PREPRINT INSTRUMENT SOCIETY of AMERICA
18th Annual ISA Conference and Exhibit—Sept. 9-12, 1963, Chicago
Preprint Number 37.2.63

Responsibility of all statements in this paper rests with the authors. • All rights reserved. • For permission to publish write ISA, 530 Wm. Penn Pl., Pittsburgh 19, Pa.

HIGH FREQUENCY MICROVOLT MEASUREMENTS

by F. X. Ries
G. Rebuldela
Electronic Engineers
Radio Standards Laboratory
National Bureau of Standards
Boulder, Colorado

ABSTRACT

This paper discusses the basic principles, design features, applications and techniques utilized in voltage measurements in the microvolt region by the National Bureau of Standards Calibration Center. The standard that was developed to perform measurements in this region is the RF Micropotentiometer. A full description is given and the characteristics of this instrument are discussed. The technique used in determining the error in the RF Micropotentiometer, in terms of the National Reference Standards, is described.

A physical description of the Microvolt Calibrator, which incorporates a set of RF Micropotentiometers, is covered in detail. The voltage range of the Microvolt Calibrator is from 1 microvolt to 100, 000 microvolts, covering frequencies from 50 kc to 900 Mc. The accuracies, as determined from the uncertainties of measurements, vary from 2 percent to 5 percent depending on the frequency and voltage level.

INTRODUCTION

New developments in the electronic field have greatly increased the need for accurate voltage standards in the microvolt region. A device fulfilling this need, called the RF Micropotentiometer[1], has been developed by the National Bureau of Standards. Presently, a set of these devices which has been calibrated in terms of the National Reference Standard, has been incorporated in a Microvolt Calibrator. A detailed discussion of this Microvolt Calibrator is presented. Included in this discussion are design features, basic principles of the RF Micropotentiometer, as well as the applications and techniques utilized in voltage measurements in the microvolt region. The region referred to here is from 1 microvolt to 100, 000 microvolts covering frequencies from 50 kc/s to 900 Mc/s.

GENERAL DESCRIPTION AND CHARACTERISTICS OF THE RF MICROPOTENTIOMETER

The RF Micropotentiometer, which is the most stable, accurate, and reliable working standard in the microvolt region, is a low impedance source of a known RF voltage. This device, as shown in Fig. 1, consists of a radial resistor in series with a thermoelement which is enclosed in a special housing. The radial resistors range from 1 milliohm to 1 ohm. These resistors are thin film resistors made of platinum, platinum gold or silver, depending on the desired resistance[2]. The thermoelement is the UHF type with a straight through heater and the plane of the thermocouple leads is 90° from the plane of the heater. Fig. 2 is a schematic diagram of the RF Micropotentiometer. It can be seen from this diagram that this device is a source of voltage, V, across the resistor, R. The thermocouple output caused by the current, I, flowing through the heater of the thermoelement is an indication of this output voltage.

In order to cover the range from 1 microvolt to 100, 000 microvolts, various combinations of resistor and thermoelement sizes must be used. Table 1 presents a typical set of combinations which will cover the above voltage range.

The resistance of the radial resistor is chosen below 1 ohm to minimize the error introduced by loading the output with a 50 ohm system. The size of the thermoelements do not exceed 100 milliamperes in order that the input power requirements may be minimized. Also, the larger thermoelements have an appreciable error due to skin effect at the higher frequencies. These reasons dictate the selection of values that appear in this table.

The Electronic Calibration Center of the Radio Standards Laboratory of the National Bureau of Standards in Boulder uses a set of RF Micropotentiometers similar to the set in this table to compare unknown standards to the National Reference Standard. These unknown standards may be submitted by industry as well

Superior numbers refer to similarly-numbered references at the end of this paper.

as by any government agency provided these standards are of high enough quality to warrant calibration.

