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HELIUM RESEARCH CENTER

INTERNAL REPORT

AN RC BRIDGE AND DETECTOR FOR THE MEASUREMENT

OF SMALL CAPACITANCE CHANGES

BY

J. R. McVey

J. L. Gordon

BRANCH Laboratory Services

PROJECT NO. 820.1

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ILLUSTRATIONS

AN RC BRIDGE AND DETECTOR FOR THE MEASUREMENT OF SMALL CAPACITANCE CHANGES

by

J. R. McVey[1] and J. L. Gordon[2]

ABSTRACT

An instrument for the purpose of detecting small changes in air dielectric capacitance is described. It consists of an RC bridge circuit with the associated power supply and detector.

The bridge has a 26 VAC input and sine wave output which is compared with a square wave in the detector. The dc output from the detector is a measure of bridge unbalance in millivolts, with a minimum sensitivity of 10^{-3} pico-farads at 200 pico-farads.

The bridge and detector assembly were designed to monitor the rate of diffusion of gases and were used successfully for this purpose. A small change in gas mixture composition changes the gas-dielectric constant; therefore, the capacitance value of a small air-type capacitor inserted into the gas mixture changes proportionally, and is recorded as a function of time.

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INTRODUCTION

Measurement of capacitance in the 10^{-5} pico-farad (MMF) range to indicate changes in gaseous dielectric composition has become extremely important in some research projects. An instrument was constructed using an air capacitor as a sensing device to follow the changing composition of binary gas mixtures during diffusion. It is capable of measuring minute changes in capacitance with a resolution of 10^{-5} pico-farad. Other devices have been described for determining diffusion (1-4)[3/] and dielectric constants (5-7), but the need for analytical

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3/ Underlined numbers in parentheses refer to items in the list of references at the end of this report.

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accuracy at the temperatures and pressures being studied brought about this unique method.

APPARATUS DESCRIPTION

The basic system design is shown by the block diagram in figure 1. An RC-type bridge is excited with 26 volts, 960 cycles from a tuning-fork oscillator. When the bridge is balanced, giving no signal output,

$$\frac{R_1}{Xc_1} = \frac{R_2}{Xc_2} \tag{1}$$

Xc is the reactance, in ohms, of capacitor C and is defined by

$$Xc = \frac{1}{2\pi fC}; \tag{2}$$

f is frequency in cps, and C is capacitance in farads. A phase angle is given by

$$\tan \theta = \frac{Xc}{R}$$

$$(R = R_1 \text{ when } Xc = Xc_1). \qquad (3)$$

When either C changes, the corresponding Xc will change, unbalancing the bridge in both phase and amplitude. The detector is both phase and amplitude sensitive.

The system consists of four basic units: 300v B+ power supply, 6.3v filament supply, bridge assembly, and detector (figure 1). The power supplies are conventional and will not be discussed with the exception that B+ should be highly regulated and have low ripple content as indicated.

Detection of the bridge-error signal is accomplished by comparison of two signals. A 960 cycle tuning-fork oscillator supplies 26 VAC to the bridge circuit and to a reference-squaring amplifier. This amplifier shapes a square-wave signal which is sent to a diode converter to be compared with the amplified output signal from the bridge. A phase-inverting and adjusting amplifier is inserted between the reference-squaring amplifier and the oscillator to insure an inphase condition between the bridge excitation signal and the reference square wave, because both amplitude and phase unbalance of the bridge are being detected. Any unbalance of the bridge is amplified and sent to the

diode converter, which is a phase-sensitive rectifier. The diode converter compares the amplified bridge output with the reference square-wave voltage and produces a dc output voltage proportional to the amount of amplitude and phase difference present. Beating the bridge sine-wave output against the reference square-wave allows detection of extremely small amplitude and phase changes. A complete electrical schematic is shown in figure 3.

The bridge assembly shown in figure 2, has a switching arrangement for two unknown capacitors and a reference capacitor. All leads are shielded and grounded to the chassis. R_2 and R_5 (figure 2) are provided for initial bridge calibration with C_1 and C_2 known. R_3 and R_4 are coarse and fine balance potentiometers used during capacitance measurements.

The capacitance detector and bridge assembly are shown in figures 5 - 8. The detector in figure 7 is equipped with a null meter, null meter switch, bridge-amplifier switch, balance dial, and phase adjustment dial. The system is designed to operate in the 200 pf range, and large deviation from this range would require changing R_1 and R_6 values, substituting R_6 for R_2 in equation (1).

OPERATION

To operate the system, place the bridge-amplifier switch in the amplifier position, the meter switch "off", and turn on filament and diode converter, which is a phase-sensitive rectifier. The diode converter compares the amplified bridge output with the reference square-wave voltage and produces a dc output voltage proportional to the amount of amplitude and phase difference present. Beating the bridge sine-wave output against the reference square-wave allows detection of extremely small amplitude and phase changes. A complete electrical schematic is shown in figure 3.

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OPERATION

To operate the system, place the bridge-amplifier switch in the amplifier position, the meter switch "off", and turn on filament and

B+ power. After a 15 minute warm-up period, the amplifier is nulled by turning the meter switch "on" and adjusting the amp-null dial to a null on the indicator. The dc output jacks can be used to connect the amplifier to a recorder, potentiometer, or other sensitive device. The meter switch should be "off" when the dc jacks are used since the meter has a loading effect on the output signal. Once the amplifier is nulled, the system is ready for calibration.

