PB 161624

NBS

Technical Note No. 123

Boulder Laboratories

FUNCTIONAL AND DESIGN PROBLEMS OF THE NBS RF VOLTAGE BRIDGE

BY

L. F. BEHRENT

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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January 1961

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ABSTRACT

A detailed presentation is given of the practical solutions to the design and operating problems encountered in constructing a Thermistor Bridge similar to that used by the NBS for RF Voltage Standardization. Measurement and operating techniques, critical structural features, as well as the proper use of available components are discussed.

FUNCTIONAL AND DESIGN PROBLEMS OF THE NBS RF VOLTAGE BRIDGE

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1.00 - Introduction

A little over ten years ago, a thermistor bridge was developed by the NBS for rf voltage standardization. (Selby & Behrent, 1950) Recently this bridge was modified and reconstructed to make its operation simpler and more trouble-free, and to improve its physical appearance. Basically, however, its design and operation remain the same. The numerous requests for detailed information about its design, and the design and functional problems associated with the construction and use of such a bridge motivated the preparation of this paper as a supplement to the earlier one. Therefore, a familiarity with the previous paper is assumed.

2.00 - General Description

The rf voltage bridge is a bolometer bridge in which two thermistors are used as the bolometer elements. The thermistors used have an average diameter of 0.015 inch and 1.0 mil platinum leads. These thermistor beads are mounted symmetrically in 0.030 inch gaps in a specially-designed thermistor mount. The bolometer bridge is not operated as an equal-arm Wheatstone Bridge. Two arms of the bridge, the thermistor arm and an adjacent arm, R_T, are 200 ohms each, while the other two bridge arms, R_b, are equal and have resistances around 300 ohms. See Figure 2. These latter bridge elements are adjustable to permit balancing the bridge when no rf is applied.

The principle of power substitution is used in making measurements with the bridge. After the initial dc balance, rf power is applied to the thermistors and balance is restored by removing an essentially equal amount of dc power by inserting resistance between the dc biasing source and the bridge. Since the rf resistances of the thermistors are essentially equal to their dc values, the rf voltage across the thermistors can be calculated using (1) for rf voltages of 0.1 volt and above, and (2) for voltages below 0.1 volt.

$$V_{RF} = \frac{R_T}{(R_T + R_b)(1 + a)} \left(a\, V_{R2} \left[2V_o - V_{R2} \right] \right)^{\frac{1}{2}} \qquad (1)$$

$$V_{RF} = \frac{R_T}{(R_T + R_b)(1 + a)} \left(a \left[V_{R2} - V_{R1} \right] \left[2V_o - V_{R2} - V_{R1} \right] \right)^{\frac{1}{2}} \qquad (2)$$

The bridge is housed in two cabinets except for the biasing batteries which are kept in covered carts beneath the table on which the bridge is placed. The larger cabinet contains the dc bridge components, the dc measuring potentiometer, standard cell, and associated ac, dc, and rf controls necessary to operate the bridge. The smaller cabinet houses the thermistor mount and the microammeters which continuously monitor the condition of the thermistors.

Figure 1 presents a front view of the larger cabinet. The functions of the front panel connectors and controls are outlined in Table I.

3.00 - Design Requirements

The earlier paper contains a detailed analysis of the allowable errors for all component parts and all measured dc quantities. For convenience these results are summarized in Table II so that a comparison may be made between design requirements and the components selected for use in the bridge.

3.10 - Bridge Resistors, R_T and R_b

The actual, measured values of all resistors used in the bridge arms, both fixed and adjustable, are within ± 0.1% of their nominal values. Experimental data compiled by the National Bureau of Standards have shown that the combined effects of both aging and ambient temperature variations for resistors of the type used here are not likely to exceed 100 parts per million per year. Therefore, the nominal values for R_T and R_b can safely be used in (1) or (2) for calculating the magnitude of applied rf voltage.

Each R_b arm consists of a fixed resistor with adjustable resistance decades connected in parallel with it to provide vernier adjustment. See Figure 2. Good quality decades are used having multi-leaf contacts and wiping action at all contact surfaces to minimize contact resistance. Inasmuch as both R_b arms must be adjusted simultaneously by equal amounts in maintaining bridge balance, like decades are mechanically coupled and driven from a single knob control on the bridge panel. The fixed resistors are bolted to terminal blocks on the rear of the R_b decade assembly, and short, heavy copper leads connect them to the bridge circuit so that lead resistance is negligible compared with the bridge-arm resistances.

3.20 - Shorting Relay and Associated Resistances

To maintain bridge balance when rf voltage is applied to the thermistors, an equivalent amount of dc power is withdrawn from the bridge by inserting resistance in series with it. With the withdrawal of rf, full dc bias is applied to the bridge by shorting out the series resistance with a relay connected across it. Unless the voltage drop, V_{R1}, across these relay contacts, when closed, is no more than a few microvolts, at rf levels between 20 and 100 mv, a correction must be applied to the calculations of rf voltage. In the original version of the bridge the relay contacts used had optically-flat silver-plated contact surfaces. During the years that it was in use it had an essentially constant voltage drop of 25 μv across closed contacts. Amalgamation of the contacts with mercury was tried. It did reduce the drop considerably but, because of the maintenance required with such surfaces, amalgamation was not resorted to.

In the reconstructed bridge, a mercury relay replaces the earlier model, primarily because a relay mounted in a cabinet is rather difficult to service, and the mercury relay, with its totally enclosed contacts, is more trouble-free. A consistently reproducible 70 μv drop exists across all pairs of paralleled, closed contacts of this mercury relay. For rf levels of 100 mv and less, then, another term, V_{R1}, must be included in this equation for calculating rf voltage applied. To reduce V_{R1} to this low a level required connecting in parallel all three pairs of contacts of the mercury relay, a model which was originally manufactured for use in controlling three-phase power circuits.

The resistive network across which the mercury relay contacts are connected consists of four ten-turn potentiometers connected in a series-parallel arrangement, A, B, C, and D, Figure 2. Resistor A and B are for coarse adjustment, while C and D provide the vernier adjustment. Wide copper strap is used to interconnect these components. With the resistors shown, the dc bias can be adjusted to balance the bridge adequately for rf voltage input levels between 0.2 and 1.0 volts. The overall network resistance needed within this rf voltage range is from 6 to 85 ohms. To measure higher rf voltages, greater resistance must be connected in series with the bridge to obtain an rf balance. For example, with 1.5 volts rms applied to the thermistors approximately 1100 ohms are needed to produce a balance. For the range, then, between 1.0 and 1.5 volts, an external 1000-ohm, ten-turn potentiometer is connected in series with A, B, C, and D externally. This resistor has not been permanently connected to the system because its minimum resistance is too high and unstable to obtain a bridge balance at low rf levels.

Below 0.2 volt rf, an external slide-wire is connected across the shorting relay contacts in parallel with the whole network of A, B, C, and D so that a very low resistance can be obtained, adjustable in increments of 1 milliohm or less, and which remains acceptably stable. Rough adjustment is made using the slide-wire, and the potentiometers provide vernier control.

3.30 - Measurement of α

The microammeters used in the earlier bridge to indicate the thermistor unbalance, α, have been removed. Very-high impedance dc vacuum-tube voltmeters connected across the decoupling capacitors in the thermistor mount are now used to indicate the unbalance, by monitoring the voltage drops across the thermistors to warn the operator of malfunction in the thermistor mount.

The magnitude of the unbalance is now measured directly using the same dc measuring potentiometer provided for determining V_o, V_{R2}, and V_{R1} with an accuracy of ± 0.02%. To measure α, an adjustable resistive divider comprised of resistors R_{V1} through R_{V12}, R_{a2}, R_{a3}, and switch SW_4 is connected across either thermistor and the dividing ratio is adjusted until the dc measuring potentiometer indicates 1.000 volts. Without altering the divider ratio, the divider and potentiometer are transferred to the other thermistor by SW_3, and the voltage drop is measured by the precision dc potentiometer. This new voltage is the value of α. The only requirements placed on the divider are that its input impedance be at least one megohm to eliminate error due to shunting of the thermistor by the dividing network, and that the short-time stability shall be of the order of ± 0.01%. Using this approach to measure α makes the error in α negligible, and eliminates one step previously necessary in calculating V_{RF}.

3.40 - Bridge Sensitivity

The original bridge, with an R_T = 200 ohms and R_b of approximately 300 ohms, using a moving coil or D'Arsonval galvanometer could detect a change in R_T of .01 ohms in 200 ohms. Considerable difficulty has been experienced in using this type of galvanometer because of vibration, even when specially mounted. Therefore, in the present bridge, electronic galvanometers with 1000 ohms input impedance and a current sensitivity of 10^{-9} amperes per mm are used for both the bridge and the dc measuring potentiometers. Not only has this removed the vibration problem but it has also improved the bridge sensitivity. A change in R_T of 0.0005 ohms in 200 ohms can now be detected.

3.50 - Measurement of V_o, V_{R2}, and V_{R1}

At low rf voltage levels, the difference between the bias battery voltage, V_o, and the voltage applied to the bridge itself becomes quite small. Therefore the measurement points at which these voltages are determined must be carefully chosen. In determing V_o, (see Figure 2) one connection to the dc measuring potentiometer should preferably be located at (1) and the other at (3). In this way the total voltage drop occurring between the bridge and terminals (1) and (3) is measured. Then the bias voltage applied to the bridge itself can be accurately found. To determine V_{R2} and V_{R1}, the measuring potentiometer should be connected between (2) and (1).

4.00 - Operating Essentials

The operational procedure for making rf voltage measurements was briefly outlined in the previous paper. Many small details which would be obvious to the experienced operator were omitted. Since an objective of this paper is to provide information for those who are interested in using such a bridge but may lack experience with it, a recommended procedure will be given here in detail. Some steps are included to guide the operator in completing the measurement more quickly. Inadequate attention to each step could prolong the measurement interval, and possibly result in a deterioration of measurement accuracy because of the additional delay. To illustrate, in step 4 of the following procedure, when operating the bridge around 1 volt and higher, if the operator applies rf voltage to the bridge in large increments, he may find upon rebalancing the bridge that the change in loading on the source has raised the rf input level too high for the test voltmeter indication he desires. Then he must reduce the rf level and rebalance, repeating these steps until the bridge balances at the desired rf voltage level. In addition to the time spent in repeated adjustments, it is conceivable, that with some rf voltmeters, damage to the voltmeter could occur since the operator would have no warning of the extent of the overvoltage.

