The CISPR "20db per decade" Extrapolation Rule Explored

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***Abstract*— Measurements and analysis were performed to obtain a direct comparison (in a fully qualified ANSI C63.4:2003/CISPR 22 compliant 10m TDK semi-anechoic Chamber) between 10 meter and 3 meter test distances to determine how well the "*20db per decade*" rule applied to OATS/SAC radiated emissions compliance measurements. Proposed mitigating techniques are made after an analysis of the theoretical NSA models reveals some interesting relationships.**

Introduction

CISPR 22 and CISPR 11, two of most widely referred to EMC standards in the world continues to promulgate the myth that "*20dB per decade*" shall be used to normalize measured data at 3 meters to the reference 10 meter distance for determining compliance in OATS facility. No one topic has caused manufacturers and test labs more grief and headache than this one very erroneous assumption made law by including it into the two benchmark standards. In spite of the many examples of empirical data which proves this assumption inconsistent when measuring radiated emissions from real word electronic products, the CISPR 22 and CISPR 11 committees seem to continue the promulgation of the regulatory issues and problems arising by their sanctioning of the "*20dB per decade*" rule in extrapolation of standards limits.

<u>CISPR 22:2008 10.3.1 Antenna-to-EUT distance</u>

Measurements of the radiated field shall be made with the antenna located at the horizontal distance from the boundary of the EUT as specified in Clause 6. The boundary of the EUT is defined by an imaginary straight-line periphery describing a simple geometric configuration encompassing the EUT. All ITE intersystem cables and connecting ITE shall be included within this boundary (see also Figure 2).

NOTE If the field-strength measurement at 10 m cannot be made because of high ambient noise levels, or for other reasons, measurement of class B EUTs may be made at a closer distance, for example 3 m. An inverse proportionality factor of ***<u>20 dB per decade</u>*** *should be used to normalize the measured data to the specified distance for determining compliance. Care should be taken in the measurement of large EUTs at 3 m at frequencies near 30 MHz, due to near field effects.*

The "*20dB per decade*" rule is obtained from the free space path loss derived from Friss equation and holds true only under these conditions.

$$FSPL = 20\log(d) + 20\log(f) - 27.56\ dB.$$

FSPL:Free Space Path Loss
d: separation distance (m)
f: frequency (MHz)

The "*20 dB per decade*" rule assumes a "1 over d" linear drop off. In the far field this 20 dB rule assumes that the field source is an infinite line source. A point source "*infinitesimally small*" would be a "*40dB rule*" or "1 *over d squared*". A far field plane wave is constant over distance; i.e., the field strength does not drop off with distance ---- One can think of that plane wave as the "*0 dB rule*".

In the real world of testing at an OATS (Open Area Test Site), products and the antennas used for the measurements are combinations of all three types of sources (point source, line source, and plane wave source) depending on distance, frequency, and electrical size.

In an open area test site we have the following conditions which invalidate all the conditions for the "*20dB per decade*" rule;

1. A highly reflective ground reference plane – providing a reflected wave front not present in free space model used in deriving the "20dB per decade" extrapolation rule.

2. A relatively large receive antenna that can interact with the emissions source as the separation distance approaches the size of the sensing receive antenna – Ultra broadband biconnilog antennas can be up to 1.4 meter in length.

3. A relatively large radiation source – A typical EUT such as a personal computer system will span 2m or more in effective radiation width when power and I/O cables are included in the system envelope. Radiation sources are usually multiple and distributed in nature predominantly from cables below the 300MHz range.

4. Near Field effects predicated by the relative size of source, observer and test distance used.

5. A receive antenna height scan from 1 to 4 meters perpendicular to the horizontal means the actual separation distance changes as the receive antenna's height is adjusted.

The above conditions further impact the "*20dB per decade*" rule as the wavelengths approach the dimensions of the antenna, EUT and test distance used. The most problematic area where "*20dB per decade*" rule causes the most havoc is in the 30-400MHz range.

In Hewlett-Packard's 2002 [2] study by Allen Crumm & Ken Hall of their 33 test sites using a single reference source, comparisons between the 10 meter and 3 meter averages clearly demonstrated that the seven 3 meter test sites underestimated the compliance margins by a mean of up to 7dB in the frequency range below 300MHz (Figure 1). This study was performed with a relatively small CW transmitting source normalized to the FCC limits at a 10 meter reference site.

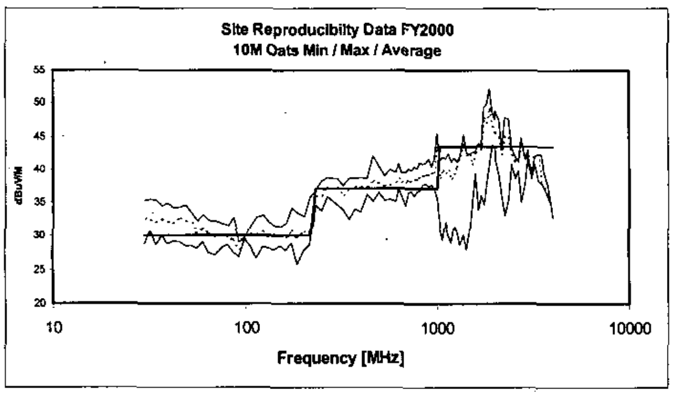

Figure 5. The measured minimums, maximums, and means of fourteen 10 meter OATS.

