COMPARISON ON
VOLTAGE REFLECTION COEFFICIENT (VRC)
OF AN RF SOURCE

FINAL REPORT

EMPIR 15RPT01
RFMICROWAVE

May 17th, 2019

CONTENTS

1. Objective and general information

An intercomparison exercise has been carried out on Voltage Reflection Coefficient (VRC) of an RF signal generator fitted with Type N female connector between the interested EMPIR project partners. The purpose of the exercise is to provide confidence in scalar VRC measurements among the different laboratory partners with capability and experience in measurement of Voltage Reflection Coefficient of active devices. This demonstration of capability could be subsequently claimed before national accreditation bodies or before third parts (customers and stakeholders).

This inter-laboratory comparison exercise has taken place in the frame of the Project of Development of RF and Microwave Metrology Capability (EMPIR 15RPT 01 'RFMicrowave'). The comparison was also registered as EURAMET EM-1461 comparison.

Seven participants have taken part in the comparison exercise: TUBITAK UME Turkey, SIQ Slovenia, GUM Poland, EIM/NQIS Greece, NIS Egypt, METAS Switzerland and INTA Spain as the pilot laboratory.

The comparison has been performed by measuring scalar Voltage Reflection Coefficient at 50 MHz, 2 GHz, 8 GHz, 12 GHz, 15 GHz and 18 GHz for an output power level of 0 dBm (CW signal).

INTA (Instituto Nacional de Técnica Aeroespacial) in Spain has acted as the pilot laboratory. The travelling standard has been provided by INTA. INTA was responsible for monitoring of the standard's performance during the circulation, as well as for evaluation and reporting of the comparison results.

The comparison has been carried out in accordance with the CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons [1]. In this document the obtained results of this international comparison on scalar VRC of a RF source are presented. As an additional parameter, phase of complex VRC has also been measured by one of the participants. In this case the results are given but obviously not compared.

2. Travelling standard

The travelling standard is a Synthesized CW Generator (see Figure 1). The identification of the travelling standard is as follows:

Manufacturer	: Hewlett Packard
Model	: 83712A
Serial number	: 3339A00223
Frequency Range	: 0.01 GHz -20 GHz

Figure 1. Representative photo of the travelling standard

The comparison exercise has consisted in the measurement of output VRC of the generator, at the following frequencies: 50 MHz, 2 GHz, 8 GHz, 12 GHz, 15 GHz and 18 GHz. The parameter under test has been be measured for an output level of 0 dBm.

The travelling standard was supplied by INTA. The general specifications of standard are given in Table 1.

The participants submitted their measurement results on in a calibration certificate containing at least the six (6) measurement points detailed above. The results have been expressed as measured VRC plus its associated expanded uncertainty for a confidence level of 95.45%.

Table 1. General specifications of HP 83712A Synthesized CW Generator

Frequency	10 MHz to 20 GHz
Maximum Power	10 MHz to 1 GHz, +13 dBm CW 1 GHz to 18 GHz, +10 dBm CW
Connector Type	Type N female
Output Impedance	Nominal 50 Ω
Maximum SWR	< 2.0:1
Dimensions	D: 498 mm W: 426 mm H: 133 mm
Weight	< 16 kg
Power requirement	198 V – 264 V AC, 48 Hz – 66 Hz, 400 VA maximum

3. Participant laboratories

The pilot institute for this comparison is INTA (Spain). The contact details of the coordinator are given below:

Pilot Institute	:	Instituto Nacional de Técnica Aeroespacial (INTA)
Coordinator	:	Manuel Rodríguez Higuero Tel: +34 91 520 1859 Fax: +34 91 520 1645 E-mail: rodriguezm@inta.es

The participant institutes and contact persons with their addresses are given in Table 2.

Table 2. Participant laboratories

Country	Institute	Acronym	Shipping Address	Contact Person
SPAIN	Instituto Nacional de Técnica Aeroespacial	INTA	Instituto Nacional de Técnica Aeroespacial (INTA) Centro de Metrología y Calibración – Edificio B-15 Ctra. a Ajalvir, p.k. 4,5 28850 Torrejón de Ardoz (Madrid) SPAIN	Manuel RODRIGUEZ rodriguezm@inta.es Tel: +34 91 520 1859 Fax: +34 91 520 1645
TURKEY	Ulusal Metroloji Enstitüsü	TUBITAK UME	TUBITAK Ulusal Metroloji Enstitüsü (UME) TUBITAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, TURKEY	Murat CELEP murat.celep@tubitak.gov.tr Tel: +90 262 679 50 00 Fax: +90 262 679 5001
SLOVENIA	Slovenski Institut za Kakovost in Meroslovje	SIQ	Slovenski Institut za Kakovost in Meroslovje (SIQ) Trzaška cesta 2 SI-1000 Ljubljana SLOVENIA	Borut PINTER borut.pinter@siq.si Tel: +386 (0)1 4778 322 Fax: +386 (0)1 4778 303
POLAND	Central Office of Measures	GUM	Central Office of Measures (GUM) Elektoralna 2 00-139, Warsaw POLAND	Łukasz USYDUS l.usydus@gum.gov.pl Tel: +48 22 581 9503 Fax: +48 22 581 9499
GREECE	National Quality Infrastructure System	EIM/NQIS	National Quality Infrastructure System (NQIS/EIM) Industrial area of Thessaloniki, Block 45, GR-57022 Sindos GREECE	George KRIKELAS gkrik@eim.gr Tel: +30 2310 569 975 Fax: +30 2310-569 996
EGYPT	National Institute for Standards	NIS	National Institute for Standards (NIS) President Sadat (Tersa) St El-Haram, El-Giza P.O. box: 136 Giza Code: 12211 EGYPT	AbdelRahman SALLAM Sallam2050@gmail.com
SWITZERLAND	Federal Institute of Metrology	METAS	Federal Institute of Metrology (METAS) Lindenweg 50 CH-3084 Bern-Wabern SWITZERLAND	Daniel STALDER daniel.stalder@metas.ch Tel: +41 58 387 0491 Fax: +41 58 387 0210

4. Measurement calendar

The measurement calendar for the comparison exercise is given in Table 3. The circulation of travelling standard was organized so that the number of entrances in and departures from the EU were minimized. However, the travelling standard finally had to be sent again to the pilot laboratory so that the expiry date of the ATA carnet which accompanied the equipment was not reached. After this the standard was sent onto the last participant with no ATA carnet[1].

The pilot laboratory performed three different sets of measurements: two measurements previously to the launching of the intercomparison exercise and a final measurement by the completion of the exercise, once all the participants had performed their measurements. With the two initial measurements the stability of the travelling standard was assessed, whereas with the third measurement by the pilot laboratory it was demonstrated that no damage or unwanted drift had been suffered by the standard, and that its performance showed the stability required for the exercise. An analysis of the stability of the travelling instrument by the closing of the measurement loop is included in this report.

Once a participant was ready with the measurement of the travelling standard, each laboratory arranged delivery of the equipment to the next participant in the schedule list.

The travelling standard was checked for damage immediately after reception in each laboratory. No noticeable damages were detected.

Table 3. Measurement calendar

Acronym of Institute	Country	Measurements
INTA	Spain	28th February to 7th March 2017
INTA	Spain	19th and 20th April 2017
NIS	Egypt	
TUBITAK UME	Turkey	8th to 16th August 2018
SIQ	Slovenia	16th to 27th April 2018
GUM	Poland	22nd May 2018
EIM/NQIS	Greece	15th to 21st June 2018
METAS	Switzerland	3rd to 17th January 2019
INTA	Spain	11th and 12th March 2019

[1] The travelling standard was not always sent together with its ATA carnet. This was done at the election of each partner, following its national regulations for export of scientific equipment.

5. Transport case

The travelling standard and miscellaneous equipment travelled in a well-protected package whose dimensions were approximately (75 cm length x 67 cm width x 42 cm height) and a weight, including the travelling standards, of approx. 30 kg.

The content of the transport case is given in below.

- Travelling standard: Hewlett Packard Synthesized CW Generator model 83712A, serial number 3339A00223
- ATA carnet

6. Transportation of travelling standard

The comparison was initially organised in one single loop. As mentioned before, the travelling standard had to be sent back to the pilot laboratory in order for the expiry date of the ATA carnet not to be reached. After this, a second loop with just one participant (METAS Switzerland) was added.

Each participant laboratory was responsible for the transportation of the travelling standard to the next laboratory. The cost of transportation was paid by the laboratory which was sending the travelling standard.

INTA sent the travelling standard to the first and to the last laboratory and the costs of transportation from INTA to these two laboratories were paid by INTA. Each participant was responsible for the transportation expenses to the next participant laboratory in the list.

The estimated cost of the travelling standard and miscellaneous equipment (in order for the carrier company to include a transportation insurance covering any damage caused to the equipment) was 1,000 EUR.

After arrival in the participant's laboratory, the standard have been checked and allowed to stabilise in a temperature and, possibly, humidity controlled room for at least one day before use.

Each institute had at least two weeks available for measurement. This included the measurement itself and the stabilisation of the standard. The initially foreseen measurement calendar was delayed mainly due to difficulties in coping with the different customs departments of the many countries involved.

6.1. Failure of travelling standard

N.A.

6.2. Financial aspects

Each participant laboratory was responsible for costs for the transportation expenses to the following laboratory, measurements as well as any damage that may have occurred within its country. Visual and mechanical inspection, as well as measurement by the pilot laboratory, revealed no damage at all.

The overall costs for the organisation of the comparison were covered by the pilot institute. The pilot institute had no insurance for any loss or damage of the travelling standard, except for the insurance related to the delivery to the first and to the last participant in the list (first and last transportation of the standards).

7. Measurement parameters and working frequency points

The parameter measured and the working frequency points are given in Table 4.

Table 4. Measurement parameter & working frequency points

Parameter	Output power level @ generator (CW signal)	Measurement Frequencies
Scalar Voltage Reflection Coefficient (VRC)	0 dBm	50 MHz, 2 GHz, 8 GHz, 12 GHz, 15 GHz and 18 GHz

The parameter under test is scalar Voltage Reflection Coefficient.

Also the following information should be given:

- Ambient temperature,
- Ambient relative humidity,
- Pin depth of the travelling standard.

No correction has been applied for the ambient temperature and relative humidity.

8. Measurement results of the pilot laboratory

All participants have issued a Calibration Certificate (alternatively a Measurement Report), including all measured data together with their expanded uncertainty, for a confidence level of 95.45%.

As measurement result for INTA, the mean value of the three measurements performed in February – March 2017, in April 2017 and in March 2019 was taken. The measurement uncertainty was computed as a function of the individual measurements and their associated uncertainties:

$$x_{INTA} = \sum_{i=1}^{N} \frac{x_{meas\ i}}{N}$$

$$U(x_{INTA}) = 2 \cdot \sqrt{\left(\frac{max[x_{meas\ i}] - min[x_{meas\ i}]}{2 \cdot \sqrt{3}}\right)^2 + \left(\frac{max[U(x_{meas\ i})]}{2}\right)^2}$$

Where the subindex *i* stands for each individual measurement by the pilot laboratory. The observed differences between the three rounds of measurements, made by INTA for control purposes, are negligible and show that there has been no significant drift in the measured parameters of the DUT during the comparison.

9. Assigned Value and Figure of Merit

The Intercomparison Assigned Value (AV) for each measurement frequency has been calculated using the results of all seven participant laboratories. The method used will be the Weighed Mean of those participants not considered as outliers.

9.1. Determination of outliers

The determination of outliers is based on the well-known 3·MAD criterion, which makes use of the Median of all participants and of the calculated 'Median of Absolute Deviations' (MAD). Those participants whose difference with respect to the Median is demonstrated to be more than three times the Median of Absolute Deviations have been considered as outliers, and as such have not been taken into account in the determination of the Weighted Mean and thus of the Assigned Value of the intercomparison.

Computation of the Median: The Median is a robust estimator for the Assigned Value of a set of results, as provided by the participants in an intercomparison. It is defined as the value situated exactly in the middle of the distribution of all participants (assuming an odd number of participants), thus leaving the same number of participants above and below. When the number of participants is even, it is defined as the Mean Value of those two whose results leave the same number of participants above and below:

$$\tilde{x} = \mathrm{Median}\{x_i, i = 1 \dots N\}$$

By definition, the Median of a set of results minimises the sum of the distances of all participants with respect to the Median, whereas the Mean Value minimises the sum of the squares of the distances of all participants with respect to the Mean Value. This makes the Median more robust to the presence of outliers (values abnormally situated with respect to the distribution of the rest of participants).

Computation of MAD (Median of Absolute Deviations): It is defined as the Median of the absolute deviations, those being the absolute values of the differences between the participants and the Median:

$$MAD = \mathrm{Median}\{|x_i - \tilde{x}|, i = 1 \dots N\}$$

In case that the scatter of participants would follow a Gaussian distribution, the following approximate relationship exists between the MAD and the experimental Standard Deviation:

$$\sigma_x \cong 1.483 \cdot \mathrm{MAD}$$

Criterion for determination of outliers: The usual criterion for the determination of outliers is as follows: those participants whose absolute deviation with respect to the Median exceeds three times the MAD is considered to be abnormally situated (above or below) with respect to the rest of participants. An outlier is subsequently eliminated from the determination of the intercomparison Assigned Value.

$$\mathrm{x}_i \in \mathrm{Outliers} \Leftrightarrow |x_i - \tilde{x}| \geq 3 \cdot \mathrm{MAD}$$

For a (theoretically assumed) Gaussian distribution, this criterion is equivalent to a confidence level of 95% due to the following approximate relationship:

$$3 \cdot \mathrm{MAD} \cong 2 \cdot \sigma_x$$

9.2. Computation of the Assigned Value

As Assigned Value for a set of intercomparison results, the Weighted Mean is generally accepted as representative of the dispersion of the laboratory results, weighted by their respective measurement uncertainties:

$$x_{AV} \equiv \sum_{i=1}^{N} \omega_i \cdot \mathrm{x}_i$$

Where the weights ω_i for each participant are defined as:

$$\omega_i = \frac{U^{-2}(x_i)}{U^{-2}(x_1) + \cdots + U^{-2}(x_N)}$$

In case that all measurement uncertainties, as provided by the participant laboratories, is the same or nearly the same, the Weighted Mean coincides with the Arithmetic Mean.

9.3. Uncertainty associated to the Assigned Value

The uncertainty of the Weighted Mean is given by:

$$U^2(x_{AV}) = \sum_{i=1}^{N} \omega_i^2 \cdot U^2(x_i)$$

This expression can be simplified introducing the definition of the weights ω_i:

$$\frac{1}{U^2(x_{AV})} = \frac{1}{U^2(x_1)} + \cdots + \frac{1}{U^2(x_N)}$$

9.4. Figure of Merit

As a figure of merit for each participant, the Normalized Error with respect to the Comparison Assigned Value and its associated uncertainty is computed:

$$E_{norm} = \frac{|x_{LAB} - x_{AV}|}{\sqrt{U^2(x_{LAB}) + U^2(x_{AV})}}$$

x_{LAB} is the Measured Value for each participant laboratory

x_{AV} is the Assigned Value of the intercomparison

$U(x_{LAB})$ is the measurement Uncertainty for each participant laboratory

$U(x_{AV})$ is the Uncertainty associated to the Assigned Value

The proposed figure of merit applies to all seven participants. A Normalized Error less than unity can be considered satisfactory, and excellent if it lies below a few tenths, showing a good level of agreement between the seven participant laboratories. The evaluation criteria for E_{norm} which are given below:

If $|E_{norm}| \leq 1$ then it is successful

If $|E_{norm}| > 1$ then it is unsuccessful

10. Measurement instructions

10.1. Precautions

- Do not connect adapter/connectors whose pin depth is not appropriate to the IEEE STD 287 [5] standard to the travelling standards.
- Avoid extreme temperature, humidity or pressure changes as well as violent impacts.

10.2. Before the measurements

- Clean the connectors with dried air and isopropyl alcohol.
- No initial tests are required.
- Use the suitable (12 lb-in for N type) torque wrench when connecting the travelling standard.
- It should be allowed to stabilize in a temperature and humidity controlled environment for at least 1 day before commencing measurements.

10.3. Powering of the standard during the measurements

- All type of the measurement instruments, which have 220 VAC power suppliers like power meters, have to plug in to power supplier at least 120 minutes before calibration.

10.4. Environmental conditions

- The ambient temperature and humidity must be measured. No corrections have been performed for temperature and humidity effects.
- At any case, in their respective calibration certificates each laboratory will report about the ambient conditions held at their premises during measurement of the travelling standard.

10.5. Methods of measurement

Each participant institute has made use of its own measurement method. A brief description of the measurement methods used by the participants follows:

SIQ Slovenia: The calibration certificate issued does not provide additional information about the measurement method (the ripple technique) applied. The list of measurement standards used is as follows: N9030B PXA Signal Analyser; 11691D Directional Coupler; M1404N Coaxial Termination; 04191-85300 Short; 778D Directional Coupler; Type BNC (f) Short; 18N50.

The calibration procedure used is: 09069P01/2019-04-01. Calibration was carried out by comparison of values indicated, or set, on the item under calibration, with values of measurands, realized with measurement standards.

EIM/NQIS Greece: The device under test was kept in the laboratory environment for the required time interval prior to the calibration. This time interval was not less than 24 hours. The calibration was conducted according to the “injection technique”. A second generator is used in combination with the DUT, connected via a directional bridge or a directional coupler. The second generator injects a signal which has a small fixed frequency offset (for example 10 Hz) from the DUT’s output frequency. The difference in frequency should be within the control bandwidth of the level control. The original and reflected signals will add and subtract at a rate of 10 Hz. The resultant signal is detected with a spectrum analyser in ‘zero span’ mode, connected to the third port of the bridge / coupler. The variation in amplitude with time is observed using the cursors to measure the maxima and minima. With the DUT replaced by an open and a short, a reference level can also be measured. Configuring the Spectrum Analyser to report in units of voltage, the Voltage

Reflection Coefficient can be calculated as: $\rho_l = Z_{DUT}/Z_{max}$. Where Z_{DUT} = half (max – min) signal with DUT connected and Z_{max} = mean signal with Open & Short connected.

For the calibration the following standards have been used:

1. Generator HP 83630A (D1/0051)
2. Spectrum Analyser Hewlett Packard 8566
3. Directional bridge Hewlett Packard 86205A
4. Directional coupler Krytar 0995-0098
5. Female open (S/N: 2157, D1/1269)
6. Female short (S/N: 2300, D1/1269)
7. Cable 11500C
8. Cable 11500D (Δ1/1285)
9. Cable 11500E (Δ1/1286)
10. Cable 11500F
11. Adapter 3.5mm (f-f) (Δ1/3208)
12. Adapter N(m)-SMA(f) (Δ1/2067)
13. Adapter N(m-m) 1250-1475 (D1/1871)

METAS Switzerland: The output Voltage Reflection Coefficient was measured using a passive reflectometer method. The different states of the switchable reflect standard were characterized using a calibrated Network Analyser.

The source match measuring station is used for the calibration of the complex source match of RF generators with a nominal impedance of 50Ω. A direct measurement technique called reflectometer is used in which the output power signal of the generator under test is simultaneously the test signal. The benefit here is that the generator’s output stage, which typically contains a control circuit to stabilise the level, is not influenced by an external test signal as it is the case with the active injection test method.

Figure 2 shows the source match measurement setup. Using a switchable reflect standard with different characterized states, the device under test is terminated into different known load impedances ΓL while the resulting RF power P_{PM} is measured simultaneously at the directional coupler output. Based on the quantities that are known - measured power and the characterization data of the switchable reflect standard - the desired reflection coefficient Γ_{DUT} is determined.

Verification is done by inserting a characterized attenuator between the DUT and the switchable reflect standard. The de-embedded verification results must be consistent with the results. Measurements of the power level P_{PM} are performed for each state of the switchable reflect standard.

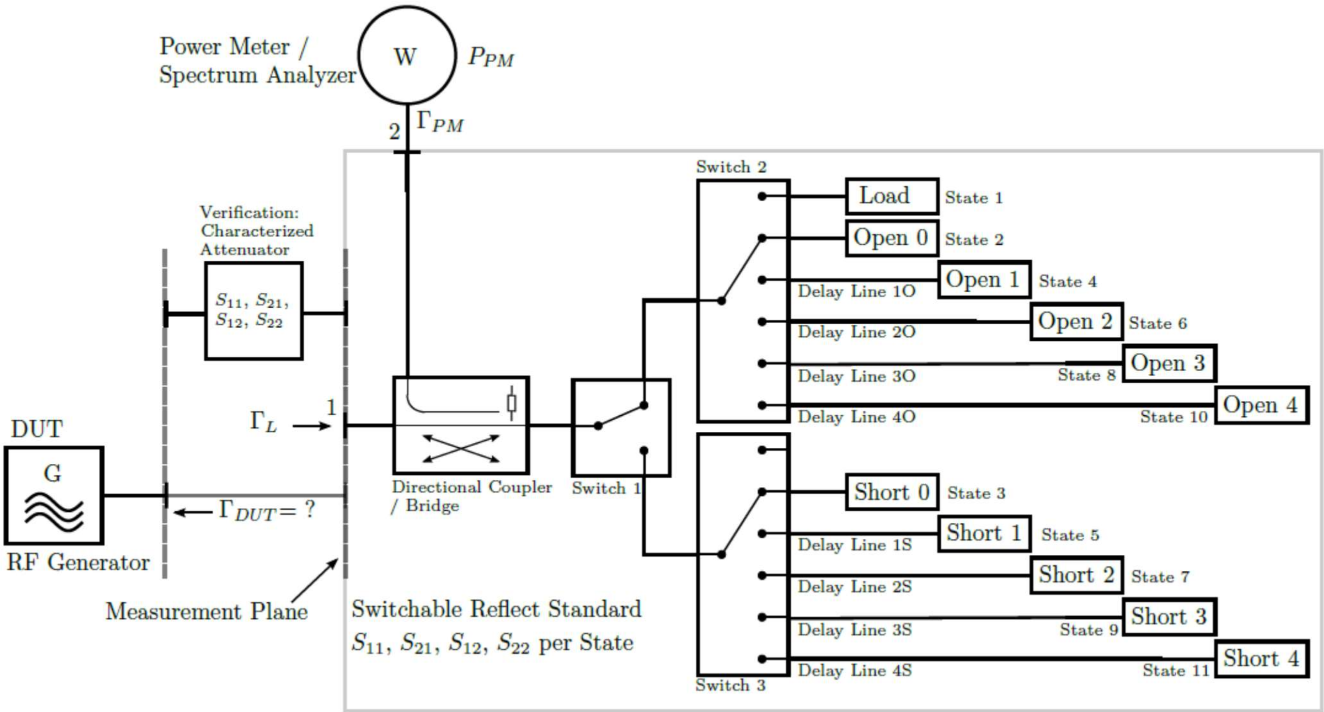


Figure 2. Measurement setup used by METAS

The measured data is analysed with the program 'METAS Source Match Tools' to determine the source match of the generator Γ_{DUT} and the power level P_{DUT}. The program uses an over-determined non-linear regression algorithm to determine the unknown quantities. Known input quantities are the measured power levels P_{PM} and the characterization data of the switchable reflect standard (S_{11}, S_{21}, S_{12} and S_{22} per state) and power meter (Γ_{PM}).

For the measurements the METAS internal software 'Source Match Measurement Switched Mismatches' has been used.

For the calculation of the results including uncertainties the METAS internal software 'METAS Source Match Tools' has been used.

For the analysis of the results the METAS software 'METAS VNA Tools II' has been used.

The standards used in the measurement are as follows: (i) switchable Reflect Standard, self-made at METAS, s/n none, S-parameter traceable to reflection standards; (ii) Signal Analyser, Rohde & Schwarz, FSW67, s/n 103220, linearity traceable to a calibrated step attenuator.

The uncertainty budget is at the end of this report. 'METAS UncLib' has been used for calculation of the uncertainties. This way uncertainties are traced back to the primary realisation of SI traceability for the S-parameters.

<u>TUBITAK UME Turkey</u>: For measurement of the voltage reflection coefficient (VRC) of the travelling standard, the effect of the level control was taken into account. So, an auxiliary signal generator was used which transmits a wave with a slightly offset carrier frequency into the travelling standard.

The difference in frequency should be within the control bandwidth of the level control. A directional coupler couples a part of these outgoing superimposed waves to the spectrum analyser. The frequency offset results in a beat of the superimposed outgoing waves. The VRC value is the ratio between the maximum and minimum amplitude of the beat.

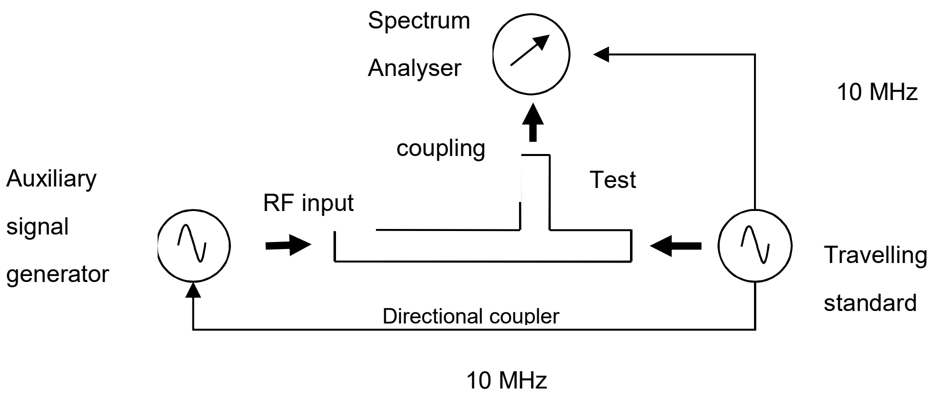


Figure 3. Measurement setup used by TUBITAK UME

The measurement set-up used for the comparison on voltage reflection coefficient (VRC) of an RF source is given in Figure 3 above. As seen from figure, the travelling standard, auxiliary signal generator and spectrum analyser were connected to the test, RF input and coupled ports of the directional coupler respectively. 10 MHz of all instruments were locked.

