Detection and measurement of low frequency variations of the atmospheric potential gradient

by Raymond E Hare

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Engineering Physics
Montana State University

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DETECTION AND MEASUREMENT OF LOW FREQUENCY VARIATIONS OF THE ATMOSPHERIC POTENTIAL GRADIENT

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Approved:

Head, Major Department

Chairman, Examining Committee

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ABSTRACT

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HISTORICAL BACKGROUND

The year 1750 marked the beginning of the development of our present day knowledge of atmospheric electricity. Four men of Philadelphia; Franklin, Kinnersley, Hopkinson, and Sing, experimented with electricity and their discoveries became the basis for the Franklinian Theory. The discovery of the effect of pointed bodies of "drawing off and in throwing off the electrical fire" can be said to be the beginning of the great amount of work which was to be done in the field of atmospheric electricity.

In 1752 Dalibard succeeded in drawing sparks from a 40 foot vertical rod as a result of the suggestions made by Franklin to a London merchant, Collinson. In the same year Franklin performed his famous kite experiment.

About 1766, DeSaussure developed the first, or at least one of the first, electrometers and went on to develop the "mobile conductor" method of measuring the electric field in which a conductor attached to an electrometer was suddenly raised a meter or more from the earth.

By 1860 Lord Kelvin had presented such comprehensive interpretations of the known facts relating to the electric field, that a new interest and activity was stimulated. Lord Kelvin was also responsible for the beginning of continuous registration of air potential at Kew Observatory.

With the development of the idea of ions in gases by J. J. Thomson and his associates, a general picture was developed by Elster and Geitel and the modern epoch can be said to have begun about the turn of the 20th Century.

Numerous measurements of the electric field undertaken by the Carnegie Institution of Washington during the years 1909-1929 and made during cruises of the magnetic-survey yacht Carnegie, showed that the electric field strength is fairly constant over the oceans and has a value of about 130 volts per meter. Measurements of the field at land stations, taken over a period of many years, show that the value of the electric field varies considerably with location. These field value averages vary from less than 100 volts per meter at some locations to better than 300 volts per meter at some other locations. The field has irregular short period variations of its value as well as hourly, seasonal, and yearly variations. In the long run, however, the field shows no increase or decrease but rather varies about a mean value.

Frequency phenomena of the potential gradient have been investigated by several men. The first measurements were made by C. T. R. Wilson (15) while investigating thunderstorms. Later the cathode-ray oscilloscope was utilized by Norinder (10) and by Appleton and Chapman (1) in investigations of nearby lightning discharges and by Appleton, Watt, and Herd (2) for distant discharges. Whipple and Scrase (14) also made measurements using a sharp discharge point.

None of these investigators indicated the presence of sub-audio and low audio frequencies but Khastgir and Roy (7) stated that atmospherics below 100 cps did not occur although they neglected to say what reasons they had for this statement. Since apparently no investigations were directed primarily to the detection of low frequency phenomena, it was decided to direct the main effort to the detection of possible frequencies below 100 cps.

THE GENERATING VOLTMETER

The radioactive collector (5) is the most commonly used method of measuring the atmospheric potential gradient and consists of a short metal rod or a small metal disk coated with a radioactive material which brings the collector to the potential of the air. Because the radioactive collector presents a serious problem of maintaining good insulation, is affected adversely by moisture conditions, and furthermore has poor response to rapid variations of the electric field, this means of measurement was deemed unsatisfactory.

After some deliberation, the generating voltmeter (6, 8, 13) was selected as being best suited to the type of measurements desired. The instrument constructed was patterned chiefly after one described by W. H. Macky (8).

The generating voltmeter is a refined version of the test plate method first described by C. T. R. Wilson (15). It consisted of a plate which was alternately exposed to and shielded from the electric field by means of a grounded rotating vane.

The equivalent electrical circuit of the generating voltmeter is that shown in Figure 1.

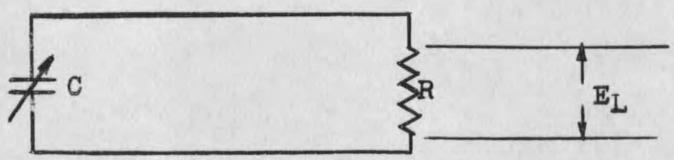

Figure 1 - The equivalent electrical circuit of the generating voltmeter.

The capacity C of the system is composed of two parts, a constant component C_0 and a periodic component $C_1 f(t)$, where C_1 is the magnitude of the variable capacity and f(t) is some function describing the manner in which the variable component of the capacity varies. The instantaneous capacity of the system is thus represented by the expression

$$C = C_0 + C_1 f(t).$$

Writing the sum of the voltage drops around the circuit produces the expression

$$\frac{q}{C} + iR = 0.$$

Substituting terms gives

$$\frac{\int i \, dt}{C_0 + C_1 f(t)} + iR = 0$$

and by differentiating and rearranging terms the differential equation

$$\frac{di}{i} + \frac{1 + RC_1 f'(t)}{R\left[C_0 + C_1 f(t)\right]} dt = 0$$

is obtained. The solution of this differential equation is

$$i = F(t) + k$$

where the constant k is known as a consequence of the initial condition that i = 0 when t = 0.

The voltage E_L developed across the load R is then given by

$$E_L = iR = RF(t) + K$$

where K = kR.

However, there are undoubtedly other voltages which are induced in the instrument. One of these is probably induced by the potentials and fluctuations of potential present in the motor circuit. Another of the voltages induced in the instrument may be due to a frictional charge gathered by the collector plates as a consequence of the air flowing across them. If this is true, then it might be suspected that the potential due to this frictional charge would be a constant quantity with a ripple effect superimposed on it because of the movement of the rotating grounded shielding vane. Although this ripple component is undoubtedly present, it is doubtful if its magnitude is large enough to have any effect. The voltages induced in the instrument as a result of these effects add to the potential induced by an electric field of one polarity and subtract from that induced by a field of opposite polarity. Thus the response of the generating voltmeter is not the same for both positive and negative electric fields.

The numerical value of the potential developed by these effects can be determined experimentally with the aid of the calibration curves shown in Figure 3 on page 13. Writing the equations of the straight portions of the two calibration curves as

$$E_1 = m\mathcal{E}_1 + A$$
$$E_2 = m\mathcal{E}_2 + B$$

and remembering that $\mathcal{E}_1 = -\mathcal{E}_2$ and adding the two equations gives

$$\Delta E = |E_1| + |E_2| = |A| + |B|$$

The sum of the induced voltages E_i developed because of extraneous effects is then

$$E_i = \frac{|A| + |B|}{2}$$

The curved portion of the two calibration curves is probably the region where the extraneous potentials mentioned above begin to take effect as the value of the electric field is reduced and finally dominate the signal as the field value approaches zero. The fact that the voltage E_i is less than the voltage E_0 indicated on the graph for a zero external field indicates that either the extraneous potentials mentioned above do not include all the possibilities or the solution of the differential equation has a component responsible for this difference between E_0 and E_i.