4.10 - Measurement Procedure - High-Voltage Levels (0.1 to 1.9v)

The procedure to follow in using the bridge is outlined in the following steps.

1. Connect rf voltmeter to the thermistor mount and energize the voltmeter.

2. Energize bridge by closing switch SW_5.

3. With SW_{RF} open, balance the bridge with dc by adjusting resistors R_{bl}. Continue periodic adjustment until bridge drift has essentially ceased, a process which may require an hour or more.

4. With A, B, C, and D at maximum resistance - highest dial readings - close SW_{RF} and apply about one-third the desired rf voltage to the bridge. With A and B, roughly balance the bridge. Then raise the rf level toward the desired rf voltmeter indication. Readjust A and B to restore balance. When the desired rf level is reached,

open SW_{RF} and recheck dc bridge balance. Where V_{RF} is expected to exceed 1.0 volt, add a 1 K ohm, ten-turn potentiometer in series with the network A, B, C, and D.

5. Correct dc balance by adjusting R_{b1}.

6. Check potentiometer standard cell balance. Adjust according to instructions furnished with the potentiometer.

7. Check rf voltmeter zero - make necessary adjustments.

8. Close SW_{RF} and obtain final rf balance using C and D (SW_1 in V_{R2} position, SW_2 in V position).

9. Measure V_{R2} and record - if outside range of potentiometer, switch SW_1 to $V_{R2} \times 10$ and measure.

10. Change SW_1 to V_o position and measure and record voltage.

11. Turn SW_2 to "a" position.

12. By means of controls a, a_2, and a_3, adjust the voltage across the potentiometer to read exactly 1 volt. SW_4 corresponds to "a".

13. Change SW_3 to its other position and measure the dc voltage. Record this value as a.

14. Record R_{b1}.

15. Open SW_{RF} and recheck bridge balance and rf voltmeter zero. If either or both are off, repeat the measurement.

4.20 - Low RF Voltage Level Procedure (20 to 100 mv)

16. With the bridge energized, adjust for a dc balance as in steps 2 and 3.

17. Check rf voltmeter zero. Make necessary adjustments.

18. With A, B, C, and D at maximum resistance, connect a good quality low resistance slide-wire (1 to 2 ohms) across the terminal blocks at the top center of the bridge panel.

19. Apply sufficient rf voltage to the bridge to give the desired rf voltmeter indication. With the external slide-wire, roughly balance the bridge. Examination of the rf voltmeter indication may show a change in the level; readjust the rf and again rebalance the bridge. Repeat as often as necessary until the rf and dc balances of the bridge coincide at the proper rf level.

20. Remove the rf by opening SW_{RF} and recheck voltmeter zero and bridge balance. Make the necessary adjustments to both.

21. Close SW_{RF} and if the rf level indication on the rf voltmeter is correct, balance the bridge until the rf and dc balances coincide as exactly as possible by means of A, B, C, and D. (SW_1 in V_{R2} position, SW_2 in V position)

22. Check dc potentiometer standard cell balance. Adjust according to manufacturer's instructions.

23. Measure and record V_{R2}.

24. Change SW_1 to V_o position; measure and record V_o.

25. Turn SW_2 to a position and SW_3 to either position.

26. With controls a, a_2, and a_3 adjust the voltage at the potentiometer to read exactly 1.0000 volt.

27. Turn SW_3 to its other position and measure the dc voltage.

This is equal to a. For some pairs of thermistors, it may be possible to adjust to 1.000 volt only when switched to the thermistor of lower resistance.

28. Record R_{b1}.

29. Open SW_{RF} and recheck bridge balance and rf voltmeter zero. If either or both have changed, repeat the measurement.

30. When measuring rf voltages between 20 and 50 mv, maximum galvanometer sensitivity is required. The bridge should be kept in balance within ± 3 large-scale divisions of the galvanometer if measurement accuracy is to be maintained.

4.30 - Calculations

The equation used in calculating the value of the applied rf voltage for levels above 0.1 volt is presented in (1).

$$V_{RF} = \frac{R_T}{(R_T + R_b)(1 + a)} \left(a \, V_{R2} \left[2V_o - V_{R2} \right] \right)^{\frac{1}{2}} \qquad (1)$$

where

R_T = 200 ohms

R_b = the combined resistance of R_{b2} in shunt with the adjustable decade resistors R_{b1};

R_{b2} will be either 300, 340 or 400 ohms depending upon the battery condition. R_{b1} is read directly from the dials;

a is determined from steps 11, 12 and 13;

V_{R2} is determined in step 9;

V_o see step 10.

At levels below 0.1 volt the voltage drop, V_{R1}, across the mercury relay MS must be included in the calculation.

$$V_{RF} = \frac{R_T}{(R_T + R_b)(1 + a)} \left(a\,[V_{R2} - V_{R1}][2V_o - V_{R2} - V_{R1}] \right)^{\frac{1}{2}} \qquad (2)$$

V_{R1} can be measured with no rf applied and SW_1 in the V_{R2} position.

4.40 - Precautions (In anticipation of some of the operating difficulties which may arise, a few precautions are included at this point.)

1. The rf voltage applied to the bridge when calibrating rf voltmeters must be filtered sufficiently to reduce the harmonics 50 to 60 db below the fundamental.

2. In measuring to an accuracy of ± 1%, the amplitude stability of the rf source must be ± 0.1% or better.

3. The batteries biasing the bridge must be serviced and recharged once each year. When the bridge is not in use, a load equal to the bridge resistance must be connected across these batteries to prevent a false charge build-up.

4. Periodically the voltage drop across the mercury relay in its closed condition must be measured. If this drop varies by more than 5-10 microvolts with repeated closing of the relay, the relay should be replaced.

5. R_{b1} should normally have a resistance value around 5000 to 6000 ohms for proper resolution in balancing the bridge. In adjusting for a balance, this resistance should never be reduced below 2500 ohms or damage to the thermistors is possible. When no balance can be obtained with R_b = 5000 to 6000 ohms, the fixed resistances R_{b2} should be replaced with higher or lower ohmic values depending on the bias battery voltage -- a larger R_{b2} for $V_o > 8$ volts and a smaller R_{b2} for $V_o < 8$ volts.

6. While the microammeters in the thermistor mount cabinet cannot be used to measure a, they serve to indicate the general condition of the thermistors. If one meter reading goes to zero or both meters read less than 20 µa, de-energize the bridge at once or damage to the thermistors may result. When one or both meters read close to zero, there may be excessive rf applied to the thermistors, driving their resistances down to a dangerously low value, leading to burn-out of one or both. When one meter goes to zero and the other to full scale, a thermistor has opened or one of the decoupling condensors in the mount has become shorted.

7. In connecting the external slide-wire resistance to the bridge, use heavy low-resistance leads or it may not be possible to balance the bridge for rf voltage levels around 20 mv.

8. When calibrating an rf voltmeter, the meter should be connected to the mount with the same connector or connectors which will be used when measurements are made with the voltmeter. In any case, clip-lead connections are to be avoided at radio frequencies. Remember that the rf voltage is accurately known

to ± 1% at the surface of the core in which the thermistors are mounted. The use of connectors will make the voltage at the face of the probe different.

9. Check for rf leakage when the rf voltmeter has been connected to the bridge and rf applied. Some rf voltmeter probes are not adequately shielded. An external shield is oftentimes necessary over the probe and cable to the voltmeter. Make certain that the rf source and cables connecting the source to the bridge are properly shielded also. In some instances the source may also require shielding by placing it within a double-screened cabinet.

10. There must always be a dc return path for the thermistors through the rf source if α is to be measured.

5.00 - Symptoms of Bridge Malfunctioning

5.10 - Erratic or Continuous Rapid Drift of the Bridge

1. RF and dc instability: If the bridge drifts on both rf and dc balance in an erratic or excessively rapid manner, the instability can be due to the following causes:

   a. Poor control of the ambient temperature of the room in which the equipment is located.

   b. Batteries need recharging or replacement.

   c. Excessive heat is being transferred from the rf probe to the thermistor mount.

   d. A faulty resistor in the bridge circuit or dirty contacts in the decade resistance units R_{bl}.

e. A faulty connection in the dc bridge and/or leads from the biasing source to the bridge.

2. RF instability only: When the erratic behavior or drift is observed only on rf, the causes may be the following:

   a. RF leakage currents.

   b. Instability of the rf source.

   c. A faulty rf cable.

   d. SW_{RF} may require repair.

5.20 - Drift in V_o

When the battery voltage applied to the bridge fails to remain constant to 1 part in 10^4 per measurement interval, the batteries may need recharging or replacement.

5.30 - Unbalance Microammeters

In order to measure the degree of unbalance, α, between the thermistors, there must be a dc return path through the rf source. The two microammeters should indicate the same current within ± 20%. Departures greater than this should be investigated. Following are the more commonly occurring conditions and their causes:

1. One meter indication decreases to zero, or near zero. If this condition prevails only when rf is applied, excessive rf is being applied to the thermistors. When the condition prevails on dc, one of the decoupling capacitors in the mount has shorted. If at the same time the other meter goes to full scale, one thermistor has opened.

2. Both meters read approximately the same but there is no decrease in their reading with rf applied. When this happens, even though there is other evidence of rf at the thermistors, look for lack of a dc return path through the rf source.

3. On dc balance the meters read widely different. If potentiometric measurement of α indicates that both the thermistors are well matched, one of the vacuum tube voltmeter circuits in which the microammeters are connected is not functioning or requires readjustment.

6.00 - Construction Details

(Some construction details are given to assist anyone interested in duplicating the thermistor bridge for his own laboratory.)

6.10 - Thermistor Mount Cabinet (Figure 3)

This cabinet houses the thermistor mount and the microammeters which continuously indicate the condition of the thermistors in the mount. The external appearance of the front, top and rear panels is shown in the views of Figure 3. The square opening in the center of the top panel provides access to the surface of the thermistor mount core, where the rf voltage applied to the bridge is standardized. Here a wide variety of adapter plates can be fastened to the mount to permit connecting rf devices to be calibrated with any type of rf connection desired. Figure 4 shows the circuitry in the smaller cabinet. Two shielded six-conductor cables (see Figure 3 also) are used to connect the components to the remainder of the system. Fanning strips FS_1 and FS_2 which terminate the cables are connected to terminal strip TS_1 on the rear of the main cabinet.

