Final Report

Bilateral Comparison on Electric Field Measurements Between TÜBİTAK UME and SASO NMCC

GULFMET.EM.RF-S1

UME-EM-D3-2.23.6.a

Çağlar ASLAN
Abdullah M. ALROBAISH
Osman ŞEN

(Rev. 0)
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1. Introduction

It was planned to organise a bilateral comparison on electric field measurements between TÜBİTAK UME and SASO NMCC, in the frame of the Project of Development and Realization Measurement and Calibration System for the National Measurement and Calibration Center (NMCC) at Saudi Standards, Metrology and Quality Organization (SASO).

The bilateral comparison was carried out in accordance with the “Technical Protocol of Bilateral Comparison on Electric Field Measurements between TÜBİTAK UME and SASO NMCC [1] (Annex C) and the “CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons” [2]

The correction factor (CF) of each probe was determined at the frequencies of 100 Hz, 1 kHz, 10 MHz, 100 MHz, 1 GHz, 9 GHz and 18 GHz and at the indicated field level of 30 V/m.

TÜBİTAK UME was the pilot institute. The travelling standards were provided by TÜBİTAK UME. TÜBİTAK UME also was responsible for monitoring the standard performance during the circulation and the evaluation and for reporting the comparison results.

2. Travelling Standard

Electric field probes and analyzer/meter were used as travelling standards in this comparison. The travelling standards and details are given in Figure 1 and Table 1 respectively.

These standards were chosen for its high accuracy and stability in time.

(a) (b)

Figure 1. The photos of the travelling standards

(a) BN2245/90.31 and EFA 300 (b) EF 0691, EF 6091 and NBM-550

Table 1. The general specifications of the travelling standards

No	Device	Manufacturer/ Model	Serial Number	General Specifications
1	Electric Field Probe, Field Analyser	Wandel&Golterman/ EFA 300 BN2245/90.31	A-0074, A-0098	Frequency Range: 5 Hz to 32 kHz Measurement Range: 10 V/m to 100 kV/m Noise Level: 4.5 V/m Internal Batteries: NiMH Batteries (5x C-Cell), rechargeable Operating Temperature: 0 °C to +50 °C
2	Broadband Field Meter	Narda/ NBM-550	B-1002	Frequency Range: 100 kHz to 60 GHz Measurement Range: 0.01 V/m to 100 kV/m Internal Batteries: 3.7 V, 5.5 Ah, rechargeable Operating Temperature: -10 °C to +50 °C
3	Electric Field Probe	Narda/ EF 0691	A-0107	Frequency Range: 100 kHz to 6 GHz Measurement Range: 0.35 to 350 V/m Noise Level: 0.35 V/m Operating Temperature: -10 °C to +50 °C
4	Electric Field Probe	Narda/ EF 6091	01135	Frequency Range: 100 MHz to 60 GHz Measurement Range: 0.7 V/m to 300 V/m Noise Level: 0.7 V/m Operating Temperature: -10 °C to +50 °C

3. Participant Institutes

The pilot institute for this comparison was TÜBİTAK UME (Turkey). The contact details of the coordinator are given below:

Pilot Institute:	TÜBİTAK Ulusal Metroloji Enstitüsü (UME)
Coordinator :	Osman ŞEN Tel: +90 262 679 50 00 Fax: +90 262 679 50 01 E-mail: osman.sen@tubitak.gov.tr

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

Table 2. The information of the participant institutes

Country	Institute	Acronym	Shipping Address	Contact Person
Turkey	TÜBİTAK Ulusal Metroloji Enstitüsü	TÜBİTAK UME	TÜBİTAK Ulusal Metroloji Enstitüsü (UME) TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, TURKEY	Osman ŞEN osman.sen@tubitak.gov.tr Tel: +90 262 679 50 00
Saudi Arabia	SASO The National Measurement and Calibration Center	SASO NMCC	Saudi Standards, Metrology and Quality Organization of The Kingdom of Saudi Arabia (SASO) Riyadh 11471, P.O. Box 3437 KINGDOM of SAUDI ARABIA	Abdullah M. ALROBAISH a.robaish@saso.gov.sa Tel: +966 11 252 97 30

4. Time Schedule

The time schedule for the comparison is given in Table 3. The circulation of the travelling standards was organized to monitor the performance of the travelling standards. Each institute had one week to carry out the measurements.

Table 3. The time schedule for the comparison

Participant	Country	Measurement Dates
TÜBİTAK UME	Turkey	20.10.2016 – 25.10.2016
SASO NMCC	Saudi Arabia	13.12.2016 – 18.12.2016
TÜBİTAK UME	Turkey	20.01.2017 – 25.01.2017

5. Measurement Quantities and Points

Participants were required to calculate the correction factors (CF) using the following formula for the measurement points given Table 4 and declare them in the measurement report.

$$\text{Correction Factor (Linear)} = \frac{\text{Actual Field (V/m)}}{\text{Indicated Field (V/m)}}$$

$$\text{Correction Factor (dB)} = 20\times \log\left(\left(\text{Correction factor (linear)}\right)\right)$$

Table 4. Measurement levels & frequencies

Frequency	Level for Electric Field Measurements	Relevant Travelling Standard
100 Hz	30 V/m	BN2245/90.31 electric field probe with EFA 300 field analyser
1 kHz	30 V/m	
10 MHz	30 V/m	EF 0691 electric field probe with NBM-550 field meter
100 MHz	30 V/m	
1 GHz	30 V/m	EF 6091 electric field probe with NBM-550 field meter
9 GHz	30 V/m	
18 GHz	30 V/m	

6. Measurement Method

Participants were required to use its own measurement method.

The measurement method used by each participant is given in Annex A and Annex B.

7. Measurement Uncertainty

Participants were required to provide the detailed uncertainty budget and the expanded uncertainty according to IEEE Std. 1309 [3] and the JCGM 100 “Guide to the Expression of Uncertainty in Measurement” [4] for the coverage probability of approximately 95%.

The uncertainty budgets provided by each participant are given in Annex A and Annex B.

8. Measurement Report

Participants were required to report:

- The date and time of the measurements,
- A detailed description of the method used,
- The measurement standards used in the comparison measurements,
- Software used in the comparison measurements
- The environmental conditions during the measurements,
  - ambient temperature
  - relative humidity
- Results of measurement; which is prepared in a format given in the Technical Protocol.

The results were presented to the pilot institute in the format of the logarithmic (dB) correction factors of the travelling standards at the prescribed frequencies and field level given in the Technical Protocol.

9. Comparison Results

The comparison was organised in a single loop of two institutes.

The results of the measurements carried out by participants of comparisons were evaluated by the E_n criteria.

9.1. The Comparison Reference Value

The comparison reference value (CRV) x_{ref} as a weighted average and its uncertainty U_{ref} were calculated using Equations 1 and 2 [5].

$$x_{ref} = \frac{x_{UME1}/U_{UME1}^2 + x_{UME2}/U_{UME2}^2}{1/U_{UME1}^2 + 1/U_{UME2}^2} \tag{1}$$

$$\frac{1}{U_{ref}^2} = \frac{1}{U_{UME1}^2} + \frac{1}{U_{UME2}^2} \tag{2}$$

Where;

x_{UME1} is the result of first measurement performed by TÜBİTAK UME

x_{UME2} is the result of second measurement performed by TÜBİTAK UME

U_{UME1} is the expanded uncertainty of the first measurements performed by TÜBİTAK UME (k=2)

U_{UME2} is the expanded uncertainty of the second measurements performed by TÜBİTAK UME (k=2)

The measurement results of the UME and SASO NMCC and the comparison reference values for each frequency are presented in Table 5.

Table 5. Comparison reference values and its uncertainties (k=2)

Frequency	UME1		SASO NMCC		UME2		CRV	
	CF (dB)	U_{UME1} (dB)	CF (dB)	U_{SASO} (dB)	CF (dB)	U_{UME2} (dB)	x_{ref} (dB)	U_{ref} (dB)
100 Hz	-0.54	1.70	-0.35	2.00	-0.49	1.70	-0.52	1.20
1 kHz	-0.54	1.70	-0.35	2.00	-0.45	1.70	-0.50	1.20
10 MHz	0.26	1.72	0.42	2.02	0.10	1.72	0.18	1.22
100 MHz	-0.18	1.72	-0.92	2.02	-0.08	1.72	-0.13	1.22
1 GHz	-1.11	2.02	-1.51	2.54	-1.26	2.02	-1.19	1.42
9 GHz	1.51	2.02	1.36	2.54	1.46	2.02	1.49	1.42
18 GHz	3.23	2.02	3.05	2.54	3.15	2.02	3.19	1.42

