Guidelines for the construction and use of an EMI diagnostic site

Proper construction of an electromagnetic interference (EMI) diagnostic site helps electronic product manufacturers with pre-compliance testing and troubleshooting, and reduces testing costs.

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As global electromagnetic compatibility (EMC) requirements increase, electronic/electric products are required to meet various EMC requirements before being placed on the market. In the United States, the Federal Communications Commission (FCC) is the government agency which implements the EMC requirements for commercial electronic/electric products. Currently, the FCC has requirements for the control of EMI only (i.e., emissions), which can be found in the 47 Code of Federal Register, 47CFR. Electromagnetic susceptibility (EMS, i.e., immunity) is not addressed in the United States at this time.

The European Union requires that electronic/electric products meet both emission and immunity requirements before being placed on the European market. Starting January 1, 1996, European countries harmonized their test standards to remove trade barriers between countries in the European Union. The harmonized test standards can be found in the European Norm (EN) series of standards. Harmonized emission test standards are based on CISPR standards. Harmonized immunity test standards are based on IEC standards.

Asian countries, such as China, Japan, and Taiwan, have their own EMC requirements. China will implement its EMC requirements on January 1, 2000. Test standards are not clear at this time. Japan enacted the "Agreement of Voluntary Control for Interference by Information Technology Equipment" (VCCI) in 1985 to control the electronic interference from information technology equipment. Taiwan has gradually implemented its EMC requirements since January 1, 1997.

From experience, emission testing has always had a higher failure rate when compared to immunity testing. Performing EMI troubleshooting in a test laboratory is not cost-effective. Building an EMI diagnostic site can reduce the cost burden. An EMI diagnostic site can be simple or complex, depending on the demand. The following sections will introduce the test equipment and the facility, a simple EMI diagnostic site and a professional EMI diagnostic site. The readers can justify their own demand.

This article focuses on line-conducted emission and radiated emission measurement sites. Disturbance power measurement using an absorbing clamp is not within the scope of this article.

TEST EQUIPMENT

A detailed specification for the test equipment and facility can be found in CISPR 16-1.[1] Some guidelines for choosing basic test equipment and facilities are included here.

Spectrum Analyzer or Receiver

There are many different kinds of spectrum analyzers and receivers (this article refers to a measurement instrument as a receiver) available on the market, with prices ranging from $10,000 to $100,000. The key factor is to choose a receiver in the frequency range of interest. Table 1 lists test frequency ranges required by different government agencies.

Besides frequency range, a quasi-peak detector and an average detector are the second important factors to consider. It is the reference detector for the frequency range 9 kHz to 1 GHz. If the emission from the equipment under test (EUT) is a broadband signal, test data taken using a quasi-peak detector will be lower when using a peak detector. For European compliance testing, an average detector is needed, in addition to a quasi-peak detector, for line-conducted emission measurements for the frequency range 0.15 MHz to 30 MHz. For a continuous wave signal, there is little difference in the test data retrieved from peak, quasi-peak, and average readings. Resolution bandwidth is another factor to consider when choosing a receiver. The resolution bandwidth for line-conducted emission testing is 9 kHz. For radiated emission measurements below 1 GHz, the resolution bandwidth is 120 kHz. A receiver with a function generator is of great help for site attenuation, but not mandatory.

Antenna

There are various antennas on the market, the price ranging from several thousand dollars to around $20,000. Frequency range is also a key factor to consider. For the frequency range 30 MHz to 1000 MHz, a dipole antenna is used as the reference antenna. Due to the low sensitivity of a dipole antenna at the frequency range 300 MHz-1000 MHz, and the difficulty of tuning the dipole antenna to its length for specific test frequencies over the test frequency range, a linear polarized broadband antenna is normally used for ease of operation. Table 2 lists several different antenna types.

Antenna Mast

An antenna mast is a non-conductive post to hold an antenna and to move the antenna up and down. The height of an antenna mast is either 4 meters (for 3-meter and 10-meter measurements) or 6 meters (for 30-meter measurements). A professional type of antenna mast includes a controller to control the antenna's height and orientation (horizontal or vertical).

Line Impedance Stabilization Network (LISN), Artificial Mains Network (AMN)

An AMN or a LISN is used to provide isolation to spurious signals in the mains supply lines (AC power) and to prevent the mains voltage from being applied to the measuring receiver. It is good practice to insert a transient limiter at the input of the receiver to protect the front end of the receiver and to avoid costly repairs.

Non-conductive Table and Turntable

A non-conductive table is used to hold tabletop equipment under test (EUT) during emission testing. A floor-standing EUT is placed on top of the ground plane.

A manual turntable made of non-conductive material can be built inexpensively or a motorized turntable and controller can be used to rotate the EUT. A professional type turntable is made of metal, mounted flush with the referenced ground plane (floor) and has a motor beneath it to control the rotation.

Ground Plane

The quality of the ground plane is key to the quality of an emission test site. A ground plane is a highly conductive, metallic material placed on the floor and used as a reference. The metallic material can be wire mesh, sheet aluminum, or copper sheeting, etc. The ground plane connects to earth ground through ground rods driven into the earth.

