



Investigation of alternating components of earth potentials
by Weston B Farrand

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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Abstract:

The presence of alternating earth potentials is established by use of a ground wire and a grounded vacuum tube voltmeter.

The alternating potentials appear to consist of several frequencies and energies. The investigation was carried out using filter circuits, vacuum tube voltmeter and wire recorder. The potential varies from day to day in energy values. The maximum value reported is 45 millivolts for 1000 foot electrode separation. The frequency range is from 800 to 5000 cycles per second with the higher frequencies containing a great deal more energy than the lower frequencies.

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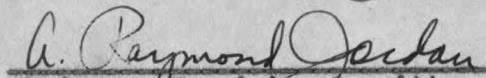
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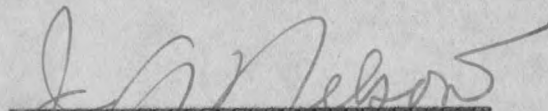
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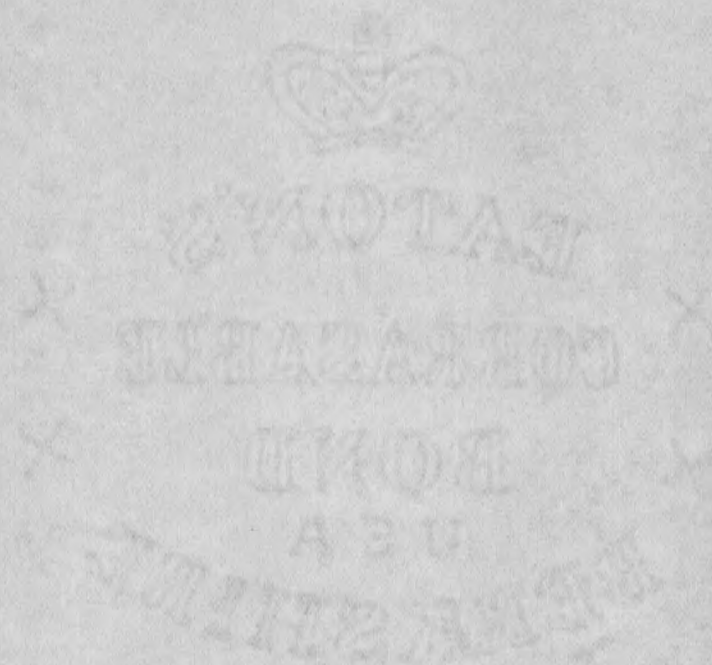

Dean, Graduate Division

Bozeman, Montana
June, 1951

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Cap 2

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Abstract

The presence of alternating earth potentials is established by use of a ground wire and a grounded vacuum tube voltmeter. The alternating potentials appear to consist of several frequencies and energies. The investigation was carried out using filter circuits, vacuum tube voltmeter and wire recorder. The potential varies from day to day in energy values. The maximum value reported is 45 millivolts for 1000 foot electrode separation. The frequency range is from 800 to 5000 cycles per second with the higher frequencies containing a great deal more energy than the lower frequencies.

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Introduction

The problem consisted of (1) determining if low frequency earth potentials existed; (2) determining some of the characteristics of the potentials if they did exist; (3) determining, if possible, some of the causes of such potentials.

Historical Background

The literature cites this type of problem under the title of "Earth Currents". The strict definition of "earth currents" should be construed as excluding all man-made flow of electricity like that due to leakage from power lines and currents that are purely local in nature.⁸ In order to determine current flow, it is necessary to know the potential gradient and the specific conductivity of the region of earth involved in the investigation. The measurement of the horizontal potential gradient is not a difficult task, but the determination of the specific conductivity is almost impossible. This difficulty arises from the fact that the earth is made up of a heterogeneous mixture of various types of soils, all with different specific conductivities.⁹ Thus it is apparent that the proper title should be "earth potentials".