CALIBRATION OF A WORKING STANDARD SET OF RF MICROPOTENTIOMETERS AGAINST THE NATIONAL REFERENCE STANDARD

There are two techniques that can be used to calibrate the working standard set of RF Micropotentiometers in terms of the National Reference Standard. The two thermistor, bolometer bridge[3] is the National Reference Standard referred to in both of these techniques. The RF Micropotentiometer with the highest voltage output is calibrated against the bolometer bridge. Other RF Micropotentiometers are then compared to this one, using the technique as diagrammed in Fig. 3. In this figure, M_1 is the calibrated RF Micropotentiometer and M_2 is the unknown RF Micropotentiometer. The rf outputs of M_1 and M_2 are first set to the same level using the transfer instrument which is normally a very sensitive rf receiver. The attenuator setting and the dc output of M_2 are noted. The attenuation is lowered until a usable reading can be taken on the dc output of M_1. At this point the attenuator setting and the dc output of M_1 are noted.

The rf output of M_2 can then be determined by the attenuation change and the known output of M_1 as determined from the bolometer bridge calibration.

The second technique is an extension of the first technique, whereby the attenuation is kept constant, thus eliminating the need for a standard attenuator. This technique may be used if the RF Micropotentiometers' maximum output voltages do not differ by more than 3 to 1.

If the precision of measurement is sufficient and much care is taken during the measurement, two RF Micropotentiometers can be compared without an appreciable loss in accuracy. If adjoining RF Micropotentiometers in a set similar to that listed in Table 1 are compared against each other, the amount of error in each of the units can be determined provided the error in any one of the units is known. Instrumentation has been refined at the National Bureau of Standards to such an extent that the second technique has been proven to be valid by a comparison with the first technique.

THE MICROVOLT CALIBRATOR

The Microvolt Calibrator used at the National Bureau of Standards covers the entire frequency range from 50 kc/s to 500 Mc/s from 1 microvolt to 100,000 microvolts and 500 to 900 Mc/s from 10 to 100,000 microvolts.

A block diagram of this RF Microvolt Calibrator is presented in Fig. 4. A set of RF Micropotentiometers similar to those in Table 1 is incorporated in this Calibrator. This set of RF Micropotentiometers was calibrated as explained previously. The rf-dc difference technique is used here to obtain the maximum long-term stability. The rf-dc difference technique is merely the process of observing the output of the RF Micropotentiometers when dc is applied as compared to the output voltage when rf is applied, for the same thermocouple output.

This Microvolt Calibrator is a source of known rf voltage which is used to calibrate the output of unknown devices. This requires a very sensitive transfer instrument with sufficient frequency and level stability to be able to discern one-hundredth of one microvolt out of one microvolt. The optimum transfer device obtainable is an rf receiver.

In order that the unknown and the standard devices be properly terminated, the input impedance of the receiver must be 50 ohms. This is accomplished by either attenuating the level to a few microvolts using a T pad attenuator of 20 db or greater or a matching network at levels below 10 microvolts, where 20 db of attenuation is not tolerable.

Since the output of the unknown and the standard are compared, the transfer device must have a stability of at least 0.1 percent over a 2 minute period, which is the time needed to make one complete measurement. The sensitivity of the receiver, therefore, must be in the order of 0.1 percent.

At the present time, commercial receivers are used with slight modifications. Two different receivers, one covering frequencies from 50 kc/s to 65 Mc/s, and another with a range from 55 to 900 Mc/s provide the necessary frequency coverage. The latter receiver employs a range extension unit, making possible the extension of the operating frequency from 250 to 900 Mc/s. This unit tunes continuously from 250 to 475 Mc/s and from 475 to 900 Mc/s in two bands.

