

Field Probes As EMI Diagnostic Tools

Effective Use of Magnetic and Electric Field Probes Can Speed Identification of EMI Problems

Finding solutions to nettlesome electromagnetic interference (EMI) problems in electronic devices is sometimes like buying a jigsaw puzzle at a garage or lawn sale, that is, there are probably some pieces missing, and maybe some irrelevant pieces from another puzzle mixed in. Nevertheless, the goal is still to assemble enough pieces to “get the picture.” EMI work is like that because the goal is usually to build and sell some electronic product, where EMI is a side show. There may simply not be the time or money available to develop a detailed or complete understanding of all EMI problems, so long as your product passes its final regulatory tests. In these situations, speed is more important than precision, and a qualitative understanding of the EMI phenomena may have to suffice.

This is not to say that one should have a single-minded pursuit of the quickest “fix” that seems to solve an EMI problem. Quick “fixes,” where the reason why it works is not clearly understood, have the nasty tendency to sometimes work only once. Consequently, it’s still important to gain insight into the physics underlying an EMI problem. Magnetic and electric field probes are effective diagnostic tools for providing that insight.

Final EMI testing to demonstrate compliance with regulatory requirements is necessary, but usually is not an efficient way to solve EMI problems. EMI tests at an open area test site (OATS) or in an absorber lined chamber (ALC) are usually the most accurate, but also are very time consuming. Trying to solve EMI problems in such an environment is usually a matter of trying some change and seeing if the EMI drops or not. Such an approach is usually hit-and-miss, and success is as much a case of luck as perceptiveness.

Electrical circuits produce magnetic and electric fields which will radiate radio-frequency (RF) energy that may exceed EMI limits. This is particularly true in digital circuits or switching power supplies, where high-order harmonics can produce strong RF fields. In cases where RF currents are forced to flow in other than straight lines, magnetic fields will be strongest. In other cases, such as those where RF currents are low but potential differences are high, near electric fields may dominate.

Trading off speed for accuracy, magnetic or electric field probes can be effective tools to speed EMI diagnosis by helping you to find the sources of EMI at the PC board or assembly level. That doesn’t mean that one form of

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testing should be done instead of the other, but rather that they complement each other.

For example, start by identifying the frequencies where emissions are troublesome with a preliminary test of a product prototype in an ALC or OATS. Then, use field probes to explore the near electric and magnetic fields produced by the product and in some cases help identify the specific emissions source. With an understanding of the underlying reasons for the EMI, several possible solutions usually reveal themselves. You can evaluate these design changes using EMI field probes, then clarified with further OATS or ALC measurements. You can then choose the best one or ones that meet product cost goals as well as the EMI goals.

Magnetic Field Probes

Historically, engineers have used all sorts of small loop antennas as near magnetic field probes. One of the simplest is to simply solder a small loop of hook-up wire between the center pin

and shield of a BNC connector.

However, these simple antennas respond to both electric and magnetic fields, making them less effective diagnostic tools than probes designed specifically for electric or magnetic fields.

A more effective near-field probe for characterizing magnetic field sources on PCBs or other electronic structures is the electrically small shielded loop antenna with a balun feed¹. These are essentially identical to direction-finding loop antennas used in the early days of radio, but much smaller. By shielding the antenna and paying close attention to balance, the probe will be more sensitive to magnetic fields and then to electric fields.

The output voltage from an electrically small loop is proportional to a perpendicular incident magnetic field, as shown in Figure 1. Using Faraday's law, this voltage is:

$$V_m = n C B A \cos \theta$$

Where: n = number of turns in loop (typically one for small probes)

C = angular frequency = 2π frequency

B = incident magnetic field

A = area enclosed by loop

θ = angle between perpendicular to loop plane and the B -field vector.

"Electrically small" means the loop is small compared to a wavelength at the frequency of interest, and there is negligible phase shift of the current flowing around the loop. For diagnostic EMC work, matching the probe's impedance to the receiver or spectrum analyzer to which it's connected is not necessary. This is because the equivalent circuit for a small loop antenna is composed of a radiation resistance, the simple ohmic resistance of the loop, and the inductance of the loop. All are usually very small, typically having impedances much smaller than the typical 50- Ω input impedance of most receivers or spectrum analyzers. Consequently, a small loop antenna acts

nearly as an ideal voltage source, and any impedance mismatch can be ignored.

