[8] D. P. Snowden and H. Saltsburg, "Coaxial chamber for measurement of frequency-dependent conductivity in powdered semiconductors," *Rev. Sci. Instr.*, vol. 34, pp. 1263–64; November, 1963.
[9] R. A. Waldron, "Theory of a strip-line cavity for measurement of dielectric constant and gyromagnetic-resonance line-widths," IEEE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-12, pp. 123–131; January, 1964.
[10] Richard W. Peters, ed. "Handbook of Tri-Plate Microwave Components," Sanders Associates, Inc., Nashua, N. H.; 1956.

Method Free from Mismatching Errors for Measuring the Loss of Attenuators

In his recent communication,[1] Weinschel called attention to a method by Rabinovich[2] which employs two directional couplers for the measurement of the insertion loss of a microwave component. Rabinovich reports that his measurement technique results in a substantial reduction in mismatch error compared with the mismatch error which occurs with conventional attenuation measurement techniques. Specifically, Rabinovich states that a mismatch error (ΔN)

$$\Delta N = 20 \log_{10} \left| (1 - S_{22}\Gamma_l) \right| \quad (1)$$

exists with his method, compared with a mismatch error

$$\Delta N = 20 \log_{10} \left| \frac{(1 - \Gamma_0\Gamma_1)(1 - S_{22}\Gamma_l)}{(1 - \Gamma_0\Gamma_l)} \right| \quad (2)$$

which exists with conventional attenuation techniques.

It should be noted that (1) is based on Rabinovich's analysis of his technique with ideal couplers utilized in the measurement system. I should like to point out that if the effects of finite coupler directivity and coupler main line VSWR are considered in the analysis, the following expression for mismatch error will result:

$$\Delta N = 20 \log_{10} \left| \frac{(1 - \Gamma_g\Gamma_1)(1 - S_{22}\Gamma_l)}{(1 - \Gamma_g\Gamma_l)} \right| \quad (3)$$

where Γ_1 is the reflection coefficient looking toward the input port of the component under test, with the output port terminated in Γ_l, Γ_0 is the generator reflection coefficient, and Γ_g is the equivalent generator coefficient[3] of coupler 1 (installed between the generator and the component under test).

Comparison of (2) and (3) reveals that the mismatch error is identical with either conventional attenuation measurement techniques or Rabinovich's technique (assuming $\Gamma_0 = \Gamma_g$, and Γ_1 and Γ_l are the same in both measurement systems). Even if the reflection coefficients are not the same, the reported method does not result in complete elimination of two of the three mismatch error terms as claimed by Rabinovich.

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[1] B. O. Weinschel, "Letter to the editor," TRANS. ON MICROWAVE THEORY AND TECHNIQUES (*Correspondence*), vol. MTT-12, p. 145; January, 1964.

[2] B. E. Rabinovitch, "Method free from mismatching errors for measuring the loss of attenuators," *Izmeritelnaya Tekh.*, pp. 44–47; March, 1962. English translation in *Meas. Tech.*, pp. 238–243; September, 1962.

[3] G. F. Engen, "Amplitude stabilization of a microwave signal source," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-6; pp. 202–206; April, 1958.

Microwave and High-Frequency Calibration Services of the National Bureau of Standards

INTRODUCTION

Calibration services in the microwave and high-frequency regions available from the National Bureau of Standards presently extend in frequency from approximately 30 kHz to 26.5 GHz.[1] These services include most of the usual electrical quantities of interest in precision measurements with limitations in frequency range, magnitude of quantity, and accuracy of calibration.

The calibration services listed are excerpted from NBS Miscellaneous Publication 250 which was issued November 22, 1963. This document contains reprints from the Federal Register, as well as other information and is for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402. The price is 70 cents.

Because the listing of calibration services in the microwave and high-frequency regions is too lengthy to be included in one issue of the TRANSACTIONS, the services will be published in parts for the next several issues. Included below are the calibration services for the measurement of CW power and effective noise temperature. In subsequent issues of the TRANSACTIONS the services for

1) attenuation and field strength,
2) reflection coefficient and immittance, and
3) voltmeters and signal generators will be presented.