Previous investigations have dealt with the direct component of the potentials only. In trying to measure the DC component of the potential, several things have to be taken into account. Contact potential between the earth and the electrode has caused a great deal of trouble. If the contact potential were steady it could be taken into account, but the degree of moisture in the soil changes the value of the contact potential. These contact potential changes, coupled with the contact resistance changes,

gave great current variations through the recording D'Arsonval galvanometer. Because these changes were unpredictable, correction factors became only approximations, and no conclusion could be drawn concerning the actual potential level.¹⁰

Because of the difficulties mentioned, W. J. Rooney, one of the recent investigators of earth potentials, has stated that only the variations can be considered. Rooney has pointed out that world-wide variations in earth-potentials coincide with world-wide variations in magnetic fields. In fact, the presence of a world-wide magnetic storm coincides with earth-potential storms. He points out that these also coincide with sunspot activity.¹⁰

Using the data from the 20 to 30 stations located about the earth, O. H. Gish has mapped the direction of the potential gradient and the results indicate that there is a circulatory tendency to the DC component of earth potentials. The areas where these circulatory actions seem to take place coincide with the general land areas. That is, on the continent of North America there is a closed flow of electricity. On the Europe-Asia continent there is another closed flow; on all other continents there is the same type of closed flow.³

The presence of earth-potential storms and magnetic storms often coincides with brilliant auroral displays. The effect of polar disturbances is also detected in the recordings of earth-potentials.⁴

One of the present day theories concerning the causes of earth-potentials and magnetic fields is the circulation of ionized air in the ionosphere. When the correlation between auroral displays and earth

potentials is considered, this theory begins to look very reasonable. The auroral displays are thought to be brought about by the ionization of the air in the ionosphere by the sun's rays and the action of the earth's magnetic field on the ionized particles. When there are brilliant auroral displays, there is an intense ionization of air throughout the whole of the ionosphere. This ionised air will circulate and actually be a flow of electricity which will induce a DC current flow in the earth below.

Although there are discrepancies in this theory it is the only one that covers the main facts with any degree of success. Several details are not included in the theory and several results predicted by the theory have not been observed as yet. 3, 10, 11, 6

Equipment

The equipment used in this investigation of the alternating component of the earth-potentials can be divided into two parts. The preliminary investigation required a minimum of equipment and was only planned to determine the presence or absence of the AC component. The secondary investigation required some method of analyzing the frequency and for this reason, some method of making a permanent record was needed.

The availability of a Hewlett-Packard Harmonic Wave Analyser made it desirable that the method of recording be of the type that is capable of being played back several times. The ease of handling and editing, and the possibility of playing fairly long records by an endless loop arrangement, implied that a tape or wire would be a satisfactory method if a recording technique could be found for the very low frequencies.

The initial investigation did not indicate any frequency range, and it was assumed that frequencies below 100 cycles per second would be the only frequencies present. Because of this assumption, the first recording unit was built to record only these frequencies. It has since been modified to record all frequencies from one cycle per second up to 5,000 cycles per second.

In building the low frequency recorder, a great deal of help was derived from an article in the November, 1950 issue of the "Review of Scientific Instruments" by Paul Green, Jr. Green's article indicated how he had used a frequency modulation technique to overcome the low frequency recording difficulties on magnetic tape.⁵ The equipment used in our studies was a wire recorder and consequently the same circuit could not

be used for our purposes. His general method of recording has been used but the circuits are similar in the same way that radar and radio circuits are alike.

The low frequencies are recorded in a somewhat different fashion than the higher frequencies. The higher frequencies are recorded directly on the wire, whereas the lower frequencies are used to modulate a higher frequency. The wire handling unit is a Webster Chicago wire recorder head with a rewind speed used for speed step-up on the play-back for the lower frequencies. The lower frequencies are played back at a higher speed than recording because the analysis of these lower frequencies is much easier at higher frequencies.

The recording section is actually a multi-purpose section. The initial frequencies are amplified by a "starved circuit" type of pre-amplifier which is directly coupled to a cathode follower. This stage is very sensitive to small voltage fluctuations and uses a large amount of negative feedback to stabilize the tube. The "starvation" of the tube comes from lowering the screen grid potential to one-tenth of the normal operating potential and placing a very high resistance in the plate circuit. The cathode follower and preamplifier give an amplification of approximately 1,700. The output of the cathode follower is fed to a switch which makes it possible to place the output across a set of earphones, an oscilloscope, the recording head (for the direct recording of the higher frequencies) or to the grids of a simple multivibrator.⁵

The multivibrator has a square wave output which is fed to the recording head. The frequency is varied in phase with the low frequency

feeding the multivibrator.

