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ELECTRONIC PHASE METER

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Summary

An improved form of direct-reading audio-frequency phase meter is described.

The phase between two sinusoidal voltages is measured by converting them to square waves through two separate channels of amplifier-limiters. A direct comparison of these square waves gives a measure of the phase between the original voltages. Two methods of comparing the square waves are described - one involves their direct addition in a circuit having two tubes with a common plate resistor, while in the other method the square waves are used to produce voltage "spikes" which in turn control a "trigger" type unambiguous phase-indicating circuit.

Tests on this phase meter show that it records and indicates unambiguously the phase between two input voltages from 0 to 360 degrees, to a sensitivity of 0.5 degree, over a range of frequencies from 100 to 5000 c/s and for a voltage range of 1 to 30 volts. The relationship between phase-meter readings and phase is linear. A 72-hour stability test on the instrument showed that the maximum drift after the first 15 minutes of warm-up was approximately ± 1.6 degrees while the maximum rate of drift was 0.25 degrees per hour.

Description of Equipment

The phase meter described in this report embodies principles and circuits used in several other types of phase meters [1,2]. It is believed that the circuit modifications incorporated in the instrument have increased its reliability over that of similar devices reported in the literature.

(1) Edward L. Ginston, "Electronic Phase-Angle Meter", Electronics, May 1942, p.60.

(2) E.R. Haberland, "Direct Reading Electronic Phase Meter", Naval Ordnance Laboratory Memo. #7900.

The phase meter consists of two channels of cascaded amplifier limiter stages followed by two types of phase indicating circuits, one being designated the "Sum" indicator and the other the "Trigger" indicator (Fig. 1). These two indicating circuits are based on different principles and were incorporated in the phase meter for the purpose of making direct comparison between them.

Sinusoidal input voltages are separately amplified and clipped in the four amplifier-limiter stages of each channel. The resultant square waves are then fed to the two separate indicating circuits (Fig. 2). The circuits of the first amplifier stages of each channel are designed to give a symmetrical output into the first limiters for a voltage variation of 1 to 30 volts. It is necessary that the output of this first stage be undistorted (or symmetrical) as otherwise there will be a spurious phase-shift indication with variation of voltage amplitude. The grid-voltage swings on the other three stages of each channel are limited to $\pm$ 1.25 volts by the biased diode limiters, and hence distortion in these stages is low.

Referring to Fig. 2, the Square-wave voltage at points A1, A2, are fed to each of the indicating circuits through capacitors C17, C35, C36 and C37, repsectively. Considering the "Sum" indicator system first, the square waves are applied to the grid of tubes V9 and V18 which have a common plate resistor R32. The voltage appearing across resistor R32 is equal to the algebraic sum of the currents of the tube V9 and V18, multiplied by the value of R32. Since these tubes are operated class A it follows that the voltage across R32 is equal to the algebraic sums of the square wave inputs at points A1, A2. The diration of flow of current to resistor R32 is directly proportional to the phase angle between the applied square waves and therefore proportional to the phase angle between the sinusoidal input voltages. The average of the current through resistor R32 is, therefore, a measure of the phase angle. This average value is obtained by means of the diode rectifier, V19 and the balanced amplifier V20 using a C-1 milliammeter as the "Sum" phase indicator. The balanced amplifier circuit is arranged by means of proper meter shunts to give three ranges of phase angle measurements: 180° to 135° or 225°, 180° to 90° or 270° and 180° to 0° or 360°. It should be noted that, for each of these ranges, the phase meter reading is ambiguous about the 180° value.

The operation of the "Trigger" indicator system is as follows: the square wave voltages at points A1 and A2 are applied to the grids of amplifier tubes V21 and V22. The amplified square waves are then differentiated in the plate circuits of V21 and V22 and the resultant voltage spikes, which occur at the instant of rise and fall of the square waves, are applied to the diode polarity-discriminator tube V23, which suppresses the positive voltage spikes and passes the negative pulses to the #3 grids of the "Trigger" tubes V24 and V25. The RC values in the plate circuits of V21 and V22 are a compromise so as to give the shortest possible pulse with sufficient amplitude to fire the trigger tubes.

The trigger-tube circuit is so connected that when a negative pulse is applied to the grid of one of the tubes it will cut off, simultaneously firing the other tube. In turn, when a negative pulse is applied to the "conducting" tube it will cut off and at the same time will fire the first tube. As a result of this sequence of operation, the average plate current flowing in the plate circuit of the trigger tubes is a measure of the time interval existing between voltage spikes from the two channels of the phase meter and this time interval in turn corresponds to the relative phase of the sinusoidal input voltages.

