AN ELECTRONIC RESISTANCE LIMIT INDICATOR

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Frank Murray Pelton

1948

THESIS

This is to certify that the

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An Electronic Resistance
Limit Indicator

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AN ELECTRONIC RESISTANCE LIMIT INDICATOR

By

Frank Murray Pelton

A THESIS

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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1948

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SUMMARY

The dewpoint is the temperature at which a vapor begins to condense as a liquid. If a surface is cooled sufficiently it will in turn cool some of the vapor surrounding it, which upon reaching its dewpoint condenses on the surface. The dewpoint designed by Dr. G. J. Bouyoucos consists of a special glass tube on which are placed two or more platinum electrodes. The passage of a suitable coolant through the tube cools the surface to the dewpoint of the surrounding vapor. The presence of the condensate decreases the resistance between the platinum electrodes. The problem considered in this paper is the measurement of this resistance and a method of notifying the operator when the resistance decreases to a predetermined value. The temperature of the cell is measured by means of a thermocouple sealed in the surface near the electrodes.

The instrument as designed may also be used as a limit voltmeter for the range from 0 to 0.4 volts. This range could be adapted to any greater range with proper associated networks.

Essentially, the instrument consists of a d.c. amplifier preceeded by a low input current stage. The output of the amplifier controls an electronic switch which in turn controls an audio oscillator. The audio

signal is applied to a loud speaker.

This paper considers the problems of design and developement thoroughly and completely, giving analyses where necessary. In general, this paper could act as a guide for those contemplating the construction of an original instrument in the electronic field, showing the general methods of approach to the varied problems necessary to be solved.

Preface

The laboratory work presented in this thesis was done during the development of an original method of dew point determination due to Dr. G. J. Bouyoucos of the research staff, Soil Science Department, Michigan State College. The author's chief interest was in the measurement of the temperature and the resistance of the dew point cell, and to develop a usable instrument for dew point determination work. The entire program of work done on this problem has been outlined and emphasis placed on the measuring instruments.

Even though the problem has not been completed to date, workable results have been obtained. Both instruments described are original with the author and while they are only partially developed for this problem, they have both shown promising results.

Although part of the work was done with compensation from Michigan State College, permission has been granted by the Department of Soil Science and the Department of Electrical Engineering that the material be used for this thesis.

Frank M. Pelton

East Lansing, Michigan

May, 1948

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CHAPTER I

1.1 Introduction

The study of evaporation and moisture control processes has necessitated the measurement of the moisture content of gases containing water vapor. This may be found in terms of the Absolute Humidity, the Relative Humidity, or the Dew Point Temperature, all of which are definite related quantities when the temperature is given. The four most commonly used methods of determining the moisture content of gasses are: (1) the chemical absorption method; (2) the dew point method; (3) the psychrometric method; (4) the hygroscopic expansion method.

The chemical absorption method is limited in its use by the time and care necessary to produce accurate measurements and for that reason is generally regarded as a laboratory method and of limited value for making field measurements.

The dew point or condensation method has up to this time made use of a metal mirror which may be cooled to several degrees below the air temperature. The mean temperature at which the condensed moisture forms and evaporates from the mirror surface is recorded as the dewpoint.

The sling psychrometer is the method most used for making measurements of atmospheric moisture content. By whirling two identical thermometers, one of which has a moistened muslin wrapping on its bulb the depression of the wet bulb thermometer gives an indication of the moisture content of the air. This method inherently is of little value when the temperature is at either extreme.

The length of some hygroscopic fibers changes when they are subjected to a change in relative humidity, and by means of this property, instruments are built which indicate humidity. However, these fibers gradually change their length under steady state conditions and this makes their use subject to the constant recalibration of the instrument.

At the present time in the United States, the measurement of the atmospheric moisture is generally restricted to the sling pyschrometer and the hair hygrometer, despite the inherent disadvantages contained in both.

The method described in this paper is of the dew point type and is based on the change of resistance between two electrodes on the surface of glass cooled to the dew point temperature. It is advantageous in that only a small sample of air is required, the overall cyclic time could be made as low as 1 minute, and could be entirely automatic. The disadvantage lies in the care in manufacture of the resistance unit.

It should be noted that this method is original in that no buffer solution or substance is used to bring the resistance to a lower value. The conductivity being provided purely by the glass, the impurities in the condensate, and the water condensate itself. With this method, the resulting cell has a fixed calibration for given conditions.

CHAPTER II

2.1 General Laboratory Setup

During the experimental work done in the development of this method, a system was used similar to that shown in Figure 1. A suitable coolant was passed through the cell "A" which when the outside surface temperature reached the dewpoint of the surrounding gas, caused condensation of moisture between the electrodes "B", resulting in a change of resistance between the electrodes. This was measured by a suitable instrument "C". The temperature of the thermocouple "D" was measured by the potentiometer "E". Resistance vs temperature was plotted from this data. A calibration of the cell was made in terms of resistance at the dew point temperature determined by the sling psychrometer. Initial work was restricted to the range where the latter is accurate.

2.2 Construction of the Cell

Basically the cell consists of a glass tube which has been bent into the form of a "U" with the bottom of the "U" flattened. On this flattened portion of the tube the electrodes, which were several individual loops of platinum wire, were placed. Platinum was used to prevent corrosion difficulties. An example of the cell is shown in Figures 2 and 3.

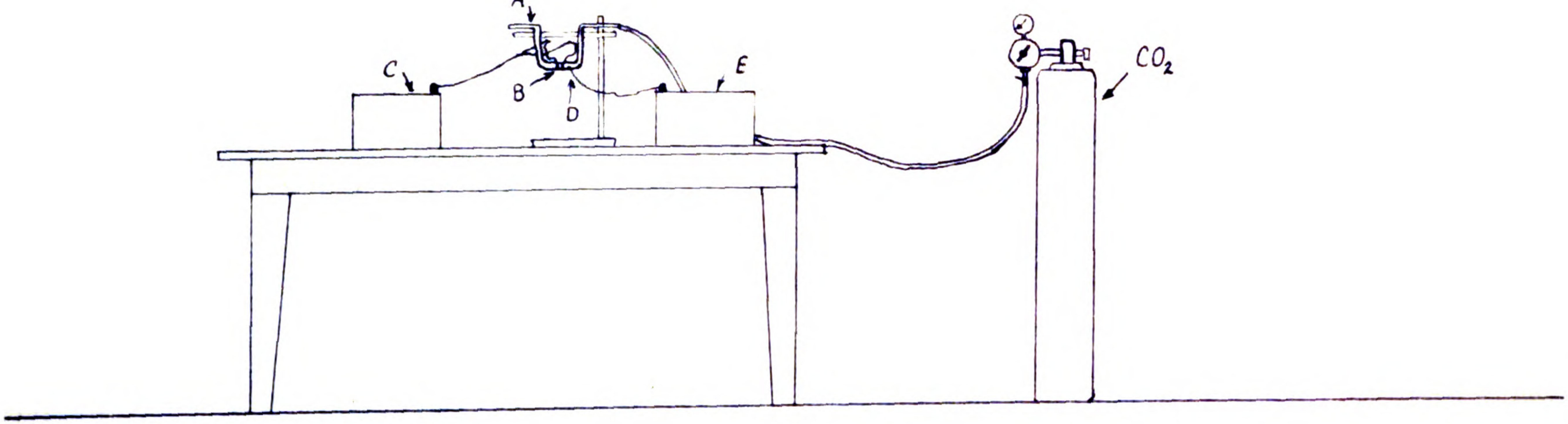


Fig. 1 General Laboratory Setup

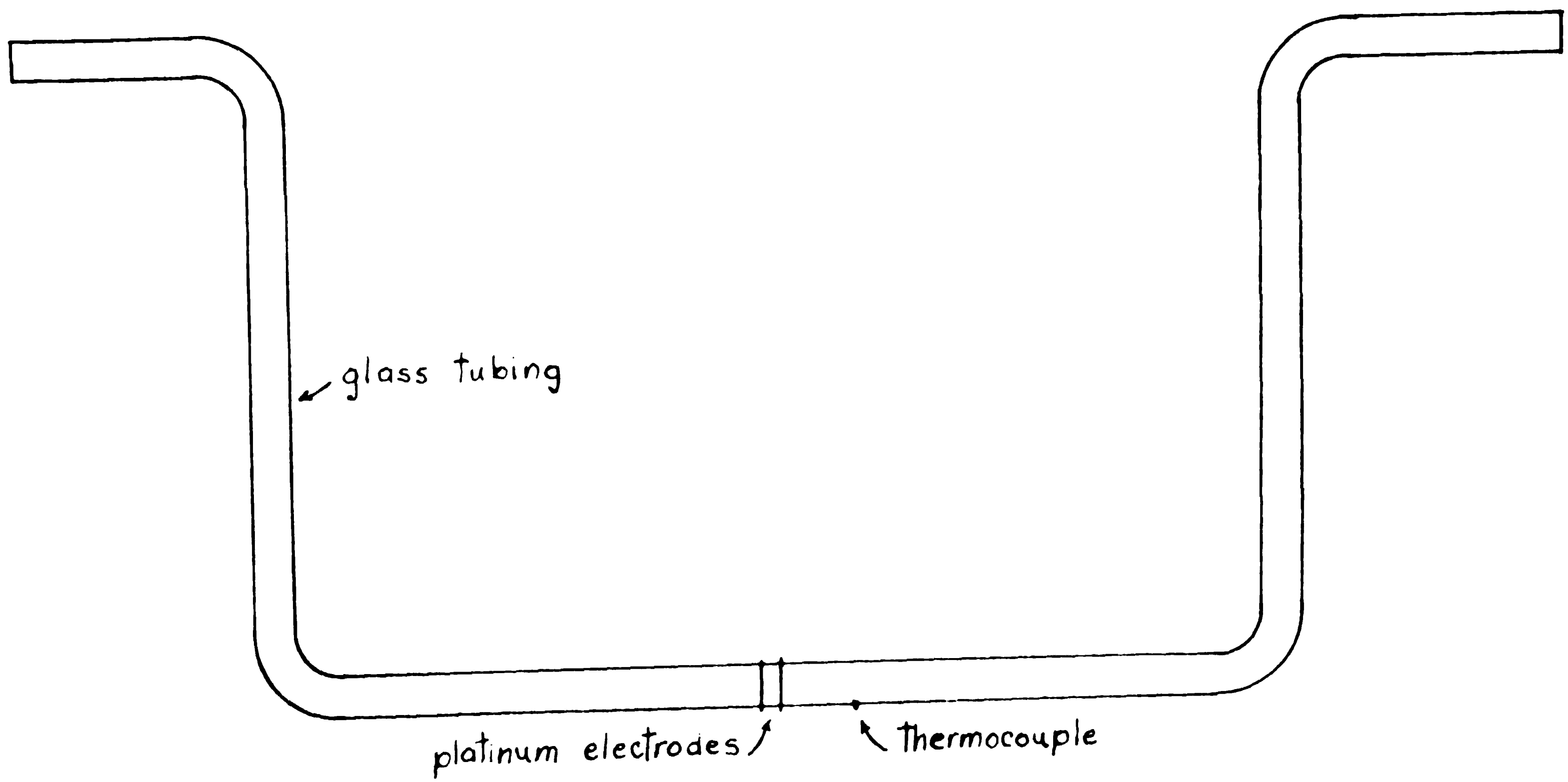


Fig 2. The Dewpoint Cell

Extreme care was necessary in the construction of the cells. After the "U" tube was formed, the loops of platinum wire were tightened in place by twisting the ends of the wires. The tubes were then heated and a slight pressure applied to the inside of the tubes, causing the glass to expand and hold the loops in place. A copper-constantine thermocouple was then sealed on the surface of the tube as near the electrodes (loops) as feasible. It was necessary that care be exercised so that the thermocouple was not "burned." After the cell was completed, it was annealed to remove strains which tend to cause breakage.

Throughout the entire program of development of this method, only the one basic design for the resistance cell has been used, although several electrode spacings and tube types have been investigated.

The glass tubing which was used to best advantage was Corning G-81 5 mm I.D. x 1 mm wall thickness. The use of extra thin walled tubing while it had the advantage of requiring less coolant and a shorter running time, resulted in considerable loss due to breakage. Thicker walled tubes physically strengthened the cell but resulted in unnecessarily long cycles and required excessive amounts of coolant.

The major source of trouble with the cells resulted from foreign matter lodging between the electrodes. This caused erratic operation of the cells and caused several of them to be useless.

The cells were cleaned by successive treatments with aqua regia, soap and water, acetone or ether, and then with alternate washing with distilled water and drying in an oven. Extreme care was exercised in keeping the cells clean after such a treatment was completed.

The spacings between electrodes was varied from about 1/64 to 1/4 inch. The very close spaced electrodes generally resulted in unstable operation, due to the inability of the above method to remove all foreign matter. When a close spaced cell was obtained which was not erratic, the operation was reliable and constant.

The wider spaced cells, while easier to clean, gave such high resistances that the change in resistance was almost immeasurable.

The choice necessitated a cell whose electrodes were close enough to give a measurable change in resistance and yet far enough that they could be easily cleaned. Practically, this was a hard medium to obtain, although several cells were obtained which had both of these characteristics. Data is shown for one of these in the following section.

2.3 Initial Measurements

The first step in the estimation of this method for the determination of the dew point was the measurement of the resistance of the cell.

An R.C.A. Voltohmist Jr. with the highest calibration of 10^9 ohms, gave only a very slight deflection of the indicator when connected to the cell in the dry state.

Recognizing that the resistance of the cell was in the order of 10^{10} ohms, the circuit of Figure 4 was assembled and measurements made. If r_1 is the resistance of the cell to be measured, R the value of a series resistance, and E is the voltage applied to the series combination (neglecting the internal resistance of the vacuum tube voltmeter) r_1 becomes

$$r_1 = \frac{R(E-v)}{v}$$

where v is the voltage measured across the resistance R.

