Near-Field Methods of Locating EMI Sources

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The near-field test is a valuable tool in EMC pre-compliance. This article is a brief overview of the fundamentals of the near-field measurements and a practical note of where and how the test should be applied.

Virtues of the Near-Field Testing

Most engineers and managers in the manufacturing business would rather not know anything about electro-magnetic compatibility (EMC). But this is where the Federal Government steps in to help. In most countries, no electronics product may be sold unless it complies with the requirements of the local governmental EMC agency. Many previously exempt industries, such as medical, etc., now have to enter the world of compliance. The radiated EMI compliance test is clearly defined in FCC p.15 and many other international and military standards and regulations. The specifics vary slightly, but the principle is the same: the product under test is placed at some distance from a well-defined antenna and the amount of radiation is measured across the required frequency band. In other words, the measurements are done in the *far field*. Testing in the far field means that the receiving antenna is placed at a sufficient distance from the product under test where the radiation irregularities resulting from the product's complex geometry are added together and are measured as a whole. In essence, the far field test can tell whether the product passes or fails as a whole but it cannot point the source of a problem. Using only the far-field test, one cannot tell whether an opening in the metal enclosure "leaks" too much radiation or a cable connected to the product carries too much RF energy that gets radiated. It is similar to trying to find out what specifically makes a noise under the hood of a car from a distance of 10 feet. One can guess that it might be a belt by its "signature" squeak, but which one out of three or four is impossible to tell. Of course, a diligent mechanic can replace all the belts just in case, taking too much time and running repair costs too high, but what if at the end it may not be a belt at all?

In order to locate the source of the problem, why not come closer to the car and take a look? As with the car, electronic assemblies also need "close up" inspection. Unfortunately, far-field antennae won't be able to help -- they are just too big for the job. The right tool is called a *near-field* probe. It can identify the exact sources of emissions down to a component or a trace. With its help the whole product can be scanned in a matter of minutes and the leaks and problematic areas can be located on the spot.

The disadvantage of the near-field probe is that there is very little correlation between near-field and far-field measurements. This is due to the complex geometry and uneven radiation patterns of the tested product. However, one thing is certain: the higher the radiation level in the near field, the higher it is in the far field. Therefore, tests performed in the near field give designers a "feel" of how the product will behave in the far field test. The near-field test can "map" the electromagnetic field around the product, easily identifying spots with high radiation levels. Designers can then make changes to either eliminate or contain the emissions.

Near-Field Primer

The measurements done for agency approval are performed at a distance of 3m or 10m. At these distances, the nature of the electromagnetic field is determined by the source, and the distance from the source. The properties of the material between the source and the point of measurement (in our case it is only air) also influence the reading.

As the test probe gets closer to the source, the nature of the electro-magnetic field changes. Near the source of radiation the field produced is mostly a function of the properties of the source. If the field is generated by an object with high current and low voltage, the field produced will be *magnetic* in nature, or H-field. If the source has high voltage but little or no current, the resulting field is *electric*, or E-field. The electromagnetic field can be characterized by its wave impedance.

Just like Ohms law stating that $R=\frac{V}{I}$, the wave impedance Z_W is a ratio of the values of the electric and magnetic components of a particular field. At any given point, the wave impedance is:

$$Z_W = \frac{E}{H} \tag{1}$$

It is important to remember that there is no such thing as a purely electric field or a purely magnetic field. A conductor with a substantial current causing an H field still carries some small voltage that creates an E field, albeit small in magnitude. Similarly, an antenna or an unterminated wire still carries some current via parasitic capacitance to ground.

As seen from the equation above, predominately magnetic (H) fields are characterized by low wave impedance, while mostly electric (E) fields have very high wave impedance.

The distance from the source also factors into the wave impedance equation. Electric and magnetic fields attenuate as this distance increases. Each field begins to produce its complementary field. As a result of this, the wave impedance changes with the distance from the source. For an H-field, the wave impedance increases with the distance from the source, for an E-field, the wave impedance decreases. The formula for a magnetic source is:

$$Z_W = 120\pi \frac{r}{\sqrt{r^2+1}} \tag{2}$$

and for an electric source is:

$$Z_W = 120\pi \frac{\sqrt{r^2+1}}{r} \tag{3}$$

where r is the distance from the source.