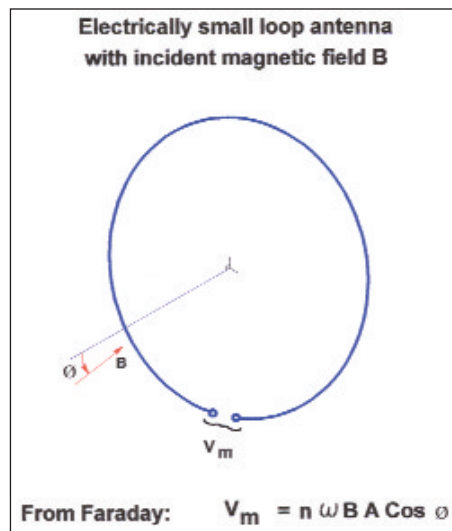


Figure 1: The output voltage from a magnetic field loop probe is proportional to the component of the field that is perpendicular to the loop's plane.

You can either build or buy a suitable magnetic field loop probe for use as an EMI diagnostic tool. As discussed earlier, the loop antenna's electric field response must be minimized. Building a loop probe with an electric field shield, with a small break at one point to keep the circulating currents from shielding the loop from magnetic fields as shown in Figure 2, has been long known to reduce a loop antenna's electric field response.

Electric fields also produce a common mode current from a loop antenna, but magnetic fields produce a differential current. Consequently, a balanced-to-unbalanced transformer, or *balun*, can also be used to further reduce electric field response. A simple common mode choke makes an adequate magnetic field probe balun.

Finally, you should insulate loop antennas that are used as field probes because you may sometimes use them around live circuits. For example, it is common to use loop probes to diagnose EMI in power supplies, where hazardous voltages may exist. Covering the loop antenna with a durable layer of plastic or rubber avoids the problem of accidentally causing short circuits. Liquid rubber dipping material of the sort sold in hardware stores for coating the handles of hand-tools meets this need well.

Electric Field Probes

E-field probes are usually small, untuned, electrically short, dipole-like structures that are sensitive to near electric fields, but not sensitive to magnetic fields. While they can be calibrated to provide reasonably accurate measurements of E-fields, they also can

provide insight about the presence and structure of E-fields even when uncalibrated.

An example of a simple E-field probe is shown in Figure 3. You can make this probe by simply peeling back a portion of the shield at the end of a coaxial cable, but leaving the insulation around the center conductor. Adding a small piece of shrinkable tubing over the end stabilizes the shield and insulates the probe from contact with electronic circuitry. Coating the whole end in plastic is another alternative. This structure is similar to that used for building sleeve or skirt antennas, and is sometimes called a "stub probe." Connect the other end of the coaxial cable to a spectrum analyzer to amplify and display the signal picked up by the probe. In some cases, you can use an oscilloscope instead ².

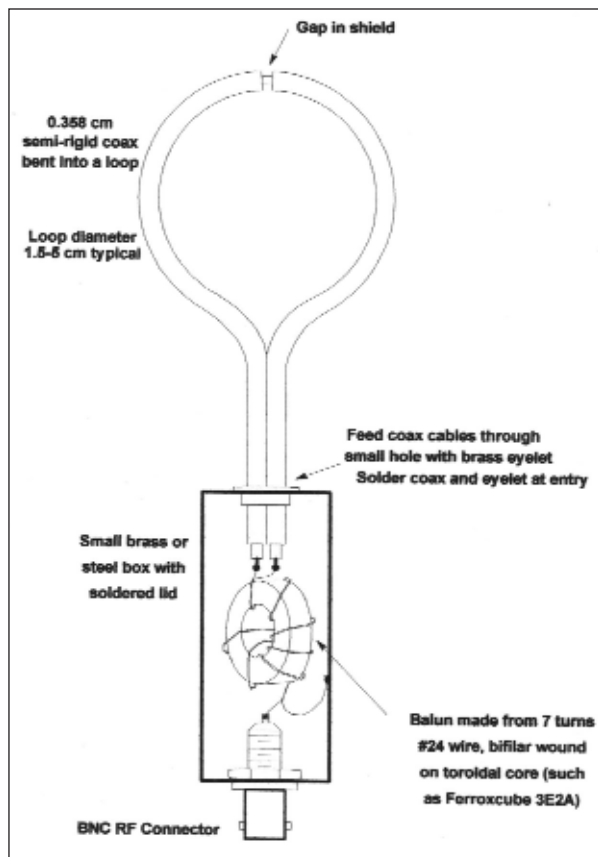


Figure 2: Shielding a loop and using a balun will reduce its response to electric fields without significantly reducing its magnetic field sensitivity.

