N. Eng. 70-C

REPORT NO. R-1434

DATE 21 March 1938

FR-1434

SUBJECT

Improvements in the Measurement of the Direct Interelectrode Capacitances of Vacuum Tubes.

567/38/LS 3-21

BY

NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

NRL Report No. R-1434
Improvements in the Measurement of the Direct Interelectrode Capacitances of Vacuum Tubes.

21 March 1938

NRL Report R-1434

FR-1434

NAVY DEPARTMENT
BUREAU OF ENGINEERING

Report of

Improvements in the Measurement of the Direct Interelectrode Capacitances of Vacuum Tubes.

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
Washington, D.C.

Number of Pages: Text - 6 Tables - 2 Plates - 10

Authorization: Eng.let. S67/38/L5(7-29-W8) of 6 August 1935.
Eng.let. S67/38(6-21-W8) of 14 July 1937.
Eng.let. S67/38(6-21-W8) of 27 July 1937.

Date of Test: 30 August 1935 to 14 March 1938.

Prepared by:

K.M. Soukaras, Asst.Radio Engineer.

C.H. Williams, Federal Communications Comm.
(formerly employed at this Laboratory).

Reviewed by:

J.T. Fetsch, Assoc.Radio Engineer,
Chief of Section.

A.H. Taylor, Principal Physicist,
Superintendent, Radio Division.

Approved by:

H.M. Cooley, Captain, USN, Director.

Distribution:
BuEngr. (5)

vhw

TABLE OF CONTENTS

APPENDICES

ABSTRACT

The measurement of the direct inter-electrode capacitances of vacuum tubes with accuracy, rapidity, and reliability has grown in importance as new types of tubes have made their appearance. The importance of accurate measurements for shielded grid tubes and for tubes employed for ultra-high frequency work has received added significance. This report intends to give a description of an improved means of making these measurements. Apparatus developed for the purpose is also described.

INTRODUCTION

(a) Authorization .

1. The development of the equipment described in this report was undertaken to supply information desired by the Bureau of Engineering in Eng.let. S67/38/L5(7-29-W8) of 6 August, 1935, Eng.let. S67/38(6-21-W8) of 14 July, 1937, and Eng.let. S67/38(6-21-W8) of 27 July, 1937.

(b) Statement of Problem

2. The problem is to devise a method, and construct equipment, by means of which interelectrode capacitance measurements of vacuum tubes are made with a high degree of accuracy, rapidity, reliability and repeatability.

(c) Known Facts Bearing on the Problem

3. In the Vacuum Tube Section, Radio Division, of the Naval Research Laboratory, the method of substitution for the measurement of the direct interelectrode capacitances of vacuum tubes has been in use for a number of years. This method was described by A.V. Loughren and H.W. Parker of the General Electric Company in the Proceedings of the Institute of Radio Engineers for June, 1929, and employs thermocouples as current indicating devices. Dissatisfaction, however, with the old means has resulted in the conception and successful development of a new means, described in this report, of making interelectrode capacitance measurements. The method developed at the Laboratory employs vacuum tube voltmeters as voltage indicating devices.

(d) Theoretical Considerations

4. Referring to the schematic circuit diagram, Plate 1, the analysis of the underlying method of measurement is given for the case of the three-electrode vacuum tube.

C_s represents the capacitance of the standard condenser.

C_{gp} is the direct capacitance we desire to measure.

GPK represents the terminals of a three-electrode vacuum tube.

C_o is the "output" capacitance of the tube under measurement.

R is a small non-inductive resistance, such that R is very much less than the capacitive reactance of C_o. Hence, i_3 is negligible with respect to $i_1 + i_2$.

Let the conditions, with the tube in circuit, be represented at any instant as shown in Fig. 2.

Then, the voltages acting have the following relationship in absolute magnitudes,

$$V_T = V_S + V_O \qquad (1)$$

where, $V_Q \ll V_T$, and, $V_Q \ll V_S$

$$V_S = \frac{i_2}{\omega C_s} = \frac{i_1}{\omega C_{gp}} \tag{2}$$

$$V_Q = (i_1 + i_2) R \tag{3}$$

When the tube is removed, the original values of V_T and V_Q are changed. By means of the driver attenuators, V_T is made equal to its original value, and by varying C_s by an amount ΔC, V_Q is also brought to its original magnitude.

Since R is constant, and V_Q and V_T are kept constant, it follows that the current through R is again equal to $i_1 + i_2$.

Obviously, the current through C_s is also $i_1 + i_2$, or the current through C_s has increased by, very approximately, the current taken by C_{gp}, that is, by i_1.

$$\therefore \quad V_S = \frac{i_2 + i_1}{\omega (C_s + \Delta C)} \tag{4}$$

Since V_T and V_Q were kept constant, V_S is also constant.

But from Eq. (2),

$$V_S = \frac{i_2}{\omega C_s} = \frac{i_1}{\omega C_{gp}}$$

Hence, $\dfrac{i_2}{i_1} = \dfrac{\omega C_s}{\omega C_{gp}}$,

or, $$\frac{i_2 + i_1}{i_1} = \frac{\omega (C_s + C_{gp}}{\omega C_{gp}}$$

$$\therefore \quad V_S = \frac{i_1}{\omega C_{gp}} = \frac{i_2 + i_1}{\omega (C_s + C_{gp})} \tag{5}$$

Comparing equations (4) and (5), we notice that they are identical provided

$$\triangle C = C_{gp} \qquad (6)$$

This is more nearly true the smaller we make R with respect to the "output" capacitive reactance, X_{co}, of the tube under measurement, such as to make i_3 negligible with respect to i_1.

The above analysis for the case of the triode is also applicable to multielectrode tubes.

(e) Narrative of Work Done at This Laboratory on the Problem

5. Except for the underlying method, which is a method of substitution of an unknown capacity, represented by the interelectrode capacity of a vacuum tube, for the known fractional capacity of a standard condenser, the equipment developed for making these measurements had its conception and origin in the Laboratory. The method of Loughren and Parker employs thermocouples as indicators of the electrical energy, whereas the Naval Research Laboratory method employs a radio frequency amplifier and vacuum tube voltmeters as radio frequency voltage indicators.