To calibrate the system, connect a known C_1 and C_2 to the bridge. C_2 (General Radio type 1422 or equivalent) should be a precision variable capacitor, and set to equal C_1. The bridge-amplifier switch is then placed to the "bridge" position and the bridge balanced using the trim adjustments on the front of the bridge assembly while observing the null meter. Fine balance is obtained by the coarse and fine adjustment dials.

A recorder or millivolt meter is then connected to the DC output jacks and the meter switch turned off. Amplifier null and bridge null are rechecked; then C_2 is changed in steps of 0.2 pf and plotted against millivolt output. The bridge can be renulled each time allowing capacitance to be read directly from the coarse and fine adjustment dials; however, in normal operation, capacitance will be obtained from a recorder with the bridge in an unbalanced condition.

A plot of capacitance versus millivolt output is shown in figure 4 showing reproducibility and linearity.

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A plot of capacitance versus millivolt output is shown in figure 4 showing reproducibility and linearity.

CONCLUSIONS

The capacitance bridge and detector described in this report was designed and built to serve as an analytical tool in fundamental gas research. It functions as a nonsampling monitor of changes in dielectric constant of a gas mixture due to any small composition change within the mixture.

Specifically, it was constructed for use in monitoring the rate at which one gas diffuses into another. A midget (1-5/16" x 1-3/8" x 1-15/16") 200 pf variable air capacitor was inserted in the gas diffusion cell and isolated by using two separate coaxial leads with the shields grounded to the cell walls (stainless steel).

When pure helium (ϵ = 1.000065) was allowed to diffuse into pure nitrogen (ϵ = 1.00056) at atmospheric pressure (8), the changing dielectric constant of the mixture resulted in 0.8 mv change in detector output. This corresponds to a capacitance difference of 127 x 10^{-3} pf.

Using a recording instrument with 0.5 μv capability, high common mode noise rejection, and one megohm input impedance, it should be possible to approach a resolution of 10^{-5} pf in the 200 pf range.