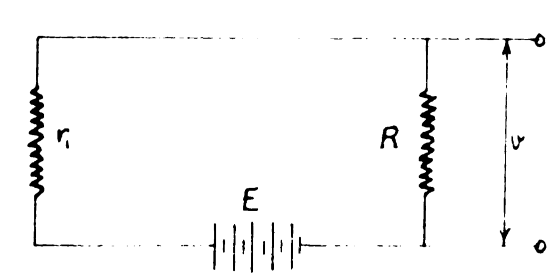


Fig. 4

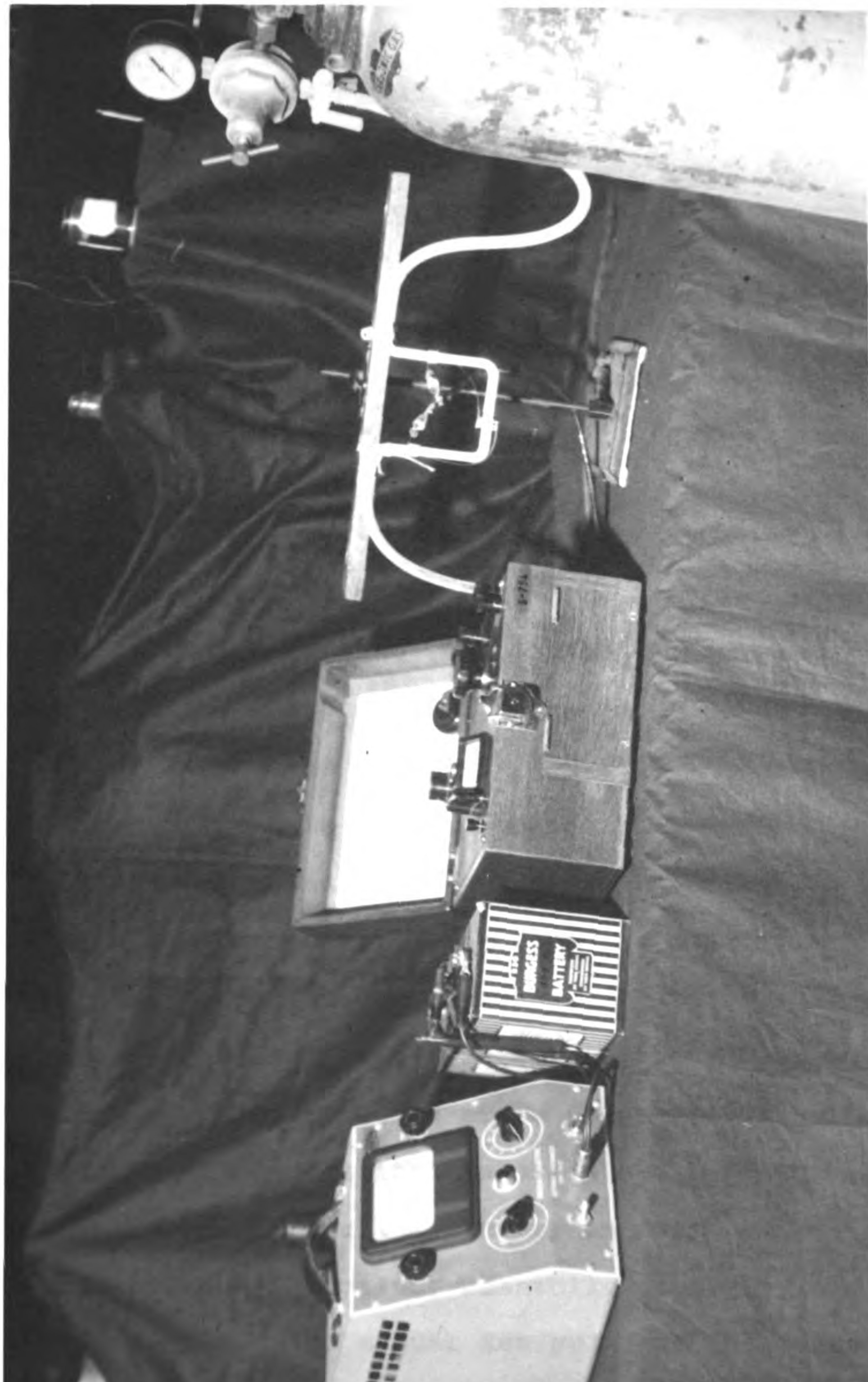
The original assumption was found to be correct and was verified as follows:

With $E = 90$ volts, $R = 2.0 \times 10^7$ ohms, and with the cell in the dry condition, v was found to be 0.01 volts and

$$r_1 = \frac{90(20)10^6}{0.01} = 1.8 \times 10^{10} \text{ ohms.}$$

Upon cooling until the moisture from the air condensed between the electrodes, the resistance decreased to about one third of that value. These readings were made on a 0-3 volt scale and were therefore only approximate.

Obviously it was possible to obtain more accuracy in these measurements by increasing both E and R, and by using a more sensitive instrument to measure the voltage v. This was accomplished by increasing E to 290 volts, using 6-20 megohm resistors in series for R and using a General Electric Model PM-17 vacuum tube voltmeter to measure the voltage v. This setup is shown in Figure 5. With the electrodes at room temperature, the VTVM read 1.13 volts on the 3 volt range. Checks on the other ranges showed the same voltage. When the resistance R was removed, the operation of the meter was erratic on all ranges, showing that it was the external resistance R and not the internal resistance of the meter which caused the single valued readings on the different scales of the instrument. The value of R was then decreased to 20 megohms whereupon the voltage v dropped to 0.34 volts. This was measured on the 0-1 volt range. There is no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internal grid resistor incorporated in the instrument on this range. The variation from linearity was due to the leakage resistance of the leads making the connections to the system. Upon cooling, the voltage v had a maximum of 7.6 volts, but returned to 0.34 volts when the cell was allowed to warm and the moisture evaporated increasing the resistance of the cell to the original dry reading previously obtained. Using the data just given, the cell resistance was again computed to be

$$r_1 = \frac{290\ (20)\ 10^6}{0.34} = 1.65 \times 10^{10} \text{ ohms with}$$

the electrodes in the dry state. These results were quite promising in that they correlated reasonably well with the data taken with the Volt-Ohmist, which resulted in a value of $r_1 = 1.8 \times 10^{10}$ ohms. This meant that for this cell which had been washed several times and subjected to many different conditions between the two sets of measurements, the dry resistance was approximately constant.

The problem of constructing an instrument which would measure and give an alarm at a desired voltage of the magnitude obtained in the above data was not particularly difficult in theory and was set aside for future consideration; meanwhile, correlations of voltage against the actual dew point as determined by a sling psychrometer were investigated.

Several sets of data were taken on a number of cells. Data for only one of the best cells will be presented in the following section. Only a selected few carefully made cells produced as good results, but it should be possible to manufacture cells of this standard commercially.

2.4 Correlation of the Dew Point with Resistance

As the voltage is indirectly a measure of the resistance and is easily measured and recorded without computation, it was used as a reference to be plotted against the temperature.

The temperature was measured by the use of a Leeds and Northrup hand potentiometer* connected to the thermocouple in the cell. This method, although inaccurate due to lag in reading of the potentiometer, proved to be sufficiently accurate for the results needed to show that a definite correlation existed.

An instrument designed by the author to make an accurate instantaneous reading of this temperature is described in Appendix III.

The measurements shown in the data on the following pages were taken over a period of several months and under various conditions. Only a very few of the runs have been omitted because of obvious errors noted at the time of making the runs (such as loose connec-

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* A description and circuit diagram for this potentiometer is given in Appendix II.

tions, dirty electrodes, etc.).

A typical run consisted of (1) measuring the dry resistance and room temperature, and then (2) passing a small flow of carbon dioxide to cool the cell, and (3) recording simultaneously the voltage v and the temperature T in (degrees F.) as read on the instruments. After the run was completed (i.e. frost had formed on the surface of the glass) a determination of the dew point was made with a Tycos sling psychrometer. A plot of the voltage as a function of temperature was made for each run and the voltage marked which corresponded to the temperature indicated as the dew point by the sling psychrometer. A weighted average was chosen to be the calibration point as being the voltage at which the dew point was reached. (This voltage was of the same order of magnitude for all of the cells but a distinct calibration for each was necessary) Twenty-five runs were made on Cell #1, and that data is shown on the following pages.

A graph of a typical run showing the gradual decrease of resistance with the decrease of temperature and the characteristic knee of the curve is shown in Figure 6. Note that the resistance increases as the temperature is further decreased. This is due to the formation of ice or frost on the surface of the glass which has a lower conductivity than that of the water.

Table I shows the data for 25 runs obtained from cell #1. As each run was completed, a graph was drawn of the temperature vs. voltage, and the dew point temperature as found from the sling psychrometer was marked and the voltage at this point noted. The average of these voltages was taken as the voltage at the dew point for calibration of the cell.

The readings of the psychrometer were interpreted with the use of the standard Psychrometric tables, published by the U.S. Weather Bureau, U.S. Department of Agriculture.

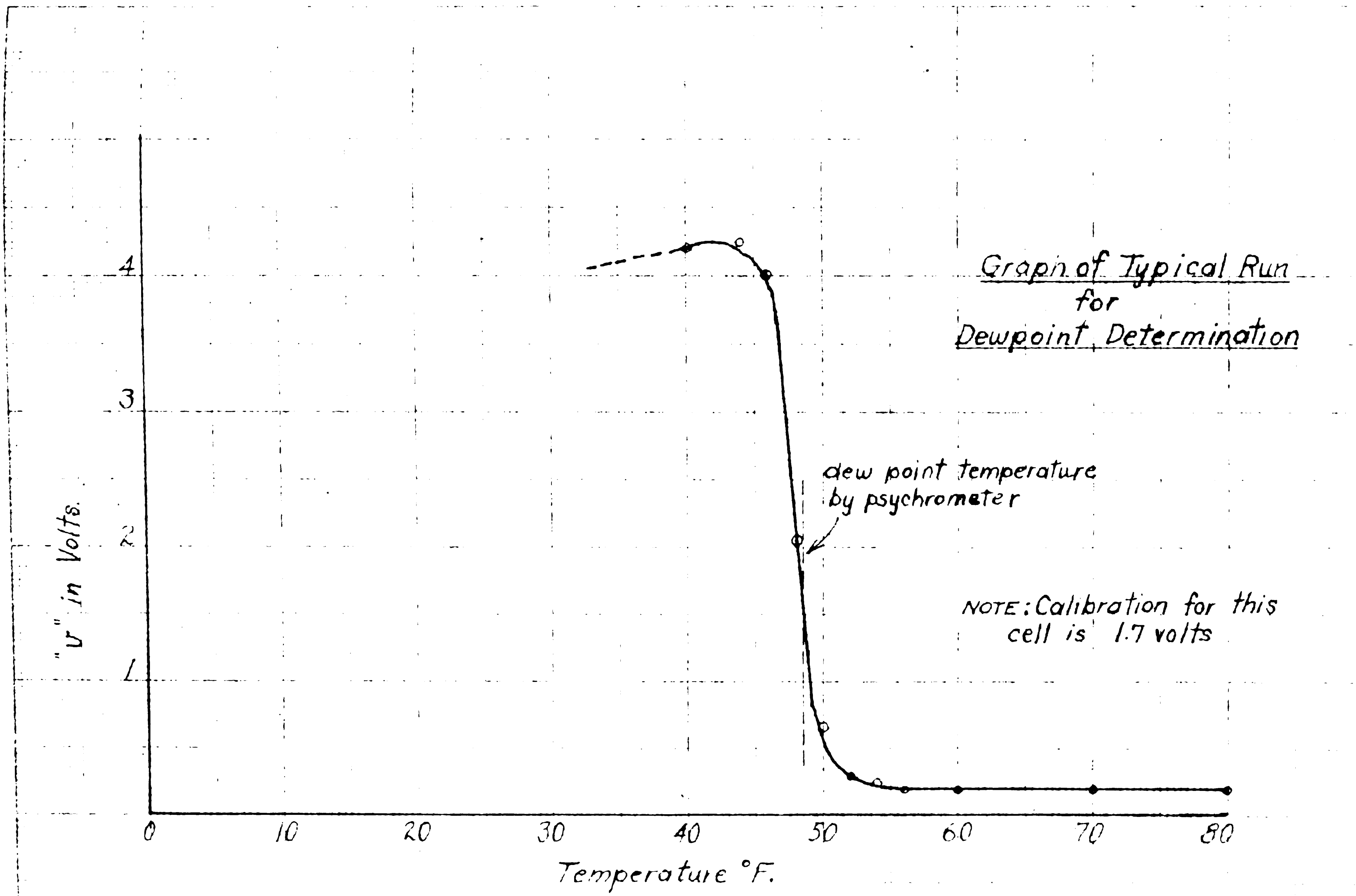

Graph of Typical Run
for
Dewpoint Determination
dew point temperature
by psychrometer
NOTE: Calibration for this
cell is 1.7 volts
"U" in Volts.
Temperature °F.
0
10
20
30
40
50
60
70
80
1
2
3
4

Fig 6.

Table I.

Room temp.	Dew Pt. psychr.	Dew Pt. Resis.	Relative Humidity	Error
74.3	50.5	50.6	44.0	+0.1
72.8	47.75	47.3	40.8	-0.45
73.1	47.35	45.5	40.0	-1.75
73.0	46.75	46.0	40.0	-0.75
71.0	43.0	43.25	36.0	+0.25
70.5	43.0	43.5	35.5	+0.50
72.5	46.0	44.8	40.5	-1.2
72,5	47.5	46.5	42.5	-1.0
71.8	49.0	47.6	43.5	-1.4
72.5	49.5	49.0	44.5	-0.5
70.5	50.0	49.4	48.5	-0.6
70.5	50.0	49.5	48.5	-0.5
70.0	48.7	48.5	48.5	-0.2
69.5	47.5	47.0	45.5	-0.5
69.0	47.2	46.7	45.0	-0.5
75.0	54.0	55.6	48.0	+1.6
75.2	54.0	56.0	47.0	+2.0
75.2	54.0	54.0	48.0	0.0
75.6	55.0	55.6	49.0	+0.6
75.6	55.0	55.6	49.0	+0.6
75.6	55.0	55.3	49.0	+0.3
75.7	55.0	55.1	49.0	+0.1
75.7	55.0	56.0	49.0	+1.0
74.0	54.0	55.0	49.0	+1.0

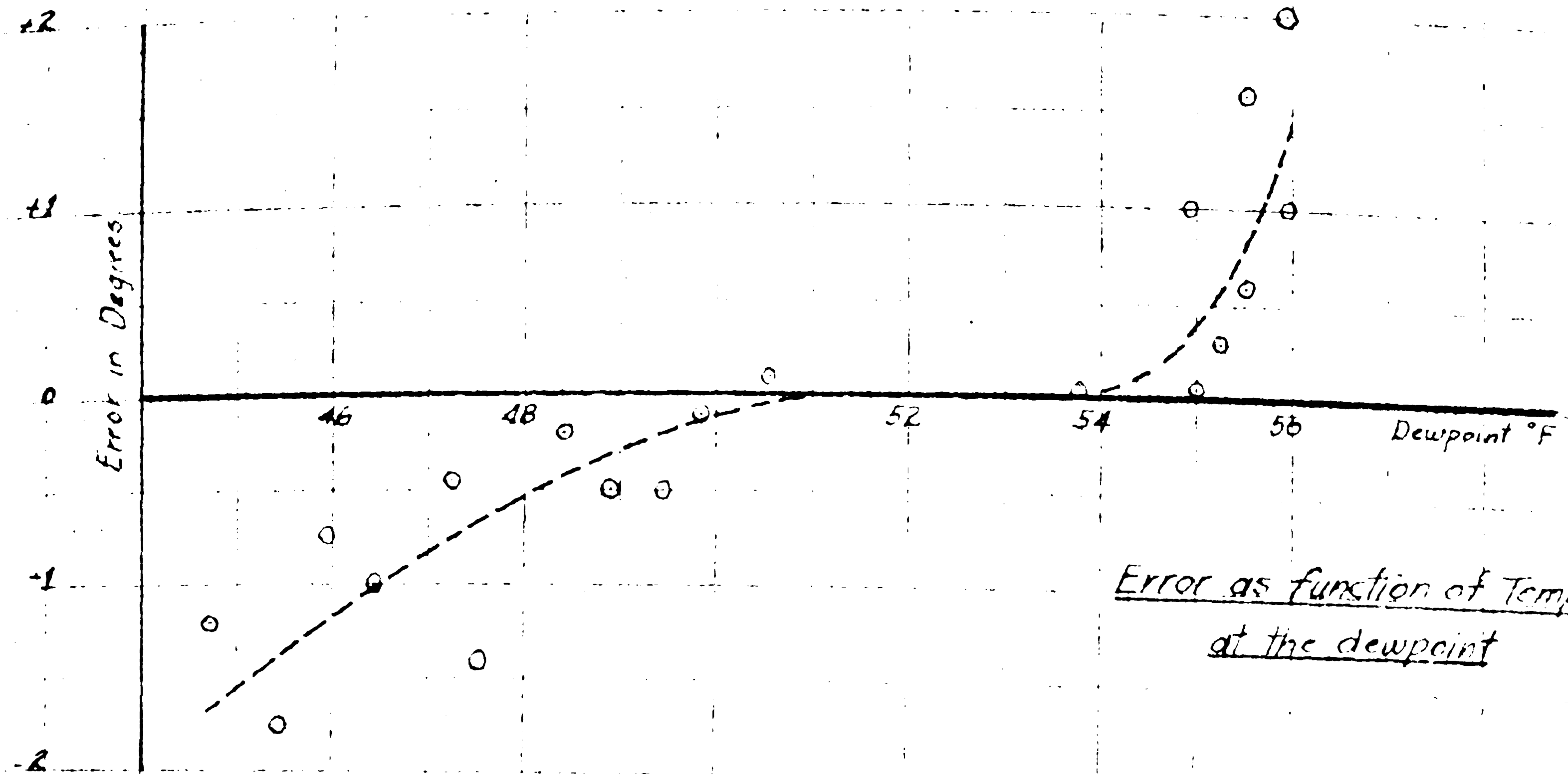
The air is considered positive if the dew point is greater by resistance than that by the psychrometric method.

