NRL REPORT 3517

FR-3517

A METHOD OF MEASURING SMALL RADIO-FREQUENCY POWERS

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August 9, 1949

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ABSTRACT

The sensitivity of the standard bolometer bridge circuit is increased ten-fold by switching between a standard and unknown power at the resonant frequency of the indicating galvanometer. This technique has the advantage of reducing the masking effects due to drifts in ambient temperature and supply voltages for the bridge circuit. Powers may be measured to one microwatt and below.

PROBLEM STATUS

This is an interim report on this problem; work is continuing.

AUTHORIZATION

NRL Problem No. R10-05R

A METHOD OF MEASURING SMALL RADIO-FREQUENCY POWERS

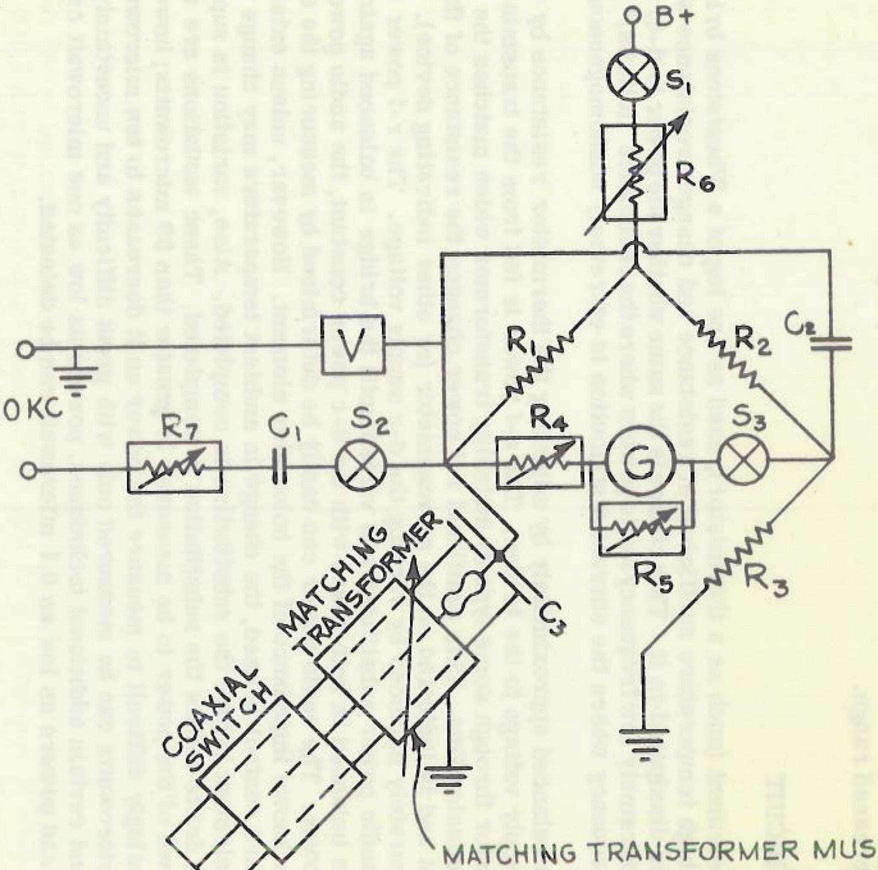
INTRODUCTION

During the investigations of r-f wattmeters, it was realized that there was a need to lower the range of measuring radio-frequency powers from ten microwatts to lower than one microwatt, in order to investigate thoroughly and accurately the properties of directional couplers and other power dividers. Although the bolometer element (thermistor) was sufficiently sensitive to detect this power, the effect was masked by the drifts in ambient temperature and supply voltage for the bridge circuit. Accordingly, a study was undertaken, and the result is a method which permits "seeing through" the masking drifts. The basic bolometer bridge circuit which has been in use for many years at the Naval Research Laboratory and other laboratories will be described, together with the additions which gave the increased range.