The potential developed across the load was examined by means of a suitable meter and an oscilloscope.

The collector plates of the instrument consisted of the two opposite quadrants of a circular sheet of aluminum having a radius of eight centimeters. These two quadrants had a banana plug attached to each one and were plugged into receptacles which were mounted in insulators of hard rubber. This made it possible to remove the collector plates quickly and easily at any time. The two quadrants were joined electrically. The rotor was also formed of the opposite quadrants of a circular piece of aluminum but these were joined at the center. The rotor was mounted at the top of a vertical shaft which operated in two sets of ball bearings set in a bushing. The shaft was rotated at approximately 27 rps by means of a small 12 volt direct current motor and was coupled to the motor by means of a piece of rubber tubing. The modest current requirements of 0.4 amperes for the motor insured a minimum of trouble in supply by means of a storage battery. All of these parts were mounted by means of appropriate brackets inside a metal box. The top of the box was cut back 0.5 centimeters all around the two stator plates. Power and signal leads were brought out of the box by means of plug and socket arrangements.

The signal from the generating voltmeter was applied to a General Radio Company Sound Level Meter Type 759. In addition to the indicating meter contained in this instrument, the amplified signal was also available at an output jack for application to an oscilloscope.

In order to make outdoor measurements with the instrument, the box was buried in the ground so that the top of the instrument was flush with the surface of the earth. A large aluminum sheet, cut out so that it fits around the instrument, was placed on the surface of the ground in the manner shown in Figure 2a. For calibration of the instrument, a wooden rack was placed over the instrument and another sheet of aluminum was placed over the top of the rack as shown in Figure 2b. The distance between the two sheets was 40 centimeters. Various voltages were applied across the plates and the output of the generating voltmeter was read from the sound level meter for each voltage applied. The magnitude of the electric field between the plates was easily computed by dividing the voltage applied to the plates by the distance separating them. The value of the electric field is expressed in units of volts per centimeter or in volts per meter. A typical calibration curve is shown in Figure 3.

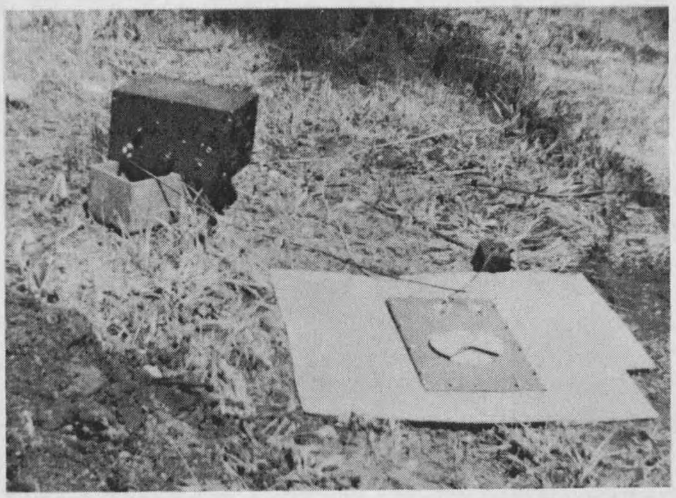

Figure 2a - The generating voltmeter in operating position.

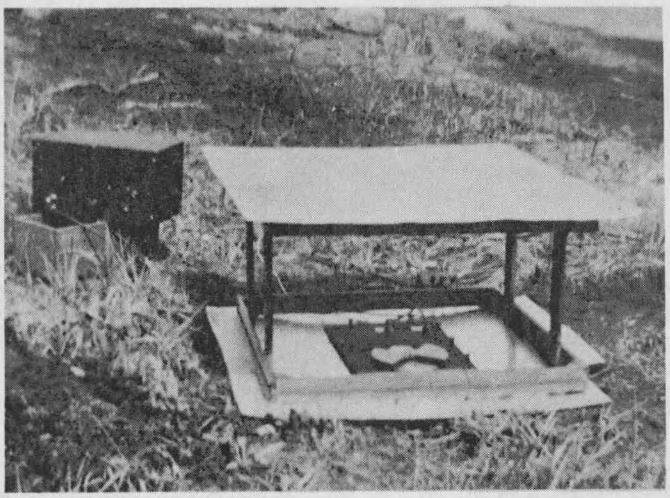

Figure 2b - Method of calibration of the generating voltmeter.

