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NMC–NMIJ bilateral comparison of millimeter-wave attenuation in WR-15 waveguide band at 50 GHz and 54 GHz

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ABSTRACT

This paper reports on a bilateral comparison of millimeter-wave attenuation in WR-15 waveguide band between the National Metrology Institute of Japan (NMIJ) and the National Metrology Centre, A*STAR (NMC). Different types of attenuation measurement systems were independently developed at both laboratories. The systems are based on a stabilized single-channel intermediate frequency (IF) substitution method at NMIJ, and a dual-channel audio frequency substitution method at NMC. A comparison was carried out at 50 GHz and 54 GHz using a programmable step attenuator fitted with precision coaxial to waveguide adaptors as a traveling standard. Good agreement of the measurement results between both laboratories was verified in the attenuation range up to 60 dB.

1. Introduction

The demand for radio frequency (RF) attenuation standards in broadband frequency ranges has been increasing recently. Each national metrology institute (NMI) widely provides attenuation calibration services of which international equivalence is guaranteed [1]. For international comparisons of RF attenuation, the key comparison CCEM.RF-K19.CL has been carried out at 60 MHz and 5 GHz and completed in 2009 [2]. Moreover, the new key comparison CCEM.RF-K26 was started in the frequency range up to 40 GHz in 2014 [3]. To meet the industry's demand, some NMIs have established the attenuation standard in the millimeter-wave range [1], however, to the authors' best knowledge, there has been no comparison of the attenuation measurements over 50 GHz among the NMIs.

NMIJ and NMC have independently developed the attenuation standards including WR-15 waveguide band (50–75 GHz) to date [4]. To verify the validity of the attenuation measurement system in NMIJ and NMC, a bilateral comparison of attenuation in WR-15 waveguide band was conducted from December 2013 to March 2014. A programmable step attenuator fitted with precision waveguide to coaxial adaptors was used as a traveling standard (TS), and the attenuation was measured at 50 GHz and 54 GHz. NMC had served as the pilot laboratory, provided the TS and performed the first measurement of the TS. In this paper, we describe the measurement system used in each NMI and report on the results of this bilateral comparison.

2. Traveling standard and measurement protocol

To carry out a reliable comparison, it is important to select an appropriate attenuator as the TS. A rotary-vane attenuator (RVA) is commonly used in the waveguide band. The RVA has an advantage covering a full waveguide band frequency range, however, it requires particular attention as follows [6]:

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Fig. 1. Traveling standard for attenuation in WR-15 waveguide band.

Table 1
Attenuator switches setting for this comparison.

Attenuation (dB)	Activated switch		
	1	2	3
0			
10	X		
20		X	
30	X	X	
40	X		X
50		X	X
60	X	X	X

(1) The RVA requires especial care in shipping because it is very sensitive to mechanical stress.
(2) Repeatability gets worse (due to its setting resolution) when it is used in higher attenuation range.

On the other hand, a programmable coaxial step attenuator has been adopted for the key comparisons [2,3]. Moreover, it is easy to integrate into the measurement systems of both laboratories. Therefore, we have attentively selected the programmable step attenuator. A coaxial step attenuator (Agilent Technologies 84905M, Serial No. MY46150166) fitted with precision waveguide to coaxial adaptors was selected as the TS, as shown in Fig. 1. The step attenuator can set the attenuation from 0 to 60 dB in 10 dB steps. According to the manufacturer's specifications, the upper operating frequency of the attenuator is 50 GHz since it has used 2.4 mm connectors for its input and output ports. However, since the theoretical upper limit of the cutoff frequency of the 2.4 mm connector was 56.5 GHz [7], the performance of the attenuator was carefully checked at 50 GHz and 54 GHz prior to the start of the comparison. Consequently, good port impedance matching, stability and repeatability were confirmed at both frequencies. Therefore the comparison was carried out at these two frequencies. To convert the coaxial ports of the attenuator to waveguide flanges UG385/U for WR-15, precision adaptors (Flann Microwave, 25095-VM70) are attached to the coaxial ports. The adaptors should remain connected to the attenuator to ensure good repeatability throughout this comparison. The TS is driven by a control unit Agilent 11713A/B/C (option 24 V) which provides both manual and remote control (via computer).

The incremental attenuation in dB of the TS from the datum position (0 dB) to the setting value is the primary measurand. Each laboratory should provide the following measurements at 50 GHz and 54 GHz: Nominal attenuation steps 10 dB, 20 dB, 30 dB, 40 dB, 50 dB and 60 dB. The switch setting of the control unit required to set the attenuation values is shown in Table 1.

3. Measurement techniques

3.1. NMIJ's method

NMIJ has developed an attenuation measurement system based on a single-channel intermediate frequency (IF) substitution method using an inductive voltage divider (IVD) as a reference standard [8]. The system achieves highly stable measurement by using a phase-locked loop (PLL) technique. Fig. 2 shows simplified diagram of the attenuation measurement system in WR-15 waveguide band (Details of the measurement principle are described in [4]). The system uses double conversion technique to obtain the IF signal of 10 kHz which is stabilized by the PLL circuit after the second conversion. At the insertion point of the device under test (DUT), each test port has tuners with isolators for minimizing the mismatch uncertainty. Even if a reflection coefficient of the DUT is comparatively large, the mismatch uncertainty can be reduced because this system can adjust the reflection coefficient of the test port to a minimum value by the tuners.

The RF attenuation of the DUT is directly calibrated with the IVD by the null detection up to 80 dB. The null is achieved by adjusting the IVD according to the DUT settings. The attenuation is determined from the ratio of the IVD values. The value of the IVD to maintain null balancing state at a detector is D_i when the DUT is set to 0 dB. In the same manner, the IVD is adjusted to D_f when the DUT is set to a particular attenuation. Then the attenuation is determined as

$$A = 20\log_{10}\frac{D_f}{D_i}\ \text{(dB)} \tag{1}$$

The system achieves a wide dynamic range by a direct measurement, whereas the NMC's measurement system uses a gauge block attenuator for the attenuation range over 30 dB. Therefore, the contribution of linearity should be carefully considered. The linearity was evaluated by measuring a particular attenuator at different signal levels [4]. Then the uncertainty due to the linearity was estimated from the difference of the attenuation measured at each signal level. The IVD is traceable to the Japan national standard of AC voltage ratio at 10 kHz. All measurements were carried out at the room temperature of (23 ± 1) °C and the relative humidity of (50 ± 20)%.

3.2. NMC's method

NMC has developed an attenuation measurement system using a dual-channel audio frequency (AF) substitution method. Fig. 3 shows the diagram of the attenuation measurement system in WR-15 waveguide band. The measurement principle is similar to another WR-10 band attenuation measurement system of NMC which had been described in [5]. The mm-wave signals are down-converted to main-path and reference-path AF signals at 5.02 kHz. The reference AF signal provides a frequency ref-