FCC/VDE RADIATED MEASUREMENTS — POTENTIAL DIFFERENCES IN TEST RESULTS BETWEEN TEST SITES AS A FUNCTION OF EXTRAPOLATION AND THE USE OF PUBLISHED ANTENNA FACTORS

Application of equations given in ANSI C63.4 to determine the theoretical site attenuation at different heights and distances and actual site calibration measurements reveal some causes and relationships that can contribute to potential differences in product emission measurements at different sites when measurements are made according to FCC, VDE, or CISPR rules.

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INTRODUCTION

The ANSI 63.4 draft on open field test sites recommends a procedure for site calibration that compares site attenuation measured on a given site to site attenuation curves calculated for a standard or ideal site. A standard or ideal site is defined as a plane homogeneous metal surface of infinite extent where the relative dielectric constant of the surface shall be taken as infinite. The theoretical site attenuation A for the standard site is given by:

$$A = \frac{279.1\, AF_T\, AF_R}{f_m \cdot E_D^{max}} \qquad \textbf{Equation 1}$$

or, in decibels,

$$A(\mathrm{dB}) = -20 \log f_m + 48.92 + AF_T(\mathrm{dB/m}) + AF_R(\mathrm{dB/m}) - E_D^{max}\ (\mathrm{dB{\cdot}\mu V/m}) \qquad \textbf{Equation 2}$$

where

f_m	frequency, in megahertz
AF_R(dB/m)	antenna factor of receiving antenna, in decibels/meter
AF_T(dB/m)	antenna factor of transmitting antenna, in decibels/meter
E_D^{max}(dB·μV/m)	maximum electric field in receiving-antenna height-scan range $h_2^{min} < h_2 < h_2^{max}$ from a theoretical half-wave dipole with 1 pW of radiated power

The FCC rules on measurement of computer devices are described in MP-4 ("FCC Methods of Measurement of Radio Noise Emissions from Computing Devices")[1] and provide measurement procedures for Class B products measured from 3 to 30 meters with limits defined at a measurement distance of 3 meters and for Class A products measured from 3 to 30 meters with limits defined at a measurement distance of 30 meters. Measurements may be made at any distance but if measured at a distance other than the specified limit distance the data is to be extrapolated to the limit distance using an extrapolation factor of 20 dB/decade, (i.e., 20 dB fall off factor from 3 to 30 meters). CISPR 22[2], the international standard for measurement on ITE (Information Technology Equipment) says essentially the same thing with some variation in limits. Several problems become apparent when one calculates the site attenuation curves for various heights and distances. Other problems become apparent when one attempts to actually perform the site calibration and/or product measurements. The key problems are:

1. Site attenuation when calculated for different heights and distances does not conform to the 20 dB/decade fall off between 3 and 30 meters or 10 dB fall off between 3 and 10 or 10 and 30 meters in either vertical or horizontal polarization. As a result serious differences in measurement data can occur on products measured at two different sites if the measurement techniques are not identical.
2. Accurate knowledge of antenna factors is required to make the site calibration measurements and accurate product measurements. Published antenna factors do not necessarily provide this knowledge. (Note: ANSI 63.4[4] warns of this in the procedure.)
3. Unless one measures and determines the antenna factors on an ideal site including mutual coupling factors it is difficult to determine actual antenna factors.
4. It is difficult to build an ideal test site particularly if the test site is large, which is required if one is to measure large computer systems. Therefore, imperfections in the site can cause deviations from the ideal.
5. The ±4 dB acceptance criteria cited in ANSI 63.4 indicates there can be a possible 8 dB difference in product measurements between two acceptable test sites.
6. Product emissions when measured at different distances and or at different sites do not necessarily conform to the fall off factors predicted by the ideal site attenuation curves or the 20 dB/decade extrapolation described in MP-4 and CISPR 22.

