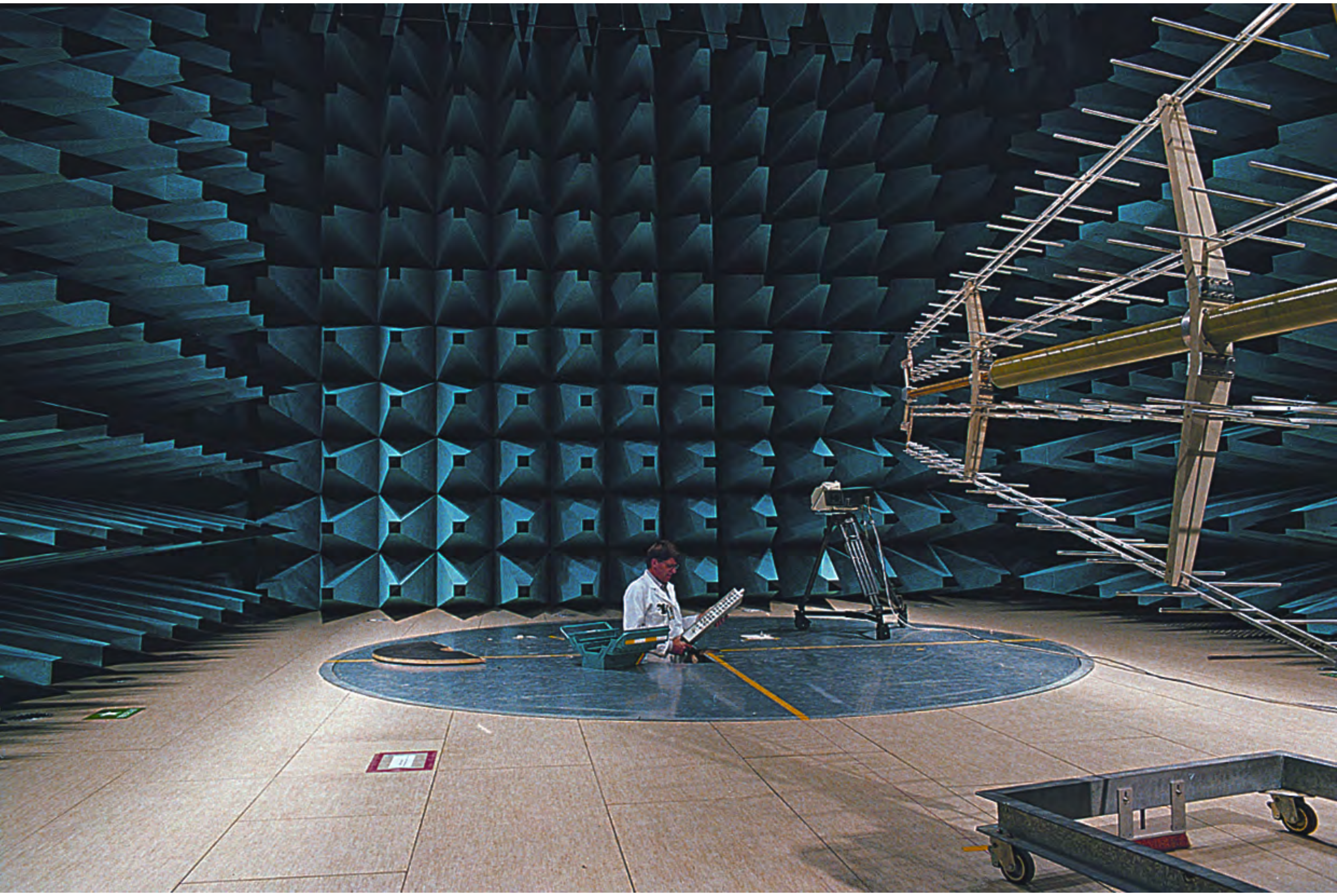
Why 50% of Products Fail EMC Testing the First Time



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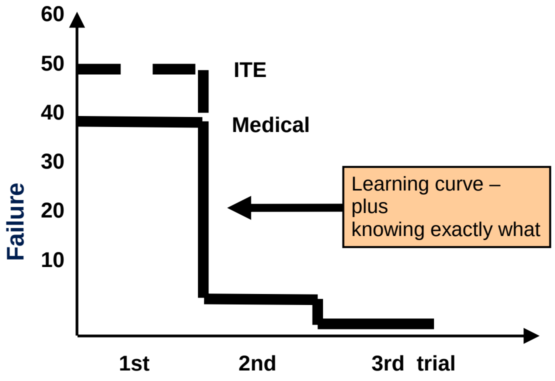
Summary

A large percentage of electronic products fail to meet their target EMC requirements the first time they are tested. In this article we look at some of the possible reasons for that failure rate, and what designers and manufacturers can do to improve the success rate and therefore time to market.

