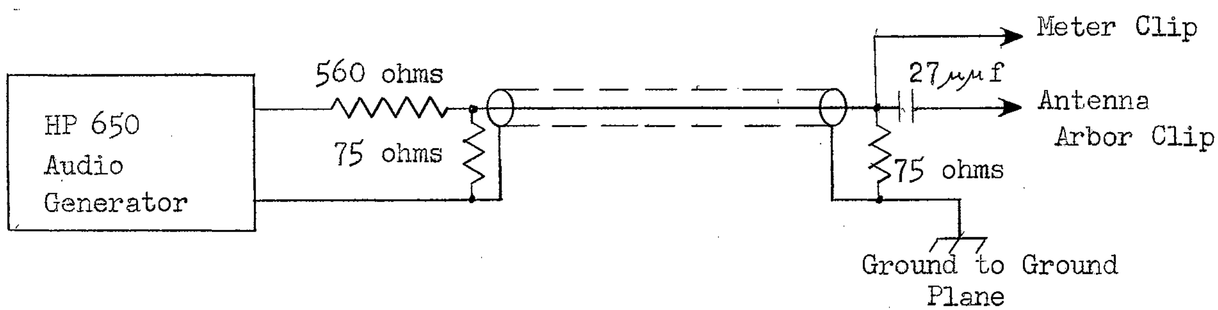


Figure 20. Dummy Antenna for HFDF-2 Calibration

A 150 kilocycle signal is fed into the line with the Hewlett-Packard 650 test oscillator, and the voltage, V_{in}, is read at the meter clip with a Hewlett-Packard 400D VTVM. At the same time the voltage, V_{out}, at the sense receiver input terminal is also observed. The ratio of these two voltages is then the gain of the preamp circuitry, $g_p = \frac{V_{out}}{V_{in}}$. g_p times the antenna effective height is the total gain to the sense receiver input, g_s. Thus

$$g_s = 1.22\ g_p\ \frac{\text{Volts}}{\text{Volts/meter}}$$

for the HFDF-2 sense antenna. g_s should be about 0.7 volts/volt/meter.

It is next desired to determine the effective 150 kilocycle energy content of a pulse at the sense receiver terminals. The energy of a 1 microsecond pulse may be computed by the Fourier integral. Consider a 1 microsecond pulse symmetrical about the origin and with a height of P volts as shown in Figure 21.

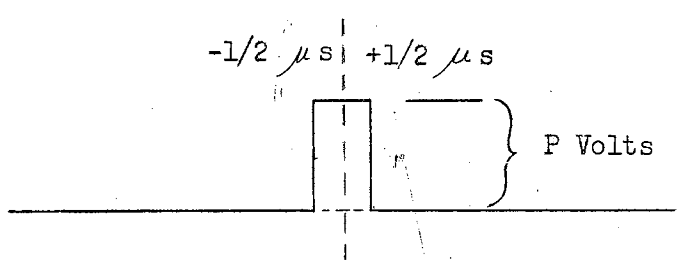


Figure 21. Test Pulse

The Fourier integral may be used to calculate the energy content of this pulse at any frequency. Since it is an even function of time, only the $a(\omega)$ term will have a value. Thus

$$g(\omega) = a(\omega) = \frac{1}{\pi}\int_{-\infty}^{+\infty} f(t)\cos\omega t\ dt$$

$$g(\omega) = \frac{1}{\pi} \int_{\frac{-10^{-6}}{2}}^{\frac{10^{-6}}{2}} P \cos \omega t \, dt$$

$$g(\omega) = \frac{P}{\pi \omega} \int_{\frac{-10^{-6}}{2}}^{\frac{10^{-6}}{2}} \cos \omega t \, \omega dt$$

$$g(\omega) = \frac{P}{\pi \omega} \Big[\sin \omega t\Big]_{\frac{-10^{-6}}{2}}^{\frac{10^{-6}}{2}}$$