At the first stage, the travelling standard was set to test level of 0 dBm at different frequencies. The auxiliary signal generator was set to 100 Hz less than test frequency value and to the unmodulated minimum power level. The spectrum analyser was set to Zero span, same test frequency and level. The scale of spectrum analyser was linear level. The voltage of the signal was measured by varying the level in order to get line in the middle on the display of the spectrum analyser.

At the second stage, the travelling standard was disconnected from the directional coupler in order to have an open test port. The level of the auxiliary signal generator was increased until to get same voltage value measured at the first stage.

Finally, the travelling standard was connected to the directional coupler. The travelling standard was set to the desired power level and frequency. The auxiliary signal generator was set to the power level measured at the stage two and frequency of that minus 100 Hz. The maximum voltage V_{max} and minimum voltage V_{min} were read from the sinusoidal figure displayed on the spectrum analyser.

NIS Egypt: Measurement of Voltage Reflection Coefficient (VRC) of the signal generator is carried on using the injection method technique shown in Figure 4 [6-Fig. 2]. A short description is as follows: an HP synthesized CW generator model 83712A (DUT) feeds 0 dBm output power at frequencies (50 MHz, 2 GHz, 8 GHz, 12 GHz, 15 GHz and 18 GHz) alternatively to Keysight directional bridge model 86205A and Keysight directional coupler model 773D, both covering a part of the stated frequency range. For frequency range from 50MHz to 2GHz port 1 of the directional bridge is connected with DUT HP synthesized CW generator, port 2 is injected by reference R&S signal generator, port 3 is connected with R&S spectrum analyser. For frequency range from 2 GHz to 18 GHz the output port of the directional coupler is injected by reference R&S signal generator, input port is connected with DUT HP synthesized CW generator, coupled port is connected with R&S spectrum analyser. The VRC is given by:

$$|\Gamma| = \frac{Z_{UUT}}{Z_{Max}}$$

Where Z_{DUT} = half (max-min) signal with DUT connected and Z_{Max} = mean signal with open & short connected at test ports (port 2 of directional bridge, input port of directional coupler) according to the stated frequency. The spectrum analyser is adjusted at zero span (time-domain mode) and a frequency offset of 100 Hz is added for DUT and reference generators in order to detect the maximum and minimum signal. The contributions to VRC measurement uncertainty budget are Type A (repeatability of the VRC measurements), and Type B, the return loss of 86205A bridge or 773D coupler directivity, the test port match and the uncertainty with which their values are known, linearity of R&S spectrum analyser, and R&S Signal generator uncertainty [7]. The uncertainty of directivity and test port match are calculated according to [8].

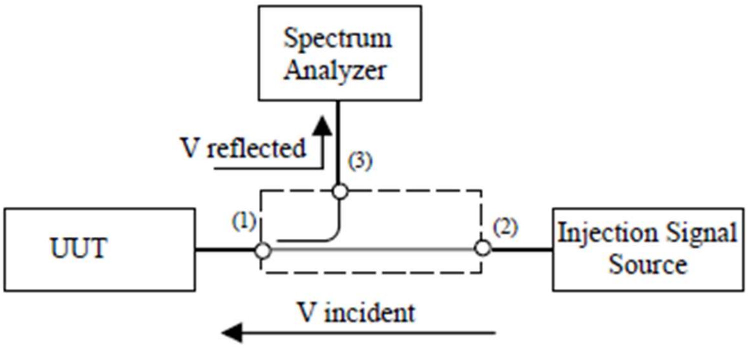


Figure 4. Measurement setup used by NIS

GUM Poland: The measurements have been made using a directional coupler with the DUT connected to the 'Input' port and a sliding short connected to the 'Test' port. The DUT's VRC magnitude was derived from the maximum and minimum values indicated by the power meter (with the power sensor connected to the 'Incident' port of the coupler). The sliding short used for these measurements is a USSR-made type HK3-1 element, of not the best quality, whose Reflection Coefficient in magnitude is usually less than unity. Due to this fact the short's VRC at the certain positions (where readings on the power meter were either a minimum or a maximum) were measured using a VNA, calibrated with the calibration kit listed below. Thus, the actual Reflection Coefficient of the sliding short and its uncertainties were taken into account in the DUT's VRC calculations and in the final uncertainty budget.

The standards used in the measurements were: (i) directional coupler Hewlett Packard, model 11692D, serial number 1212A04401; (ii) power sensor Hewlett Packard, model 8481D, serial number 3318A07727; (iii) power meter Hewlett Packard, model 438A, serial number 3017U01578; (iv) Vector Network Analyser Agilent, model E8364B, serial number MY43030326; (v) calibration kit Agilent, model 85054B, serial number MY39200148.

INTA Spain: INTA made use of the ripple technique. By definition, it is a scalar method which relies on the interaction between two signals, the main signal reflected by high reflection (a short) and the signal reflected at the generator's output connector. The two signals are separated by means of a directional device (a coupler) and their path difference increased by means of an airline. The interaction between the two signals, as a consequence of the path difference introduced by the airline, gives rise to a ripple signal whose peak-to-peak value (divided by two) indicates the magnitude of the output VRC of the generator under test.

Main sources of uncertainty are the corrections made on the peak-to-peak value, which depend on the known Reflection Coefficient of the short and the Insertion Losses of the directional coupler and of the airline. Additional sources of uncertainty are the Directivity and Reflection Coefficient of the airline, which may interact with the main signals so that its effect must be accounted for in the uncertainty budget. Also the uncertainty associated to the algorithm for computation of the envelope of the ripple signal does play a role, since determination of the mean value and of the peak-to-peak value are dependent on it.

A further refinement of the method consists in filtering the original ripple signal (in which two different ripple contributions with different 'rates of variation' are normally present) in order to obtain two ripples with a single 'rate of variation' each. The two different rates are due to the presence of two different paths for the incoming signals: the directional coupler in one measurement setup and the coupler plus the airline in the second setup.

10.6. Reported ambient conditions during measurements

The participants have reported the following ambient conditions held during measurement of the travelling standard:

Table 5. Measurement ambient conditions

Acronym of Institute	Country	Temperature	Relative Humidity
SIQ	Slovenia	(23 ± 2) °C	(50 ± 20) %
EIM/NQIS	Greece	22.6 °C ≤ T[2] ≤ 24.0 °C	65% ≤ HR[3] ≤ 79%
METAS	Switzerland	(23 ± 1) °C	(45 ± 10) %
NIS	Egypt	(23 ± 1) °C	(45 ± 1) %
TUBITAK UME	Turkey	(23 ± 1) °C	(45 ± 15) %
GUM	Poland	(23 ± 1) °C	(44 ± 2) %
INTA	Spain	(23 ± 1) °C	< 70 %

11. Measurement uncertainty

The uncertainty of measurement must be calculated according to Ref. [2] for a confidence level of 95.45% (in the case of infinite degrees of freedom or an assumed Gaussian probability density function, this corresponds to a coverage factor k=2).

All contributions to the measurement uncertainty, or at least the most relevant ones, should be listed in the measurement report or calibration certificate submitted by each participant.

Each laboratory has declared its measurement uncertainty budget where all (or at least the most relevant) contributions are stated and its combination briefly described, according to the format given in Annex A of the intercomparison protocol.

[2] Measurement uncertainty ± 0.2 °C

[3] Measurement uncertainty ± 2%

12. Reporting of results

The results have been sent to the pilot laboratory. Each measurement report or calibration certificate contains information such as:

- Details of participant laboratory.
- The date of the measurements.
- A brief description of the measurement method and system used.
- The measurement standards used in the comparison measurements.
- Software used in the comparison measurements (if used).
- The environmental conditions during the measurements:
    - Ambient Temperature
    - Relative Humidity
- Results of measurement; the measurement results have been provided according to the Annex A of the intercomparison protocol.
- A statement of traceability.
- Model function of measurement with explanations of the symbols.
- Expanded measurement uncertainty, estimated for a confidence level of 95.45%.

13. Measurement results of the participant laboratories

The pilot laboratory is responsible for the preparation of this Analysis Report.

13.1. Measurement of scalar Reflection Coefficient

Reflection Coefficient (VRC) @ 50 MHz

Laboratory	VRC (magnitude)	Uncertainty (±)
TUBITAK UME	0.052	0.095
METAS	0.0418	0.0043
INTA	0.0445	0.0090
EIM/NQIS	0.0591	0.0092
SIQ	0.044	0.020
NIS	0.043	0.026

Reflection Coefficient (VRC) @ 2 GHz

Laboratory	VRC (magnitude)	Uncertainty (±)
TUBITAK UME	0.034	0.099
METAS	0.0386	0.0049
GUM	0.0290	0.0069
INTA	0.040	0.012
EIM/NQIS	0.0377	0.0094
SIQ	0.022	0.049
NIS	0.044	0.064

Reflection Coefficient (VRC) @ 8 GHz

Laboratory	VRC (magnitude)	Uncertainty (±)
TUBITAK UME	0.038	0.098
METAS	0.0367	0.0074
GUM	0.040	0.015
INTA	0.070	0.024
EIM/NQIS	0.089	0.016
SIQ	0.055	0.042
NIS	0.062	0.063

Reflection Coefficient (VRC) @ 12 GHz

Laboratory	VRC (magnitude)	Uncertainty (±)
TUBITAK UME	0.134	0.083
METAS	0.099	0.011
GUM	0.116	0.013
INTA	0.103	0.033
EIM/NQIS	0.170	0.019
SIQ	0.112	0.037
NIS	0.145	0.064

Reflection Coefficient (VRC) @ 15 GHz

Laboratory	VRC (magnitude)	Uncertainty (±)
TUBITAK UME	0.099	0.086
METAS	0.102	0.012
GUM	0.102	0.019
INTA	0.096	0.033
EIM/NQIS	0.175	0.019
SIQ	0.10	0.11
NIS	0.125	0.091

Reflection Coefficient (VRC) @ 18 GHz

Laboratory	VRC (magnitude)	Uncertainty (±)
TUBITAK UME	0.057	0.094
METAS	0.055	0.013
GUM	0.043	0.023
INTA	0.055	0.025
EIM/NQIS	0.110	0.013
SIQ	0.07	0.15
NIS	0.069	0.092

13.2. Measurement of phase

Only one of the participant laboratories, METAS Switzerland, has been able to provide measured phase of the complex Reflection Coefficient. Although it can't take part in the comparison exercise, we reproduce here the results obtained for the phase of the parameter under test.

Phase of Reflection Coefficient (VRC) as measured by METAS

Frequency	VRC (phase, °)	Uncertainty (± °)
50 MHz	-55.4	5.7
2 GHz	-35.7	7.3
8 GHz	-87	13
12 GHz	-81.8	8.1
15 GHz	15.0	9.4
18 GHz	175	16

14. Assigned Value and Figure of Merit of the participants

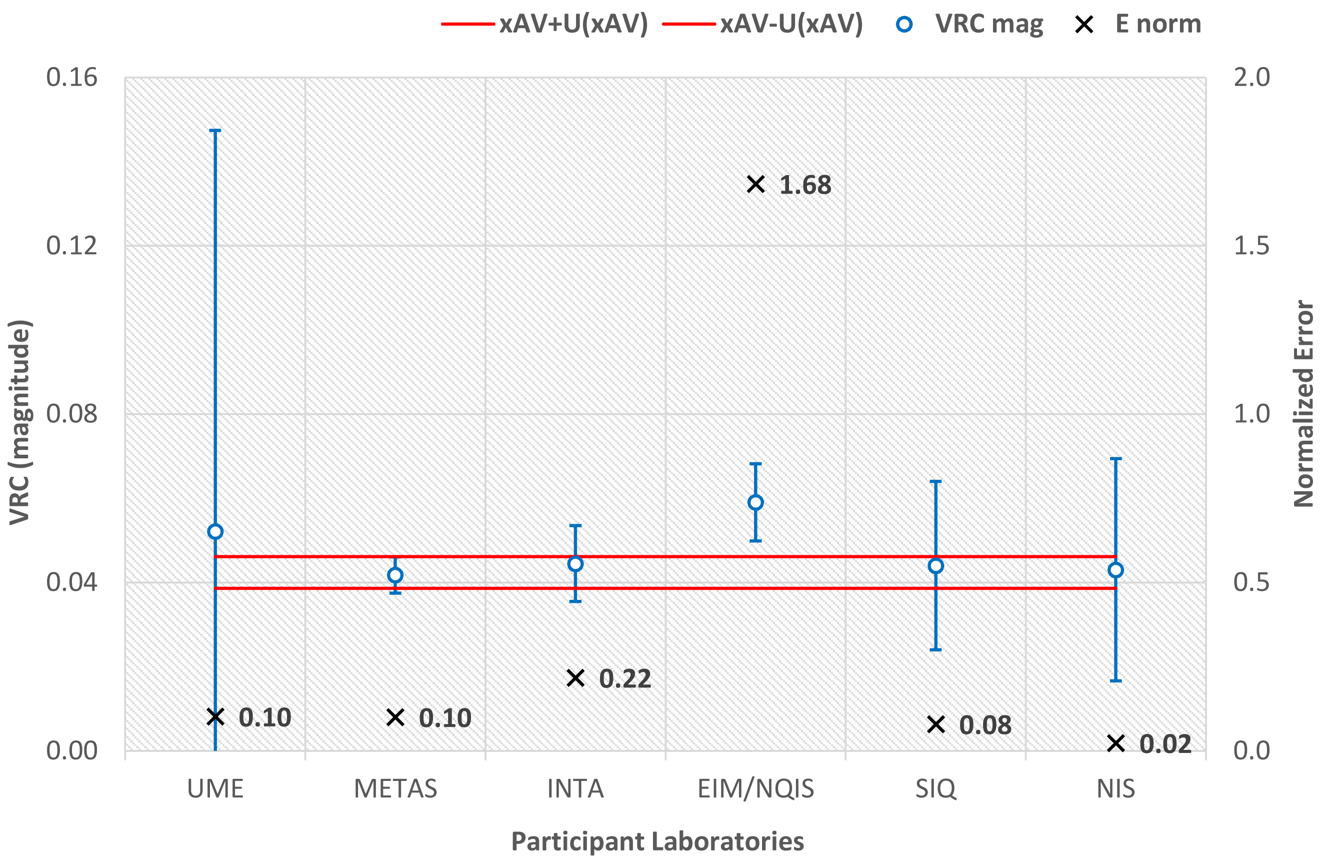
Applying the statistical tools seen in the precedent section, the following results are obtained. In all graphs, the calculated Assigned Values are indicated with coloured horizontal lines: Comparison Assigned Value (x_{AV}) is not shown for the sake of simplicity. The red solid lines represent the combination of the Assigned Value plus or minus its associated uncertainty $U(x_{AV})$.

Those participant laboratories considerer outliers have not been taken into account in the determination of the Assigned Values. They are shown in yellow for clarity of inspection.

14.1. Measurement of scalar Reflection Coefficient

Reflection Coefficient (VRC) @ 50 MHz

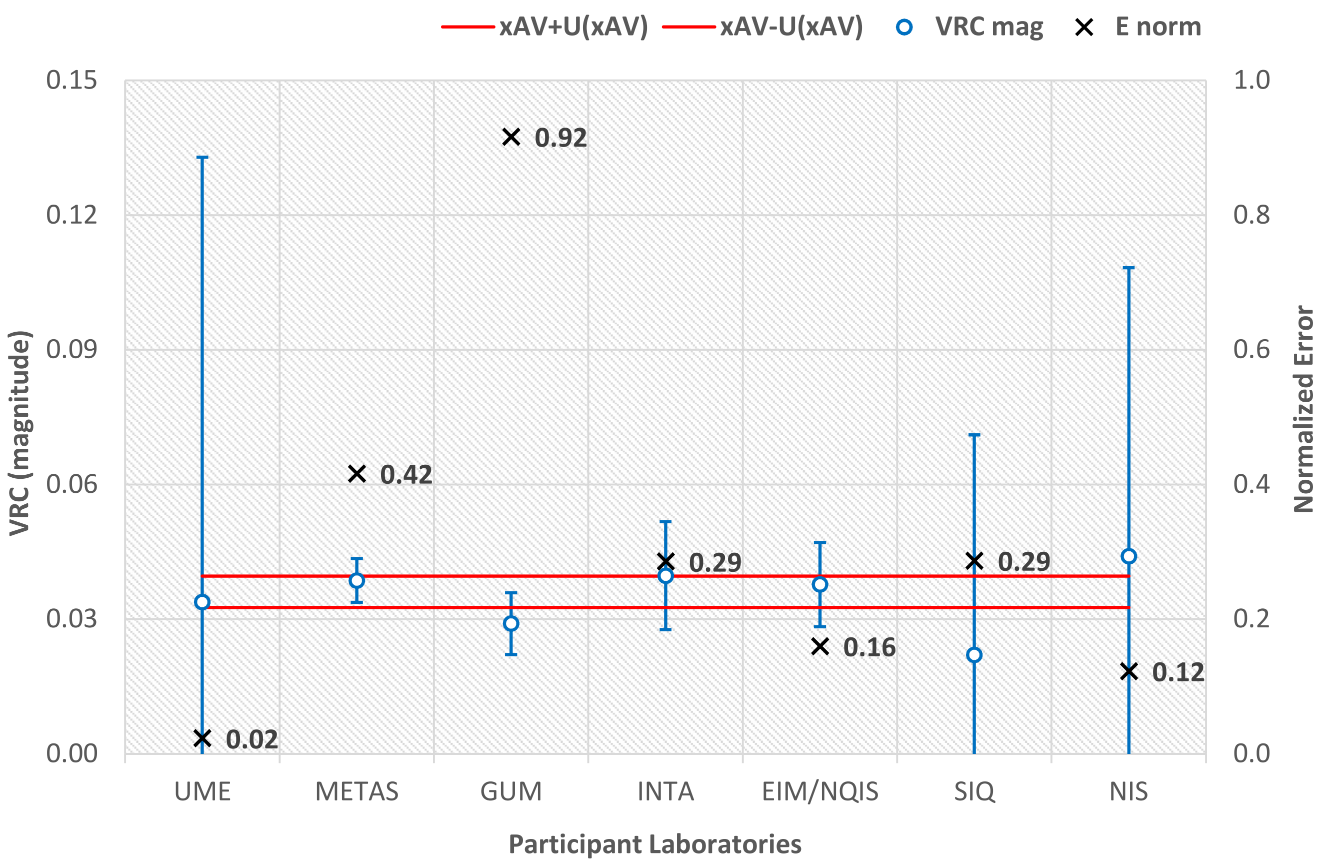
Laboratory	VRC (magnitude)	U (±)	Outlier (Yes/No)	Assigned Value	U (±)	Enorm
TUBITAK UME	0.052	0.095	Yes[4]	0.0424	0.0038	0.10
METAS	0.0418	0.0043	No	0.0424	0.0038	0.10
INTA	0.0445	0.0090	No	0.0424	0.0038	0.22
EIM/NQIS	0.0591	0.0092	Yes[4]	0.0424	0.0038	1.68
SIQ	0.044	0.020	No	0.0424	0.0038	0.08
NIS	0.043	0.026	No	0.0424	0.0038	0.02



[4] TUBITAK UME and EIM/NQIS have not been taken into account in the determination of the Assigned Value

Reflection Coefficient (VRC) @ 2 GHz

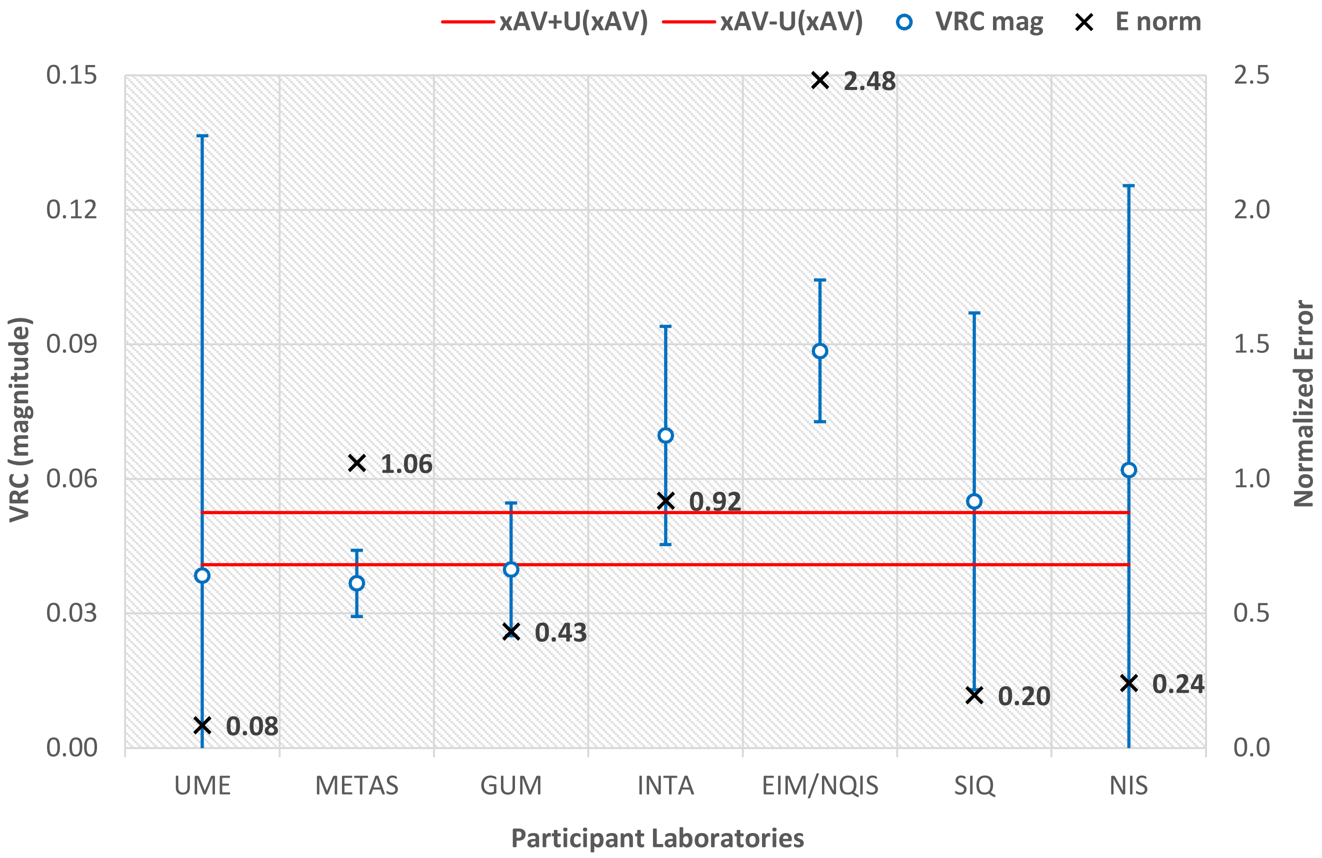
Laboratory	VRC (magnitude)	U (±)	Outlier (Yes/No)	Assigned Value	U (±)	Enorm
TUBITAK UME	0.034	0.099	No	0.0361	0.0035	0.02
METAS	0.0386	0.0049	No	0.0361	0.0035	0.42
GUM	0.0290	0.0069	No	0.0361	0.0035	0.92
INTA	0.040	0.012	No	0.0361	0.0035	0.29
EIM/NQIS	0.0377	0.0094	No	0.0361	0.0035	0.16
SIQ	0.022	0.049	Yes[5]	0.0361	0.0035	0.29
NIS	0.044	0.064	No	0.0361	0.0035	0.12



[5] SIQ has not been taken into account in the determination of the Assigned Value

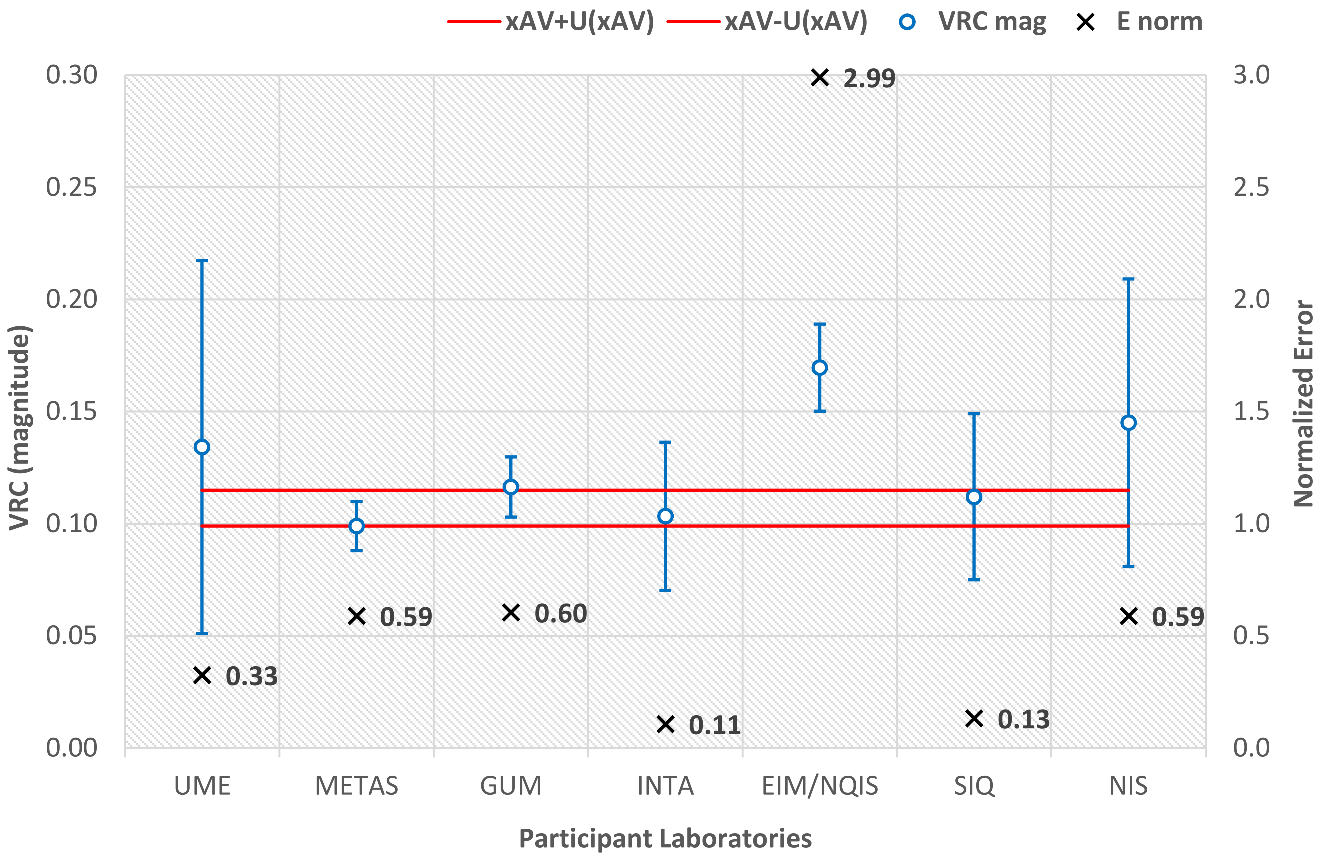
Reflection Coefficient (VRC) @ 8 GHz

Laboratory	VRC (magnitude)	U (±)	Outlier (Yes/No)	Assigned Value	U (±)	Enorm
TUBITAK UME	0.038	0.098	No	0.0467	0.0058	0.08
METAS	0.0367	0.0074	No	0.0467	0.0058	**1.06**
GUM	0.040	0.015	No	0.0467	0.0058	0.43
INTA	0.070	0.024	No	0.0467	0.0058	**0.92**
EIM/NQIS	0.089	0.016	No	0.0467	0.0058	**2.48**
SIQ	0.055	0.042	No	0.0467	0.0058	0.20
NIS	0.062	0.063	No	0.0467	0.0058	0.24



