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# FIELD EQUIPMENT FOR IONOSPHERE MEASUREMENTS

By Theodore R. Gilliland and Archer S. Taylor

ABSTRACT

Field equipment for the automatic recording of virtual heights and critical frequencies of the ionosphere layers is described. Such equipment is useful for special investigations, such as during solar eclipses, to supplement the systematic recording which has been in progress at Washington since 1932. A frequency range from 790 to 14,000 kc/s is covered. Only 1 minute is required for the recording cycle. Records are made on 35-mm positive film. The transmitter is pulsed by means of a Thyratron and resistance-capacitance network controlled by a magnetic synchronizing device. The equipment is mounted in an automobile trailer and is complete, including a primary source of power.

CONTENTS



## I. INTRODUCTION

The need for ionosphere recording apparatus that could be readily transported from place to place has been apparent since the beginning of systematic recording of ionosphere characteristics at Washington in 1932. Although more or less systematic observations are now made at a number of places on the earth, furnishing, to a limited extent, a world-wide picture of the changes in the ionosphere, the need remains for field equipment which can be used for special experiments requiring the selection of time and position of the observations.

Several examples of such special experiments may be cited to demonstrate the usefulness of transportable and self-contained recording equipment. Observations may be made in the paths of solar eclipses. These are of special interest in ionosphere studies, since they give, in a unique manner, an indication of the structure and mechanism of formation of the various strata. The extent of clouds of ions responsible for sporadic reflections may readily be investigated. The variation of the effects of ionosphere storms and sudden ionosphere disturbances, as well as the variation of the regular ionosphere characteristics with latitude and longitude, may be studied in detail. Measurements at high latitudes are of particular interest in the study of the relation of the earth's magnetic field to the ionosphere, as well as in the study of anomalies in transmission over paths that pass through high latitudes. Also, the calculations now used to extend vertical-incidence data to transmission over a distance may be checked by direct observation.

Compactness and minimum weight are important characteristics which the equipment should have. It also should be arranged for ease of installation and be self-contained, including shelter, primary source of power, and means of transportation. The equipment should be capable of recording automatically for several days without attention.

Past experience has indicated the desirability of a system which would record more quickly and more frequently than any heretofore developed. Frequent operation is especially desirable for observations during such rapid ionosphere changes as solar eclipses, ionosphere storms, sudden ionosphere disturbances, and sunrise periods. Fast recording also offers a saving in power consumption and reduces the effect of interference with outside radio services caused by the recording. Furthermore, if the records are made frequently enough, and if they are properly registered on motion-picture film, it should be possible to project them as a motion picture. Such projection would be of value for demonstration purposes and would probably show in a unique manner the progress of changes in the condition of the ionosphere. Although the present recorder was not designed for this type of registration, its performance has demonstrated the feasibility of the method. The recording system described in this paper requires only 1 minute to make a complete record, and with some modification could be adapted for ½-minute operation.

Before setting down the details of the component parts of the apparatus, a brief general description of the experiment and quantities measured may be of value. The method of measuring the heights and ionization densities of the various layers is fundamentally that developed by Breit and Tuve [1][1], with numerous modifications which allow for automatic registration and for variation of the radio frequency over an extensive band [2, 3, 4]. The apparatus consists of a radio transmitter, receiving set, and recording oscillograph. The transmitter and receiving set are always in tune with each other, and their frequency is changed continuously over the band. Instead of having the transmitter emit a continuous wave, the emission is broken up into a series of short pulses of about $10^{-4}$ second duration. For each pulse transmitted the receiving set receives one pulse directly and, at short intervals of time later, others which have been reflected from the ionosphere layers. These time intervals give a measure of the heights reached in the ionosphere. The function of the recorder is to register these time intervals automatically so that a continuous record of heights of the ionosphere layers may be obtained. The low-frequency waves are in general returned from a lower layer where the density of ionization is low. As the frequency is increased, the waves penetrate farther into the lower layer until a certain critical frequency is reached. As the frequency is further increased, the waves pass through the lower layer and are reflected from the next higher and more intensely ionized layer, and so on. Every layer has a characteristic critical frequency from which its maximum density of ionization may be computed [5]. If the frequency is increased to a high enough value, the waves will pass through the highest and most intensely

[1] Figures in brackets indicate the literature references at the end of this paper.

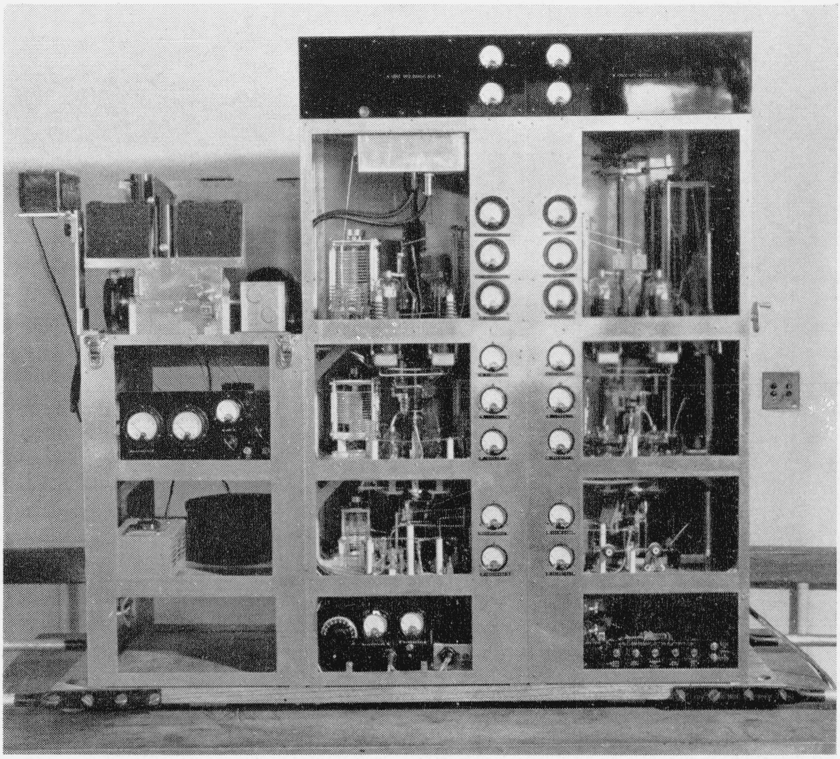

FIGURE 1.—*Front view of transmitter and recorder.*

The left-hand unit contains the recorder; the central unit contains equipment for frequency bands 3 and 4; and the right-hand unit, for bands 1 and 2.