The average trigger-plate currents are measured by means of the balanced circuit shown in Fig. 2. Both recording and indicating milliammeters are used, together with proper meter shunts, to give three ranges of phase-angle measurements: 130° - 180° - 230°; 80° - 180° - 280° and 0° - 180° - 360°. A zero centered meter is used for convenience so that the center of the scale is the 180-degree position. The phase-angle readings in the trigger-indicating circuit are unambiguous, but the circuit is inherently unstable for phase angles in the neighborhood of 0 and 360 degrees because under this condition the order of firing of the trigger tubes alternates irregularly with the result that the indicating meter swings from one end of its scale to the other. Fixed, regulated bias of 105 volts on the #1 grid of this trigger circuit was used as recommended in reference 2. The operation of this circuit over a period of several months proved it to be very stable and satisfactory.

The phase meter indicating circuits are adjusted to read correctly for the 180-degree and for the 0/360-degree relationship between the input voltage as follows:

1. With the meter switch S_2 and the range switch S_1 in position 1 the meters are adjusted for their mechanical zeros.

2. The meter switch is moved to position 2 and the sum meter is set at zero by means of the "zero adjust" control on the right hand side of the panel; this control is the balancing resistor in the plate circuits of tube V_{20}.

3. The meter switch is then advanced to position 3 and the phase of one of the input voltages is adjusted to give a minimum reading on the sum meter. The sum meter reading is then set at zero by means of the "sum bal." adjustment, which consists of the variable resistor in the cathode circuit of tube V_{18}. This adjustment equalizes the gains of the sum tubes. For a more precise adjustment the range switch is set on position 3.

4. The trigger meter is then set at zero by advancing the meter switch to position 4 and adjusting the "zero adjust" control on the left-hand side of the panel. This control is the variable resistor in the plate circuits of V_{24} and V_{25}. The above procedure determines the proper circuit conditions to

give zero readings on the meters for a 180-degree phase relationship between the input voltages to the phase meter.

The 0/360-degree phase relationship between the input voltages can be indicated by the sum tube only and is obtained as follows:

The range switch is set at position 1 and the phase of one of the input voltages is then adjusted to give a maximum reading on the sum meter. The sum meter reading is then set at 45 [(360° = 180 + (4 x 45))] by means of the "range 1 adjustment" on the right-hand side of the panel.

Since the trigger phase-indicating circuit is unstable within ± 1 degrees of 0/360° it is necessary to adjust the trigger meter, by means of the "range 1 adj." on left-hand side of the panel, for a phase difference between the input voltage somewhat less than 360 degrees. This adjustment of the trigger phase-indicating circuit can be made in terms of the sum meter reading or by means of a known phase difference between the input voltages to the phase meter.

Likewise, the more sensitive ranges of the phase meter can be adjusted by means of the least sensitive range or by means of a known phase difference between the input voltages. In practice these methods have been found to check each other to within ± 0.5 degree.

Constructional details of the phasemeter are shown in figures 3, 4 and 5.

Calibration of the phasemeter was obtained by means of pairs of sinusoidal voltages having a fixed frequency ratio of 10 to 1 and a fixed relative phase. These calibration voltages were derived from the primary frequency standard of the National Bureau of Standards Radio Station WWV.

The calibration procedure consisted of feeding a sinusoidal voltage of desired frequency directly to one channel of the phasemeter while simultaneously feeding this same voltage to the other channel of the phasemeter through a phase shifter. The output of this phase shifter was also connected to one set of deflection plates of an oscilloscope, while the other set of plates was connected to a reference sinusoidal voltage with a frequency 10 times the frequency of the calibrating-voltage frequency and with a fixed phase relative to the calibrating voltage.

The resulting Lissajou figure on the screen of the oscilloscope indicated the phase shift between the input voltages to the phasemeter for any two positions of the phase shifter and could be read to within 0.5 degrees, or less. Calibration points were obtained in steps of 18 electrical degrees by rotating the phase shifter until cycles were matched on the Lissajou figure.

The phase shifter, of capacitance-goniometer type, used in this calibration proceedure was capable of introducing a continuously variable phase shift of from 0 to 360 degrees.

Performance

A series of tests on the phase meter gave the following results:

(a) When the amplitudes of both signals were varied slowly and independently, keeping the relative phase constant, the phase meter readings varied as follows:

Input voltage range volts rms	Indicated phase change, degrees "Trigger"	"Sum"
1 - 10	± 0.25	± 0.25
1 - 20	± 0.8	± 0.35
1 - 30	± 1.0	± 0.50

(b) For very rapid random changes in the amplitudes of input voltages from 1 to 20 volts, rms, the phase-meter readings showed a phase change of ± 1.0 degrees. These rapid changes in input voltages were made by manually operating two potentiometers; the time required to vary the signal voltage from one extreme to the other was of the order of about one-quarter second.