The play-back of the higher frequencies is performed through the same amplification circuit used to record it. This is accomplished by means of the switching arrangement that is shown on Figure 2. The play-back of the lower frequencies consists of two amplification stages of which the first is the "starved circuit" type, followed by a clipping and differentiating circuit, a multivibrator and a low pass filter. The clipper is a bistable circuit which can be adjusted to change from one state to the other each time the input wave crosses the zero axis. The large rectangular pulses produced are differentiated to feed sharp triggers to the monostable multivibrator. The multivibrator generates a constant-width and constant-height pulse passing the multivibrator output through a low pass filter whose cut-off frequency is lower than the lowest excursion of the carrier. Only the average value of the pulse train remains at the output. This is proportional to the instantaneous carrier frequency and corresponds, therefore, to the desired signal originally impressed upon the carrier.⁵

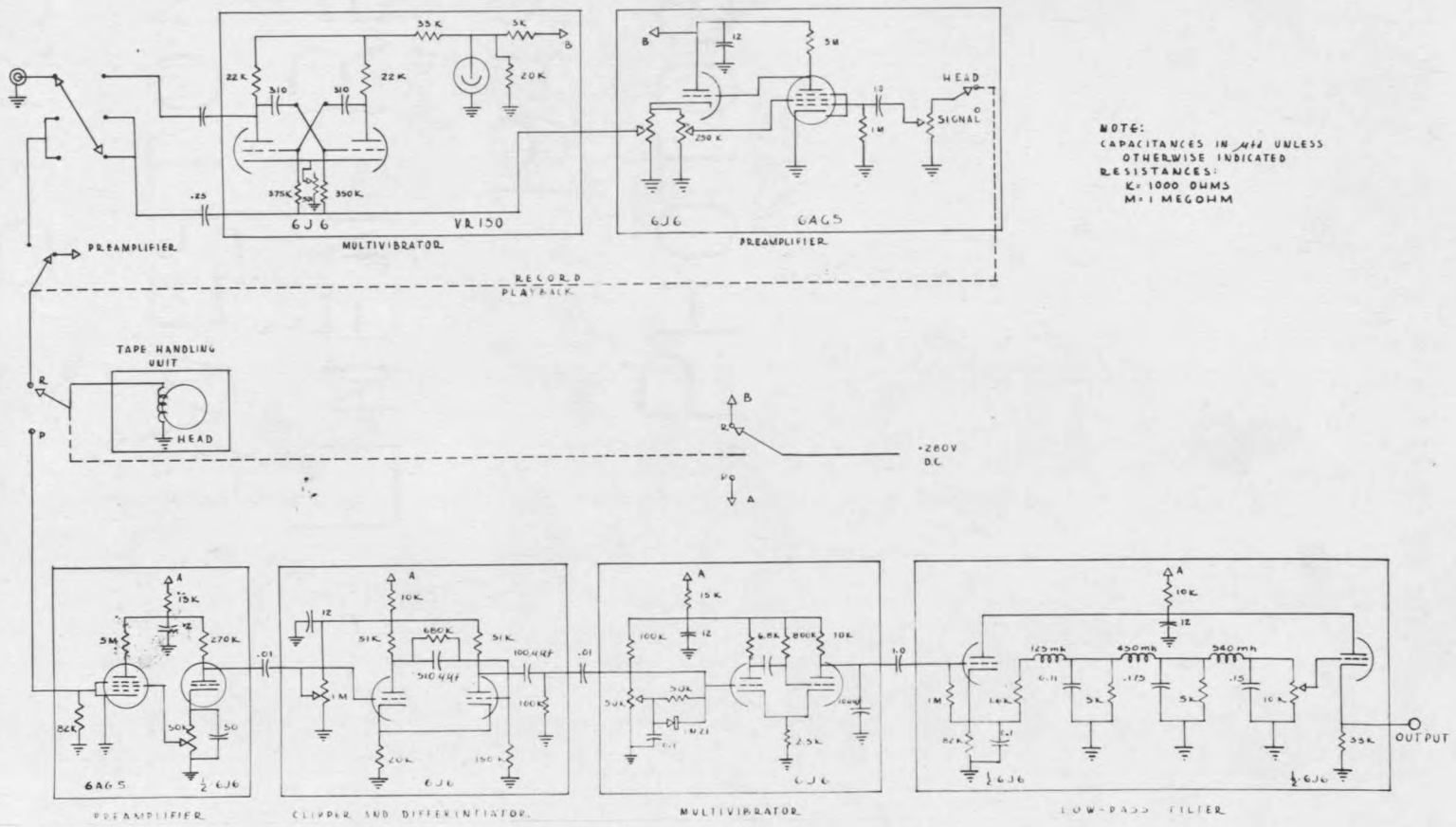
The center carrier frequency of the recording section is 1,000 cycles per second and because of the speed-up of the play-back, the center carrier frequency of the play-back section is 6,000 cycles per second. (The wire speed-up is 6 times the recording speed).

