EMC STANDARDS

The EMC standards that a particular electronic product must meet depend on the product application (commercial or military) and the country in which the product is to be used. These EMC regulatory standards are set by the appropriate government agency and are imposed in order to control the amount of electromagnetic interference in the environment. Thus, meeting these government standards does not guarantee that a product is immune to EMC issues. For this reason, manufacturers commonly impose EMC requirements that are even more stringent than the government standards given a product that must operate in the vicinity of some other sensitive equipment (emissions), or a product that must operate in a particularly harsh environment (susceptibility).

STANDARDS AND STANDARD MAKING BODIES

International

International Electrotechnical Commission (IEC)
http://www.iec.ch/

- operates closely with the International Organization for Standardization (ISO)
- standards written by a committee of the IEC [Special International Committee on Radio Interference (CISPR)].
- The IEC EMC standard is commonly referred to as “CISPR 22". This standard has been adopted by the European Economic Community (EEC) in addition to several other countries.

Europe

European Telecommunications Standards Institute (ETSI)
http://www.etsi.org/

- responsible for standards involving information and communication technologies in Europe.

European Committee for Electrotechnical Standardization (CENELEC)
http://www.cenelec.org

- mission is to prepare voluntary electrotechnical standards that help develop a single European market.

United States (Commercial)

Federal Communications Commission (FCC)
http://www.fcc.gov/

- charged with regulating interstate and international communications by radio, television, wire, satellite and cable.
- EMC standards are included in the FCC Rules and Regulations, Title 47, Part 15, Subpart B regulates "unintentional radio-frequency devices".

United States (Military)

Department of Defense (DoD)
http://dodssp.daps.mil/

- EMC standards for equipment used by the US military are contained in MIL-STD 461E.

FCC Title 47 - Telecommunication
Part 15 - Radio Frequency Devices
http://wireless.fcc.gov/rules.html

Subpart A - General
Subpart B - Unintentional Radiators
Subpart C - Intentional Radiators

Definitions from FCC Part 15 Subpart A

Radio frequency (RF) energy - Electromagnetic energy at any frequency in the radio spectrum between 9 kHz and 3,000,000 MHz.

Unintentional radiator - A device that intentionally generates radio frequency energy for use within the device, or that sends radio frequency signals by conduction to associated equipment via connecting wiring, but which is not intended to emit RF energy by radiation or induction.

Intentional radiator - A device that intentionally generates and emits radio frequency energy by radiation or induction.

Incidental radiator - A device that generates radio frequency energy during the course of its operation although the device is not intentionally designed to generate or emit radio frequency energy. Examples of incidental radiators are dc motors, mechanical light switches, etc.

Digital device - An unintentional radiator (device or system) that generates and uses timing signals or pulses at a rate in excess of 9,000 pulses (cycles) per second and uses digital techniques.

Class A digital device - A digital device that is marketed for use in a commercial, industrial or business environment, exclusive of a device which is marketed for use by the general public or is intended to be used in the home.

Class B digital device - A digital device that is marketed for use in a residential environment notwithstanding use in commercial, business and industrial environments. Examples of such devices include, but are not limited to, personal computers, calculators, and similar electronic devices that are marketed for use by the general public.

Other Definitions

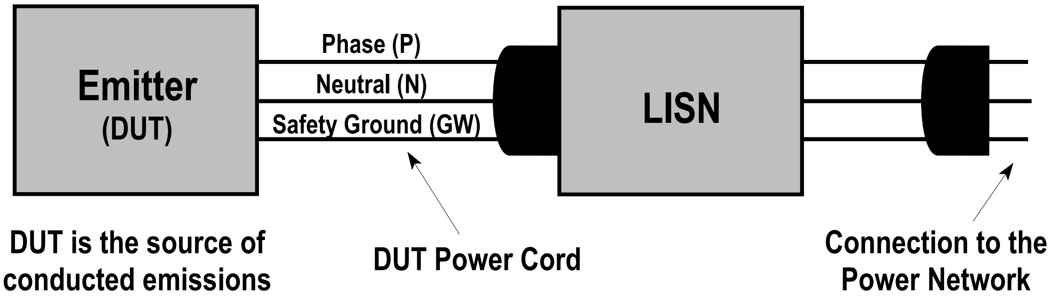
Peak detection - in terms of spectral measurements, a peak detector will always yield the highest spectral value.

Quasi-peak detection - historically meant to simulate the human response to noise, the spectral measurement is weighted according to its repetition frequency.

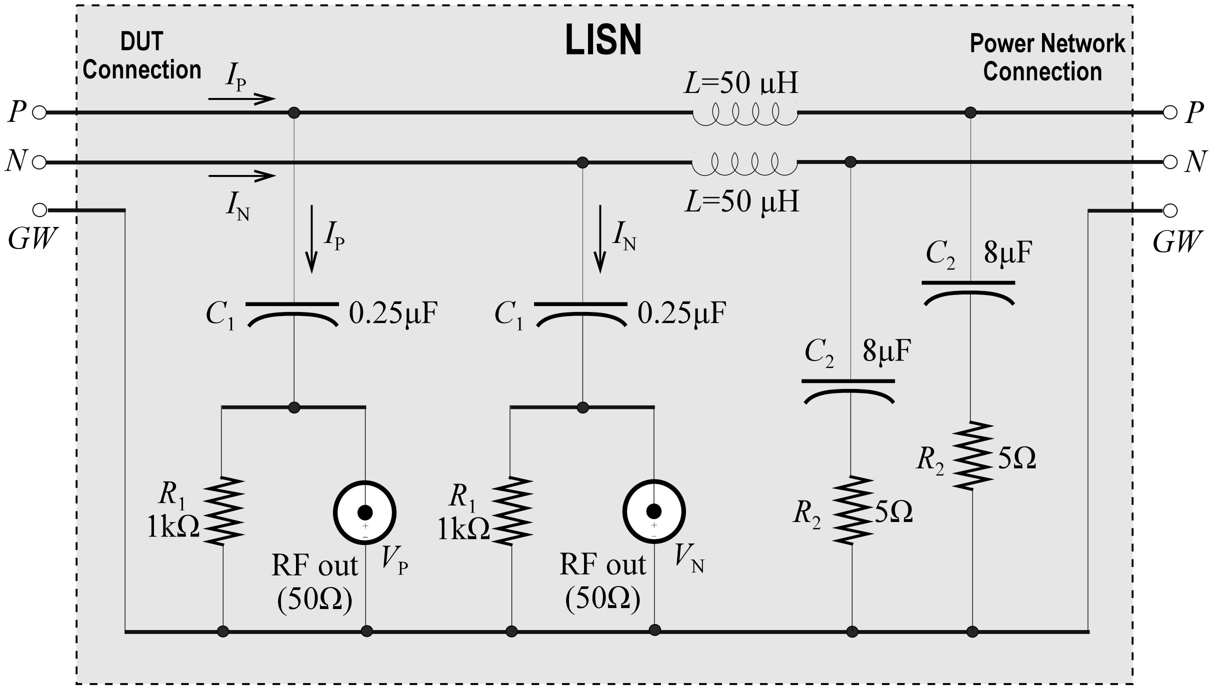
CONDUCTED EMISSIONS STANDARDS AND TESTING

The purpose of imposing conducted emissions standards on products is to reduce the overall noise level on a given power network. Any device connected to the power network can conduct noise currents that flow out of the device and onto the power network of an installation and eventually onto the overall power grid. Not only can this noise affect devices connected to the power network through conductive coupling, the electrical length of the conductors that comprise the power network may allow this noise to also radiate effectively.

The device used to measure conducted emissions is known as a Line Impedance Stabilization Network (LISN). The LISN is inserted in series with the power cord of the DUT as shown below. In the United States, an AC voltage of 120 V-rms at 60 Hz exists between the phase (P) and neutral (N) conductors. The third conductor is a safety ground that is commonly called the "green wire" (GW). The noise currents to be measured by the LISN exist on the phase and neutral conductors.



