Tools Of The Trade

EMC Design Checklist

Signal Termination
- RC Terminations (33 ohms + 27 pF) on periodic signals
- Group high frequency sources together; minimize trace runs of high frequency signals
- Do not source/sink I/O (whether internal or external) through high frequency devices
- Position oscillators and crystals away from I/O and openings in the chassis
- Snub switching power supply waveforms to minimize high frequency energy

Decoupling & Power Distribution
- Connect all ground pins of high frequency circuits together
- Maintain 0V reference (bond 0V to chassis)
- Solid power and ground planes
- Do not insert impedances into Vcc/power traces

Bonding Checklist
- Bond 0V to chassis ground
- Bond 0V to connector frames and shells
- Bond connector frames to chassis
- Bond metal frames together

Filtering
- Filters are installed at enclosure walls
- LC filter on unshielded cables
- Plan for capacitor on shielded lines

Cabling
- Route cables to avoid coupling
- Use only fully-shielded cables
- Fully terminate shield grounds to metal/metalized connector shells
- Terminate shells to chassis

Shielding
- The Business Card Test

Suppressors
- Use correctly rated suppressor line-to-line and line-to-ground
- Gas Tubes
- Varistors
- SAD (Silicon Avalanche Diodes)

Tools Of The Trade 2

In response to regular requests for information from our customers on the fundamentals of EMC and safety compliance, we have assembled a series of informational brochures. These brochures are intended to aid design engineering professionals with the basics in many areas; from design features to international compliance to terminology, we intend to cover them all. To receive other brochures in the series or for more information give us a call at 1-800-839-1649.

Dealing with EMI/RFI

The 10 Basic Steps to Successful EMC Design

Part Two: Steps Six to Ten

Most designers can improve the EMC performance of their products by observing relatively uncomplicated design guidelines. Part 1 in this series covered Steps 1 to 5 for successful EMC designs: 0V noise return, proper shield grounding, signal terminations, layout essentials and power distribution. In this offering we conclude our discussion of the critical design issues for EMC with a look at filtering, filter installation, sealing the enclosure, analog circuits, and switched-mode power supplies.

VI. Filtering

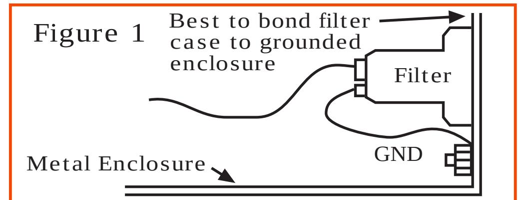
Do not allow a conductor to exit or enter an enclosure or system without doing something to it; either shield it or filter it. You should shield or filter the conductor.

In the first of this series, we discussed the effective use of shielded cables. If filtering is in order, use the right filter. All filter elements—inductors, ferrites, and capacitors—have an inherent frequency response. Judicious combinations of inductance and capacitance provide wideband filtering.

For most systems, use the filter that works up to at least 500 MHz response and up to 1,000 MHz is even better. The filter should not resonate or become useless at too low a frequency. This means that leads are kept short, and filter elements are placed at the entry/exit point of any enclosure.

VII. Filter Installation

Figure 1



Install the filter ground connections with short leads to the enclosure (Figure 1). Better yet, bond the filter case or ground connection directly to the enclosure. Installing a filter with long leads is akin to not putting in a filter at all.

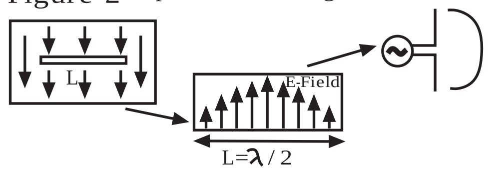
Make sure that any ground connections which usually impact the filter capacitors are referenced to the 0V reference to return noise currents to their source. This is as critical as the proper use of the 0V return to the performance of cable shields.

VIII. Sealing the Enclosure

The overriding concern with enclosures is maintaining the integrity of the box. The perfect electronics enclosure is a six-sided metal box with no openings. In a so-called perfect enclosure, all the seams seal shut perfectly.

Problems start when openings are created to install items like buttons, displays, and access panels. Leakage occurs when the openings become a significant portion of a wavelength. When this happens, the energy passes through essentially uninterrupted.

Figure 2 Aperature Leakage Model



To comprehend the effect of leaky enclosures, you must understand the concept of electrical length and resonance. Figure 2 shows a crack or aperture of length L in an otherwise perfectly sealed enclosure. This aperture might be for an access panel, an opening for a display panel or the mating seams from the assembly of the device.

Noise currents flow along the metallic skin of the enclosure. These currents can be caused by internal signal harmonics or an external interference coupling onto the enclosure wall. At low frequencies, the currents flow around the aperture and the opening has no great effect because the currents remain essentially undisturbed. As the frequency increases the opening tends to interrupt the currents more significantly.