Since $\omega = 2\pi f$ and $\frac{360}{2\pi}$ radians = degrees

$$g(\omega) = \frac{P}{\pi^2 f} \sin 180 \times 10^{-6} f$$

If $f = 150{,}000$ cycles/second

$$g(\omega) = \frac{10^{-3} P}{\pi^2 \times 150} \sin 180 \times 10^{-6} \times 150 \times 10^{3}$$

$$g(\omega) = .312P \times 10^{-6} \text{ volt-seconds or } .312P \text{ microvolt-seconds}$$

If a pulse of P volts is applied to the sense receiver input, it is the same as a pulse on the antenna of W energy content where

$$W = 0.312 \, P/g_s \text{ microvolt-seconds/meter}$$

Calibration Procedure

To perform the calibration, the dummy antenna is connected in place of the sense antenna and g_s is measured as explained earlier in this chapter.

It is necessary to set up a reference channel which will moniter the energy content of the sferics received. The 75 kilocycle frequency sampling channel of the Q-3 has the necessary circuitry and is used as the moniter. It will be referred to as the 75 kilocycle channel because of its use on the Q-3 but during the HFDF calibration it will operate with the 150 kilocycle signal from the sense receiver. The sense receiver is connected to the 75 kilocycle deflection amplifier input by coaxial cable. A coax tee may be used to secure the additional output from the sense receiver. The intensification of the 75 kilocycle beam is accomplished by connecting the HFDF-2 intensification unit to the 75 kilocycle cathode-ray tube grid. A short jumper wire may be connected from J806A to J806B on the Q-3 to accomplish this. A pulse or sferic excitation of the sense receiver will now cause a deflection of the 75 kilocycle trace which is proportional to the 150 kilocycle energy of the excitation.

A 1 microsecond pulse is applied to the calibration input of the HFDF and the amplitude is adjusted for approximately a 30 mm zero to peak display on the 75 kilocycle indicator. The waveforms at TP 801B and TP 802B should be checked to be sure that no clipping is present. The pulse amplitude is measured while the pulse generator is triggered slowly with the unipulse switch. The HFDF display on the Q-3 indicator may be checked at this time to make sure that the HFDF is properly tuned. Test pulses are placed on the film by running the camera while slowly actuating the unipulse switch. About five test pulses from each quadrant should be placed on the film. The HFDF is then switched to operate position using care to see that the gain settings are not adjusted.

Sufficient film is run to assure the reception of several sferics from each quadrant.

Film Analysis for the Calibration Procedure

After the calibration film has been developed the relative lengths of the strobes for the calibration pulses and the sferics may be determined. The lengths of the strobes of the test pulses on both beams are observed and recorded and their average ratio is computed. The same is done for the sferics. Let r_s be the average ratio of the lengths of HFDF strobes to 75 kilocycle channel strobes for the sferics and r_p be the same ratio for the test pulses. The constant $C_A = 1.4\ r_s/r_p$ is the ratio of the length of the DF strobe with sferic excitation to the length of the DF strobe with pulse excitation of the same energy content. The apparent energy content of a 1 microsecond pulse of P volts referred to the DF antenna will be

$$W_{DF} = W/C_A = 1.4 \cdot 0.312\ P/g_s C_A \text{ microvolt-seconds/meter}$$

Let $$C = 0.437/g_s C_A = \text{calibration constant}$$

Thus $$W_{DF} = C\ P \text{ microvolt-seconds/meter}$$

The above procedure is summarized in Table I which provides a simple method of calibration.

