EMI Troubleshooting, Measurements and Common Problems

presented by:

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For Interference Technology



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www.design-4-emc.com

www.edn.com/electronics-blogs/4376432/The-EMC-Blog

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Instructor Biography

Kenneth Wyatt is a senior EMC engineer at Wyatt Technical Services LLC, an independent consulting firm that specializes in EMC and RF design, troubleshooting, and training services to commercial and industrial manufacturers in the consumer, computer, network and telecommunications, industrial, medical, scientific, and automotive industries. Previously Kenneth was senior EMC engineer for Hewlett-Packard and later, Agilent Technologies, in Colorado Springs, Colorado. While at Agilent and HP Ken was responsible for providing comprehensive EMC design, training and troubleshooting services to the design community for a wide range of test and measurement equipment. He also was responsible for managing the day-to–day technical aspects of Agilent's EMC product environmental and EMC test lab.

Prior to Agilent, Ken worked as a product design engineer for 10 years at various aerospace firms on projects ranging from DC-DC power converters to RF and microwave systems for shipboard and space systems.

A prolific author and presenter, Ken has written or presented topics including RF amplifier design, RF network analysis software, EMC design of products and using simple tools, probes and techniques for EMC troubleshooting. He has been published in numerous magazines such as, RF Design, Interference Technology (ITEM), InCompliance,, Test & Measurement World, EDN, Safety & EMC (China), Electronic Design, Microwave Journal, and the HP Journal. He currently authors The EMC Blog for EDN.com. He's presented EMC design, measurement and troubleshooting seminars across the U.S., Europe and Asia.

Ken is a senior member of the IEEE and a long time member of the EMC Society. He has also served as a U.S. delegate to the International Electrotechnical Commission (IEC) for the international EMC standard, IEC 61326 (ISM product family). He received a degree in electronic engineering at California State University – Long Beach and a degree in Biology with additional coursework in physics at the University of California - Irvine.

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What does EMC stand for?

Electromagnetic Compatibility

1. Electronic products do not interfere with their environments (Emissions)
2. The environments do not upset the operation of electronic products (Immunity)
3. (From a performance level) The electronic product does not interfere with itself (an aspect of Signal Integrity)

Note: EMI – electromagnetic interference

RFI – radio frequency interference

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Common issues leading to radiated emissions

1. Discontinuous current return paths
2. Poorly-terminated I/O cable shields
3. Slot radiation from shields

All the above can cause radiated emissions and susceptibility to radiated sources and ESD

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Why do products radiate?

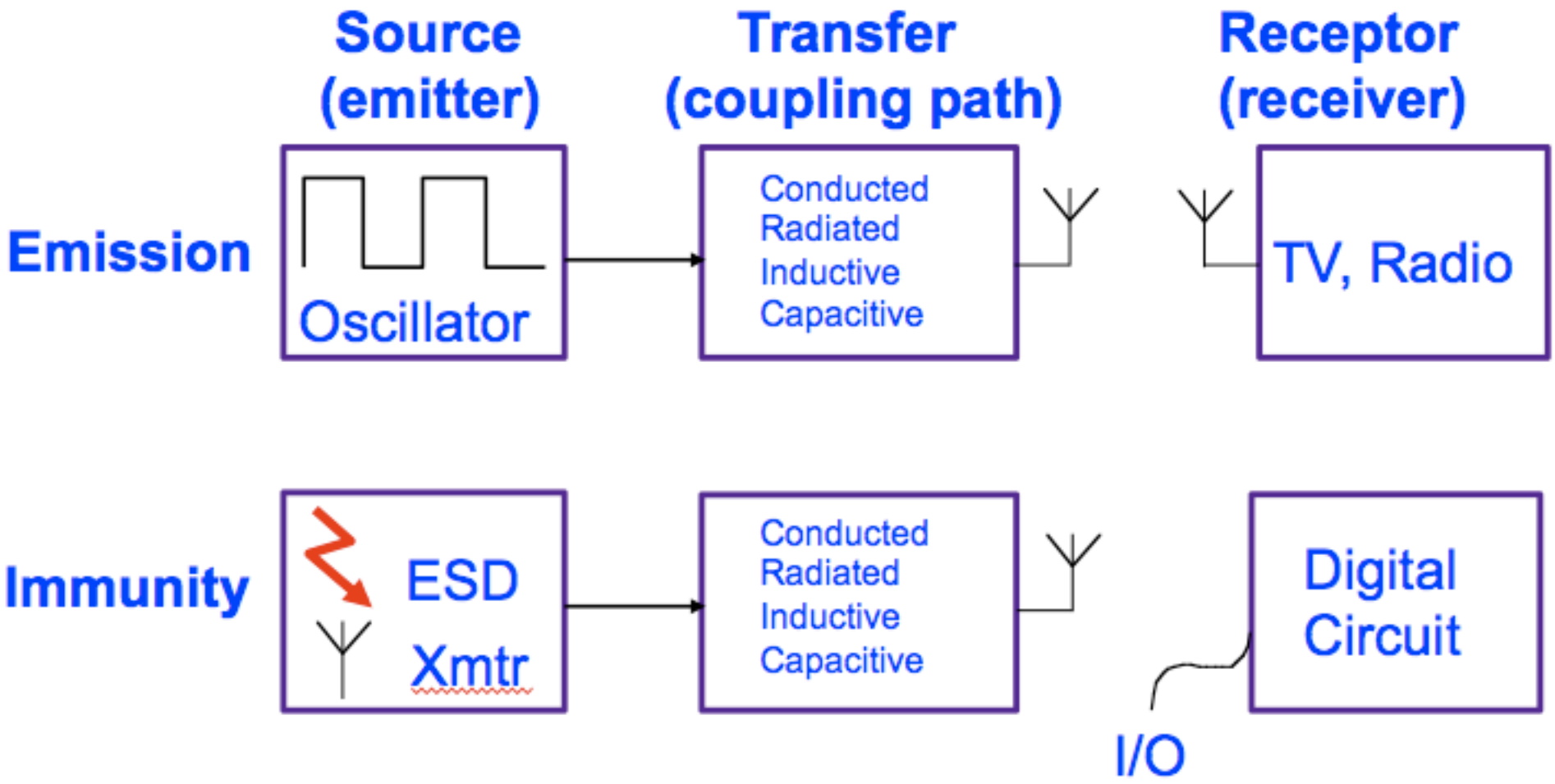
- Energy + Coupling Path + Antenna = EMI

Take away any of the three elements and no EMI…

- No energy >>> No EMI
- No coupling path >>> No EMI
- No antenna >>> No EMI

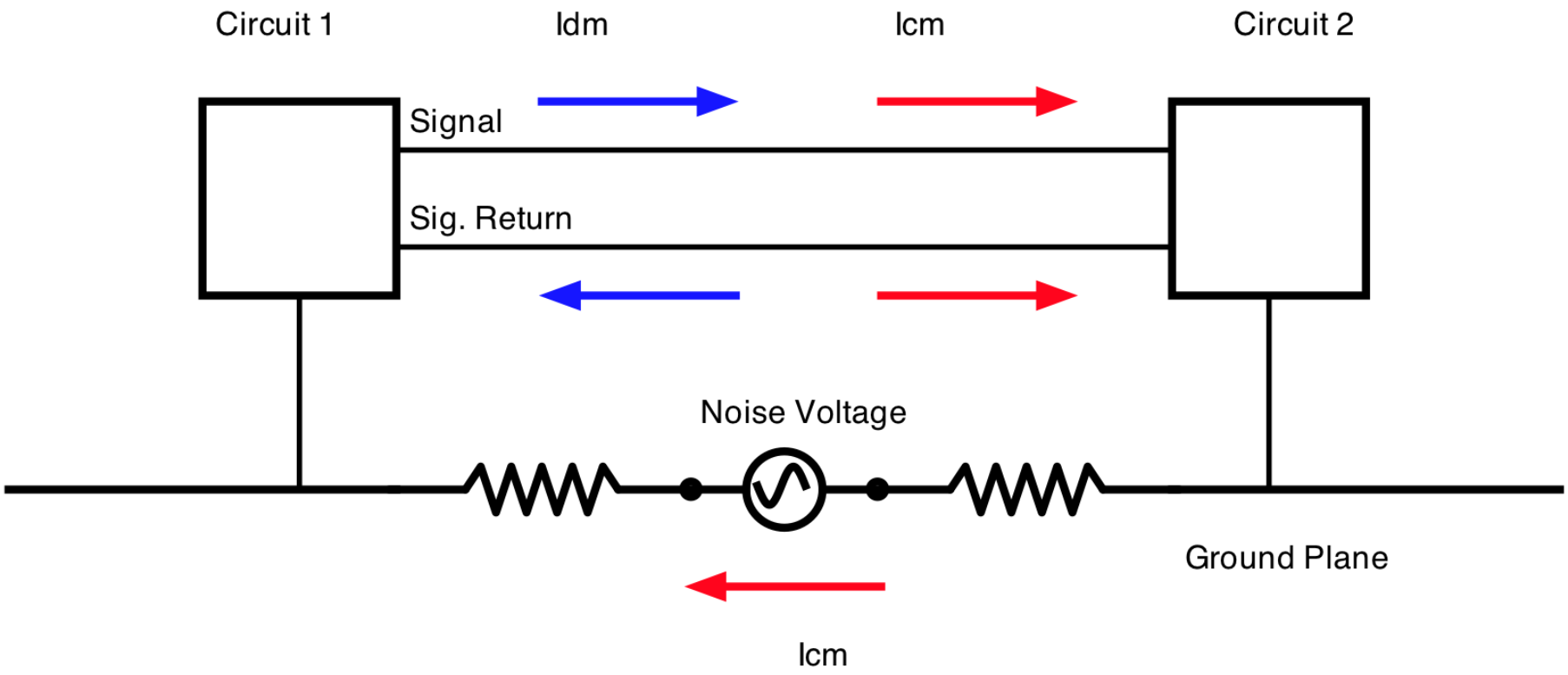
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Source - path - receptor model



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Generation of common-mode (CM) currents

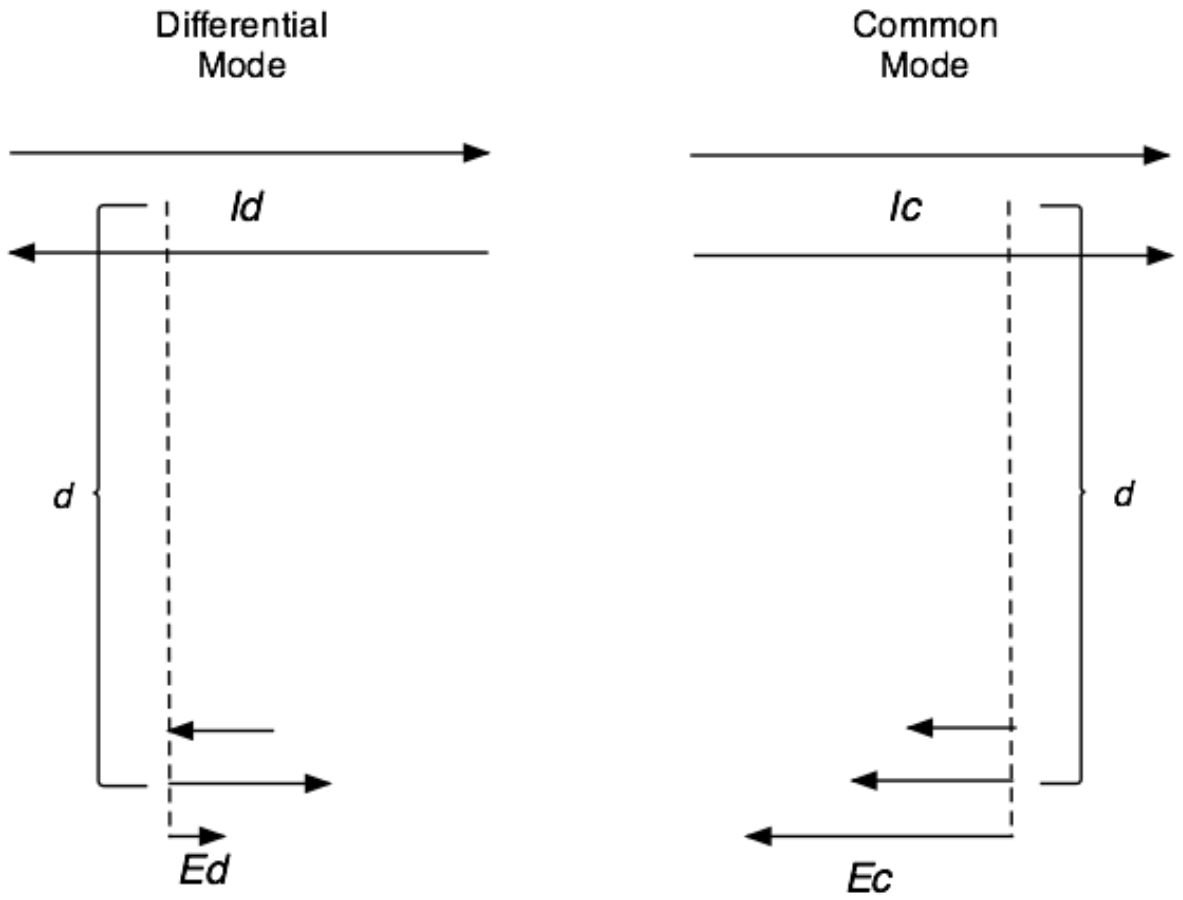


Any voltage difference between two grounds will drive common-mode currents (ground loop) between the signal and return wires.

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Differential- versus common-mode emissions

Currents are *phasors*.



DM current tends to cancel

CM currents add and most likely dominant!

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Differential-mode emission equation (reflecting surface)

$$\left|E_{D,\max}\right| = 2.63\times10^{-14}\,\frac{\left|I_D\right| f^2 Ls}{d}$$

High frequency currents in a LOOP

Assuming electrically short lengths, (*L< half wavelength)*.

To reduce E_D, we can:

1. Reduce the current level (also by slowing rise times)
2. Reduce the loop area

Note the relatively small factor 1x10^{-14}

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Common-mode emission equation

$$\left|E_{C,\max}\right| = 1.257 \times 10^{-6} \frac{\left|I_C\right| fL}{d}$$

High frequency currents in a WIRE

Assuming electrically short length, *(L< half wavelength)*.

