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International Comparison CCEM.RF-K2.W (GT-RF-78-13) on Noise Power In IEC-R100 Waveguide – Final Report

by

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Abstract

This report describes the measurements and results of international comparison CCEM.RF-K2.W (formerly GT-RF-78-13) on noise power in IEC-R100 waveguide, which took place between September 1985 and April 1992. With the inception of the Mutual Recognition Arrangement (MRA) between National Measurement Institutes in 1999 it was decided that this comparison should be designated as an Interim Key Comparison approved for provisional equivalence under the MRA. For approval for provisional equivalence all measurement results must be published and this report is being published to fulfil this requirement.

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General Introduction

This report, first issued by NPL in unpublished form describes the measurements and results of the international comparison originally designated GT-RF-78-13 on noise power in IEC-R100 waveguide. 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 report was assembled by M W Sinclair of NPL and was submitted to the GT-RF (the RF Working Group of CCEM) for approval. With the inception of the Mutual Recognition Arrangement (MRA) between National Measurement Institutes in 1999 [1], CCEM decided that this comparison should be designated as an Interim Key Comparison approved for provisional equivalence under the MRA. It was then re-designated as comparison CCEM.RF-K2.W. For approval for provisional equivalence all measurement results must be published. This report is therefore being published here to fulfil this requirement.

D Adamson
R N Clarke
NPL, July 2001

Reference

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

1. Introduction

This report describes a comparison of electrical noise power in R100 waveguide at frequencies of 9.0, 10.0 and 11.2 GHz. It was agreed under the auspices of the RF Working Group of the BIPM. The pilot laboratory was the National Physical Laboratory (NPL) based at the Defence Research Agency (formerly Royal Signals and Radar Establishment), Malvern UK. The other participants were the Physikalisch-Technische Bundesanstalt (PTB), Germany, the Laboratoire Central des Industries Electriques (LCIE), France, the National Measurement Laboratory of the Combined Scientific and Industrial Research Organisation (CSIRO), Australia, the National Institute of Metrology (NIM), China, and the National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards (NBS), USA. The Electrotechnical Laboratory (ETL), Japan were included in the original list of participants, but later withdrew due to pressure of other work.

2. Travelling Standards

The participants agreed to the use of two travelling standards which were waveguide argon gas discharge tube noise sources. One each of these was provided by NPL and NIST. The NPL standard was a Nore Microwave NTM16/7 serial number 158 designated BIPM TS1. The NIST standard was of their own design, serial number NBS INTL-X1 designated BIPM TS2. The travelling standards were accompanied by their own power supplies both of which were of Nore Microwave manufacture type NM5. The NIST power supply was specially modified to operate with their standard. Both noise sources were operated in the "hot cathode" mode, which implies that the heater was operated continuously throughout the measurements. The same flange was used on both travelling standards, the hole positions and diameters being entirely compatible with 154 IEC - UBR100. It was established before commencement of the comparison that the systems used by all participants had input flanges that would mate with the travelling standards with no difficulty.

The power supplies included a socket on the front panel to allow for independent monitoring of the discharge tube anode current during operation. The pilot laboratory provided a facility for monitoring the anode current. A jack inserted into the monitoring socket introduced a high stability 10 ohm resistor in series with the anode circuit. The voltage across the resistor was a measure of the anode current.

3. Measurement Requirements

The required parameter to be measured was the noise temperature of the travelling standards. To avoid confusion as to the precise definition of this parameter, it was further requested that the participants should state whether their result was in terms of Effective Noise Temperature (associated with the noise power delivered to a perfectly matched load) or Available Noise Temperature (associated with the noise power delivered to a conjugately matched load). Conversion between the two is easily accomplished using the expression: -

$$T_e = T_a(1 - |\Gamma_s|^2) \qquad (1)$$

where T_a is the available noise temperature, T_e is the effective noise temperature and $\tilde{A}_s$ is the source reflection coefficient. The results would also be stated in terms of excess noise ratio (ENR), which is defined as:-

$$ENR(dB) = 10.\mathrm{Log}_{10}\left(\frac{T_a - T_0}{T_0}\right) \qquad (2)$$

where T_0 is the standard reference temperature 290 K.

The measurement sequence was chosen to fulfil several requirements. In order that the results should include some measure of the repeatability of connection, the participants were asked to make four separate connections of the standard at each frequency. When the standard was connected they were then asked to make four comparisons with their system standard. This would give some indication of the stability of the measurement system. The former requirement was met by all participants, but the latter was not possible in every case due to the different measurement methods employed.

All participants were using superheterodyne receivers and were asked to indicate whether their measurements were single sideband (SSB) or double sideband (DSB). In the former case the local oscillator (LO) is set to the measurement frequency (F_0) plus or minus the intermediate frequency (IF) and the IF response is produced only by a signal centred on the measurement frequency. This is often accomplished by preceding the mixer by a bandpass filter centred on the measurement frequency. In the latter case no bandpass filter is present and two sidebands situated on either side of the LO frequency and spaced from it by the IF produce an output at the intermediate frequency. The local oscillator is normally set to the measurement frequency F_0 and the noise temperature measured is the mean of that in the two sidebands. It subsequently emerged that all laboratories with the exception of NPL were employing a DSB system. The most commonly used IF in the DSB systems was 30 MHz.

4. Circulation of Standards

The travelling standards were circulated in a double loop. This ensured that they were measured by the pilot laboratory on three separate occasions throughout the comparison as a check on overall stability. The order of the loops is shown below.