Why do 50% fail?

During the last several years, we have observed that initial EMC test failure rates for electronic products have decreased gradually. Improved success may be the result of growing awareness of EMC design considerations, use of EMC software, reduced circuit dimensions or all of these factors. Nevertheless, we continue to see EMC test failure rates around 50%.

Looking more deeply into the numbers, we note that, for example, medical products are slightly more successful (~40% initial failure) at meeting their EMC objectives than information technology equipment (ITE). One might expect otherwise from the added performance constraints of the medical EMC standard IEC 60601-1-2 over the ITE standards CISPR 22 and 24, but two factors may work in favor of medical products. They are often designed more conservatively and with more review than ITE, and the IEC 60601-1-2 standard it self allows justified derogations from the limits. But overall, the same basic EMC considerations apply to both medical and ITE.



Fortunately, the EMC learning curve for products that fail initially is quite steep. Presumably taking advantage of both the EMC education provided by the first go-around, as well as the pinpointing of EMC problems, manufacturers reduce the failure rate on the EMC re-testing to the level of 5% - 7%. Very challenging products may require a third round of EMC testing, for which we observe a failure rate reduced to 1% - 2%.

Based on our experiences with a wide variety of equipment suppliers, we can summarize the leading observed causes of initial EMC failure as:

- Lack of knowledge of EMC principles
- Failure to apply EMC principles
- Application of incorrect EMC regulations
- Unpredicted interactions among circuit elements
- Incorporation of non-compliant modules or subassemblies into the final product

These topics are discussed briefly in the context of a product design and development program intended to maximize the likelihood of success in the initial EMC testing.

EMC regulations

Although RF interference considerations have existed since the advent of radio, commercial EMC regulations (both emissions and immunity) are relatively recent – and continuously changing. Equipment designers and regulatory compliance engineers have to work hard to identify and keep abreast of the EMC regulations that impact their products. Of course, regulations should not be the only design driver.

In the USA, the Communications Act of 1934 established the framework for resolving radio interference issues. Parallel laws were enacted around the world, with Germany providing early leadership in laws and standards that provided a model for the European Union.

After the Second World War and the growth of electronics, specialized EMC standards were created to assure reliable equipment operation in such critical applications as aircraft, military, medical and automotive. The regulation of RF emissions from consumer products was given a boost from the advent of the personal computer. Numerous complaints of interference to radio and TV reception from personal computers led in the United States to the adoption of Subpart J to the FCC's Part 15 rules in 1979. The regulation of RF emissions from personal computers has spread throughout the world, with a few examples shown below:

• FCC Part 15, subpart J	1979
• IEC CISPR 22	1985
• VCCI in Japan	1985
• Canada Radio Act	1988
• Australian EMC Framework	1996
• Taiwan ITE EMI	1997
• Korea ITE EMC	1998
• Singapore EMI for telecom	2000

In 1989 the FCC consolidated its Part 15 rules into Subparts A, B and C. But thanks to the unstoppable flow of new communication technologies, the Part 15 rules have grown back to include Subpart G, with a new Subpart H already proposed. Today, RF emissions are regulated in most developed countries to protect broadcast services (radio, TV) and sensitive services (radio-navigation, satellite communications, radio-astronomy).

The first widespread application of RF immunity requirements was introduced with the European Union's EMC Directive published in 1989 and originally to take effect in 1992. However, the lack of suitable EMC standards – and the lagging preparedness of manufacturers – led to a delay until 1996. The original EMC Directive 89/336/EEC is replaced by a new Directive 2004/108/EC, with a transition period 20 July 2007 – 20 July 2009. EMC for radio equipment in the EU is mandated by the R&TTE (Radio and Telecommunications Terminal Equipment) Directive 1999/5/EC.

Worldwide EMC regulations, including limits and measurement procedures, are changing constantly and represent a moving target for product development.