A double-shielded, 50-ohm coaxial cable connects the Type N connector on the under side of the thermistor mount (Figure 5) to the rf connector, also Type N, on the rear panel. Another rf cable between the latter and a similar Type N connector on the rear of the main cabinet transmits rf voltage from the output of the special coaxial switch in the main cabinet to the thermistor mount.

Since the 0.01 μf (C_d in Fig. 4) mica blocking capacitors built into the thermistor mount introduce series impedance between the test rf voltmeter and the thermistors at low frequencies, enough additional capacitance, $C_{d_{ext}}$, is connected in parallel externally to make the mount usable down to 30 kc. In Figure 6 a typical method of mounting and connecting external capacitors is shown.

6.20 - Bridge Cabinet

The general arrangement of components within the larger bridge cabinet is shown in Figure 7. The cell supplying dc current for the precision dc measuring potentiometer consists of Ni-Cd cells on continuous trickle charge to stabilize their output. Details for this circuit are given in Figure 8, and the text of Section 6.30. The schematic for the vacuum-tube voltmeters is shown in Figure 9 and the descriptive text is presented in Section 6.40. Details regarding the construction of the Wheatstone Bridge are given in Figures 11 and 12 and Section 6.50.

6.30 - Potentiometer DC Current Supply

When the Ni-Cd cells need replacement, the new cells should be brought to full charge according to the manufacturer's instructions. Then the cells are connected to the trickle charger with a milliameter in series with the cells temporarily. It would also be well to connect a milliameter in series with the dc measuring potentiometer to which the dc current supply is connected. Usually it will be necessary only to vary R_{28} (Figure 8) to adjust the charging current to 40 ma and R_{29} to set the current at the measuring potentiometer to 1 ma.

When the output from the supply does not remain steady, the charging current and the load current should be checked. Readjustment of either or both currents might be required. Ordinarily, once the dc current supply has been placed in service, R_{27} does not require readjustment unless there has been a large change in the 110 volt 60-cycle ac line input.

6.40 - a Monitoring Vacuum-Tube Voltmeters

Figure 9 presents the complete schematic for the simple vacuum tube voltmeters used to continuously monitor the condition of the thermistors, while Figure 10 represents that part of the voltmeter circuits in the main cabinet. Connections to the indicating microammeters and the measuring points on the thermistor mount in the other cabinet are made through terminals h---n of terminal strip TS_1 and the corresponding terminals of fanning strip FS_1 (see Figure 4).

6.50 - DC Bridge Construction

The schematic for the portion of the dc bridge in the main cabinet is included in Figure 11, and the physical arrangement of the components is shown in Figure 12. The resistors comprising the bridge arms are mounted on two bakelite panels. The adjustable decade resistance units which comprise the vernier adjustments for the R_b arms are mounted on the lower half of both the front and rear panels. The upper half of the front panel is occupied by the variable resistors A, B, C, and D, while the fixed resistors R_T and R_{b2} are attached to the upper half of the rear panel. Each pair of decades having the same ohmic range is coupled mechanically together with insulated shaft couplings. In this way, one knob for each pair adjusts both R_b arms by the same amount.

The rf cable from the thermistor mount cabinet connects to rf connector RF_1, and the signal generator supplying the rf voltage connects at RF_2.

Terminals o, p and q of fanning strip FS_2 connect to the corresponding terminals of terminal strip TS_1.

References

Selby, M. C., and L. F. Behrent, A bolometer bridge for standardizing radio-frequency voltmeters, J. Research NBS 44, 15 - 30 (Jan. 1950).

TABLE I

Panel Control Functions (Figure 1)

Connectors and Controls	Purpose
RF Input	A Type N connector through which rf power from an rf source is supplied to the bridge.
SW_{RF}	A coaxial switch connected between the rf input connector and the thermistor mount. With this switch in the "out" position, no rf is applied to the bridge and a microswitch actuated by the switch handle causes mercury relay MS, Figure 2, to close, applying full dc bias to the bridge. When the rf switch is closed, rf passes to the mount and the microswitch causes the mercury relay to open, placing the combination of resistors A, B, C, and D in series with the bridge to keep the bridge in balance.
PWR	Controls 60 cps mains to the auxilliary equipment associated with the bridge such as the mercury relay, electronic galvanometers, and the VTVMS. When in the "off" position, the switch places a dummy load across the biasing batteries.
A B C D	The coarse and vernier variable resistors which constitute R_2 in series with the bridge when the mercury relay MS is open.
R_{b1}	These four resistor decades are the adjustable vernier resistors of the R_b arms of the bridge. On dc, adjusting them balances the bridge.

Table I continued

Connectors and Controls	Purpose
SW_1	Voltage divider for use when the dc voltages applied to the dc measuring potentiometer exceed 1.5 volts. (For measuring V_{R2} and V_o.) In position "V_{R2}" the potentiometer measures that voltage directly. In the $V_{R2} \times 10$ position, the potentiometer measures only 1/10 of V_{R2}. In the V_o position 1/10 of V_o is measured.
SW_2	Connects the potentiometer either to SW_1 for measuring dc bridge voltages V_o and V_{R2} or to SW_3 for determining α, the unbalance ratio between the two thermistors in the mount. At position "α" the potentiometer measures the voltage drops across the thermistors. In the other position, V, bridge voltages are measured.
SW_3	Connects the potentiometer across each of the thermistors for determining α.
SW_4	This switch, labeled "a" on the bridge, together with the controls labeled a_2 and a_3, provides a convenient means of measuring α. SW_4 is adjusted in steps until with the continuous adjustment of a_2 and a_3 the potentiometer reads 1 volt across either R_{T1} or R_{T2}. Switching to the other thermistor, the potentiometer voltage measurement equals the value of α directly.

TABLE II

Allowable Errors in Component Parts and Measured Quantities

Component	Measured Quantity	Allowable Error in %
R_T		± 0.17 For R_T = 200 ohms
R_b		± 0.17 R_b = approx. 300 ohms
	α	± 1.2 for $\alpha = 1.4$ * ± 0.6 for $\alpha = 2.0$
	V_o	± 0.17 - 0.20 Δ
	V_{R2}	0.17 - 0.24 Δ
	V_{R1}	1.1 □

* For α between the ideal 1.00 and 1.4, high accuracy is not needed.

Δ For rf voltages between 20 mv and 1.5 volts.

□ With the dc measuring potentiometer used 110 μv can be measured to ± 1 μv which represents about 1%.

LIST OF COMPONENTS

PART NO.	RESISTANCES	QUANTITY
R_{b2}	300-ohm working std. type, ± 0.1%	2
"	340-ohm working std. type, ± 0.1%	2
"	400-ohm working std. type, ± 0.1%	2
R_T	200-ohm working std. type, ± 0.1%	1
R_{b1}	9 × 1000-ohm decade resistance assembly, ± 0.1%	2
"	9 × 100-ohm decade resistance assembly, ± 0.1%	2
"	9 × 10-ohm decade resistance assembly, ± 0.1%	2
"	9 × 1-ohm decade resistance assembly, ± 0.1%	2
R_L	200-ohm w.w. 1/2 watt resistor	1
R_{d1}	100 K ohm, 1 watt, precision, ± 1.0%, calibrated after installation	2
R_{d2}	10 K ohm, 1 watt, precision, ± 1.0%, calibrated after installation	2
"	1 K ohm, 1 watt, precision, ± 1.0%, calibrated after installation	2
"	100-ohm, 1 watt, precision, ± 1.0%, calibrated after installation	2
	(10 K + 1 K + 100 ohm in series constitutes R_{d2})	
A	1.15-ohm, 10-turn potentiometer	1
B	100-ohm, 10-turn potentiometer	1
C	25-ohm, 10-turn precision potentiometer	1
D	500-ohm, 10-turn potentiometer	1
R_{a2}	1 K ohm, 10-turn precision potentiometer	1
R_{a3}	250 K ohm carbon potentiometer	1
R_{v1}	250 K ohm 1/2 watt carbon, ± 5%	1
R_{v2}	100 K ohm 1/2 watt carbon, ± 5%	1
R_{v3}	100 K ohm 1/2 watt carbon, ± 5%	1
R_{v4}	100 K ohm 1/2 watt carbon, ± 5%	1

List of Components (continued)
Page Two

PART NO.	RESISTANCES	QUANTITY
R_{v5}	100 K ohm 1/2 watt carbon, ± 5%	1
R_{v6}	100 K ohm 1/2 watt carbon, ± 5%	1
R_{v7}	100 K ohm 1/2 watt carbon, ± 5%	1
R_{v8}	100 K ohm 1/2 watt carbon, ± 5%	1
R_{v9}	100 K ohm 1/2 watt carbon, ± 5%	1
R_{v10}	100 K ohm 1/2 watt carbon, ± 5%	1
R_{v11}	100 K ohm 1/2 watt carbon, ± 5%	1
R_{v12}	510 K ohm 1/2 watt carbon, ± 5%	1
R_{13}, R_{14}	10-meg, carbon, 1/2 watt	2
R_{15}, R_{16}	1-meg, carbon, 1/2 watt	2
R_{17}, R_{18} R_{19}, R_{20}	200-ohm, carbon, 1/2 watt	4
R_{21}, R_{22} R_{23}, R_{24}	10 K ohm, carbon, 1 watt	4
R_{25}, R_{26}	3 K, w.w., 2-watt potentiometer	2
R_{27}, R_{28}, R_{29}	100-ohm, w.w., 1-watt potentiometer	3

PART NO.	CAPACITORS	QUANTITY
C_1, C_2	1000 µf, 12-volt, electrolytic	2
C_3, C_4	16 µf, 200-volt, electrolytic	2
$C_{d_{ext}}$	0.25 µf-mica, external additional capacitance, 3 placed in parallel with each of the built-in capacitances of the mount	6

PART NO.	GALVANOMETERS	QUANTITY
Bridge & Potentiometer	Electronic, current sensitivity 1×10^{-9} amp/mm, internal resistance approx. 1000 ohms, both input terminals off ground	2