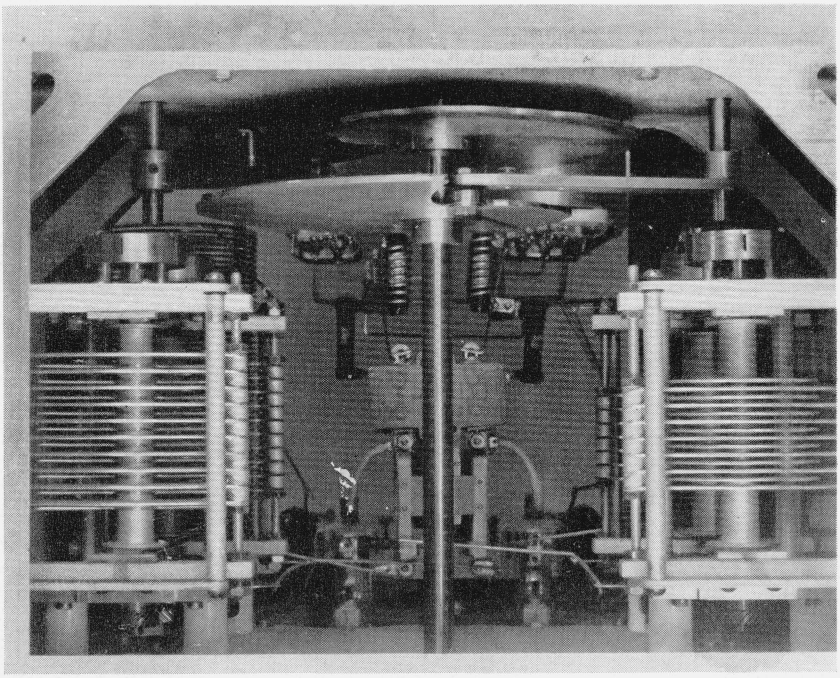

FIGURE 2.—*Rear view of one section of transmitter, showing the pair of cams used for tuning the condensers in the next section above the one shown.*