To reduce E_C, we can:

1. Reduce the current level (also by slowing rise times)
2. Reduce the line length (shorter PC traces)
3. Diverting or blocking the current

Note the relatively larger factor, $1x10^{-6}$

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Discontinuous return paths

Most PC board problems can be traced to discontinuous signal return paths. This is becoming more of an issue with increasing clock frequencies used today.

Ideally, a high frequency signal travels out a trace and (due to mutual inductance) returns immediately under that trace as the wave propagates along the transmission line (*the path of least impedance*)

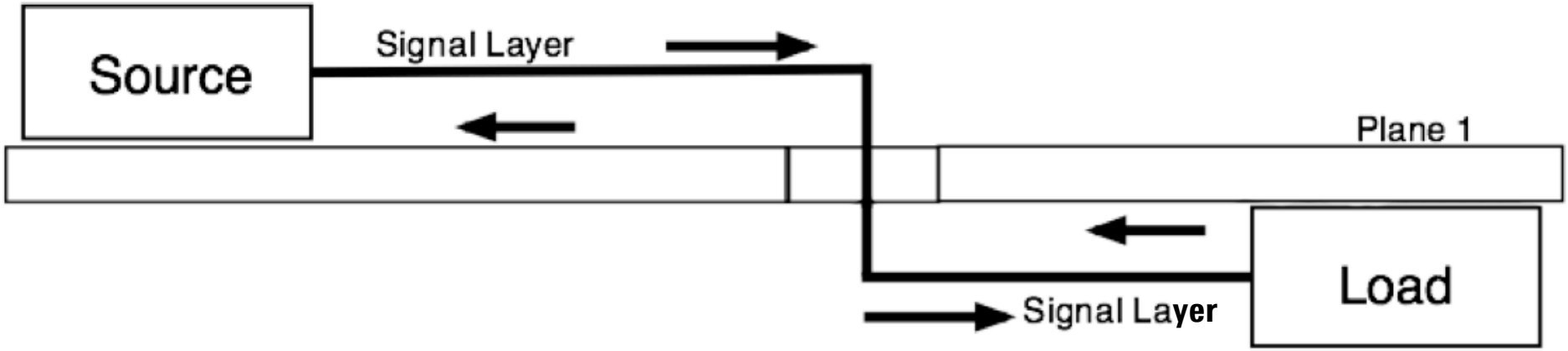
- ***All too often, the return path is broken by***

- a discontinuity, such as a gap or slot in the ground plane or power plane

- changing reference planes without a defined return current path

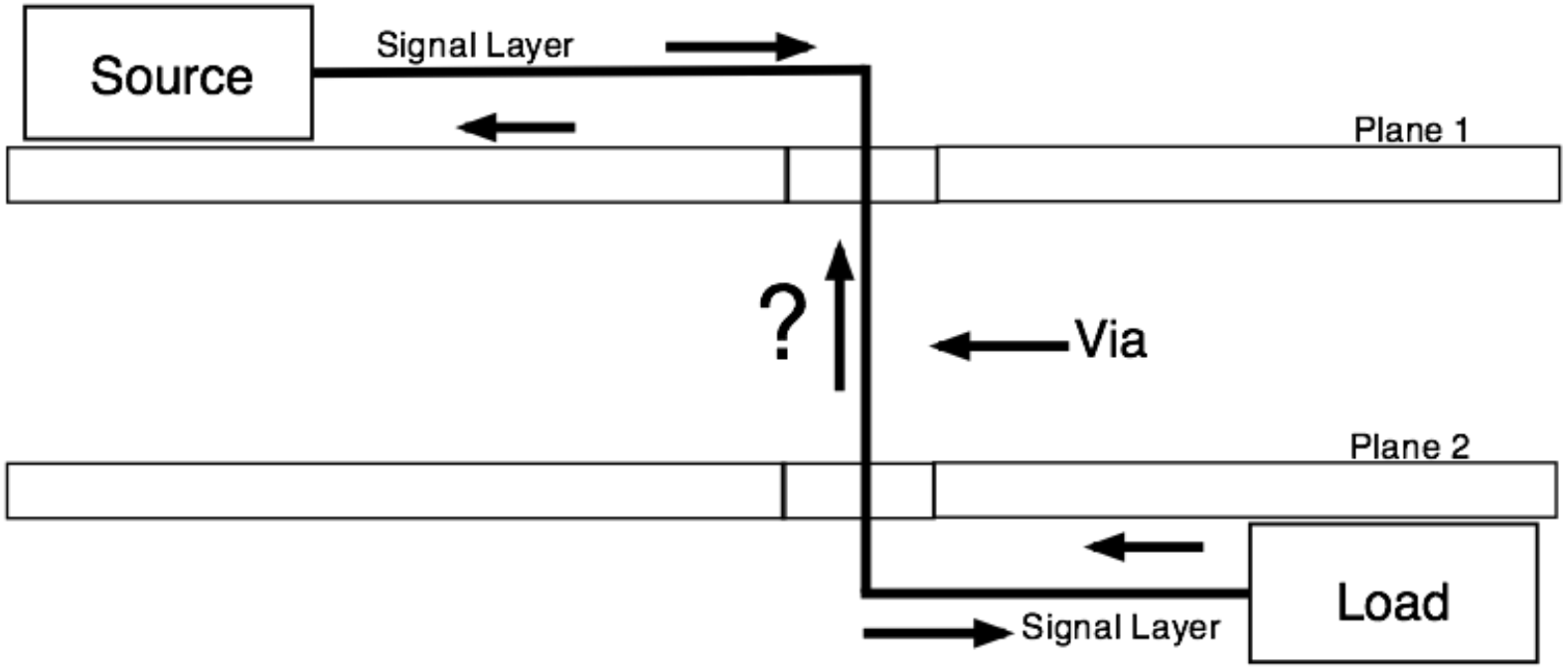
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Trace passing through plane with via



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Trace passing through two planes with via

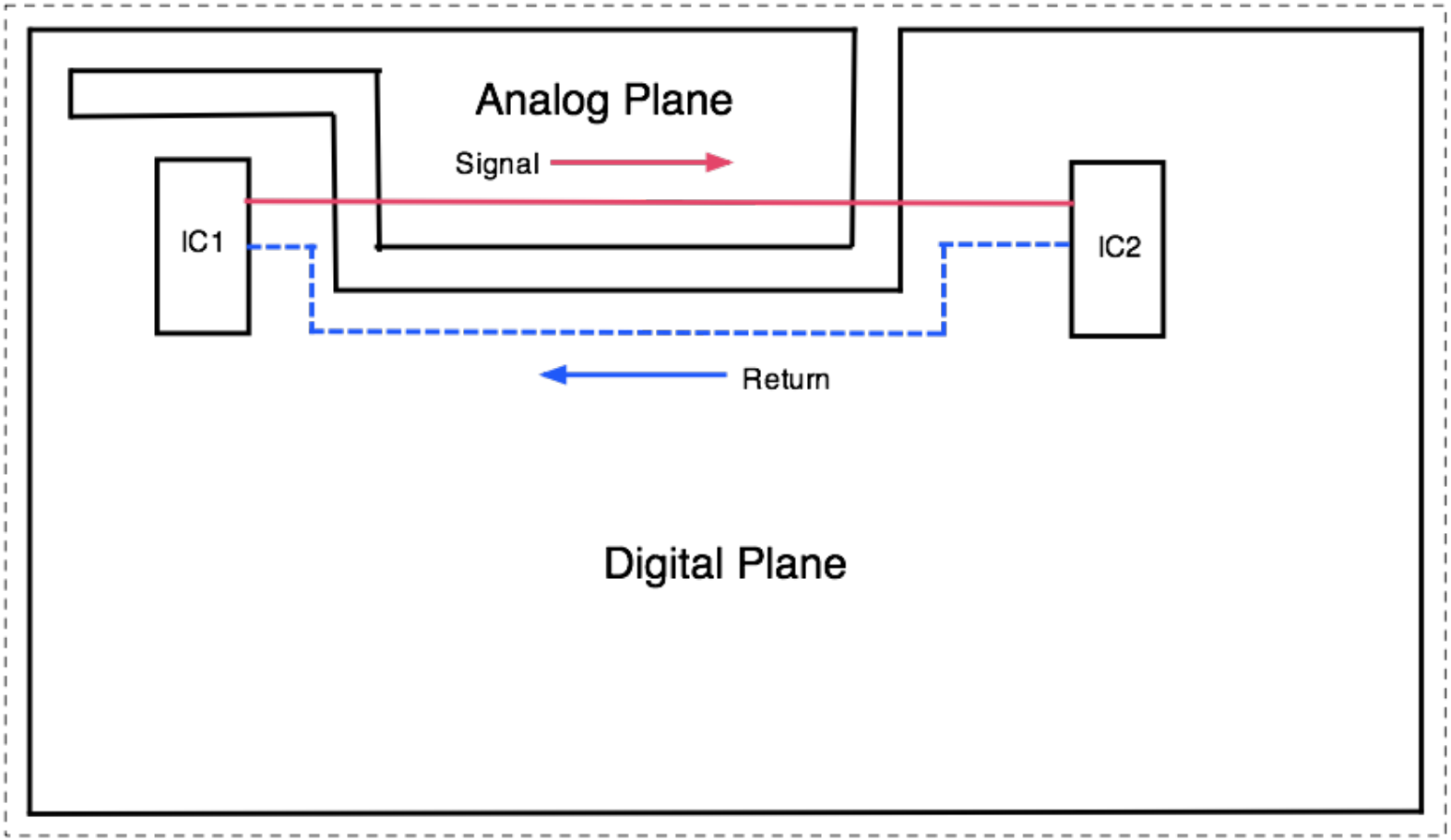


Scenario: signal traces referenced to different planes.

Question: where does the return signal current flow?

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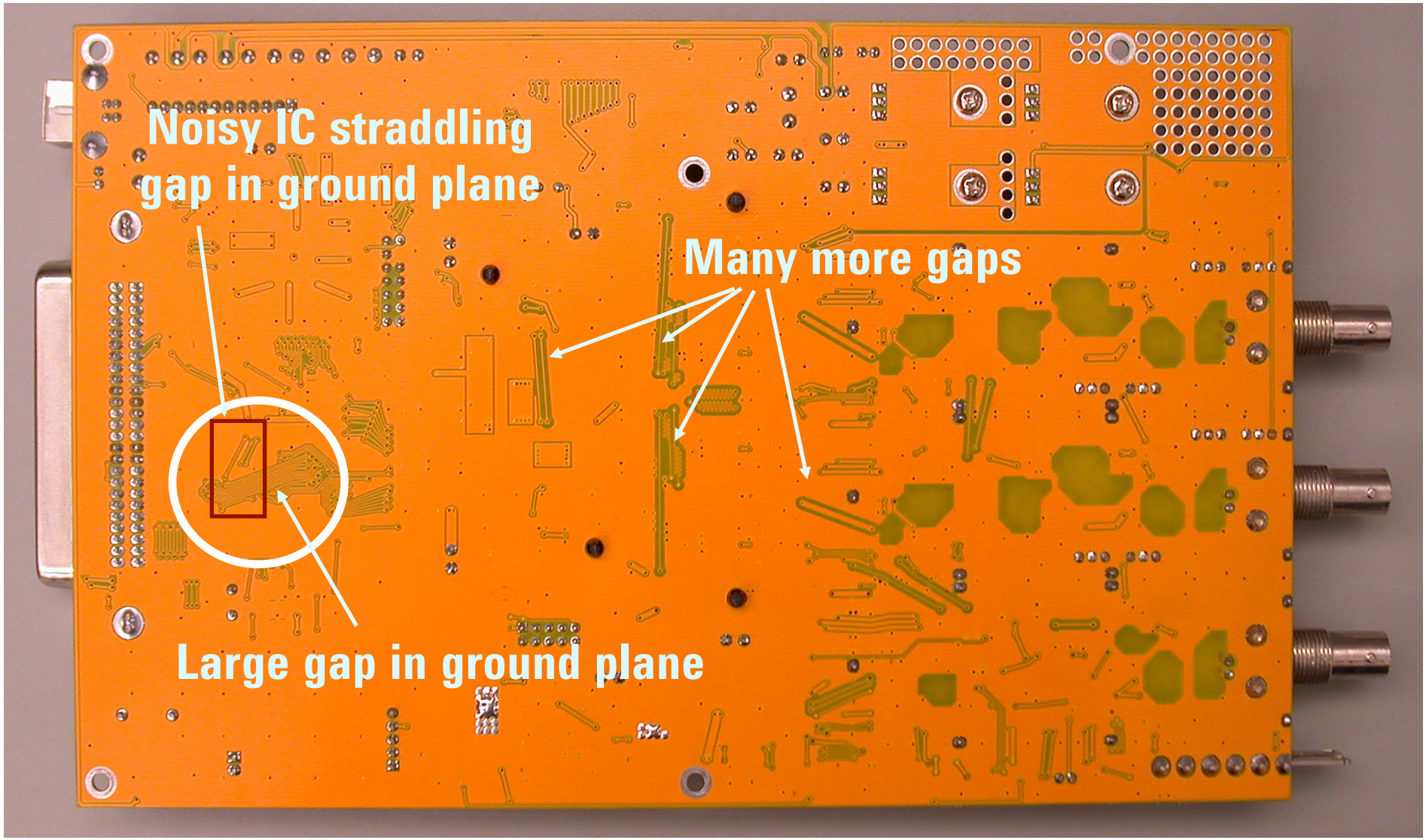
Discontinuous return paths (examples)



Routing a trace over an unrelated (e.g. analog) plane can cause noise coupling to other circuitry. Traces should never cross analog planes.

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Slots in signal return plane



Temporary bridge with copper tape reduced emissions 17 dB!

