Applications of HF Current Probes

There are many applications for high-frequency (or RF) current probes, besides simply measuring RF currents in cables. Here are a few advanced applications. First, let's look at the concept of transfer impedance.

TRANSFER IMPEDANCE

Transfer impedance is simply the voltage at the probe port divided by the current in the measured wire or cable. In other words, the CM current (Ic) in microamps in the conductor under test is determined from the reading of the current probe output (V) in microvolts divided by the current probe transfer impedance (Z_t) in Ohms.

$$\mathbf{Ic = V/Zt \quad (1)}$$

or, in dB

$$\mathbf{Ic(dB\mu A) = V(dB\mu V) - Zt(dB\Omega) \quad (2)}$$

The typical transfer impedance of the current probe throughout the frequency range is determined by passing a known RF current (Ic) through the primary test conductor and noting the voltage (V) developed across a 50-Ohm load. Then,

$$\mathbf{Zt = V/Ic \text{ (in standard units)} \quad (3)}$$

or

$$\mathbf{Zt(dB\Omega) = V(dB\mu V) - Ic(dB\mu A) \quad (4)}$$

The Com-Power CLCE-400 probe is a commonly used troubleshooting tool and has a flat frequency response from 100 kHz to 400 MHz (Figure 1). The transfer impedance is about 7Ω (approximately +5 dBΩ on the graph), therefore, a 1 mA current will produce a 7 mV output voltage from the current probe.

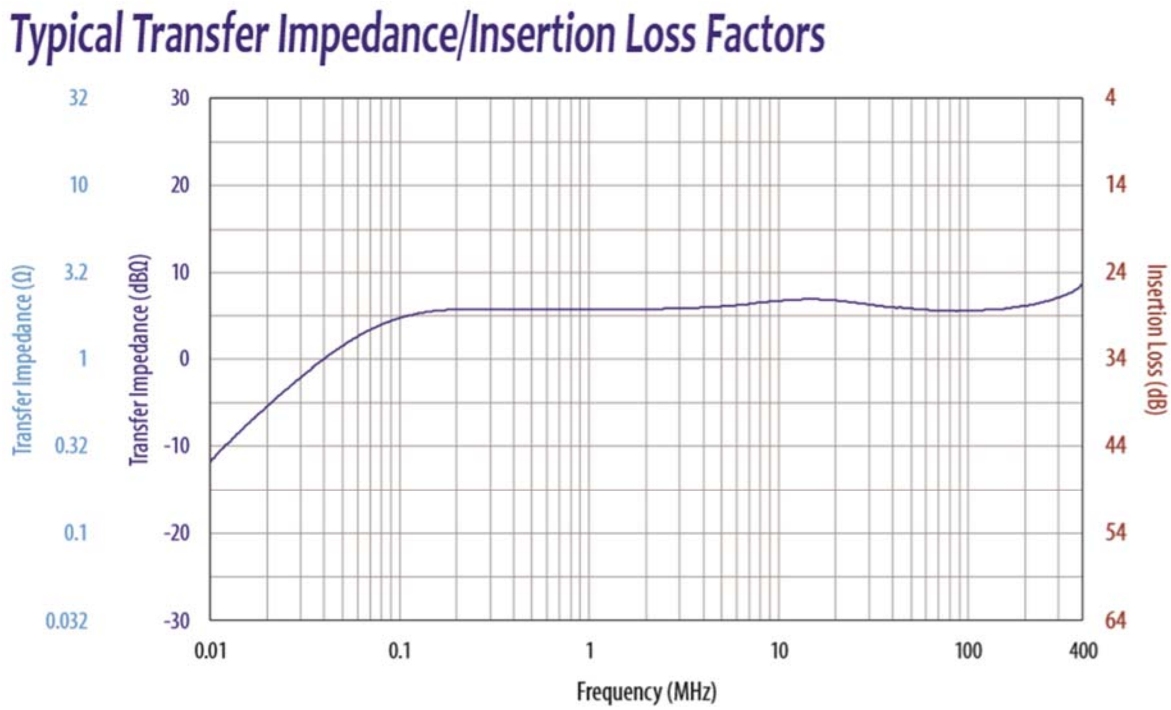

Figure 1 - Transfer impedance (Zt) graph of the CLCE-400 current probe. The x-axis is frequency, while the y-axis is dBΩ, Zt(Ω) or insertion loss (dB). Use this to calculate the value of Ic (Equation 2), given the measured voltage at the probe terminals V(dBμV) and Zt.