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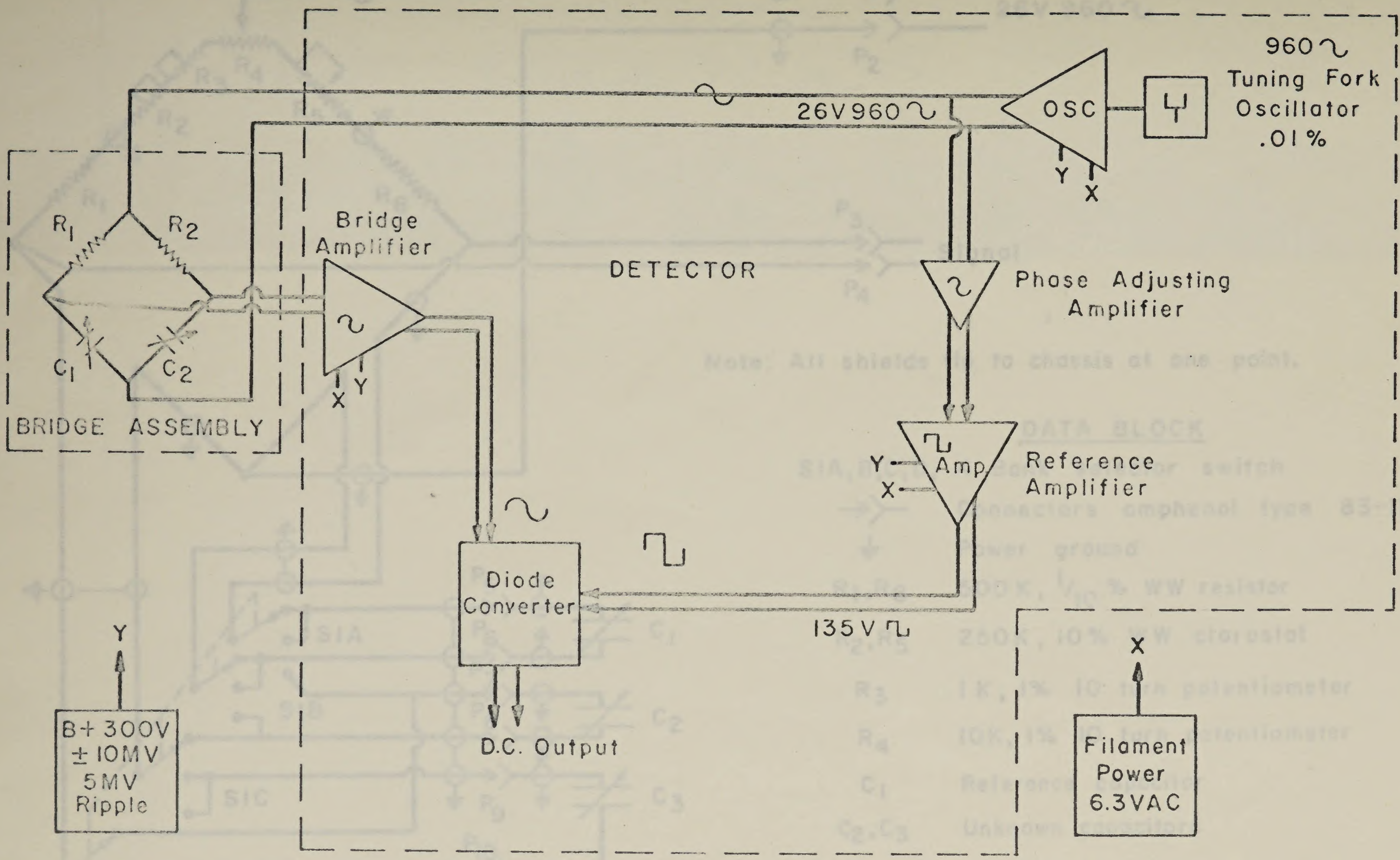