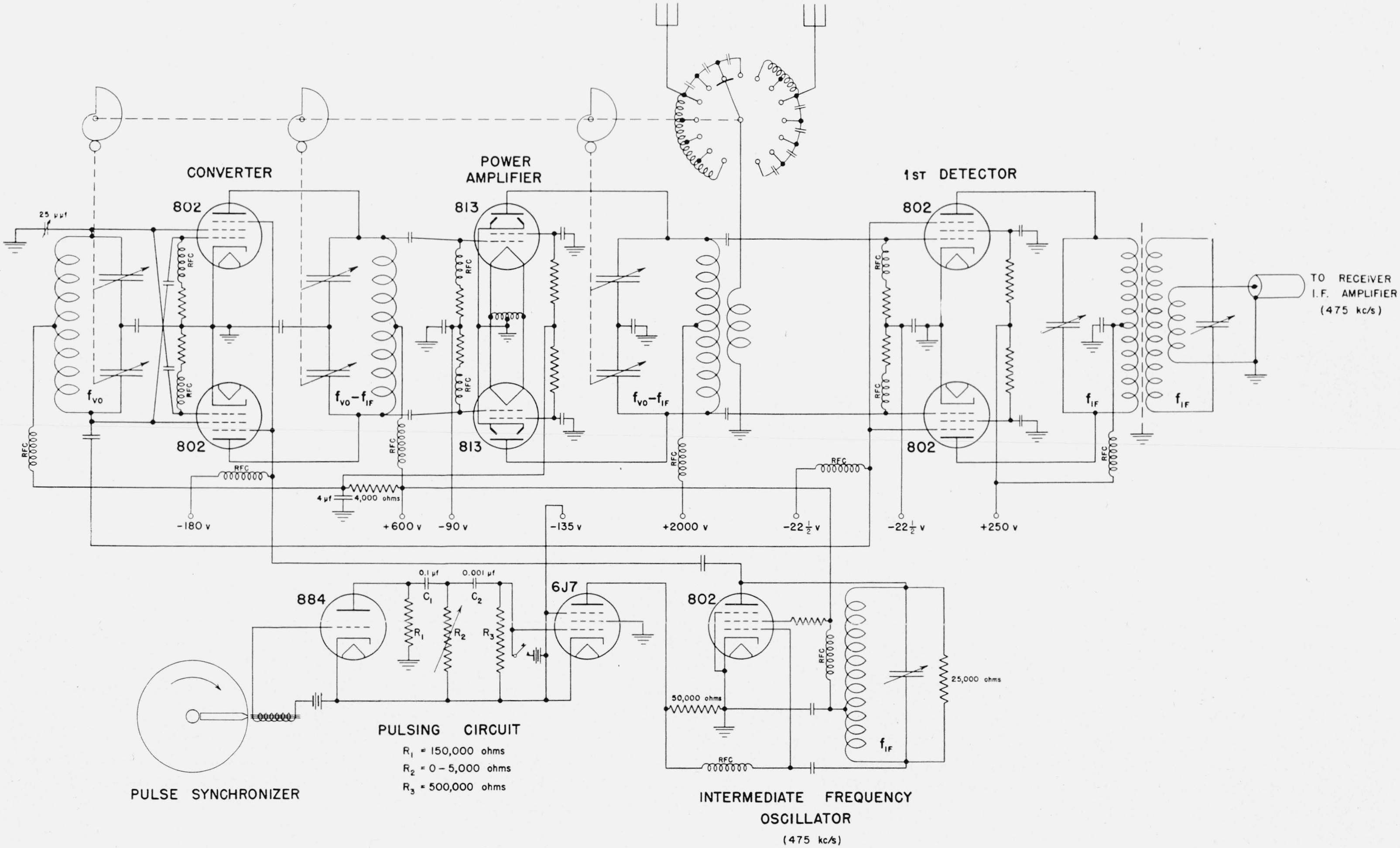


FIGURE 3.—*Simplified circuit diagram of one frequency band of the portable transmitter.*

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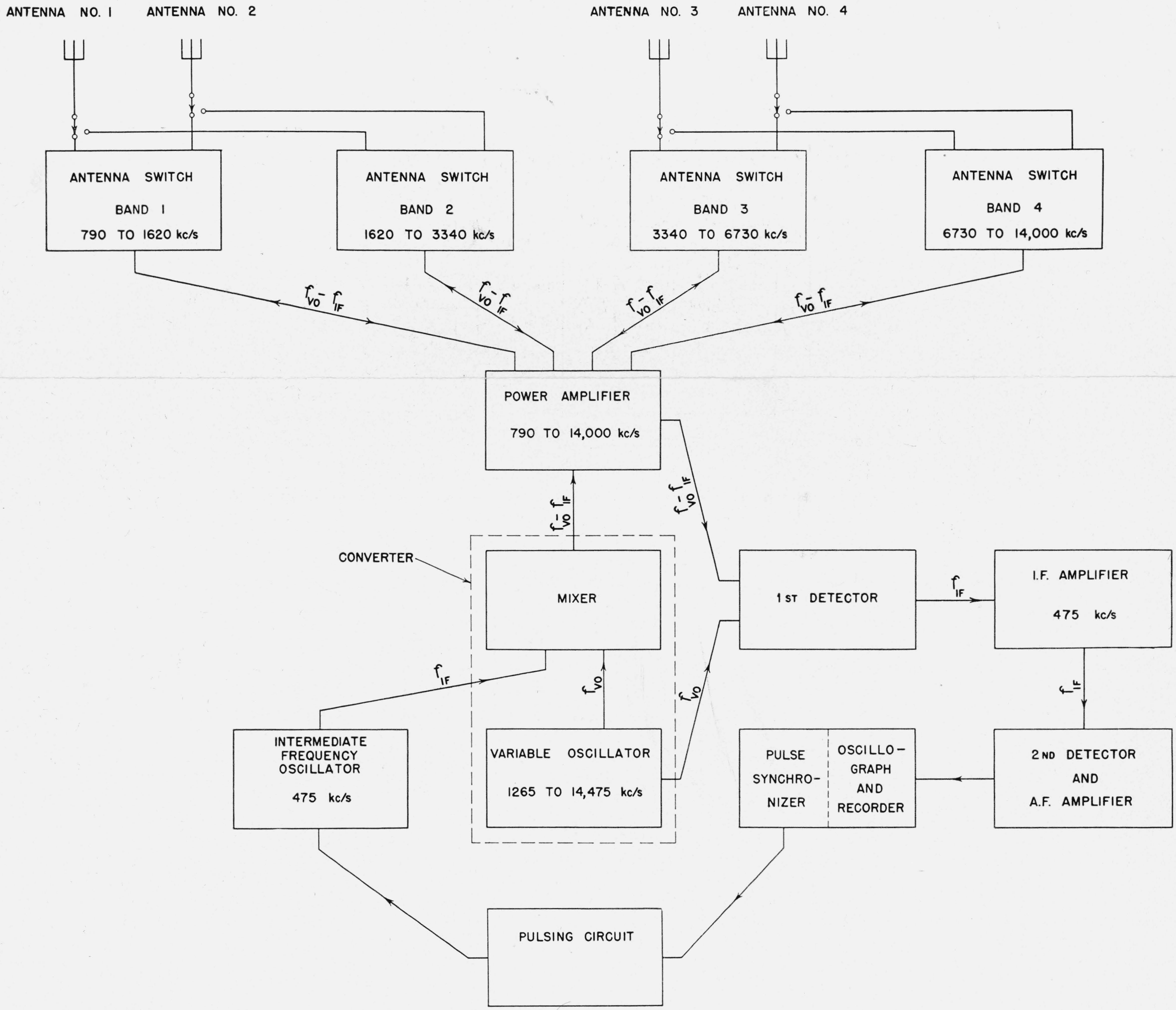


FIGURE 4.—*Block diagram, showing the method of operation of the entire apparatus.*

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ionized layer and will not return to earth. With a sufficient knowledge of critical frequencies and virtual heights of the various layers, it is possible to interpret and predict certain characteristics of long-distance radio transmission. The large changes in these quantities with time of day, with season, and with phases of the sunspot cycle have already been studied in considerable detail [6]. With the field apparatus it is possible to study one more variable, that of geographical position, in more detail.