The opening starts to impede the flow of the current. As a result, AC voltage builds up across the aperture. As the frequency increases, the length of the aperture becomes a significant portion of a wavelength. This occurs when the length, L, approaches a half-wavelength (L = l/2). At this frequency, the aperture is said to resonate and the energy propagates through the slot.

Table 1

Frequency (MHz)	$\lambda/2$ (cm)	Design Goal (cm)($\lambda/10$)
1	15,000	3,000
10	1,500	300
100	150	30
1,000	15	3
10,000	1.5	0.3

Table 1 shows the relationship between half-wave resonance and frequency. The formula is based on the relationship of wavelength, frequency, and the speed of light:

$$\lambda = c/f = 3 \times 10^8 \text{ m/fHz}$$

The first column in Table 1 is the highest frequency of interest. This is not the highest clock generated by the circuitry. Rather, this represents the highest frequency due to harmonics of the clock or other internal signals. For state-of-the-art systems clocking at up to 500 MHz, for example, a reasonable frequency is 2000 MHz.

The third column states our design goal, which is one-tenth of a wavelength. At 1 GHz, one tenth of a wavelength is 3cm, a little larger than 1 inch. Consequently, no gap, aperture, crack, or slit should be greater than 3cm in length. And it does not matter how skinny the crack is—a hairline crack will leak very nicely.

Here's a good rule of thumb: If a business card can be inserted into any opening of the enclosure, then the potential for leakage exists from that opening. This rule is good to about 1GHz. If your system uses clock speeds in the hundreds of megahertz, then the maximum size opening must be reduced.

As a final word on shielding and related uses, pay attention to the metal parts in a system. These are the frames, brackets, and other metal assemblies that make up the bones and skeleton of the system. Particularly for systems made up of separate subassemblies and modules, make sure that low-impedance bonding is present between the various elements. If not, RF currents often may flow between these parts.

If the metal parts are not bonded together, these currents generate voltages that, at high frequencies, may create radiating electric fields. To bond metal parts, wide braided or strap-like jumpers may be used, or the mechanical design should reduce the impedance between attached parts. These parts must have metal-to-metal conducting contact to affect a low impedance.

IX. Dealing with Analog Circuits

The implementation of the European EMC Directive has highlighted a relatively unexplored area of circuit sensitivity: analog response to RF energy. This phenomenon actually is one of the oldest EMI effects, with its roots in the earliest days of radio and electronics.

The effect is caused by the out-of-band response of circuits to RF energy. Because every circuit contains parasitic elements which create frequency windows where energy can enter circuits and affect the circuit operation. The mechanism is similar to a diode detector in an AM radio.

The RF, when incident on a p-n junction, is rectified. The resulting modulation from the RF carrier is, in effect, an in-band signal to the circuit.

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This in-band signal becomes an issue as the EMC Directive mandates conformance with radiated and, in some cases, conducted immunity requirements. The test consists of injecting RF energy into UUTs.

In the latest standards, the RF signal with frequencies of 150 kHz to 80 MHz is modulated with a 1-kHz AM at a depth of 80%. This very wide frequency range opens the parasitic frequency windows, if they exist, and creates errors in circuits.

Figure 3 Low Pass Filter

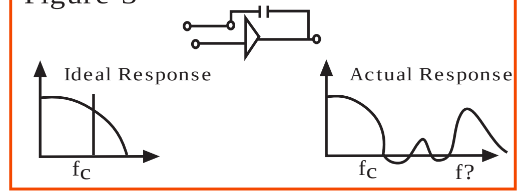


Figure 3 shows an active low-pass filter and its ideal and actual response curves. Parasitic reactance in the circuit creates out-of-band responses and frequency windows where energy can enter the circuit.

Because analog circuits have high sensitivity and typically use p-n junction components, they create an ideal way for RF to be rectified and demodulated, resulting in added noise.

To combat this effect, it is necessary to provide low-pass filtering on input lines. The most useful of the low-pass topologies is a combination of a ferrite bead and capacitor. Fortunately, this circuit also is useful for suppressing emissions.

Another approach to reducing the response of the circuits to RF is to desensitize them. For example, in many temperature measurement circuits, there is a diode for compensation purposes. The p-n junction of the component is susceptible to RF. A simple bypass capacitor placed across this junction is often enough to reduce the sensitivity of the circuit to the external RF.

X. Switch-Mode Power Supplies

One of the more problematic areas in EMC system design is switching power supplies. The focus of this discussion is on emissions from switching power supplies.

The easiest way to deal with switching emissions is to make them someone else's problem; in other words, make compliance a part of the procurement specification. If this option is available, then the power supply must be compliant in a stand-alone configuration, fully loaded and with nominal-length DC leads attached. For good measure, a margin of 6 dB should be specified.