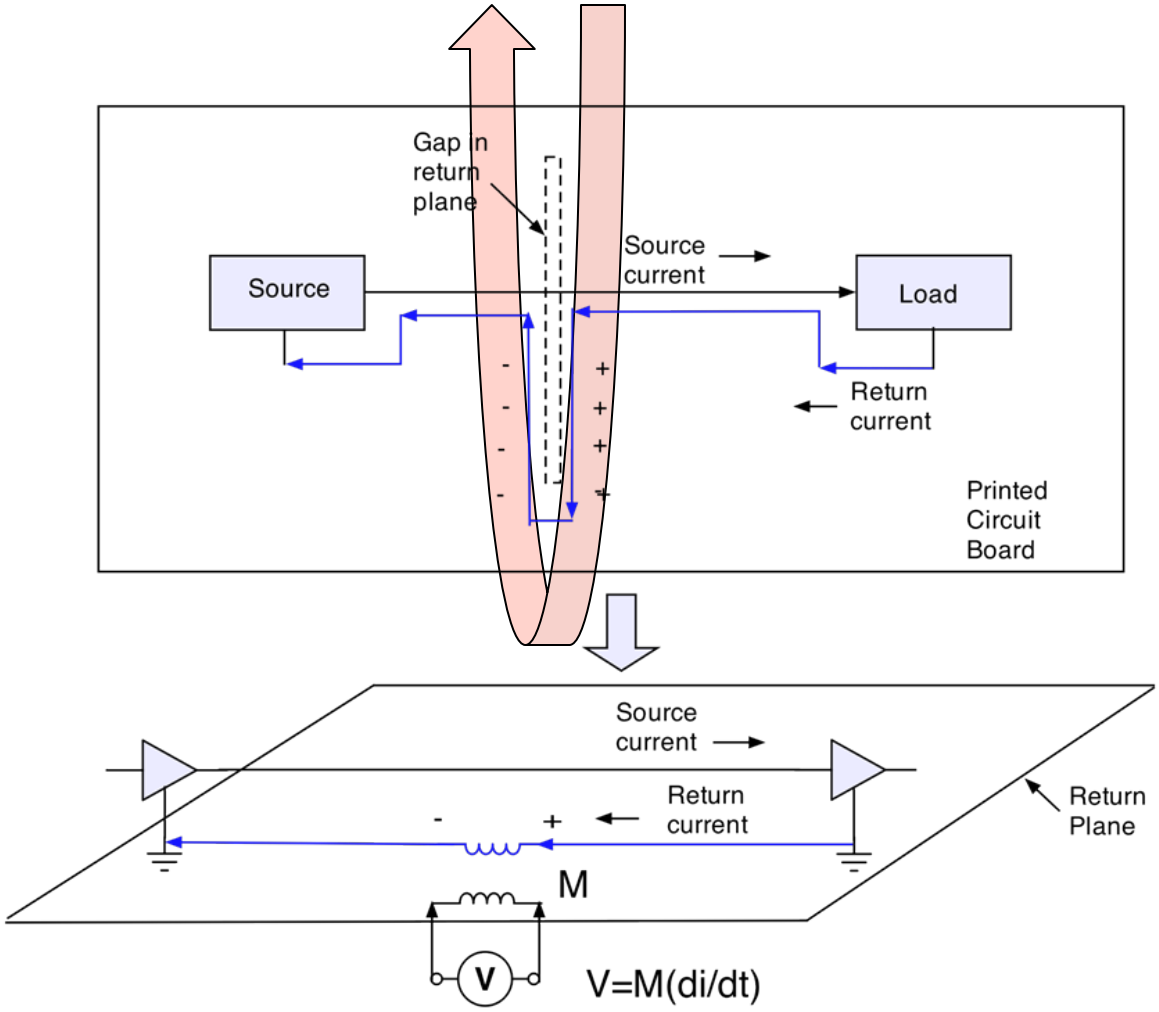
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Generation of common-mode emissions

We know differential-mode current flows in a loop.

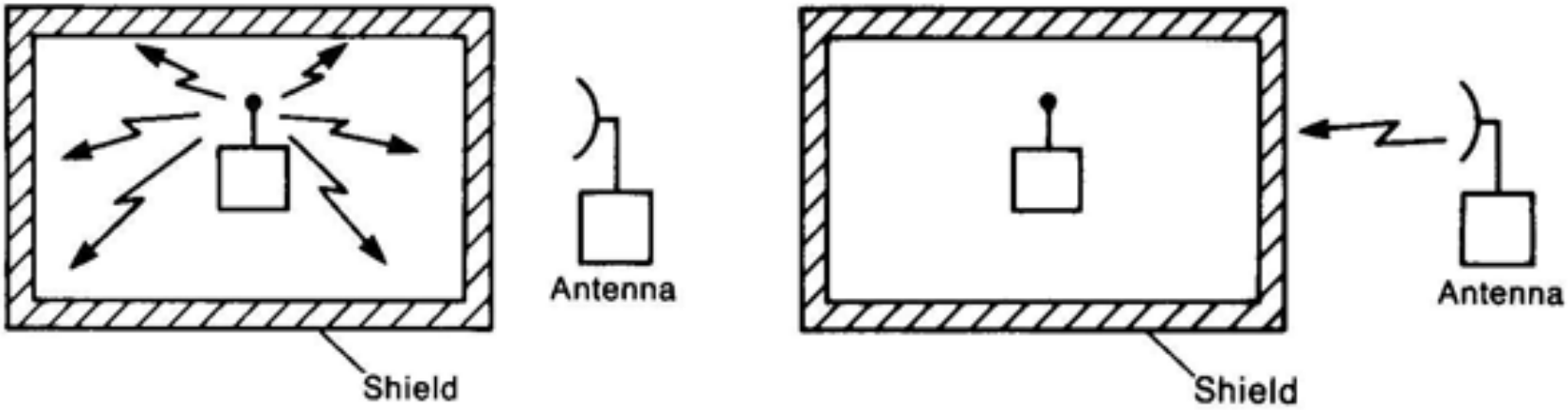
At high frequencies, this loop area is minimized, due to mutual inductance between the signal trace and return plane.

A gap in the return plane forces the return current to flow in a bigger loop, creating a mutual inductance (M), which causes "flux-wrapping" around the ground plane and a potential, V = M(di/dt), thereby creating an on-board common-mode (CM) "noise" source.



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Principle of a shield



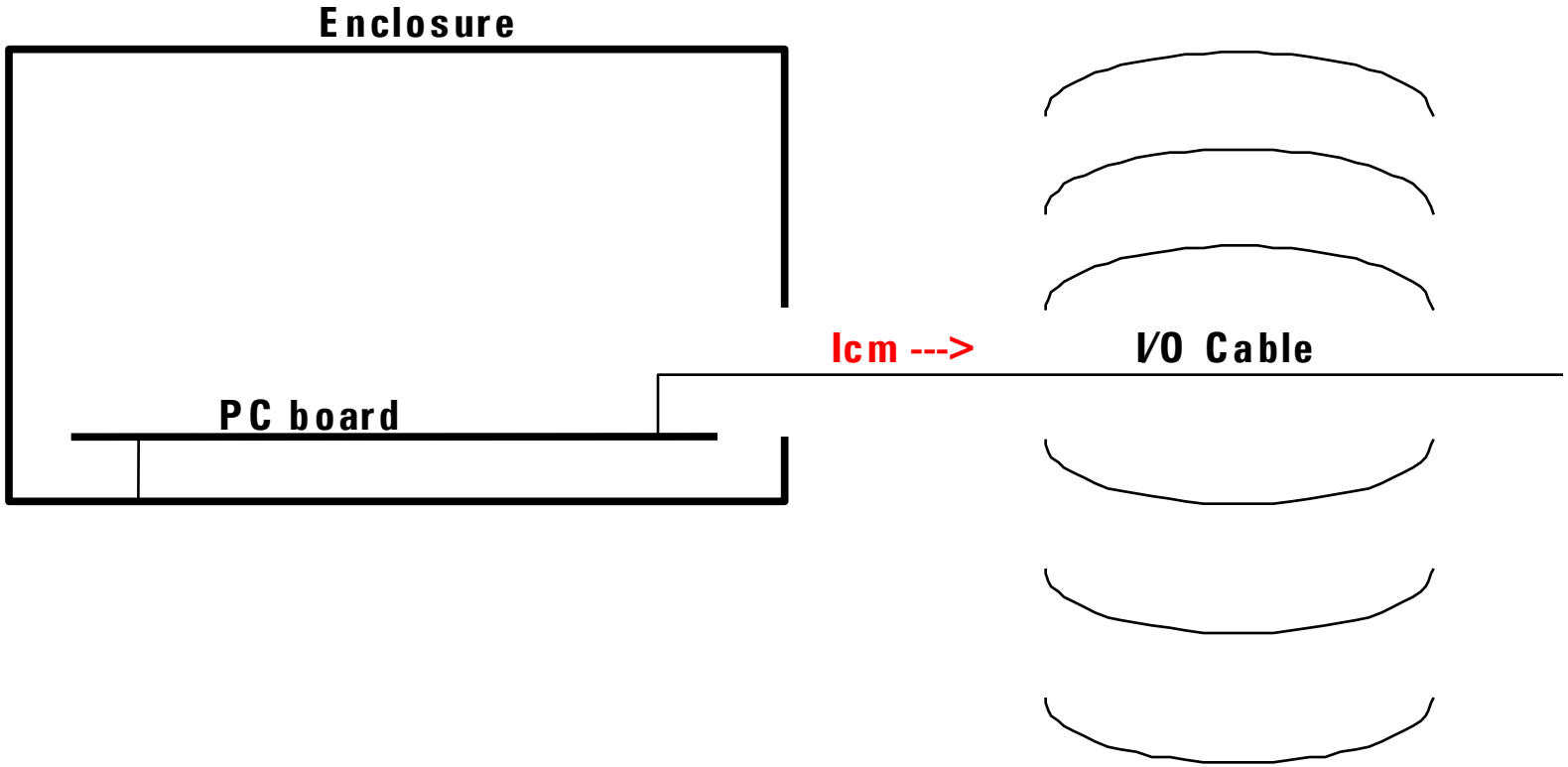
E-Field $$\mathrm{SE} = 20 \log_{10} \left| \frac{\hat{E}_i}{\hat{E}_t} \right|$$

H-Field $$\mathrm{SE} = 20 \log_{10} \left| \frac{\hat{H}_i}{\hat{H}_t} \right|$$

Enclosures protect against interference and reduce external circuit disturbances.

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Never penetrate a shield with a wire or cable



Penetrating a shield with a wire defeats the shield!
Noise currents on the inside will couple to the wire and travel outside the shield, causing radiated emissions. Transmitters on the outside may interfere with circuits.

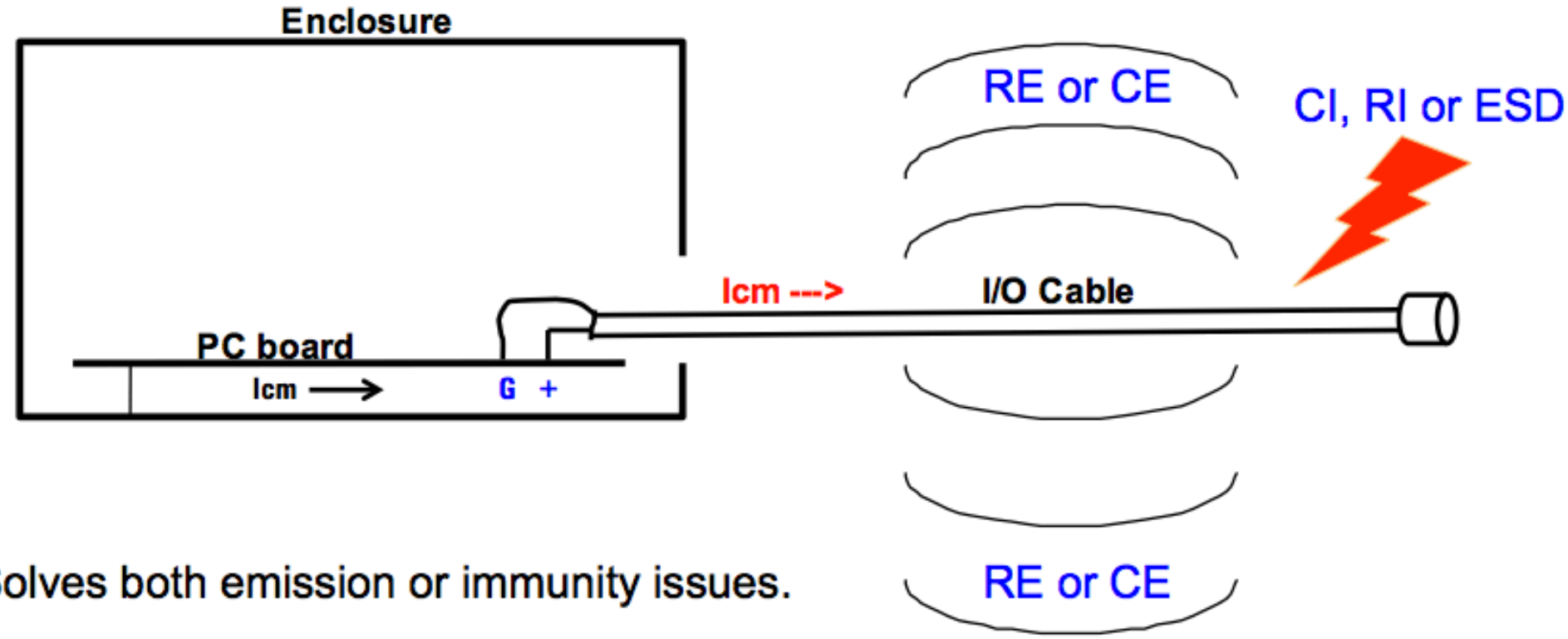
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Poor cable grounding – pigtail 1

Divert the current back to the shielded enclosure

- Proper termination of the cable shield back to the enclosure is the key

Block the current with a high-impedance ferrite choke



Solves both emission or immunity issues.