APPLICATION 1: PREDICTING PASS/FAIL

It is possible to predict whether a particular cable will pass or fail radiated emissions by measuring the CM current at the offending harmonic frequency, reading the transfer impedance of the probe, Zt (dBΩ), and solving for Ic (using Equation 2 above). Plugging Ic (Amps) into Equation 1 will calculate the E-field level in V/m. The length of the cable is L(m) and the offending harmonic frequency is f(Hz). Use a test distance, d, of either 3 or 10m to predict the outcome at those test distances and to compare to test limits. This equation is valid for electrically short lengths of L.

$$\left|\hat{E}_{C,max}\right| = 1.257 \times 10^{-6} \frac{|\hat{I}_C| f L}{d} \qquad (1)$$

Where: *Ec* is the E-field (dBμV), *Ic* is the measured harmonic current (A), *f* is the harmonic frequency of concern (Hz), *L* is the length of the cable (m) and *d* is the test distance from antenna to EUT (according the EMC test standard (often 3m or 10m). Refer to Reference 2 for more.

Once you've determined a particular cable has CM currents that may cause a RE failure, you should to examine the connector where the cable is attached to the product enclosure. Very often the issue is a poor or non-existent bonding between the connector shield and enclosure shield. These points must be bonded well to permit the CM currents to flow back to their source within the product, avoiding associated cable radiation.

This lack of bonding occurs especially if the connectors are circuit board mounted and penetrate loosely through the shielded enclosure. Poorly bonded connectors allow internally-generated CM currents to leak out and flow on the outside of I/O cables. If these currents are allowed out of the enclosure, the attached cables will act as radiating antennas – often resonating around 100 to 300 MHz, due to their typical 1m length. Please refer to the references for more information.

APPLICATION 2: MEASURING CM VERSUS DM CURRENTS

When faced with excessive conducted emissions from switching power supplies, one of the first things to investigate is to determine the adequacy of is the power line filter. Line-powered switching supplies generally have both common mode (CM) and differential mode (DM) sections of the filter as shown in the generalized schematic in Figure 2. Many DC power converters may only have a differential mode filter, typically a "PI" topology. This will do little to filter common mode currents.

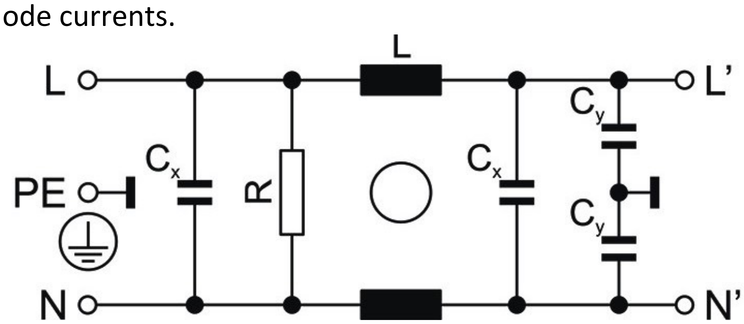

Figure 2 – A common form of power line filter. The common mode inductor, L, and capacitors, Cy, are the common mode filter components and the Cx capacitors filter differential mode. Resistor, R, ensures the stored voltage across Line and Neutral discharge safely when the line cord is pulled from the outlet socket. Figure, courtesy Schurter Group.

To measure conducted emissions in the power line, we use a line impedance stabilization network (LISN). For example, Com-Power's model LIN-120C (Figure 3) would work for most mains voltages from 90 to 270 VAC. With a LISN, we are actually measuring the vector sum of the common mode and differential mode conducted voltages.

Figure 3 - An example of Com-Power's most popular LISN, the model LIN-120C.

