AFRIMETS.EM.RF-S1

Attenuation and reflection measurements for coaxials at 100 MHz, 1 GHz and 10 GHz – Type N Connector

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CONTENTS

1 Introduction

The AFRIMETS TC-EM meeting of 26 July 2016 held in Cairo, Egypt, approved a supplementary comparison [1] on RF attenuation and voltage reflection coefficient (VRC) to be piloted by the National Metrology Institute of South Africa (NMISA).

This report describes the supplementary comparison of two fixed attenuators (RF attenuation) and two mismatched loads (VRC), which was conducted between April 2017 and May 2018. Three national metrology laboratories and/or designated institutes namely, NMISA (South Africa), NIS (Egypt) and DEFNAT (Tunisia) participated. The motivation to conduct the comparison was to confirm the consistency of RF attenuation and reflection measurements of the participating AFRIMETS members.

2 Organisation of the comparison

2.1 Participants

The Pilot laboratory is the National Metrology Institute of South Africa (NMISA). The list of participants in the comparison are shown in the table below

Table 2-1. List of participants

Country	Institute	Acronym	Contact person	e-mail	Shipping address
South Africa	National Metrology Institute of South Africa	NMISA	Linoh Magagula	lmagagula@nmisa.org	Building 5, CSIR Scientia campus, Meiring Naude Road, Pretoria, 0001, South Africa
Tunisia	Designated National Institute DEFNAT	DEFNAT	Abdelkarim MALLAT Nadia FEZAI	metrologie@defense.tn	Direction Générale des Transmissions et de l'Informatique, Base Militaire Bab Saadoun EL Omrane 1005 Tunis TUNISIE.
Egypt	National Institute of Standards	NIS	Abdel Rahman Sallam	Sallam2050@gmail.com	National Institute of Standards (NIS) Tersa Street, El Haram, Giza P.O. Box: 136 Giza Code 12211 Giza – EGYPT

2.2 Measurement schedule

The artefacts were sent to the participating laboratories in the order listed in Table 2-2. The dates for the comparison were as shown in the table below for the completion of measurements (and dispatch) of the artefacts in each laboratory. Some of the participants do not use ATA carnet, so to prevent confusion each participating laboratory sent the artefacts back to the Pilot laboratory after completing their measurements and the Pilot laboratory sent the artefacts to the next participant, that is, in a star configuration.

Table 2-2. Measurement schedule

Institute	Measurement & Dispatch
NMISA (1)	April 2017
DEFNAT	May – June 2017
NMISA (2)	June – July 2017
NIS	September 2017 – May 2018
NMISA (3)	May 2018

On arrival at the participating laboratory, the devices and their packaging were carefully checked for any damage that may have been caused during transit, and each participant sent a confirmation email to acknowledge receipt to the pilot laboratory. However, one participant (NIS) 'hand-carried' the artefacts from the pilot laboratory to their laboratory and shipped it back to the pilot laboratory after completing their measurements.

2.3 Unexpected incidents

No incident involving the travelling standards was reported. However, the original measurement schedule as per the Technical Protocol [2] changed as one participant waited too long for their calibration standards to arrive from their supplier (or service provider) before they performed measurements on the travelling standards.

3 Travelling standards and required measurement

The travelling standards and required measurements are given below.

3.1 Description of standards

The travelling standards are described in Table 3-1 below. It is worth mentioning that that the mismatch load (Maury 2561C), which appears in the Technical Protocol [2], was replaced with Maury 2561A before the comparison started after discovering it was faulty.

Table 3-1. Description of the travelling standards

Device	Identifier	Model	Serial no.	Nominal value	Impedance (Ω)	Connector
Attenuator	ATT-1	HP 8491B	17693	3 dB	50	Type N (male/female)
Attenuator	ATT-2	HP 8491B	23897	20 dB	50	Type N (male/female)
Mismatch load	L-1	Maury 2562C	6046	VSWR 1.20	50	Type N (male)
Mismatch load	L-2	Maury 2561A	5423	VSWR 1.20	50	Type N (female)

3.2 Measurement methods

The participants were asked to give a brief overview of the measurement methods used in this comparison, which are typically also used in their laboratories for normal calibration. These are summarised below.

NMISA

Attenuation measurements were performed by direct measurement against a measuring receiver while reflection measurements (VRC) were obtained by direct measurement against a VNA. The measuring receiver was calibrated using step attenuators, Keysight 8494G and Keysight 8496G. The step attenuators were calibrated using a voltage ratio method employing an inductive voltage divider standard. The VRC measurement with the VNA is traceable through airlines calibrated at an overseas national metrology institute. The VNA was first calibrated with the relevant calibration kit (Agilent 85054B) before measurement of the travelling standards.

The attenuation measurement setup was as follows:

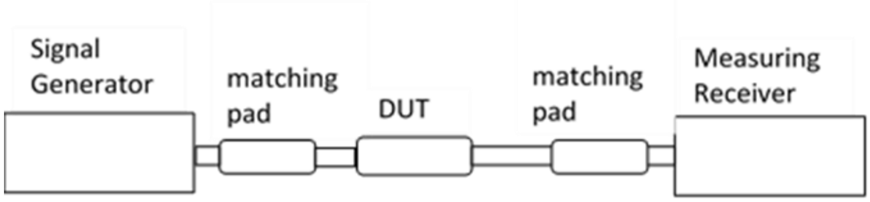

Figure 1. Attenuation measurement setup

The DUT was connected between matching pads after the zero-reference was set on the receiver at the measurement level before the DUT was inserted. The power level of the signal from the generator was set as to not overload the receiver or be insufficient when the DUT is inserted. The relative power after the DUT is inserted is equal to the insertion loss of the DUT.

NIS

The attenuation and reflection (VRC) measurements were carried out using a R&S ZVA-40 VNA. The VNA was calibrated before doing the measurements using the SOLT method (with sliding load). The traceability of the VNA setup is based on the calibration kit Agilent 85054B, which is generic and traceable to NIST. The measurement results are based on 8 different connector orientations of the travelling standards. Measurement uncertainty is calculated according to the new EURAMET guide [3] using VNA Tools software. The calculation is based on basic uncertainty contributions contained in the VNA Tools database. Measurement setup was previously characterised to populate the VNA Tools database.

DEFNAT

DEFNAT used the series IF substitution method to perform attenuation measurements and then used a reflectometer system, which employs a directional tuner and stub tuner (as well as spectrum analyser for low frequencies) for reflection (VRC) measurements. The traceability of the attenuation measurements is through a VM7 (attenuator and signal calibrator). The reflectometer method, which employs a directional coupler and stub tuner is the primary method for determining the reflection coefficient.
The measurement setup for attenuation was as shown below.

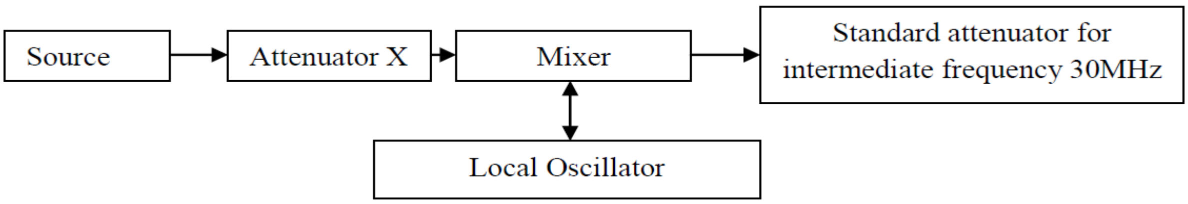

Figure 2. Attenuation measurement setup

The measurement setup for the reflection measurements was as shown below.

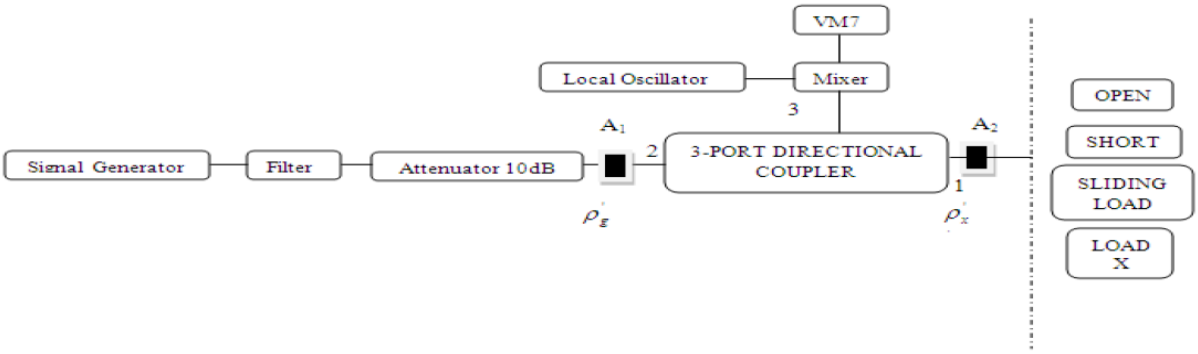

Figure 3. Measurement setup for reflection (VRC) measurements

3.3 Measurement instructions

The required measurements are given below:

3 dB HP8491B attenuator: *attenuation* and *VRC* at 100 MHz, 1 GHz, 10 GHz
20 dB HP8491B attenuator: *attenuation* and *VRC* at 100 MHz, 1 GHz, 10 GHz
Maury 2562C Mismatch load : *VRC* at 100 MHz, 1 GHz, 10 GHz
Maury 2561A Mismatch load : *VRC* at 100 MHz, 1 GHz, 10 GHz

3.4 Deviation from the protocol

The mismatch load Maury 2561C specified in the protocol was replaced by a Maury 2561A mismatch load before the start of the comparison after discovering that it was faulty. Also, according to the protocol the comparison reference value was to be computed using weighted mean of the NMISA measurement results. However, the arithmetic mean was used to compute the comparison reference values. The weighted mean applies if the measurement results of the same parameter are obtained using different measurement systems or from different laboratories. In the case of NMISA, the same measurement system and laboratory was used to obtain the attenuation results. Likewise, for the voltage reflection coefficient results.