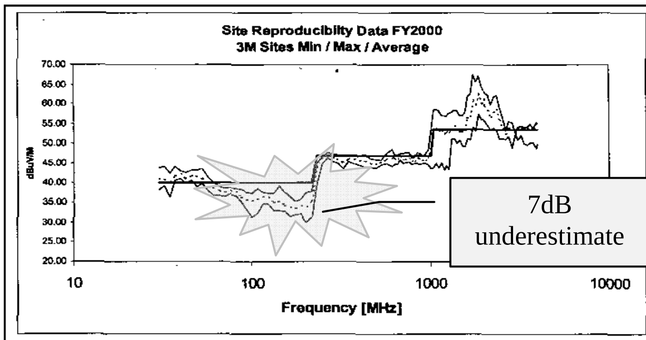

Figure 7. The measured minimums, maximums, and means of seven 3 meter sites.

Figure 1. 10m and 3m OATS comparison from HP 2002 [2] study

I. Methodology

In order to represent real life products which are relatively large, it was decided not to use the comb generator reference sources which are battery operated devices designed to be point sources with a low volumetric presence. To obtain stable and repeatable curves from a relatively large volumetric source, we selected our largest biconnilog antenna an EMCO 3143 (27MHz - 2GHz, 1.5 meters wide) which provided a stable and matched broadband response and radiation pattern and occupies about the same volume as a personal computer system. Selecting a broadband responding antenna allows for the use of a tracking generator on the spectrum analyzer so that the trace maximization feature can be employed. The 200ms sweep times obtainable in this setup allows for a smooth maximization process when the receive antenna is scanned in the 1 to 4 meters antenna height scans.

The large transmit biconnilog antenna is mounted on a non-metallic mast at a 1 meter height which closely approximates a computer system mounted on an 80 centimeter high table. (Figure 2 & 3). With the antennas placed vertically, the spectrum analyzer trace is placed in max hold while the receive antenna height is varied from 1 to 4 meters and back down to 1 meter. The plots are captured and the process is repeated at both 3 meter and 10 meter standard test distances as well as for the horizontal polarizations.

No correction factors are used and the plots obtained are for a simple direct 3 meter to 10 meter comparison of a fixed large stable broadband source. Since the only parameter which is changing is the test distance from 10 meters to 3 meters, a true delta relationship of the maximized emissions levels can be captured over the frequency range of interest.

II. Test Setup

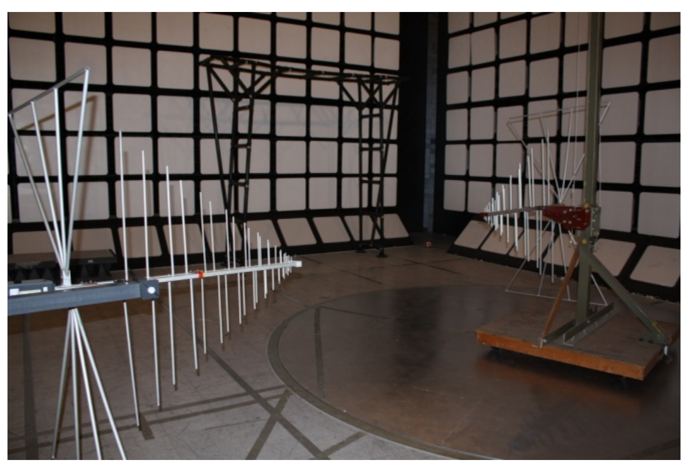

Figure 2 Test setup for 3m vertical measurement

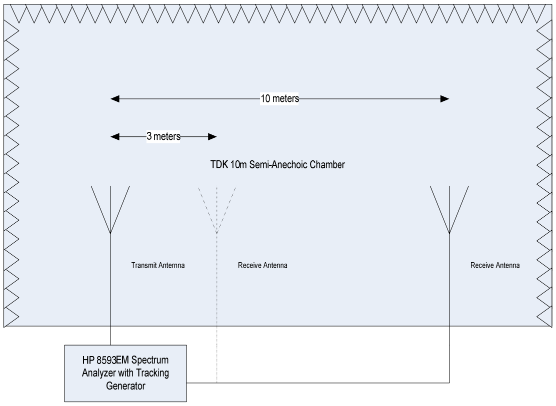

Figure 3. Block Diagram of test setup

III. MEASUREMENT DATA

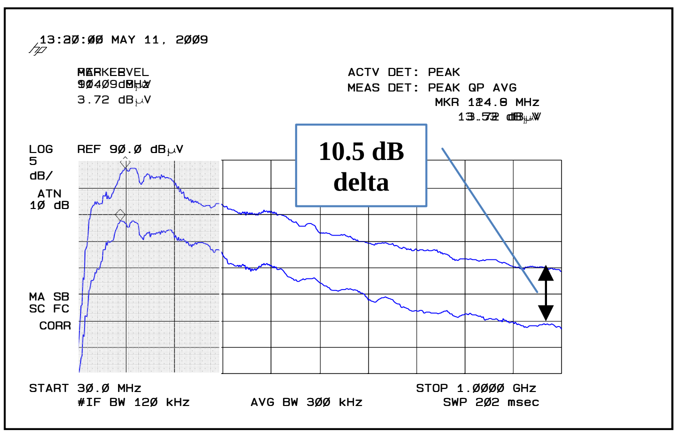

Figure 4. Horizontal 10 meter to 3 meter comparison

The "*20dB per decade*" rule predicts that there should be a uniform **10.5dB** (*20 log (10/3))* difference between the two maximized emissions curves between the reference 10 meter test distance (the lower curve) and the extrapolated 3 meter test distance (the upper curve). One would expect that horizontally polarized emissions would not be impacted too greatly by the ground plane reflection and in this polarization, quasi-free-space conditions exist for a fair portion of the frequency range. This occurs because the main reflecting surfaces in this polarization will be the vertical wall surfaces of the chamber treated with RF absorbers.