## II. TRANSMITTER

The transmitter is composed of two units, each complete with a set of tubes and arranged for sweeping through two frequency bands. The limits of the four frequency bands are as follows: Band 1, 790 to 1,620 kc/s; band 2, 1,620 to 3,340 kc/s; band 3, 3,340, to 6,730 kc/s; band 4, 6,730 to 14,000 kc/s. Switching from one band to another is accomplished by relays. Each band requires three cams for operating the tuning condensers. Cams for the power amplifiers of bands 1 and 2 are shown in figure 2. The two transmitter units are contained in the central and right-hand sections shown in figure 1. The left-hand section contains the recorder.

Figure 3 is a simplified circuit diagram of one of the four bands of the transmitter with switching relays omitted. It will be noted in this figure, as well as in the complete block diagram of the system shown in figure 4, that the output frequency of the transmitter is always the difference between a fixed frequency, $f_{IF}$, and a variable frequency, $f_{VO}$. This circuit arrangement was devised [7] in order to maintain the receiving set always accurately in tune with the transmitter. The fixed, or *IF*, oscillator is set at a value equal to the intermediate frequency, $f_{IF}$, of the receiving set. This oscillator operates only during the time of each short pulse. During this time, its output is mixed with the variable oscillator frequency, $f_{VO}$, in the converter circuit shown at the left of figure 3. Thus, with the plate circuit of the converter tuned to $f_{VO}-f_{IF}$, the difference frequency will be impressed on the grids of the power amplifier tubes and will be amplified and emitted from the antennas. It will be noted that the variable oscillator utilizes the screens of the converter tubes while the fixed frequency, $f_{IF}$, is applied to the suppressors.

During the time of the pulse, $f_{VO}-f_{IF}$ will also be impressed on the grids of the first detector of the receiving set. After the end of the pulse, i. e., after the intermediate frequency oscillator stops, the tuned antenna and plate tank circuit of the transmitter power amplifier provide preselection tuning for the returning echoes. The signal voltage of the returning pulse energy is applied through the coupling condensers to the control grids of the first detector. Although the transmitter output is cut off with the stopping of the *IF* oscillator, the variable oscillator runs continuously, so that $f_{VO}$ is always applied to the suppressor grids of the first detector. With the two frequencies, $f_{VO}-f_{IF}$ and $f_{VO}$, applied to the first detector and with the plate circuit tuned to $f_{IF}$, a voltage at this frequency will be applied through the transmission line to the *IF* amplifier. Thus, if the *IF* oscillator is always tuned to the same frequency as that of the *IF* amplifier, the receiving set is automatically locked in tune with the transmitter.

The rate of change of frequency is chosen so that the logarithm of the frequency is proportional to time. With a pulse rate of 20 per second, the increment of frequency between pulses ranges from about 2 kc/s at the lower frequencies to 38 kc/s at the higher frequencies. Since the variable oscillator frequency is changing continously, the receiver will be slightly detuned at the time the signal returns from the ionosphere. However, even at high frequencies, where the rate of change is greatest, the receiver is detuned by only about 2 kc/s for signals returning from a virtual height of 400 km.

## III. ANTENNA SYSTEM

Four ⅃-type antennas are used, each antenna serving for two different frequency ranges. Each is used first in the ¼-wavelength range, and later in the ¾-wavelength range. Table 1 indicates the ranges for each antenna.

TABLE 1.—*Antenna frequency ranges*

| Antenna number | ¼ wave-length for— | ¾ wave-length for— | Frequency ranges for which used |
|---|---|---|---|
| | *kc/s* | *kc/s* | *kc/s* |
| 1 | 700 | 2, 100 | 790 to 1, 130<br>1, 620 to 2, 350 |
| 2 | 1, 000 | 3, 000 | 1, 130 to 1, 620<br>2, 360 to 3, 340 |
| 3 | 3, 000 | 9, 000 | 3, 340 to 4, 810<br>6, 730 to 9, 770 |
| 4 | 4, 300 | 12, 900 | 4, 810 to 6, 730<br>9, 770 to 14, 000 |

Tap switches attached to the camshaft are used to tune the antennas in the manner indicated at the top of figure 3. In the ¼-wavelength range condensers only are used, whereas in the ¾-wavelength range both inductances and condensers are used. The switch arms, contacts, and slip rings for bands 1 and 2 are shown at the top of figure 5.

The antennas are supported by guyed bamboo masts, each made up of three 12-foot sections. The arrangement as set up in the field is shown in figure 6.

## IV. PULSING CIRCUIT

The pulsing voltage used to control the intermediate-frequency oscillator is generated by the discharge of a condenser through a grid-controlled Thyratron type 884 tube. Synchronization of the pulse with the rotation of the recorder mirror is obtained by means of a permanent magnet attached to the mirror shaft, with its magnetic axis perpendicular to the axis of rotation. An earphone with cover and diaphragm removed is supported near the rotating magnet, so that as the magnet passes the pole piece of the earphone, a voltage pulse is induced in the coil. The magnet is attached to the mirror shaft so that only one of its poles comes near enough to the earphone to induce an appreciable voltage. By shaping the pole of the rotating magnet and properly placing the earphone, a short pulse of about 100-volts amplitude can be produced for controlling the discharge of the 884 tube.