In the listing of services, a number appears under the heading "Item" which identifies the specific calibration to be performed. It is desirable to use these numbers when requesting or referring to the specific calibration services. A description of the calibration to be performed is given. For the calibration services listed, a preliminary letter, stating clearly the calibrations desired, should be sent to the Engineering Division, Radio Standards Laboratory, National Bureau of Standards, Boulder, Colo. 80201, prior to shipment of interlaboratory standards, to determine if and when the requested calibrations can be made. A formal purchase order covering the calibrations to be performed should accompany or precede the shipment of interlaboratory standards. The time for completion of a calibration in this listing of regularly scheduled services usually is one month after receipt of an acceptable interlaboratory standard and a valid purchase order.

Following the listing of calibration services is a series of charts indicating the magnitudes of quantities, the frequency range, and the over-all estimated accuracy of calibrations performed.

Some of the calibration techniques and systems used in performing the listed services have been reported in more detail in the literature,[2] and an indication of present developments and future plans also have been made.[3,4] The announcement of calibration services for microwave power[5,6] and noise[7] have appeared in the *NBS Technical News Bulletin*. Also, the calibration services available from the Boulder Laboratories of the National Bureau of Standards have been presented in a brochure which is available free upon request. It may be obtained from the Office of the Coordinator, Calibration Services, National Bureau of Standards Boulder, Colo. 80301.

MICROWAVE REGION

201.900 *General*

1) Microwave calibration services presently available include measurements in power, impedance, frequency, attenuation, and noise. The frequency range covered for each of the measurements is given below.

In performing microwave calibrations, a considerable amount of time usually is needed to prepare the system for measurement operation. Much of this preparation is related to the adjustment of the system to the frequency of operation selected for the calibration. Time and cost often can be reduced by minimizing the number of times the operating frequency of the calibration system must be readjusted. To help in achieving this reduction in costs, a list of suggested calibration frequencies is presented in the following table. These frequencies are suggested for use in connection with this schedule and for interlaboratory standards utilizing terminations consisting of the standard waveguide sizes given below

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[1] *Note:* Although low-frequency (dc) calibration services are not included here, many services in this frequency area are available from NBS at both Washington, D. C., and Boulder, Colorado.

[2] R. E. Larson, "Microwave measurements in the NBS electronic calibration center," *Proc. IEE*, vol. 109, pt. B, Suppl. No. 23, pp. 644–650; 1962.

[3] R. C. Powell, "Current Developments in High-Frequency Calibration Services," NBS Misc. Publ. 248, pp. 45–48; August 16, 1963, for sale by Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 20402. Price $1.75.

[4] R. E. Larson, "Development of Improved Microwave Calibration Systems," NBS Misc. Publ. 248, pp. 49–54; August 16, 1963.*

[5] "Waveguide power calibration service," *NBS Tech. News Bull.*, vol. 47, p. 31; February, 1963.

[6] "Extension of waveguide power calibration service," *NBS Tech. News Bull.*, vol. 47, p. 141; August, 1963.

[7] "Calibration of microwave noise sources," *NBS Tech. News Bull.*, vol. 47, p. 31–34; February, 1963.

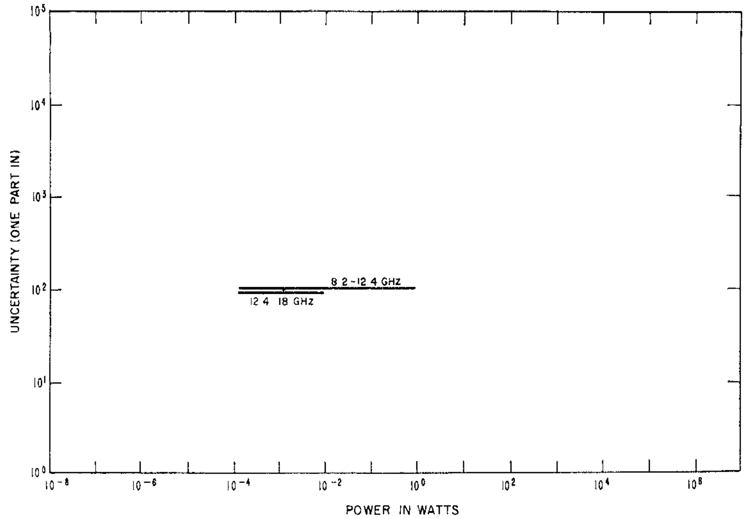

Fig. 1—Microwave CW power calibrations (rectangular waveguide).

