

Interlaboratory Comparison of Microwave Power Measurement Using Type N Coaxial Line

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Abstract - An interlaboratory comparison of microwave power measurement (project UME-EM-10-02) was carried out among eight (8) laboratories in Turkey. In this comparison, it was requested to make microwave power measurements at +10 dBm, 0 dBm and -15 dBm power levels with 0.03 GHz, 1 GHz, 7 GHz, 12 GHz and 18 GHz frequencies with their own measurement systems and methods. The measurement results and the expanded uncertainties were presented by the participant laboratories. Also, the normalized score (E_n) of each participant laboratory were calculated and presented to evaluate the performance of the laboratories. Most of the results in measuring power on a type N coaxial line show good agreement. According to the calculated E_n values, corrective actions were proposed to some of the participant laboratories.

Keywords: Comparison, microwave, power, uncertainty.

I. Introduction

Interlaboratory comparisons and proficiency tests are important tools for the assessment of calibration/test laboratory technical competence [1, 2]. According to the TS EN ISO/IEC 17025 standard, the calibration or test laboratories that are accredited by an accreditation agency must guarantee their measurement accuracy through participation in interlaboratory comparisons or proficiency-testing programmes. In the context of this requirement for the accredited laboratories, the Turkish Accreditation Agency (TÜRKAK) and the National Metrology Institute of Turkey (TÜBİTAK UME) collaborated to conduct an interlaboratory comparison in the area of microwave power measurements. Traceability of the microwave power is obtained by using microcalorimeter system [3, 4]. The frequencies and power levels for the comparison were determined at a stakeholder meeting organized by TÜBİTAK UME in February 2010. The comparison aimed to check the quality of microwave power measurements in the defined range.

II. Technical Protocol for the Comparison

In this comparison, TÜBİTAK UME composed a protocol in which participants were asked to present their results at the measurement points given in Table 1, including a statement of uncertainty with a coverage factor of $k=2$ [5]. Also it was recommended that the participants keep the travelling standard at a temperature of $(23 \pm 1)^\circ\text{C}$ and $(45 \pm 10)\%$ relative humidity for 24 hours before starting the measurement. Meanwhile, participants were urged to utilize the measurement system they used for the best measurement uncertainty for their accreditation scopes.

Table 1. Measurement points

Power (dBm)	Frequencies (GHz)
-15	0.03, 1, 7, 12, 18
0	0.03, 1, 7, 12, 18
+10	0.03, 1, 7, 12, 18

A. Traveling standard

As a microwave power source, a commercially available R&S SMP04 signal generator was used as the travelling standard. Its frequency and power range are between 10 MHz and 40 GHz, -20 dBm and +10 dBm, respectively.

The power output connector of the travelling standard is N type female.

B. Participant laboratories and schedule

TÜBİTAK UME acted as the coordinator and pilot laboratory for the comparison. Eight calibration laboratories participated in this comparison. Seven of them made power measurements within the entire defined range and one of them measured power below 1 GHz. In the original circulation scheme, each laboratory was allowed 1 week for measurements and transportation of the standard. The travelling standard was measured by TÜBİTAK UME before and after participant laboratory measurements. The measurements were completed within a period of twenty eight weeks. Each participating laboratory was assigned a code name consisting of a single letter.

III. Measurement Results

The participants were asked to submit measurement results at the different microwave power levels for the five different frequencies with expanded uncertainties ($k=2$) and model functions on the template uncertainty budget table given by TÜBİTAK UME. Also, use of the “ISO Guide for the expression of uncertainty in measurement” or “EA-4.02 Expression of the uncertainty of measurement in calibration” documents was recommended for uncertainty calculations of the comparison measurements. The +3 dBm and -7 dBm output power data obtained since 2002 were used to analyze the behaviour of the long term drift of the travelling standard. The standard uncertainty of the long term drift is smaller than 0.08 dB. In order to observe the behaviour of the travelling standard during the comparison, it was measured by TÜBİTAK UME before and after participant laboratory measurements. The measurement results indicated that output power at +10 dBm and 0 dBm of the travelling standard were stable during the comparison [6]. Then, the comparison reference value (CRV) and its variance was calculated using the weighted mean equation $\bar{X} = \sum_{i=1}^n (X_i / \sigma_i^2) / \sum_{i=1}^n (1 / \sigma_i^2)$, and $\sigma^2 = 1 / \sum_{i=1}^n (1 / \sigma_i^2)$ ($n=10$, number of the measurement done by the pilot laboratory) respectively for each frequency point and power level.