From the foregoing data, it is obvious that the error is considerable in some cases. Seeking a correlation with some of the factors involved, it was found that there was a definite relationship between the error between the dew point by the two methods and the dew point by the resistance method. This was plotted and is shown in Figure 7. No satisfactory explanation for this has yet been given.

With this correction factor the average error was reduced to only 0.1%. This small error is well within the experimental error assumed for this work.

2.5 Dew Point by a Recorder

Although not pertinent to the rest of the problem, an investigation of the use of a recorder to plot both temperature and resistance as a function of time was made. The preliminary work is outlined in Appendix VI .



Error as function of Temperature at the dewpoint

Fig 7

CHAPTER III

3.1 The Basic Resistance Limit Indicator

It was necessary to take precautions in the gathering of the data as previously described. The work required two people to make the simultaneous readings of temperature and voltage. Thus, rather than to make a plot of the temperature vs. voltage for each run, it was desirable to make an instrument indicate when the dew point temperature was reached. It seemed reasonable that a vacuumtube voltmeter with a relay in the plate circuit of the tube would accomplish the purpose, with the relay controlling a buzzer or bell. Such a unit was constructed and is shown in Figures 8 and 9. The bias was controlable with R_2 and the relay could be made to close at voltages of 0 to 4.5 volts. This unit gave fiarly satisfactory results for about one month when it was found that the tube characteristics had changed greatly. It was found that this was due to severe positive voltages having been applied to the grid of the 1T4 vacuum tube, caused by allowing the leads to the cell to become shorted while the high voltage was on. After the replacement of the tube, the unit functioned normally.

At times when relative humidity increased to high values for a period of time, the leakage resistance

Fig 8. Basic Limit Indicator

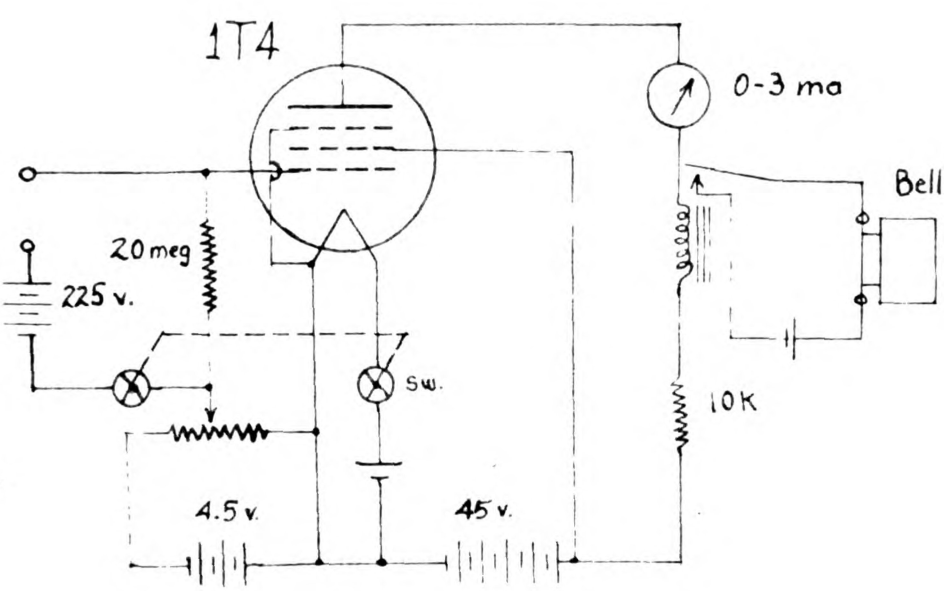


Fig 9. Circuit Diagram.

of the instrument and its associated lead cable became less than that of the cell and the resultant measurements were of no value.

The entire unit was enclosed in a small cabinet, and was thus adaptable to portable construction. Miniature Eveready type 467 "B" batteries were used to supply the high voltage to be placed in series with the measured cell. A Burgess type Z30 "B" battery was used as the plate supply for the 1T4 vacuum tube. A Burgess 4FH 1.5 volt "A" battery was used for the filament supply. No appreciable lowering of voltages was found even after several months of intermittent use.

3.2 The Connecting Cable

A cable which would allow a leakage resistance no less than about 10^{13}ohms was necessary for this instrument and it was obtained by using a very good grade of waterproof twin cable originally meant for outside use on light circuits. After cutting the necessary length from the stock roll, it was placed in an oven whose temperature was just below that of the softening temperature of the rubber covering. After 24 hours in the oven repeated applications of G. E. Glyptal #1201 Red were made over the entire cable and care was taken to insure complete impregnation of the insulating materials which were exposed at the termina tions of the cable. Small alligator clips were fastened to one end to permit temporary connections to the dew point cell. The other end was connected to terminals on the front of the indicator panel. After a long period of use, this cable developed surface cracks and the leakage conductance again became too great for this application.

Leakage resistances internal to the indicator were cut to a minimum by suspending all wiring in the initial circuit and paraffining all wiring and suspensions.

3.3 Necessity for More Sensitive Instrument

During the experimentation with the wider spaced electrodes, it was necessary to measure much higher values of resistance and this was tried by several methods.

The method using the G. E. vacuum tube voltmeter was again assembled with $R. = 20 \times 10^7$ ohms. Indications were that the resistance was of the order of 10^{12} ohms. This was barely distinguishable on this setup. Thus if these cells were to be used, a new instrument would have to be built which would respond to roughly .01 volt change across the resistor R. The design of this instrument is the major problem to be considered in this paper.

PART II The Sensitive Resistance Limit Indicator

CHAPTER IV

4.1 General Considerations

As mentioned in the previous section, the need was apparent for an instrument which would respond to a given change in the voltage across the resistance R of about 0.01 volts. (Figure 4) With a 2.0×10^7 ohm resistor in series with the cell and batteries of 300 volts, this would correspond to a minimum resistance of about 10^{12} ohms. With this in mind, it seemed probable that an all electronic instrument could be built which could eliminate all mechanical components such as relays which are sensitive to physical changes, shocks, etc., the following were compiled as a set of prerequisites for such an instrument:

4.2 Necessary Requirements

(1) With a versatile instrument in consideration, it was necessary that a switching system be employed to change the resistor R and thus change the range and sensitivity of the instrument. This would require that the grid current be in the order of one-one hundredth of the current to be measured. If the resistance at the limiting point is to be 10^{12} ohms, using 300 volts in series, the resultant measured current would be

$$I_{meas} = \frac{0.01}{2 \times 10^7} = 5.0 \times 10^{-10} \text{ amperes.}$$

Thus the grid current to cause no error greater than about 1% should be less than 10^{-12} amperes.

(2) The elimination of the relay and the substitution of a suitable electronic switching circuit would be desirable. This should control an oscillator which would make a very distinct keying with a minimum of grid bias change.

(3) Although after the dew point cell has proven reliable, a portable instrument using batteries will be desirable, but one which could be used from 117 volt A.C. power source would be satisfactory. The unit should be so designed that it would be reasonably independent of line voltage variations and other physical changes.

4.3 Desirable Features

(4) To measure the resistance on both the warming and cooling cycles, a switch circuit would be necessary to start and stop keying the oscillator at the same value of input voltage.

(5) To obtain an indication of the stage of the cycle, a meter showing the value of the resistance should also be included and should be roughly calibrated from infinite to any desired point depending on the range switch. This calibration should be fairly accurate by multiples of ten so that only one meter scale would be necessary for all sensitivity ranges.

(6) Some means for limiting the voltage applied to the input grid should be included so the input tube could not be destroyed by allowing the cell leads to become shorted while the voltage was connected.

(7) A means for varying both the pitch and volume of the audio oscillator should be included to apply for varying external hearing conditions.

(8) The unit should if possible, be entirely self-containing so that the least amount of trouble would be necessary in transporting it.

(9) Common design practices and layout principles should be followed, and in addition no "special" tubes or associated equipment should be included unless absolutely necessary. The cost should be kept as low as feasible without sacrificing too much on the high standard of construction desired.

(10) Operation and alignment should be possible with a common vacuum tube voltmeter and should not be unnecessarily complicated.

4.4 Block Diagram

With the above considerations in mind, the block diagram in Figure 10 was drawn and each of its parts then considered in detail. It consists of an input stage which will fulfill the need for the very low grid current, a direct current amplifier controlling an electronic switch which will key at the same point

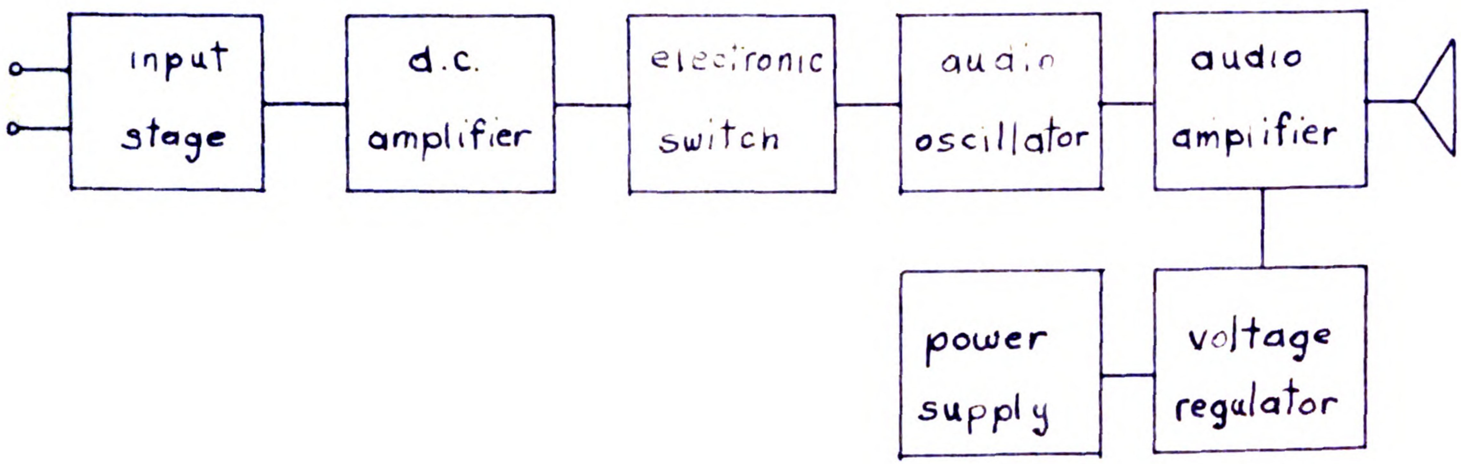


Fig 10. Block Diagram

at which it unkeys and with no intervening manual operation. This is to control a suitable audio oscillator and the output of this amplified by conventional audio amplifier feeding a speaker. The power supply should be well regulated and be of heavy enough current capacity so that the unit would be amply supplied.

CHAPTER V

5.1 General Design Considerations

The nature of the application of the resistance limit indicator being developed, required that extreme care be exercised to incorporate the utmost reliability in the instrument. At the same time the cost was an important factor and wherever possible, it was held to a minimum. Yet versatility was also desired and some things were included which would not be required in a production instrument but were desirable for experimental purposes. For example, the use of volume and pitch controls on the oscillator, while not entirely necessary were quite convenient in use.

5.2 The Low Input Current Stage

The measurement of currents in the order of 10^{12} amperes requires that the grid current of the input tube be less than that value and generally about at least one one-hundredth of that value. The grid current in the normal operation of most receiving type tubes is caused by one or more of the following:[1]

(a) electrons from the filament thermionic

(b) electrons emitted by the grid

(c) positive ions given off by the filament

(d) photoelectric electrons given off by the grid due to the light from the filament

(e) electrons emitted by the grid due to the soft X-rays given off by the plate caused by the plate current

(f) ionization by collision with gaseous molecules

(g) leakage currents in the tube socket connections

With ordinary receiving type tubes the flow of electrons to the grid due to the thermionic emission by the filament may be reduced by a suitable negative bias voltage applied to the control grid. The electrostatic field produced around the grid repels the electrons and reduces that component of the grid current. The reduction of the operating voltage and thus the operating temperature of the filament or heater will reduce the heating of the neighboring electrodes, and if they are made from special materials, a negligable amount of thermions are emitted. The flow of positive ions may be reduced greatly by inserting a positive space charge grid between the hot cathode and the control grid. This compels the positive ions to be bent back and returned to the cathode. This space charge grid also serves to collect any negative space charge which may be present in the tube. The lowering of the filament temperature will also reduce the production of photoelectrons from the grid. The use of plate and anode voltages less than about 6 volts will eliminate even the softest X-rays produced at the plate.
This will also greatly reduce the effect of ionization

by collision and thus reduce that portion of the grid current.

5.2a Electrometer Tubes and Circuits

Special vacuum electrometer tubes which eliminate as much as possible the causes listed above, are available on the market. The best known among these is the General Electric Company Pliotron type FP54.[2] With a very sensitive galvonometer and other associated equipment one of these tubes may be made to detect currents as small as 10^{17} amperes. This tube could be used for the detection of the currents in the order of 10^{12}such as those produced in the dew point cell, with the circuit previously described (Part I) however, the price of $55. is a prohibiting factor.

The Victoreen Instrument Company produces their type VX41[3] electrometer tube which will measure currents of 10^{-12}amperes and would also be suitable for this application. The price of $12.50 is more reasonable, but the use of a receiving tube if possible would further reduce the cost to about $2.00 maximum and if it is possible to measure the current necessary with this type tube, it would definitely be preferable.

A circuit has been described[4] using a type 1A6 receiving tube, and reports good results in measuring currents down to 10^{-12}amps. Beyond this point the -

system becomes erratic and therefore unusable. This type tube requires a very high input resistance which is not possible in the dew point system because of the leakage resistance of the input cable connecting the cell to the measuring instrument.

The General Electric Company has recently produced a direct current amplifier which uses in the input stage a #954 acorn type receiving tube. It is operated as a space charge grid type tube, and is also used with an input resistance of a high value, (in this instance, 4.0×10^{10} ohms.) Due to the construction of this tube and its physical size, experiments were run with the lower values of input resistance, and the tube was found to perform satisfactorily when the conditions were such that the effects listed previously in this section were minimized.

Following is the data taken on several #954 type receiving tubes picked at random from general stock.

5.2b The 954 Operating Characteristics

To the author's knowledge, the operating characteristics of the 954 as a space charge grid type tube are not available commercially, thus the optimum conditions were to be found by experiment only. The circuit shown in Figure 11 was assembled and the characteristic curves obtained for this tube.