6. The reason for discarding thermocouples in favor of vacuum tube voltmeters is that the former have certain distinct drawbacks. It is well known that at best a thermocouple exhibits a certain amount of sluggishness which is a distinct obstacle to an identical repetition of the reading. Furthermore, thermocouples suffer from crystallization and aging effects. Their lives are relatively short and uncertain. On many occasions they have been known to fail when most needed without any evident or known cause. The replacement expense and the unusual care they demand when connected in any electrical circuit are reasons for avoiding the use of thermocouples, whenever it is possible to do so.

7. The method of substitution was employed for its inherent merit, particularly because it was possible to design and construct standard condensers of the coaxial cylindrical type with a high degree of accuracy. The importance of repeatability of readings, high sensitivity and stability was constantly borne in mind during this development and it is felt that equipment has been developed and a technique of measurement perfected which combine to make the operation of the equipment simple, direct, instantaneous, and trustworthy.

METHODS

(a) Circuit diagrams, photographs.

8. The schematic circuit diagram of the 500 KC crystal-controlled driver is given on Plate 3. It consists of a crystal-controlled, type 6A6 class B twin amplifier tube, used as a push-pull oscillator, feeding two type 837 radio frequency power amplifier pentodes, arranged, similarly, for push-pull operation. The output wave form of the driver at 500 KC was found to be perfectly sinusoidal, as viewed on the screen of a cathode ray oscillograph. Plate 3 also gives the schematic circuit diagram of the vacuum tube voltmeter and that of the power pack, the latter supplying power to both the driver and the tube voltmeter. The power pack employs a type 5Z4 full-wave

high-vacuum rectifier tube. The vacuum tube voltmeter consists of two tubes. A type 85 duplex-diode triode tube connected as a simple diode rectifier for producing rectification of the impressed radio-frequency voltage from the output of the crystal-controlled driver. The rectified average voltage from the diode is used to vary the bias of a type 77 triple-grid amplifier tube which in turn feeds a direct current indicating instrument. A photograph of the driver and the vacuum tube voltmeter, housed in a single unit, is given on Plate 5.

9. The schematic circuit diagram of the intermediate frequency amplifier is given on Plate 4. The amplifier consists of two stages of amplification, as shown. The tubes employed are of the all-metal type 6K7 triple-grid super-control amplifier. Plate 4 also gives the schematic circuit diagram of the vacuum tube voltmeter and that of the power pack, the latter supplying power to both the amplifier and the tube voltmeter. The power pack employs a type 5Z4 full-wave high-vacuum rectifier tube. The vacuum tube voltmeter consists of two tubes. A type 6R7 duplex-diode triode all-metal tube, connected up as a simple diode rectifier for producing rectification of the impressed radio-frequency voltage from the output of the amplifier. The rectified average voltage from the diode is used to vary the bias of a type 6J7 triple-grid amplifier all-metal tube, which in turn feeds a direct current indicating instrument. A photograph of the amplifier and the vacuum tube voltmeter, housed in a single unit, is given on Plate 6.

10. A short discussion of the voltage amplification capability of the intermediate frequency amplifier as built might be of interest. With 100 volts output of the amplifier, the overall gain, including the input and output transformers, was measured at 388,000. Table 1 gives in tabulated form the values of input and output voltage of the amplifier over a range of 5 to 140 output volts. Plate 10 gives a curve of input microvolts against output volts. It will be noted that the graph is a straight line in the range 20 to 100 output volts. This, incidentally, is the range at which the amplifier is being used.

(b) Description of Experiments.

11. Refer to Plate 2 which is a simplified block schematic diagram showing the arrangement and position of the various items making up the measuring circuit. "A" is a crystal controlled driver of substantially constant frequency which feeds 500 kilocycles of radio frequency energy to the measuring circuit "C", by means of series capacitance attenuators "B". The input voltage is measured by vacuum tube voltmeter "E". The standard coaxial condenser is normally connected in parallel with the direct capacitance of this tube, determination of which capacitance we desire to accomplish. A small non-inductive resistance is connected to the "output" of the tube under measurement, followed by an amplifier "D" which, in turn, feeds the second vacuum tube voltmeter "E".

12. By means of the driver attenuators, the gain control of the amplifier, and other controls on the vacuum tube voltmeters, the latter may be made to give a certain desired indication in milliammeters "F" when the tube is in circuit. When the tube is either taken out of circuit, or its connection to the circuit is broken at a specified point, the voltmeters will produce different deflections of the milliammeters. These indications are positive and instantaneous in their actions. Again, by means of the driver attenuators and the variable standard condenser, the deflections are made exactly equal to their original value. The variation of the standard capacitance read accurately by means of

a Veeder counter, measuring the amount of travel of the inner cylindrical rod of the standard condenser, gives by direct substitution the interelectrode capacitance desired of the tube.

DATA OBTAINED

(a) Data in Tabular Form

13. Considerable data have been accumulated over the past year and one-half in the measurement of the direct interelectrode capacitances of vacuum tubes of various sizes, types, and manufacture. These data have been, during this time interval, reported on to the Bureau of Engineering in connection with authorized type approval work on vacuum tubes. Most of the data have been obtained with the first experimental model of the equipment. The first model made use of the original crystal-controlled oscillator, which, however, was rebuilt and greatly improved. The first model of the intermediate frequency amplifier was also rebuilt, making use of metal type tubes and in other ways improving the electrostatic and electromagnetic shielding of leads and circuits. The second model is the one described in this report. The values of capacitance obtained by the second model have been found to be identical with those obtained by the first model. The data given on Table 2 have actually been obtained a year ago by the first model and some of it have since been checked to the last decimal place by the second model, recently completed. The data shown on Table 2 represent a comparison of the data obtained at the Laboratory with those of a certain well-known manufacturer of vacuum tubes, identified in this report as manufacturer A. The manufacturer's data are given to the first decimal place, whereas those obtained at the Laboratory are given to the second decimal place. It will be noted that the agreement is quite satisfactory. Another set of data obtained at the Laboratory is also shown on Table 2. These data were obtained to the third decimal place and all tubes except the fourth repeated identically 100%. The fourth tube repeated to within 0.01 $\mu\mu f$. It is intended that more data, which will be accumulated in the normal course of events by means of the second model recently completed, will be sent to the Bureau in a supplementary report.