ANALYSIS

The initial equations described in ANSI C63.4 developed by A. Smith[4] include antenna factors. Removing the antenna factors from the equation, a set of normalized site attenuation curves devoid of antenna factor considerations but based on calculated values of E_D^{max} for both horizontal and vertical polarization, can be formed. (Note: Normalized site attenuation is now incorporated in ANSI C63.4) These equations are described as follows:

Equation 3

$$E_{DH}^{max} = \frac{\sqrt{49.2}\,[d_2^2 + d_1^2|\rho_h|^2 + 2d_1d_2|\rho_h| \cos(\phi_h - \beta[d_2 - d_1])]^{1/2}}{d_1d_2}$$

(evaluated over height scan)

Equation 4

$$E_{DV}^{max} = \frac{\sqrt{49.2}R^2\,[d_2^6 + d_1^6|\rho_V|^2 + 2d_1^3d_2^3|\rho_V| \cos(\phi_V - \beta[d_2 - d_1])]^{1/2}}{d_1^3d_2^3}$$

(evaluated over height scan)

where

$$d_1 = [R^2 + (h_1 - h_2)^2]^{1/2}$$

$$d_2 = [R^2 + (h_1 - h_2)^2]^{1/2}$$

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

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

K = relative dielectric constant

σ = conductivity, in seimens/meter

By varying the parameters in Equations 3 and 4 for different heights and distances, a family of curves for E_D^{max} can be drawn. Figure 1 is a family of such curves and identifies horizontal polarization curves for 3 meters, 10 meters and 30 meters separation for 1 and 2 meter transmit heights and with receiving heights varied from 1 to 4 meters for each transmit height. For 30 meter separation the curves reflect receive heights between 1 and 4 meters (CISPR) and also 2 and 6 meters (FCC). The anticipated is immediately obvious.

- Predicted signal strength is stronger at the higher frequencies than lower ones,
- Signal strength at the receive antenna is stronger when at 3 meters than when at 10 or 30 meters, and
- Higher signal strength is observed at the receive antenna when it is raised to 6 meters than when it is raised to only 4 meters.

Figure 2 shows a similar set of E_D^{max} curves for vertical polarization. However, for vertical polarization it becomes obvious quite readily that antenna height variations do not influence field strength anticipation significantly below 200 MHz. Above 200 MHz variations in predicted field strength can be observed due to change in transmit or receive height of the antennas.

Normalizing the site attenuation equation (Equation 1) the following equation results:

$$A_{norm} = 279.1 / f_m \cdot E_D^{max}$$

Equation 5

Using this equation and the values of E_D^{max} shown in Figures 1 and 2, a family of curves can be generated for the theoretical site attenuation. Figure 3 shows the family of curves generated in the horizontal polarization and Figure 4 depicts a family of curves for the vertical polarization.

The key observation to be made in both these graphs is that the variance in expected field strength or site attenuation is not constant with frequency and distance.

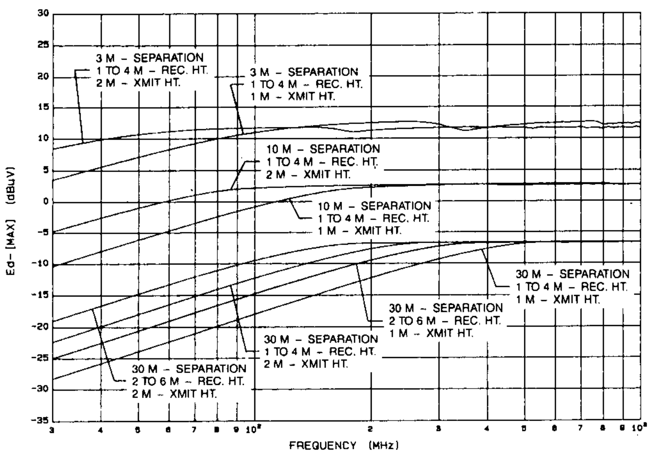

Figure 1. Comparison of E_D^{max} Curves – Horizontal.

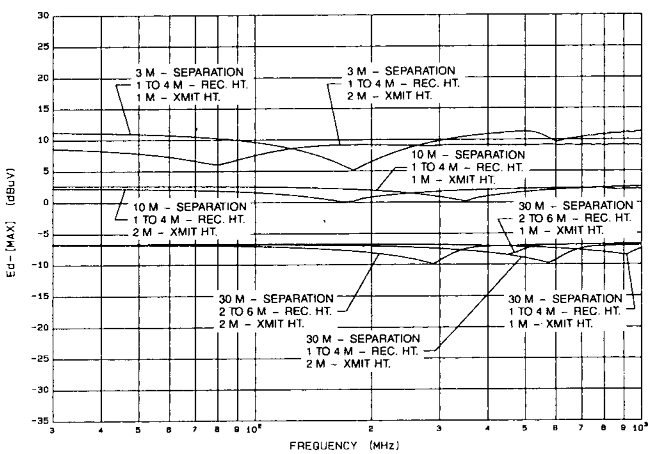

Figure 2. Comparison of E_D^{max} Curves – Vertical.