Using Field Probes To Find EMI

Electromagnetic fields from electronic circuitry are invisible, but magnetic and electric field probes are useful tools to help visualize electric and magnetic field structure and to locate EMI sources. Sometimes these effects are very subtle. It's not always easy to identify or predict what circuit structures will produce RF fields. You can use EMI probes to help find these sources and trace their field lines.

One technique is to use the directional coupling characteristics of a magnetic field loop probe. Loop probes respond to that portion of a magnetic field that is perpendicular to the plane of the loop, as described above. A circuit loop on a PC board produces a magnetic field that is vertical when centered on the circuit loop, but curves over to return to some other part of the PC board.

Another such case is where RF currents flowing in curving paths around an

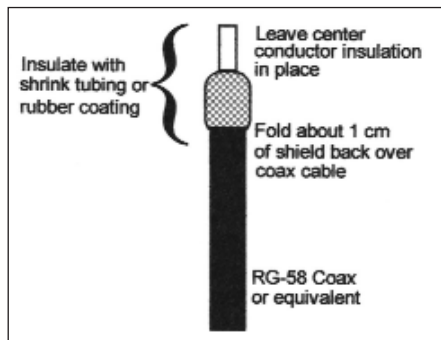


Figure 3: A simple electrical field “stub” probe can be made by simply folding back a small length of coax cable shield over itself.

opening or cutout in an otherwise continuous ground-plane layer of a printed circuit board will produce magnetic fields in the vicinity of the cutout³. These sheet currents flow past the opening or break in curving paths, much the way they would in half-turn coils, producing a small magnetic field. Because the curving is opposite in rotation on each side of the opening, the fields produced will be of opposite

polarity. Invisible flux lines flow vertically from the shield or PC board at the center of the curving currents, then are parallel to the surface between these two points.

Holding a loop probe with its plane parallel to the PC board will allow one to detect these current loops as “hot spots.” Then, turning the loop probe so its plane is perpendicular to the PC board and probing just outside of a “hot spot” should show where the magnetic field bends over to return to the PC board.

Shield leakage will also produce magnetic fields that are easily detectable with a loop probe because the strongest magnetic fields will occur where the shield currents are forced to flow in a curving path, such as near a seam fastener or corner⁴. Search for shield “hot spots” by holding a loop probe parallel to the shield’s surface and probing in the vicinity of seams or other shield breaks. The strongest fields

should be near where the conductivity across the seam is best, such as at a screw or other “tack point,” because this is where the currents are flowing across the seam.

In my experience, it’s more difficult to pinpoint the source of EMI by probing for E-fields than magnetic fields. E-fields are produced by high-impedance sources, where structures are acting like capacitors. That is, some potential difference exists between two electrically conductive points or traces, producing an electric field between them. In electronics circuits, these near E-fields tend to be less precise indicators of an EMI source than do magnetic fields.

While this means that E-field probes may be less useful as EMI diagnostic tools than loop probes, they can still provide useful information. For example, you may discover which pin or wire in a cable bundle is “hot” with RF that may radiate and produce EMI by carefully probing along the pins in a connector with an E-field stub probe.

Using Probes To Test For Immunity

You can also connect magnetic and electric probes to the output of a signal generator to produce fields for EMI immunity troubleshooting. While using probes in this way lacks precision, they are useful tools to find shield imperfections or sensitive points in circuits.

When using loop probes in this way, remember that they are nearly the electrical equivalent of a short, so it is prudent to use the minimum signal generator output that does the job. Adding a 50-ohm resistor in series with the probe should protect the signal generator and limit the current flowing in the probe.

When using probes as field sources, rotate a loop probe or changing the orientation of an e-field probe by 90 degrees to alter the coupling of the field it produces. This can help give you insight into how EM energy is coupling into a sensitive point in a circuit or assembly.

