Workbench EMC Measurements

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Workbench EMC measurements are simple, inexpensive precompliance tests that a product designer can perform early in the development phase of a product in order to obtain an indication of the EMC performance of that product. These are simple measurements requiring limited, relatively inexpensive equipment that can be performed in the designer's own laboratory. Although not as accurate as legitimate EMC measurements, performed at a certified EMC test facility, the fact that they are simple, quick and can easily be performed at your workbench, more than compensates for the accuracy degradation, especially when performed early in the design phase of a product.

The advantages of early EMC testing during the design phase of a product include:

- Increased probability of passing the final compliance test
- Minimizes the number of retests required for compliance at an EMC test laboratory
- Eliminates surprises late in the design (due to EMC failures)
- Insures that EMC considerations are part of the original design, not add-ons

Data from EMC test laboratories indicate that 50% of the products submitted for final compliance testing fail the first time. By using the simple workbench EMC measurements described here, that statistic can be reduced, such that only 10 or 15% of the products fail regulatory compliance tests the first time.

Test Environment. Radiated emission test facilities are carefully designed and constructed to control reflections. The objective is to have only one reflective surface, and that is the ground plane. An open area test site (OATS) does this by locating the facility in an open field with no metallic objects nearby. The one reflective surface consists of the metallic ground plane at the site. A large semi-anechoic chamber accomplishes the same objective by having a metallic ground plane (the chamber floor) and using rf absorber material (carbon loaded pyramidal cones and/or ferrite tiles) on the walls and ceiling to absorb rf energy and prevent reflections.

The workbench EMC measurement environment (your design lab), however, is just the opposite from that described above. It has many uncontrolled reflective surfaces such as, metal file cabinets, metal desks, chairs, lab benches, and possibly metal walls. Therefore, you do not want to do a radiated emission test in this environment; rather you need to measure some parameter that is proportional to the radiated emission, not the radiated emission itself.

What you definitely do not want to do is build a small-shielded room (non-absorber loaded), place your product and a receiving antenna inside the room, and attempt to measure the radiated emissions. This approach maximizes the errors associated with such a test. The large reflections from the walls and ceiling will produce nulls and peaks in the radiated emission pattern, producing errors as large as ± 40 dB (Cruz and Larsen, 1986).

Useful workbench EMC measurements must be made such that they are not affected (or at least minimally affected) by the uncontrolled environment in which the tests are being performed.

Antennas versus Probes. We will not use antennas as part of our workbench EMC tests. Antennas are large (usually a significant fraction of a wavelength) in size and are sensitive to nearby reflections, and interact with surrounding metal objects. Rather, we will use small probes that are much smaller than a wavelength, can be used close to surrounding metal objects, and are very insensitive to reflected rf energy. The probes that we use will be a few inches or smaller in size, compared to antennas, which have dimensions of many feet. For example, at 30 MHz a tuned dipole antenna is 16.4 feet long (5 meters).

Three of the most useful EMC precompliance measurements to make are:

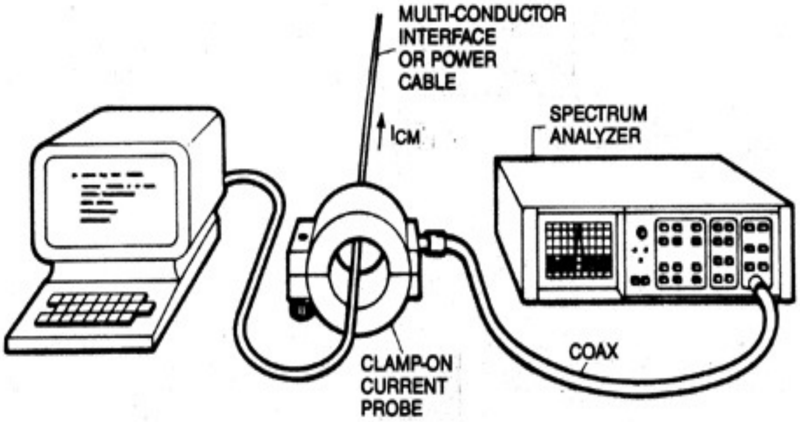
- Common-mode currents on cables
- Near field, magnetic field measurements
- Conducted emissions on the ac power line

None of the above will require the direct measurement of a radiated field.

