CALIBRATION REPORT

FREE SPACE RADIATED ELECTROMAGNETIC FIELD MEASUREMENT SYSTEM

HILLSBORO, OREGON
DECEMBER 1, 1998

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1.0 QUICK REFERENCE

Facility Type	Fully Anechoic Room (Free Space Chamber) : Free Space Radiated Electromagnetic Field Measurement System
Operator and Address	CKC Laboratories, Inc. 5289 NE Elam Young Pkwy., Suite G-900 Hillsboro, OR 97124 (800) 500-4362 fax : 503-693-3543
Facility Designator	Hillsboro, Chamber A
Dimensions	8.5m x 6.0m x 3.0m (l,w,h)
Absorber	Fair-Rite Corporation, #42 material, 5.5mm thickness, All interior surfaces
Facility Supervisor	Kyle Holgate
Calibration Date	October 16, 1998
Report Date	December 1, 1998
Calibration Procedure Used	CKC Laboratories, Inc. Reference #: LP098002
Measurement Uncertainty	Overall (30 MHz – 1000 MHz) : +/- 4.5 dB Combined, Expanded Measurement Uncertainty including instrumentation (type : Normal, k=2, 95% confidence): Traceable to NIST
	Radiated Immunity Tests
	30 MHz – 1000 MHz
	Radiated Emissions Tests
	30 MHz – 1000 MHz
Calibration Performed By	________________________ Kyle Holgate Hillsboro Supervisor
Report Prepared By	________________________ Clark Vitek EMC Staff Engineer
Approved By	________________________ Dennis Ward Director of Laboratories

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2.0 INTRODUCTION

This report summarizes the measurements performed by CKC Laboratories, Inc. for calibration and validation of the facility described herein for the performance of radiated electromagnetic field measurements. The methods and measurements used to prepare this document are described in CKC's ISO Guide 25 Accredited Quality Manual as referenced.

3.0 DESCRIPTION OF CALIBRATION METHOD CKC LP980002

The method of calibration, including computation of resulting uncertainty, is fully described in CKC internal laboratory procedure LP098002. A description of this method is as follows :

1. Volumetric Sampling : The ability of the facility and equipment to generate or receive an isotropic electromagnetic field is sampled by use of a NIST traceable isotropic field probe over the volume to be occupied by the equipment under test. In the Vertical plane, the sample locations are at 4 heights spaced 0.5m from 0.4m below the table top height to 1.9m above the table top location. In the horizontal plane, the sample locations are at the front edge of the table top (4 locations spaced 0.5m apart), at the center of the turntable, and at the front of the turntable. The total positions sampled are 24 (6 locations at 4 heights). These locations are selected to represent the front half of the EUT test volume since a turntable is used during actual testing to rotate the back half to the front half. Figures 1 - 5 provide a description of the field sampling locations and the EUT test volume.
2. Based on the Volumetric Sample the average Gain over isotropic of the Facility and Equipment is computed at each frequency of measurement (1% frequency increments from 30 MHz – 1 GHz), and the Type A uncertainty in this value is computed using the (n-1) unbiased method.
3. The resulting Type A uncertainty is combined with Type B uncertainties of the instrumentation used during the calibration and expanded (k=2) to represent a 95% statistical confidence. The Type A and Type B combination is performed using root-sum-squared techniques. The instrumentation used for calibration includes the isotropic field probe, the spectrum analyzer or power meter, and a directional coupler used for monitoring of power.
4. For statement of the measurement uncertainty during subsequent radiated electromagnetic field immunity measurements, the above combined, expanded uncertainty may be used for the statement of measurement uncertainty. This is because all instrumentation used, including the facility and equipment, is identical to that which will be used during the performance of a future radiated immunity tests.
5. For radiated emissions measurements, the above uncertainty computed in Step 3 must be further RSS combined with the Type B uncertainty of a measurement pre-amplifier and any associated additional cabling not included during the previous Type A determination. This is because a preamplier will

be used for the measurement of emissions and not for immunity measurements. The resulting RSS combined uncertainty for emissions measurements is then expanded by an expansion factor of k=2 to represent a 95% confidence. Note that the above technique for computation of radiated emissions measurement uncertainty invokes reciprocity of electromagnetic fields since the Type A determination is performed using the receive antenna as a transmitter, and an isotropic probe located in the volume that will later be occupied by the equipment under test (EUT).

4.0 FACILITY AND EQUIPMENT DESCRIPTION

Figure 1 shows the layout of the Fully Anechoic Room (Free Space Chamber) listed in Section 1.0 that is the subject of this report. Figure 2 is a photograph of the facility.

Table 1 lists all equipment that are considered included in the Type A evaluation of measurement uncertainty. Any changes in the equipment listed in Table 1 requires re-validation of the results listed in this report.

Table 2 lists the equipment used to perform the measurements contained in this report.

5.0 AMBIENT CONDITIONS AT TIME OF CALIBRATION

Temperature Range	: 65 – 75 degrees F
Relative Humidity Range	: 25% - 75%

Electromagnetic ambients at least –40 dB below calibration level at all frequencies. (measurements performed in shielded, anechoic environment)

6.0 CALIBRATION RESULTS

Figure 6 shows the Forward Power Required to Generate 1 V/m at each of the volumetric sample locations. Figure 7 shows the resulting mean facility Gain over Isotropic, in decibels. Figure 8 shows the mean combined correction factor, C_{dB} to be used to convert field strength in the sample volume to a receiver voltage. Figure 9 Shows the Type A uncertainty, also in decibels, in CdB (uncombined, unexpanded). Figure 10 shows the combined, expanded (k=2)measurement uncertainty including all measurement instrumentation for radiated electromagnetic field immunity measurements. Figure 10 also shows the combined, expanded (k=2) measurement uncertainty including all measurement instrumentation for radiated electromagnetic field emissions measurements.

Sample Calculations, including all equations used to prepare Figure 5 – 10 are included as Appendix A to this Report.

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Appendix B contains a detailed discussion of Measurement Uncertainty, including general verification of the methods utilized in this report by comparison to actual Equipment Under Test results on an Open Area Test Site (OATS).

Appendix C contains the calibration data (raw data) used to generate the above figures. This data is maintained by CKC's documentation control as Excel Files attached to this report.

7.0 REQUIRED CALIBRATION INTERVAL

The results of this report are considered valid for one year without additional calibrations required except in the case of a change in the facility construction or in the equipment listed in Table 1. The equipment listed in Table 2 must be calibrated according to its regular interval.

As an alternative to annual calibration, it is preferred that calibration be continuously maintained by performing a sample at one calibration location per week within the required volumetric sample. The individual calibration points must be included in the sample population data for that point and the result must be no increase in measurement uncertainty beyond the amount specified in Section 1.0. This will result in a full validation of all points every 24 weeks. If this weekly verification is performed, at least once per year, this report shall be updated with an Annex using the most recent 24 weeks' of volumetric data.

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TABLE 1 : EQUIPMENT UNDER CALIBRATION
HILLSBORO, OREGON FREE SPACE MEASUREMENT SYSTEM
HILLSBORO SYSTEM A

Equipment	Model#	Serial#	CKC Designator
Free Space Chamber	CKC608530	1	Hillsboro FSA
Cables, Coaxial 50 ohms	(fixed installation)	Cable A	Hillsboro FSA
Antenna	EMCO Biconilog, Model 3143A	9409-1047	Hillsboro FSA

TABLE 2 : EQUIPMENT USED TO PERFORM CALIBRATION

Equipment	Manufact	Model#	Serial#	Date Last Cal	Date Cal Due
Spectrum Analyzer	HP	8568	2207A01865	1/15/98	1/15/99
Signal Generator**	Marconi	2022D	2207A01865	12/21/97	12/21/98
Directional Coupler	Werlatone	c2630	5156	5/27/98	5/27/99
Isotropic Field Probe	AR	FP2031	15888	8/21/98	8/21/99
Field Monitor	AR	FM2000	14413	4/15/98	4/15/99
Amplifier**	AR	150A100A	18241	4/30/98	4/30/99
Amplifier**	AR	30W1000M7	18694	4/13/98	4/13/99

** : This equipment requires operational check only and is not included in uncertainty calculations. Uncertainty is determined by equipment used to monitor frequency and forward power during immunity tests, or to measure emissions (frequency and power) during emissions tests.