In Figure 4, one does note that the difference between the 3 meter and 10 meter curves start to vary more below the 300MHz range probably due to predominant near field effects at the longer wavelengths. The difference is further exacerbated below 80MHz where much higher deltas are observed possibly due to both enhanced near field effects as well as the very steep gradient of the antenna response in this range in both the transmit and receive transducers.

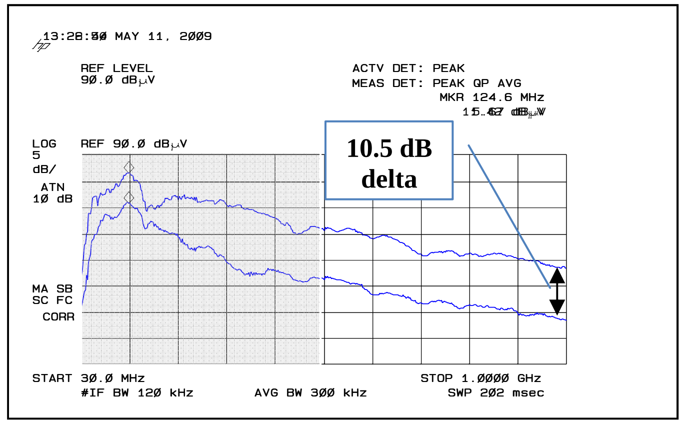

Figure 5. Vertical 10 meter to 3 meter comparison

In the vertical polarization measurements of Figure 5, one can notice a marked deviation in the predicted **10.5dB** constant occurring below 500MHz. The major source for this deviation is believed to be the reflected wave contributed by the reference ground plane which the receive vertically polarized antenna now sees. In fact there is a marked under-estimate occurring below 200MHz at the 3 meter test distance of up to 7dB. This observation is significant since on standard computer system setup, the main vertical radiating elements are all the dangling I/O and power cables hanging off the edge of the table.

IV. ANALYSIS FROM CALCULABLE NSA FOR OATS/SAC

A theoretical model of the OATS/SAC (Open Area Test Site/Semi-Anechoic Chamber) measurement can be found form the NSA (Normalized Site Attenuation) model initially carried out by [6] Smith, German, and Pate IEEE 1982. Manny Barron [3] [4] provided further tools for analyzing the NSA models further in 2000 and 2001 where the model was programmed using Excel spreadsheets. Mr. Barron was kind enough to provide the E_d^{max} NSA spreadsheets to assist in the preparation of this paper.

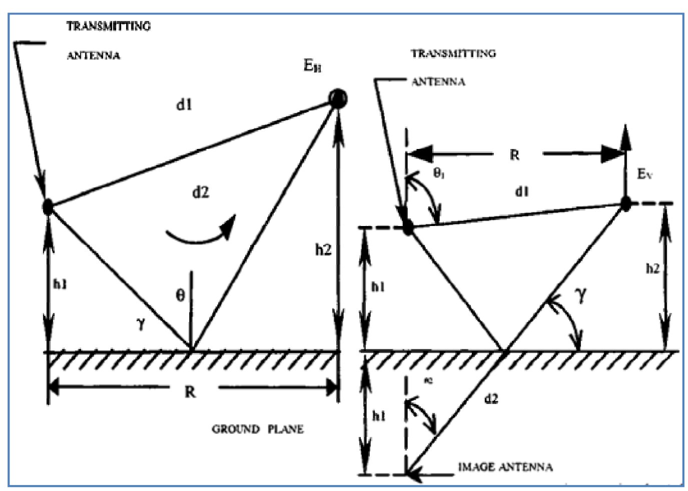

Figure 6. Model for Horizontal (Left) and Vertical (Right)

$$E_{DH}^{MAX} = \frac{\sqrt{49.2}\left[d_2^2 + d_1^2|\rho_H|^2 + 2d_1d_2|\rho_H|\cos\left[\phi_H - \frac{2\pi}{\lambda}(d_2 - d_1)\right]\right]^{\frac{1}{2}}}{d_1d_2}$$

$$E_{DV}^{MAX} = \frac{\sqrt{49.2}R^2\left[d_2^2 + d_1^2|\rho_V|^2 + 2d^3{}_1d^3{}_2|\rho_V|\cos\left[\phi_V - \frac{2\pi}{\lambda}(d_2 - d_1)\right]\right]^{\frac{1}{2}}}{d^3{}_1d^3{}_2}$$

with $d_1 = [R^2 + (h_2 - h_1)^2]^{0.5}$ and $d_2 = [R^2 + (h_2 + h_1)^2]^{0.5}$

$$\rho_H = \frac{\sin\gamma - (K - j60\lambda\sigma - \cos^2\gamma)^{\frac{1}{2}}}{\sin\gamma + (K - j60\lambda\sigma - \cos^2\gamma)^{\frac{1}{2}}}$$

$$\rho_V = \frac{(K - j60\lambda\sigma)\sin\gamma - (K - j60\lambda\sigma - \cos^2\gamma)^{\frac{1}{2}}}{(K - j60\lambda\sigma)\sin\gamma + (K - j60\lambda\sigma - \cos^2\gamma)^{\frac{1}{2}}}$$

Legend
h_1 = fixed transmitting antenna height
h_2 = variable receiving antenna height
R = antenna separation relative to ground plane
K = dielectric constant
σ = conductivity
ρ = reflection coefficient
ϕ = Phase angle of reflection coefficient
λ = Wave length of frequency of interest

Figure 7. Theoretical OATS/SAC E_D^{MAX} NSA

The NSA requirements is incorporated in ANSI and CISPR standards in the characterization of appropriate OATS and alternative test sites used in radiated emission measurements and is the foundation for site attenuation characterization in site qualifications. From these papers the theoretical NSA model is expressed as follows:

$$NSA_{TH} = -20\log_{10}(f) + 48.9 - E_D^{MAX}$$

Where: NSA_{TH} = NSA theoretical value
f = frequency in MHz
E_D^{MAX} = maximum received field strength

The E_D^{MAX} parameter contains the primary model for the NSA theoretical calculations and is addressed in the ANSI C63.5 standard as well as in the open literature. The geometry of this model is summarized in Figure 6 along with the associated mathematical representation in Figure 7.