There are also three variable frequency signal generators to provide continuous frequency coverage throughout the entire range. To achieve the desired frequency and output level stability of the calibration system, the sources must meet specifications similar to those of the receivers. The sources must have a constant power output and maintain it to better than 0.1 percent over the period of time needed to complete a calibration cycle. The frequency stability of these generators must be at least

0.001 percent over the same period of time since the bandwidth of the receivers is narrow. The power sources, like the receivers, were bought commercially. As mentioned earlier, there are three signal generators in use. The generator that is used to cover frequencies from 50 kc/s to 65 Mc/s is continuously adjustable from 1 microvolt to 3 volts into a 50 ohm resistive load. The mid-frequency generator covers frequencies from 10 to 480 Mc/s in 5 bands with an output level of 0.1 microvolt to 1 volt. The higher frequencies are covered by the third generator, which covers frequencies from 450 to 1230 Mc/s in one band and has an output level of 0.1 microvolt to 0.5 volt. It is evident from the frequencies just mentioned that overlapping exists in order to cover the entire frequency range from 50 kc/s to 900 Mc/s.

As seen in Fig. 4, variable attenuators have been inserted between the low frequency generator and the input to the micropotentiometers. These attenuators, which are accessible from the front of the Calibrator, increase the efficiency of the calibration procedure. They are used primarily at the lower frequencies, from 50 kc/s to 65 Mc/s where no problems due to impedance matching exist. Sufficient power is obtainable from the lower frequency generator to assure this. However, this problem becomes significant at the higher frequencies. Therefore, the variable attenuator is replaced by a three stub tuner for matching above 100 Mc/s and varying the input power to the micropotentiometers. This three stub tuner can also be adjusted from the front of the Calibrator.

A dc source and associated measuring devices are also needed since the ac-dc difference technique is used. The dc source is capable of delivering 1 to 1000 milliamperes of current. This source is composed of a nickel-cadmium battery which is maintained at full charge at all times by a trickle charger. This battery has a current dividing circuit across it for varying the current through the above range. The value of current is obtained by measuring the voltage drop across a standard resistor with a dc potentiometer. This current can be measured to an accuracy of 0.1 percent. The dc voltage across the output resistor is measured with a dc potentiometer which has an accuracy of 0.2 percent or better at 100 microvolts. This accuracy is improved as the voltage is increased. The output of the thermocouple is detected by a Lindeck Potentiometer which provides high resolution.

The operation of the Microvolt Calibrator may be performed in the following manner:

1) The voltage range of the unknown device is determined and the proper standard is selected.
2) The dc voltage level at which the unknown device is to be calibrated is applied to the standard RF Micropotentiometer and the dc detecting device associated with it is nulled against the thermocouple output. This step is repeated for the unknown device.
3) The rf generator is tuned to the desired frequency and then connected to the input of the unknown micropotentiometer.
4) The transfer instrument is connected to the output of the unknown RF Micropotentiometer.
5) The rf voltage level is increased until the dc detecting device again reaches null.
6) The output of the transfer instrument is noted.
7) The rf generator and transfer instrument are switched to the standard RF Micropotentiometer.
8) The rf input level is increased until the output of the transfer instrument reaches the same level as noted in step 6.
9) The dc detecting device of the standard is brought to a null.
10) The rf generator is disconnected and dc voltage is applied to the input of the standard.
11) The dc potentiometer is connected to the output of the standard.
12) The dc voltage is increased until the standard dc detecting device reaches the same null as set on rf, and the dc output of the standard is read with the dc potentiometer.
13) Steps 10, 11, and 12 are performed on the unknown.

The rf output of the standard is computed from the dc value obtained in step 12 and the correction to this standard obtained from the National Reference Standard. Thus, the rf voltage of the standard is equal to the product of the dc voltage reading in step 12 and the correction of the standard at a particular frequency, or

$$V_{rfs} = V_{dcs} \times \text{Correction.}$$

Since the rf output of the standard and the unknown were kept the same by means of the transfer instrument, the computed rf output of the standard is equal to the rf output of the unknown. The rf-dc difference can be calculated from the standard rf output and the dc output of the unknown micropotentiometer obtained in step 13 or,

$$\text{rf-dc difference } (\%) = \frac{V_{rfs} - V_{dcx}}{V_{dcx}} \times 100$$

Since dc voltages cannot be measured below 100 microvolts to the accuracy needed, an alternate method is necessary. Therefore, at measurements below 100 microvolts, the dc voltage value is calculated from the resistance of the radial output resistor and the current through it. The dc resistance is determined at a higher voltage level by the four terminal current voltage method.

