

Attachment A :

Technical Justifications For Acceptance of Fixed Height Free Space Radiated Emissions Measurements

The following technical justifications are provided as a summary for acceptance of fixed height Free Space measurements :

Justification #1 : Theoretical Comparison of Fixed height Free Space Chamber to 1-4m scan height OATS based on Normalized Site Attenuation (NSA) modeling :

The attached article “An Analytical Comparison of Radiated Emission Test Facilities” shows that the range of possible results obtained for maximized emissions based on an EUT source within a typical 1.5m test volume is more tightly bound by a fixed height free space measurement than a 1-4m scan height OATS over much of the frequency range of 30 – 1000 MHz. This means that the maximized emissions obtained in an ideal fixed height free space chamber will be less dependent on the source location within the test volume, reducing variations in the test results due to changes in the test setup such as equipment and cable placement. The article also compares the fixed height free space environment to a fixed height semi-anechoic environment to show that there is a significant difference between fixed height measurements in free space and fixed height measurements over a ground plane. It is observed that the fixed height free space measurements much more closely approximate the results achievable on an ideal full scan height OATS than are possible with fixed height semi-anechoic measurements.

It is also proposed based on these theoretical considerations that testing at fixed height in free space will also present a practical improvement in test repeatability over most present day full scan height OATS type measurements. This is because in order to obtain the results shown in the analysis for a full 1-4m scan height OATS, the equipment under test must be setup in a maximized configuration every time, and the antenna must be scanned the full 1-4 meters at every frequency, for small incremental turntable angles. In most cases, this fully correct OATS procedure would require much more test time than is presently commercially acceptable. A common OATS time saving practice is to scan in frequency while holding either the turntable angle or antenna scan height as constant. This practice can significantly compromise the true theoretical quality of the full scan height OATS because in many cases the correct, maximized emissions is not obtained across all frequencies and turntable angles since the practice of iterative approximation of turntable angle and height is not necessarily a closed solution within a fixed number of turntable / antenna height iterations. For example, assume the antenna height is held fixed at a particular frequency, the table is rotated to find the maximum angle, the height is then varied to find a new maximum at the new angle, the turntable is rotated again to double check, and a new maximum is found at another angle based on the fact that a new height used. It is clear that this procedure, although in theory a time savings may only actually save time because the operator chooses not to perform enough iterations to obtain the maximum emissions. In free space, at a fixed height, the theoretical maximum is obtained from the EUT by consideration of only two variables (frequency and turntable angle), which greatly simplifies the problem of finding the maximum emissions and reduces the possibility that the quality of the

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measurement will be further compromised by inadequate investigation of all of the required variables.

Justification #2 : Analysis of Measurement Data

CKC Laboratories, Inc. has performed an extensive statistical study of the correlation from the Free Space Rooms to the OATS based on measurement of actual devices and systems. Based on a comparison of 1575 data points taken in three free space chambers and four OATS on a total of 10 different systems, the following results were obtained :

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

Frequency Range	# Data Points	% Data Within		
		+/- 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%

Note that to obtain the above results, CKC Laboratories, Inc. applied a correction factor based on a 1 meter assumed source height above ground for all measurements performed in the Free Space Chamber.

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Justification #3 : Free Space Chamber to OATS Correlation is within Typically Assumed Uncertainty for OATS based on a 95% Statistical Confidence

Although there is not yet any definitive method for calculation of OATS measurement uncertainty, the above statistical data suggests that the Free Space to OATS uncertainty is within the generally accepted measurement uncertainty of OATS sites assumed to be between +/- 4 dB and +/- 6 dB. The following table shows the values of OATS to OATS correlation based on various levels of assumed individual OATS measurement uncertainty, calculated to reflect a 95% statistical confidence and including all measurement instrumentation. The OATS/OATS correlation value is the Root Sum Squared (RSS) combined value of two OATS assumed to have the specified 95% confidence measurement uncertainty :

Assumed Individual OATS Uncertainty including all instrumentation (k=1.96, Gaussian, 95% Confidence)	95% Confidence OATS / OATS Correlation (RSS combination of two OATS, Gaussian)	Measured 95% Confidence Free Space / OATS Correlation (from above, measured overall value)
+/- 4 dB	5.66 dB	+/- 6.8 dB
+/- 5 dB	7.07 dB	+/- 6.8 dB
+/- 6 dB	8.49 dB	+/- 6.8 dB

This comparison shows that the individual Free Space Chamber uncertainty is likely to be between +/- 4 dB and +/- 5 dB, assuming that the OATS is also between this value. If the OATS uncertainty is higher, the individual Free Space Chamber uncertainty contribution to the +/- 6.8 dB correlation value is lower.

Present Draft uncertainty calculations by CISPR indicate that the OATS uncertainty is approximately +/- 6.0 dB when broadband antennas are used as was the case for the above practical study. This would suggest that the overall Free Space 95% confidence uncertainty value is +/- 3.2 dB based on a reverse Root Sum Squared calculation of the +/- 6.8 dB correlation and an assumed OATS uncertainty of +/- 6.0 dB.