Figure 3 shows that condenser $C_1$ becomes charged through resistors $R_1$ and $R_2$. The bias voltage on the grid of the 884 tube is adjusted

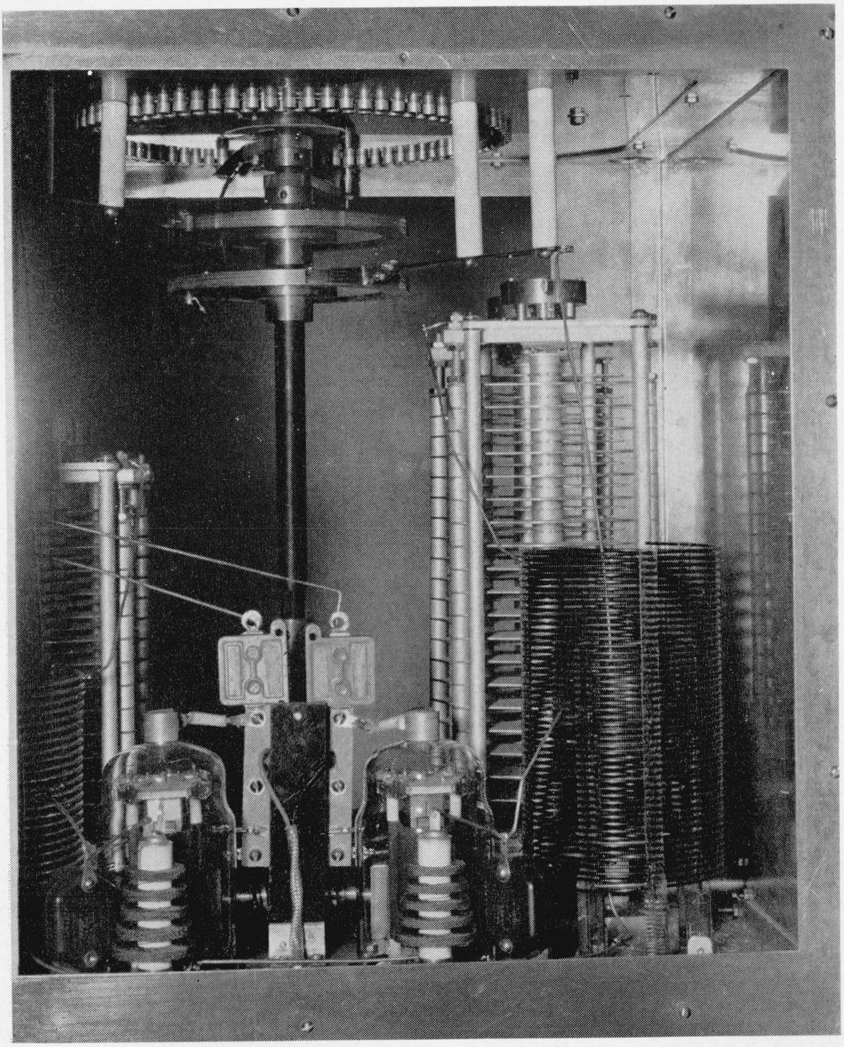

FIGURE 5.—*Power amplifier section of frequency bands 1 and 2.*

The slip rings, switch arms, and contacts for the antenna tuning switch are at the top.

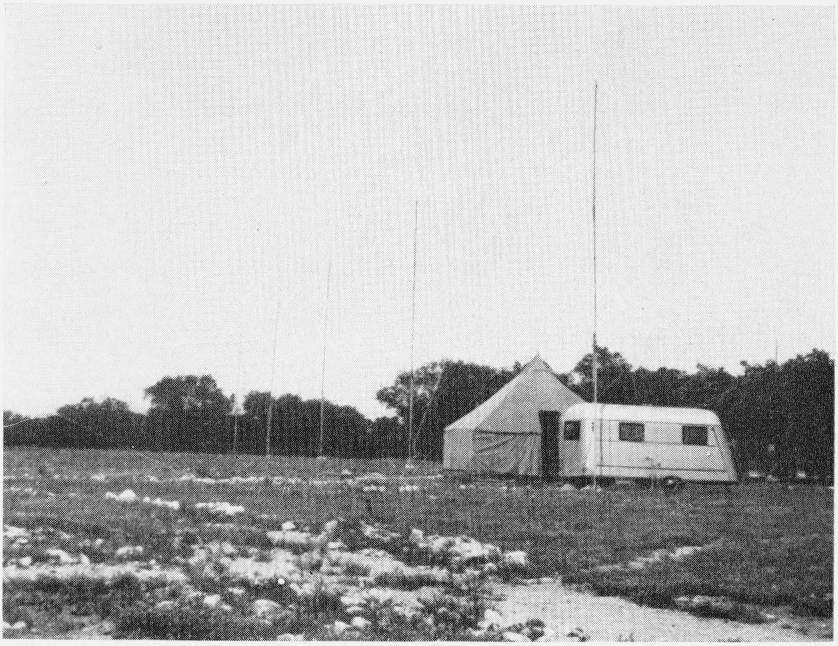

FIGURE 6.—*Equipment as installed in the field, showing arrangement of bamboo masts and antennas.*

so that the condenser $C_1$ can discharge only when the synchronizing pulse is induced in the earphone. The network $C_1R_2$, $C_2R_3$ was suggested by N. Smith to aid in producing a pulse more nearly rectangular in shape than could be obtained with a simple resistance-capacitance circuit. The solid curve of figure 7 (A) represents the voltage applied to the grid of the 6J7 tube when condenser $C_1$ of figure 3 discharges. For comparison, the dashed curve represents the voltage applied to the grid of the 6J7 tube if $C_2$ and $R_3$ are eliminated. In figure 7 (B) the solid line indicates the shape of the pulse formed as the 6J7 plate current varies from saturation to cut-off. The dashed line shows the