Common-Mode Currents on Cables. By far the most useful single precompliance measurement that you can make is to measure the common-mode current on all the cables attached to your product.

The radiation from a cable is directly proportional to the common-mode current on that cable. The common-mode current is the unbalanced current (current not returned) on the cable. If this current is not returned on the cable, where does it go? Into radiation, that's where! In the case of intentional signals (differential-mode signals), the current flows down one wire of the cable and returns on an adjacent wire, hence the net current is zero and the common-mode radiation is eliminated.

Since cables are always a major source of product radiation, measuring the common-mode current is one of the most useful things that you can learn to do. The common-mode current can easily be measured with a calibrated high-frequency clamp-on current probe and a spectrum analyzer as shown in the following figure.



Make it a habit to measure the common-mode currents on *all* your cables! Do it early in the development process, on prototype models, while it is still easy to make a change to the product, and prior to performing final EMC compliance testing. If you fail the precompliance common-mode current test, you will also fail the radiated emission test.

For a commercial Class B product (FCC or EU requirements), the current must be less than approximately 5 µA, 15 µA for a Class A product. For some MIL standards requirements the allowable current will be less than 1 µA. Use the above limits for all external cables that are one-meter long or longer. For cables shorter than one meter, the allowable current is inversely proportional to the cable length. For example, for a half-meter long cable the maximum current would be 10 µA for a Class B product, 30 µA for a Class A product.

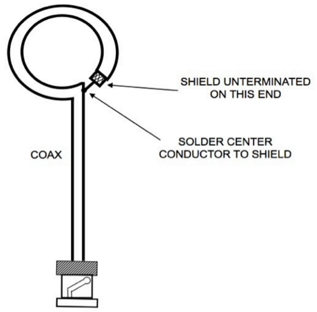
This technique works equally well on shielded or unshielded cables. This is also a good way to determine the effectiveness of your cable shield termination. If you use common-mode filters on your cables or ferrite cores to suppress common-mode radiation the current probe measurement will indicate their effectiveness. Just measure the current before and after inserting the filter (or ferrite), or as you vary the way that the cable shield is terminated.

All cables should be measured regardless of their intended purpose. Measure the signal cables, the power cord (ac or dc), fiber optic cables, monitor cables, I/O cables, telecom cables, and any other cables that are attached to the product. If it's connected to the product it can be a source of common-mode radiation!

Measure one cable at a time with the common-mode current clamp. Use common-mode chokes, filters, cable shields, etc. to reduce the current to less than the allowable level for the requirement that you are trying to meet, then go on and repeat the process on the next cable. When you get through all the cables, start over again since the current may have increased on some of the previously fixed cables. Keep this iterative process up until the common-mode current on all the cables are below the allowable limit. At this point you can feel confident that the cables will no longer present a problem when you do a radiated emission test at a qualified EMC test facility.

Caution, common-mode cable currents can be the result of energy coupled into the cable from the product under test, (this is what we want to measure), as well as energy picked up from external sources such as local FM and TV broadcast stations (this is what we do not want to measure). All measurements must, therefore, be validated to assure that you are measuring what you think you are measuring. A simple validation test in this instance is to turn the product off and see if the reading goes away. If it remains, it is due to external pickup. FM radio stations are commonly picked up this way; so any signal in the 88 to 108 MHz frequency range (in the United States) should be suspect.

Near Field Measurements. The above cable current measurement provides information about radiation from the cables. What is needed next is a simple way to detect the differential-mode radiation coming directly from the product. Differential-mode radiation is the result of currents flowing around loops on the printed circuit board. These current loops act as small loop antennas that radiate magnetic fields. What we can do, therefore, is to measure the magnetic field close to the printed circuit board using a small magnetic field loop probe and a spectrum analyzer.