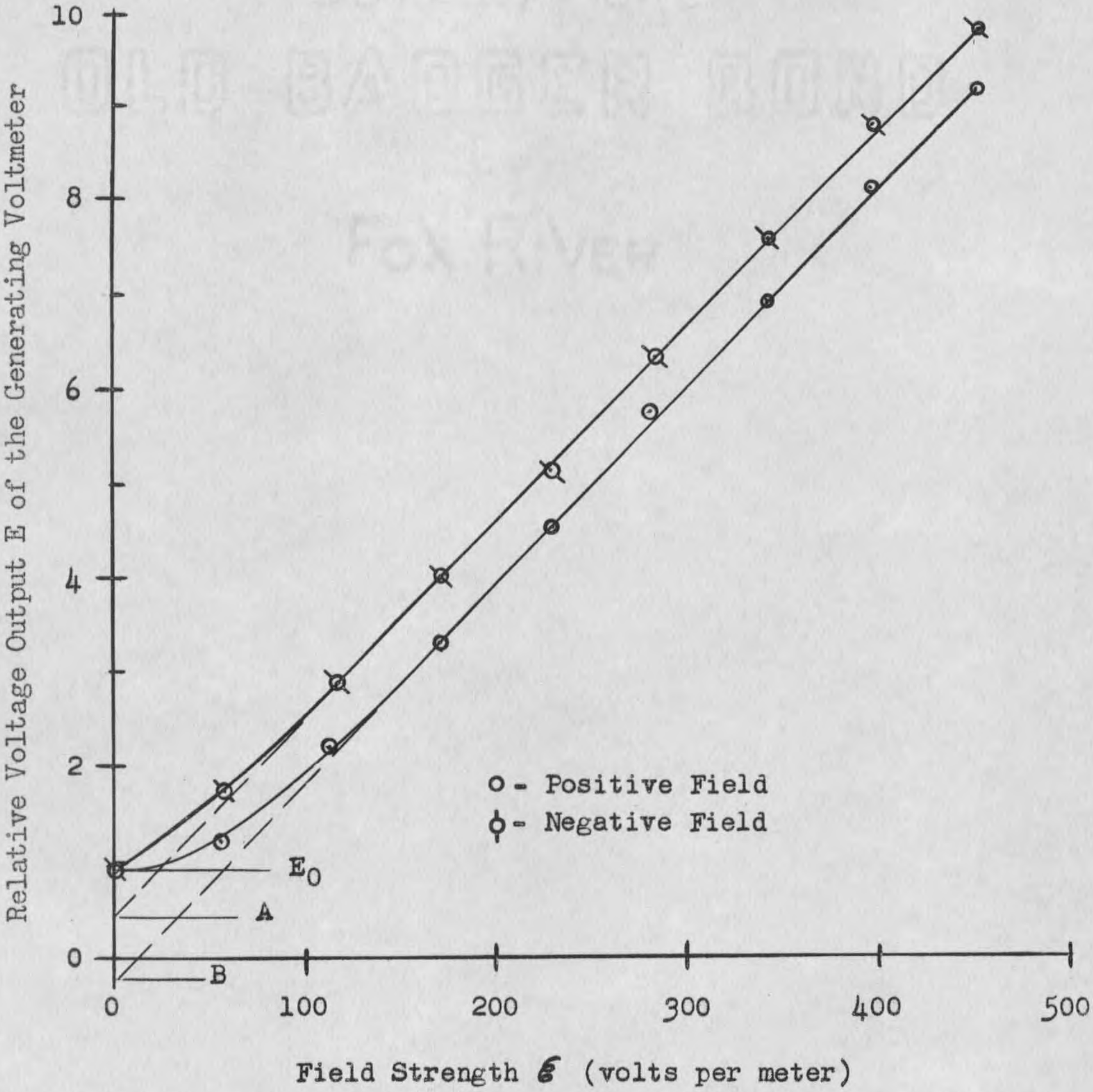

Figure 3 - Calibration curves of the generating voltmeter for positive and negative fields.

Since the quantity of charge developed on the plates of the generating voltmeter is proportional to the capacity of the instrument, a graph of the capacity of the system as a function of the displacement of the rotor should be an indication of the anticipated wave form of the output of the instrument. The capacity was measured by means of a General Radio Company Impedance Bridge Type 650-A and the results are plotted in Figure 4. The angle of zero displacement was taken with

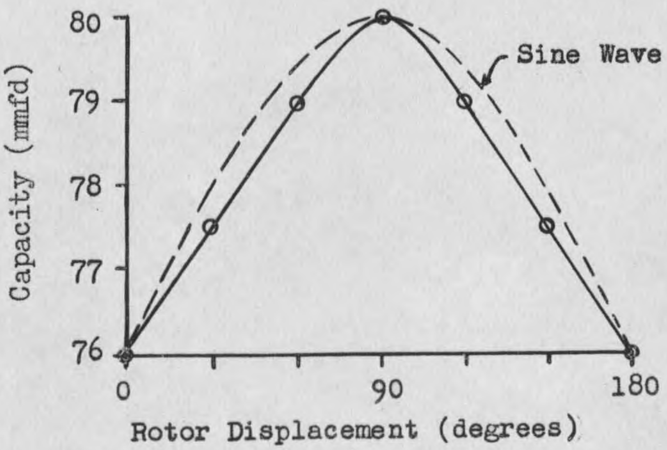

Figure 4 - The capacity of the generating voltmeter versus the angular displacement of the rotor.

the collector plates uncovered by the rotor. At 90° the stator was completely covered and at 180° the stator was uncovered again. The capacity was measured every 30° of angular displacement. As a means of comparison, a sine wave is shown in Figure 4 drawn to the same scale. The actual wave from the instrument is shown in Figure 5.

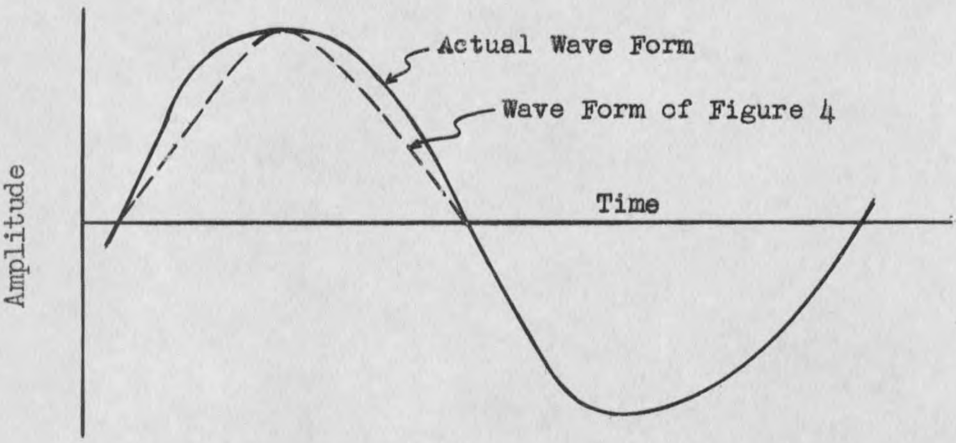

Figure 5 - The actual wave form of the output of the generating voltmeter compared with the wave form shown in Figure 4.

This was obtained by drawing on squared paper the wave form viewed on the oscilloscope screen. The capacity wave of Figure 4 is also shown in Figure 5 for comparison.

FREQUENCY RESPONSE AND SENSITIVITY

For determination of frequency response, a square wave is perhaps the most desirable since passage of harmonics up to the tenth are required for the production of a good square wave. However, since a satisfactory square wave source was not available for outdoor use, it was decided to use a sawtooth wave which was readily obtained from the sweep output of an oscilloscope. The source used for the sawtooth wave was a Du Mont Type 274 oscilloscope.

By visual comparison (on another oscilloscope) of the sawtooth wave with the sine wave output of a calibrated oscillator, the frequency of the sawtooth source was determined in terms of the settings of the sweep frequency controls. Several determinations of this kind over a period of several days showed that the frequency control settings were essentially constant over a considerable period of time.

A Ballantine Electronic Voltmeter Model 302 was then calibrated in terms of the peak to peak amplitude of the sawtooth wave at frequencies of 45, 1020, and 4500 cps. A graph of the voltmeter readings versus the sawtooth amplitude at these three frequencies showed that the three curves had essentially the same slope. The sawtooth amplitude was determined on a Tektronix Cathode-Ray Oscilloscope Type 512 by means of the internal voltage calibrator. The average of the three sets of data taken at the above mentioned frequencies is shown in Table I and is plotted in Figure 6. The slope of this curve was determined to be

$$\frac{\Delta \text{ SAWTOOTH VOLTAGE}}{\Delta \text{ METER READING}} = \frac{100 - 0}{29.6 - 0} = 3.38.$$

Thus to obtain the amplitude of the sawtooth wave, it was only necessary to multiply the voltmeter reading by the figure 3.38.

TABLE I - Amplitude of the sawtooth wave as a function of the voltmeter reading.