(c) For a time-voltage variation of 100 volts to 120 volts the phase-meter readings varied ± 0.25 degrees. These results were obtained for a range of signal frequencies from 100 c/s to 5000 c/s and for input voltages from 2 volts to 15 volts.

(d) After the first 15 minutes of warm-up the phase-meter readings showed an indicated drift of ± 1.6 degree over a period of 72 hours, with a maximum rate of drift of 0.25 degrees per hour.

(e) The curve of phase-meter reading versus phase was found to be linear within one degree over a range of input frequencies from 100 c/s to 5000 c/s.

(f) The phase-meter readings were found to be independent of frequency from 100 c/s to 5000 c/s.

Throughout all the above tests of the phase meter the "sum" and the "trigger" indicators checked each other very closely. However, the trigger indicator has the advantage of being unambiguous while in the circuit shown in Fig. 2 the sum-indicator circuit is about twice as sensitive as the trigger circuit.

August 1, 1947

List of Components

C_1 - 0.5	µf	600 v.	Paper		C_{26} - 8.0	µf	450 v.	Paper
C_2 - 8.0	"	450 v.	"		C_{27} - 0.5	"	600 v.	"
C_3 - 1.0	"	600 v.	"		C_{28} - 8.0	"	450 v.	"
C_4 - 8.0	"	450 v.	"		C_{29} - 1.0	"	600 v.	"
C_5 - 0.5	"	600 v.	"		C_{30} - 8.0	"	450 v.	"
C_6 - 8.0	"	450 v.	"		C_{31} - 0.5	"	600 v.	"
C_7 - 1.0	"	600 v.	"		C_{32} - 8.0	"	450 v.	"
C_8 - 8.0	"	450 v.	"		C_{33} - 1.0	"	600 v.	"
C_9 - 0.5	"	600 v.	"		C_{34} - 8.0	"	450 v.	"
C_{10} - 8.0	"	450 v.	"		C_{35} - 0.5	"	600 v.	"
C_{11} - 1.0	"	600 v.	"		C_{36} - 0.5	"	600 v.	"
C_{12} - 8.0	"	450 v.	"		C_{37} - 0.5	"	600 v.	"
C_{13} - 0.5	"	600 v.	"		C_{38} - 1.0	"	600 v.	"
C_{14} - 8.0	"	450 v.	"		C_{39} - 8.0	"	450 v.	"
C_{15} - 1.0	"	600 v.	"		C_{40} - .00025	µf	500 v.	Mica
C_{16} - 8.0	"	450 v.	"		C_{41} - .01	"	600 v.	Paper
C_{17} - 0.5	"	600 v.	"		C_{42} - .000015	"	500 v.	Ceramicon
C_{18} - 8.0	"	450 v.	"		C_{43} - 8.0	"	450 v.	Paper
C_{19} - 0.5	"	600 v.	"		C_{44} - .00025	"	500 v.	Mica
C_{20} - 8.0	"	450 v.	"		C_{45} - .01	"	600 v.	Paper
C_{21} - 1.0	"	600 v.	"		C_{46} - .000015	"	500 v.	Ceramicon
C_{22} - 8.0	"	450 v.	"		C_{47} - 8.0	"	450 v.	Paper
C_{23} - 0.5	"	600 v.	"		C_{48} - 1.0	"	600 v.	"
C_{24} - 8.0	"	450 v.	"		C_{49} - 0.2	"	600 v.	"
C_{25} - 1.0	"	600 v.	"		C_{50} - 1.0	"	600 v.	"

List of Components

C_{51}	-	.008	μf.	500 v.	Mica	R_{24}	-	200	ohms		1/2 w
C_{52}	-	40.	μf	150 v.	Electrolytic	R_{25}	-	10 k	"		1 w
R_1	-	150 k	ohms	1/2 w		R_{26}	-	10 k	"		1 w
R_2	-	30 k	"	1/2 w		R_{27}	-	60 k	"		1/2 w
R_3	-	100	"	1/2 w		R_{28}	-	25 k	"		1/2 w
R_4	-	10 k	"	1 w		R_{29}	-	300 k	"		1/2 w
R_5	-	10 k	"	1 w		R_{30}	-	500 k	"		1/2 w
R_6	-	60 k	"	1 w		R_{31}	-	1500 k	"		1/2 w
R_7	-	25 k	"	1/2 w		R_{32}	-	20 k	"		4 w
R_8	-	300 k	"	1/2 w		R_{33}	-	65 k	"		1/2 w
R_9	-	500 k	"	1/2 w		R_{34}	-	150 k	"		1/2 w
R_{10}	-	200	"	1/2 w		R_{35}	-	30 k	"		1/2 w
R_{11}	-	10 k	"	1 w		R_{36}	-	100	"		1/2 w
R_{12}	-	10 k	"	1 w		R_{37}	-	10 k	"		1 w
R_{13}	-	60 k	"	1/2 w		R_{38}	-	10 k	"		1 w
R_{14}	-	25 k	"	1/2 w		R_{39}	-	60 k	"		1/2 w
R_{15}	-	300 k	"	1/2 w		R_{40}	-	25 k	"		1/2 w
R_{16}	-	500 k	"	1/2 w		R_{41}	-	300 k	"		1/2 w
R_{17}	-	200	"	1/2 w		R_{42}	-	500 k	"		1/2 w
R_{18}	-	10 k	"	1 w		R_{43}	-	200 k	"		1/2 w
R_{19}	-	10 k	"	1 w		R_{44}	-	10 k	"		1 w
R_{20}	-	60 k	"	1/2 w		R_{45}	-	10 k	"		1 w
R_{21}	-	25 k	"	1/2 w		R_{46}	-	60 k	"		1/2 w
R_{22}	-	300 k	"	1/2 w		R_{47}	-	25 k	"		1/2 w
R_{23}	-	500 k	"	1/2 w		R_{48}	-	300 k	"		1/2 w

