SIM Key Comparison of S-parameters SIM.EM.RF-K5b.CL

H. Silva[1], G. Monasterios[1], S. Padilla[2], R. Ginley[3], A. Michaud[4], P. S. Negi[5]
[1]INTI (Instituto Nacional de Tecnología Industrial)
metrologiarf@inti.gob.ar
[2]CENAM (Centro Nacional de Metrología)
[3]NIST (National Institute of Standards and Technology)
[4]NRC (National Research Council)
[5]NPLI (National Physical Laboratory of India)

***Abstract*—The first RF key comparison within the Inter-American Metrology System (SIM) Regional Metrology Organization has been carried out. The purpose of it was to establish the degree of equivalence of scattering parameters measurements of both 1-port and 2-port coaxial devices among national metrology institutes (NMIs) that belong to SIM region and in support of CIPM Mutual Recognition Agreement (MRA). The travelling standards were four devices with Type-N coaxial connectors and $50\ \Omega$ of characteristic impedance: a matched load, a mismatched load and two attenuators of 3 dB and 20 dB. Four SIM institutes participated in the comparison as well as NPLI.**

***Index Terms*—Measurement, measurement standards, measurement techniques, precision measurements, radio frequency, scattering parameters, measurement uncertainty.**

I. Introduction

The key comparison CCEM.RF-K5b.CL [1] established the Key Comparison Reference Value (KCRV) for scattering parameters measurements in coaxial elements fitted with Type-N connector in the frequency range from 2 GHz to 18 GHz. In that comparison, NMIs from several metrology regions took part including two laboratories from SIM.

As a consequence, the SIM.EM.RF-K5b.CL comparison in RF was proposed, being the first comparison in high frequency to be carried out within the SIM region. The aim was to assess measurement capabilities of SIM NMIs in S-parameters. Traveling standards and measurement frequency points were selected based on the CCEM comparison ones. It allowed to link the results between SIM and CCEM comparisons through the laboratories participating in both. INTI (Argentina) provided the travelling standards and acted as pilot laboratory for the comparison.

II. Travelling Standards,Measurement points and participants

The travelling standards were a matched load, a mismatched load (nominal VSWR 2.0) and two attenuators, of 3 dB and 20 dB respectively, with $50\ \Omega$ characteristic impedance. The coaxial connector of the matched and mismatched loads was a Type-N (male) connector. In the case of attenuators, they were insertable devices, i.e. one connector was Type-N (male) and the other was Type-N (female).

Participants were asked to measure the reflection coefficient of the loads and the four s-parameters of the attenuators from 2 GHz to 18 GHz in 1 GHz steps but the analysis of the results was done only for S_{11} (one-port devices) and S_{21} (two-port devices) in 2 GHz, 9 GHz and 18 GHz. These frequencies were chosen to cover the low, medium and high frequency range.

TABLE I: SIM.EM.RF-K5b participants

Country	NMI
Argentina	INTI
Mexico	CENAM
USA	NIST
Canada	NRC
India	NPLI

III. Computation Of Results

A. Comparison reference value

The Comparison Reference Value (CRV) is determined using an unweighted mean of the measurement results reported by the participants:

$$z_m = \frac{1}{N}\sum_{i=1}^{N} z_i \tag{1}$$

where z_m is the complex CRV, z_i is the complex value reported by laboratory i and N is the total number of participants in the comparison exercise. The CRV uncertainties are determined by a 2×2 matrix covariance:

$$V_m = \begin{pmatrix} u^2(x_m) & u(x_m, y_m) \\ u(y_m, x_m) & u^2(y_m) \end{pmatrix} \tag{2}$$

where:

$$u^2(x_m) = \frac{1}{N(N-1)}\sum_{i=1}^{N}(x_i - x_m)^2 \tag{3}$$

$$u^2(y_m) = \frac{1}{N(N-1)}\sum_{i=1}^{N}(y_i - y_m)^2 \tag{4}$$

$$u(x_m, y_m) = \frac{1}{N(N-1)}\sum_{i=1}^{N}(x_i - x_m)(y_i - y_m) \tag{5}$$

In (3), (4) and (5), x_m and y_m are the real and imaginary parts of the CRV. x_i and y_i are the real and imaginary parts of the individual reported values.

978-1-5386-0974-3/18/$31.00 ©2018 IEEE

B. Degrees of equivalence

The degree of equivalence (DoE) d_i for the laboratory i with respect to the CRV is given by:

$$d_i = z_i - z_m \tag{6}$$

and the covariance matrix associated is:

$$V_{d_i} = V_m + (1 - \frac{2}{N})V_i \tag{7}$$

where V_i is the covariance matrix from measurement uncertainties reported by the participants. The degrees of equivalence defined above are complex-valued magnitudes. The next expression is used to reduce the number of dimensions [3]:

$$y = |d_i| \tag{8}$$

$$dy = |d_i|\sqrt{(d_i^T \ V_{d_i}^{-1} d_i)^{-1} k^2} \tag{9}$$

where the factor k is a suitable coverage factor chosen to give a 95% confidence level. If d_i follows a bivariate Gaussian distribution and the degrees of freedom are sufficiently high, then $k = 2.45$ is assumed. dy is the distance from y to the confidence boundary through the origin of the coordinate system, so if $dy > y$ the DoE is considered consistent.

IV. Reported Results

The reported resuts for each participant are shown in tables II to V.