(b) Statement of Probable Errors

14. The overall accuracy of the measurement depends upon the following factors: (a) Frequency stability as controlled by the crystal; (b) The shape at resonance of the selectivity curve of the intermediate frequency amplifier; (c) Possible reaction effects of the amplifier due to possible high gain that may produce instability; (d) The accuracy with which the standard of capacitance employed may be designed and built.

15. The precautions taken and the care with which each item was designed and constructed have all combined to make the effects enumerated in paragraph 14 of negligible consequence. It is felt that equipment has been developed for the measurement of the direct interelectrode tube capacitances that is capable of making the desired measurements with accuracy, rapidity, and reliability exceeding anything known before.

CONCLUSIONS AND RECOMMENDATIONS

(a) Conclusions

16. The method of substitution for the measurement of interelectrode

capacitances of vacuum tubes of all types from the smallest to the largest found in practice has been found to be technically sound in itself and capable of a high degree of accuracy.

(b) Recommendations

17. It is recommended that the Bureau of Engineering request the various manufacturers supplying the Naval Service with vacuum tubes to submit to the Laboratory representative types of their manufactured tubes accompanied by their respective interelectrode capacitance data which should be obtained with greater than ordinary care. These tubes should be remeasured at the Laboratory and data compared to discover the degree of accuracy and the adequacy of the equipment employed by each manufacturer.

-o-

TABLE 1

Table of intermediate frequency amplifier input microvolts and output volts with constant gain setting.

Signal Generator Output (μvolts)	Amplifier Output (Volts)	Amplifier Gain Setting (Divisions)
8.00×10^2	140	88
4.23×10^2	120	88
2.58×10^2	100	90
2.00×10^2	80	90
1.45×10^2	60	90
9.02×10	40	90
4.13×10	20	90
3.53×10	20	90
1.71×10	10	90
8.90	5	90

TABLE 2

1. (a) NRL Data

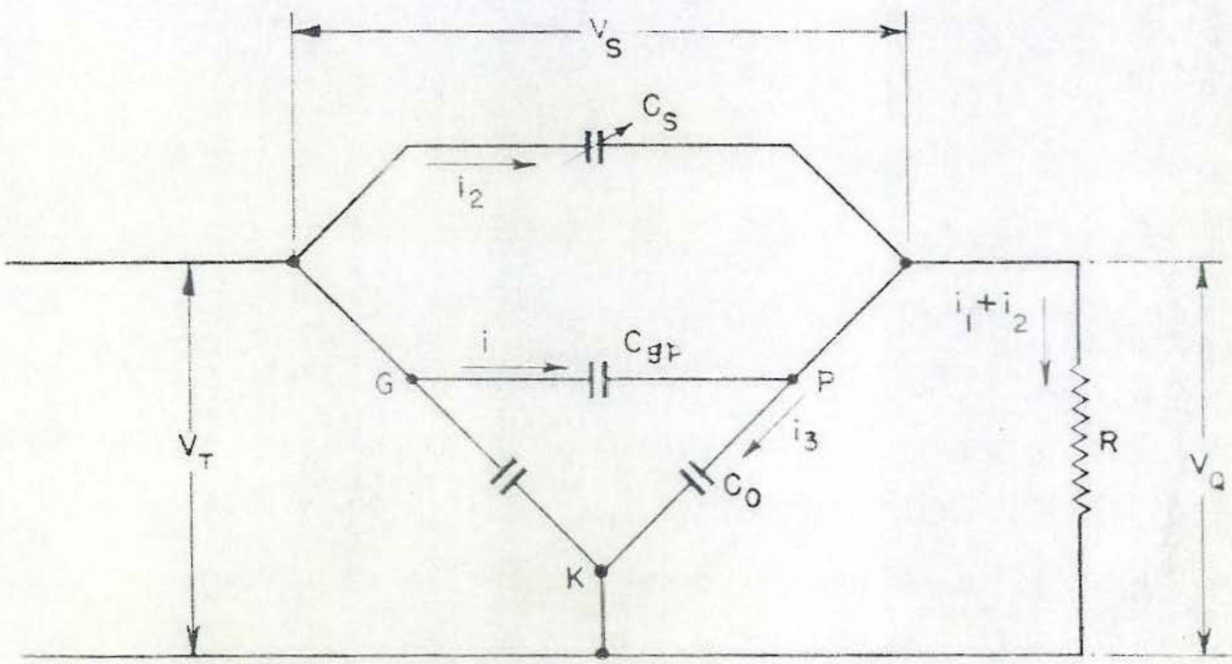
Type of Tube	Serial Number	C_{g-p} ($\mu\mu f$)	C_{g-K} ($\mu\mu f$)	C_{p-K} ($\mu\mu f$)
38211	57433	13.62	5.10	4.68
	57444	13.80	5.30	4.76
	57448	13.72	5.40	4.76
	57471	13.70	5.09	4.72

(b) Manufacturer A's Data

38211	57433	13.6	5.1	4.7
	57444	13.6	5.3	4.7
	57448	13.6	5.4	4.8
	57471	13.6	5.1	4.7