BASIC BRIDGE CIRCUIT

A bolometer element (such as a thermistor), used as one leg of a Wheatstone bridge (Figure 1), has a high temperature coefficient of resistance and changes resistance when heated by any power dissipated in it. This change is the same whether the power is d-c, audio, of r-f except for extremely low frequency audio powers where the resistance "follows," or at extremely high frequency where the current distribution is extremely nonhomogeneous.

The bridge is balanced approximately by adjusting the thermistor resistance by variation of the d-c supply voltage to the bridge. The r-f power is fed from the transmission line to the thermistor through some type of matching transformer which matches the element to the transmission line. This additional r-f power changes the resistance of the bolometer element and is indicated on the galvanometer (or other indicating device). The bridge is then accurately balanced by varying the d-c supply voltage. The r-f power is removed and the audio power substituted and varied until the bridge is balanced again. Since the bridge is balanced in both cases with the d-c power constant, the audio power is equal to the r-f power. The audio power can easily be determined by measuring the audio voltage across the known impedance of the bolometer element. However, unless extensive ambient temperature control is used, the change in ambient temperature may change the resistance of the element before the substitution is completed. Also, variation in supply voltage may cause drifts before the substitution is completed. These variations are very small when the level of the power to be measured is greater than 50 microwatts; however, it becomes increasingly difficult to measure the power as it decreases to ten microwatts. Power below 10 microwatts can be measured only with great difficulty and uncertainty. With this bridge and certain additional techniques, powers as low as one microwatt can be measured easily, and powers as low as 0.1 microwatt can be detected.



MATCHING TRANSFORMER MUST
PROVIDE D-C GROUND FOR CENTER
CONDUCTOR OF COAXIAL LINE

SUGGESTED CIRCUIT CONSTANTS

$R_1 = R_2 = 200\Omega$ (±0.1%)
R_3 = OPERATING RESISTANCE OF THERMISTOR - 200Ω (±0.1%)
R_4 = GALVANOMETER SENSITIVITY CONTROL
R_5 = GALVANOMETER DAMPING CONTROL
R_6 = D-C CONTROL
R_7 = AUDIO POWER CONTROL
C_1 = D-C BLOCKING CAPACITOR $1.0\mu f$
$C_2 = 0.25\mu f$
C_3 = BUILT-IN CAPACITOR
S_1 = D-C SWITCH
S_2 = AUDIO SWITCH
S_3 = GALVANOMETER SWITCHES (TOGGLE SWITCH AND TAP SWITCH IN PARALLEL)
V = AUDIO VOLTMETER

Fig. 1 - Basic bridge circuit

THE LOW-POWER BRIDGE

The complete circuit for measuring power below 10 microwatts is shown in Figure 2. The basic bridge circuit is the same, except that the switches on the audio and r-f powers are controlled by relays; when the audio switch is "on" the r-f switch is "off," and vice versa. These relay switches are driven by a gas tube controlled by a multivibrator. With only the r-f power present (audio power off), the frequency of the multivibrator is adjusted so that, when it is the same as the resonant frequency of the galvanometer, the latter will vibrate with greatest amplitude. This alone is an advantage since using the galvanometer at its resonant frequency increases the sensitivity of the galvanometer. The audio power is then introduced into the circuit and as the audio power is increased, the vibration will become less and less until the vibration stops entirely. If the audio power is increased beyond that of the r-f power, the galvanometer will again begin to vibrate but in opposite phase with the position of the relays. When the vibration is brought to a null (or minimum), the r-f power is equal to the audio power. The audio power may then easily be calculated from the measured voltage across the known thermistor resistance.