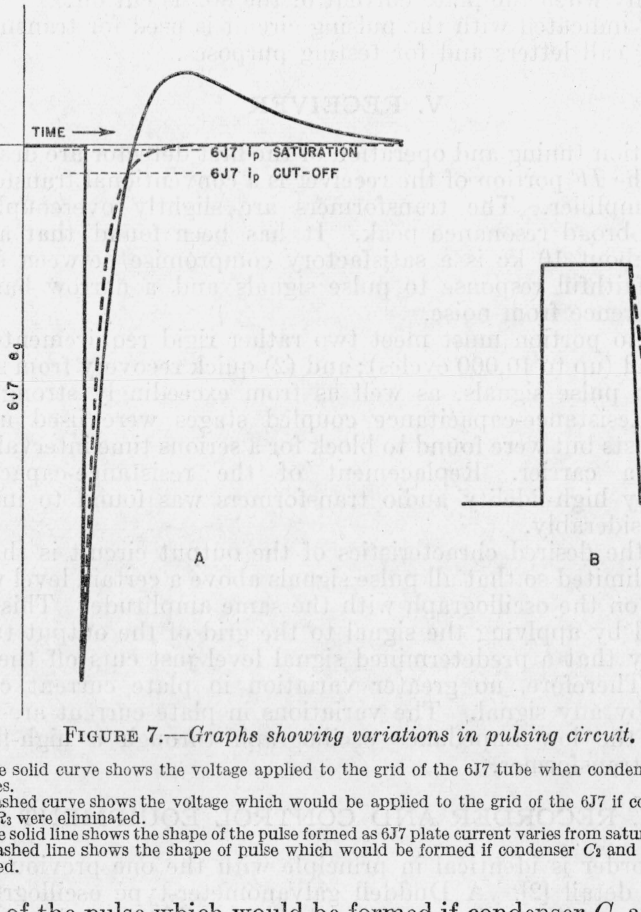


FIGURE 7.—*Graphs showing variations in pulsing circuit.*

*A.* The solid curve shows the voltage applied to the grid of the 6J7 tube when condenser $C_1$, figure 3, discharges.
The dashed curve shows the voltage which would be applied to the grid of the 6J7 if condenser $C_2$ and resistor $R_3$ were eliminated.
*B.* The solid line shows the shape of the pulse formed as 6J7 plate current varies from saturation to cut-off. The dashed line shows the shape of pulse which would be formed if condenser $C_2$ and resister $R_3$ were eliminated.

shape of the pulse which would be formed if condenser $C_2$ and resistor $R_3$ were eliminated. It can be shown that the best shaped pulse is obtained if the time constant $C_1R_2$ is equal to $C_2R_3$ and if $R_3$ is large compared with $R_2$. In practice, however, either time constant may be as much as 10 times the other without seriously affecting the shape of the pulse. Therefore, only $R_2$ is varied when adjusting the duration of the pulse. Somewhat better control of the duration would be obtained by using ganged rheostats, or a step-by-step arrangement so that both $R_2$ and $R_3$ could be adjusted simultaneously with a single control.

The variations shown in figures 7 (A) and 7 (B) occur each time the magnetic synchronizer starts a discharge through the 884 tube. The voltages and load of the 6J7 are adjusted so that plate current saturation occurs with about minus 1 volt on the grid and cut-off with about minus 6 or 7 volts. When the 6J7 tube is drawing saturation current, the voltage across the 50,000-ohm resistor prevents operation of the *IF* oscillator. During the time of the pulse, the 6J7 tube draws no plate current, and the 50,000-ohm resistor then acts as the grid resistor of the *IF* oscillator. The tank circuit of the oscillator is loaded by means of a resistor, in order to damp out the oscillations more rapidly when the plate current of the 802 is cut off.

The key indicated with the pulsing circuit is used for transmitting identifying call letters and for testing purposes.

## V. RECEIVER

Preselection tuning and operation of the first detector are described above. The *IF* portion of the receiver is a conventional transformer-coupled amplifier. The transformers are slightly overcoupled to produce a broad resonance peak. It has been found that a band width of about 10 kc is a satisfactory compromise between a wide band for faithful response to pulse signals and a narrow band for less interference from noise.

The audio portion must meet two rather rigid requirements: (1), a wide band (up to 10,000 cycles); and (2) quick recovery from signals other than pulse signals, as well as from exceedingly strong pulse signals. Resistance-capacitance coupled stages were used in preliminary tests but were found to block for a serious time interval when receiving a carrier. Replacement of the resistance-capacitance coupling by high-fidelity audio transformers was found to improve results considerably.

One of the desired chracteristics of the output circuit is that the output be limited so that all pulse signals above a certain level will be impressed on the oscillograph with the same amplitude. This is accomplished by applying the signal to the grid of the output tube in such a way that a predetermined signal level just cuts off the plate current. Therefore, no greater variation in plate current can be produced by any signal. The variations in plate current are transferred to the low impedance oscillograph through a high-fidelity matching transformer.

## VI. RECORDER AND CONTROL EQUIPMENT

The recorder is identical in principle with the one previously described in detail [2]. A Duddell galvanometer-type oscillograph is used with a rotating mirror to record the time between the emission of the pulse and the reception of the echo. Through the use of proper lenses and masks, the direct pulse and each of the reflections produce traces on the photographic film or paper moving slowly parallel to the axis of the rotating mirror. Since the magnetic synchronizer described above is on the same shaft with the mirror, the direct pulse always occurs when the mirror is in the same position. Hence the direct trace is a straight line, whereas the traces for the echoes vary in position, depending on the virtual height of the reflection point. The recording film or paper is moved at a constant speed, and the