The accuracies of the Microvolt Calibrator are presented in Table 2. These accuracies are determined by the uncertainties in the primary standards, which are the bolometer bridge and the standard attenuator and the precision with which the measurements can be made. Some of the difficulties encountered in these measurements are: rf leakage, dc ground currents in the detecting devices, sensitivity of the transfer instrument, determination of the voltage plane, loading effects and finding sources which provide sufficient power.

CONCLUSIONS

The present facilities resulted from the need for voltage measurements in the microvolt region. The inherent characteristics of the RF Micropotentiometer make it a very good working standard as well as an interlaboratory standard. In turn, these interlaboratory standards can be used to calibrate devices such as 1) signal generators, 2) millivoltmeters, 3) attenuators at very low levels, 4) field strength meters and, 5) checking sensitivity of rf receivers. A Calibrator was developed at the National Bureau of Standards so that the time required in the calibration of interlaboratory standards could be greatly reduced.

At the present time there is a need for improved accuracies over the entire voltage and frequency range. There is also a need for measurements in the range from 1 microvolt to 10 microvolts from 500 to 900 Mc/s, and from 1 microvolt to 100, 000 microvolts from 900 to 1000 Mc/s. In addition there is a need for measurements below 1 microvolt. Investigations into these needs have been initiated.

SUMMARY

The RF Micropotentiometer was developed by the National Bureau of Standards to fulfill the need of an accurate, stable source of voltage in the microvolt region. A set of these RF Micropotentiometers which were calibrated against the National Reference Standards, serve as transfer devices between other laboratory standards and the National Reference Standard. This standard set of micropotentiometers are incorporated in a Microvolt Calibrator which has a frequency and voltage range from 50 kc/s to 900 Mc/s and from 1 microvolt to 100, 000 microvolts respectively.

Special techniques are involved in obtaining optimum results. This also requires the selection of precision instruments necessary to constitute an accurate calibrating system. However, there are limitations and uncertainties in the primary standards and difficulties encountered in measurements that seriously affect the precision of the system. These sources of errors serve as a basis for the assigned accuracies for a particular voltage and frequency range.

REFERENCES

1. Myron C. Selby, "RF Micropotentiometers, Radio and Television News, October, 1953.
2. Lewis F. Behrent, "Fabrication of Radio Frequency Micropotentiometer Resistance Elements," Vol. 51, Research Paper 2426, July, 1953.
3. Myron C. Selby and Lewis F. Behrent, "A Bolometer Bridge for Standardizing Radio Frequency Voltmeters," NBS Journal of Research, Vol. 44, Research Paper, p. 2055, January, 1950.

TABLE I: COMBINATIONS OF RF MICROPOTENTIOMETEF ELEMENTS TO COVER 1-100,000 μVOLTS

NOMINAL VOLTAGE RANGE MICROVOLTS	RESISTANCE OF RADIAL RESISTOR MILLIOHMS	THERMOELEMENT SIZE MILLIAMPERES
1-5	1	5
5-15	3	5
15-45	9	5
45-135	27	5
135-400	81	5
400-1,200	240	5
1,200-3,600	360	10
3,600-11,000	440	25
11,000-33,000	660	50
33,000-100,000	1,000	100

