NBS MILLIMETER WAVE POWER STANDARDS

Morris E. Harvey
National Bureau of Standards
Boulder, Colorado

Abstract

The NBS standards for millimeter wave power measurements are calorimeters which are used to determine the effective efficiency of transfer standards (bolometer units). A careful error analysis has been made and the effective efficiency of bolometer units may be determined with uncertainty limits of ± 0.28 percent.

Summary

Microwave Calorimeter

Microwave calorimeters at NBS have evolved from a design by Macpherson and Kerns[1]. Modifications and improvements to the original design were made by Engen[2]. Both of these calorimeters covered the frequency range 8.2 to 12.4 GHz (WR-90 or X-band). A number of foreign standards laboratories have duplicated the Engen calorimeter after they were supplied with shop drawings and other technical assistance. NBS calorimeters in the frequency ranges 12.4 to 18 GHz and 18 to 26.5 GHz are of similar design to the WR-90 calorimeter.

There are two mm wave calorimeters in use at NBS. One covers the frequency range 26.5 to 40 GHz (WR-28) and the most recent covers the range 50 to 75 GHz (WR-15). A simplified design is used in the mm wave calorimeters. They employ a modified twin calorimeter design which will be referred to here as nonidentical twin. A photograph of the WR-15 calorimeter is shown in figure 1.

The calorimeters are electrical-power-to-temperature transducers. Power is absorbed in a calorimetric body (bolometer unit) which causes the temperature of the calorimetric body to increase until it reaches a steady-state value. The steady-state temperature is a function of power absorbed in the calorimetric body. The twin calorimeter design uses two "calorimetric" bodies one of which serves as a thermal reference. A differential temperature sensor is connected between the two. The differential temperature is a measure of the power dissipated in the calorimetric body. The relationship of this differential temperature to the electrical power is obtained by applying a known dc power to the bolometer. A second measurement of temperature and dc power made with mm wave power applied provides the information necessary to compute the effective efficiency of the bolometer unit.

The twin calorimeter design has the advantage of suppressing the influence of environmental temperature changes. This suppression is due to the thermal similarity between the calorimetric body and the thermal reference body. That is, the temperature of the two bodies will change very nearly the same amount after a change in the environmental temperature. Therefore, the output of the differential temperature sensor will not be a function of changes in the environmental temperature. It is difficult to construct a twin calorimeter with precisely identical bodies because the identity and symmetry are not only a function of the thermal capacity of the bodies, but also the multiple thermal resistances which couple the bodies to the calorimeter environment.

In a nonidentical twin calorimeter, the calorimetric body and the thermal reference body are of different shapes, and have different relative locations within the calorimeter. Therefore, they have different convection and radiation resistances to the calorimeter environment. The mm wave calorimeters are operated in a water bath[3,4] which has a temperature stability of $\pm 10^{-5}$ K during a measurement. This degree of stability permits the use of the nonidentical twin design.

The nonidentical twin design has several advantages over previous designs. The simplicity of the calorimeter reduces construction costs by fifty percent. Direct thermal coupling of the calorimetric body and the reference body to the calorimeter environment greatly reduces the time necessary to prepare for a measurement. The bodies attain the temperature of the water bath one and one half hours after the calorimeter is placed in the bath as compared to about 72 hours in the WR-90 twin-load calorimeter. Although not important in the mm wave calorimeters, the design provides a more compact, lightweight calorimeter, which would be of advantage in the large waveguide sizes (e.g. WR-137, etc.).

The WR-15 calorimeter has an improved thermal isolating waveguide section. To allow sufficient temperature difference between the calorimetric body and the water bath, a thin walled (0.05 mm thick) waveguide is used. The previous difficulties in fabricating and terminating this section in a good flange surface have been solved by a dual thickness electroformed section. This electroformed waveguide is also of advantage as its microwave absorption may be evaluated by a sliding short method[5].

Bolometer Unit

A bolometer unit is used as a transfer standard and its effective efficiency is determined in the calorimeter. Effective efficiency is defined as the ratio of retracted dc bolometer power to the total microwave power absorbed in the bolometer and mount. The calibrated bolometer units are used as working standards to calibrate a variety of power meters or to make precision power measurements. These bolometer units (figure 2) are constructed to meet the dual requirements of a calorimetric body and of a transfer standard.

Error Analysis

Since corrections may be made for certain systematic errors, considerable effort has gone into the determination of the magnitude of these errors affecting the measurement of effective efficiency of bolometer units. The magnitudes of systematic errors are not known precisely so that their limits of systematic uncertainty were determined. Also, an estimate was made of the 3 σ limits of the random uncertainty, which is $\pm$ 0.05 percent of the effective efficiency. The total uncertainty is the sum of the systematic uncertainty and the random uncertainty. The total uncertainty for the WR-28 bolometer unit effective efficiency is +0.26 to -0.18 percent, and $\pm$ 0.28 percent for the WR-15 bolometer unit.