Loop 1	**Loop 2**
NPL(M)	NPL(M)
↓	↓
NIM	PTB
↓	↓
CSIRO	LCIE
↓	↓
NIST	NPL(M)

Order of Circulation of Transfer Standards

5. Discussion of the Results

The results of the comparison are given in tables 1 to 4 and in the graphs of figures 4 to 8. The noise temperatures are all available noise temperatures. Where participant's results were supplied in terms of effective noise temperatures, they were converted to available noise temperatures using equation 1. The value of reflection coefficient used was as measured by the pilot laboratory, although some laboratories made and reported their own measurement of reflection coefficient.

The whole series of measurements spanned the period from September 1985 to April 1992. There were significant delays throughout because of customs importation difficulties, failure of measuring equipment and environmental control systems and illness of participating staff. The major delay occurred at the pilot laboratory where failure of a vital component in the measuring system necessitated a complete rebuild and evaluation of the radiometer being used. The participants were informed of the completion of the measurements and were given a summary of the principal results late in 1992. It was clear at that time that not all participants had used the same techniques for derivation of the uncertainty values. Further time elapsed in an attempt to obtain better uniformity but with little success. Thus the uncertainties as reported here are those as originally supplied by the participants. Where possible these have been reported at the 95% confidence level.

The power supply for travelling standard TS1 was found to be faulty on its final return to the pilot laboratory. The measurements were thus completed with a power supply of the same manufacture and type. These power supplies are now known to give different results from one supply to another even when the anode current is the same in each case. These differences have been measured to be as large as 20 Kelvin in noise temperature. Despite this problem the three sets of results produced by the pilot laboratory show a reasonable degree of repeatability as indicated in table 1 below.

	Spread on Results (K)	
Freq.(GHz)	TS1	TS2
9	4	14
10	11	20
11.2	37	52

Table 1 : Pilot Laboratory Results Spread

Figures 4 to 6 and 10 to 12 also include a value for TS2 obtained by NIST before shipping the travelling standard to NPL. In figures 7 to 12 the horizontal line represents the mean value for all the laboratories. In calculating this value only one value was used for those laboratories where more than one measurement was performed, this being obtained by taking the mean value of the separate measurements. Inspection of figures 7 to 12 indicates that with three exceptions the uncertainty limits embrace the mean value. Thus for the most part the comparison shows good agreement between the participating laboratories.

Laboratory	Date	Frequency(GHz)					
		9.0		10.0		11.2	
		Temp. (K)	ENR (dB)	Temp. (K)	ENR (dB)	Temp. (K)	ENR (dB)
NPL(M)	Sept.1985	11,168	15.742	11,232	15.767	11,244	15.772
NIM	Nov.1985	11,289	15.790	11,282	15.787	11,496	15.871
CSIRO	May 1986	11,197	15.753	11,201	15.755	11,157	15.737
NIST	Dec.1986	11,210	15.758	11,219	15.762	11,225	15.764
NPL(M)	Oct.1989	11,172	15.743	11,233	15.767	11,259	15.778
PTB	Nov.1990	11,174	15.744	11,171	15.743	11,244	15.772
LCIE	April 1991	11,388	15.829	11,354	15.815	11,391	15.829
NPL(M)	April 1992	11,168	15.742	11,243	15.771	11,281	15.786

Table 2 : BIPM Comparison GT/RF 78-13

NPL(M) Travelling Standard NTM16/7 S.No.158 - BIPM TS1

Laboratory	Date	Frequency(GHz)					
		9.0		10.0		11.2	
		Temp.(K)	ENR (dB)	Temp.(K)	ENR (dB)	Temp.(K)	ENR (dB)
NIST	Aug.1985	10,899	15.633	10,971	15.662	11,027	15.685
NPL(M)	Sept.1985	10,861	15.617	10,982	15.666	11,036	15.688
NIM	Nov.1985	10,563	15.493	10,648	15.529	10,899	15.633
CSIRO	May 1986	10,889	15.628	10,985	15.668	10,929	15.645
NIST	Dec.1986	10,923	15.642	10,986	15.668	11,048	15.693
NPL(M)	Oct.1989	10,868	15.620	10,983	15.667	11,054	15.696
PTB	Nov.1990	10,872	15.622	10,933	15.647	11,053	15.695
LCIE	April 1991	11,112	15.719	11,036	15.689	11,200	15.754
NPL(M)	April 1992	10,881	15.626	11,004	15.676	11,090	15.710

Table 3: BIPM Comparison GT/RF 78-13

NIST Travelling Standard INTL - X1 - BIPM TS2

Freq. (GHz)	TS1				TS2			
	Mean Value		Standard Dev.		Mean Value		Standard Dev.	
	K	dB	K	dB	K	dB	K	dB
9.0	11237	15.768	85	0.034	10869	15.620	176	0.072
10.0	11244	15.772	65	0.026	10928	15.645	141	0.052
11.2	11296	15.792	124	0.049	11030	15.686	107	0.043

Table 4: BIPM Comparison GT/RF 78-13

Mean Values and Standard Deviations

Laboratory	Date	Frequency (GHz)		
		9.0	10.0	11.2
NPL(M)	Sept 1985	0.125	0.101	0.084
NIM	Nov 1985	0.297	0.258	0.238
CSIRO	May 1986	0.125	0.087	0.092
NIST	Dec 1986	0.096	0.094	0.071
NPL(M)	Oct 1989	0.123	0.100	0.082
PTB	Nov 1990	0.122	0.096	0.077
LCIE	April 1991	0.110	0.126	0.075
NPL(M)	April 1992	0.116	0.096	0.076