In order to provide an explanation for the observed difference between the measured maximized emissions curves, the NSA modeling were carried out using the same parameters as those carried out in the measurement portion.

The results of this exercise are shown in Figure 8 showing the vertical NSA for 3 meter, 10 meter and 30 meter distances. The dotted line indicates the extrapolated 3 meter characteristic using the *"20dB per decade"* rule provided by

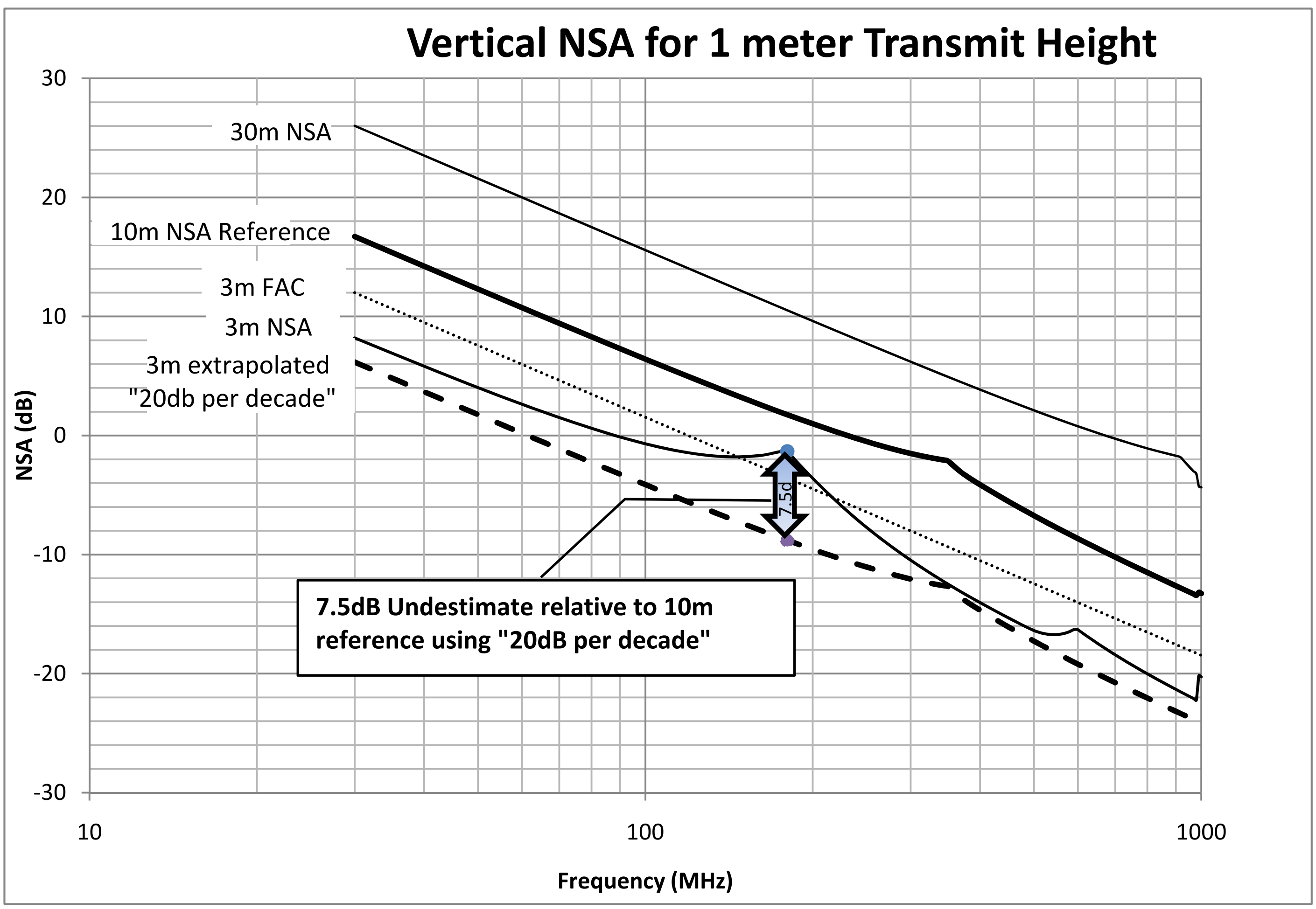

Figure 8. Theoretical NSA for 1m Antenna Height Vertical Polarization

CISPR 11 and CISPR 22 standards. One can observe from these curves the overall underestimate that results from the application of the extrapolated *"20dB per decade"* rule to the actual 3 meter NSA curve. The maximum underestimate between the "*20dB per decade"* extrapolated 3 meter data and the NSA 3 meter data was found to be 7.5dB which corresponds very closely to the measured differences in the maximized emissions measurements.

Clearly, the application of the *"20dB per decade"* extrapolation rule does not provide an equal and equivalent alternative to the reference limits specified at 10 meters.