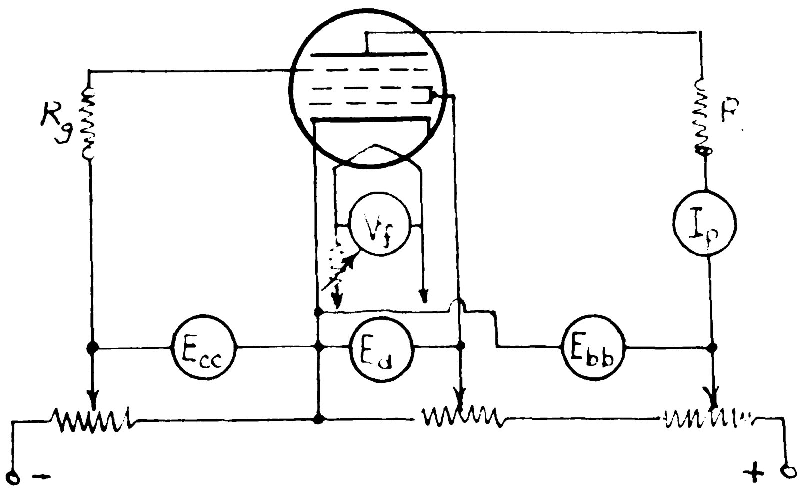


Fig 11. Testing Circuit

The grid current was determined by changing the external grid resistors and thereby calculating the voltage across these resistors after the characteristic curves were known.

Figure 12 gives the common curves and Figure 13 gives the variables as a function of filament voltage (a.c.)

5.2 (c) The Hum Problem

The problem of 60 cycle pick up hum was contemplated presented itself immediately upon putting the unit into operation. Thus it was necessary to put in some sort of filtering circuit to eliminate response much above that of direct current with fairly slow variation of the order of 1 cycle per second. The construction of an L-C filter for this frequency was deemed to be unnecessary as the inclusion of a shunt condenser would satisfactorily limit the frequency response of the amplifier. The logical place to supress the hum was in the low-level stage and preferably in the plate so as to minimize leakage resistances in the condenser from affecting the calibration of the instrument. Assuming that a 10,000 ohm plate resistor in the first stage and a time constant of 1 cps. would be suitable a condenser of

$$C = \frac{t}{r} = 10^{-4}$$ farads or 100 micro farads would

suffice. As the plate of this tube is run at the fairly low voltage of 8 volts, this size capacitor was easily available. No serious trouble in lag due to the condenser charge was encountered. The power for this stage is small and as the regulation should be very good, it was desirable to isolate this stage from the large bleeder supply and obtain the necessary

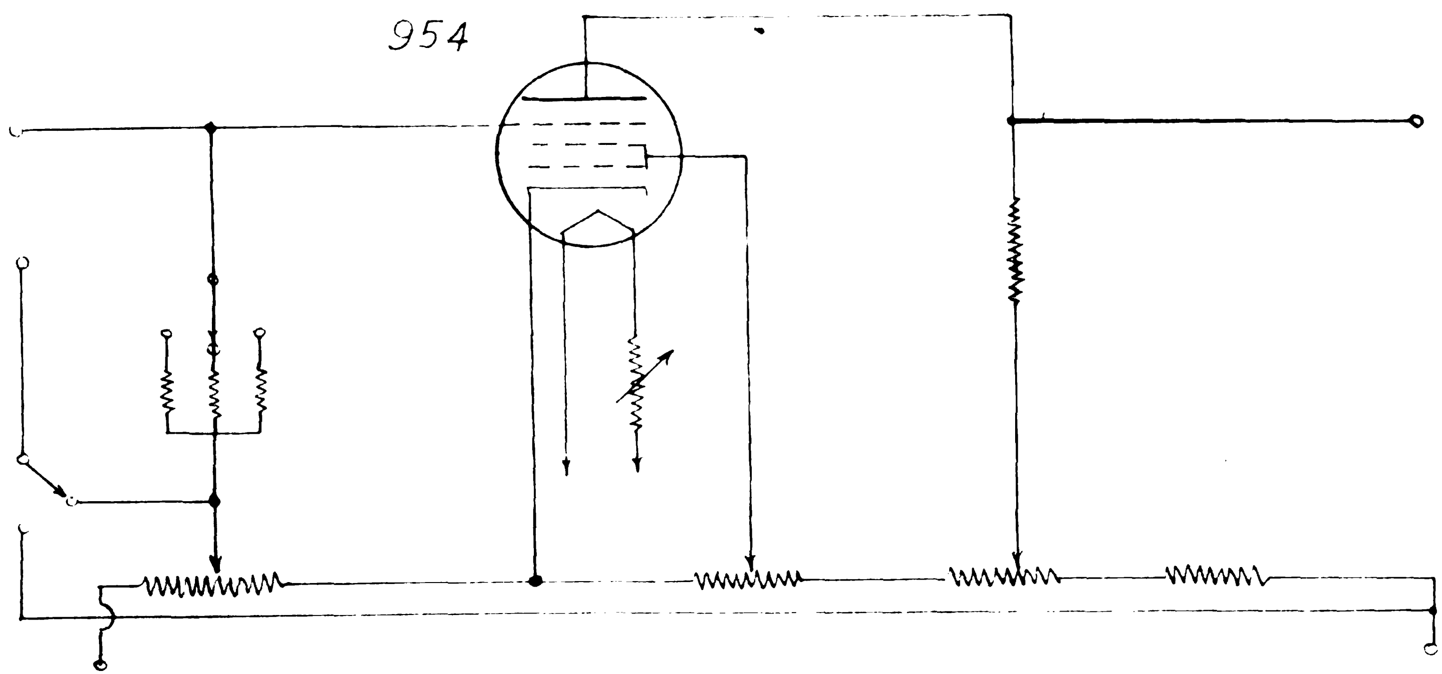


Fig 14. Input Stage and Bleeders

voltages from a separate bleeder system fed from the regulated voltage from the power supply. This was formed completely from wire wound resistors and 4-watt wire-would potentiometers as shown in the circuit, Figure 14, of the resultant first stage, and its associated bleeder system.

5.3 The Direct Current Amplifier

The problem of the direct current amplifier to be used for such an application is always difficult. The inclusion of batteries was definitely undesirable, and this required the use of a common power source for all stages. Several circuits are in use for this type application, and are considered here.

Perhaps the most used type is that shown in Figure 15 in which the power for each stage is taken from a common bleeder. This has a serious disadvantage in the variation of the voltages on the several taps along the bleeder resistor. This causes drift and thus might result in a quite unstable instrument. If, however, the current in the bleeder circuit is much greater than that in the circuits obtaining power from the bleeder, this variation is minimized and the resultant drift is reduced.

The change in resistance of the bleeder due to changes in temperature is also a common cause of drift, so the bleeder resistors should be over-rated, and also

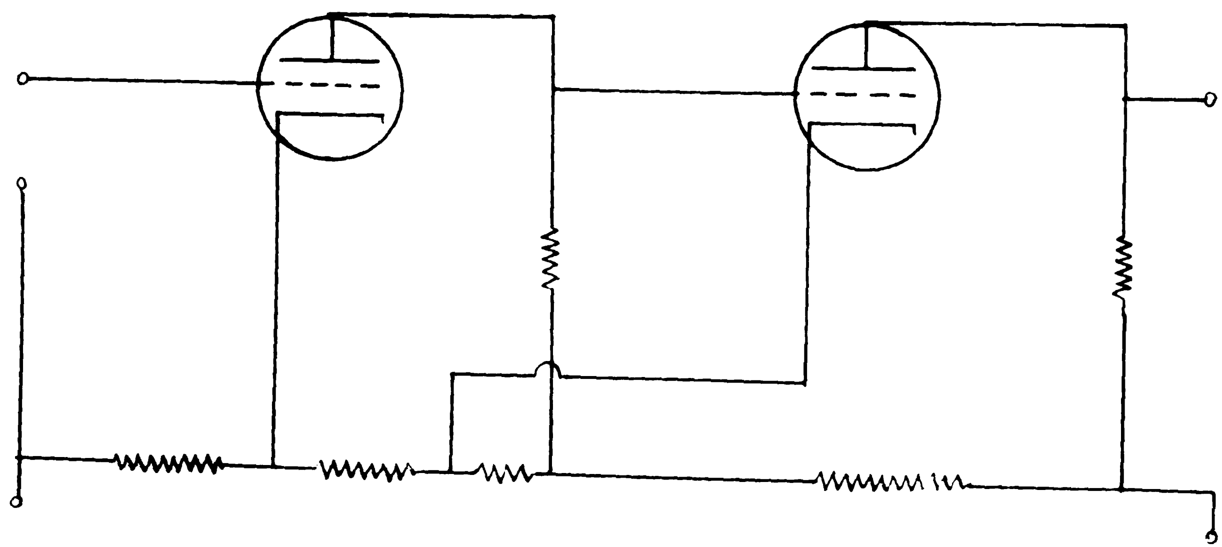


Fig 15. D.C. Amplifier with single bleeder supply.

be allowed to come to the steady state condition as soon as possible. This can be done by keeping the temperature of the bleeders constant, by ventilation. In general this type of amplifier should not be used when it is possible to avoid it.

Another method of stabilizing the above type circuit is to use a balanced type amplifier. This requires twice the number of tubes and associated parts but results in an amplifier which is fairly independent of supply voltage variations. A typical circuit is shown in Figure 16.

A second type of circuit commonly used in D.C. amplifiers is that shown in Figure 17. It makes use of the voltage divider network which is returned to the high negative voltage V_2, to get a resultant grid voltage which may be applied to the following stage. The main disadvantages of this type circuit are that the gain is reduced by the previously mentioned voltage divider network and also that a quite high voltage is needed for a power source.

A more satisfactory circuit has been described by Miller[5] and is shown in Figure 18. It is similar to the foregoing circuit with the exception that a voltage regulator tube has been substituted for the resistor R_1 in Figure 17. By returning R_2 to ground and proportioning the currents correctly, it is possible to produce the correct bias voltage E_{cc2} shown in Figure 18.

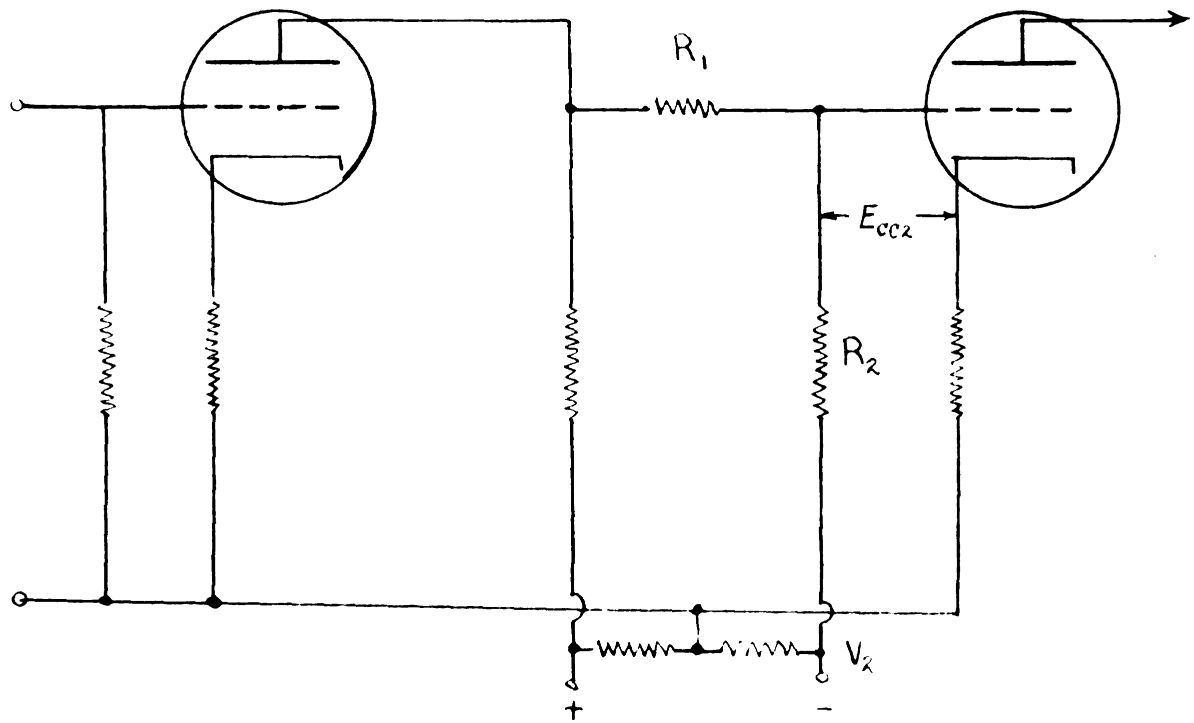


Fig 17. Another Common D.C. Amplifier

The gain of this amplifier is that normally obtained from the usual resistance coupled amplifier and may be shown to be

$$\text{Gain} = K = \frac{R_1}{R_1 + r_p}$$

Obviously this is the most satisfactory of those herein described.

The electronic switch in this unit necessarily must change in either direction at very close to the same absolute voltage. If it was possible to make the unit sufficiently stable, no intervening amplifier would be necessary, but hum etc., picked up in the initial stage and that present in the power supply output limits this stability.

To obtain the approximate hum voltage normally obtained from a few feet of exposed unshielded wiring such as might be used near the cell of this unit, the following circuit was assembled and rough measurements taken.

