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Report on a

Generating Voltmeter Circuit

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ABSTRACT

A circuit and apparatus for use with a generating voltmeter in measuring electric fields is described. The device is stable, portable, and linear. The magnitude and direction of electric fields from 50 to 1000 volts per centimeter can be measured. Power is sufficient to operate a recorder.

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I. Introduction

The generating voltmeter circuit described below was developed during a program of research on the problem of precipitation-static which is encountered on aircraft under certain weather conditions. The degree to which the aircraft becomes charged during flight is an essential item of data in such research. It is convenient if the apparatus for measuring this quantity be portable, self-powered, stable, linear, polarity sensitive, and capable of actuating a recorder. The circuit described satisfied these conditions.

II. Apparatus

(A) Circuit - The circuit of the instrument is shown in Plate 1. It is seen that the device consists of a rotating mechanical system driven by a small motor or by the slip-stream, and a two-tube, battery operated, resistance coupled amplifier for raising the power level to a value sufficient to actuate a meter or recorder. A synchronous mechanical rectifier is used.

(B) Theory - Referring to Plate 1, the rotating sector plates A periodically expose the stationary pick-up plate B to the existing electric field. During an interval when A is in the process of uncovering B the field draws a charge from the ground (the body of the aircraft) through the resistor R. In the absence of the capacitor the signal presented to the grid of the first tube would be proportional to the instantaneous current through R, or to dq/dt , where q is the charge induced on B. In this case the signal would be proportional to the existing field, which is the objective, and also to the rate at which A uncovers B. The latter effect is undesirable since the speed of the rotating plates cannot be conveniently held constant. However, if the capacitor C be added, and if the time constant RC be large compared with the longest electrical period anticipated, an electrical integration is performed on the signal. The resulting signal potential is then independent of speed. For a selected time constant RC the ratio of R to C should be as small as the resulting sacrifice in signal size will permit. In the device here described, R is 100 megohms, C is .001 microfarads, and RC is .1 second.

The first tube must have small grid current and an input resistance that is large compared to the value of R employed. The 1E5-GP is a good tube in these respects. It is housed adjacent to plate system, the whole being hereafter referred to as the voltmeter "head."

It is seen that the first tube is self-biased by R_1 , which is not by-passed. The second tube, a miniature power tube, is used as a cathode follower, self-biased by R_2 . The cathode circuit is then completed to ground through the meter and synchronous switch S. This switch is cam-operated from the rotating shaft of the voltmeter head. The action is such that the switch remains closed during half an electrical cycle.

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The phasing is mechanically adjusted for optimum half wave rectification of the AC current wave in the 304. R_{11} is a zero control for cancelling the effect on the meter of the static space current in the 304.

A voltage of the proper phase for negative feed-back is obtained by inserting R_8 in the plate circuit of the 304. This voltage is fed back through blocking condenser C_3 and resistor R_4 , R_5 , or R_6 to the cathode of the first tube. The degeneration so obtained stabilizes the circuit performance with respect to changes in tube characteristics and supply potentials. It also increases the effective grid resistance and signal handling ability of the first tube.

Sensitivities of 1000, 500, and 250 volts per centimeter, full scale, are obtained by switching the feed-back resistors R_4 , R_5 , or R_6 . These resistors are adjustable for initial calibration purposes. This method of changing sensitivity by altering the amount of negative feed-back is superior to the conventional potential divider gain control in that the circuit stability is always the maximum possible, consistent with the required amplification, whereas with the conventional circuit the stability remains constant at its least value.

The circuit is designed to actuate either an internal meter or an external Esterline Angus Graphic recorder. Both instruments have a scale of .5-0-.5 milliamperes. Resistor R_{12} should be adjusted to make the two meters agree.

Pressing the "Zero" push-button removes all signals from the 304, permitting the operator to check the instrument zero at any time.

Pressing the "Test" push-button places about 67 volts on plate E in the voltmeter head. This provides a convenient test signal for checking the overall performance of the apparatus.

The "On-Off" switch breaks all battery circuits, minimizing battery deterioration when idle. Batteries are housed in the 6 by 7 by 12 inch control box, which then weighs 19 pounds. The control box is connected to the head by means of a seven wire cable of any reasonable length.