V. Regulatory Impact

Historically, the choice of the 10 meter OATS as the reference site back in the 80's was selected because it proved to be the most available and affordable type of testing range commercially viable at that time. The allowance of alternative test distance such as 3 meters using a *"20dB per decade*" extrapolation factor was supposedly to provide an equal and almost equivalent alternative to the reference 10 meter limit prescribed. The reality was to provide an alternate method which severely underestimated the emissions compliance margins by as much as 7.5dB when compared to the reference 10 meter limits. Although many studies and technical papers on the subject have demonstrated this rather large underestimation, the reality moving forward is that the *"20dB per decade"* rule will most probably be grandfathered into the upcoming CISPR 32 standard. The question thus arises how best to mitigate the underestimate resulting from the continued adoption of the *"20dB per decade*" extrapolation rule.

From a regulatory compliance aspect, carrying out compliance measurements at a 3 meter test distance introduces a major exposure to manufacturer's and independent test houses. If a regulatory compliance report is based on 3 meter measurements applying the *"20dB per decade"* extrapolation rule provided in the CISPR standards, the resulting actual product compliance margin will be off by as much as 7.5dB in comparison to the 10 meter reference limit. In order to reduce this exposure which is inherent in applying the CISPR standards as written, applying alternate compliance limits may mitigate the exposure manifested and serves as a risk management reduction that may ensure a 3 meter compliance report is not rendered invalid when subjected to a 10 meter reference comparison.

The previous theoretical NSA cuve was only carried out for vertical 1 meter transmit height to simplify the analysis and

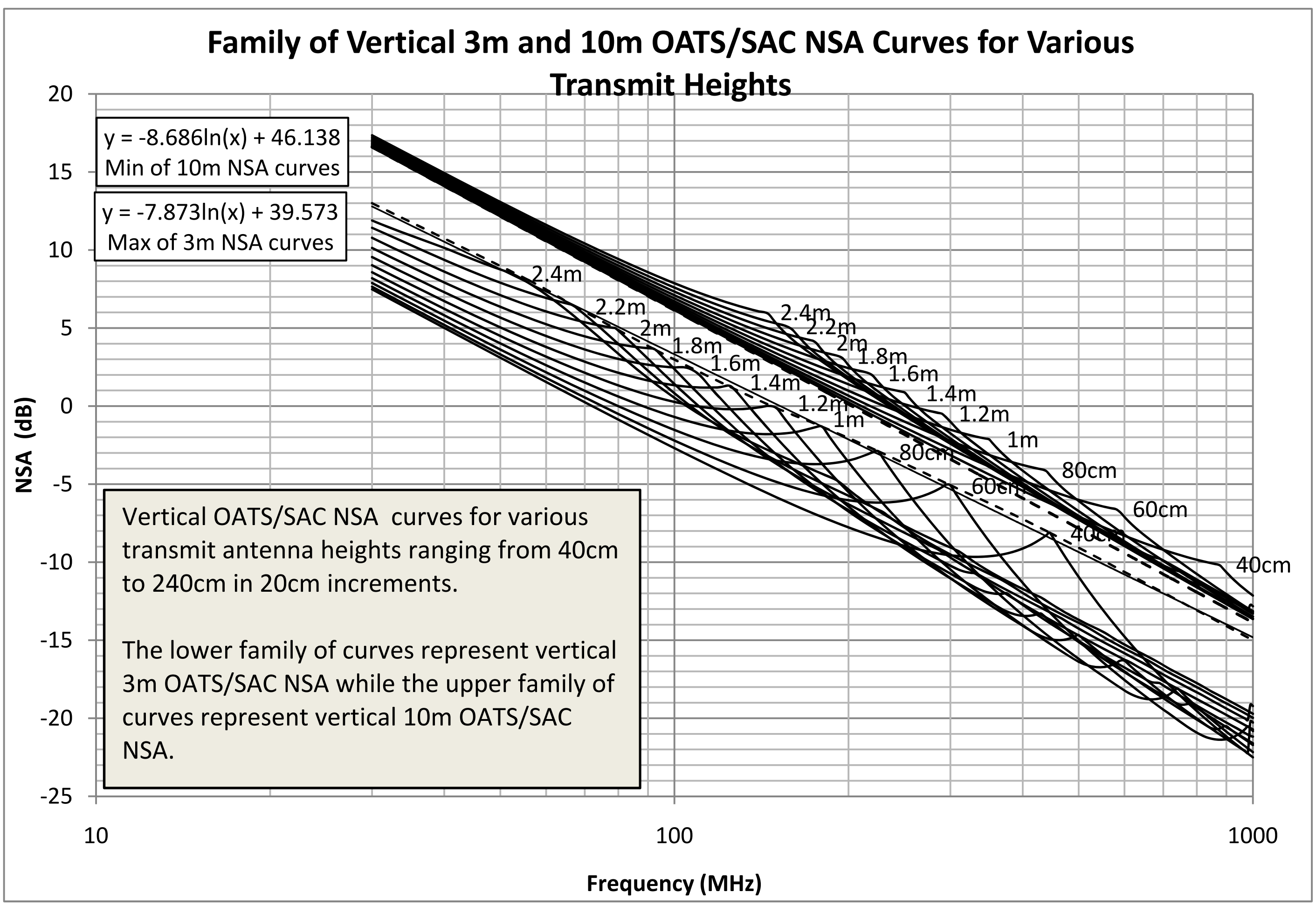

Figure 9. Family of Vertical 3m and 10m OATS/SAC NSA curves for various transmit heights

comparisons. To take into account other EUT heights and other test volumes, a family of curves was generated from 40 centimeter to 2.4 meter transmitter height to determine if a set of compliance limits could be obtained from the NSA curves. This modelling was also caried out for FAC (Fully Anechoic Chamber) model where the free space NSA model is less complex due to the absense of the ground plane reflection. (Figures 9 & 10) The FAC facility is being considered for incoporation into future CISPR standards as an equivalent and equal alternative measurement facility to SAC/OATS measurements.