Reflection Coefficient (VRC) @ 12 GHz

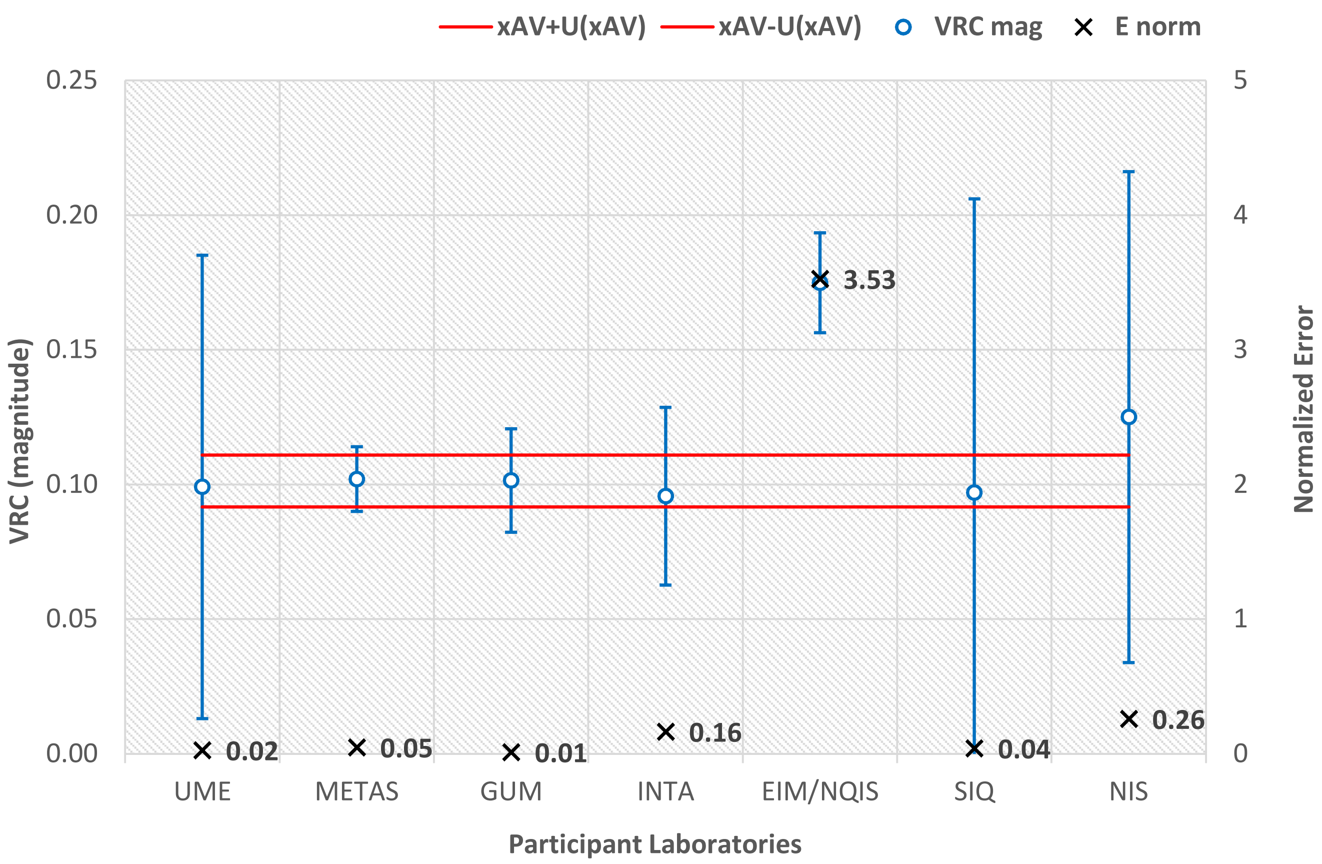
Laboratory	VRC (magnitude)	U (±)	Outlier (Yes/No)	Assigned Value	U (±)	Enorm
TUBITAK UME	0.134	0.083	No	0.1070	0.0079	0.33
METAS	0.099	0.011	No	0.1070	0.0079	0.59
GUM	0.116	0.013	No	0.1070	0.0079	0.60
INTA	0.103	0.033	No	0.1070	0.0079	0.11
EIM/NQIS	0.170	0.019	Yes[6]	0.1070	0.0079	2.99
SIQ	0.112	0.037	No	0.1070	0.0079	0.13
NIS	0.145	0.064	No	0.1070	0.0079	0.59



[6] EIM/NQIS has not been taken into account in the determination of the Assigned Value

Reflection Coefficient (VRC) @ 15 GHz

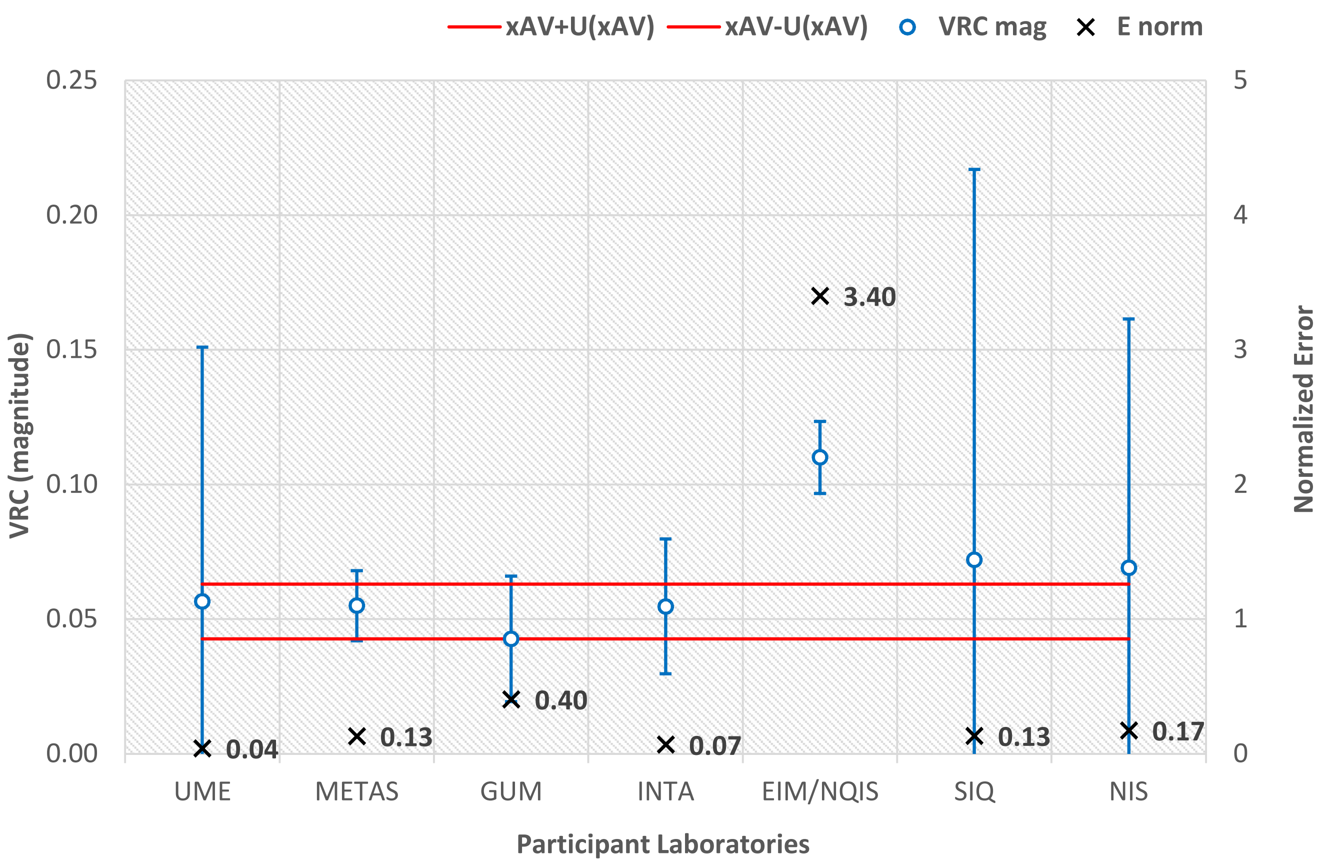
Laboratory	VRC (magnitude)	U (±)	Outlier (Yes/No)	Assigned Value	U (±)	Enorm
TUBITAK UME	0.099	0.086	No	0.1013	0.0096	0.02
METAS	0.102	0.012	No	0.1013	0.0096	0.05
GUM	0.102	0.019	No	0.1013	0.0096	0.01
INTA	0.096	0.033	No	0.1013	0.0096	0.16
EIM/NQIS	0.175	0.019	Yes[7]	0.1013	0.0096	3.53
SIQ	0.10	0.11	No	0.1013	0.0096	0.04
NIS	0.125	0.091	Yes[7]	0.1013	0.0096	0.26



[7] EIM/NQIS and NIS have not been taken into account in the determination of the Assigned Value

Reflection Coefficient (VRC) @ 18 GHz

Laboratory	VRC (magnitude)	U (±)	Outlier (Yes/No)	Assigned Value	U (±)	Enorm
TUBITAK UME	0.057	0.094	No	0.053	0.010	0.04
METAS	0.055	0.013	No	0.053	0.010	0.13
GUM	0.043	0.023	No	0.053	0.010	0.40
INTA	0.055	0.025	No	0.053	0.010	0.07
EIM/NQIS	0.110	0.013	Yes[8]	0.053	0.010	3.40
SIQ	0.07	0.15	No	0.053	0.010	0.13
NIS	0.069	0.092	No	0.053	0.010	0.17



[8] EIM/NQIS has not been taken into account in the determination of the Assigned Value

15. Evaluation of results

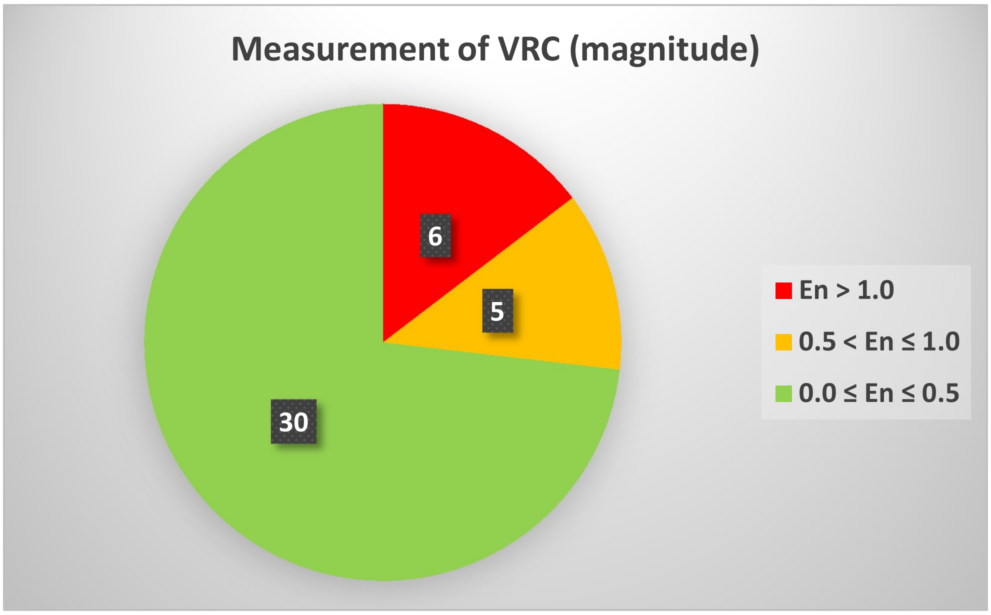
15.1. Evaluation of the participation of laboratories

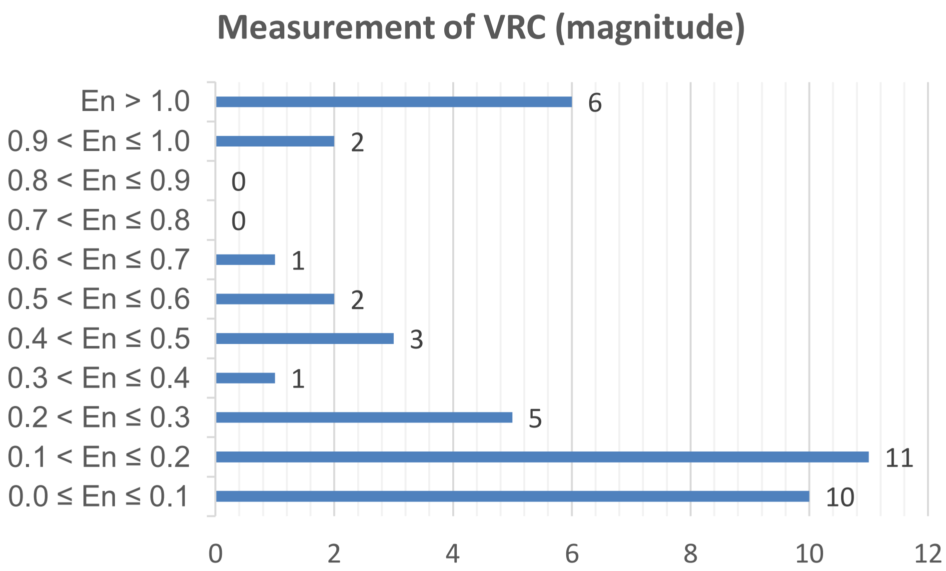
The laboratory responsible for the organisation of this intercomparison exercise makes the following comments and remarks:

- As regards the homogeneity of the intercomparison results in terms of measurement uncertainty, the uncertainties of the participants are comparable. In principle, it is this homogeneity in the measurement uncertainties what makes this exercise feasible for analysis by consensus. Moreover, the existence of a small number of outliers reinforces our opinion (7 of a global amount of 41 measuring points analysed). These anomalous results, by definition of the method of analysis, have been excluded from the calculation of the Assigned Value. Those participants considered ‘anomalous’ should perhaps review their measurement procedures and the accuracy of the standards used in this exercise, even if they obtain a normalized error less than unity.
- A comparison between participants based exclusively on the normalized error obtained would be clearly biased due to the lack of homogeneity among participants. Those laboratories with larger measurement uncertainties can get a normalized error smaller than other participants with better measurement capability. Also those participants considered as outliers may exhibit a reduced normalized error for the same reasons, even though they have not been taken into account in the determination of the Assigned Value.
- Considering only the figures of merit obtained by the participants, the results of the comparison exercise are considered satisfactory in view of the measurement results provided by the laboratories. Most participants obtain a normalized error less than unity for the required measurement frequencies.
- Each participant should take into account the number of measurements for which it has obtained a normalized error greater than unity, and perhaps revise their measurement procedures accordingly, in order to detect the origin of the observed discrepancies. When necessary, the appropriate corrective and / or preventive actions should be taken according to its internal QA system or to the national accreditation body in each case.
- In view of the overall results (which are more thoroughly analysed in the following paragraph), the results of the comparison exercise is considered successful by the organiser.
- However, as a final remark about the number of outliers (7 outliers among 41 measurement points analysed, or a ratio of 17 percent), the detection of ‘anomalous’ participants is certainly method-dependent. A different method for determination of outliers could be applied and the results might be different. Even the Assigned Value of the comparison could be affected. Nevertheless, the method based on the Median and on the 3·MAD criteria is usually considered as appropriate for the analysis of results in intercomparisons. One of its drawbacks is that it works well under the assumption of a Gaussian population of analysed data, which is not often the case with a reduced number of participants, or when not all participants provide measurement results for all frequencies required.

15.1.1. Measurement of scalar Reflection Coefficient

The total number of measurement points is 41. The number of normalized errors exceeding unity is 6, almost 15 percent. The number of measurement points for which the normalized error is comprised between 0.5 and unity is 5, or a percentage of 12. The ratio of normalized errors less than 0.5 (30 values representing 73% of occurrences) shows a very good agreement with respect to the Assigned Value of the comparison. For 85% of occurrences the normalized error is acceptable, 35 out of 41 measurement points.





We show below the number of measurement points for which each participant has obtained normalized errors: (i) above unity (not acceptable); (ii) between 0.5 and unit (acceptable); and (iii) below 0.5 (excellent).

15.1.2. Measurement of scalar Reflection Coefficient

Laboratory	Enorm > 1 (not acceptable)	0.5 < Enorm ≤ 1 (acceptable)	Enorm ≤ 0.5 (excellent)
TUBITAK UME			6
METAS	1	1	4
GUM		2	3
INTA		1	5
EIM/NQIS	5		1
SIQ			6
NIS		1	5

15.2. Drift of the travelling standard

An analysis based on the existing characterizations made by the RF & Microwaves Laboratory follows. Measurements were made at the beginning and at the conclusion of comparison exercise. With these measurements INTA participates in the determination of the Assigned Value of the comparison, made by consensus among the participants.

As a figure of merit the time drift has been computed for the RF source under test for a time period covering a time span which can be comparable to the duration of the comparison exercise. To do this the following expression has been used:

$$\sqrt{(b \cdot T)^2 + \frac{\sum_{i=1}^{N}(X_i - \langle X_i \rangle)^2}{N-2}}$$

Where:

- b is the slope of the least-squares fitting (or trend line) made for the set of N values measured.
- T is the time period along which the potential time drift is estimated, so that b·T represents an indication of the time drift experienced by the parameters under test from the date of the last calibration at INTA to the date estimated for the next re-calibration. We consider the potential time drift experienced until 31 January 2020, in order to cover a time period comparable to the duration of the comparison exercise.
- Xi are the values of the measured parameter of the RF source (scalar Reflection Coefficient) along time.
- <Xi> = a+b·ti are the estimated values over the least-squares trend line, computed on the same dates as the measurement points on the time axis, ti. a it is the y-intercept.
- N is the number of measurements.

15.2.1. Measurement of scalar Reflection Coefficient

Frequency	Scatter Δ[9]	Change in slope[10]	Temporary drift[11]	Uncertainty[12]
2 GHz	0.0000	-0.0005	0.0005	0.012
8 GHz	0.0019	-0.0026	0.0032	0.024
12 GHz	0.0002	0.0018	0.0018	0.033
15 GHz	0.0000	-0.0005	0.0005	0.033
18 GHz	0.0001	0.0009	0.0009	0.025

[9] Scatter of the measured values

[10] Increase / decrease with the slope of the least-square fitting curve, evaluated on January 31st, 2020

[11] Temporaty drift during a period of time comparable to the duration of the intercomparison exercise. It is obtained as the root-sum-of-squares of contributions (4) and (5). It should be less than (or of the same order of magnitude as) the measurement uncertainty

[12] Expanded uncertainty associated to the values measured by the pilot laboratory

15.3. 'Closing-of-loop' criteria

Under conditions of stability of the traveling standard, as it is the present case, the 'Closing-of-Loop' Index (CoL) is the defined as the following normalized error:

$$CoL = \frac{|x_I - x_F|}{\sqrt{U^2(x_I) + U^2(x_F)}}$$

Where:

- x_I is the initial measured value, at the beginning of the measurement loop
- x_F is the final measured value, at the end of the measurement loop
- $U(x_I)$ is the initial measurement uncertainty, at the beginning of the measurement loop
- $U(x_F)$ is the final measurement uncertainty, at the end of the measurement loop

In our case, the initial and final characterization of the traveling standard made by the pilot laboratory will be taken. These measurements were carried out before the measurements made by the participants laboratories and at the conclusion of the measurement loop, in February 2017 and March 2019, respectively.

Alternatively, and in order to include all the information available for the traveling standard, the generalized normalized error can be defined for any number of points (in principle it converges when applied to a stable piece of equipment with many calibrations over time):

$$CoL = \frac{\sum_{i=1}^{N} |x_i - \bar{X}|}{(N-1) \cdot \sqrt{\sum_{i=1}^{N} U^2(x_i)}}$$

The above criteria shall be applied to all the parameters under test of an intercomparison exercise. Its value should be less than unity in all cases.

15.3.1. Measurement of scalar Reflection Coefficient

Frequency	'Closing-of-loop' Index
50 MHz	0.08
2 GHz	0.06
8 GHz	0.09
12 GHz	0.05
15 GHz	0.01
18 GHz	0.03

16. Final report of the comparison

The pilot laboratory is responsible for the preparation of this Analysis Report.

The Draft A of the comparison report was sent to the participants for discussion, amendment if applicable, and eventually for approval. This draft version was confidential and no identification of the participants was made.

All laboratories unanimously agreed to identify themselves and thus to give up confidentiality.

The participants had two weeks to send their comments about Draft A Report. Once all amendments have been taken into account, and after final approval by all participants, this Draft B Report becomes the Final Report.

17. Confidentiality

The results and/or the Final Report will not be revealed to third parts without the written permission of all the participant laboratories.

It is beforehand expressed the initial intention of INTA to eventually present the comparison results to the Spanish Accreditation Body (ENAC) in order to show competence in the measurement field here concerned, according to the requirements of ISO/IEC 17025:2017. At any case, ENAC will not be treated as any other third part and no permission from the participant laboratories will be necessary.

Once the comparison is finished, and in case that all seven participants agree, the results could be published or presented at Scientific Forums.

Eventually, this analysis document will be sent to MSU and EURAMET as the final report for the comparison project. Final decision about making it public or even accessible via the web page will be thus made by MSU and EURAMET.

17.1. Identification of laboratories

The measurement results contained in Draft A of the Final Report were published without identification of the participant laboratories. The correspondence between each set of data and the participants were only known by the pilot laboratory. Each laboratory was informed separately about the identification of its own data.

After all seven participants agreed to be identified and expressly resigned from the confidentiality commitment of the intercomparison exercise, the Final Report is now published with identification of laboratories.

Resigning from confidentiality required the written consent of all seven participants, and would not have been applicable in case any of them did not agree, or in case the pilot laboratory did not receive the corresponding written permissions previously to the issuing of the Final Report.

18. Acknowledgement

The pilot of the intercomparison wishes to thank all the participant laboratories for their willingness to take part in this exercise, as well as for the compliance with the deadlines in the transport schedule and in the measurement slots. Also for the care taken in the handling of the travelling standard.

This work was supported by the project 15RPT01 RFMicrowave. This project has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

19. References and applicable documentation

[1] CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons, 2007 (available on the BIPM website: http://www.bipm.org/utils/common/pdf/CC/CCEM/ccem_guidelines.pdf

[2] Evaluation of measurement data - Guide to the Expression of Uncertainty in Measurement (GUM), JCGM 100:2008, First edition, September 2008 (available on the BIPM website: http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf

[3] UNE-EN ISO/IEC 17043:2010: "Conformity assessment — General requirements for proficiency testing", International Standardization Organization", 2010

[4] International Standard ISO 13528: "Statistical Methods for Use in Proficiency Testing by Interlaboratory Comparison". Reference number ISO 13528:2015(E)

[5] IEEE 287-2007, IEEE Standard for Precision Coaxial Connectors (DC to 110 GHz), 2007

[6] P. Roberts, "Measuring Output VSWR for an Active Levelled Source", Measurement Science Conference, 2008

[7] P. Roberts and P. Bunyan, "Source Match Measurement for a Levelled Generator", Fluke Precision Measurement Ltd, PCAR & PB, September 2006

[8] J. Hurll, "Uncertainty and Confidence in Measurements", chapter 3, Microwave Measurements, 3th edition, The Institution of Engineering and Technology, 2007

20. Annex I – Measurement report from TUBITAK UME Turkey

COMPARISON ON
VOLTAGE REFLECTION COEFFICIENT (VRC)
OF AN RF SOURCE

TUBITAK UME
REPORT

EMPIR 15RPT01
RFMICROWAVE

CONTENTS

TUBITAK UME REPORT

1. PARTICIPANT INFORMATION

Laboratory Name:	TUBITAK UME
Name of contact person:	Aliye Kartal Dogan, Murat Celep
Telephone number:	+90 262 6795000 -4500-4555
Fax:	+90 262 6795001
E-mail:	murat.celep@tubitak.gov.tr, aliye.dogan@tubitak.gov.tr
Address:	PO 54 41470 Gebze Kocaeli

2. MEASUREMENT DATE:

3. ENVIRONMENTAL CONDITIONS

Temperature : (23 ±1) °C

Relative Humidity : (45±15)%

4. STANDARDS USED IN MEASUREMENT

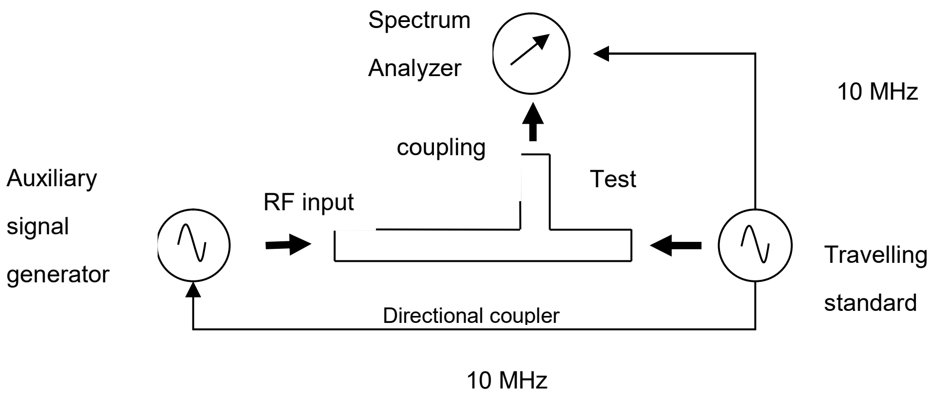
Instrument Name	Manufacturer	Type / Model	Serial Number	Traceability
Signal Generator	Agilent	E8257D	MY45140783	TÜBİTAK UME
Spectrum Analyzer	Agilent Technologies	8565EC	4208A00737	TÜBİTAK UME
Directional Coupler	Hewlett Packard	HP86205A	3140A01797	TÜBİTAK UME
Directional Coupler	Agilent	773D	MY52180258	TÜBİTAK UME

5. DESCRIPTION OF MEASUREMENT METHOD

The voltage reflection coefficient (VRC) measurement of the travelling standard, the effect of the level control was taken into account. So, an auxiliary signal generator is used which transmits a wave with a slightly offset carrier frequency into the travelling standard.