The control box, recorder, and a motor driven head are shown in Plate 2.

(C) Adjustment and Calibration - The semi-variable resistor R_{10} should first be set so that the meter can be brought to zero (with S closed) by means of the "Zero" control R_{11} . The proper setting of R_{10} is at about 4500 ohms. Resistor R_{12} should be chosen so that internal and external meters agree.

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The phasing of the synchronous rectifier S should next be adjusted. This is most conveniently done by connecting an oscilloscope between the cathode of the 304 and ground. The rotor is run at normal speed and an electric field provided either by auxiliary means or by pressing the "Test" push-button. The angular position of the cam should then be adjusted so that the commutation transients seen on the oscillograph lie on the same horizontal level.

The electric field should then be removed and the instrument deliberately unbalanced by turning the "Zero" control. If the positive and negative parts of the resulting square wave, as seen on the oscilloscope, are equal in length, the cam adjustment is completed. If they are not, it indicates that the time of closure of switch S is longer or shorter than the open time. The position of the stationary switch contact must therefore be altered to make the open and closed times equal. Since the above two adjustments interlock somewhat, the whole procedure should be repeated as a check. The preceding scheme of adjustments may appear to be involved but it is far more direct and certain than attempting to adjust the phasing and timing for a maximum meter reading on a test signal. It should be noted that since the vanes A and E in the voltmeter head are double, the cam must be of such shape as to provide two switching sequences per mechanical cycle.

The generating voltmeter is calibrated by placing the head in a known electric field, provided by a high voltage supply and a pair of large parallel plates. Resistors R_4 , R_5 , and R_6 are then set so that full scale meter readings are obtained for fields of 1000, 500 and 250 volts per centimeter on ranges 1, 2, and 3, respectively.

The circuit constants of Plate 1 are correct for the particular head used. The important dimensions of this head were: radius of sector plates = 8.2 cm; angular dimension of sector plates = 90° ; separation between plates A and B = 2.5 mm.

(D) Performance - Full scale sensitivities of 1000, 500, and 250 volts per centimeter are provided. The least count on the 250 volts per centimeter range is 10 volts per centimeter per division.

The zero stability, after a few minutes warm-up, is within two divisions per hour. Zero drift can be corrected at will.

The linearity is within plus or minus three percent of full scale deflection on all ranges.

Both magnitude and sense of the electric field are indicated.

A test signal is provided which can be used at any time to check the overall operation of the device. The test deflection adds

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algebraically to that due to any external electric field. This test deflection is approximately 14, 28 and 56 percent of full scale deflection on the 1000, 500 and 250 volts per centimeter ranges, respectively.

The dependence of sensitivity on rotor speed is negligible until the speed is so low that vibration of the indicator becomes excessive.

The absolute accuracy of the device will depend almost solely on the care taken in setting up the plate system used to provide the known fields during calibration. The plates should be separated by a distance at least ten times as great as the thickness of the head, and each dimension of each (square) plate should be at least ten times as great as the plate separation. These conditions are awkward to satisfy. Fortunately, in the intended application, high absolute accuracy is not a pressing requirement, although stability and repeatability must be good.

The current demand on each "A" dry cell is .050 amperes, and on each "B" battery is 5 milliamperes. These requirements are nominal for the size of batteries here recommended.