List of Components (continued)
Page Three

PART NO.	BATTERIES	QUANTITY
	Low discharge, 2 volts per cell, 600 ampere-hour	4

PART NO.	D. C. MEASURING POTENTIOMETER	QUANTITY
	Precision, having ± 0.01% accuracy and voltage ranges of 0-0.01601, 0-0.1601, 0-1.601 volts	1

PART NO.	MERCURY RELAY	QUANTITY
	Three circuit, normally open, with solenoid operated from 110-volt, 60-cycle, a.c. line	1

PART NO.	TRANSFORMERS	QUANTITY
T_1, T_2	Filament transformers, 110 ac input, 6.3 volt, 2 amp output	2
T_3	Filament transformer, 110 ac input, 6.3 volt, 1.2 amp output	1

PART NO.	MISCELLANEOUS	QUANTITY
D_1, D_2, D_3 D_4, D_5	Diodes, type 1 N 1084, M 500	4
L	Lamp, 6.3 volt	1
M_1, M_2	0-100 μ amp dc meter	2
E	Nickle-cadmium cells, 1.30 volts per cell fully charged, 4-amp/hour rating for 5 hours.	3

CAPTIONS FOR ILLUSTRATIONS

Figure 1	Front view of the 1% thermistor bridge control cabinet showing the location of controls, indicators,and connectors.
Figure 2	Schematic diagram of the 1% bridge.
Figure 3	Three views of the cabinet housing the thermistor mount showing the location of meters and connectors.
Figure 4	Schematic of the circuitry in the thermistor mount cabinet.
Figure 5	Cross-sectional view of the thermistor mount.
Figure 6	A typical method of mounting and connecting external capacitors in parallel with the built-in blocking capacitors in the thermistor mount.
Figure 7	Interior view of the bridge cabinet from the rear to illustrate the placement of major components of the bridge.
Figure 8	Schematic of the dc current source for the precision dc measuring potentiometer.
Figure 9	Schematic of the vacuum-tube voltmeters used for monitoring the condition of the thermistors.
Figure 10	Schematic of that portion of the vacuum-tube voltmeter circuits contained in the main cabinet.
Figure 11	Schematic of the part of the dc bridge located in the main cabinet.
Figure 12	Physical arrangement of components of the bridge assembly.

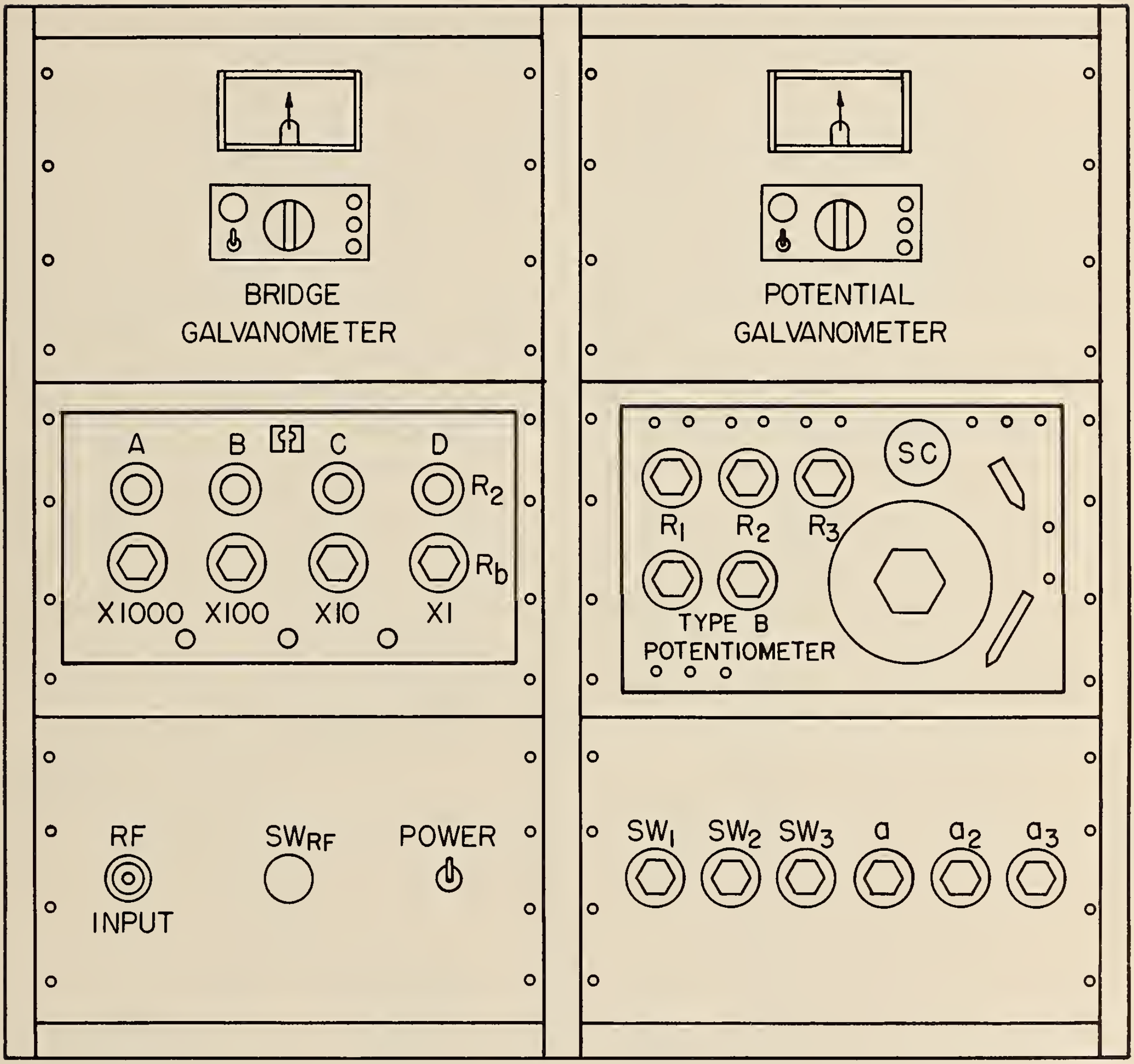
BRIDGE
GALVANOMETER
POTENTIAL
GALVANOMETER
A
B
C
D
R_2
R_b
X1000
X100
X10
X1
SC
R_1
R_2
R_3
TYPE B
POTENTIOMETER
RF
INPUT
SW_{RF}
POWER
SW_1
SW_2
SW_3
a
a_2
a_3

Figure 1

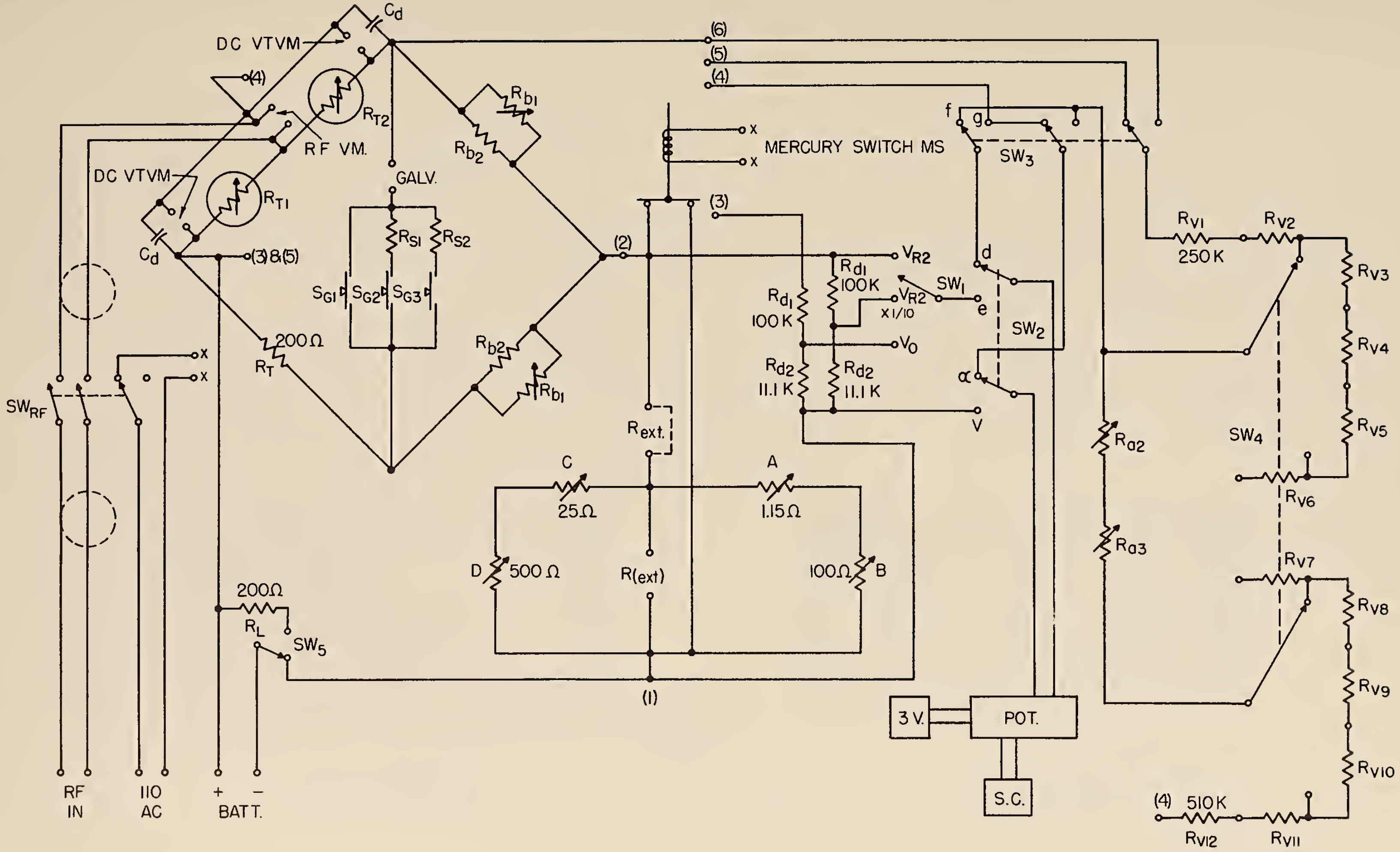
DC VTVM
Cd
(4)
RT2
RF VM.
DC VTVM
RT1
Cd
(3)&(5)
GALV.
RS1
RS2
SG1
SG2
SG3
Rb1
Rb2
200Ω
RT
Rb2
Rb1
(2)
(6)
(5)
(4)
(3)
x
x
MERCURY SWITCH MS
f
g
SW3
d
SW1
e
SW2
α
V
VR2
Rd1
100K
VR2
X 1/10
V0
Rd2
11.1 K
Rd1
100K
Rd2
11.1 K
Rext.
C
25Ω
A
1.15Ω
D
500 Ω
R(ext)
100Ω
B
(1)
200Ω
RL
SW5
SWRF
x
x
RF
IN
110
AC
+
–
BATT.
3 V.
POT.
S.C.
RV1
250K
RV2
RV3
RV4
RV5
SW4
RV6
Ra2
Ra3
RV7
RV8
RV9
RV10
(4)
510K
RV12
RV11