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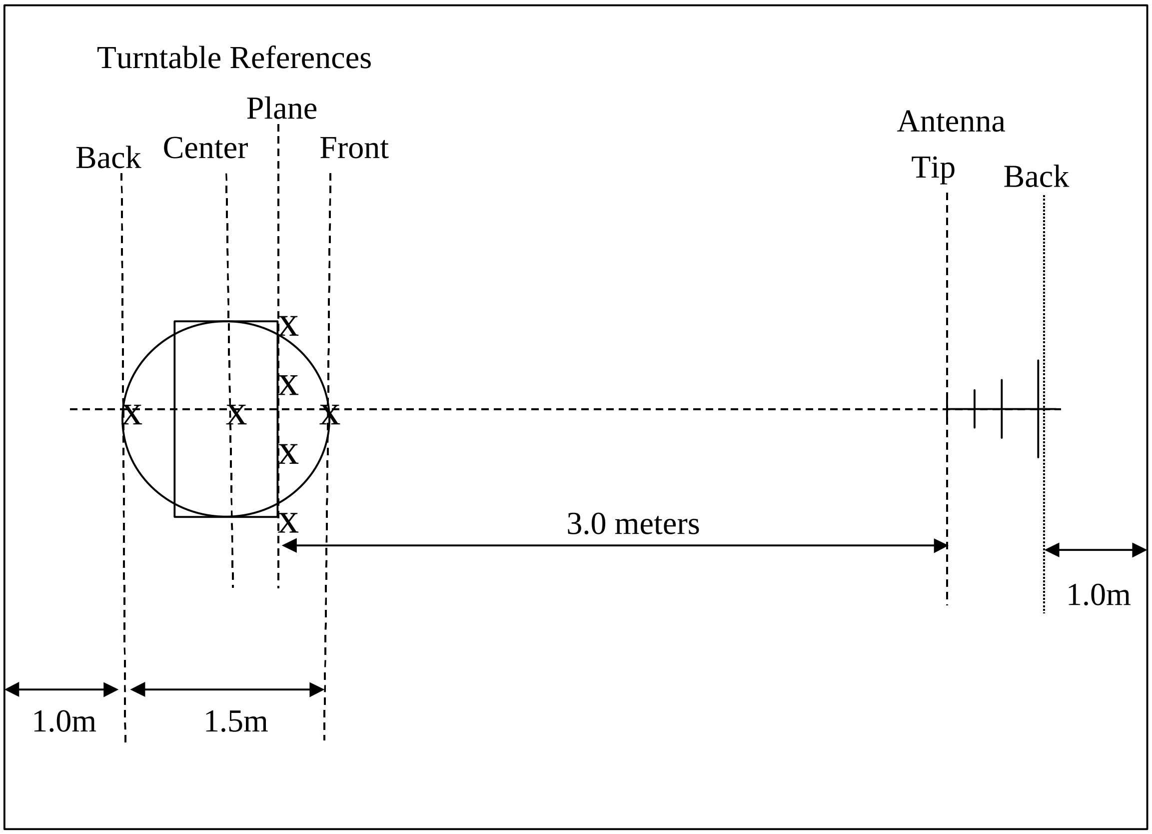
FIGURE 1 : DIAGRAM OF TEST FACILITY (PLAN VIEW)
SHOWING LOCATION OF 1.5M DIAMETER EUT VOLUME



Overall Dimensions and Absorber Details :

- Interior Room Dimensions :
  - Length (8.5m)
  - Width (6.0m)
  - Height (3.0m)

- Absorber Information (30 MHz - 1 GHz) :
  - All Surfaces (including Floor) : Fair-Rite Corporation P/n 3642011601, 5.5mm thickness

- Absorber >1 GHz (future) :
  - All Surfaces (including floor)
  - Between EUT and Antenna Only (1m Test Distance) :
  - AEMI-12-EM Pyramidal

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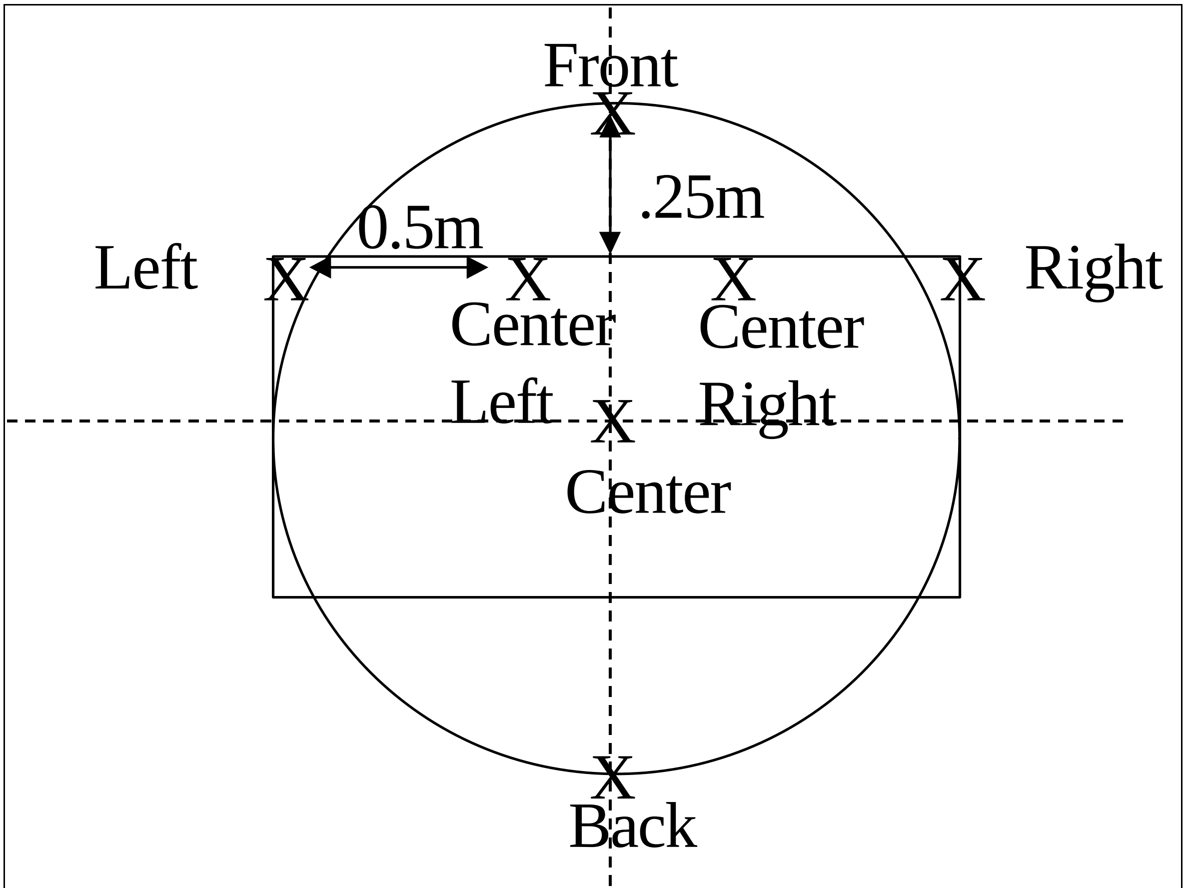
FIGURE 2 : PHOTOGRAPH OF FACILITY SHOWING EUT VOLUME

FIGURE 3 : CALIBRATION PROCEDURE
DETAIL SHOWING LOCATION OF SAMPLE POINTS IN EUT VOLUME
(PLAN VIEW)



X = calibration sample point

Position of standard 1.5m x 1.0m table top in 1.5m test volume.

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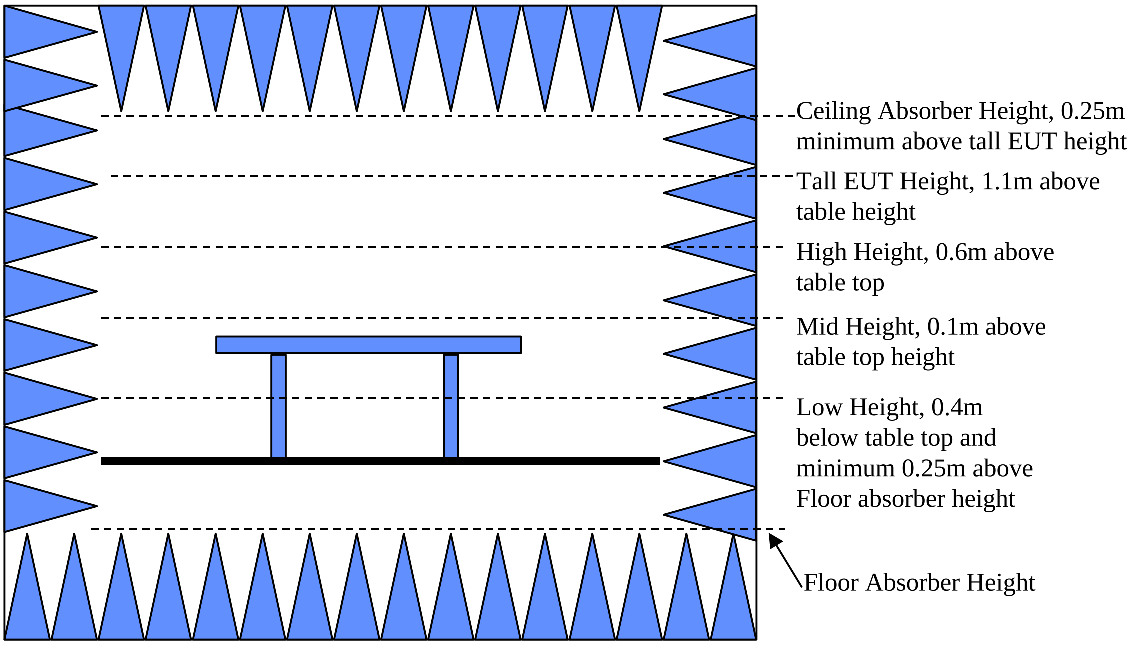
FIGURE 4 : CALIBRATION PROCEDURE
DETAIL SHOWING LOCATION OF REQUIRED FIELD SAMPLE POINTS
(ELEVATION VIEW FROM ANTENNA)



Heights Required to be Sampled : Low, Mid and High for Standard EUT's under 0.6m above table top. Tall EUT height required only for EUT's extending 0.6m to 1.1m above table top height.