At some distance from the source, called the transitional region, both fields will end up with the same wave impedance that thereafter stays the same. This wave impedance, called the characteristic impedance, is the property of the media in which the field is propagated. For air, this impedance is 377Ω. As seen from the equation above, a constant wave impedance means that the ratio of E and H fields beyond the transitional region becomes the same for all types of fields regardless of how they began. The field before the transitional regional is called the near field (or Fresnel region), and the field beyond it is called the far field (or Fraunhofer region).

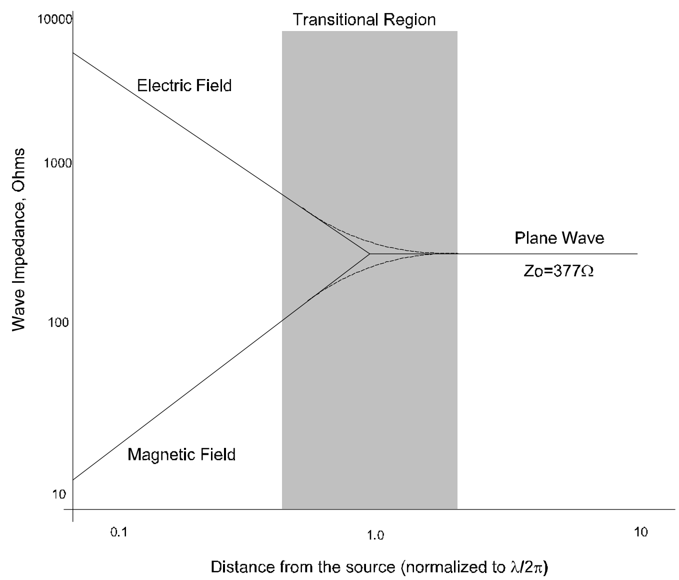


Figure 1. Wave Impedance as a Function of a Distance

Figure 1 shows the transition from the near field to the far field. As seen, in the near field each component has to be considered separately.

The transition zone lies at a point of:

$$r = \frac{\lambda}{2\pi} \tag{4}$$

where r is the distance from the source; λ is the wavelength of the signal.

Figure 2 shows how far the transition zone is from the source as a function of signal frequency. As seen, for the frequencies of interest (30MHz to 1GHz) all radiated compliance tests (classes A and B) are conducted completely in the far-field.

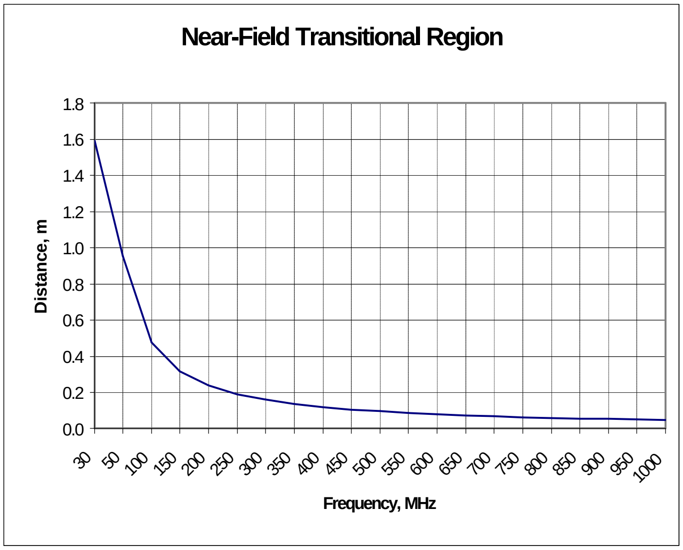


Figure 2. Transitional Region as a Function of Frequency

The Validity of the Near-Field Measurements

Our interest is in compliance measurements. As discussed above, far-field measurements performed at the final compliance test do not help in locating the source of the problem. Near-field measurements are the only way to pinpoint sources of offensive radiation. But how good and reliable are these tests and how to interpret their results?