When troubleshooting conducted emissions issues, one method is to separately break out the DM and CM emissions by using a current probe. Note that this is not directly comparable to the LISN measurement, which is a voltage, but it will still provide some useful information on which mode is noisiest.

We're all probably familiar with the procedure for measuring CM currents. We simply clamp the current probe around both line and neutral wires and make the measurement (Figure 4). Remember, CM currents flow out both wires in the same direction and normally ends up radiating out as well as conducting back into the mains. This is shown in the yellow trace of Figure 10 below.

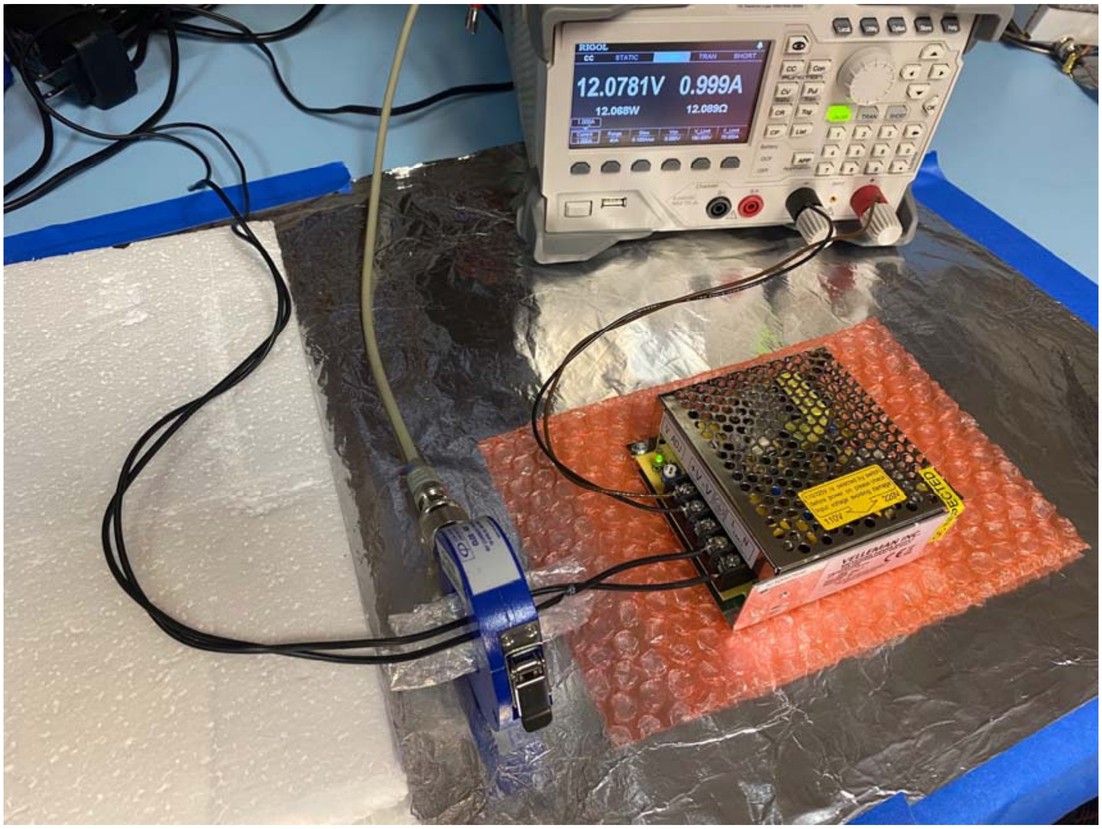

Figure 4 – Measurement of common mode currents in both the line and neutral wires. Stuffing some insulation around the wires keeps them from touching the metal case of the current probe and affecting the measurement.

On the other hand, to measure DM currents and cancel out the CM currents, we need to configure the wires such that they feed through the current probe in opposite directions (Figure 5). This cancels the CM currents. Note that when we do this, the voltage reading will be twice the actual DM current (6 dB higher). This is shown in the violet trace in Figure 6. We must also be careful not to exceed the maximum current rating for the probe. For the case of the CLCE-400, this is 100A (DC to 400 Hz).

