Bilateral Comparison of RF Power Measurements with 2.4 mm Connectors between SCL and NMC, A*STAR

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***Abstract* — This paper presents a bilateral comparison of RF power measurements with 2.4 mm connectors carried out between the National Metrology Centre of the Agency for Science, Technology and Research (NMC, A*STAR) of Singapore and the Standards and Calibration Laboratory (SCL) of Hong Kong. The comparison demonstrates the precision measurement capabilities and validates the equivalence of coaxial power calibration services with 2.4 mm connectors at both the laboratories.**

***Index Terms* — Bilateral comparison, measurement standards, power measurements, uncertainty.**

I. Introduction

Precision power measurements are increasingly demanded at higher frequency for different scientific and industrial applications. Correspondingly, measurement equipment and devices (e.g., power sensor and meter) with reliable accuracy are required, hence necessary calibrations.

Both the National Metrology Centre of the Agency for Science, Technology and Research (NMC, A*STAR) of Singapore and the Standards and Calibration Laboratory (SCL) of Hong Kong have recently developed their capabilities in coaxial power calibration services with 2.4 mm connectors, which could support the operations up to 50 GHz.

Since both the laboratories (NMC, A*STAR and SCL) missed previous international comparison CCEM.RF-S1.C (GTRF/02-03) [1] to demonstrate the precision measurement capabilities and validate the equivalence of coaxial power calibration services with 2.4 mm connectors, a bilateral power comparison with 2.4 mm connectors becomes significant for them and has been planned to test their existing calibration systems and standards.

In this paper, the results from this bilateral comparison will be analyzed and reported.

II. Traveling Standard

An Agilent N8487A thermocouple power sensor (S/N: MY52460013) provided by the SCL was used as the Traveling Standard, together with an Agilent E4419B power meter (S/N: MY40510624). Both the laboratories (NMC, A*STAR and SCL) performed their measurements using this power meter relative to its reference power of 1 mW at 50 MHz.

The calibration factors of the power sensor relative to its 50 MHz value were measured by each laboratory. Due to the limitation of the signal source at the SCL (up to 40 GHz), this bilateral comparison of RF power measurements with 2.4 mm connectors only covered the frequency points from low frequency up to 40 GHz. In addition to the calibration factor, the corresponding uncertainties were also given following each laboratory's own method.

It is noted that the reference power standard at the NMC, A*STAR is traceable to the National Institute of Standards and Technology's (NIST) primary standard, while the reference standard at the SCL is traceable to the Korea Research Institute of Standards and Science's (KRISS) primary standard.

III. Measurement System and Methodologies

NMC, A*STAR used a typical measurement setup [2-3] implemented with a *direct comparison transfer* technique which was proposed by the NIST [4]. Measurements were carried out at a temperature of (23 ± 2) ºC and a relative humidity of (55 ± 10) %. The reference standard (with a calibration factor K_{STD}) is measured on Port 2 of a 2.4 mm power splitter, and then replaced with the traveling standard which is treated as an unknown device under test (DUT). A monitoring power sensor is connected to Port 3 of the splitter for power leveling.

The calibration factor K_{DUT} of the DUT is determined through

$$K_{DUT} = K_{STD} \times \frac{P_{DUT}}{P_{STD}} \times \frac{P_{3STD}}{P_{3DUT}} \times \frac{|1-\Gamma_{DUT}\Gamma_{EG}|^2}{|1-\Gamma_{STD}\Gamma_{EG}|^2}\,. \quad (1)$$

Here, P_{DUT} and P_{3DUT} are the powers measured at Port 2 using the DUT and that at Port 3 using a monitoring power sensor respectively. P_{STD} and P_{3STD} are the powers measured at Port 2 using the reference standard and that at Port 3 using the same monitoring power sensor. Γ_{STD} is the reflection coefficient of the reference standard, Γ_{DUT} is the reflection coefficient of the DUT, and Γ_{EG} is the equivalent source match term of Port 2. Detailed description of eq. (1) can be obtained in [3-4].