Figure 2

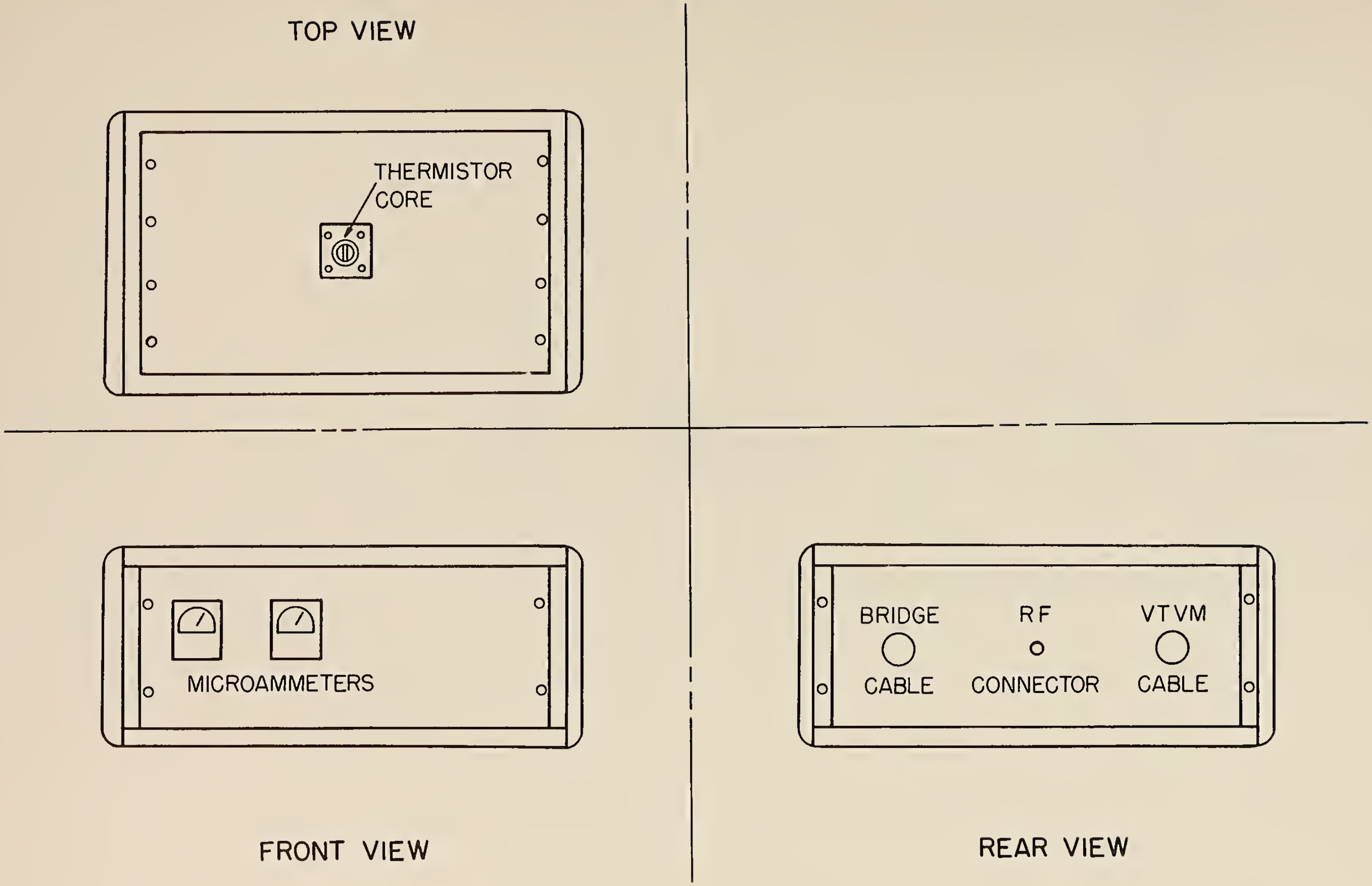
TOP VIEW
THERMISTOR
CORE
MICROAMMETERS
FRONT VIEW
BRIDGE
CABLE
RF
CONNECTOR
VTVM
CABLE
REAR VIEW

Figure 3

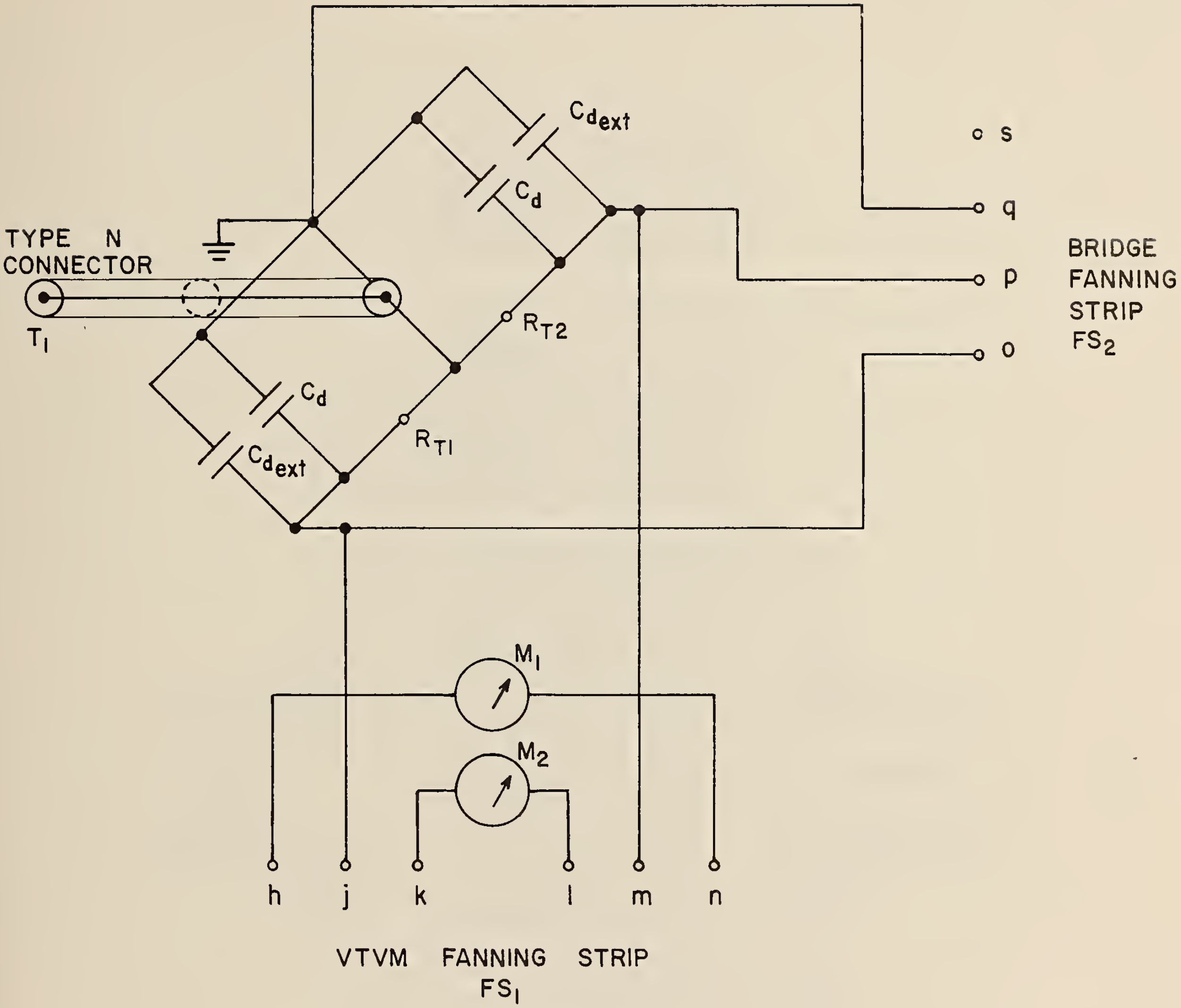
$C_{d\,ext}$
C_d
s
q
p
o
BRIDGE FANNING STRIP FS_2
TYPE N CONNECTOR
T_1
R_{T2}
C_d
R_{T1}
$C_{d\,ext}$
M_1
M_2
h
j
k
l
m
n
VTVM FANNING STRIP FS_1