Table 5: BIPM Comparison GT/RF 78-13

Measured Differences (TS1 - TS2) dB

Laboratory	Frequency (GHz)					
	9.0		10.0		11.2	
	TS1	TS2	TS1	TS2	TS1	TS2
NPL(M)	0.033	0.033	0.035	0.034	0.034	0.033
NIM	0.082	0.082	0.082	0.082	0.082	0.082
CSIRO	0.050	0.050	0.050	0.050	0.050	0.050
NIST	0.062	0.067	0.070	0.071	0.057	0.055
NPL(M)	0.033	0.033	0.035	0.034	0.034	0.033
PTB	0.026	0.025	0.024	0.024	0.023	0.023
LCIE	0.090	0.100	0.100	0.100	0.100	0.100
NPL(M)	0.033	0.033	0.035	0.034	0.034	0.033

Table 6: BIPM Comparison GT/RF 78-13

Uncertainties (as supplied)

Transfer Standard	Frequency (GHz)		
	9.0	10.0	11.2
TS1	0.015	0.012	0.005
TS2	0.025	0.014	0.014

Table 7: BIPM Comparison GT/RF 78-13

Reflection Coefficient $|\Gamma|$

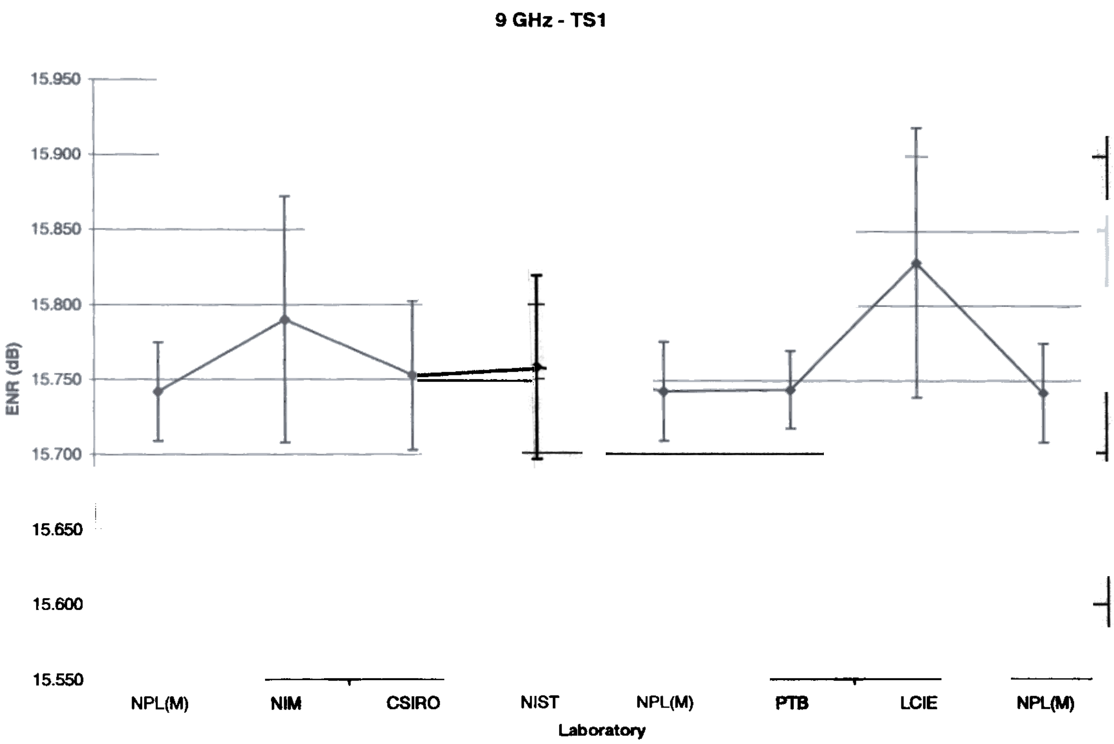
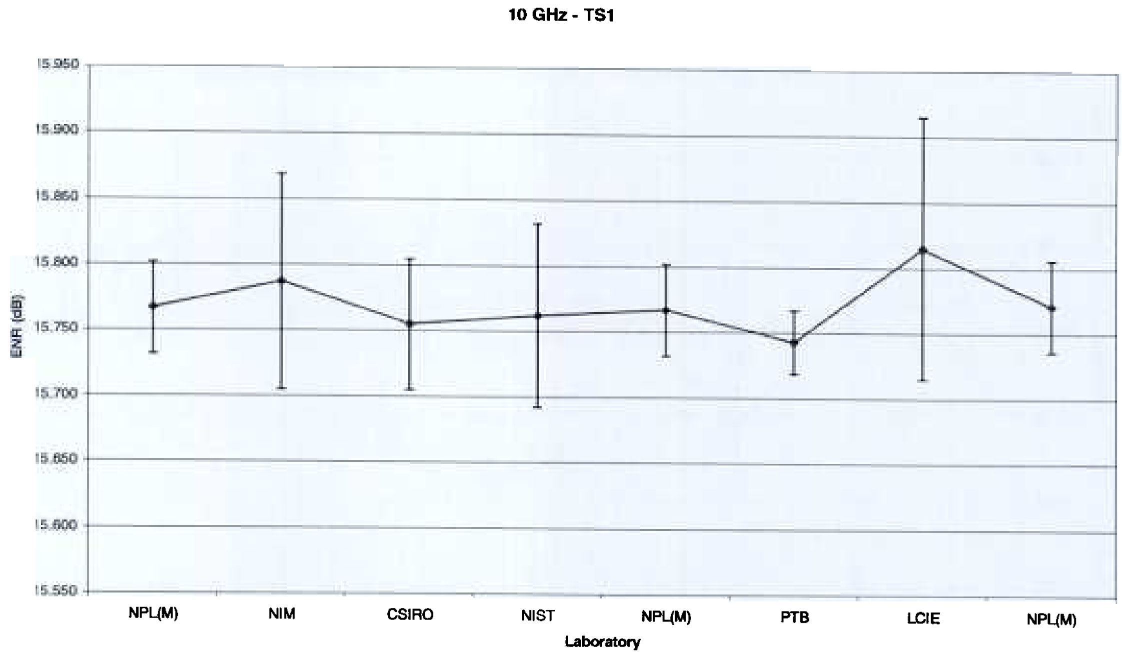