Each film record must have a calibration mark on it if it is to be of value in determining the energy content of the sferics. The calibration marks may be placed on the film by applying a 1 microsecond pulse to the calibrator. The pulse measured at the sense receiver input should be of such amplitude that its apparent energy content

TABLE I

HFDF-2 CALIBRATION SHEET

Date ______________________ Start Time ______________________

Sense Amplifier Gain Check:

150 kc Voltage at Meter Clip Lead, V_1 = __________ $g_p = \frac{V_2}{V_1}$ = ______________

Voltage at Sense Receiver Input, V_2 = __________ $g_s = 1.22\ g_p$ = ______________

Energy Comparison Run:

Quadrant	Pulse Excitation: Pulse Amplitude_____volts Pulse Width_____µs		Sferic Excitation	
	HFDF Strobe	75 kc Strobe	HFDF Strobe	75 kc Strobe
I				
II				
III				
IV				
TOTALS	(1)	(2)	(3)	(4)

$r_r = (1) \div (2)$ = ______________ $r_s = (3) \div (4)$ = ______________

$C_A = 1.4\ r_s \div r_r$ = ______________

$C = \frac{.312}{g_s\ C_A}$ = ______________ $\frac{\text{Microvolt-sec}}{\text{Meter}}$ /volt corresponds to the maximum sferic energy content expected on the sferic run. After checking to see that the receivers are tuned properly, the calibration marks may be put on the film by running the camera and unipulsing the pulse generator. The azimuth rotation switch on the calibrator should be used to place calibration marks in all four quadrants. When the film is developed, the calibration marks may be used to establish a scale of sferic length to energy content, since the length of the calibration marks corresponds to a known energy content.

CHAPTER X

RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

An improved 150 kilocycle instantaneous direction finder has been developed and is presently being used at the sferics laboratory. The system was not completed in time to secure an abundance of data on Oklahoma's severe storms during the severe storm season of 1960, but sufficient film records have been made to prove the operational feasibility of the HFDF-2. Experience with the HFDF-2 has shown that its increased sensitivity and stability will make it an effective instrument in sferics research. Sections of a film record made with the Q-3 and HFDF-2 are shown in Figures 22, 23, 24, and 25. The lower trace in each picture is the HFDF-2 record. These pictures show the definition and clarity which is characteristic of 150 kilocycle direction finding equipment.

Although the principal goal of this project was to design and build an improved version of the HFDF-1, the development of the HFDF-2 has also been an experiment in system engineering. Originally it was necessary to decide what capabilities were to be expected of the HFDF-2 and to outline a general way that these specifications could be met. The functions necessary to meet the specifications were then divided into logical groups and each group was assigned to a unit of the HFDF-2. With this grouping completed, specifications were written for each of the units. Unit design could then commence without fear of building a