Sawtooth Amplitude (volts)	Voltmeter reading at (volts) 45 cps	1020 cps	4500 cps	Mean (volts)
100	29	30	29.8	29.6
82	24	26	24.5	24.8
65	18.8	20.2	19.8	19.6
53	15	16	15.5	15.5
36	10	10	10	10
17	4.1	4.6	4.5	4.4
9.5	2.7	2.8	2.9	2.8
4.9	1.4	1.45	1.4	1.42
1.4	0.31	0.33	0.3	0.31

To determine the frequency response of the generating voltmeter, the sawtooth was applied to the calibration plates and the output of the instrument was amplified with the sound level meter. The output of the amplifier was examined on the screen of the oscilloscope. The sawtooth was readily detected from the lowest available frequency of less than 8 cps to a frequency of 10 kc. Because the sawtooth wave form, at a frequency of 10 kc, degenerates into a wave form resembling a sine wave, the harmonics involved in the composition of the sawtooth became negligible and the upper limit of frequency response of the generating voltmeter was 10 kc. Since the instrument also detected steady fields, the frequency range of the instrument was

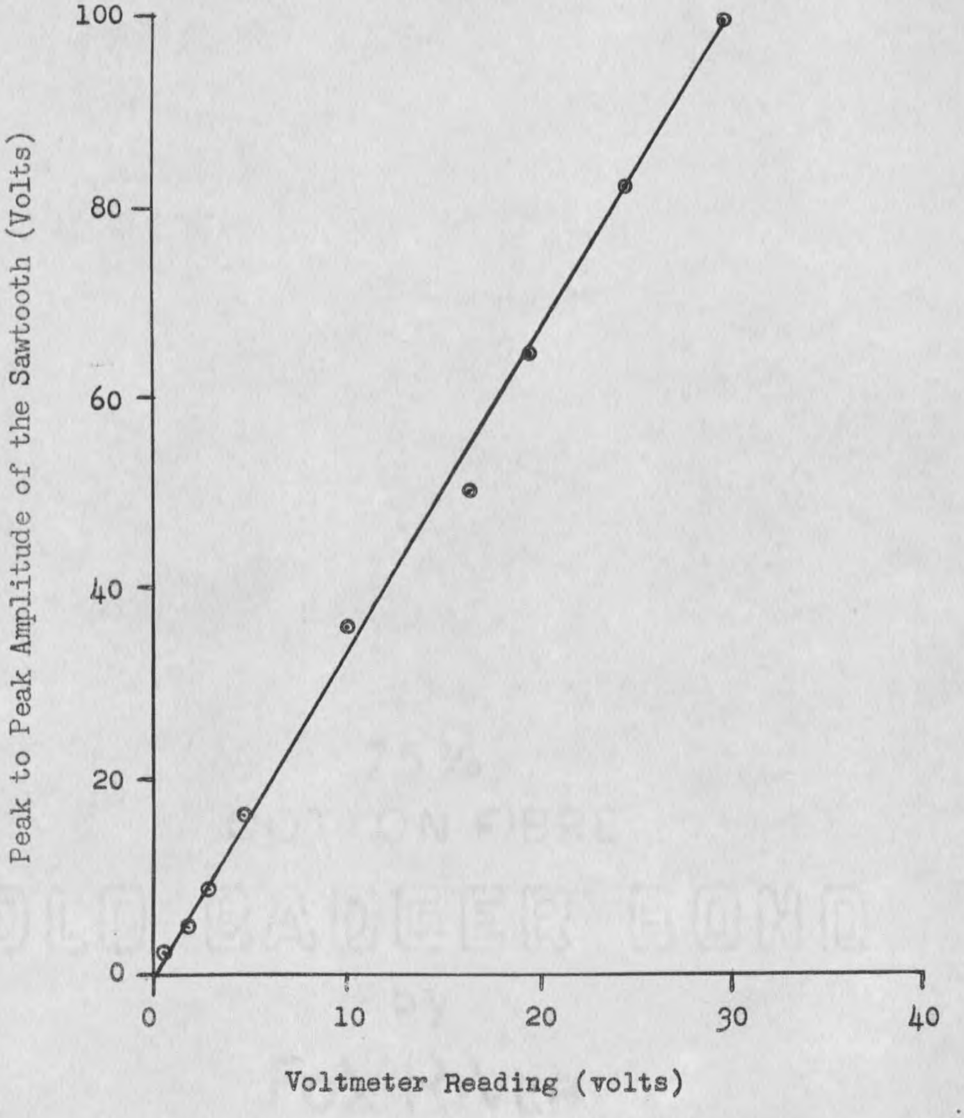

Figure 6 - The amplitude of the sawtooth as a function of the voltmeter reading.

said to be from zero frequency to 10 kc. At a frequency of 10 kc, the detection of the signal cut off quite sharply.

To determine the sensitivity, the magnitude of the sawtooth was reduced until the signal could be barely detected on the oscilloscope screen. The minimum voltages detected and the corresponding electric field strengths are shown in Table II.

TABLE II - Sensitivity of the generating voltmeter.

Frequency	Voltmeter reading (volts)	Sawtooth amplitude (volts)	Field strength- $\mathcal{E}$ (volts/meter)
45 cps	1.24	4.18	10.5
1020 "	1.85	6.25	15.5
4500 "	1.35	4.56	11.4

THE BATTERY OPERATED OSCILLOSCOPE

In the early stages of the investigations, the desirability of having a battery operated oscilloscope became evident. Previously an oscilloscope had been operated from a gasoline operated motor-generator set but electrical radiation from this apparatus was so serious that readings taken with the generating voltmeter were useless. Some thought was given to building up an oscilloscope but an extensive amount of design is necessary to provide proper frequency response in the amplifiers. For this reason the conversion of a standard model was deemed more satisfactory. The high gain of the vertical amplifier of the Du Mont Type 168 five inch oscilloscope dictated the selection of this instrument and measurements of the current requirements were made. These current requirements were small enough to be readily supplied by regular B batteries. Two battery packs were formed from regular radio type B batteries, one of 350 volts and one of 1125 volts. Filaments of the tubes were readily supplied from three automobile type storage batteries. One battery supplied the cathode-ray tube through a dropping resistor to provide the required 2.5 volts. The horizontal and vertical amplifier filaments were operated from another battery. A separate battery supplied the filament of the sweep generator tube through a dropping resistor since it was found that this tube would not operate from the same supply with the amplifier tubes. The battery operated oscilloscope has proved to be highly satisfactory.

OUTDOOR MEASUREMENTS WITH THE GENERATING VOLTMETER

To eliminate interference with the measurements by 60 cycle radiation from power lines, it was necessary to select a site of operations as distant from power lines as could be reached conveniently. For this reason, all but two or three sets of outdoor measurements were taken in Hyalite Canyon; at first in a meadow at Langohr Campground and later in a larger and more secluded meadow several miles further up the canyon. The first two or three attempts at measurement of the electric field were not reliable since they were devoted chiefly to becoming acquainted with the instrument.

The first noteworthy fact that was observed was the presence of a number of short period pulses in the signal. These pulses correlated well with similar pulses observed by A. R. Jordan while taking measurements of the magnetic field with a large coil. However, a greater number of pulses were observed by A. R. Jordan and it was apparent that only the strongest pulses were observed with the generating voltmeter.

At this time the signal lead was increased to a length of about 15 meters and the sound level meter was removed to this distance in order to reduce the distorting effect of near bodies on the electric field. After this the pulses were reduced both in magnitude and frequency of occurrence.

Some tests were then made using several different circuit configurations. With the rotor left stationary, the zero level was below 24 db on the indicating meter of the sound level meter but pulses were present which were as high as 40 db. The rotor was then grounded to the case of the generating voltmeter and it was noted that the zero level and pulse meter readings then averaged 20 db higher.