	Frequency Range (MHz)	
Standards; Countries	**Line Conducted Emission**	**Radiated Emission**
AS/NZS 3548; Australia, New Zealand	0.15 - 30	30 - 1000
CNS 13438; Taiwan	0.15 - 30	30 - 1000
EN 55011, EN55022; European Union	0.15 - 30	30 - 1000
FCC Part 15; US	0.45 - 30	30 - 1000*
VCCI; Japan	0.15 - 30	30 - 1000

* For EUT clock frequency from 1.703 to 108 MHz. It is 30 MHz for the clock frequency below 1.705 MHz, 2000 MHz for 108-500 MHz, 5000 MHz for 500-1000 MHz, 5th harmonics of the highest frequency or 40 GHz for the clock frequency above 1000 MHz.

Table 1.

FACILITY

There are two types of test sites: an Open Area Test Site (OATS), which

Antenna	Frequency Range**	Measurement Field
Dipole Antenna	30 MHz - 1000 MHz	E-field
Biconical Antenna	30 MHz - 200 MHz	E-field
Biolog Antenna	26 MHz - 1000 MHz	E-field
Log-Periodic Antenna	200 MHz - 1000 MHz	E-field
Loop Antenna	60 Hz - 30 MHz	H-field
Ridged Horn Antenna	1 GHz - 40 GHz	E-field
Rod Antenna	10 kHz - 30 MHz	E-field

** The frequency range listed here is for reference only. The exact frequency range depends on the antenna manufacturer(s).

Table 2.

is a reference site, and an anechoic chamber. An OATS is less expensive than an anechoic chamber and easy to construct, although in a high ambient noise area, where the signal-to-noise ratio is low, an anechoic chamber is desirable to identify emission frequencies.

The size of a test site refers to the distance between the EUT and the antenna. A 3-meter site means the distance between the antenna and the EUT is 3 meters. A list of required measurement distances is included in Table 3.

For the measurement distance interpolation, the following equation applies only when the ambient noise is high:

$$L_2 = L_1 (d_1/d_2)$$

where

L_1 = the specified limit in microvolts per meter at the distance d_1

L_2 = the new limit at the distance d_2

This equation is not practical in all cases. Some research was done by Mr. Garn and Mr. Kremser in 1993.[2] CISPR 11[3] allows use of a closer measurement distance, but the limits remain the same.

Open Area Test Site (OATS)

An OATS is a test site without conductive materials above a horizontal ground plane. It can be an ellipse boundary with the antenna and EUT located on the same plane. A simple site setup consists of a ground plane, an antenna, and an antenna mast. A tarp-type weather protection enclosure is commonly used in the US to protect the EUT from the elements. A professional site is a building made of non-conductive material.

Anechoic Chamber

An anechoic chamber is a shielded enclosure lined with ferrite tile[4] and/or foam absorber material. As ambient noise increases, a number of EMC agencies are considering the acceptance of emission test data taken from an anechoic chamber environment. The commercially available size of an affordable chamber is 7 m x 3 m x 3 m or 9 m x 6 m x 6 m. The latter one may be used to take final 3-meter emission data which is accepted by some government agencies. The former one is mainly used for immunity testing and/or as a pre-scan for emission testing.

A SIMPLE EMI DIAGNOSTIC SITE

A simple EMI diagnostic site includes a receiver, an antenna, and a table. To minimize the cost, the receiver and antenna can be rented. The antenna can be replaced by a pin probe and/or a sniffer probe. The construction of a pin probe and a sniffer probe is shown in Figure 1. A 10-pF capacitor is connected to the center conductor of the coaxial cable for a pin probe. For a sniffer probe, the center conductor is tied to the shell (ground braid) of the coaxial cable by using a piece of copper wire. The exposed wire should be covered with electrical tape to protect the sniffer wire and to avoid an electric short circuit. A pin probe is used to locate the noise source by contacting the circuit trace, while a sniffer probe is moved around the EUT sniffing for RF leaks.

The EUT is placed on the table. An antenna connected to a receiver is placed at the required distance from the EUT. The placement of the EUT and the antenna should not change during troubleshooting.

	Measurement Distance (meters)	
Standards; Countries	Class A	Class B
AS/NZS 3548; Australia, New Zealand	30	10
CNS 13438; Taiwan	10	10
EN 55011; European Union	30	10
EN 55022; European Union	10	10
FCC Part 15; US	10	3
VCCI; Japan	10	10

Table 3.

Before performing any modification, record the emission level. This recorded level is used as a reference level from the receiver. If the emission level is hard to distinguish from the ambient noise, move the antenna closer to increase the signal to noise ratio. After each modification, record the emission level. By comparing the emission level from each modification, the engineer is able to figure out how effective the modification(s) has been. Test data is relative data. If the emission level is hard to distinguish from the ambient noise, moving the antenna closer will help to increase the signal-to-noise ratio.