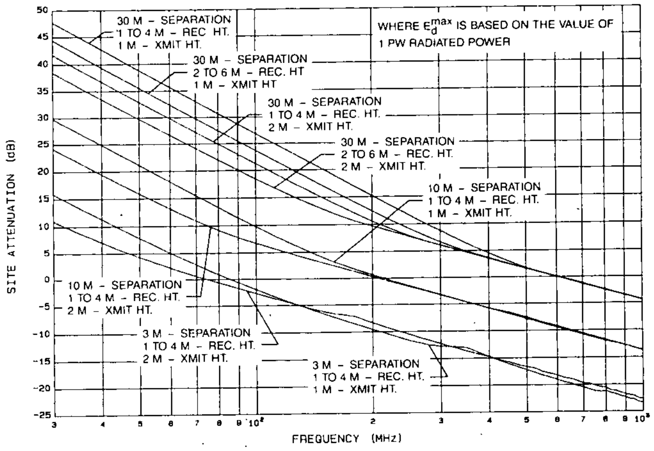

Figure 3. Site Attenuation Curves – Horizontal.

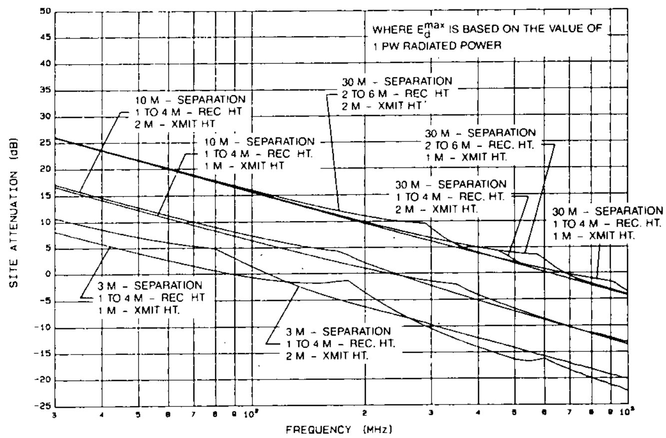

Figure 4. Site Attenuation Curves – Vertical.

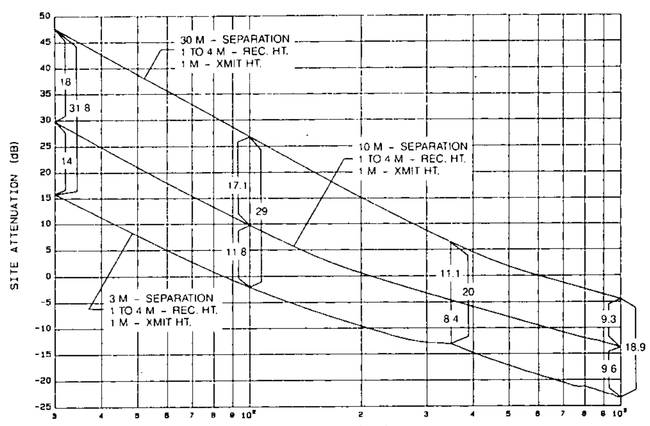

Figure 5. Comparison of Horizontal Site Attenuation Curves.

Figure 5 provides a comparison of site attenuation curves for separation distances of 3, 10 and 30 meters, 1 meter height and 1 to 4 meters variations in receive height. (Note: Mutual coupling factors are not included in the curves.) The deviation between 3 and 30 meters is close to 32 dB at 30 MHz, 29 dB at 100 MHz, 20 dB at 350 MHz and about 18.5 dB at 1000 MHz. From 3 to 10 meters at 30 MHz the variation is 14 dB, 11.5 dB at 100 MHz, and 9.5 dB at 1000 MHz. From 10 to 30 meters the deviation is 18 dB at 30 MHz, 17 dB at 100 MHz, 15 dB at 200 MHz, and 9.5 dB at 1000 MHz.