The difference frequency should be within the control bandwidth of the level control. A directional coupler couples a part of these outgoing superimposed waves to the spectrum analyzer. The frequency offset, results in a beat of the superimposed outgoing waves. The VRC value is the ratio between the maximum and minimum amplitude of the beat.

The measurement set-up used for the comparison on voltage reflection coefficient (VRC) of an RF source is given in Figure 1. As seen from figure, the travelling standard, auxiliary signal generator and spectrum analyzer were connected to the test, RF input and coupled ports of the directional coupler respectively. 10 MHz of all instruments were locked.



At the first stage, the travelling standard was set to test level of 0 dBm at different frequencies. The auxiliary signal generator was set to 100 Hz less than test frequency value and to the unmodulated minimum power level. The spectrum analyzer was set to Zero span, same test frequency and level. The scale of spectrum analyzer was linear level. The voltage of the signal was measured by varying the level in order to get line in the middle on the display of the spectrum analyzer.

At the second stage, the travelling standard was disconnected from the directional coupler in order to have a open test port. The level of the auxiliary signal generator was increased until to get same voltage value measured at the first stage.

Finally, the travelling standard was connected to the directional coupler. The travelling standard was set to the desired power level and frequency. The auxiliary signal generator was set to the power level measured at the stage two and frequency of that minus 100 Hz. The maximum voltage V_{max} and minimum voltage V_{min} were read from the sinusoidal figure displayed on the spectrum analyzer.

6. MEASUREMENT RESULTS:

Frequency	Voltage Reflection Coefficient of travelling standard @ 0 dBm			
	VRC Magnitude	Uncertainty (CL = 95.45%)	VRC Phase (if measured)	Uncertainty (CL = 95.45%)
50 MHz	1,11	0,21	--	--
2 GHz	1,07	0,21	--	--
8 GHz	1,08	0,21	--	--
12 GHz	1,31	0,22	--	--
15 GHz	1,22	0,21	--	--
18 GHz	1,12	0,21	--	--

7. UNCERTAINTY BUDGET

7.1. Voltage Reflection Coefficient (VRC) measurement uncertainty budget

Model function : $VRC = \frac{Vmax+\delta Reproducibility+\delta Resolution+\delta spec.analyzer+\delta directivity}{Vmin++\delta Reproducibility+\delta Resolution+\delta spec.analyzer+\delta directivit}$

Frequency : 50 MHz

Output Level (CW) : 0 dBm

Definition of contribution	Expected Value x_i	Standard Uncertainty $u(x_i)$	Distribution Function	Sensitivity Coefficient c_i	Uncertainty contribution $u(y_i)$
Vmax measurements	42,55 mV	0,153 mV	Normal	0,0260	0,0040
Vmin measurements	38,47 mV	0,132 mV	Normal	-0,0287	-0,0038
Reproducibility of measurements	--	0,0100	Normal	1,106	0,0006
Resolution of spectrum analyzer	--	0,0014978	Rectangular	1,106	0,0009
Effect of spectrum analyzer	--	0,005773	Normal	1,106	0,0064
Effect of directivity of directional coupler	--	0,100	Normal	1,106	0,1000
Measured Value	**1,11**	**Combined Uncertainty**			0,100
		Expanded Uncertainty (CL = 95.45%)			**0,201**

Model function : $VRC = \frac{Vmax + \delta Reproducibility + \delta Resolution + \delta spec.analyzer + \delta directivity}{Vmin + + \delta Reproducibility + \delta Resolution + \delta spec.analyzer + \delta directivity}$

Frequency : 2 GHz

Output Level (CW) : 0 dBm

Definition of contribution	Expected Value x_i	Standard Uncertainty $u(x_i)$	Distribution Function	Sensitivity Coefficient c_i	Uncertainty contribution $u(y_i)$
Vmax measurements	22,57 mV	0,151 mV	Normal	0,0476	0,0072
Vmin measurements	21,01 mV	0,151 mV	Normal	-0,0511	-0,0077
Reproducibility of measurements	--	0,0100	Normal	1,074	0,0006
Resolution of spectrum analyzer	--	0,001497801	Rectangular	1,074	0,0009
Effect of spectrum analyzer	--	0,005773063	Normal	1,074	0,0062
Effect of directivity of directional coupler	--	0,100	Normal	1,074	0,1000
Measured Value	**1,07**	**Combined Uncertainty**			0,101
		Expanded Uncertainty (CL = 95.45%)			**0,202**

Model function : $VRC = \frac{Vmax + \delta Reproducibility + \delta Resolution + \delta spec.analyzer + \delta directivity}{Vmin + + \delta Reproducibility + \delta Resolution + \delta sp \quad .analyzer + \delta directivity}$

Frequency : 8 GHz

Output Level (CW) : 0 dBm

Definition of contribution	Expected Value x_i	Standard Uncertainty $u(x_i)$	Distribution Function	Sensitivity Coefficient c_i	Uncertainty contribution $u(y_i)$
Vmax measurements	19,68 mV	0,120 mV	Normal	0,0549	0,0066
Vmin measurements	18,21 mV	0,145 mV	Normal	-0,0593	-0,0086
Reproducibility of measurements	--	0,0100	Normal	1,081	0,0006
Resolution of spectrum analyzer	--	0,001497801	Rectangular	1,081	0,0009
Effect of spectrum analyzer	--	0,005773063	Normal	1,081	0,0062
Effect of directivity of directional coupler	--	0,100	Normal	1,081	0,1000
Measured Value	**1,08**	**Combined Uncertainty**			0,101
		Expanded Uncertainty (CL = 95.45%)			**0,202**

Model function : $VRC = \frac{Vmax+\delta Reproducibility+\delta Resolution+\delta spec.analyzer+\delta directivity}{Vmin++\delta Reproducibility+\delta Resolution+\delta spec.analyzer+\delta directivity}$

Frequency : 12 GHz

Output Level (CW) : 0 dBm

Definition of contribution	Expected Value x_i	Standard Uncertainty $u(x_i)$	Distribution Function	Sensitivity Coefficient c_i	Uncertainty contribution $u(y_i)$
Vmax measurements	17,00 mV	0,342 mV	Normal	0,0769	0,0263
Vmin measurements	13,00 mV	0,235 mV	Normal	-0,1006	-0,0236
Reproducibility of measurements	--	0,0100	Normal	1,308	0,0006
Resolution of spectrum analyzer	--	0,001497801	Rectangular	1,308	0,0009
Effect of spectrum analyzer	--	0,005773063	Normal	1,308	0,0075
Effect of directivity of directional coupler	--	0,100	Normal	1,308	0,1000
Measured Value	**1,31**	**Combined Uncertainty**			0,106
		Expanded Uncertainty (CL = 95.45%)			**0,213**

Model function : $VRC = \frac{Vmax+\delta Reproducibility+\delta Resolution+\delta sp\quad .analyzer+\delta directivity}{Vmin++\delta Reproducibility+\delta Resolution+\delta spe\quad .analyzer+\delta directivity}$

Frequency : 15 GHz

Output Level (CW) : 0 dBm

Definition of contribution	Expected Value x_i	Standard Uncertainty $u(x_i)$	Distribution Function	Sensitivity Coefficient c_i	Uncertainty contribution $u(y_i)$
Vmax measurements	18,31 mV	0,294 mV	Normal	0,0665	0,0196
Vmin measurements	15,03 mV	0,257 mV	Normal	-0,0811	-0,0208
Reproducibility of measurements	--	0,0100	Normal	1,219	0,0006
Resolution of spectrum analyzer	--	0,001497801	Rectangular	1,219	0,0009
Effect of spectrum analyzer	--	0,005773063	Normal	1,219	0,0070
Effect of directivity of directional coupler		0,100	Normal	1,219	0,1000
Measured Value	**1,22**	**Combined Uncertainty**			0,104
		Expanded Uncertainty (CL = 95.45%)			**0,218**

Model function : $VRC = \frac{Vmax+\delta Reproducibility+\delta Resolution+\delta spec.analyzer+\delta directivity}{Vmin++\delta Reproducibility+\delta Resolution+\delta spec.analyzer+\delta directivity}$

Frequency : 18 GHz

Output Level (CW) : 0 dBm

Definition of contribution	Expected Value x_i	Standard Uncertainty $u(x_i)$	Distribution Function	Sensitivity Coefficient c_i	Uncertainty contribution $u(y_i)$
Vmax measurements	14,87 mV	0,089 mV	Normal	0,0751	0,0067
Vmin measurements	13,31 mV	0,097 mV	Normal	-0,0840	-0,0082
Reproducibility of measurements	--	0,0100	Normal	1,117	0,0006
Resolution of spectrum analyzer	--	0,001497801	Rectangular	1,117	0,0009
Effect of spectrum analyzer	--	0,005773063	Normal	1,117	0,0065
Effect of directivity of directional coupler		0,100	Normal	1,117	0,1000
Measured Value	**1,12**	**Combined Uncertainty**			0,101
		Expanded Uncertainty (CL = 95.45%)			**0,202**

21. Annex II – Measurement report from METAS Switzerland

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Institute of Metrology METAS

Measurement Report

Object	**RF Signal Generator, Hewlett Packard, 83712A, SN: 3339A00223**
Order	Determination of the output voltage reflection coefficient.
Applicant	**EMPIR 15RPT01 RFMicrowave** C2.c Task 2.3 Characterisation of microwave signal generators output VRC
Traceability	The reported measurement values are traceable to national standards and thus to internationally supported realisations of the SI units.
Date of Measurement	03. to 17.01.2019

3003 Bern-Wabern, 1 February 2019

For the Measurements	Daniel Stalder
Approved by	Dr Markus Zeier, head of laboratory Laboratory RF and Microwave

METAS
Lindenweg 50, 3003 Bern-Wabern, Switzerland, phone +41 58 387 01 11, www.metas.ch

Extent of the Measurement

Parameter	Frequency	Power Level
Output Reflection Coefficient Γ	50 MHz, 2 GHz, 8 GHz, 12 GHz, 15 GHz, 18 GHz	1 mW (0 dBm)

Measurement Procedure

Summary

The output voltage reflection coefficient was measured using a passive reflectometer method. The different states of the switchable reflect standard were characterized using a calibrated network analyzer.

Measurement Report

Description

The source match measuring station is used for the calibration of the complex source match of RF generators with a nominal impedance of 50 Ω.
A direct measurement technique called reflectometer is used in which the output power signal of the generator under test is simultaneously the test signal. The benefit here is that the generator's output stage, which typically contains a control circuit to stabilise the level, is not influenced by an external test signal as it is the case with the active injection test method.
Figure 1 shows the source match measurement setup. Using a switchable reflect standard with different

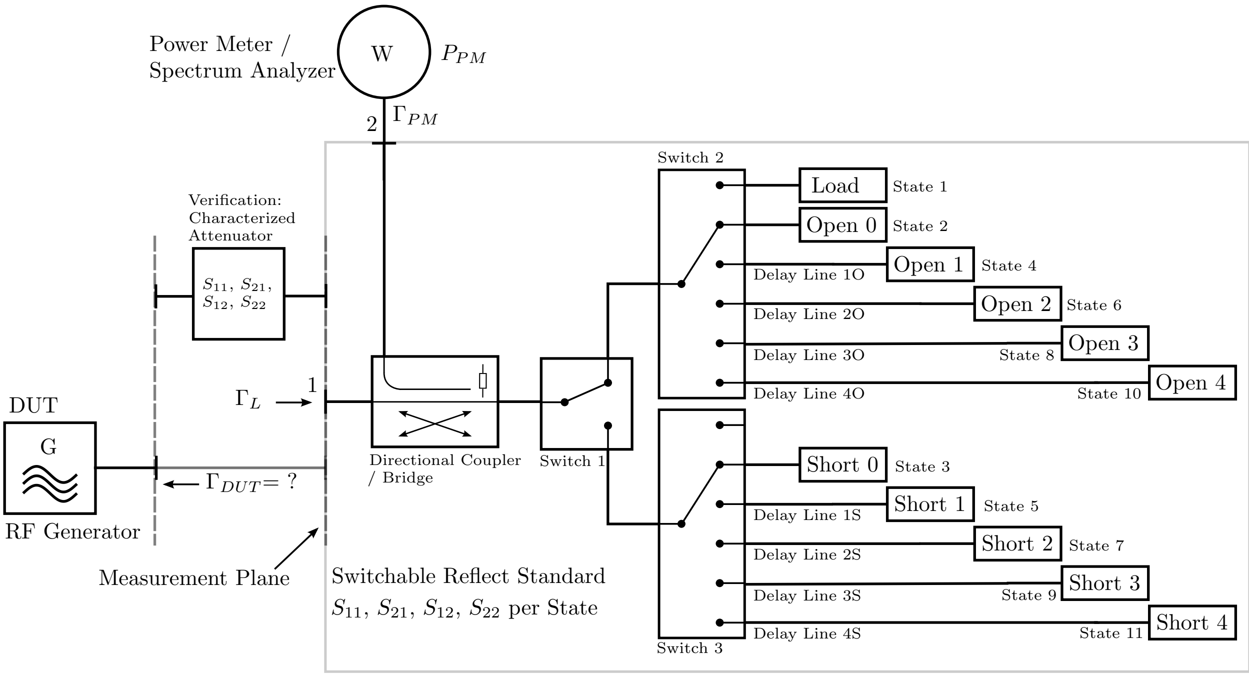


Figure 1: Source Match Measuring Setup

characterized states, the device under test is terminated into different known load impedances Γ_L while the resulting RF power P_{PM} is measured simultaneously at the directional coupler output. Based on the quantities that are known - measured power and the characterization data of the switchable reflect standard - the desired reflection coefficient Γ_{DUT} is determined.
Verification is done by inserting a characterized attenuator between the DUT and the switchable reflect standard. The de-embedded verification results must be consistent with the results.

Measurement Model

Consider the setup as 2-port with DUT-generator at port 1 and the power sensor at port 2 (see 2). The complexity of the coupler and the composition consisting of switches, delay lines and load/opens/shorts are included in this 2-port model. The 2-port model can be characterized by the s-parameter S_{11}, S_{21}, S_{12} and S_{22} (one set for each reflection state of the switchable reflect standard). This way the system can be easily characterized in the assembled state.

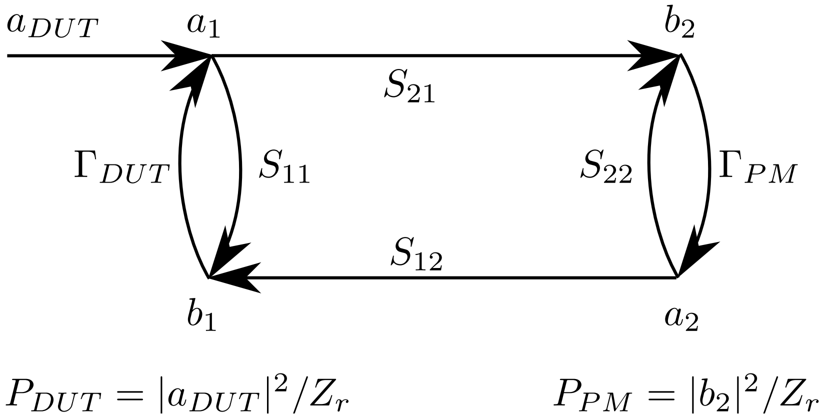


Figure 2: Measurement Model

The relation between the measured power at the power meter and the source match of the DUT is according to (1).

$$P_{PM} = P_{DUT} \cdot \left| \frac{S_{21}}{(1 - \Gamma_{DUT} \cdot S_{11}) \cdot (1 - \Gamma_{PM} \cdot S_{22}) - \Gamma_{DUT} \cdot \Gamma_{PM} \cdot S_{21} \cdot S_{12}} \right|^2 \quad (1)$$

P_{PM} in (W) is the measured incident power at the power meter / spectrum analyzer.
Γ_{PM} is the complex reflection coefficient of the power meter / spectrum analyzer.
Γ_{DUT} is the complex reflection coefficient of the DUT.
P_{DUT} in (W) is the output power of the DUT delivered to a perfect load.
S_{XX} are the complex s-parameters of the switchable reflect standard (1 is the input port connected to the DUT, 2 is the output port connected to the power meter).

Measurement and Analysis

Measurements of the power level P_{PM} are performed for each state of the switchable reflect standard. The measured data is analyzed with the program 'METAS Source Match Tools' to determine the source match of the generator Γ_{DUT} and the power level P_{DUT}. The program uses an over-determined non-linear regression algorithm to determine the unknown quantities. Known input quantities are the measured power levels P_{PM} and the characterization data of the switchable reflect standard (S_{11}, S_{21}, S_{12} and S_{22} per state) and power meter (Γ_{PM}).

Software used in the Measurement

- For the measurements the METAS internal software ‘Source Match Measurement Switched Mismatches‘ has been used.
- For the calculation of the results including uncertainties the METAS internal software ‘METAS Source Match Tools‘ has been used.
- For the analysis of the results the METAS software ‘METAS VNA Tools II‘ has been used.

Measurement Conditions

- Ambient temperature: $(23 \pm 1)\,^{\circ}\mathrm{C}$
- Relative humidity: $(45 \pm 10)\,\%$
- The devices were thermally balanced for at least 4 h (warm up)
- The result is the mean of ≥ 4 measurement series.

Standards used in the Measurement

- Switchable Reflect Standard, self made at METAS, SN: none, S-parameter traceable to reflection standards
- Signal Analyzer, Rohde & Schwarz, FSW67, SN: 103220, Linearity traceable to a calibrated step attenuator

Measurement Results

Connector Pin-Depth

- Used coupling torque: (1.36 ± 0.1) N·m

Device under test	**Pin-depth**
RF Signal Generator, Hewlett Packard, 83712A, SN: 3339A00223	(-53.3 ± 3.8) µm

The coaxial connectors were cleaned and inspected. The results of the pin-depth measurements comply with the manufacturer specifications.

Output Voltage Reflection Coefficient Γ

Frequency (MHz)	Γ **Zr: 50 Ω** **Mag**	Γ **Zr: 50 Ω** **U(Mag)**	Γ **Zr: 50 Ω** **Phase (°)**	Γ **Zr: 50 Ω** **U(Phase) (°)**
50	0.0418	0.0043	-55.4	5.7
2000	0.0386	0.0049	-35.7	7.3
8000	0.0367	0.0074	-87	13
12000	0.099	0.011	-81.8	8.1
15000	0.102	0.012	15.0	9.4
18000	0.055	0.013	175	16

The uncertainty budget is at the end of this report. We have used METAS UncLib for the calculation of the uncertainties. This way uncertainties are traced back to the primary realisation of SI traceability for the s-parameters. Listing of each individual uncertainty contribution would lead to a huge table, which would not be useful. In the listings below, the uncertainties are therefore grouped into main categories.

Uncertainty of Measurement

The reported uncertainty of measurement is stated as the combined standard uncertainty multiplied by a coverage factor $k = 2$. The measured value (y) and the associated expanded uncertainty (U) represent the interval ($y \pm U$) which contains the value of the measured quantity with a probability of approximately 95 %. The uncertainty was estimated following the guidelines of the ISO (GUM:1995).
The measurement uncertainty contains contributions originating from the measurement standard, from the calibration method, from the environmental conditions and from the object being calibrated. The longterm characteristic of the object being calibrated is not included.

Measurement Report

Uncertainty Budget	Magnitude	50 MHz
Value	0.04181	
Std Unc	0.00211	
U95	0.00422	
Description	Unc Component	Unc Percentage
VNA Calibration	0.00083	15.30
Cable Stability	0.00164	60.43
Connector Repeatability	0.00047	5.06
VNA Drift	0.00004	0.04
VNA Noise	0.00060	8.03
Type-A of P_PM	0.00041	3.80
VNA Linearity	0.00057	7.35

Uncertainty Budget	Phase	50 MHz
Value	-55.41	
Std Unc	2.83	
U95	5.66	
Description	Unc Component	Unc Percentage
VNA Calibration	1.13	15.89
Cable Stability	2.08	53.85
Connector Repeatability	0.65	5.28
VNA Drift	0.08	0.08
VNA Noise	0.82	8.43
Type-A of P_PM	0.57	4.03
VNA Linearity	1.00	12.44

Uncertainty Budget	Magnitude	2 GHz
Value	0.03855	
Std Unc	0.00243	
U95	0.00487	
Description	Unc Component	Unc Percentage
VNA Calibration	0.00113	21.50
Cable Stability	0.00203	69.81
Connector Repeatability	0.00047	3.66
VNA Drift	0.00006	0.05
VNA Noise	0.00005	0.04
Type-A of P_PM	0.00011	0.19
VNA Linearity	0.00053	4.74

Uncertainty Budget	Phase	2 GHz
Value	-35.71	
Std Unc	3.62	
U95	7.24	
Description	Unc Component	Unc Percentage
VNA Calibration	1.68	21.62
Cable Stability	3.00	68.74
Connector Repeatability	0.69	3.67
VNA Drift	0.13	0.12
VNA Noise	0.07	0.04
Type-A of P_PM	0.14	0.16
VNA Linearity	0.86	5.66

Uncertainty Budget	Magnitude	8 GHz
Value	0.03666	
Std Unc	0.00366	
U95	0.00731	
Description	Unc Component	Unc Percentage
VNA Calibration	0.00121	10.95
Cable Stability	0.00338	85.53
Connector Repeatability	0.00043	1.40
VNA Drift	0.00007	0.04
VNA Noise	0.00005	0.02
Type-A of P_PM	0.00015	0.16
VNA Linearity	0.00050	1.90

Uncertainty Budget	Phase	8 GHz
Value	-86.99	
Std Unc	6.22	
U95	12.44	
Description	Unc Component	Unc Percentage
VNA Calibration	1.91	9.42
Cable Stability	5.61	81.33
Connector Repeatability	0.67	1.18
VNA Drift	0.11	0.03
VNA Noise	0.11	0.03
Type-A of P_PM	0.36	0.32
VNA Linearity	1.72	7.68

Measurement Report

Uncertainty Budget	Magnitude	12 GHz
Value	0.09939	
Std Unc	0.00514	
U95	0.01027	
Description	Unc Component	Unc Percentage
VNA Calibration	0.00125	5.90
Cable Stability	0.00484	88.66
Connector Repeatability	0.00072	1.98
VNA Drift	0.00009	0.03
VNA Noise	0.00006	0.02
Type-A of P_PM	0.00024	0.24
VNA Linearity	0.00092	3.19

Uncertainty Budget	Phase	12 GHz
Value	-81.75	
Std Unc	4.02	
U95	8.03	
Description	Unc Component	Unc Percentage
VNA Calibration	0.72	3.23
Cable Stability	3.91	94.78
Connector Repeatability	0.41	1.07
VNA Drift	0.04	0.01
VNA Noise	0.03	0.01
Type-A of P_PM	0.10	0.06
VNA Linearity	0.37	0.85

Uncertainty Budget	Magnitude	15 GHz
Value	0.10236	
Std Unc	0.00589	
U95	0.01177	
Description	Unc Component	Unc Percentage
VNA Calibration	0.00152	6.70
Cable Stability	0.00554	88.60
Connector Repeatability	0.00075	1.62
VNA Drift	0.00014	0.06
VNA Noise	0.00007	0.01
Type-A of P_PM	0.00040	0.47
VNA Linearity	0.00094	2.54

Uncertainty Budget	Phase	15 GHz
Value	15.01	
Std Unc	4.69	
U95	9.37	
Description	Unc Component	Unc Percentage
VNA Calibration	0.82	3.06
Cable Stability	4.57	95.25
Connector Repeatability	0.42	0.80
VNA Drift	0.03	0.01
VNA Noise	0.03	0.00
Type-A of P_PM	0.14	0.09
VNA Linearity	0.42	0.80

Uncertainty Budget	Magnitude	18 GHz
Value	0.05502	
Std Unc	0.00619	
U95	0.01239	
Description	Unc Component	Unc Percentage
VNA Calibration	0.00187	9.13
Cable Stability	0.00580	87.62
Connector Repeatability	0.00071	1.32
VNA Drift	0.00008	0.02
VNA Noise	0.00009	0.02
Type-A of P_PM	0.00028	0.22
VNA Linearity	0.00081	1.69

Uncertainty Budget	Phase	18 GHz
Value	175.32	
Std Unc	7.58	
U95	15.17	
Description	Unc Component	Unc Percentage
VNA Calibration	1.90	6.30
Cable Stability	7.23	90.75
Connector Repeatability	0.74	0.95
VNA Drift	0.13	0.03
VNA Noise	0.09	0.02
Type-A of P_PM	0.31	0.16
VNA Linearity	1.01	1.78

22. Annex III – Measurement report from GUM Poland

1. PARTICIPANT INFORMATION

Laboratory name:	Główny Urząd Miar
Name of contact person:	Łukasz Usydus
Telephone numer:	+48 22 5819503
Fax:	-
E-mail:	lukasz.usydus@gum.gov.pl
Address:	Elektoralna 2, 00-139 Warszawa, Poland

2. MEASUREMENT DATE: 22.05.2018

3. ENVIRONMENTAL CONDITIONS:

Temperature : (23 ± 1) ^{o}C

Relative Humidity : (44 ± 2) %

4. STANDARDS USED IN MEASUREMENTS

Instrument Name	Manufacturer	Type / Model	Serial Number	Traceability
Directional coupler	Hewlett-Packard	11692D	1212A04401	NPL/GUM
Power sensor	Hewlett-Packard	8481D	3318A07727	GUM
Power meter	Hewlett-Packard	438A	3017U01578	GUM
Vector Network Analyzer	Agilent	E8364B	MY43030326	Keysight / Various NMIs
Calibration Kit	Agilent	85054B	MY39200148	NPL

5. DESCRIPTION OF MEASUREMENT METHOD

The measurements have been made using directional coupler with the DUT connected to the „Input" port and a sliding short connected to the „Test" port. The DUT's VRC magnitude was derived from the maximum and minimum values indicated by the power meter (with the Power sensor connected to the „Incident" port of the coupler). The sliding short used for these measurements is a USSR-made type HK3-1 element, of not the best quality, which reflection coeffcient magnitude is usually less than 1. Due to his fact the short's VRC at the certain positions (where readings on the power meter were either min or max) were measured using VNA calibrated with the cal kit listed in the table above. Thus, the actual reflection coefficient of the sliding short and its uncertainties were taken into account in the DUT's VRC calculations and the final uncertainty budget.