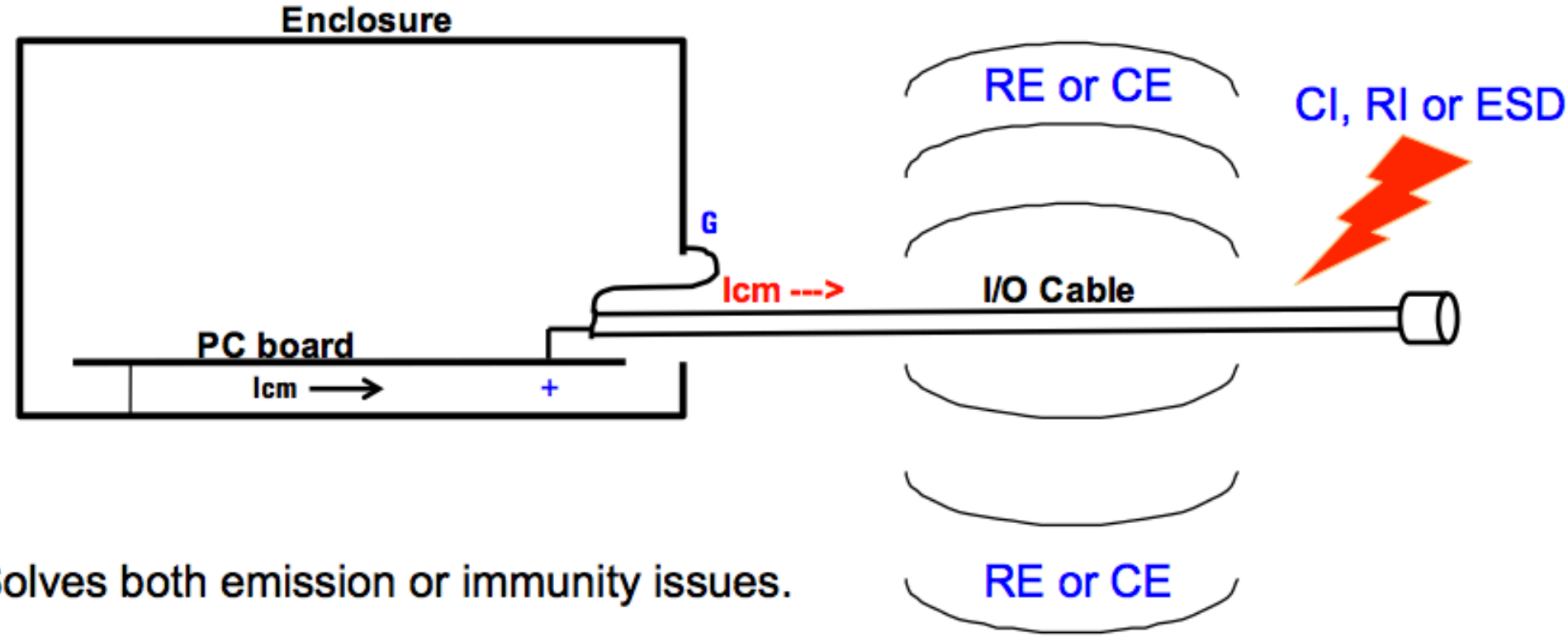
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Poor cable grounding – pigtail 2

Divert the current back to the shielded enclosure

- Proper termination of the cable shield back to the enclosure is the key

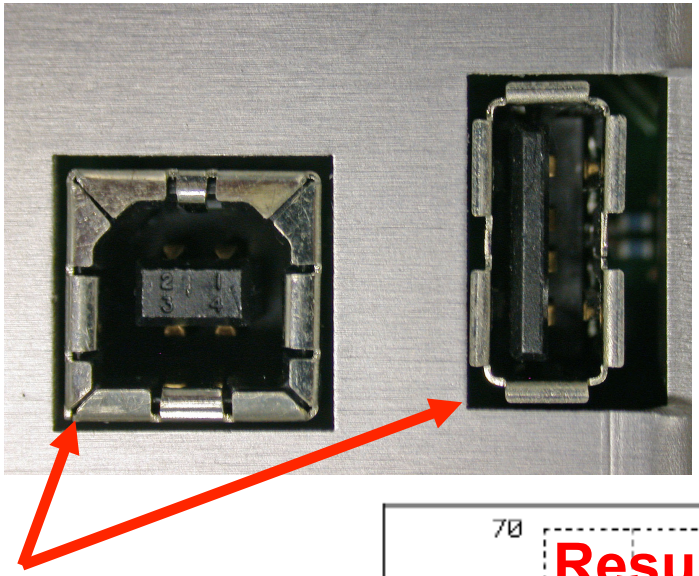
Block the current with a high-impedance ferrite choke

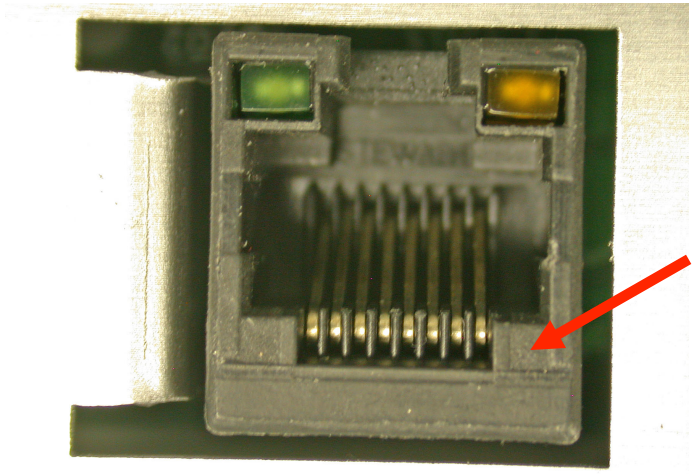


Solves both emission or immunity issues.

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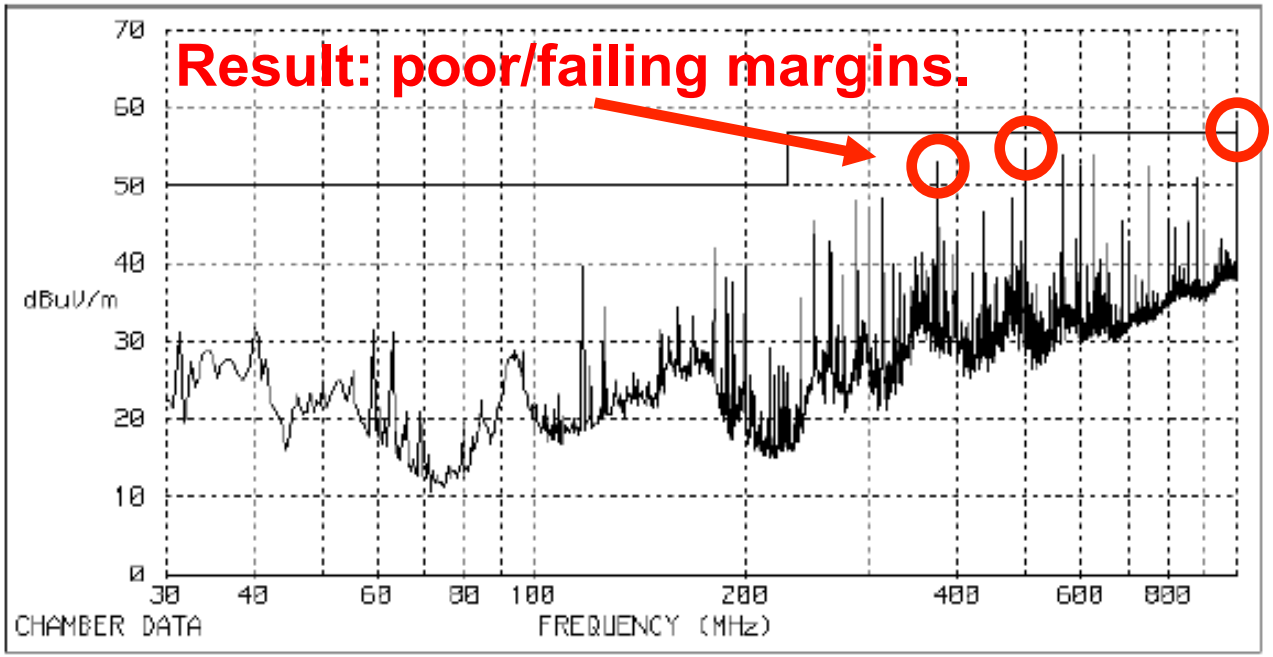
Importance of I/O connector grounds





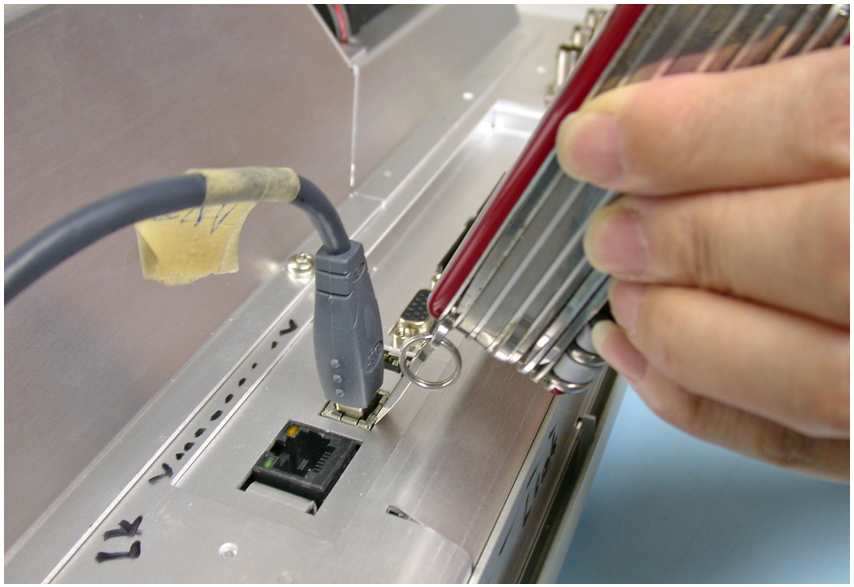
LAN conn needs gnd shell.

Note a lack of good connection between chassis enclosure and connector ground.



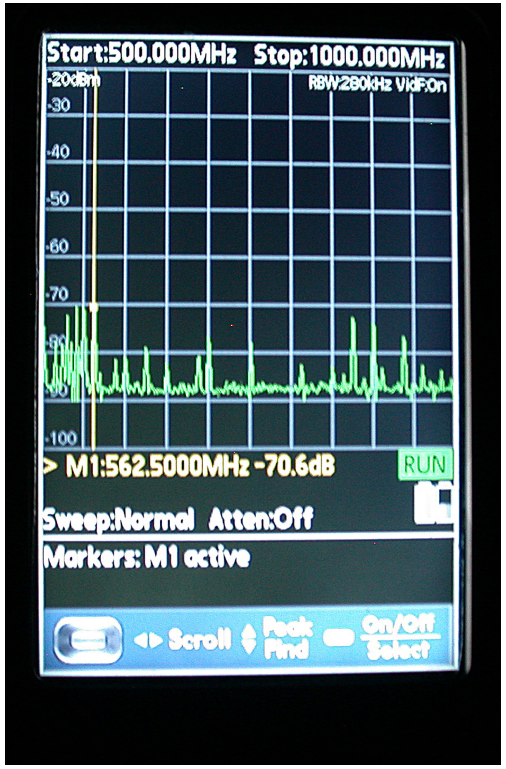
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Result after simple connection to chassis

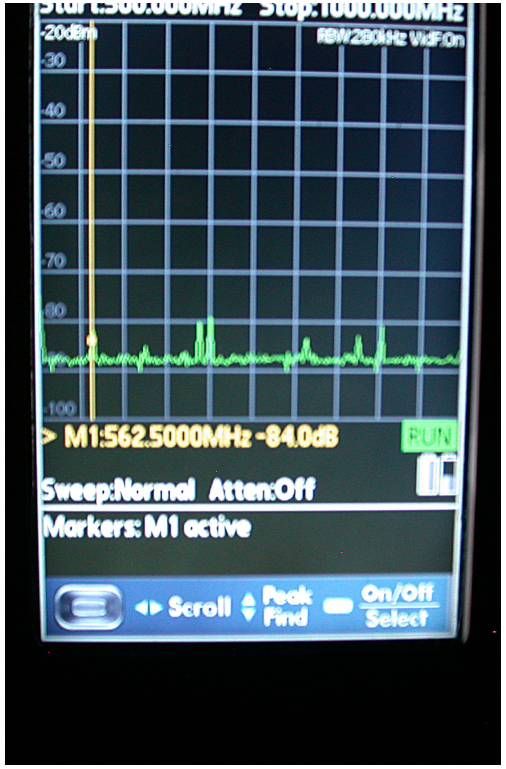


Test setup:
Current probe on USB cable. Connection between connector ground shell and chassis enclosure made with screwdriver blade.

Looking from 500 to 1000 MHz



Before

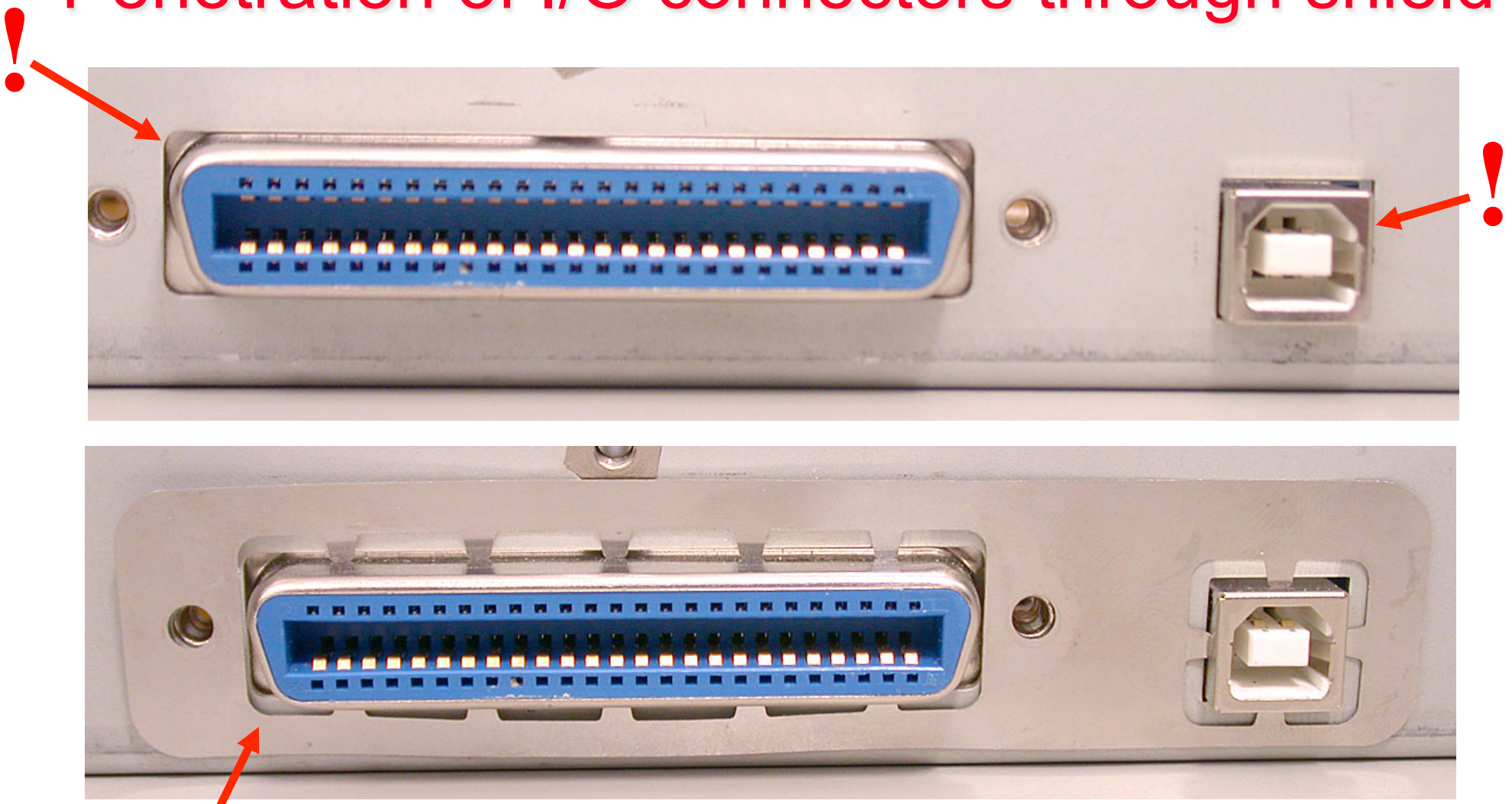


After

Some harmonics dropped by 10-15 dB!