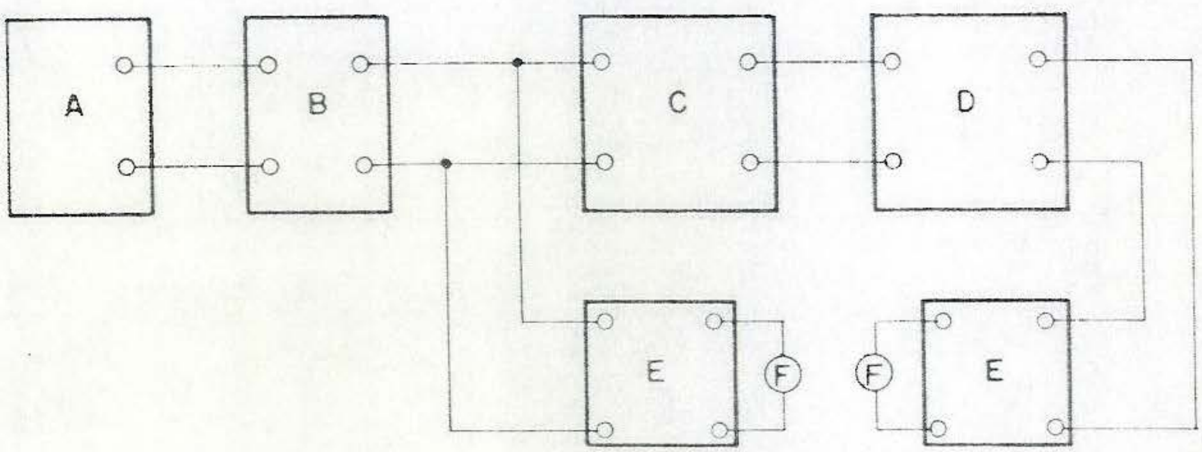
2. NRL DATA

Type of Tube	Serial Number	C_{g-K} ($\mu\mu f$)
38152	7418	1.635
	7435	1.585
	7436	1.630
	7450	1.675
	7451	1.625



CIRCUIT ANALYSIS FOR THE MEASUREMENT OF
INTERELECTRODE CAPACITIES OF TRIODES

NOTE:- $i_3 \ll i_1$ AND THEREFORE NEGLIGIBLE IF $R \ll X_{C_0}$



A FUNCTIONAL DIAGRAM SHOWING THE EQUIPMENT AND METHOD OF MEASUREMENT OF DIRECT CAPACITANCES OF VACUUM TUBES.

A = 500 KC. DRIVER.

B = SERIES CAPACITANCE ATTENUATORS.

C = MEASURING UNIT, WITH TUBE UNDER MEASUREMENT AND STANDARD CAPACITOR.

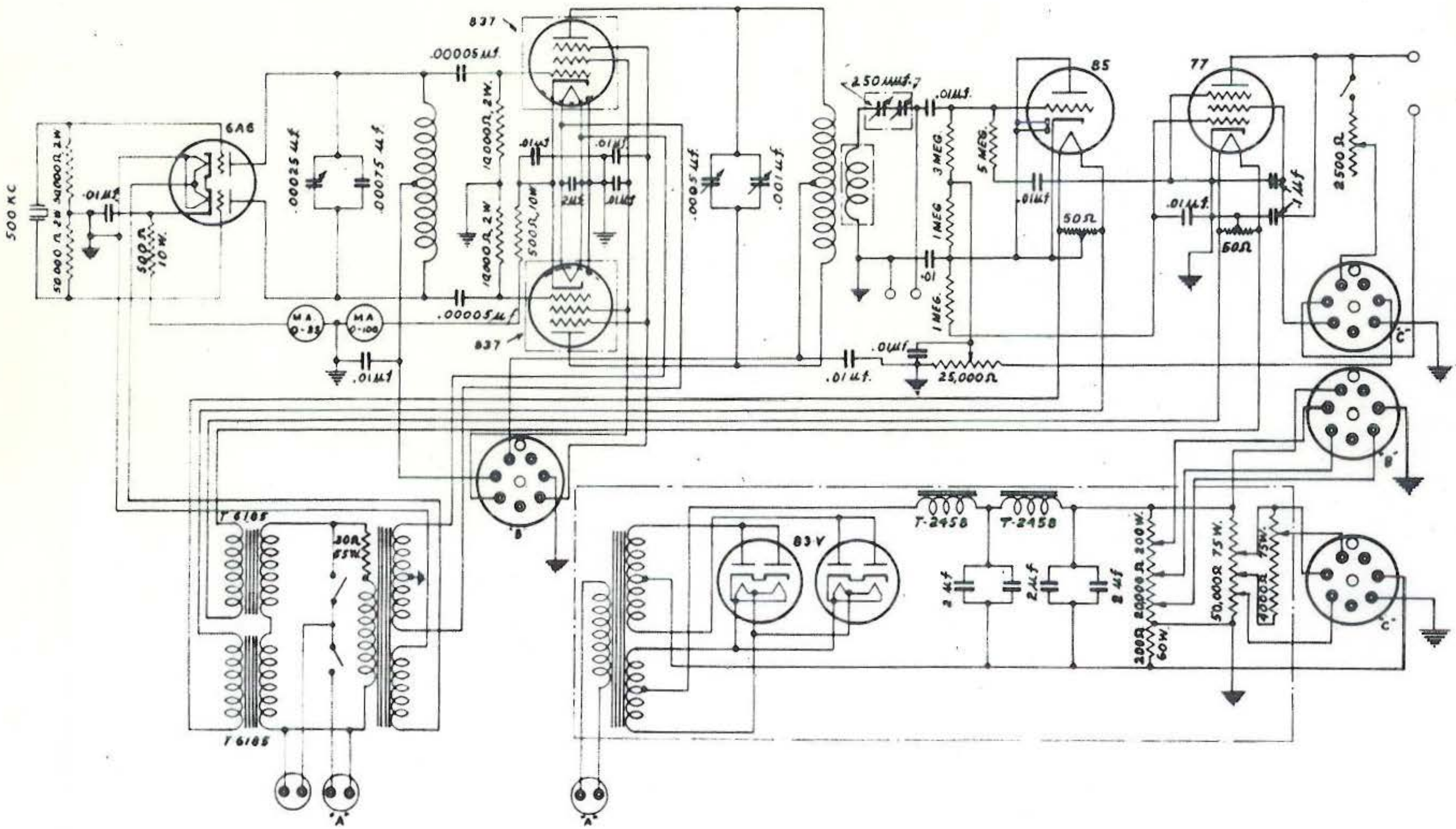
D = 500 KC. INTERMEDIATE FREQUENCY AMPLIFIER.