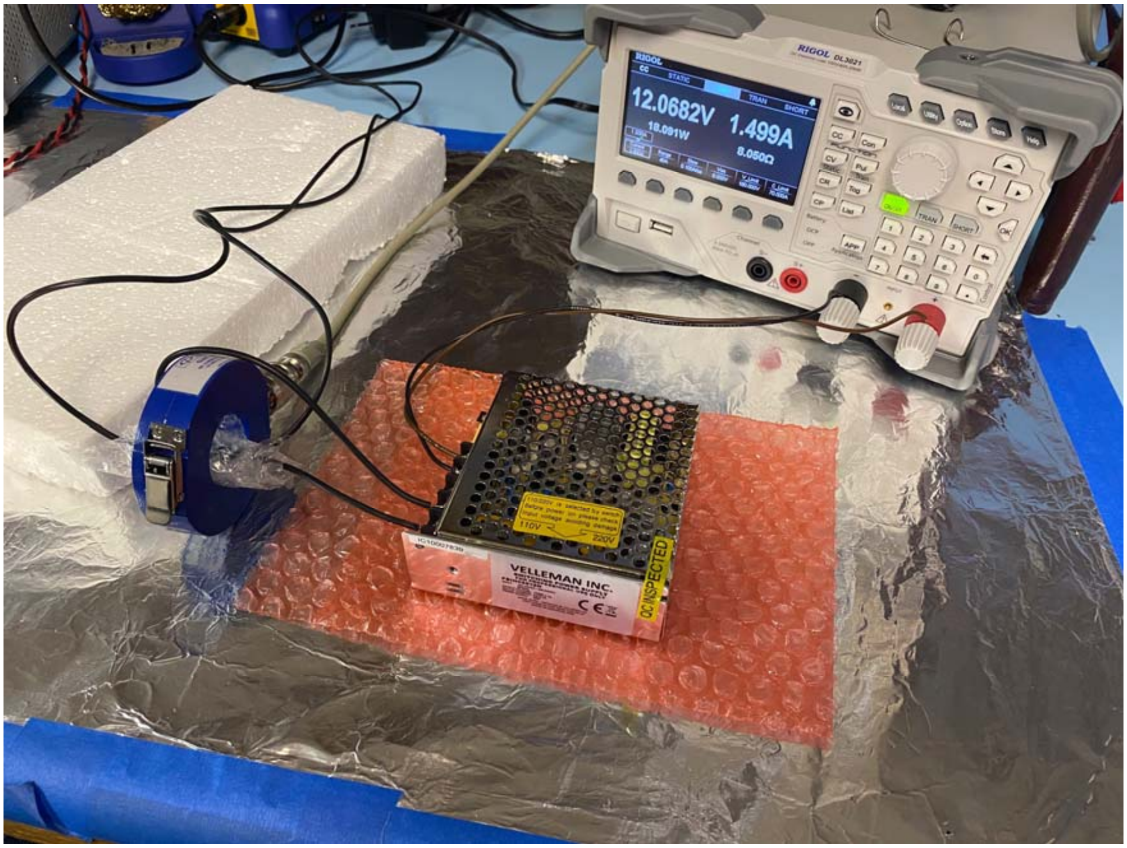

Figure 5 – Configuration of the wires to measure differential mode currents.