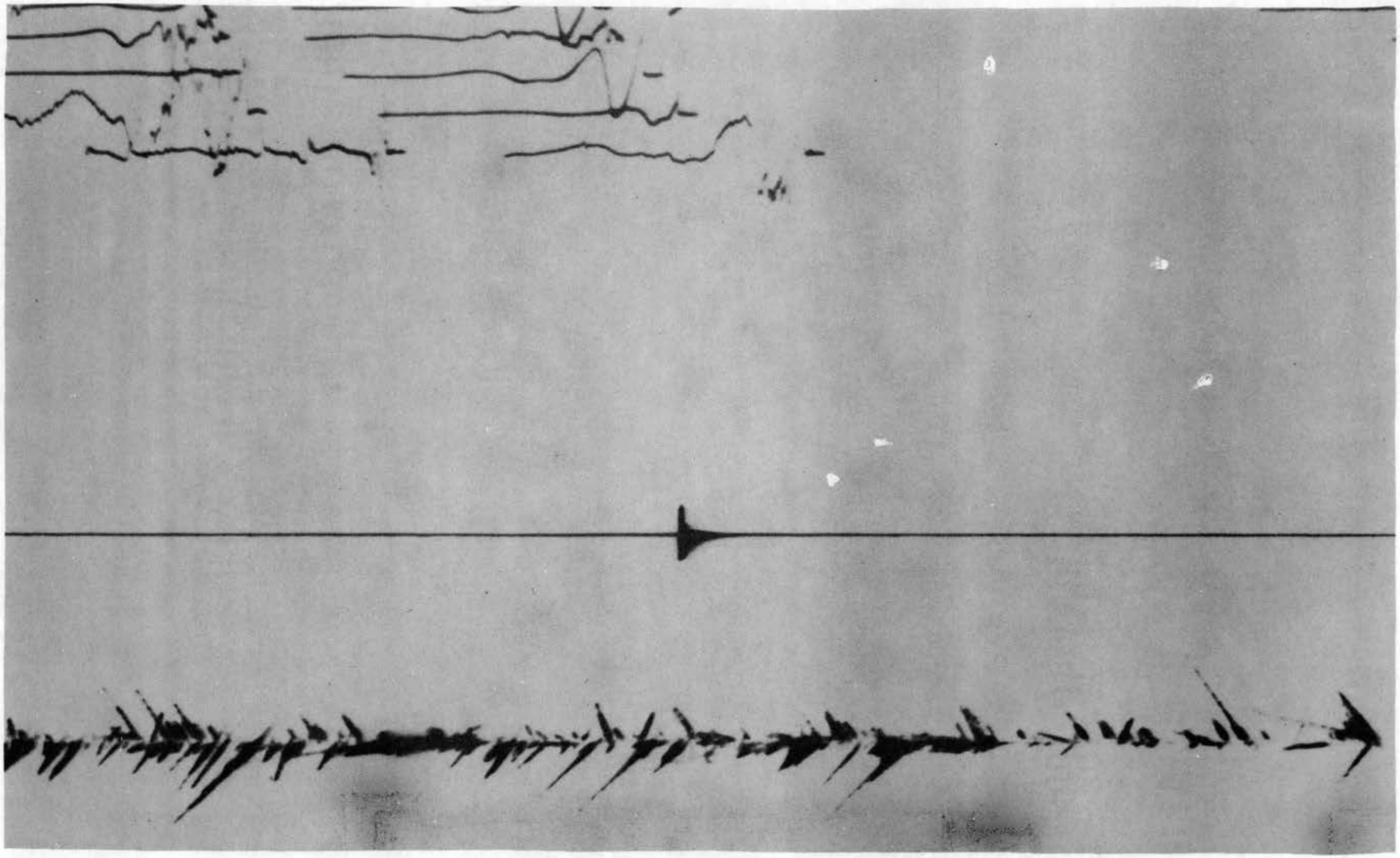


Figure 22. Sample of HFDF-2 Film Record