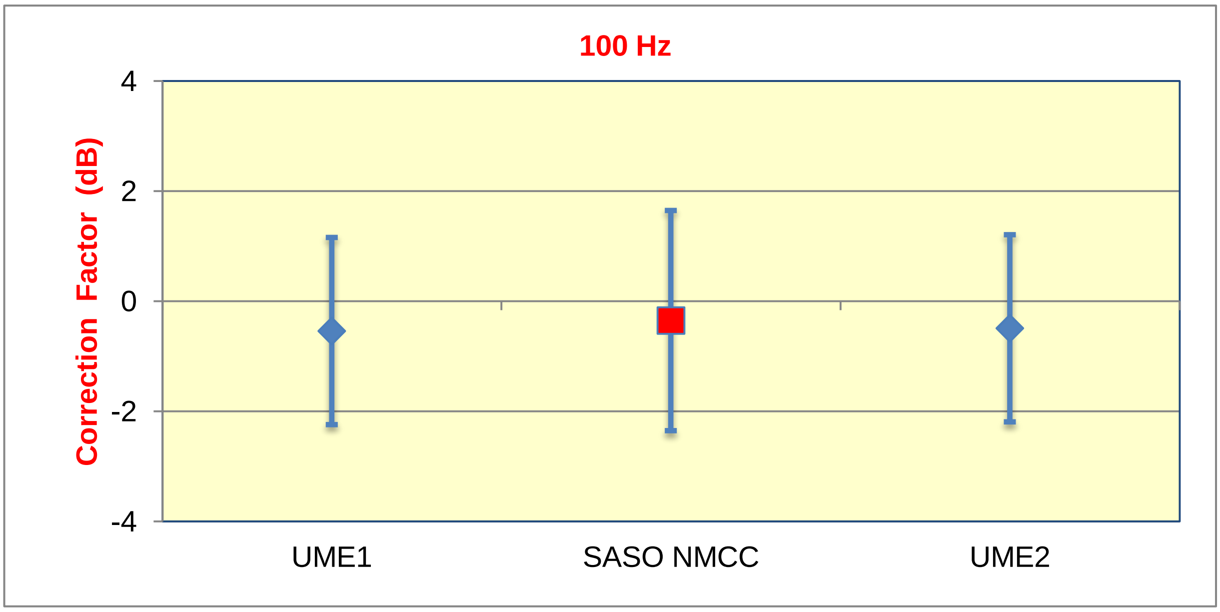

Figure 2. Measurement results for 100 Hz

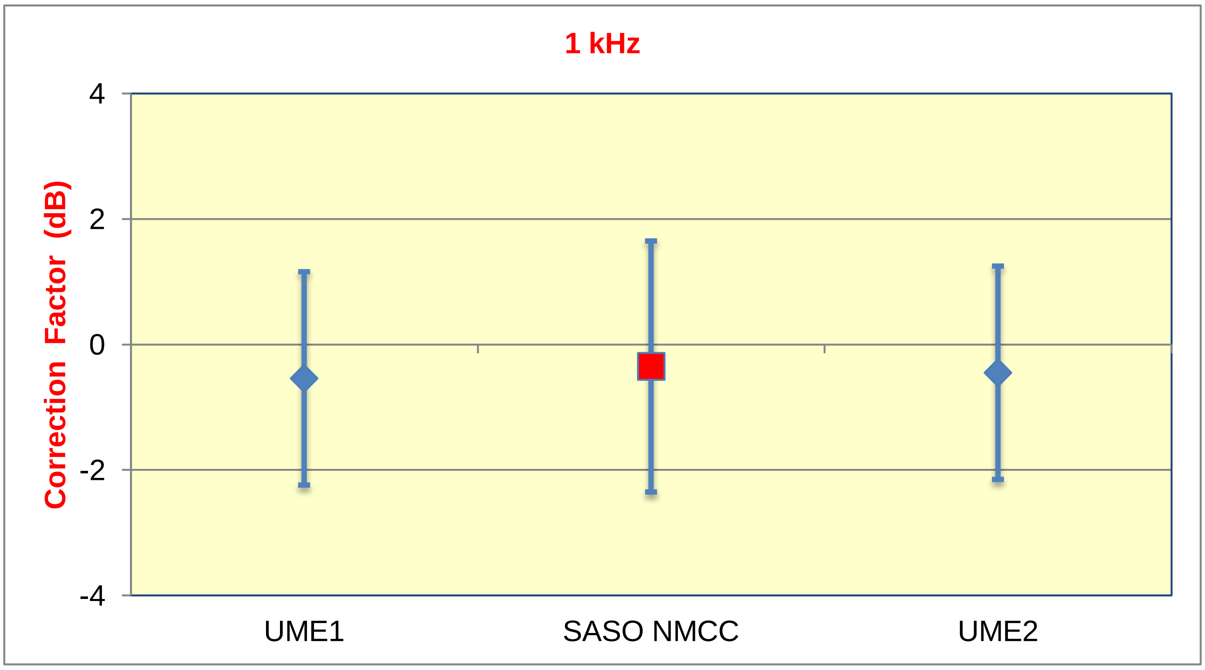

Figure 3. Measurement results for 1 kHz

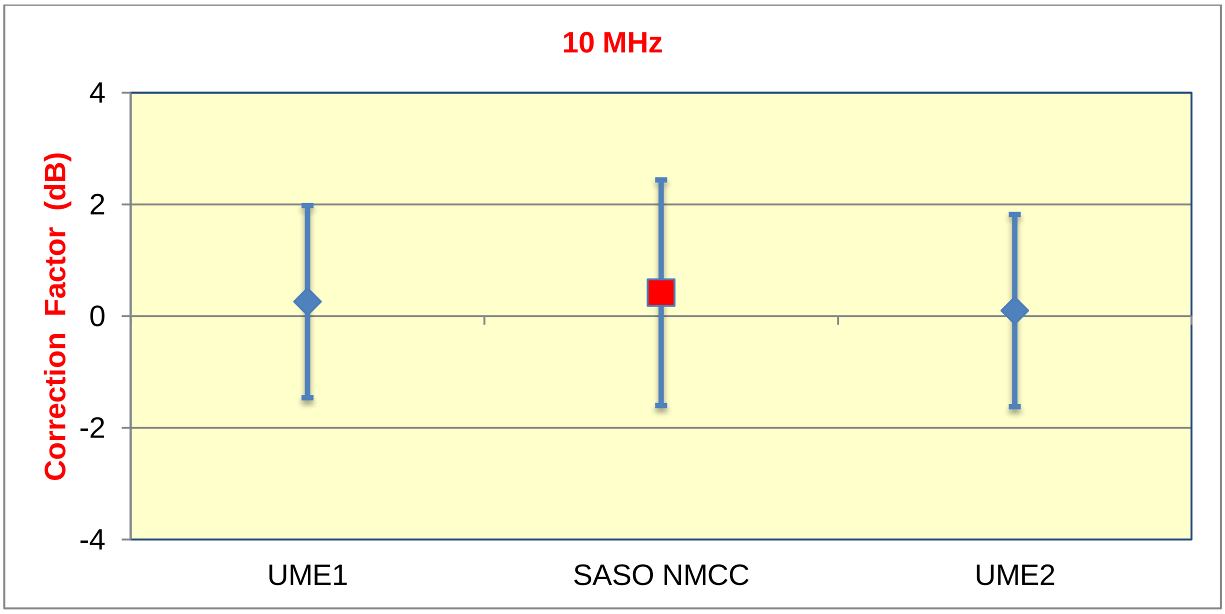

Figure 4. Measurement results for 10 MHz

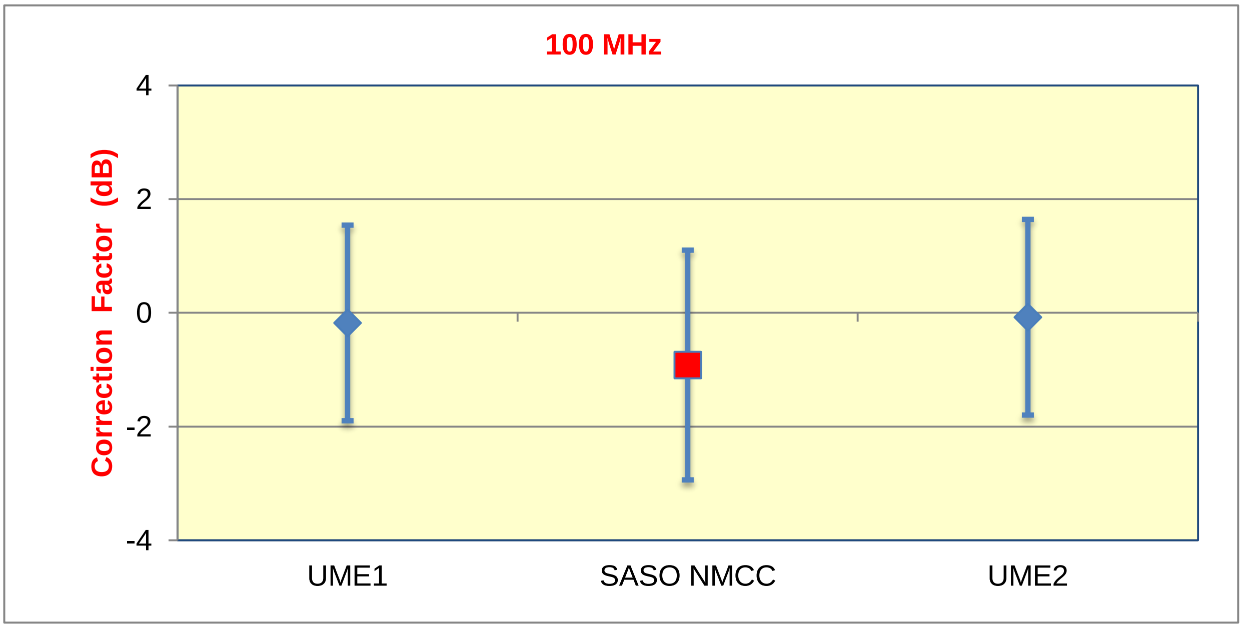

Figure 5. Measurement results for 100 MHz

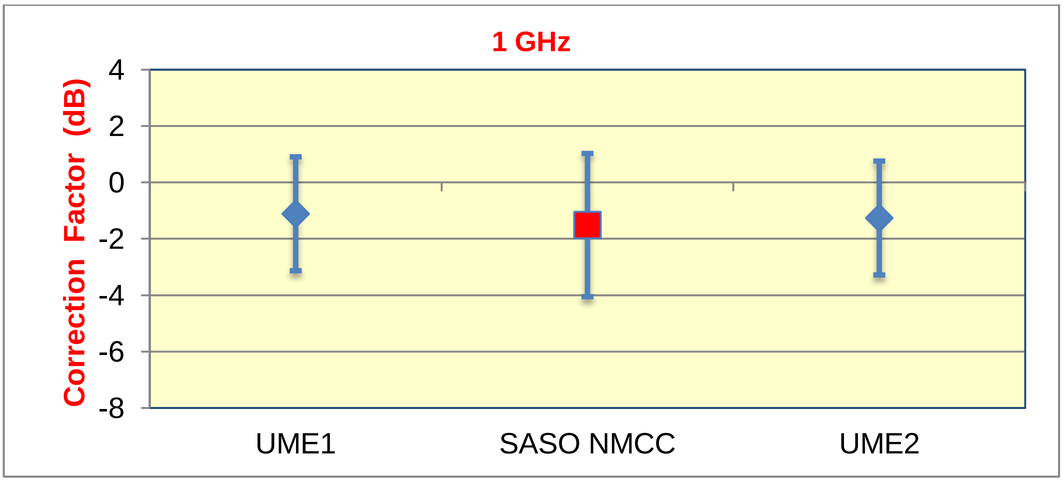

Figure 6. Measurement results for 1 GHz

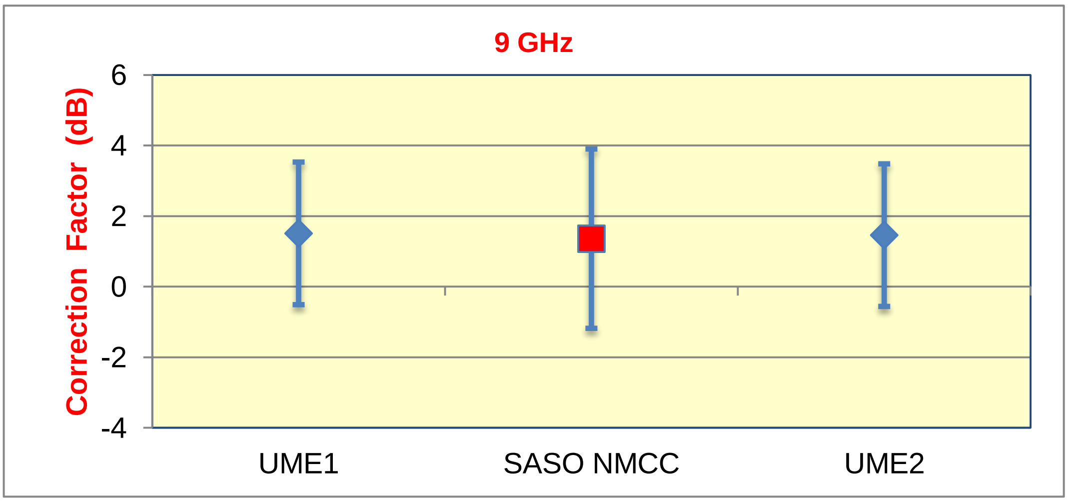

Figure 7. Measurement results for 9 GHz

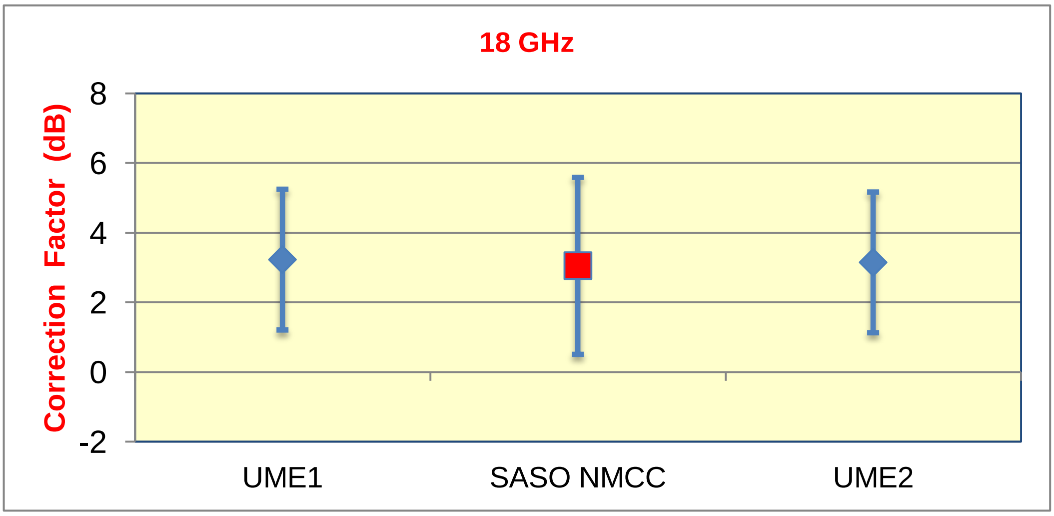

Figure 8. Measurement results for 18 GHz

9.2. Comparison Result

The E_n criteria defined at ISO/IEC 17043 "Conformity assessment – General requirements for proficiency testing" [6] was calculated using Equation 3.

$$\mathrm{E_n} = \frac{(x_{SASO} - x_{ref})}{\sqrt{U_{SASO}^2 + U_{ref}^2}} \qquad (3)$$

x_{SASO} is the correction factor declared by SASO NMCC

x_{ref} is the comparison reference value

U_{SASO} is expanded uncertainty declared by SASO NMCC (k=2)

U_{ref} is expanded uncertainty of the comparison reference value (k=2)

If $|E_n| \leq 1$ then it is satisfactory

If $|E_n| > 1$ then it is unsatisfactory

The calculated E_n numbers for SASO NMCC are given in Table 6. As shown in Table 6, as all the $|E_n|$ numbers for the correction factors for measurement points are less than 1. Therefore, the comparison results are accounted satisfactory.

Table 6. E_n numbers of SASO NMCC

Frequency	x_{SASO} (dB)	U_{SASO} (dB)	x_{ref} (dB)	U_{ref} (dB)	$\lvert E_n \rvert$
100 Hz	-0.35	2.00	-0.52	1.20	0.07
1 kHz	-0.35	2.00	-0.50	1.20	0.06
10 MHz	0.42	2.02	0.18	1.22	0.10
100 MHz	-0.92	2.02	-0.13	1.22	0.33
1 GHz	-1.51	2.54	-1.19	1.42	0.11
9 GHz	1.36	2.54	1.49	1.42	0.04
18 GHz	3.05	2.54	3.19	1.42	0.05

10. Report of the Comparison

The results of the GULFMET.EM.RF-S1 regional supplemental comparison has been analyzed and reported in this Draft A report by the pilot institute, TÜBİTAK UME. The Draft A report has been approved by all participants.

11. References

[1] Technical Protocol, “Bilateral Comparison on Magnetic Field Measurements Between TÜBİTAK UME and SASO NMCC”, GULFMET.EM.RF-S1, UME-EM-D3-2.23.6 (a), Rev.2, 2017

[2] 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)

[3] IEEE Std. 1309:2005, "IEEE Standard for calibration of electromagnetic field sensors and probes, excluding antennas, from 9 kHz to 40 GHz".

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

[5] W. Bich, M. Cox, T. Estler, L. Nielsen, W. Woeger, “Proposed guidelines for the evaluation of key comparison data”, April 2002. Available at: http://www.bipm.org/cc/CCAUV/Allowed/3/CCAUV02-36.pdf.