For board-level troubleshooting, use a scribe to probe the trace to find the emission source. The scribe will act as an antenna. Checking the waveform (overshoot and undershoot) from an oscilloscope and the emission level from the receiver at the same time is another way to find the emission source.

This simple EMI diagnostic site is only able to read relative radiated emission data. It works fine if the EUT has pre-scan test data from a test laboratory.

To perform line-conducted emission measurements at this simple EMI diagnostic site, an earth-connected ground plane (minimum size: 2 meters x 2 meters) must be provided. This ground plane must extend at least 0.5 meter beyond the EUT. A vertical conductive surface at least 2 meters x 2 meters adjacent to the ground plane may be required by some test standards. The AMN or LISN is placed on top of the ground plane. If the ambient nose becomes an issue, filter the AC power mains.

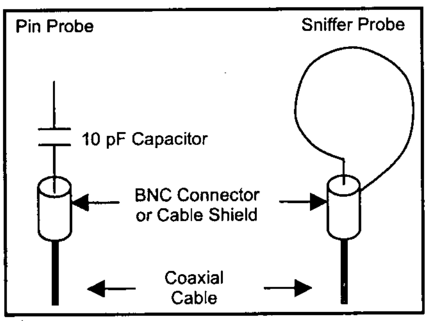

Figure 1. Pin probe and smiffer probe configurations.

A PROFESSIONAL EMI DIAGNOSTIC SITE

A professional EMI diagnostic site includes a receiver, an antenna, an antenna mast, a turntable, and a ground plane. The ground plane can be placed over soil, black top, concrete, or on a roof top. The ground plane assures that there will be no reflections from buried utilities or other metal materials. The ground plane must have an earth reference via ground rods. Ground rods must be evenly spaced and firmly bonded to the ground plane. Using a cold water pipe for an earth ground connection may be problematic. There may be a PVC interconnection in the line. It is recommended that a good earth ground connection be made. Use a meter and take some measurements. Ground rods are always the best way to go; you can then be sure of a good, known good earth ground.

Be aware of your surroundings. Metal obstructions must be eliminated. Position your OATS away from chain-link fencing, large utility cabinets, metal buildings, and automobiles. With the popularity of cellular phones, cellular towers are everywhere. Having cellular towers looming over your test site will cause ambient levels to cloud your readings (frequency dependent). Another example is a test site near a construction site that utilizes an arc welder. This can cause broadband noise at the low end of the frequency measurement spectrum.

Site attenuation is a must. It is a validated procedure to qualify as a test site. The normalized site attenuation (NSA) method is commonly used to evaluate an OATS. This method is stated in CISPR 16-1[1] and ANSI C63.4: 1992.[5] The deviation allowance is ± 4 dB. If this proves to be too difficult to perform on your own, have a test laboratory come out and do it for you. If the initial site attenuation data does not meet the ± 4 dB deviation requirement, check the following troubleshooting tips:

1. *Grounding the ground plane.* Make sure (by measurement) that there is a good bond between ground rods and the ground plane
2. *Shielding of the coaxial cable between antenna and receiver.* If the coaxial cable between the antenna and receiver does not go through a metal tube, add ferrites onto the coaxial cable, spaced evenly about every 6 inches to help bring the NAS into specification, especially for vertical polarization.
3. *Antenna factors.* The antenna factors may change over time. Make sure that the calibration is valid. Also, the quality of the antennas on the market varies. Try different antennas if possible. Renting before purchasing gives one the opportunity to make this evaluation.
4. *Calibration of the receiver.* Calibration of the receiver should be performed on at least a yearly basis, in order to deliver accurate readings.
5. *Amplifier Gain* (if any). Preamps used in the test setup must be accounted for just like antenna factors and cable loss.

The emission level can be obtained by using the following calculation:

Emission Level = Reading from Receiver - Antenna Factor - Cable Loss + Amplified Gain (if any)

The unit of measurement for radiated emission levels can be μV/m (FCC) or dBμV/m (European Union, etc.). The receiving antenna must be moved up and down during measurement scans. It becomes more important as the frequency goes higher. Rotating the turntable is another factor that affects the reading of radiated emission levels.

Pre-compliance software is available for EMI testing. It is easy to use. Add your antenna factors and cable loss to a memory card and along with pre-loaded software known as "personality" cards, the limits of various test requirements can be selected and loaded into the receiver. Turn on the display line to see the limit line and observe the results. Calculations are done for you with displayed results on the receiver's screen.

This professional EMI diagnostic site is also good for taking line-conducted emission data. A vertical conductive surface at least 2 meters x 2 meters may be required by some test standards. The AMN or LISN is placed on top of the ground plane.

SUMMARY

For the manufacturer who periodically requires EMI compliance testing, choose the simple EMI diagnostic site. For the manufacturer who routinely needs to have a product comply to an EMI standard, setting up a professional EMI diagnostic site is a good idea. The benefits of having an EMI site at your disposal may make the difference between getting your product to market or losing the sale altogether.

REFERENCES

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