RF emissions limits have been established for the threshold sensitivities of typical "victim" receivers such as radio and TV, and on the "protection distances" that may be available to increase the spacing between RF emitter and victim. The common protection distances are 10 meters for residential environments and 30 meters for non-residential. Most emissions standards allow scaling to other measurement distances such as 3 meters.

The equipment designer needs to know that the interpretation of EMC environments can differ between jurisdictions. In the USA, the FCC has defined the Part 15 Class A environment as anything except residential or consumer. EU generic EMC regulations define Class B more broadly. It may include commercial and light industrial environments. For ITE, however, it is acceptable to allow Class A emissions in commercial and light industrial locations.

EMC environment

	USA	EU+
Class A	non-residential	industrial
Class B	residential	residential, commercial, light industrial

Emissions increase

Immunity disturbances

Immunity environments are generally defined by the electromagnetic "threats" or disturbances that may exist there. For example, the generic industrial immunity standard IEC 61000-6-2 defines an industrial environment both from the nature of the AC connection:

- *to a power network supplied from a high or medium voltage transformer dedicated to the supply of an installation feeding manufacturing or similar plant*

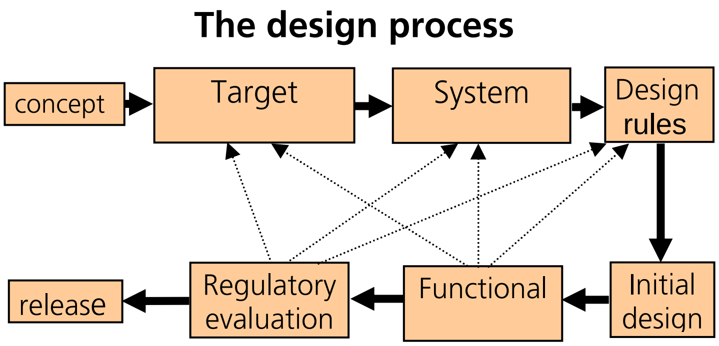
which could conduct disturbances from the equipment to other "victims," and to the surrounding "threats" as:

- *industrial, scientific and medical (ISM) apparatus*
- *heavy inductive or capacitive loads are frequently switched*
- *currents and associated magnetic fields are high*

The equipment designer or design team needs to assure that their EMC objectives take into account any regulatory differences among jurisdictions regarding the definitions of the EMC environment.

Consider EMC early in the design process

There are many opportunities during the product development process between concept and market entry where EMC criteria should be established, validated, tested and perhaps modified. The feedback implied in Figure 3 does not necessarily mean a mid-course correction (although one might be justified), but rather an opportunity to capture EMC information for use in future projects as a means of process improvement. ISO 9000-registered manufacturers should consider including



The design process

these review steps in their equipment development program.

Some specific EMC considerations are suggested below for each of the design steps shown in Figure 3:

Target Specifications	**The details (include functional and regulatory—EMC)** Are all the jurisdications specified? Have the requirements changed? Is the environment correct?
System Architecture	**The structure and details—EMC** How many layers in PCBs? Are reactive circuits located away from I/O ports? Are I/O ports isolated/shielded? Are IC families appropriate for speeds needed? Will housing provide shielding?
Design Rules	**The circuit and layout constraints—EMC** Are RF signal traces short and/or embedded? Are bypass caps located and sized optimally? Are ground planes low-impedance, and earth bypass provided? Have sensitive designs been modeled?
Regulatory Evaluation	**Is it legal? If not modify—EMC** Were places provided for optional filtering/bypassing? Are ferrites cost-effective? Can spring fingers be added to the enclosure? Will a shielded cable help? Board re-spin?