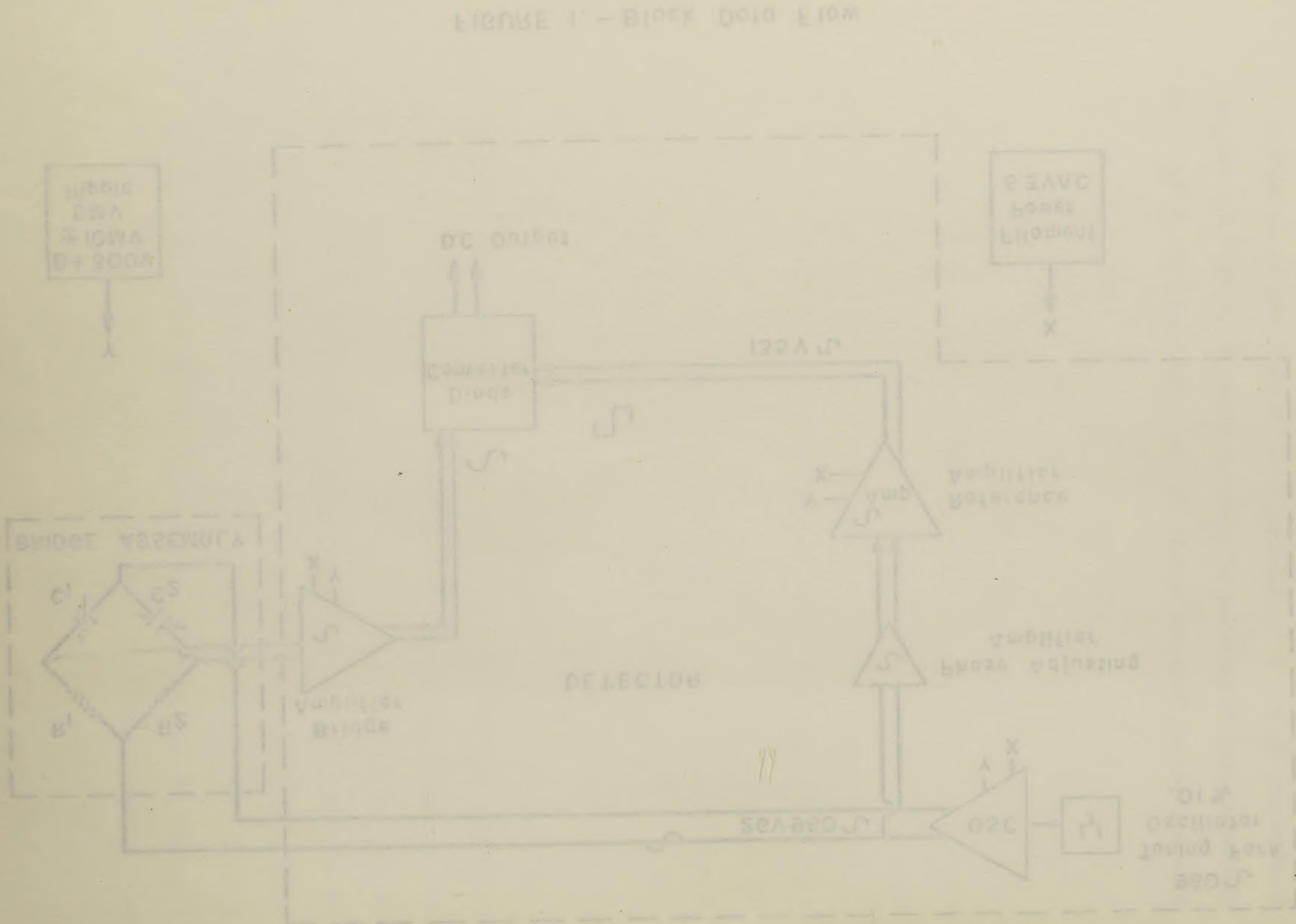
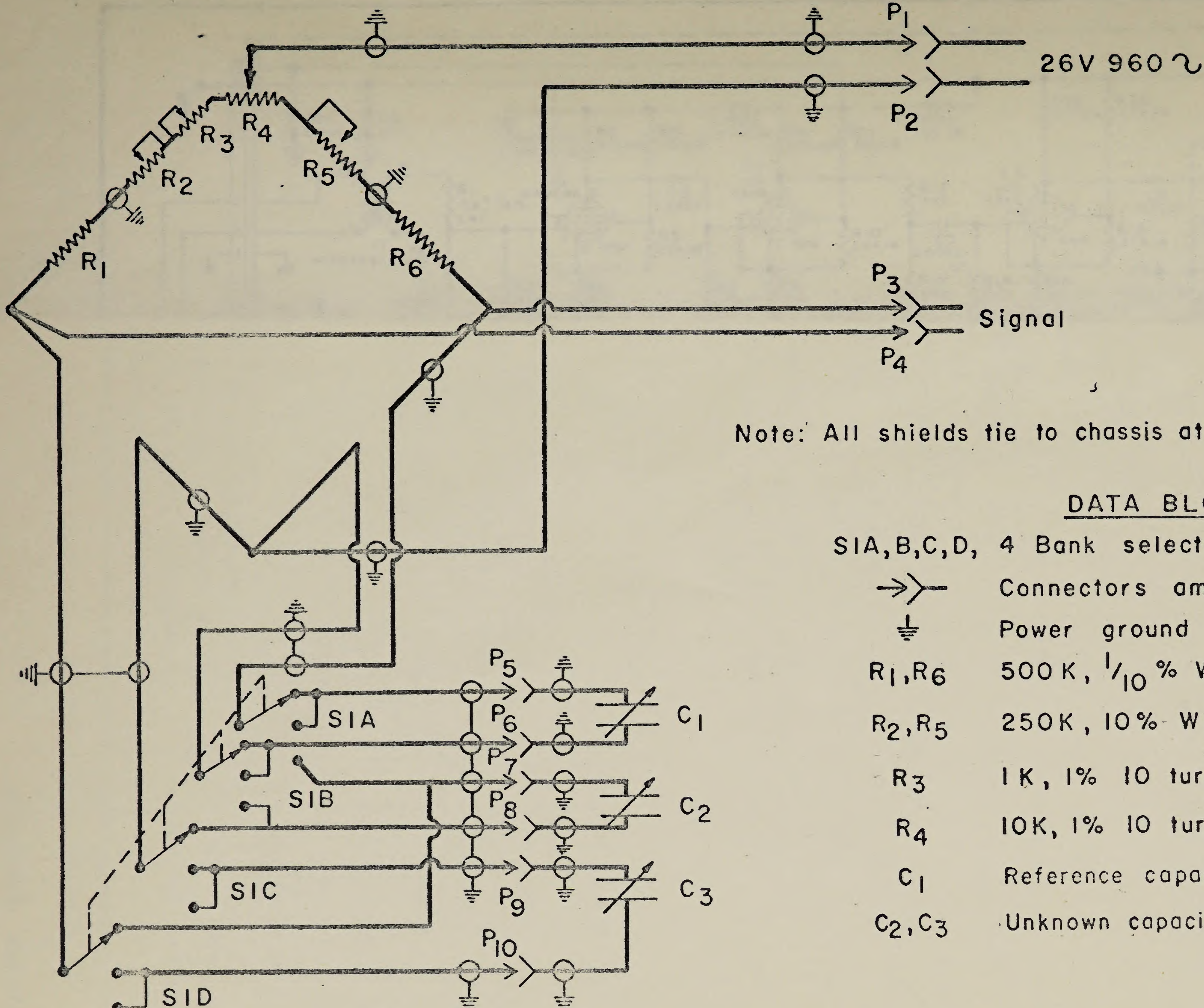