CIRCUIT CONSIDERATIONS

The basic bridge circuit is shown in Figure 1. The resistors R_1, R_2, R_3 must be precision resistors since the accuracy of the power measurement depends upon knowing the resistance of the thermistor. If R_1 and R_2 are equal, it is seen from the Wheatstone bridge relations that, when the bridge is balanced, the operating resistance of the thermistor is equal to R_3. It is for this reason that the bridge must be operated close to balance. Resistor R_3 is set in this bridge to be 200 ohms since most of the thermistor mounts were designed for a 200-ohm resistance. However, R_3 may be changed to agree with the impedance for which the thermistor mount is designed. The matching transformer may be any of the many types used. However, it must present a d-c short between inner and outer conductor so as to provide a d-c and audio return for the thermistor. The coaxial switch is driven by solenoids and designed to maintain constant impedance. This particular electrical drive uses 28 volts and requires a special power supply.

The bridge is powered by two parallel heavy-duty 45-volt batteries. Although this technique "sees through" usual power supply drifts, there are certain limitations, and it is therefore desirable to use batteries which are not erratic. To permit the fine control of the d-c current in the bridge and still allow a wide range, the dropping resistor R_6 (as shown in Figure 3) consists of an 11-position switch adding 820 ohms per step in series with a 1000-ohm helipot. In addition, there is a fixed 1000-ohm resistor to prevent accidental overload.

The galvanometer is chosen for high sensitivity, medium period, and low critical damping resistance. When automatic switching is being used the galvanometer should be undamped, but, when manual switching is used critical damping is desirable. For this reason, and to allow a wide choice of galvanometers, the variable damping resistor R_5 is placed across the galvanometer. One position of the switch is open leaving the galvanometer undamped. To provide variable sensitivity of the galvanometer circuit, the step resistor R_4 is provided. The switch S_3 is actually two switches in parallel. One switch is a tap switch which can be used for momentary surges to obtain initial balance; the other is a toggle switch which can be closed when balance is secured.

The audio circuit consists of a 10-kc source which can be finely controlled by the resistor network R_7 (Figure 3) consisting of 10 steps of 82 ohms each in series with a 100-ohm helipot. A condenser C_1 is used to block the d-c circuit isolating the d-c Wheatstone