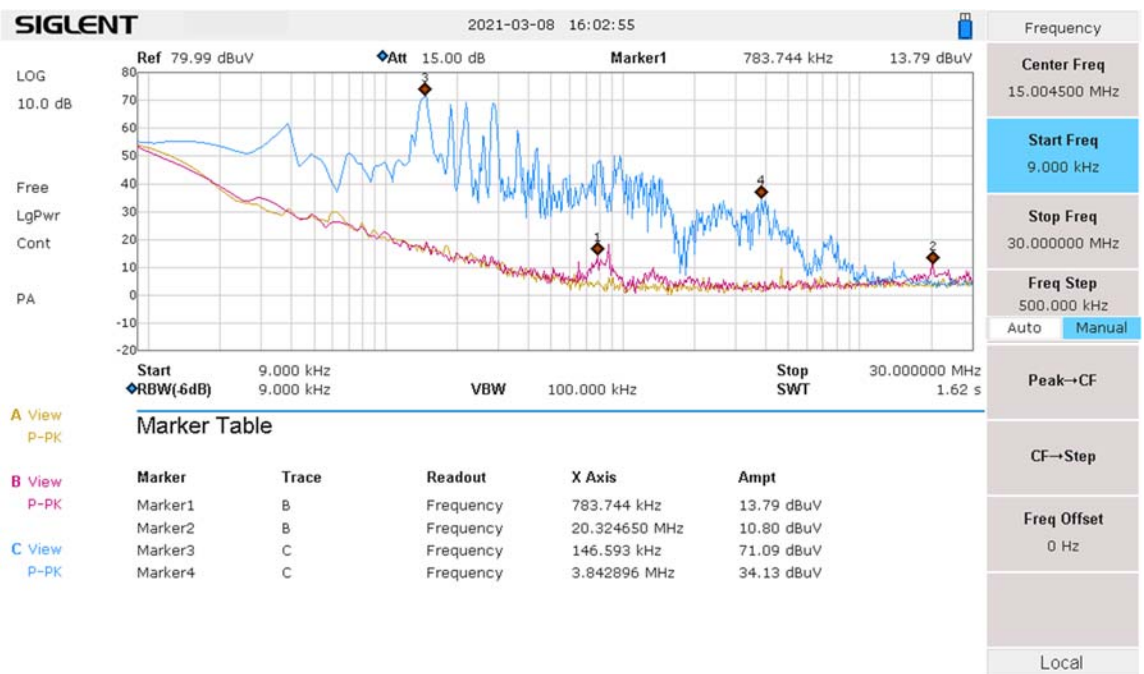

Figure 6 – A measurement of ambient noise floor (yellow trace), common mode (violet trace) and differential mode (blue trace) using a current probe. Note how the differential mode contains the dominant noise current.

Note that in Figure 6, we see that the DM currents are substantially larger than the CM currents. The fundamental switching frequency for this power supply can be observed as 146 kHz (Marker 3). Higher-order harmonics of the switch frequency are also present. This suggests the CM section of the line filter is adequate, while the DM filtering could use some additional work.

For example, a small series inductor in the line side would provide more impedance for the X-capacitor (Cx) to work with. An alternative would be to increase the differential mode inductance of the common mode choke. Increasing Cy will not likely be an option, because this will increase the leakage current to chassis, which could exceed the 3.5 mA maximum as dictated by most product safety standards.

This technique of isolating the common mode and differential mode components of conducted noise currents may be a valuable tool for your troubleshooting toolbox. The Würth Elektronik (WE) 744 998 filter design kit includes several unpopulated boards with a variety of filter components and makes a handy tool for evaluating different filter designs (Figure 7).