[6] ISO / IEC 17043 “Conformity assessment — General requirements for proficiency testing”, International Standardization Organization”, 2010

ANNEX A. Measurement Report of TÜBİTAK UME

1. PARTICIPANT INFORMATION

Institute Name	TÜBİTAK UME
Contact Persons	Osman ŞEN, Çağlar ASLAN
Telephone No	+90 262 679 50 00
Fax No	+90 262 679 50 01
E-mail	osman.sen@tubitak.gov.tr, caglar.aslan@tubitak.gov.tr
Address	TÜBİTAK UME Gebze Yerleşkesi Barış Mah.Dr. Zeki Acar Cad. No: 1 Gebze 41470 Kocaeli TURKEY

2. MEASUREMENT DATE

20.10.2016 – 25.10.2016 (First measurements)

3. ENVIRONMENTAL CONDITION

Temperature : (22 ± 2) °C

Relative Humidity : (45 ± 10) %rh

4. REFERENCES USED IN MEASUREMENT

Instrument Name	Manufacturer	Type / Model
Signal Generator	Agilent Technologies	33120A
Signal Generator	IFR Inc.	2023A
Signal Generator	Agilent Technologies	E8257C
Power Sensor	Rohde & Schwarz	NRV-Z55
Power Sensor	Rohde & Schwarz	NRP-Z55
Power Meter	Rohde & Schwarz	NRVD
Power Meter	Rohde & Schwarz	NRP2
50 Ohm Termination	Schaffner	50R50WCW

Instrument Name	Manufacturer	Type / Model
40 dB Attenuator	Aeroflex / Weinschel	45-40-34
Directional Coupler	Bonn Elektronik	BDC 0125-40/500
Directional Coupler	Bonn Elektronik	BDC 0810-40/500
Horn Antenna	Schwarzbeck	BBHA 9120E
Horn Antenna	A-INFO	JXTXLB-90-15-C-NF
Horn Antenna	A-INFO	JXTXLB-62-15-C-NF
Directional Coupler	Amplifier Research	DC6180M2
Directional Coupler	PNR 90-303A-40F-40R-6-6	K412107z-01
Directional Coupler	PNR 62-303A-30F-30R-6-6	K412407z-01
TEM Cell	IFI	CC103SEX
TEM Cell	IFI	CC105SEXX

5. MEASUREMENT PROCEDURE FOR ELECTRIC FIELD

5.1. ELECTRIC FIELD MEASUREMENT FOR 100 Hz, 1 kHz, 10 MHz, 100 MHz

The measurements were performed in accordance with the “Technical Protocol of bilateral comparison on electric field measurements between TÜBİTAK UME and SASO NMCC” and the IEEE Std 1309:2005 Calibration Method B using calculated field strength. In the frequency range 100 Hz to 100 MHz, two Transverse Electromagnetic (TEM) cells were used to generate a calculable electric field level. The calculable electric field was calculated from the dimensions of the TEM cell, its impedance, and from the net power of the TEM Cell input as shown in the following equation:

$$E = \frac{\sqrt{P_{net} Z_0}}{b}$$

where;

E : RMS Electric field strength (V/m)

P_{net} : Net power of the TEM Cell input/output (W)

Z_0 : The real part of the characteristic impedance of the TEM Cell (Ω)

b : The distance from the upper wall to the center plate (m)

The general calibration setups are depicted in Figure 1 and Figure 2.

