Radiated Emission Measurements at 1/3/5/10/30 Meters

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Measurements at Closer Distances

- There is a growing tendency to measure radiated emissions at distances closer to the Equipment Under Test
- Laboratories then use the **Inverse Distance Falloff** assumption to estimate the value of the field at the regulatory distance further from the equipment

Inverse Distance Falloff

- Inverse Distance falloff is quoted frequently in many EMC standards and by regulatory authorities
- The physics of Inverse Distance Falloff assumes a small source in a free-space environment and far-field conditions
- It is abbreviated 1/d
  - where d is distance

Inverse Distance Falloff

- The standards and regulations often ignore the assumptions that make up the 1/d rule
  - Most test sites have a reflective ground plane **not a free-space environment**
  - Most real sources that are measured are **not “small”**
  - Most real sources are close to the antenna and the receiving antennas are **not in the “far-field” of the source**

Inverse Distance Falloff

- The 1/d rule has been used for many years by regulatory organizations such as the FCC
- It was used to justify moving measurement distances from 1600 meters to 300 meters, from 300 meters to 30 meters and from 30 meters to 10 meters
- Should it continue to be used from 10 meters to 5 meters? To 3 meters? To 1 meter?

Technical Basis

- Inverse Distance may work for a small source when the antenna is in the “far-field” of the source
- Historically, it has been used in the frequency range from 30 MHz to 1000 MHz **regardless** of the source size
- It is also presently being used in the frequency range 1 GHz to 40 GHz

Small Size

- **Small** can be defined as small in physical size and small relative to the wavelength
- **Small** physical size is easy to picture but the standards committees are grappling with the issue of defining "small physical size"
  - Amendment 1 to CISPR 11 defines "small equipment" to be "equipment, either positioned on a table top or standing on the floor, which, including its cables, fits in a cylindrical test volume of 1.2 m in diameter and 1.5 m above the ground plane"

Small Size

- **Small** relative to the wavelength is more complex
- **Below 30 MHz**, the wavelengths are 10 meters or longer, so, almost everything is electrically small
- **From 30 to 300 MHz**, the wavelength varies from 10 meters to one meter. Most products are small at 30 MHz but equivalent in size at 300 MHz
- **Above 300 MHz**, the wavelength is one meter or shorter and most products are large compared to the wavelength

Reflective/Free Field Environment

- Most measurements in the frequency range from 30 MHz to 1000 MHz are made in a **Reflective Environment**
  - The reflective environment is primarily due to the metallic ground plane between the product (under test) and the receiving antenna
- **Above 1000 MHz**, the newest test methods call out absorber material to be placed on at least part of the floor to simulate a Free Field environment

Free-Field Environment

- Fully Anechoic rooms continue to be investigated for measurements in the range 30 – 1000 MHz
- They more closely meet the **Free-Field** environment criteria for 1/d falloff
- They can still be challenged due to near-field limitations; that is, the proximity of the EUT to the receiving antenna

Inverse Distance at 3/10 meters

- For a table-top product, the maximum size of a typical table is 1.5 by 1 meter and it is 0.8 meter high
- At 30 MHz, a table-top product the size of a typical table would be small versus a 10-meter wavelength
- At 300 MHz, any product the size of the table is equivalent in size to the wavelength of 1-meter
- At 600 MHz, any product the size of the table is twice the size of the wavelength of 0.5-meter

Floor-Standing Products

- Floor-Standing Products are typically about two meters tall and one meter wide
- Again, a two-meter wavelength starts at 150 MHz so the product is “relatively small” below that frequency and “relatively large” above it
- At 300 MHz, the width of the product would be comparable to the wavelength and the height would be equivalent to two wavelengths

Small Product

So, a typical electronic product (an unintentional radiator) **may** be small below 150 MHz but it is definitely **not small** relative to the wavelength above 150 MHz

- transceivers (cell phones, etc.) are small to higher frequencies

Far-Field

- When the product under test is **“small”**
- **and** we are in “free space”
- **and** in the far-field of the device under test, the 1/d rule works reasonably well
  - But, what is the far-field?
  - One wavelength, two wavelengths, three wavelengths?