Small, shielded magnetic field loop probes are available from a number of manufacturers at very reasonable prices, a few hundred dollars or less. As an alternative to a commercial magnetic field probe a simple homemade probe can be constructed from a 50-ohm coaxial cable. One end of the cable should be formed into a 1/2 to 1 inch diameter loop with the cable center conductor soldered to the shield as shown in the figure. The shield should not be terminated on this end.

Although the magnetic field probe can be calibrated, the results of the near field measurement cannot be extrapolated to the far field to determine the magnitude of the radiated field. Therefore, measurements made with a magnetic field probe are qualitative not quantitative. They are still, however, very useful in indicating excessive sources of differential-mode radiation as well as in doing A/B comparisons, when a change or modification is made to the product.

Scan the probe over the printed circuit board looking for “hot spots” (locations with strong magnetic fields). When a “hot spot” is found, check the printed circuit board in that vicinity for violations of good EMC design practices. A common violation is often an interrupted signal circuit return current path caused by a split or slot in the PCB ground/power plane. After making changes to the board, retest to confirm that the magnetic field has decreased in amplitude. In some cases you may find that it is an integrated circuit that is causing most of the emission. In this case you should consider using a board level shield over the component or components.

The magnetic field probe can be held vertical or horizontal when performing the tests. If the probe is vertical, it will have to be rotated 0 to 90 degrees in order to detect the maximum field strength.

Because small magnetic field loop probes are insensitive to remote external fields, you can usually safely assume that what you observe is coming from the nearby PCB. However, this assumption can be validated by moving the probe away from the board, and verifying that the magnitude of the reading drops significantly.

If your product is housed in a shielded enclosure, electromagnetic field leakage through the enclosure apertures can also be measured using the magnetic field probe. Place the probe next to the enclosure with the plane of the loop parallel with the shield. Move the probe along the seam or aperture and search for a strong magnetic field. After making changes to the enclosure (e.g. reduce the size of the aperture, reduce the length of the seam, etc.), retest to confirm that the magnetic field has decreased in amplitude.

The above two EMC precompliance measurements will give you a good handle on both the radiated emission coming directly from your product, as well as from the cables.

Conducted Emissions. In addition to radiated emission tests, EMC regulations also require measurement of conducted emissions on the ac power line. Simple precompliance conducted emission tests can easily be performed using a line impedance stabilization network (LISN) and a spectrum analyzer. Commercial LISNs can be purchased, or if only needed occasionally rented from a number of EMC test equipment rental companies. Two LISNs are required, one connected to each side of the ac power line. Hence, many LISN manufacturers package two LISNs in one enclosure and provide a means of switching the measuring port from one side of the ac power line to the other.

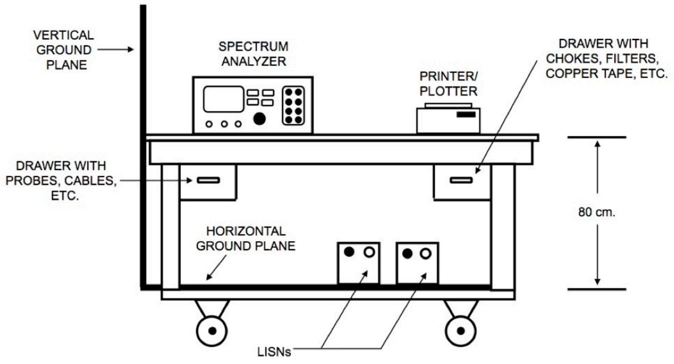
The conducted emission precompliance tests can be performed similarly to the way they are specified in the regulations. For precompliance tests, however, the measurements are often performed without the ground planes. A even better approach is to set up the ground planes around a nonmetallic laboratory bench, even if they are not as large as specified by the regulations, and perform the conducted emission tests on that bench.

Caution, noise can be coupled into the LISN, especially at low frequencies, from the facility ac power line. Adding a power line filter between the LISN and the facility power line can help reduce or eliminate this noise. As with all measurements a validation test should be done, in the conducted emission case turn off the power to the equipment under test and confirm that the reading goes away.