The long term drift of the travelling standard, the variance of the weighted mean and reproducibility of the measurements were used to calculate the CRV uncertainty for each power level. The CRVs and their uncertainties for +10 dBm and 0 dBm are given in Figure 1 and Figure 2 respectively. Figure 3 shows the results of the pilot laboratory’s measurements at -15 dBm. The expanded uncertainties for the -15 dBm power level were calculated as 0.174 dB, 0.155 dB, 0.195 dB, 0.190 dB and 0.306 dB for frequencies 0.03 GHz, 1 GHz, 7 GHz, 12 GHz and 18 GHz respectively. Also, Figure 3 shows that there was a drift at -15 dBm measurements during the comparison period. So, the CRV value was separately calculated for each laboratory.

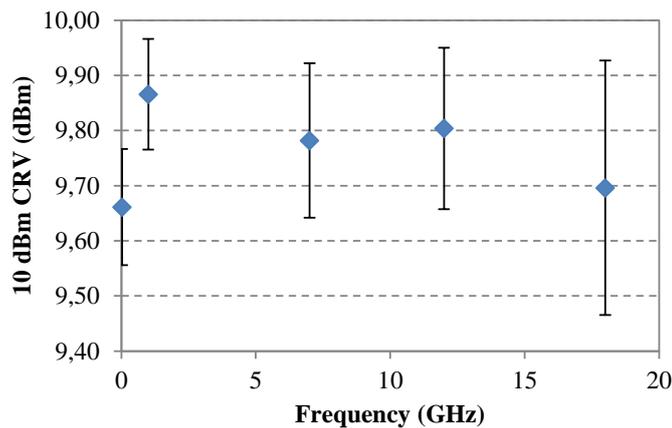


Figure 1. Comparison reference value of +10 dBm

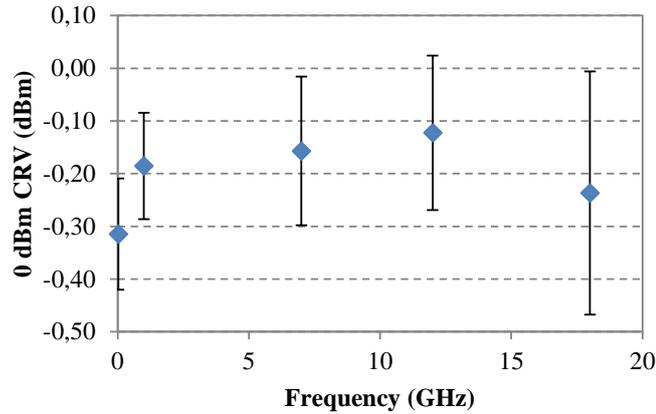


Figure 2. Comparison reference value of 0 dBm

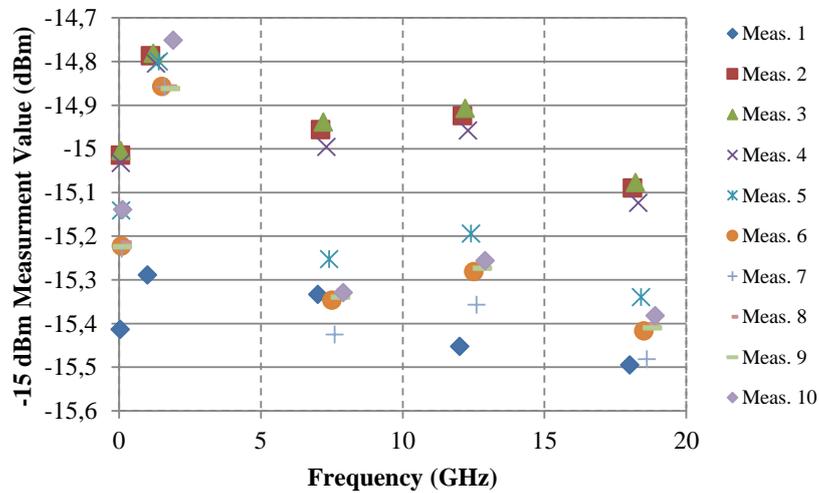


Figure 3. Pilot laboratory measurements at -15 dBm during the comparison

IV. Analysis of the Results

The participant laboratories submitted their reports to the pilot laboratory. The reports were evaluated according to the ISO/IEC 17043 standard [7]. The D (difference) values, calculated by the formula $D_{LabX} = P_{LabX} - P_{CRV}$ were given as the comparison results, where P_{LabX} is the result of X laboratory (X : A, B, C, D, E, F, G, H) and P_{CRV} is the comparison reference value. The D values and expanded uncertainties ($U(D)$) of the laboratories at the measurement points of +10 dBm, 0 dBm and -15 dBm are given in Table 2, Table 3 and Table 4, respectively. The subscript of the D indicates the frequency of the measurement in GHz.