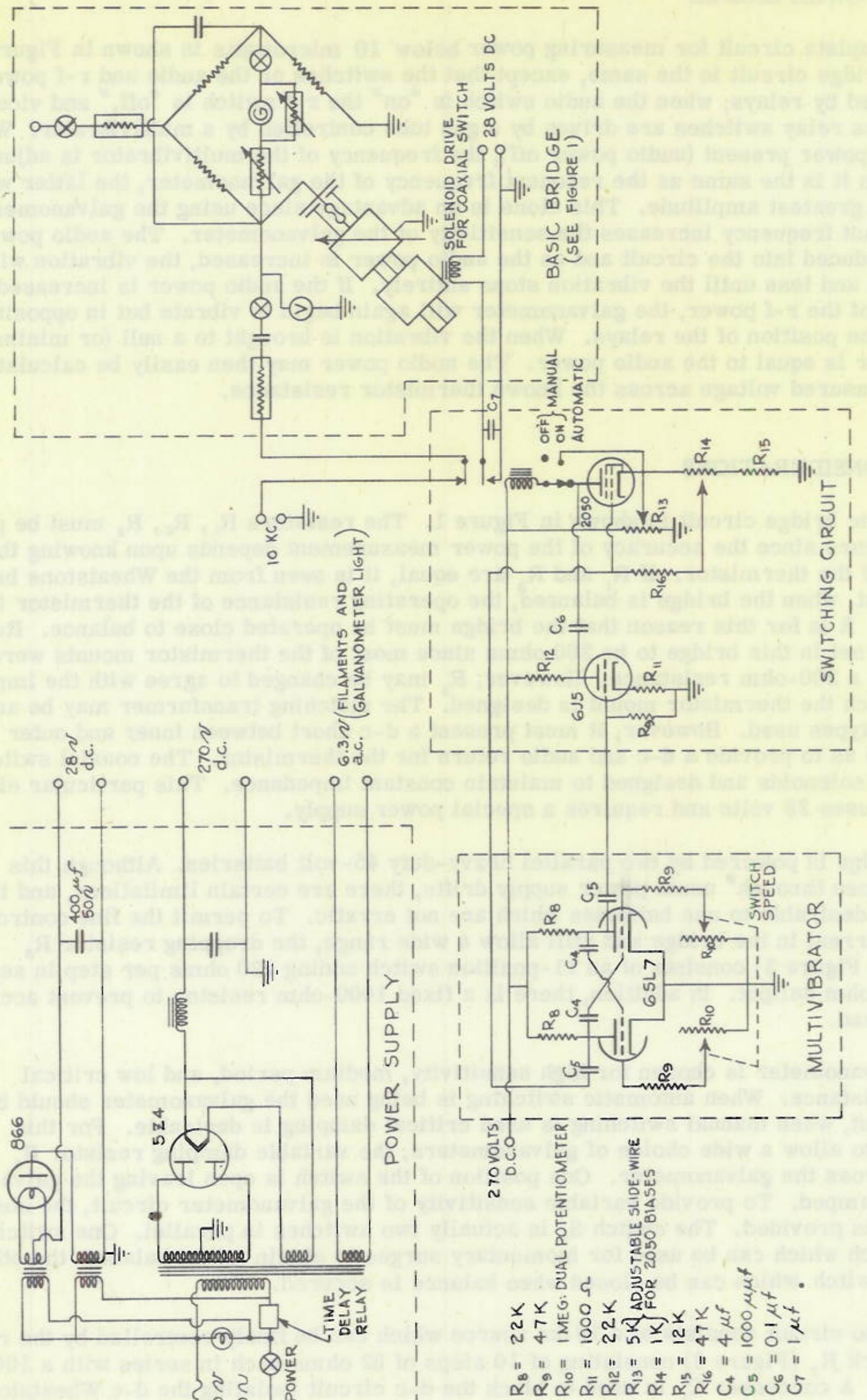


Fig. 2 Wide-range microwatt bridge

bridge. The switch S_2 is provided to permit manual control of the audio signal. A Ballantine voltmeter was used to measure the audio voltage. In order to prevent the sensitivity control from changing the impedance of the circuit into which the audio works, a condenser C_2 is placed across the galvanometer circuit.

The power supply is conventional. It provides 6 volts for the filaments, 275 volts for the multivibrator and keying circuits, and 28 volts to drive the coax relay switch. The freerunning 6SL7 multivibrator frequency is controlled between 0.1 cps and 2 cps by the dual grid resistors. The signal from one plate of the multivibrator controls the grid of the 2050 and the grid from the other plate controls the grid of a 6J5. The output of the 6J5 is placed on the plate of the 2050. This arrangement drives the plate of the 2050 negative as the grid goes negative, insuring cutoff for the 2050 and positive control of the relay switches. Figure 4 shows the front panel arrangement of the equipment; Figure 5, the chassis arrangement; and Figure 6, the equipment with accessories connected for operation.

ERROR CONSIDERATIONS

The main errors in this technique of power measurement are those generally occurring in this audio-substitution type of measurement, plus the error unique to this system in obtaining a null vibration.

Probably the largest error which occurs in the measurement is due to the matching transformer and coax switch and varies in magnitude depending on the quality of the transformer and switch. This error can be made lower than 2 percent through good design, and since this error is not a fault of the technique, it is assumed that the transformer and switch are of a quality at least this good. Since the power is measured as $(E_A{}^2/R_T)$, where E_A is the audio voltage and R_T is the thermistor resistance, error can be introduced by measurement of either quantity. The accuracy in determining R_T depends on the resistance of three 0.1-percent resistors and upon how close the bridge can be brought to balance. The resistors may introduce an error of 0.3 percent, and the small unbalance of the bridge will cause an error of less than 0.2 percent. The total error in R_T is then less than 0.5 percent. A Ballantine Model 300 A voltmeter is used to measure the audio voltage and, although this voltmeter is carefully calibrated against a standard, it may have an error as high as 2 percent and will introduce a 4-percent error in power measurement. An audio source with very low harmonic content is used to power the bridge, and since the Ballantine tends to read the r.m.s. voltage, the error introduced from this source is negligible. The total error introduced in the standard bridge should not exceed 4.5 percent if no additional error is introduced by failure of the operator to duplicate readings.