FIGURE 1. — Block Data Flow





Note: All shields tie to chassis at one point.

DATA BLOCK

S1A,B,C,D,	4 Bank selector switch
→≻–	Connectors amphenol type 83-1SP
⏚	Power ground
R_1, R_6	500 K, $^1/_{10}$ % WW resistor
R_2, R_5	250K, 10% WW clarostat
R_3	1 K, 1% 10 turn potentiometer
R_4	10K, 1% 10 turn potentiometer
C_1	Reference capacitor
C_2, C_3	Unknown capacitors

FIGURE 2.– Bridge Circuit

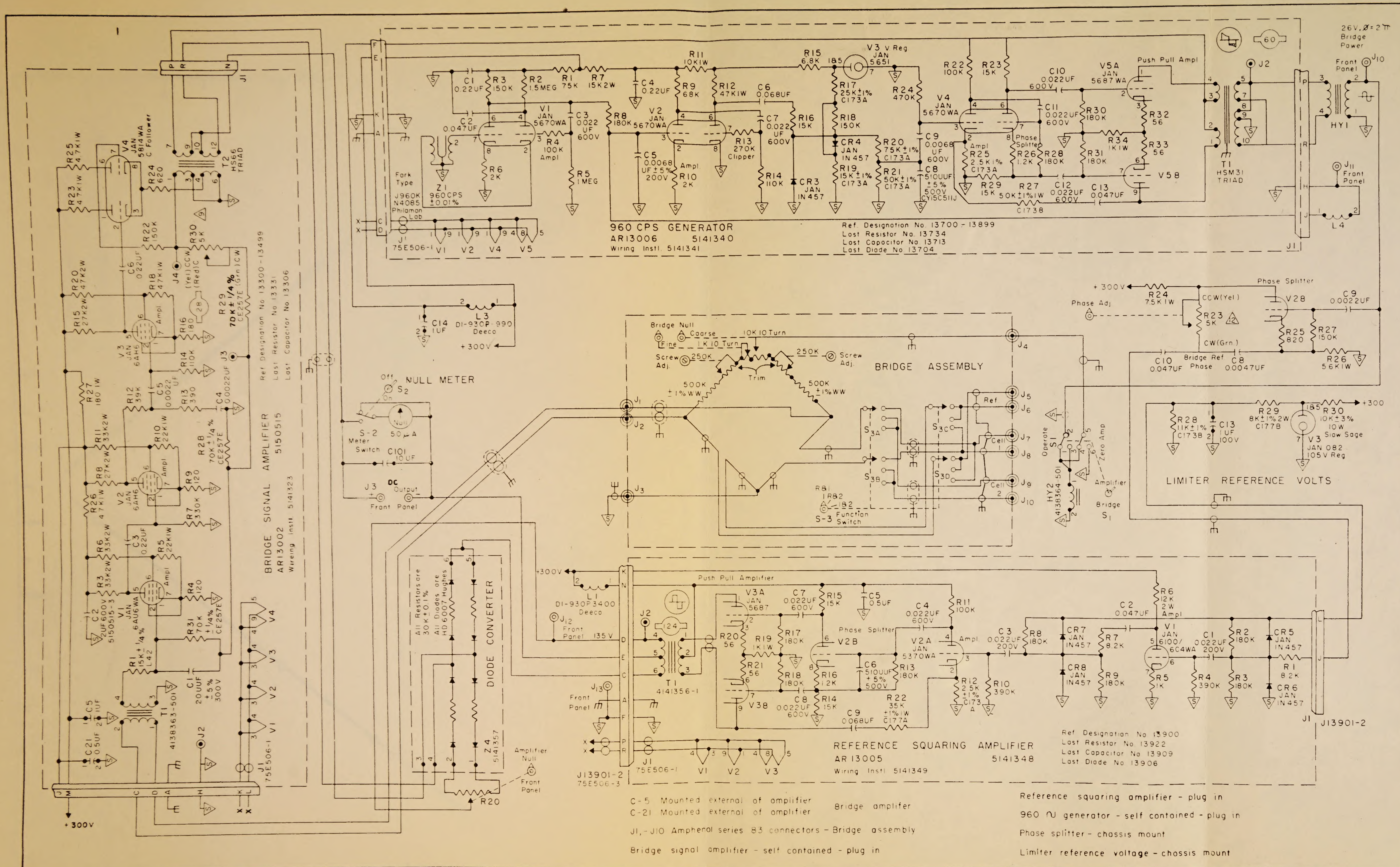
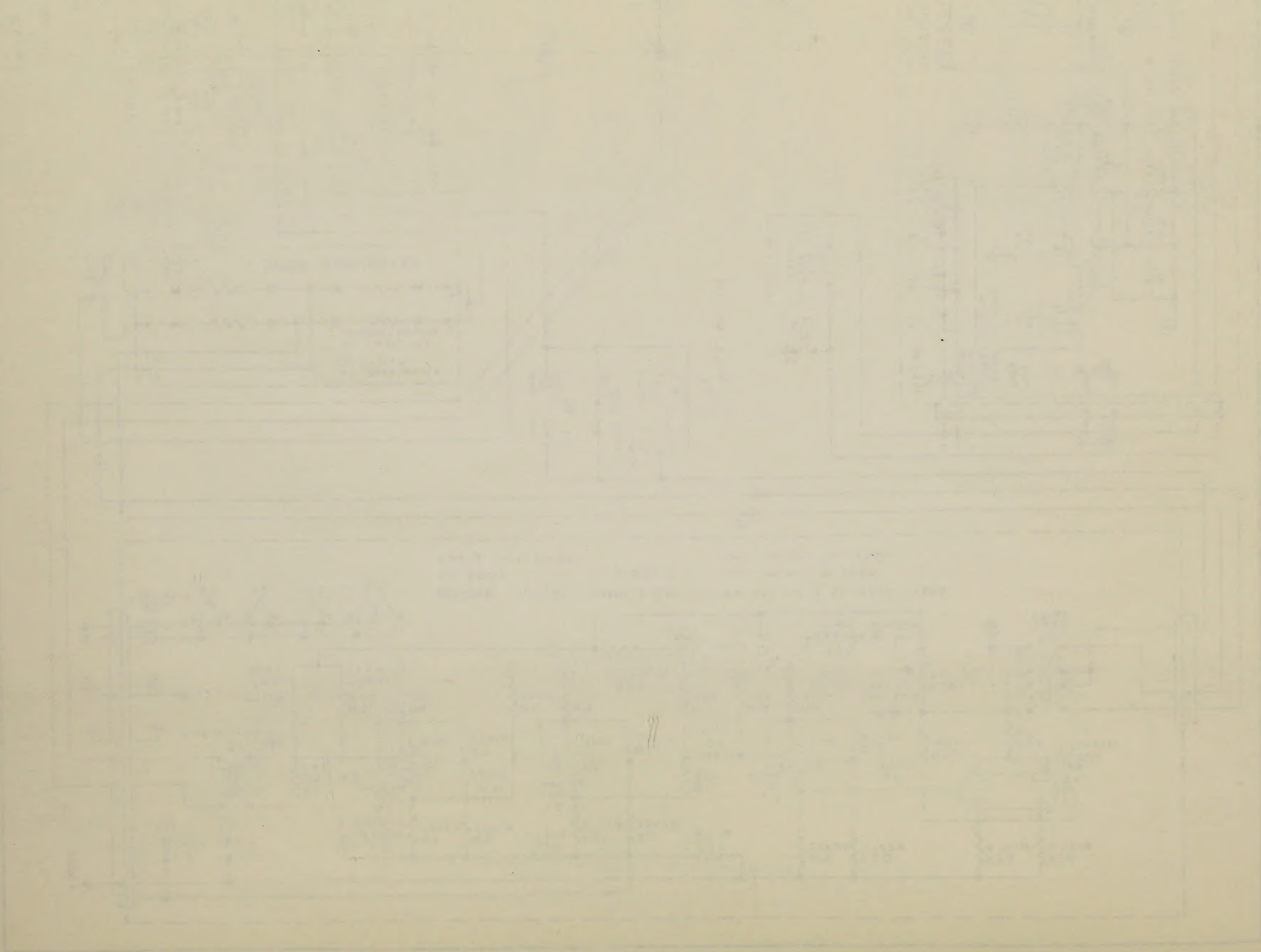