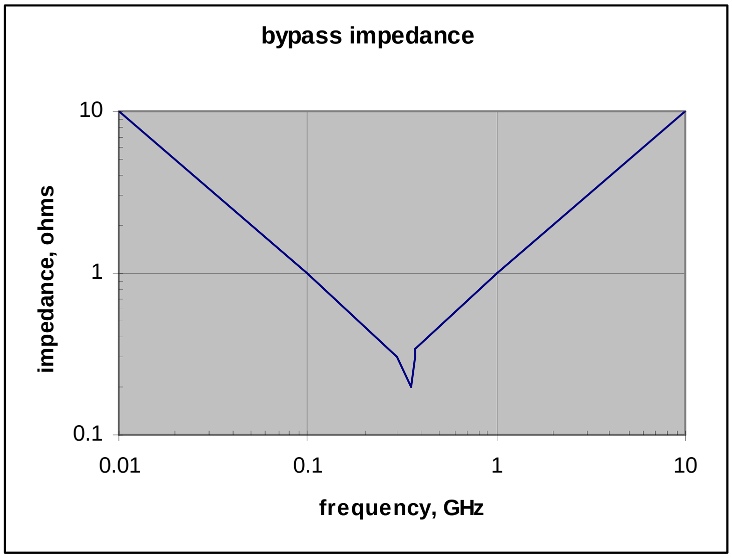
Design for compliance

Numerous books provide a thorough treatment of EMC design. In a limited space we can only mention a few key considerations for each of the major categories of:

- Components
- Logic families
- PCB layout and I/O
- Cables
- Enclosure and shielding
- Software and firmware

Components

Smaller, leadless components are contributing to the increased EMC testing success rate in two ways: (1) the absence of leads reduces the connection inductances, allowing more effective bypassing and lower ground bounce, and (2) the smaller components permit smaller PC boards, reducing trace lengths that can radiate or absorb RF energy.



The effect of lead inductance is illustrated in Figure 4 for a leaded bypass capacitor. At low frequencies the capacitive impedance decreases as frequency increases, allowing for good bypass characteristics. Above a resonant point determined by the capacitor's nominal value and its internal and external lead inductances, impedance increases with frequency – reducing the capacitor's effectiveness at the higher frequencies. Leadless bypass capacitors are more effective at high frequencies owing to their lower connection inductances.

The same argument can be applied to the parallel power and ground planes in a PC board. These constitute effective bypass capacitors with low inductances.

Logic families

Selection of logic families for a particular design should use the slowest speed consistent with target functionality. Excessive speed and/or high loads can cause EMC problems, because:

- Emissions increase with power consumption
- Emissions increase with slew rate/clock speed
- Emissions increase with ground bounce
- Emissions increase with output loading

Designers confronted with the need to pass high-speed signals over long distances might wish to consider using LVDS (Low-voltage differential signaling) logic. LVDS is often used to communicate video data from the base of a laptop computer to its flat-screen display. The key benefits of LVDS include a low voltage excursion and differential drive.

PCB layout and I/O

Key decisions faced by the designer include number of planes and locations of components. Planes can be used to good advantage for shielding (of internal traces) or bypassing (using the capacitance described above). There are tradeoffs because effective bypassing requires the planes to be as close together as possible, but for shielding they have traces between them. Where unshielded cables exit the PCB, any digital logic planes should be kept away because the planes carry noise.

Traces should be kept as short as possible, and their high frequency impedance is minimized when the ratio of length to width is no greater than 3:1. Short straight current elements radiate fields that are:

- Proportional to the current they carry
- Proportional to their (electrical) length
- Increasing with frequency

Similarly, small current loops radiate fields that are:

- Proportional to the current
- Proportional to the square of the loop radius -- and the square of frequency

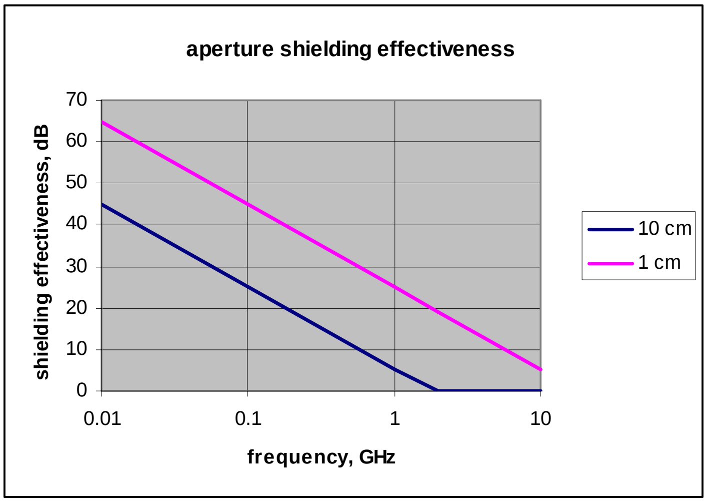
Locate I/O drivers as far as possible away from sources of high frequency (clocks) and near the ports they serve. Otherwise, the high frequency energy will couple to the cables on the I/O ports and the cables will radiate above the applicable limits.

