Using the RF Current Probe

This application note describes one of the most valuable tools in the EMC engineer's "bag of tricks" – the high-frequency (or RF) current probe. Current probes are invaluable for measuring high-frequency common-mode (CM) currents flowing on wires or cables.

Experience has proven that poorly terminated (bonded or filtered) cable shields are the number one cause for radiated emissions failures during EMC compliance testing. By measuring the CM currents (sometimes referred to as "antenna" currents) on these cables it's possible to troubleshoot and apply fixes to a product right there in your development lab.

You can also predict, to a good degree of accuracy, whether a given cable current will pass or fail in the measurement chamber. This will save you tons of time trying to apply fixes at the test facility while the clock is ticking away your test time.

COMMON-MODE CURRENTS

Let's consider CM currents and how they are generated, because it is not intuitive as to how current may travel in the same direction through both the signal and signal-return wires in a cable or PC board.

Referring to Figure 1, note that due to finite impedance in the system grounding, including circuit board signal/power return planes, there will be a voltage difference between any two points within that return plane or ground structure. For example, simultaneous digital switching causes current peaks ("ground bounce") in the ground return plane, can create voltage drops, which drive CM currents throughout the system. These CM currents will tend to propagate throughout common cabling or circuit traces and between circuits or sub-systems.

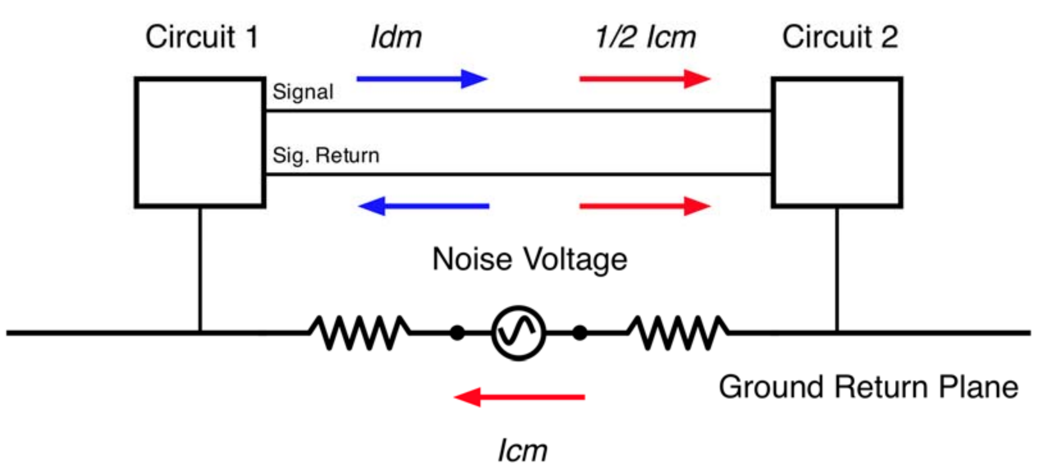

Figure 1 - Digital signal currents are depicted by the differential mode (DM) currents (blue arrows). The undesired common mode (CM) currents (red arrows) come from a variety of

sources, but the most common is from ground bounce, due to impedances in ground return planes.

CURRENT PROBES: THEORY OF OPERATION

The RF current probe is an “inserted-primary” type of radio frequency current transformer. When the probe is clamped over the conductor or cable in which current is to be measured, the conductor forms the primary winding. The clamp-on feature of this probe enables easy placement around any conductor or cable. This is essentially a broadband high-frequency transformer. High-frequency currents can be measured in cables without physically disturbing the circuit.

Since the current probe is intended for “clamp-on” operation, the primary shown in Figure 2 is actually the electrical conductor or cable in which CM currents are to be measured. This primary is considered as one turn since it is assumed that the CM currents flow through the conductor and return to the source via a return conductor such as a frame, common ground plane, or earth. On some current probe models the secondary output terminals are resistively loaded internally to provide substantially constant transfer impedance over a wider frequency range.

