SHIELDING CONSIDERATIONS FOR CABLES AND INTERCONNECT SYSTEMS

Docket 20780 Defined

FCC Docket 20780, establishing radiation limits from various computing devices, has caused consternation and panic in some segments of the computer manufacturing industry. The FCC defines two classes of computing devices. Class A includes products designed for use in industrial environments. Class B refers to computing devices designed for home use. Both classes involve those devices which generate timing signals in excess of 10,000 cycles per second and use digital techniques. Regulations cover emissions up to 1000 MHz.

At frequencies between 10 kHz and 30 MHz for both Classes A and B, the FCC is concerned only with conducted emissions, i.e., power line emissions conducted from the computing device to the power source. This article will not treat emissions in this range, since the thrust of the article is shielding for radiated emissions.

Since Class B devices are intended for use in the home, the interference potential to radio communications is considered to be higher. Therefore, the radiations limits imposed by the FCC are more stringent. Radiation limits for both Classes A and B are as follows:

Frequency (F) (MHz)	Class A (Distance 30 meter) Field Strength (μV/M)	Class B (Distance 3 meter) Field Strength (μV/M)
30-88	30	100
88-216	50	150
216-1000	70	200

At first glance, the Class B requirements seem to be more liberal. With recalculation according to the assumption of far field, the following formula applies:

$$E_{30} = E_d \left(\frac{d}{30}\right)$$

which, in turn, gives rise to the following when both are to be measured at 30 meters:

Frequency (F) (MHz)	Class A Field Strength (μV/M)	Class B
30-88	30	10
88-216	50	15
216-1000	70	20

Digital systems operating in frequency range of 30 to 1000 MHz radiate emissions that are known to be effectively damped by metal or metal-coated cabinets. However, most design engineers neglect the potential radiation from cables and cable assemblies in the early design stages. The FCC regulation requires computing devices to be tested as complete systems, including cables and cable assemblies.

Cable Emissions

Cable transmit signals that are mostly TTL type levels (0 to +5V), but occasionally transmit open collector signals, higher level bi-level signals (±15V), or signals as great as ±30 Volts. Therefore, cable assemblies should be designed to attenuate signals as great as ±30 Volts to lower than Class A or B requirements, as the use requires. Since at the test distance of 3M (30M for Class A) the radiation appears as far field radiation (varies as 1/r), the more complex case of near field $1/r^2$ or $1/r^3$ variations can be ignored.

In order to design shielding for cables and cable assemblies, an investigation of radiated field relations is necessary.

For electric field intensity, E = volt/meter.

For magnetic field intensity, H = Amperes/meter.

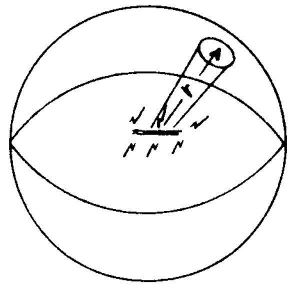
The characteristic impedance of free space is

$$Z_O \text{ ohms/square} = 120\pi R = \frac{E}{H}$$

Power density is defined as follows:

$$P_d \left(\frac{W}{M^2}\right) = E \times H \quad (1)$$
$$= \frac{E^2}{Z_O}$$

Since measurements are made at a distance of 3 or 30 meters, the inverse distance law of power radiation governs the electric fields at a distance from a radiator (cable).



Power Density

$$P_d = \frac{P}{4\pi r^2}\left(\frac{W}{M^2}\right)$$

$$E = \frac{\sqrt{30P}}{r}\left(\frac{V}{M}\right)$$

Figure 1. Spreading of Field Radiated from Cable

In order to better gauge the required cable shield attenuation, compute to the Class A 30 meter distance. For example, where E = 10 V/M at r = 30 meters, the radiated power is

$$P_R = \frac{E^2}{120\pi} \times 4\pi r^2 = 3 \times 10^{-9} \text{ watts.}$$

This is the radiation limit for Class B devices for 30-88 MHz.