Far-Field – FCC OET Bulletin 65 Definition

- **Far-Field Region –** That region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. In this region (also called the free space region), the field has a predominantly plane-wave character, i.e., locally uniform distribution of electric field strength and magnetic field strength in planes transverse to the direction of propagation

Far-Field – FCC OET Bulletin 65 Definition

- **Near-Field Region –** A region generally in proximity to an antenna or other radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave character, but vary considerably from point to point. The near-field region is further subdivided into the reactive near-field region, which is closest to the radiating structure and that contains most or nearly all of the stored energy, and the radiating near-field region where the radiation field predominates over the reactive field, but lacks substantial plane-wave character and is complicated in structure. For most antennas, the outer boundary of the reactive near-field region is commonly taken to exist at a distance of one-half wavelength from the antenna surface.

Far-Field

- **At 30 MHz**, the far-field begins at **10 meters** from the EUT for one wavelength, at 20 meters for two wavelengths, and 30 meters for three wavelengths
- **At 100 MHz**, the far-field begins at **3 meters** for 1 wavelength, 6 meters for 2 wavelengths, and 9 meters for 3 wavelengths
- **At 300 MHz**, the far-field begins at **1 meter** for 1 wavelength, 2 meters for 2 wavelengths, and 3 meters for 3 wavelengths

Technical Papers on Inverse Distance Falloff

- Over the years there have been a number of technical papers written addressing the issue of inverse-distance falloff plus near-field and far-field criteria
- Let’s take a look at some of those papers

Early papers – 1970s and before

- CBEMA is the Computer and Business Equipment Manufacturer's Association
- They released a 1977 Report that stated
  - **89 percent of receiving antennas** found within 100 meters of commercial Electronic Data Processing/ Office Equipment installations can be expected to be **30 meters** or more from the installations
  - The CBEMA report therefore **chose 30 meters** as a reasonable control distance for **Class A computers**

Early papers – 1970s and before

- **In a 1973 article**, Herman Garlan of the FCC said “the rules then in effect permitted a field-strength level of 50 uV/m at 100 feet (30 meters) on frequencies between 88-108 MHz.”
- The German VDE organization used a 30-meter test distance for Class A equipment in the 1970s
- **The FCC adopted 30-meters as the preferred measurement distance for Class A computer equipment in 1979**

Early papers – 1980s

- Because of high-ambient levels, antenna mast issues due to a 6-meter mast-height, and Normalized Site Attenuation challenges; **the FCC modified the 30-meter test distance to 10-meters in the early 1980s**
- FCC Docket 80-284 changed the distance from 30-meters to 10-meters for Class A equipment
- Due to high ambient-levels at its testing laboratory in Offenbach, Germany; the German VDE organization switched to testing at a 10-meter antenna distance in the late 1970s

Early papers – 1960s

- A 1969 paper by William E. Cory and Frank C. Milstead said “Propagation predictions in the near field, while less accurate, can be made to within about 10 db.”
- A 1969 paper by Albert A. Smith, Jr. said he found “a complex relationship between surface waves and space waves below 100 MHz.”

Early papers – 1970s

- Again, Herman Garlan's paper said "The original low-power rule, the $\lambda/2\pi$ rule, was adopted in 1938. This rule provided a reasonable operating standard on frequencies up to 1600 kHz. While this standard served the needs of 1938, by the end of World War II, in 1945, it was hopelessly inadequate."

Early papers – 1980s

- A paper by Robert F. German and Ralph Calcavecchio in 1980 stated that “1/r works for electrically short dipoles.”
- It went on to say that “Actual EMI sources may be more complex (than electrically short dipoles) and the topic of future work.”

Early papers – 1980s

- Another IBM paper, by T. M. Madzy and K.S. Nordby, in 1981 said “The radiation from more than 25 different products showed **a great variation from the 20 dB attenuation often assumed between three and 30-meter field strength levels”**
- It went on to say “In fact, a very large source could in the extreme show a **falloff approaching 0-db** because it contains a large number of geometrically distributed sources, both horizontally and vertically. The fields from such multiple sources superimpose and may generate an almost plane wavefront.”

Early papers – 1980s

- Another paper; by Arlon T. Adams, Yehuda Leviatan, and Knut S. Nordby; showed that ‘the measurement distances of 3 to 30 meters may lie in the near or the far field depending on the dimensions of the product and the frequencies emitted.”
- It said further that “Thus, measurements made at short distances and then normalized to larger distances will yield far-fields **smaller than they should be.”**

Early papers – 1980s

- In 1987, J. D. Gavenda said in his paper that "the presence of a conducting ground plane causes reflected signals which interfere with constructively or destructively, depending on height above the ground plane and frequency, with the direct signal."
  - **"This invalidates any simple inverse-distance falloff rule, so correction factors must be used in the extrapolations"**