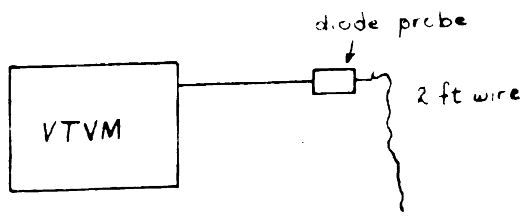


Fig. 19 Hum Measurement

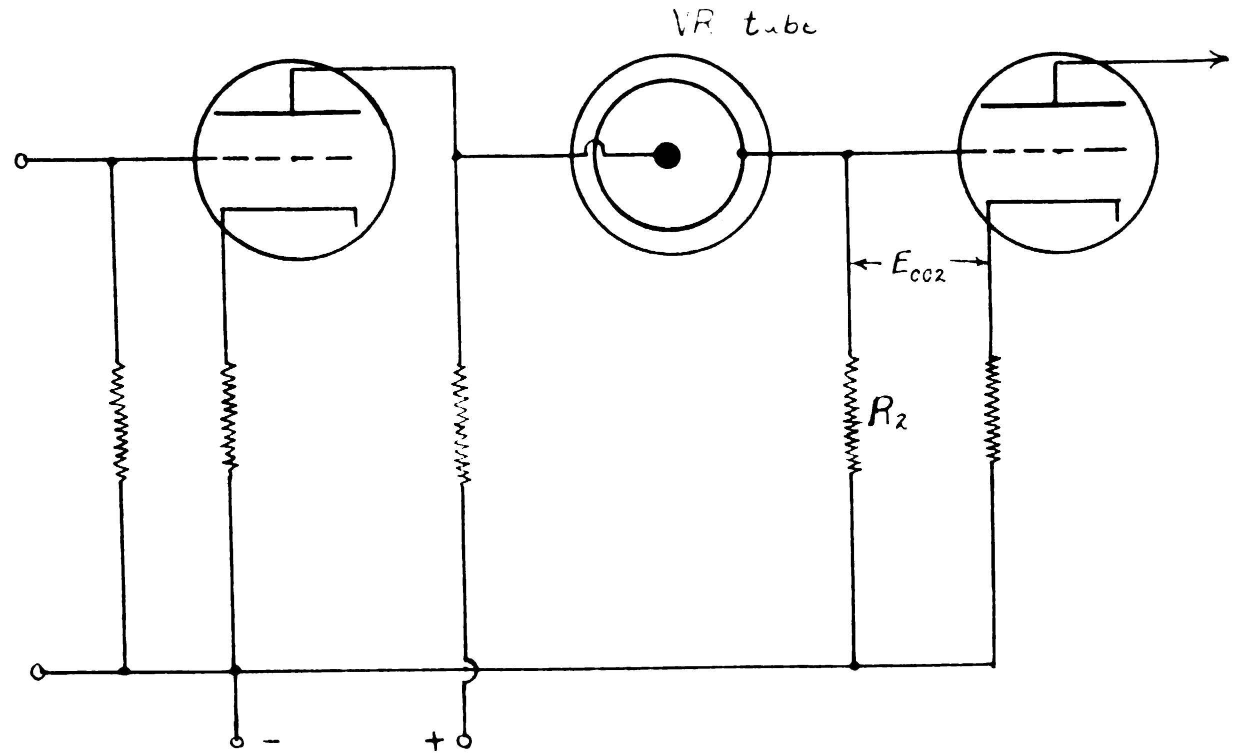


Fig 18. The Miller Coupling Circuit

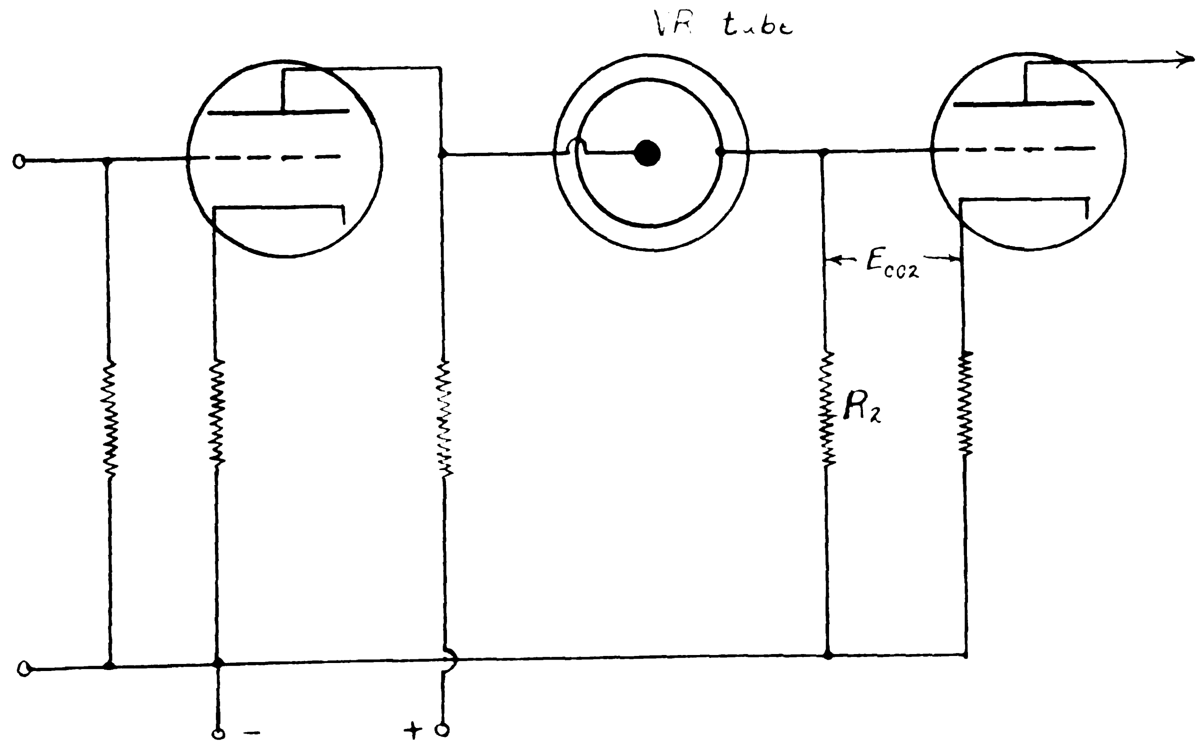


Fig 18. The Miller Coupling Circuit

It was found that a voltage of approximately .4 volts was impressed upon the wire when about 2 feet were exposed or unshielded, to the average varying electromagnetic and electrostatic fields present in the laboratory. Upon touching the wire with the hand, a voltage of about 11.6 volts was found. Assuming that the cell is to be operated with a shielded cable except for the terminations at the cell and at the instrument, and that the cell is equivalent to the two feet of wire used in the above measurement, it is seen that the first stage will have at all times the observed .4 volts A.C. impressed on its grid. When the first stage has a gain of K, the 100 micro-micro farad condenser placed across the plate of this tube will reduce this to about .0026 K-volts.

Further reduction of the A.C. component of the signal voltage may be obtained through the use of more shunt condensers on the following stages, the only limitations on these being that the time constant for the associated circuit be of the order of 1 second. Thus the gain needed for the amplifier stage is small and is further dependent only on the stability obtainable in the rest of the system.

In all respects, a gain of 100 would be more than sufficient to operate the electronic switch without serious trouble from either hum or power supply variations.

Considering the design of the type amplifier described by Miller, and previously mentioned in this section, as applied to a 6AC7 type tube, it is found that the gain obtainable is about 200. (Appendix IV)

A modification of the first d.c. amplifier described was constructed and used in this instrument, using 2 triode 6SJ7 stages. The Miller circuit was then inserted to make a comparison with the above, and the results are shown in Chapter VI.

5.4 The Electronic Switch

Recalling the necessity for the electronic switch in the normal cooling and warming cycle to produce a change in either direction at the same voltage without any intervening operation, manual or otherwise, it was necessary that some type of temporary switching mechanism be utilized.

A modification of the familiar Eccles Jordan flip-flop circuit is the one shot circuit shown in Figure 20. The operation of the switch may be described as follows:

Assume that tube #1 is drawing current and has a bias as prescribed by the normal operating characteristics for the tube. The voltage divider system consisting of R_3 and R_4 in series, is connected to the #1 plate. If the current drain through R_1 is considerably greater than the bleeder current through

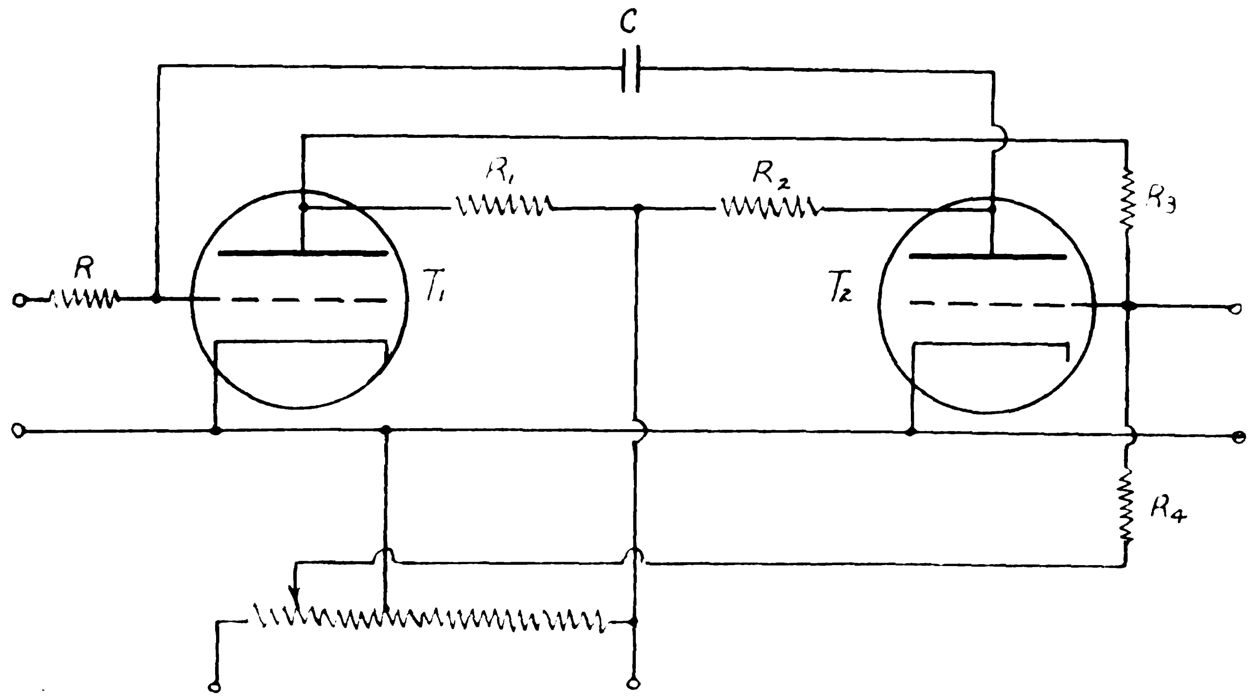


Fig 20. The One-Shot Circuit (Modified)

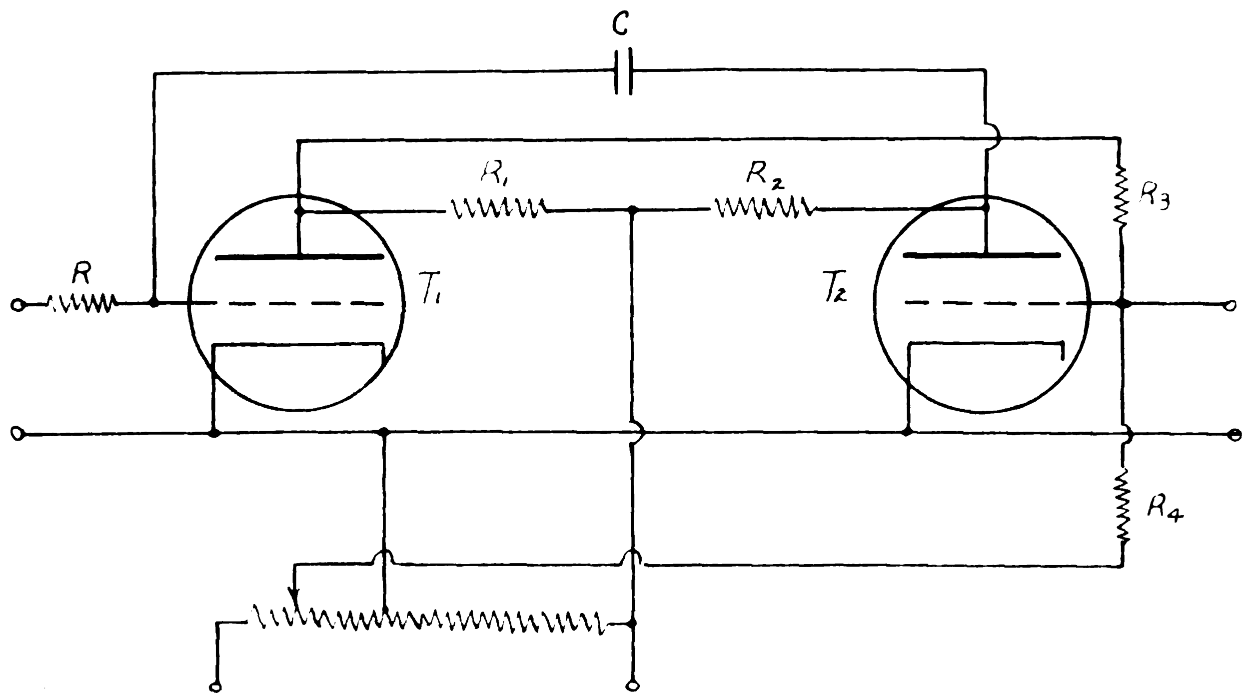


Fig 20. The One-Shot Circuit (Modified)

R_3 and R_4, the potential of the #2 grid will be a function of the potential of the #1 plate. Thus, if the potential of the #1 grid is decreased sufficiently, and thus increasing the potential of the #1 plate, the #2 grid voltage will also be raised thereby causing an increase of current and an increased voltage drop in R_2. This decreased potential is fed back to the #1 grid by the condenser C. This causes complete cut-off of the #1 tube and the #2 tube assumes complete control.

This is a temporary condition however, as the charge is then discharged through the series circuit R, R_2 and voltage source E_{bb}. This returned the grid of #1 tube to above the curoff point and the switching operation takes place in the other direction. When the voltage applied to #1 grid is just slightly below the switching potential, the circuit will oscillate with a keyed period of

$$t_1 = C\ (R+R_2)$$

the unkeyed period of the oscillatory cycle will depend on the difference of the keying potential and that of the applied potential and is

$$t_2 = RC\ \ln \frac{V_1}{R(e_1-e_2)}$$

A mathematical analysis of the above circuit is given in Appendix V.

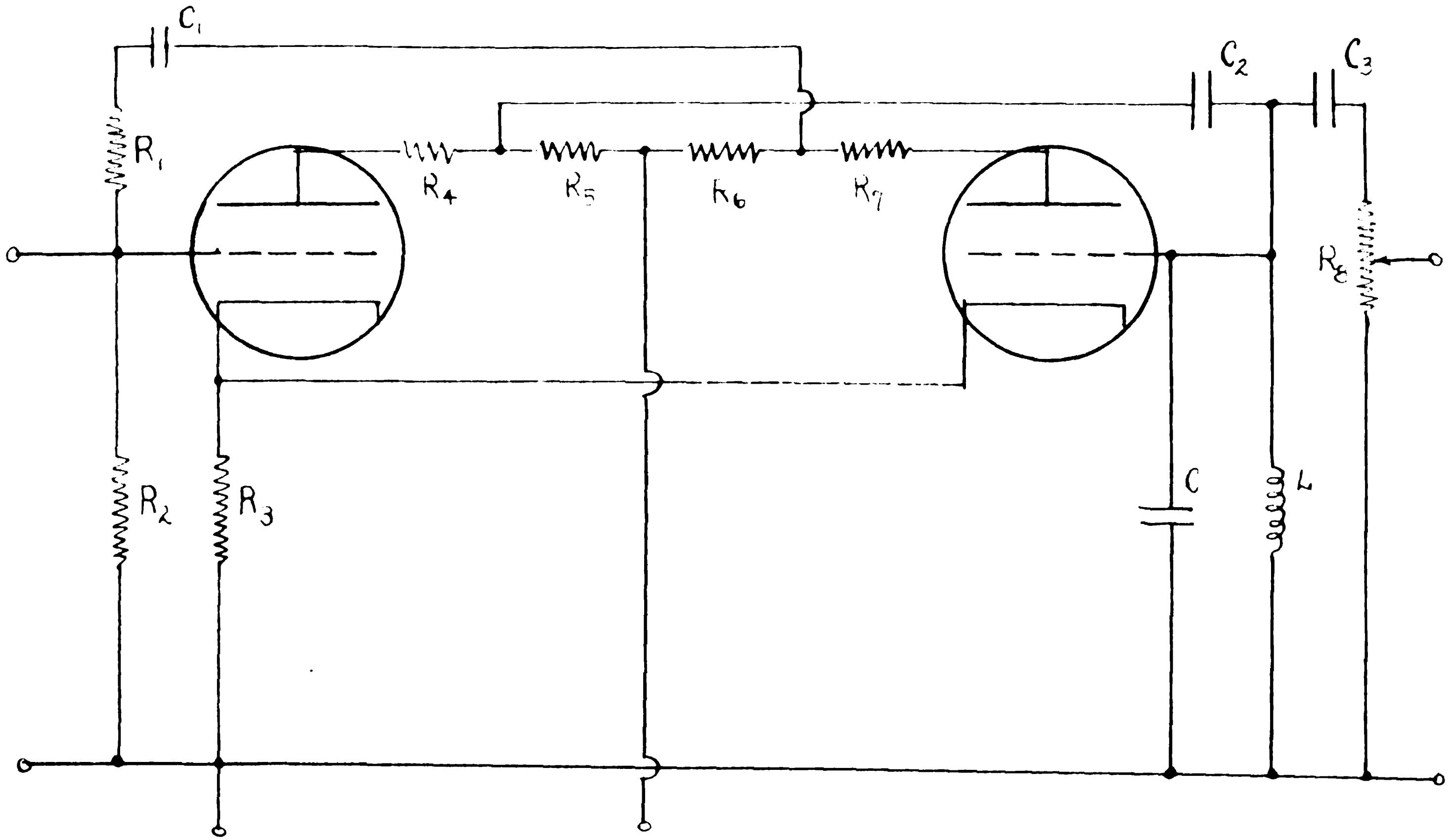


Fig 21. Stabilized Multivibrator Oscillator

5.5 The Audio Oscillator

It was necessary that the audio oscillator to be used in this application go from a non-oscillatory to an oscillatory state with a minimum change of grid potential. Preliminary experiments showed that a conventional tuned plate audio oscillator required about 5 volts change in grid bias to pass through this transient condition, and that the change was not abrupt but very irregular and erratic. Thus it was necessary to find an oscillator which would be more suitable for this application. This was found in the multivibrator type audio oscillator as used in the Army's tape keyer TG-10B. The circuit for this oscillator is shown in Figure 21. It was found that only about 1 volt was required to start the oscillations and that the frequency changed very little when the circuit was oscillating.