The FAC NSA characterization can be found in CISPR 16-1-4:2003+A1:2004 Section 5. For simplification, the theroetical FAC or free space NSA formula specified in this section of CISPR 16-1-4 excluding near field correction factors is stated as follows;

$$NSA_{\mathrm{calc}} = 20\log_{10}\left(\frac{5.Z_0.d}{2\pi}\right) - 20\log_{10}(f_{\mathrm{m}})$$

Where d: separation distance
Z_0:reference impedance
f_m:frequency in MHz

From the family of curves (Figures 9 & 10), the following items can be obsered;

1. The minimum separation between the 10 meter OATS/SAC reference curves and the 3 meter OATS/SAC curves is about 2dB at 230MHz and about 1dB at 1000MHz. This would imply that to ensure product compliance when testing at the 3 meter measurement distance, a compliance limit of the 10 meter reference limit plus a 2dB relaxation may be used from 30MHz to 230MHz and a 1dB relaxation from 230MHz to 1000MHz.
2. In the case of fully anechoic chambers, the minimum separation between the 3 meter FAC NSA and the 10m reference OATS/SAC NSA curves is about 4.5dB. This would imply that to ensure product compliance when testing at 3 meter measurement distance in a fully anechoic chamber, a compliance limit of the 10 meter reference limit plus 4.5dB may be used.
3. The family of curves for each measurement distance demonstrates the pronounced effect of the ground plane in reducing the predicted fall off with distance. The 3 meter curves would indicate that the EUT height contributes to a large portion of the spread between the family of curves and that as the separation distance approaches the same dimensions

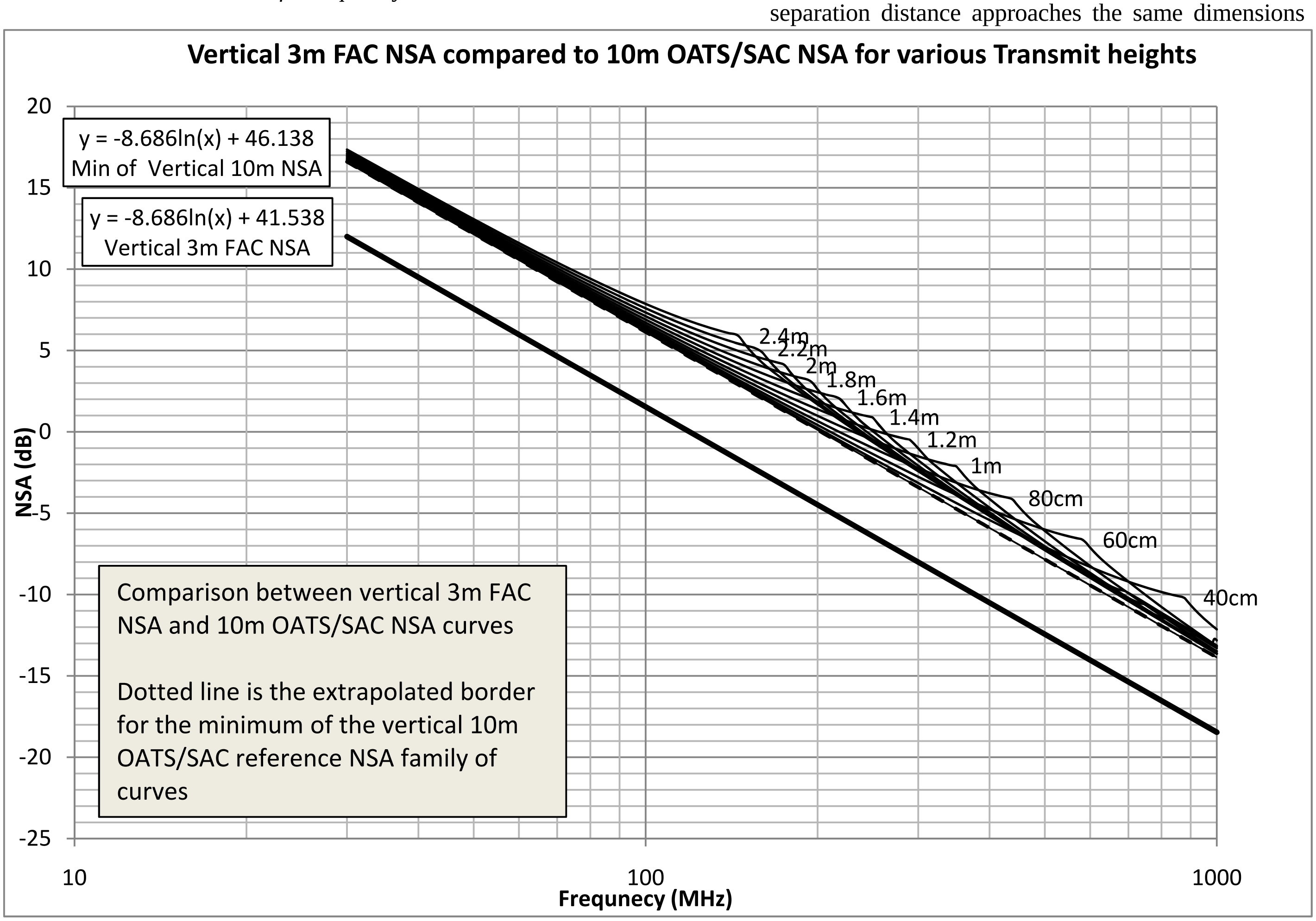

Figure 10. Family of Vertical 3m FAC and 10m OATS/SAC NSA curves for various transmit heights

as the antenna search height and EUT height variation, the Q factor of the resonant peaks in the NSA seem to become more pronounced.