E = VACUUM TUBE VOLTMETER.

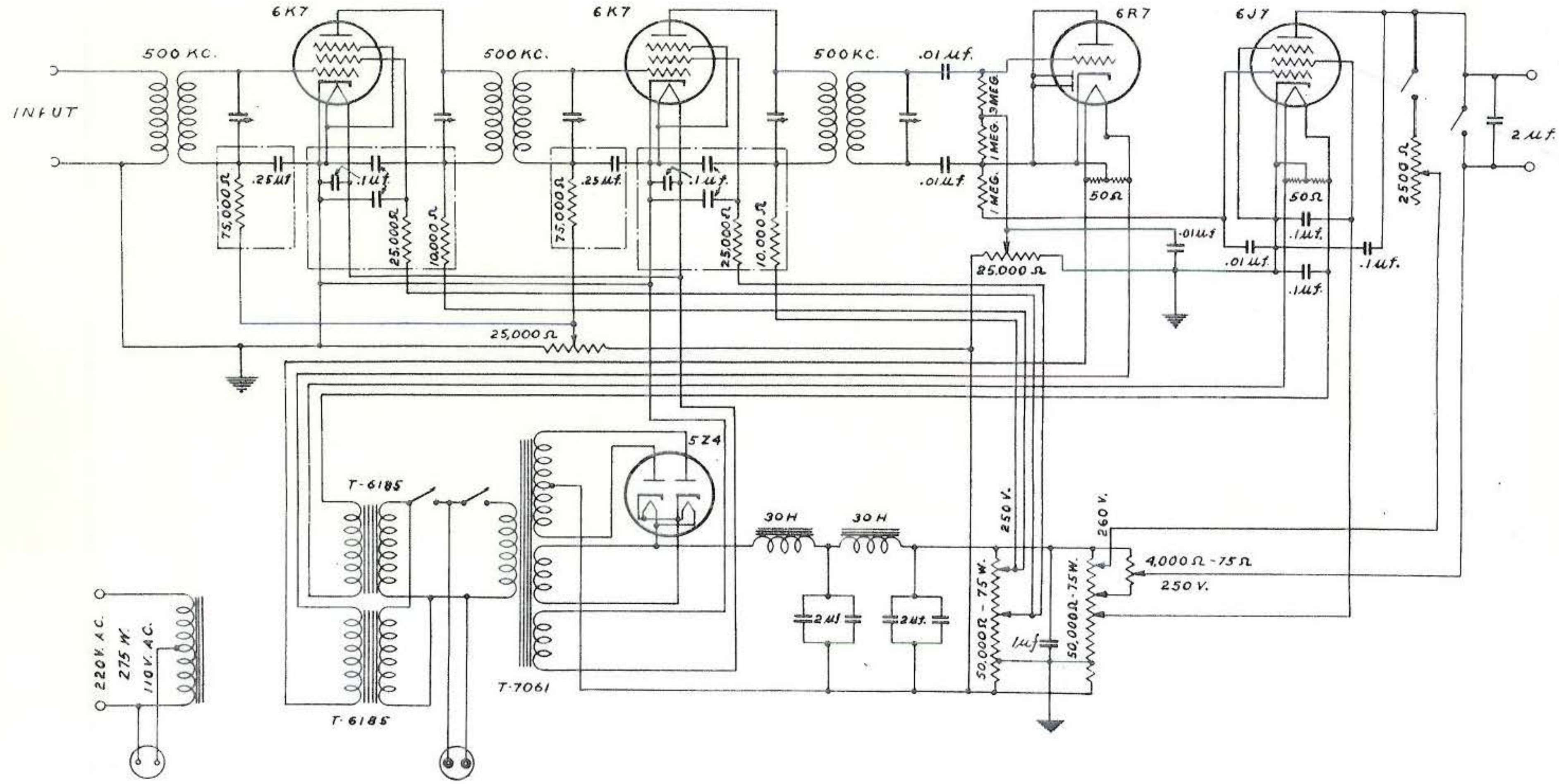
F = DIRECT CURRENT MILLIAMMETER.