Note that this conclusion is also supported by calibration reports for CKC's sample Free Space Chamber, using a completely different method of determination of measurement uncertainty. CKC's calibration procedure, based on a volumetric sample of the field in the volume to be occupied by the EUT shows a Total, Combined Expanded measurement uncertainty based on calibration data of +3.2/-3.8 dB in Vertical polarity, and +3.3 / -4.3 dB in Horizontal polarity.

For more detailed information on the calculation of typical measurement uncertainty of the Free Space chamber, see the attached article "Determination Of 95% Confidence Measurement Uncertainty Of Free Space Chambers Calculated By Two Independent Methods" and the sample calibration report for CKC's Hillsboro, Oregon facility.

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Justification #4 : Scan Height and Directional Gain Considerations :

As demonstrated in Justification #1 the primary reason for an antenna height scan on an OATS is to maximize the phase relationship between the direct and reflected paths to the antenna. Failure to scan antenna height on an OATS or in a semi-anechoic chamber can result in large errors at frequencies where the direct and reflected signals are out of phase. Justification #1 showed that for an isotropic model radiator, such as that used to develop the NSA model, the use of a free space chamber closely approximates a full 1-4m scan height OATS in the frequency range of 200 MHz – 1 GHz, and below 200 MHz provides an improved environment for obtaining the maximum signal from the EUT. These considerations aside, the question of directional behavior of the EUT still remains, and it is theoretically possible for an EUT to have an “Upward” gain that would contribute to an increased signal at the top of a 1-4m height scan beyond that which could be attributed to ground plane influence.

To address this concern, it is useful to consider the angles formed by the EUT and the receive antenna in various facilities and configurations.

Frequency Range	OATS Test Distance (meters)	Maximum OATS Angle in 1 –4 meter Scan height formed to EUT source 0.8m above ground plane	Proposed Free Space Test Distance	Angle formed from EUT source at Table Top Height to antenna 0.7m above table Top height
30 – 1000 MHz	10 Meters	17.74 Degrees	3 Meters	13.13 Degrees
Above 1000 MHz	3 Meters	46.84 Degrees	1 Meter	35 Degrees

From this comparison it can be seen that in the frequency range of 30 MHz – 1 GHz, a similar scan angle can be achieved in a 3 Meter Free Space room as on a 10 Meter OATS.

Above 1 GHz, the comparison shows a greater discrepancy, but this does not tell the entire story. Above 1 GHz, the change in path length due to the straight antenna height scan of 1 – 4 meters causes a change in test distance from 3.01m (when the antenna is at the 1m height, and the EUT is assumed at 0.8m) to 4.39 meters, which will result in a 3.07 dB decrease in measured isotropic E-field at the 4m height. Thus, any EUT would have to have at least 3.07 dB of Gain focused in a 12 Degree pattern (from 35 Degrees to 47 Degrees) for any difference to be observed in the Free Space to full scan height OATS results.

In order to properly obtain the maximum emissions in this direction CKC believes that it would be more appropriate to use a scan arc to maintain approximately 1 meter distance above the EUT. This “scan arc” would ensure that the test distance remains constant and the maximum emissions from the EUT is obtained. CKC believes that an accurate scan arc measurement

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system can be more easily developed in a free space environment where ground plane reflection is not a concern.

CONCLUSIONS (Justifications)

Measurements performed at a fixed height in a 3 Meter Free Space chamber provide similar to lower measurement uncertainty than a 10 Meter full scan height (1 –4 meter) OATS or Semi-Anechoic chamber in the frequency range of 30 MHz – 1 GHz. This conclusion is supported both by theoretical considerations, and by practical consideration of the problems posed by simultaneous requirement to vary antenna height, frequency of investigation, and turntable angle on an OATS. Two independent methods have been employed to assess the 95% confidence level of Free Space measurement uncertainty : 1) Calculation of the typical Free Space measurement uncertainty by reverse Root Sum Squared (RSS) calculation based on multiple measurements of Equipment Under Test (EUT's) and the assumed OATS uncertainty based on CISPR draft values, and 2) determination of measurement uncertainty of the Free Space chamber by using calibration of the field strength over the volume to be occupied by the EUT with an isotropic field probe and power meter. By both methods, the total, combined expanded ($k=1.96$) measurement uncertainty for a 95% statistical confidence is between ± 3.2 and ± 5.5 dB. This is believed to be below the value of OATS uncertainty, which is expected to be between ± 4 dB and ± 6 dB when similar equipment (broadband antenna) is used. Note that these statements comparing measurement uncertainty include site uncertainty and uncertainty due to measurement instrumentation, but do not necessarily include expansion for operator introduced errors, which are considered to be greater on the OATS due to the larger number of variables required to investigate during the test (such as ambients and antenna scan height). Lastly, it is concluded that large variations in received signal strength often observed on the OATS with height scan are most likely caused by the interference pattern formed by the ground plane and not due to EUT directional gain as often believed. This latter conclusion is supported by the theoretical considerations as well as measurements of multiple EUT's in the Free Space room at a fixed antenna height that show correlation to the full scan height OATS is possible within the above stated uncertainty in the frequency range of 30 MHz - 1 GHz. At frequencies above 1 GHz, CKC proposes that a free space standard for measurement be adopted, and that a "scan arc" method be developed either by tipping of the EUT or the use of a 1 meter fixed radial distance scan over the top hemisphere of the EUT volume.