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**International Comparison
CCEM.RF-K7a.F (GT-RF-86-1)
on Electric Field Strength -
Report on Measurements at NPL**

by

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Abstract

This report describes measurements undertaken by NPL in an international comparison of Electric Field Strength. This was carried out under the auspices of the Metre Convention and originally was designated as comparison GT-RF-86-1. The majority of measurements in the comparison were reported by the pilot laboratory in the *IEEE Transactions on Electromagnetic Compatibility* in 2000 - however, the measurements in this report were not included in that paper. To allow GT-RF-86-1 to be approved for provisional equivalence as an Interim Key Comparison (designated CCEM.RF-K7a.F) all measurement results must be published. This report is therefore being published to complement the *IEEE Transactions* paper: all of the comparison results are covered between them.

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1 Introduction to NPL Facilities

Over the frequency range 20 Hz to 300 MHz three sizes of Crawford type TEM cells are used having nominal septum to outer conductor spacings of 150, 300 and 915 mm. The large cell permits measurement of larger low frequency probes and loop antennas, while the smaller cells offer wider operating bandwidths for smaller probes.

Between 150 MHz and 2.44 GHz an NPL designed tapered TEM cell can be used. This type of cell is equivalent to one elongated input taper of a Crawford Type cell terminated in microwave absorbing material. The cell is operated with septum to outer conductor spacings between 200 and 280 mm.

From 2.45 GHz to 45.5 GHz the Standard Field method is used in an anechoic chamber with external dimensions of 5 m x 3 m x 3 m. The measurement of the microwave antenna gain is performed in a larger anechoic chamber using the extrapolation three-antenna method.

The measurement laboratories are temperature controlled at $23 \pm 2^\circ\text{C}$.

2 Description of TEM Cells

The TEM cell measurements up to 100 MHz were made using an IFI Model CC-102 cell. The specifications are given in the table:

PARAMETER	IFI Model CC-102
Manufacturer's bandwidth	0 - 200 MHz
NPL Bandwidth	0 - 150 MHz
Outer Cell Dimensions mm	1960x 970 x 660
Septum Width , 2w	680 mm
Inside Width, 2a	899
Inside Height, 2b	599 mm
Length of rectangular cross section, L	900 mm
Ratio a/b	1.5
Ratio w/a	0.76
Septum to wall gap, G	110 mm
Septum Thickness,t	~1.5 mm
Access Door mm	330 x 203 (side) also access hole on top and side

The measurements from 300 MHz to 1000 MHz were made using the NPL Tapered cell. The cell has a length of 3.4 m and forms a pyramid with base dimensions 1.8 m x 1.2 m ($a/b = 1.5$).

**International Comparison CCEM.RF-K7a.F (GT-RF-86-1) on Electric Field Strength -
Report on Measurements at NPL**

General Introduction

This report, first issued by NPL in unpublished form in 1998, describes measurements undertaken by NPL in the international comparison of Electric Field Strength which was originally designated GT-RF-86-1. The comparison was sponsored by the Consultative Committee on Electricity and Magnetism (CCEM) set up by the International Committee of Weights and Measures (CIPM) under the Metre Convention. The majority of measurements undertaken in the comparison were reported by the pilot laboratory NIST (National Institute of Science and Technology, USA) in the *IEEE Transactions on Electromagnetic Compatibility* [1]. However, the measurements in the present report were not included in that paper. With the inception of the Mutual Recognition Arrangement (MRA) between National Measurement Institutes in 1999 [2], CCEM decided that this comparison should be designated as an Interim Key Comparison approved for provisional equivalence under the MRA. It was re-designated as comparison CCEM.RF-K7a. For approval for provisional equivalence all measurement results must be published. This report is being published to fulfil this requirement. Taken together, this report and reference [1] cover all of the results obtained in the comparison.

References:

[1] M Kanda, D Camell, JPM de Vreede, J Achkar, M Alexander, M Borsero, H Yashima, NS Chung & H Trzaska, 2000, '*International comparison GT/RF 86-1 electric field strengths : 27 MHz to 10 GHz*', *IEEE Trans. Electromagn. Compat.*, **EMC-42**, No. 2, pp 190-205.

[2] See website: http://www.bipm.fr/enus/8_Key_Comparisons/introduction.html

Unlike commercially available G-TEM Cells it has no lumped resistive elements and therefore has a low frequency cutoff determined by the reflections from the load formed by 1.6 m pyramidal microwave absorber. The thickness of the septum is also tapered to achieve rigidity without the need for dielectric support pillars. The cell is used with one side of the outer conductor, normal to the septum, removed. This allows easy access for probes and preferentially radiates the unwanted waveguide modes into the room. The optimum insertion point for probes is where the height between the septum and outer conductor (b) lies between 200 and 280 mm.