PLATE 2

PLATE 3

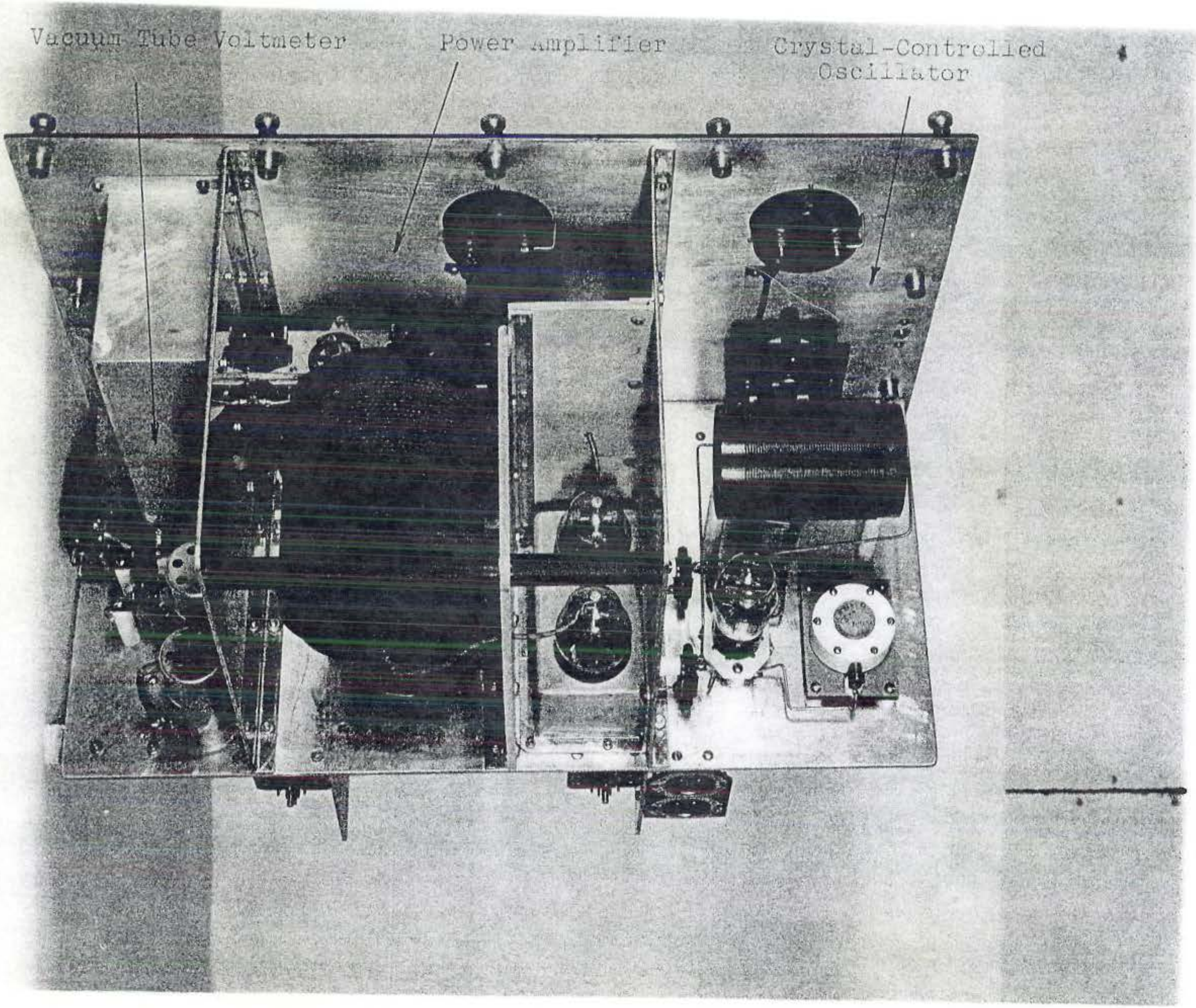


500 KC. DRIVER AND VACUUM TUBE VOLTMETER
USED WITH INTERELECTRODE CAPACITANCE
MEASURING EQUIPMENT.



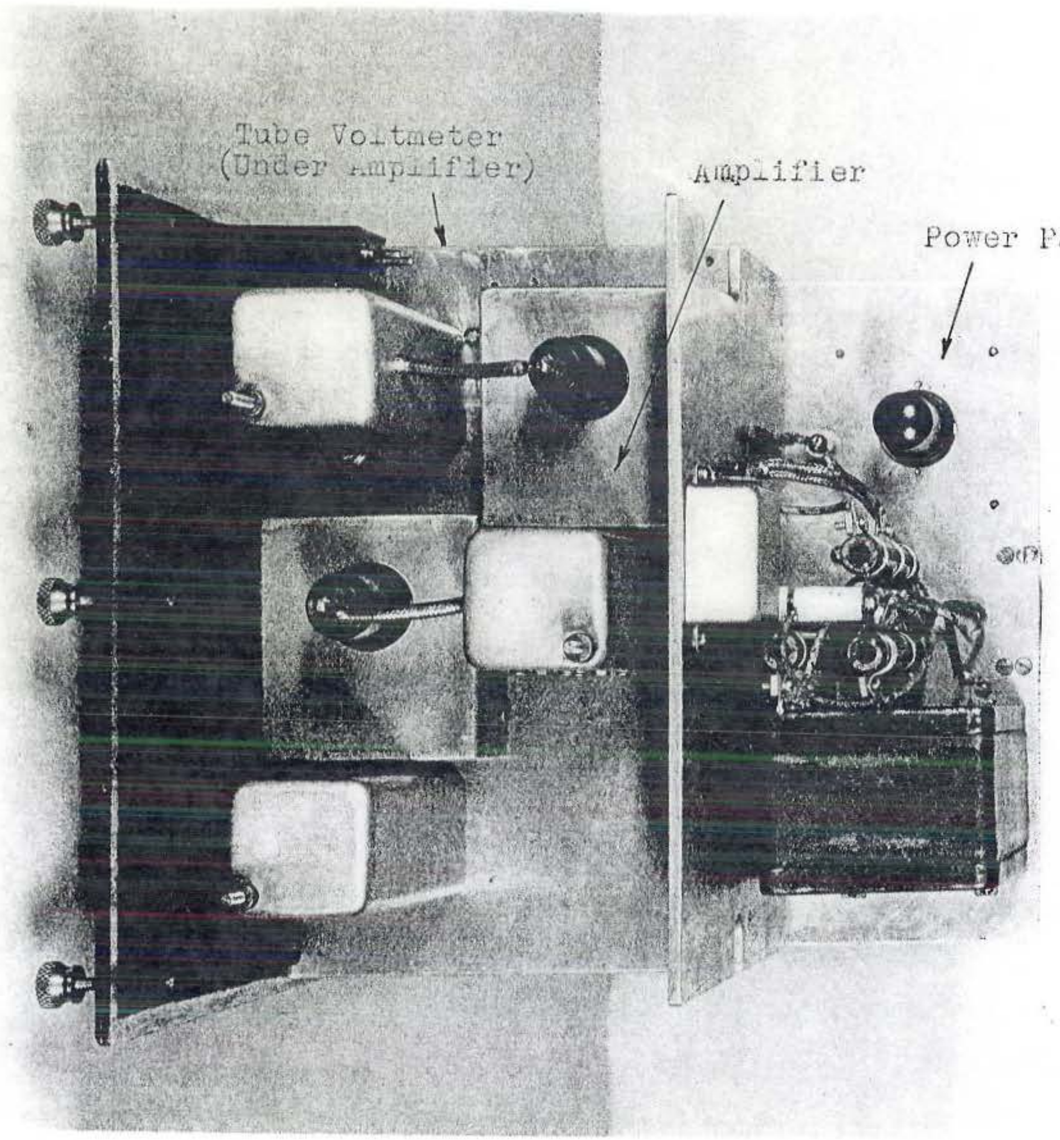
500 KC. AMPLIFIER AND VACUUM TUBE VOLTMETER
USED WITH INTERELECTRODE CAPACITANCE
MEASURING EQUIPMENT.