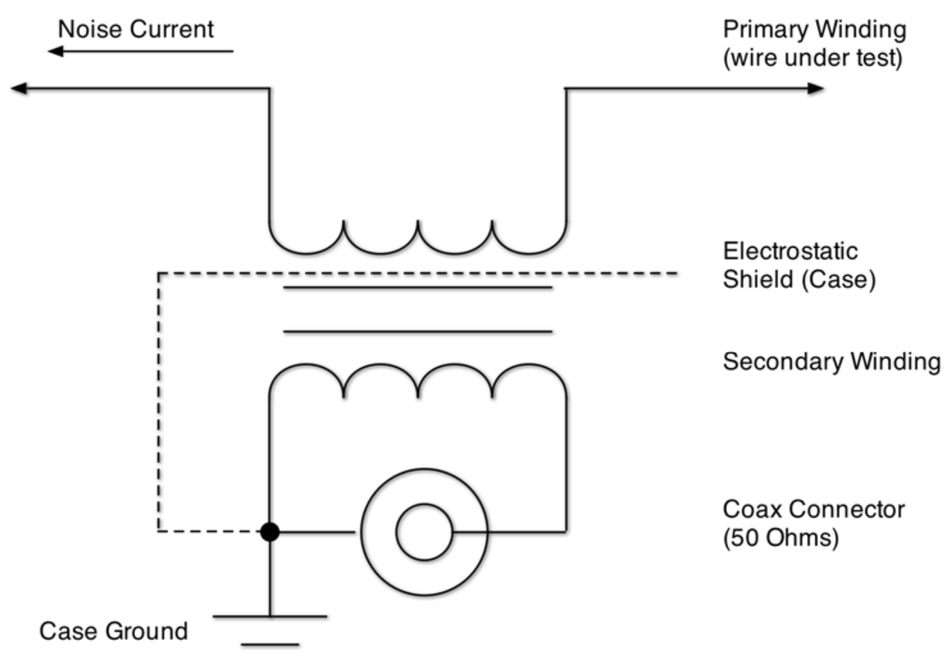

Figure 2 - The basic current probe (high-frequency current transformer).

COMMERCIAL CURRENT PROBES

RF current probes are designed to measure very small RF currents in wires or cables up to several hundred MHz. Common mode noise currents that get coupled to cables cause radiated emissions, so these are helpful in measuring and characterizing the harmonic currents.

By monitoring the amount of CM currents, we can start the troubleshooting effort in order to reduce or eliminate the coupling, and hence, the radiation.

Figure 3 - Example of the Com-Power CLCE-400 current probe, which is calibrated from 10 kHz to 400 MHz.

Specifications (Com-Power CLCE-400)

- Frequency Range: 10 kHz to 400 MHz
- Window (Aperture) Inside Diameter: 1.25" (32 mm)
- Outside Diameter: 2.83" (72 mm)
- Height: 0.76" (19.3 mm)
- Weight: 0.275 lbs. (0.125 kg)
- Connector: Type-N (Female)
- Transfer impedance (ZtΩ): 7Ω*
- Transfer impedance (dBΩ): -21 to 17 dBΩ (typical)*
- Max Primary Current (DC-400 Hz): 100 Amps
- Max Primary Current (RF): 4 Amps
- Max. Core Temperature: 248°CF (120°C)
- Related Accessories Available from Com-Power:
    - FCLCE-1000 Calibration Fixture
    - TEP-050 50Ω Terminator

- SPA-900TG Spectrum Analyzer

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.

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

or, in dB

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

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,

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

or

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

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 4). 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.