Figure 6 is essentially the same curve except the antenna height is varied between 2 and 6 meters at 30 meters. This causes the fall off factor to change from 32 to 28 dB from 3 to 30 meters, and from 18 dB to 14 dB from 10 to 30 meters at 30 MHz. At 100 MHz the fall off factor is now 14 instead of 17 dB.

Figure 7 is a presentation of vertical site attenuation curves for 1 meter transmit height and receive heights of 1 to 4 meters at distances of 3, 10 and 30 meters.

The fall off factor between 3 and 10 meters at 30 MHz is 8.5 dB, but at 175 meters it is 3.5 dB.

From 3 to 30 meters at 30 MHz it is 17.5 dB but at 175 MHz it is 12 dB.

The reader can study the curves to find the variations for other heights and distances. Figures 8 and 9 show site attenuation curves for 2 meter transmit heights. Figures 10, 11, 12, and 13 show the variations more dramatically when compared to a straight 20 dB/decade extrapolation as recommended in MP-4. (Note: Figures 10, 11, 12, and 13 are essentially identical to curves developed and presented in unpublished papers by B. Cooperstein of Xerox Corporation and G. Becker of Control Data during concurrent studies made while this study was being performed.)

The second problem stated in the introduction related to accurate knowledge of antenna factors. Our initial attempt to make site calibration measurements on our test site using the calculated site attenuation curves resulted in what appeared to be a failure of our site to meet the site calibration criteria.

Figures 14 and 15 describe our initial measurements as compared to

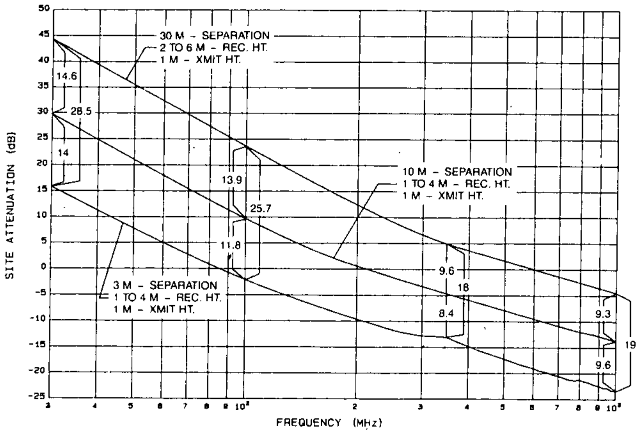

Figure 6. Comparison of Horizontal Site Attenuation Curves.

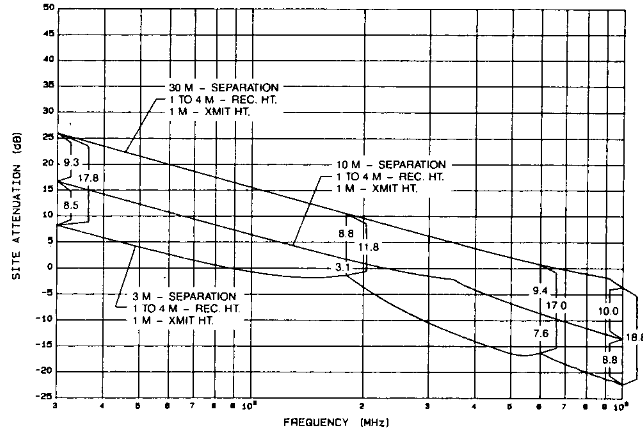

Figure 7. Comparison of Vertical Site Attenuation Curves.

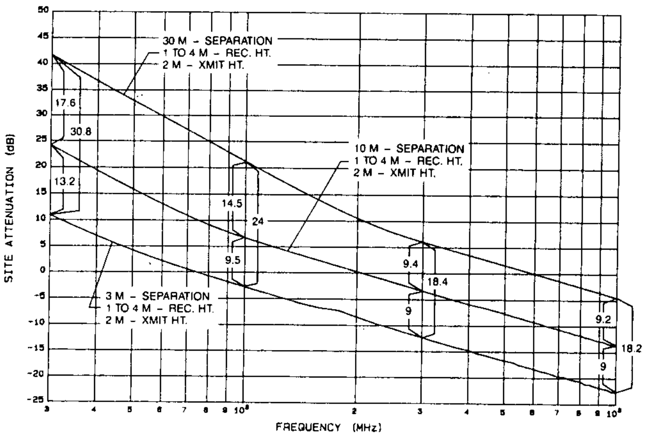

Figure 8. Comparison of Horizontal Site Attenuation Curves.