Early papers – 1980s

- Joseph DeMarinis, in a 1987 paper, said **"It is well known that signal falloff versus site distance does not follow the 1/distance-rule which is proscribed by the regulatory standards and that very large correlation errors can exist between test results taken at different distances.** It was of particular interest to the project at hand to try and understand the relationship between 3-meter and 10-meter sites."
  - **The study showed a falloff of between 3 to 11 dB for vertical signals and 8-13 dB for horizontal signals from 30 -1000 MHz**

Early papers – 1990s

- In 1993, H. F. Garn, E. Zink, and R. Kremser wrote a paper that showed a falloff from 1db to 18 db for 3 to 10 meters for a setup representing a typical personal computer.
  - **They concluded that "based on the present specifications, compliance tests at a 3-meter distance should not be allowed."**
  - **They meant that 3-meter measurements should not be allowed to prove compliance to a 10-meter limit**

Early papers – 1990s

- Christopher L. Holloway and Edward F. Kuester, in a 1996 paper, showed a comparison of OATS and semi-anechoic chambers.
  - **It concluded that: "This comparison is quite good at frequencies higher than 300 MHz, but at lower frequencies (30-300 MHz), large discrepancies are often observed due to reflections from the chamber walls."**

Early papers – 2000s

- A paper given in 2009 by Blankenship, Arnett, and Chen at the 2009 IEEE International Symposium on EMC used a NSA approach to look at falloffs from 3 to 10 meters.
  - **The paper predicted a frequency-dependent falloff factor between 3 and 10 meters**

Technical Papers showing 1/d

- No papers were found that show that a 1/d relationship works for real-life products
- I repeat, **NO papers** were found that show that a 1/d relationship works for real-life products from 30 – 1000 MHz

Technical Papers - Conclusions

- **The weight of the evidence of the published technical papers is that 1/d does not work from 3 to 10 meters**
- There is evidence that **a frequency-dependent correction factor might work** and that it would be more realistic than the commonly used, but inaccurate, 1/d factor

United States FCC Rules

- FCC Docket 20780 expanded Part 15 of the FCC Rules to include computers and microprocessor-based devices
- When FCC Docket 20780 was adopted in 1979, it had an Appendix A which described the test procedures
- In September, 1983; Appendix A was deleted and the test procedures were published in MP-4

United States FCC Rules

- A revised version of MP-4 was released in July of 1987
- Par 4.3.1 stated:
  - "Equipment subject to a limit at 30 meters may be measured at a distance of from 3 to 30 meters provided that the results are extrapolated to an equivalent signal at 30 meters utilizing an inverse linear distance extrapolation factor (20dB/decade).
  - **No technical basis was given for this extrapolation factor**

United States FCC Rules

- Paragraph 15.109 – Radiated Emission Limits
  - Class B products are tested at 3-meters
  - Class A products are tested at 10-meters
- **Par. 15.109 (c) allows testing using CISPR 22, 1997 Edition.**

United States FCC Rules

- Par. 15.109 (g) allows testing using CISPR 22, 1997 Edition.
  - As an alternative to the radiated emission limits shown in paragraphs (a) and (b) of this section, digital devices may be shown to comply with the standards contained in **Third Edition of the CISPR Pub.22.**
- **Testing to CISPR 22 was first allowed under FCC ET Docket 92-152 (around 1993) and it allowed using CISPR 22 (Second Edition).**

United States FCC Rules

- Par. 15.109 (g) (3) says
  - The measurement distances shown in CISPR Pub. 22, including measurements made in accordance with this paragraph above 1000 MHz, are considered, for the purpose of Par. 15.31(f)(4) of this part, to be the measurement distance specified in this part.
  - ????

United States FCC Rules

- Par. 15.31(f)(4) says
  - When measurement distances of 30 meters or less are specified in the regulations, the Commission will test the equipment at the distance specified unless measurement at that distance results in measurements being performed in the **near field.**
  - NOTE – **Near Field is not defined in Part 15 of the FCC Rules but it is defined in OET Bulletin 65 (as shown in an earlier slide)**

CISPR 22

- The internationally accepted standard for emissions from Information Technology Equipment (ITE)
- Latest edition is Edition 6 released in 2008

CISPR 22 - Sixth Edition – 2008
Clause 10 – Method of Measurement of Radiated Disturbance

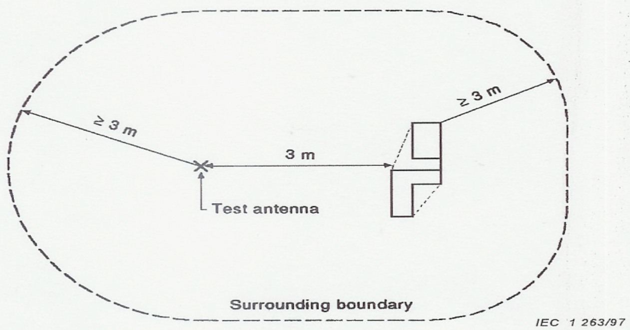
10.3.1 – Antenna-to-EUT distance

- 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 (of CISPR 22).