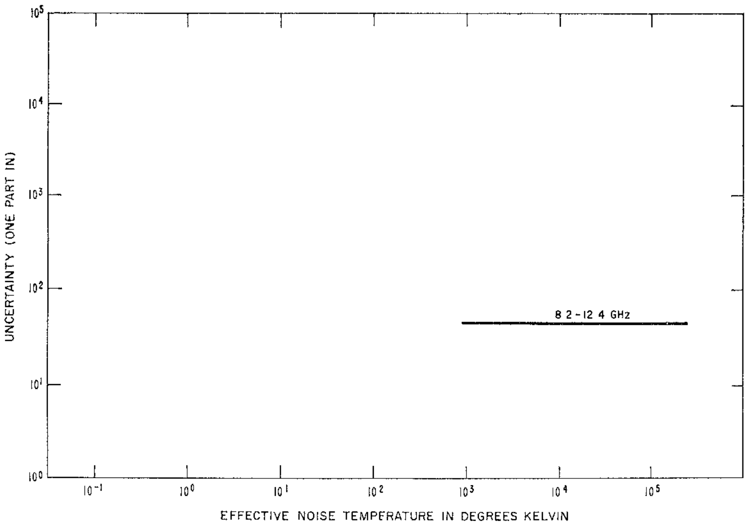

Fig. 2—Microwave noise calibrations (rectangular waveguide).

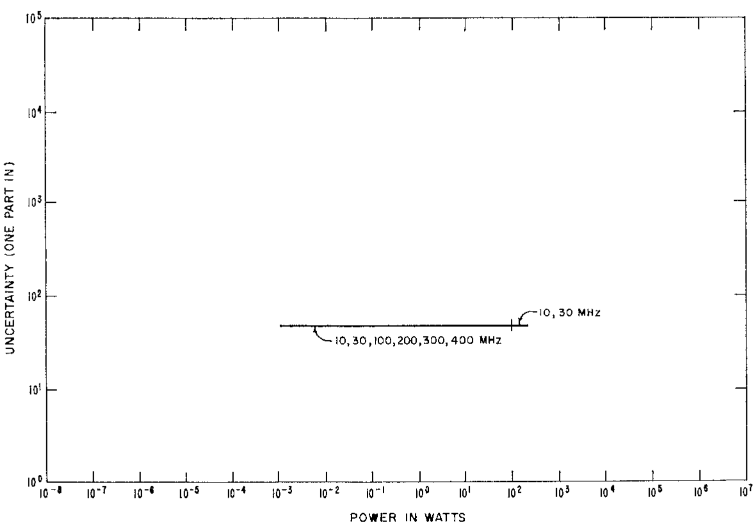

Fig. 3—High-frequency CW power calibrations (coaxial).

in the table of suggested calibration frequencies. It should be emphasized that the suggested frequencies are primarily for economy and for convenience to those requesting calibrations. In general the calibration instrumentation for the microwave region is intended to provide complete and continued frequency coverage as appropriate for the various waveguide sizes. Those having need for calibrations at other than suggested frequencies usually can be accommodated.

EIA Waveguide Designation	Frequency Range, GHz	Suggested Calibration Frequencies GHz		
		No. 1	No. 2	No. 3
WR284	2.60– 3.95	2.85	3.25	3.55
WR187	3.95– 5.85	4.35	4.90	5.25
WR137	5.85– 8.20	6.45	7.00	7.40
WR112	7.05–10.0	7.75	8.50	9.00
WR90	8.20–12.4	9.00	9.80	11.2
WR62	12.4 –18.0	13.5	15.0	17.0
WR42	18.0 –26.5	19.8	22.0	23.8
WR28	26.5 –40.0	29.0	33.0	37.0

2) Fees: The fees to be charged for the following calibration services performed at the Boulder Laboratories are not fixed at this time, but estimates will be furnished on request to those who plan to submit standards for calibration.

201.910 *Continuous Low-Level Power Measurements on Waveguide Bolometer Units and Bolometer-Coupler Units*

1) Power measurements are made on barretter-type bolometer units having nominal resistance of either 100 or 200 ohms at a bias current between 3.5 and 10 ma, and on thermistor-type bolometer units having a nominal resistance of either 100 or 200 ohms at a bias current between 5 and 15 ma. Bolometer units should be of the fixed tuned or untuned broad-band type.