Cables

Conductors exiting the enclosure can perform as effective antennas, radiating at frequencies that are sourced within the enclosure. If the conductors are a pair of wires driven differentially, the opposite and equal signal components on each will tend to cancel one another and any radiated emissions will be minimized. If the signals on each connector are not equal in amplitude and opposite in phase – as with a single-ended drive – some energy will be radiated and may cause regulatory limit failure.

Robust cable shielding can be an effective method of suppressing the emissions from a conductor carrying a single-ended signa. However, the outer shield onsuch shielded cables should be returned via the connector to an enclosure ground and not a signal ground. The signal ground is generally polluted by noise that, if connected to the cable shield, could cause the cable shield to radiate above regulatory emission limits.

Enclosure and shielding



The equipment enclosure can provide shielding to reduce RF emissions or improve immunity, only if the enclosure is conductive (metal or plastic) and preserves the continuity of a conductive path around the electronic circuitry inside. Any seams or holes in the enclosure must be sufficiently small to attenuate electromagnetic disturbances that could enter or exit. Small openings (see Figure 5) can be tolerated, depending on the frequencies of concern. In this chart the dimensions of 1 cm and 10 cm represent the diameter of a circular opening, the diagonal of a rectangular opening, or the length of a thin slit or seam. Non-conductive enclosures provide good protection from electrostatic discharge (ESD) but afford no shielding.

Software and firmware

Not all of the “heavy lifting” for EMC compliance needs to be accomplished with hardware. Many of the most common immunity disturbances allow the equipment being tested to temporarily degrade performance during the test, but recover automatically. This functionality can be provided by good software/firmware design at no hardware cost. These are prudent features in any case, not just for EMC compliance:

- checkpoint routines and watchdog timers.
- checksums, error detection/correction codes.
- ‘sanity checks” of measured values.
- poll status of ports, sensors, actuators.
- read/write to digital ports to validate.

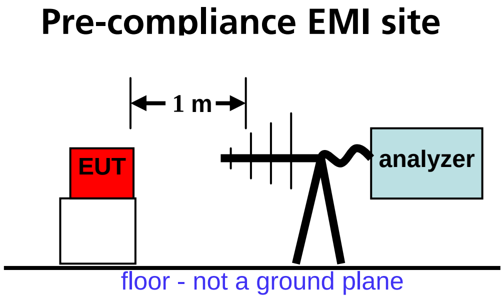
Pre-compliance testing

In cases where the product development uses modules or subassemblies that have not been previously evaluated for EMC, or where marginal EMC performance of the product is suspected, it is prudent to perform some pre-compliance EMC testing. This can only provide approximate results but could reveal problems at an early stage when the corrections can be made quickly and cost-effectively.

If the developed product has been tested on an accredited EMC site and failed (or even passed), the accredited test results can be used to correlate with results on a pre-compliance site to decrease the uncertainty of the pre-compliance results.

Pre-compliance RF emissions sites

It is possible to set up a simple 1m emissions site in an office or factory. By bringing the measurement antenna (which can be rented for the purpose) closer than 3m to the equipment being tested, interference from ambient emissions is minimized. At frequencies above about 100 MHz reflections from any ground plane are not relevant in this configuration, so the customary office or factory floor is acceptable. The antenna is kept at a fixed height of 1m. This site is not well-suited to large equipment, with dimensions near or larger than 1m. See Figure 6.



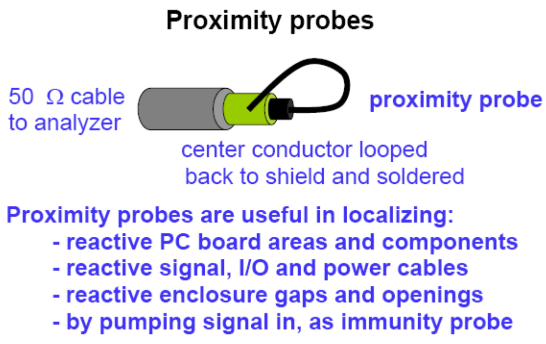
If ambient radiated emissions are very high, they can be excluded from the 1m pre-compliance site by constructing a screened room around it using a wooden frame and metal mesh. Radiated reflections will be introduced, so any measurements made in the screened room are subject to additional uncertainties. The screened room can also be used for conducted emission measurements using a LISN (Line Impedance Stabilization Network) or AMN (Artificial Mains Network).