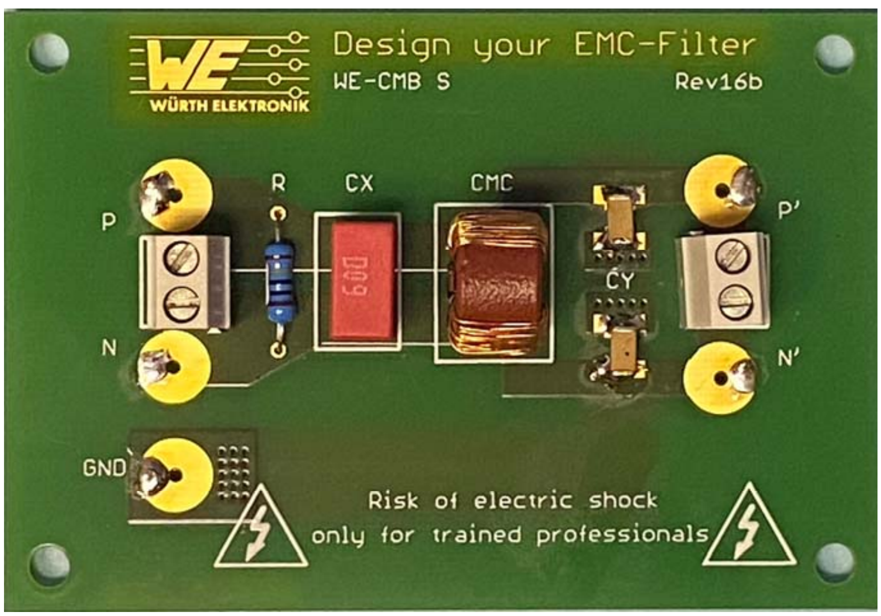

Figure 7 - This is the filter board from the Würth Elektronik filter kit with components added to suppress conducted emissions in the range 10 kHz to 30 MHz.

APPLICATION 3: TROUBLESHOOTING RADIATED EMISSIONS (THE 3 STEPS)

The current probe is used in Step 2 of the process below and can greatly speed up troubleshooting of radiated emissions issues. This three-step process for troubleshooting radiated emissions has proven itself time and again and can be performed right on the lab bench.

Step 1 - Near Field Probing

Most near field probe kits, such as the Com-Power model PS-400 or PS-500, come with both E-field and H-field probes. Deciding on whether to use an H-field or E-field probe depends on whether you'll be probing currents - that is, high di/dt - (circuit traces, cables, etc.) or high voltages - that is, dV/dt - (switching power supplies, etc.) respectively. Both types of probes are useful for locating leaky seams or gaps in shielded enclosures.

Start with the H-field probe (Figure 8) and sniff around the product enclosure, circuit board(s), and attached cables. The objective is to identify major noise sources and specific narrow band and broadband frequencies. Compare the harmonic frequencies with known clock oscillators or other high frequency sources.