Figure 1



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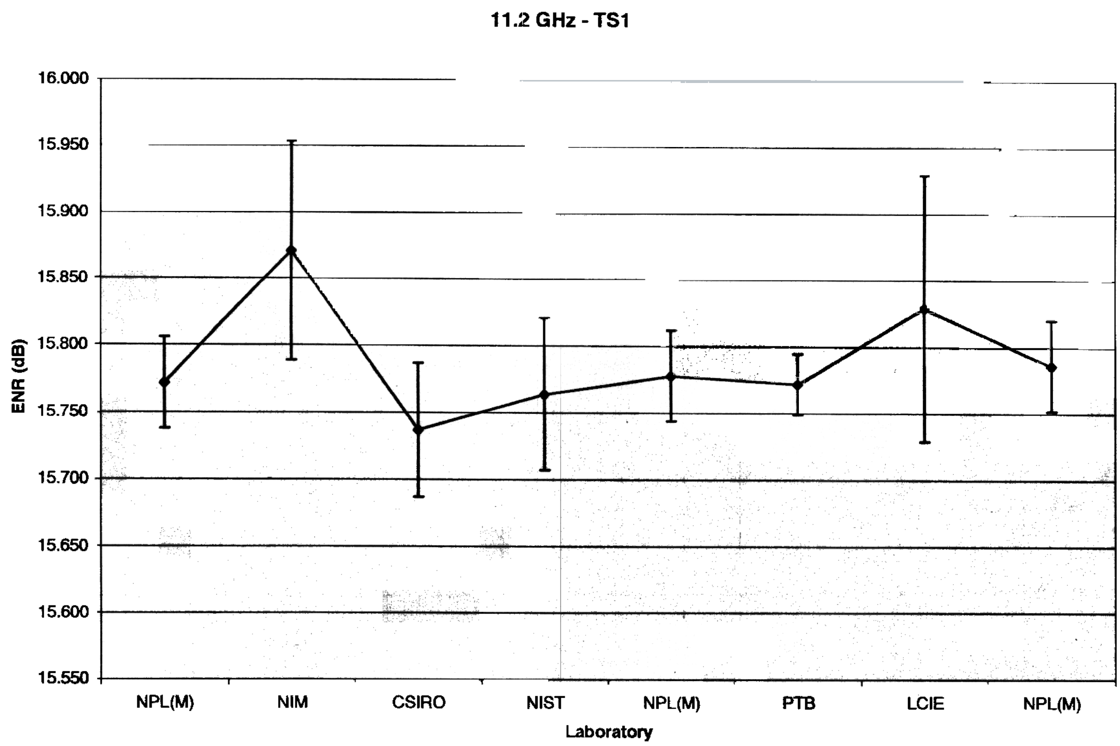