6. MEASUREMENT RESULTS

Frequency	Voltage Reflection coefficient of Travelling Standard @ 1 mW (0 dBm)	
	VRC magnitude	Uncertainty (CL = 95.45%)
2 GHz	0.0290	0.0069
8 GHz	0.0398	0.0148
12 GHz	0.1164	0.0134
15 GHz	0.1015	0.0192
18 GHz	0.0426	0.0233

7. UNCERTAINTY BUDGET

Model function : ISO-GUM

Frequency : 2 GHz

Output level (CW) : ca. 1 mW (0 dBm)

Definition of contribution	**Expected Value x_i**	**Standard Uncertainty $u(x_i)$**	**Distribution Funtcion**	**Sensitivity coefficient c_i**	**Uncertainty contribution $u(y_i)$**
Power ratio measurement	1.0550	0.0023	rectangular	0.5123	0.0012
Coupler's $\lvert S_{21} \rvert$	0.9632	0.0023	normal	-0.5471	0.0013
Coupler's $\lvert S_{12} \rvert$	0.9633	0.0023	normal	-0.5470	0.0013
Sliding short's $\lvert \Gamma \rvert$ at max. power reading	0.9985	0.0073	normal	-0.2576	0.0019
Sliding short's $\lvert \Gamma \rvert$ at min. power reading	0.9922	0.0073	normal	-0.2718	0.0020
Measured value	0.0290	**Combined Uncertainty**			0.0035
		Expanded Uncertainty (CL = 95.45%)			0.0069

Model function : ISO-GUM

Frequency : 8 GHz

Output level (CW) : ca. 1 mW (0 dBm)

Definition of contribution	**Expected Value x_i**	**Standard Uncertainty $u(x_i)$**	**Distribution Funtcion**	**Sensitivity coefficient c_i**	**Uncertainty contribution $u(y_i)$**
Power ratio measurement	1.0696	0.0112	rectangular	0.5529	0.0062
Coupler's $\lvert S_{21} \rvert$	0.9231	0.0035	normal	-0.6199	0.0022
Coupler's $\lvert S_{12} \rvert$	0.9232	0.0035	normal	-0.6198	0.0022
Sliding short's $\lvert \Gamma \rvert$ at max. power reading	0.9888	0.0064	normal	-0.2790	0.0018
Sliding short's $\lvert \Gamma \rvert$ at min. power reading	0.9928	0.0064	normal	-0.2985	0.0019

Measured value	0.0398	Combined Uncertainty	0.0074
		Expanded Uncertainty (CL = 95.45%)	0.0148

Model function : ISO-GUM

Frequency : 12 GHz

Output level (CW) : ca. 1 mW (0 dBm)

Definition of contribution	Expected Value x_i	Standard Uncertainty $u(x_i)$	Distribution Funtcion	Sensitivity coefficient c_i	Uncertainty contribution $u(y_i)$
Power ratio measurement	1.2092	0.0051	rectangular	0.5037	0.0026
Coupler's $\|S_{21}\|$	0.9067	0.0060	normal	-0.6135	0.0037
Coupler's $\|S_{12}\|$	0.9063	0.0060	normal	-0.6138	0.0037
Sliding short's $\|\Gamma\|$ at max. power reading	0.9923	0.0084	normal	-0.2543	0.0021
Sliding short's $\|\Gamma\|$ at min. power reading	0.9884	0.0084	normal	-0.3075	0.0026
Measured value	0.1164	**Combined Uncertainty**			0.0067
		Expanded Uncertainty (CL = 95.45%)			0.0134

Model function : ISO-GUM

Frequency : 15 GHz

Output level (CW) : ca. 1 mW (0 dBm)

Definition of contribution	Expected Value x_i	Standard Uncertainty $u(x_i)$	Distribution Funtcion	Sensitivity coefficient c_i	Uncertainty contribution $u(y_i)$
Power ratio measurement	1.1674	0.0117	rectangular	0.5594	0.0066
Coupler's $\|S_{21}\|$	0.8749	0.0062	normal	-0.6930	0.0043
Coupler's $\|S_{12}\|$	0.8755	0.0061	normal	-0.6926	0.0042
Sliding short's $\|\Gamma\|$ at max. power reading	0.9912	0.0084	normal	-0.2816	0.0024
Sliding short's $\|\Gamma\|$ at min.	0.9951	0.0085	normal	-0.3288	0.0028

power reading					
Measured value	0.1015	**Combined Uncertainty**			0.0096
		Expanded Uncertainty (CL = 95.45%)			0.0192

Model function : ISO-GUM

Frequency : 18 GHz

Output level (CW) : ca. 1 mW (0 dBm)

Definition of contribution	**Expected Value x_i**	**Standard Uncertainty $u(x_i)$**	**Distribution Funtcion**	**Sensitivity coefficient c_i**	**Uncertainty contribution $u(y_i)$**
Power ratio measurement	1.0679	0.0154	rectangular	0.6065	0.0093
Coupler's $\|S_{21}\|$	0.8817	0.0059	normal	-0.7112	0.0042
Coupler's $\|S_{12}\|$	0.8817	0.0059	normal	-0.7112	0.0042
Sliding short's $\|\Gamma\|$ at max. power reading	0.9918	0.0084	normal	-0.3057	0.0026
Sliding short's $\|\Gamma\|$ at min. power reading	0.9922	0.0084	normal	-0.3264	0.0028
Measured value	0.0426	**Combined Uncertainty**			0.0117
		Expanded Uncertainty (CL = 95.45%)			0.0233

23. Annex IV – Calibration certificates from INTA Spain

CERTIFICADO DE CALIBRACIÓN
Certificate of Calibration

Número **42962**
Number

Página 1 de 4 páginas
Page ___ of ___ pages

Ministerio de Defensa. Secretaría de Estado de la Defensa.
INSTITUTO NACIONAL DE TÉCNICA AEROESPACIAL
Centro de Metrología y Calibración – Campus Torrejón
Carretera de Ajalvir, p.k. 4,5
28850 Torrejón de Ardoz (Madrid) – ESPAÑA
Teléfono: (+34) 915 201 859

OBJETO *Item*	**Generador de señal sintetizado (conector Tipo N hembra)** ***Synthesized CW Generator***
MARCA *Mark*	**Hewlett Packard**
MODELO *Model*	**83712A**
IDENTIFICACIÓN *Identification*	**3339A00223**
SOLICITANTE *Applicant*	**INTA - Centro de Metrología y Calibración** **Laboratorio de Radiofrecuencia y Microondas** **Ctra. Torrejón a Ajalvir, p.k. 4,5** **28850 Torrejón de Ardoz, Madrid** **(Spain)**
FECHA/S DE CALIBRACIÓN *Date/s of Calibration*	**28 de febrero al 7 de marzo de 2017**

Signatario/s autorizado/s
Authorised Signatory/ies

Fecha de Emisión
Date of issue
8 de marzo de 2017

Manuel Rodríguez Higuero
Jefe del Laboratorio de RF y Microondas

Ref: **OT-RF2017-0610**

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The measurements are traceable to recognised "National Metrology Institutes", via calibration or intercomparison exercises. This certificate may not be partially reproduced, except with the prior written permission of the issuing laboratory.

CALIBRATION:

Before any measurement was made, the Unit Under Test was connected to the mains (220 V @ 50 Hz) and kept in Stand-By state at room temperature within the Laboratory for at least 24 hours. Ambient temperature during measurement was 23°C ± 1°C and relative humidity less than 70%.

Mesurement System: the measurement configuration used makes use of the following equipment:

- Directional Coupler, Amplifier Research model DC3002A, serial number 305138
- Directional Coupler, Narda model 3292-2, serial number 03162
- Short Circuit, model INMET 7002, s/n 64671
- Power Meter, Hewlett Packard model 436A, serial number 3103U07436
- Power Sensor, Agilent 8481D, serial number MY51310006
- 30 cm Air Line, Wiltron model SC4934-30, serial number 400001
- 3 m cable, Utiflex serial number FA210B0030007071

Measurement procedure: RF/MPR/7231/302/INTA "Medida del Coeficiente de Reflexión (Source Match) de una Fuente de Radiofrecuencia". The procedure is based on the ripple technique making use of a calibrated airline. FFT is subsequently used in order to filter out the obtained ripple signal, splitting it into two 'processed' ripples.

For measurement at 50 MHz a modification of the measurement procedure is applied which makes use of a long cable in order to induce the ripple signal at the required 'rate of variation' for determination of VRC at low frequencies. No filtering is applied in this case.

UUT configuration: Measurement of Source Match was made for the following setup:

- Nominal Output Level: +0 dBm
- Output mode: CW signal

Measurement results are contained in Table 1 as measured Source Match (VRC) and its associated uncertainty. All working standards and instrumentation used in the calibration are traceable to the National Physical Laboratory (NPL) of the United Kingdom and to the Eidgenössische Institut für Metrologie (METAS) of Switzerland.

The measured values correspond to the moment and ambient conditions under which they were taken. No consideration is made about the stability of the UUT and / or the measurement system.

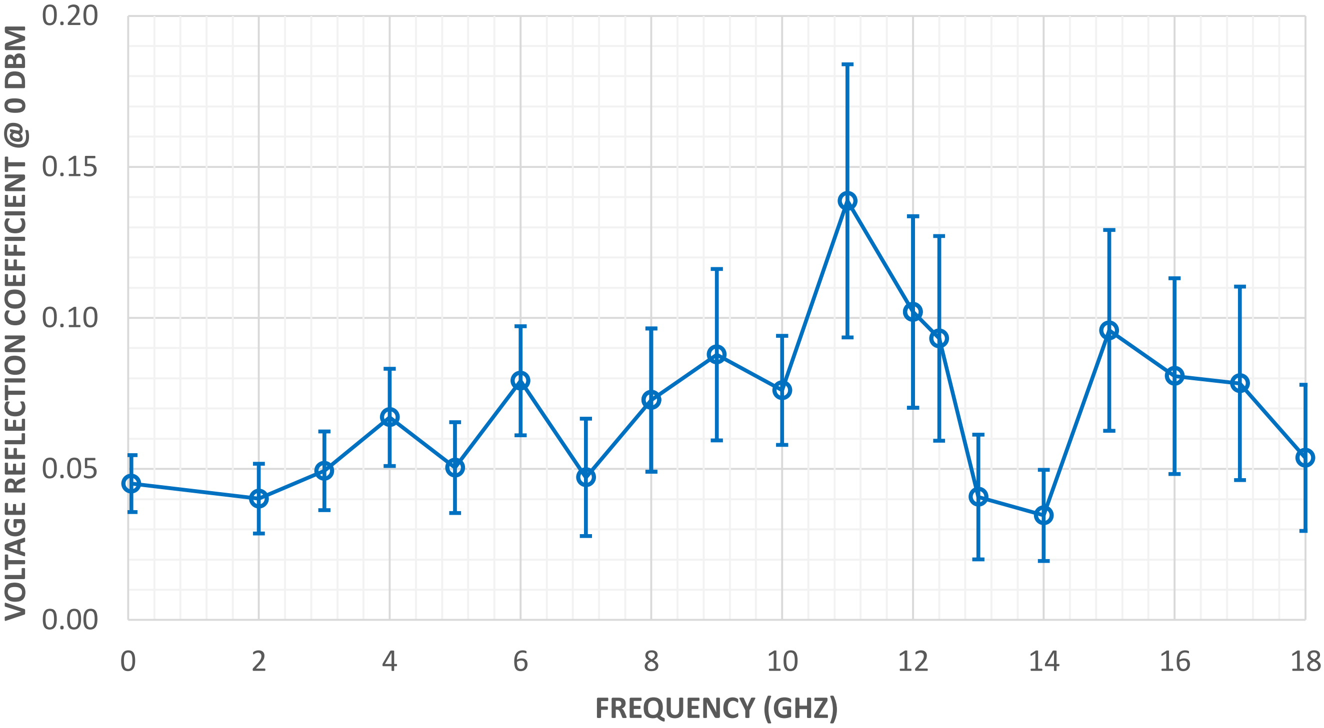
The expanded uncertainty has been obtained by multiplying the standard uncertainty by a coverage factor k such that the probability of coverage or confidence level is 95.45% (*k* = 2 in all cases, unless otherwise stated in the table). The standard measurement uncertainty has been determined in accordance with document EA-4/02 M: 2013, 'Assessment of measurement uncertainty in calibrations'.

Tabla 1

Frequency (GHz)	Source Match (VRC)	Coverage factor *k*	Uncertainty (±)
0.05	**0.045**	**2.00**	**0.009**
2	**0.040**	**2.10**	**0.012**
3	0.049	2.13	0.013
4	0.067	2.11	0.016
5	0.050	2.21	0.015
6	0.079	2.09	0.018
7	0.047	2.32	0.019
8	**0.073**	**2.21**	**0.024**
9	0.088	2.05	0.028
10	0.076	2.07	0.018
11	0.139	2.00	0.045
12	**0.102**	**2.03**	**0.032**
12.4	0.093	2.02	0.034
13	0.041	2.28	0.021
14	0.035	2.10	0.015
15	**0.096**	**2.01**	**0.033**
16	0.081	2.10	0.032
17	0.078	2.18	0.032
18	**0.054**	**2.16**	**0.024**

Finally a graphical representation of the parameter under test is included. It is intended for information purposes only and it is not part of the content of this certificate as regards measured values and their associated uncertainty (the values contained in the tables always prevail).

ANNEX – GRAPHICAL REPRESENTATION OF SOURCE MATCH



Frec (GHz)	IL línea	u IL línea	IL acopl	u IL acopl	Γ corto	u Γ corto	Γ g corr	k	u Γg	SWR corr	Γ g	D (dB)	u D	D eff	TPM	u TPM	TPm eff	Γ line	u Γ line	Γ line eff
0.05							0.045	2.00	0.009											
2	0.077	0.010	0.317	0.031	0.994	0.004	0.040	2.10	0.012	1.08	0.040	33.4	0.013	0.025	0.035	0.017	0.038	0.001	0.003	0.003
3	0.095	0.016	0.375	0.031	0.994	0.004	0.049	2.13	0.013	1.10	0.049	33.5	0.013	0.025	0.022	0.017	0.028	0.002	0.003	0.003
4	0.111	0.017	0.340	0.031	0.993	0.004	0.067	2.11	0.016	1.14	0.067	35.4	0.012	0.021	0.026	0.017	0.031	0.003	0.003	0.004
5	0.125	0.016	0.327	0.031	0.993	0.004	0.050	2.21	0.015	1.11	0.050	34.1	0.013	0.023	0.016	0.017	0.023	0.003	0.003	0.004
6	0.138	0.017	0.401	0.031	0.993	0.004	0.079	2.09	0.018	1.17	0.079	40.7	0.017	0.020	0.019	0.017	0.026	0.005	0.003	0.006
7	0.150	0.027	0.449	0.031	0.993	0.004	0.047	2.32	0.019	1.10	0.047	29.7	0.020	0.038	0.032	0.017	0.036	0.005	0.003	0.005
8	0.161	0.032	0.420	0.031	0.993	0.004	0.073	2.21	0.024	1.16	0.073	29.4	0.021	0.040	0.029	0.017	0.033	0.004	0.003	0.005
8	0.161	0.032	0.420	0.031	0.993	0.004	0.073	2.21	0.024	1.16	0.073	29.4	0.021	0.040	0.029	0.017	0.033	0.004	0.003	0.005
9	0.172	0.036	0.406	0.045	0.993	0.004	0.088	2.05	0.028	1.19	0.088	27.0	0.027	0.052	0.068	0.020	0.071	0.003	0.003	0.004
10	0.181	0.036	0.426	0.040	0.993	0.004	0.076	2.07	0.018	1.16	0.076	37.0	0.036	0.039	0.013	0.020	0.024	0.003	0.003	0.004
11	0.188	0.027	0.494	0.040	0.993	0.005	0.139	2.00	0.045	1.32	0.139	23.7	0.047	0.081	0.033	0.020	0.039	0.001	0.003	0.003
12	0.199	0.033	0.499	0.042	0.992	0.004	0.102	2.03	0.032	1.23	0.102	30.1	0.056	0.064	0.053	0.020	0.057	0.003	0.003	0.004
12	0.199	0.033	0.499	0.042	0.992	0.004	0.102	2.03	0.032	1.23	0.102	30.1	0.056	0.064	0.053	0.020	0.057	0.003	0.003	0.004
12.4	*0.203*	*0.054*	*0.473*	*0.067*	0.992	0.004	0.093	2.02	0.034	1.21	0.093	*25.2*	*0.083*	0.099	*0.048*	*0.035*	0.059	*0.004*	*0.004*	0.005
13	0.208	0.042	0.442	0.054	0.993	0.004	0.041	2.28	0.021	1.08	0.041	30.0	0.064	0.072	0.053	0.030	0.060	0.006	0.003	0.006
14	0.216	0.042	0.458	0.062	0.992	0.004	0.035	2.10	0.015	1.07	0.035	27.2	0.056	0.071	0.088	0.030	0.093	0.009	0.003	0.010
15	0.224	0.054	0.523	0.053	0.992	0.004	0.096	2.01	0.033	1.21	0.096	23.4	0.055	0.087	0.054	0.029	0.062	0.011	0.003	0.011
16	0.231	0.049	0.581	0.050	0.992	0.004	0.081	2.10	0.032	1.18	0.081	24.1	0.062	0.088	0.044	0.029	0.053	0.011	0.003	0.011
17	0.238	0.042	0.575	0.049	0.991	0.004	0.078	2.18	0.032	1.17	0.078	31.6	0.071	0.076	0.023	0.029	0.037	0.012	0.003	0.012
18	0.245	0.033	0.545	0.057	0.993	0.004	0.054	2.16	0.024	1.11	0.054	25.2	0.063	0.084	0.058	0.029	0.065	0.014	0.004	0.015

Nº medidas
5

E max (+)	E max (-)	Γ g max	E min (+)	E min (-)	Γ g min	u vect (U_1)	u alg (U_2)	U_3	k_3	Gr. Libertad	k95.45-k_3	U_4	U_5	σ	U_6	u comb	k	u exp Γg
1.08499	1.00343	0.045	0.99677	0.93091	0.036	0.004	**0.005**	**0.004**	**2.029**	**88**	0.0001	0.0001	0.0000	**0.008**	0.003	0.005	2.10	**0.012**
1.10227	1.00399	0.055	0.99611	0.91637	0.044	0.005	**0.005**	**0.004**	**2.033**	**77**	0.0001	0.0002	0.0001	**0.009**	0.004	0.006	2.13	**0.013**
1.14168	1.00512	0.076	0.99484	0.88778	0.059	0.008	**0.005**	**0.004**	**2.037**	**69**	-0.0001	0.0002	0.0001	**0.011**	0.005	0.008	2.11	**0.016**
1.10535	1.00498	0.056	0.99508	0.91315	0.045	0.005	**0.005**	**0.004**	**2.025**	**101**	0.0000	0.0002	0.0001	**0.011**	0.005	0.007	2.21	**0.015**
1.16648	1.00737	0.090	0.99236	0.86938	0.070	0.010	**0.005**	**0.004**	**2.033**	**76**	0.0003	0.0003	0.0002	**0.012**	0.005	0.009	2.09	**0.018**
1.10009	1.00646	0.054	0.99404	0.92173	0.041	0.006	**0.005**	**0.004**	**2.039**	**65**	0.0001	0.0002	0.0001	**0.015**	0.007	0.008	2.32	**0.019**
1.15539	1.00684	0.085	0.99338	0.88344	0.063	0.011	**0.005**	**0.004**	**2.053**	**48**	0.0001	0.0003	0.0003	**0.018**	0.008	0.011	2.21	**0.024**
1.15539	1.00684	0.085	0.99338	0.88344	0.063	0.011	**0.005**	**0.004**	**2.053**	**48**	0.0001	0.0003	0.0003	**0.018**	0.008	0.011	2.21	**0.024**
1.20085	1.00731	0.111	0.99342	0.86756	0.072	0.019	**0.005**	**0.004**	**2.101**	**26**	0.0001	0.0005	0.0004	**0.016**	0.007	0.014	2.05	**0.028**
1.15881	1.00626	0.088	0.99376	0.87857	0.066	0.011	**0.005**	**0.004**	**2.122**	**22**	-0.0022	0.0004	0.0003	**0.011**	0.005	0.009	2.07	**0.018**
1.32216	1.00780	0.184	0.99234	0.80448	0.110	0.037	**0.005**	**0.005**	**2.129**	**21**	-0.0030	0.0006	0.0004	**0.014**	0.006	0.023	2.00	**0.045**
1.22850	1.00762	0.130	0.99298	0.85196	0.083	0.023	**0.005**	**0.004**	**2.076**	**34**	0.0005	0.0005	0.0004	**0.016**	0.007	0.016	2.03	**0.032**
1.22850	1.00762	0.130	0.99298	0.85196	0.083	0.023	**0.005**	**0.004**	**2.076**	**34**	0.0005	0.0005	0.0004	**0.016**	0.007	0.016	2.03	**0.032**
1.22194	1.00931	0.124	0.99223	0.86635	0.074	0.025	**0.005**	**0.004**	**2.147**	**18**	0.0016	0.0007	0.0006	**0.016**	0.007	0.017	2.02	**0.034**
1.09321	1.00804	0.049	0.99351	0.93469	0.034	0.008	**0.005**	**0.004**	**2.135**	**20**	-0.0015	0.0003	0.0002	**0.016**	0.007	0.009	2.28	**0.021**
1.08698	1.01200	0.044	0.99107	0.94270	0.028	0.008	**0.005**	**0.004**	**2.100**	**26**	0.0009	0.0002	0.0002	**0.010**	0.004	0.007	2.10	**0.015**
1.23036	1.01529	0.128	0.98707	0.85998	0.075	0.026	**0.005**	**0.004**	**2.112**	**23**	0.0024	0.0006	0.0006	**0.013**	0.006	0.017	2.01	**0.033**
1.18804	1.01453	0.105	0.98787	0.88052	0.065	0.020	**0.005**	**0.004**	**2.106**	**25**	-0.0013	0.0005	0.0005	**0.022**	0.010	0.015	2.10	**0.032**
1.17724	1.01517	0.098	0.98669	0.88029	0.064	0.017	**0.005**	**0.004**	**2.090**	**29**	0.0005	0.0004	0.0004	**0.023**	0.010	0.015	2.18	**0.032**
1.13253	1.01781	0.069	0.98610	0.91382	0.043	0.013	**0.005**	**0.004**	**2.098**	**27**	-0.0012	0.0004	0.0002	**0.017**	0.008	0.011	2.16	**0.024**

CERTIFICADO DE CALIBRACIÓN
Certificate of Calibration

Número **43308**
Number

Ministerio de Defensa. Secretaría de Estado de la Defensa.
INSTITUTO NACIONAL DE TÉCNICA AEROESPACIAL
Centro de Metrología y Calibración – Campus Torrejón
Carretera de Ajalvir, p.k. 4,5
28850 Torrejón de Ardoz (Madrid) – ESPAÑA
Teléfono: (+34) 915 201 859

OBJETO *Item*	**Generador de señal sintetizado (conector Tipo N hembra)** ***Synthesized CW Generator***
MARCA *Mark*	**Hewlett Packard**
MODELO *Model*	**83712A**
IDENTIFICACIÓN *Identification*	**3339A00223**
SOLICITANTE *Applicant*	**INTA - Centro de Metrología y Calibración** **Laboratorio de Radiofrecuencia y Microondas** **Ctra. Torrejón a Ajalvir, p.k. 4,5** **28850 Torrejón de Ardoz, Madrid** **(Spain)**
FECHA/S DE CALIBRACIÓN *Date/s of Calibration*	**19 y 20 de abril de 2017**

Signatario/s autorizado/s
Authorised Signatory/ies

Fecha de Emisión
Date of issue
20 de abril de 2017

Manuel Rodríguez Higuero
Jefe del Laboratorio de RF y Microondas

Ref: **OT-RF2017-1009**

CALIBRATION:

Before any measurement was made, the Unit Under Test was connected to the mains (220 V @ 50 Hz) and kept in Stand-By state at room temperature within the Laboratory for at least 24 hours. Ambient temperature during measurement was 23°C ± 1°C and relative humidity less than 70%.

Mesurement System: the measurement configuration used makes use of the following equipment:

- Directional Coupler, Amplifier Research model DC3002A, serial number 305138
- Directional Coupler, Narda model 3292-2, serial number 03162
- Short Circuit, model INMET 7002, s/n 64671
- Power Meter, Hewlett Packard model 436A, serial number 3103U07436
- Power Sensor, Agilent 8481D, serial number MY51310006
- 30 cm Air Line, Wiltron model SC4934-30, serial number 400001
- 3 m cable, Utiflex serial number FA210B0030007071

Measurement procedure: RF/MPR/7231/302/INTA “Medida del Coeficiente de Reflexión (Source Match) de una Fuente de Radiofrecuencia”. The procedure is based on the ripple technique making use of a calibrated airline. FFT is subsequently used in order to filter out the obtained ripple signal, splitting it into two ‘processed’ ripples.