In order to make an accurate measurement of the DUT noise currents, the LISN must block noise currents from the power network from contaminating the test results. The LISN measurements should to be independent of where the DUT/LISN test setup is connected to the power network. The impedance seen looking into the power network can vary from location to location. Thus, the LISN must present a constant impedance to the DUT over the frequency range of interest, irregardless of the power network connection point.

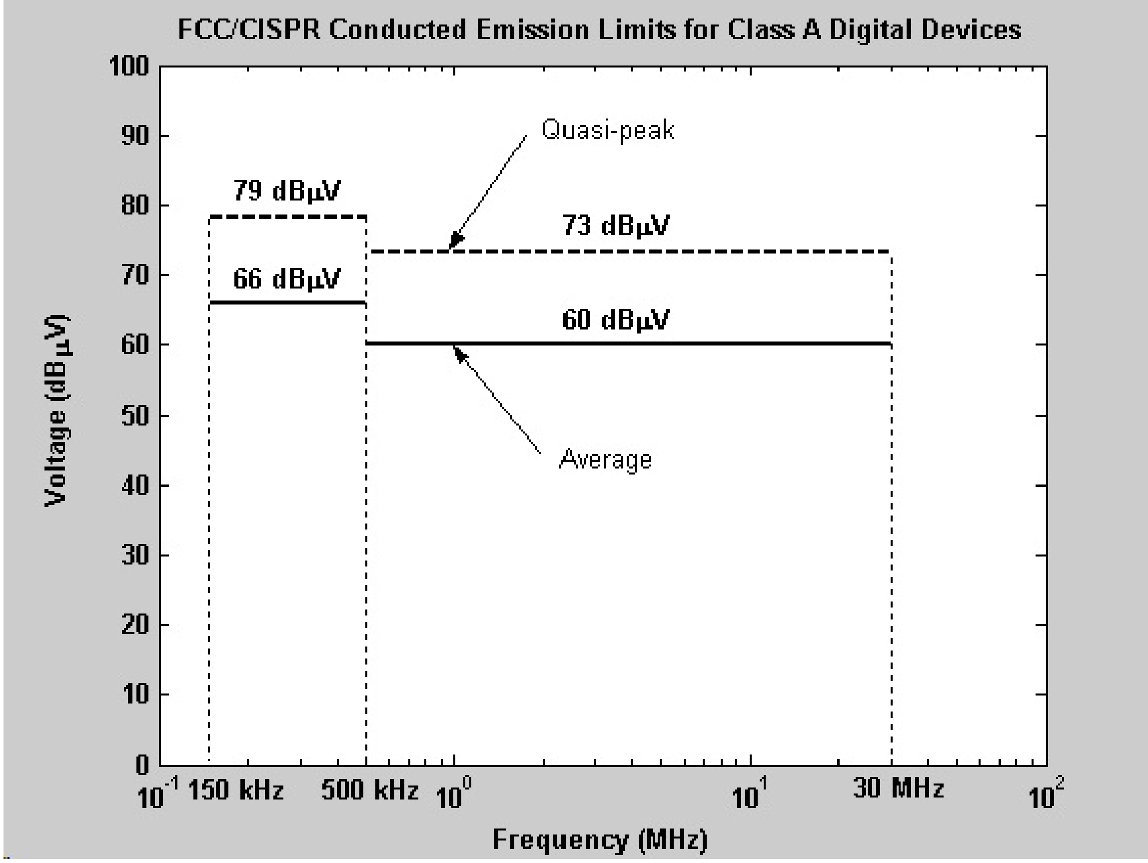


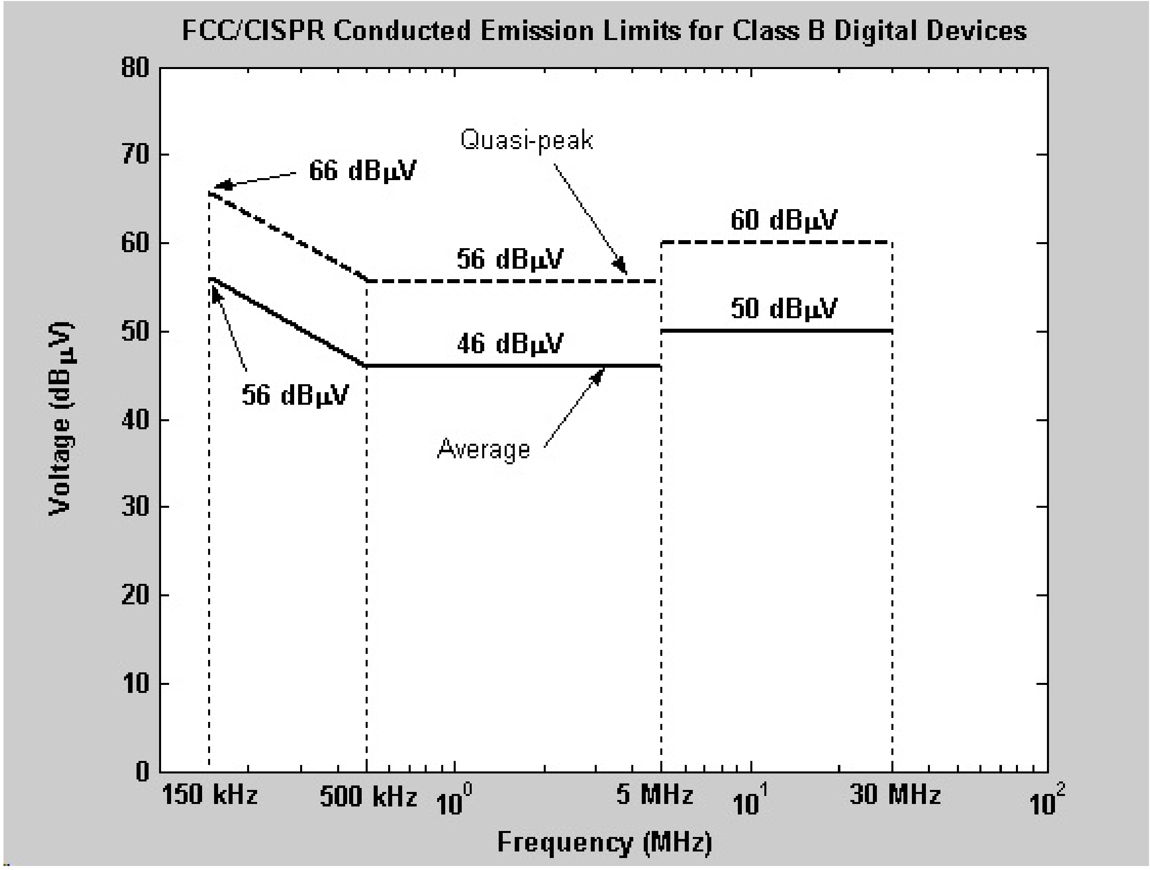
The purpose of the inductors labeled L and the capacitors labeled C_2 in the LISN shown above are to block the high-frequency noise on the power network from the LISN. The inductor L acts like an RF choke while the capacitor C_2 acts like an RF shunt. The combination of L and C_2 blocks the high frequency noise from the power network while allowing the 60 Hz power signal to pass through since the inductor is essentially a short circuit at 60 Hz and the capacitor is essentially an open circuit at 60 Hz.

Since the inductor L presents a high impedance to the noise currents on the phase and neutral conductors (I_P and I_N), the noise currents are shunted through the paths formed by C_1 in series with the parallel combination of R_1 and the 50 Ω RF output. The 50 Ω resistances in the LISN circuit represent the standard 50 Ω RF input of a spectrum analyzer. The capacitor C_1 has a very small impedance at the noise signal frequencies. The resistor R_1 provides a discharge path for C_1 in the event that 50 Ω resistance is disconnected. Essentially all of the noise current passes through the 50 Ω resistance since R_1 is so much larger. Overall, the impedance presented to the DUT looking into the LISN is approximately 50 Ω for both the phase and neutral conductors over the frequency range of interest.

Note that the actual conducted emissions from the DUT take the form of noise currents on the phase and neutral conductors of the power network. However, the conducted emissions measurements by the LISN take the form of a measured noise voltages. These noise voltages are directly proportional to the corresponding noise currents. Thus, the conducted emissions standards dictate noise voltage limits (typically in units of dBμV) and not noise current limits.