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FIGURE 5 : CALIBRATION PROCEDURE
DETAIL SHOWING CALIBRATION DATA POINT REFERENCES IN PLANE OF UNIFORMITY LOCATED AT FRONT EDGE OF EUT TABLE TOP IN EUT VOLUME (ELEVATION VIEW FROM ANTENNA)

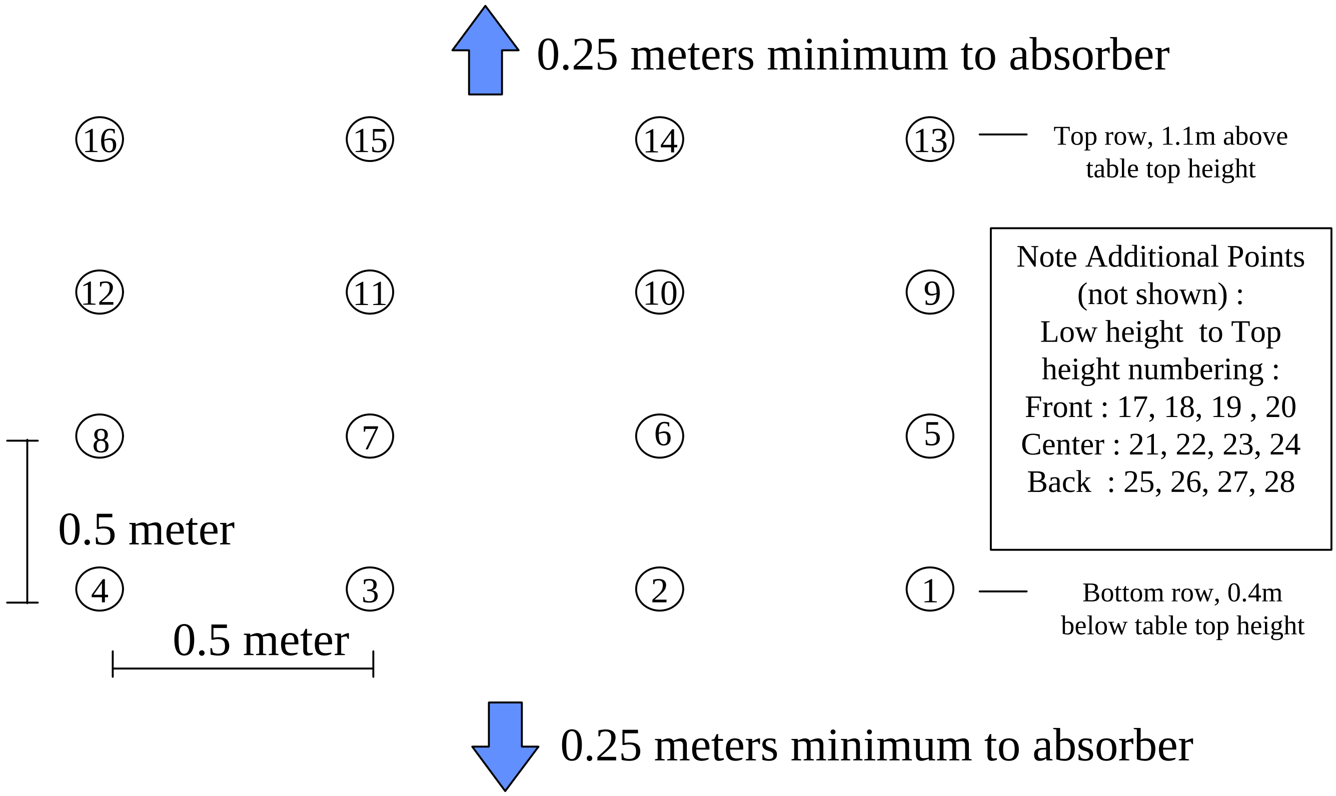

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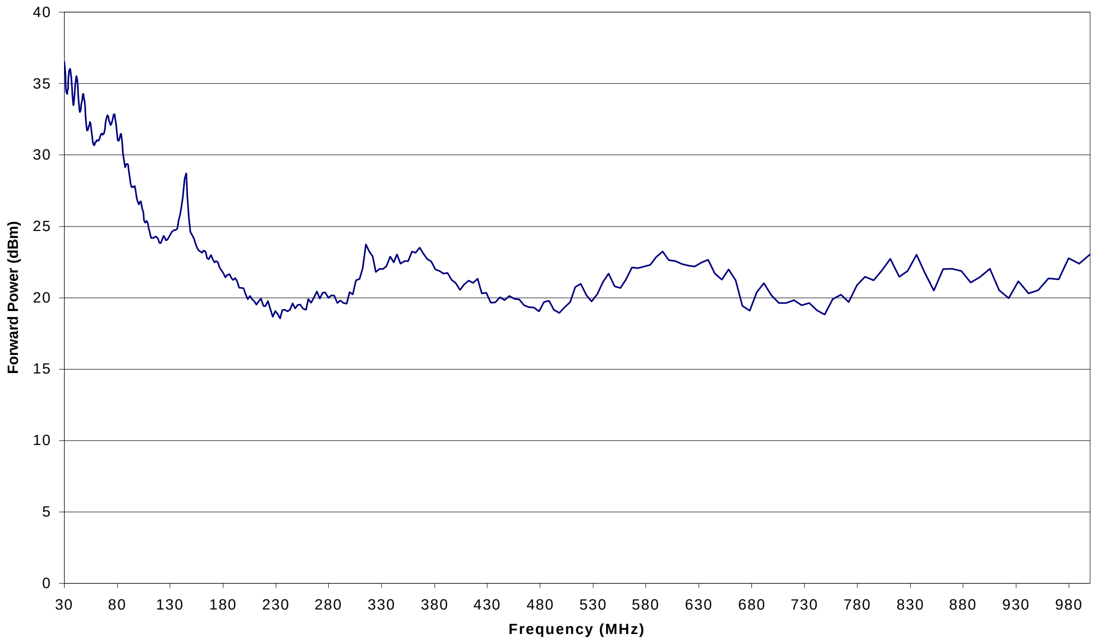
FIGURE 6 : AVERAGE FORWARD POWER REQUIRED TO GENERATE 1 V/M
3 METER TEST DISTANCE AS DEFINED IN LP098002

