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SHORT MILLIMETER WAVE REGION HIGH ACCURACY POWER METER WITH SELF-CALIBRATION FUNCTION

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Abstract

A high-precision power meter with a self-calibration function in the short-millimeter wave region (94GHz) has been developed. As a result of self-calibration, a high effective efficiency (99.86 %) of the built-in thin-film barretter mount has been obtained, and a reliable measurement of millimeter wave power with an overall accuracy of ±1 % has become possible. [1], [2]

Introduction

In the short millimeter wave region, the calorimeter method is used to measure the absolute power as same as in the microwave region, However, calorimeter method requires so large equipment and takes much time and so tedious.

On the other hand, there are several simple measuring methods. One is the use of bolometer mount substituted by D.C or low frequency power. Another is the use of thermopile mount utilizing thermo-electric power. The other is the use of diode mount which using rectified power. However, those methods are necessary to calibrate by other standard measurement system.

One of those methods, it is expected high accurate measurement by using the bolometer mount method, because this method is able to calibrate directly by using the bolometer mount as the thermal load of calorimeter. In this method, the effective efficiency of the bolometer mount is defined as the ratio of D.C substitutinal power to the net consumed millimeter wave power.

Therefore, the true value of the incident RF power is decided to compensate the D.C substitutional power with the attenuation of waveguide, the reflection and the effective efficiency of the bolometer mount.

In this time, employing those method, we developed the high accuracy and convenient power meter at 94GHz by means of including self-calibration function which can calibrate the effective efficiency of the bolometer mount with the calorimeter.

Construction of the Power Meter

The power meter consists of a calorimeter mount and a controller (including an indicator). The former consists of a triple jacket, input wave guide, an adiabatic wave guide with four thermo-electric elements (peltier elements) and a thin-film barretter mount. [2]

The latter consists of an indicator which can directly read the input power, an amplifier with a thermo-electric detecting voltage, a cooling-current controller, and a bolometer bridge circuit (refer Fig. 1-a,b)

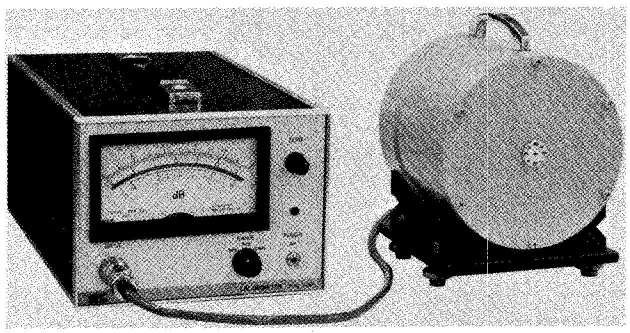

Fig. 1-a A view of powermeter

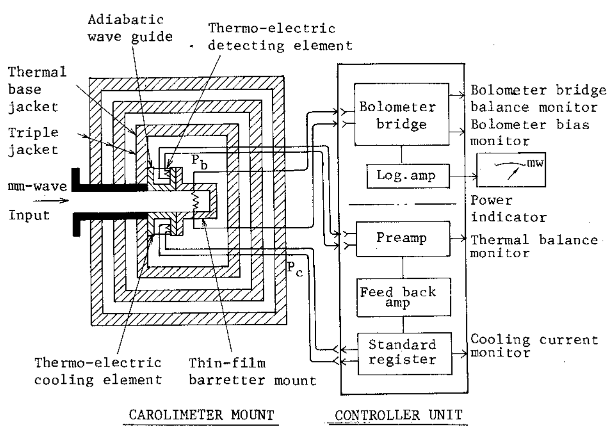

Fig. 1b

Schematic Diagram of Self-calibrated Power Meter

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Power Measurement

The power of a millimeter wave injected from an input flange is applied to the bolometer mount through the input wave guide and the adiabatic wave guide. A part of the power returns to the power source side because of an impedance mismatching. Another part of the power becomes heat after being absorbed by the inner wall of the input wave guide and the adiabatic wave guide. The millimeter wave power entering the bolometer mount can be detected as a variation of the bolometer mount can be detected as a variation of the bolometer baias power. The millimeter wave power (Pin) injected from the input flange can be expressed using the following formula,

$$P_{IN} = \frac{1}{(1-|\Gamma|^2)} \cdot \frac{1}{S} \cdot \frac{\Delta P_b}{\eta_e} \qquad (1)$$

where, the ratio of power absorbed by the input wave guide and the adiabatic wave guide in S, the reflection coefficient as seem from the input flange is Γ , the effective efficiency of the bolometer mount is ηe, and the variance of the bolometer bias power is Δ Pb.

By measuring Γ , S and η_e in advance, the millimeter wave power (Pin) can be immediately obtained by multiplying the coefficient by the variance Δ Pb.