The reason for this is readily seen by examining the circuit in Figure 7. The equivalent circuit shown in the same figure better

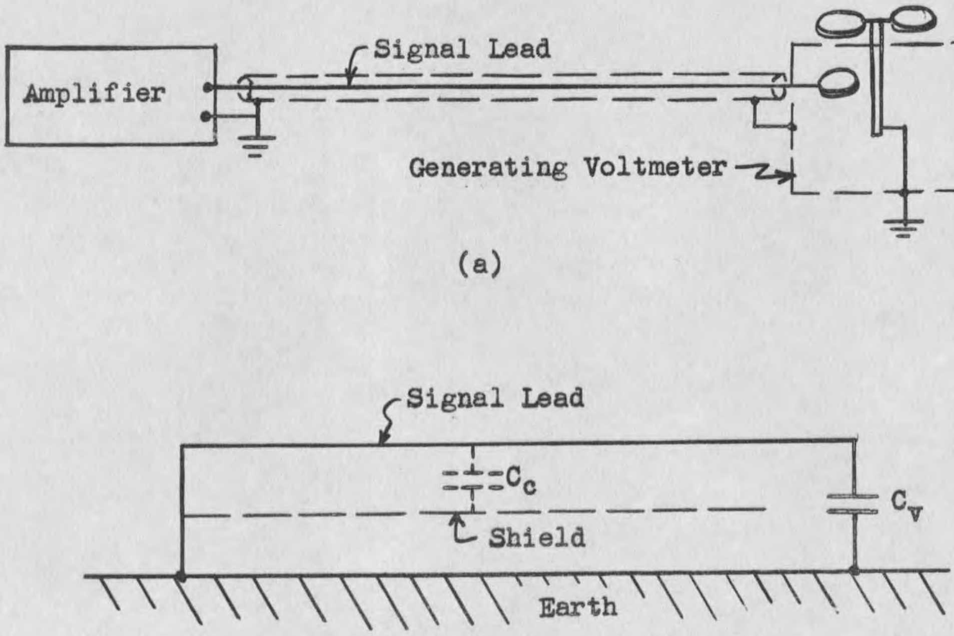

Figure 7 - (a) Circuit initially used in measurements with the generating voltmeter, (b) the equivalent circuit.

illustrates the situation. As shown in the figure, C_v represents the capacity of the generating voltmeter and C_c is the distributed capacity-to-ground of the signal lead. When the stator was grounded, the capacity C_v was removed from the circuit and so reduced the attenuation of any signal which entered the system. The system was thus basically the same as that used by W. B. Farrand (4) in his investigations of earth potentials. From these facts it must be assumed that the pulses observed up to this time were actually only caused by ground currents of high amplitude.

In order to eliminate any effects due to ground currents, the amplifier was returned to a position one meter from the generating voltmeter and was supplied through short, unshielded leads. This made it possible to operate with only one ground point in the system and also eliminated possible attenuation of the signal by the cable. When necessary, the output of the amplifier was applied to the oscilloscope through a long shielded lead.

With the amplifier returned to a position near to the generating voltmeter, it was seen that pulses were still present, although these pulses were of lower magnitude and did not occur as frequently as before. These variations in the field were of several different kinds. Some were of relatively low magnitude and of regular occurrence, while others were of quite high magnitude but seemed to occur in a completely random manner.

The first type were present in the wave form as small variations which modified the smooth wave form. These were at first thought to be due to electrical noise in the motor circuit which was being picked up in the signal lead. For this reason, a heavy iron case was placed around the motor to serve as a magnetic and electrostatic shield. Operation of the generating voltmeter with this shield in place did not reduce the distortion of the wave, but rather caused it to become much greater. Apparently the presence of the shield caused mechanical vibrations in the rotor and its drive system. For this reason the shield was dispensed with. Later, a collar tapered in such a manner as to steady the upper ball bearing was added to the instrument, and this somewhat reduced the small variations of the wave form. Furthermore, the fact that these variations were of constant magnitude and disappeared from the trace at the times when the atmospheric field was high or when a field of about 200 volts per meter or higher was applied to the calibrating plates, indicate that these variations were noise due to mechanical vibrations in the instrument. These facts, in addition to the lack of sensitivity of the generating voltmeter, indicate that this instrument was not well suited to the type of measurements undertaken. The generating voltmeter is, however, ideally suited to the measurement of high magnitude electric fields and should be capable of measuring fields up to the breakdown potential.

The high magnitude random pulses mentioned previously occurred as transients of very short duration. At some times they occurred more frequently than at other times, although they were never very common. Apparently these pulses were most frequent when storm conditions prevailed in the surrounding area. Generally these pulses seemed to be aperiodic in structure and nearly always of very short duration. A very few of them of relatively long duration were detected. One of these transients was identified as having a duration corresponding to the period of the generating voltmeter, which operates at 27 rps. Some other of these pulses (of long duration) had periods corresponding to frequencies of 30 cps and 10 to 15 cps.

THE ANTENNA

Because so few pulses were observed using the generating voltmeter, another method of measurement became necessary. For this purpose an antenna was erected. As a first try, a horizontal antenna 70 meters in length was erected at a height above the earth of 1.5 meters. This short low antenna developed sufficient voltage for detection of the signal by means of the oscilloscope without the aid of an amplifier. Watt and Appleton (2) state that it is believed that by making the ratio of the flat top of the antenna to the down lead of the order of 30 to 1, that no appreciable error can result from taking an effective height within 3% of the geometric height. The desirability of knowing the effective height is evident from the expression $\mathcal{E} = V/h_e$ where, h_e is the effective height, V is the voltage developed by the antenna, and $\mathcal{E}$ is the value of the electric field strength. If h_e is given in meters and V is in volts, then $\mathcal{E}$ has the dimensions of volts per meter.

Examination of the signal from the antenna showed that a great number of pulses were present. These pulses appeared to be of two types. One type consisted of pulses having a quasi-periodic (a damped oscillation) structure and generally had a moderate magnitude. The other type consisted of aperiodic pulses of shorter duration than those of the quasi-periodic group. In addition to these, there were a large number of transients, aperiodic in form, and having magnitudes at least several times as great as the others previously mentioned. Typical examples of the quasi-periodic and the aperiodic pulses are shown in Figure 8.