Figure 4

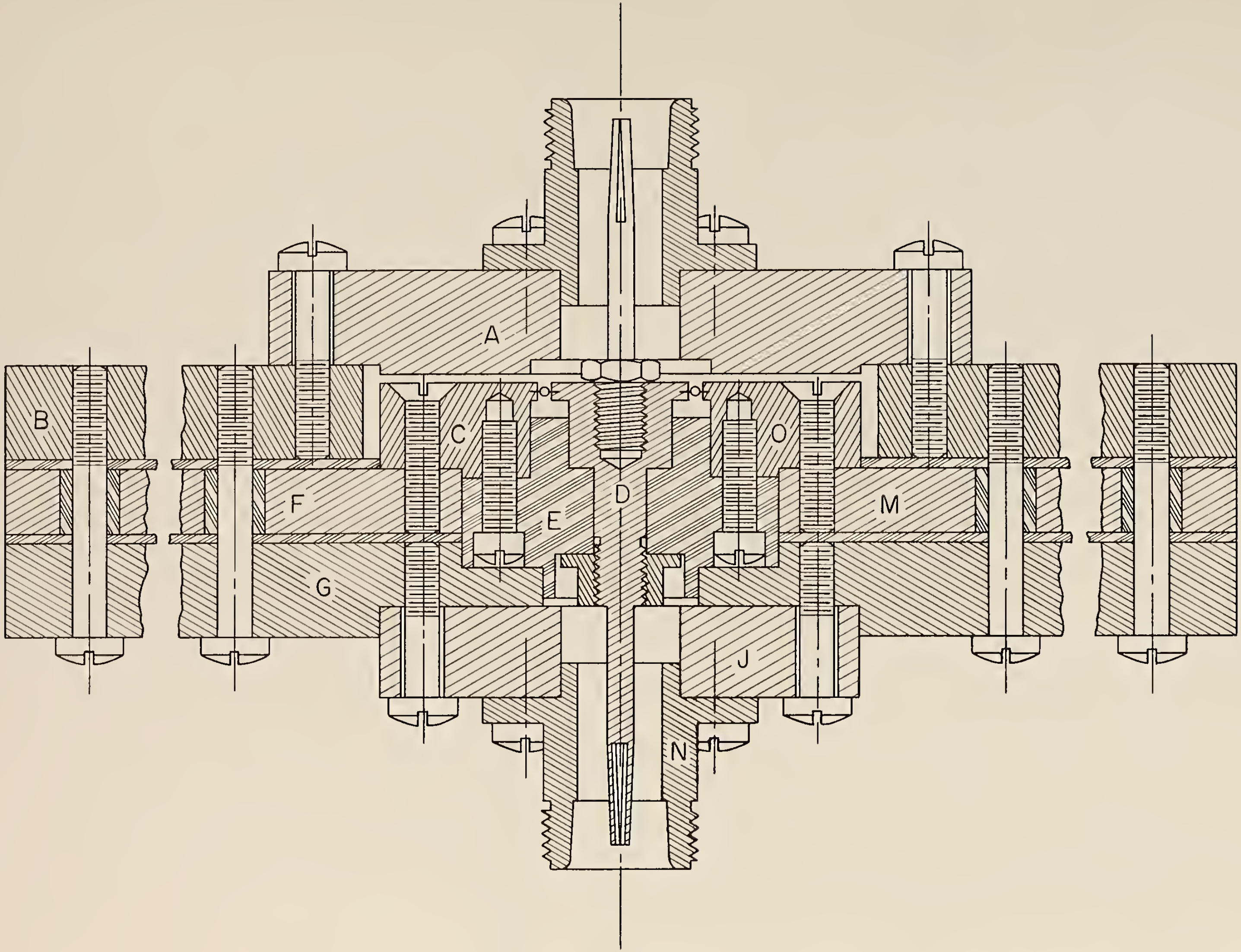

Figure 5

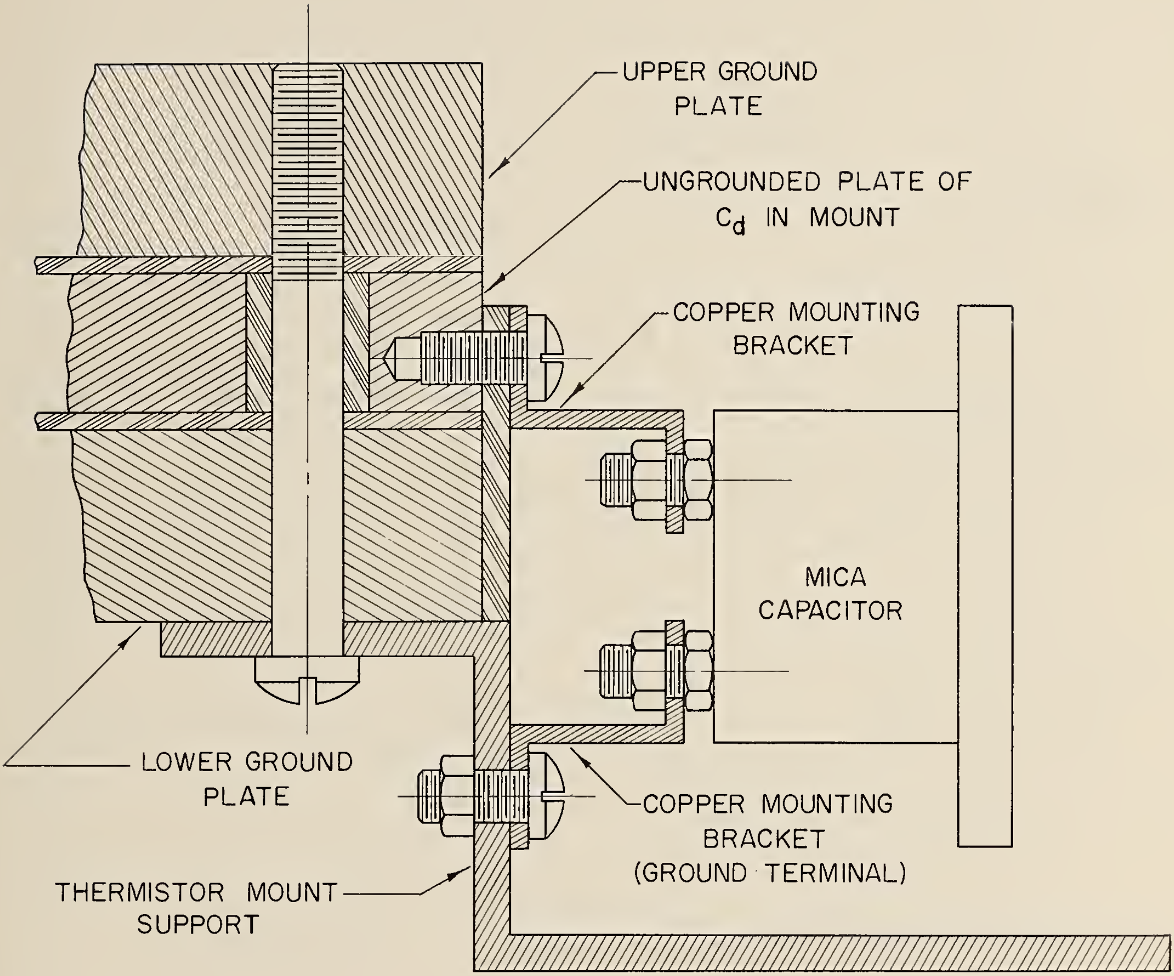
UPPER GROUND PLATE
UNGROUNDED PLATE OF C_d IN MOUNT
COPPER MOUNTING BRACKET
MICA CAPACITOR
LOWER GROUND PLATE
COPPER MOUNTING BRACKET (GROUND TERMINAL)
THERMISTOR MOUNT SUPPORT

Figure 6

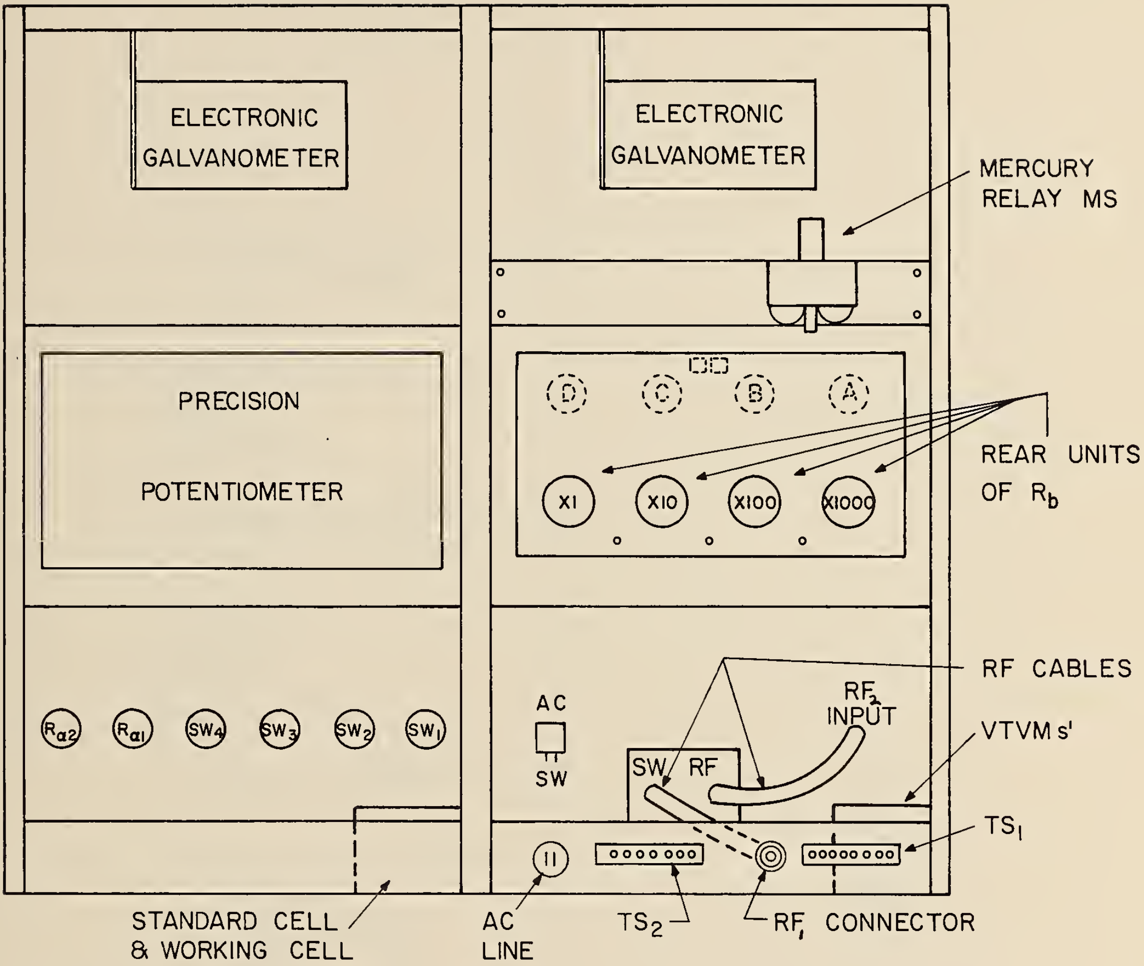
ELECTRONIC GALVANOMETER
ELECTRONIC GALVANOMETER
MERCURY RELAY MS
PRECISION POTENTIOMETER
D
C
B
A
X1
X10
X100
X1000
REAR UNITS OF R_b
R_{a2}
R_{a1}
SW_4
SW_3
SW_2
SW_1
AC SW
SW RF
RF_2 INPUT
RF CABLES
VTVM s'
TS_1
STANDARD CELL & WORKING CELL
AC LINE
TS_2
RF_1 CONNECTOR