Vertical Polarity



Horizontal Polarity

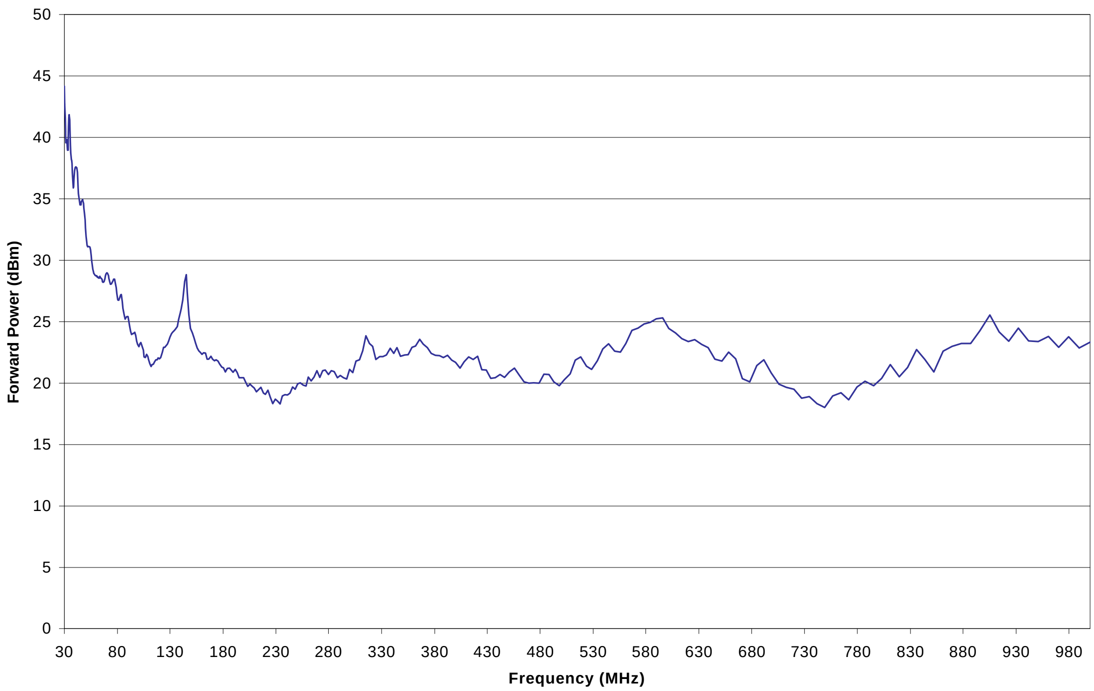


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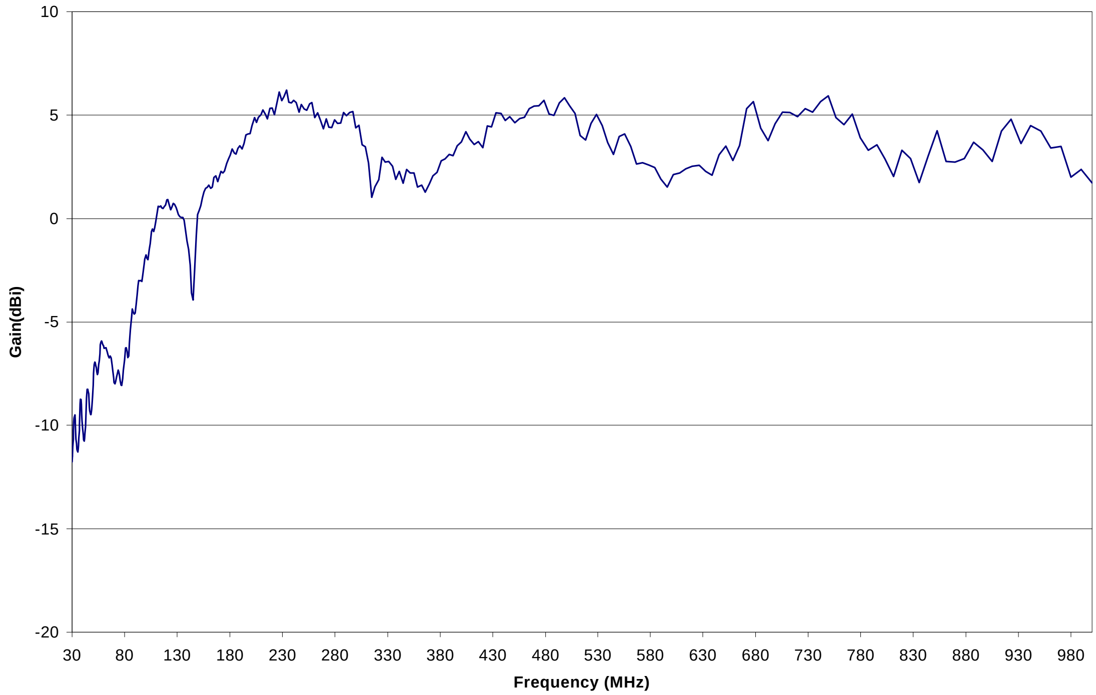
FIGURE 7 : AVERAGE SYSTEM GAIN OVER ISOTROPIC BASED ON VOLUMETRIC SAMPLE AT 24 LOCATIONS IN EUT VOLUME

Vertical Polarity



Horizontal Polarity

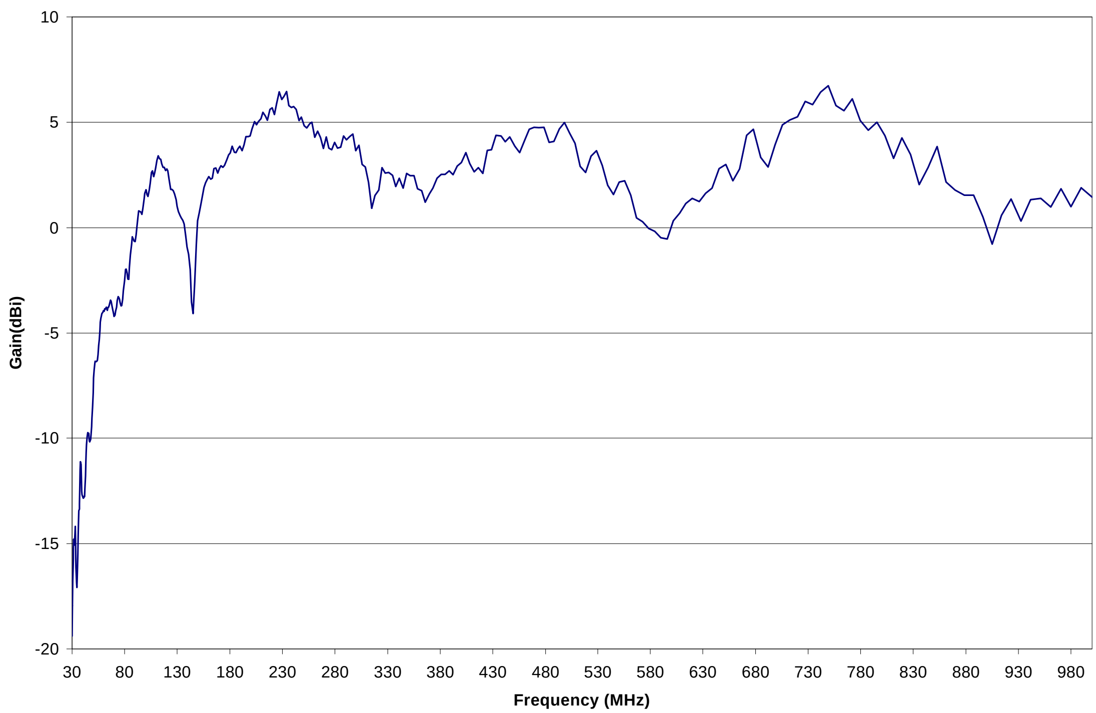


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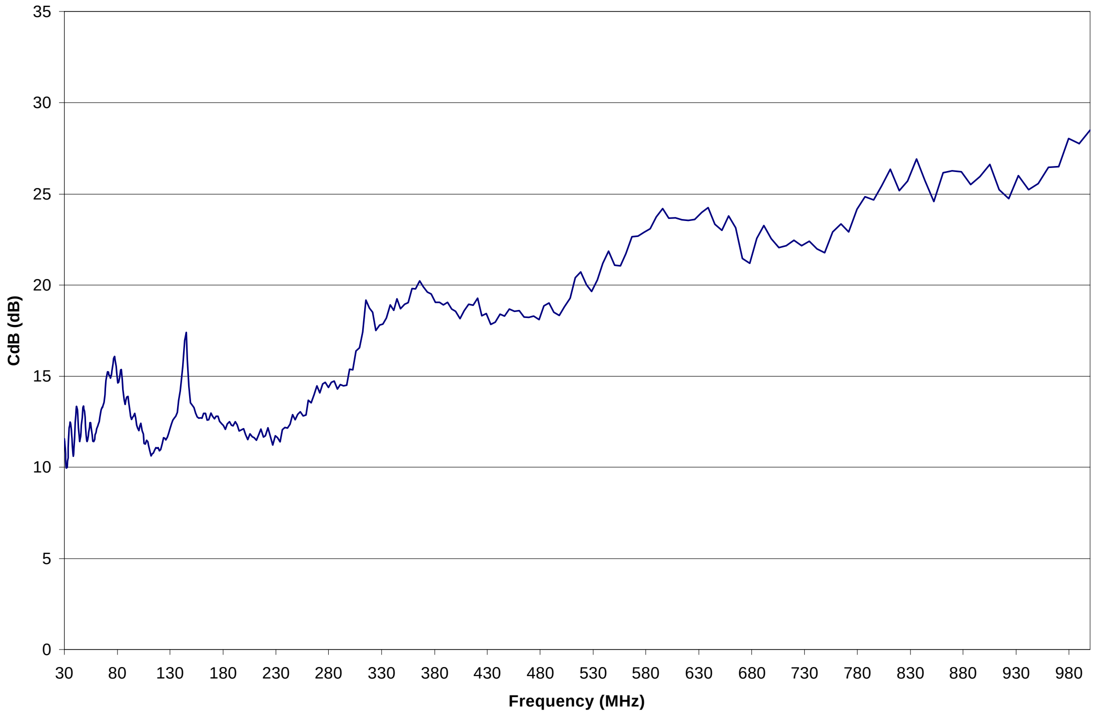
FIGURE 8 : TRANSDUCER FACTOR, C_{dB} (in DECIBELS) : ADD TO CONVERT RECEIVER VOLTAGE (in dBuV) TO FIELD STRENGTH (in dBuV/m)
3 Meter Test Distance