The NIST probes were positioned in the centre of the TEM cell to an accuracy of 5 mm. The high impedance leads were brought out of the cell perpendicular to both the electric field and the direction of propagation. The power was measured at the input to the Tapered Cell using a high directivity coupler and power meter. The power was measured at the output of the Crawford Type TEM Cells through high power attenuators. The input power to the cells was generated using a Marconi signal synthesiser and Amplifier Research solid state amplifiers. Unwanted harmonics of the signal frequency were removed using low pass filters. The equipment calibration parameters were stored in a computer which interpolated the data points and also controlled the measurement sequence.

3 Description of Anechoic Chamber

Over the frequency range 2.45 GHz to 40 GHz the NIST probes were measured in an anechoic chamber using the standard field method. The transmitting equipment was carried on a purpose built carriage which ran on linear bearings on precision-ground rails fixed to the floor of the anechoic chamber. The carriage was driven along the rails by a stepper motor under computer control, and the distance measured using an optical encoder running on the rail. All the equipment was controlled by the computer which was connected by IEEE-488 interface cables linked through an optical fibre bus extender to the computer situated at the far (closed) end of the chamber.

To produce a calculable plane-wave field, the output of a synthesised source was fed to a high power amplifier and then via a low pass filter to the input of a directional coupler. A calibrated power meter and coupler system was used to measure the power incident on an antenna which was connected to the output of the coupler.

4 Notes and observations

All measurements for this intercomparison were performed twice and the probe and measuring system allowed about 30 minutes to stabilise. The zero offset of the probe under test was measured at the start of the measurement and is given in the results. The zero offset in this case is the reading on the voltmeter with no applied field.

The four sensors were carefully aligned with the electric field vector and the d.c. output measured on a high impedance digital voltmeter shunted by the supplies 100 Mohm resistor. For all measurement settings it was found necessary to use the in-built low pass filter to produce a stable reading. The low pass filter has a cut-off of 45 Hz, which removes the effects of 50 Hz mains frequencies and harmonics.

- 4.3 The measurement system for 30 and 40 GHz was designed to generate relatively high field strengths for safety monitoring applications. The test levels of 5 and 10 V/m were too low to be measured. At the 20 V/m test level the noise floor of the microwave amplifier gave a reading from the probe of 0.1 mV for probe 92-81 and 0.075 mV for probe 92-82. This is an appreciable part of the total probe output at 20 V/m and as the probe sensitivity is reducing with frequency, the measurement at 40 GHz may not be valid.

The measurement uncertainties given in the tables have been calculated at the 2-sigma level, as is the normal practice for field strength measurements at NPL.

INTERCOMPARISON OF ELECTRIC FIELD STRENGTHS

8 mm Probe, s/n 92-81

Laboratory: NPL (UK)

Measurement date: 14 June 1995

Field Strength V/m	Reported Parameter	Frequency GHz							
		0.3	0.5	1.0	2.45	5.0	10.0	30.0	40.0
5V/m TEMCell	Probe o/p mV	0.200	0.210	0.223	-	-	-	-	-
	Zero offset	-0.031	-0.031	-0.031	-	-	-	-	-
	Uncertainty %	9	9	9	-	-	-	-	-
5V/m Anechoic	Probe o/p mV	-	-	-	0.270	0.292	0.474	-	-
	Zero offset	-	-	-	-0.04	-0.04	-0.04	-	-
	Uncertainty %	-	-	-	5	5	5	-	-
10V/m TEM Cell	Probe o/p mV	0.881	0.926	0.967	-	-	-	-	-
	Zero offset	-0.031	-0.031	-0.031	-	-	-	-	-
	Uncertainty %	9	9	9	-	-	-	-	-
10V/m Anechoic	Probe o/p mV	-	-	-	1.197	1.322	2.00	-	-
	Zero offset	-	-	-	-0.04	-0.04	-0.04	-	-
	Uncertainty %	-	-	-	5	5	5	-	-
20V/m TEM Cell	Probe o/p mV	3.53	3.67	3.84	-	-	-	-	-
	Zero offset	-0.031	-0.031	-0.031	-	-	-	-	-
	Uncertainty %	9	9	9	-	-	-	-	-
20 V/m Anechoic	Probe o/p mV	-	-	-	4.746	5.248	7.710	0.873	0.190
	Zero offset	-	-	-	-0.04	-0.04	-0.04	-0.04	-0.04
	Uncertainty %	-	-	-	5	5	5	5	See Para 3.3