Figure 7

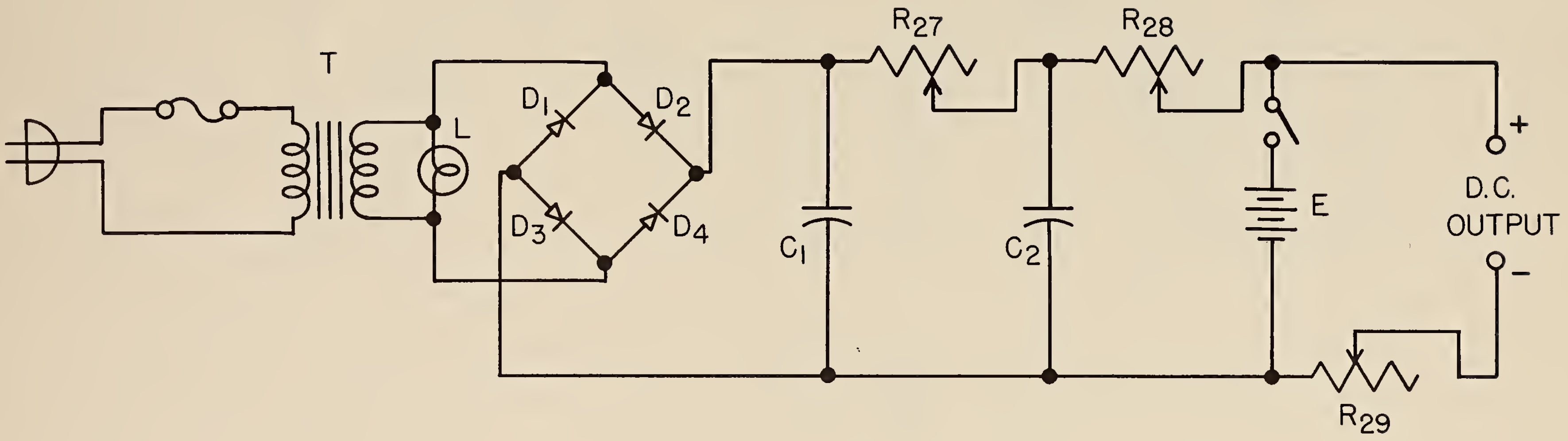

Figure 8

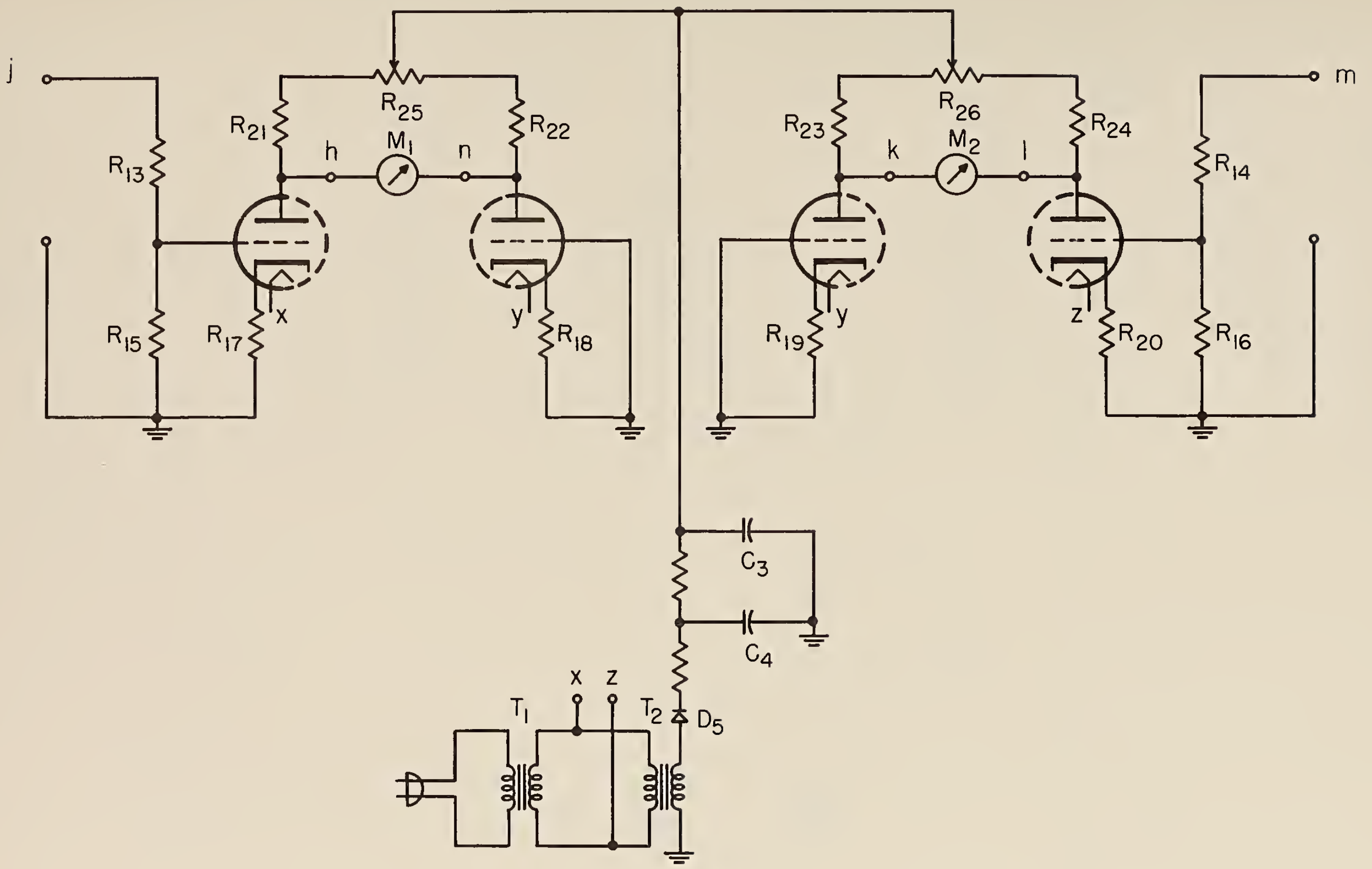
j
m
R25
R26
R21
R22
R23
R24
R13
R14
h
M1
n
k
M2
l
x
y
y
z
R15
R17
R18
R19
R20
R16
C3
C4
x
z
T1
T2
D5

Figure 9

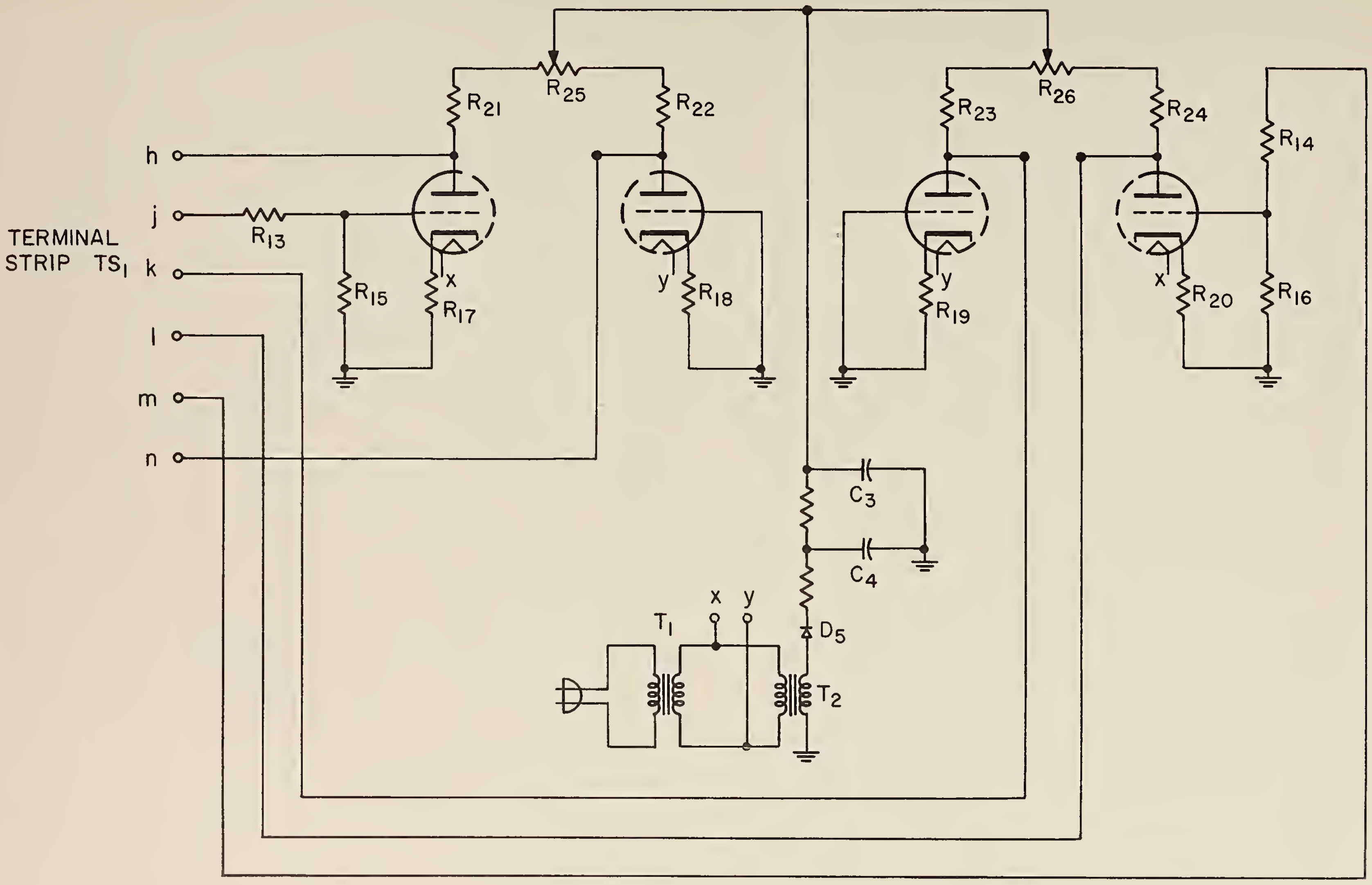
TERMINAL STRIP TS$_1$
h
j
k
l
m
n
R$_{13}$
R$_{15}$
R$_{17}$
x
R$_{21}$
R$_{25}$
R$_{22}$
y
R$_{18}$
R$_{23}$
R$_{26}$
R$_{24}$
R$_{19}$
y
x
R$_{20}$
R$_{14}$
R$_{16}$
C$_3$
C$_4$
D$_5$
T$_1$
x
y
T$_2$

