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Realization of 2.4 mm coaxial microcalorimeter system as national standard of microwave power from 1 MHz to 50 GHz

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A R T I C L E I N F O

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A B S T R A C T

A 2.4 mm coaxial microcalorimeter system based on thermoelectric principle has been realized as a national standard of microwave power at National Physical Laboratory India (NPLI). The design is based on two symmetrical and thermally isolated transmission lines, one connected to power standard and the other connected to an identical power standard used as a thermal reference. The main function of the system is to determine the temperature variation between the two power standards, which is of the order of few milli-Kelvin, using a specially designed thermopile. The coaxial microcalorimeter along with the thermocouple power sensor will provide traceable measurements from 1 MHz to 50 GHz. An interlaboratory measurement comparison of microwave power for the validation of the 2.4 mm coaxial microcalorimeter system has been carried out between NPLI and Laboratoire National de Métrologie et d'Essais (LNE) France. The difference between the effective efficiency evaluated by the two laboratories was less than 0.5% at all frequency points. The normalized error value of NPLI for effective efficiency varies between −0.23 and +0.09 with respect to LNE. The result shows good agreement in assigning the effective efficiency to power sensor among the two labs within their claimed expanded uncertainty. It proves the degree of equivalence in measurements between two national metrology institutes (NMIs).

1. Introduction

Since 1960s, microcalorimeter forms the basis of national standard of microwave power measurements and provides highest quality calibration of power measuring devices. They are being used as national standards of microwave power in various NMIs of the world. This is the main method for the realization of a microwave power national standard by assigning the effective efficiency to power sensor as a function of frequency using microcalorimeter [1]. This technique was initially considered for waveguide calorimeter systems [2,3] due to low loss of microwave power and good uncertainty. Progress in the development of coaxial microcalorimeter systems over the years has made it more useful in broad frequency range. These are developed by the researchers in 50 Ω coaxial line with GR900, PC7, N-type, 3.5 mm, 2.92 mm and 2.4 mm connectors [4–10]. In co-ordination with LNE, 2.4 mm coaxial microcalorimeter system has been commissioned at NPLI in November 2014. The principle of operation is similar to that developed by LNE-France [11]. The word “microcalorimeter” means measure of low power but, the main emphasis is on instrumentation configuration of the system. The assigned parameter is effective efficiency of the power sensor rather than the microwave power. The microwave power measurement system is critical to precision, accurate, repeatable and traceable measurements. The thermoelectric power sensor with all its electronic parts removed as shown in Fig. 1 being used as microwave power standard in coaxial microcalorimeter system. The main part of the sensor is a sensitive element which includes a simple circuit consisting of the coaxial 2.4 mm input connector, a coplanar waveguide transmission line, a thin film RF load and a thermocouple for measuring the temperature of the RF load. The 2.4 mm coaxial microcalorimeter is a twin type microcalorimeter system consisting of two symmetrical thermally isolated transmission lines first one connected to standard under testing (SUT) and the second to a passive standard (Dummy) used as a thermal reference. A block diagram of the coaxial microcalorimeter system is shown in Fig. 2. The microwave power is measured in terms of DC voltages with the effective efficiency calculated from a thermal and high frequency analysis of the thermal isolation lines. With these conditions, the microwave power lost in SUT can be measured and therefore its effective efficiency can be determined. The thermoelectric power sensors have the advantage that their frequency range is wide as it spans from DC to 50 GHz. They are

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Fig. 1. A thermocouple power sensor.

also compatible with DC power substitution method. Hence, they can be easily used in direct comparison technique [12,13] for assigning calibration factors and disseminating the power standards to maintain the traceability as per ISO 17025.

2. Microcalorimeter design

The 2.4 mm coaxial microcalorimeter system along with the thermocouple power sensor performs calibration from 1 MHz to 50 GHz. The lowest and highest frequency specifications are fixed by the measurement capability of the Vector Network Analyzer (VNA) available at the laboratory and the performance specification of a thermocouple power standard respectively. The microcalorimeter design is composed of a heat sink made of gold plated copper to dissipate the heating due to RF power, a container head and a metallic container in nickel plated copper and a water vat with a support structure. Its core parts include thermal isolation lines, thermopile and power sensors with input RF and output DC connectors as shown in Fig. 3. The mechanical design of coaxial microcalorimeter includes a water vat, a microcalorimeter head and a handling system. The water vat is a cylindrical container filled with water that maintains stable thermal conditions around the microcalorimeter head. The microcalorimeter head is a metallic shell inside which the thermal isolation lines are mounted and connected to the power standards along with the thermopile. Plastic tubes, heat sink and mechanical interface for lifting the microcalorimeter head are specially designed. Estimated weight of the microcalorimeter head is about 50 kg. The handling system is an engine crane used to lift the microcalorimeter head from water vat.

Thermopile, which is an important part of coaxial microcalorimeter works on the principle of Seebeck effect. Thermopile measures the potential difference relative to the thermal difference between the power sensor under calibration and the reference power sensor. Thermopile has thirteen copper-constantan junctions performing this measurement with a sensitivity of 533 μV/K. Microwave power applied to the sensor is absorbed by the 50 ohm load and a fraction of the power is absorbed in the body of the sensor. This fraction of power has to be calculated using the measured thermopile voltages due to rise in temperature of the sensor for assigning the effective efficiency. Moreover, inside the power sensors, a thermocouple measures the rise in temperature of the RF load due to absorption of electrical power (RF/LF). The sensitivity of the detector is 230 μV/mW. The operating power ranges from 1 μW to 100 mW. The main objective of the microcalorimeter design is to thermally insulate the coaxial lines from the microcalorimeter body using specifically designed coaxial thermal isolation lines. To get a good level of isolation and electrical conductivity both inner and outer conductors of the coaxial lines are made up of gold plated $NiCr_{20}Ti$. The isolation lines have a high thermal resistance and a good electrical conductivity to provide a low-loss accurate transmission line feeding the sensor under calibration with a sufficient RF power level for the whole frequency range. These two characteristics of the isolation lines make them an important part of the coaxial microcalorimeter system design. The cross sectional view of coaxial thermal isolation lines is shown in Fig. 4. The precise dimensions of the isolation lines assure a 50 Ω characteristic impedance and TEM propagation mode. The microwave attenuation measurements of thermal isolation lines in dB using VNA helps in assigning effective efficiency at the input of the sensor for each frequency.

The performance of 2.4 mm coaxial microcalorimeter system has been verified and validated by an interlaboratory measurement comparison between LNE and NPLI using a thermocouple power sensor as an artifact in the period 2014–16. The calibration has been performed over the specified range of the system at required frequency points. As

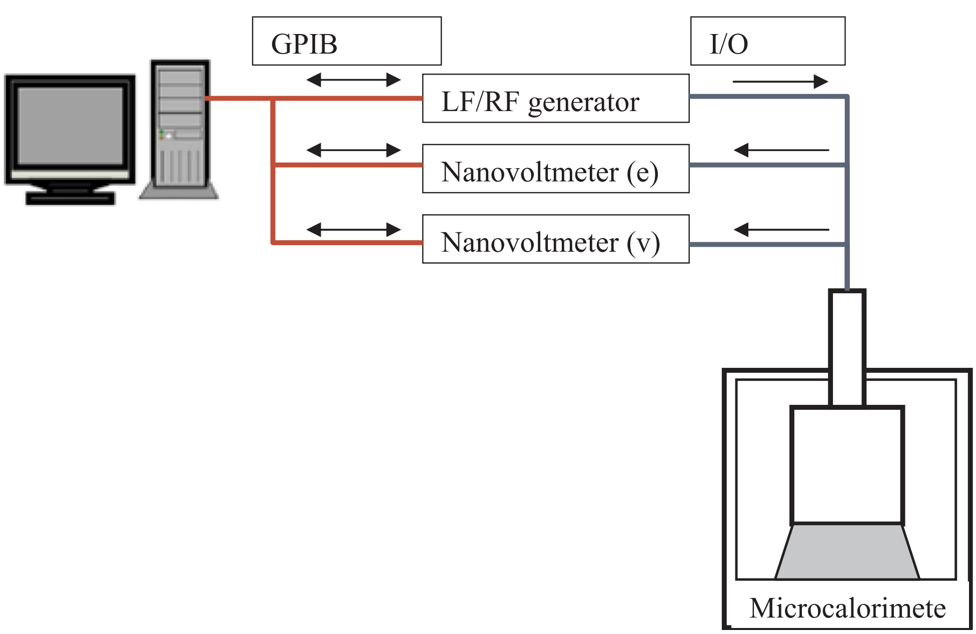

Fig. 2. A block diagram of the coaxial microcalorimeter system.