Vertical Polarity



Horizontal Polarity

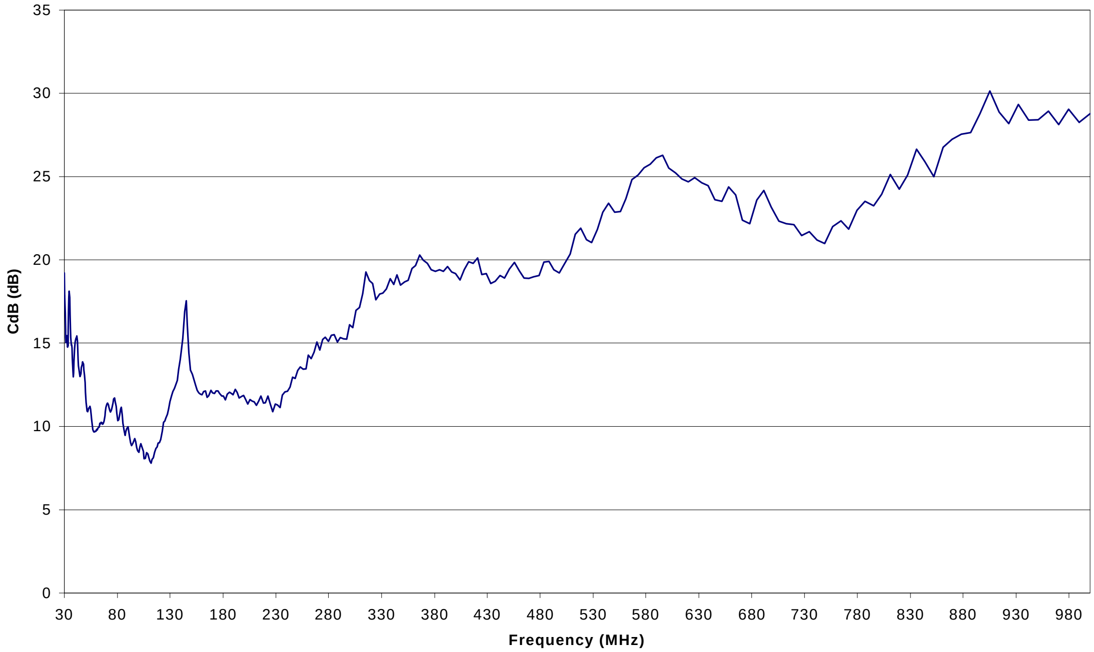


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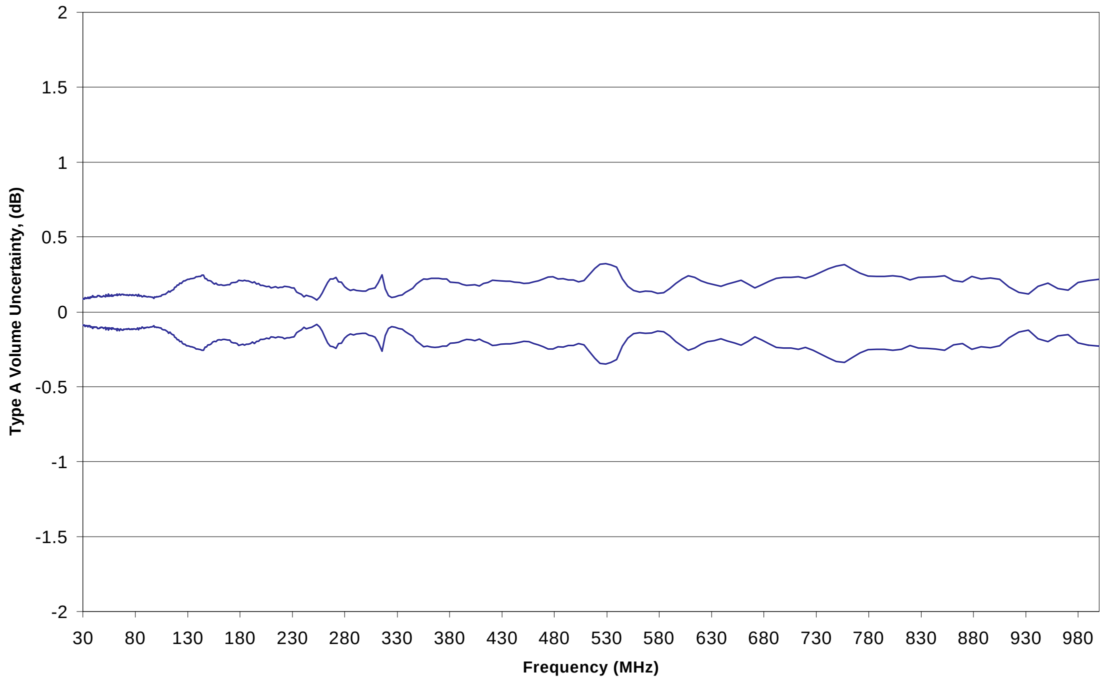
FIGURE 9 : VOLUMETRIC STANDARD (k=1) UNCERTAINTY IN FIELD STRENGTH GENERATED OR RECEIVED BASED ON SAMPLE OF 24 LOCATIONS IN TEST VOLUME
(TYPE A MEASURED, Normal, computed using n-1 unbiased method)