Since near-field readings are greatly dependent on the geometry of the source and its properties, any attempt to provide correlation between measurements performed in the near field to those done in the far field will not deliver usable results. The only correlation is that, in general, the stronger the field near the source, the stronger it will register in the far field. In addition to the basic correlation problem, the following issues haunt the precision and repeatability of near-field measurements:

- Small movements of the near-field probe may produce much greater relative change of distance from the source *r* than the same absolute change in the far-field. Readings of the field strength will be affected accordingly.
- A near-field probe has finite dimensions. Slight repositioning of the probe vs. the device under test (DUT) may put the near-field antenna in a place where the geometry of the DUT alters field strength readings, thus rendering repeatability of the measurements next to impossible.

There are just too many variables to make the numerical results of near-field tests trustworthy. Of course, one could "calibrate" the near-field probe and produce an elaborate specification of its performance.

If the readings taken with the near-field probe cannot be trusted, what are the benefits of using it? This question may especially intrigue those engineers used to precision in measurements. The answer is simple: the near-field test provides only relative results. The near-field test can show where the emission is stronger and where it is weaker and what type of field is dominant (i.e. what specifically is causing it). With the help of the near-field test, experience and intuition one can easily isolate the source of the problem and take actions to solve it.

Types of Near-Field Probes

H-Field Probes

The magnetic, or H, field is caused by current. Examples of H-field sources are PCB traces with relatively high current, terminated wires and cables, etc. Sometimes, an H-field is generated by currents in the metal enclosure where it was induced by high-level EM radiation from the circuit board inside.

Appropriately, the sensing element of an H-field is a simple coil which is inductively coupled to the emitting trace or wire. An example of such a probe is shown in Figure 3. The H-field probe is connected to a spectrum analyzer via a cable or is incorporated into a self-contained device.

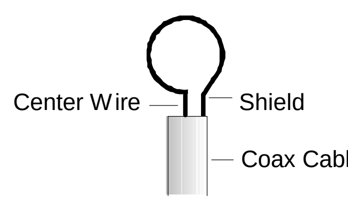
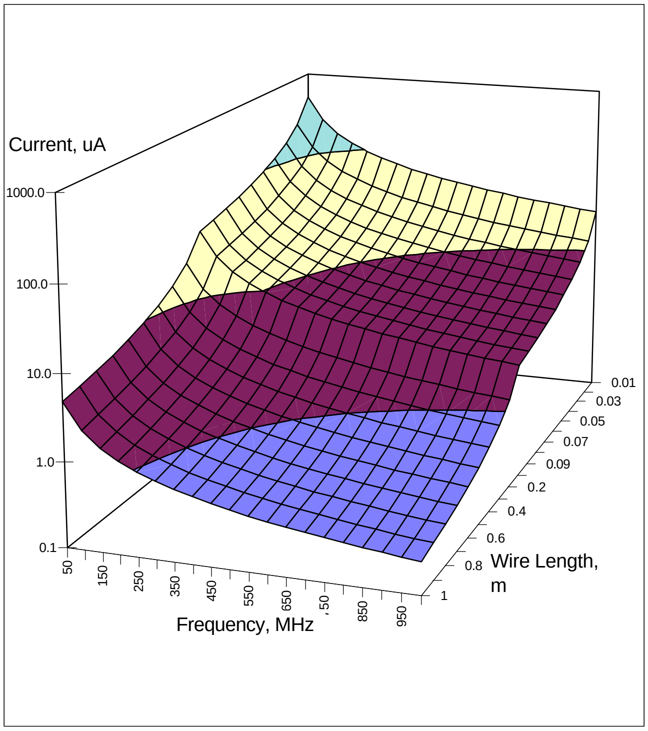


Figure 3. Simplest H-Field Probe

The H-field probe provides maximum output when its loop is aligned with the current-carrying wire and is in immediate proximity to it. Both these features serve the purpose of locating exact sources of radiation. Using the directional properties of the H-probe, the user can actually follow the wire or trace with the excessive radiation. By rotating the probe, the traces with little or no radiation can be exempt from suspicion.