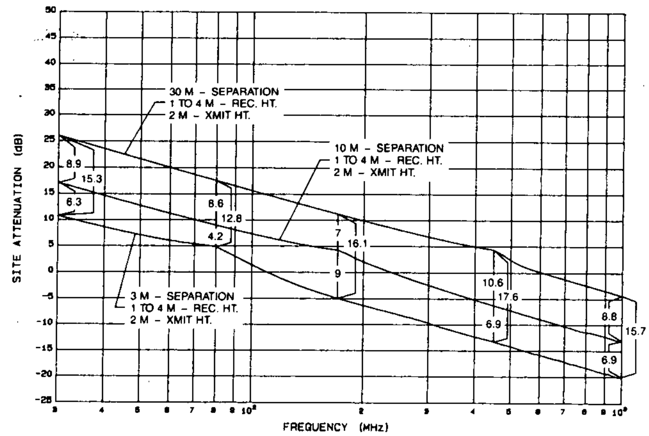

Figure 9. Comparison of Vertical Site Attenuation Curves.

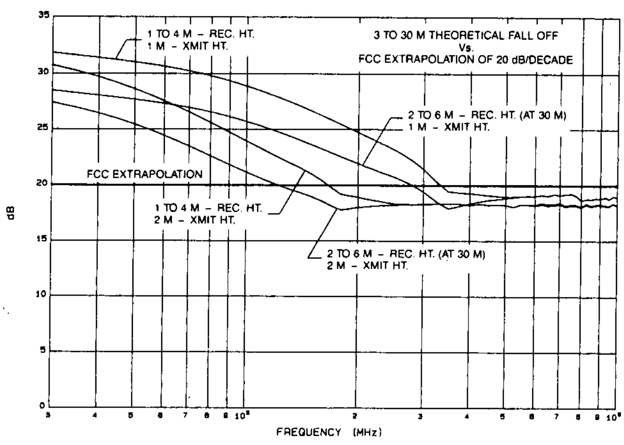

Figure 10. Horizontal Fall Off Variations With Distance.

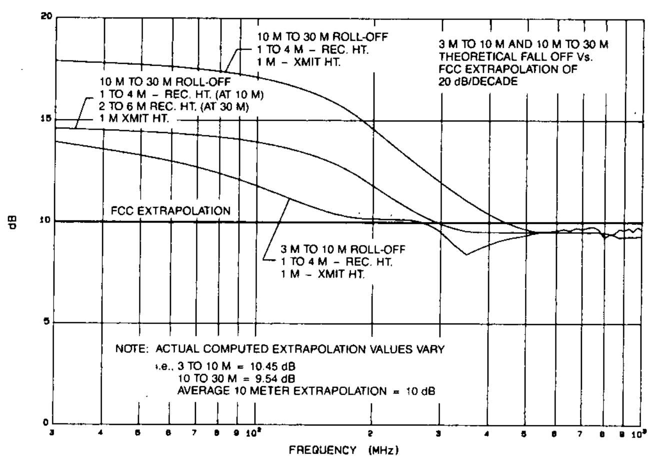

Figure 11. Horizontal Fall Off Variations With Distance.

the curves for horizontal and vertical polarizations. As can be seen the data indicates a variation from the theoretical in excess of the ±4 dB band around the curve (VDE permits ±3 dB for an acceptance site; ANSI C63.4 specifies ±4 dB). We recognized our site and ground plane had some imperfections; however, we did not feel it was as imperfect as the data suggested. We used broadband biconicals from 30 to 300 MHz and log periodic antennas from 300 to 1000 MHz for transmit and receive antennas.