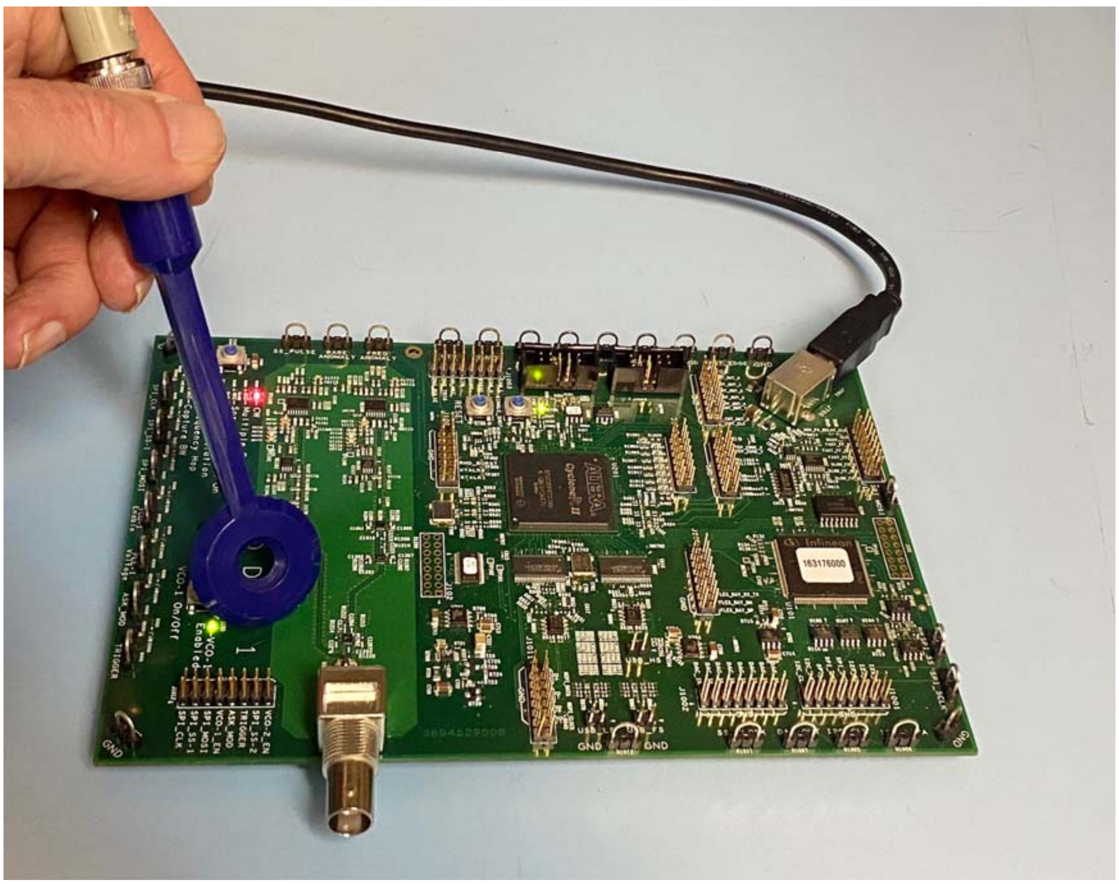

Figure 8 - A near field probe is used to help identify potential sources of emissions.

Step 2 – Use a Current Probe to Measure Cables

Next, measure any attached I/O or power cables with a current probe (Figure 9). It’s a good idea to slide the current probe back and forth to maximize the largest harmonics. This is because some frequencies will resonate in different places, due to standing waves on the cable.

Document the locations of the top several harmonics and compare with the list determined by near field probing. These will be the most likely to actually radiate and cause test failures, because they are flowing on antenna-like structures (cables).

Use the transfer impedance chart to calculate the actual current at a particular harmonic frequency. Then use the equation in APPLICATION 1 above and calculate the expected E-field (dBμV) and compare with the test limits according to the appropriate EMC standard for your product to determine a first-order "pass/fail". Note that it only takes 5 to 8 μA of high frequency current to fail the FCC or CISPR Class B test limits.

Figure 9 - Use of a current probe to measure high frequency currents flowing on I/O and power cables.

Step 3 - Troubleshooting with a Close-Spaced Antenna

Once the product's harmonic profile is fully characterized, it's time to see which harmonics actually radiate. To do this, we use an antenna spaced at least 1m away from the product or system under test to measure the actual emissions (Figure 10). Typically, it will be leakage from attached I/O or power cables, as well as leakage in the shielded enclosure. Compare this data to that of the near field and current probes. Can you now determine the probable source(s) of the emissions noted?

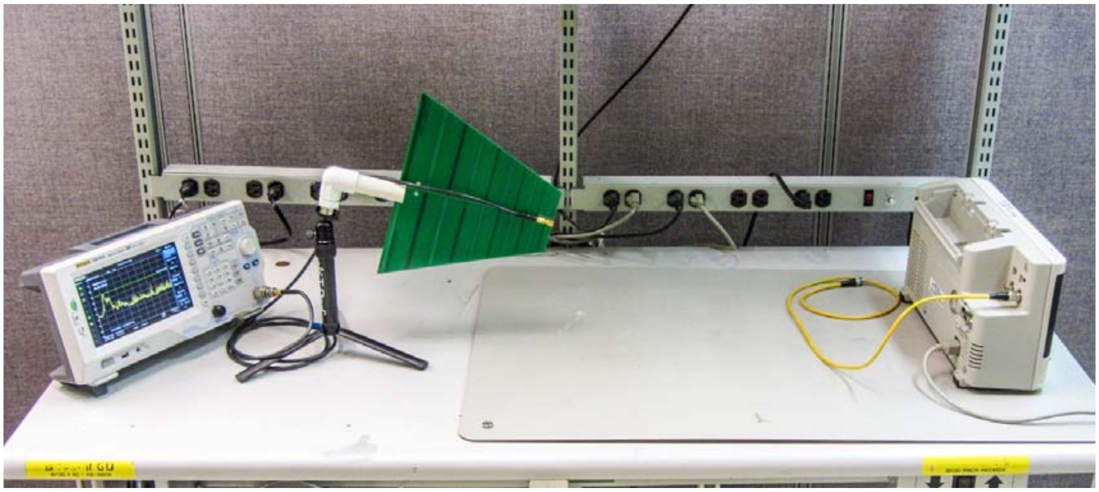

Figure 10 - A typical test setup to measure actual radiated emissions while troubleshooting the causes.

