Impact of Radiated Emission Standards on Receiver Sensitivity and the Ambient Electromagnetic Noise Environment

by

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Abstract

This paper shows the impact of codified radiated emission standards like the United States Code of Federal Regulations (CFR) 47, Part 15¹ (commonly known as FCC Part 15, Class A, Class B, and FCC Part 18), and the European Community "Euronorm" EN55022², basic Radiated Emission Specifications, etc, on the ambient electromagnetic environment. Covered in this paper are the typical communication systems field strength signal sensitivity, and calculated distances at which devices meeting the different emission standards will have minimal or non-measurable impact on the sensitivity of a typical communications receiver. Finally, the paper presents an approach for approximating the impact of a group of subject devices on the ambient EM environment of a communication site. As a closing example, the estimated radiation limit for a hypothetical US household with both intentional and unintentional radiators is estimated.

Introduction

In the United States and in other nations concerned with electromagnetic compatibility between consumer devices and important communication facilities, all devices intended to be marketed for use in both consumer and commercial facilities must meet mandated electromagnetic radiation standards. To understand the impact of such standards, we must examine existing radiation standards in the United States, emerging radiation standards adapted by the European Community, then relate these standards to the sensitivity of an idealized communication receivers.

Radiation standards cover both the maximum allowable electric field measurable at specified distances and conducted emission than can be measured by sampling currents in power leads to covered devices. This paper only examines the effects of radiated electric field specifications.

United States Emission Standards

Radiated emission standards in the United States are codified in the Code of Federal Regulations #47, Parts 15 and 18. CFR Part 15, popularly known as FCC (Federal Communications Commission) Part 15, covers the allowable emissions of low power devices not requiring licenses for normal operation. Part 18 covers the emission limits for devices intended to be used in industrial, scientific, and medical (ISM) applications.

US CFR Part 15 Emission Limits

The CFR Part 15 low power devices can either be unintentional or intentional electromagnetic radiators. Unintentional electromagnetic radiators include common household appliances, radio receivers, microwave ovens, television receivers,

and personal computers. Intentional radiators not requiring licences include devices like garage door openers, microwave sensors, intrusion alarms, wireless telephones, personal communication devices, vehicular collision avoidance radars, and other low power transmitters. Manufacturers and marketeers of devices emitting electromagnetic energy can only legally market such "radio frequency" devices that are either certified or verified to meet FCC Part 15 provisions. Under the FCC regulations, operators of devices are only authorized to use them for as long as "the radio frequency devices do not cause harmful interference."

There are essentially two major radiated emission limit provisions of CFR Part 15. The first part is contained in "Subpart B" which is commonly referred to as FCC Class A and Class B radiated emission limits (Figure 1). Subpart B, "Class B" limits apply to all unintentional radiators not covered by legislated exceptions. This category includes personal computers, TV sets, and radio receivers intended to be marketed for use in residences. One of the significant "exception" to the Subpart B or Class B limit applies to digital computers intended for commercial applications. The limit for FCC Part 15, "Class A" devices is higher than class B devices and is shown as the upper curve in Figure 1. The emission limits for Class B devices were specified to be measured at a standard distance of 3 meters. Anecdotally, these levels were selected as levels low enough so as not to cause harmful interference to radio and television receivers located 3 meters away. This is a separation distance normally expected in two adjacent US residential rooms.

Figure 1. CFR 47 Part 15, Subpart B, Unintentional Radiators' Limits.

A less known provision of CFR Part 15 is covered in "Sub Part C, Intentional Radiators." Figure 2 shows the radiation limits extracted by the author from various provisions of Sub Part B. Note the "Generic" specification which is the normal emission limits of intentional radiators, or in some cases, the out-of-band limits of intentional radiators specifically exempted elsewhere. For example, a cordless telephone operating in the 46.61 to 49.97 MHz band is allowed to emit up to 10,000 $\mu\text{V}/\text{m}$ in its design transmitter frequency. The same cordless telephone is not authorized to exceed the Sub Part C "Generic" limits outside its transmitter operating frequency.

For the purposes of Part 15 verification or certification, the FCC recommends instrumentation to device under test (DUT) separation distances of 300 meters at frequencies from 9 kHz to 490 kHz, 30 meters from 500 kHz to 30 MHz, and 3 meters above 30 MHz.

Figure 2. CFR 47 Part 15, Subpart C, Intentional Radiators' Limits.