2) Power measurements are made on bolometer units at power values of 0.1 to 10 mw.

3) Power measurements are made on bolometer-coupler combinations having coupling ratios from 3 to 20 db. A bolometer unit of the fixed tuned or untuned broad-band type should be permanently attached to the side arm of the coupler. The three-port directional coupler should have good design features with a directivity of 40 db or greater and a VSWR no greater than 1.05 for the input and output ports of the main arm of the coupler.

4) Effective efficiency for bolometer units is defined as the ratio of the substitued dc power in the bolometer mount to the microwave power dissipated within the bolometer unit.

5) Calibration factor for bolometer units is defined as the ratio of the substituted dc power in the bolometer unit to the microwave power incident upon the bolometer unit.

6) Calibration factor for bolometer-coupler units is defined as the ratio of the substituted dc power in the bolometer unit on the side arm of the directional coupler to the microwave power incident upon a non-reflecting load connected to the output port of the main arm.

Item	Description
	Measurement of effective efficiency of bolometer unit at a single frequency of the following waveguide sizes terminated with standard waveguide connectors:
201.910a-1	WR90 (8.2–12.4 GHz)
201.910a-2	WR62 (12.4–18.0 GHz)
	Measurement of calibration factor of bolometer unit at a single frequency of the following waveguide sizes terminated with standard waveguide connectors:
201.910b-1	WR90 (8 2–12.4 GHz)
201.910b-2	WR62 (12.4–18.0 GHz)
	Measurement of calibration factor of bolometer-coupler unit at a single frequency of the following waveguide sizes terminated with standard waveguide connectors:
201.910c-1	WR90 (8.2–12.4 GHz)
201.910c-2	WR62 (12.4–18.0 GHz)
201.910z	Special calibrations not covered by the above schedule

201.911 *Continuous Low-Level Power Measurements on Waveguide Dry Calorimeters*

Power measurements are made on dry calorimeters at power values of 10 to 100 mw.

Item	Description
201.911a-1	Measurement of output voltage vs input microwave power for dry calorimeter at a single frequency of WR90 waveguide (8.2–12.4 GHz) terminated with standard waveguide connectors.
201.911a-2	Each additional power value at the same frequency as Item 201.911a-1.
201.911z	Special calibrations not covered by the above schedule.

201.950 *Effective Noise Temperature Measurements of Noise Sources*

1) Effective noise temperature measurements are made of waveguide noise sources (usually a gas-discharge tube in a terminated mount) under conditions of continuous, unmodulated operation in the range 900 to 300,000°K (excess noise ratio range 3.3 to 30 db).

2) The direct current required for normal operation of the gas-discharge tube should not exceed 300 ma but should be sufficient to prevent excessive plasma oscillations.

3) The waveguide noise source must have an input VSWR no greater than 1.7.

4) The gas-discharge tube should be secure in the mount, and the output port of the unit should be terminated with a matched load.

Item	Description
201.950a-1	Measurement of effective noise temperature of noise source in WR90 waveguide at a single frequency selected from 9.0, 9.8, and 11.2 GHz.
201.950z	Special calibrations not covered by the above schedule.

HIGH-FREQUENCY REGION

201.800 *General*

1) In the high-frequency region of approximately 30 kHz to 300 MHz and higher, calibration services are available for voltage, power, immittance, attenuation, and field strength. Interlaboratory standards are limited at present to those designed for CW measurements and having coaxial terminals (usually Type N connectors). No general provisions have yet been made for standards with balanced transmission-line terminals.

Stable RF power sources and detectors are required to perform such measurements. This is accomplished by the use of crystal-controlled RF power sources and receivers. RF power sources have power stabilization circuits that provide a power output constant to within 0.1 per cent or better over periods of one hour or more. Special low-noise, crystal-controlled receivers meet the exacting requirements to monitor or detect these signals. In using standards at high frequencies it is often desirable, and even necessary, to duplicate these conditions.