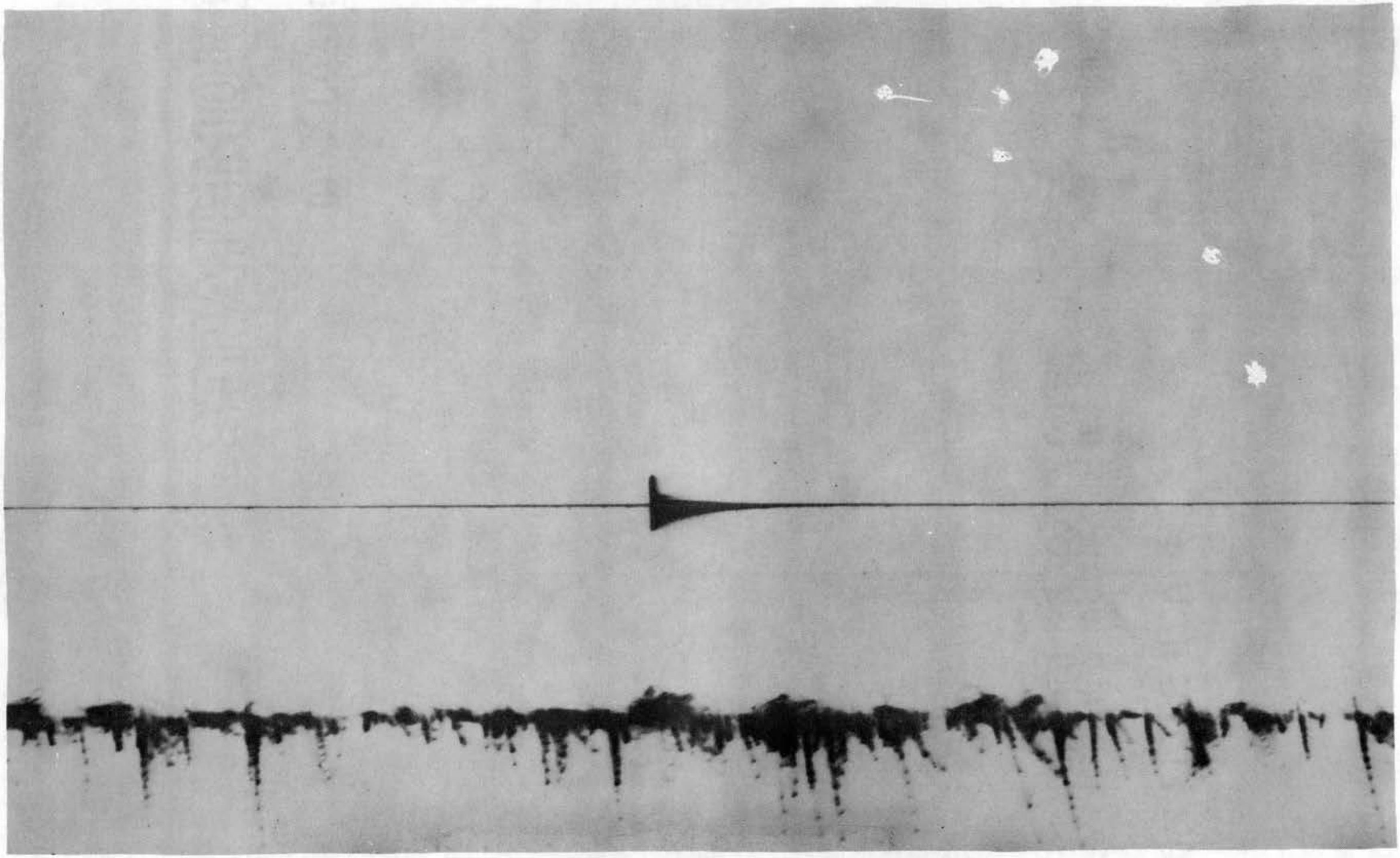


Figure 23. Sample of HFDF-2 Film Record.