The pitch of the oscillator was made variable through the use of several condensers. These were switched into the resonant circuit formed by L and C shown in the above figure. Although this was not necessary to the operation of the dew point work, it was thought feasible because of the advantage obtained in that the operator might change the pitch and thus eliminate partial fatigue when using the instrument for long periods of time. This change in the L-C stabilizing circuit did not appreciably affect the

voltage at which the circuit broke into oscillation.

5.6 The Audio Amplifier

As it was necessary to hear the audio tone, the output of the oscillator was amplified by a two stage conventional R-C coupled amplifier. This allowed a high enough level to be fed to a remote position if it became necessary to do so. A volume control was included so the operator might adjust the sound to a suitable level. The output was fed to a 6" PM speaker.

5.7 The Power Supply

In order that the instrument hold its calibration over a reasonable period of time, it was necessary that the voltage supply be very well regulated. In general there are two methods of regulating a d.c. voltage electronically. (1) By shunting a gas diode regulator tube across the poorly regulated supply, and (2) by inserting either a series or shunt high vacuum triode controlled by a pentode tube amplifier. The former is the simplest, but does not afford quite as good regulating characteristics as the latter. However, due to the number of tubes and the extra equipment for the latter, the gas diode type regulator was chosen.

The necessity for a low ripple voltage is obvious as the direct current supply is used to supply the

bias voltages all through the amplifier, and as any change in the grid voltages of the first stages is amplified and results in a correspondingly larger change on the grid of the switch tube. To lower this ripple voltage to a usable value, it was necessary to employ a two section filter. The voltage regulator provides additional filtering. The two section filter causes the inclusion of additional resistance and therefore reduces the overall regulation. Also the necessity for a high voltage (300 volts) at fairly high current for this type of instrument requires either that an extra high voltage power transformer be used, or that condenser input be used on the filter. The former is considerably more costly and would require more space on the chassis, while the latter affords still poorer regulation. Some of the disadvantages of the condenser input filter would be overcome through the use of an excessively high bleeder current, thus improving the regulation and obtaining the necessary high voltage. Since the overall regulation was the important feature, and this being obtained by using the high bleeder current and the gas diode regulator tubes, it was necessary that the regulation of the power supply proper be only sufficient to maintain the output voltage which supplied the VR tubes slightly greater than that required to keep them in continuous discharge. The change of the currents being drawn from

the bleeder and power supply was calculated to be less than about 10 milliamperes throughout the completion of one cycle, and for very small voltage settings, almost negligible, thus the change in voltage due to the slant characteristic of the gas diode regulator tubes will not appreciably affect the output voltage.

In addition to the above, it was desirable that the instrument be fused to prevent damage in event of parts failure, or higher than normal input line voltage. The fuse was to be mounted in the back of the cabinet.

The complete power supply and regulator circuit diagram is given in Figure 22.

5.8 The Complete Circuit Diagram

Having chosen each component part and arrived at a suitable circuit for each, the problem remained to combine the individual parts into one workable unit. The details of the small calculations necessary are not included but are obvious upon reference to the complete circuit diagram shown in Figure 23. A parts list is shown in Table II.

5.9 The Layout Problem

Certain parts, such as the transformer, chokes and filter condensers, require a large percentage of the top of any chassis on which a unit of this type is to be built. Thesewere placed along the back side of the chassis so as to allow the remaining circuits

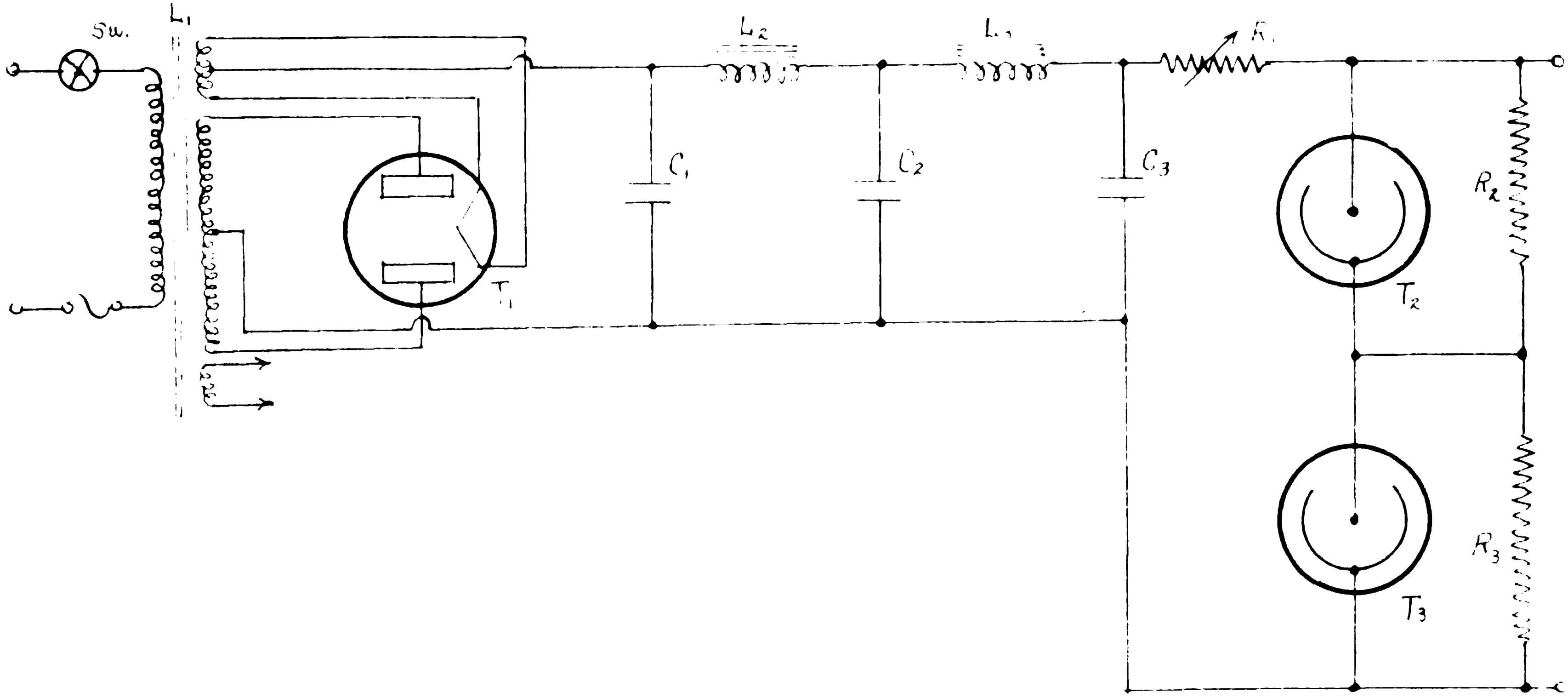


Fig 22. Power Supply & Regulator Circuits

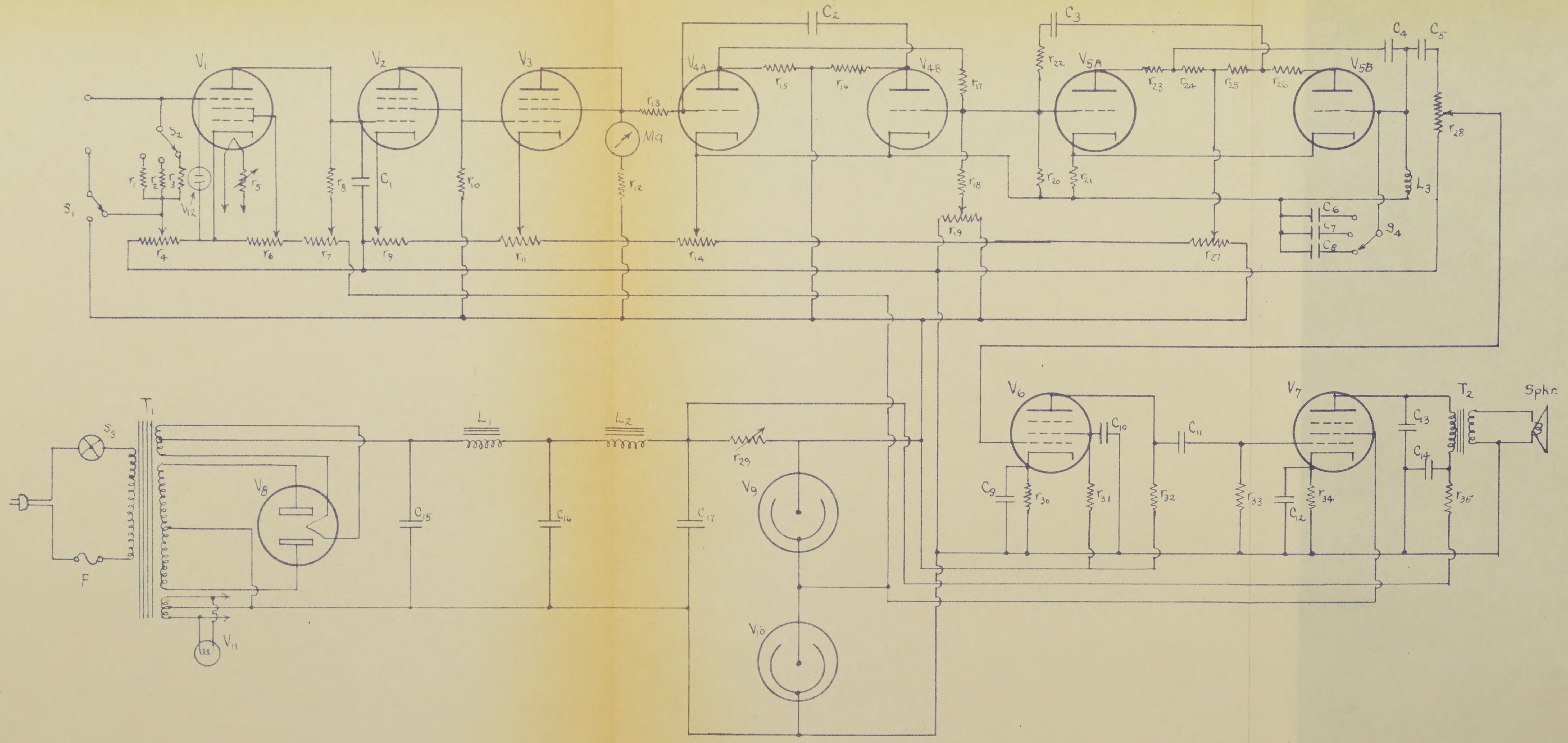


Fig 23. Complete Circuit Diagram for Resistance Limit Indicator

Fig 23. Circuit Diagram

Table II. Parts List for the Sensitive Resistance Limit Indicator.

Resistors:

The following resistance values are in ohms and are ½ or 1 watt resistors unless otherwise noted.

#	value	wts.
1	1M	
2	10M	
3	20M	
4	50	4
5	15	
6	200	
7	500	
8	10K	
9	see note	
10	.1M	
12	.1M	
13	20K	
15	.1M	
16	.1M	
17	.2M	
18	.5M	
19	50K	
20	68K	
21	10K	
22	.39M	
23	27K	

#	value	wts.
24	27K	
25	27K	
26	27K	
28	1M	
30	1.4K	4
31	2M	
32	.5M	
33	.1M	
34	400	10
35	2.5K	25

NOTE: resistors 9,11, 14, 27, 29, are composed of 3-2500 ohm 100 wt. resistors in series.

Tubes:

1	954
2	6SJ7
3	6SJ7
4	6SN7
5	6SN7
6	6SJ7
7	6L6
8	5U4
9	VR150
10	VR150
11	P- 47
12	NE-2

Condensers:

Values are in micro-farads, 600 v. wkg unless other-wise noted.

#	value	v.
1	100	50
2	.25	
3	.05	
4	.05	
5	.05	
6	.01	
7	.04	
8	.1	
9	8.0	50
10	.05	
11	.05	
12	8.0	50
13	.002	
14	20.	
16	8.	
17	20.	

Other Parts:

T_1	Stancor P-4081
T_2	Stancor A-3823
L_1 & L_2	8 hy. @ 100ma.
L_3	Thordarson T20C52
Spkr.	Jensen PM6C

which would require controls to be placed along the front panel. Care was taken to avoid stray coupling between the power transformer and the input stages. Also the cables which carried the raw dc from the rectifier were run separately from the cables carrying only signal, dc supply, and filament supply voltages. The individual parts were mounted in a fixed position as much as possible by using Jones mounting strips throughout. Mounted in this way, there was very little instability due to vibration.

The electronic switch stage was not included when the instrument was first said out, but was later found necessary and included. A preferred arrangement is shown in Figures 24 and 25. The change indicated would further decrease the length of wiring and simplify the wiring procedure considerably. The unit, while quite compact, has been designed so as to make each part have its own place. The large bleeder resistors were mounted external to the unit both for space considerations and to allow them to be better ventilated. The 6" loud speaker was mounted on the front panel and was protected by a copper screening. The indicator meter was mounted as shown in the panel view, Figure 24.