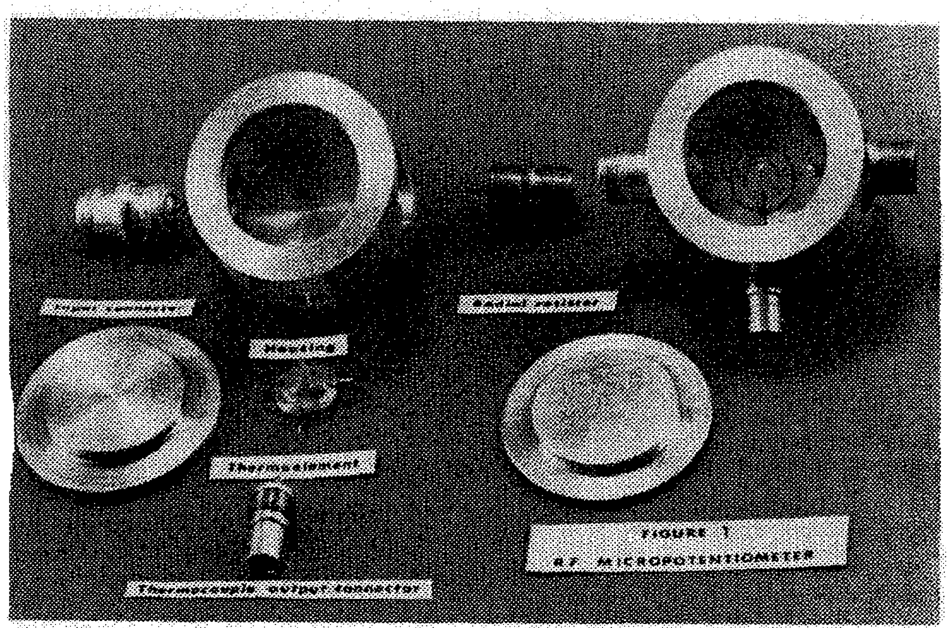
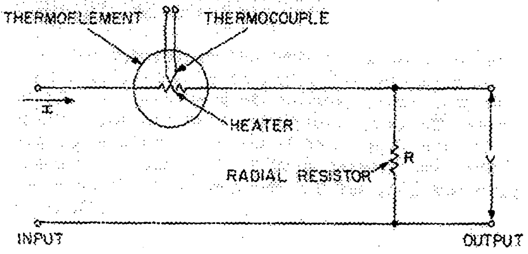


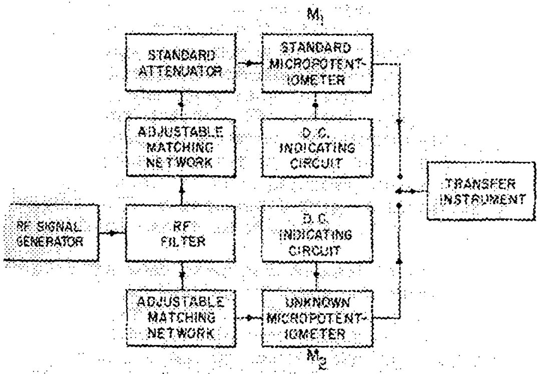
FIGURE 1
RF MICROPOTENTIOMETER

TABLE 2: MICROVOLT CALIBRATOR ACCURACIES

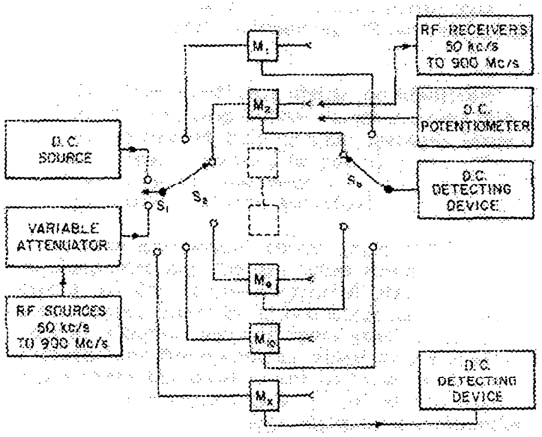
FREQUENCY Mc/s	VOLTAGE RANGE MICROVOLTS	ACCURACY PERCENT
0.05 – 300	1 – 100	5
300 – 500	1 – 100	10
0.05 – 10	100 – 100,000	2
10 – 300	100 100,000	3
300 – 900	100 – 100,000	5



SCHEMATIC DIAGRAM OF RF MICROPOTENTIOMETER
FIGURE 2



BLOCK DIAGRAM OF RF MICROPOTENTIOMETER CALIBRATION
FIGURE 3



BLOCK DIAGRAM OF MICROVOLT CALIBRATOR
FIGURE 4