We also used the published antenna factors from the manufacturer in calculating the field strength. Subsequently we purchased an additional set of antennas which were sent to the National Bureau of Standards (NBS) for calibration. The NBS calibrates antennas in horizontal polarizations only and at a transmit height of 3 meters over a carefully constructed ground plane. The variance in antenna factors (published vs NBS measured) is shown in Figure 16. Applying the new correction factors to the previously measured data resulted in the new site calibration data as shown in Figures 17 and 18. Mutual coupling factors were not deter-

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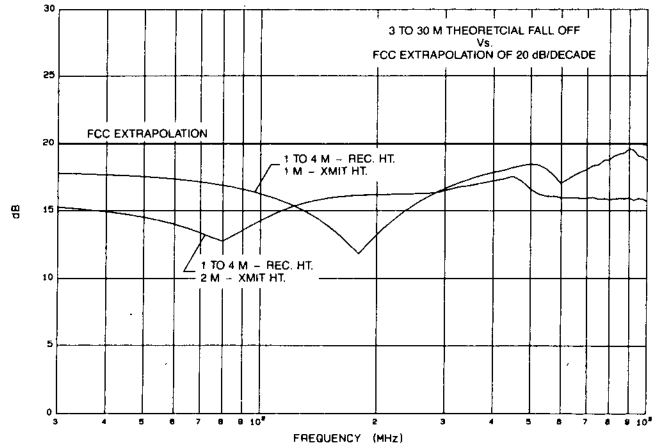

Figure 12. Vertical Fall Off Variations With Distance.

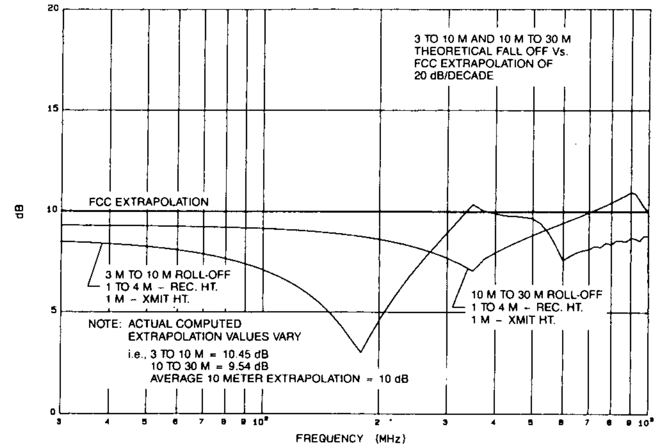

Figure 13. Vertical Fall Off Variations With Distance.

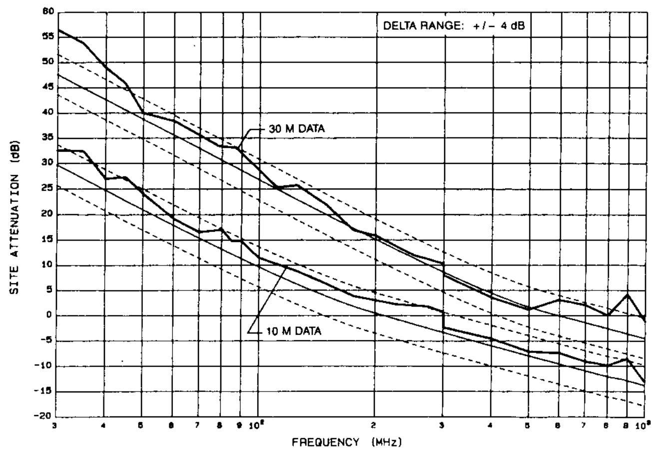

Figure 14. Initial Site Attenuation – Horizontal.

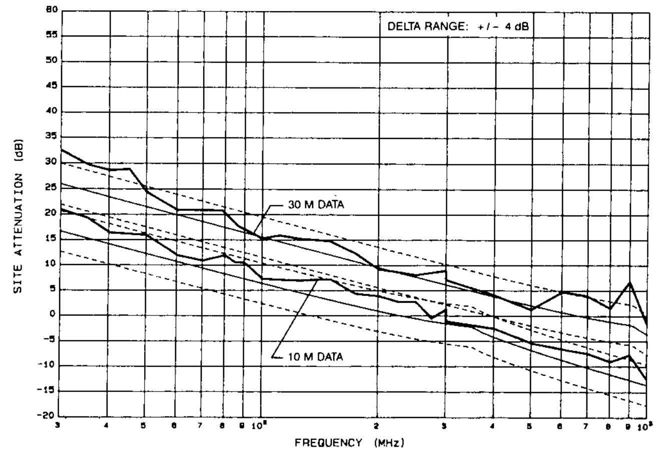

Figure 15. Initial Site Attenuation Data – Vertical.