4 Stability of the travelling standards

The stability of the travelling standards throughout the duration of the comparison, obtained from NMISA's combined three sets of measurements for April 2017, July 2017 and May 2018, are shown graphically in the following figures:

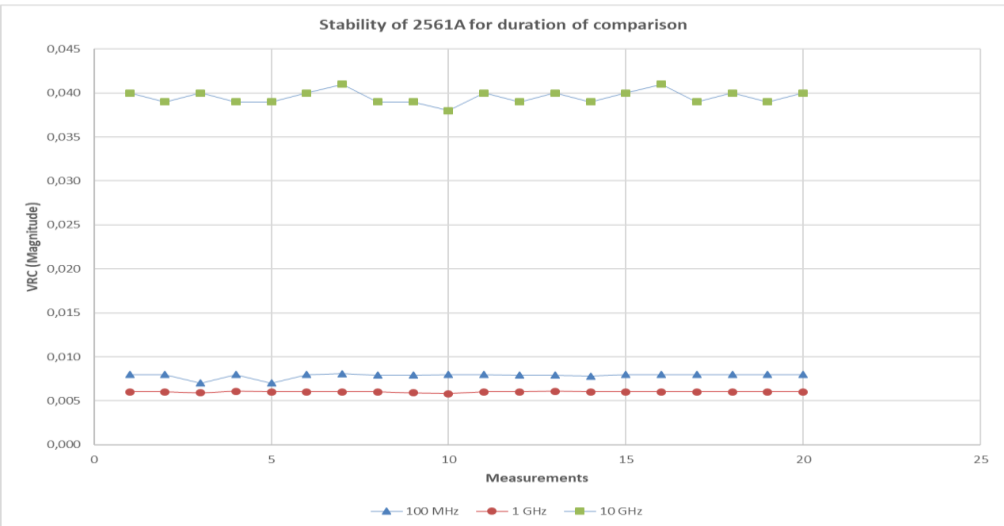

Figure 4. Stability of Maury 2561A for duration of comparison

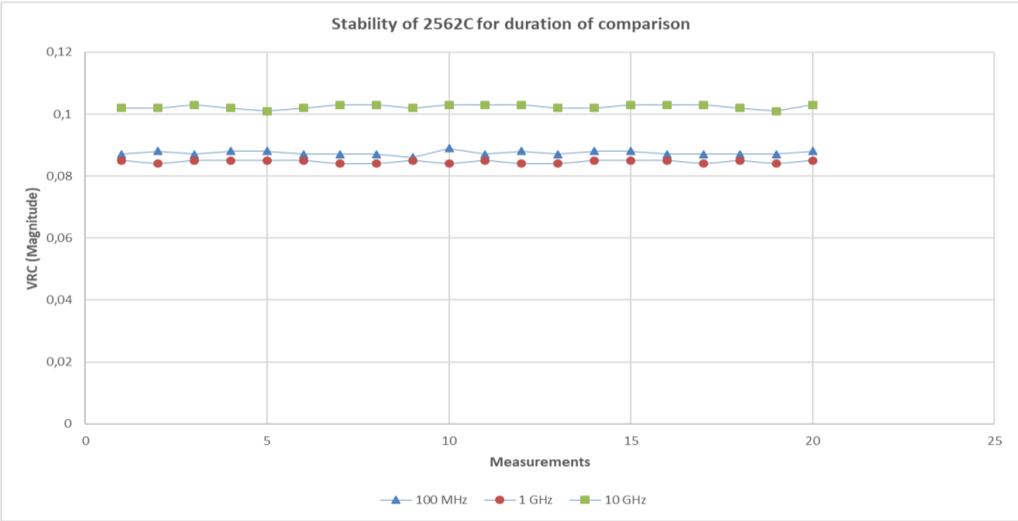

Figure 5. Stability of Maury 2562C for duration of comparison

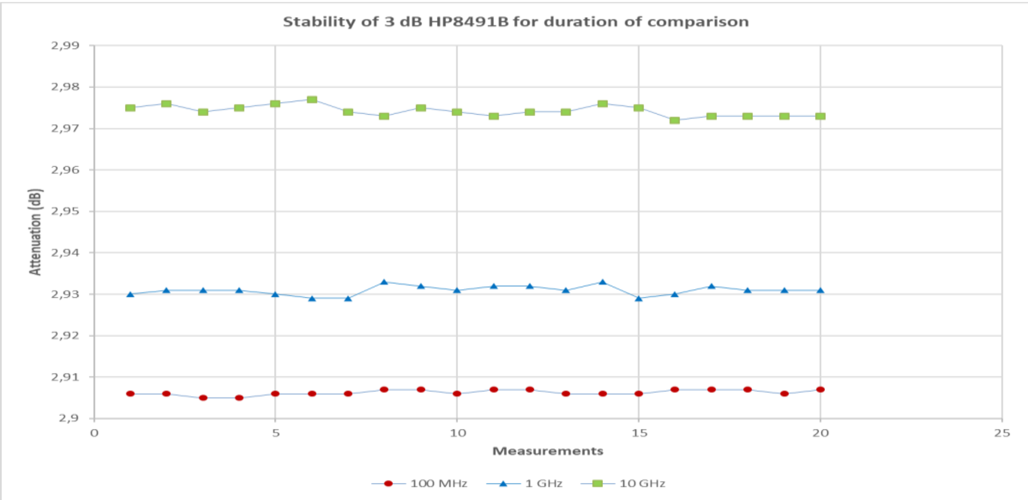

Figure 6. Stability of 3 dB HP 8491B for duration of comparison

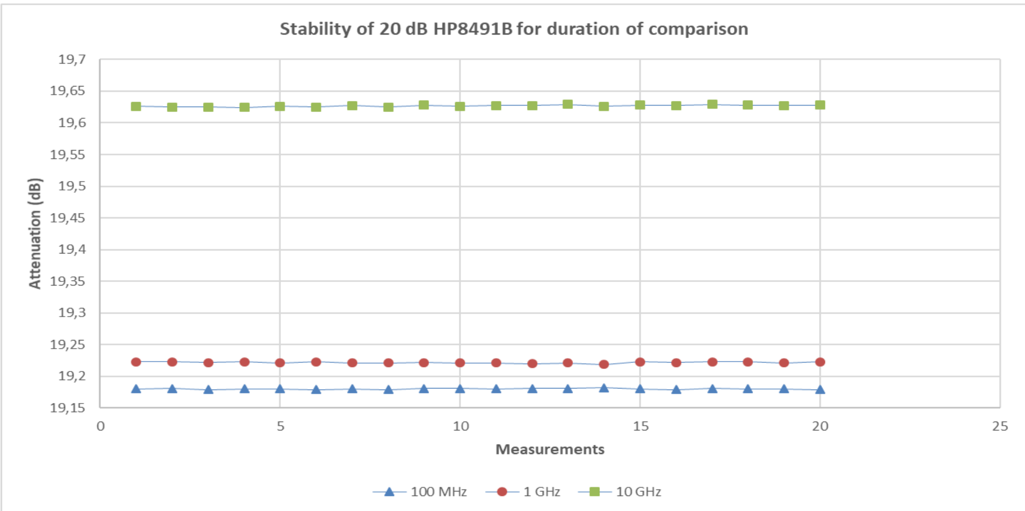

Figure 7. Stability of 20 dB HP 8491B for duration of comparison

Considering the uncertainty of the measurements, the stability of the standards is considered good for all frequencies for the duration of the comparison. Therefore, no additional uncertainty corrections have been added to the participant's results, nor has any drift correction been performed.

5 Discussion of comparison results

The comparison results are discussed below. Participants were asked in the protocol to provide estimates of the uncertainties (at k =1) or the combined standard uncertainty for the measurands. The participants' detailed uncertainty calculations/budgets are given in Appendix A, Appendix B and Appendix C. This report proceeds with the discussion of results at expanded uncertainties (k = 2).

5.1 Results of participants

In the following tables, the measurement results of the participants for the RF attenuation and reflection (VRC) of the attenuators and mismatch loads, respectively, at the relevant frequency points are listed.