- 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 the boundary (see also Figure 2).

CISPR 22 - Sixth Edition – 2008
Clause 10 – Method of Measurement of Radiated Disturbance – 10.3.1 – Antenna-to-EUT Distance



There shall be no reflecting object inside the volume defined on the ground by the line corresponding to this figure and defined in height by a horizontal plane ≥3 m above the highest element of either aerial or equipment under test.

NOTE See 10.4.3 for applicability of the alternate test site. Also, the peripheral string method is described in 10.3.1.

Figure 2 – Minimum alternative measurement site

CISPR 22 - Sixth Edition – 2008
Clause 10 – Method of Measurement of Radiated Disturbance

10.3.1 – Antenna-to-EUT distance

Note – If the field-strength measurement at 10 meters 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 meters. **An inverse proportionality factor of 20 dB per decade 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 meters at frequencies near 30 MHz due to near-field effects

CISPR 22 - Sixth Edition – 2008
Clause 10 – Method of Measurement of Radiated Disturbance

10.3.2 – Antenna-to-ground distance

- The antenna should be adjusted between **1 meter and four meters in height** above the ground plane for maximum meter reading at each test frequency

10.3.3 – Antenna-to-EUT Azimuth

- Antenna-to-EUT azimuth shall also be varied during the measurements to find the maximum field-strength readings

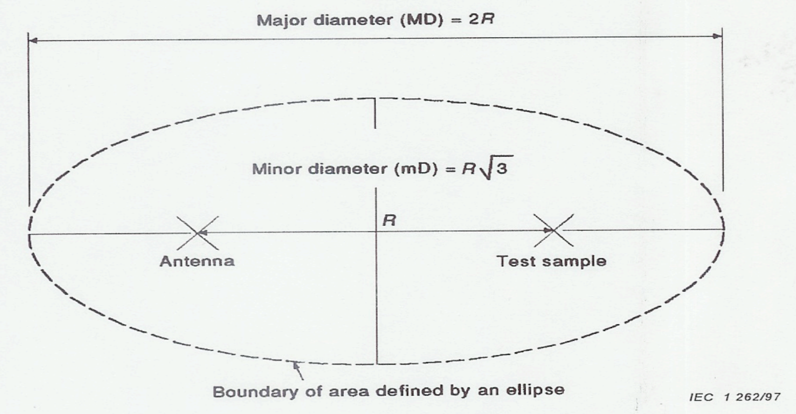
- For measurement purposes, it may be possible to rotate the EUT

- When this is not practicable, the EUT remains in a fixed position and measurements are made around the EUT

10.3.4 – Antenna-to-EUT Polarization

- Antenna-to-EUT polarization **(horizontal and vertical)** shall be varied during the measurements to find the maximum field-strength readings.

CISPR 22 - Sixth Edition – 2008
Clause 10 – Method of Measurement of Radiated Disturbance



Volume above earth to be free of reflecting objects.

NOTE Characteristics of test site described further in 10.4. See also Clause 6 for the value of R.

Figure 1 – Test site

CISPR 22 - Sixth Edition – 2008
Annex A (Normative) – Site Attenuation Measurements of Alternative Test Sites – Figure A.1