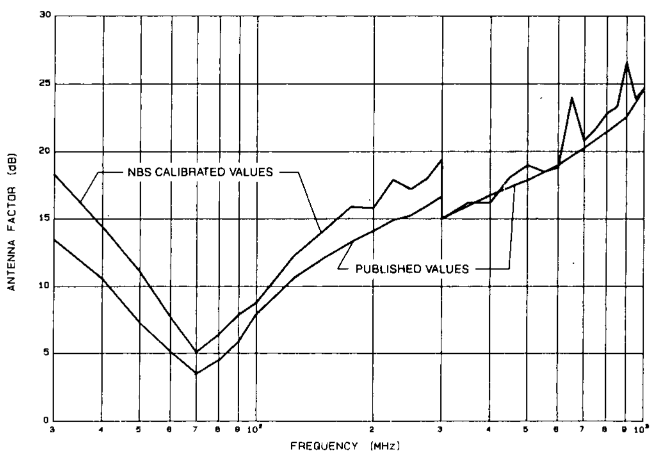

Figure 16. Antenna Factor Comparison.

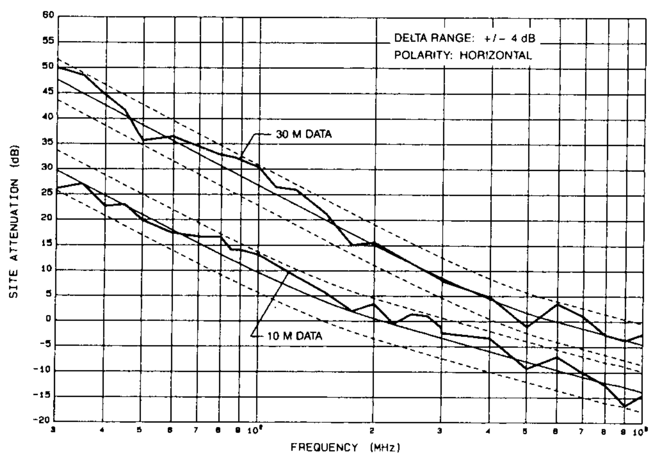

Figure 17. Site Calibration Data Using NBS Antenna Factors.

mined for these antennas and are not included in the data or in the theoretical curves. Mutual coupling is expected to have minimal influence at distances of 10 meters or greater and at antenna heights of 1 meter or greater. As can be seen the new site calibration measurements with the new antenna factors now show the site to meet the acceptability criteria. However, as can also be seen, the calibration data still shows variances from the ideal by typically ±3 dB and at some frequencies by 4 dB. In fact the curves at different distances on the same site show variations on the order of 2 dB. Assume that measurements on another acceptable test site show variations of ±4 dB also but at different frequencies; this would then suggest that product emission measurements could vary by up to 8 dB on 2 different test sites both of which satisfy the site acceptability criteria.

However an offsetting factor to this last conclusion is the last prob-

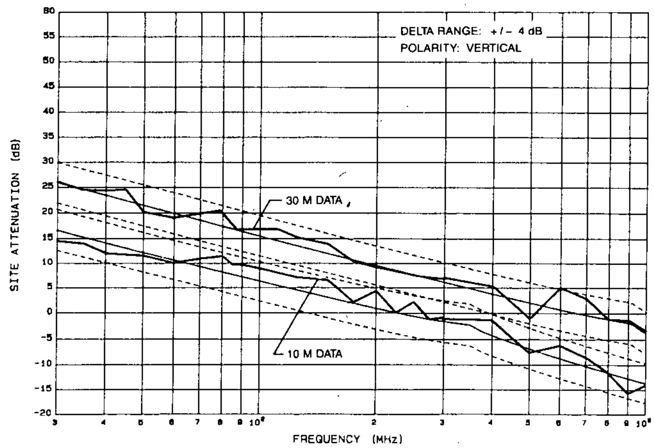

Figure 18. Site Calibration Data Using NBS Antenna Factors.