Vertical Polarity



Horizontal Polarity

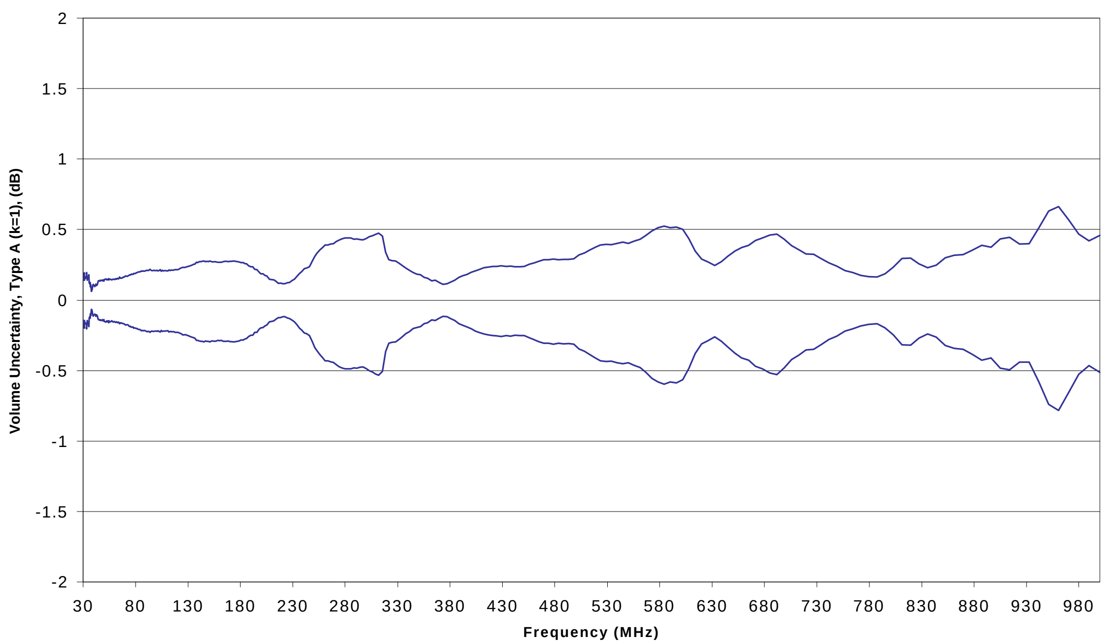


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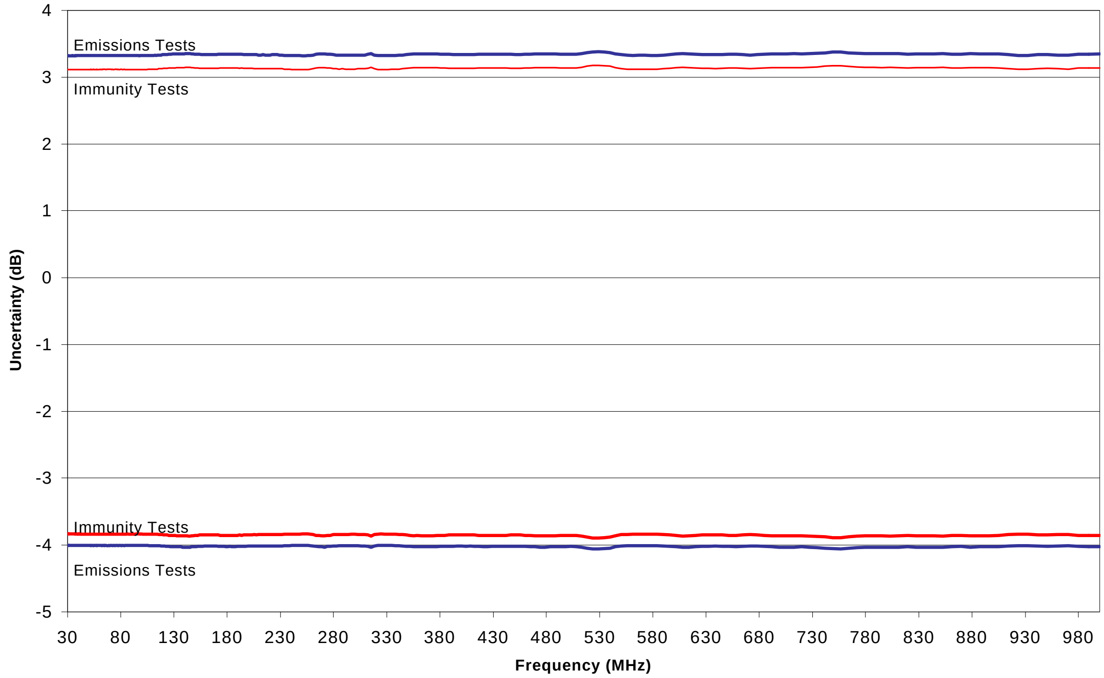
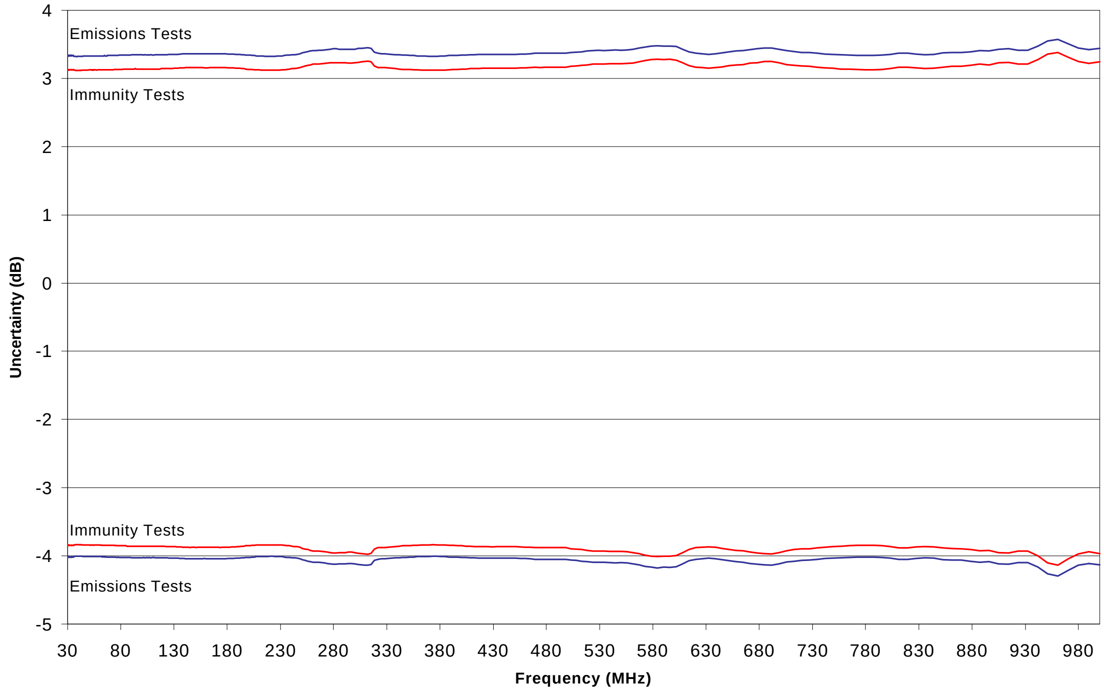
FIGURE 10 : TOTAL COMBINED (RSS METHOD), EXPANDED (k=2, Normal) MEASUREMENT UNCERTAINTY INCLUDING ALL INSTRUMENTATION: 95% CONFIDENCE VALUES

Vertical Polarity



Horizontal Polarity



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APPENDIX A : SAMPLE CALCULATIONS

Prepared By :

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A.1 CALCULATION OF MEAN FORWARD POWER REQUIRED TO GENERATE 1 V/M IN EUT VOLUME

This section Describes the calculations required to obtain the results shown in Figure 6 of the main body of this report.

STEP 1 : Normalize the Power Results for Each Data Point

The mean forward power required to Generate 1 V/m in the EUT Volume is determined by sampling of the forward power to the measurement system including the cables, antenna, and facility at multiple locations within the volume. Due to uncertainty characteristics (floor noise) of the isotropic field probes typically used for this sampling, sampling of the field strength is usually actually performed at some level higher than 1 V/m such as 3 V/m or 10 V/m. This requires normalizing the results to 1 V/m as in the following example for a sample point (i) follows :

E_i = Measured E Field at Sample Point (i). (V/m)
P_i = Measured Forward Power Required to Generate E_i (in dBm) on Forward Power monitor port of Directional Coupler.
D = Directional Coupler Forward Power Monitor Port Insertion Loss (in dB)
Pn_i = Normalized Forward Power Required to Generate 1 V/m at point (i). (Watts)

Sample Calculation :

Assume the following are determined by measurement at a point (i) :

$E_i = 3.78$ *V/m*
$P_i = 3.1$ *dBm*

And the following is contained in the report of calibration for the directional coupler used :

D = -40.5 dB

The Normalized Forward Power, Pf_i in Watts, required to generate 1 V/m at point (i) based on this data is obtained as follows :

$$Pf_i(watts) = .001 \cdot Watt \cdot \log_{10}^{-1}\left(\frac{P_i - D - 20\log_{10}(E_i)}{10}\right) \qquad \textbf{(a1)}$$

$$= .001 \cdot \log_{10}^{-1}\left(\frac{3.1 - (-40.5) - 20 \cdot \log(3.78)}{10}\right)$$

$$Pf_i(watts) = 1.6$$

This calculation is performed for all sample points measured in the test volume at each frequency measured (usually 1% frequency increments).

PC Users Note : These notes are intended to aid to the use of the sample Excel Workbook which may be used for all calculations described in this section. The raw data for power and field strength described in Step 1 are contained on worksheets "Edata" and "PowerData". The Directional Coupler Insertion Loss is contained on sheet "DirectCoupler".

<u>STEP 2 : COMPUTATION OF MEAN FORWARD POWER TO GENERATE 1 V/M IN TEST VOLUME AT EACH FREQUENCY OF INTEREST</u>

After Normalization, a matrix of Normalized Forward Power (in watts) required to generate 1 V/m exists separately for each polarity (horizontal and vertical) representing all sample locations at each frequency of interest.

The mean forward power required to generate 1 V/m in the test volume is obtained from the following expression :

$$\overline{P_f}(watts) = \sum_{i=1}^{n} \frac{Pf_i(watts)}{n} \qquad \text{(a2)}$$

Sample Calculation :

> *Assume the following matrix of normalized power is obtained from Step 1 for a sample of 24 points in the EUT volume at 30 MHz, Horizontal Polarity :*
>
> *Sample Location :*
> *(1,2... 24)*
>
> *Normalized Power (watts) :*
> *(22.28, 26.85, 26.85, 27.48, 23.04, 25.80, 22.00, 24.51, 24.51, 28.04, 24.51, 25.08, 29.63, 27.48, 28.78, 30.13, 22.00, 17.58, 18.11, 23.95, 33.24, 28.78, 28.78, 36.96)*
>
> *Average Power to Generate 1 V/m at 30 MHz, Horizontal Polarity :*

$$\overline{P_f}(watts) = \sum_{i=1}^{24} \frac{Pf_i(watts)}{24} = 26.10 \ \ Watts = 44.17 \ dBm$$

PC Users Note : The Normalized Forward Power for Each Data Point is contained on the Worksheet "Pnormalized". The Average Forward Power in Watts and in dBm are shown on the Worksheet "Summary". A Chart of the Average Forward Power is "Pchart".

SECTION A.2 : CALCULATION OF AVERAGE SYSTEM GAIN OVER ISOTROPIC AND AVERAGE SYSTEM TRANSDUCER FACTOR, C_{dB}

The following calculations are used to generate Figures 7 and 8 of the main body of this report.