Once the emission sources are identified, you can use your knowledge of filtering, grounding, and shielding to mitigate the problem emissions. Try to determine the coupling path from inside the product to any outside cables. In some cases, the circuit board may need to be redesigned by optimizing the layer stack-up or by eliminating high speed traces crossing gaps in return planes, etc. By observing the results in real time with an antenna paced some distance away, the mitigation phase should go quickly.

TROUBLESHOOTING TIPS USING CURRENT PROBES

Here are a few troubleshooting tips using current probes.

1. When evaluating the harmonics on a cable by using a current probe, if sliding the probe back and forth changes the harmonic levels, part of the coupling may be near-field radiation, rather than conducted through the cable.
2. When using a pair of current probes; one on each of two cables, if the harmonics are the same in each, the source is in the middle. If one cable has stronger harmonics, then you'll want to work on that side first. See Figure 11 below.
3. Measuring the currents on two suspect legs of a dipole should read the same. Placing the two suspect legs through the same current probe should cause a big decrease due to current cancellation. See Figure 11 below.
4. When measuring video cable currents and large cable movements cause big changes in amplitude, the coupling is likely inductive – otherwise, it's more likely capacitive.
5. If you suspect inductive coupling, the phase at the victim will be 180-degrees from the source. This may be observed on an oscilloscope with H-field probes or current probes. Try syncing the scope trigger at the source using a scope probe.

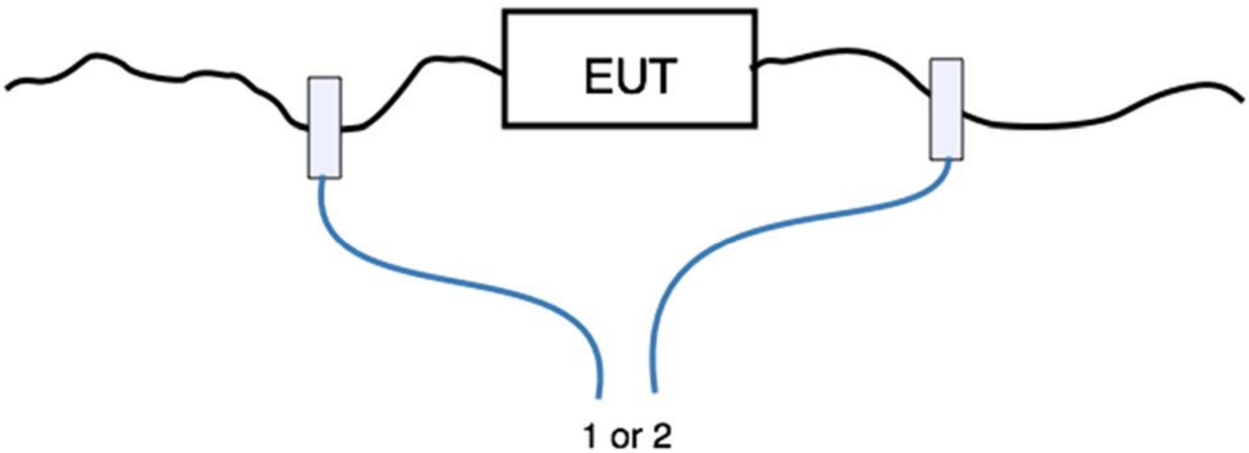

Figure 11. When measuring two cables from a system and the harmonic currents are approximately the same (point 1 is the same as point 2), the source is at the center (the EUT) and the two cables are acting as a dipole antenna. You may notice a peak in harmonic strength at the half-have length of the two cables combined. If the harmonic currents are larger in one side or the other, then you'll want to troubleshoot just that cable.

SUMMARY

Use of a current probe is vital during the troubleshooting process. Poorly bonded cable connectors can be readily identified and fixed. The radiated E-field from a product I/O cable may be calculated by measuring the high-frequency common mode currents flowing in the cable. All this may be performed right at the designer's workbench and without the expense of a third-party test facility or shielded chamber.

REFERENCES – PAPERS (Need to review these for Com-Power)

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