An important thing to know is that not every spectrum analyzer or voltmeter has a full-wave rectifier. A practical implication of this is that a typical H-probe may produce different results at 180^0 rotation. Not recognizing this fact can lead to ignoring important sources of strong radiation. Some H-field probes have two coils positioned in opposite directions and a balun transformer. Such a probe has much better bi-directional properties.

The diameter of the loop determines several important parameters: sensitivity of the probe, its frequency response, and the ability to identify exact sources of emission. The larger the diameter of the loop, the more magnetic field flux lines the loop will cross and the better the inductive coupling will be with the offending wire. This results in higher sensitivity of the larger loop. At the same time, a large loop may not be able to differentiate between several traces, nor to tell which one is the culprit. The large loop has higher inductance that the smaller one. It leads to the loop's lower resonance frequency beyond which the loop is unusable. Some manufacturers produce a kit of several H-probes suited for different frequency bands. The ideal case, however, would be a small loop with sufficient sensitivity as it would satisfy the major requirement: the ability to locate sources of radiation within the required frequency band.

Even a small current in a conductor can produce a noticeable electro-magnetic field if the conductor is sufficiently long. The field strength can be calculated as:

$$E = 1.25\ \frac{Ifl}{r} \qquad (5)$$

where E is field strength, µV/m
I - current through the conductor, µA
f - signal frequency, MHz
l - length of conductor, m
r - distance from the conductor, m

Figure 4 shows what current strength will produce a field of 100µV/m at a distance of 3m as a function of signal frequency and conductor length. As seen, a near-field H-probe that can reliably detect 5µA is well suited for the job.

E-Field Probes

The electric, or E field is caused by voltage. Examples of E-fields are unterminated cables and wires, PCB traces leading to high-impedance logic, whether it be high-impedance inputs or tri-state outputs of logic ICs.

A most common home-grown E-field probe for the near-field is very simple - it is just a piece of short wire extending from the shielded coaxial cable, as shown in Fig. 5. The smaller the antenna (the extended piece of the central wire), the easier it would be to pinpoint the exact source of radiation. Sensitivity, however, will suffer. The sensitivity of the near-field probe/spectrum analyzer combination is important not in absolute numbers, but rather in the strength of the field it is able to detect. A typical near-field probe is usually attached to the spectrum analyzer. A probe combination that can detect electric field with a strength of ~5 mV/m is adequate for use with equipment that is to be certified for FCC class B. A less sensitive probe combination will miss important

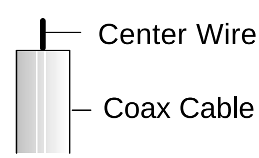


Figure 5. Simplest E-Field Probe

emission sources, while one too sensitive can prompt a panic situation where even a quite lame and insignificant emission spot will be treated as an emergency.

Points of Interest

A near-field test can do the following:

- pinpoint the exact location of a component, circuit area or trace with high emission levels
- predict radiated EMC test results
- pre-test your product prior to the official compliance test in order to identify potential problems early
- quickly troubleshoot a product which failed the compliance test
- find EM leakage on enclosures, cables and connectors
- find sources of interference preventing a product from functioning properly.

It is very important to use near-field probes properly and to correctly interpret the results. Nothing can substitute for hands-on experience with actual near-field probes and with correlating the results of the far-field test with near-field measurements. However, there are some notes of interest that may help in near-field tests.

There is seldom an exclusively electric or an exclusively magnetic field. Always use both probes in order to understand the nature of emission and what you are fighting against. As an example, if a PCB trace generates response only in an E-probe, but not in an H-probe, it is probably an electric field. However, it is unlikely to find many occasions where only an H-probe is affected. Usually, if the trace emits a magnetic field, an E-field is also present. This happens because traces almost never carry current with very little voltage.