Table 5-1. Results for 3 dB HP 8491B

Laboratory	Frequency (MHz)	Attenuation (dB)	Uncertainty (k=2)
NMISA (1)	100	2.906	0.015
	1000	2.931	0.020
	10000	2.976	0.030
DEFNAT	100	2.911	0.066
	1000	2.936	0.068
	10000	3.004	0.094
NMISA (2)	100	2.907	0.015
	1000	2.932	0.020
	10000	2.974	0.030
NIS	100	2.903	0.074
	1000	2.901	0.076
	10000	2.980	0.076
NMISA (3)	100	2.907	0.015
	1000	2.931	0.020
	10000	2.973	0.030

Table 5-2. Results for 20 dB HP 8491B

Laboratory	Frequency (MHz)	Attenuation (dB)	Uncertainty (k=2)
NMISA (1)	100	19.180	0.015
	1000	19.223	0.020
	10000	19.625	0.030
DEFNAT	100	19.196	0.070
	1000	19.239	0.068
	10000	19.629	0.078
NMISA (2)	100	19.181	0.015
	1000	19.221	0.020
	10000	19.627	0.030
NIS	100	19.180	0.074
	1000	19.181	0.074
	10000	19.617	0.076
NMISA (3)	100	19.180	0.015
	1000	19.223	0.020
	10000	19.628	0.030

Table 5-3. Results for Maury 2562C

Laboratory	Frequency (MHz)	VRC	Uncertainty (k=2)
NMISA (1)	100	0.087	0.005
	1000	0.085	0.005
	10000	0.102	0.005
DEFNAT	100	0.087	0.020
	1000	0.079	0.0128
	10000	0.112	0.0106
NMISA (2)	100	0.087	0.005
	1000	0.084	0.005
	10000	0.103	0.005
NIS	100	0.088	0.006
	1000	0.087	0.008
	10000	0.102	0.010
NMISA (3)	100	0.087	0.005
	1000	0.085	0.005
	10000	0.102	0.005

Table 5-4. Results for Maury 2561A

Laboratory	Frequency (MHz)	VRC	Uncertainty (k=2)
NMISA (1)	100	0.008	0.005
	1000	0.006	0.005
	10000	0.038	0.005
DEFNAT	100	0.007	0.0068
	1000	0.006	0.0028
	10000	0.042	0.0054
NMISA (2)	100	0.008	0.005
	1000	0.006	0.005
	10000	0.039	0.005
NIS	100	0.007	0.004
	1000	0.006	0.004
	10000	0.040	0.006
NMISA (3)	100	0.008	0.005
	1000	0.006	0.005
	10000	0.039	0.005

5.2 Evaluating comparison reference value, CRV

The comparison reference values (CRVs) are determined as the mean of the pilot laboratory measurements. As such, the arithmetic means of the measured values at the measurement points for the respective artefacts are the CRVs [4]. The uncertainties of the CRVs are calculated as follows [5]:

$$u^2(x) = \frac{1}{N^2}\sum_1^N u^2(x_i), \qquad (1)$$

where N is the number of values used in the calculation and $u(x_i)$ is the corresponding uncertainty. The comparison reference values (CRVs) and uncertainties (k=2) are as shown in the tables below.

Table 5-5. Reference values (CRV) for 3 dB HP 8491B

Frequency (MHz)	Reference value (dB)	Uncertainty (k=2)
100	2.907	0.009
1000	2.931	0.012
10000	2.974	0.017

Table 5-6. Reference values (CRV) for 20 dB HP 8491B

Frequency (MHz)	Reference value (dB)	Uncertainty (k=2)
100	19.180	0.009
1000	19.222	0.012
10000	19.627	0.017

Table 5-7. Reference values (CRV) for Maury 2562C

Frequency (MHz)	Reference value (dB)	Uncertainty (k=2)
100	0.087	0.003
1000	0.085	0.003
10000	0.102	0.003

Table 5-8. Reference values (CRV) for Maury 2561A

Frequency (MHz)	Reference value (dB)	Uncertainty (k=2)
100	0.008	0.003
1000	0.006	0.003
10000	0.039	0.003

The results, reflecting the unilateral degrees of equivalence with respect to the comparison values, at expanded uncertainties, are shown in the following figures.

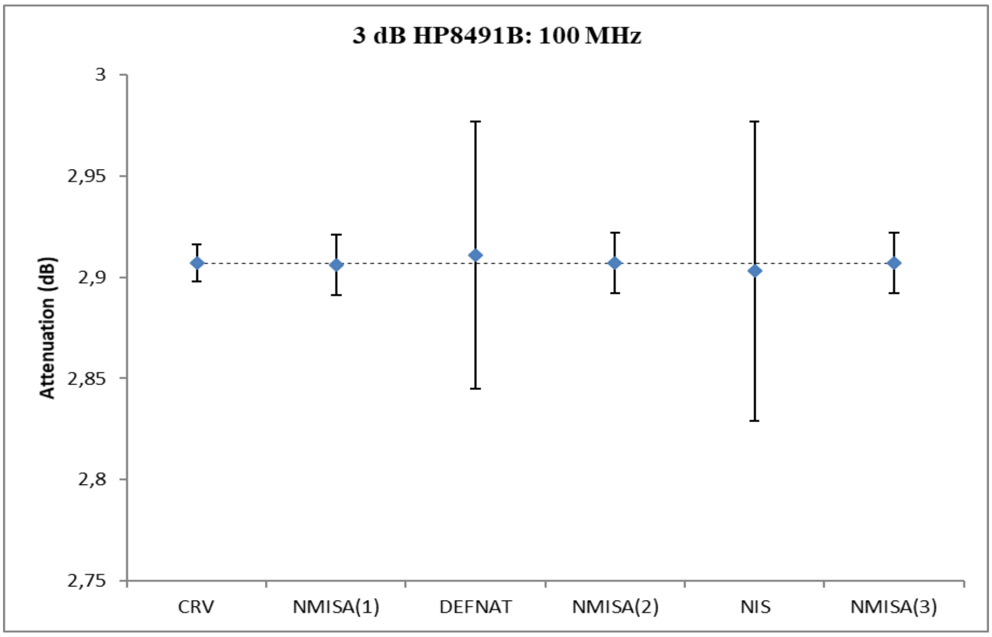

Figure 8. 3 dB HP8491B at 100 MHz

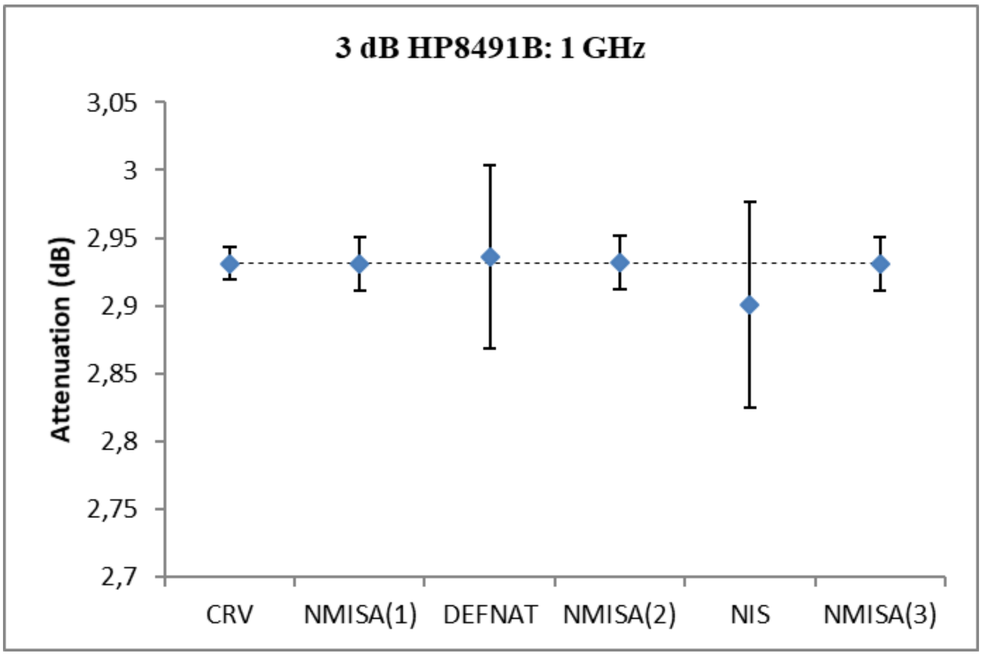

Figure 9. 3 dB HP8491B at 1 GHz.