For measurement at 50 MHz a modification of the measurement procedure is applied which makes use of a long cable in order to induce the ripple signal at the required ‘rate of variation’ for determination of VRC at low frequencies. No filtering is applied in this case.

UUT configuration: Measurement of Source Match was made for the following setup:

- Nominal Output Level: +0 dBm
- Output mode: CW signal

Measurement results are contained in Table 1 as measured Source Match (VRC) and its associated uncertainty. All working standards and instrumentation used in the calibration are traceable to the National Physical Laboratory (NPL) of the United Kingdom and to the Eidgenössische Institut für Metrologie (METAS) of Switzerland.

The measured values correspond to the moment and ambient conditions under which they were taken. No consideration is made about the stability of the UUT and / or the measurement system.

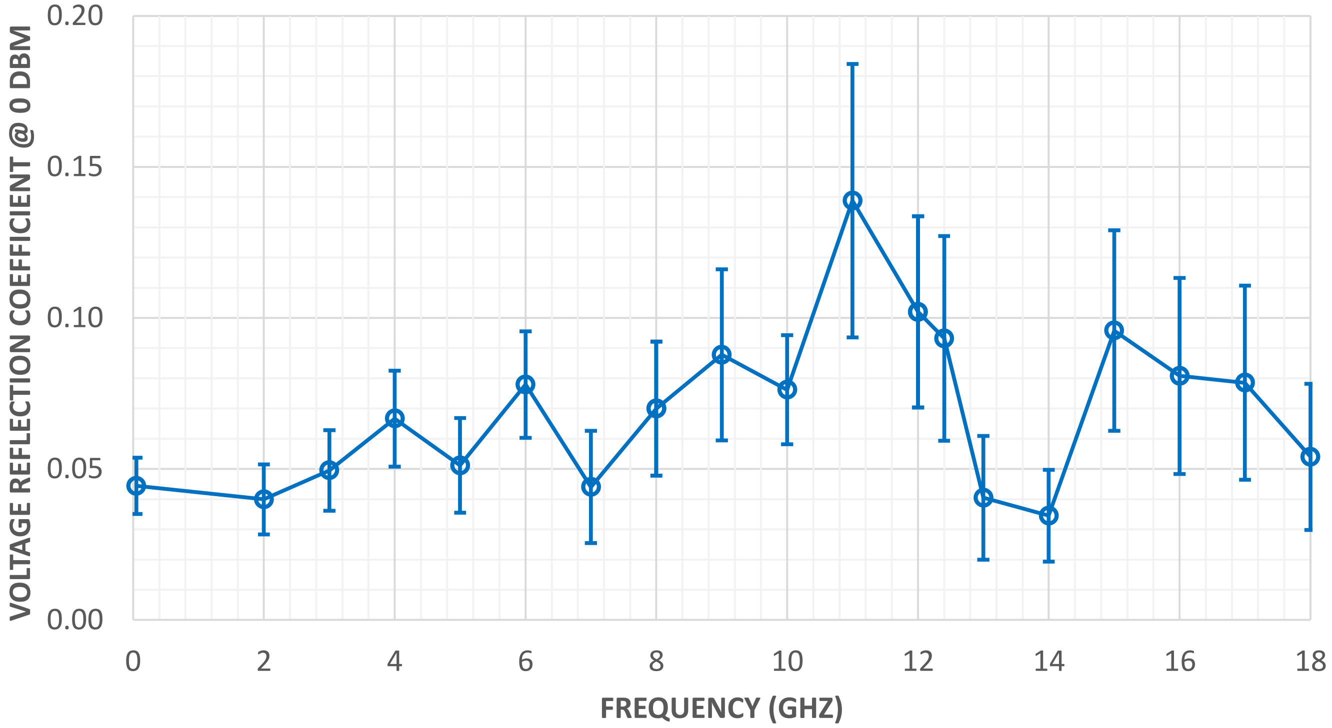
The expanded uncertainty has been obtained by multiplying the standard uncertainty by a coverage factor k such that the probability of coverage or confidence level is 95.45% (k = 2 in all cases, unless otherwise stated in the table). The standard measurement uncertainty has been determined in accordance with document EA-4/02 M: 2013, ‘Assessment of measurement uncertainty in calibrations’.

Table 1

Frequency (GHz)	Source Match (VRC)	Coverage factor *k*	Uncertainty (±)
0.05	**0.044**	**2.00**	**0.009**
2	**0.040**	**2.11**	**0.012**
3	0.050	2.14	0.013
4	0.067	2.11	0.016
5	0.051	2.23	0.016
6	0.078	2.09	0.018
7	0.044	2.32	0.019
8	**0.070**	**2.20**	**0.022**
9	0.088	2.05	0.028
10	0.076	2.07	0.018
11	0.139	2.00	0.045
12	**0.102**	**2.02**	**0.032**
12.4	0.093	2.02	0.034
13	0.040	2.28	0.021
14	0.035	2.10	0.015
15	**0.096**	**2.01**	**0.033**
16	0.081	2.10	0.032
17	0.079	2.18	0.032
18	**0.054**	**2.15**	**0.024**

Finally a graphical representation of the parameter under test is included. It is intended for information purposes only and it is not part of the content of this certificate as regards measured values and their associated uncertainty (the values contained in the tables always prevail).

ANNEX – GRAPHICAL REPRESENTATION OF SOURCE MATCH



Cliente: Laboratorio de RF y Microondas

Modelo: HP 83712A
Nº de serie: 3339A00223

20/04/2017

Frec (GHz)	IL línea	u IL línea	IL acopl	u IL acopl	Γ corto	u Γ corto	Γ g corr	k	u Γg	SWR corr	Γ g	D (dB)	u D	D eff	TPM	u TPM	TPm eff	Γ line	u Γ line	Γ line eff
0.05							0.044	2.00	0.009											
2	0.077	0.010	0.317	0.031	0.994	0.004	0.040	2.11	0.012	1.08	0.040	33.4	0.013	0.025	0.035	0.017	0.038	0.001	0.003	0.003
3	0.095	0.016	0.375	0.031	0.994	0.004	0.050	2.14	0.013	1.10	0.050	33.5	0.013	0.025	0.022	0.017	0.028	0.002	0.003	0.003
4	0.111	0.017	0.340	0.031	0.993	0.004	0.067	2.11	0.016	1.14	0.067	35.4	0.012	0.021	0.026	0.017	0.031	0.003	0.003	0.004
5	0.125	0.016	0.327	0.031	0.993	0.004	0.051	2.23	0.016	1.11	0.051	34.1	0.013	0.023	0.016	0.017	0.023	0.003	0.003	0.004
6	0.138	0.017	0.401	0.031	0.993	0.004	0.078	2.09	0.018	1.17	0.078	40.7	0.017	0.020	0.019	0.017	0.026	0.005	0.003	0.006
7	0.150	0.027	0.449	0.031	0.993	0.004	0.044	2.32	0.019	1.09	0.044	29.7	0.020	0.038	0.032	0.017	0.036	0.005	0.003	0.005
8	0.161	0.032	0.420	0.031	0.993	0.004	0.070	2.20	0.022	1.15	0.070	29.4	0.021	0.040	0.029	0.017	0.033	0.004	0.003	0.005
8	0.161	0.032	0.420	0.031	0.993	0.004	0.070	2.20	0.022	1.15	0.070	29.4	0.021	0.040	0.029	0.017	0.033	0.004	0.003	0.005
9	0.172	0.036	0.406	0.045	0.993	0.004	0.088	2.05	0.028	1.19	0.088	27.0	0.027	0.052	0.068	0.020	0.071	0.003	0.003	0.004
10	0.181	0.036	0.426	0.040	0.993	0.004	0.076	2.07	0.018	1.17	0.076	37.0	0.036	0.039	0.013	0.020	0.024	0.003	0.003	0.004
11	0.188	0.027	0.494	0.040	0.993	0.005	0.139	2.00	0.045	1.32	0.139	23.7	0.047	0.081	0.033	0.020	0.039	0.001	0.003	0.003
12	0.199	0.033	0.499	0.042	0.992	0.004	0.102	2.02	0.032	1.23	0.102	30.1	0.056	0.064	0.053	0.020	0.057	0.003	0.003	0.004
12	0.199	0.033	0.499	0.042	0.992	0.004	0.102	2.02	0.032	1.23	0.102	30.1	0.056	0.064	0.053	0.020	0.057	0.003	0.003	0.004
12.4	*0.203*	*0.054*	*0.473*	*0.067*	0.992	0.004	0.093	2.02	0.034	1.21	0.093	*25.2*	*0.083*	0.099	*0.048*	*0.035*	0.059	*0.004*	*0.004*	0.005
13	0.208	0.042	0.442	0.054	0.993	0.004	0.040	2.28	0.021	1.08	0.040	30.0	0.064	0.072	0.053	0.030	0.060	0.006	0.003	0.006
14	0.216	0.042	0.458	0.062	0.992	0.004	0.035	2.10	0.015	1.07	0.035	27.2	0.056	0.071	0.088	0.030	0.093	0.009	0.003	0.010
15	0.224	0.054	0.523	0.053	0.992	0.004	0.096	2.01	0.033	1.21	0.096	23.4	0.055	0.087	0.054	0.029	0.062	0.011	0.003	0.011
16	0.231	0.049	0.581	0.050	0.992	0.004	0.081	2.10	0.032	1.18	0.081	24.1	0.062	0.088	0.044	0.029	0.053	0.011	0.003	0.011
17	0.238	0.042	0.575	0.049	0.991	0.004	0.079	2.18	0.032	1.17	0.079	31.6	0.071	0.076	0.023	0.029	0.037	0.012	0.003	0.012
18	0.245	0.033	0.545	0.057	0.993	0.004	0.054	2.15	0.024	1.11	0.054	25.2	0.063	0.084	0.058	0.029	0.065	0.014	0.004	0.015

Nº medidas
5

E max (+)	E max (-)	Γ g max	E min (+)	E min (-)	Γ g min	u vect (U_1)	u alg (U_2)	U_3	k_3	Gr. Libertad	k95.45-k_3	U_4	U_5	σ	U_6	u comb	k	u exp Γg
1.08453	1.00343	0.044	0.99677	0.93126	0.036	0.004	0.005	0.004	2.029	88	0.0001	0.0001	0.0000	0.008	0.003	0.005	2.11	0.012
1.10254	1.00399	0.055	0.99611	0.91617	0.045	0.005	0.005	0.004	2.033	77	0.0001	0.0002	0.0001	0.009	0.004	0.006	2.14	0.013
1.14075	1.00511	0.075	0.99485	0.88843	0.059	0.008	0.005	0.004	2.037	69	-0.0001	0.0002	0.0001	0.011	0.005	0.008	2.11	0.016
1.10689	1.00500	0.057	0.99506	0.91200	0.046	0.005	0.005	0.004	2.025	101	0.0000	0.0002	0.0001	0.012	0.005	0.007	2.23	0.016
1.16381	1.00734	0.089	0.99241	0.87120	0.069	0.010	0.005	0.004	2.033	76	0.0003	0.0003	0.0002	0.011	0.005	0.008	2.09	0.018
1.09345	1.00638	0.050	0.99415	0.92651	0.039	0.006	0.005	0.004	2.039	65	0.0001	0.0002	0.0001	0.014	0.006	0.008	2.32	0.019
1.14908	1.00677	0.081	0.99348	0.88761	0.061	0.010	0.005	0.004	2.053	48	0.0001	0.0003	0.0003	0.016	0.007	0.010	2.20	0.022
1.14908	1.00677	0.081	0.99348	0.88761	0.061	0.010	0.005	0.004	2.053	48	0.0001	0.0003	0.0003	0.016	0.007	0.010	2.20	0.022
1.20077	1.00731	0.110	0.99342	0.86760	0.072	0.019	0.005	0.004	2.101	26	0.0001	0.0005	0.0004	0.016	0.007	0.014	2.05	0.028
1.15920	1.00627	0.088	0.99376	0.87831	0.066	0.011	0.005	0.004	2.122	22	-0.0022	0.0004	0.0003	0.011	0.005	0.009	2.07	0.018
1.32235	1.00780	0.184	0.99234	0.80439	0.110	0.037	0.005	0.005	2.129	21	-0.0030	0.0006	0.0004	0.014	0.006	0.023	2.00	0.045
1.22856	1.00762	0.130	0.99298	0.85193	0.083	0.023	0.005	0.004	2.076	34	0.0005	0.0005	0.0004	0.016	0.007	0.016	2.02	0.032
1.22856	1.00762	0.130	0.99298	0.85193	0.083	0.023	0.005	0.004	2.076	34	0.0005	0.0005	0.0004	0.016	0.007	0.016	2.02	0.032
1.22195	1.00931	0.124	0.99223	0.86634	0.074	0.025	0.005	0.004	2.147	18	0.0016	0.0007	0.0006	0.016	0.007	0.017	2.02	0.034
1.09257	1.00803	0.049	0.99352	0.93511	0.034	0.008	0.005	0.004	2.135	20	-0.0015	0.0003	0.0002	0.016	0.007	0.009	2.28	0.021
1.08673	1.01200	0.044	0.99108	0.94286	0.028	0.008	0.005	0.004	2.100	26	0.0009	0.0002	0.0002	0.010	0.004	0.007	2.10	0.015
1.23028	1.01529	0.128	0.98707	0.86003	0.075	0.026	0.005	0.004	2.112	23	0.0024	0.0006	0.0006	0.013	0.006	0.017	2.01	0.033
1.18810	1.01453	0.105	0.98787	0.88048	0.065	0.020	0.005	0.004	2.106	25	-0.0013	0.0005	0.0005	0.022	0.010	0.015	2.10	0.032
1.17773	1.01517	0.098	0.98667	0.88001	0.064	0.017	0.005	0.004	2.090	29	0.0005	0.0004	0.0004	0.023	0.011	0.015	2.18	0.032
1.13332	1.01782	0.069	0.98608	0.91336	0.044	0.013	0.005	0.004	2.098	27	-0.0012	0.0004	0.0002	0.017	0.008	0.011	2.15	0.024

CERTIFICADO DE CALIBRACIÓN
Certificate of Calibration

Número **49072**
Number

Ministerio de Defensa. Secretaría de Estado de la Defensa.
INSTITUTO NACIONAL DE TÉCNICA AEROESPACIAL
Centro de Metrología y Calibración
Carretera de Ajalvir, p.k. 4,5
28850 Torrejón de Ardoz (Madrid) – ESPAÑA
Teléfono: (+34) 91 520 1516 / E-mail: metrologia.calibracion@inta.es

OBJETO *Item*	**Generador de señal sintetizado (conector Tipo N hembra)** ***Synthesized CW Generator***
MARCA *Mark*	**Hewlett Packard**
MODELO *Model*	**83712A**
IDENTIFICACIÓN *Identification*	**3339A00223**
SOLICITANTE *Applicant*	**INTA - Centro de Metrología y Calibración** **Laboratorio de Radiofrecuencia y Microondas** **Ctra. Torrejón a Ajalvir, p.k. 4,5** **28850 Torrejón de Ardoz, Madrid** **(Spain)**
FECHA/S DE CALIBRACIÓN *Date/s of Calibration*	**11 y 12 de marzo de 2019**

Signatario/s autorizado/s
Authorised Signatory/ies

Fecha de Emisión
Date of issue
14 de marzo de 2019

Manuel Rodríguez Higuero
Jefe del Laboratorio de RF y Microondas

Ref: **OT-RF2019-0564**

CALIBRATION:

Before any measurement was made, the Unit Under Test was connected to the mains (220 V @ 50 Hz) and kept in Stand-By state at room temperature within the Laboratory for at least 24 hours. Ambient temperature during measurement was 23°C ± 1°C and relative humidity less than 70%.

Mesurement System: the measurement configuration used makes use of the following equipment:

- Directional Coupler, Amplifier Research model DC3002A, serial number 305138
- Directional Coupler, Narda model 3292-2, serial number 03162
- Short Circuit, model INMET 7002, s/n 64671
- Power Meter, Hewlett Packard model 436A, serial number 3103U07436
- Power Sensor, Agilent 8481D, serial number MY51310006
- 30 cm Air Line, Wiltron model SC4934-30, serial number 400001
- 3 m cable, Utiflex serial number FA210B0030007071

Measurement procedure: RF/MPR/7231/302/INTA "Medida del Coeficiente de Reflexión (Source Match) de una Fuente de Radiofrecuencia". The procedure is based on the ripple technique making use of a calibrated airline. FFT is subsequently used in order to filter out the obtained ripple signal, splitting it into two 'processed' ripples.

For measurement at 50 MHz a modification of the measurement procedure is applied which makes use of a long cable in order to induce the ripple signal at the required 'rate of variation' for determination of VRC at low frequencies. No filtering is applied in this case.

UUT configuration: Measurement of Source Match was made for the following setup:

- Nominal Output Level: +0 dBm
- Output mode: CW signal

Measurement results are contained in Table 1 as measured Source Match (VRC) and its associated uncertainty. All working standards and instrumentation used in the calibration are traceable to the National Physical Laboratory (NPL) of the United Kingdom and to the Eidgenössische Institut für Metrologie (METAS) of Switzerland.

The measured values correspond to the moment and ambient conditions under which they were taken. No consideration is made about the stability of the UUT and / or the measurement system.

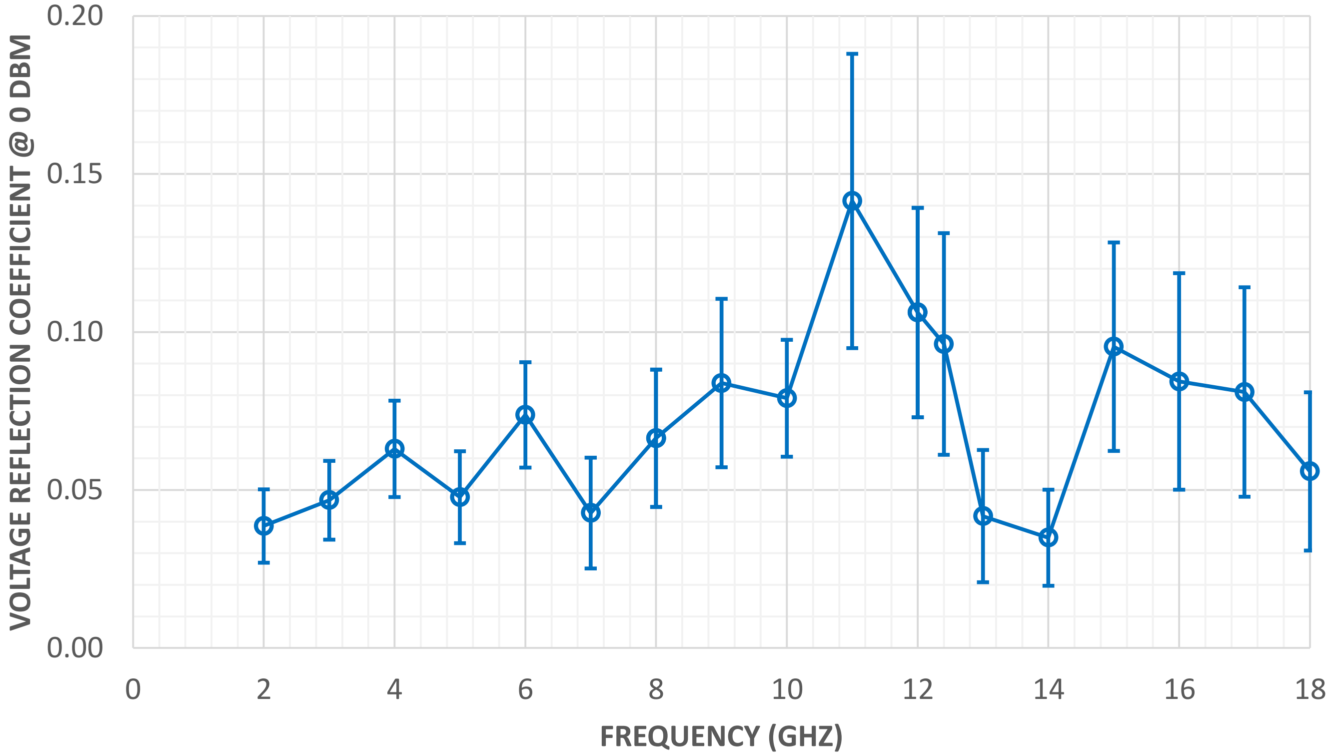
The expanded uncertainty has been obtained by multiplying the standard uncertainty by a coverage factor k such that the probability of coverage or confidence level is 95.45% (k = 2 in all cases, unless otherwise stated in the table). The standard measurement uncertainty has been determined in accordance with document EA-4/02 M: 2013, 'Assessment of measurement uncertainty in calibrations'.

Table 1

Frequency (GHz)	Source Match (VRC)	Coverage factor *k*	Uncertainty (±)
2	**0.039**	**2.11**	**0.012**
3	0.047	2.13	0.013
4	0.063	2.11	0.015
5	0.048	2.21	0.015
6	0.074	2.09	0.017
7	0.043	2.28	0.018
8	**0.066**	**2.21**	**0.022**
9	0.084	2.05	0.027
10	0.079	2.06	0.019
11	0.141	2.00	0.047
12	**0.106**	**2.02**	**0.033**
12.4	0.096	2.02	0.035
13	0.042	2.28	0.021
14	0.035	2.10	0.015
15	**0.095**	**2.01**	**0.033**
16	0.084	2.11	0.034
17	0.081	2.18	0.033
18	**0.056**	**2.15**	**0.025**

Finally a graphical representation of the parameter under test is included. It is intended for information purposes only and it is not part of the content of this certificate as regards measured values and their associated uncertainty (the values contained in the tables always prevail).

ANNEX – GRAPHICAL REPRESENTATION OF SOURCE MATCH



Cliente: Laboratorio de RF y Microondas

Modelo: HP 83712A
Nº de serie: 3339A00223

14/03/2019

Frec (GHz)	IL línea	u IL línea	IL acopl	u IL acopl	Γ corto	u Γ corto	Γ g corr	k	u Γg	SWR corr	Γ g	D (dB)	u D	D eff	TPM	u TPM	TPm eff	Γ line	u Γ line	Γ line eff
2	0.077	0.010	0.317	0.031	0.994	0.004	0.039	2.11	0.012	1.08	0.039	33.4	0.013	0.025	0.035	0.017	0.038	0.001	0.003	0.003
3	0.095	0.016	0.375	0.031	0.994	0.004	0.047	2.13	0.013	1.10	0.047	33.5	0.013	0.025	0.022	0.017	0.028	0.002	0.003	0.003
4	0.111	0.017	0.340	0.031	0.993	0.004	0.063	2.11	0.015	1.13	0.063	35.4	0.012	0.021	0.026	0.017	0.031	0.003	0.003	0.004
5	0.125	0.016	0.327	0.031	0.993	0.004	0.048	2.21	0.015	1.10	0.048	34.1	0.013	0.023	0.016	0.017	0.023	0.003	0.003	0.004
6	0.138	0.017	0.401	0.031	0.993	0.004	0.074	2.09	0.017	1.16	0.074	40.7	0.017	0.020	0.019	0.017	0.026	0.005	0.003	0.006
7	0.150	0.027	0.449	0.031	0.993	0.004	0.043	2.28	0.018	1.09	0.043	29.7	0.020	0.038	0.032	0.017	0.036	0.005	0.003	0.005
8	0.161	0.032	0.420	0.031	0.993	0.004	0.066	2.21	0.022	1.14	0.066	29.4	0.021	0.040	0.029	0.017	0.033	0.004	0.003	0.005
8	0.161	0.032	0.420	0.031	0.993	0.004	0.066	2.21	0.022	1.14	0.066	29.4	0.021	0.040	0.029	0.017	0.033	0.004	0.003	0.005
9	0.172	0.036	0.406	0.045	0.993	0.004	0.084	2.05	0.027	1.18	0.084	27.0	0.027	0.052	0.068	0.020	0.071	0.003	0.003	0.004
10	0.181	0.036	0.426	0.040	0.993	0.004	0.079	2.06	0.019	1.17	0.079	37.0	0.036	0.039	0.013	0.020	0.024	0.003	0.003	0.004
11	0.188	0.027	0.494	0.040	0.993	0.005	0.141	2.00	0.047	1.33	0.141	23.7	0.047	0.081	0.033	0.020	0.039	0.001	0.003	0.003
12	0.199	0.033	0.499	0.042	0.992	0.004	0.106	2.02	0.033	1.24	0.106	30.1	0.056	0.064	0.053	0.020	0.057	0.003	0.003	0.004
12	0.199	0.033	0.499	0.042	0.992	0.004	0.106	2.02	0.033	1.24	0.106	30.1	0.056	0.064	0.053	0.020	0.057	0.003	0.003	0.004
12.4	*0.203*	*0.054*	*0.473*	*0.067*	0.992	0.004	0.096	2.02	0.035	1.21	0.096	*25.2*	*0.083*	0.099	*0.048*	*0.035*	0.059	*0.004*	*0.004*	0.005
13	0.208	0.042	0.442	0.054	0.993	0.004	0.042	2.28	0.021	1.09	0.042	30.0	0.064	0.072	0.053	0.030	0.060	0.006	0.003	0.006
14	0.216	0.042	0.458	0.062	0.992	0.004	0.035	2.10	0.015	1.07	0.035	27.2	0.056	0.071	0.088	0.030	0.093	0.009	0.003	0.010
15	0.224	0.054	0.523	0.053	0.992	0.004	0.095	2.01	0.033	1.21	0.095	23.4	0.055	0.087	0.054	0.029	0.062	0.011	0.003	0.011
16	0.231	0.049	0.581	0.050	0.992	0.004	0.084	2.11	0.034	1.18	0.084	24.1	0.062	0.088	0.044	0.029	0.053	0.011	0.003	0.011
17	0.238	0.042	0.575	0.049	0.991	0.004	0.081	2.18	0.033	1.18	0.081	31.6	0.071	0.076	0.023	0.029	0.037	0.012	0.003	0.012
18	0.245	0.033	0.545	0.057	0.993	0.004	0.056	2.15	0.025	1.12	0.056	25.2	0.063	0.084	0.058	0.029	0.065	0.014	0.004	0.015

