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.

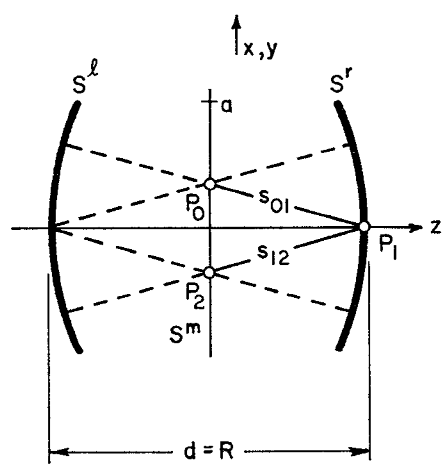

Fig. 1—Geometry of the confocal resonator system illustrating the V-type eigenmodes. S^l and S^r represent the left and right reflectors, respectively; S^m is the plane of symmetry which is of mathematical nature.

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.

$$\kappa_p X_p(x_2) = \int_{-\infty}^{+\infty} K(x_2, x_0) X_p(x_0) dx_0 \quad (1)$$

with the eigenvalue κ_p and the kernel

$$K(x_2, x_0) = 2F e^{ikd/2} e^{-i4\pi F x_2 x_0} \int_{-1}^{+1} \cdot e^{i2\pi F(x_1 - x_2 - x_0)^2} dx_1 \quad (2)$$

where we have introduced the dimensionless variable x/a for x. The Fresnel Number F is defined by $F = a^2/\lambda d$, where $2a$ is a single dimension of the square reflectors and d their separation. k is the propagation constant for the wavelength λ. According to Erdélyi, (1) can be written equivalently

$$\kappa_p X_p(x_2) = e^{i(kd/2 + \pi/4)} \int_{-1}^{+1} X_p(x_0) e^{-i\pi F x_2 x} \left(\sqrt{\frac{F}{2}} + \frac{e^{-i3\pi/4}}{2\pi} D \right) dx_0 \quad \text{as} \quad F \to \infty \quad (3)$$

with

$$D = \frac{e^{i\pi F(2+x_2+x_0)^2/2}}{(2 + x_2 + x_0)} + \frac{e^{i\pi F(2-x_2-x_0)^2/2}}{(2 - x_2 - x_0)} + \sum_{n=1}^{\infty} \frac{(2n-1)! e^{-in\pi/2}}{(\pi F)^n} \left[\frac{e^{i\pi F(2+x_2+x_0)^2/2}}{(2 + x_2 + x_0)^{(2n+1)}} + \frac{e^{i\pi F(2-x_2-x_0)^2/2}}{(2 - x_2 - x_0)^{(2n+1)}} \right] \quad (4)$$

subject to the condition

$$-2 < (x_1 = x_2 + x_0) < 2.$$

In contrast to the corresponding integral equations as found in several recently published papers, the kernel (2) contains a Fresnel Integral due to the boundary conditions, and these conditions are subject to Maxwell's Equations. This yields the significant result that, since the eigenfunctions are complex for a finite F, the reflectors do not coincide with a surface of constant phase as is widely assumed. Attention is directed to a postulate of classical electrodynamics to illustrate this physical result. If and only if the reflectors coincide with a surface of constant phase, any solution of Helmholtz's Equation which satisfies Maxwell's Equations subject to this boundary condition is of the purely standing-wave nature. A standing wave, however, does not yield losses even though the resonator does not have side walls. In the limit as $F \to \infty$, D can be neglected in comparison to $\sqrt{F}$ and (3) yields the geometrical-optics solution which is identical with the basic integral equation used in the papers referred to above. It is the familiar Fourier Integral, and thus the diffraction losses $\alpha_D = 1 - |\kappa_p \kappa_q|^4 \equiv 0$.

If F is large but finite, (4) becomes significant as $x_0 \to \pm 1$ with $x_2 \approx \pm x_0$ in a steady-state solution. Thus, away from the axis the imaginary part of the eigenfunction increases and finally predominates. Associated with this imaginary part is the traveling-wave type component in the solution of Helmholtz's Equation, but this component represents the diffracted waves. Close to the axis D may also be ignored and the eigenfunctions of (3) can be expressed in terms of the one-dimensional harmonic oscillator wave functions. This is, however, true if and only if F is very large. These eigenfunctions are purely real and the reflectors coincide with a surface of constant phase, but only close to the axis. In this region the waves resonate between the reflectors. We direct attention to the significant fact that if F is small, the eigenfunctions of (3), neglecting the second term with D in (3), are the Legendre Polynomials near the axis. This is because the prolate spheroidal wave functions are usually normalized in a way such as this.

In the light of the facts discussed above' the formulas offered in several recent papers are not consistent with the experiments. The numerical results for the diffraction losses of a confocal-type resonator as reported by other investigators are, therefore, questionable.

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H. Lotsch
Microwave Lab.
Stanford University
Stanford, Calif.