Spectrum Analyzer. The most expensive piece of test equipment required for the above precompliance measurements is the spectrum analyzer. However, many companies will already have a spectrum analyzer for other purposes, or they can be rented from EMC test equipment rental companies. Most of the major spectrum analyzer manufacturers (Agilent, Anritsu, etc.) produce portable spectrum analyzers priced in the $10,000 -

$15,000 range. In addition a number of small, hand held, analyzers are now available, that are adequate for precompliance EMC measurement purposes, for under $2,000.

EMC Crash Cart. Rather than having all the equipment needed for workbench EMC measurements scattered all over the lab, where it may or may not be easy to find when needed, why not combine it all together in one place, in what I call an "EMC Crash Cart." This can easily be accomplished by starting with a non-conductive cart and making some modifications to it, by adding a couple of drawers and ground planes as shown in the figure below.



The cart can be made of wood, plastic, or fiberglass, but not metal. The cart can be rolled to wherever it is needed, and has everything required, to perform the precompliance tests as well as apply fixes to the equipment if necessary. The spectrum analyzer and a plotter, or printer (both optional), can be placed on the top of the cart. One of the two drawers can be used for the necessary precompliance test equipment, such as:

- Common-mode current clamp.
- Magnetic field loop probe.
- Required interconnecting cables, attenuators, etc.
- Small hand tools.

The second drawer can be used to hold EMC mitigation components that are used to reduce the emissions such as:

- Snap-on common-mode chokes (ferrite).
- Aluminum foil and copper tape.
- Copper braid for grounding straps.
- Small metal cable clamps for improving cable shield terminations.
- AC power-line filters.
- Filter-pin connectors in common connector configurations.
- AC power line capacitors (safety agency listed) to use for X- and Y-capacitors in power line filters, 1000 pf to 2 µF.
- Connector backshell grounding clips and gaskets for common connectors.

- An assortment of conductive EMC gaskets and spring fingers to provide electrical conductivity across enclosures seams.
- Resistors, 10 to 1,000 Ω, to dampen clock oscillations, etc.
- Small ceramic capacitors, 100 pF to 0.1 μF
- Small ferrite beads with 50 to 100 Ω impedance at the frequencies of interest.
- Sandpaper to remove paint and nonconductive coatings from enclosures.

For most precompliance measurements the spectrum analyzer and plotter (if used) will remain on the cart. However, when performing conducted emission test, remove the spectrum analyzer and plotter from the crash cart, and place the equipment under test (assuming that it is a table top size product) on the cart, 40 centimeters from the vertical ground plane. This will properly locate the product under test with respect to the vertical and horizontal ground planes as requited by the commercial conducted emission regulations. The ground planes will be smaller than specified, but that will only have a minor, if any, effect on the test results

By using the crash cart, everything needed to perform the necessary precompliance measurements and apply fixes to the product will be readily available in one location. This will save time and prevent you from having to look all over the lab for what you need. This approach will also encourage you to use the equipment, since you don't have the excuse of, I don't know where all the equipment is!

Get into the habit of always performing these workbench EMC measurements, and you will save both money and time when you do your official regulatory compliance EMC tests. For additional information on performing these simple workbench EMC measurements, as well as additional immunity tests, see Ott, 2009.

Suggested Precompliance Test Equipment List

Clamp-on current probe: Fischer Custom Communications Model F-33-1 (20-250 MHz and/or F-61 (40-1,000 MHz)

Magnetic field loop probe: Fischer Custom Communications F-301, or Beehive Electronics Model 100A and Model 100C.

LISN: Solar Electronics Type 8012-50-R-24-BNC Dual LISN

Spectrum analyzer: Rigol DSA815-TG, EMI option not required, (9kHz-1.5 GHz) (available from TEquipment.net), or Thurlby Thandar Instruments Model PSA1301T (150 KHz-1.3GHz) (available from Newark Electronics or Saelig Electronics)

References

Cruz and Larsen, *Assessment of Error Bounds for Some Typical MIL-STD 462 Type of Measurements*, NBS Technical Note 1300, October 1986.

Ott, *Electromagnetic Compatibility Engineering*, Chapter 18, Precompliance EMC Measurements, John Wiley & Sons, 2009