<u>List of Components</u>

R_{49}	-	500 k	ohms	1/2 w
R_{50}	-	200	"	1/2 w
R_{51}	-	10 k	"	1 w
R_{52}	-	10 k	"	1 w
R_{53}	-	60 k	"	1/2 w
R_{54}	-	25 k	"	1/2 w
R_{55}	-	300 k	"	1/2 w
R_{56}	-	500 k	"	1/2 w
R_{57}	-	200 k	"	1/2 w
R_{58}	-	10 k	"	1 w
R_{59}	-	10 k	"	1 w
R_{60}	-	60 k	"	1/2 w
R_{61}	-	25 k	"	1/2 w
R_{62}	-	300 k	"	1/2 w
R_{62A}	-	500 k	"	1/2 w
R_{63}	-	1000	"	1/2 w
R_{64}	-	1000	"	Wire-wound variable
R_{65}	-	50 k	"	1/2 w
R_{66}	-	100 k	"	1/2 w
R_{67}	-	75 k	"	1/2 w
R_{68}	-	75 k	"	1/2 w
R_{69}	-	500 ohms		1/2 w
R_{70}	-	100 K	"	1/2 w
R_{71}	-	2000	ohms	Wire-wound variable
R_{72}	-	15 k	"	1 w

R_{73}	-	15 k	ohms	1 w
R_{74}	-	4000	ohms	Wire-wound Variable (Total maximum resistance)
R_{75}	-	25 k	"	" "
R_{76}	-	60 k	"	" "
R_{77}	-	250 k	ohms	1/2 w
R_{78}	-	500	"	1/2 w
R_{79}	-	25 k	"	1 w
R_{80}	-	5000 ohms	"	1 w
R_{81}	-	50 k	"	1/2 w
R_{82}	-	10 k	"	1/2 w
R_{83}	-	100 k	"	1/2 w
R_{84}	-	200 k	"	1/2 w
R_{85}	-	500 k	"	1/2 w
R_{86}	-	250 k	"	1/2 w
R_{87}	-	50 k	"	2 w
R_{88}	-	1000	"	Wire-wound Variable (Total maximum resistance)
R_{89}	-	22 k	"	" "
R_{90}	-	60 k	"	" "
R_{91}	-	7500	"	1 w
R_{92}	-	250 k	"	1/2 w
R_{93}	-	500	"	1/2 w
R_{94}	-	50 k	"	1/2 w
R_{95}	-	25 k	"	1 w

List of Components

R_{96}	-	5000	ohms	1 w
R_{97}	-	10 k	"	1/2 w
R_{98}	-	100 k	"	1/2 w
R_{99}	-	200 k	"	1/2 w
R_{100}	-	500 k	"	1/2 w
R_{101}	-	250 k	"	1/2 w
R_{102}	-	50 k	"	2 w
R_{103}	-	7500	"	1 w
R_{104}	-	500	"	Wire-wound variable
R_{105}	-	15 k	"	10 w
R_{106}	-	5000	"	25 w
R_{107}	-	75	"	1/2 w
R_{108}	-	10 k	"	4 w
R_{109}	-	75	"	1/2 w
R_{110}	-	1600 ohm		1/2 w

V_1, V_{10}	-	6AB7
V_3, V_5, V_7, V_9, V_{12}	-	6AC7
V_{14}, V_{16}, V_{18}	-	6AC7
V_2, V_4, V_6, V_8, V_{11}	-	6H6
V_{13}, V_{15}, V_{17}, V_{19}, V_{23}	-	6H6
V_{20}	-	6SN7
V_{21}, V_{22}	-	6SJ7
V_{24}, V_{25}	-	6SA7
V_{26}	-	VR-150/30