PLATE 4



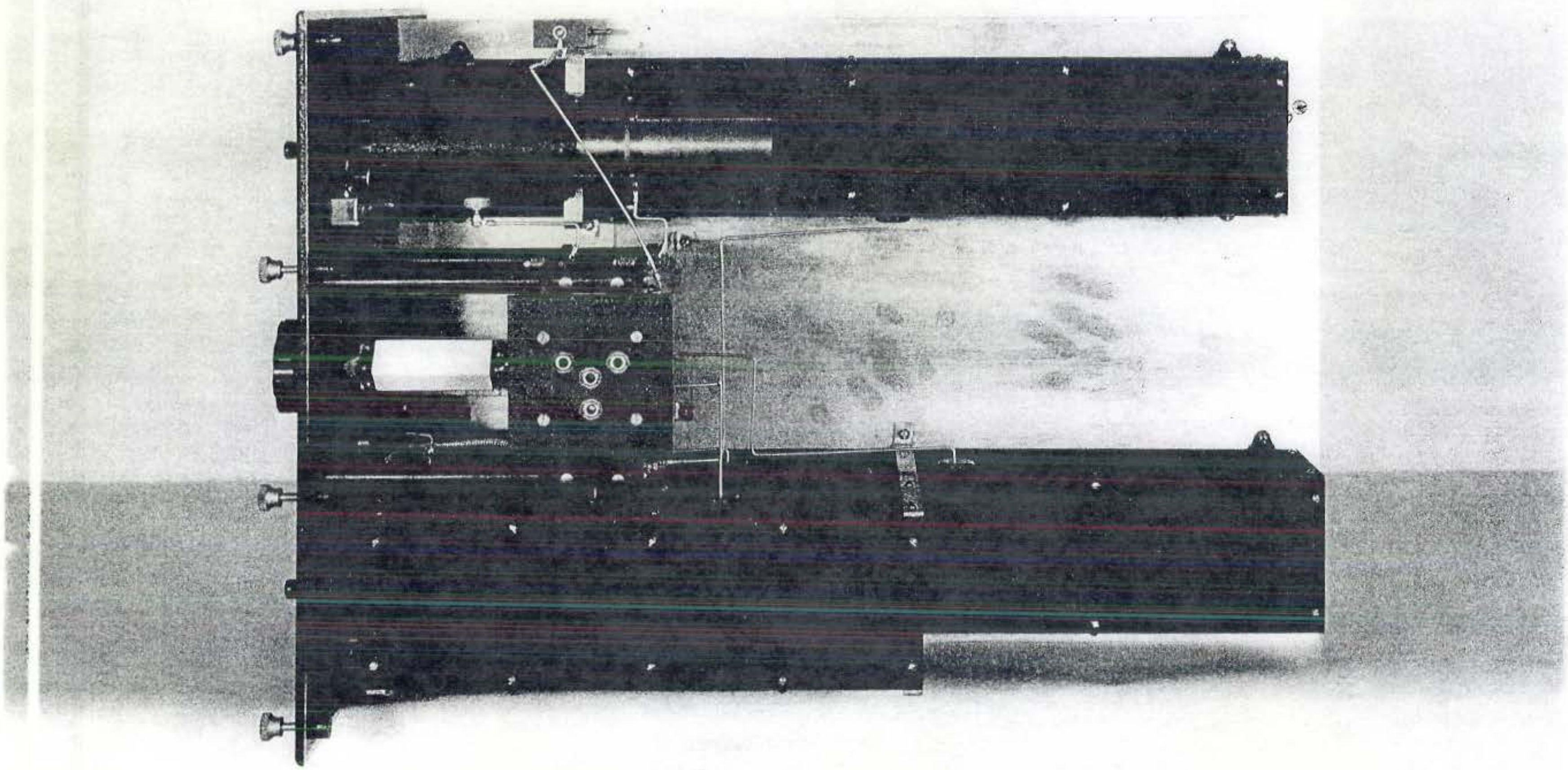
Exposed Rear Angle View of
500 KC. Driver and Tube Voltmeter