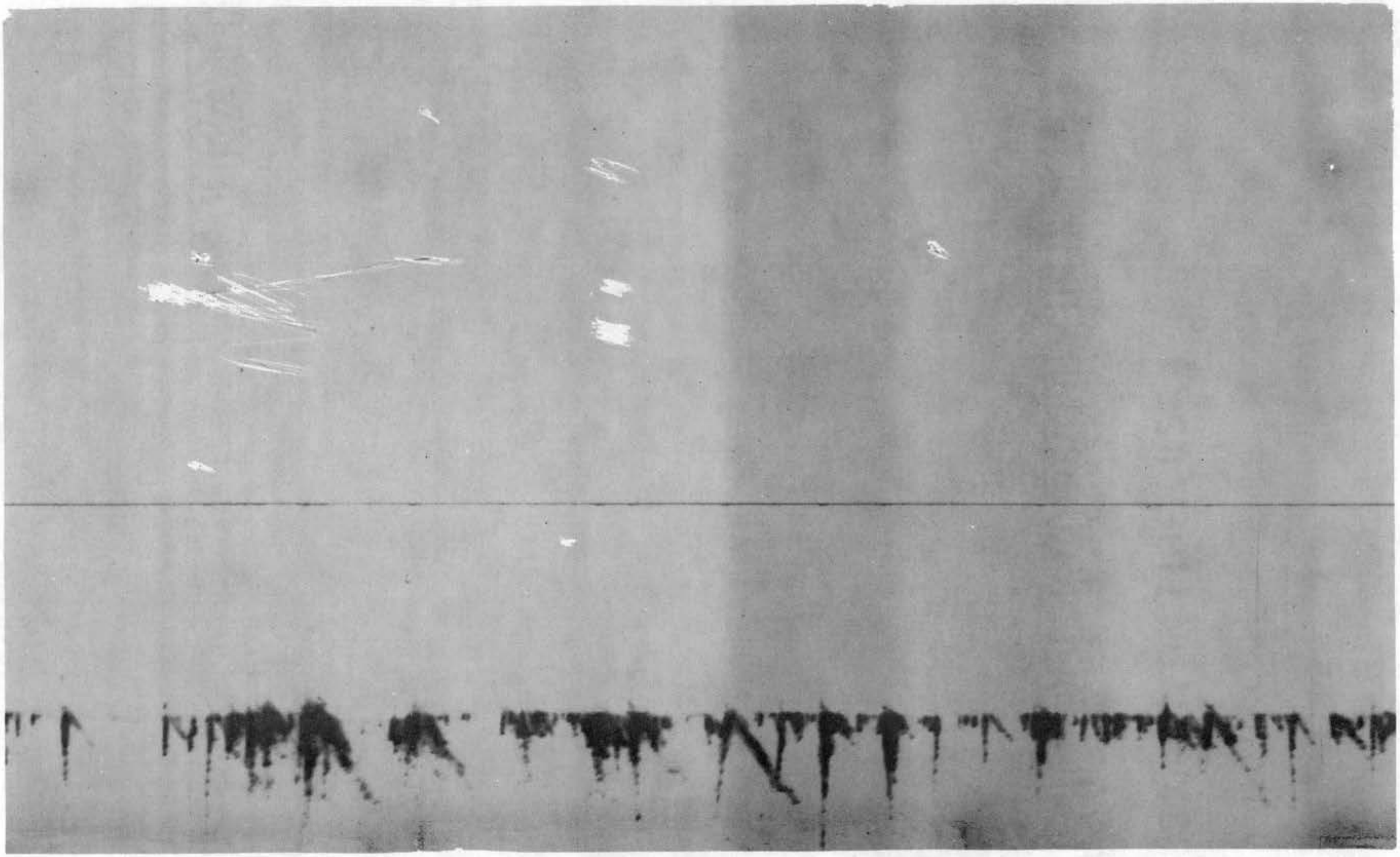


Figure 24. Sample of HFDF-2 Film Record

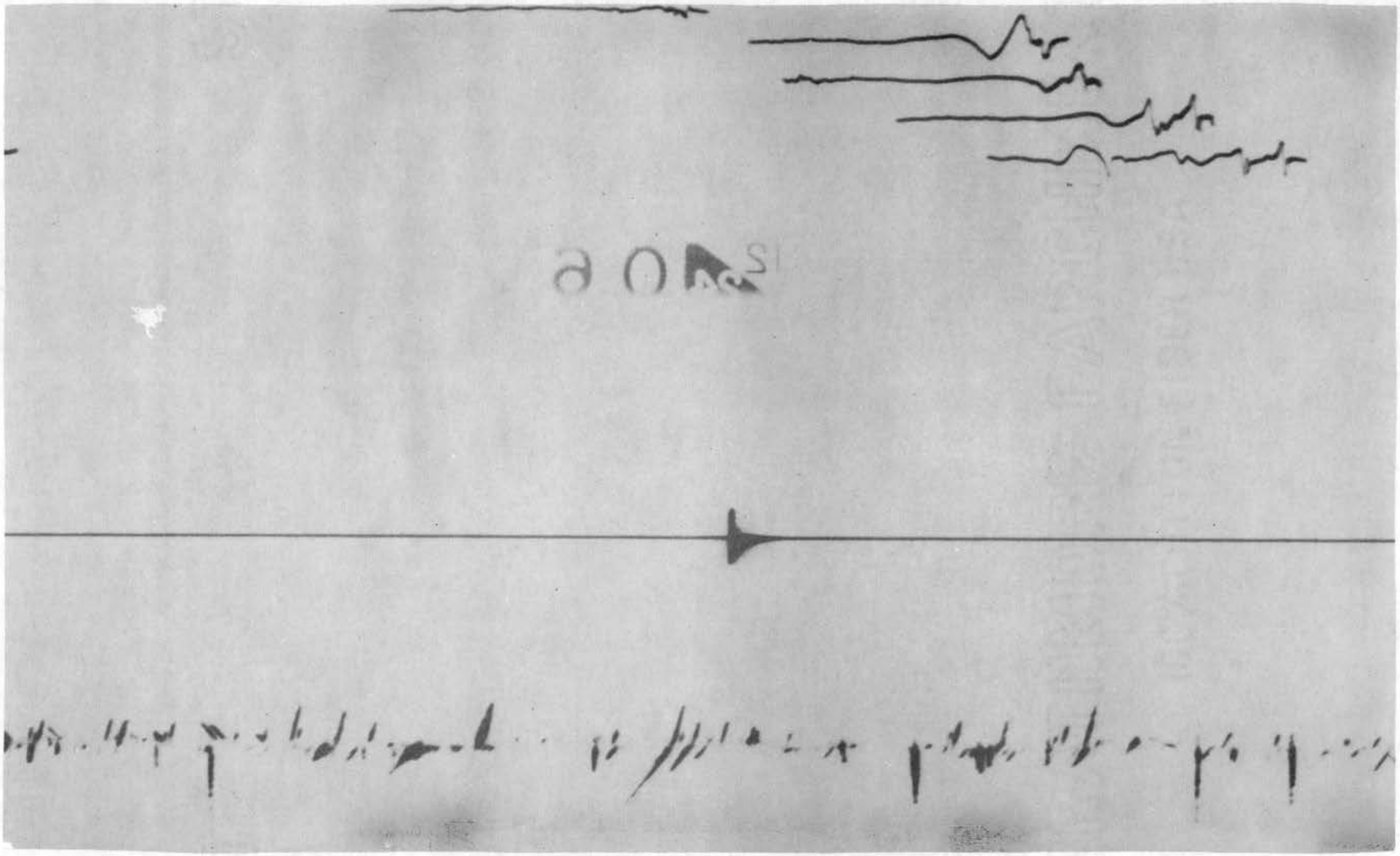


Figure 25. Sample of HFDF-2 Film Record.

unit which would be incompatible with the rest of the system. The design of each unit was usually reduced to an undergraduate level circuit problem after its characteristics had been specified. The unit approach was carried through to the physical construction and resulted in a system which is easy to maintain and to modify at will. The system approach to the design of the HFDF-2 has resulted in an assembly of units which are logically grouped in circuitry and in physical arrangement.

It is expected that the HFDF-2 will be used in future storm seasons to analyze sferics resulting from severe storms and tornados.

A very elaborate method of tornado identification has been developed by Dr. R. D. Kelly and is explained in his doctoral thesis, "Development of Electronic Equipment for Tornado Tracking". (2). It is expected that very similar techniques will be used for tornado identification with the HFDF-2. The increased sensitivity of the HFDF-2 should permit identification of severe storms at a much greater range than was possible with the HFDF-1. At increased range the radar will not be of any value and other methods of locating storms will have to be found.

It is expected that the higher sensitivity of the HFDF-2 will create problems in correlating the storm data received with the severe storm criteria for the HFDF-1. Locally heavy thunderstorms have already produced sferic rates in excess of 1500 per second on the film record. A rate of some 17 to 20 per second on the HFDF-1 was taken to be indicative of a severe storm. Further research should investigate these observations and determine a severe storm criteria for the HFDF-2. Continued operation and observation of the HFDF-2 should reveal many other interesting and significant phenomenon.

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VITA

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