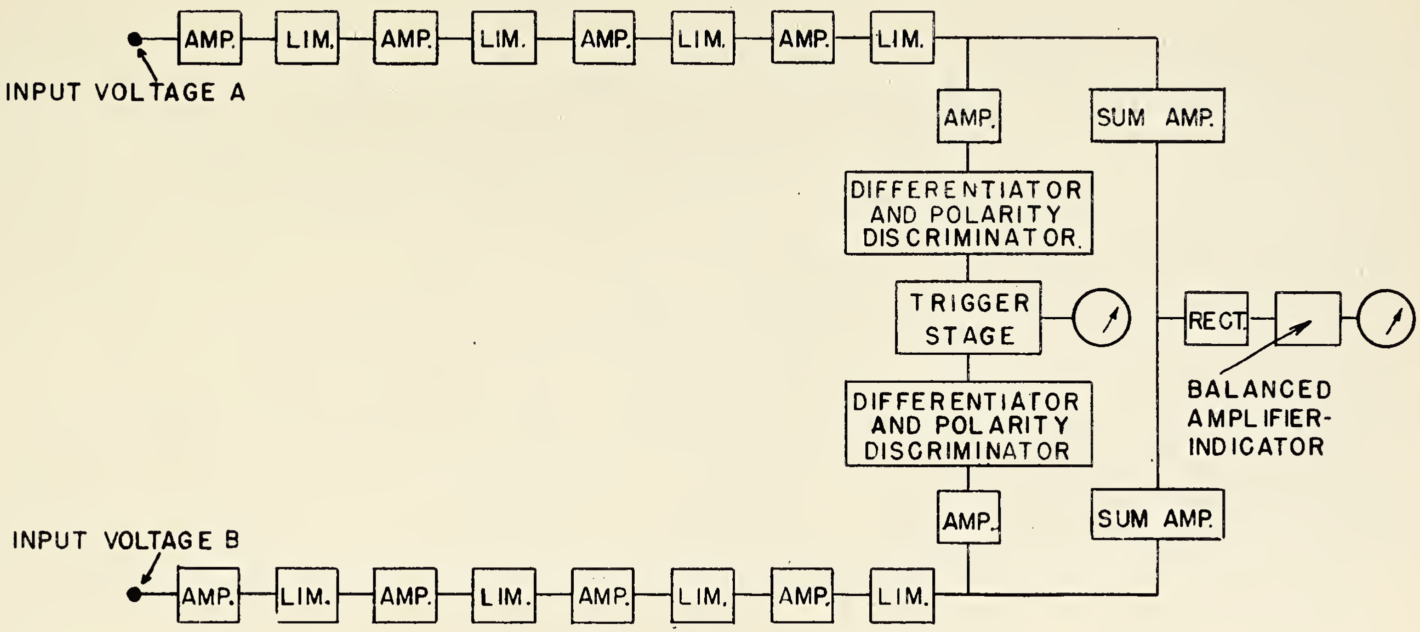

Fig. 1 BLOCK DIAGRAM OF ELECTRONIC PHASEMETER

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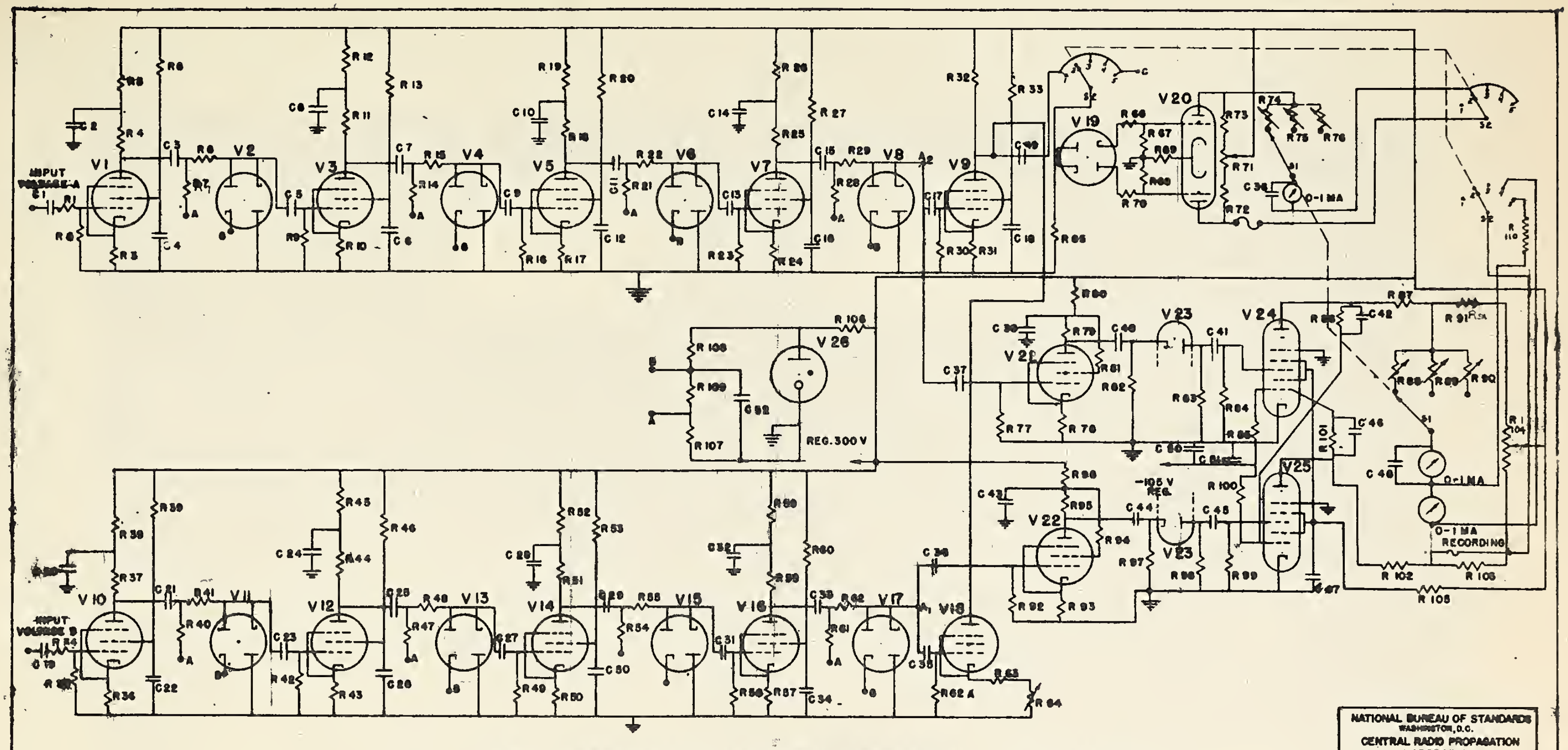