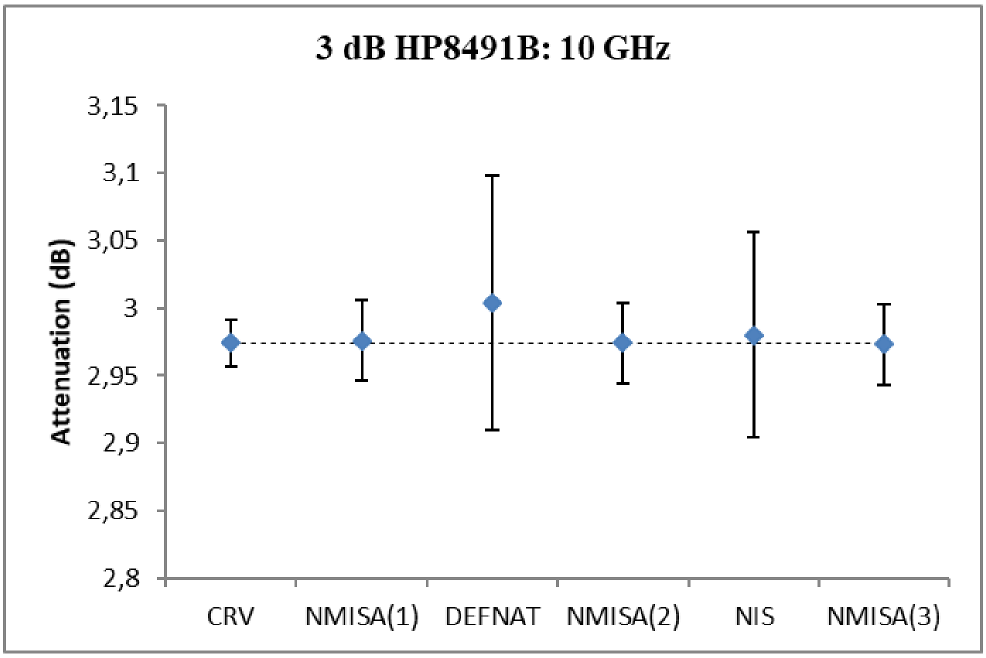

Figure 10. 3 dB HP8491B at 10 GHz.

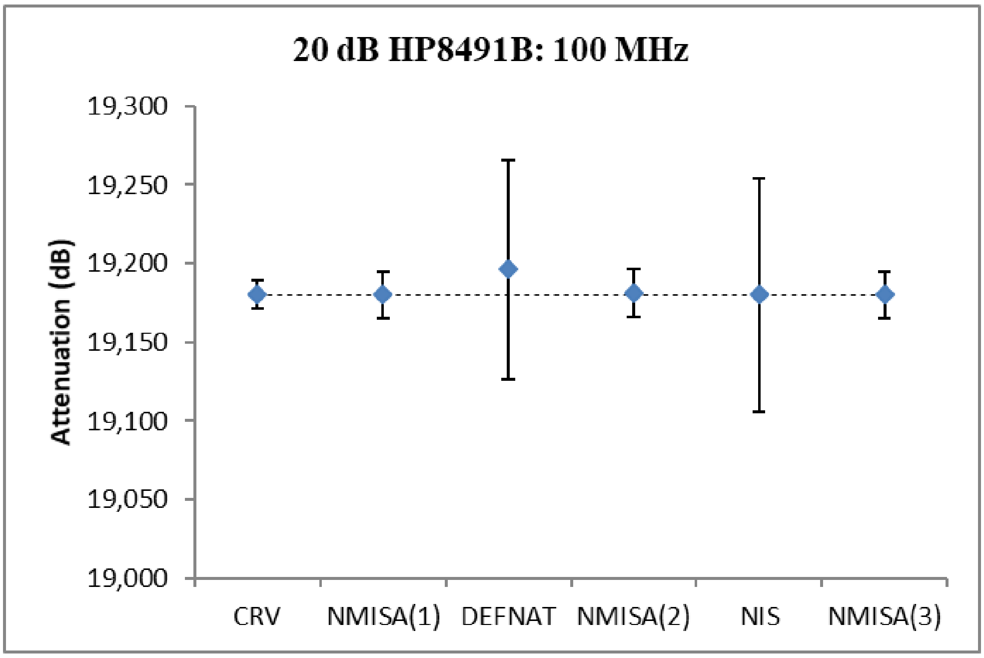

Figure 11. 20 dB HP8491B at 100 MHz

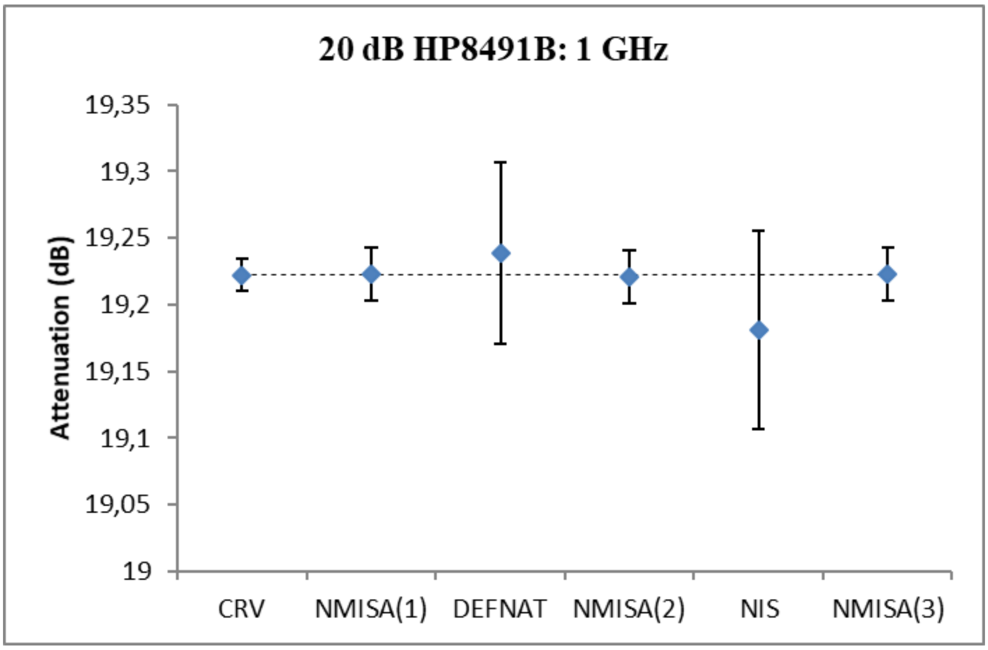

Figure 12. 20 dB HP8491B at 1 GHz.

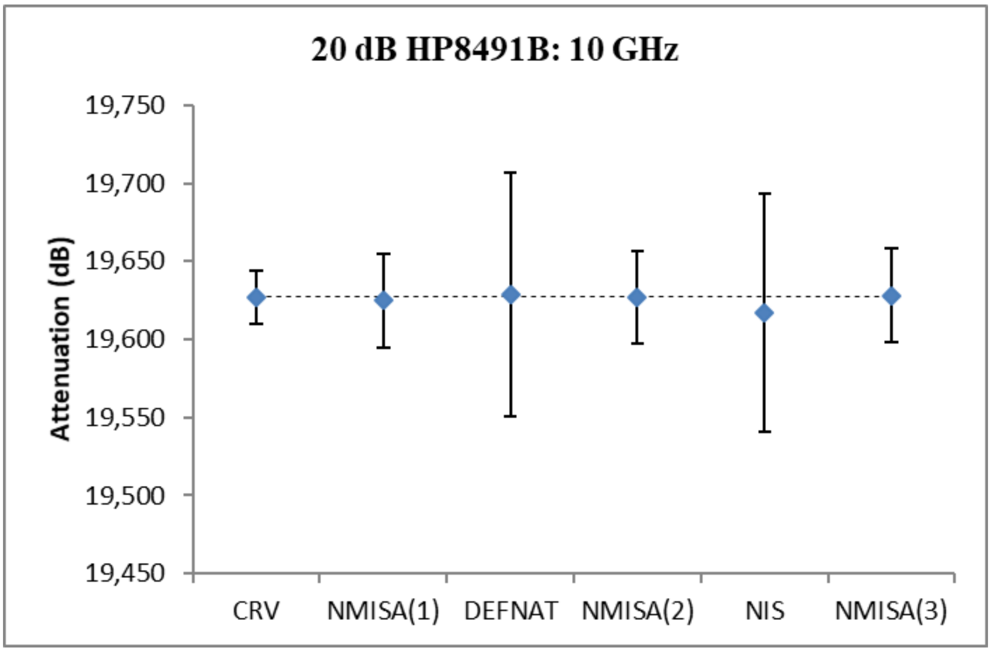

Figure 13. 20 dB HP8491B at 10 GHz.