The wiring was done with the standard color coding procedure: black for negative or chassis; red for high voltages from the d.c. supply; yellow for the bias

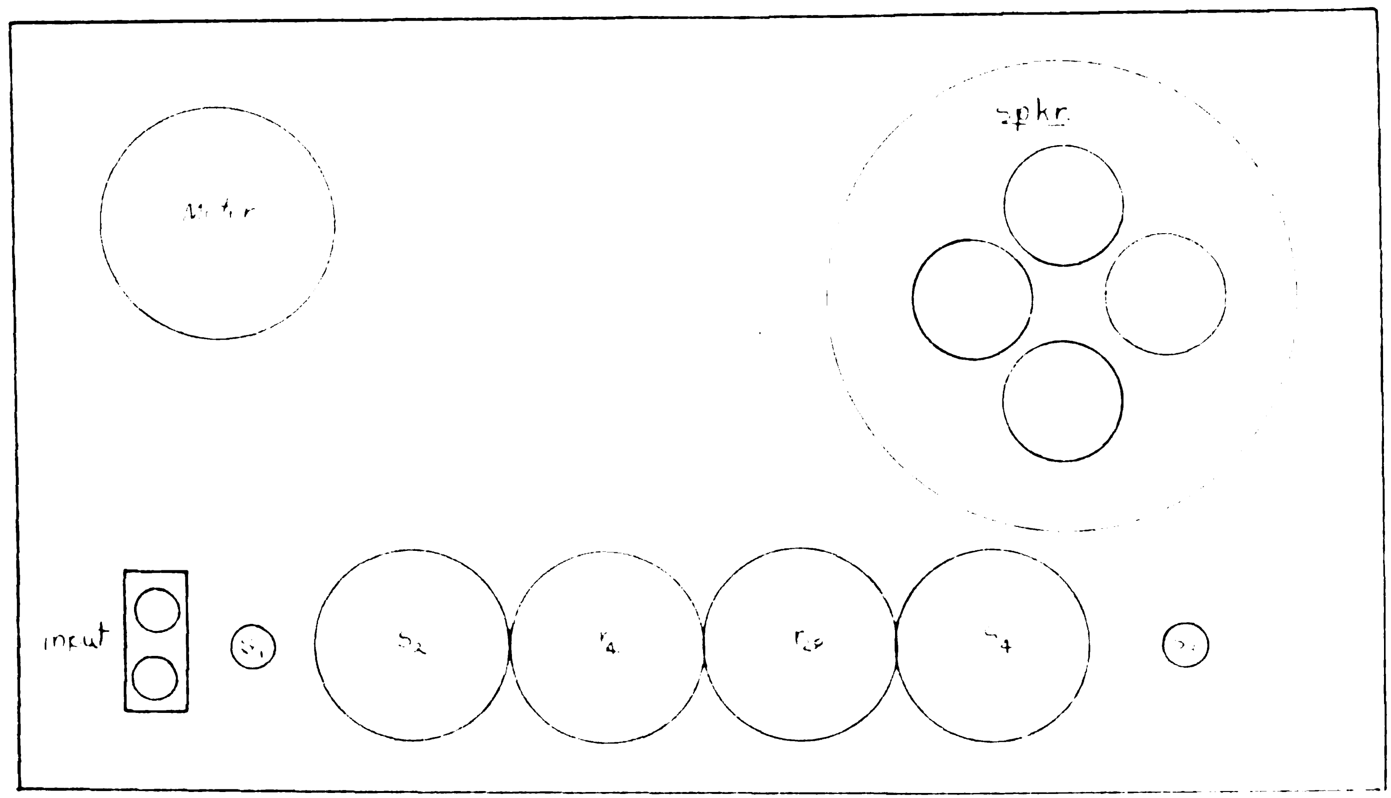


Fig 24. Panel Layout

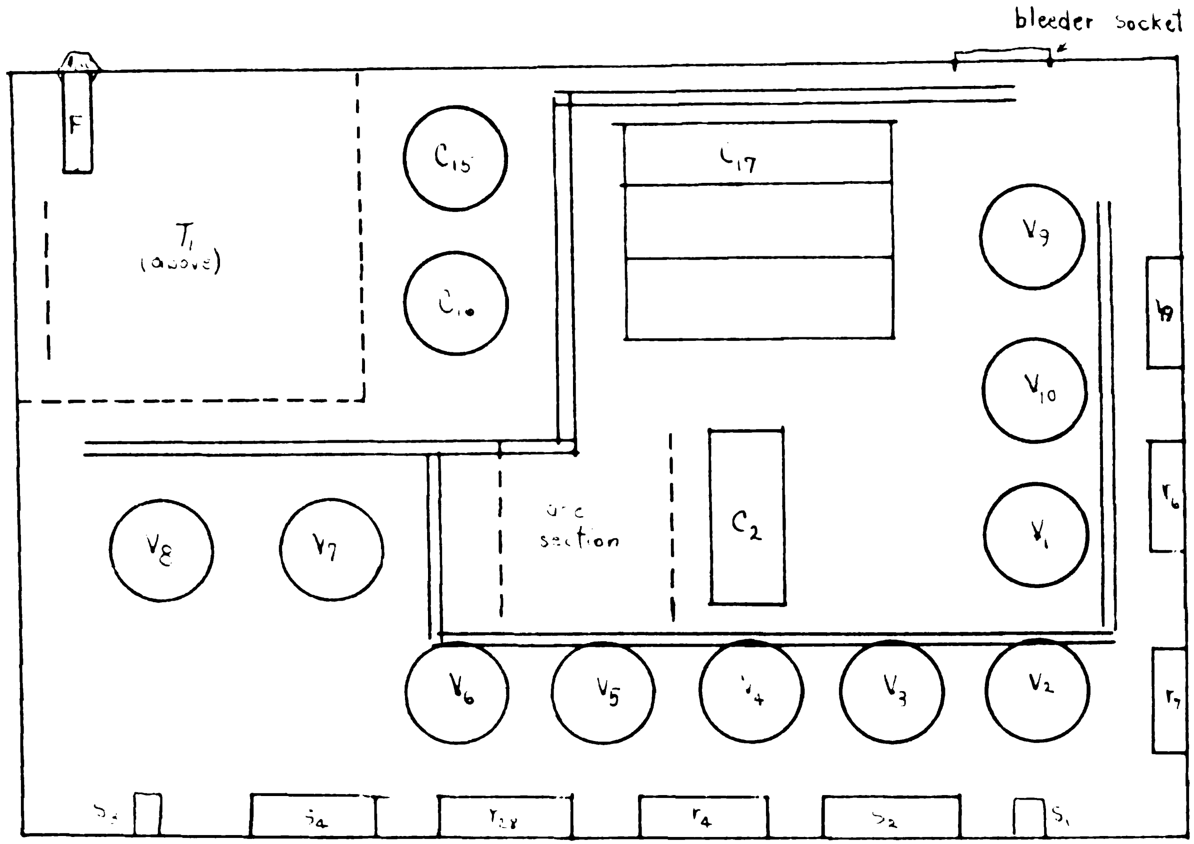
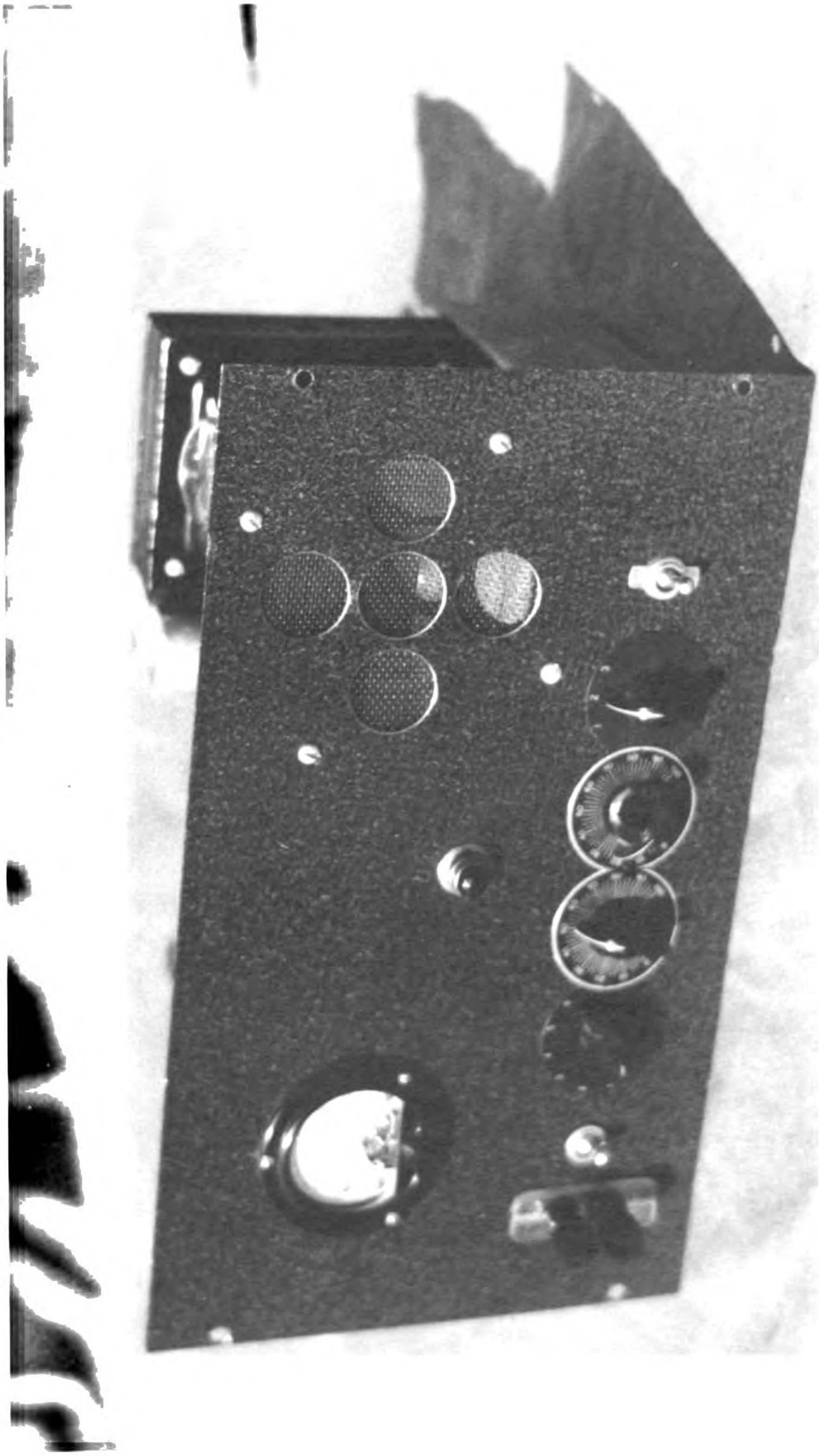
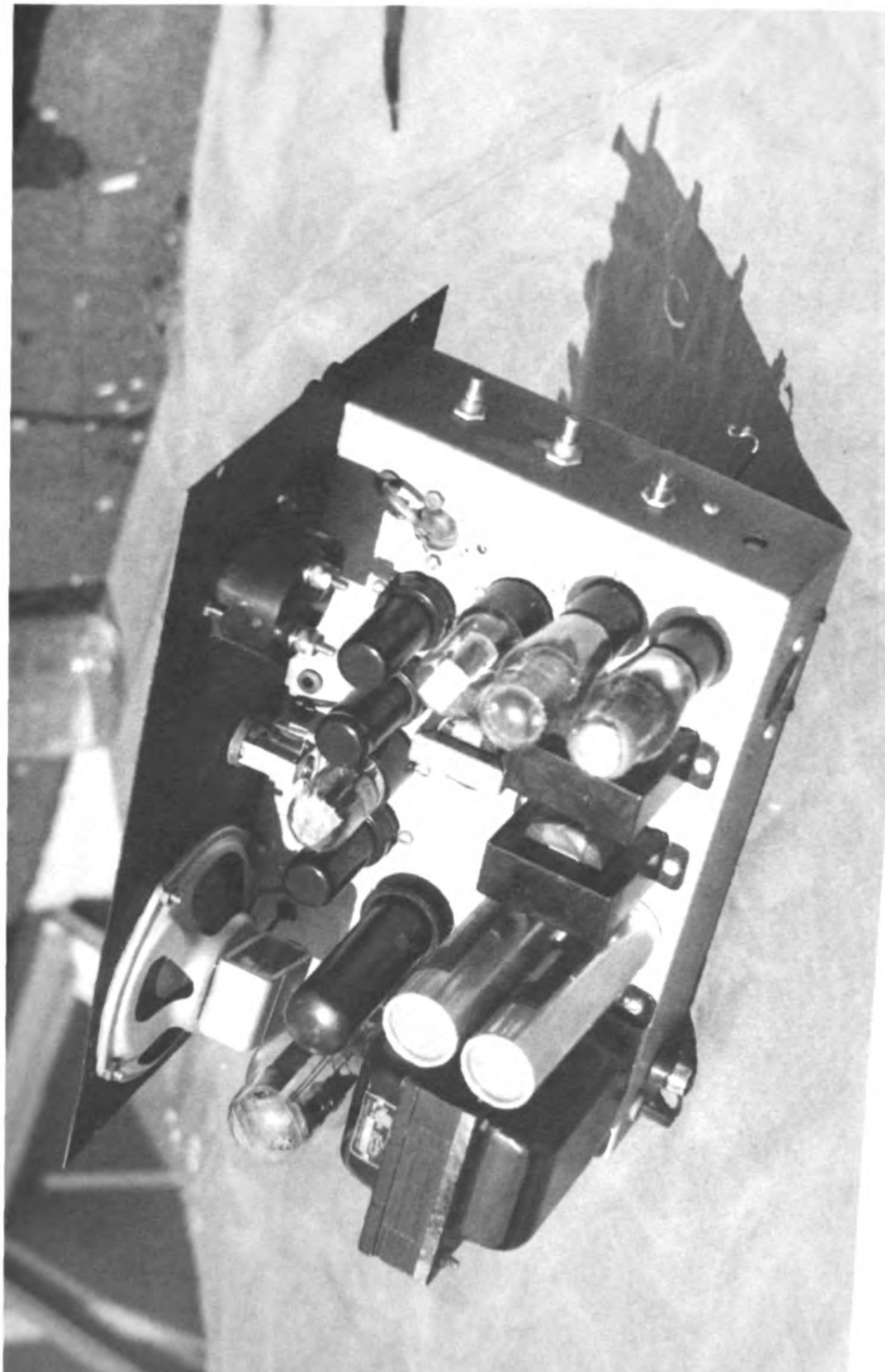


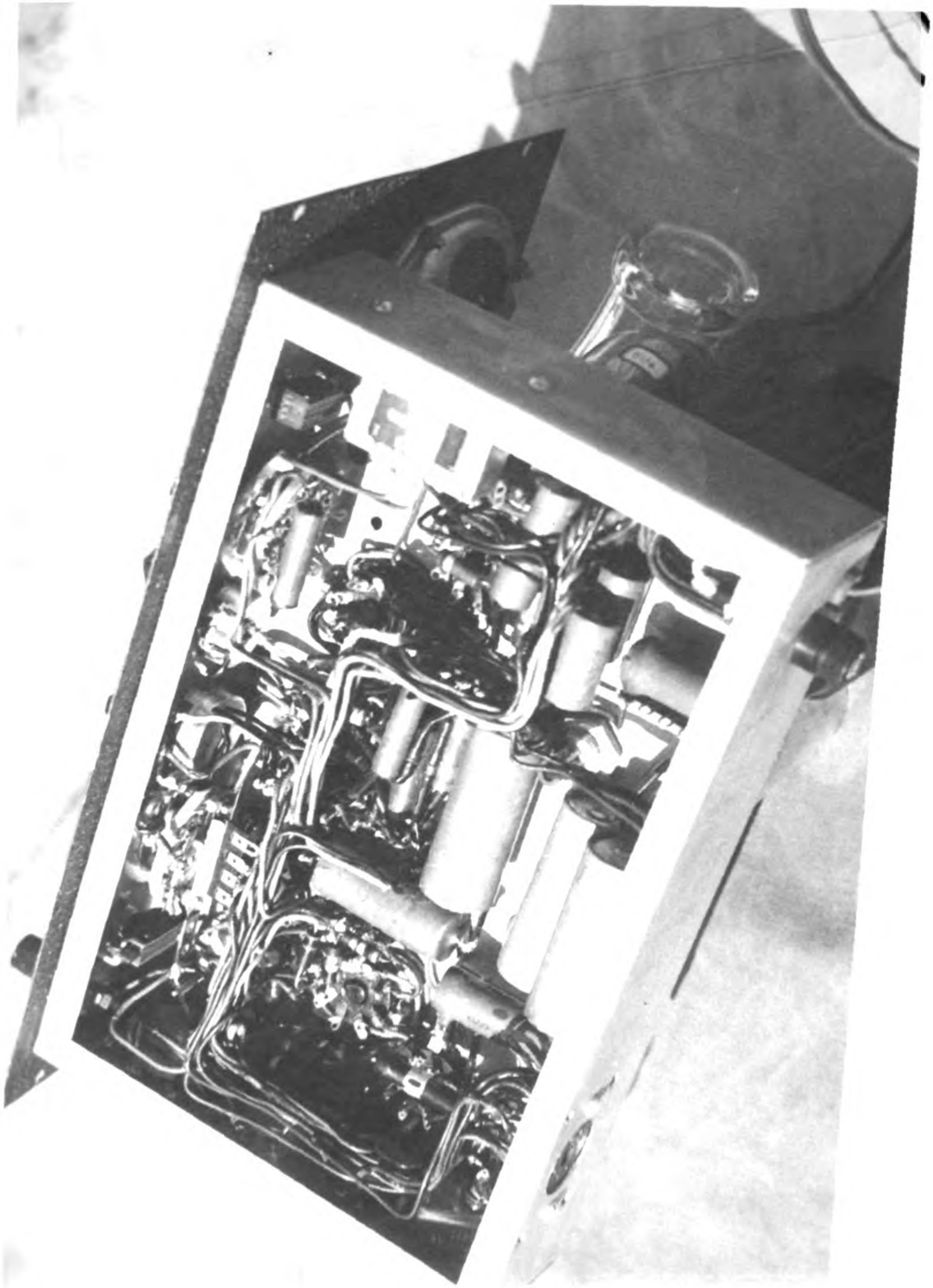
Fig 25. Chassis Layout (Bottom View)

voltages; green for the a.c. filament supply voltages; and blue for those carrying the signal voltages. The general layout of the wiring is shown in Figure 25.