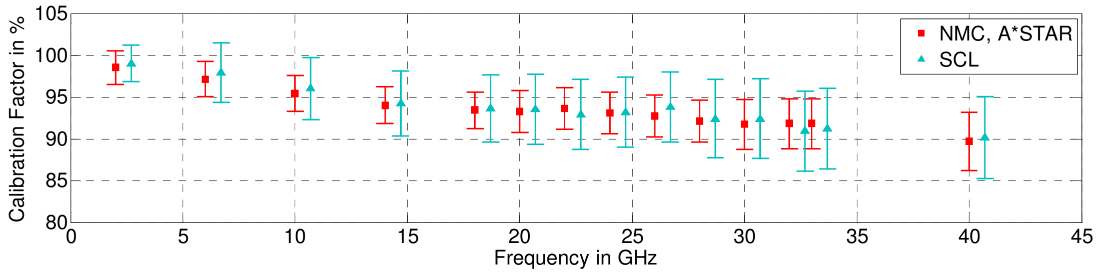

Fig. 1. Test results of the traveling standard. Uncertainty bars are shown for $k = 2$. Frequency values are shifted for better readability.

SCL also applied a similar calibration methodology. The measurements were carried out at a temperature of (23 ± 1) ℃ and a relative humidity of (45 ± 8) %.

Table 1. Calibration factors and their uncertainties at NMC and SCL.

f (GHz)	K_{NMC} (%)	U_{NMC} (%)	K_{SCL} (%)	U_{SCL} (%)	E_n
2	98.5	2.0	99.0	2.2	0.16
6	97.1	2.1	97.9	3.6	0.18
10	95.4	2.1	96.0	3.7	0.13
14	94.0	2.2	94.2	3.9	0.03
18	93.4	2.2	93.6	4.0	0.03
20	93.3	2.5	93.5	4.2	0.04
22	93.6	2.5	92.9	4.2	0.14
24	93.1	2.5	93.2	4.2	0.03
26	92.7	2.5	93.8	4.2	0.23
28	92.1	2.5	92.4	4.7	0.06
30	91.7	3.0	92.4	4.8	0.12
32	91.8	3.0	90.9	4.8	0.16
33	91.8	3.0	91.2	4.8	0.11
40	89.7	3.5	90.1	4.9	0.06

IV. Results and Analysis

The test results of the traveling standard at each laboratory, together with their expanded uncertainties are shown in Fig. 1, and also summarized in Table 1. It is noted that the expanded uncertainties were estimated according to the *ISO Guide to the Expression of Uncertainty in Measurement* (JCGM 100:2008) [5] in this bilateral comparison exercise, with the uncertainty components relevant and significant to the calibration process included.

Fig. 2 presents the difference in results evaluated in term of the error E_n normalized with respect to the stated uncertainties using the following formula [6]:

$$E_n = \frac{K_A - K_B}{\sqrt{U_A^2 + U_B^2}}, \qquad (2)$$

where K_A and K_B are the test results of calibration factor, and U_A and U_B are their corresponding expanded uncertainties (at a 95% confidence level, $k = 2$) evaluated by each laboratory. According to [6], the discrepancies between the testing results are acceptable when $|E_n| \le 1$.

As shown in Fig. 2, the normalized error E_n indicates good agreement of the results in the whole frequency range under comparison with $|E_n| < 0.25$. The observations demonstrate the measurement capability and degree of equivalence between RF power measurements with 2.4 mm connectors performed at both the laboratories, NMC, A*STAR of Singapore and SCL of Hong Kong.

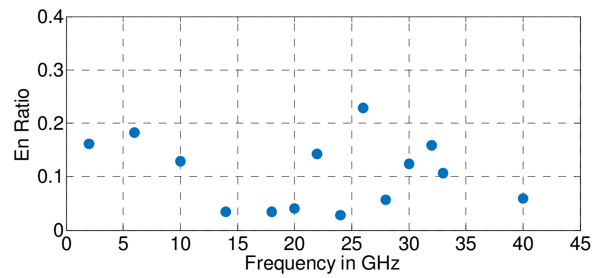

Fig.2. E_n ratio for the inter-laboratory comparison between SCL and NMC, A*STAR.

V. Conclusion

This paper reported a bilateral comparison of RF power measurements with 2.4 mm connectors between the NMC, A*STAR of Singapore and the SCL of Hong Kong. The comparison has demonstrated the precision measurement capabilities and validated the equivalence of coaxial power measurements with 2.4 mm connector at both the laboratories.

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