4. The largest variations are observed at 3 meter where the family of curves results in variance of about 7dB spread. As the separation distance increases to 10m, this variance reduces to 3dB and it is observed the resonance caused by the ground plane reflection seems to be reduced. The cause may be that the height factor of the test volume seems to play a less critical role as the transmit source appears more and more as a point source with increasing separation distance.

The above observations can therefore provide a guideline in proposing product compliance limits at 3 meters which would ensure product compliance when referenced to the 10 meter limits for a fairly comprehensive EUT height variation.

The following Table 1 results if this strategy is carried out. One can see from the above table that because of resonant effect of the ground plane, the predicted *"20dB per decade"* falloff between 10 meters to 3 meters does not materialize and as such the limits can only be adjusted slightly to maintain the same protection requirements.

	Class B Limits (dBµV/m)		
	Reference	OATS/SAC	FAR
Frequency (MHz)	10m	3m	3m
30-230	30	32	34.5
230-1000	37	38	41.5
	Class A Limits (dBµV/m)		
	Reference	OATS/SAC	FAR
Frequency (MHz)	10m	3m	3m
30-230	40	42	44.5
230-1000	47	48	51.5

Table 1. Proposed 3m CISPR product compliance limits based on providing essentially the same basic protection as the referenced 10 meter reference limits.

An alternative to the simplified approach of adjusting straight line regulatory limits to ensure the same essential protection requirements are met in shorter test distances than the reference 10 meters is to perhaps apply additional 3 meter extrapolation correction factors. These correction factors could be derived from a comparison between the minimum separation differences between the 10 meter and 3 meter OATS/SAC NSA family of curves for all EUT heights likely

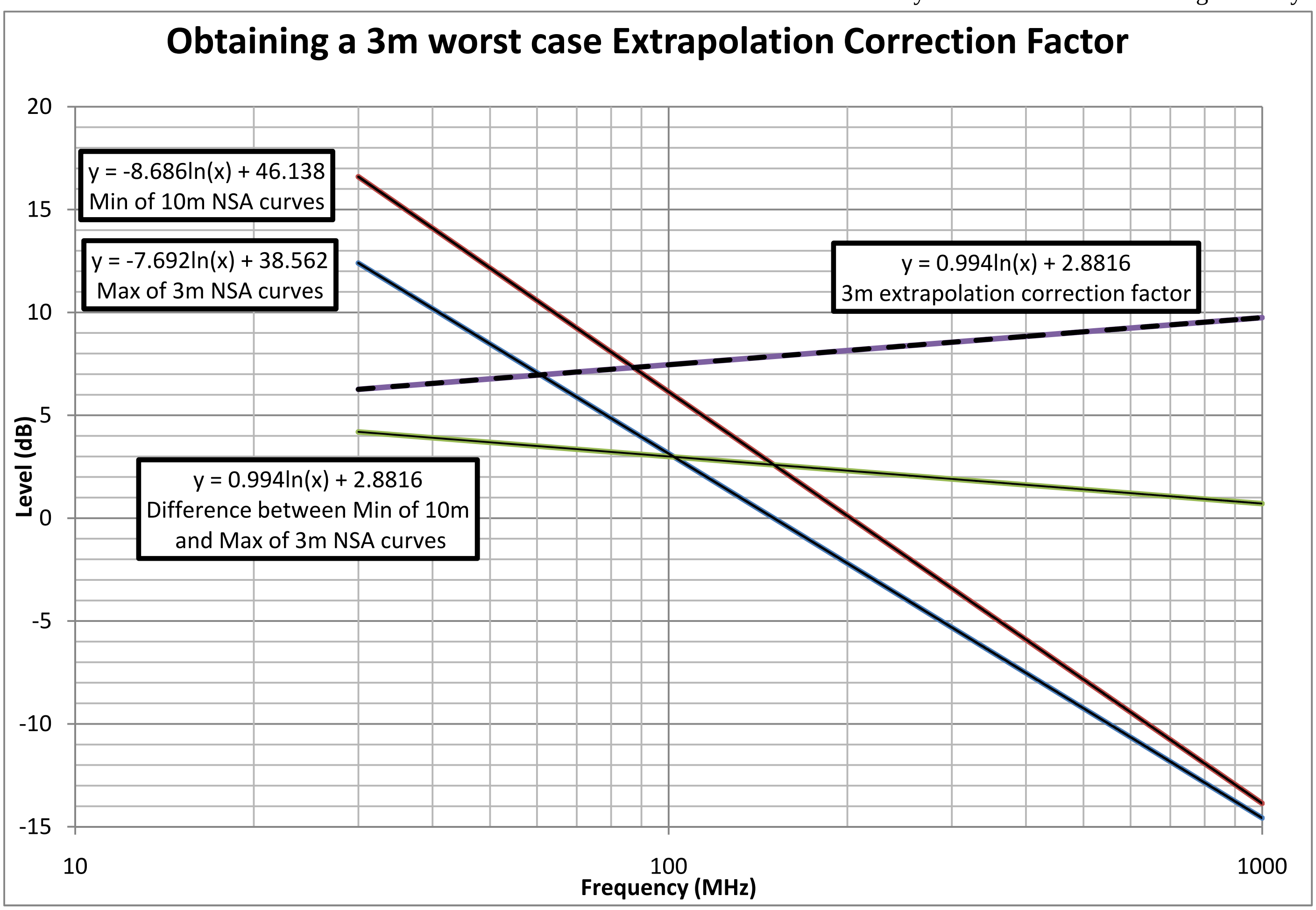

Figure 11. Obtaining a 3m extrapolation correction factor

to be encountered in the test facility. Such a strategy has been adopted in the above graph in Figure 11 where a 3 meter distance correction factor has been derived to be added the other 3 meter correction factors to offset the underestimating effect of extrapolating the 3 meter limits using the *"20dB per decade"* extrapolation rule.