FIGURE 3.- Capacitance Detector and Bridge Assembly



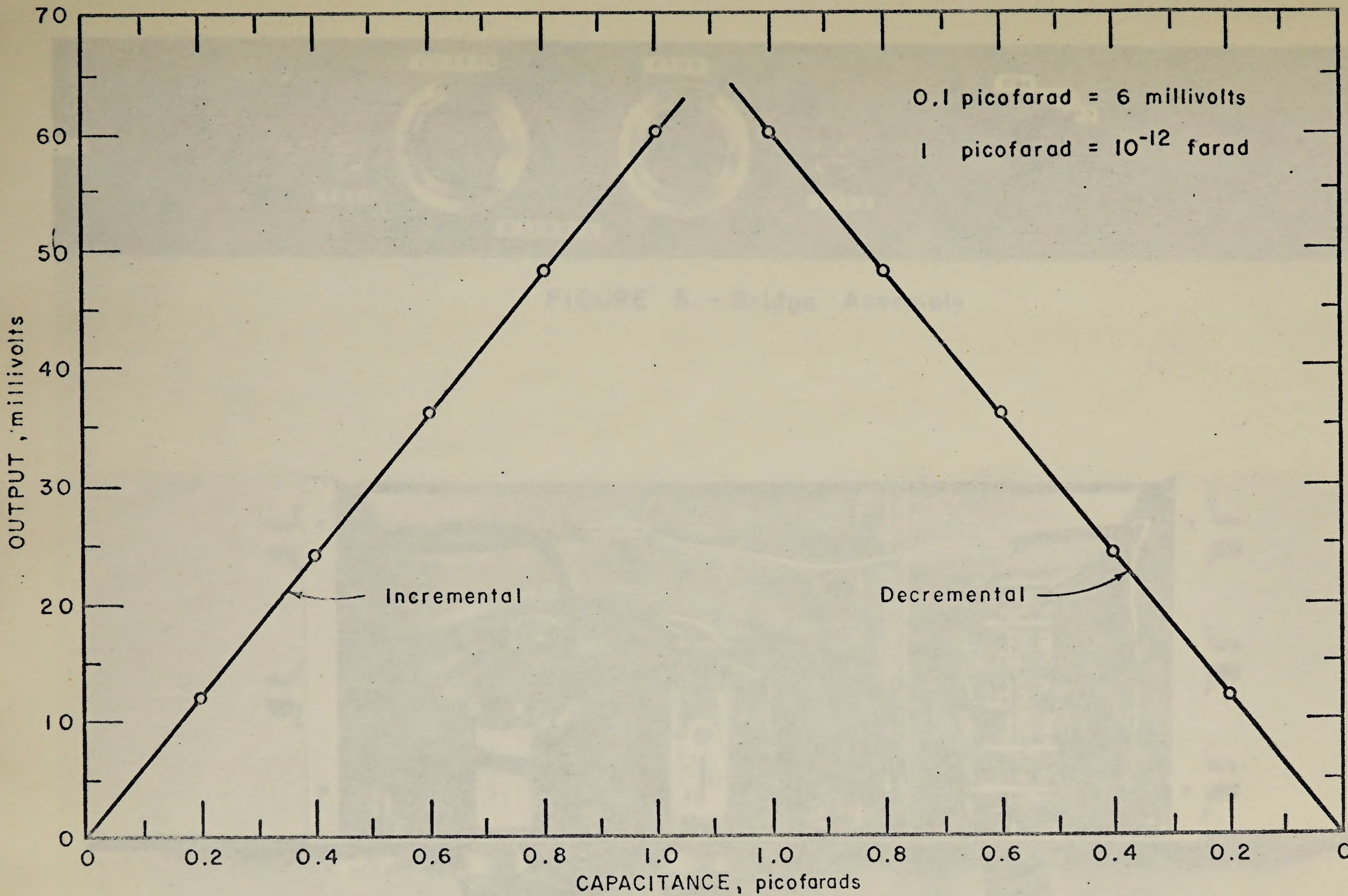


FIGURE 4.- Bridge Linearity and Reproducibility

