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

Abstract:
An instrument for measuring, the potential gradient' of the earth's electric field, the generating voltmeter, is described arid its frequency response and sensitivity characteristics are determined. Lack of sufficient sensitivity of the generating voltmeter for the desired purposes dictated the use of an antenna as a means of detecting the signal. Series LC circuits having the resonance peak below 100 cps are applied to the antenna signal in order to attenuate the frequencies above 100 cps. The presence in the electric field of frequencies below 100 cps is established but these low frequencies are found to be relatively rare compared to the higher frequencies.

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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.

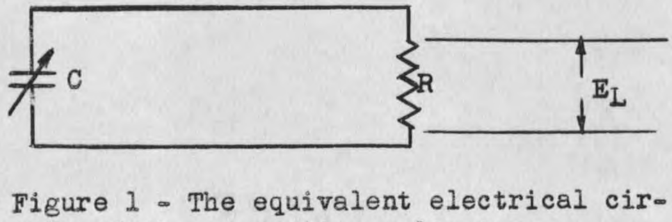

Figure 1 - The equivalent electrical circuit of the generating voltmeter.

The capacity C of the system is composed of two parts, a constant component C_0 and a periodic component $C_1f(t)$, 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

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

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.

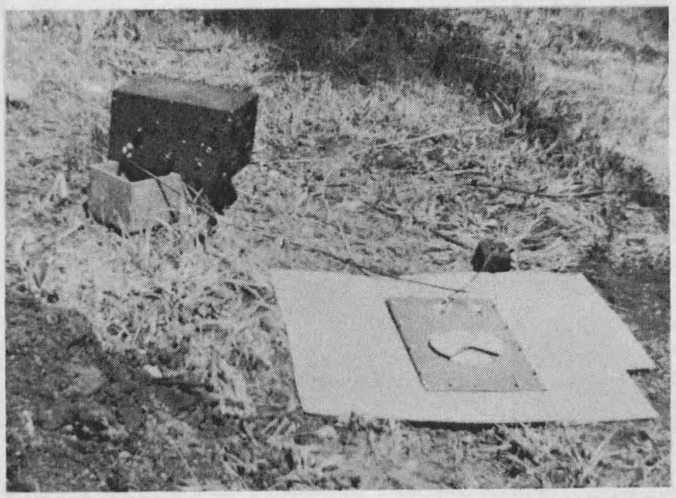

Figure 2a - The generating voltmeter in operating position.

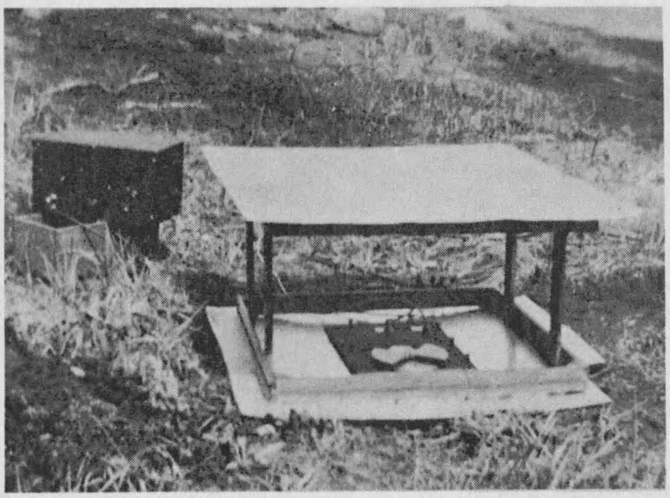

Figure 2b - Method of calibration of the generating voltmeter.

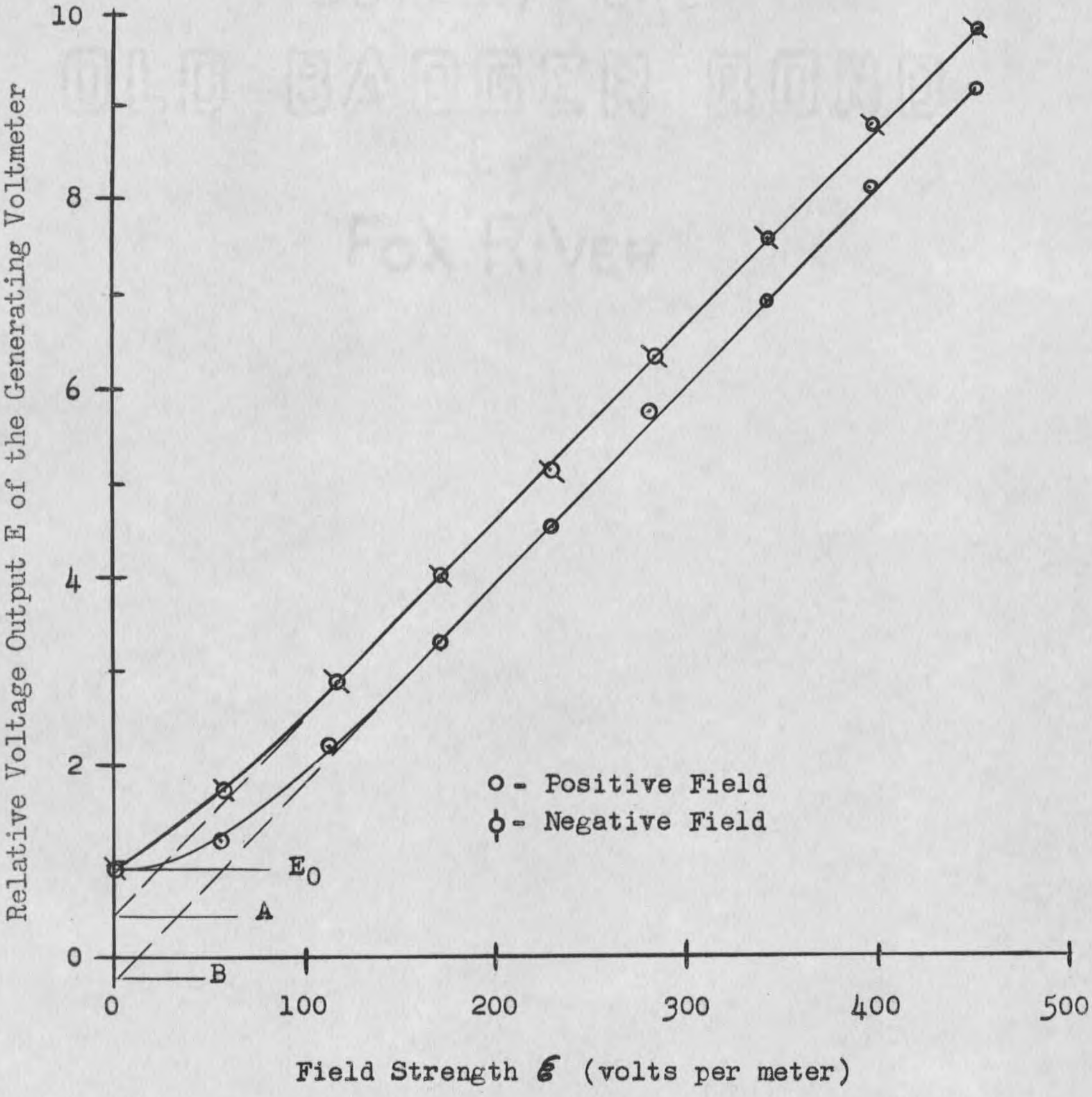

Figure 3 - Calibration curves of the generating voltmeter for positive and negative fields.