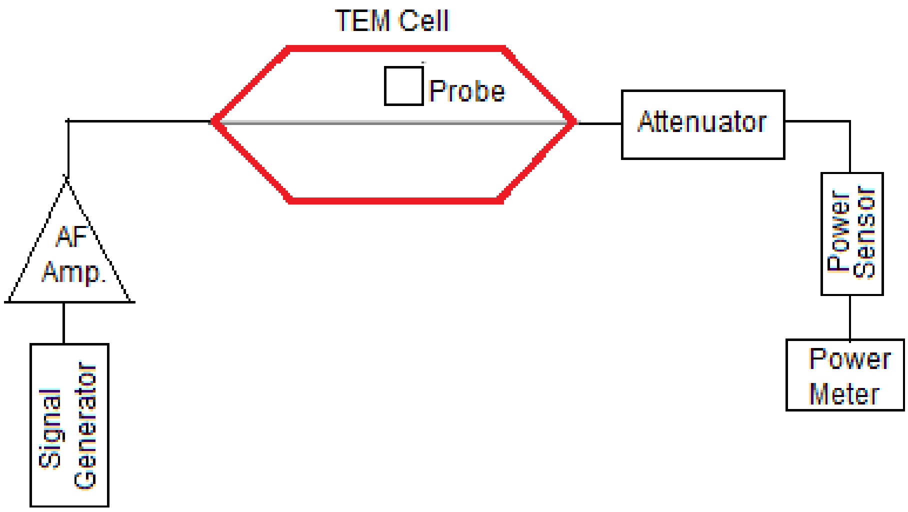

Figure 1. Measurement setup for 100 Hz, 1 kHz

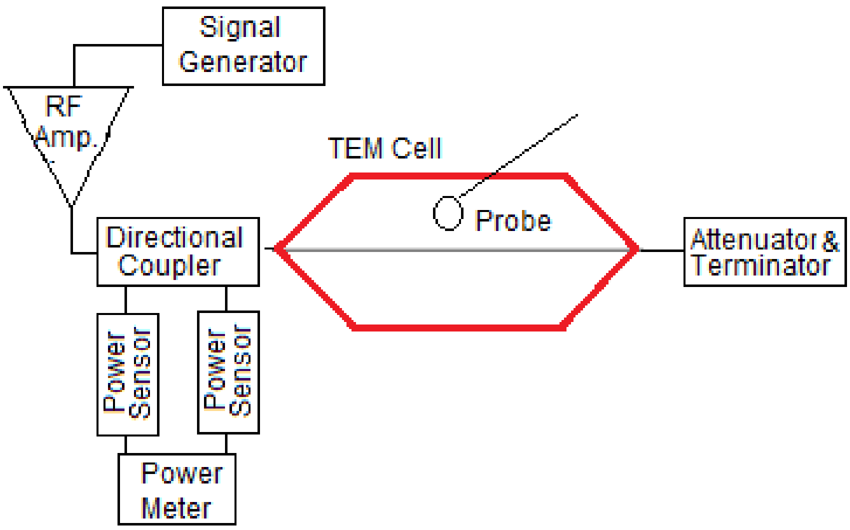

Figure 2. Measurement setup for 10 MHz, 100 MHz

5.2. ELECTRIC FIELD MEASUREMENT FOR 1 GHz, 9 GHz, 18 GHz

The measurements were performed in accordance with the technical protocol bilateral comparison on electric field measurements between TÜBİTAK UME and SASO NMCC and the IEEE Std 1309:2005 Calibration Method B using calculated field strength in a full-anechoic chamber, whose net dimensions (from tip to tip of absorbers) are 2.6 m (w) x 5.6 m (l) x 2.3 m (h), by using a transmitting horn antenna, The net power fed into the antenna, its gain and the distance between the antenna and the field probe under calibration.

The calculable electric field was calculated as shown in the following equation:

$$E = \sqrt{\frac{\eta P_{net} g}{4 \pi d^2}}$$

where;

E	:	Free space RMS electric field strength (V/m)
P_{net}	:	Net power to the transmitting antenna (W)
g	:	The gain of the transmitting antenna in the direction toward the receiving point relative to an isotropic radiator (dimensionless)
d	:	The distance from the transmitting antenna to the probe in meter
η	:	The intrinsic impedance of propagation medium in ohms (377 Ω)

The general calibration setup is depicted in Figure 3 and Figure 4.

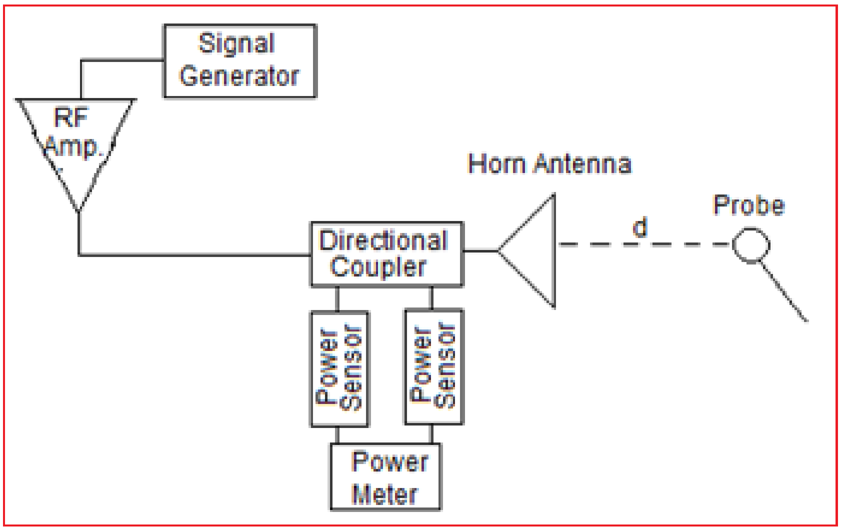

Figure 3. Measurement setup for 1 GHz

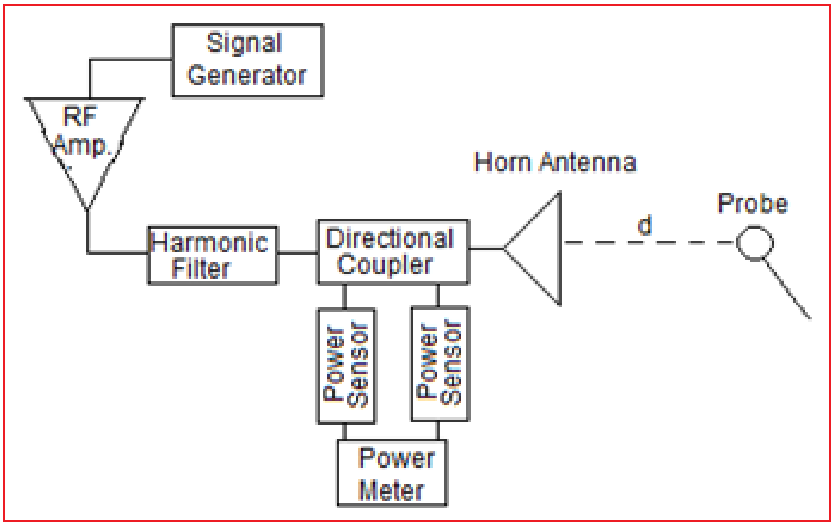

Figure 4. Measurement setup for 9 GHz, 18 GHz

6. MEASUREMENT RESULTS

The electric field measurement results, the correction factors and uncertainty values are presented in Table 1.

Table 1. Measurement results

Frequency	Actual Field (V/m)	Indicated Field (V/m)	Correction Factor (Linear)	Correction Factor (dB)	Uncertainty (dB) (k=2)	Ambient Temperature (°C)	Ambient Humidity (%rh)
100 Hz	30.71	32.80	0.94	-0.54	1.70	22 ± 2	45 ± 10
1 kHz	30.68	32.63	0.94	-0.54	1.70	22 ± 2	45 ± 10
10 MHz	30.74	29.96	1.03	0.26	1.72	22 ± 2	45 ± 10
100 MHz	30.72	31.40	0.98	-0.18	1.72	22 ± 2	45 ± 10
1 GHz	30.31	34.52	0.88	-1.11	2.02	22 ± 2	45 ± 10
9 GHz	30.22	25.46	1.19	1.51	2.02	22 ± 2	45 ± 10
18 GHz	30.0	20.62	1.45	3.23	2.02	22 ± 2	45 ± 10

7. UNCERTAINTY BUDGETS

The uncertainty budgets are given between Table 2 and Table 8.