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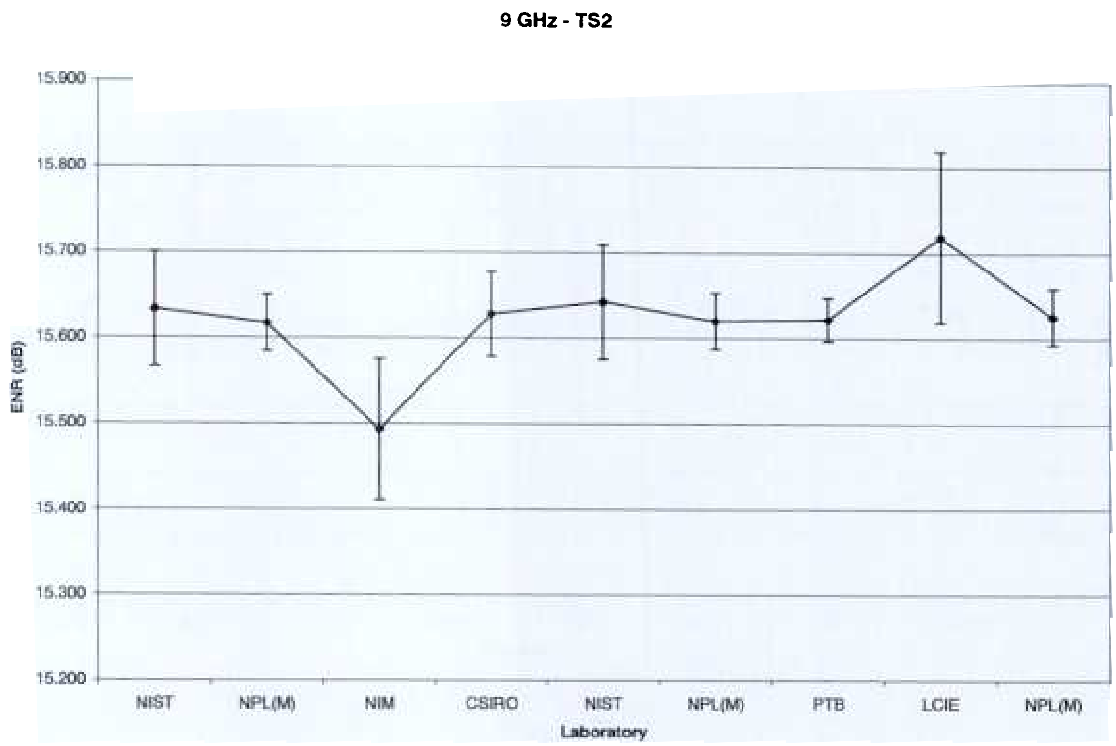
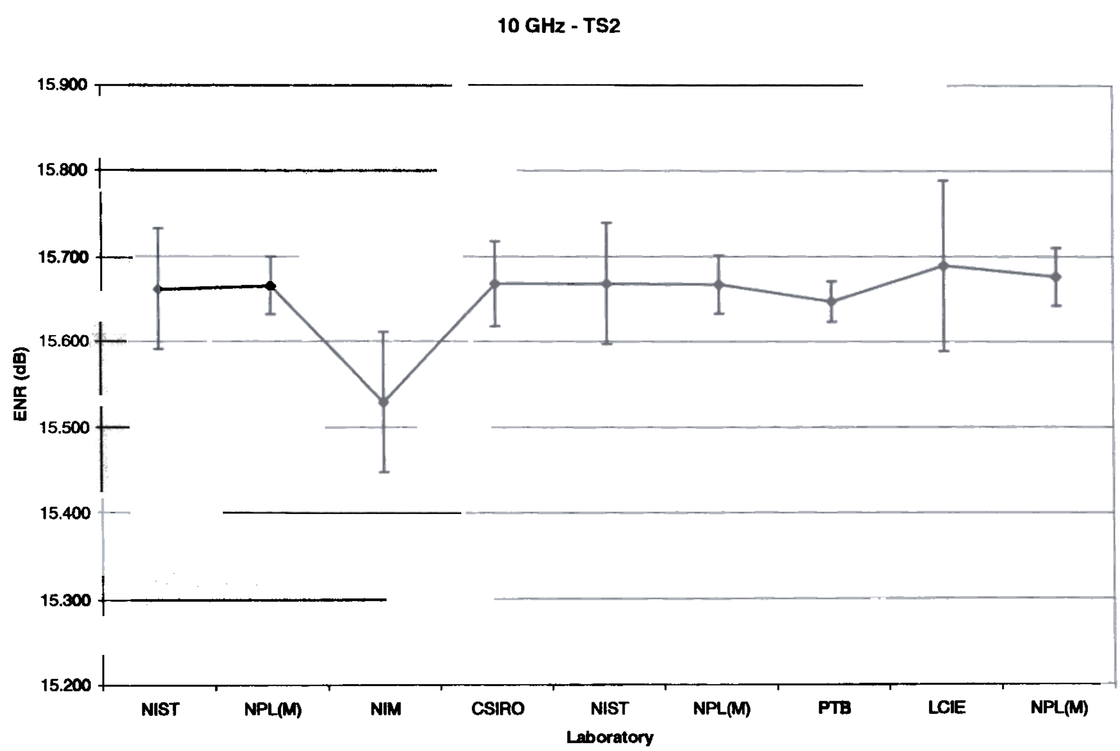


Figure 4



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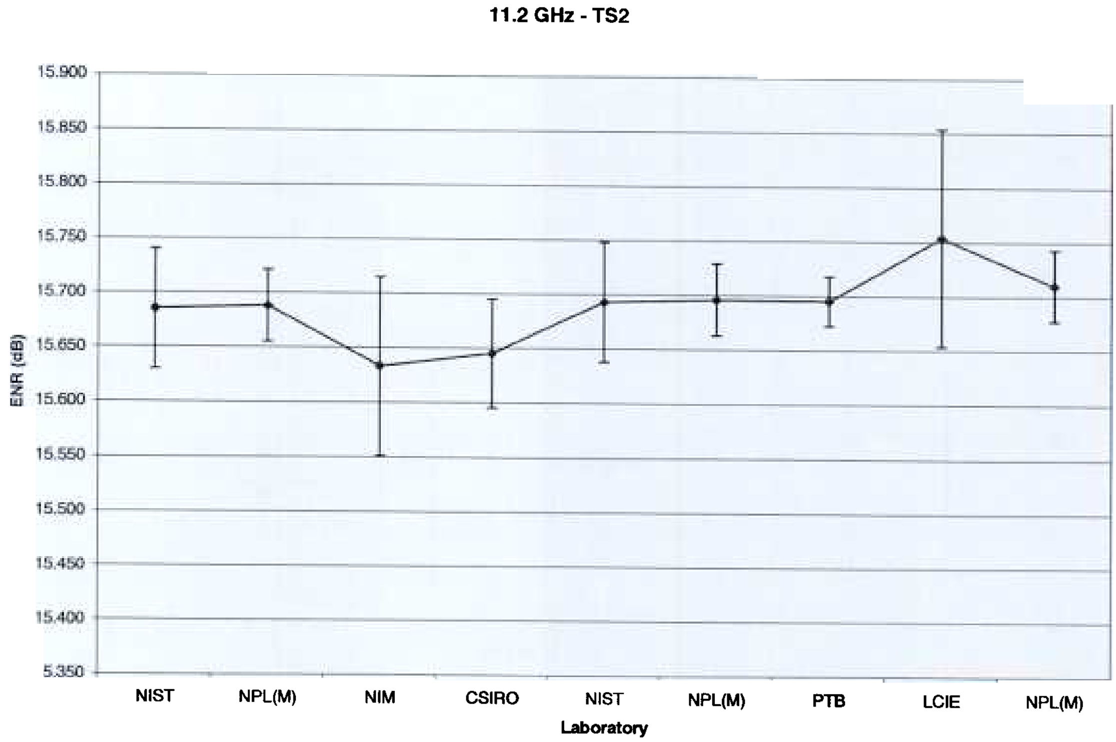