Prior to 2002, the conducted emissions standards set forth by the FCC in Part 15 and by CISPR 22 were different. In 2002, the FCC changed the conducted emissions standards in Part 15 to match those of CISPR 22 in an effort to "harmonize our domestic requirements with the international requirements developed by the International Electrotechnical Commission (IEC), International Special Committee on Radio Interference (CISPR)." The frequency range on the previous version of the FCC conducted emissions standards was 450 kHz to 30 MHz while the frequency range on the current FCC/CISPR standards is 150 kHz to 30 MHz.





The conducted emissions limits for class A and class B digital devices are listed in both *quasi-peak* and *average* values. Note that the quasi-peak and average value limits are different by a constant value of 13 dBµV (4.47 µV) for class A devices and 10 dBµV (3.16 µV) for class B devices.

FCC Part 15 / CISPR 22 Conducted Emissions Limits (Class A)

Frequency (MHz)	Quasi-Peak		Average	
	µV	dBµV	µV	dBµV
0.15-0.5	8912.5	79.0	1995	66.0
0.5-30	4467	73.0	1000	60.0

FCC Part 15 / CISPR 22 Conducted Emissions Limits (Class B)

Frequency (MHz)	Quasi-Peak		Average	
	μV	dBμV	μV	dBμV
0.15-0.5	1995-631	66.0-56.0	631-199.5	56.0-46.0
0.5-5	631	56.0	199.5	46.0
5-30	1000	60.0	316	50.0

Example

The FCC/CISPR Class A conducted emissions limit (average) is 60 dBμV at 1 MHz. Determine the current level that corresponds to this conducted emissions limit in (a.) μA and (b.) dBμA.

$$V_P = V_N = 60\ \text{dB}\mu\text{V} = 10^{-6}10^{3}\ \text{V} = 1\ \text{mV}$$

$$V_P = I_P R_L \qquad V_N = I_N R_L \qquad R_L = 50\ \Omega$$

$$I_P = I_N = \frac{1\ \text{mV}}{50\ \Omega} = 20\ \mu\text{A}$$

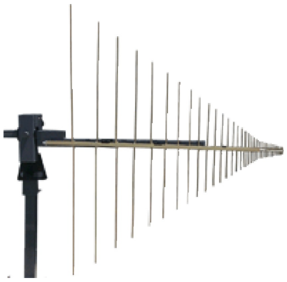
$$I_{P,\text{dB}\mu\text{A}} = I_{N,\text{dB}\mu\text{A}} = 20\log_{10}\left[\frac{20\times 10^{-6}}{10^{-6}}\right] = 26.02\ \text{dB}\mu\text{A}$$

RADIATED EMISSIONS STANDARDS AND TESTING

The purpose of imposing radiated emissions standards on products is to maintain lower levels of radiated interference in order that problems caused by radiative coupling between systems may be reduced. Radiated emissions are more difficult to measure than conducted emissions given that the quantity of interest for radiated emissions is the electromagnetic field (the required standards are defined in terms of the radiated electric field measured in dBμV/m). The radiation characteristics of the DUT will be directive, just like an antenna. That is, the DUT will have a radiation pattern that is a function of θ and φ (azimuth and elevation angles). This requires that the DUT be rotated during the radiated emissions measurement to find the worst case orientation for radiated emissions. In fact, when testing the DUT, the system cables and wiring harnesses that may exist in the product must be positioned in such a way that the radiated emissions are maximized (positioned in the worst case orientation that might be seen in the production of the device). In order to make the radiated emissions tests both accurate and repeatable, the radiated emissions standards contain specific details as to how the measurements are to be performed.

According to the FCC standard, radiated emissions should be measured on an open area test site (OATS). The OATS should have a conducting ground plane of sufficient size on which both the DUT and receiving antenna are placed. The FCC standard states that the separation distance between the DUT and the receiving antenna (R) should be 10m for Class A devices and 3m for Class B devices. The receiving antenna should be a tuned dipole over the frequency range of interest and measurements should be made for vertically polarized radiated fields (dipole is perpendicular to the ground plane) and for horizontally polarized radiated fields (dipole is parallel to the ground plane). When using a true tuned dipole antenna, the antenna should be one-half wavelength long. Thus, for every frequency data point, the antenna length would have to be adjusted. Broadband dipole antennas (log-periodic dipole antenna and the biconical antenna) are commonly used in order to allow the user to automate the radiated emissions test.