If you are responsible for the design, then the problem becomes a little tougher, but not unmanageable. Properly done, emissions can be contained and controlled without extraordinary means.

The primary noise culprit is the FET switch. For maximum efficiency, FETs are designed to switch as quickly as possible. The voltage on the switch may be as high as 700 V. Transitions may create dV/dT on the order of 1 GV/s.

Two principal high-frequency noise sources are present in switching power supplies: harmonics of the switching frequency and broadband noise created by under-damped oscillations in the switching circuit. These sources may combine to create energy up to 150 MHz or higher. For a system switching at a 50 kHz base frequency, this means that the 3,000th harmonic of the base frequency may be radiating.

Figure 4 Underdamped (Ringing) Waveform
• Typical in switching units

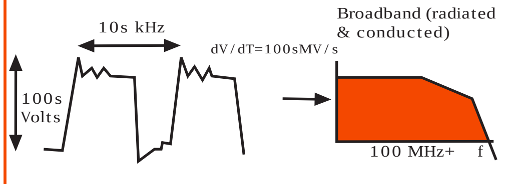


Figure 4 is the output voltage of a switching FET. Note the ringing of the signal. The under-damped oscillatory waveform creates an extremely broadband noise signal, which usually cannot be discriminated easily into any set of discrete signals.

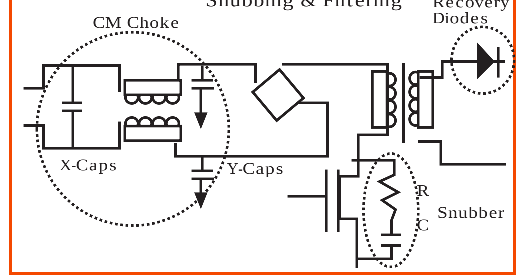
To manage this problem, it is possible to snub the switching waveform with a series RC network. This is installed across the output of the FET. The combination of these components tends to increase the damping on the system, reducing the instability in the circuit significantly.

This problem also afflicts systems using IGBT switching components, such as inverters and motor drivers. The IGBTs are favored for their fast response and high-power handling capability, which cause noise problems. The same snubbing remedy is suggested.

Another necessary ingredient in a switching power supply is the installation of an AC power-line input filter. A combination of common-mode and differential-mode elements is normally needed in a successful filter design.

The trick with power-line filtering lies in fine tuning the filter elements for the job at hand. This is made difficult by the unknown and widely varying impedance associated with power circuits. The combination of these design elements are shown in figure 5.

Figure 5 Switching Power Supplies
• Remedies:
Snubbing & Filtering



Other items to consider include the upcoming implementation of the harmonic current requirements spelled out in IEC 1000-3-2/EN61000-3-2. These specifications stipulate a maximum level of harmonic current (up to 2 kHz) that systems can draw from the AC line. Harmonic current filtering may require large inductors and capacitors that must be accounted for in the housing/enclosure for the system.

For More Information

For detailed information on Steps 1 to 5 of the 10 Basic Steps to Successful EMC Design, see Part 1 of this article, the first Tools of the Trade brochure, *Running the EMC Gauntlet*.

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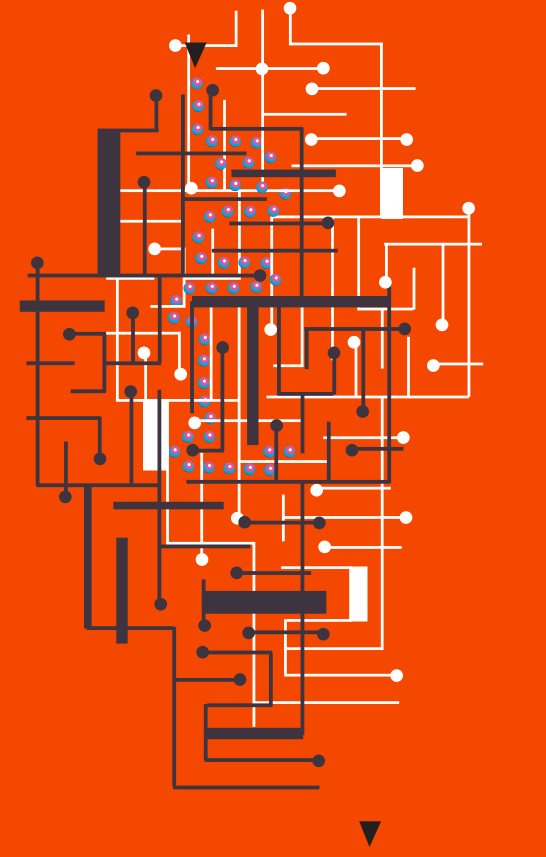

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Tools Of The Trade II