The overall accuracy of a measurement of the millimeter wave power using this power meter is determined by the total sum of the following items:

a) The measuring accuracy of the reflection coefficient as seen from the input flange
b) The measuring accuracy regarding insertion loss of the input wave guide and the adiabatic wave guide
c) The measuring accuracy of the effective efficiency

Among these items, a) and b) can be measured with an accuracy of about $\pm$0.1% by making a precise measurement. The overall accuracy is mostly determined by item c).

Cariblation of the Effective Efficiency

The temperature difference between the bolometer mount and the thermal base jacket is detected as the electric voltage by the thermoelectric detecting element equipped to the adiabatic wave guide, and is always maintained at zero by establishing a negative feedback regarding the detected voltage to the thermoelectric cooling element through the amplifier and the feedback controller.

Heat generated in the bolometer mount is transferred to the outside through a thermoelectric cooling element. At this time, the power (Pbt) applied to the bolometer mount is equal to the cooling power (Pc). Also, the cooling power (Pc) is proportional to the cooling current (Ic), and is expressed as Pc = C Ic

The following relations hold for the bolometer bias power (Pb), the cooling current (Ic) and the millimeter wave power (Pm) supplied to the bolometer mount, where the suffix. 1 refers the state when a millimeter wave is not applied. Suffix. 2 refers the state when a millimeter wave is applied.

1. If the millimeter wave not applied,

$$(1-K)P_{b1} = C\, I_{c1} \qquad (2)$$

2. If the millimeter wave is applied,

$$(1-K)\{P_{b2}+(1-\sigma)P_m\} + \sigma P_m = C\, I_{c2} \qquad (3)$$

In these formula, K expresses the ratio of the outgoing power from the surface of the bolometer mount, and σ the ratio of the power absorbed by the inner wall of the bolometer mount.

The effective efficiency ηe can be expressed by the following formula according to the definition.

$$\eta_e = \frac{\Delta P_b}{P_m} = \frac{P_{b1}-P_{b2}}{P_m} \qquad (4)$$

From formulas (2), (3) and (4), the following formula is obtained.

$$\eta_e = \frac{1}{1+(\frac{I_{c2}}{I_{c1}}-1)/(1-\frac{P_{b2}}{P_{b1}})}\left(1+\frac{K\sigma}{1-K}\right) \qquad (5)$$

Here, the term, $\frac{K\sigma}{1-K}$ at the right side represents the effect due to the difference between distributions of heat generated by the direct current and the millimeter wave. It is treated as an error term. [3], [4] From equation (5), it is found that the effective efficiency (η_e)can be obtained by measuring the bolometer bias power (Pb) and the cooling current (Ic) for the case that a millimeter wave is not applied, and the case that a millimeter wave is applied, respectively.

Explanation of Components of the Calorimeter Mount

The overall accuracy of a measurement regarding the power of a millimeter wave is mostly determined by the effective efficiency. To increase the accuracy of the effective efficiency, excellent characteristics are required for each devices.

a) Bolometer Mount

As the thermal load of the calorimeter, it is required that the matching characteristics for a millimeter wave is excellent and that the effective efficiency is high.

The thin-film barretter mount developed for this power meter, shows excellent characteristics. The band region for less than 1.2 of VSWR is 5 GHz (center frequency is 94 GHz), the sensitivity for the direct current is about 3 Ω/mW, and the effective efficiency (by self-calibration) is 99.86 %.

b) Adiabatic Wave Guide

The structure of the adiabatic wave guide is shown in Fig. 2.

It has a structure in which a WRI-900 (WR-10) wave guide is made of an ABS resin plated with gold. Four peltier elements (two thermo-electric detecting elements and two thermo-cooling elements) are inserted into a BRJ-95 flange.

The thermal resistance of the wave guide is 5.9×10^{-2} hr deg/J

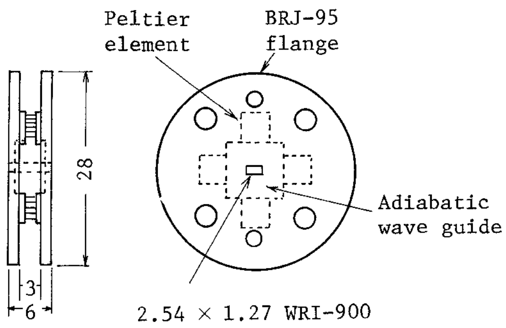

Fig. 2 Structure of the Adiabatic wave guide part

c) Jacket

It is necessary to establish a stable standard reference point regarding temperature for a precise measurement of the effective efficiency. For this purpose, generally, a method, in which the temperature control is made by putting the calorimeter into a liqid (oil bath and so on), is frequently used. However, large scale equipment is required, a long time is necessary for the measurement, and handling becomes complicated. Therefore, a dry-type jacket of a practical size, by which sufficient temperature stability can be obtained, was designed.