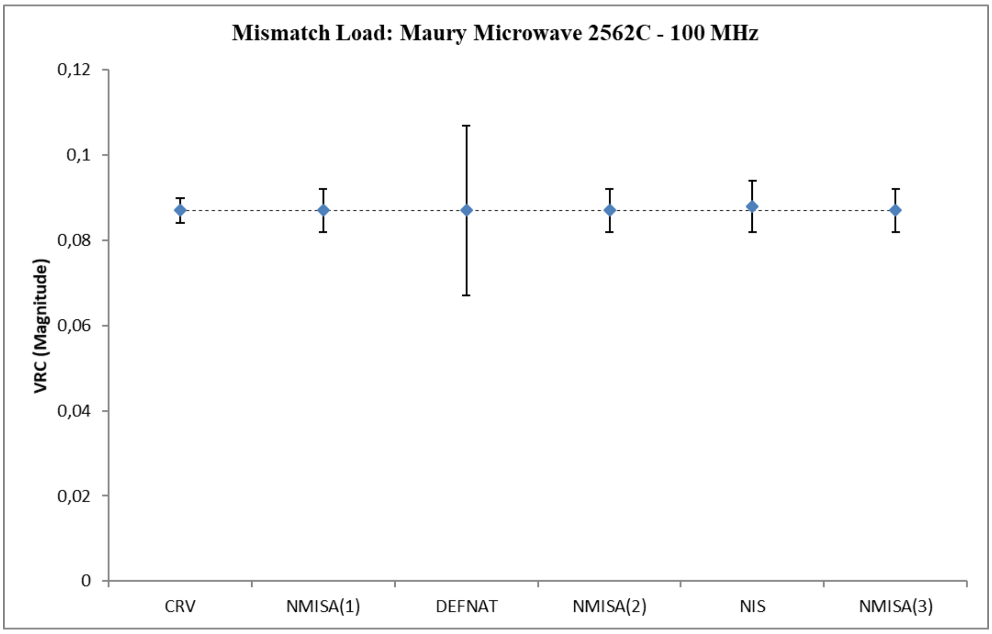

Figure 14. Maury 2562C at 100 MHz

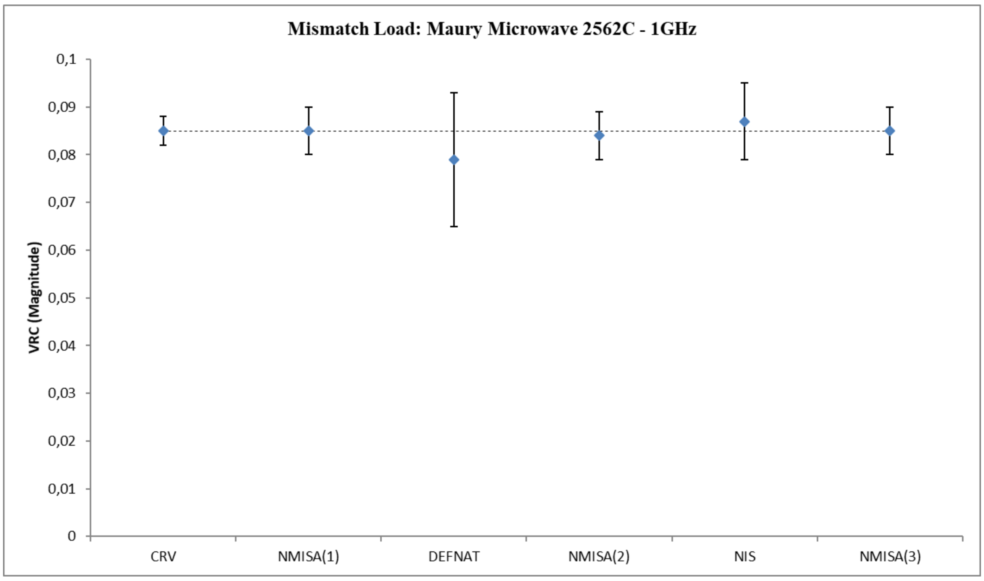

Figure 15. Maury 2562C at 1 GHz.

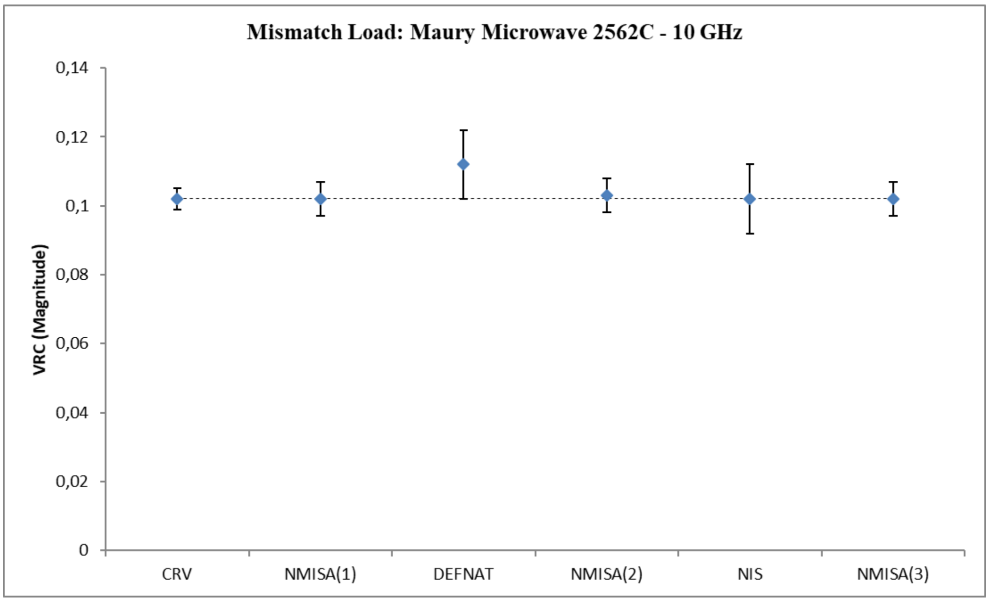

Figure 16. Maury 2562C at 10 GHz.

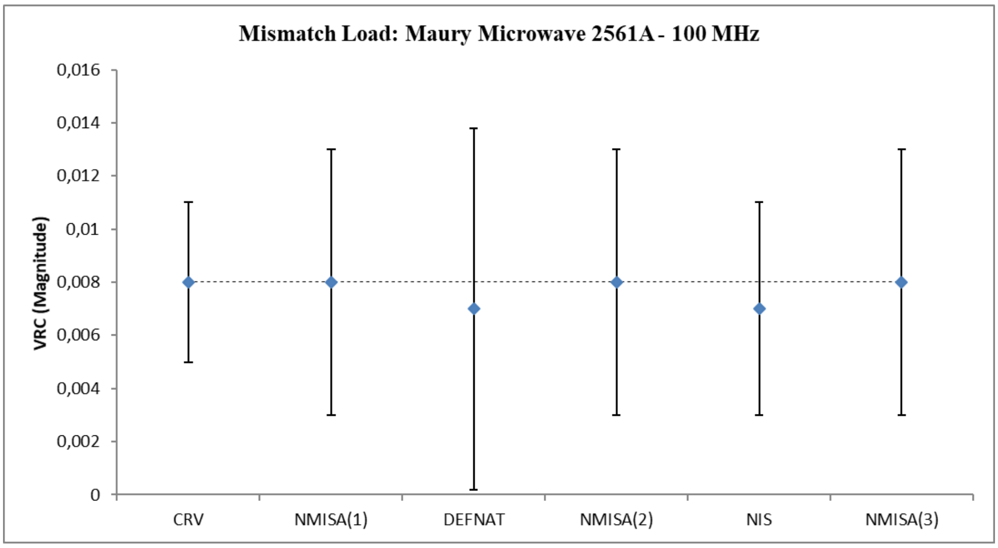

Figure 17. Maury 2561A at 100 MHz.

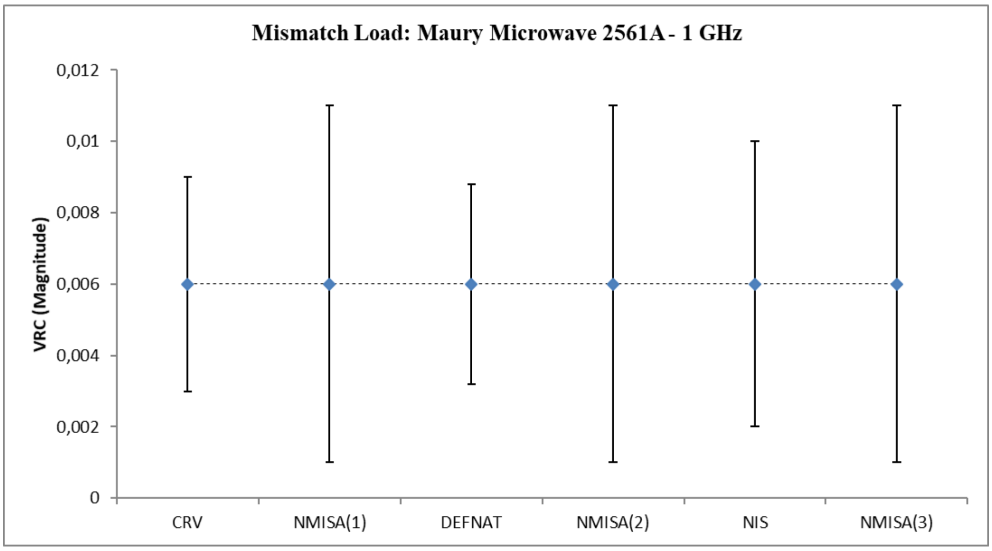

Figure 18. Maury 2561A at 1 GHz.