Figure 6

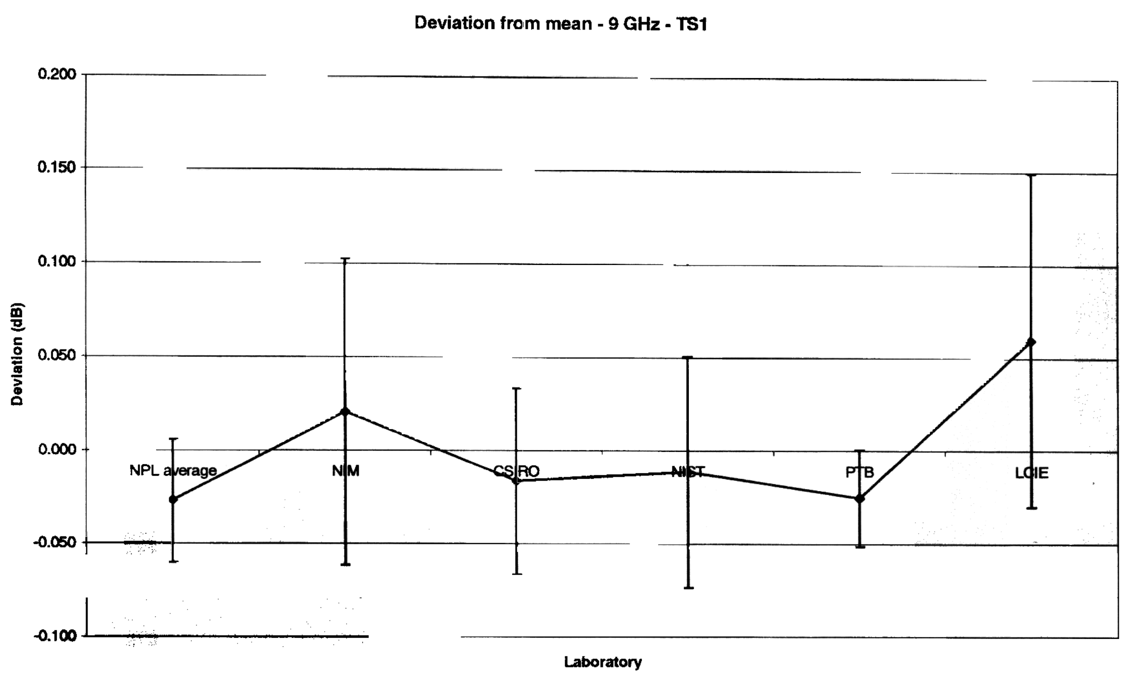
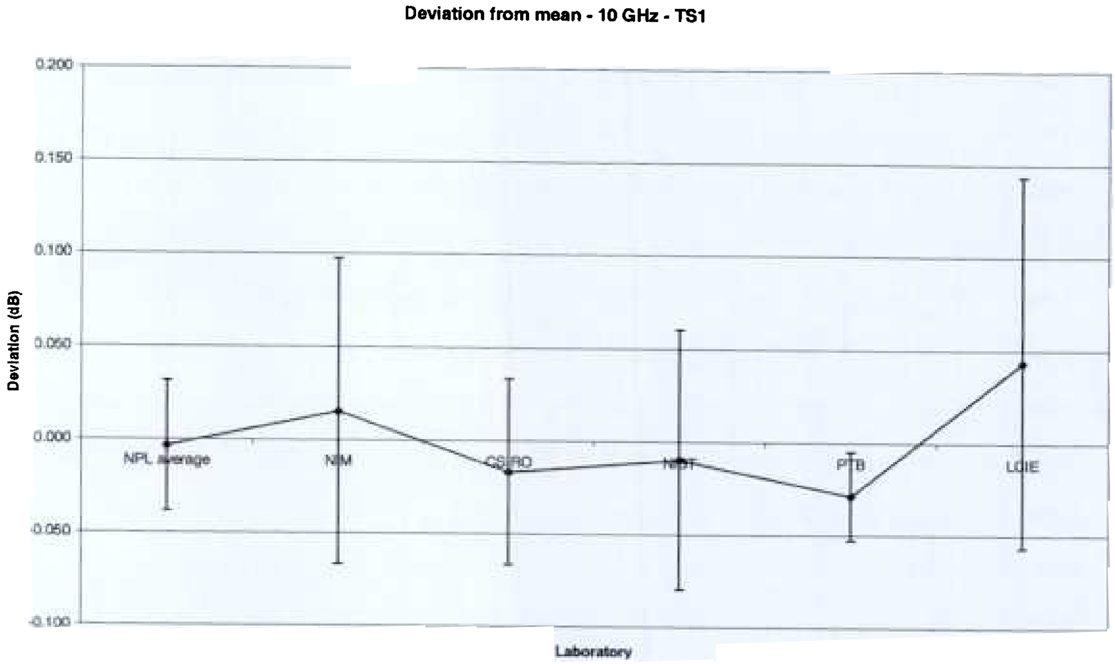


