Waveguide Microcalorimeters for Millimeter-wave Power Standards

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Abstract—This paper describes recent activities for constructing millimeter-wave waveguide microcalorimeters that will serve as primary power standards at the Korea Research Institute of Standards and Science (KRISS). The design schemes of the V- and W-band waveguide microcalorimeters are briefly presented and their basic performances are introduced. Computer simulation results of an adiabatic line are shown and discussed. The measurement system for the microcalorimeters is described.

Keywords—measurement standards; millimeter-wave measurement; microcalorimeter; waveguide

I. INTRODUCTION

Mobile communication industry and the government of the Republic of Korea have plans to test the 5th generation (5G) mobile communication networks in Pyeong Chang 2018 Winter Olympic Games and to provide a commercial 5G service by 2020 [1, 2]. The Korea Research Institute of Standards and Science (KRISS) has accordingly developed V- and W-band waveguide microcalorimeters to support the demand on the millimeter-wave power standards that will cover from 50 GHz to 110 GHz [3, 4]. For the time being, the transfer standards of the millimeter-wave power calibration systems are traceable to a foreign national metrology institute, and they provide calibration services for a limited number of frequencies [5].

The KRISS has endeavored to make its own waveguide microcalorimeters to replace the transfer standards with KRISS traceable ones. In this paper, we will discuss the design concept and key components of the V- and W-band waveguide microcalorimeters.

II. V-BAND WAVEGUIDE MICROCALORIMETER AT KRISS

A. Design Concept

KRISS has developed several coaxial microcalorimeters [6, 7]. They have a dry-type metal shield thermostat, a thermopile module, and a twin-type adiabatic line. The basic concept of the V-band waveguide microcalorimeter was not changed comparing to the concept applied to design the coaxial microcalorimeters. However we modified the structure of the microcalorimeter to upright design. Fig. 1 shows the structure of the V-band waveguide microcalorimeter at KRISS. The thermostat has a triple metal shield. Its two outer shields have active temperature controlled shield, and the inmost one has a passive shield. The target temperature and the stability of the inmost shield is 23 °C and ± 1 mK/h, respectively.

B. Key Components

The thermostat of the microcalorimeter system is usually different from a general-purpose one. To deliver the millimeter-wave power from the external source to the transfer standard, we have to construct an rf-transmittable path to the inmost part of the thermostat. At the same time, the path should have to be adiabatic for good signal to noise ratio (SNR) from a thermopile module in the thermostat [8]. The adiabatic lines of waveguide microcalorimeters are usually simpler than those of coaxial microcalorimeters, but it is still a big challenge to make an rf-transmittable very small hole in a adiabatic material such as acrylonitrile butadiene styrene (ABS) plastics.

Fig. 1. Measurement system with the V-band waveguide microcalorimeter at KRISS.

This work was supported by the Korea Research Institute of Standards and Science under the project “Development of Technologies for Next-Generation Electromagnetic Wave Measurement Standards,” through grant 16011004.
In order to construct the adiabatic elements of V- and W-band waveguide calorimeters, we adopted an electroforming process instead of a gold-plating process on plastic material.

Fig. 2 shows simulation results using the finite-element method for the V-band waveguide adiabatic line of the microcalorimeter. The isothermal line of Fig. 2(a) shows that the electroformed thin-wall, 0.2 mm, waveguide section is effectively preventing the outgoing heat flow from a hot spot, a thermistor mount shown in the upper part, to the outside of the inmost shield. This isolation results in higher temperature around the thermopile module than Fig. 2(b), and it ultimately improve the SNR of the thermopile voltage signal as a natural result.

Fig. 3 shows the V-band waveguide microcalorimeter with its measurement system. The system is calorimetric, so we try to perform the measurement automatically in a remote place. It is consist of four digital multimeters for voltage and temperature measurements, a V-band source module, a function generator for triggering, and a computer for control. The V-band source module was constructed for automated measurement and the module consists of a signal generator, a frequency multiplier, and a motorized attenuator. The motorized attenuator was adjusted to set a constant substituted power in the reference standard at each measuring frequency.

III. W-BAND WAVEGUIDE MICROCALORIMETER AT KRISS

Fig. 4 shows the W-band waveguide microcalorimeter at KRISS. The design concept of the W-band waveguide microcalorimeter was modified. We adopt a water-bath concept to overcome the power shortage from a W-band source module. Generally, in proportion to the increase of frequency of a millimeter-wave source module, the available power of the source rapidly decreases. The nominal power output of commercial W- and D-band waveguide frequency multipliers are usually less than 7 mW. Under the limited input power condition, we can improve the SNR of thermopile module with two different approaches. First one is to minimize the transmission path from the source module to the reference standard to maximize the signal, and the other one is the improvement of the thermal stability of a thermostat to minimize the noise.

We have tried to shorten the waveguide path of the microcalorimeter, and adopted a passive single-shield structure to put the microcalorimeter in a space-limited sub-millikelvin temperature stable water bath.
Another challenging issue is acquiring transfer standards in the W-band. We are using a Hughes 45776H as the transfer standard of the microcalorimeter, but the model was obsolete over 10 years ago. Some national metrology institutes have tried to develop their own millimeter-wave transfer standards to replace the old ones [9].

Fig. 5 shows preliminary data of the V- and W-band waveguide microcalorimeters with Hughes 4577xH thermistor mounts. The uncorrected effective efficiency of the W-band thermistor mount is quite lower than that of V-band one in Fig. 5(a). The lower uncorrected effective efficiency usually accompanies the higher uncertainty in the measured data. Fig. 5(b) shows the increase of standard deviation of measurement data in proportion to the decrease of effective efficiency.

IV. FURTHER WORK
We will hopefully finish the evaluation of V-band waveguide microcalorimeter this year with a proven procedure [7, 10]. The W-band waveguide microcalorimeter will be intensively tested to check the basic performance of the system. KRISS will start to design and test D-band waveguide components for a D-band waveguide microcalorimeter.

References