Table 2. Uncertainty budget for 100 Hz

Source of Uncertainty x_i	Uncertainty U_x (dB)	Probability Distribution	Divisor	Sensitivity Coefficient C_i	Uncertainty Contribution $(U_i \times C_i)^2$ (dB)
Power meter reading error	0.50	Rectangular	1.732	1	0.083
Power sensor reading error	0.10	Normal	2	1	0.003
TEM cell impedance error	1.00	Rectangular	1.732	1	0.333
Error of TEM cell septum distance	0.30	Rectangular	1.732	1	0.030
Impedance mismatch error	0.20	U-shaped	1.414	1	0.020
Probe position error	0.50	Rectangular	1.732	1	0.083
TEM cell uniformity error	0.50	Rectangular	1.732	1	0.083
Non-uniformity field error due to probe	0.45	Rectangular	1.732	1	0.068
Error from attenuator	0.20	Rectangular	1.732	1	0.013
Repeatability	0.04	Normal	1	1	0.002
				Combined Uncertainty	**0.85**
				Expanded Uncertainty (k=2)	**1.70**

Table 3. Uncertainty budget for 1 kHz

Source of Uncertainty x_i	Uncertainty U_x (dB)	Probability Distribution	Divisor	Sensitivity Coefficient C_i	Uncertainty Contribution $(U_i \times C_i)^2$ (dB)
Power meter reading error	0.50	Rectangular	1.732	1	0.083
Power sensor reading error	0.10	Normal	2	1	0.003
TEM cell impedance error	1.00	Rectangular	1.732	1	0.333
Error of TEM cell septum distance	0.30	Rectangular	1.732	1	0.030
Impedance mismatch error	0.20	U-shaped	1.414	1	0.020
Probe position error	0.50	Rectangular	1.732	1	0.083
TEM cell uniformity error	0.50	Rectangular	1.732	1	0.083
Non-uniformity field error due to probe	0.45	Rectangular	1.732	1	0.068
Error from attenuator	0.20	Rectangular	1.732	1	0.013
Repeatability	0.07	Normal	1	1	0.005
				Combined Uncertainty	**0.85**
				Expanded Uncertainty (k=2)	**1.70**

Table 4. Uncertainty budget for 10 MHz

Source of Uncertainty x_i	Uncertainty U_x (dB)	Probability Distribution	Divisor	Sensitivity Coefficient C_i	Uncertainty Contribution $(U_i \times C_i)^2$ (dB)
Power meter reading error	0.50	Rectangular	1.732	1	0.083
Power sensor reading error	0.10	Normal	2	1	0.003
TEM cell impedance error	1.00	Rectangular	1.732	1	0.333
Error of TEM cell septum distance	0.30	Rectangular	1.732	1	0.030
Impedance mismatch error	0.20	U-shaped	1.414	1	0.020
Probe position error	0.50	Rectangular	1.732	1	0.083
TEM cell uniformity error	0.50	Rectangular	1.732	1	0.083
Non-uniformity field error due to probe	0.50	Rectangular	1.732	1	0.083
Error of directional coupler	0.20	Normal	2	1	0.010
Repeatability	0.12	Normal	1	1	0.014
				Combined Uncertainty	**0.86**
				Expanded Uncertainty (k=2)	**1.72**

Table 5. Uncertainty budget for 100 MHz

Source of Uncertainty x_i	Uncertainty U_x (dB)	Probability Distribution	Divisor	Sensitivity Coefficient C_i	Uncertainty Contribution $(U_i \times C_i)^2$ (dB)
Power meter reading error	0.50	Rectangular	1.732	1	0.083
Power sensor reading error	0.10	Normal	2	1	0.003
TEM cell impedance error	1.00	Rectangular	1.732	1	0.333
Error of TEM cell septum distance	0.30	Rectangular	1.732	1	0.030
Impedance mismatch error	0.20	U-shaped	1.414	1	0.020
Probe position error	0.50	Rectangular	1.732	1	0.083
TEM cell uniformity error	0.50	Rectangular	1.732	1	0.083
Non-uniformity field error due to probe	0.50	Rectangular	1.732	1	0.083
Error of directional coupler	0.20	Normal	2	1	0.010
Repeatability	0.08	Normal	1	1	0.006
				Combined Uncertainty	**0.86**
				Expanded Uncertainty (k=2)	**1.72**

Table 6. Uncertainty budget for 1 GHz

Source of Uncertainty x_i	Uncertainty U_x (dB)	Probability Distribution	Divisor	Sensitivity Coefficient C_i	Uncertainty Contribution $(U_i \times C_i)^2$ (dB)
Power meter reading error	0.5	Rectangular	1.732	1	0.083
Power sensor reading error	0.1	Normal	2	1	0.003
Impedance mismatch error between horn antenna and directional coupler	0.2	U-shaped	1.414	1	0.020
Impedance mismatch error from forward power sensor	0.2	U-shaped	1.414	1	0.020
Impedance mismatch error from reverse power sensor	0.2	U-shaped	1.414	1	0.020
Impedance mismatch error from directional coupler	0.2	U-shaped	1.414	1	0.020
Distance error between probe and antenna	0.5	Rectangular	1.732	1	0.083
Horn antenna alignment	0.2	Rectangular	1.732	1	0.013
Error of directional coupler	0.2	Normal	2	1	0.010
Reflection error from floor	0.2	Rectangular	1.732	1	0.013
Flexibility error from cables	0.2	Rectangular	1.732	1	0.013
Heating error from cables	0.2	Rectangular	1.732	1	0.013
Reflection error from chamber	0.6	Rectangular	1.732	1	0.120
Instrument linearity error	0.2	Rectangular	1.732	1	0.013
Horn antenna gain error	1.5	Normal	2	1	0.563
Repeatability	0.11	Normal	1	1	0.012
				Combined Uncertainty	**1.01**
				Expanded Uncertainty (k=2)	**2.02**

Table 7. Uncertainty budget for 9 GHz

Source of Uncertainty x_i	Uncertainty U_x (dB)	Probability Distribution	Divisor	Sensitivity Coefficient C_i	Uncertainty Contribution $(U_i \times C_i)^2$ (dB)
Power meter reading error	0.5	Rectangular	1.732	1	0.083
Power sensor reading error	0.1	Normal	2	1	0.003
Impedance mismatch error between horn antenna and directional coupler	0.2	U-shaped	1.414	1	0.020
Impedance mismatch error from forward power sensor	0.2	U-shaped	1.414	1	0.020
Impedance mismatch error from reverse power sensor	0.2	U-shaped	1.414	1	0.020
Impedance mismatch error from directional coupler	0.2	U-shaped	1.414	1	0.020
Distance error between probe and antenna	0.5	Rectangular	1.732	1	0.083
Horn antenna alignment	0.2	Rectangular	1.732	1	0.013
Error of directional coupler	0.3	Normal	2	1	0.023
Reflection error from floor	0.2	Rectangular	1.732	1	0.013
Flexibility error from cables	0.2	Rectangular	1.732	1	0.013
Heating error from cables	0.2	Rectangular	1.732	1	0.013
Reflection error from chamber	0.6	Rectangular	1.732	1	0.120
Instrument linearity error	0.2	Rectangular	1.732	1	0.013
Horn antenna gain error	1.5	Normal	2	1	0.563
Repeatability	0.04	Normal	1	1	0.002
				Combined Uncertainty	**1.01**
				Expanded Uncertainty (k=2)	**2.02**

Table 8. Uncertainty budget for 18 GHz

Source of Uncertainty x_i	Uncertainty U_x (dB)	Probability Distribution	Divisor	Sensitivity Coefficient C_i	Uncertainty Contribution $(U_i \times C_i)^2$ (dB)
Power meter reading error	0.5	Rectangular	1.732	1	0.083
Power sensor reading error	0.1	Normal	2	1	0.003
Impedance mismatch error between horn antenna and directional coupler	0.2	U-shaped	1.414	1	0.020
Impedance mismatch error from forward power sensor	0.2	U-shaped	1.414	1	0.020
Impedance mismatch error from reverse power sensor	0.2	U-shaped	1.414	1	0.020
Impedance mismatch error from directional coupler	0.2	U-shaped	1.414	1	0.020
Distance error between probe and antenna	0.5	Rectangular	1.732	1	0.083
Horn antenna alignment	0.2	Rectangular	1.732	1	0.013
Error of directional coupler	0.3	Normal	2	1	0.023
Reflection error from floor	0.2	Rectangular	1.732	1	0.013
Flexibility error from cables	0.2	Rectangular	1.732	1	0.013
Heating error from cables	0.2	Rectangular	1.732	1	0.013
Reflection error from chamber	0.6	Rectangular	1.732	1	0.120
Instrument linearity error	0.2	Rectangular	1.732	1	0.013
Horn antenna gain error	1.5	Normal	2	1	0.563
Repeatability	0.06	Normal	1	1	0.004
				Combined Uncertainty	**1.01**
				Expanded Uncertainty (k=2)	**2.02**

ANNEX B. Measurement Report of SASO NMCC

1. PARTICIPANT INFORMATION

Institute Name	SASO NMCC
Prepared by	Abdullah M. ALROBAISH
Telephone No	+966 11 252 9711
E-mail	a.robaish@saso.gov.sa
Measurement Carried out by	Saleh AlMojaewel, Tariq AlOtaibi
Address	Saudi Standards, Metrology and Quality Organisation of The Kingdom of Saudi Arabia (SASO) Riyadh 11471, P.O. Box 3437 Kingdom of Saudi Arabia