Figure 2 shows the various wave forms in the different portions of the circuit such as preamplifier, clipper and other parts with the sections shown in a block diagram.

The latest readings have been taken with a Ballantine battery

operated vacuum tube voltmeter Model 302 and General Radio Sound Level Meter Model 759-B. The output of these meters has been fed to the oscilloscope in a conventional manner. The oscilloscope is a Dumont Model 168, which was converted to battery operation by Mr. Raymond Hare.

Figure 1



General Procedure

Weather, atmospheric conditions, time and soil conditions make it very difficult to predict or control an investigation in geo-physical work. This lack of control makes it necessary for the investigators to record all of the conditions present when readings are taken and it also makes it necessary to take a great number of readings under all possible conditions. The time available has made it impossible to conform to the above-mentioned conditions, therefore the results of measurements taken and included in this report should be used only to indicate direction and general procedure in any following investigations.

In order to keep the variables to a minimum, the majority of the readings were taken near Jordan, Montana, which eliminated great variations in the soils. A few readings have been taken near Bozeman, Montana, in upper Hyalite Canyon. These isolated spots were chosen because they are free of man-made earth potentials. (A power line or power plant "contaminates" the soil for several surrounding miles.)

Both preliminary investigations and later wire recordings were conducted at Jordan and trials have been made in many other spots. The other trials have been made to eliminate the possibility of the earth potentials being a local phenomenon. Readings have been taken in Colorado, Wyoming and eastern Montana with the conclusion that these earth potentials are present in all of the spots indicated and are probably present over the entire earth's surface. The intensity varied in the different locations, but whether this was due to the different weather conditions or to the location is not known.

The most recent field trips indicate that the initial problem did not cover the entire field. The initial intention was to detect and record low frequencies (below 100 cycles per second) and the equipment was built with that idea in mind. Recent modifications in the wire recorder make it possible to use it for any frequency up to 5,000 cycles with very little attenuation, but the modifications have been completed for such a short time that it has been impossible to use the recorder in the field.

The basic experimental procedure and field equipment is relatively simple. Modifications of the field arrangement have been made to eliminate some of the possible sources of potentials but future modifications are necessary. Two metal rods 18 inches in length are driven into the ground 1,000 feet apart. Connected to rod A. is 1,000 feet of field telephone wire. The wire is laid out toward rod B. where it is connected to either a wire recorder or a battery-operated vacuum tube voltmeter. Rod B. is then used as a ground for the instrument. The indicating meters used in this investigation are a Ballantine battery-operated vacuum tube voltmeter, Model 302 and a General Radio Sound Level Meter Model 759-B. The wire recorder used was built in the Physics department in the last year and more information will be given later concerning these instruments.

The initial readings and investigations indicated that direction made no difference in signal strength. Perhaps in a more sensitive instrument the signal strength difference would be noticeable, but at the present no directional readings are required.

The preliminary investigations showed the presence of an AC component in the earth potentials and later investigations were for the purpose of

determining the signal strength and frequency. Attempts were made to eliminate the possibility of atmospherics and to narrow the causes of these earth potentials somewhat.