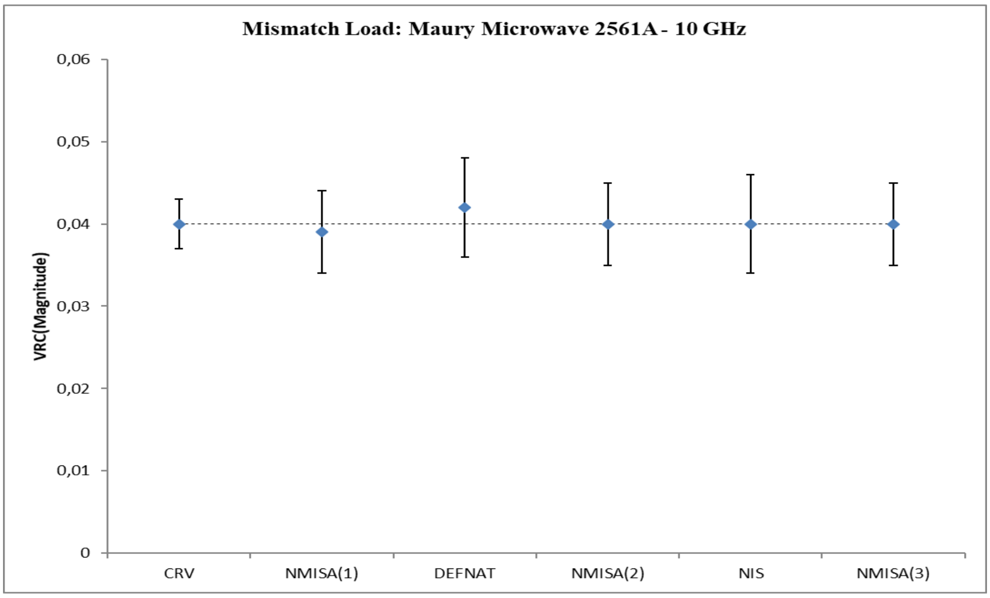

Figure 19. Maury 2561A at 10 GHz.

5.3 Normalized error (E_n)

The normalised error is used as a measure of the agreement between the results of the participants with respect to the calculated reference value. It is defined as the difference between the participant's result and the reference value normalised with respect to the sum of their expanded uncertainties.

$$E_n = \frac{X_{LAB} - X_{CRV}}{\sqrt{U_{LAB}^2 + U_{CRV}^2}}, \qquad (1)$$

where E_n is the normalised error.
X_{LAB} participant's measurement result.
X_{CRV} is the calculated comparison reference value.
U_{LAB} and U_{CRV} are the expanded uncertainties of the participant and reference value, respectively.

Table 5-9 Normalised error between participants and reference value

Artefact	Freq (GHz)	E_n(DEFNAT)	E_n(NIS)	E_n(NMISA(1))	E_n(NMISA(2))	E_n(NMISA(3))
3 dB	0,01	0,1	-0,1	-0,1	0,0	0,0
	1	0,1	-0,4	0,0	0,0	0,0
	10	0,3	0,1	0,1	0,0	0,0
20 dB	0,01	0,2	0,0	0,0	0,1	0,0
	1	0,2	-0,5	0,0	0,0	0,0
	10	0,0	-0,1	-0,1	0,0	0,0
2562C	0,01	0,0	0,1	0,0	0,0	0,0
	1	-0,5	0,2	0,0	-0,2	0,0
	10	0,9	0,0	0,0	0,2	0,0
2561A	0.01	-0,1	-0,2	0,0	0,0	0,0
	1	0,0	0,0	0,0	0,0	0,0
	10	0,5	0,1	-0,2	0,0	0,0

In the above table, $|E_n| < 1$ indicates an agreement between the participant's measured value and the calculated reference value.

6 Summary and conclusions

In this comparison, two fixed attenuators (3 dB and 20 dB, HP 8491B) and two mismatch loads (2562C and 2561A, Maury) were used as travelling standards.

The calibration systems used by the participants in this comparison are different for the attenuation measurements. Yet, only one participant (DEFNAT) used a different system to determine the reflection measurements (VRC). The determination of the comparison reference value (CRV) is calculated from measurement values from NMISA (mean of the respective measurement values obtained at the beginning, middle and end of the comparison), which is the pilot laboratory. The agreement between participants' measurements is good as evidenced by the normalised error, which is less than unity for all frequency points for both the attenuation measurements and voltage reflection coefficient measurements.

7 References

[1] CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons, March 21, 2007. http://www.bipm.org/utils/common/pdf/ccem_guidelines.pdf.

[2] Technical Protocol, AFRIMETS Supplementary Comparison, AFRIMETS.EM.RF-S1, Attenuation and reflection measurements for coaxials as 100 MHz, 1 GHz and 10 GHz – Type N Connector, L. Magagula and P. Silwana, January 2017.

[3] Guidelines on the Evaluation of Vector Network Analysers (VNA), EURAMET Calibration Guide No. 12, Version 3.0

[4] CCQM Guidance note: Estimation of consensus KCRV and associated Degrees of Equivalence, Version:10, Status: Released for reference, April 2013

[5] Update to Proposal for KCRV & Degree of Equivalence for GTRF key comparisons. J Randa (NIST), GT-RF / 2005-04, February 2005.

[6] Proposal for KCRV & Degree of Equivalence for GTRF key comparisons. J Randa, NIST, 8/18/00

8 Appendix A : NIS uncertainty budget

Mandatory

Final uncertainty values for all measurements presented.

A list of uncertainty contributors and uncertainty budget for attenuation for 3 dB HP8491B attenuator at 100 MHz, 1 GHz and 10 GHz is given below.

Contribution	0.1 GHz	1 GHz	10 GHz
Cal Load	0.0009	0.0040	0.0036
Cal Open	0.0009	0.0032	0.0046
Cal Short	0.0010	0.0030	0.0039
Conn. Rep.	0.0003	0.0009	0.0012
Cable	0.0361	0.0361	0.0361
VNA Drift	0.0009	0.0009	0.0009
VNA Linearity	0.0070	0.0070	0.0068
VNA Noise	0.0005	0.0002	0.0002
Combined	0.0368	0.0373	0.0375

A list of uncertainty contributors and uncertainty budget for attenuation for **20 dB HP8491B** attenuator at 100 MHz, 1 GHz and 10 GHz is given below.

Contribution	0.1 GHz	1 GHz	10 GHz
Cal Load	0.0017	0.0026	0.0029
Cal Open	0.0019	0.0019	0.0036
Cal Short	0.0018	0.0018	0.0030
Conn. Rep.	0.0006	0.0011	0.0012
Cable	0.0361	0.0361	0.0361
VNA Drift	0.0016	0.0016	0.0016
VNA Linearity	0.0069	0.0069	0.0065
VNA Noise	0.0006	0.0002	0.0002
Combined	0.0369	0.0370	0.0372

A list of uncertainty contributors and uncertainty budget for reflection for **Maury 2561A load** at 100 MHz, 1 GHz and 10 GHz is given below.

Contribution	0.1 GHz	1 GHz	10 GHz
Cal Load	0.00126	0.00126	0.00202
Cal Open	0.00002	0.00002	0.00019
Cal Short	0.00002	0.00001	0.00013
Conn. Rep.	0.00033	0.00033	0.00053
Cable	0.00141	0.00141	0.00141
VNA Drift	0.00003	0.00003	0.00003
VNA Linearity	0.00008	0.00002	0.00004
VNA Noise	0.00001	0.00000	0.00000
Combined	0.00192	0.00192	0.00254

A list of uncertainty contributors and uncertainty budget for reflection for **Maury 2562C** load at 100 MHz, 1 GHz and 10 GHz is given below.

Contribution	0.1 GHz	1 GHz	10 GHz
Cal Load	0.00157	0.00281	0.00398
Cal Open	0.00018	0.00020	0.00050
Cal Short	0.00021	0.00021	0.00033
Conn. Rep.	0.00033	0.00033	0.00053
Cable	0.00158	0.00158	0.00164
VNA Drift	0.00003	0.00003	0.00004
VNA Linearity	0.00007	0.00005	0.00006
VNA Noise	0.00001	0.00000	0.00000
Combined	0.00227	0.00325	0.00438

9 Appendix B: DEFNAT uncertainty budget

Mandatory

Final uncertainty values for all measurements presented.

Lists of uncertainty contributors and uncertainty budget for attenuation for **3 dB HP8491B** attenuator at 100 MHz, 1 GHz and 10 GHz are given below.