TABLE II: Matched load - DoE with respect to CRV of $\mathbf{S_{11}}$

	Freq=2 GHz		Freq=9 GHz		Freq=18 GHz	
	y	dy	y	dy	y	dy
INTI	0.0015	0.0053	0.0038	0.0070	0.0030	0.0097
NIST	0.0015	0.0050	0.0030	0.0092	0.0063	0.0144
NRC	0.0010	0.0101	0.0059	0.0121	0.0088	0.0163
CENAM	0.0010	0.0024	0.0030	0.0053	0.0040	0.0086
NPLI	0.0041	0.0036	0.0098	0.0127	0.0137	0.0103

TABLE III: Mismatched load - DoE with respect to CRV of $\mathbf{S_{11}}$

	Freq=2 GHz		Freq=9 GHz		Freq=18 GHz	
	y	dy	y	dy	y	dy
INTI	0.0015	0.0059	0.0054	0.0118	0.0070	0.0159
NIST	0.0031	0.0076	0.0056	0.0110	0.0052	0.0163
NRC	0.0001	0.0100	0.0087	0.0163	0.0092	0.0199
CENAM	0.0020	0.0032	0.0052	0.0080	0.0046	0.0073
NPLI	0.0052	0.0106	0.0117	0.0178	0.0159	0.0144

TABLE IV: 3 dB Attenuator - DoE with respect to CRV of $\mathbf{S_{21}}$

	Freq=2 GHz		Freq=9 GHz		Freq=18 GHz	
	y	dy	y	dy	y	dy
INTI	0.0012	0.0014	0.0008	0.0017	0.0073	0.0063
NIST	0.0006	0.0045	0.0031	0.0097	0.0018	0.0168
NRC	0.0014	0.0049	0.0029	0.0054	0.0015	0.0076
CENAM	0.0010	0.0017	0.0021	0.0042	0.0080	0.0146
NPLI	0.0016	0.0027	0.0014	0.0048	0.0035	0.0070

TABLE V: 20 dB Attenuator - DoE with respect to CRV of $\mathbf{S_{21}}$

	Freq=2 GHz		Freq=9 GHz		Freq=18 GHz	
	y	dy	y	dy	y	dy
INTI	0.0003	0.0005	0.0006	0.0008	0.0007	0.0008
NIST	0.0001	0.0007	0.0006	0.0024	0.0006	0.0025
NRC	0.0005	0.0048	0.0011	0.0048	0.0004	0.0048
CENAM	0.0003	0.0004	0.0002	0.0007	0.0011	0.0017
NPLI	0.0003	0.0007	0.0004	0.0013	0.0013	0.0053

V. Linkage With CCEM.RF-K5b.CL

For those NMIs that participated only in the SIM comparison, the DoE with respect to KCRV from CCEM comparison [1] was calculated by means of the approach detailed in [2] which is based on the degree of equivalence with respect to the KCRV and the degree of equivalence d_i from the linking laboratories. Finally, this linked DoE is reduced in the number of dimensions by means of (8) and (9), as shown in tables VI to VIII.

TABLE VI: Matched load - DoE with respect to KCRV of $\mathbf{S_{11}}$

	Freq=2 GHz		Freq=9 GHz		Freq=18 GHz	
	y	dy	y	dy	y	dy
INTI	0.0006	0.0080	0.0042	0.0111	0.0022	0.0133
CENAM	0.0009	0.0057	0.0034	0.0089	0.0037	0.0120

TABLE VII: 3 dB Attenuator - DoE with respect to KCRV of $\mathbf{S_{21}}$

	Freq=2 GHz		Freq=9 GHz		Freq=18 GHz	
	y	dy	y	dy	y	dy
INTI	0.0018	0.0032	0.0035	0.0055	0.0093	0.0092
CENAM	0.0012	0.0031	0.0057	0.0072	0.0068	0.0175

TABLE VIII: 20 dB Attenuator - DoE with respect to KCRV of $\mathbf{S_{21}}$

	Freq=2 GHz		Freq=9 GHz		Freq=18 GHz	
	y	dy	y	dy	y	dy
INTI	0.0002	0.0008	0.0005	0.0027	0.0004	0.0042
CENAM	0.0001	0.0008	0.0004	0.0027	0.0021	0.0045

VI. Conclusion

The first Key Comparison in radio frequency magnitudes has been carried out in the SIM region. A variety of VNA calibration methods has been applied by the participants, allowing to test the performance of different type of S-parameter measurement systems based on vector network analyzers.

Scattering parameters measurements in 2 GHz, 9 GHz and 18 GHz have shown, in general, good consistency between participants and with respect to CRV with only few exceptions.

A linking method between both (SIM and CCEM) comparisons was proposed and it has shown that both set of results also have good consistency.

References

[1] C.P.Eio, "CCEM key comparison CCEM.RF-K5b.CL (GT-RF/92-3) scattering coefficients by broad-band methods, 2-18 GHz - Type N Connector, final report of the pilot laboratory", kcdb.bipm.org, 2010.

[2] H.Silva, G. Monasterios, "Key comparison SIM.EM.RF-K5b.CL scattering coefficients by broad-band methods, 2 GHz-18 GHz - type N connector, final report", kcdb.bipm.org, 2016.

[3] M Zeier, On the analysis of multidimensional quantities in measurement comparisons, *CPEM Conference Digest*, pages 458-459, July 2006.