Nº medidas
5

E max (+)	E max (-)	Γ g max	E min (+)	E min (-)	Γ g min	u vect (U_1)	u alg (U_2)	U_3	k_3	Gr. Libertad	k95.45-k_3	U_4	U_5	σ	U_6	u comb	k	u exp Γg
1.08170	1.00341	0.043	0.99680	0.93340	0.035	0.004	**0.005**	**0.004**	**2.029**	**88**	0.0001	0.0001	0.0000	**0.008**	0.004	0.005	2.11	**0.012**
1.09675	1.00394	0.052	0.99617	0.92051	0.042	0.005	**0.005**	**0.004**	**2.033**	**77**	0.0001	0.0002	0.0001	**0.009**	0.004	0.006	2.13	**0.013**
1.13275	1.00504	0.071	0.99495	0.89407	0.056	0.007	**0.005**	**0.004**	**2.037**	**69**	-0.0001	0.0002	0.0001	**0.010**	0.005	0.007	2.11	**0.015**
1.09963	1.00492	0.053	0.99516	0.91746	0.043	0.005	**0.005**	**0.004**	**2.025**	**101**	0.0000	0.0002	0.0001	**0.011**	0.005	0.007	2.21	**0.015**
1.15471	1.00725	0.083	0.99255	0.87745	0.065	0.009	**0.005**	**0.004**	**2.033**	**76**	0.0003	0.0003	0.0001	**0.011**	0.005	0.008	2.09	**0.017**
1.09073	1.00635	0.048	0.99419	0.92848	0.038	0.005	**0.005**	**0.004**	**2.039**	**65**	0.0001	0.0002	0.0001	**0.014**	0.006	0.008	2.28	**0.018**
1.14118	1.00667	0.077	0.99362	0.89288	0.058	0.010	**0.005**	**0.004**	**2.053**	**48**	0.0001	0.0002	0.0002	**0.016**	0.007	0.010	2.21	**0.022**
1.14118	1.00667	0.077	0.99362	0.89288	0.058	0.010	**0.005**	**0.004**	**2.053**	**48**	0.0001	0.0002	0.0002	**0.016**	0.007	0.010	2.21	**0.022**
1.19108	1.00719	0.105	0.99357	0.87308	0.069	0.018	**0.005**	**0.004**	**2.101**	**26**	0.0001	0.0004	0.0003	**0.015**	0.007	0.013	2.05	**0.027**
1.16537	1.00635	0.091	0.99364	0.87422	0.069	0.011	**0.005**	**0.004**	**2.122**	**22**	-0.0022	0.0004	0.0003	**0.011**	0.005	0.009	2.06	**0.019**
1.32937	1.00788	0.188	0.99223	0.80108	0.112	0.038	**0.005**	**0.005**	**2.129**	**21**	-0.0030	0.0007	0.0004	**0.014**	0.006	0.023	2.00	**0.047**
1.23868	1.00777	0.136	0.99280	0.84650	0.086	0.025	**0.005**	**0.004**	**2.076**	**34**	0.0005	0.0005	0.0004	**0.016**	0.007	0.016	2.02	**0.033**
1.23868	1.00777	0.136	0.99280	0.84650	0.086	0.025	**0.005**	**0.004**	**2.076**	**34**	0.0005	0.0005	0.0004	**0.016**	0.007	0.016	2.02	**0.033**
1.22961	1.00942	0.129	0.99210	0.86248	0.076	0.026	**0.005**	**0.004**	**2.147**	**18**	0.0016	0.0007	0.0006	**0.017**	0.007	0.017	2.02	**0.035**
1.09543	1.00808	0.051	0.99347	0.93325	0.035	0.008	**0.005**	**0.004**	**2.135**	**20**	-0.0015	0.0003	0.0002	**0.016**	0.007	0.009	2.28	**0.021**
1.08760	1.01201	0.044	0.99106	0.94233	0.028	0.008	**0.005**	**0.004**	**2.100**	**26**	0.0009	0.0003	0.0002	**0.010**	0.004	0.007	2.10	**0.015**
1.22903	1.01527	0.127	0.98710	0.86066	0.075	0.026	**0.005**	**0.004**	**2.112**	**23**	0.0024	0.0006	0.0006	**0.013**	0.006	0.016	2.01	**0.033**
1.19652	1.01466	0.110	0.98769	0.87590	0.067	0.021	**0.005**	**0.004**	**2.106**	**25**	-0.0013	0.0005	0.0005	**0.023**	0.010	0.016	2.11	**0.034**
1.18332	1.01526	0.101	0.98654	0.87675	0.066	0.018	**0.005**	**0.004**	**2.090**	**29**	0.0005	0.0005	0.0004	**0.024**	0.011	0.015	2.18	**0.033**
1.13771	1.01789	0.072	0.98598	0.91080	0.045	0.013	**0.005**	**0.004**	**2.098**	**27**	-0.0012	0.0004	0.0002	**0.018**	0.008	0.012	2.15	**0.025**

24. Annex V – Calibration certificate from EIM/NQIS Greece

ΠΙΣΤΟΠΟΙΗΤΙΚΟ ΔΙΑΚΡΙΒΩΣΗΣ
CERTIFICATE OF CALIBRATION

Αριθμός πιστοποιητικού /*Certificate number :EHF-18-011-D*

Εκδόθηκε από / *Issued by* :
Ελληνικό Ινστιτούτο Μετρολογίας
Hellenic Institute of Metrology
Εργαστήριο Υψηλών Συχνοτήτων
Laboratory of High Frequency

ΒΙ.ΠΕ. Θεσσαλονίκης, Ο.Τ.45
Τ.Κ. 57022 – Θεσσαλονίκη
Industr. Area Thessaloniki, Block 45
GR 57022 Thessaloniki
Τηλ./Tel. +030 2310 569999, Fax +030 2310 569996
e-mail: gkrik@eim.gr

Πελάτης: *Customer:*	INTA (Instituto Nacional de Técnica Aeroespacial), Centro de Metrología y Calibración – Edificio B-15 Ctra. a Ajalvir, p.k. 4,5, 28850 Torrejón de Ardoz (Madrid), SPAIN
Κωδικός αντικειμένου *Item Code*	-
Περιγραφή: *Description:*	Γεννήτρια σύνθεσης σημάτων CW *Synthesized CW generator*
Κατασκευαστής: *Manufacturer:*	Hewlett Packard
Τύπος: *Type:*	83712A
Αριθμός Σειράς: *Serial Number:*	3339A00223
Ημερομηνία Παραλαβής: *Date of receipt:*	30-05-2018
Ημερομηνία Διακρίβωσης: *Date of Calibration:*	15/06 – 21/6/2018

Σφραγίδα / *Seal* :	Ημερομηνία έκδοσης *Date of issue:*	Υπεύθυνος Διακρίβωσης / *Person Responsible:*	Υπεύθυνος Εργαστηρίου / *Laboratory Head:*
	26-04-2019	Γ. Κρικέλας	Γ. Κρικέλας

ΠΙΣΤΟΠΟΙΗΤΙΚΟ ΔΙΑΚΡΙΒΩΣΗΣ
CERTIFICATE OF CALIBRATION

Αριθμός πιστοποιητικού /*Certificate number :EHF-18-011-D*

Συνθήκες Διακρίβωσης *Ambient Conditions*	Από *From*	Έως *To*	Αβεβαιότητα *Uncertainty*
Θερμοκρασία – *Temperature* [^oC] :	22.6	24.0	0.2
Σχετική Υγρασία – *Relative Humidity* [%]:	65	79	2
Πίεση Αέρα - *Air Pressure* [hPa] :			

Κατάσταση αντικειμένου προς διακρίβωση /*Condition of object to be calibrated* :

Η συσκευή παραλήφθηκε σε καλή κατάσταση.

The device has been received in good condition.

Διαδικασία Διακρίβωσης / *Calibration Procedure*:

Η συσκευή αποθηκεύθηκε στο χώρο του εργαστηρίου για το απαιτούμενο χρονικό διάστημα πριν τη διαδικασία διακρίβωσης. Το χρονικό αυτό διάστημα δεν ήταν μικρότερο από 24 ώρες. Η διακρίβωση πραγματοποιήθηκε σύμφωνα με την «τεχνική έγχυσης»: μια δεύτερη γεννήτρια χρησιμοποιείται σε συνδυασμό με την υπό έλεγχο γεννήτρια (DUT), συνδεδεμένη διαμέσου μια κατευθυντικής γέφυρας ή ενός κατευθυντικού συζεύκτη. Η δεύτερη γεννήτρια «εγχέει» ένα σήμα που έχει μια μικρή, σταθερή, απόκλιση συχνότητας (για παράδειγμα 10Hz) από τη συχνότητα της εξόδου του DUT. Η διαφορά στη συχνότητα πρέπει να είναι εντός του εύρους ζώνης ελέγχου του ελέγχου πλάτους. Το αρχικό και ανακλώμενο σήμα προστίθενται και αφαιρούνται με ένα ρυθμό 10Hz. Το προκύπτον σήμα ανιχνεύεται με έναν αναλυτή φάσματος σε τρόπο λειτουργίας «μηδενικού εύρους», συνδεδεμένου στην τρίτη θύρα της γέφυρας/του συζεύκτη. Η μεταβολή του πλάτους στο χρόνο παρατηρείται με τη χρήση των δρομέων για τη μέτρηση των ελαχίστων και μεγίστων. Με αντικατάσταση του DUT με ένα ανοιχτοκύκλωμα κι ένα βραχυκύκλωμα μπορεί επίσης να μετρηθεί κι ένα επίπεδο αναφοράς. Ρυθμίζοντας τον αναλυτή φάσματος να μετράει σε μονάδες τάσης, ο Συντελεστής Ανάκλασης Τάσης (VRC) μπορεί να υπολογισθεί ως εξής: $\rho_l = Z_{DUT}/Z_{max}$. Όπου Z_{DUT} = μισό (μέγιστο – ελάχιστο) σήμα με συνδεδεμένο το ΔUT και Z_{max} = μέσο σήμα, με συνδεδεμένο ανοιχτοκύκλωμα και βραχυκύκλωμα.

Ο εξοπλισμός που χρησιμοποιήθηκε για τη διακρίβωση αποτελούνταν από: 1) Γεννήτρια HP 83630A (Δ1/0051), 2) Αναλυτή φάσματος Hewlett Packard 8566B (Δ1/0040), 3) Κατευθυντική γέφυρα Hewlett Packard 86205A (Δ1/1690), 4) Κατευθυντικός συζεύκτης Krytar 0995-0098 (Δ1/3200), 5) Θηλυκό ανοιχτοκύκλωμα (Δ1/1269a), 6) Θηλυκό βραχυκύκλωμα (Δ1/1269d), 7) Καλώδιο 11500C (Δ1/1284), 8) Καλώδιο 11500D (Δ1/1285), 9) Καλώδιο 11500E (Δ1/1286), 10) Καλώδιο 11500F (Δ1/1286), 11) Προσαρμογέας HP 3.5mm (f-f) (Δ1/3208), 12) Προσαρμογέας H&S 33 N-SMA-50-1/NE, N(m)-SMA(f) (Δ1/2067), 13) Προσαρμογέας HP N(m-m) 1250-1475 (Δ1/1871), 14) Προσαρμογέας HP 1250-1745 3.5mm(f)-N(f)

The Device Under Test was kept in the laboratory environment for the required time interval prior to the calibration. This time interval was not less than 24 hours. The calibration was conducted according to the "injection technique": a second generator is used in combination with the DUT, connected via a directional bridge or a directional coupler. The second generator injects a signal which has a small fixed frequency offset (for example 10Hz) from the DUT's output frequency. The difference in frequency should be within the control bandwidth of the level control. The original and reflected signals will add

and subtract at a rate of 10 Hz. The resultant signal is detected with a spectrum analyzer in 'zero span' mode, connected to the third port of the bridge/coupler. The variation in amplitude with time is observed using the cursors to measure the maxima and minima. With the UUT replaced by an open and a short, a reference level can also be measured. Configuring the spectrum analyzer to report in units of voltage, the Voltage Reflection Coefficient can be calculated as: $\rho_l = Z_{DUT}/Z_{max}$*. Where* Z_{DUT} *= half (max – min) signal with UUT connected and* Z_{max} *= mean signal with Open & Short connected.*
For the calibration the following standards have been used: 1) Generator HP 83630A (D1/0051), 2) Spectrum analyzer Hewlett Packard 8566B (D1/0040), 3) Directional bridge Hewlett Packard 86205A (D1/1690), 4) Directional coupler Krytar 0995-0098 (D1/3200), 5) Female open (D1/1269a), 6) Female short (D1/1269d), 7) Cable 11500C (D1/1284), 8) Cable 11500D (D1/1285), 9) Cable 11500E (D1/1286), 10) Cable 11500F (D1/1287), 11) Adapter HP 3.5mm (f-f) (Δ1/3208), 12) Adapter H&S 33 N-SMA-50-1/NE, N(m)-SMA(f) (Δ1/2067), 13) Adapter HP N(m-m) 1250-1475 (D1/1871), 14) *Adapter HP 1250-1745 3.5mm(f)-N(f)*

Ιχνηλασιμότητα / *Traceability*:

Οι μετρήσεις είναι ιχνηλάσιμες στα Εθνικά Πρότυπα του ΕΙΜ καθώς και στα Εθνικά Πρότυπα μελών της EURAMET, του NIST και άλλων αναγνωρισμένων Εθνικών Ινστιτούτων Μετρολογίας.

Traceable to EIM's National Standards, as well as to National Standards administered by EURAMET members, NIST or other recognized National Standards.

Αβεβαιότητα / *Uncertainty*:

Η αβεβαιότητα που αναφέρεται είναι το γινόμενο της τυπικής αβεβαιότητας (u) με τον συντελεστή κάλυψης k = 2 (διευρυμένη αβεβαιότητα) και προσδιορίστηκε σύμφωνα με την οδηγία JCGM 100: 2008 "Evaluation of measurement data — Guide to the expression of uncertainty in measurement". Γενικά, η τιμή της μετρούμενης ποσότητας περιέχεται στο προσδιοριζόμενο εύρος με πιθανότητα 95% περίπου. Η εκτίμηση της αναφερόμενης αβεβαιότητας δεν εμπεριέχει ενδεχόμενες μακροπρόθεσμες μεταβολές.

Reported is the expanded uncertainty which results from the standard uncertainty (u) by multiplication with the coverage factor k = 2. It has been evaluated according to the JCGM 100: 2008 "Evaluation of measurement data — Guide to the expression of uncertainty in measurement". Generally, the value of the measuring quantity is found within the attributed interval with a probability of approximately 95%. The reported uncertainty does not include an estimate of long-term variations.

Αποτελέσματα Διακρίβωσης / *Calibration Results* :

ΠΙΝΑΚΑΣ 1 / *TABLE 1*

Συντελεστής ανάκλασης τάσης / *Voltage Reflection Coefficient (VRC)*

Συχνότητα / *Frequency (GHz)*	Συντελεστής ανάκλασης τάσης / *Voltage Reflection Coefficient* (VRC)	Αβεβαιότητα / *Uncertainty* (CL=95.45%)
0.05	0.0591	0.0092
2	0.0377	0.0094
8	0.089	0.016
12	0.170	0.019
15	0.175	0.019
18	0.110	0.013

Παρατηρήσεις / *Comments*

ΤΕΛΟΣ ΠΙΣΤΟΠΟΙΗΤΙΚΟΥ / *END OF CERTIFICATE*

25. Annex VI – Calibration certificate from SIQ Slovenia

CERTIFIKAT O KALIBRACIJI / CALIBRATION CERTIFICATE

Applicant	INSTITUTO NACIONAL DE TECNICA AEROESPACIAL (INTA) CTRA. A AJALVIR, P.K.4,5 ES-28850 TORREJON DE ARDOZ (MADRID)
Owner	INSTITUTO NACIONAL DE TECNICA AEROESPACIAL (INTA) CTRA. A AJALVIR, P.K.4,5 ES-28850 TORREJON DE ARDOZ (MADRID)
Instrument	Synthesized CW Generator
Manufacturer	HEWLETT PACKARD
Type	83712A
Serial Number	3339A00223
Environmental conditions	Temperature: 23°C ± 2°C Relative humidity: 50% ± 20% Power supply: 230V ± 1%
Calibration date	16. April 2018 - 27. April 2018
Recommended recalibration	27. April 2019 The stated recalibration date is recommended based on general experience for the equipment type. The actual recalibration interval shall be defined by the user taking into account the type of application, frequency and conditions of use.
Conclusion	Complies with specifications. All measured values lie within the allowable tolerance limits as stated by the manufacturer and given along with the measurement results. Measured values were chosen to be representative for the overall performance of the type of the instrument.

Izvedel / Performed by:	Potrdil / Approved by:	Datum / Date:
BORUT PINTER Senior calibration engineer	MATJAŽ LINDIČ Assistant to TMT Director	2. April 2019 Ref.: 19/01052

S I Q Ljubljana

Tržaška cesta 2, SI-1000 Ljubljana, Slovenija

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Calibrated parameters:

1. Connector pin depth
2. Generator Output Voltage Reflection Coefficient

Measurement standards used:

E1	08/509	N9030B PXA
E2	07/100	11691D
E3	07/170A	M1404N
E4	07/121F	Type BNC (f) short
E5	02/266B	04191-85300
E6	07/113B	18N50
E7	07/079	778D

Calibration procedure:

SIQ protokol:	09069P01/2019-04-01	*Ref.:*	MN601000C	04/2015-09
			MN621000C	04/2014-11
			MN624000C	02/2018-09

Calibration was carried out by comparison of values indicated, or set, on the item under calibration, with values of measurands, realized with measurement standards.

Abbreviations and symbols:

Parameters marked with an index "s" represent the ("true") value of the item under calibration
Parameters marked with index "x" represent values indicated or set on the item under calibration

mv	min. or max allowable value of the measured parameter
(n), N	(relative) expanded measurement uncertainty, expressed as double standard uncertainty
ρ	Absolute value of generator voltage reflection coefficient; |Γ|
VSWR	Voltage Standing Wave Ratio ((1+ρ)/(1-ρ))
	Voltage reflection coefficient uncertainty N(ρ) must be taken in such a manner so that ρ is never negative.
√	ρ <= mv - N; compliance with specifications
►	ρ > mv + N; non-compliance with specifications

Limits of error for individual measured parameters are stated along with the measurement results and are calculated from manufacturer's specifications given in:
HP 83711, 83712, 83731 and 83732 Synthesized Signal Generator; Calibration Guide;
Manual p.n.: 83731-90125; Revision Date: November 1998

MEASUREMENT RESULTS

1. Connector pin depth

Connector pin depth is measured relatively to the reference connector.
Allowable values are taken from IEEE 287 (GPC).
Connector with pin depth greater than mv max can damage connectors connected to it.
Connector with pin depth smaller than mv min can increase reflection.

	Connector	*depth* [mm]	*N* [mm]	*mv min* [mm]	*mv max* [mm]
►	RF OUTPUT 50 Ω; N(f)	-0,267	0,021	-0,076	0,000

2. Generator Output Voltage Reflection Coefficient

Px = 0 dBm

	f [MHz]	*ρ_gen*	*N_ρ_gen*	*mv*	*VSWR*
√	30	0,047	0,023	0,333	1,099
√	40	0,044	0,022	0,333	1,092
√	50	0,044	0,020	0,333	1,091
√	60	0,044	0,017	0,333	1,091
√	70	0,043	0,017	0,333	1,090
√	80	0,043	0,018	0,333	1,090
√	90	0,041	0,020	0,333	1,086
√	100	0,042	0,023	0,333	1,087
√	110	0,040	0,021	0,333	1,083
√	120	0,039	0,018	0,333	1,081
√	130	0,038	0,017	0,333	1,080
√	140	0,038	0,017	0,333	1,078
√	150	0,037	0,018	0,333	1,076
√	160	0,036	0,021	0,333	1,075
√	170	0,036	0,019	0,333	1,074
√	180	0,035	0,016	0,333	1,073
√	190	0,035	0,014	0,333	1,073
√	200	0,035	0,013	0,333	1,072
√	210	0,034	0,013	0,333	1,071
√	220	0,033	0,013	0,333	1,069
√	230	0,034	0,013	0,333	1,070
√	240	0,033	0,010	0,333	1,068
√	250	0,032	0,007	0,333	1,065
√	260	0,030	0,004	0,333	1,063
√	270	0,029	0,003	0,333	1,060
√	280	0,027	0,004	0,333	1,056
√	290	0,024	0,007	0,333	1,050
√	300	0,020	0,008	0,333	1,041
√	310	0,018	0,011	0,333	1,036
√	320	0,015	0,013	0,333	1,031
√	330	0,014	0,014	0,333	1,028
√	340	0,012	0,016	0,333	1,025
√	350	0,010	0,019	0,333	1,021

	f [MHz]	ρ_gen	N_ρ_gen	mv	VSWR
√	360	0,008	0,023	0,333	1,016
√	370	0,006	0,028	0,333	1,012
√	380	0,004	0,024	0,333	1,008
√	390	0,002	0,023	0,333	1,004
√	400	0,002	0,032	0,333	1,004
√	410	0,004	0,027	0,333	1,008
√	420	0,006	0,026	0,333	1,013
√	430	0,008	0,026	0,333	1,017
√	440	0,011	0,029	0,333	1,023
√	450	0,014	0,034	0,333	1,028
√	460	0,016	0,036	0,333	1,033
√	470	0,018	0,033	0,333	1,037
√	480	0,019	0,029	0,333	1,039
√	490	0,018	0,028	0,333	1,036
√	500	0,016	0,028	0,333	1,033
√	510	0,016	0,028	0,333	1,033
√	520	0,017	0,029	0,333	1,035
√	530	0,018	0,029	0,333	1,037
√	540	0,021	0,031	0,333	1,042
√	550	0,023	0,033	0,333	1,046
√	560	0,027	0,032	0,333	1,055
√	570	0,030	0,027	0,333	1,063
√	580	0,035	0,023	0,333	1,072
√	590	0,039	0,019	0,333	1,081
√	600	0,044	0,017	0,333	1,092
√	610	0,049	0,015	0,333	1,103
√	620	0,055	0,015	0,333	1,117
√	630	0,060	0,015	0,333	1,127
√	640	0,065	0,013	0,333	1,140
√	650	0,071	0,011	0,333	1,153
√	660	0,076	0,010	0,333	1,165
√	670	0,081	0,010	0,333	1,176
√	680	0,088	0,011	0,333	1,193
√	690	0,094	0,014	0,333	1,208
√	700	0,100	0,018	0,333	1,223
√	710	0,107	0,019	0,333	1,240
√	720	0,110	0,019	0,333	1,246
√	730	0,116	0,018	0,333	1,263
√	740	0,123	0,019	0,333	1,280
√	750	0,129	0,021	0,333	1,296
√	760	0,135	0,025	0,333	1,312
√	770	0,137	0,029	0,333	1,317
√	780	0,146	0,032	0,333	1,342
√	790	0,144	0,030	0,333	1,337
√	800	0,151	0,028	0,333	1,356
√	810	0,154	0,029	0,333	1,363
√	820	0,163	0,031	0,333	1,389
√	830	0,164	0,036	0,333	1,392
√	840	0,174	0,044	0,333	1,421
√	850	0,172	0,046	0,333	1,415

	f [MHz]	*ρ_gen*	*N_ρ_gen*	*mv*	*VSWR*
√	860	0,174	0,041	0,333	1,422
√	870	0,174	0,039	0,333	1,422
√	880	0,172	0,038	0,333	1,416
√	890	0,167	0,040	0,333	1,401
√	900	0,165	0,044	0,333	1,395
√	910	0,159	0,049	0,333	1,378
√	920	0,158	0,052	0,333	1,376
√	930	0,156	0,046	0,333	1,371
√	940	0,152	0,040	0,333	1,359
√	950	0,148	0,038	0,333	1,349
√	960	0,148	0,038	0,333	1,349
√	970	0,147	0,040	0,333	1,344
√	980	0,145	0,043	0,333	1,338
√	990	0,139	0,047	0,333	1,322
√	1000	0,020	0,041	0,333	1,040
√	1010	0,009	0,036	0,333	1,018
√	1020	0,010	0,042	0,333	1,021
√	1030	0,012	0,041	0,333	1,024
√	1040	0,012	0,038	0,333	1,025
√	1050	0,014	0,034	0,333	1,028
√	1060	0,015	0,030	0,333	1,030
√	1070	0,016	0,029	0,333	1,032
√	1080	0,016	0,029	0,333	1,034
√	1090	0,018	0,031	0,333	1,036
√	1100	0,018	0,036	0,333	1,037
√	1110	0,020	0,035	0,333	1,040
√	1120	0,021	0,032	0,333	1,042
√	1130	0,021	0,028	0,333	1,043
√	1140	0,022	0,023	0,333	1,045
√	1150	0,022	0,021	0,333	1,045
√	1160	0,024	0,018	0,333	1,048
√	1170	0,024	0,016	0,333	1,050
√	1180	0,026	0,014	0,333	1,053
√	1190	0,026	0,012	0,333	1,054
√	1200	0,027	0,009	0,333	1,056
√	1210	0,027	0,006	0,333	1,056
√	1220	0,028	0,005	0,333	1,058
√	1230	0,030	0,007	0,333	1,061
√	1240	0,031	0,010	0,333	1,064
√	1250	0,031	0,013	0,333	1,064
√	1260	0,033	0,017	0,333	1,068
√	1270	0,033	0,022	0,333	1,067
√	1280	0,035	0,027	0,333	1,072
√	1290	0,034	0,032	0,333	1,071
√	1300	0,032	0,037	0,333	1,067
√	1310	0,035	0,034	0,333	1,072
√	1320	0,036	0,034	0,333	1,075
√	1330	0,036	0,036	0,333	1,076
√	1340	0,037	0,039	0,333	1,077
√	1350	0,037	0,044	0,333	1,078