Frequency 0,1GHz

Contributor	Standard Uncertainty u(xi)	Probability distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $C_i u(x_i)$	Degrees Of Freedom ν_i
A	$2{,}8.10^{-04}$	A	1	$2{,}8.10^{-04}$	19
BR	$1{,}3.10^{-02}$	B	1	$1{,}3.10^{-02}$	-
BL1	$2{,}9.10^{-02}$	B	1	$2{,}9.10^{-02}$	-
BL2	$5{,}4.10^{-03}$	B	1	$5{,}4.10^{-03}$	-
BL3	$2{,}5.10^{-09}$	B	1	$2{,}5.10^{-09}$	-
BL4	$2{,}9.10^{-04}$	B	1	$2{,}9.10^{-04}$	-
BL5	$2{,}3.10^{-03}$	B	1	$2{,}3.10^{-03}$	-
BL6	$2{,}3.10^{-03}$	B	1	$2{,}3.10^{-03}$	-
BL7	$2{,}9.10^{-03}$	B	1	$2{,}9.10^{-03}$	-
BL8	$8{,}6.10^{-03}$	B	1	$8{,}6.10^{-03}$	-
-	-	-	**Combined standard uncertainty U_{total}(dB)**	$3{,}3.10^{-02}$	

Frequency 1GHz

Contributor	Standard Uncertainty u(xi)	Probability distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $C_i u(x_i)$	Degrees Of Freedom ν_i
A	$1{,}0.10^{-03}$	A	1	$1{,}0.10^{-03}$	19
BR	$1{,}3.10^{-02}$	B	1	$1{,}3.10^{-02}$	-
BL1	$2{,}9.10^{-02}$	B	1	$2{,}9.10^{-02}$	-
BL2	$5{,}4.10^{-03}$	B	1	$5{,}4.10^{-03}$	-
BL3	$2{,}5.10^{-09}$	B	1	$2{,}5.10^{-09}$	-
BL4	$2{,}0.10^{-03}$	B	1	$2{,}0.10^{-03}$	-
BL5	$2{,}3.10^{-03}$	B	1	$2{,}3.10^{-03}$	-
BL6	$2{,}3.10^{-03}$	B	1	$2{,}3.10^{-03}$	-
BL7	$2{,}9.10^{-03}$	B	1	$2{,}9.10^{-03}$	-
BL8	$1{,}1.10^{-02}$	B	1	$1{,}1.10^{-02}$	-
-	-	-	**Combined standard uncertainty U_{total}(dB)**	$3{,}4.10^{-02}$	

Frequency 10GHz

Contributor	Standard Uncertainty u(xi)	Probability distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $C_i u(x_i)$	Degrees Of Freedom ν_i
A	$7,6.10^{-03}$	A	1	$7,6.10^{-03}$	19
BR	$1,3.10^{-02}$	B	1	$1,3.10^{-02}$	-
BL1	$2,9.10^{-02}$	B	1	$2,9.10^{-02}$	-
BL2	$5,4.10^{-03}$	B	1	$5,4.10^{-03}$	-
BL3	$2,5.10^{-09}$	B	1	$2,5.10^{-09}$	-
BL4	$2,2.10^{-02}$	B	1	$2,2.10^{-02}$	-
BL5	$2,3.10^{-03}$	B	1	$2,3.10^{-03}$	-
BL6	$2,3.10^{-03}$	B	1	$2,3.10^{-03}$	-
BL7	$2,9.10^{-03}$	B	1	$2,9.10^{-03}$	-
BL8	$2,5.10^{-02}$	B	1	$2,5.10^{-02}$	-
-	-	-	**Combined standard uncertainty U_{total}(dB)**	$4,7.10^{-02}$	

Lists of uncertainty contributors and uncertainty budget for attenuation for **20 dB HP8491B** attenuator at 100 MHz, 1 GHz and 10 GHz are given below.

Frequency 0,1GHz

Contributor	Standard Uncertainty u(xi)	Probability distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $C_i u(x_i)$	Degrees Of Freedom ν_i
A	$2,7.10^{-04}$	A	1	$2,7.10^{-04}$	19
BR	$1,6.10^{-02}$	B	1	$1,6.10^{-02}$	-
BL1	$2,9.10^{-02}$	B	1	$2,9.10^{-02}$	-
BL2	$5,4.10^{-03}$	B	1	$5,4.10^{-03}$	-
BL3	$1,2.10^{-07}$	B	1	$1,2.10^{-07}$	-
BL4	$5,7.10^{-04}$	B	1	$5,7.10^{-04}$	-
BL5	$2,3.10^{-03}$	B	1	$2,3.10^{-03}$	-
BL6	$2,3.10^{-03}$	B	1	$2,3.10^{-03}$	-
BL7	$2,9.10^{-03}$	B	1	$2,9.10^{-03}$	-
BL8	$1,1.10^{-02}$	B	1	$1,1.10^{-02}$	-
-	-	-	**Combined standard uncertainty U_{total}(dB)**	$3,5.10^{-02}$	

Frequency 1GHz

Contributor	Standard Uncertainty u(xi)	Probability distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $C_i u(x_i)$	Degrees Of Freedom ν_i
A	$1,4.10^{-03}$	A	1	$1,4.10^{-03}$	19
BR	$1,6.10^{-02}$	B	1	$1,6.10^{-02}$	-
BL1	$2,9.10^{-02}$	B	1	$2,9.10^{-02}$	-
BL2	$5,4.10^{-03}$	B	1	$5,4.10^{-03}$	-
BL3	$1,2.10^{-07}$	B	1	$1,2.10^{-07}$	-
BL4	$2,9.10^{-03}$	B	1	$2,9.10^{-03}$	-
BL5	$2,3.10^{-03}$	B	1	$2,3.10^{-03}$	-
BL6	$2,3.10^{-03}$	B	1	$2,3.10^{-03}$	-
BL7	$2,9.10^{-03}$	B	1	$2,9.10^{-03}$	-
BL8	6.10^{-03}	B	1	6.10^{-03}	-
-	-	-	**Combined standard uncertainty U_{total}(dB)**	$3,4.10^{-02}$	

Frequency 10GHz

Contributor	Standard Uncertainty $u(xi)$	Probability distribution	Sensitivity Coefficient c_i	Uncertainty Contribution $C_i u(x_i)$	Degrees Of Freedom v_i
A	$5{,}0.10^{-03}$	A	1	$5{,}0.10^{-03}$	19
BR	$1{,}6.10^{-02}$	B	1	$1{,}6.10^{-02}$	-
BL1	$2{,}9.10^{-02}$	B	1	$2{,}9.10^{-02}$	-
BL2	$5{,}4.10^{-03}$	B	1	$5{,}4.10^{-03}$	-
BL3	$1{,}2.10^{-07}$	B	1	$1{,}2.10^{-07}$	-
BL4	$1{,}5.10^{-02}$	B	1	$1{,}5.10^{-02}$	-
BL5	$2{,}3.10^{-03}$	B	1	$2{,}3.10^{-03}$	-
BL6	$2{,}3.10^{-03}$	B	1	$2{,}3.10^{-03}$	-
BL7	$2{,}9.10^{-03}$	B	1	$2{,}9.10^{-03}$	-
BL8	$1{,}3.10^{-02}$	B	1	$1{,}3.10^{-02}$	-
-	-	-	**Combined standard uncertainty U_{total}(dB)**	$3{,}9.10^{-02}$	

Uncertainty contributors:

BR: standard VM7
BL1: drift of VM7
BL2: correction on linearity of mixer
BL3: system noise
BL4: short time drift of DUT
BL5: resolution
BL6: reading stability
BL7: reproducibility of connectors and/or compensation of directivity of load
BL8: mismatch and/or compensation of generator
BL9: short circuit

Lists of uncertainty contributors and uncertainty budget for reflection for **Maury 2561A** load at 100 MHz, 1 GHz and 10 GHz are given below, respectively.

Frequency 0.1 GHz

Contributor	**Standard Uncertainty u(xi)**	**Probability distribution**	**Sensitivity Coefficient *ci***	**Uncertainty contribution ci u(xi)**	**Degree of freedom**
A	$1{,}9.10^{-04}$	**A**	**1**	$1{,}5.10^{-04}$	4
BR	$1{,}8.10^{-04}$	**B**	1	$1{,}8.10^{-04}$	-
BL1	$2{,}5.10^{-04}$	**B**	1	$2{,}5.10^{-04}$	-
BL2	$2{,}8.10^{-05}$	**B**	1	$2{,}8.10^{-05}$	-
BL3	$1{,}5.10^{-03}$	**B**	1	$1{,}5.10^{-03}$	-
BL4	$3{,}1.10^{-03}$	**B**	1	$3{,}1.10^{-03}$	-
BL5	$1{,}2.10^{-05}$	**B**	1	$1{,}2.10^{-05}$	-
BL6	$2{,}2.10^{-04}$	**B**	1	$2{,}2.10^{-04}$	
-	-	-	Combined Standard uncertainty U_{total}	$\mathbf{3{,}4.10^{-03}}$	

Frequency 1 GHz

Contributor	Standard Uncertainty u(xi)	Probability distribution	Sensitivity Coefficient *ci*	Uncertainty contribution ci u(xi)	Degree of freedom
A	$9,6.10^{-04}$	**A**	**1**	$9,2.10^{-04}$	4
BR	$5,6.10^{-05}$	B	1	$5,6.10^{-05}$	-
BL1	$2,4.10^{-04}$	B	1	$2,4.10^{-04}$	-
BL2	$5,6.10^{-05}$	B	1	$5,6.10^{-05}$	-
BL4	$1,7.10^{-05}$	B	1	$1,7.10^{-05}$	-
BL5	$2,8.10^{-05}$	B	1	$2,8.10^{-05}$	-
BL6	$1,0.10^{-03}$	B	1	$1,0.10^{-03}$	-
BL7	$2,7.10^{-04}$	B	1	$2,7.10^{-04}$	-
BL8	$4,5.10^{-06}$	B	1	$4,5.10^{-06}$	-
BL9	$1,3.10^{-03}$	B	1	$8,2.10^{-04}$	
-	-	-	**Combined Standard uncertainty U_{total}**	$\mathbf{1,4.10^{-03}}$	