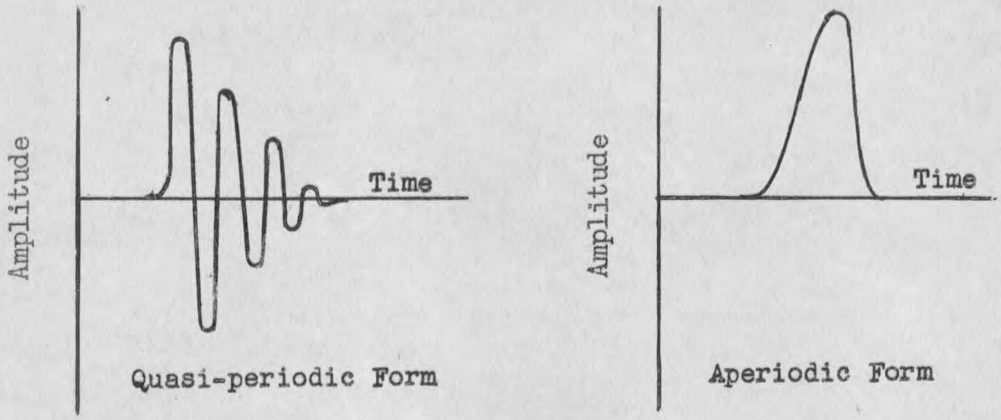

Figure 8 - Typical wave forms of the quasi-periodic and the aperiodic form detected by means of the antenna.

In order to determine any possible energy trend dependent on the period of the pulses, a Hewlett Packard Harmonic Wave Analyzer Model 300A was used to measure the antenna signal. Sensitivity of the analyzer was great enough to permit measurement of the antenna signal without additional amplification. Measurements were taken at certain specific frequencies throughout the range of the analyzer to its upper limit of 16 kc. Three readings were taken at each frequency; the minimum meter reading, the average (or most common) peak reading, and the maximum (highest observed magnitude) peak reading. Table III is a tabulation of three runs through the frequency spectrum with the harmonic wave analyzer. Since the minimum reading was

TABLE III - Voltages of the antenna signal at different frequencies measured with the harmonic wave analyzer.

Frequency	Minimum (mv)	Average (mv)	Maximum (mv)	Ave.-Min. (mv)	$\mathcal{E}_{av-min.}$ (v/m)
40 cps	.06	.2	.3	.14	$.93 \times 10^{-4}$
80 "	.04	.4	1.	.36	2.4 "
100 "	.06	.3	.5	.24	1.6 "
200 "	.05	.3	.6	.25	1.67 "
400 "	.06	.4	.9	.34	2.26 "
800 "	.1	.4	.8	.3	2. "
1.6 kc	.5	.65	.75	.15	1. "
3.2 "	.05	.25	.8	.2	1.33 "
6.4 "	.3	.4	.6	.1	.67 "
12.8 "	.1	.3	.4	.2	1.33 "
16. "	.04	.4	.6	.36	2.4 "
40 cps	.12	.2	.3	.08	.53 "
80 "	.04	.1	.3	.06	.4 "
100 "	.03	.12	.4	.09	.6 "
200 "	.02	.15	.4	.13	.87 "
400 "	.3	.4	.6	.1	.67 "
800 "	.03	.15	.6	.12	.8 "
1.6 kc	.06	.15	.4	.09	.6 "
3.2 "	.04	.2	1.	.16	1.07 "
6.4 "	.06	.2	.4	.14	.93 "
12.8 "	.03	.2	.3	.17	1.13 "
16. "	.1	.2	.6	.1	.67 "
40 cps	.26	.3	.4	.04	.27 "
80 "	.1	.16	.3	.06	.4 "
100 "	.03	.14	.3	.11	.73 "
200 "	.04	.12	.2	.08	.53 "
400 "	.25	.3	.35	.05	.33 "
800 "	.02	.1	.2	.08	.53 "
1.6 kc	.08	.15	.3	.07	.47 "
3.2 "	.04	.14	.3	.1	.67 "
6.4 "	.1	.24	.4	.14	.93 "
12.8 "	.04	.24	.4	.2	1.33 "
16. "	.02	.1	.9	.08	.53 "

considered to be the measure of the background level, the difference between the average and the minimum readings was the measure of the magnitude of the transients appearing. These differences are listed in Table III and the field strength values corresponding to these voltages were computed on the basis of an effective height of 1.5 meters. Table IV lists the magnetic field values obtained by A. R. Jordan and the electric field values computed from them. That these values of the electric field were of the same order of magnitude as

TABLE IV - Magnetic field values obtained by A. R. Jordan and the electric field values computed from them.

Frequency	Average magnetic field-H (oersteds)	Average electric field-$\mathcal{E}$ (volts/meter)	Maximum magnetic field-H (oersteds)	Maximum electric field-$\mathcal{E}$ (volts/meter)
40 cps	2.1×10^{-8}	6.3×10^{-4}	9.5×10^{-8}	28.5×10^{-4}
100 "	1.4 "	4.2 "	3.7 "	11.1 "
200 "	1.2 "	3.6 "	2.64 "	7.92 "
400 "	0.64 "	1.92 "	1.82 "	5.46 "
800 "	0.18 "	0.54 "	0.72 "	2.16 "
1.6 kc	0.14 "	0.42 "	0.55 "	1.65 "
3.2 "	0.25 "	0.75 "	0.69 "	2.07 "
6.4 "	0.29 "	0.87 "	--	--

$\mathcal{E}$ (volts/meter) = H (oersteds)$\times 3 \times 10^4$

those values obtained from the antenna, indicated that the effective height was at least approximately the same as the geometric height. Since the accuracy of the wave analyzer meter, or any meter, is poor for a pulse type of signal as a result of meter inertia, and since A. R. Jordan states that the accuracy of his field values is no better than 10%, it may well be that the effective height of the antenna was within 3% of the geometric height.

In Figure 9 the values of average-minus-minimum given in Table III are plotted. The mean of the three trials is also plotted from the data in Table V. The figure indicates that there was no decided tendency for the energy of the pulse to be dependent on the period of the pulse.

TABLE V - Mean values of average-minus-minimum values for three trials.

Frequency	Average-minus-minimum Trial 1	Trial 2	Trial 3	Mean (mv)
40 cps	.14	.08	.04	.087
80 "	.36	.06	.06	.16
100 "	.24	.09	.11	.147
200 "	.25	.13	.08	.153
400 "	.34	.1	.05	.163
800 "	.3	.12	.08	.167
1.6 kc	.15	.09	.07	.103
3.2 "	.2	.16	.1	.153
6.4 "	.1	.14	.14	.127
12.8 "	.2	.17	.2	.19
16. "	.36	.1	.08	.18

Although the wave analyzer indicated the presence of low frequencies, this was not considered as decisive evidence because of the high background level within the analyzer at these low frequencies. Furthermore, no visual evidence was obtained up to this time, probably because of the abundance of the shorter period pulses.