Plate 5

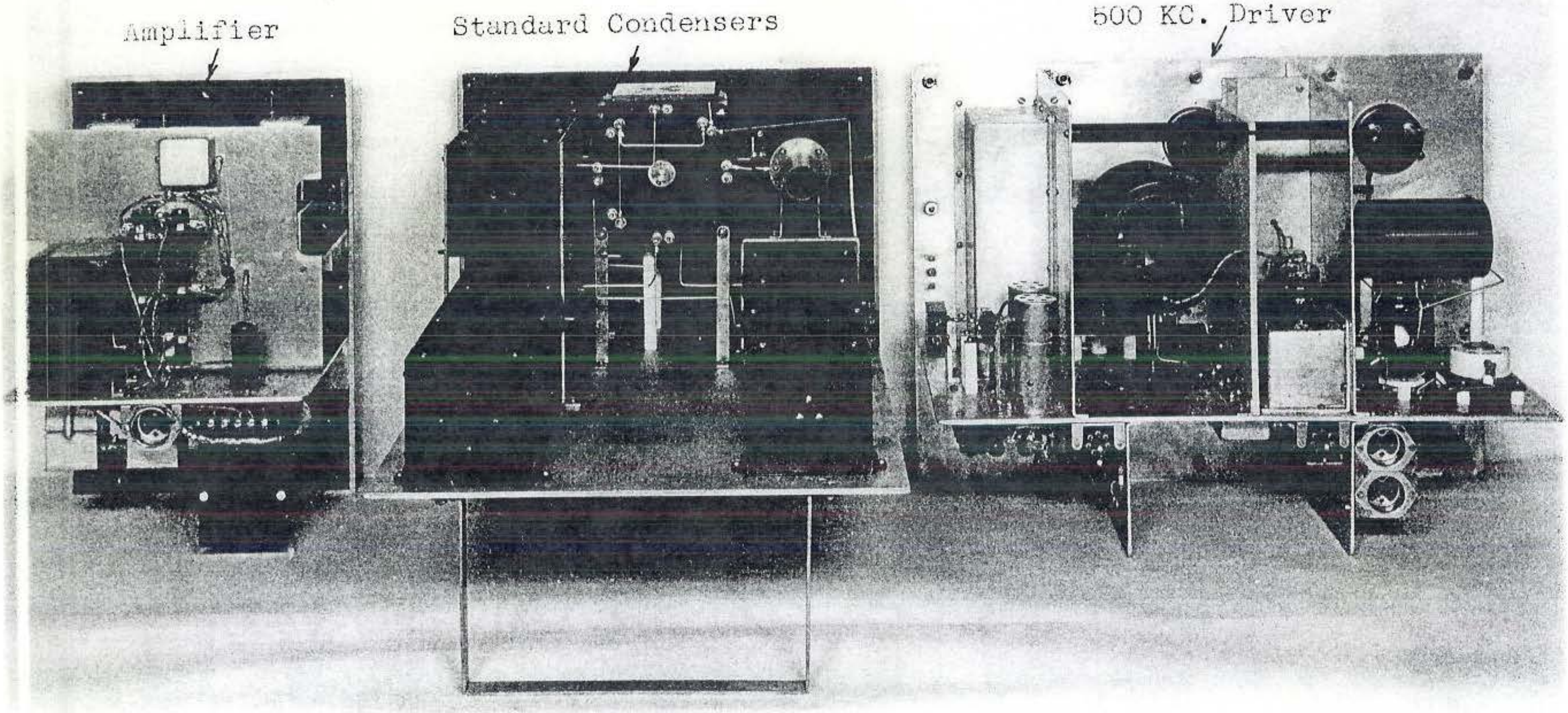


Exposed Top View of Amplifier,
Tube Voltmeter and Power Pack.

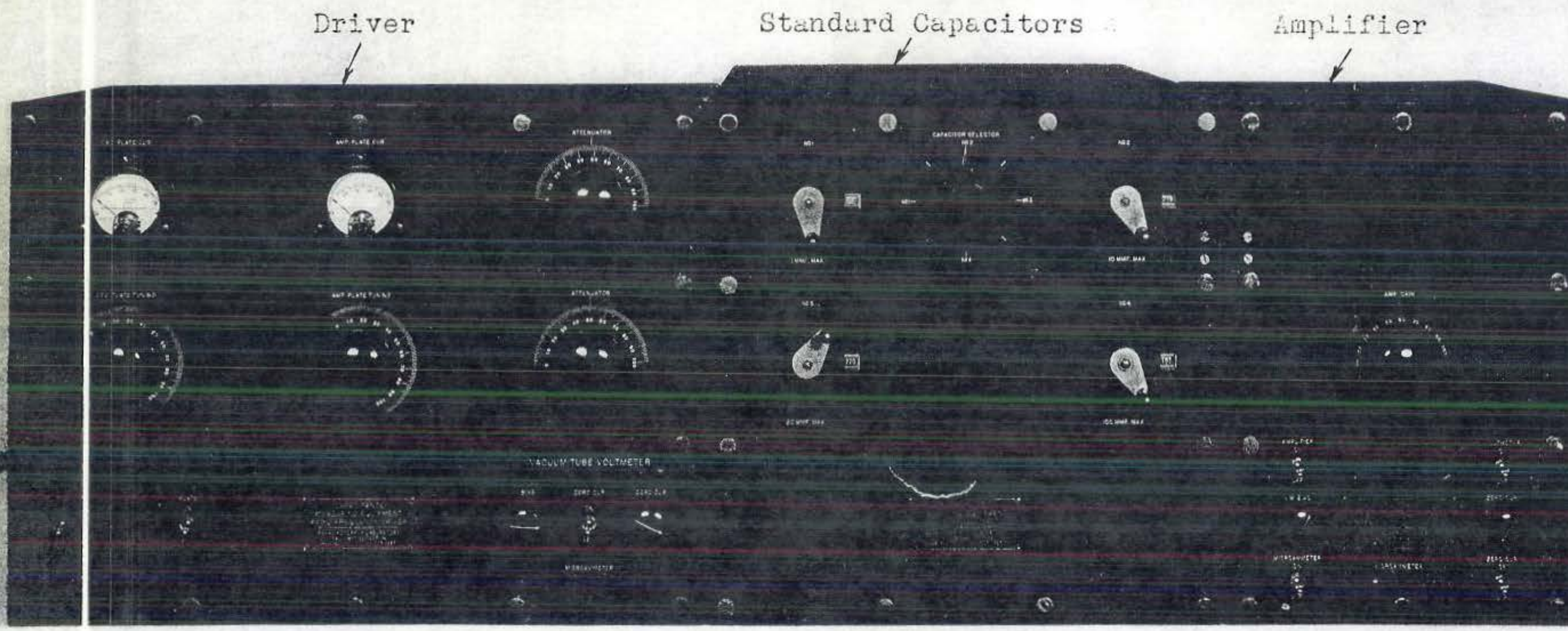
Plate 7



Exposed Top View of Unit
Containing the Standard Condensers



Exposed Back View of the Equipment.



Front View of Entire Equipment.

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE