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Waveguide Microcalorimetry Status at NMIs

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Abstract

Measurement of radio frequency (RF) power is extremely important in RF metrology and great strides have been made over the last couple of decades to enhance its accuracy. This paper briefly summarized the recent developments concerning the power standards as well as current capabilities of various national metrology institutes (NMIs) worldwide.

1. Introduction

Radio frequency (RF) power is a key quantity in RF metrology, which is well defined and measureable. In this context, various national metrology institutes (NMIs) worldwide realize the primary power standard. In order to calibrate the power sensors for measurement of RF power, the NMIs have employed primary power standards designed to meet their requirements in terms of dynamic range and measurement frequency bands. RF/DC substitution calorimetry [1] is generally used as a primary power standard. It measures the temperature change of a thermistor detector under various conditions of RF power and DC bias. RF power is measured by comparing the temperature rise (i.e., thermopile emf) produced by the RF with that produced in the same load by the dc power, which can be measured accurately. Diode and thermoelectric detectors are also being used instead of bolometric (thermistor) based detectors due to shifting manufacturing trends. In reality, corrections are required because of the non-uniform response to identical RF and dc powers. These corrections are used to evaluate the "effective efficiency", which is the ratio of substituted equivalent DC power and absorbed signal. Microcalorimeter and dry-load calorimeters are generally used by NMIs. The focus of this paper is on microcalorimeters in which the effective efficiency of an inserted bolometer (or thermoelectric) mount is measured. This calorimetric load (bolometer mount) is used as a secondary standard for power measurements after calibration.

Both coaxial and waveguide calorimeters are used by NMIs. Coaxial microcalorimeters are broadband but are generally limited to frequencies below 50 GHz due unavailability of reliable thermally insulated coaxial lines at higher frequencies. Due to this reason, waveguide calorimeters are more viable at millimeter wave frequencies [2].

This paper will focus on waveguide calorimeters above 50 GHz. The current status at various NMIs is presented in Section 2 followed by conclusion.

2. Current Status at NMIs:

With rapid development of power standards at millimeter-wave frequencies, the waveguide calorimeters are being employed at NMIs for realization of primary power standards. These calorimeters are preferred beyond 40 GHz because of intrinsic difficulties in production of thermally insulated coaxial transmission lines at higher frequencies. Furthermore, the uncertainties associated with the measurements for coaxial sensors are high and coax millimeter-wave thermistors are not available at these frequencies [2].

National physical laboratory (NPL), the NMI of UK, has a waveguide calorimeter capable of measuring power from 75 to 110 GHz based on dual identical loads to achieve better thermal balance between measurement flange and reference ring [3]. NPL is also working on a calorimeter based on a similar design capable of operating beyond 110 GHz. The primary power standards of National Institute of Metrology (NIM), China are waveguide microcalorimeters (WR-22 and WR-15) based on twin line structure and thermopile. The operating frequency ranges are 33 to 50 GHz and 50 to 75 GHz [4], [5]. National Metrology Centre, Agency for Science, Technology and Research (A*STAR), Singapore has also developed WR-15 microcalorimeter [5]. National Institute of Standards and Technology (NIST), USA had developed a number of waveguide based calorimeters in the 1990s for measurement of effective efficiency of bolometric sensors up to 110 GHz [6] but due to unavailability of commercial bolometric sensors for the WR-15 range, NIST has developed a newer version capable of calibrating modern thermoelectric power sensors [7]. Physikalisch-Technische Bundesanstalt (PTB), Germany has recently developed a waveguide twin type microcalorimeter based upon a novel measuring quantity, referred to as generalized efficiency. It can measure RF power from 75 to 110 GHz [2]. PTB also has a WR-15 waveguide calorimeter [8]. Istituto Nazionale di Ricerca Metrologica (INRIM), Italy has mainly developed coaxial based microcalorimeters because of their broadband features [9]. Korea Research Institute of Standards and Science (KRISS), Korea has recently developed a V-band microcalorimeter. A W-band microcalorimeter is also under development at KRISS [10]. National Metrology Institute of Japan (NMIJ) has developed a broadband rectangular waveguide calorimeter covering both V- and W- frequency bands having good effective efficiency by utilizing a flat millimeter-wave absorber. Their system also incorporates a thermal feedback to keep the temperature of RF absorbers constant during measurement [11].

As mentioned earlier that the calibration of power sensors can be described in terms of effective efficiency for which various approaches have been used at different NMIs. In this context, a novel approach was developed at PTB. It was based on the measurement of offset shorts of variable lengths followed by a single calibration of an unknown thermistor [12]. It was applied to waveguide calorimeter up to 50 GHz with promising results. At NIST, the line, offset short, foil short, and through techniques were compared with each other for the determination of effective efficiency and the through technique was found to be better by a factor of 2.5 [13]. A new method for the measurement of microcalorimeter was developed in [14]. Its operating principle is based on varying the reference resistance of its power meter bridge through which the mismatch of thermistor mount is changed. Afterwards, the microcalorimeter is evaluated at different mismatch levels so that effective efficiency of the thermistor mount can be used. Calibration of power meters in the frequency range from 110 to 170 GHz was reported in [15], using the calorimeter described in [11] having high sensitivity and fast measurement speed.

3. Conclusion

A review of waveguide based microcalorimeters being used by various NMIs for the purpose of power measurement standardization is presented. It is concluded that there is an increased tendency towards the millimeter wave calorimeters utilizing thermoelectric sensors due to manufacturing trends not favoring thermistor based sensors at these frequencies [7].

4. References

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