Table 2. The differences and the expanded uncertainties of the participant laboratories at +10 dBm

Participant	$D_{0,03}$	$U(D_{0,03})$	D_1	$U(D_1)$	D_7	$U(D_7)$	D_{12}	$U(D_{12})$	D_{18}	$U(D_{18})$
Lab A	-0.001	0.180	0.004	0.180	-0.122	0.260	-0.024	0.260	-0.026	0.370
Lab B	0.006	0.200	0.034	0.230	0.083	0.350	0.074	0.350	0.021	0.350
Lab C	-0.090	0.300	-0.050	0.300	-0.098	0.300	-0.052	0.300	0.007	0.400
Lab D	-0.060	0.181	-0.020	0.174	-0.021	0.202	-0.007	0.447	0.054	0.348
Lab E	0.304	0.076	0.098	0.076	-	-	-	-	-	-
Lab F	-0.041	0.220	0.044	0.200	0.088	0.200	0.146	0.230	0.154	0.250
Lab G	-0.051	0.200	-0.086	0.200	-0.082	0.200	-0.054	0.200	-0.086	0.300
Lab H	0.101	0.076	-0.067	0.076	-0.249	0.079	-1.016	0.085	-0.695	0.133

Table 3. The differences and the expanded uncertainties of the participant laboratories at 0 dBm

Participant	$D_{0.03}$	$U(D_{0.03})$	D_1	$U(D_1)$	D_7	$U(D_7)$	D_{12}	$U(D_{12})$	D_{18}	$U(D_{18})$
Lab A	0.015	0.180	0.025	0.180	-0.073	0.260	0.013	0.260	-0.003	0.370
Lab B	0.001	0.200	0.025	0.240	0.046	0.350	0.038	0.350	0.017	0.350
Lab C	-0.116	0.200	-0.044	0.200	-0.092	0.200	-0.041	0.200	0.010	0.200
Lab D	-0.035	0.136	-0.019	0.136	0.007	0.136	0.014	0.136	0.059	0.136
Lab E	-0.030	0.429	0.059	0.381	-	-	-	-	-	-
Lab F	0.015	0.130	0.055	0.130	0.107	0.130	0.163	0.170	0.167	0.200
Lab G	-0.035	0.200	-0.065	0.200	-0.063	0.200	-0.037	0.200	-0.073	0.300
Lab H	0.010	0.076	-0.048	0.076	-0.232	0.079	-1.008	0.085	-0.689	0.133

Table 4. The differences and the expanded uncertainties of the participant laboratories at -15 dBm

Participant	$D_{0.03}$	$U(D_{0.03})$	D_1	$U(D_1)$	D_7	$U(D_7)$	D_{12}	$U(D_{12})$	D_{18}	$U(D_{18})$
Lab A	0.008	0.180	0.033	0.180	-0.103	0.260	-0.077	0.260	0.001	0.370
Lab B	0.125	0.200	0.079	0.240	0.088	0.360	0.054	0.360	0.027	0.360
Lab C	-0.009	0.400	-0.042	0.400	-0.144	0.400	-0.127	0.400	-0.054	0.500
Lab D	0.037	0.255	0.080	0.237	-0.002	0.280	-0.029	0.678	0.065	0.529
Lab E	0.036	12.280	0.021	10.920	-	-	-	-	-	-
Lab F	0.144	0.550	-0.682	0.540	-0.045	0.530	0.068	0.540	0.082	0.550
Lab G	0.040	0.200	-0.030	0.200	-0.248	0.200	-0.221	0.200	-0.224	0.300
Lab H	-0.098	0.076	-0.118	0.076	-0.140	0.079	-0.227	0.085	-0.271	0.133

The maximum and minimum D values were 0.304 dB and -1.016 dB respectively, and the expanded uncertainties were between 0.076 dB and 0.447 dB at the +10 dBm nominal power level. For the 0 dBm nominal power level, the maximum and minimum D values were 0.167 dB and -1.008 dB respectively, and the expanded uncertainties were between 0.076 dB and 0.429 dB. Also, at the -15 dBm nominal power level, the maximum and minimum D values were 0.144 dB and -0.682 dB, respectively, and expanded uncertainties were between 0.076 dB and 12.280 dB. According to these results, it can be clearly seen that the expanded uncertainties of Laboratory E for -15 dBm at 30 MHz and 1 GHz frequencies are greater than the expected uncertainty. This was found to be due to an incorrect calculation of the uncertainty budget by the participant laboratory. Also, the measurement results of Laboratory H above 7 GHz frequencies were relatively different than expected. It was thought that this difference can be attributed to the measurement system or method utilized.

The normalized score (E_n) was used to evaluate the performance of the participant laboratories. E_n values were calculated using Equation 1 [7] and the results are given in Table 5.

$$E_n = (P_{LabX} - P_{CRV}) / \sqrt{U_{LabX}^2 - U_{CRV}^2} \quad (1)$$

where U_{LabX} is the expanded uncertainty of the X participant result and U_{CRV} is the expanded uncertainty of the comparison reference value. If the X participant's $|E_n|$ value is smaller or equal to 1 (≤ 1), this indicates that participant laboratory has satisfactory performance. However, an $|E_n|$ value greater than 1 (> 1) means unsatisfactory performance and indicates that the participant laboratory needs a correction in its measurement process.