Fig. 2 SCHEMATIC WIRING DIAGRAM OF ELECTRONIC PHASEMETER — DIV. 14, SEC. 5-A-1

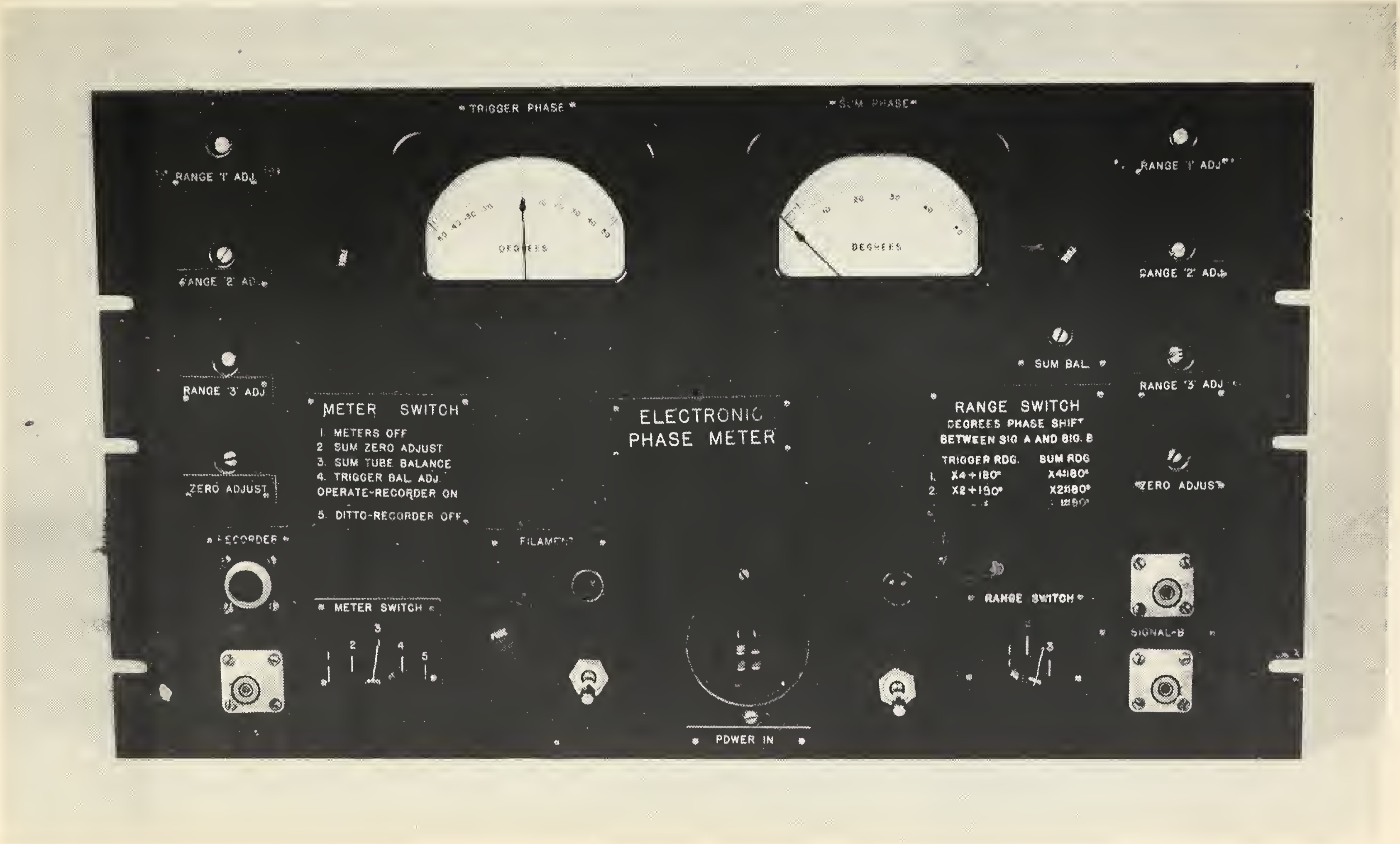

Fig. 3. FRONT VIEW OF ELECTRONIC PHASEMETER.