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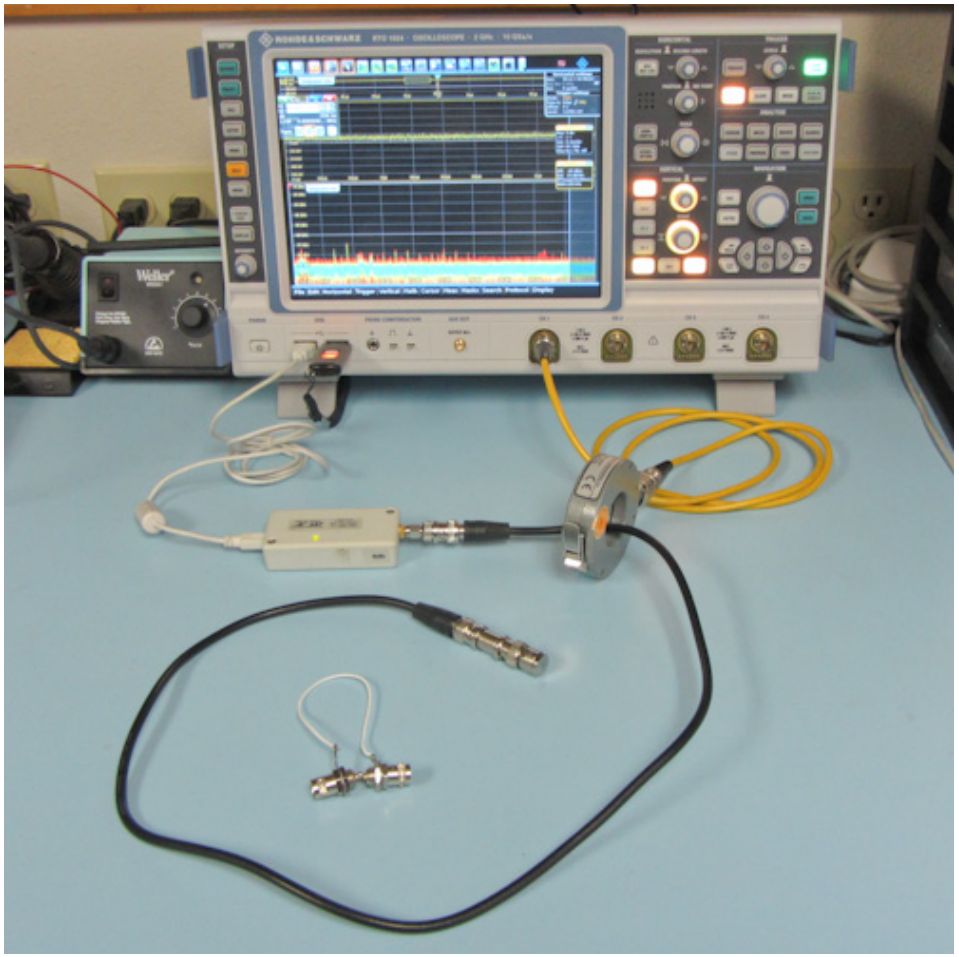
Penetration of I/O connectors through shield



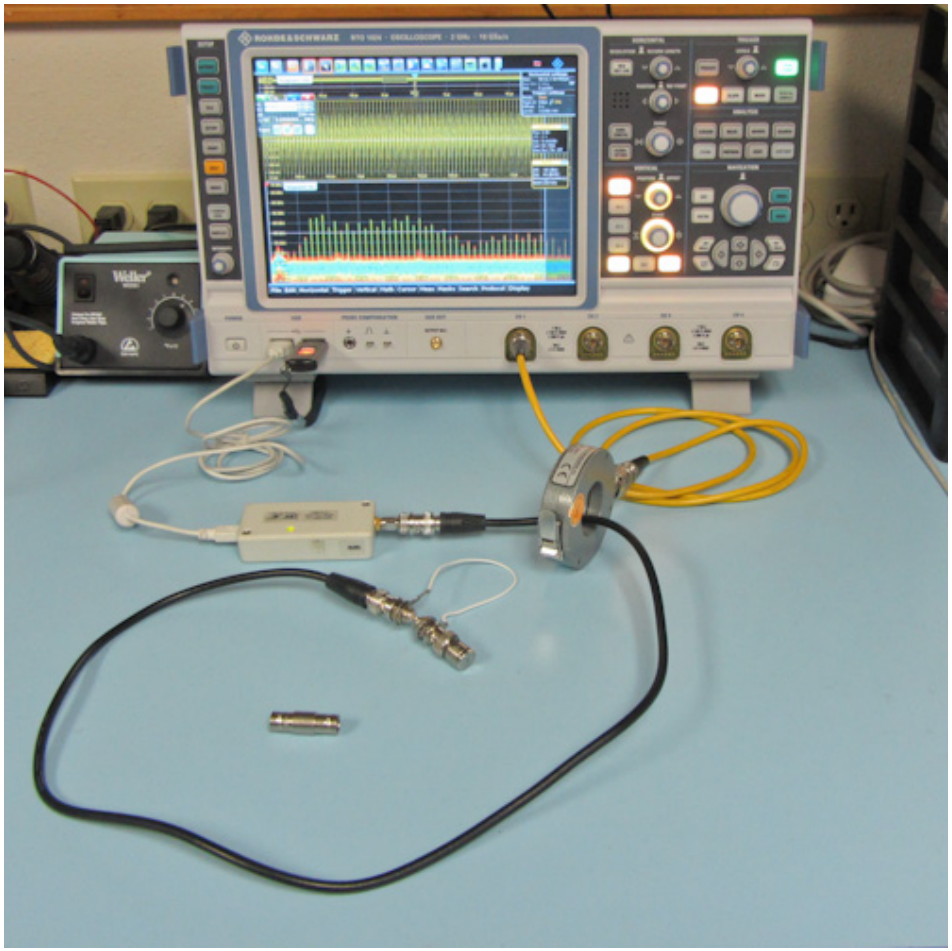
Shim with fingers added to shunt internal noise currents.

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Demo – pigtail terminations



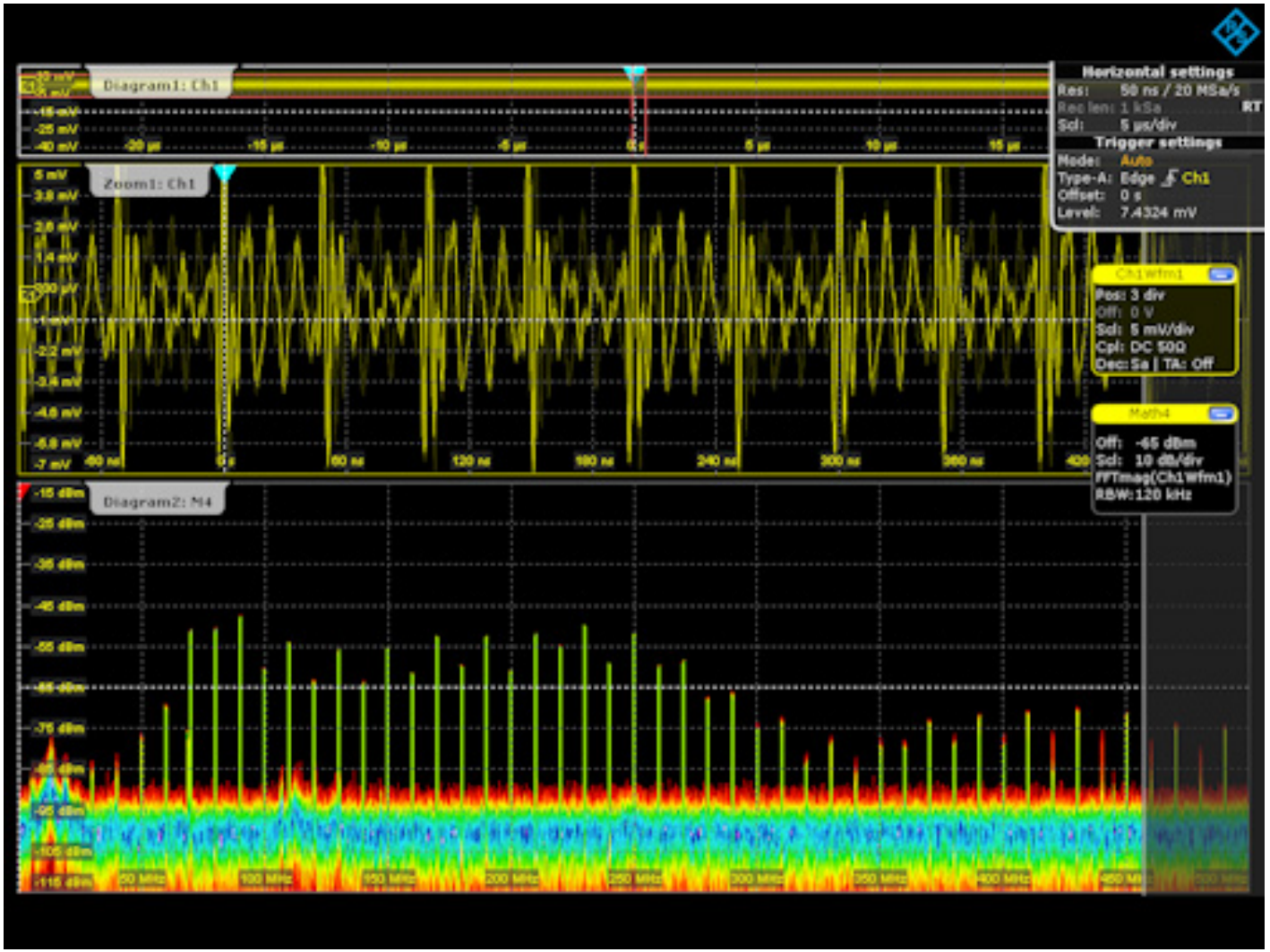
No Pigtail



With 6" Pigtail

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Demo – pigtail terminations

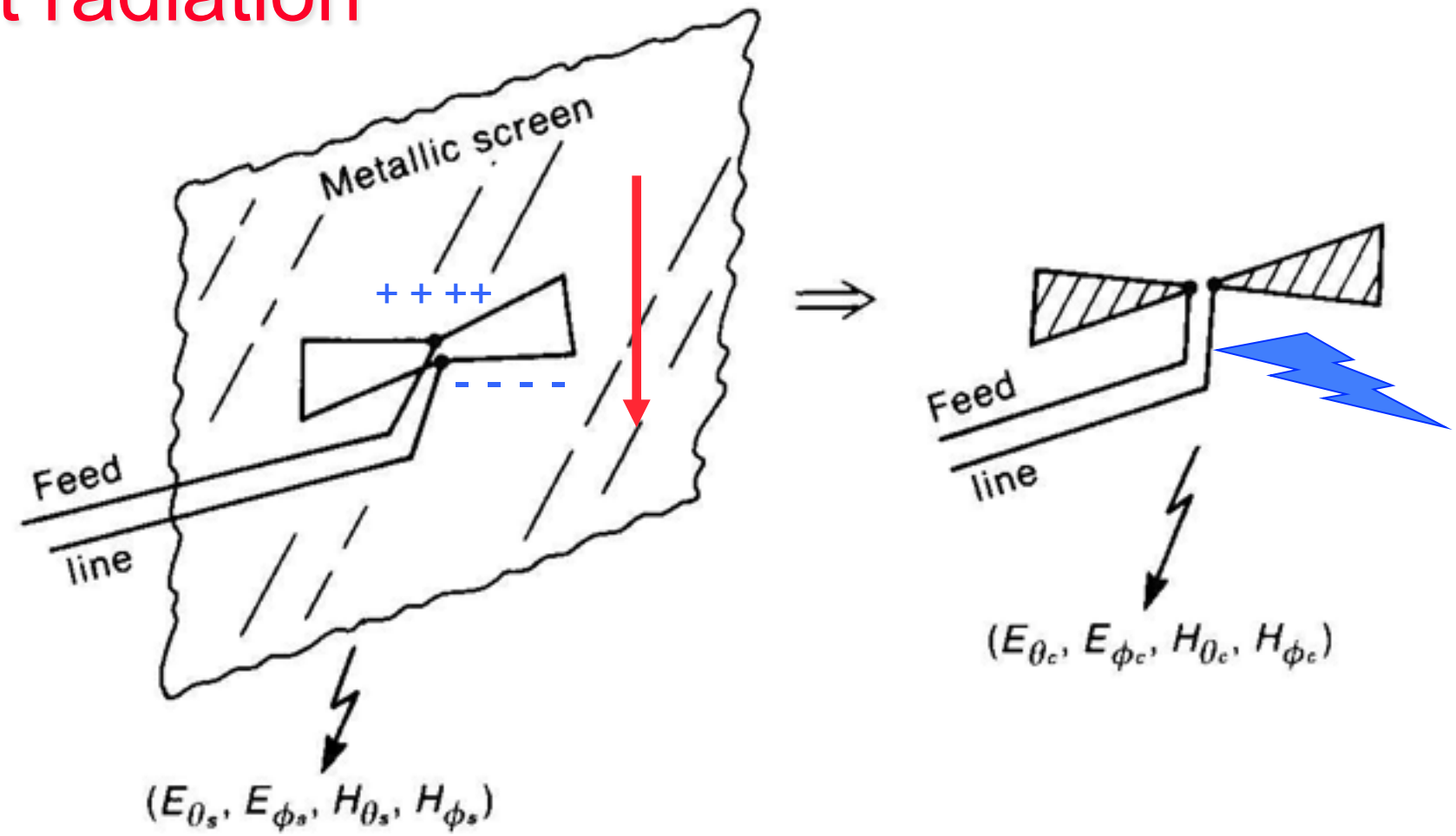


With 6" Pigtail (Close-up of screen) – a 40+ dB average increase!