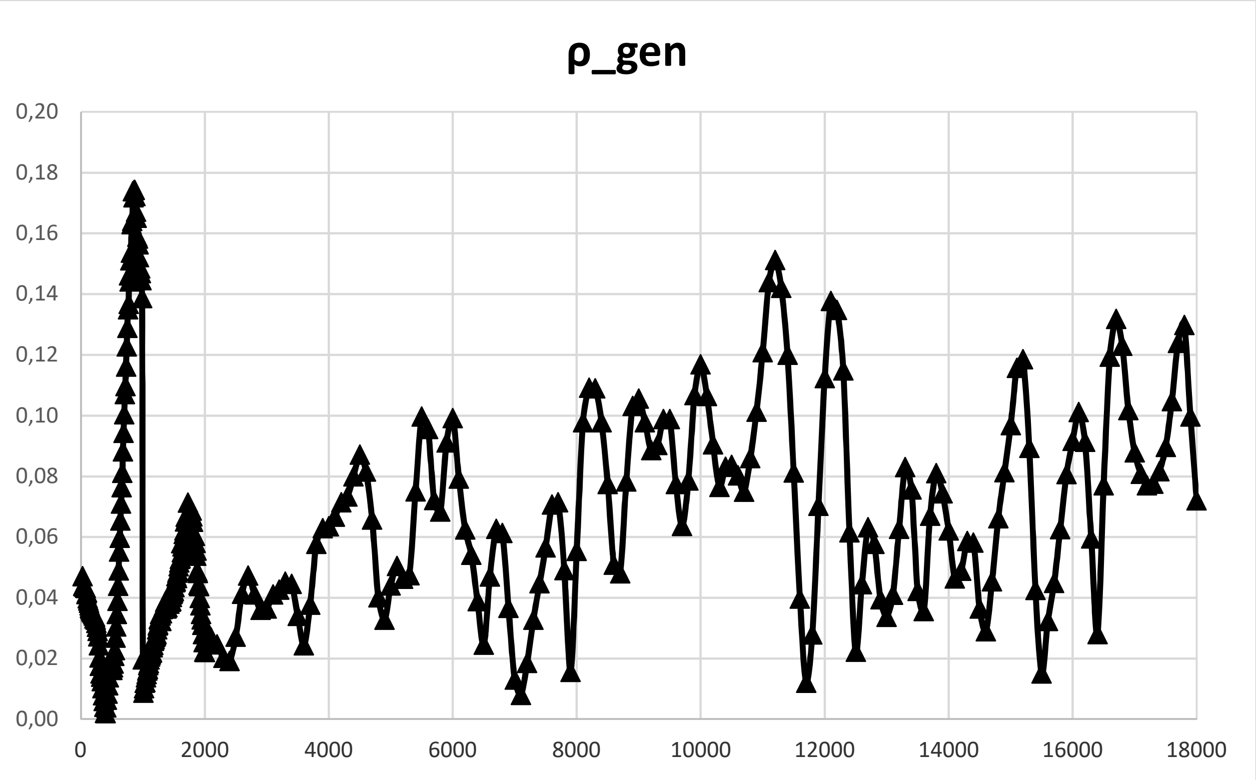
	f [MHz]	*ρ_gen*	*N_ρ_gen*	*mv*	*VSWR*
√	1360	0,039	0,052	0,333	1,080
√	1370	0,039	0,059	0,333	1,081
√	1380	0,036	0,068	0,333	1,076
√	1390	0,039	0,061	0,333	1,080
√	1400	0,037	0,057	0,333	1,076
√	1410	0,039	0,056	0,333	1,082
√	1420	0,038	0,056	0,333	1,080
√	1430	0,038	0,058	0,333	1,079
√	1440	0,039	0,064	0,333	1,081
√	1450	0,039	0,071	0,333	1,080
√	1460	0,039	0,079	0,333	1,081
√	1470	0,040	0,078	0,333	1,084
√	1480	0,041	0,068	0,333	1,086
√	1490	0,042	0,059	0,333	1,087
√	1500	0,042	0,051	0,333	1,088
√	1510	0,043	0,048	0,333	1,091
√	1520	0,045	0,047	0,333	1,094
√	1530	0,045	0,046	0,333	1,095
√	1540	0,047	0,046	0,333	1,099
√	1550	0,046	0,040	0,333	1,097
√	1560	0,048	0,031	0,333	1,101
√	1570	0,049	0,023	0,333	1,103
√	1580	0,050	0,016	0,333	1,106
√	1590	0,052	0,012	0,333	1,109
√	1600	0,053	0,009	0,333	1,111
√	1610	0,053	0,009	0,333	1,112
√	1620	0,058	0,012	0,333	1,123
√	1630	0,055	0,016	0,333	1,116
√	1640	0,057	0,018	0,333	1,121
√	1650	0,059	0,021	0,333	1,125
√	1660	0,061	0,025	0,333	1,130
√	1670	0,062	0,030	0,333	1,133
√	1680	0,065	0,036	0,333	1,139
√	1690	0,067	0,044	0,333	1,143
√	1700	0,066	0,056	0,333	1,141
√	1710	0,067	0,061	0,333	1,144
√	1720	0,067	0,060	0,333	1,143
√	1730	0,071	0,061	0,333	1,154
√	1740	0,066	0,058	0,333	1,142
√	1750	0,068	0,059	0,333	1,147
√	1760	0,069	0,064	0,333	1,148
√	1770	0,068	0,070	0,333	1,146
√	1780	0,067	0,078	0,333	1,145
√	1790	0,069	0,086	0,333	1,148
√	1800	0,067	0,072	0,333	1,143
√	1810	0,065	0,065	0,333	1,139
√	1820	0,061	0,056	0,333	1,129
√	1830	0,061	0,050	0,333	1,129
√	1840	0,060	0,046	0,333	1,128
√	1850	0,058	0,042	0,333	1,123

	f [MHz]	ρ_gen	N_ρ_gen	mv	VSWR
√	1860	0,054	0,042	0,333	1,114
√	1870	0,055	0,041	0,333	1,117
√	1880	0,049	0,034	0,333	1,102
√	1890	0,048	0,025	0,333	1,101
√	1900	0,044	0,017	0,333	1,093
√	1910	0,044	0,010	0,333	1,092
√	1920	0,040	0,006	0,333	1,083
√	1930	0,037	0,007	0,333	1,078
√	1940	0,035	0,013	0,333	1,072
√	1950	0,033	0,021	0,333	1,068
√	1960	0,031	0,032	0,333	1,064
√	1970	0,028	0,033	0,333	1,058
√	1980	0,025	0,037	0,333	1,052
√	1990	0,022	0,042	0,333	1,045
√	2000	0,022	0,049	0,333	1,045
√	2100	0,027	0,031	0,333	1,055
√	2200	0,025	0,041	0,333	1,050
√	2300	0,020	0,039	0,333	1,041
√	2400	0,019	0,058	0,333	1,039
√	2500	0,027	0,051	0,333	1,056
√	2600	0,041	0,043	0,333	1,086
√	2700	0,047	0,041	0,333	1,099
√	2800	0,041	0,036	0,333	1,086
√	2900	0,036	0,025	0,333	1,075
√	3000	0,036	0,026	0,333	1,076
√	3100	0,041	0,024	0,333	1,086
√	3200	0,043	0,029	0,333	1,089
√	3300	0,045	0,053	0,333	1,095
√	3400	0,045	0,047	0,333	1,093
√	3500	0,034	0,048	0,333	1,070
√	3600	0,024	0,051	0,333	1,050
√	3700	0,038	0,041	0,333	1,078
√	3800	0,058	0,024	0,333	1,123
√	3900	0,063	0,016	0,333	1,134
√	4000	0,064	0,005	0,333	1,136
√	4100	0,067	0,006	0,333	1,143
√	4200	0,071	0,012	0,333	1,154
√	4300	0,073	0,018	0,333	1,158
√	4400	0,080	0,021	0,333	1,174
√	4500	0,087	0,039	0,333	1,191
√	4600	0,082	0,039	0,333	1,178
√	4700	0,066	0,060	0,333	1,141
√	4800	0,040	0,053	0,333	1,083
√	4900	0,033	0,066	0,333	1,068
√	5000	0,044	0,064	0,333	1,092
√	5100	0,050	0,059	0,333	1,106
√	5200	0,046	0,062	0,333	1,097
√	5300	0,047	0,045	0,333	1,099
√	5400	0,075	0,045	0,333	1,162
√	5500	0,100	0,031	0,333	1,221

	f [MHz]	ρ_gen	N_ρ_gen	mv	VSWR
√	5600	0,096	0,027	0,333	1,211
√	5700	0,072	0,047	0,333	1,156
√	5800	0,068	0,049	0,333	1,147
√	5900	0,091	0,061	0,333	1,200
√	6000	0,099	0,100	0,333	1,220
√	6100	0,079	0,080	0,333	1,172
√	6200	0,062	0,095	0,333	1,133
√	6300	0,054	0,105	0,333	1,114
√	6400	0,039	0,081	0,333	1,081
√	6500	0,025	0,077	0,333	1,050
√	6600	0,047	0,071	0,333	1,099
√	6700	0,063	0,049	0,333	1,134
√	6800	0,061	0,052	0,333	1,131
√	6900	0,037	0,068	0,333	1,076
√	7000	0,013	0,075	0,333	1,026
√	7100	0,008	0,087	0,333	1,016
√	7200	0,018	0,105	0,333	1,038
√	7300	0,033	0,108	0,333	1,068
√	7400	0,045	0,104	0,333	1,094
√	7500	0,057	0,075	0,333	1,120
√	7600	0,071	0,076	0,333	1,152
√	7700	0,071	0,046	0,333	1,154
√	7800	0,049	0,031	0,333	1,103
√	7900	0,016	0,030	0,333	1,032
√	8000	0,055	0,042	0,333	1,117
√	8100	0,098	0,073	0,333	1,217
√	8200	0,109	0,056	0,333	1,245
√	8300	0,109	0,065	0,333	1,244
√	8400	0,098	0,046	0,333	1,217
√	8500	0,077	0,034	0,333	1,168
√	8600	0,051	0,024	0,333	1,107
√	8700	0,048	0,022	0,333	1,101
√	8800	0,078	0,031	0,333	1,170
√	8900	0,103	0,055	0,333	1,230
√	9000	0,106	0,050	0,333	1,236
√	9100	0,098	0,058	0,333	1,217
√	9200	0,089	0,055	0,333	1,194
√	9300	0,090	0,046	0,333	1,198
√	9400	0,099	0,034	0,333	1,219
√	9500	0,099	0,019	0,333	1,219
√	9600	0,077	0,006	0,333	1,168
√	9700	0,064	0,014	0,333	1,136
√	9800	0,079	0,031	0,333	1,171
√	9900	0,107	0,037	0,333	1,239
√	10000	0,117	0,061	0,333	1,264
√	10100	0,106	0,056	0,333	1,238
√	10200	0,090	0,069	0,333	1,199
√	10300	0,077	0,080	0,333	1,166
√	10400	0,083	0,070	0,333	1,181
√	10500	0,084	0,107	0,333	1,183

	f [MHz]	ρ_gen	N_ρ_gen	mv	VSWR
√	10600	0,080	0,082	0,333	1,174
√	10700	0,075	0,105	0,333	1,162
√	10800	0,086	0,115	0,333	1,188
√	10900	0,101	0,099	0,333	1,225
√	11000	0,121	0,132	0,333	1,275
√	11100	0,144	0,104	0,333	1,336
√	11200	0,151	0,109	0,333	1,356
√	11300	0,142	0,090	0,333	1,331
√	11400	0,120	0,086	0,333	1,273
√	11500	0,081	0,063	0,333	1,177
√	11600	0,040	0,064	0,333	1,083
√	11700	0,012	0,044	0,333	1,024
√	11800	0,028	0,044	0,333	1,057
√	11900	0,070	0,044	0,333	1,151
√	12000	0,112	0,037	0,333	1,253
√	12100	0,138	0,038	0,333	1,319
√	12200	0,135	0,026	0,333	1,311
√	12300	0,115	0,027	0,333	1,259
√	12400	0,061	0,032	0,333	1,131
√	12500	0,022	0,042	0,333	1,045
√	12600	0,044	0,058	0,333	1,093
√	12700	0,063	0,096	0,333	1,135
√	12800	0,058	0,087	0,333	1,122
√	12900	0,040	0,130	0,333	1,082
√	13000	0,034	0,106	0,333	1,070
√	13100	0,041	0,124	0,333	1,085
√	13200	0,063	0,120	0,333	1,134
√	13300	0,083	0,100	0,333	1,181
√	13400	0,076	0,105	0,333	1,164
√	13500	0,042	0,078	0,333	1,088
√	13600	0,036	0,058	0,333	1,074
√	13700	0,067	0,047	0,333	1,144
√	13800	0,081	0,036	0,333	1,176
√	13900	0,074	0,024	0,333	1,161
√	14000	0,062	0,030	0,333	1,132
√	14100	0,046	0,030	0,333	1,097
√	14200	0,049	0,032	0,333	1,103
√	14300	0,059	0,042	0,333	1,125
√	14400	0,058	0,045	0,333	1,123
√	14500	0,036	0,058	0,333	1,076
√	14600	0,029	0,060	0,333	1,060
√	14700	0,045	0,072	0,333	1,095
√	14800	0,066	0,114	0,333	1,142
√	14900	0,081	0,096	0,333	1,177
√	15000	0,097	0,109	0,333	1,214
√	15100	0,116	0,116	0,333	1,262
√	15200	0,119	0,095	0,333	1,269
√	15300	0,089	0,106	0,333	1,196
√	15400	0,043	0,067	0,333	1,089
√	15500	0,015	0,055	0,333	1,031

	f [MHz]	ρ_gen	N_ρ_gen	mv	VSWR
√	15600	0,032	0,052	0,333	1,067
√	15700	0,045	0,044	0,333	1,094
√	15800	0,063	0,068	0,333	1,133
√	15900	0,081	0,084	0,333	1,175
√	16000	0,092	0,095	0,333	1,202
√	16100	0,101	0,109	0,333	1,225
√	16200	0,091	0,112	0,333	1,201
√	16300	0,059	0,100	0,333	1,126
√	16400	0,028	0,109	0,333	1,058
√	16500	0,077	0,091	0,333	1,167
√	16600	0,119	0,055	0,333	1,271
√	16700	0,132	0,050	0,333	1,304
√	16800	0,123	0,033	0,333	1,280
√	16900	0,102	0,045	0,333	1,227
√	17000	0,088	0,059	0,333	1,193
√	17100	0,081	0,073	0,333	1,176
√	17200	0,077	0,101	0,333	1,167
√	17300	0,078	0,123	0,333	1,168
√	17400	0,082	0,116	0,333	1,178
√	17500	0,090	0,154	0,333	1,197
√	17600	0,105	0,160	0,333	1,234
√	17700	0,124	0,155	0,333	1,283
√	17800	0,130	0,184	0,333	1,298
√	17900	0,100	0,161	0,333	1,221
√	18000	0,072	0,145	0,333	1,155



Conclusion:
The item under calibrations was found to comply with manufacturers specifications, as given along with measurement results, for appropriately marked parameters.

Measurement results and their respective uncertainties refer to the measurements carried out during calibration and have no implication to the long term stability of the item.

26. Annex VII – Measurement report from NIS Egypt

ANNEX A

PARTICIPANT REPORT

1. PARTICIPANT INFORMATION

Laboratory Name:	Microwave laboratory
Name of contact person:	Abdel Rahman Salam
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2. MEASUREMENT DATE:

3. ENVIRONMENTAL CONDITIONS

Temperature : (23 ± 1) °C

Relative Humidity : (45 ± 1) %

4. STANDARDS USED IN MEASUREMENT

Instrument Name	Manufacturer	Type / Model	Serial Number	Traceability
Directional Bridge	Keysight	86205A	MY31403156	NIST
Directional Coupler	Keysight	773D	MY52180488	NIST
Spectrum analyzer	Rohde & Schwartz	FSP	1164.4391.30	PTB
Signal generator	Rohde & Schwartz	SMB-100A	175957	PTB

Pin depth

Device	Model	Serial number	Type	Recession (mm)	Protrusion (mm)
Synthesized CW generator	Hewlett Packard 83712A	3339A00223	Male-port	0.004953	-

5. DESCRIPTION OF MEASUREMENT METHOD

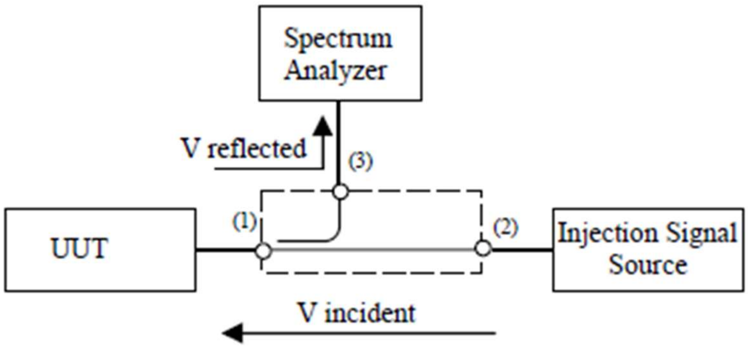

Fig.1. Diagram showing equipment setup.

The voltage reflection coefficient (VRC) of the signal generator is carried on using the injection method technique Fig.1 [1-Fig. 2]. A short description is: An HP synthesized CW generator model 83712A (DUT) feeds 0 dBm output power at frequencies (50MHz, 2 GHz, 8GHz, 12GHz , 15GHz , 18GHz) alternatively to keysight directional bridge model 86205A and keysight directional coupler model 773D both covering a part of the stated frequency range. For Frequency range from 50MHz to 2GHz directional bridge port 1 is connected with UUT HP synthesized CW generator, port 2 is injected by reference R&S signal generator, port 3 is connected with R&S spectrum analyser. For Frequency range from 2GHz to 18GHz directional coupler output port is injected by reference R&S signal generator, input port is connected with UUT HP synthesized CW generator, coupled port is connected with R&S spectrum analyser. The VRC is given by $|\Gamma| = Z_{UUT} / Z_{Max.}$ where Z_{UUT} = half (max-min) signal with UUT connected and $Z_{Max.}$ = mean signal with open & short connected at test ports (port 2 of directional bridge, input port of directional coupler) according to the stated frequency. The spectrum analyser is adjusted at zero span (time-domain mode) and a frequency offset of 100 Hz is added for UUT and reference generators in order to detect the maxima and minima signal. The contributions of VRC measurement uncertainty budget are Type A repeatability of the VRC measurements, Type B, the return loss of 86205A bridge or 773D coupler directivity, test port match and the uncertainty with which their values are known, linearity of R&S spectrum analyser, and R&S Signal generator uncertainty [2]. The uncertainty of directivity and test port match are calculated according to [3].

6. MEASUREMENT RESULTS:

Frequency	Voltage Reflection Coefficient of travelling standard @ 0 dBm			
	VRC Magnitude	Uncertainty (CL = 95.45%)	VRC Phase (if measured)	Uncertainty (CL = 95.45%)
50 MHz	0.043	0.0264	-	-
2 GHz	0.044	0.0643	-	-
8 GHz	0.062	0.0634	-	-
12 GHz	0.145	0.0641	-	-
15 GHz	0.125	0.0911	-	-
18 GHz	0.069	0.0924	-	-

7. UNCERTAINTY BUDGET

7.1. Voltage Reflection Coefficient (VRC) measurement uncertainty budget

Model function : $u_{\Gamma_{DUT}} = D + T\,\Gamma_{DUT} + M\,\Gamma_{DUT}^{\ 2} + R_{\Gamma_{DUT}}$

Frequency : 50 MHz

Output Level (CW) : 0 dBm

Definition of contribution	Expected Value x_i	Standard Uncertainty $u(x_i)$	Distribution Function	Sensitivity Coefficient c_i	Uncertainty contribution $u(y_i)$
Measurement Repeatability (Γ_{DUT})	0.043	0.0008	Normal	1	0.0008
Bridge Directivity (D)	0.010	0.0131	Rectangular	1	0.0131
Test port match (M)	0.070	0.0001	Rectangular	1	0.0001
Linearity of spectrum analyser (T)	0.000	0.0005	Rectangular	1	0.0005
Random contributions $R_{\Gamma_{DUT}}$ (Ref. signal generator at 0 dBm)	0.001	0.0010	Normal	1	0.0010
Measured Value	0.043	**Combined Uncertainty**			0.0132
		Expanded Uncertainty (CL = 95.45%)			0.0264

Model function : $u_{\Gamma_{DUT}} = D + T\,\Gamma_{DUT} + M\,\Gamma_{DUT}{}^2 + R_{\Gamma_{DUT}}$

Frequency : 2 GHz

Output Level (CW) : 0 dBm

Definition of contribution	**Expected Value** x_i	**Standard Uncertainty** $u(x_i)$	**Distribution Function**	**Sensitivity Coefficient** c_i	**Uncertainty contribution** $u(y_i)$
Measurement Repeatability (Γ_{DUT})	0.044	0.0015	Normal	1	0.0015
Bridge Directivity (D)	0.032	0.0321	Rectangular	1	0.0321
Test port match (M)	0.100	0.0002	Rectangular	1	0.0002
Linearity of spectrum analyser (T)	0.000	0.0005	Rectangular	1	0.0005
Random contributions $R_{\Gamma_{DUT}}$ (Ref. signal generator at 0 dBm)	0.001	0.0010	Normal	1	0.0010
Measured Value	0.044	**Combined Uncertainty**			0.0321
		Expanded Uncertainty (CL = 95.45%)			0.0642

Model function : $u_{\Gamma_{DUT}} = D + T\,\Gamma_{DUT} + M\,\Gamma_{DUT}{}^2 + R_{\Gamma_{DUT}}$

Frequency : 8 GHz

Output Level (CW) : 0 dBm

Definition of contribution	**Expected Value** x_i	**Standard Uncertainty** $u(x_i)$	**Distribution Function**	**Sensitivity Coefficient** c_i	**Uncertainty contribution** $u(y_i)$
Measurement Repeatability (Γ_{DUT})	0.062	0.0012	Normal	1	0.0012
Bridge Directivity (D)	0.032	0.0317	Rectangular	1	0.0317
Test port match (M)	0.130	0.0005	Rectangular	1	0.0005
Linearity of spectrum analyser (T)	0.000	0.0005	Rectangular	1	0.0005
Random contributions $R_{\Gamma_{DUT}}$ (Ref. signal generator at 0 dBm)	0.001	0.0010	Normal	1	0.0010
Measured Value	0.062	**Combined Uncertainty**			0.0317
		Expanded Uncertainty (CL = 95.45%)			0.0634

Model function : $u_{\Gamma_{DUT}} = D + T\,\Gamma_{DUT} + M\,\Gamma_{DUT}{}^{2} + R_{\Gamma_{DUT}}$

Frequency : 12 GHz

Output Level (CW) : 0 dBm

Definition of contribution	Expected Value x_i	Standard Uncertainty $u(x_i)$	Distribution Function	Sensitivity Coefficient c_i	Uncertainty contribution $u(y_i)$
Measurement Repeatability (Γ_{DUT})	0.145	0.0044	Normal	1	0.0044
Bridge Directivity (D)	0.032	0.0317	Rectangular	1	0.0317
Test port match (M)	0.130	0.0027	Rectangular	1	0.0027
Linearity of spectrum analyser (T)	0.000	0.0005	Rectangular	1	0.0005
Random contributions $R_{\Gamma_{DUT}}$ (Ref. signal generator at 0 dBm)	0.001	0.0010	Normal	1	0.0010
Measured Value	0.145	**Combined Uncertainty**			0.0321
		Expanded Uncertainty (CL = 95.45%)			0.0641

Model function : $u_{\Gamma_{DUT}} = D + T\,\Gamma_{DUT} + M\,\Gamma_{DUT}{}^{2} + R_{\Gamma_{DUT}}$

Frequency : 15 GHz

Output Level (CW) : 0 dBm

Definition of contribution	Expected Value x_i	Standard Uncertainty $u(x_i)$	Distribution Function	Sensitivity Coefficient c_i	Uncertainty contribution $u(y_i)$
Measurement Repeatability (Γ_{DUT})	0.125	0.0021	Normal	1	0.0021
Bridge Directivity (D)	0.045	0.0455	Rectangular	1	0.0455
Test port match (M)	0.170	0.0027	Rectangular	1	0.0027
Linearity of spectrum analyser (T)	0.000	0.0005	Rectangular	1	0.0005
Random contributions $R_{\Gamma_{DUT}}$ (Ref. signal generator at 0 dBm)	0.001	0.0010	Normal	1	0.0010
Measured Value	0.125	**Combined Uncertainty**			0.0455
		Expanded Uncertainty (CL = 95.45%)			0.0911

Model function : $u_{\Gamma_{DUT}} = D + T\,\Gamma_{DUT} + M\,\Gamma_{DUT}^{\;2} + R_{\Gamma_{DUT}}$

Frequency : 18 GHz

Output Level (CW) : 0 dBm

Definition of contribution	**Expected Value** x_i	**Standard Uncertainty** $u(x_i)$	**Distribution Function**	**Sensitivity Coefficient** c_i	**Uncertainty contribution** $u(y_i)$
Measurement Repeatability (Γ_{DUT})	0.069	0.0015	Normal	1	0.0015
Bridge Directivity (D)	0.045	0.0462	Rectangular	1	0.0462
Test port match (M)	0.170	0.0008	Rectangular	1	0.0008
Linearity of spectrum analyser (T)	0.000	0.0005	Rectangular	1	0.0005
Random contributions $R_{\Gamma_{DUT}}$ (Ref. signal generator at 0 dBm)	0.001	0.0010	Normal	1	0.0010
Measured Value	**0.069**	**Combined Uncertainty**			0.0462
		Expanded Uncertainty (CL = 95.45%)			**0.0924**

7.2. References

1. P. Roberts "Measuring Output VSWR For An Active Levelled Source", Measurement Science Conference, 2008.

2. P. Roberts, P. Bunyan "Source Match Measurement for a Levelled Generator", Fluke Precision Measurement Ltd, PCAR & PB Sept. 2006.

3. J. Hurll, "Uncertainty and confidence in measurements", ch3. Microwave Measurements, 3rd edition, The Institution of Engineering and Technology, 2007.