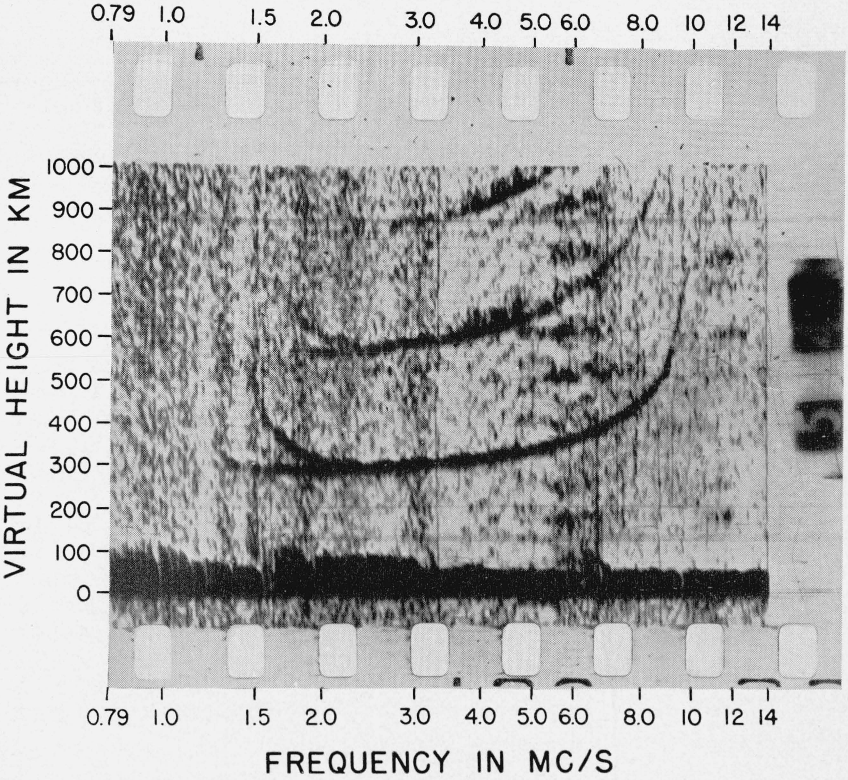


FIGURE 8.—*Sample record made with portable apparatus, September 27, 1940, 5:45 p. m., at Patos, Brazil, latitude 7°1′ S., longitude 37°17′ W.*

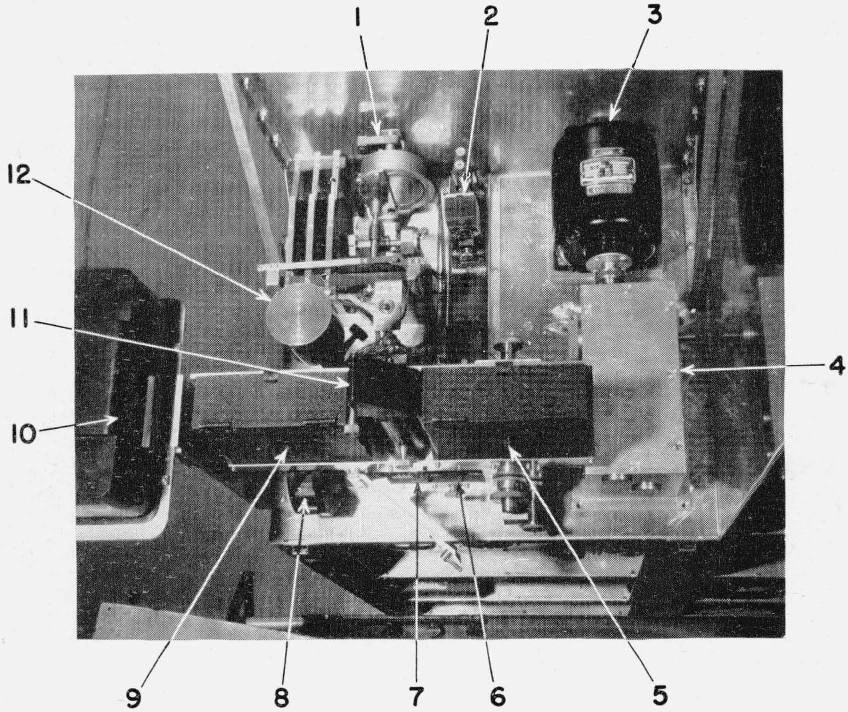


Figure 9.—*Recorder.*

1, control clock; 2, oscillograph element; 3, motor which drives recorder mirror, pulse synchronizer, film feed, and transmitter tuning cams; 4, gear box; 5, take-up magazine; 6, recording guide; 7, time-marking shutter (solenoid in rear); 8, pulse synchronizer (earphone magnet not shown); 9, supply magazine; 10, time-marking clock; 11, mirror to reflect image of clock onto film (the lens is supported in the tube below the mirror); and 12, lamp housing for time-marking lamp.