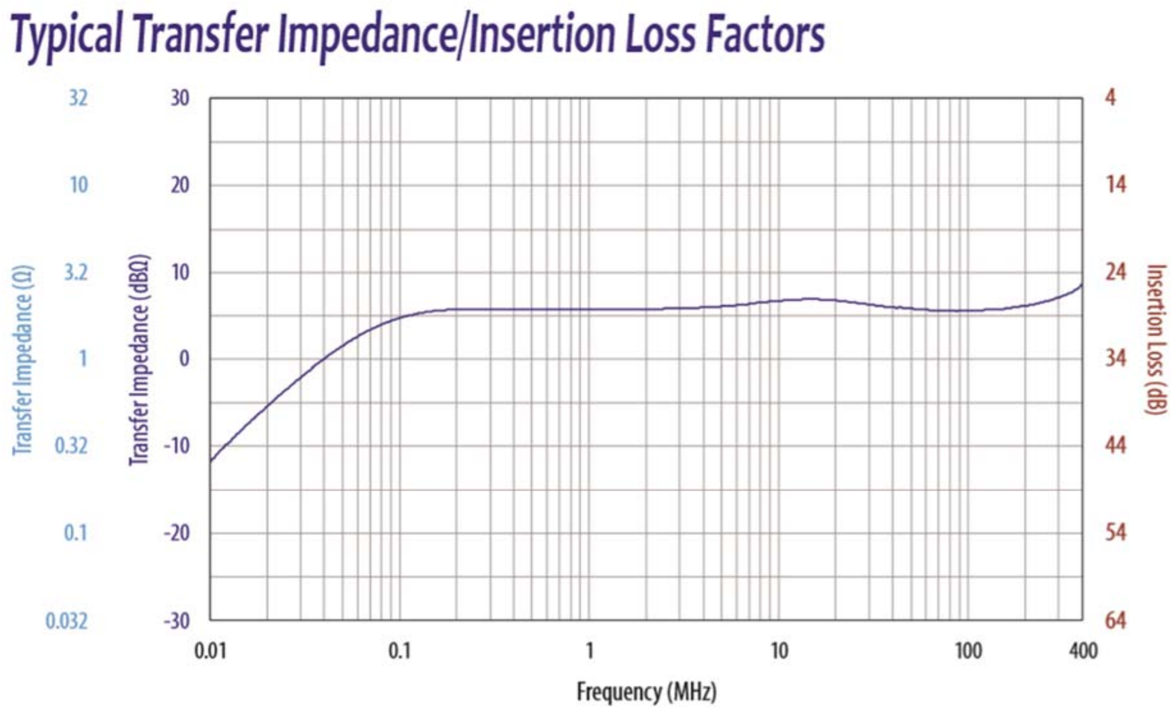

Figure 4 - Transfer impedance (Zt) graph of the CLCE-400 current probe. The x-axis is frequency, while the y-axis is dBΩ, Zt(Ω) or insertion loss (dB). Use this to calculate the value of Ic (Equation 2), given the measured voltage at the probe terminals V(dBμV) and Zt.

USING A CURRENT PROBE TO MEASURE CM CURRENTS

To measure common mode cable currents (including power cables) with a current probe, simply snap in around the cable under test (Figure 5). It's a good idea to slide the current probe back and forth to maximize the harmonics. This is because some frequencies will resonate in different places, due to standing waves on the cable.

Once you've identified the frequencies of the top several harmonics you can start the troubleshooting process, working backwards to the specific sources that could be causing those harmonics.

Use the transfer impedance chart to calculate the actual current at a particular harmonic frequency. Note that it only takes 5 to 8 μA of high-frequency current to fail the FCC or CISPR Class B test limits.

Figure 5 - Use of a current probe to measure high frequency currents flowing on I/O and power cables.

PROBE CALIBRATION

The accurate calibration of RF current probes requires a calibration fixture (Figure 6). The probe must be properly calibrated before the user uses the probe. Com-Power sells several types of calibration fixtures that attempt to maintain a 50Ω impedance. A 50Ω load is connected to the output port and a calibrated network analyzer is connected to the input port of the fixture and probe port. The probe to be characterized is clamped around the fixture and the frequency is swept while measuring the probe output.

Knowing the current through the wire in dBμA and the probe output in dBμV, the transfer impedance may be plotted graphically by subtracting: V(dBμV) – Ic(dBμA) (expressed in dB). In this case, Zt(dBΩ) = V(dBμV) – 73.

Figure 6 - Com-Power sells calibration fixtures for all their probe models. These are used with a vector network analyzer to verify or recalibrate the current probes.

SUMMARY

Common mode currents in I/O or power cables cause frequent EMC compliance test failures. Use of an RF current probe can measure these harmonic currents in cables and is vital during the troubleshooting process. Poorly bonded cable connectors can be readily identified and fixed. 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)

1. Andre and Wyatt, EMI Troubleshooting Cookbook for Product Designers, SciTech Publishing, 2014, pages 44-47.
2. Aschenberg & Grasso, Radiation from Common-Mode Currents – Beyond 1 GHz (Three Methods Compared)
3. Goodblood, Electromagnetic Compatibility, 1990, Prentice Hall, pages 31-34.
4. Mardiguian, EMI Troubleshooting Techniques, McGraw-Hill, 2000, pages 39-49.
5. Montrose & Nakauchi, Testing for EMC Compliance, 2004, Wiley Interscience, pages 116-124, 143-145, and 159-161.
6. Ott, Electromagnetic Compatibility Engineering, Wiley, 2009, pages 690-693.

7. Ott, Measuring Common-Mode Currents on Cables, www.hottconsultants.com/techtips/tips-cm.html
8. Paul, Introduction to Electromagnetic Compatibility (2nd Edition), Wiley Interscience, 2006, pages 518-532.
9. Smith, High Frequency Measurements and Noise in Electronic Circuits, Van Nostrand Reinhold, 1993, pages 41-44, 159-182, 192-209.