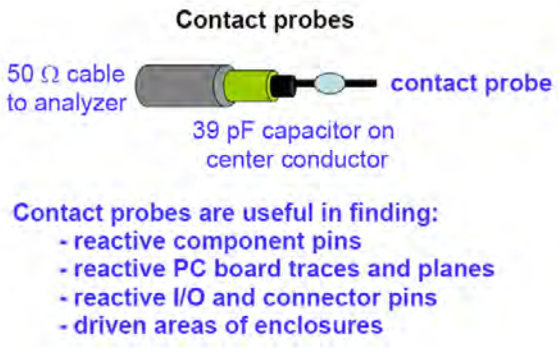
Pre-compliance tools – emissions

With a suitable pre-compliance site available, you can perform simple diagnostic tasks to isolate, identify and mitigate sources of RF emissions. Take a set of baseline measurements across the frequency range of interest, using a suitable EMI receiver or spectrum analyzer (which can be rented for the purpose). Then, perform a succession of operations in turn and observe the results on the screen of the measuring instrument:

- Wiggle I/O or AC cables to correlate with emissions.
- Remove I/O cables one by one to determine effect on emissions.
- Shield AC cable to chassis with tin foil.
- Selectively add ferrites, line filters or bypassing to localize reactive cable.
- Use EMI probes (below)

If an emission of interest has been identified, its source on the equipment or circuit board can likely be identified by using either a proximity probe or a contact probe; see Figures below.





The proximity probe is moved around the enclosure or circuit board until an emission is located at the same frequency as the one found using the antenna. By locating the highest emission with the proximity probe, you have likely – but not definitely – located the source of the emission. The contact probe allows you to touch individual PC traces or component leads in searching for the frequency of interest.

Pre-compliance tools – immunity

Immunity pre-testing requires you to generate electromagnetic disturbances that simulate the requirements in the applicable immunity or EMC standards. The simplest way to perform ESD pre-compliance testing is to rent an ESD "gun" for the purpose. Be sure to review the ESD standard such as IEC 61000-4-2 in order to follow the test procedures and setup as closely as possible. Use a similar approach to surge testing for a standard such as IEC 61000-4-5, and be sure to comply with safety precautions as the surge voltages can be hazardous.

RF radiated immunity testing is normally performed in a shielded chamber to avoid radiating illegal RF signals across the radio spectrum. Unless you have constructed a screened room and determined that it provides sufficient shielding effectiveness to prevent unwanted emissions from inside to outside, you should confine any RF radiated emissions pre-compliance testing to the use of certified and/or licensed radio transmitters approved for use in the USA or in the test location. Some convenient transmitter types and their operating frequency bands (for US operation) are listed below:

– CB radio	27 MHz
– Portable phone handset	49 MHz (be sure to check; many now operate in the 900 MHz, 2.5 and 5 GHz bands)
– Garage door opener	300 MHz
– Walkie-talkie	460 MHz
– Cell phone, analog/TDMA	800 MHz
– Cell phone, PCS	1900 MHz
– Wireless LAN, Wi-Fi	2450 MHz

If insufficient RF immunity is observed during pre-compliance testing, you can experiment with conductive spring fingers to bridge enclosure discontinuities, filters at low RF frequencies and ferrite beads typically above 50 MHz.

Modifications for compliance

Prudence dictates that a product which has never before undergone EMC testing be designed with a few extra EMC "hooks" that can be used in the event of EMC problems during regulatory testing. Such "hooks" can be as simple as PCB locations for extra bypass capacitors and/or ferrite beads, or alternate connections for a larger AC line filter. If the equipment passes the regulatory EMC testing with flying colors, the optional positions remain unpopulated. This precaution can avoid board re-spins and a subsequent delay in time-to-market, or even slipping outside of the marketing "window."

Conclusion

In summary, to increase the EMC success rate the designer should:

- Be sure the regulatory specifications are correct and current
- Take into account the impact of equipment architecture on EMC, and ensure that purchased modules also comply.
- Consider EMC design rules, manual and/or automatic
- Include places for EMC compliance modifications
- Perform pre-compliance testing where possible

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