Photographs of the completed instrument are shown in Figures 26, 27, and 28. These too, will show much of the general type of construction used.







CHAPTER VI

6.1 Experimental Results

After construction was finished and the unit had been properly aligned, the operation was satisfactory except for considerable drift. In view of the type of circuit employed, a check was made of the voltages internal to the bleeders. Both were checked with the potentiometer circuit and after only a fifteen minute warmup period, the voltages were found to remain within 0.1% thenceforth. It was found that with the plate lead removed from the #954 input tube, the amplifier and switch circuits became very stable and over a two hour test run varied less than 0.01 volts refered to the input. The trouble was finally located in a poor filament dropping resistor in the first stage. On replacement with a higher wattage resistor, the operation was much better. A small amount of drift would be tolerable as the unit could be recalibrated at any time.

No particular difficulty was encountered with any of the circuits used.

With the heavy bleeder current of 40 ma., the common d.c. amplifier was very stable and the operation was not improved by the insertion of the Miller circuit; however, if the regulation of the voltage along the bleeder resistance had been poor, this would not be true.

The input stage was run as shown in section 5.2b and resulted in about unity gain. The d.c. amplifier had an overall gain of 167, and was very sufficient.

The reader is asked to note that this instrument has not been completely developed as applicable to the dewpoint problem, and therefore a few of the mechanical refinements such as the cabling of the internal wiring has not been completed.

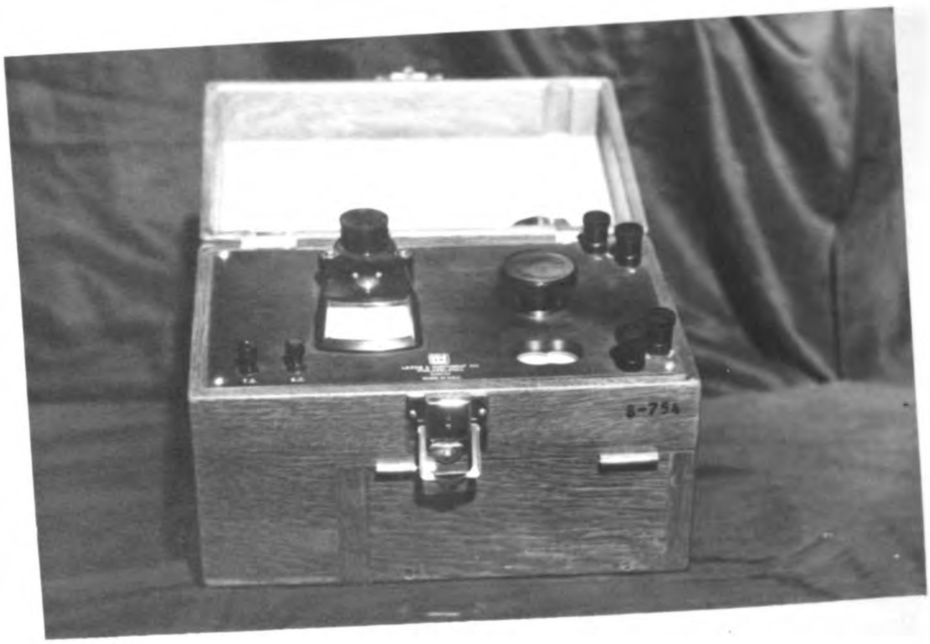
APPENDIX I

For those wishing additional information about the General Electric Model PM-17 vacuum tube voltmeter, the circuit diagram is shown in Figure 29, as obtained from the operating instruction booklet.

This instrument was particularly useful in that it has an input impedance of over 200 megohms on the 0-1 d.c. volt range. This assured the operator that there was no possibility of the internal resistance affecting the measured voltage.

A photograph of this instrument is shown in Figure 30.

Fig 29. The G.E. Model PM-17 V.T.V.M.



APPENDIX II

The Leeds and Northrup potentiometer used in these experiments was a very good instrument, but it did not lend itself to obtaining an instantaneous reading of the temperature. The lag in time required to read the instrument limited its accuracy in this problem.

A potentiometer measures the temperature by measuring the output voltage from a thermocouple, and calibrating it in terms of temperature. This is done with an arrangement similar to the circuit shown in Figure 32. A battery is placed in series with a variable resistance and a calibrated slidewire. By inserting a standard cell in series with a galvonometer and placing these across a known portion of the slidewire, the voltage may be adjusted precisely by varying the resistor R until the galvonometer is zeroed. Then the circuit may be connected to a thermocouple and the temperature read by again zeroing the galvonometer and reading the calibrations on the slidewire. The time lag occurs in this operation.

A photograph showing the L and N potentiometer used is shown in Figure 31.

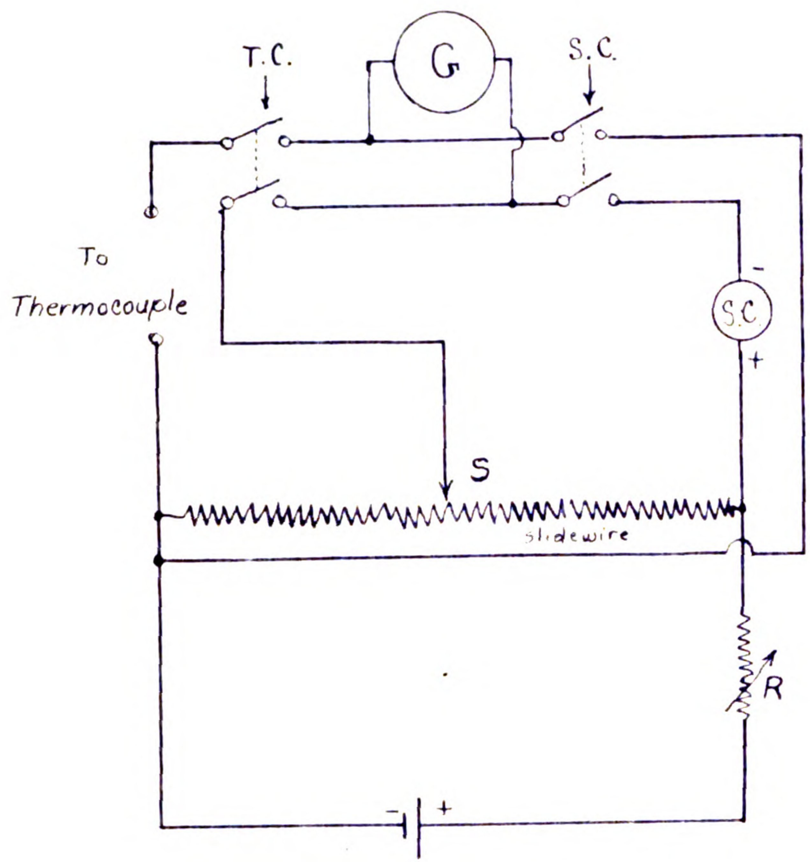


Fig 32. The Basic Potentiometer Circuit

APPENDIX III

It was necessary to measure the temperature of the dew point cell. This was accomplished by measuring the voltage produced by a copper-constantine thermocouple which was sealed in the surface of the cell near the electrodes. Originally it was planned to do this with a Leeds and Northrup hand potentiometer calibrated for that purpose. It was found, however, that there was considerable error due to the time lag in reading the temperature after the signal was given by the alarm circuit already discussed. This was due to the operation of adjusting the potentiometer manually to obtain a zero reading on the galvonometer.

It was therefore necessary to acquire an instrument which would measure and give an indication of the temperature of the thermocouple instantly. Cost again was an important factor, and thus, as all of the commercial instruments designed for this purpose were too expensive, the problem of design and construction of such an instrument was undertaken.

Essentially the problem consisted of measuring a potential in the order of a few millivolts and to have the value of the voltage instantly available.

An instrument has been designed by the author to measure this temperature to 0.2°F. instantaneously. This instrument is now in the latter stages of development and will be released at a later date.

APPENDIX IV

Considering the circuit in figure 18, let the amplification factor of the tube be u, and the associated plate and grid resistors R_1 and R_2 respectively. The tube T_2 is a gas diode voltage regulator type whose voltage drop is assumed constant.

The load presented to the plate of tube T_1 is then,

$$R = \frac{R_1 R_2}{R_1 + R_2}$$

and the gain becomes

$$K = \frac{u\, R_1}{\dfrac{R_1 R_2}{R_1 + R_2} + r_p}$$

where r_p is the plate resistance of the tube. Normally, R_1 is much less than R_2

so,

$$K = \frac{R_1}{R_1 + r_p}$$

which is the gain for an ordinary resistance coupled amplifier for mid-range frequencies.

APPENDIX V

Considering the modified one-shot circuit shown in figure 20, assuming the applied voltage v_1 volts above the voltage necessary to cause the switching action, the condenser C will charge through the resistance circuit formed by R and R_2 according to the equation

$$R'\frac{dq}{dt} + \frac{q}{C} = v_1$$

whose solution is

$$e_1 - e_2 = \frac{v_1}{R'}\left(1 - e^{\frac{-(t_1-t_2)}{RC}} \right)$$

where $R' = R + R_2$, and $e_1 - e_2$ are the limiting voltages for the switching operation. The quatity (t_1-t_2) is the time of duration of the keyed pulse and is equal to

$$T = RC \ln \frac{v_1}{R\ (e_1-e_2)}$$

APPENDIX VI

An attempt was made to plot both temperature and conductivity as a function of time through the use of a Brown Instrument Company, 12 point recorder originally intended for use with copper-constantine thermocouples. Alternate points were connected in parallel and the recorder was used as a two point instrument.

The range of the instrument was -100°F to +250°F, and was quite hard to read within about two degrees.

The resistance element of the dewpoint cell was connected to point 1 through a battery which caused the voltage developed across the internal resistance of the recorder to be recorded. Thus the voltage read was proportional to the conductivity of the resistance cell.

The alternate set of points were used to measure the temperature of the thermocouple on the dew point cell.

The results were not entirely satisfactory due to an inherent drift present in the recorder when measuring currents in the order of 10^{-8} amperes. A sample run is shown in figure 33.

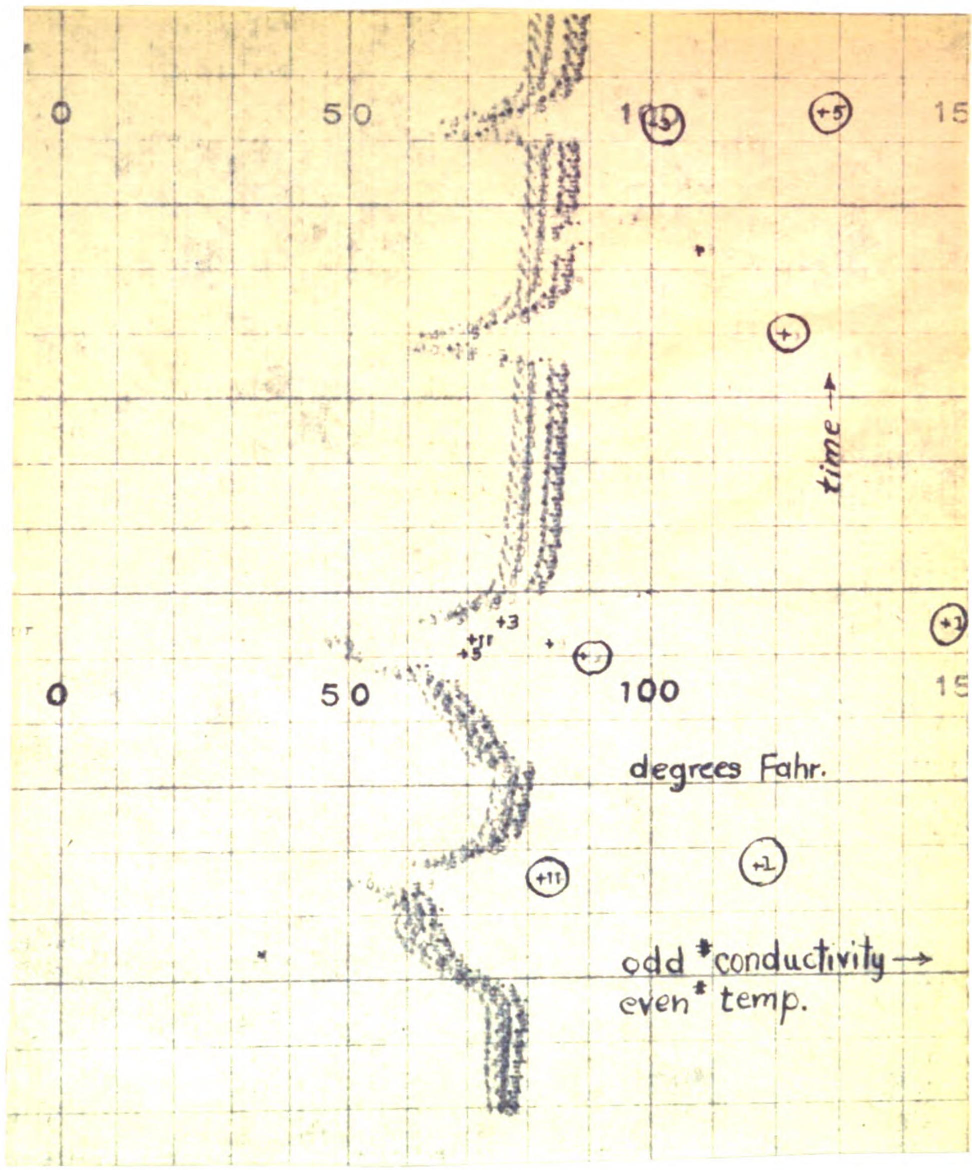


Figure 33. Data as gathered by a recorder showing temperature and conductivity as a fuction of time.

REFERENCES

1. Hund, High Frequency Measurements. (see also references given by Hund pg. 104 ff.)
2. G. E. Bulletin # GET 484B
3. Electrometer tube catalog, Victoreen Instrument Co.
4. Rev. Sci. Inst., 9:229
5. S.E. Miller, Electronics, Nov. -41.

BIBLIOGRAPHY

Everitt, <u>Communications Engineering</u>

Eastman, <u>Fundamentals of Vacuum Tubes</u>

Michaels, <u>Advanced Electrical Measurements</u>

Laws, <u>Electrical Measurements</u>

<u>Applied Electronics</u>, MIT Staff.

Hund, <u>High Frequency Measurements</u>

Hund, <u>High Frequency Phenomena</u>

Brainerd et al, <u>U.H.F. Techniques</u>

Skilling, <u>Transient Electric Currents</u>

Terman, <u>Radio Eng. Handbook</u>

F. T. & T., <u>Reference Data for Radio Eng.</u>

Army publication, <u>TM11-432</u>

Army publication, <u>TM11-466</u>

R.C.A. publication, <u>RC-15</u>

Laboratory notes from EE 434, Michigan State College

Also General Reading in the following Periodicals:

<u>Rev. Sci. Inst.</u>

<u>Jour. Sci. Inst.</u>

<u>Physics Rev.</u>

<u>Proc. I.R.E.</u>

<u>QST</u>

<u>Electronics</u>

<u>Radio News</u>