Finding Resonances In Structures

You can use a magnetic field loop probe with a directional coupler, and a spectrum analyzer with an internal tracking RF signal generator as shown in Figure 4, to form an absorption wave meter for locating natural resonances in metallic structures⁵. For example, a structural resonance may be formed by a gap in a shield or a ground plane (which will act as an aperture antenna), or by a cable or PC board trace that acts like a resonant dipole. When excited by RF currents induced in the structure by nearby electronics, these otherwise passive resonant structures may form efficient antennas that can worsen EM emissions.

This phenomenon is particularly troublesome when the structural resonant frequencies coincide with clock harmonics produced by nearby electronics because these harmonics are often strong sources of EMI. When found, you can dampen these resonances (for example, by adding a ferrite to a cable that is resonant) or possibly alter them in some way such that its resonance does not coincide with a clock harmonic. And since structures are often developed in advance of the electronics they will contain, finding structural resonances may allow you to proactively find and address some potential EMI sources long before they become a problem.

The equipment configuration is shown in Figure 4, where the internal tracking generator output is set to follow the spectrum analyzer’s swept input frequency. Feed the output of the tracking generator through a directional coupler to separate the forward and reverse energy. Since a magnetic loop antenna is nearly equivalent to a short circuit, most of the tracking generator’s output is reflected back from the loop. A portion of this reflection is redirected to the spectrum analyzer’s input by the directional coupler.

When you hold the loop probe near a structure that has a natural resonance within the frequencies swept by the spectrum analyzer, some portion of the incident energy is absorbed at the

resonant frequency. At this frequency, a dip appears in the spectrum analyzer's trace because less energy is reflected back from the loop probe. Typically, the spectrum analyzer is set to sweep some interesting band, such as part of the 30-1000 MHz band commonly tested for EMI in commercial products. For convenience, adjust the spectrum analyzer's reference level so the reflection from the loop probe traces a line near the top of the analyzer's screen.

Once you have configured the equipment to make this measurement, use a methodical strategy to find structural resonances and their proximity in frequency and physical distance to potential excitation sources. For example:

1. This effect is subtle and can easily be missed, so you should set the spectrum analyzer's vertical sensitivity to 1 dB per division and set the frequency span no larger than

necessary, such as 100 MHz to start. Step these spans in frequency until you have searched all frequencies of interest. Finally, move the loop probe very slowly as you probe around the structure.

2. Make a list of every structural resonance found, taking note of its frequency, physical location, and if the resonance is sharp and narrow or broad.
3. Using a spreadsheet, make a separate list of all clock frequencies and harmonics produced by the associated electronics. Add the structural resonance data in separate columns, listing the resonances alongside the nearest potential clock harmonic frequency.

Where structural resonances and clock harmonics coincide, anticipate strong EMI from the finished product. When these situations occur, find ways to make these radiating systems inefficient in case you need them later. For

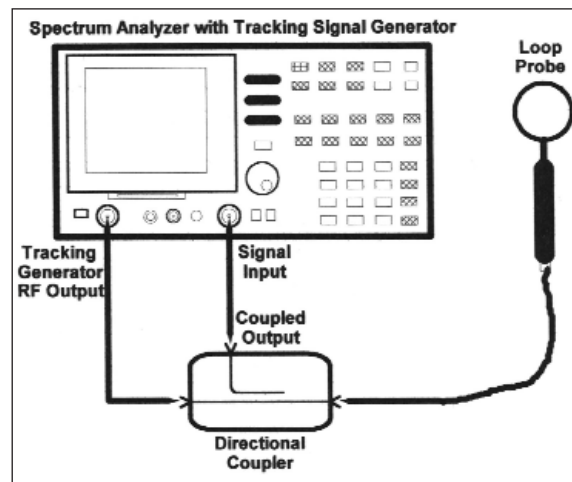


Figure 4: A spectrum analyzer with an internal tracking RF generator can be used with a directional coupler and loop probe to explore electronic assemblies or structures for natural resonances.

example, you can reduce most of this EMI by either dampening the resonance, moving the resonance frequency away from the excitation frequency, reducing the magnitude of the excitation currents, or some combination of all of these.

Conclusion

Electric and magnetic field probes can be very helpful EMI diagnostic tools, not only to find sources of EMI, but also to anticipate EMI problems. While the information is sometimes imprecise and qualitative, using EM field probes can contribute valuable insight that can make the difference in keeping a product's development schedule on track. ■

About The Author

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