CFR Part 18 Industrial, Scientific, Medical Devices Radiation Limits

The radiated emission limits of industrial, scientific, and medical devices legally allowed to be marketed in the United States must meet the technical provisions of CFR Part 18, Sub Part C. Generally, these are devices which use radio frequency energy to accomplish their designed functions. The RF power and emission of these devices at their authorized operating frequencies (Table 1) is limited only by safety regulations. However, for the protection of other users of the radio frequency spectrum, out-of-band ISM radiated limits are as shown in Figure 3. In this figure, note that the specified measurement distances of 300 meters and 1600 meters imply that US ISM devices may be very noisy and still meet mandated limits. Also note that emissions of microwave ovens intended for use at homes are also covered by CFR Part 18.

In addition to the authorized ISM frequencies, ISM devices are also allowed to operate at frequencies above 9 kHz as long as the ISM devices do not exceed the limits in Figure 3 and do not operate in the safety, search and rescue prohibited bands.

Table 1. Authorized ISM Frequencies.

ISM Frequency (MHz)	Tolerance (+/-)
6.78	15 kHz
13.56	7 kHz
27.12	163 kHz
40.68	20 kHz
915	13 MHz
2450	50 MHz
5800	75 MHz
24,125	125 MHz
61,250	250 MHz
122,500	500 MHz
245,000	1 GHz.

Figure 3. CFR 47 Part 18, ISM Radiation Limits.

European Community Radiated Emission Limits

Basic Radiation Standard, EN 55022

The European Community have adopted radiation emission standards that are more stringent than those currently enforced by the US Federal Communications Commission^{2,6}. These standards are published as "Euronorms" and the basic standards is in publication EN 55022, "Basic Radiation Limits for Information Technology Equipment." Like the FCC Part 15 regulations, EN 55022 "Class A" devices are intended for the commercial-industrial market, and "Class B" devices are intended for residential use (Fig 4). All other EN radiated emission standards in the 30-1000 MHz range refer to EN 55022 as the base regulation. Slight modifications of the base regulations exist for

Figure 4. EN55022 Basic Device Radiation Limits.

applicability to impulsive noise on home appliances and other unintentional radiation devices. Currently, there is no EC common "basic" radiated standards below 30 MHz and above 1 GHz.

EN50081, ISM Radiation Limits

The radiated emission limits for industrial, scientific, and medical equipment intended to be legally marketed in the European Community after 1992 must comply with the provisions of EN50081 as shown in Figure 5. In addition to individual device emission limit applicability, EN 50081 also applies as "in-situ" radiation limit for facilities where ISM devices are in use. At such, the maximum radiated emissions are measured 30 meters from the walls of the facility.

Figure 5. EN50081 ISM Devices and Facilities Radiation Limits.

Impact of Device Radiated Emission Limits on Communication Receivers and the EM Environment

In order to satisfactorily assess the impact of existing device radiated emission standards on communication facilities and the electromagnetic environment, we must examine two quantities. First, we will need to examine the standards so we can estimate the maximum radiation of the devices at locations further than the recommended measurement distances. A suggested method is discussed in the Appendix and will allow us to translate the device emission limits. For example, the 30 MHz, 30 dBμV limit at 3 m for EN55022 Class A devices would become -20.46 dBμV/m at 1 km. If this value is less than the sensitivity of the communication receiver in use at such a distance, then the device would have insignificant effect to the performance of the receiver.

The second item to consider is the sensitivity of the communications receiver operating in the environment affected by the radiating devices. Figure 6 shows the calculated sensitivity of a communication system using a unity gain antenna in the presence of CCIR defined Quiet Rural Area³ ambient noise, and ambient noise in an "average quiet site⁴." In this figure, we can see that external noise from devices have more significant impact at lower frequencies than at higher frequencies. System sensitivity at frequencies below about 100 MHz is greatly affected by external, man-made noise. On the other hand, higher frequency performance is affected more by the noise figure of the receiver front end. The curves in this figure is defined by the following equation^{5,7}:

$$E(\text{dB}\mu\text{V/m}) = -96.67 + 10\log(B) - G_a(\text{dB}) \\ + 20\log(F_{\text{MHz}}) + S/N(\text{dB}) + 10\log(fa + Tr/T_0)$$

Figure 6. Idealized Receiver Sensitivity for Antenna Gain of One and Bandwidth of One Hz.

Knowing the receiver sensitivity limit and the device emission limit, we could then calculate distances at which individual devices will have insignificant impact to the operations of a receiver at a communications site. Table 2 shows distances vs frequency at which individual devices would be guaranteed to be 2 dB or more below the reception thresholds in a radio quiet site which meets CCIR Quiet Rural Area ambient conditions.