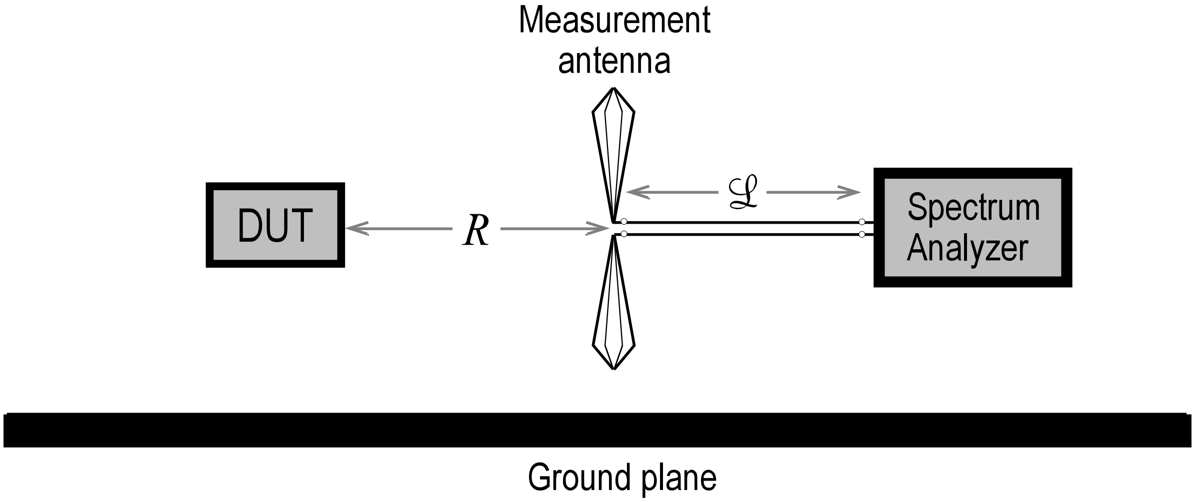
Biconical Antenna

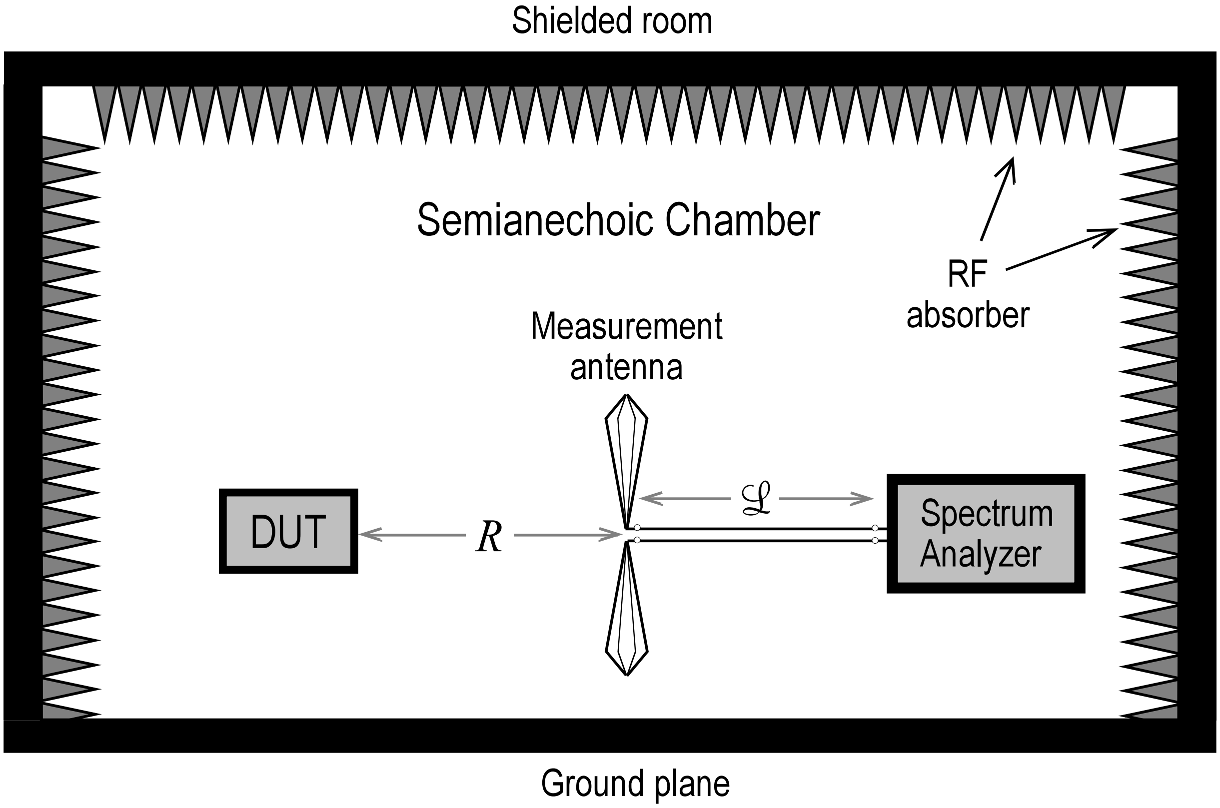


Log-Periodic Dipole Antenna

The OATS radiated emissions measurements can be complicated by unwanted ambient signals over the frequency band of interest. In many cases, companies will initially test their products in a *semianechoic* chamber. A semianechoic chamber is a shielded room with RF absorbing material on the walls and ceiling. In order to simulate the OATS, the floor of the semianechoic chamber should be a conducting ground plane. Thus, waves are reflected from the ground plane of the semianechoic chamber just as they are in the OATS. The absorbing material on the walls of the semianechoic chamber allow the relatively small volume of the chamber to simulate the open space of the OATS. The semianechoic chamber has the advantage that the ambient signals are eliminated by the shielded room.

Open Area Test Site (OATS)

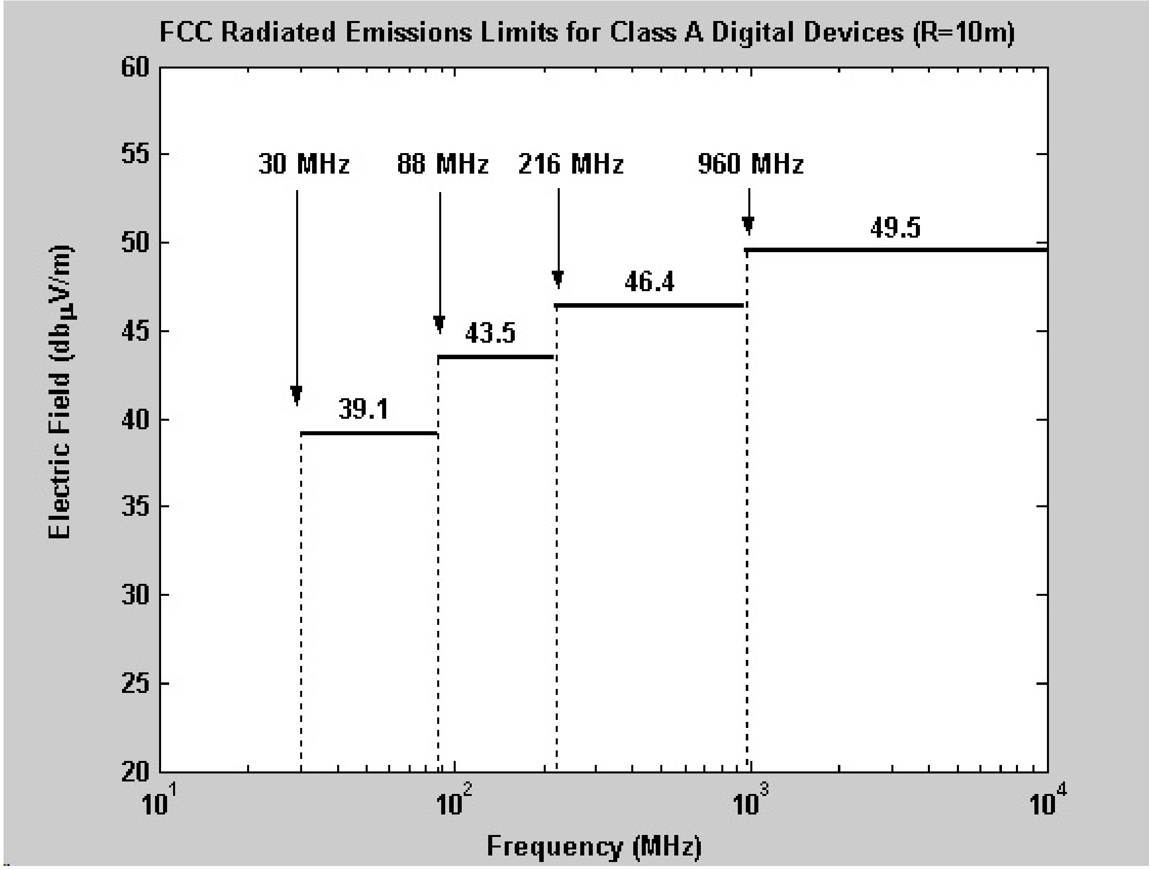




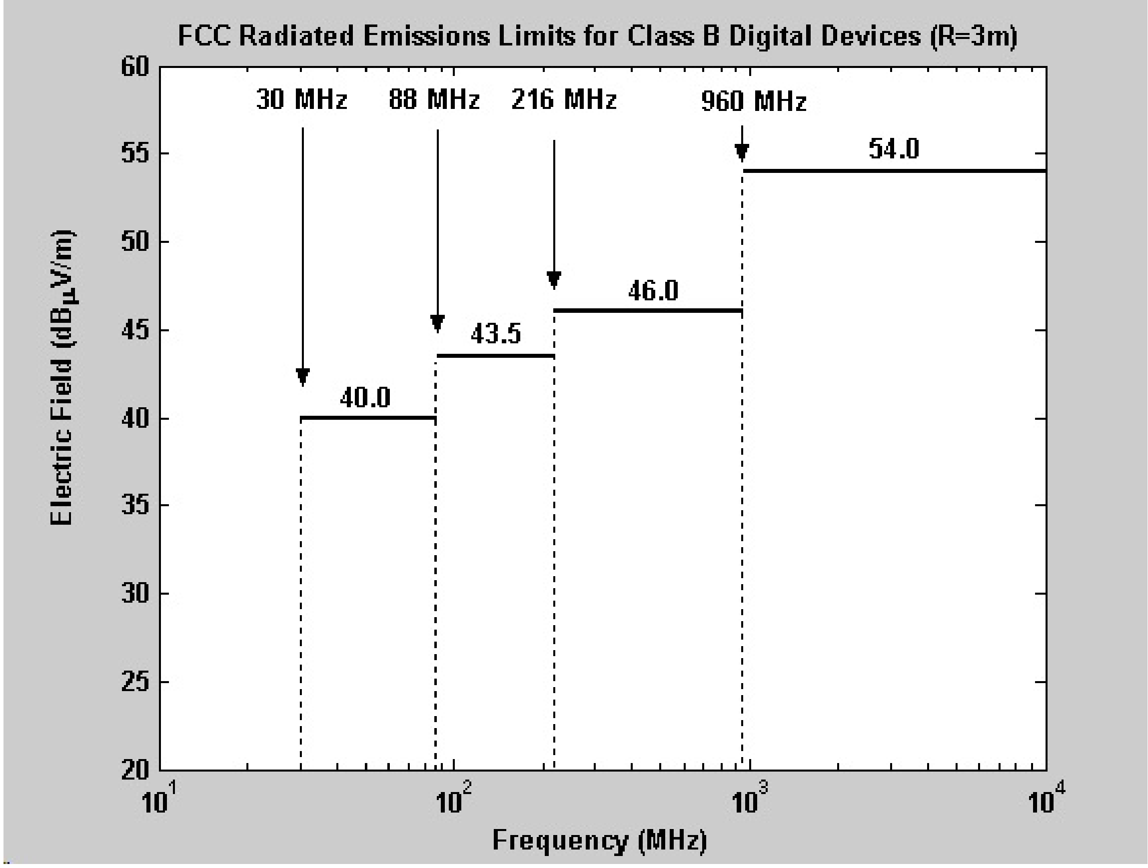
Unlike the FCC and CISPR conducted emissions limits (which are the same), the FCC and CISPR radiated emissions standards define different radiated emissions limits. There are also differences in the two standards with regard to the radiated emissions measurement setup. In particular, the two standards define different separation distances for Class A and Class B device measurements.