When the desired accuracy regarding the measurement of the effective efficiency (the aim of overall accuracy $\pm1\%$) is set at $\pm0.5\%$, it is required that the temperature stability of the standard reference point be less than $\pm0.1\%$ (5×10^{-4}°C) of a temperature rise of about 0.5°C of the bolometer mount, by considering the control accuracy of the power measuring system and the accuracy of measuring instruments. Under the condition that the temperature variation of the external environment is ±1°C with a period of 30 min. (normal environmental condition of a standard room), the calculation of heat is made using a spherical triple jacket model (refer Fig. 3-a). The results are shown in Fig. 3-b.

When the most outer radius is 70 mm and the radius of the thermal base jacket is 30 mm, the effect of temperature variation on the external environment becomes Δ Tamb $\simeq 4.1\times10^{-4}$ °C and the desired condition is satisfied.

At this time, the temperature rise of the thermal base jacket is $\Delta\tau_j \simeq 0.2$°C and the time constant is $\tau_j \simeq 1.1$ hour. The temperature rise of the thermal base jacket is larger than the desired value regarding temperature stability. This has, however, a far greater time constant than τ_j at the stationary state, and can be treated as an error of the next order of magnitude. Experimental results by measuring the temperature rise with a thermister put on the thermal base jacket show good agreement with calculated values.

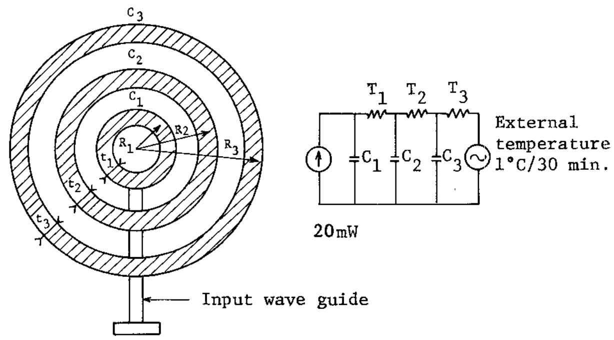

Fig. 3-a The spherical model of triple jacket and the thermo-electric equivalent circuit

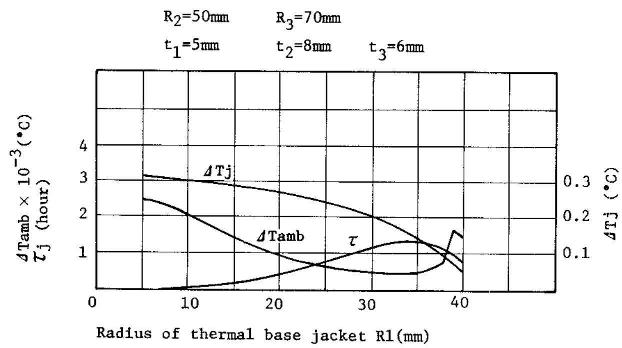

Fig. 3-b The calculation results of the spherical triple jacket model

Control Circuit

The control circuit consists of an indicator which gives the power of a millimeter wave (mW unit), an amplifier of thermo-electric detecting voltage, a cooling-current control circuit to control to maintain the temperatures of the bolometer mount and the temperature-standard jacket at the same temperature, and the bolometer-bridge circuit. These circuits are contained in one unit.

An Example of a Measurement of the Effective Efficiency and evaluation of errors

An example measurement of the effective efficiency of the built-in thin-film barretter mount is shown in Table 1.

The results of an investigation regarding the accuracy of the measurement is shown in Table 2. (please refer to reference [4] for the method of evaluation of errors).

As a result of the measurement, the effective efficiency of the built-in thin-film barretter mount was determined to be 99.86 ±0.83%. This performance is the same as those of a bolometer mount of 10 GHz. [3]

Table 1 Example of measurement of the effective efficiency (Pin≃10mW. f=94GHz)

N	Time	I_{c2} (mA)	I_{c1}(mA)	P_{b2} (mW)	P_{b1}(mV)	η_e
1	20:05	16.588	16.571	6.1079	14.340	0.9982
2	20:15	16.648	16.637	6.0996	14.331	0.9989
3	20:25	16.617	16.604	6.1040	14.335	0.9986

η_e = 0.9986, Standard deviation σ = ±0.00058

Table 2 Measurement accuracy of effective efficiency

System error	Mismatch error	Emis	±0.005%
	Distribution Equivalence error	Edis	-0.39 %
	Attenuation error	Eatt	-0.30 %
	Cooling current measuring error	Ec	±0.199%
	Bolometer bias power measuring error	Eb	±0.092%
Random error	=3σ	E ran	±0.18
Overal accuracy of effective efficiency			+0.48, -1.17 } ±0.83

Conclusion

A high precision, rectangular waveguide type power meter with self-calibration function has been developed in a short millimeter wave region (94 GHz).

For precise measurement of the millimeter wave power, it's necessary to calibrate the power meter at every measurement or periodically.

This power meter is able to calibrate easily by the built-in calorimeter, thus achieving an overall accuracy of ±1%.

Acknowledgment

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