Atmospherics have been eliminated or the effect of them has been determined to a great degree. The tests to determine the value of the atmospherics have been many and varied. The first test was to disconnect the ground at rod A and use the 1,000 feet of field line as an antenna. If atmospherics were inducing a voltage in the wire, the value of it should have been much higher when it was ungrounded. When the line was used as an antenna, no signal at all was detected, thus implying that if a voltage was being induced by atmospherics, it was of very low signal strength. It also eliminated atmospherics from the main cause of the signal. The next test was to use a shielded cable and regular cable and switch from one to the other rapidly and see if there was a signal variation. In this case there was a signal variation but not of the type one would suspect if atmospherics were causing the main signal. An increase of signal strength was found when the shielded cable, grounded at the meter end, was used. Shielded cable has the effect of cutting the atmospheric signal level down in ordinary cases. Assuming this to be true in this case implies that the atmospherics are inducing a small voltage in the wire but this voltage is out of phase with the earth potentials.

The frequency range covered by the potentials has been determined to a large extent by the use of an oscilloscope and filter circuit in the field. The oscilloscope indicated that the uppermost frequency was near 5,000 cycles per second. The use of a 420 millihenry choke and a

variable condenser as the filter circuit has indicated what frequencies contain the majority of the energy and also the upper limit of the signal frequency. Figure 2 is a graph of the average readings (which are proportional to the energy) versus the upper frequency limit. The filter circuit is shown on the graph also.