Standard	***R* (Class A)**	***R* (Class B)**
FCC Title 47 Part 15	10m	3m
CISPR 22	30m	10m

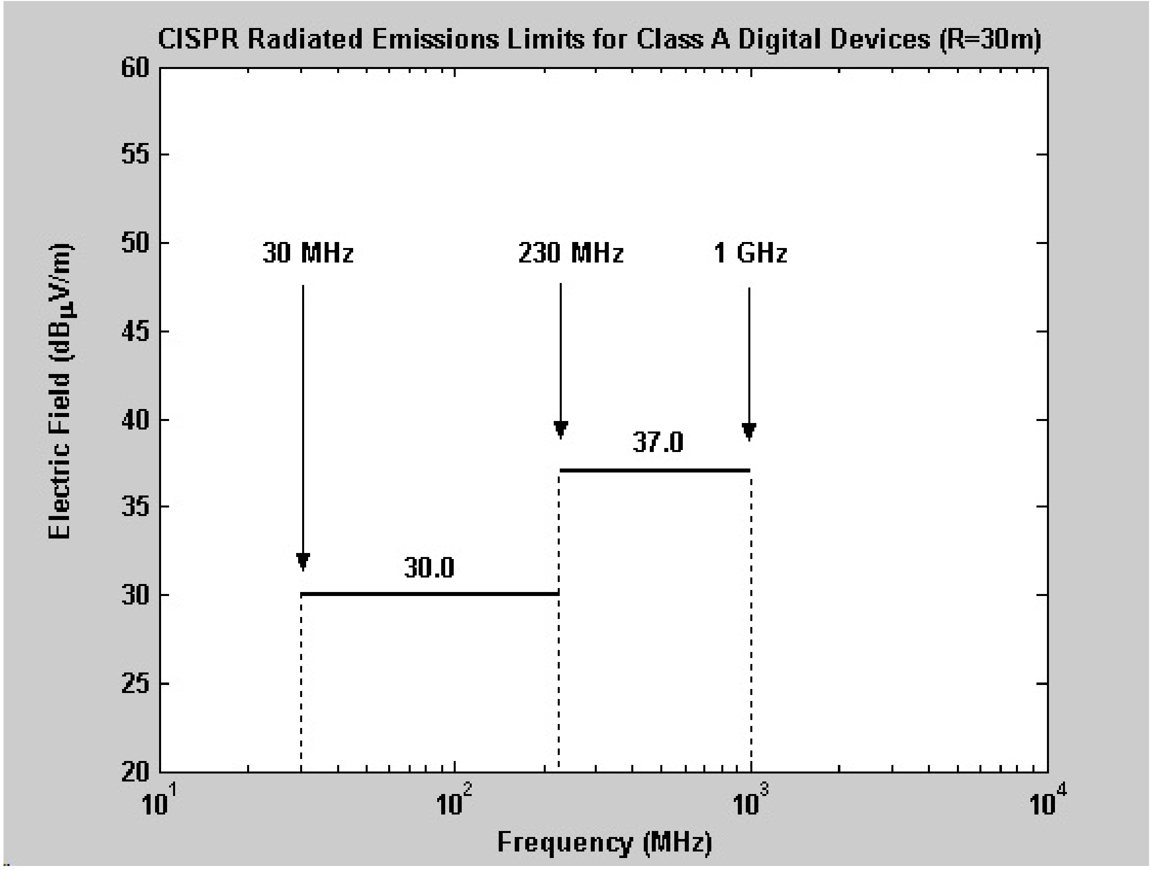
The differences in the separation distances between the DUT and the receiving antenna complicate the interpretation of the two standards.

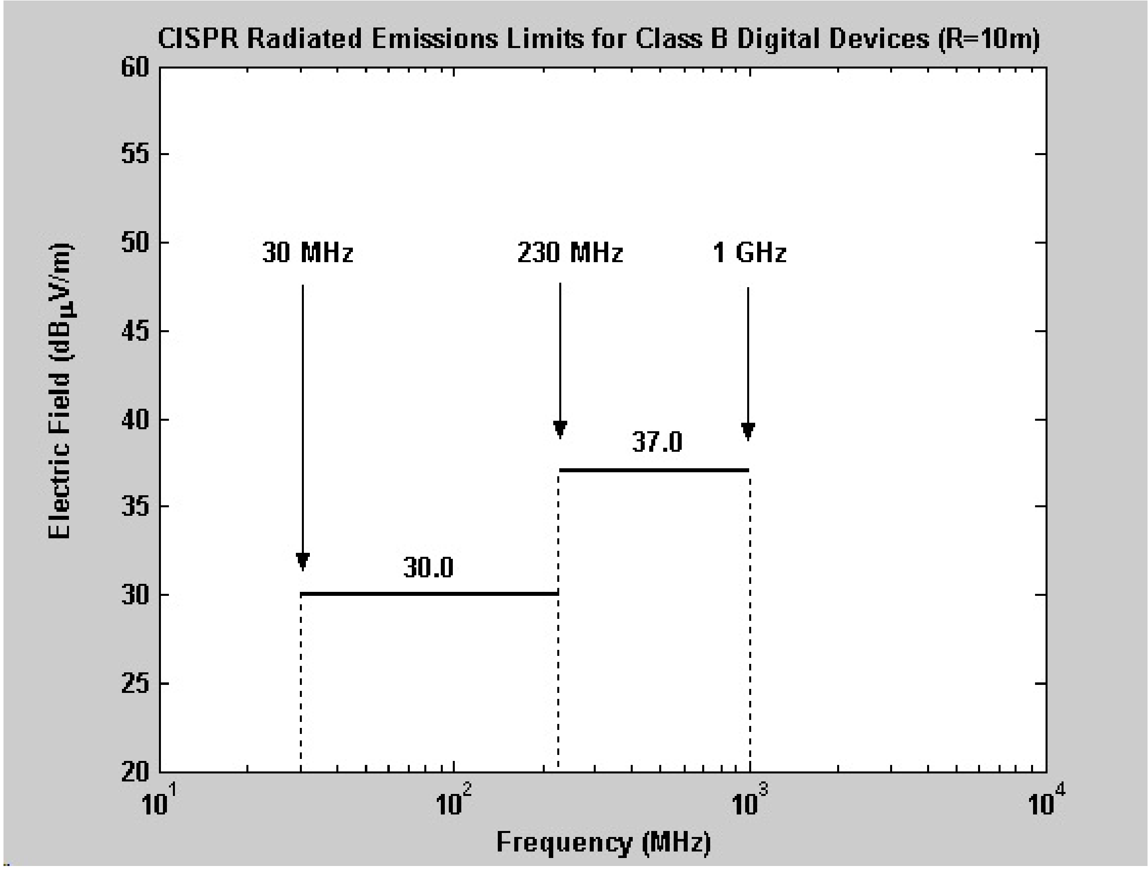


FCC Radiated Emissions Limits for Class A Digital Devices (R=10m)



FCC Radiated Emissions Limits for Class B Digital Devices (R=3m)


CISPR Radiated Emissions Limits for Class A Digital Devices (R=30m)
Electric Field (dBμV/m)
Frequency (MHz)
60
55
50
45
40
35
30
25
20
10^1
10^2
10^3
10^4
30 MHz
230 MHz
1 GHz
30.0
37.0