As a means of removing the short period pulses from the signal, the use of a band-pass or low-pass filter able to pass the frequency

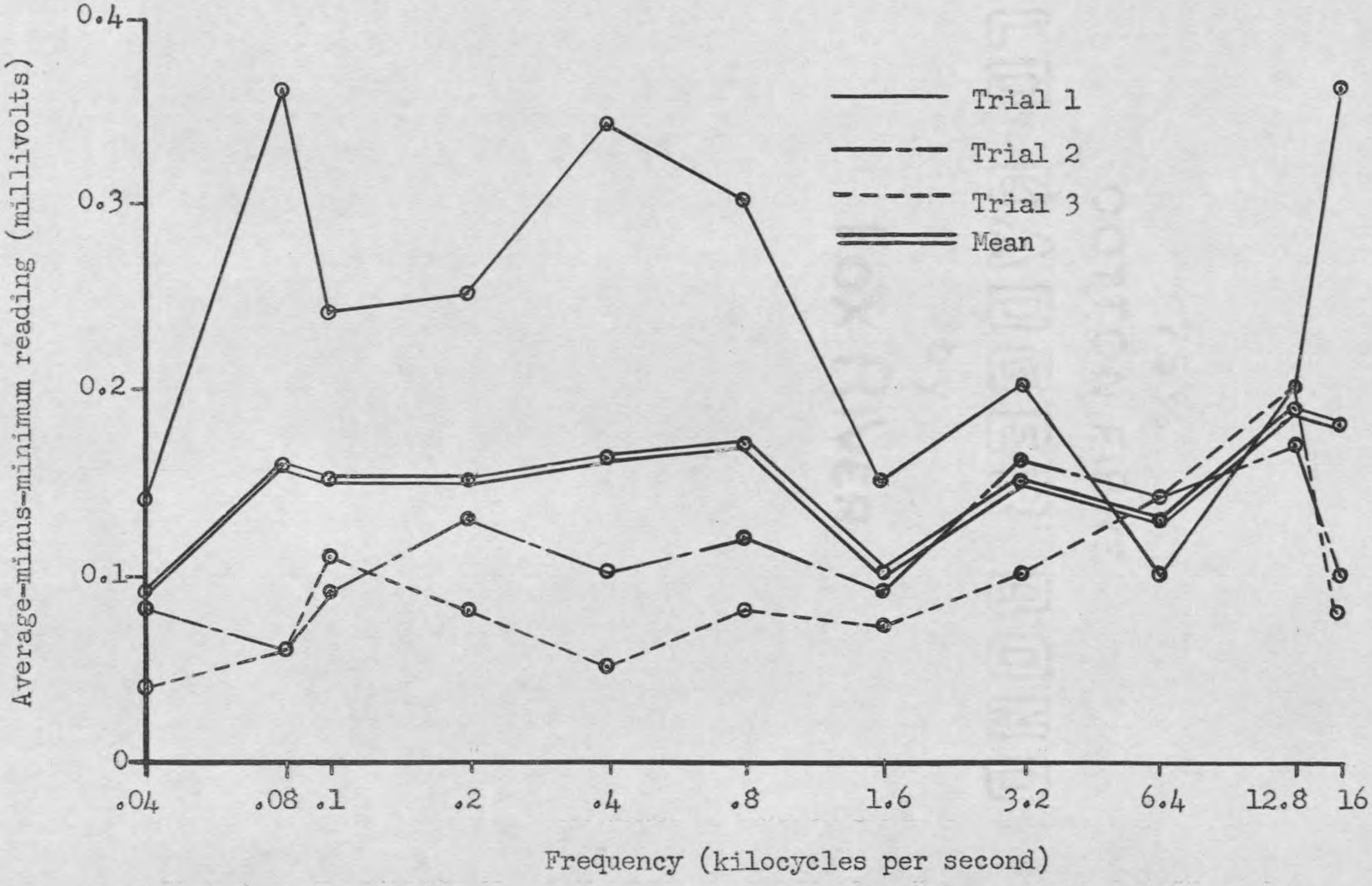

Figure 9 - The average-minus-minimum readings of Table III as a function of frequency.

band below 100 cps was considered. Computations for values of filter constants (12) showed that values of inductance and capacity required for these low frequencies were of unwieldy size and in addition there must be impedance matching networks on both the input and output of the filter. The difficulty in matching the antenna impedance was evident when it was considered that the inductance, radiation resistance, and the capacity of the antenna needed to be known. The antenna capacity was easily measured by means of a General Radio Impedance Bridge Type 650-A and was found to be 620 micromicrofarads. The measurement of the inductance and the radiation resistance (11) posed a problem, since it required a large loop (9) to radiate energy into the antenna and rather elaborate methods of comparison with standards. This loop also had to be several wavelengths from the antenna which in this case would have had to be a distance greater than 3×10^6 meters.

As an alternative to the low pass filter, a series LC circuit made resonant somewhere in the frequency range below 100 cps was used. By using an audio frequency choke having an inductance of 250 henrys, it was possible to obtain resonance using values of capacitance of less than one microfarad which was easily supplied by means of a decade box. Because of the distributed antenna constants, a shift of the resonance peak took place when the circuits were introduced into the antenna system. An attempt was made to measure this shift by radiating a sine wave into the antenna, but it proved to be impossible to radiate sufficient energy to suppress the 50 cps generator wave.

As a means of avoiding this problem, it was decided to amplify the signal with an amplifier and to then apply the LC circuits to the output of the amplifier. In this way any possible shift of the resonance peak due to the amplifier constants was of no consequence since the resonance curves were determined under the actual conditions under which the LC circuits were used. The circuit and resonance curves are shown in Figure 10 for several values of C. Table VI indicates the attenuation of the signal from the response at resonance for the three values of capacity used. L was held constant at a rated value of 250 henrys. Actually the inductance of the choke was dependent on both the frequency and the magnitude of the signal.

Application of these circuits to the antenna signal gave immediate and definite indications of the presence of low frequencies. It is difficult to say what the exact periods were but they appeared to correspond to frequencies of 15 to 50 cps. These figures were established by setting the sweep controls of the oscilloscope so that three complete waves appeared when the 50 cps generator was operating. Under this condition, the sweep was operating at approximately 17 cps. By then observing the fraction of the trace which a transient occupied, an approximation of the time of duration of the transient was obtained.