Figure 7



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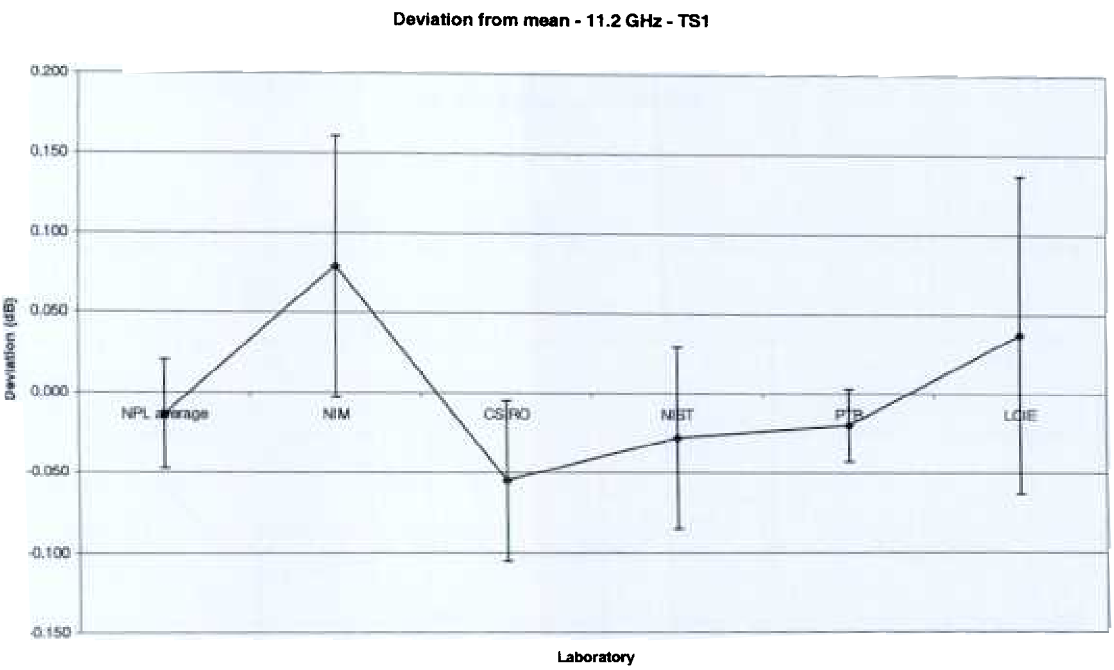