2. MEASUREMENT DATE

13.12.2016 -18.12.2016

3. ENVIRONMENTAL CONDITION

Temperature : (22 ± 2) °C

Relative Humidity : (45 ± 10) %rh

4. REFERENCES USED IN MEASUREMENT

Instrument Name	Manufacturer	Type / Model
Signal Generator	Agilent Technologies	33500B
Signal Generator	Agilent Technologies	N5171B
Signal Generator	Agilent Technologies	N5183A
Power Sensor	Rohde & Schwarz	NRP-Z55
Power Meter	Rohde & Schwarz	NRP 2
50 Ohm Termination	PASTERNACK	PE6189

Instrument Name	Manufacturer	Type / Model
40 dB Attenuator	Aeroflex / Weinschel	45-40-34
Directional Coupler	Bonn Elektronik	BDC 0125-40/500
Directional Coupler	Bonn Elektronik	BDC 0810-40/500
Horn Antenna	Schwarzbeck	BBHA 9120E
Horn Antenna	A.H. Systems	SAS-585
Horn Antenna	A.H. Systems	SAS-586
Directional Coupler	PNR 90-303A-40F-40R-6-6	K412107z-01
Directional Coupler	PNR 62-303A-30F-30R-6-6	K412407z-01
TEM Cell	IFI	CC103SEX
TEM Cell	IFI	CC105SEXX

5. MEASUREMENT PROCEDURE FOR ELECTRIC FIELD

5.1. ELECTRIC FIELD MEASUREMENTS FOR 100 Hz, 1 kHz, 10 MHz, 100 MHz

The electric field measurements were carried out according to the “Technical Protocol of Bilateral Comparison on Electric Field Measurements between TÜBİTAK UME and SASO NMCC” and the IEEE Std 1309:2005. The calculable electric field level was generated by using two types of TEM cell at frequencies of 100 Hz, 1 kHz, 10 MHz, 100 MHz as 30 V/m. The calculable electric field level was calculated by means of the formula given below.

$$E = \frac{\sqrt{P_{net} Z_0}}{b}$$

Where;

E is the RMS Electric field strength (V/m)

P_{net} is the net power of the TEM Cell input/output (W) ($P_{fwd} - P_{ref}$)

Z_0 is the characteristic impedance of the TEM Cell (Ω)

b is the distance from the upper wall to the center plate (m)

The general measurement setups are shown in Figure 1 and Figure 2.

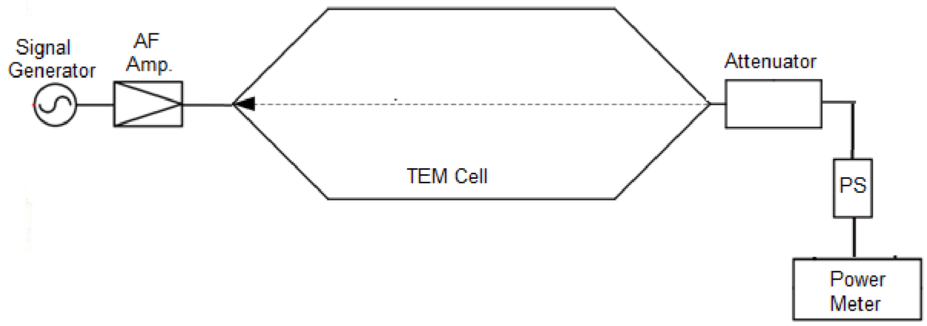

Figure 1. Schematic view of the electric field measurement for 100 Hz, 1 kHz

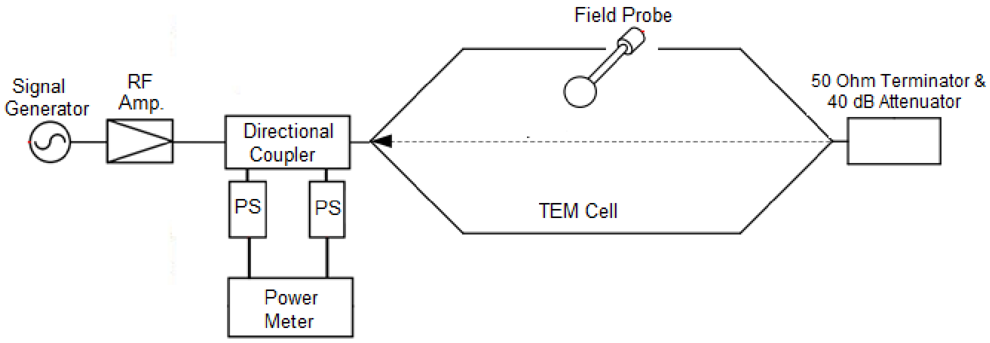

Figure 2. Schematic view of the electric field measurement for 10 MHz, 100 MHz

5.2. ELECTRIC FIELD MEASUREMENTS FOR 1 GHz, 9 GHz, 18 GHz

The electric field measurements were carried out according to the "Technical protocol of bilateral comparison on electric field measurements between TÜBİTAK UME and SASO NMCC" and the IEEE Std 1309:2005. A coaxially fed double ridged guide horn antenna for 1 GHz frequency and the standard gain horn antennas for 9 GHz, 18 GHz frequencies were used as the transmitting sources to generate known reference fields in the fully anechoic chamber. The directional coupler, the power sensor and power meter were used to determine the input of the transmitting horn antenna.

The calculable electric field level was calculated by using the equation below.

$$E=\sqrt{\frac{\eta P_{net}g}{4\pi d^2}}$$

Where;

E : Free space RMS electric field strength (V/m)

P_{net} : Net power to the transmitting antenna (W)

g : The gain of the transmitting antenna in the direction toward the receiving point relative to an isotropic radiator (dimensionless)

d : The distance from the transmitting antenna to the probe in meter

η : The intrinsic impedance of propagation medium in ohms (377 Ω)

The general calibration setup is shown in Figure 3 and Figure 4.

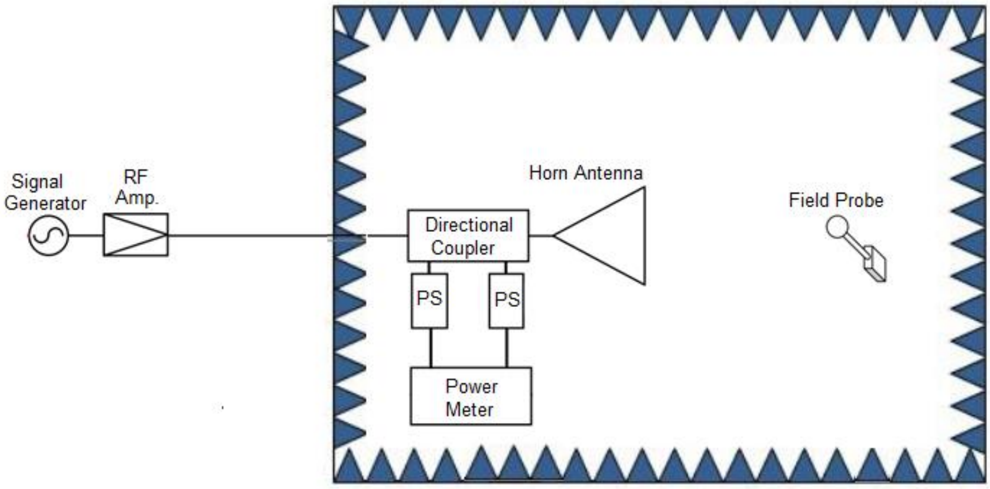

Figure 3. Schematic view of the electric field measurement for 1 GHz

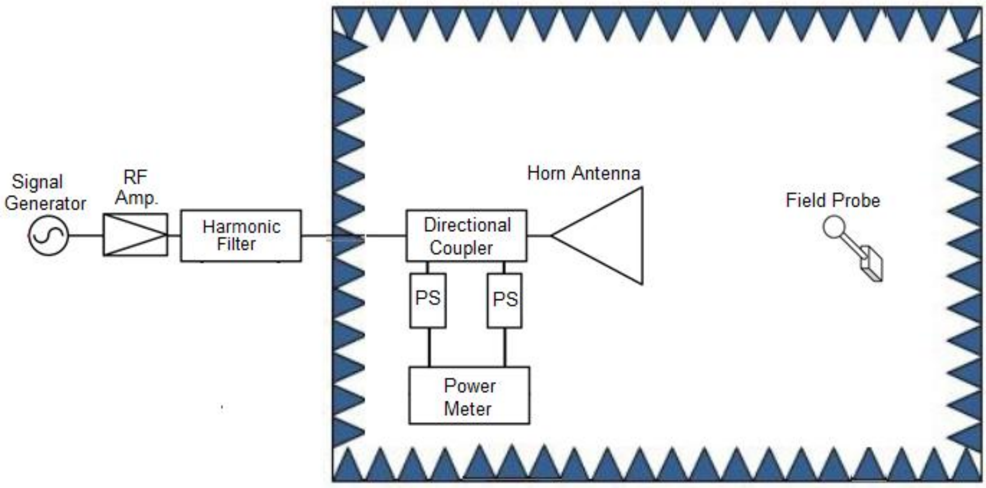

Figure 4. Schematic view of the electric field measurement for 9 GHz, 18 GHz

6. MEASUREMENT RESULTS

Frequency	Actual Field (V/m)	Indicated Field (V/m)	Correction Factor (Linear)	Correction Factor (dB)	Measurement Uncertainty (dB) (k=2)	Ambient Temperature (°C)	Ambient Humidity (%rh)
100 Hz	30.64	32.05	0.96	-0.35	2.00	22 ± 2	45 ± 10
1 kHz	30.64	32.04	0.96	-0.35	2.00	22 ± 2	45 ± 10
10 MHz	30.51	29.05	1.05	0.42	2.02	22 ± 2	45 ± 10
100 MHz	30.70	33.96	0.90	-0.92	2.02	22 ± 2	45 ± 10
1 GHz	30.67	36.58	0.84	-1.51	2.54	22 ± 2	45 ± 10
9 GHz	30.71	26.23	1.17	1.36	2.54	22 ± 2	45 ± 10
18 GHz	30.62	21.50	1.42	3.05	2.54	22 ± 2	45 ± 10