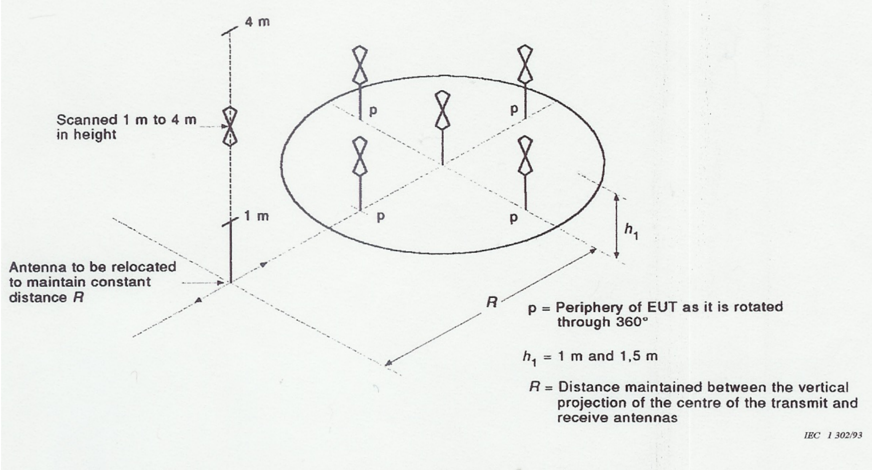


Figure A.1a – Typical antenna positions for alternate site NSA measurements in the vertical polarization

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Annex A (Normative) – Site Attenuation Measurements of Alternative Test Sites – Figure A.2 – Minimum Recommended Volume

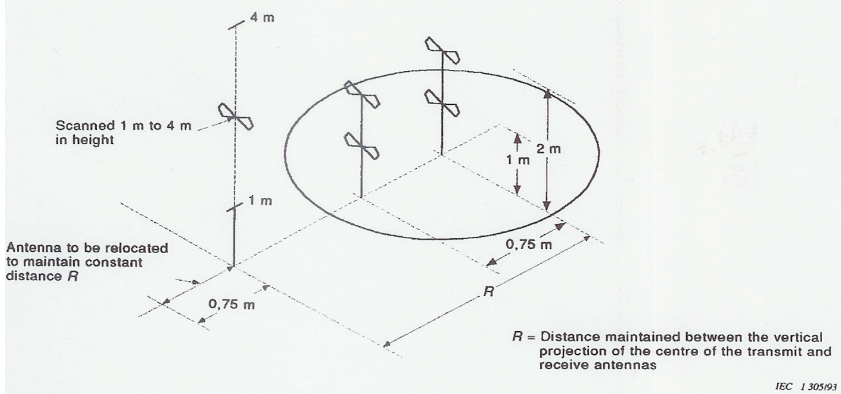

Figure A.2b – Typical antenna positions for alternate site NSA measurements in the vertical polarization for a volume not to exceed 1 m depth, 1,5 m width and 1,5 m height and rear boundary of the volume greater than 1 m from the closest material that may cause undesirable reflections

Figure A.2 – Antenna positions for alternate site measurements for minimum recommended volume

Recommendations on Falloff as per Inverse Distance

- **Time for a change to the long-standing 1/d assumption for measured results from 3 meters to 10 meters**
- **Class A Products should be tested at 10 meters as per FCC Rules**
  - **- Thirty years of experience with FCC Docket 20780 show this is effective**
- **Class B Products should be tested at 3 meters as per FCC Rules**
  - **Thirty years of experience with FCC Docket 20780 show this is effective**

Recommendations on Falloff as per Inverse Distance

- **Using a 1/d Falloff factor for testing of Class A products at 3-meters for a comparison to a 10-meter limit should be:**
- **STOPPED**
  - **It is not technically justified**

Recommendations on Falloff as per Inverse Distance

- **Ten-meter labs (OATS and Semi-Anechoic Chambers) would like to see a zero-dB fall-off from 3 meters to 10 meters (in other words, the 10-meter limit would have to be met at 3-meters)**
- **Three-meter labs (OATS and Semi-Anechoic Chambers) would like to see a 10-db fall-off from 3 meters to 10 meters (in other words, an inverse distance falloff).**

Recommendations on Falloff as per Inverse Distance

- **A possible compromise position between these two perspectives is a falloff correction factor that is frequency dependent**
- **Two key papers that could lead to a compromise are:** J. D. Gavenda's paper **and** by Blankenship, Arnett, and Chen at the 2009 IEEE International Symposium on EMC

Recommendations on Falloff as per Inverse Distance

- **J. D. Gavenda, "Effects of Electromagnetic Source Type and Orientation on Signal Falloff with Distance," 1987 IEEE EMC Symposium Record**
- **Ed Blankenship, David Arnett, and Sidney Chan, "Searching for the Elusive Correction Factor between 3m and 10m Radiated Emission Tests," 2009 IEEE International Symposium Record.**

Recommendations on Falloff as per Inverse Distance

- **More to come in the future**
- **Standards**
- **Regulations**
- **Fully-Anechoic Chambers**
- **Higher Frequencies**