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Slot radiation

Babinet's Principle says a slot or seam can be modeled as a dipole antenna.



Important! Currents perpendicular to slots will excite the slot the same as a dipole antenna.

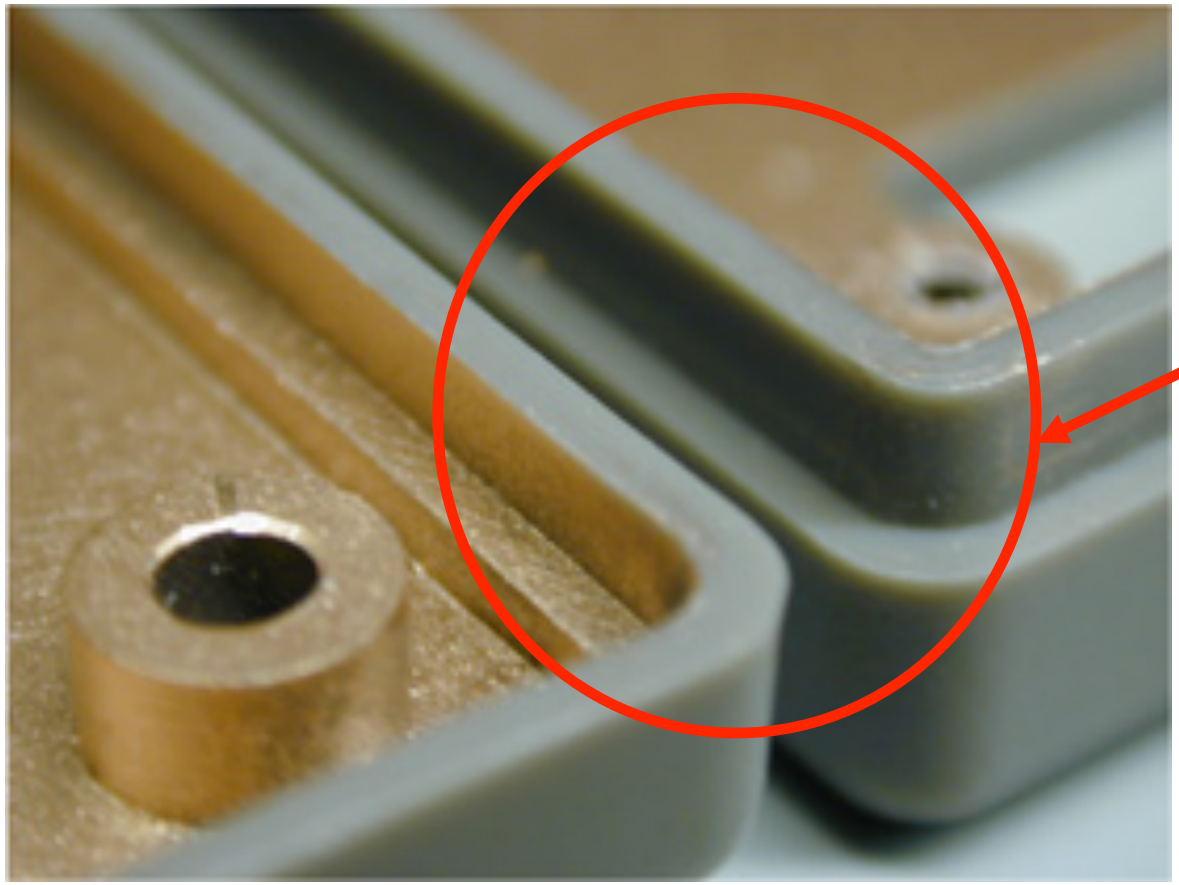
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Shielding - slot caught during design review



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Shielding - poor shield connection



Attempt at shielding module failed to connect halves!

Module halves copper-plated

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Troubleshooting radiated emissions

1. Low-cost spectrum analyzers
2. Near-field probes (E and H-field)
3. Current probes
4. Simple antennas

May be used to help pinpoint emission sources and assist in the troubleshooting process.

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The heart of the kit – a spectrum analyzer



Thurlby Thander PSA2702T

($1,695 at Newark Electronics)

1 – 2,700 MHz with all the “bells & whistles”.



“RF Explorer” WSUB3G

($269 from www.seeedstudio.com)

15 – 2,700 MHz with basic features.

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The heart of the kit – a spectrum analyzer



Rigol DSA815TG

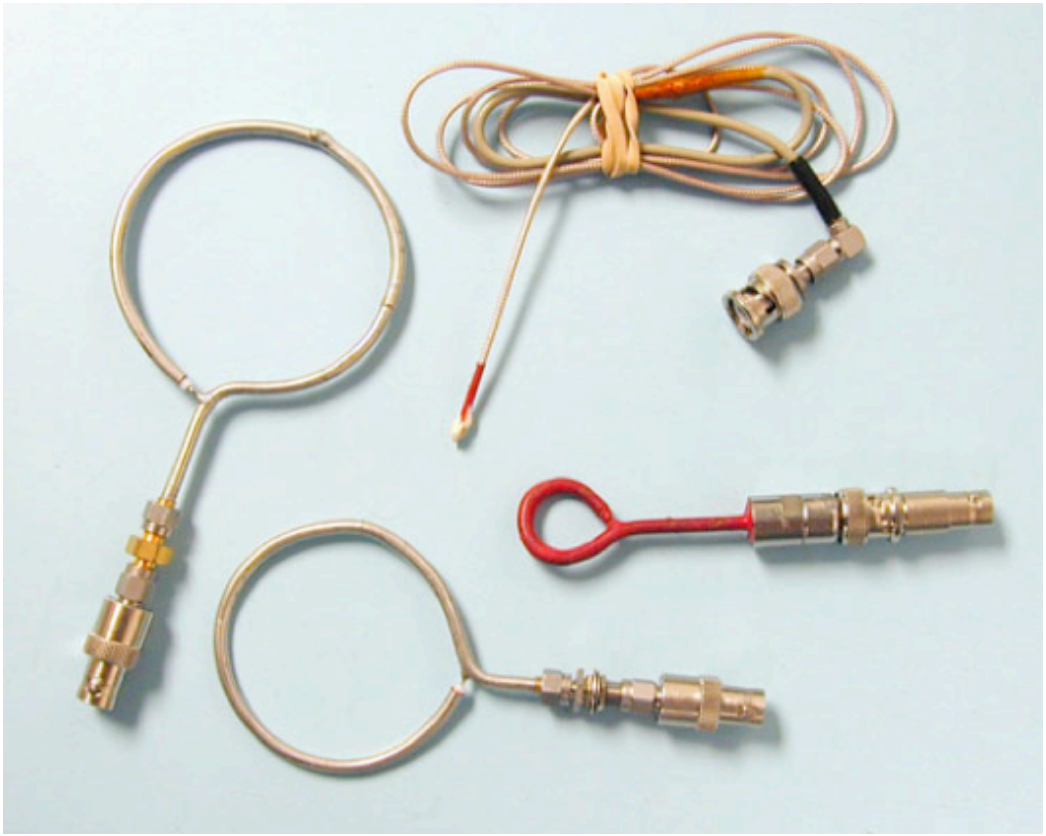
($1,295 base price, with $200 tracking generator and $599 EMI options)

9 kHz to 1.5 GHz with all the “bells & whistles” – AND MORE.

http://www.rigol.com/prodserv/DSA800/

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DIY loop probes



DIY H-field probes made from semi-rigid coax. Bend into a round (or square) shape and solder center conductor to outer shield. A ferrite choke around the handle helps block common-mode currents.

An E-field probe may be made by simply stripping off a little of the shield, allowing the center conductor to be exposed.

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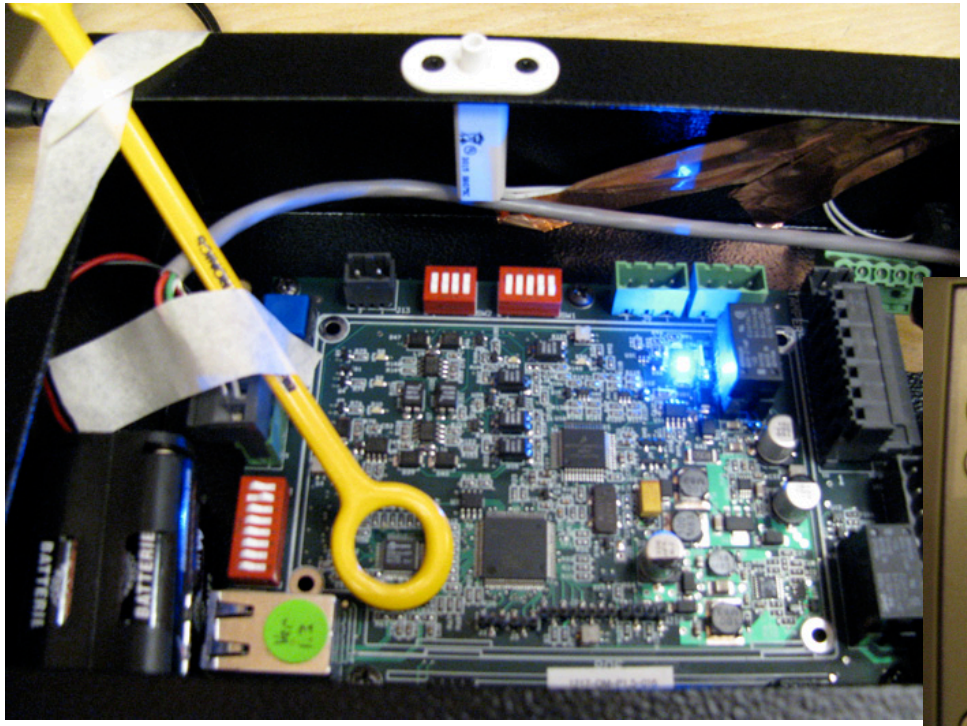
Commercial near-field probes

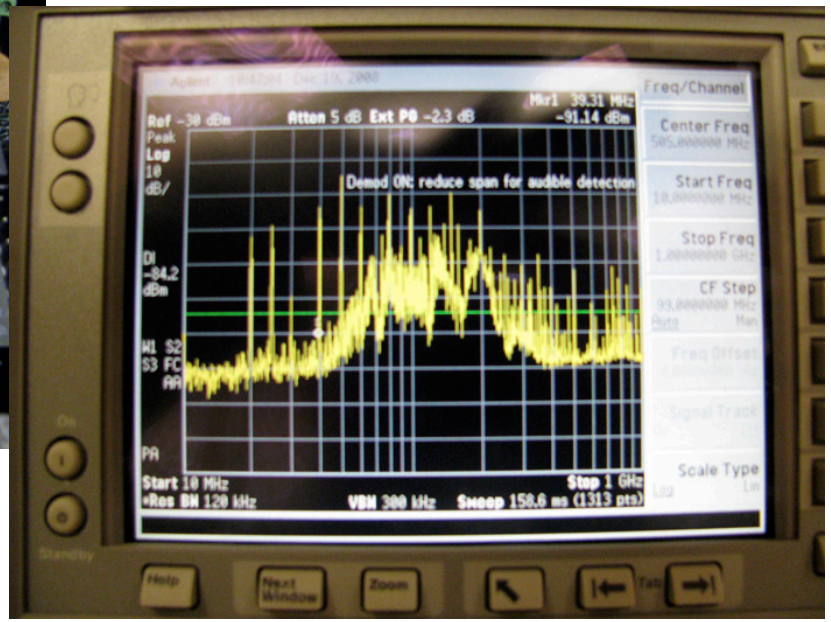


Commercial probes are available from several sources:
Beehive Electronics probes pictured…($295/set of four).
www.beehive-electronics.com

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Use near field probes to identify possible sources





Not all potential sources will be radiating structures – depends on wavelength.

http://www.edn.com/electronics-blogs/the-emc-blog/4414975/Identifying-emission-sources-and-propagating-structures

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DIY current probes



Cores used were Würth Elektronik #74270097 (material 4W620, useful from 10 to 1000 MHz).

14 turns #22 Teflon insulated.