Compared to the large number of short period pulses which were

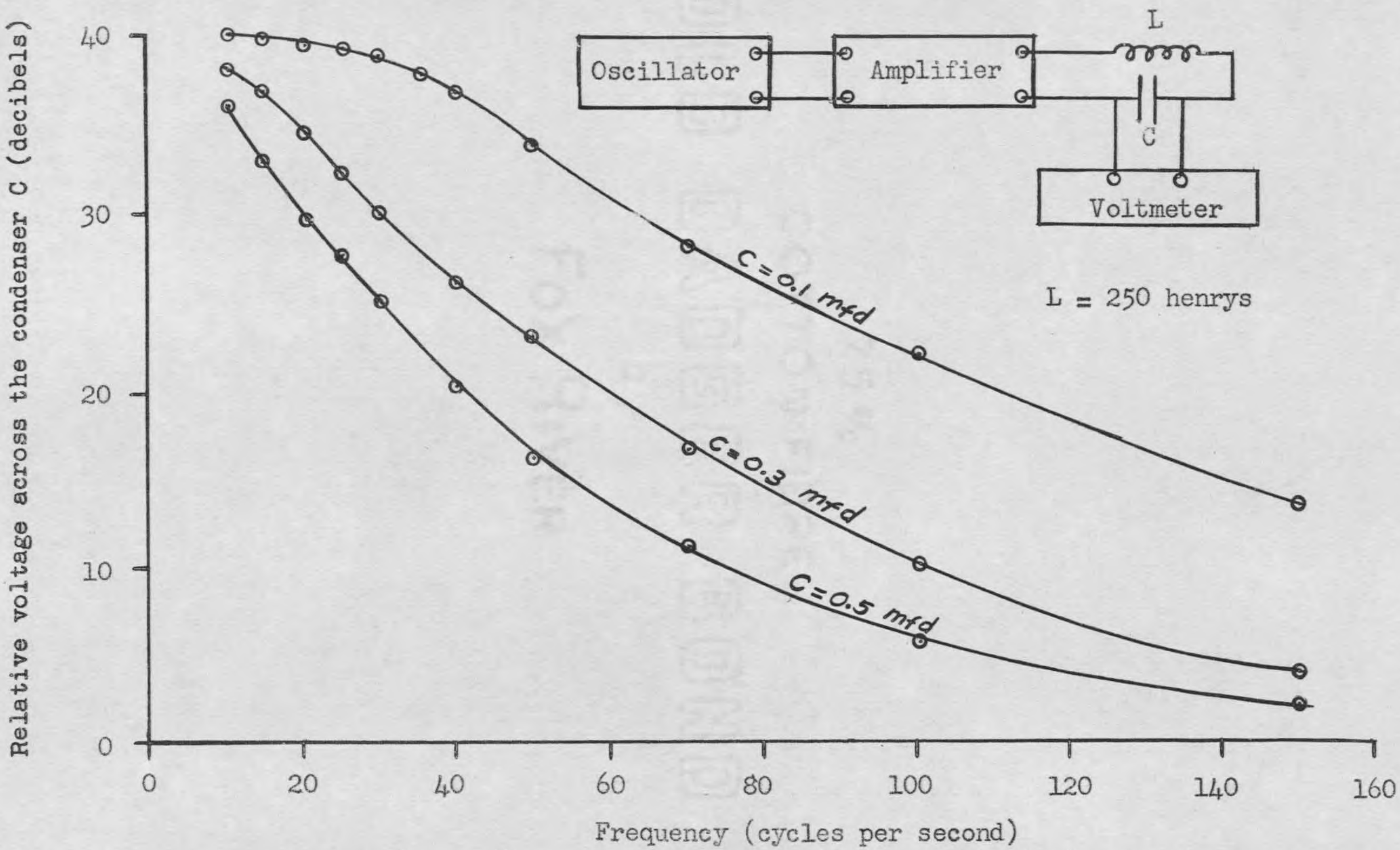

Figure 10 - Resonance curves of the LC series circuit. The curves are corrected for the non-linear frequency response of the amplifier.

TABLE VI - Attenuation of frequencies of 100 cps and 150 cps from the response at resonance for the LC series circuits.

L (henrys)	C (mfd)	Resonance frequency (cps)	Response at resonance minus the response at		Ratio of voltage at resonance to the voltage at	
			100 cps	150 cps	100 cps	150 cps
250	0.1	10	18 db	26.5 db	7.9	21.1
250	0.3	10	27.75 "	34.25 "	22.7	51.6
250	0.5	9	30.25 "	34. "	32.6	50.1

always present, it was noted that the transients having a long period were quite rare. Generally the long period transients may be said to have occurred at least several seconds apart while for the transients corresponding to frequencies above 100 cps, the oscilloscope trace showed many pulses to be present at all times.

SUMMARY

A generating voltmeter type of instrument for measurement of the electric field has been described. The frequency response of the instrument was determined to be from zero to ten kc and its sensitivity was determined but was found to be lower than desired. Because of the lack of sufficient sensitivity and the high noise level of the instrument, it was decided that the generating voltmeter was not well suited to the type of measurements made, but that it was well suited to the measurement of high magnitude fields. A few examples were obtained of transients having periods corresponding to frequencies of about 10 to 30 cps.

As a consequence of the low sensitivity of the generating voltmeter, the use of an antenna in conjunction with the battery operated oscilloscope became necessary for the detection of the signal. The antenna was 70 meters in length and was erected at a height of 1.5 meters above the earth. Two types of transients were observed while using the antenna. One was a group of quasi-periodic pulses, generally of moderate magnitudes. The other type of transients were aperiodic in form of moderate to high magnitudes, and generally had a shorter period than those of the quasi-periodic group. Series LC circuits made resonant at frequencies below 100 cps were applied in order to attenuate the transients of shorter period. In this manner, definite evidence was obtained of the presence of pulses having long periods. It was determined that these periods correspond to frequen-

cies of approximately 15 to 50 cps. These long period pulses were found to be relatively rare compared to those of short duration.

LITERATURE CONSULTED

1. Appleton, E. V., and Chapman, F. W., "On the Nature of Atmospherics-IV", Proc. Roy. Soc. (London) A, 158,1 (1937).

2. Appleton, E. V., Watt, R. A. Watson, and Herd, J. F., "On the Nature of Atmospherics-II", Proc. Roy. Soc. (London) A, 111, 615 (1926).

3. Dellinger, J. H., "Principles of Radio Transmission and Reception with Antenna and Coil Aerials", Sci. Papers Bur. Standards, No. 354, Dec. 11, 1919, Vol. 15, 435 (1919).

4. Farrand, W. B., "Investigations of Alternating Components of Earth Potentials", Unpublished thesis, Montana State College.

5. Fleming, J. A., Physics of the Earth-VIII, Terrestrial Magnetism and Electricity (McGraw-Hill Book Company, Inc., New York, 1939).

6. Gunn, Ross, "Principles of a New Portable Electrometer", Phys. Rev., 40,307 (1932).

7. Khastgir, S. R., and Roy, R., "Study of the Wave Form of Atmospherics", Phil. Mag., 40, 1129 (1949).

8. Macky, W. A., "The Measurement of Normal Atmospheric-Electric Potential-Gradients Using a Valve Electrometer", Terr. Magn. Atmos. Elect., 42, 77 (1937).

9. Moyer and Wostrel, Radio Handbook (Mc-Graw Hill Book Company, Inc., New York, 1931), first edition.

10. Norinder, H., "Lightning Currents and their Variations", J. Franklin Inst., 220,69 (1935).

11. Terman, F. E., Measurements in Radio Engineering (McGraw-Hill Book Company, Inc., New York, 1935), first edition.

12. Terman, F. E., Radio Engineers' Handbook (McGraw-Hill Book Company, Inc., New York, 1943), first edition.

13. Waddell, Raymond, Drutowski, Richard C., and Blatt, William N., "Army-Navy Precipitation-Static Project, Part II - Aircraft Instrumentation for Precipitation-Static Research", Proc. Inst. Radio Engrs., 34, 156p (1946).

14. Whipple, F. J. W., and Scrase, F. J., "Point Discharge in the Electric Field of the Earth", London Met. Office, Geophys. Mem., No. 68, 20 pp (1936).

15. Wilson, C. T. R., "Investigations on Lightning Discharges and on the Electric Field of Thunderstorms", Philos. Trans. A, 221, 73 (1920).