References

[1] Macpherson, A. C., Kerns, D. M., A microwave microcalorimeter, Rev. Sci. Instr., Vol. 26, No. 1, 27-33 (January 1955).

[2] Engen, G. F., A refined X-band microwave microcalorimeter, J. Res. NBS, (U.S.), 63C, No. 1, 77-82 (1959).

[3] Larsen, N. T., 50 microdegree temperature controller, Rev. Sci. Instr., Vol. 39, No. 1, 1-12 (January 1968).

[4] Harvey, M. E., Precision temperature-controlled water bath, Rev. Sci. Instr., Vol. 39, No. 1, 13-18 (January 1968).

[5] Engen, G. F., An extension to the sliding short method of connector and adaptor evaluation, J. Res. NBS, accepted for publication.

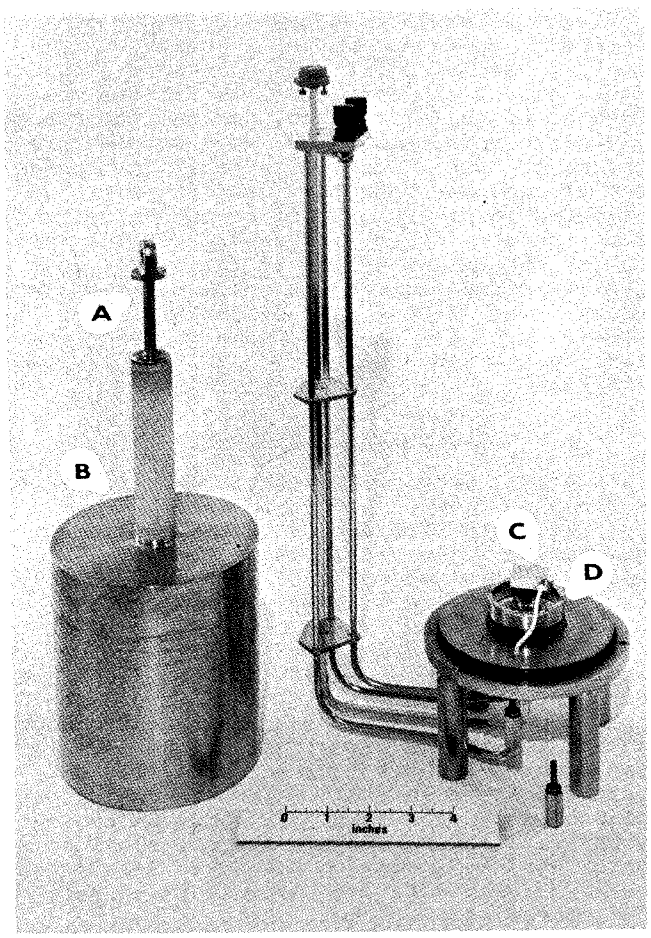

FIG. 1. MM WAVE CALORIMETER IN WAVEGUIDE SIZE WR-15 (50 TO 75 GHz). (A) HANGER, (B) COVER, (C) CALORIMETRIC BODY (BOLOMETER UNIT), (D) THERMAL REFERENCE BODY.

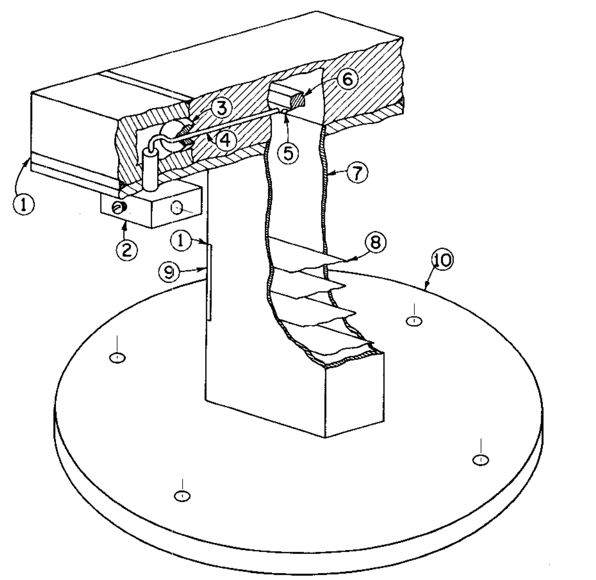

FIG. 2. MM WAVE BOLOMETER UNIT IN WAVEGUIDE SIZE WR-28 (26.5 TO 40 GHz). (1) CONDUCTIVE EPOXY, (2) DC BINDING POST, (3) MM WAVE ABSORBING MATERIAL, (4) DC LEAD, (5) THERMISTOR BEAD, (6) MATCHING STRUCTURE, (7) WAVEGUIDE, (8) THERMAL BARRIERS, (9) COVER OVER SLOTS THAT HOLD THERMAL BARRIERS, (10) FLANGE.