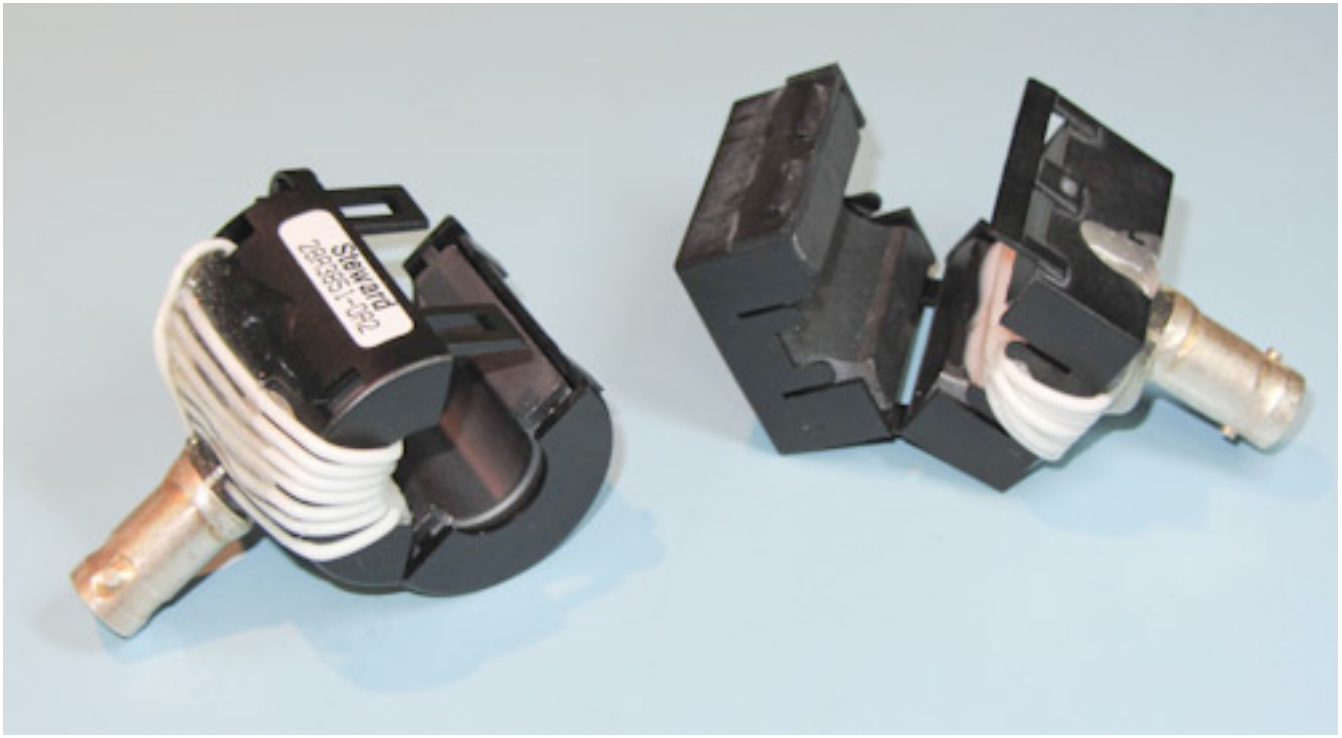
Shield with copper or aluminum foil – split around inside of core for e-field shielding. Wrap with insulating tape.

Homemade current probes work well from 10 to 1000 MHz (shown prior to E-field shielding with copper tape and insulation).

More info: http://www.interferencetechnology.com/the-hf-current-probe-theory-and-application/

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DIY current probes



Cores used were older Steward clamp-on ferrite chokes, but other brands should work as well.

7 turns #22 Teflon insulated.

Use epoxy to hold the turns tight and to mount the BNC connector.

Homemade current probes work well from 10 to 250 MHz.

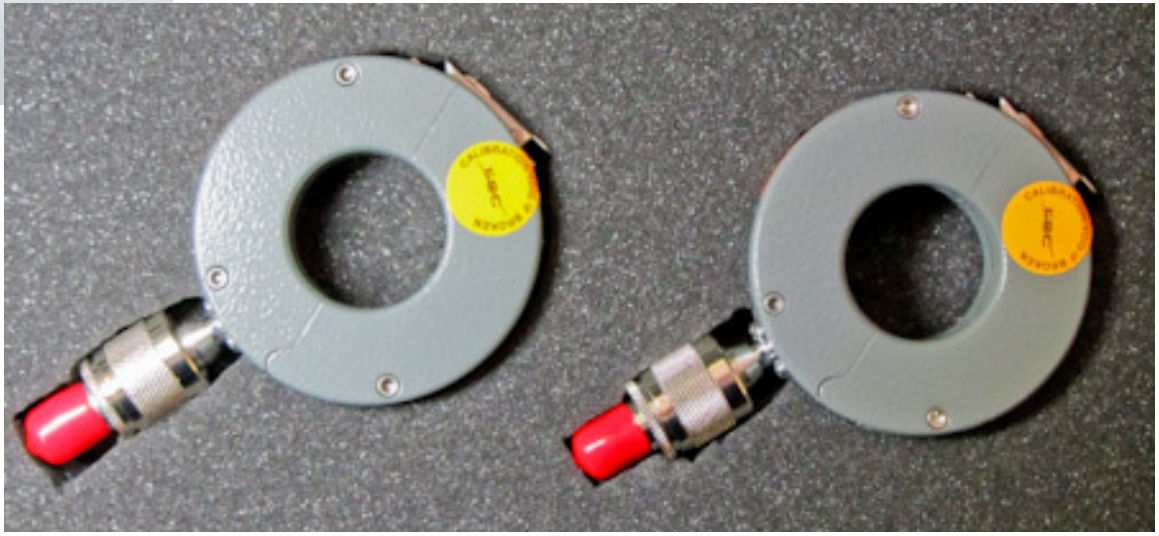
More info: http://www.interferencetechnology.com/the-hf-current-probe-theory-and-application/

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Examples of commercial current probes



Eventually, you'll want to graduate to commercial probes.



A matched set of Fischer Custom Communications F-33-1, or equivalent.

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Current probe transfer impedance

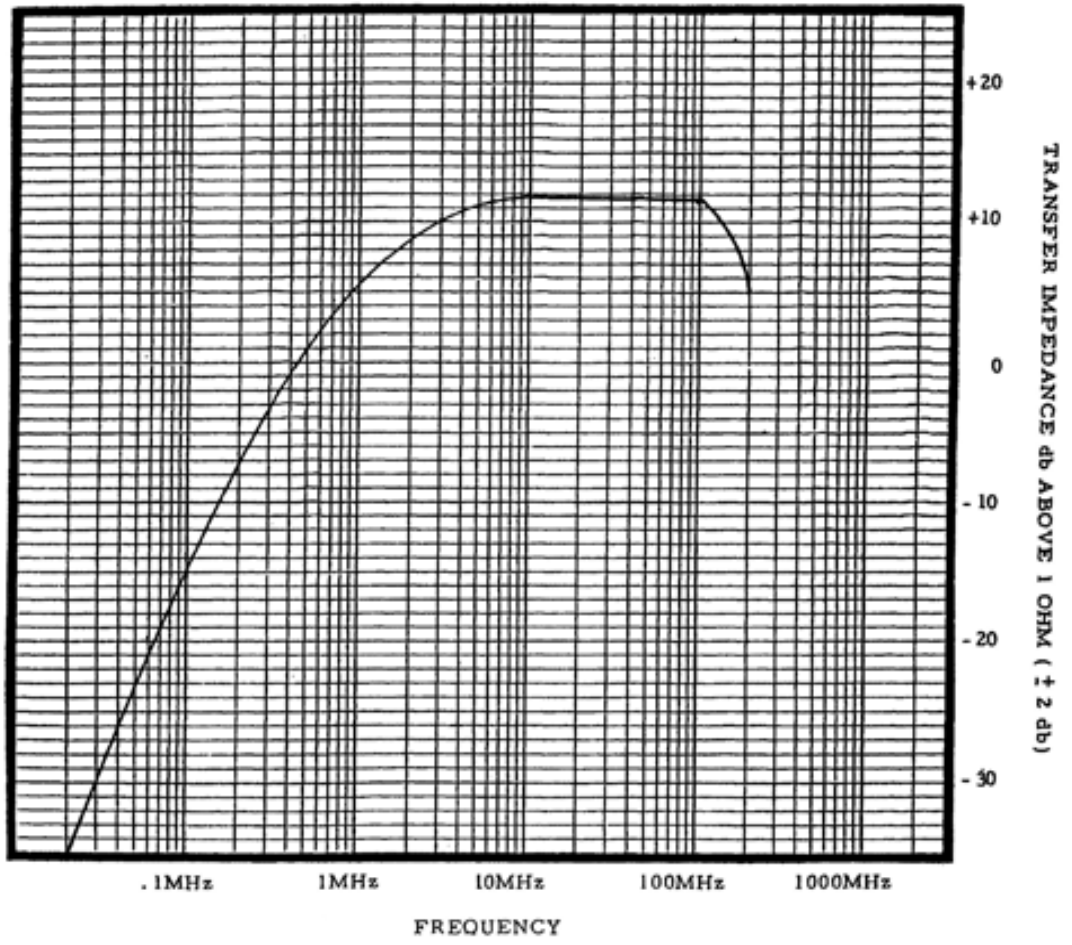
Rather than carrying out a precise calculation, it is sufficient to measure the voltage with a known current and frequency passing through the probe.

This measurement is usually expressed as "transfer impedance" (Z_T).

$$\hat{Z}_T = \frac{\hat{V}}{\hat{I}}$$

Or, expressed in dB:

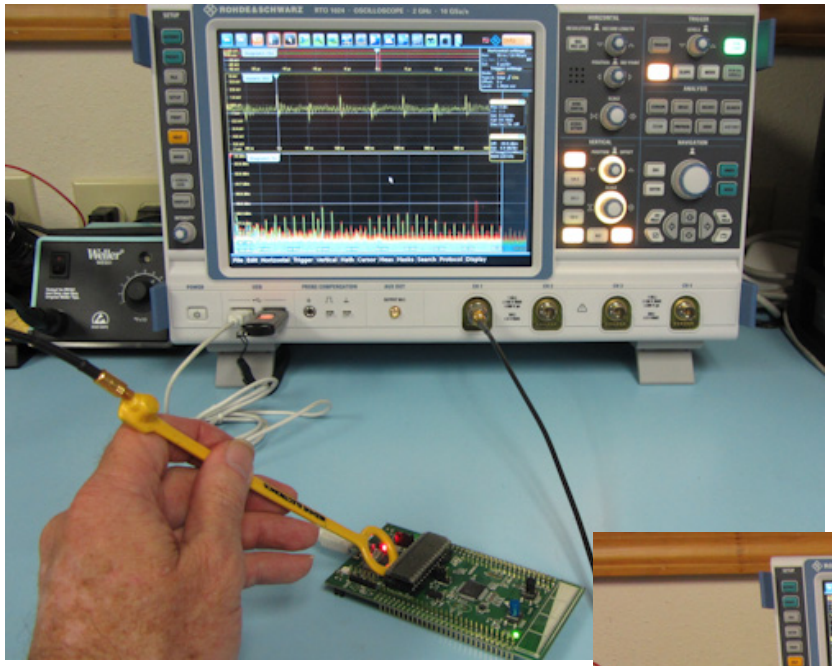
$$|\hat{Z}_T|_{\mathrm{dB}\,\Omega} = |\hat{V}|_{\mathrm{dB}\mu\mathrm{V}} - |\hat{I}|_{\mathrm{dB}\mu\mathrm{A}}$$



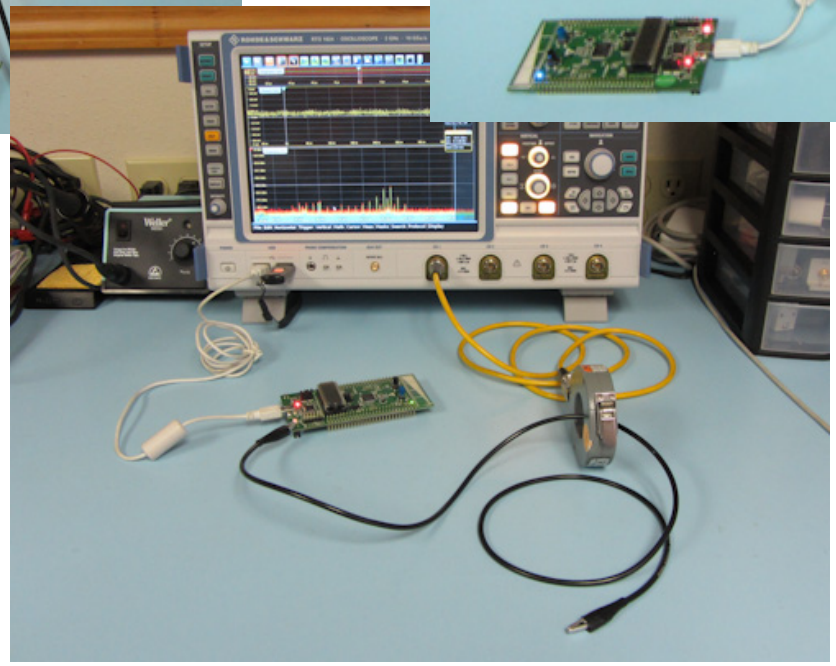
A typical measured current probe transfer impedance (courtesy of Fischer Custom Communications, Inc.)