Meter Deflection versus Frequency

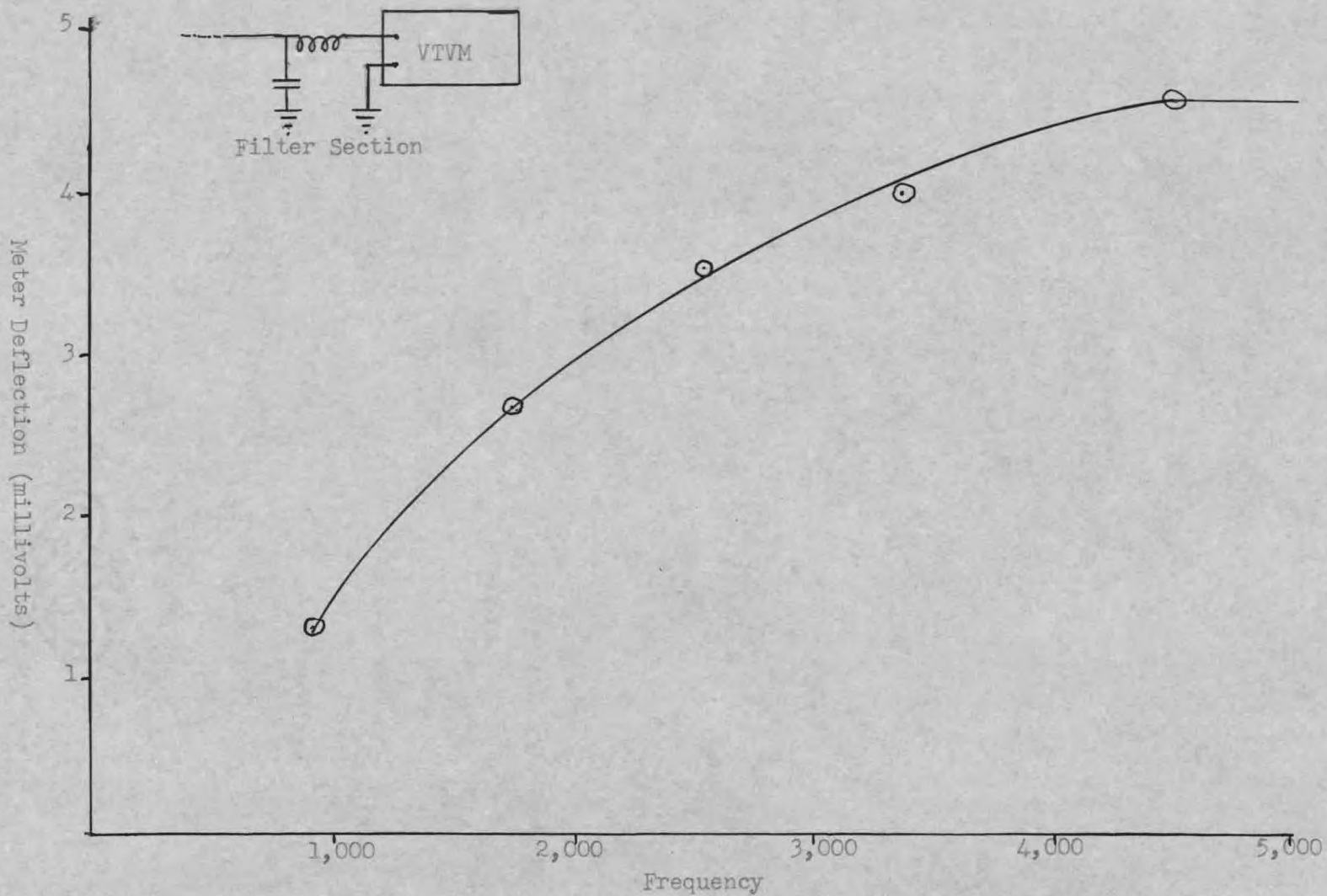


Figure 2

Meter Deflection (millivolts)

Frequency

The graph indicates that a good deal of the energy is carried by the higher frequencies. This was expected when the wave form was examined on the oscilloscope. The wave form had a rather strange appearance, appearing as if 30 to 40 oscillators set at different frequencies but the same voltage were feeding into the oscilloscope. Superimposed on these frequencies were others of much higher frequency and potential. The latter high frequencies came in highly damped pulses of initial voltage about 15 times that of the lower frequencies.

The signal voltage of these earth potentials has no set value for it apparently depends upon the weather, soil conditions and other variables. Numerous readings were taken but as no general level can be determined, only representative readings have been tabulated. Table I gives the date, time, average voltage and maximum voltage on pulses. It will be noticed that there is random effect in these readings and no conclusion can be drawn from them.

Table I

Date	Time	Average Voltage	Maximum Voltage
6-12-50	4:50 PM	0.010 volts	0.35 volts
6-13-50	2:00 PM	0.025 volts	0.10 volts
7-5-50	5:45 PM	0.030 volts	0.10 volts
7-6-50	5:30 PM	0.035 volts	0.09 volts
7-7-50	6:00 PM	0.045 volts	0.10 volts
7-14-50	6:10 PM	0.010 volts	0.02 volts
7-15-50	7:00 PM	0.040 volts	0.14 volts

Conclusions

The presence of AC potentials in the earth has been established and there seems to be some relationship with low frequency atmospherics detected and being investigated by Dr. A.R. Jordan of Montana State College. The frequency range of the AC earth potentials, although not fully established as yet, seems to lie between 50 and 3,500 cycles per second. The majority of the energy contained in the signal seems to be in the region above 1,000 cycles per second.

The possibility of induced currents in the wire from atmospherics has been virtually eliminated from the cause of the initial signal. The method by which this was done has been described under General Procedure.

Several explanations of these potentials are possible, and at the present there is nothing to eliminate any one of them as the cause. The first hypothesis concerning the cause has already been mentioned in the history of earth potentials. The circulation of ionized air in the stratosphere with its subsequent de-ionization and discharge could possibly be inducing these potentials in the earth.

Another explanation comes from the earth itself. The earth's crust is constantly slipping and changing in shape with tremendous forces and stresses being brought to bear on its internal structure. These forces and stresses could be acting on the crustal structure of many of the rocks and materials composing the crust and causing a piezo-electric effect to be manifested.

The possibility of extra-terrestrial radiation from the sun

and stars inducing a current should not be neglected. The lack of directional change in the readings indicate that the effect is caused by some vertical disturbance.

The real explanation may come from a combination of all of the effects mentioned and this seems to be the more logical reason for the earth potentials. At the present there is so little work done in this field it is impossible to arrive at any conclusion concerning the origin of earth potentials.

Future recordings and investigations will be carried on by Dr. Jordan who suggested this problem and for whose assistance I am very grateful.

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