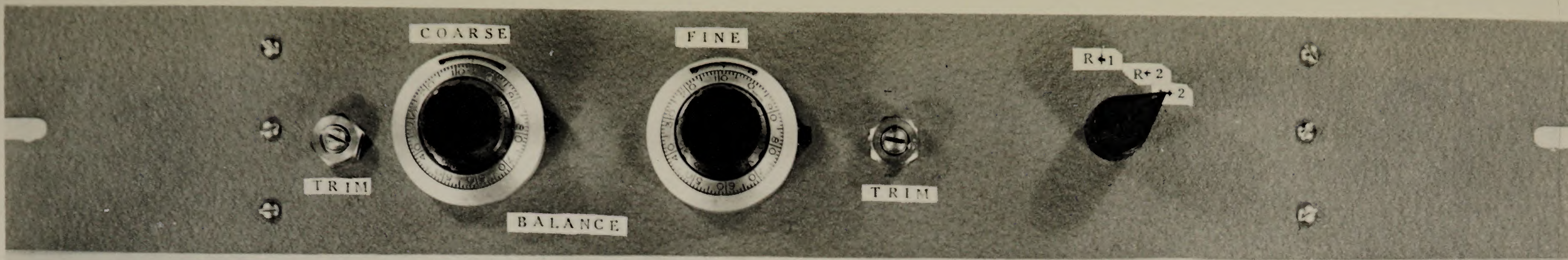


FIGURE 5. - Bridge Assembly

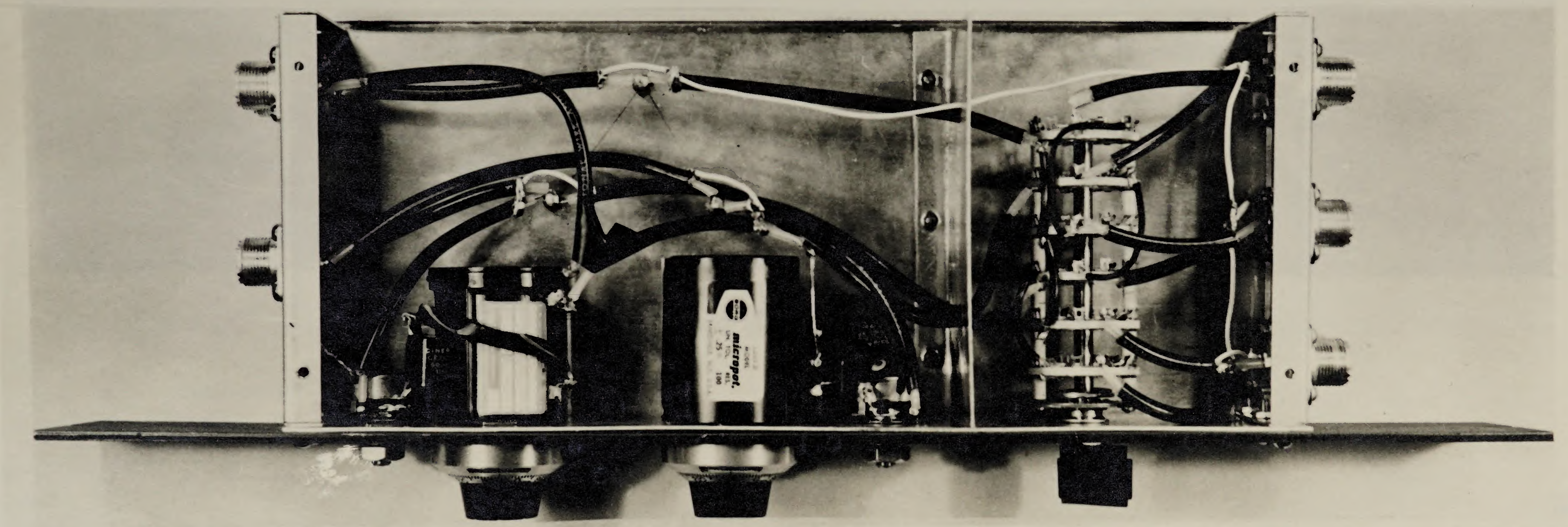


FIGURE 6. - Bridge Assembly, Internal View