High-level radiation registered with the near-field probe is not necessarily an indication of a problem in the far field. Just the opposite could be true -- the near-field probe may not show the field strength of the area which is the cause of the compliance failure. In order to understand why, one needs only to realize that in the near field the probe picks the signal only at a particular spot, while in the far-field the field strength greatly depends on the antenna properties of the radiating object. As an example, a short trace on the PCB with a strong emission level may be much less dangerous than a longer one with a lower emission level. A single small-size strong emission leak from an otherwise shielded enclosure may be much less dangerous than "lukewarm" radiation from a large area or around a long seam in the shield.

If the offending frequency is well-known and if the field carrying it is not the strongest one in the product, a spectrum analyzer will be needed. If the probe is used in the early stages of development where it is not yet clear what frequency will be of concern, a simple broad-band level indicator will do an adequate job. In many cases it may actually do a better job than a spectrum analyzer in searching for the highest emission level, since the spectrum analyzer may not provide a total signal level in the band readings. It is difficult to subjectively judge it by looking at the screen.

Case Study: Determining Shielding Needs

Place the PCB assembly into an enclosure. The prototype will do since this is the time to decide on the shielding needs. Power it up. Pass the near-field probe over all external surfaces of the enclosure. Notice where the emission is the strongest.

If there are only one or two strong emission spots and the rest of the product is relatively quiet, then placing localized small shields over these spots may suffice. If there is a mild or high radiation level over a broad area, more comprehensive shielding may be needed. After the shielding is prototyped, repeat the scan. The near-field test will tell you whether the shielding did its job. Good shielding will reduce the near-field emission down to a background level. Sometimes more than one iteration of a shield's configuration may be needed. After the decision on one or two types of shielding is made, the product needs to go to a certified lab for a far-field test. This test will show whether the shielding did its job adequately and the shield design can be finalized at the prototype stage.

Without the near-field test applying shielding is somewhat like "flying blind." As a result, more than one trip to the lab could be needed, with its increased cost and loss of precious time. The near-field test helps design proper shielding at a much earlier stage in product development, saving both time and money.

Timing is Everything

There comes a time in the design of many an electronic product when it is taken to a certified laboratory for EMC testing. The result of this test determines whether the product can be shipped or needs to be redesigned in order to comply with the regulations. Such a time comes at the worst possible moment in the schedule -- the product is fully designed and debugged, the prototype is assembled, materials for inventory have been ordered, production is planned, Marketing and Sales are loitering in the engineering quarters trying to glean how soon they can begin selling the product, and time is running out. Every day of delay can cost a company thousands (or even millions) of dollars in revenues. It is inconceivable for upper management that such an insignificant engineering procedure as an EMC compliance test can actually bring the whole operation to a halt, should the product fail the test. It is even more surprising to many that the last minute "quick fix" for the compliance problems may raise the cost of the product several dollars, ruining revenue plans, profit objectives, etc.

Since EMC compliance is almost never considered to be among the prime objectives of product development, it is seldom given enough attention. Typically, an EMC test is not a part of the plan, but rather a scheduled event somewhere at the end of the project. Yet, if one is to calculate the damage non-compliance could bring to a business, surely the bright minds in a reasonable company would assign it a very high priority from the very beginning. The wasted time due to "unforeseen" EMC problems could be weeks, if not more. The thousands of dollars spent on unnecessary tests and revisions of the prototype at the last moment fades in comparison to the lost revenues due to a schedule slip and the cost of added unplanned EMC protection parts to every shipped unit. As *Wall Street Journal* reports in its Aug. 5/94 issue, Compaq had to delay shipment of their *Elite* line of notebook computers from March to June due to the FCC compliance problems. How many companies can absorb such impact on revenues?

Smooth and timely passing of the EMC compliance test without "emergency" expenses is almost never an accident; it is a result of a good planning. The earlier electromagnetic compliance enters the scene, the fewer surprises will be waiting at the end. Most of the factors determining the EMC fate of the product are decided upon at the earliest stages of design: the product's physical architecture, the number of the PC boards in the product, the required cable interconnects, the number of layers in each board, the number of different clocks and the clock frequencies, the type of enclosure and its material, etc. Most of these decisions will be made far ahead of having a fully working system that is testable for compliance. Some large percent of guesswork is unavoidable. But having the right tools for the job can dramatically reduce the pure guesswork down to educated estimates, and further, to some level of confidence.