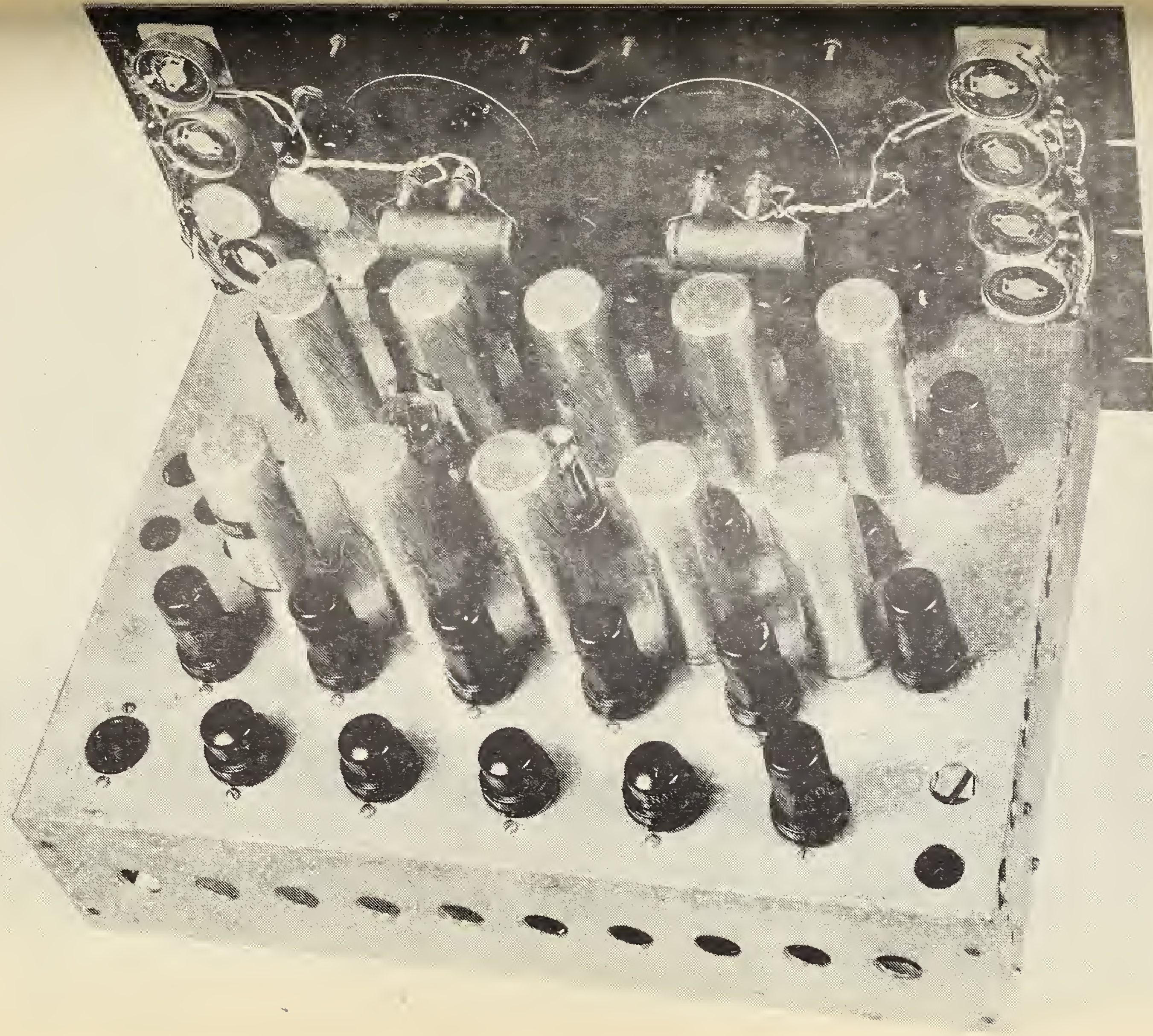

Fig. 4. REAR VIEW OF ELECTRONIC PHASEMETER.