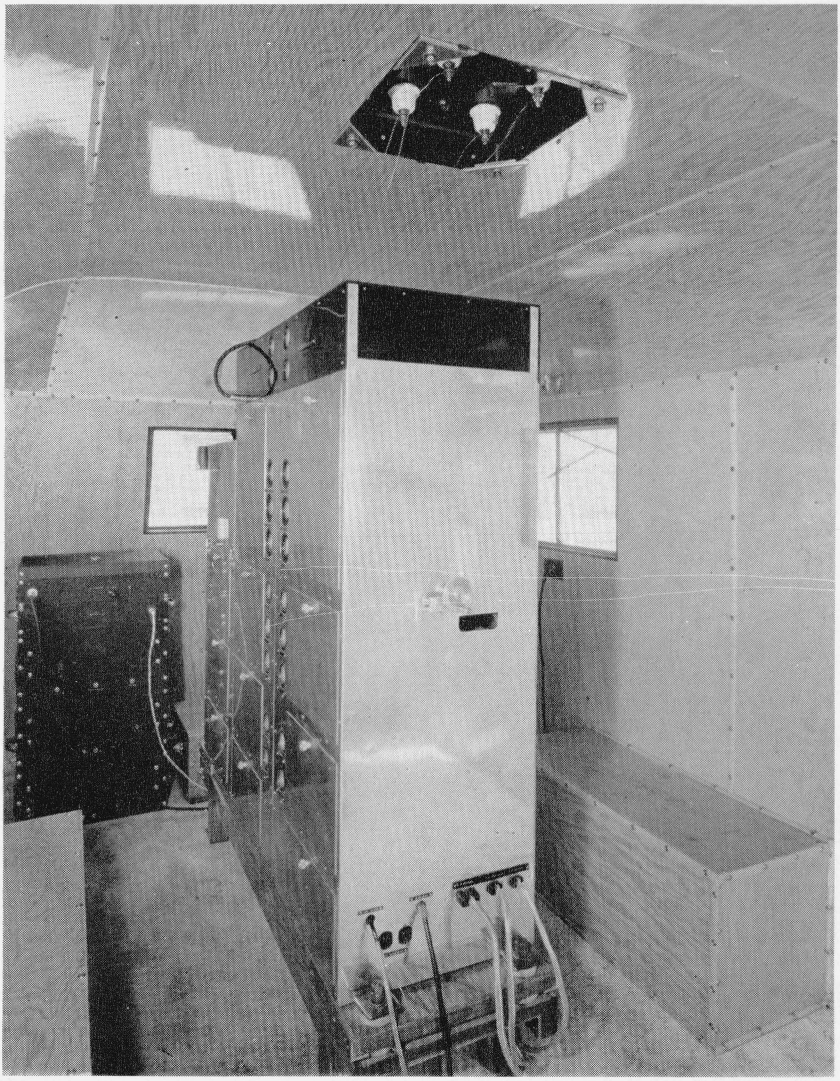

FIGURE 10.—*Interior of trailer, showing transmitter as installed for both transportation and operation.*

The receiver and power supplies are contained in the black box at left.

record can therefore be calibrated in terms of frequency versus virtual height.

In previous recorders, photographic paper has been used, permitting direct measurements without enlargement. For several reasons, however, it was decided to use 35-mm motion-picture film with the present equipment. In this manner the recorder itself was made smaller; less storage space, both for unexposed film and for completed records, was required; developing and handling equipment was much more compact. Furthermore, it was found that positive film of the type used for sound recording could be used quite satisfactorily. Since this film actually costs less per foot than larger paper, and since many more records can be made satisfactorily per foot on 35-mm film than on large paper, the operating costs were greatly reduced. Another factor was the availability of standard parts for the construction of camera and recorder as well as equipment for development and handling. Finally, it was desired to make preliminary experiments on the idea of recording ionosphere phenomena for projection as a moving picture.

It is quite important to have the time at which each record was made marked on the film with the associated record. In the present equipment an image of a drum-dial synchronous clock is exposed on the film for each record by a solenoid-operated shutter.

The complete record with associated time mark occupies two standard motion-picture frames, i. e., 1 by 1½ inches. The frequency scale from 790 to 14,000 kc/s covers about 1⅜ inches and the time mark about ⅛ inch. Virtual heights of more than 1,000 km can be recorded across the width of the film. Figure 8 shows the arrangement of the record on the film. A small projector of the type used for projecting double-frame miniature camera transparencies is used for measuring and studying the records.

In previous recorders, separate motors have been used to drive the film, to rotate the mirror and synchronizing device, and to drive the transmitter tuning camshaft. This recorder uses only one motor, which performs all three functions through an appropriate gear box. This simplifies the control mechanism and helps to reduce the size, weight, and power consumption.

For the control of a self-contained system, an independent means of accurately timing the sequence of switching is required. For this purpose, a 60-cycle voltage is produced by a precision tuning fork. This voltage is amplified sufficiently to operate two synchronous clock motors. Both the tuning fork and the amplifier are designed to operate from the primary 32-volt d-c power source. One motor drives the time-marking clock mentioned above. The other drives a series of contactor cams, which provide for 2, 4, 20, or 60 complete records per hour. The accuracy of the frequency generated by the fork is such that during a week's operation in the field the clocks drifted less than 20 seconds from correct time. Figure 9 is a close-up view of the recorder unit showing the camera, contactors, time-marking clock, etc. Figure 1 shows the position of the recorder in relation to the transmitter.

In addition to the clock contactors, there are several contactor cams on the transmitter camshaft, which control the sequence of operations, such as turning on and off the high voltages, switching bands, marking the time on the record, etc.

## VII. POWER

The primary source of power is a gasoline-engine driven generator producing 32 volts with a capacity of 28 amperes. This is used to charge two banks of automobile-type storage batteries. A small, high speed, 750-watt rotary converter is used to generate 115 volts at 60 cycles from the 32-volt supply. The converter is provided with a centrifugal governor controlling the field current to maintain the frequency constant to $\pm 1/2$ cycle. Since speed is controlled by varying the field, the voltage regulation is poor. Hence it was found advisable to use a constant-voltage transformer.

The use of storage batteries has several advantages to compensate for the loss of efficiency and added weight. One important advantage is dependability. Failure of a mechanical source of power during an eclipse, for example, would be serious, if batteries were not floating on the line for standby. Constancy of voltage is another factor. Although the voltage drifts considerably during the discharge, it is a gradual change and is not subject to sudden periodic surges, as would be the case with a reciprocating engine.

It is expected that the equipment can be operated continuously, making a record every minute for about 4 hours without recharging the batteries. By running the gasoline-engine generator in parallel with the batteries, it should be possible to operate continuously for about 10 hours. By making only one record every 3 minutes, the time of operation on batteries alone may be greatly extended, and with the gasoline engine, the supply of fuel becomes the limitation.

The complete equipment is arranged for transport in a trailer and towing truck. The transmitter is mounted through rubber to the frame of the trailer and is both transported and operated in the position shown in figure 10. Auxiliary equipment is packed in boxes and may be transported completely in the truck and trailer. During operation the gasoline-engine generator, converter, batteries, and timing equipment are placed at a distance of about 200 feet from the trailer.

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