In free space, the general relationship between electric field, E (V/m) and Power Density, P_D (watts/m^2) is :

$$E^2 = P_D \cdot Z_0 \qquad \text{(a3)}$$

where Z_0 is the free space impedance of 120π ohms.

The power density from a spherical, isotropic source is related to the transmit forward power, P_F (watts), of the source as :

$$P_D = \frac{P_F}{4\pi \cdot d^2} \qquad \text{(a4)}$$

where d is the distance in meters from the source.

The power density of a source, with gain over isotropic, is then by definition of gain as follows :

$$P_D = \frac{P_F}{4\pi \cdot d^2} \cdot G \qquad \text{(a5)}$$

where G is the numeric power gain.

Substituting equation (a5) for P_D into equation (a3) and converting to decibels one obtains :

$$G_{dBi} = 10 \cdot \log\left(\frac{E^2 \cdot d^2}{30 \cdot P_F}\right) \qquad \text{(a6)}$$

Thus, to continue with sample calculation from above, given a normalized field strength, E, of 1 V/m, and the average transmit power P_F (in watts) required to generate 1 V/m over the test volume, one may solve for the average Gain over isotropic for the Free Space electric field measurement system and corresponding system transducer factor. The gain may be computed referenced to any free space specification limit distance, d, usually 3m or 10m. This is continued in Step 3 as follows

<u>STEP 3 : Calculation of Average System Gain over Isotropic</u>

Sample Calculation :

Using the sample data presented in Step 2 above, the average system Gain over isotropic at 30 MHz, Horizontal polarity, is as follows for a 3 meter distance :

$$G_{dBi} = 10 \cdot \log\left(\frac{E^2 \cdot d^2}{30 \cdot P_F}\right) = 10 \cdot \log\left(\frac{1(v/m)^2 \cdot 3^2 (m)^2}{30 \cdot (26.1)(Watts)}\right) = -19.4\ dB_i$$

PC Users Note : Calculation of Average System Gain over Isotropic is contained on the worksheet "Summary" and plotted in the Chart "GainChart".

<u>STEP 4 : Calculation of Average System Transducer Factor</u>

The relationship between gain and transducer factor (antenna factor) is derived in SAE ARP 958[1] and presented as follows :

$$\text{System Transducer Factor, } C_{dB} = 20 \cdot \log(f_{MHz}) - 29.77 - G_{dBi} \qquad \text{(a7)}$$

The system transducer factor is used to convert a Voltage measured on a 50 ohms receiver (or spectrum analyzer) to field strength presented to the system by the Equipment Under Test for emissions tests, or to the equipment under test for immunity tests.

Sample Calculation :

Using the sample data of steps 1 - 3 above for 30 MHz, Horizontal Polarity, the following system transducer factor, C_{dB}, is obtained :

$$C_{dB} = 20 \cdot \log(f_{MHz}) - 29.77 - G_{dBi} = 20 \cdot \log(f_{MHz}) - 29.77 - (-19.4 dB_i) = 19.17 dB$$

Note that this system transducer factor encompasses the free space system of the facility, antenna, and fixed cabling, and is represented as an average presented to the test volume that will be occupied by the equipment under test (EUT).

PC Users Note : Calculation of Average System Transducer Factor, CdB, is contained on the worksheet "Summary" and plotted in the Chart "CdBChart".

A.3 CALCULATION OF MEASUREMENT UNCERTAINTY

For the matrix of normalized forward power required to generate 1 V/m in the test volume, a standard deviation and Type A (observed) measurement uncertainty can be calculated representing the uncertainty in the field strength generated or received by the system. The calculations of this section are used to generate Figures 9 and 10 of the main body of this report.

The standard deviation based on the population of forward power data is computed as follows :

$$s = \sqrt{\frac{n \cdot \sum_{i=1}^{n} {P_{f_i}}^2 - \left(\sum_{i=1}^{n} P_{f_i} \right)^2}{n \cdot (n-1)}} \tag{a8}$$

where Pf_i denotes the individual normalized power required at the individual sample points (in watts), and n is the number of points sampled.

The standard (k=1) Type A uncertainty in the required forward power to generate 1 V/m is then given (in +/- Watts) by the following expression :

$$u = \left(\frac{s}{\sqrt{n}} \right) \tag{a9}$$

Note that by strict interpretation, the use of the above equation (a9) requires the population sample to be independent measurements of the exact same quantity or parameter. Although the sample population in this case is obtained by movement of the isotropic field probe to different locations in the test volume, the use of equation (a9) is justified by the observation that the goal of this procedure is to obtain multiple samples of the same quantity which is system gain over the ideal isotropic free space value within the test volume.

By the strictest statistical interpretation, equation (a9) could be replaced by u = s, which states that the standard uncertainty is equal to the standard deviation. For the typical population of 24 data points, this results in < 1 dB of difference than equation (a9) produces when s is less than 10% of the value of average forward power. In cases where s>10% of the average forward power, the difference between methods can be more substantial with approximately 3 dB increase in uncertainty when s approaches the average value. Beside the statement of the above paragraph, it is noted that the use of equation (a9) in its present form instead of u=s produces uncertainty values consistent with experimental determination of uncertainty by an alternative method as described in Appendix B. Therefore, it is believed that the methods of this procedure produce a sufficiently independent population sample over the test volume, and the use of equation (a9) produces a substantially correct estimate of the measurement uncertainty with further confirming evidence of this statement provided by the alternate OATS comparison procedure of Appendix B.

STEP 5 : Calculation of Type A Uncertainty in Watts and in Decibels

Sample Calculation :

> *Using the sample data of Step 2 above and substituting into equation (a8), the resulting standard uncertainty is +/- 0.888 Watts.*

To convert to the Type A uncertainty in Forward Power to a Type A uncertainty in Electric Field generated or received in decibels , the resulting value of U from equation (a9) must be applied to average forward power used to compute Gain and System Transducer Factor, C_{dB} in Equations (a6) and (a7) as follows :

$$u+ \text{ (k=1, Type A, Normal, in dB)} = C_{dBupper} - C_{dBaverage} \qquad \text{(a10)}$$
$$u- \text{ (k=1, Type A, Normal, in dB)} = CdB_{average} - CdB_{lower} \qquad \text{(a11)}$$

Sample Calculation :

> *u+ and u- are computed in dB by substituting $Pf = (P_{faverage} + u)$ and $Pf=(P_{faverage} - u)$ into equations (a6) and (a7) to obtain the upper and lower values of C_{dB}. The positive and negative Uncertainties are the difference between the average value and CdB_{upper} and CdB_{lower}. Using the above computed value of u for 30 MHz, Horizontal of +/- 0.888 Watts, the resulting upper and lower values of CdB are 19.31 dB and 19.02 dB. Comparing these values to the average value of CdB = 19.17 computed in Step 4 above, the resulting Type A uncertainty (in decibels) in CdB is + 0.67 dB / -0.79 dB. Note that this represents the Type A standard (k=1) uncertainty in the field strength generated or received in the test volume. This uncertainty will be used later to combine with Type B factors of the instrumentation used for the calibration.*

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PC Users Note : The computation of Type A Uncertainty in Watts and in Decibels as described in Step 5 is contained on the Worksheet "Summary", including computation of the Upper and Lower values of CdB. A Chart of the Type A (Volumetric) uncertainty is contained on "TypeAchart"

STEP 6 : CALCULATION OF TOTAL COMBINED, EXPANDED MEASUREMENT UNCERTAINTY INCLUDING ALL INSTRUMENTATION

The calculation of the Total Combined, Expanded (k=2) Measurement uncertainty, including all instrumentation is based on the Root Sum Squared method of combination for the above calculated Type A uncertainty of the test volume with Type B factors to include the instrumentation used for the calibration and/or that will be used for subsequent measurements.

The following provides a sample list of Type B considerations.

Contribution	Probability Distribution	Expanded Uncertainty (+dB)/(-dB)	Standard (k=1) Uncertainty (+dB)/(-dB)
Field Probe	Normal (k=2)	+2/-3	+1/-1.5
Spectrum Analyzer	Rectangular (k=1.73)	+/- 2	+/- 1.15
Directional Coupler	Rectangular (k=1.73)	+- 0.5	+/- 0.289
Pre-Amplifier	Rectangular (k=1.73)	+/- 1	-/- 0.577

It is important to note that this list does not include the equipment that comprises the field generation and measurement system, i.e. the facility, antenna, and fixed cabling as this equipment is included in the Type A determination described in Steps 1 - 5 above. Note also that the Pre-Amplifier must be included if it is used (typically for emissions tests and not for immunity tests).