Table 5 shows that the $|E_n|$ values of five participant laboratories are lower than 1. The $|E_n|$ value of Laboratory F is greater than 1 at 1GHz for -15 dBm power. Laboratory E has very high uncertainties at 0.03 GHz and 1 GHz for -15 dBm power, so the $|E_n|$ value is not deemed a useful guide to the laboratory's performance at these frequencies. Also, its $|E_n|$ is greater than 1 at 0.03 GHz for +10 dBm. As for Laboratory H, the $|E_n|$ values at 7 GHz, 12 GHz and 18 GHz for +10 dBm and 0 dBm, and at 12 GHz for -15 dBm are greater than 1.

Table 5. E_n values of the participants

Participant	+10 dBm					0 dBm					-15 dBm				
	Frequency (GHz)					Frequency (GHz)					Frequency (GHz)				
	0.03	1	7	12	18	0.03	1	7	12	18	0.03	1	7	12	18
Lab A	-0.01	0.02	-0.41	-0.08	-0.06	0.07	0.12	-0.25	0.04	-0.01	0.03	0.14	-0.32	-0.24	0.00
Lab B	0.03	0.14	0.22	0.20	0.05	0.00	0.10	0.12	0.10	0.04	0.47	0.28	0.22	0.13	0.06
Lab C	-0.28	-0.16	-0.30	-0.16	0.01	-0.51	-0.20	-0.38	-0.17	0.03	-0.02	-0.10	-0.32	-0.29	-0.09
Lab D	-0.29	-0.10	-0.09	-0.01	0.13	-0.21	-0.11	0.04	0.07	0.22	0.12	0.28	-0.01	-0.04	0.11
Lab E	2.34	0.78	-	-	-	-0.07	0.15	-	-	-	0.00	0.00	-	-	-
Lab F	-0.17	0.20	0.36	0.54	0.45	0.09	0.34	0.56	0.72	0.55	0.25	-1.21	-0.08	0.12	0.13
Lab G	-0.23	-0.38	-0.34	-0.22	-0.23	-0.16	-0.29	-0.26	-0.15	-0.19	0.15	-0.12	-0.89	-0.80	-0.52
Lab H	0.78	-0.53	-1.55	-6.01	-2.61	0.07	-0.38	-1.44	-5.95	-2.59	-0.52	-0.68	-0.67	-1.09	-0.81

V. Conclusions

In order to evaluate the performance of laboratories which measure microwave power in Turkey, a national interlaboratory comparison was organized by the RF and Microwave Laboratory of TÜBİTAK ÜME. Eight laboratories participated in this comparison, which was completed in 28 weeks. The participants were asked to measure microwave power at +10 dBm, 0 dBm and -15 dBm between a frequency range of 30 MHz and 18 GHz with a Type N coaxial connector. Participant laboratories used their own measurement systems and methods to demonstrate their capabilities. The expanded uncertainties of all but one of the laboratories were consistent. It was found out that the $|E_n|$ values of three participant laboratories were greater than 1 at some power levels and frequencies. Finally, most of the results were satisfactory within the claimed uncertainty.

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References

- [1] EN ISO/IEC 17025, "General requirements for the competence of testing and calibration laboratories", 2005-05-15.
- [2] J. P. M. de Vreede, et al., "International comparison for RF power in the frequency range up to 18 GHz", IEEE Transactions on Instrumentation and Measurement, Vol. 50, No. 2, pp. 409-413, April 2001.
- [3] E. Vremera, L. Brunett, L. Oberto, M. Sellone, "Alternative procedures in realizing of the high frequency power standards with microcalorimeter and thermoelectric power sensors", Measurement, Vol. 42, Is. 2, pp. 269-276, February 2009.
- [4] R. H. Judaschke, J. Rühaak, "Determination of the Correction Factor of Waveguide Microcalorimeters in the Millimeter-Wave Range", IEEE Trans. on Instrumentation and Measurement, Vol. 58, No. 4, pp. 1104 - 1108, 2009.
- [5] Ş. Yaran, "Technical protocol of the microwave power comparison", TÜBİTAK ÜME, Kocaeli, 2010. (in Turkish)
- [6] Ş. Yaran, M. Celep, "Microwave power comparison report", ÜME-EM-10-02, TÜBİTAK ÜME, Kocaeli, 2010. (in Turkish)
- [7] ISO/IEC 17043 International Standard, "Conformity assessment – General requirements for proficiency testing", 2010-02-01.