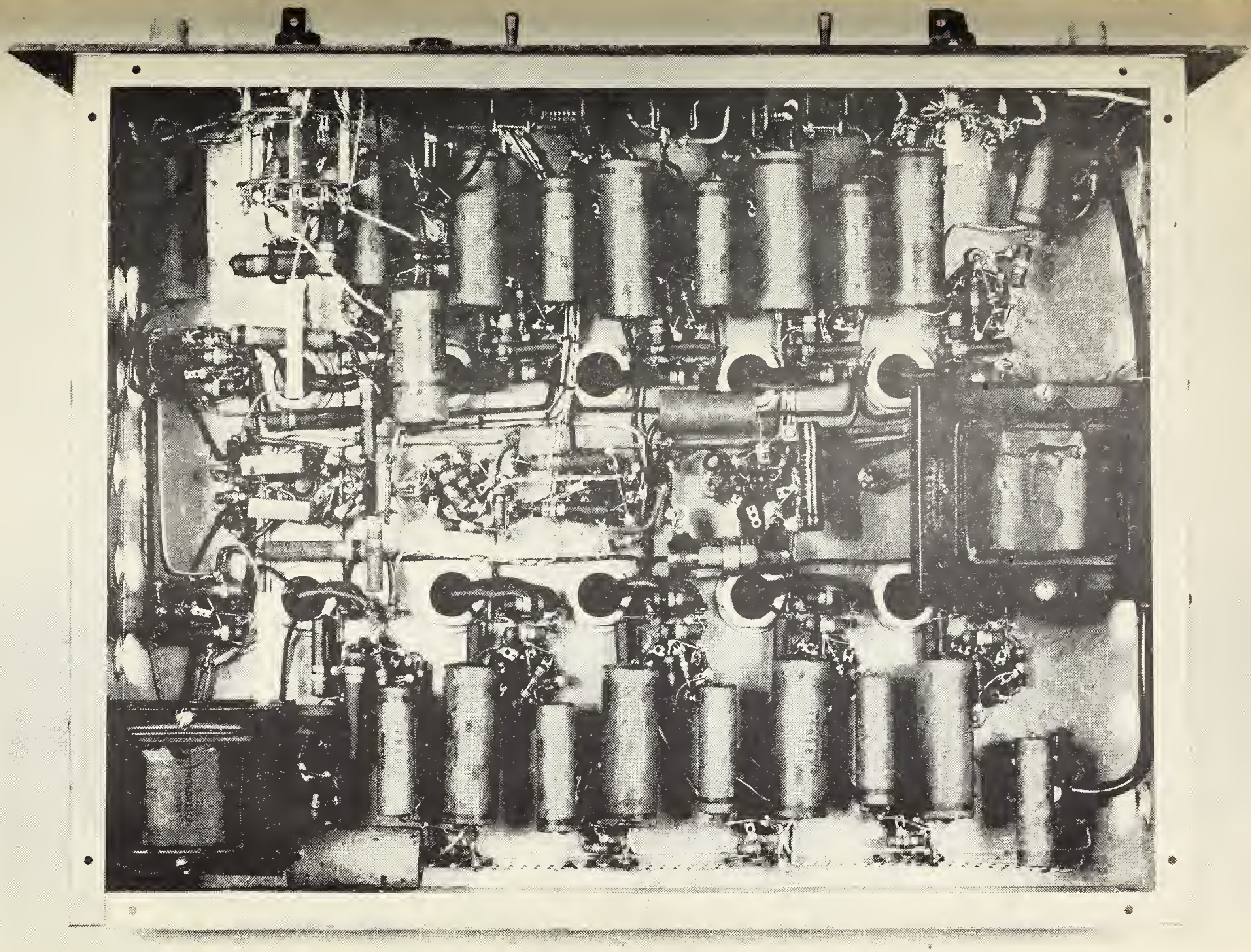

Fig. 5. BOTTOM VIEW OF ELECTRONIC PHASEMETER.