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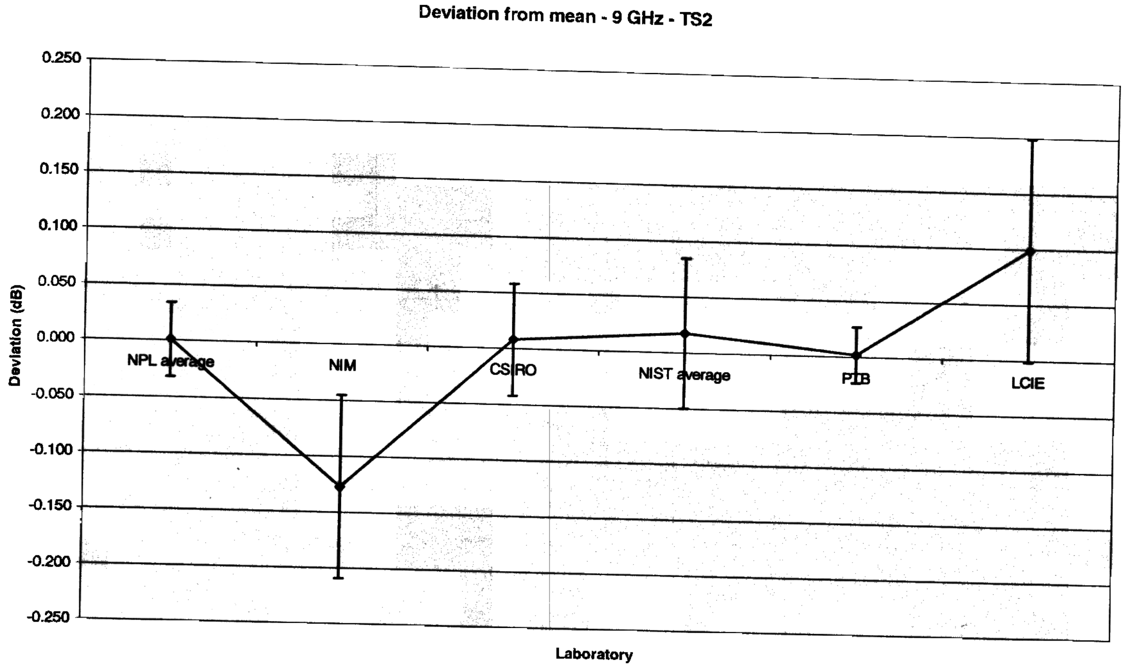
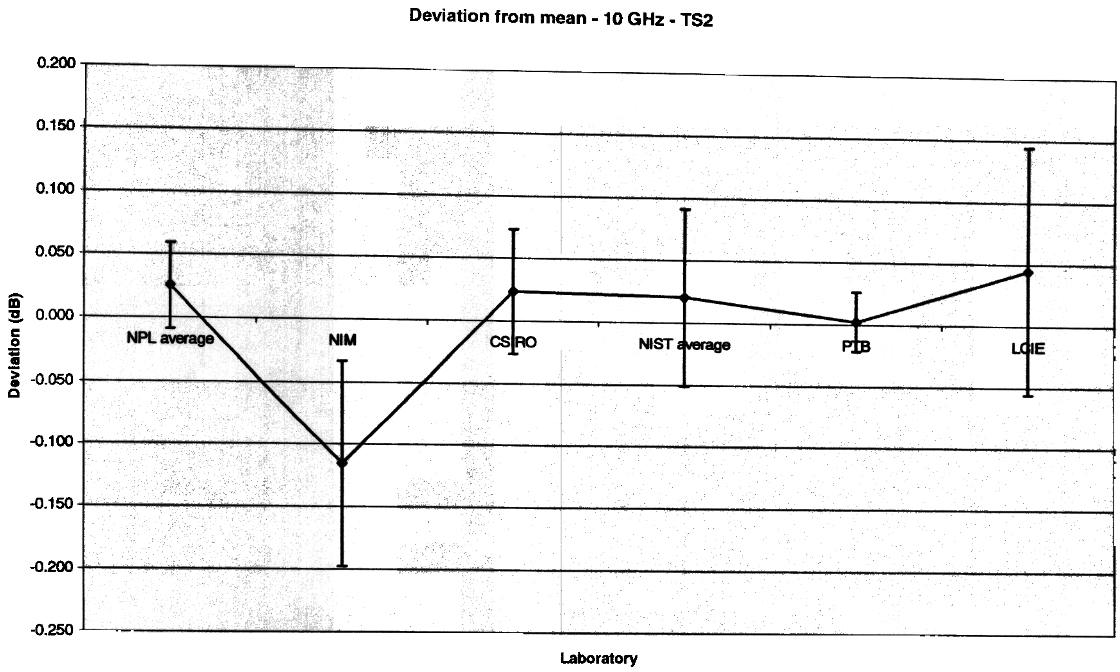


Figure 10



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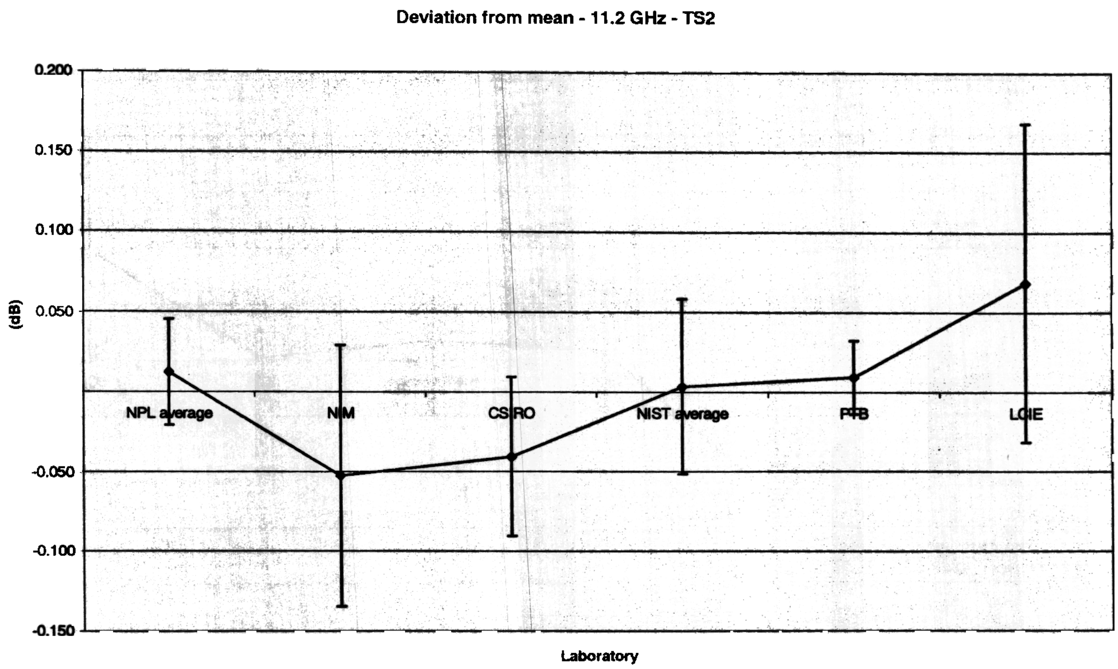
Deviation from mean - 11.2 GHz - TS2
0.200
0.150
0.100
0.050
-0.050
-0.100
-0.150
(dB)
NPL average
NIM
CSIRO
NIST average
PTB
LCIE
Laboratory

Figure 12