If we assume a condition in which a 30-foot cable made of 25 #22 Awg 7 strand wires is transmitting a ±15 volt signal, then the power consumption in the cable may easily be calculated from ohms law E = IR.

$$E = 30 \text{ volts}$$

$$R = (14.74 \text{ Ohms}/1000') \frac{30 \text{ ft.}}{1000 \text{ ft.}} = 0.44 \text{ Ohms.}$$

The total voltage drop in the cable, assuming each wire is subject to an average of 3 TTL unit loads of 16 ma each or a total of 48 ma per leg, is given by

$$\text{Voltage drop} = .048 \text{ Amp} \times .44 \text{ ohms} = 0.021 \text{ volts.}$$

Therefore, the power consumption for each line is P_S = 0.021 V × .048 Amps = .001 watts. For the total 25 lines, the power consumed in the cable is .025 watts. The maximum out of spec condition is

$$P_S = \frac{25 \times 10^{-3}}{3 \times 10^{-9}} = 83.33 \times 10^5.$$

Radiation of less than one part in 10^5 of the energy consumed in the cable would cause an out-of-spec condition.

For convenience in calculating shielding efficiency, the ratio unit of dB is used. For conditions where field intensity is measured in μV/M, the ratio of voltage is:

$$N(dB) = 20 \log \frac{V1}{V2}.$$

For example, if V_1 = 1 volt and V_2 = 1 microvolt, then

$$N(dB) = 20 \log \frac{1}{10\text{-}6} = 20(6) = 120dB.$$

As more commonly stated, V_1 is 120dB above V_2. Figure 2 compares radiated power, voltage ratio and field intensity, illustrating the actual radiations from isotropic radiator.

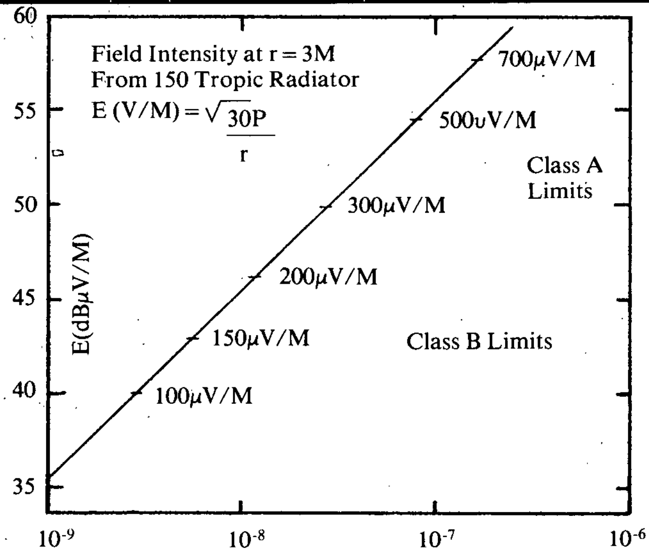


Figure 2. Radiated Power, P(W)

To meet FCC specifications, cable assemblies must be shielded to ensure emissions are 10dB less than the maximum level permitted, allowing a margin for possible leakage from the electronic chassis. A radiation level of .025 watts represents 109db/μV/M at 3 meters, or a field intensity of 0.289 V/M. For Class B devices, the cable assembly shielding must provide shielding effectiveness of 73 to 79dB. For Class A, the shielding effectiveness must be 62 to 69dB. The table below presents the FCC requirements in dB/μV/M at 3 meters.

Frequency MHz	Class A limits	Class B limits
30-88	49.5	40.0
88-216	54.0	43.5
216-1000	56.9	46.0

Shielding Solutions

Simply defined, a shield is a conductive envelope placed around a conductor or group of conductors which provides an electromagnetic barrier between enclosed wires and external fields. Shields have two primary purposes: shielding the signal from external excitation, and confining a signal to its intended electrical path. It is that second purpose to which we will devote attention.

A shield's effectiveness is measured by the degree to which electromagnetic energy is attenuated when passing through. The effectiveness is the summation of the shield's reflection, absorption, and multiple boundary losses.

Various conductive and semiconductive materials are used as electromagnetic shields. The U.S. Army Electronics Command, under their requirements SCL-1476, have tested types of shield materials. The relative shielding effectiveness was measured using cylindrical testers to obtain an absolute measurement of shielding effectiveness. In the following table, 0 = perfect shielding and 1 = no shielding (1000×10^{-3}).