CISPR Radiated Emissions Limits for Class B Digital Devices (R=10m)
Electric Field (dBμV/m)
Frequency (MHz)
60
55
50
45
40
35
30
25
20
10^1
10^2
10^3
10^4
30 MHz
230 MHz
1 GHz
30.0
37.0

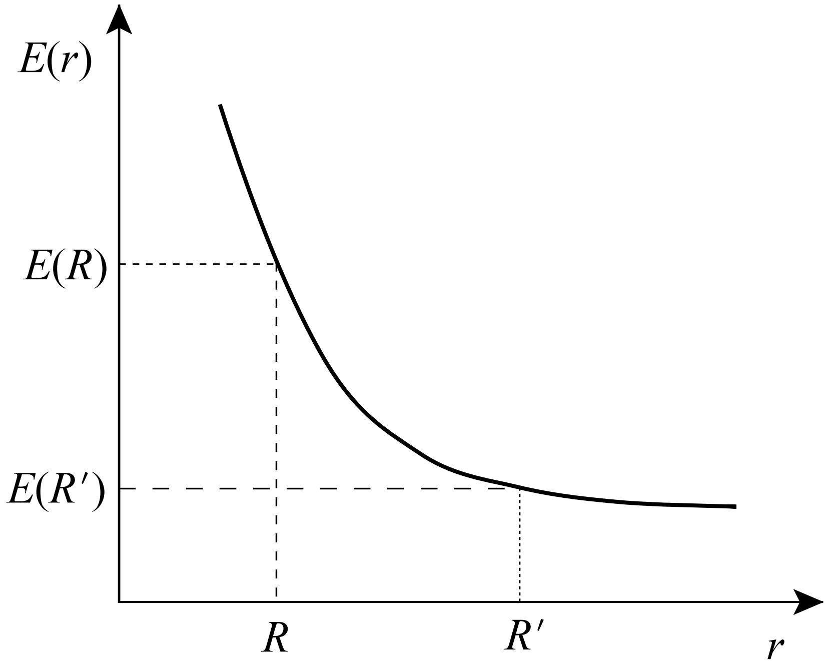
FCC Part 15 Radiated Emissions Limits

Frequency (MHz)	Class A (R = 10m)		Class B (R = 3m)	
	μV/m	dBμV/m	μV/m	dBμV/m
30-88	90	39.1	100	40.0
88-216	150	43.5	150	43.5
216-960	210	46.4	200	46.0
> 960	300	49.5	500	54.0

CISPR 22 Radiated Emissions Limits

Frequency (MHz)	Class A (R = 30m)		Class B (R = 10m)	
	μV/m	dBμV/m	μV/m	dBμV/m
30-230	31.6	30.0	31.6	30.0
230-1000	71.8	37.0	71.8	37.0

Inverse Distance Method - an approximate technique used to translate emissions levels (or emissions limits) from one value of R to another. The *far-field approximation*, which states that radiated far fields decay as $1/R$, is assumed in the inverse distance method.



$$\frac{E(R)}{E(R')} = \frac{1/R}{1/R'} = \frac{R'}{R} \qquad \Rightarrow \qquad E(R') = \frac{R}{R'}E(R)$$

Dividing both sides of this equation by any convenient reference value and taking 20 $\log_{10}(\ )$ of both sides gives

$$[E(R')]_{dB} = [E(R)]_{dB} + 20\log_{10}\left(\frac{R}{R'}\right)$$

Thus, emissions levels at a given separation distance can be translated to a different distance by simply adding the appropriate dB level to the original emission level. Note that the this additional dB term is positive if $R' < R$ and negative if $R' > R$.

Example (Translation of emission levels)

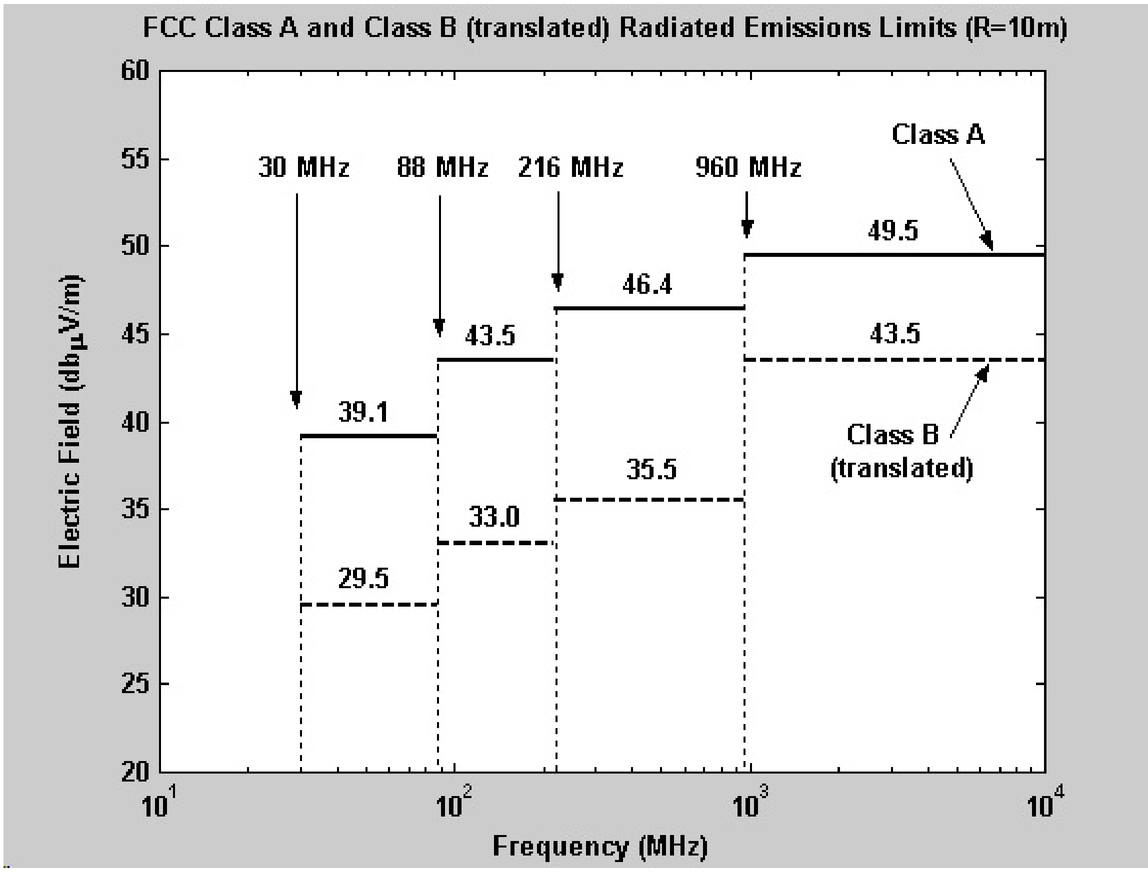
Use the inverse distance method to compare

- (a.) the FCC class A and B limits at $R = 10\text{m}$.
- (b.) the CISPR 22 class A and B limits at $R = 30\text{m}$.
- (c.) the FCC and CISPR 22 class A limits at $R = 30\text{m}$.
- (d.) the FCC and CISPR 22 class B limits at $R = 10\text{m}$.

(a.) Translate the FCC class B limits from $R = 3\text{m}$ to $R' = 10\text{m}$.