Frequency 10 GHz

Contributor	Standard Uncertainty u(xi)	Probability distribution	Sensitivity Coefficient *ci*	Uncertainty contribution ci u(xi)	Degree of freedom
A	$\mathbf{5,0.10^{-03}}$	**A**	**1**	$\mathbf{1,2.10^{-03}}$	4
BR	$5,6.10^{-05}$	B	**1**	$5,6.10^{-05}$	-
BL1	$2,4.10^{-04}$	B	**1**	$2,4.10^{-04}$	-
BL2	$5,6.10^{-05}$	B	**1**	$5,6.10^{-05}$	-
BL4	$1,7.10^{-05}$	B	**1**	$1,7.10^{-05}$	-
BL5	$2,8.10^{-05}$	B	**1**	$2,8.10^{-05}$	-
BL6	$1,0.10^{-03}$	B	**1**	$1,0.10^{-03}$	-
BL7	$6,7.10^{-04}$	B	**1**	$6,7.10^{-04}$	-
BL8	$1,1.10^{-05}$	B	**1**	$1,1.10^{-05}$	-
BL9	$5,5.10^{-03}$	B	**1**	$2,1.10^{-03}$	-
-	-	-	**Combined Standard uncertainty U_{total}**	$\mathbf{2,7.10^{-03}}$	

Lists of uncertainty contributors and uncertainty budget for **Maury 2562C** at 100 MHz, 1 GHz and 10 GHz are given below, respectively.

Frequency 0.1 GHz

Contributor	Standard Uncertainty u(xi)	Probability distribution	Sensitivity Coefficient *ci*	Uncertainty contribution ci u(xi)	Degree of freedom
A	**$1{,}7.10^{-03}$**	**A**	**1**	**$1{,}3.10^{-03}$**	4
BR	$6{,}3.10^{-04}$	B	**1**	$6{,}3.10^{-04}$	-
BL1	$1{,}9.10^{-03}$	B	**1**	$1{,}9.10^{-03}$	-
BL2	$1{,}0.10^{-04}$	B	**1**	$1{,}0.10^{-04}$	-
BL3	$9{,}1.10^{-03}$	B	**1**	$9{,}1.10^{-03}$	-
BL4	$3{,}3.10^{-03}$	B	**1**	$3{,}3.10^{-03}$	-
BL5	$4{,}5.10^{-05}$	B	**1**	$9{,}1.10^{-05}$	-
BL6	$2{,}7.10^{-03}$			$2{,}7.10^{-03}$	-
-	-	-	**Combined Standard uncertainty U_{total}**	**1.10^{-02}**	

Frequency 1 GHz

Contributor	Standard Uncertainty u(xi)	Probability distribution	Sensitivity Coefficient *ci*	Uncertainty contribution ci u(xi)	Degree of freedom
A	**$3{,}8.10^{-03}$**	**A**	**1**	**$3{,}1.10^{-03}$**	4
BR	$1{,}7.10^{-04}$	B	**1**	$1{,}7.10^{-04}$	-
BL1	$9{,}1.10^{-04}$	B	**1**	$9{,}1.10^{-04}$	-
BL2	$2{,}1.10^{-04}$	B	**1**	$2{,}1.10^{-04}$	-
BL4	$6{,}3.10^{-05}$	B	**1**	$6{,}3.10^{-05}$	-
BL5	$1{,}0.10^{-04}$	B	**1**	$1{,}0.10^{-04}$	-
BL6	$1{,}1.10^{-03}$	B	**1**	$1{,}1.10^{-03}$	-
BL7	$2{,}4.10^{-03}$	B	**1**	$1{,}6.10^{-03}$	-
BL8	$3{,}9.10^{-05}$	B	**1**	$7{,}9.10^{-05}$	-
BL9	$4{,}9.10^{-03}$	B	**1**	$4{,}9.10^{-03}$	-
-	**-**	**-**	**Combined Standard uncertainty U_{total}**	**$6{,}4.10^{-03}$**	

Frequency 10 GHz

Contributor	Standard Uncertainty u(xi)	Probability distribution	Sensitivity Coefficient *ci*	Uncertainty contribution ci u(xi)	Degree of freedom
A	**$5{,}6.10^{-03}$**	**A**	**1**	**$2{,}8.10^{-03}$**	4
BR	$1{,}7.10^{-04}$	B	**1**	$1{,}7.10^{-04}$	-
BL1	$9{,}1.10^{-04}$	B	**1**	$9{,}1.10^{-04}$	-
BL2	$2{,}1.10^{-04}$	B	**1**	$2{,}1.10^{-04}$	-
BL4	$6{,}3.10^{-05}$	B	**1**	$6{,}3.10^{-05}$	-
BL5	$1{,}0.10^{-04}$	B	**1**	$1{,}0.10^{-04}$	-
BL6	$1{,}1.10^{-03}$	B	**1**	$1{,}1.10^{-03}$	-
BL7	$2{,}8.10^{-03}$	B	**1**	$1{,}8.10^{-03}$	-
BL8	$4{,}6.10^{-05}$	B	**1**	$9{,}2.10^{-05}$	-
BL9	$7{,}2.10^{-03}$	B	**1**	$3{,}3.10^{-03}$	-
-	-	-	**Combined Standard uncertainty U_{total}**	**$5{,}3.10^{-03}$**	

Uncertainty contributors:

BR: standard VM7

BL1: drift of VM7

BL2: correction on linearity of mixer

BL3: system noise

BL4: short time drift of DUT

BL5: resolution

BL6: reading stability

BL7: reproducibility of connectors and/or compensation of directivity of load

BL8: mismatch and/or compensation of generator

BL9: short circuit

10 Appendix C: NMISA uncertainty budget

Lists of uncertainty contributors and uncertainty budget for attenuation for **3 dB HP8491B** attenuator at 100 MHz, 1 GHz and 10 GHz are given below.

Source (i)	Type	u_T(i)(dB) at 100 MHz	u_T(i)(dB) at 1 GHz	u_T(i)(dB) at 10 GHz
Mismatch	B	0,0069	0,0095	0,0147
Calibration of standard	B	0,0005	0,0005	0,0005
Resolution	B	0,0003	0,0003	0,0003
Linearity	B	0,0011	0,0011	0,0011
Isolation	B	0,0000	0,0000	0,0001
Repeatability	A	0,0003	0,0003	0,0003
Combined Standard Uncertainty(k=1)		0,0072	0,0100	0,0150

Lists of uncertainty contributors and uncertainty budget for attenuation for **20 dB HP8491B** attenuator at 100 MHz, 1 GHz and 10 GHz are given below.

Source (i)	Type	u_T(i)(dB) at 100 MHz	u_T(i)(dB) at 1 GHz	u_T(i)(dB) at 10 GHz
Mismatch	B	0,0070	0,0097	0,0148
Calibration of standard	B	0,0010	0,0010	0,0010
Resolution	B	0,0003	0,0003	0,0003
Linearity	B	0,0017	0,0017	0,0017
Isolation	B	0,0000	0,0015	0,0005
Repeatability	A	0,0003	0,0003	0,0003
Combined Standard Uncertainty(k=1)		0,0074	0,0100	0,0150

Lists of uncertainty contributors and uncertainty budget for reflection for **Maury 2561A** load at 100 MHz, 1 GHz and 10 GHz are given below.

Source (i)	Distribution	u_T(i)(dB) at 100 MHz	u_T(i)(dB) at 1 GHz	u_T(i)(dB) at 10 GHz
Effective directivity	U	0,0020	0,0020	0,0020
Effective test port match	U	0,0000	0,0000	0,0001
Ambient conditions	rectangular	0,0007	0,0007	0,0007
VNA Linearity & others	rectangular	0,0010	0,0010	0,0010
Repeatability	Gaussian	0.0001	0,0005	0,0004
Combined Standard Uncertainty(k=1)		0,0025	0,0025	0,0025

Lists of uncertainty contributors and uncertainty budget for reflection for **Maury 2562C** load at 100 MHz, 1 GHz and 10 GHz are given below.

Source (i)	Distribution	u_T(i)(dB) at 100 MHz	u_T(i)(dB) at 1 GHz	u_T(i)(dB) at 10 GHz
Effective directivity	U	0,0020	0,0020	0,0020
Effective test port match	U	0,0000	0,0000	0,0001
Ambient conditions	rectangular	0,0007	0,0007	0,0007
VNA Linearity & others	rectangular	0,0010	0,0010	0,0010
Repeatability	Gaussian	0.0001	0,0001	0,0003
Combined Standard Uncertainty(k=1)		0,0025	0,0025	0,0025