Table 2. Device Separation Distances

Standard	freq < 30 MHz	freq at or above 30 MHz
FCC Standards		
Part 18 RF Lights	0.7 km	0.7 km
Part 15 Class A	2.3 km	4.0 km
Part 15 Class B	0.7 km	0.7 km
Part 15, Subpart C	2.2 km	6.4 km
Part 18, High Power ISM	16.0 (LOS) km	16.0 (LOS) km
EN Standards		
EN 55022 Class A and ISM	0.5 km	0.8 km
EN 55022 Class B	0.3 km	0.4 km

In addition to the impact of individual devices, the paper also discusses the additive effects of electromagnetic radiation from many devices in a given geographic area. If the radiations from many devices are assumed to be noncoherent electromagnetic noise at frequencies other than the intended operating frequencies, then we can treat the radiation distant from the sources by calculating the sum of the powers from individual devices and converting this sum to the equivalent free space electric field. From the basic propagation equation in appendix, the equivalent electric field E' from i devices whose radiation limits E_i at distances d_i is known, can be calculated using the following equation:

$$E_t = \sqrt{\sum_i (E_i * d_i / d)^2}$$

As an exercise, the reader may verify that the emission limit at 1 km for a US house containing a computer, VCR, TV, AM Radio, microwave oven, garage door opener, a cordless telephone, a refrigerator, and an RF fluorescent lamp is approximately 4.6 μ V/m when all the devices are on. When the microwave oven, a low power "ISM" device is turned off, the radiated emission limit reduces to 0.85 μ V/m.

References:

1. US Code of Federal Regulations, Volume 47, Parts 15 and Parts 18.
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3. CCIR Report 258-3, "Man made Radio Noise." International Radio Consultative Committee (CCIR), ITU, Geneva, 1978.
4. Arafles, V. P. and Valdez, I. "Power Line Noise Effects and New Radio Noise Models." 1993 IEEE International EMC Symposium Records, pp 51, 52.
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6. Wall, A. L., "Recent and Potential Changes to the U.S. EMC Regulatory Requirements." 1994 IEEE International EMC Symposium Records, pp 11-18.
7. IEEE Std 473-1988, "IEEE Recommended Practice for an Electromagnetic Site Survey (10 kHz to 10 GHz)," pp 48-49.
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Appendix A

Calculation of $E_2(f)$ if $E_1(f)$ is Known

Given two observation points d_1 and d_2 meters from an isotropic radio frequency radiation source, the relationships between the electric field E_1 at d_1 and electric field E_2 at d_2 can be derived as follows:

1. The power density at distances d_1 and d_2 from an isotropic source can be calculated using the assumption that the RF energy will be distributed equally (isotropically) at the surfaces of spheres of radius d_1 and d_2 . From this assumption, if the source radiates $P_t(f)$ watts, then the power density d_1 meters away will be:

$$P_1(f) = \frac{P_t(f)}{4\pi d_1^2} \quad (1)$$

in watts/meter² and at distance d_2 meters, the power density will be

$$P_2(f) = \frac{P_t(f)}{4\pi d_2^2} \quad (2)$$

2. Note that the electric field at observation points d_1 and d_2 can also be expressed either in terms of P_n or P_t as follows:

$$P_1(f) = \frac{E_1^2(f)}{Z_w(f, d_1)} = \frac{P_t(f)}{4\pi d_1^2} \quad (3)$$

and

$$P_2(f) = \frac{E_2^2(f)}{Z_w(f, d_2)} = \frac{P_t(f)}{4\pi d_2^2} \quad (4)$$

3. Solving for E_1 and E_2 in terms of the wave impedance Z_w (f, d_1) and Z_w (f, d_2), radiated power P_t , and observation distances d_1, d_2 :

$$E_1(f) = \sqrt{\frac{Z_w(f, d_1) P_t(f)}{4\pi d_1^2}} \quad (5)$$

$$E_2(f) = \sqrt{\frac{Z_w(f, d_2) P_t(f)}{4\pi d_2^2}} \quad (6)$$

in volts/meter. If the $E_1(f)$ electric field and the distances d_1 and d_2 are known, (i.e. radiated electric field measured at distance d_1), then the electric field $E_2(f)$ at d_2 can be calculated by

(1) dividing Eq 6 by Equation 5 and then

(2) solving for $E_2(f)$ to obtain Equation 7 below.

Equation 7 is also valid for a non-isotropic source if the observation points are in the same angular bearing. Literature⁸ shows the definition of the wave impedance Z_w (f, d). Note that Z_w becomes Z_0 when d_n is large.

$$E_2(f) = E_1(f) \frac{d_1}{d_2} \sqrt{\frac{Z_w(f, d_2)}{Z_w(f, d_1)}} \quad (7)$$

$$Z_w(f, d_n) = 120\pi \frac{|\beta d_n^2 - 1 - j\beta d_n|}{|\beta d_n^2 - j\beta d_n|} \quad (8)$$

$$\beta = \frac{2\pi}{\lambda}$$