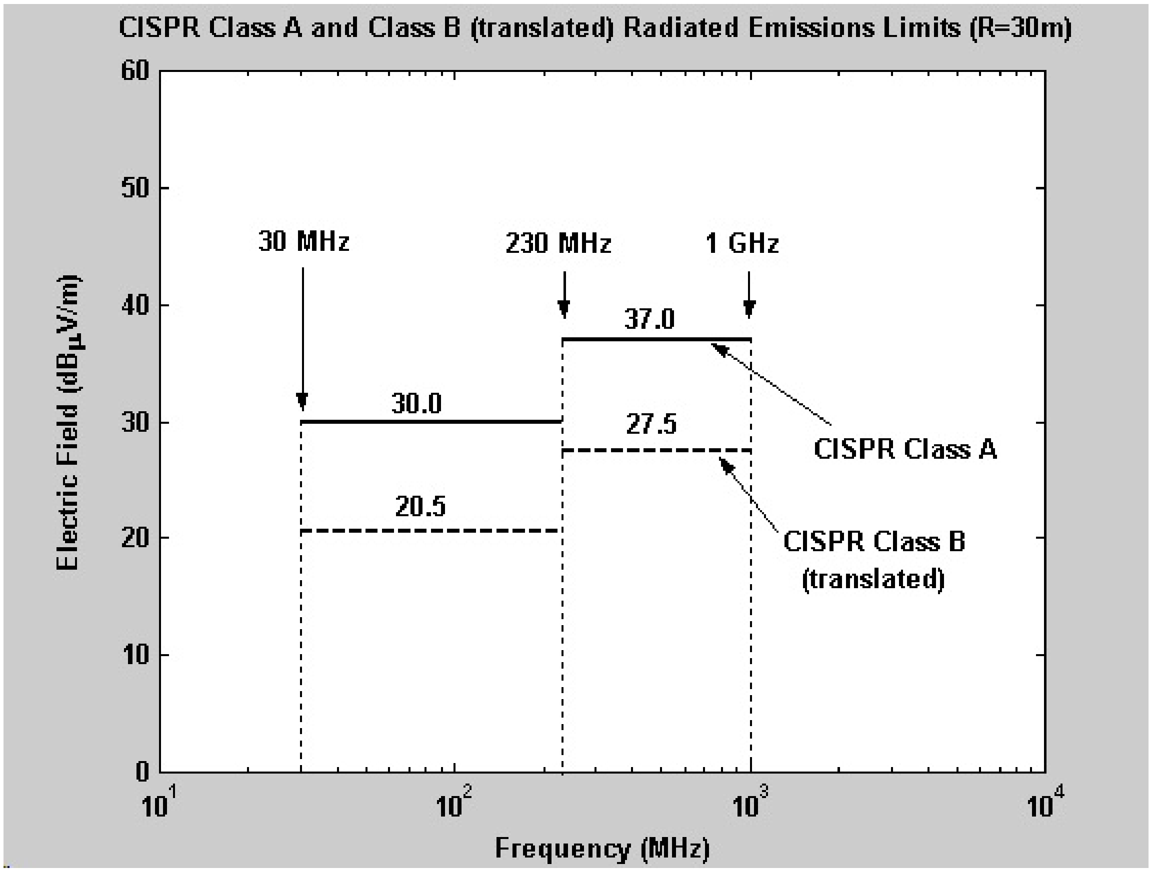
$$[E(10)]_{dB\mu V} = [E(3)]_{dB\mu V} + 20\log_{10}\left(\frac{3}{10}\right)$$

$$= [E(3)]_{dB\mu V} - 10.5\ \text{dB}$$

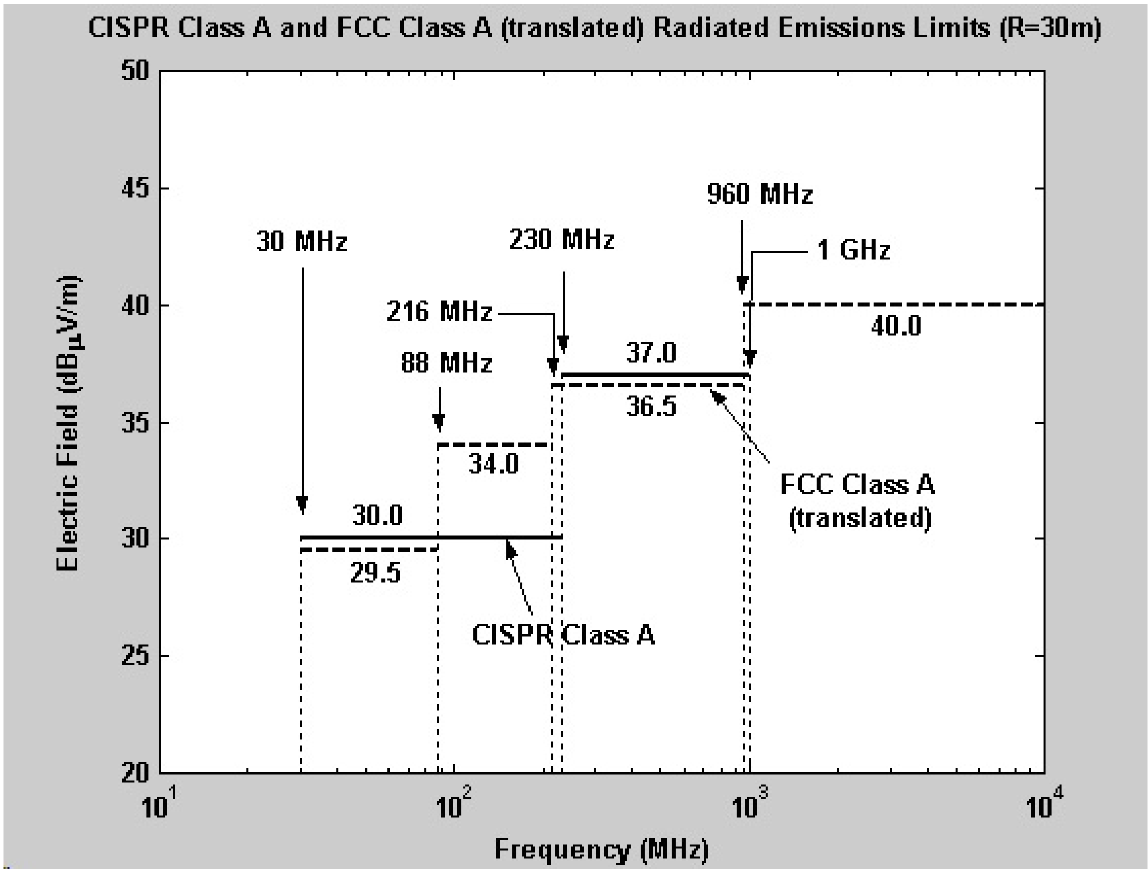


(b.) Translate the CISPR class B limits from $R = 10\text{m}$ to $R' = 30\text{m}$.

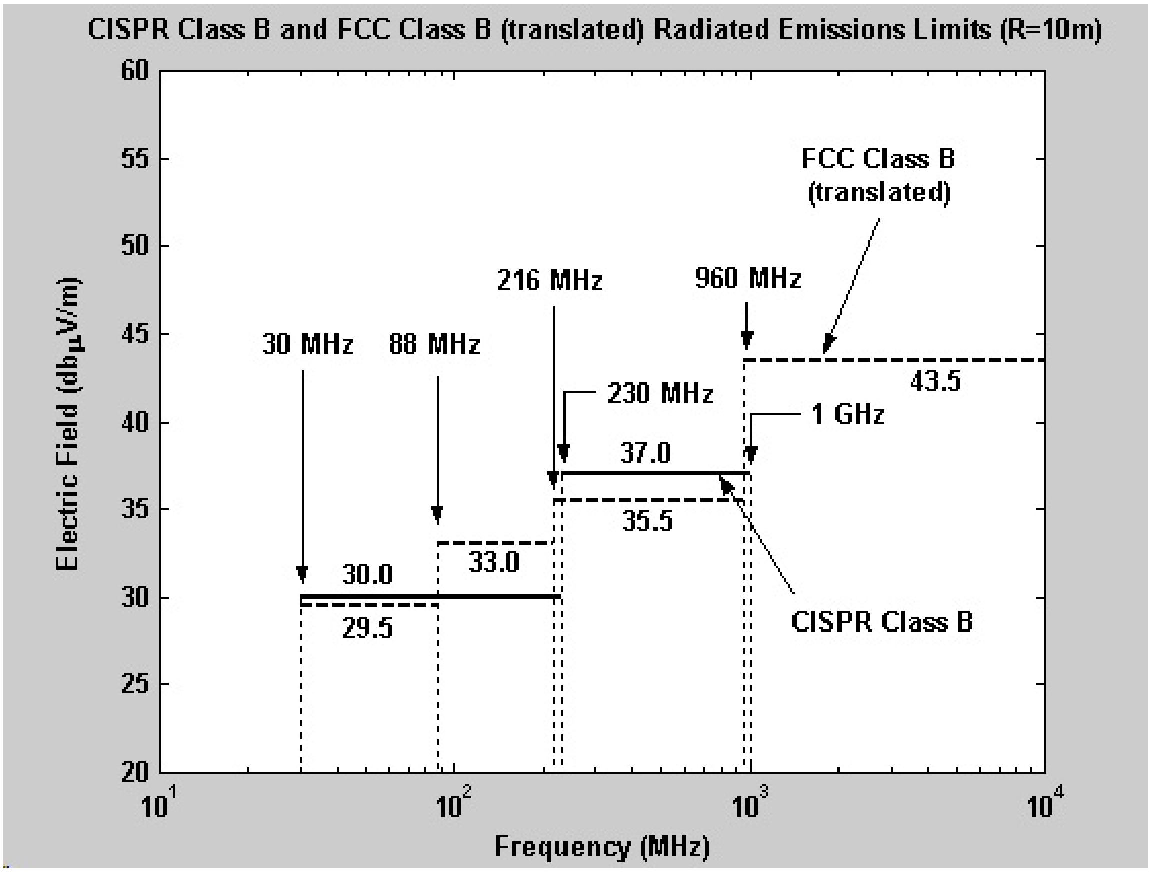
$$
\begin{aligned}
[E(30)]_{\text{dB}\mu\text{V}} &= [E(10)]_{\text{dB}\mu\text{V}} + 20\log_{10}\left(\frac{10}{30}\right) \\
&= [E(10)]_{\text{dB}\mu\text{V}} - 9.5\ \text{dB}
\end{aligned}
$$