lem stated in the introduction. That is, that product emission fall off does not necessarily correlate with that predicted by the site attenuation equations or the FCC extrapolation criteria. Although experience has shown that for vertically polarized antenna measurements on products the fall off with distance is closer to predicted values than horizontally polarized measurements, the variance can be significant for either case at different frequencies. The reason is that product emissions do not behave in the same manner as a plane wave transmitted from a horizontally or vertically polarized dipole antenna. Theoretically the horizontally or vertically oriented antenna is transmitting only a singular plane wave either horizontal or vertical in the direction of propagation at any given instant. Products emit radiation patterns that contain vertical and horizontal components simultaneously; in fact their wave fronts are probably better described as eliptically polarized and they may also emit from different locations within a configuration producing different phase relationships which can add or subtract from the data when measured at different distances.

The superposition of all possible emission polarizations and their addition or cancellation factors at different distances makes extrapolation techniques using vertical or horizontal plane wave calculations uncertain. This simply stated means that substituting new extrapolation calculations described by the site attenuation equations in place of the 20 dB/decade value described in MP-4 will not necessarily improve the accuracy of extrapolated product emission data.

CONCLUSIONS

The measurement variations that can exist between test sites, for instance different antenna factors, site imperfections, and distance fall off variations including deviations from extrapolation formulas, can result in large variations in product emission data for the same product measured at different sites, particularly if measured at different distances. Variations in measurement techniques, allowable within the guidelines, coupled with variations in EUT configurations such as putting a host or peripherals below ground and running cables vertically down versus laying cables out horizontally and testing host and peripherals as a unit/system can make measurements between different test houses unrepeatable and virtually uncorrelatable, at least within tolerable limits. One approach to reducing at least a portion of the problem would be eliminate extrapolation. For instance new rules could state that all measurements on Class A products must be made at one distance only, say 10 meters with the limit defined at the measuring distance. All Class B products might be measured at 3 meters. Size could be a determining factor, e.g., if the product is greater than 1 meter cubed it could be measured at 10 meters. All systems less than 1 meter cubed would have to be measured at 3 meters.

If a limit is defined at 10 meters and a 10 dB adjustment is permitted for measurements at 3 meters it should be recognized that for horizontal polarization, product emissions may appear higher than if measured at 10 meters. Conversely, for vertical polarization, emissions may appear lower than if measured at 10 meters. ■

ACKNOWLEDGEMENTS

As stated eariler, G. Becker of Control Data and B. Cooperstein of Xerox Corporation had concurrently produced similar information relative to the site attenuation curves reinforcing our conclusions. Al Smith from IBM provided valuable guidance when we were initially trying to develop programs to plot the curves.

REFERENCES

1. Federal Communications, "FCC Methods of Measurement of Radio Noise Emissions from Computing Devices," FCC/OST MP-4 (1983).
2. CISPR Publication 22, Draft Edition "Limits of Radiated Interference Field Strength," 1985.
3. VDE 0877 Part 2, "VDE Measurement of RFI Field Strength," 1982.
4. Open Area Test Sites, Draft Edition to American National Standard C63.4 "Methods of Measurement from Low Voltage Electrical and Electronic Equipment in the Range of 10 kHz to 16 kHz."
5. Federal Communications Commission "Characteristics of Open Field Test Sites," FCC Bulletin OST55, 1982.
6. A. A. Smith, Jr., R. F. German, and J. B. Pate, "Calculation of Site Attenuation from Antenna Factors," IEEE Transactions, Electromagnetic Compatibility Vol. EMC-24, No. 3, August 1982.
7. B. Copperstein and J. Duncan, "Measurement Differences Resulting from the Use of Linear Extrapolation with Distance on the Open Field Test Site," October 1985.
8. W. Scott Bennett, "Characterization and Calibration of Open Field EMI Test Sites," Hewlett Packard Company.
9. R. F. German and Ralph Calcavecchio, "On Radiated EMI Measurements in the VHF/UHF Frequency Range," IEEE Transactions, 1980.
10. A. A. Smith, Jr., "Standard Site Method for Determining Antenna Factors," IEEE Transactions on Electromagnetic Compatibility, Vol. EMC-25, No. 3, August 1982.
11. T. J. Dvorak and G. V. Moyer, "Field Patterns at an IEC 3M Radiation Measuring Site," Institute for Communications Technology, Federal Institute of Technology, Zurich, Switzerland, IEEE Transactions, 1980.