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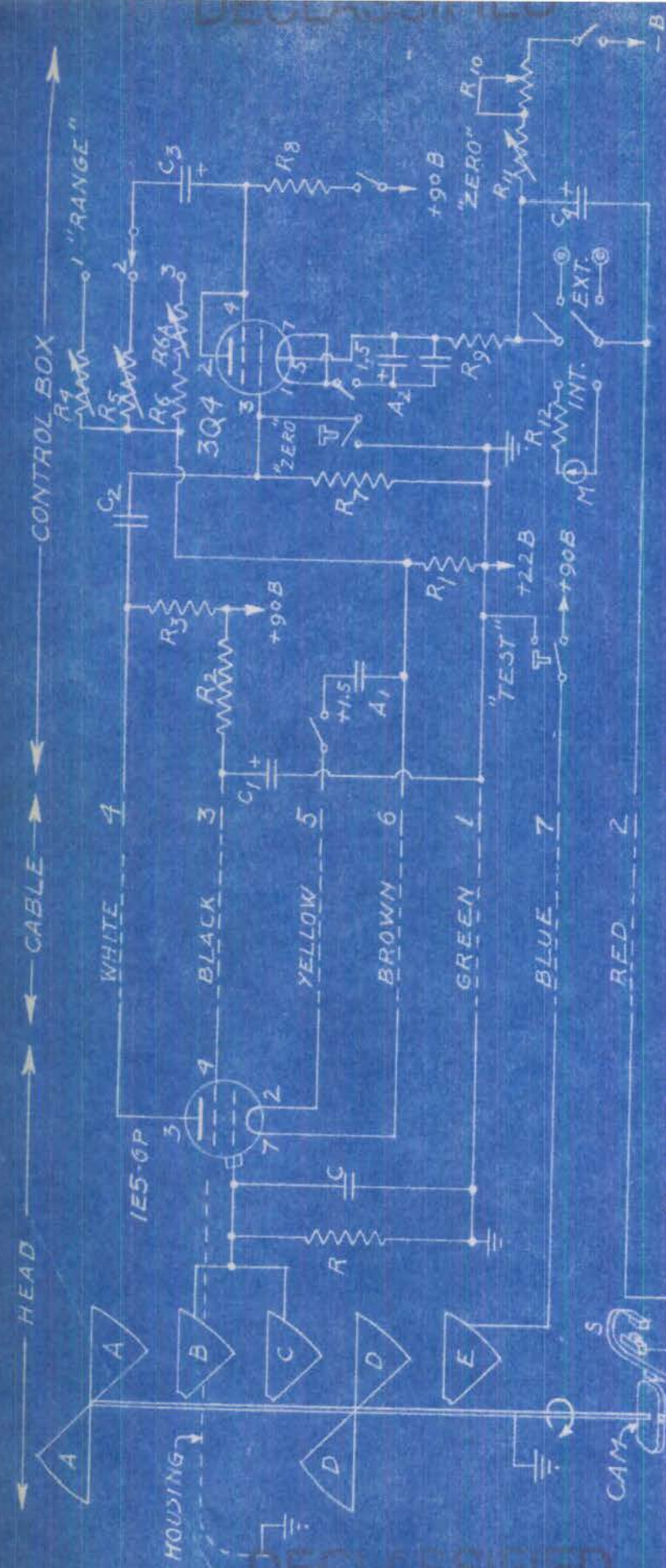
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GENERATING VOLTMETER CIRCUIT



$C = .001 \mu f$, MICA
 $C_1 = 50 \mu f$, 50V, ELEC.
 $C_2 = .05 \mu f$, 600V
 $C_3 = 8 \mu f$, 250V, ELEC.
 $C_4 = 50 \mu f$, 50V, ELEC.
 $M = .5-0-.5$ MA.
 "A" BATTERIES (3) ARE LITTLE SIXE
 "B" BATTERIES (2) ARE 2 1/2" X 4" X 6"

$R_{6A} = 120K$, 1W
 $R_7 = 4.7M$, 1/2W
 $R_8 = 2K$, 5W, WW
 $R_9 = 1K$, 5W, WW
 $R_{10} = 8.2K$, 5W, WW, 5V.
 $R_{11} = 2.5K$, WW
 $R_{12} = 1K$, 1W (SEE TEXT)
 ALL BATTERY SWITCHES ARE GANGED TOGETHER
 $M = MEGOHM$ $K = 1000$ OHMS.

$R = 100$ MEG
 $R_1 = 10K$, 1/2W
 $R_2 = 2.2M$, 1/2W
 $R_3 = .47M$, 1/2W
 $R_4 = 10K$, WW
 $R_5 = 50K$, WW
 $R_6 = 75K$, WW
 ALL BATTERY SWITCHES ARE GANGED TOGETHER
 $M = MEGOHM$ $K = 1000$ OHMS.

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PLATE 1