Figure 10

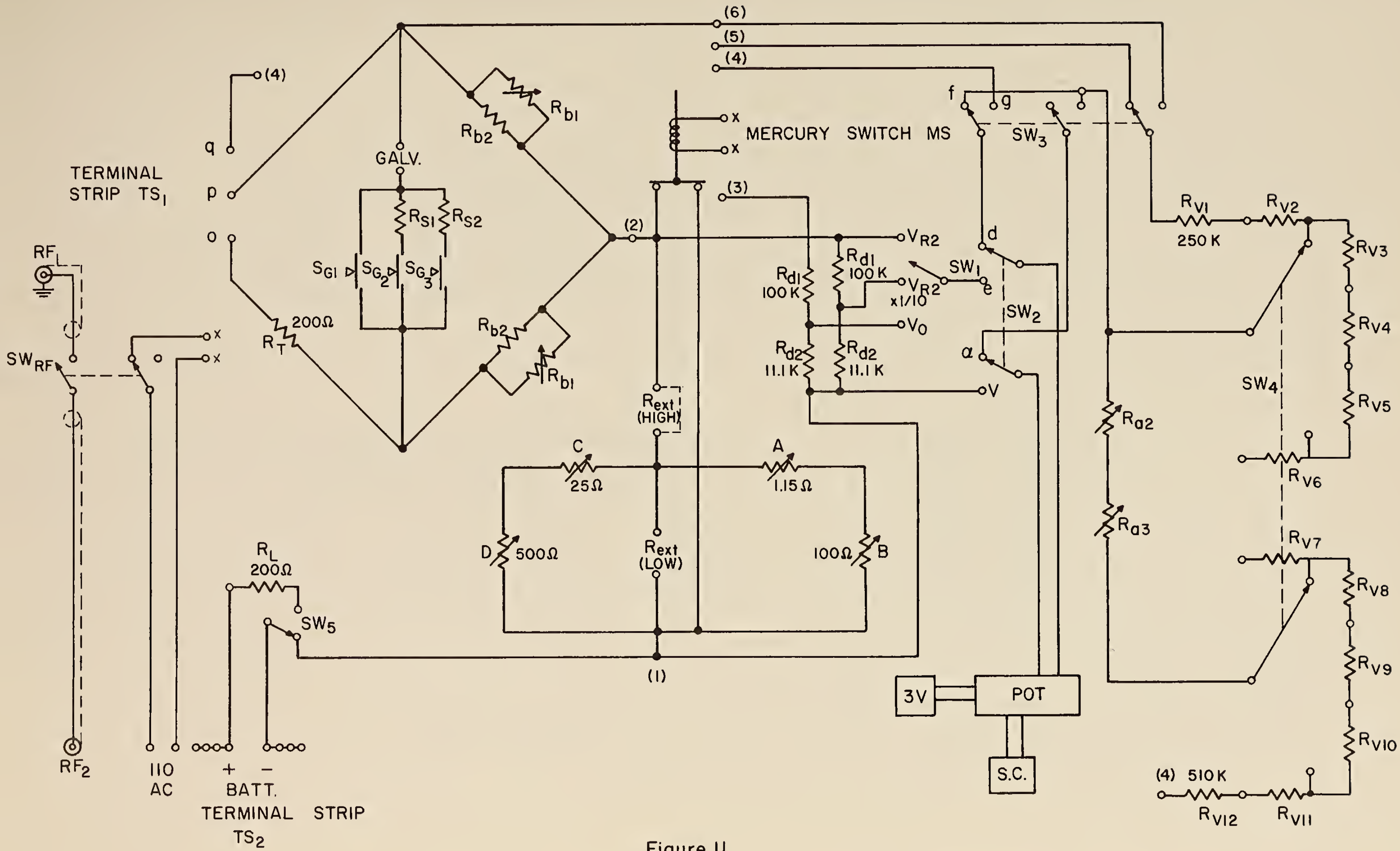
TERMINAL STRIP TS$_1$
(4)
q
p
o
RF$_L$
SW$_{RF}$
RF$_2$
x
x
110 AC
+
−
BATT.
TERMINAL STRIP TS$_2$
R$_T$ 200Ω
GALV.
R$_{S1}$
R$_{S2}$
S$_{G1}$
S$_{G2}$
S$_{G3}$
R$_{b1}$
R$_{b2}$
R$_{b2}$
R$_{b1}$
(2)
(1)
(3)
(4)
(5)
(6)
x
x
MERCURY SWITCH MS
R$_{ext}$ (HIGH)
R$_{ext}$ (LOW)
C 25Ω
A 1.15Ω
D 500Ω
100Ω B
R$_L$ 200Ω
SW$_5$
R$_{d1}$ 100 K
R$_{d1}$ 100 K
R$_{d2}$ 11.1 K
R$_{d2}$ 11.1 K
V$_{R2}$
V$_{R2}$ x1/10
V$_0$
V
SW$_1$
e
d
SW$_2$
α
f
g
SW$_3$
3V
POT
S.C.
R$_{a2}$
R$_{a3}$
R$_{V1}$ 250 K
R$_{V2}$
R$_{V3}$
R$_{V4}$
R$_{V5}$
R$_{V6}$
SW$_4$
R$_{V7}$
R$_{V8}$
R$_{V9}$
R$_{V10}$
R$_{V11}$
R$_{V12}$
(4) 510 K

Figure 11

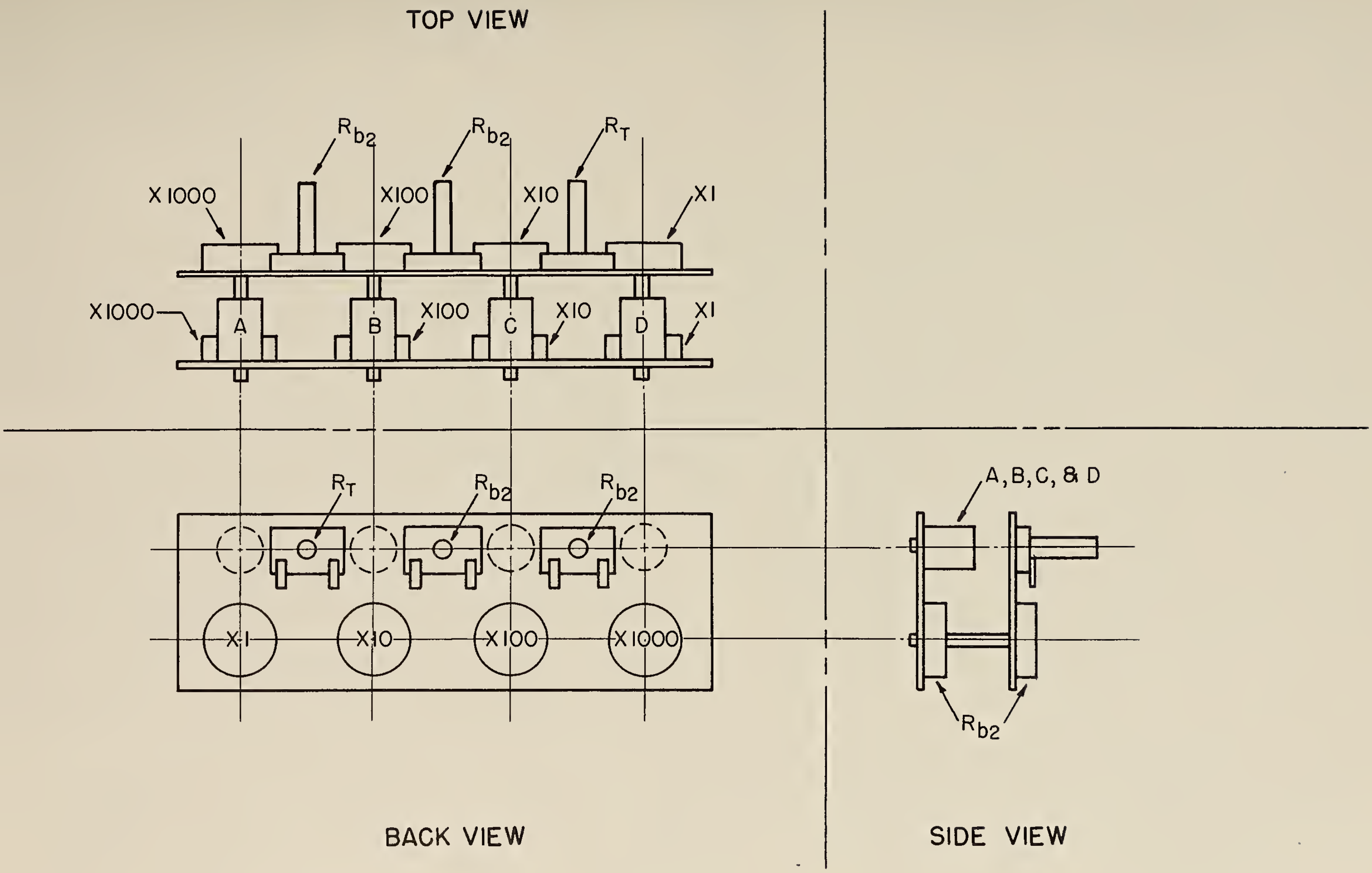
TOP VIEW
R_{b2}
R_{b2}
R_T
X1000
X100
X10
X1
X1000
A
B
X100
C
X10
D
X1
R_T
R_{b2}
R_{b2}
A, B, C, & D
X1
X10
X100
X1000
R_{b2}
BACK VIEW
SIDE VIEW

Figure 12

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics. Electrolysis and Metal Deposition.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

Radio Systems. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.


NBS