(c.) Translate the FCC class A limits from R = 10m to R' = 30m (−9.5 dB).



(d.) Use part (a.) results for FCC class B limits translated to $R = 10\text{m}$.



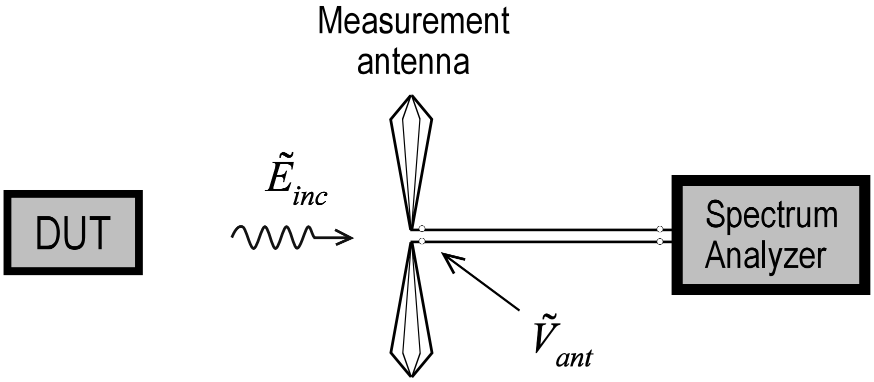
Antenna Factor

When the radiated emissions of a DUT are measured with an antenna (biconical, log-periodic, etc.), the electric field incident on the measurement antenna produces a voltage at the antenna terminals which is fed to a spectrum analyzer through a transmission line (coaxial cable). The ratio of the incident electric field at the antenna to the voltage received at the antenna terminals is defined as the *antenna factor* (*af*).

$$af = \frac{\tilde{E}_{inc}}{\tilde{V}_{ant}}$$

$\tilde{E}_{inc}$ – incident electric field magnitude at the antenna (V/m)

$\tilde{V}_{ant}$ – received voltage magnitude at the antenna terminals (V)



As a ratio of electic field to voltage, the antenna factor has units of m^{-1} and is normally expressed in units of dB. If the incident electric field is referenced to 1 μV/m while the received voltage is referenced to 1 μV, the antenna factor can be written as

$$af = \frac{\tilde{E}_{inc}/10^{-6}}{\tilde{V}_{ant}/10^{-6}}$$

Taking $20\log_{10}(\,)$ of both sides of the previous equation yields

$$20\log_{10} af = 20\log_{10}\left[\frac{\tilde{E}_{inc}/10^{-6}}{\tilde{V}_{ant}/10^{-6}}\right]$$

$$af_{dB} = 20\log_{10}\left[\frac{\tilde{E}_{inc}}{10^{-6}}\right] - 20\log_{10}\left[\frac{\tilde{V}_{ant}}{10^{-6}}\right]$$

$$= \tilde{E}_{inc,\mathrm{dB\mu V/m}} - \tilde{V}_{ant,\mathrm{dB\mu V}}$$

Expressing the received voltage in terms of the antenna factor gives

$$\tilde{V}_{ant,\mathrm{dB\mu V}} = \tilde{E}_{inc,\mathrm{dB\mu V/m}} - af_{dB}$$

The antenna factor is a function of frequency and must be known over the entire frequency range of interest. The biconical antenna and the log-periodic antenna (broadband antennas) have antenna factors which are relatively constant (non-resonant) over the frequency ranges where these antennas are used. However, the variation in the antenna factor is significant enough that the assumption of a constant antenna factor over the entire band is not valid.

For radiated emissions testing, the antenna factor can be used to determine the voltage level measured by the spectrum analyzer to the radiated field magnitude seen at the measurement antenna. Whether or not the DUT complies with the appropriate standard can be determined based on the magnitude of the radiated field at the measurement antenna.

Example (Radiated emissions testing)

A product is tested for FCC Class B radiated emissions compliance at f = 100 MHz where the distance between the DUT and the measurement antenna is 20 ft. The measurement antenna ($af = -16$ dB at 100 MHz) is connected to the spectrum analyzer by 30 ft. of RG-58U coaxial cable (attenuation = 4.5 dB/100 ft at 100 MHz). If the spectrum analyzer input voltage is 53 dBμV, determine (a.) the electric field magnitude at the measurement antenna (b.) if the product passes or fails the compliance test at 100 MHz and by how much.

(a.) The cable gain is given by

$$\text{Cable gain}_{\text{dB}}\,(\mathcal{L} = 30\text{ ft}) = \left(-\frac{4.5\text{ dB}}{100\text{ ft}}\right) \times 30\text{ ft} = -1.35\text{ dB}$$

The voltage at the transmission line input (measurement antenna) is related to the voltage at the transmission line output (spectrum analyzer) by

$$V_{out,\text{dB}\mu\text{V}} = V_{in,\text{dB}\mu\text{V}} + \text{Cable gain}_{\text{dB}}$$

$$53 = V_{ant,\text{dB}\mu\text{V}} - 1.35$$

$$V_{ant,\text{dB}\mu\text{V}} = 54.35\text{ dB}\mu\text{V} \quad (2.72\text{ V})$$

The antenna voltage is related to the incident field at the antenna by the antenna factor.

$$\tilde{V}_{ant,\text{dB}\mu\text{V}} = \tilde{E}_{inc,\text{dB}\mu\text{V/m}} - af_{dB}$$

$$\tilde{E}_{inc,\text{dB}\mu\text{V/m}} = \tilde{V}_{ant,\text{dB}\mu\text{V}} + af_{dB}$$

$$= 54.35 - 16 = 38.35\text{ dB}\mu\text{V/m}$$

(b.) The FCC class B radiated emissions standard (43.5 dBμV/m) at $R = 3$ m must be translated to $R' = 20$ ft.

$$R' = 20\ \text{ft} \times \frac{0.3048\ \text{m}}{1\ \text{ft}} = 6.096\ \text{m}$$

$$[E(R')]_{dB} = [E(R)]_{dB} + 20\log_{10}\left(\frac{R}{R'}\right)$$

$$= 43.5 + 20\log_{10}\left(\frac{3}{6.096}\right) = 37.34\ \text{dB}\mu\text{V/m}$$

Given the radiated emission of 38.35 dBμV/m and the radiated emissions limit of 37.34 dBμV/m, the product fails to comply with the standard (by 1.01 dB).