Sample Calculation :

Using the above list of Type B combination factors, and the above calculated Type A Uncertainty based on the volumetric sample data, the total combined, expanded measurement uncertainty is obtained as follows for an immunity test (excluding emission pre-amplifier) based on the sample 30 MHz, Horizontal data of Steps 2-5 above :

$$UdB+ = 2 \cdot \sqrt{[(1)^2 + (1.15)^2 + (0.289)^2 + (.67)^2]}$$

$UdB+ = 3.38$ *dB (Normal, k=2, 95% Confidence Value)*

$$UdB- = -2 \cdot \sqrt{[(1.5)^2 + (1.15)^2 + (.289)^2 + (.79)^2]}$$

UdB- = -4.14 dB (Normal, k=2, 95% Confidence Value)

Note that the above combination and expansion to a 95% confidence interval by use of the expansion factor (k=2) assumes that sufficient degrees of freedom are present as discussed in the National Institute of Standards and Technology (NIST) Technical Note 1297 (pages 9 and 10).[2] The use of a large sample population, such as 24 points, in the EUT volume helps to ensure that this is the case. For combination of Type A and Type B factors, the coverage factor (k=2) is also the recommended value by the United Kingdom NAMAS/NIS 81 document.[3]

In general, if fewer data points are used than recommended in this procedure, it may be necessary to perform an evaluation to ensure that the resulting degrees of freedom are sufficient to justify the continued use of a coverage factor (k=2).

PC Users Note : The Type B Expansion factors and the resulting combined, expanded measurement uncertainty are included in the sample workbook as worksheet "Summary". A chart of the combined, expanded uncertainty is "Uchart".

References (Appendix A)

1. <u>SAE ARP 958</u>. Society of Automotive Engineers, Standard 958, Revision A (Issue Date 1992-11-5). "Electromagnetic Interference Measurement Antennas, Standard Calibration Methods", pages 4 -5.
2. <u>NIST Technical Note 1297.</u> "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results", 1994 Edition. US Department of Commerce, National Institute of Standards and Technology.
3. NAMAS/NIS 81 "The Treatment of Uncertainty in EMC Measurements", National Physical Laboratory, Teddington, Middlesex, U.K.

ATTACHMENT D : CALIBRATION REPORT

APPENDIX B : ALTENATIVE DETERMINATION OF MEASUREMENT UNCERTAINTY OF FREE SPACE MEASUREMENT SYSTEM BASED ON MEASUREMENT OF SAMPLE EQUIPMENTS UNDER TEST AND STATISTICAL COMPARISON TO OPEN AREA TEST SITES

This main body of this calibration report utilizes a method of facility calibration based on sampling of the volume to be occupied by the Equipment Under Test (EUT) and a combined Type B and Type A uncertainty determination. The methods used in this report were developed primarily to provide harmonized definitions of the role of the facility and equipment used for radiated emissions and radiated immunity tests when the same equipment and facility are used, and to harmonize the calibration procedure. The uncertainty calculations are carried out in accordance with ISO and NIST guidelines (such as NIST technical note 1297) for expression of measurement uncertainty. Also, since all equipment used for the Type A determination is itself traceable to NIST through transfer standards, the method of calibration presented provides a more directly traceable method than presently available for OATS based on the standards ANSI C63.4 and CISPR 22.

CKC Laboratories, Inc. has performed several measurement of Equipment Under Test for the purposes of “correlation” studies between the new Free Space Standard facility and the existing OATS standard facilities. When combined for many Free Space facilities, and many OATS facilities these correlation measurements provide an alternative assessment of the measurement uncertainty of the Free Space Chambers that is independent of the calibration methods used in the main body of this report.

ATTACHMENT D : CALIBRATION REPORT

B.1 CORRELATION MEASUREMENTS OF EQUIPMENTS UNDER TEST (EUT'S) BETWEEN FREE SPACE CHAMBERS AND OATS

The overall correlation from the 3 Meter fixed height free space chambers to full scan height, 10 Meter OATS was determined to be as follows based on analysis of data from several systems and several facilities :

Free Space / OATS Correlation
Based on Measurement of EUT's

		% Data Within		
Frequency Range	**# Data Points**	**+/- 2 dB**	**+/- 4 dB**	**+/- 6.8 dB**
30 – 100 MHz	90	43%	79%	98%
100 – 200 MHz	292	52%	82%	97%
200 – 300 MHz	390	54%	81%	95%
300 – 400 MHz	301	35%	70%	91%
400 - 500 MHz	157	52%	89%	99%
500 - 600 MHz	123	57%	89%	98%
600 – 700 MHz	102	49%	84%	94%
700 – 800 MHz	73	36%	73%	99%
800 – 900 MHz	25	60%	96%	100%
900 – 1000 MHz	22	45%	100%	100%
Overall	**1575**	**48%**	**81%**	**96%**

For the purposes of the discussion that follows, an overall correlation of +/- 6.8 dB for 95% Confidence, Normal distribution will be used.

B.2 DETERMINATION OF TYPICAL FREE SPACE CHAMBER UNCERTAINTY BASED ON MULTIPLE EUT FREE SPACE TO OATS CORRELATION MEASUREMENTS

The above correlation values are the quotient (subtraction in dB) of the readings from the two types of facilities (Free Space Chamber and OATS), and therefore represents the Root Sum Square (RSS) combination of the individual uncertainties of the two facilities. To determine the individual uncertainties, one uncertainty or the other must be first assumed and/or the two uncertainties must be considered to be equal.

For the case where the two uncertainties are considered equal, the individual uncertainty of the OATS or the Free Space Chamber is obtained from the correlation value as follows:

For 95% Confidence (k=2), Assuming Normal distribution :

$$U = 1.96 \cdot \sqrt{\left(\frac{Uoats}{1.96}\right)^2 + \left(\frac{Ufs}{1.96}\right)^2} \qquad \text{(b1)}$$

where U represents the 95% Free Space Chamber/OATS correlation value and Uoats and Ufs are the total combined, expanded uncertainties of the individual sites. Using the value of U = +/- 6.8 dB determined by analysis of the data population, the individual uncertainties are obtained as follows if Uoats and Ufs are assumed to be equal :

$$U = 1.96 \cdot \sqrt{\left(\frac{Uoats}{1.96}\right)^2 + \left(\frac{Ufar}{1.96}\right)^2} = \pm 6.8dB$$

$$Uoats = Ufar = \pm 4.81dB$$

Using a similar calculation, but assuming that Uoats = +/- 6 dB as suggested in the Draft CISPR WG4 uncertainty document for measurement of broadband antennas, the resulting value of Ufs Space Chamber = +/- 3.2 dB.

Assuming a best case value of +/- 4 dB for the OATS, this results in a worst case 95% confidence uncertainty value of +/- 5.5 dB for the Free Space Chamber. Note that this is unlikely however because it would be difficult to achieve an OATS uncertainty of +/- 4 dB. This is based on typical instrumentation of +/-2 dB for the receiver, +/- 1.5 dB for the antenna, and site errors by the NSA method may be up to +/- 4 dB. An RSS combination of these values using Normal distribution similar to that applied in the procedure used in the main body of this report for the free space chamber results in an OATS uncertainty of +/- 5.74 dB for a 95% confidence.

B.3 Conclusions : Typical Free Space Chamber Uncertainty based on EUT Correlation Measurements to OATS and Comparison to Methods Employed in the Main Body of these Report

Based on measurement of actual EUT's and assumed values of OATS uncertainty between +/- 4 dB and +/- 6 dB (k=2, Normal), the typical Free Space Chamber uncertainty is as follows :

Typical Free Space Uncertainty Based on EUT Correlation to OATS

Correlation Value (+/- dB) (95% of Free Space to OATS Data Within)	Assumed OATS Uncertainty (k=2, 95% Confidence)	Resulting Free Space Chamber Uncertainty (k=2, 95% Confidence
+/- 6.8 dB	+/- 6.0 dB	+/- 3.2 dB
	+/- 4.8 dB	+/- 4.8 dB
	+/- 4.0 dB	+/- 5.5 dB

These results are based on comparisons between multiple Free Space Chambers and Multiple OATS are intended only to provide a general alternate confirmation of the methods employed in the main body of this report. The methods of the main body of this report are preferred for determination of specific system uncertainty because they are in accordance with ISO guidelines and are specific to the facility and equipment used. The typical results for a Free Space Chamber when uncertainty is evaluated using the methods of the main body of this report are presented as follows (worst case values) :

Typical Free Space Chamber Uncertainty Based on CKC Laboratories, Inc. LP980002 Method of Simultaneous, Traceable Facility and Equipment Calibration (k=2, 95% Confidence)

Horizontal Polarity	Vertical Polarity
+3.1 / - 3.8 dB	+ 3.4 / -4.2 dB

Based on the similarity of results between the methods, CKC Laboratories, Inc. has concluded that the methods employed in the main body of this report are supported both by ISO procedures and EUT correlation measurements to the OATS. Note, however, that the presentation of this Appendix applies only to table top devices, and that an ideal correction factor based on modeling of an isotropic source at a height above ground of 1 meter was employed to correct the Free Space measurements to their OATS equivalents.