7. UNCERTAINTY BUDGETS

Model function for 30 V/m level field and 100 Hz, 1 kHz frequencies:

Table 1. Uncertainty budget for BN2245/90.31 electric field probe (With EFA 300 analyzer) with 30 V/m at 100 Hz and 1 kHz

Source of uncertainty	Uncertainty U_x (dB)	Probability Distribution	Divisor	Sensitivity Coefficient C_i	Uncertainty Contribution $(U_i \times C_i)^2$ (dB)
Power meter reading error	0.50	Rectangular	1.732	1	0.083
Power sensor reading error	0.10	Normal	2	1	0.003
TEM cell impedance error	1.00	Rectangular	1.732	1	0.333
Error of TEM cell septum distance	0.30	Rectangular	1.732	1	0.030
Impedance mismatch error	0.20	U-shaped	1.414	1	0.020
Probe position error	1.00	Rectangular	1.732	1	0.333
TEM cell uniformity error	0.50	Rectangular	1.732	1	0.083
Non-uniformity field error due to probe	0.45	Rectangular	1.732	1	0.068
Error from attenuator	0.20	Rectangular	1.732	1	0.013
Repeatability	0.20	Normal	1	1	0.040
				Combined Uncertainty	**1.00**
				Expanded Uncertainty (k=2)	**2.00**

Table 2. Uncertainty budget for EF 0691 electric field probe (With NBM-550 meter) with 30 V/m at 10 MHz and 100 MHz

Source of uncertainty	Uncertainty U_x (dB)	Probability Distribution	Divisor	Sensitivity Coefficient C_i	Uncertainty Contribution $(U_i \times C_i)^2$ (dB)
Power meter reading error	0.50	Rectangular	1.732	1	0.083
Power sensor reading error	0.10	Normal	2	1	0.003
TEM cell impedance error	1.00	Rectangular	1.732	1	0.333
Error of TEM cell septum distance	0.30	Rectangular	1.732	1	0.030
Impedance mismatch error	0.20	U-shaped	1.414	1	0.020
Probe position error	1.00	Rectangular	1.732	1	0.333
TEM cell uniformity error	0.50	Rectangular	1.732	1	0.083
Non-uniformity field error due to probe	0.50	Rectangular	1.732	1	0.083
Error of directional coupler	0.20	Normal	2	1	0.010
Repeatability	0.20	Normal	1	1	0.040
				Combined Uncertainty	**1.01**
				Expanded Uncertainty (k=2)	**2.02**

Table 3. Uncertainty budget for EF 6091 electric field probe (With NBM-550 meter) with 30 V/m at 1 GHz, 9 GHz and18 GHz

Source of uncertainty	Uncertainty U_x (dB)	Probability Distribution	Divisor	Sensitivity Coefficient C_i	Uncertainty Contribution $(U_i \times C_i)^2$ (dB)
Power meter reading error	0.5	Rectangular	1.732	1	0.083
Power sensor reading error	0.1	Normal	2	1	0.003
Impedance mismatch error between horn antenna and directional coupler	0.2	U-shaped	1.414	1	0.020
Impedance mismatch error from forward power sensor	0.2	U-shaped	1.414	1	0.020
Impedance mismatch error from reverse power sensor	0.2	U-shaped	1.414	1	0.020
Impedance mismatch error from directional coupler	0.2	U-shaped	1.414	1	0.020
Distance error between probe and antenna	1	Rectangular	1.732	1	0.333
Horn antenna alignment	1	Rectangular	1.732	1	0.333
Error of directional coupler	0.2	Normal	2	1	0.010
Reflection error from floor	0.2	Rectangular	1.732	1	0.013
Flexibility error from cables	0.2	Rectangular	1.732	1	0.013
Heating error from cables	0.2	Rectangular	1.732	1	0.013
Reflection error from chamber	0.6	Rectangular	1.732	1	0.120
Instrument linearity error	0.2	Rectangular	1.732	1	0.013
Horn antenna gain error	1.5	Normal	2	1	0.563
Repeatability	0.2	Normal	1	1	0.040
				Combined Uncertainty	**1.27**
				Expanded Uncertainty (k=2)	**2.54**

ANNEX C. Technical Protocol

TECHNICAL PROTOCOL

Bilateral Comparison on Electric Field Measurements

Between TÜBİTAK UME and SASO NMCC

GULFMET.EM.RF-S1

UME-EM-D3-2.23.6 (a)

TÜBİTAK UME

(Rev. 2)
February 15, 2017

Contents

TÜBİTAK UME
GULFMET التجمع الخليجي للمترولوجيا

1. Introduction

It has been planned to organise a bilateral comparison on Electric Field Measurements between SASO NMCC and TÜBİTAK UME, in the frame of the Project of Development and Realization Measurement and Calibration System for the National Measurement and Calibration Center (NMCC) at Saudi Standards, Metrology and Quality Organization (SASO).

The calibration of the electric field probes are of fundamental importance for the traceability of the electric field measurements. The bilateral comparison will be performed by using the electric field probes.

UME is acting as the pilot institute. The travelling standard will be provided by TÜBİTAK UME. TÜBİTAK UME will be responsible to monitoring standard performance during the circulation and the evaluation and reporting of the comparison results.

The comparison will be carried out in accordance with the CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons [1].

2. Travelling Standards

The travelling standards will be supplied by TÜBİTAK UME. These standards were chosen for its high accuracy and stability in time. The photo and the general specifications of the travelling standards are presented in Figure1 and Table 1 respectively.


(a)


(b)

Figure 1. The photo of the travelling standards (a) BN2245/90.31 and EFA 300
(b) EF 0691, EF 6091 and NBM-550

1. Introduction

It has been planned to organise a bilateral comparison on Electric Field Measurements between SASO NMCC and TÜBİTAK UME, in the frame of the Project of Development and Realization Measurement and Calibration System for the National Measurement and Calibration Center (NMCC) at Saudi Standards, Metrology and Quality Organization (SASO).

The calibration of the electric field probes are of fundamental importance for the traceability of the electric field measurements. The bilateral comparison will be performed by using the electric field probes.

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2. Travelling Standards

The travelling standards will be supplied by TÜBİTAK UME. These standards were chosen for its high accuracy and stability in time. The photo and the general specifications of the travelling standards are presented in Figure1 and Table 1 respectively.

(a) (b)

Figure 1. The photo of the travelling standards (a) BN2245/90.31 and EFA 300
(b) EF 0691, EF 6091 and NBM-550

Table 1. The general specifications of the travelling standards

No	Manufacturer/ Device	Model	Serial Number	General Specifications
1	Wandel&Golterman/ Electric Field Probe, Field Analyser	EFA 300 BN2245/90.31	A-0074, A-0098	Frequency Range: 5 Hz-32 kHz Measurement Range: 10 V/m to 100 kV/m Noise Level: 4,5 V/m Internal Batteries: NiMH Batteries (5x C-Cell), rechargeable Operating Temperature: 0 °C to +50 °C
2	Narda/ Broadband Field Meter	NBM-550	B-1002	Frequency Range: 100 kHz – 60 GHz Measurement Range: 0.01 V/m – 100 kV/m Internal Batteries: 3,7V, 5,5Ah, rechargeable Operating Temperature: -10 °C to +50 °C
3	Narda/ Electric Field Probe	EF 0691	A-0107	Frequency Range: 100 kHz - 6 GHz Measurement Range: 0,35 to 350 V/m Noise Level: 0,35 V/m Operating Temperature: -10 °C to +50 °C
4	Narda/ Electric Field Probe	EF 6091	01135	Frequency Range: 100 MHz-60 GHz Measurement Range: 0,7 to 300 V/m Noise Level: 0,7 V/m Operating Temperature: -10 °C to +50 °C

3. Participant Laboratories

The pilot institute for this comparison is TÜBİTAK UME (Turkey). The contact details of the coordinator are given below:

Pilot Institute:	TÜBİTAK Ulusal Metroloji Enstitüsü (UME)
Coordinator :	Osman ŞEN Tel: +90 262 679 50 00 Fax: +90 262 679 50 01 E-mail: osman.sen@tubitak.gov.tr

Technical Protocol of Comparison on Electric Field Measurements 4/11

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

Table 2. The information of the participant institutes

Country	Institute	Acronym	Shipping Address	Contact Person
Turkey	TÜBİTAK Ulusal Metroloji Enstitüsü	TÜBİTAK UME	TÜBİTAK Ulusal Metroloji Enstitüsü (UME) TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, TURKEY	Osman ŞEN osman.sen@tubitak.gov.tr Tel: +90 262 679 50 00
Saudi Arabia	SASO The National Measurement and Calibration Center	SASO NMCC	Saudi Standards, Metrology and Quality Organization of The Kingdom of Saudi Arabia (SASO) Riyadh 11471, P.O. Box 3437 KINGDOM of SAUDI ARABIA	Abdullah M. Alrobaish a.robaish@saso.gov.sa Tel: +966 11 252 97 30

4. Time Schedule

The time schedule for the comparison is given in Table 3. The circulation of travelling standard will be organized to monitor the performance of the travelling standards. Each laboratory will have one week to carry out the measurements. Any deviation in the agreed plan should be approved by the pilot institute.