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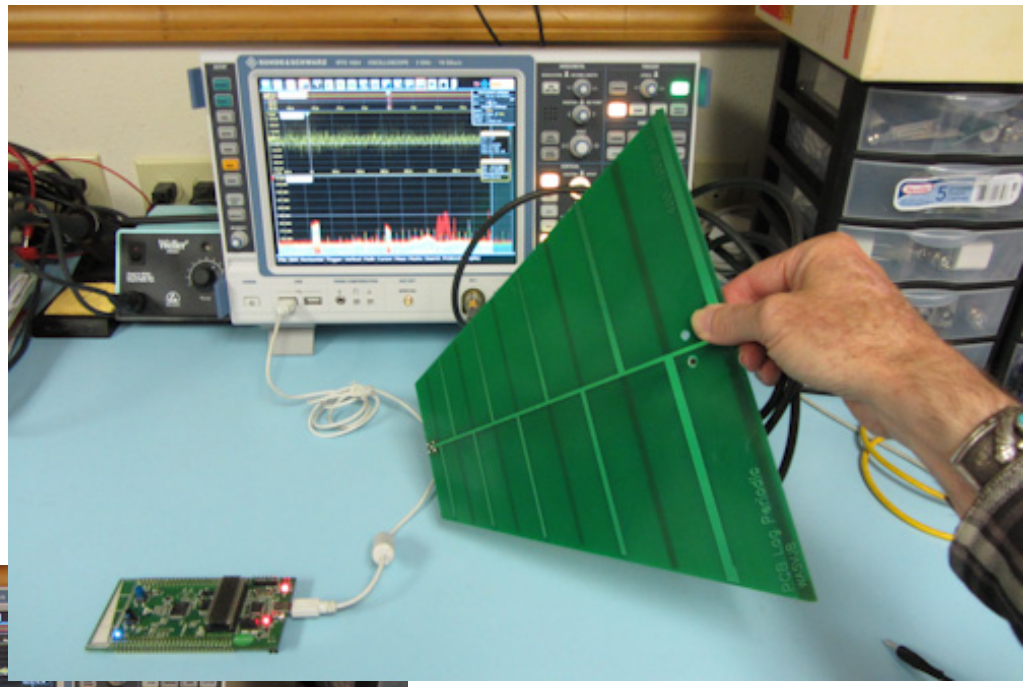
Troubleshooting radiated emissions



1 - Near field probing to identify potential sources



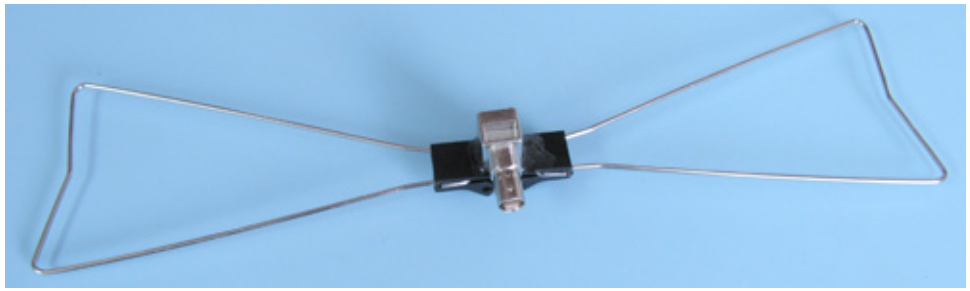
2 - Measure HF currents on I/O cables with a current probe



3 - Double-check potential sources with small antenna (typically, from about 1m away, though)

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EMC antennas made from TV antennas



"Bow Tie" UHF antenna
(300 to 800 MHz)

Note: solder in a TV-grade balun assembly to ~match 50 ohms

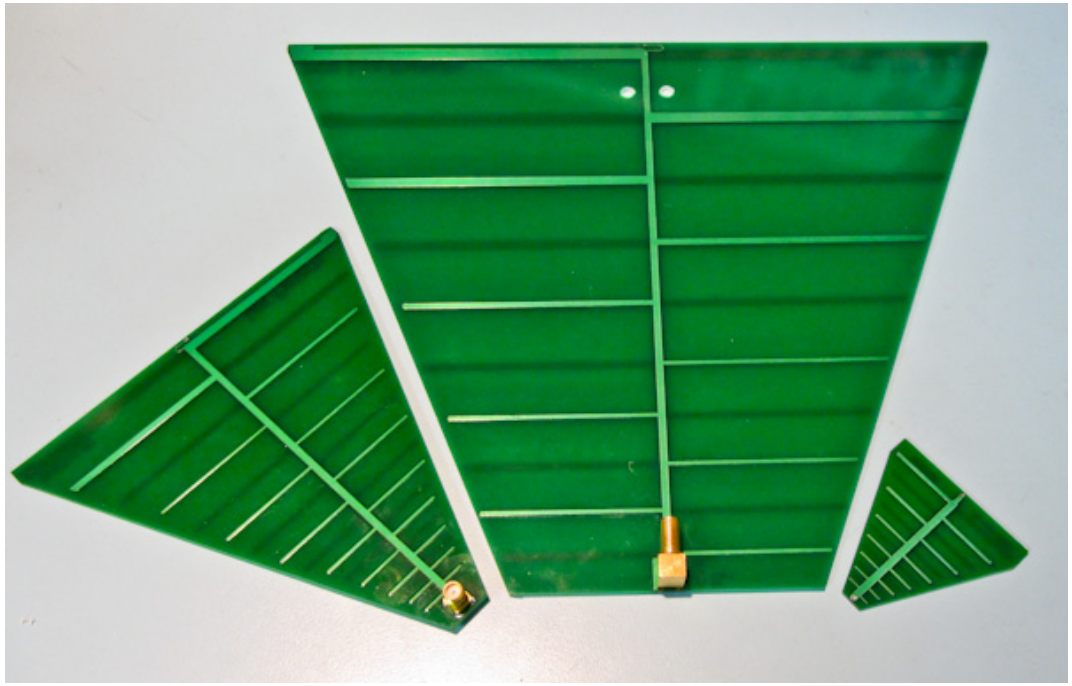


Adjustable "precision" dipole
(65 to 200 MHz)

Note: BNC connector is soldered directly to the dipole elements.

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RE troubleshooting – PC board antennas



PC board log periodic antennas (ranging from 400 MHz to 11 GHz shown). Approximate gain is 6 dB. Available from www.wa5vjb.com/.



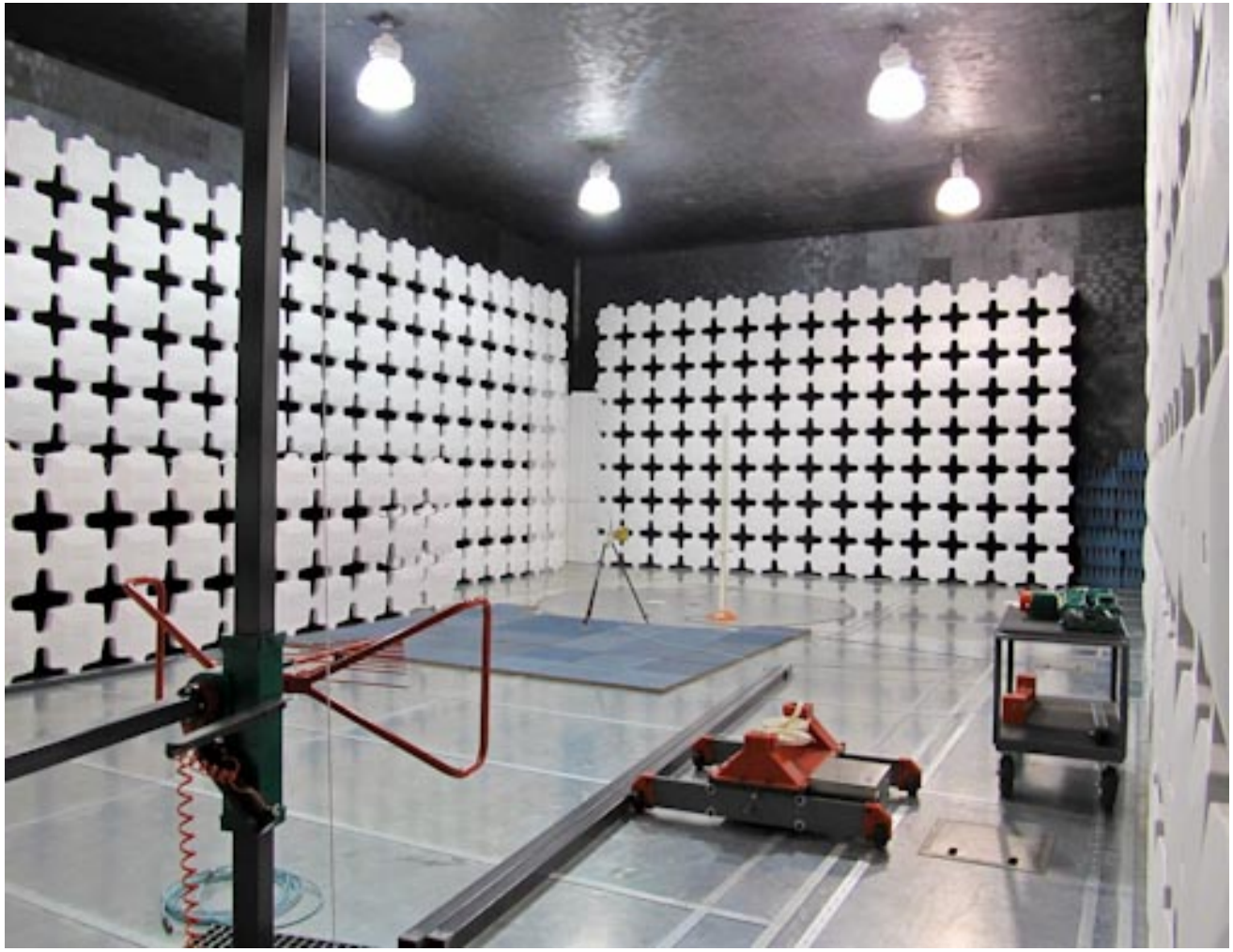
400 to 1000 MHz LP antenna on DIY mount and table-top tripod ($40).

Cost ranges from $7 to $28.

More info: http://www.tmworld.com/electronics-blogs/the-emc-blog/4403451/PC-board-log-periodic-antennas

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Semi-anechoic chamber



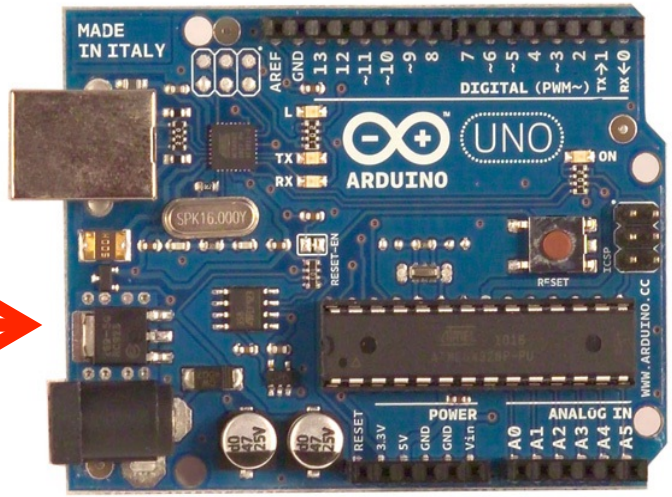
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Setting up for a RE troubleshooting test



About 1m away

EUT

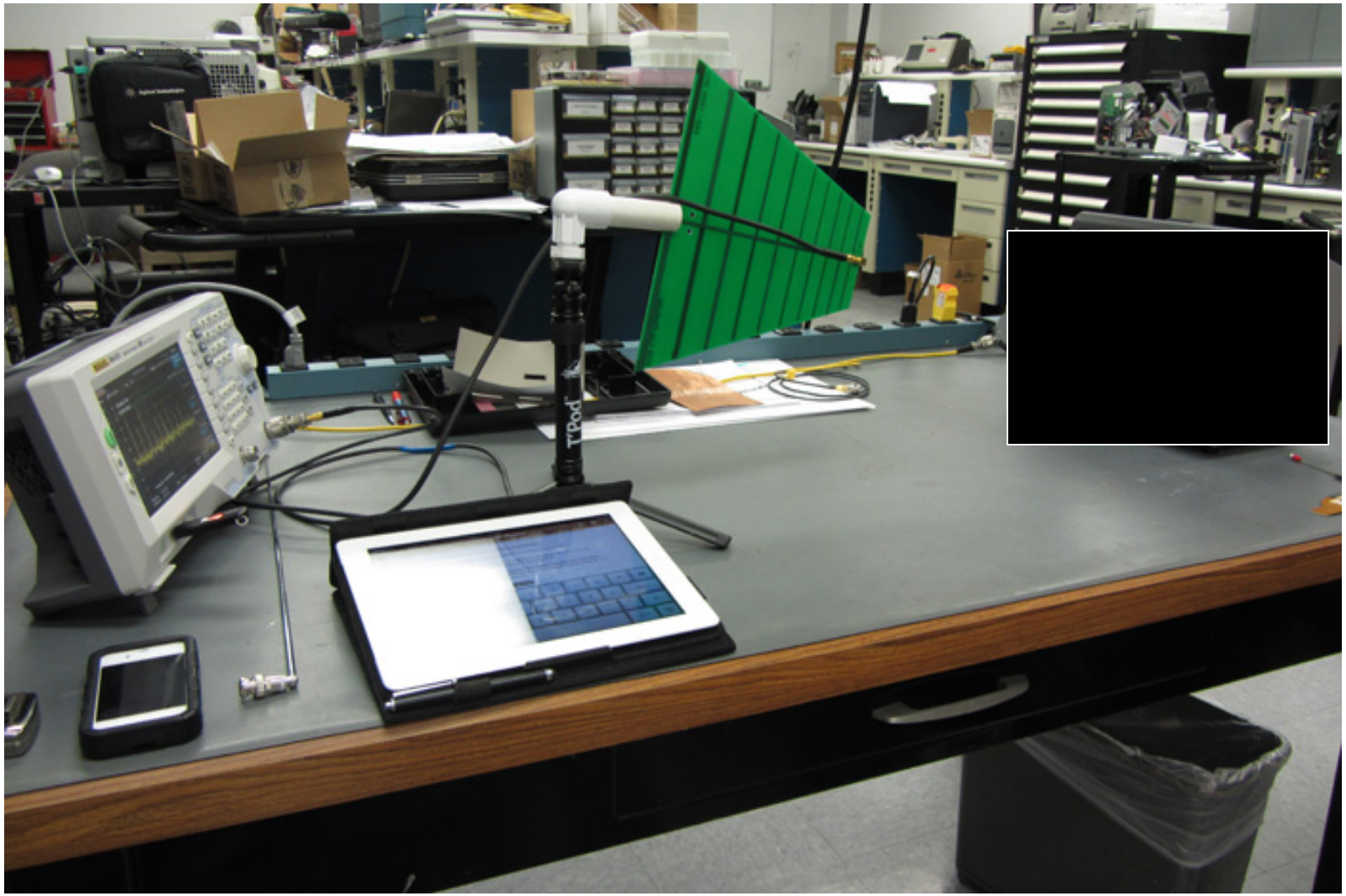


Connect power and I/O cables, then spread them out

Connect to spectrum analyzer

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Setting up for a RE troubleshooting test



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Radiated emission pre-compliance test



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Radiated emission pre-compliance test



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Summary

1. Consider the path for return currents
   - Gaps in return planes
   - Changing reference planes
2. Terminate cable shields properly
   - At the enclosure shield (360 degrees)
   - Or, for plastic enclosures > CM chokes
3. Avoid long seams in enclosures
   - 1/10th to 1/20th the highest clock (or PLL) frequency
4. Identify potential emission with near field probes & current probes > *then confirm actual radiating structures with nearby antenna measurements*

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