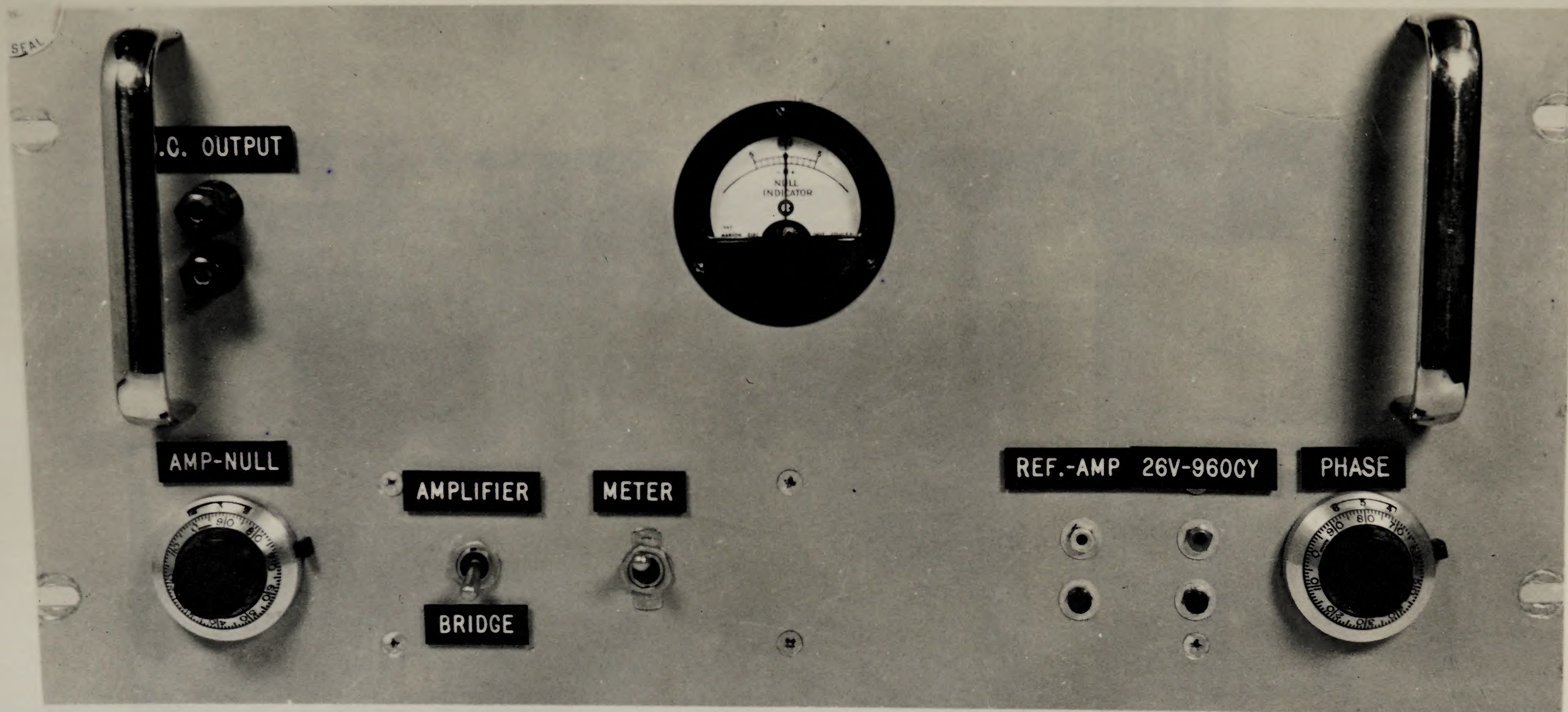


FIGURE 7. - Detector, Front View

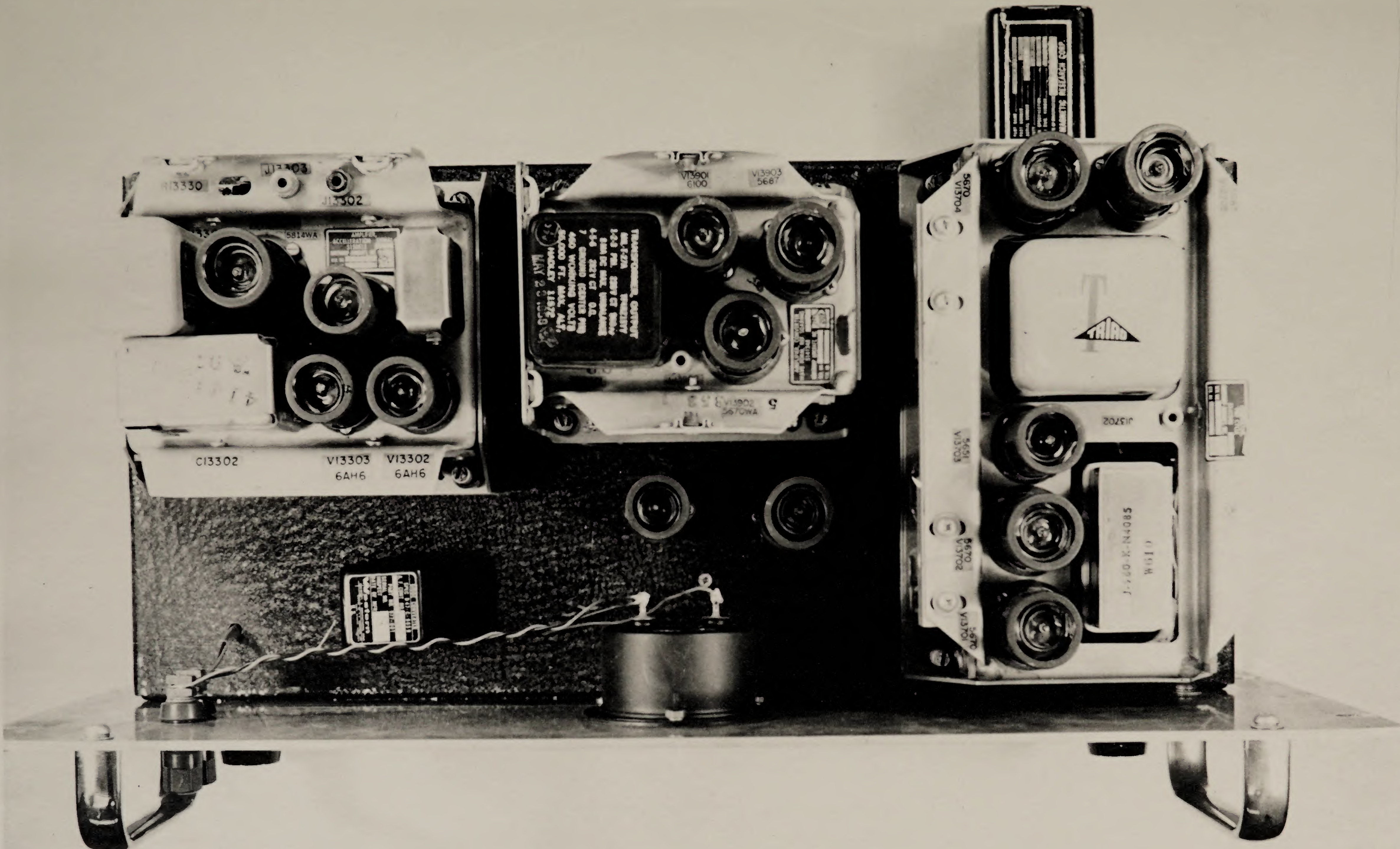


FIGURE 8. - Detector, Top View