Shield Description	Relative Shield Effectiveness @ 5 MHz
Braid, 36 AWG tinned copper, 50% coverage	2.9×10^{-3}
Braid, 36 AWG tinned copper, 75% coverage	1.06×10^{-3}
Braid, 36 AWG tinned copper, 85% coverage	$.850 \times 10^{-3}$
Braid, 36 AWG tinned copper, 95% coverage	$.636 \times 10^{-3}$
Served Shield, 36 AWG tinned copper, 100%	7.56×10^{-3}
Flat wire braid, 0.002″ thick, 48% overage	11.9×10^{-3}
Semiconductive thermoplastic	no apparent shield
Aluminum/Mylar/Aluminum tape, 50% overlap	5.2×10^{-3}
¼″ Alcoa aluminum foil, 0.005″ thick	24.0×10^{-3}
Impregnated semiconductive cloth tape	353×10^{-3}
Semiconductive block cloth tape	900×10^{-3}
Semiconductive yarn, 40-denier	350×10^{-3}

It would seem from the preceding chart, for Class A, a single braid shield over aluminum foil is sufficient. However, other shields are necessary for Class B devices (i.e., a double braid shield).

While it is a relatively simple matter to specify an effective shield for a cable, the shielding of a cable assembly may well be a different matter. To be effective, a cable shield must continue uninterrupted to the chassis on both ends of the cable assembly. If the shield is terminated by a pigtail instead of a 360° extension of the shield, then the inductance of the pigtail could become resonant with the impedance of the shield, relative to the chassis ground to which it is connected. When this resonance occurs, nearly the entire interference source voltage appears across the shield, resulting in a complete loss of shielding effectiveness.

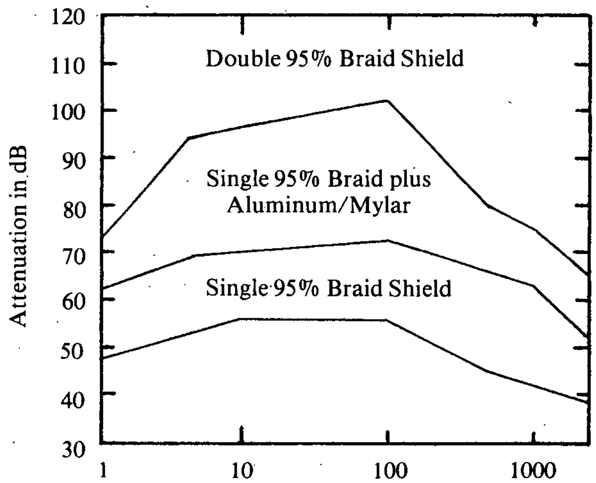


Figure 3. Frequency in MHz Cable Shielding Effectiveness

The most effective shield extension method is to bond a heavy metal (copper or nickel or aluminum) hood from the cable shield to the equipment chassis. However, this type of shielding is both difficult and superfluous, since a 1/8″ copper shield would be effective for the required frequencies in excess of 120 dB.

A good choice of shielding technique is the RS232-type assembly with a 25-position, D-subminiature connector, since many computer applications use this method. There are presently many metal hoods on the market; most of these commercial metal hoods are not completely closed and have radiation leaks. These leaks can reduce high frequency shielding effectiveness to the point where the system becomes connector-limited. A simpler and more effective technique uses a 1-3 mil copper foil shield wrapped around and soldered to the connector and cable shield. This technique has a shielding effectiveness of 70-90 dB at frequencies from 30-100 MHz only if good electrical contact is made 360° around the shield and the connector shield, as well as at all seams. Since this connector, when attached, has 360° shielding to the chassis, shielding effectiveness becomes limited only by the cable shielding itself.

In summary, then, a double braid shield, when matched with a copper foil hood, will provide the necessary 73-79dB shielding for Class B devices. For Class A devices, a single braid plus an Aluminum/Mylar Shield (when matched with a copper foil hood) will provide the necessary 62-69dB shielding.

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