Calibration services for high-frequency standards with coaxial connectors are performed at the fixed frequencies of 30, 100, and 300 kHz, and 1, 3, 10, 30, 100, 300, and 1000 MHz. Calibrations are available at other frequencies for some standards, as well as continuous frequency coverage up to 10 GHz for certain calibrations, but usually with less accuracy.

Connectors limit the accuracy of measurements in the high-frequency region to some extent. To avoid instability from this cause, precision connectors should be used on interlaboratory standards. In the case of Type N connectors, certain mechanical dimensions should fall within tolerances specified by the Armed Services Electro-standards Agency (ASESA) in Procurement Specification MIL-C-71. If dimensions fall outside the specified tolerances, there is a possibility of damaging the mating connectors on interlaboratory standards and NBS working standards. Critical dimensions of Type N connectors are indicated on drawings in the brochure referred to in the introduction.

2) Fees: The fees to be charged for the following calibration services performed at the Boulder Laboratories are not fixed at this time, but estimates will be furnished on request to those who plan to submit standards for calibration.

201.820 *RF Calorimeters, 30 kHz to 400 MHz*

1) For maximum calibration accuracy, interlaboratory RF calorimeters should repeat readings to one per cent or better with a constant power input.

2) At present only RF calorimeters utilizing Type N connectors for RF power input can be calibrated. Refer to 201.800 for special requirements for Type N connectors used on interlaboratory standards.

Item	Description
201.820a	Calibration of RF calorimeter at one frequency at 10 and 30 MHz; and at one power level from 0.001 to 200 watts.
201.820b	Calibration of RF calorimeter at one frequency at 100, 200, 300, and 400 MHz; at one power level from 0.001 to 100 watts.
201.820c	Each additional power level at the same frequency.
201.820z	Special calibrations not covered by the above schedule.

Engineering Division
Radio Standards Lab.
National Bureau of Standards
Boulder, Colo.

The Confocal Resonator System with a Large Fresnel Number (V-Type Eigenmodes)

Multimode resonators with open-walled structure pose a boundary value problem which cannot be solved analytically. It must be treated by methods of approximation. Several approaches, essentially based upon Huygens' Principle, have been reported in recent literature. The author has recognized that Huygens' Principle and the Huygens-Fresnel Principle may differ significantly if boundary conditions must be considered. He has developed a resonator theory which is applied to the V-type eigenmodes of a confocal resonator system (the individual wave trains travel along V-shaped paths). We summarize the essential results and refer to Lotsch[1] for a detailed discussion. We define an eigenmode as an energy distribution which, when launched from the plane of symmetry, reproduces itself on this same mathematical plane after a complete round trip between the reflectors. We learn from Fig. 1 that an eigensolution is reproduced in the plane of symmetry after each reflection and thus four times per eigenmode. We postulate a self-consistent field distribution for such a section of an eigenmode. We assume that this distribution can be represented as $E_y(x, y) = E_0 X(x) Y(y)$, where E_0 is a constant amplitude factor, $X(x)$ a function of x only and $Y(y)$ a function of y only.

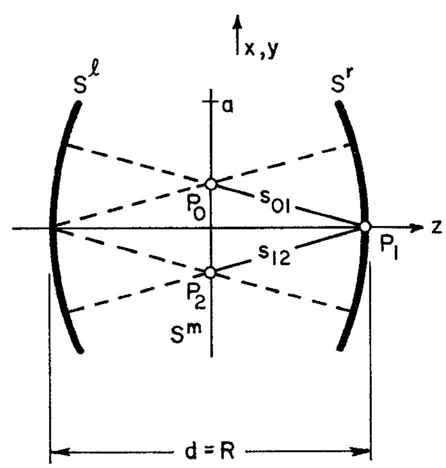

Fig. 1—Geometry of the confocal resonator system illustrating the V-type eigenmodes. S^l and S^r represent the left and right reflectors, respectively; S^m is the plane of symmetry which is of mathematical nature.

Then, the corresponding integral equation can be separated into a product of two integral equations identical in form. One of these equations depends only on x and the other one only on y. Henceforth, we deal merely with the x-dependent integral equation and use the same results for the y-dependent one. Referring to Fig. 1, the x-dependent integral equation is given by

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[1] H. Lotsch, "The Confocal Resonator System with a Large Fresnel Number (V-Type Eigenmodes)," in preparation, February, 1964.