The manual substitution error depends upon the amount of power being measured, stability of power sources, and ambient temperature. Roughly this error varies from 1 percent when measuring 100 μw to 20 or 30 percent measuring 10 μw. Generally it is not practical to measure less than 10 μw with the standard bridge. However, with the low-power vibration technique the substitution error can be kept at 1 percent down to 10 μw and will increase to 10 percent at 3 μw. One μw can be detected and measured with still less accuracy.

The only additional errors that may be introduced by the vibration technique are those due to lack of perfect synchronism between the r-f and the audio relay switches. If these contacts "stick," it would be impossible to obtain a null. However, no difficulty such as this has been experienced. Therefore, when using the vibration technique, the total error in measurement down to 10 μw is less than 5.5 percent and is less than 14.5 percent when measuring 3 μw.

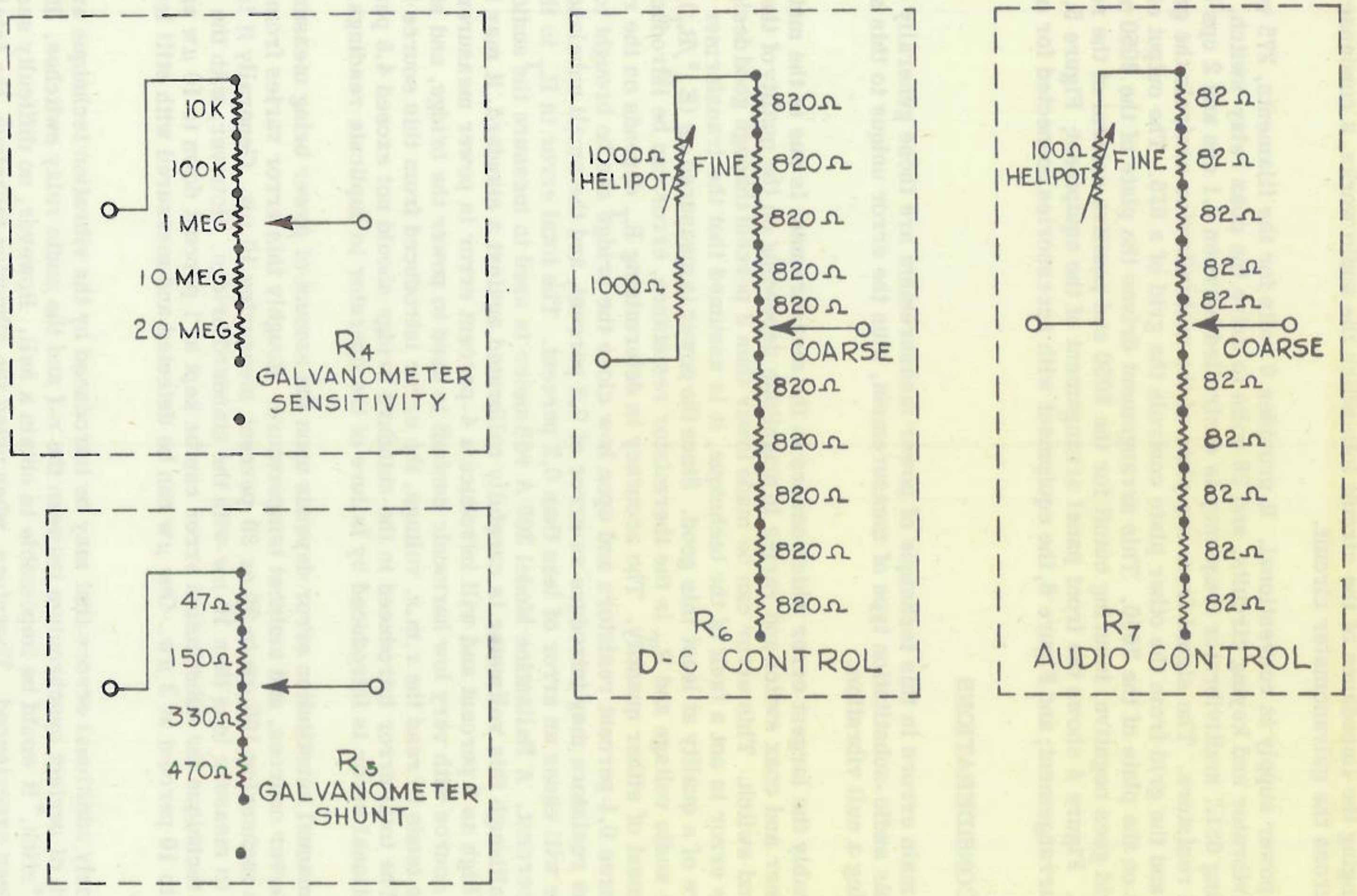


Fig. 3 - Control resistor networks

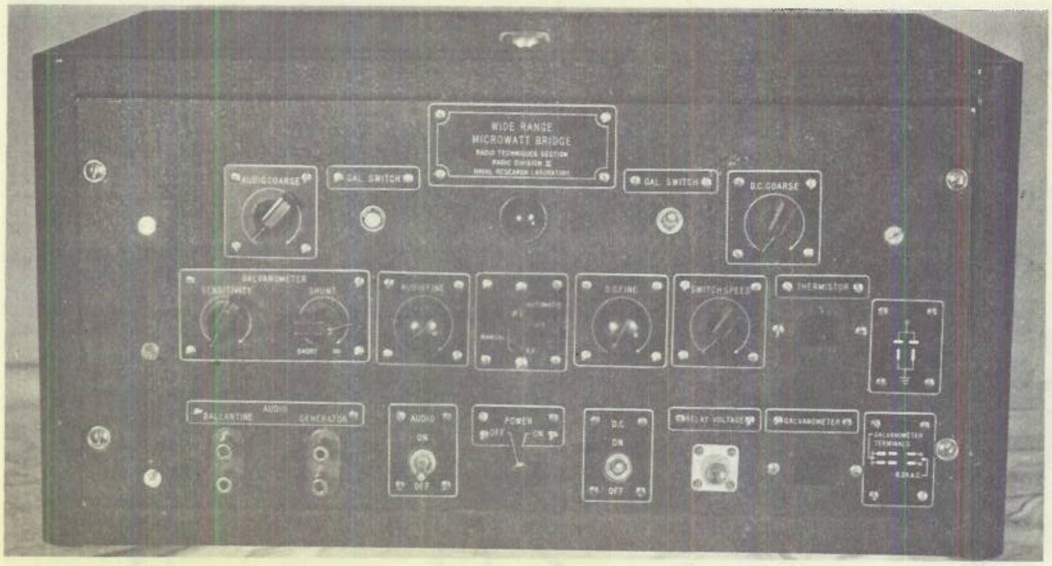


Fig. 4 - Front panel view of microwatt bridge

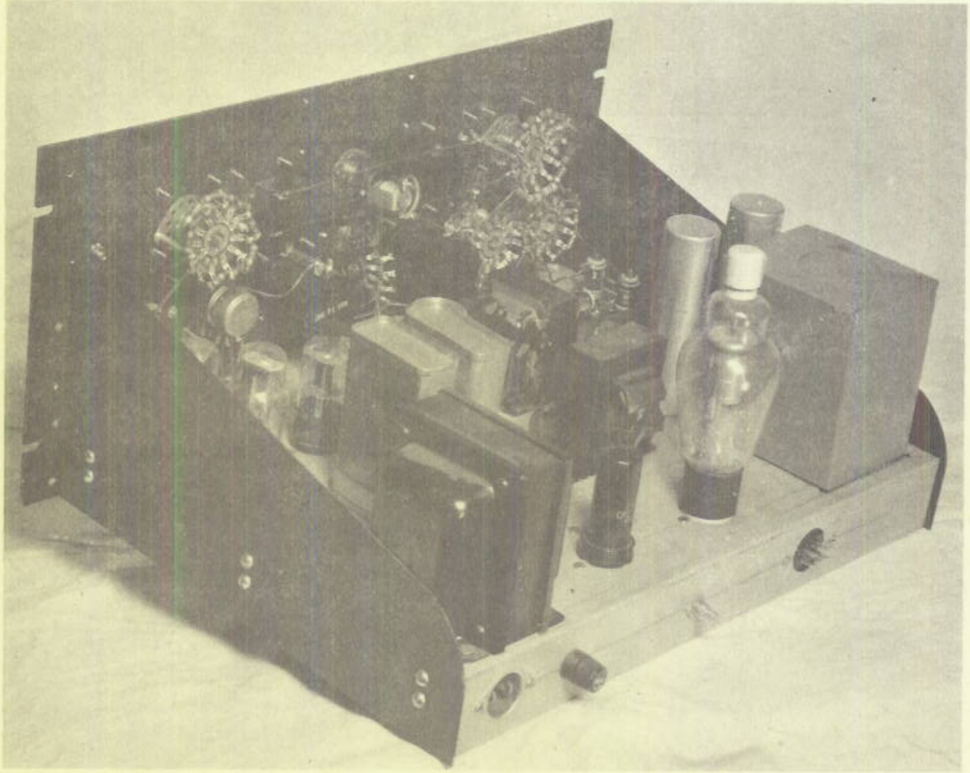


Fig. 5 - Chassis view of microwatt bridge

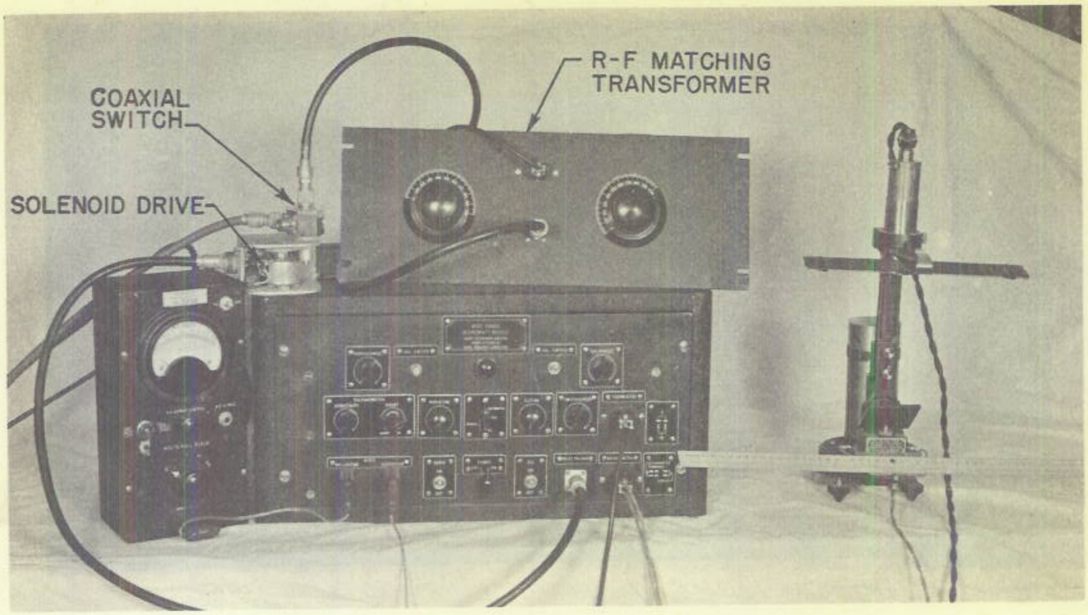


Fig. 6 - Microwatt bridge with accessories

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