Table 3. The time schedule for the comparison

Participant	Country	Measurement Dates
TÜBİTAK UME	Turkey	20.10.2016 – 25.10.2016
SASO NMCC	Saudi Arabia	13.12.2016 -18.12.2016
TÜBİTAK UME	Turkey	20.01.2017 – 25.01.2017

5. Transport Case

The travelling standard is packed in a transport case of estimated size (100 x 100 x 100) cm and a total estimated weight of 50 kg. The transport case can easily be opened for customs inspection.

The content of the transport case is given in Table 4.

Table 4. General information about transport case

No	Manufacturer/ Device	Model	Serial Number	Accessories
1	Wandel&Golterman/ Electric Field Probe, Field Analyser	EFA 300 BN2245/90.31	A-0074, A-0098	Power supply adaptors, optic to RS232 converter, optic cable and RS232 to USB converter
2	Narda/ Broadband Field Meter	NBM-550	B-1002	Optic to RS232 converter, optic cable and RS232 to USB converter
3	Narda/ Electric Field Probe	EF 0691	A-0107	-
4	Narda/ Electric Field Probe	EF 6091	01135	-

6. Transportation of Travelling Standard

The comparison will be organised in a single loop of two laboratories in order to allow close monitoring of the behaviour of the standard.

TÜBİTAK UME is responsible for the transportation of the travelling standard. TÜBİTAK UME will transport the package from TÜBİTAK UME to SASO NMCC and back to TÜBİTAK UME by hand-carrying.

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

6.1. Failure of Travelling Standard

In case of any damage or malfunction of the travelling standard, the comparison will be carried out after the travelling standard is repaired.

6.2. Financial aspects

Each participant institute is responsible for its own costs for the measurements as well as any damage that may occur within its country.

The overall costs for the organisation of the comparison are covered by the pilot institute. The pilot institute has no insurance for any loss or damage of the travelling standard.

7. Measurement Quantities and Points

The correction factors defined below are determined for each frequency given Table 5. The correction factors are obtained using the following formula;

$$\text{Correction Factor (Linear)} = \frac{\text{Actual Field (V/m)}}{\text{Indicated Field (V/m)}}$$

Correction Factor (dB)= 20× log ((Correction factor (linear))

Table 5. Measurement levels & frequencies for electric field probes

Frequency	Level for Electric Field Measurements	Relevant Travelling Standard
100 Hz	30 V/m	BN2245/90.31 electric field probe with EFA 300 field analyser
1 kHz	30 V/m	
10 MHz	30 V/m	EF 0691 electric field probe with NBM-550 field meter
100 MHz	30 V/m	
1 GHz	30 V/m	EF 6091 electric field probe with NBM-550 field meter
9 GHz	30 V/m	
18 GHz	30 V/m	

8. Calculation of the Comparison Reference Value

The Comparison Reference Value (CRV) for each measurement point will be calculated using the results of the pilot institute.

9. Measurement Instructions

9.1. Precautions

- Avoid extreme temperature, humidity or pressure changes as well as violent impacts

9.2. Before the Measurements

- It should be allowed to stabilize in a temperature and humidity controlled environment for at least 1 day before commencing measurements.
- Before the measurements, the batteries of the travelling standards should be fully charged.

9.3. Powering of the standard during the measurements

During the calibration process, the travelling standards shall not be connected to the charging unit.

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9.4. Environmental Conditions

- The ambient temperature and humidity must be measured. No corrections will be performed for temperature and humidity effects.
- Preferably, the measurements should be carried out at the ambient conditions given below;

  Temperature : (22 ± 2) °C

  Relative humidity : (45 ± 10) %rh

9.5. Method of measurement

- Each participant institute may use its own measurement method.
- The electric field measurements for 100 Hz, 1 kHz frequencies should be carried out only Z axis of the field probe. The position of the field probe is shown in Figure 2.
- The electric field measurements should be performed at one position of the field probes for other frequencies. The positions of the field monitor are shown in Figure 3 and Figure 4 respectively.
- The measurement parameters of the field monitor and analyser are given in Table.

Table 6. NBM-550 Field Meter and EFA 300 Field Analyser Parameters

NBM-550 Field Meter Parameters			EFA 300 Field Analyser Parameters		
Detector	Display	Correction frequency	Detector	Display	Filter
RMS	Actual	OFF	RMS	LIVE	5 Hz-32 kHz

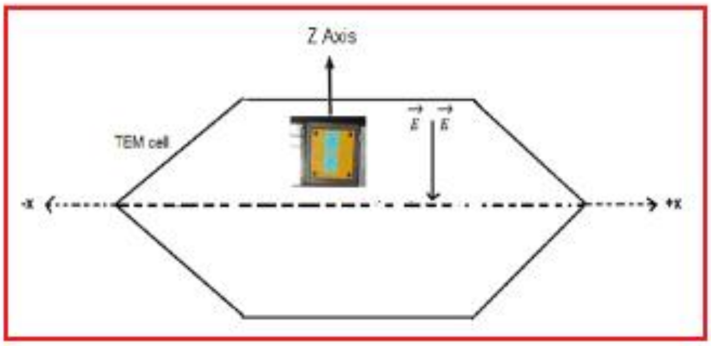

Figure 2. Measurement position of Electric field probe for TEM cell (100 Hz, 1 kHz)

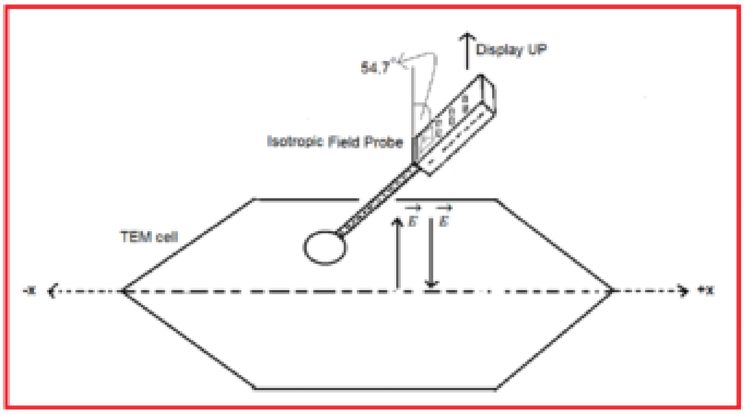

Figure 3. Measurement position of Electric field probe for TEM cell (10 MHz, 100 MHz)

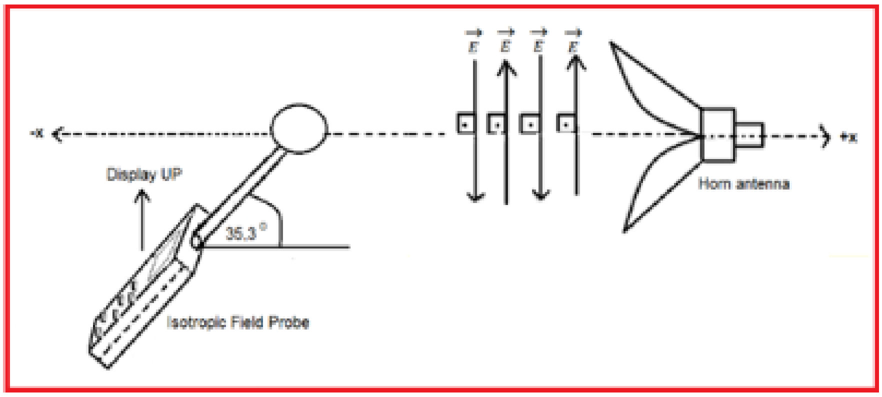

Figure 4. Measurement position of Electric field probe for fully anechoic chamber (1 GHz, 9 GHz and 18 GHz)

10. Measurement Uncertainty

The uncertainty of measurement must be calculated according to IEEE Std. 1309 [2] and the JCGM 100 "Guide to the Expression of Uncertainty in Measurement" [3] for the coverage probability of approximately 95%.

All contributions to the measurement uncertainty should be listed in the report submitted by each participant.

Even though the contributions to the uncertainty are specific to the measurement method used, it may be useful to consider the list of uncertainty sources given below.

1. Type A
2. Repeatability
3. Mismatches

4. Power sensor error
5. Power meter error
6. Directional coupler error
7. Resistor error
8. Oscilloscope error
9. Antenna gain error

This is not a complete list and should be extended with uncertainty contributions that are specific for the participants' measurement system.

11. Reporting of Results

The results should be sent to the pilot institute within 30 days of completing the measurements.

The participant shall report their results using the standard certificate that they would normally issue to a customer.

However, results shall also be reported in the pilot institute. The report must contain at least:

- Details of participating institute,
- The date and time of the measurements,
- A detailed description of the method used,
- The measurement standards used in the comparison measurements,
- Software used in the comparison measurements
- The environmental conditions during the measurements,
  - ambient temperature
  - relative humidity
- Results of measurement; The measurement results shall be prepared in accordance with Table 6:

Table 6. Measurement results

Frequency	Actual Field (V/m)	Indicated Field (V/m)	Correction Factor (Linear)	Correction Factor (dB)	Measurement Uncertainty (dB) (k=2)	Ambient Temperature (°C)	Ambient Humidity (%rh)
100 Hz							
1 kHz							
10 MHz							
100 MHz							
1 GHz							
9 GHz							
18 GHz							

12. Final Report of the Comparison

The pilot institute is responsible for the preparation of a comparison report.

The draft version of the comparison report will be issued within two months after receiving the participant report by the pilot institute. Draft report will be sent to the SASO NMCC for discussion and approval. This draft will be confidential to the participants.

The participant will have one week to send their comments on Draft Report. After approval, Draft Report will become the Final Report. The Final Report will form the basis for the publication of results.

13. References

[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] IEEE Std. 1309-2015, "IEEE Standard for calibration of electromagnetic field sensors and probes, excluding antennas, from 9 kHz to 40 GHz".

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