The extrapolation correction factor may be attractive since the resultant 3 meter extrapolation correction factor changes with frequency and would vary between 6.3dB at 30MHz to 9.7dB at 1000MHz. This extrapolation correction factor would be only applicable to 3 meter vertical polarization measurements for EUT heights up to 2.4 meters and the same approach would have to be taken to obtain the horizontal polarization extrapolation correction factors. (Table 2)

Frequency (MHz)	3m Vertical Extrapolation Correction Factor (dB)
30	6.3
40	6.5
50	6.8
60	7.0
70	7.1
80	7.2
90	7.4
100	7.5
120	7.6
140	7.8
160	7.9
180	8.0
200	8.1
300	8.6
400	8.8
500	9.1
600	9.2
700	9.4
800	9.5
900	9.6
1000	9.7

Table 2. 3m Vertical Extrapolation Correction Factors

Either of these two approaches would result in the same essential protection requirements present in the 10 meter reference being met when measuring at closer distances. The inherent exposure when employing the *"20dB per decade"* extrapolation is severely reduced by these approaches and would satisfy a risk assessment and uncertainty analysis of the alternate test distance as essentially equivalent to the reference 10m test.

VI. Conclusions

1. Making 3 meter measurements using a *"20dB per decade"* extrapolation factor on a 1 meter high emissions source may result in an underestimate of the compliance margin by as much as 7 dB.
2. The vertical polarized emissions measurements clearly demonstrate the fallacy of the "20dB per decade" rule when the predicted 10.5dB emissions level gain when moving the receive antenna from 10 meter to 3 meter distance does not materialize below 300MHz in the 1m transmit height case study.
3. Since the large majority of compliance margin below 500MHz is determined in the vertical polarization, 3 meter measurement data cannot predict compliance margins specified at 10 meter reference test distances using the *"20dB per decade"* extrapolation rule.
4. Products tested at 3 meters using the "*20dB per decade*" extrapolation may have a significant 7dB advantage over products tested at the 10 meter reference distance. Corollary to this, products tested at 3 meters and found to comply with the extrapolated "*20dB per decade*" limit may fail to comply by as much as 7dB when tested at 10 meters reference distance.
5. The major impact on the "*20dB per decade*" rule seems to be the ground plane reflection in the vertical polarization and the height of the EUT above the ground plane. With the horizontal polarization where the ground plane reflection is minimized due to the receive antenna's pattern, the deltas between the 3 meter and 10 meter curve seems more uniform above 300 MHz From the horizontal polarization curves, near Field Effects seem to become apparent below 300MHz making a much greater impact below 100MHz. Since near field effects are dependent on effective size of source, effective size of the observer and the distance between source and observer, the coupling mechanisms are probably extremely complex and unpredictable to model.
6. Manufacturers and test houses may mitigate the exposure of supporting a product's compliance using 3 meter measurements by applying product compliance limits which will ensure that if the product is re-tested at 10 meter, it will provide similar compliance margins. This strategy would ensure that the same essential protection requirements are met when carrying out radiated emissions measurements at 3 meters.
7. An alternative to broadly adjusted product compliance limits is to apply an extrapolation correction factor which would mitigate the large underestimates that results from applying the *"20dB per decade"* extrapolation rule.
8. From the analysis of the OATS/SAC NSA curves, it appears the if the transmit antenna height is dropped below 80 cm height, the resonant peaks on the NSA

move up in frequency to the higher frequency ranges above 500MHz. Since there is no practical way of performing these experimentally using vertical biconnilog antennas due to the long vertical antenna elements present, some other broadband radiating element must be employed when exploring the effects of transmission points below 80cm height.

VII. Recommendations

1. CISPR committees should determine the additional measurement uncertainty of carrying out compliance tests at 3 meter distance using the "*20dB per decade*" rule to extrapolate from the 10 meter limits. This additional measurement uncertainty should be explicitly stated in compliance reports based on 3 meter data.

2. CISPR 22 and CISPR 11 committees should initiate further studies to determine a proper correlation factor which allows for proper normalization from a 3 meter distance to a 10 meter reference test distance. Should the committee find that no such reliable correlation factor exists, the "*20dB per decade*" rule should be relinquished and the 10 meter reference limit be used in the 3m test distance.

3. Since this initial study indicates that the major area of impact to the "*20dB per decade*" rule is the vertical polarization below 500MHz frequency range, additional studies using radiating elements of different volumetric sizes and different heights should be carried out to determine how the EUT size impacts measurements other than at the reference 10 meter test distance. Constraining the studies to vertical polarization below 500MHz focuses the analysis on the areas which seems to cause the most problems.

4. Mitigating techniques have been demonstrated to reduce the underestimating effects when applying the "20dB per decade" extrapolation. These techniques can be expanded further to provide a more comprehensive exposure reduction method when carrying out radiated emissions at 3 meters and other closer test distances than the reference specifications. These techniques would go a long way in establishing the usefulness of 3 meter measurement data which currently carries little weight in the EMC community because of the large underestimation and large regulatory compliance uncertainty inherent in this measurement distance.

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