The standard far-field compliance test for radiated emission is not well suited for the early stages of product development. The first prototype board is seldom the same as its final version; cable assemblies are spaghetti-like; and the enclosure is nowhere in sight. Furthermore, the far field test cannot tell where to look for the problems.

The near field test can become the perfect tool for early pre-compliance work. Performing a near-field scan on the very first revision of the PC board can reveal future "hot" spots at the time they can be made harmless at the lowest cost. Traces can be re-routed, ground planes added, filter components, such as ferrite beads, etc. can be accommodated. Early knowledge of the radiation patterns can tell the mechanical engineer exactly where to prepare to accommodate shielding, should it become necessary. This alone can save hundreds of thousands of dollars in last-minute tooling changes.

Early detection can not be achieved with only the far-field test. No one would be able or willing to take early prototypes to the EMC laboratory for routine diagnostics. As for the financial aspects, a full-blown far-field setup on site may cost a prohibitive amount of money. On the other hand, near-field probes can be purchased for as little as $600, and can and should be as common for an electronics engineer as a multimeter or an oscilloscope.

ScanEM® Probes -- The Right Tool

Credence Technologies manufactures fully self-contained near-field EMI probes: ScanEM®-EC for detecting electric fields and ScanEM®-HC for detecting magnetic fields. In self-contained mode, ScanEM probes do not need a spectrum analyzer or any other equipment to operate and require no cords. Each probe weighs ~2 ounces (57g), and is powered by two AAA batteries that are included with the product. ScanEM-EC uses a small monopole antenna, and ScanEM-HC employs 1/4" (~6mm) diameter coil. The probes can locate sources of emission of very small size -- often down to a single pin of the connector or a single trace on the PC board, or a wire in a cable assembly.

Since in the beginning of product development it is not entirely clear which frequency may cause problem at the compliance test, ScanEM measures field strength in a broad band. ScanEM-EC has a frequency response from 2MHz to 2GHz, though it was reported by customers to perform well up to 3GHz. ScanEM-H works between 1MHz and 1GHz.

ScanEM probes do not provide absolute values of the field strength. Absolute numbers bear little significance in the near-field measurements. Rather, ScanEM probes provide relative field strength data.

In order to have real-time response, both ScanEM probes have a 5-LED level bar with resolution of ~1dB/LED. In addition to visual indication, both probes are equipped with a speaker that produces a tone with the pitch dependent on field strength. Since the human ear is extremely sensitive to differences in the pitch of sound, the slightest change in field strength can be observed by listening, without looking at the probe's display. The sound can be disabled with an easily accessible switch.

In order to accommodate for various field strengths, ScanEM probes have a Level dial that can set the background level over a broad range of amplitudes. The user would bring ScanEM to an area where emissions are considered to be at a background level. The Level dial would be then adjusted so that only the first (green) LED is on. After that, the suspected areas of the product would be scanned. The LED level bar and the pitch of the sound show deviations in field strength vs. the set "background" level. If the field strength at any point is lower than the background level, ScanEM will be quiet and the lights will be off (squelch mode). This squelch feature allows ScanEM to react only to fields stronger than the preset background level. This accelerates search for the "hot" emission spots.

The momentary power button provides power to ScanEM only when depressed. This prevents accidental battery discharge.

It should be clear that ScanEM probes do not attempt to be a replacement for a spectrum analyzer. However, ScanEM probes provide essential functionality for near-field testing at a minimum cost and with great convenience.

ScanEM probes are very easy to use and require virtually no training. Each probe is about the size of a candy bar and fits easily inside a shirt pocket.

ScanEM are available as a kit. The ScanEM probes kit model CTK015 includes both ScanEM probes, RF cable for connecting to a spectrum analyzer or an oscilloscope along with a handy, durable plastic case. ScanEM probes are made in the U.S.A.