Voltmeter Type 1065A s/n: 18238

File Ref: F14/120B/Z10726

INTERCOMPARISON OF ELECTRIC FIELD STRENGTHS

8 mm Probe, s/n 92-82

Laboratory: NPL (UK)

Measurement date: 16 June 1995

Field Strength V/m	Reported Parameter	Frequency (GHz)							
		0.3	0.5	1.0	2.45	5.0	10.0	30.0	40.0
5V/m TEM Cell	Probe o/p mV	0.191	0.206	0.214	-	-	-	-	-
	Zero offset	-0.031	-0.031	-0.031	-	-	-	-	-
	Uncertainty %	9	9	9	-	-	-	-	-
5V/m Anechoic	Probe o/p mV	-	-	-	0.262	0.285	0.310	-	-
	Zero offset	-	-	-	-0.04	-0.04	-0.04	-	-
	Uncertainty %	-	-	-	5	5	5	-	-
10V/m TEM Cell	Probe o/p mV	0.851	0.911	0.939	-	-	-	-	-
	Zero offset	-0.031	-0.031	-0.031	-	-	-	-	-
	Uncertainty %	9	9	9	-	-	-	-	-
10V/m Anechoic	Probe o/p mV	-	-	-	1.185	1.316	1.356	-	-
	Zero offset	-	-	-	-0.04	-0.04	-0.04	-	-
	Uncertainty %	-	-	-	5	5	5	-	-
20V/m TEM Cell	Probe o/p mV	3.41	3.62	3.74	-	-	-	-	-
	Zero offset	-0.031	-0.031	-0.031	-	-	-	-	-
	Uncertainty %	9	9	9	-	-	-	-	-
20 V/m Anechoic	Probe o/p mV	-	-	-	4.69	5.25	5.33	0.585	0.095
	Zero offset	-	-	-	-0.04	-0.04	-0.04	-0.04	-0.04
	Uncertainty %	-	-	-	5	5	5	5	See Para 3.3

Voltmeter Type 1065A s/n: 18238

File Ref: F14/120A/Z10725

INTERCOMPARISON OF ELECTRIC FIELD STRENGTHS

5 cm Probe, s/n 92-51 Laboratory: NPL (UK) Measurement date: 16 June 1995

Field Strength V/m	Reported Parameter	Frequency MHz							
		27	30	50	100	300	500	1000	
2V/m TEMCell	Probe o/p mV	3.32	3.33	3.28	3.35	3.46	3.17	2.50	
	Zero offset	-0.090	-0.090	0.088	-0.088	-0.064	-0.060	-0.059	
	Uncertainty %	9	9	9	9	9	9	9	
5V/m TEM Cell	Probe o/p mV	18.55	18.51	18.32	18.73	18.57	17.19	13.79	
	Zero offset	-0.09	-0.09	-0.088	-0.088	-0.066	-0.065	-0.060	
	Uncertainty %	9	9	9	9	9	9	9	
10V/m TEM Cell	Probe o/p mV	56.64	56.59	55.95	56.96	56.35	52.9	43.82	
	Zero offset	-0.090	-0.089	-0.089	-0.088	-0.063	-0.064	-0.060	
	Uncertainty %	9	9	9	9	9	9	9	

Voltmeter Type 1065A s/n: 18238

File Ref: F14/120C/Z10727

INTERCOMPARISON OF ELECTRIC FIELD STRENGTHS

5 cm Probe, s/n 92-52 Laboratory: NPL (UK) Measurement date: 14 June 1995

Field Strength V/m	Reported Parameter	Frequency MHz							
		27	30	50	100	300	500	1000	
2V/m TEMCell	Probe o/p mV	3.22	3.22	3.18	3.26	3.32	3.09	2.37	
	Zero offset	-0.095	-0.10	0.10	-0.10	-0.065	-0.065	-0.065	
	Uncertainty %	9	9	9	9	9	9	9	
5V/m TEM Cell	Probe o/p mV	18.13	18.11	17.94	18.29	17.95	16.80	13.17	
	Zero offset	-0.10	-0.10	-0.10	-0.10	-0.065	-0.065	-0.060	
	Uncertainty %	9	9	9	9	9	9	9	
10V/m TEM Cell	Probe o/p mV	56.49	55.40	54.88	55.92	54.80	51.83	42.12	
	Zero offset	-0.10	-0.10	-0.10	-0.10	-0.065	-0.065	-0.065	
	Uncertainty %	9	9	9	9	9	9	9	

Voltmeter Type 1065A s/n: 18238

File Ref: F14/120D/Z10728