Troubleshooting Today's EMI Problems

Kenneth Wyatt
Sr. EMC Engineer
Wyatt Technical Services, Inc.
ken@emc-seminars.com
www.emc-seminars.com

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Check my web site for EMC blog and troubleshooting book links!

What is EMC?

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 aspect) The electronic product does not interfere with itself (Signal Integrity)

Note: EMI – electromagnetic interference

RFI – radio frequency interference

Today’s EMI issues

- ✓ Radiated emissions (RE)
- ✓ Radiated immunity (RI)
- ✓ Electrostatic discharge (ESD)

Why?

- Violation of best engineering practices for EMC
- Lower IC supply voltages: 5 > 3.3 > 1.8 > etc.
- More low cost mobile devices (more “receivers”)
- Proliferation of wireless and high power transmitters

Why do products radiate?

- EMI = electromagnetic interference
- Energy + Coupling Path + Antenna = EMI

• *Take away any of the three elements and no EMI…*

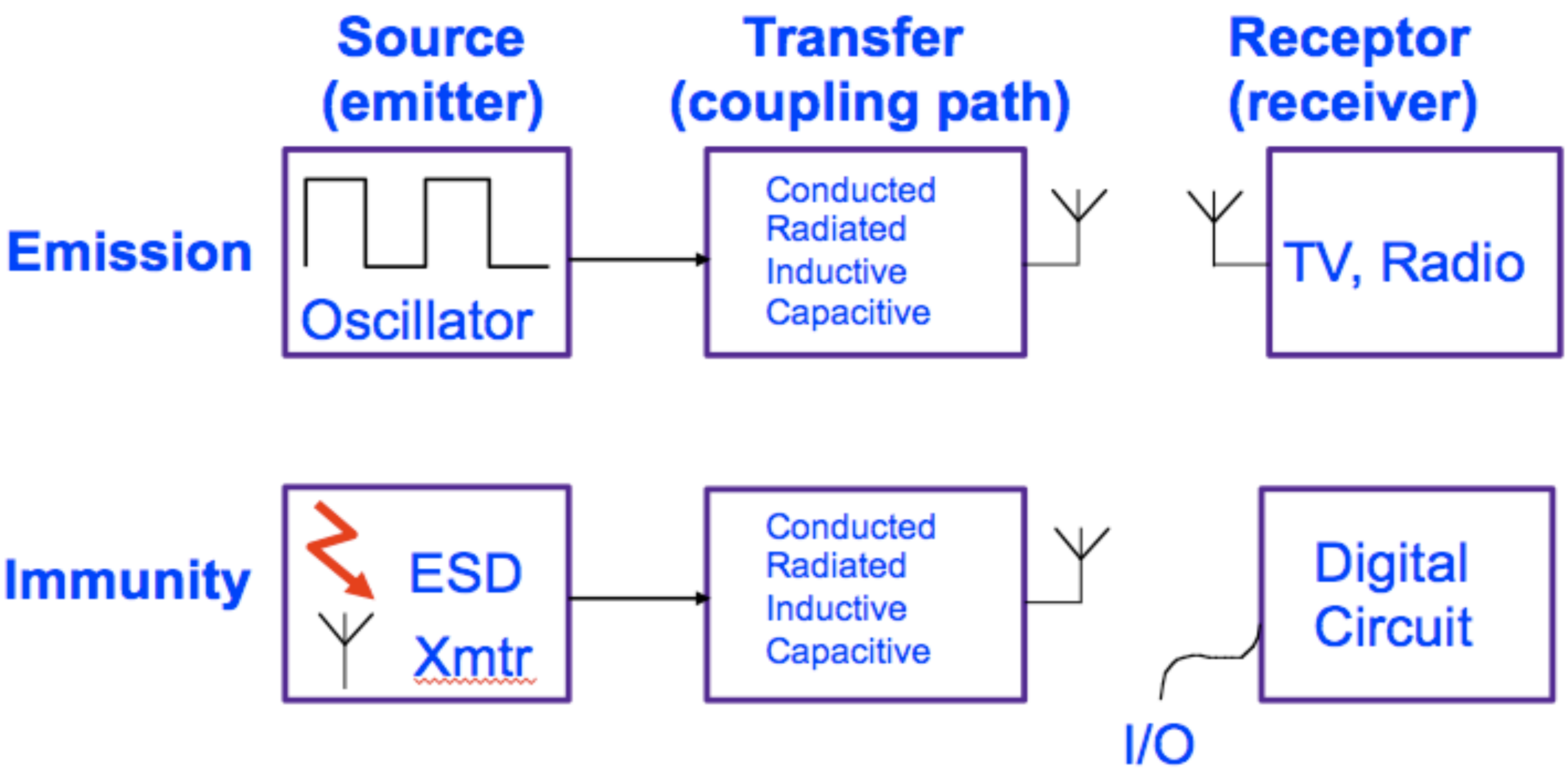
- No energy >>> No EMI
- No coupling path >>> No EMI
- No antenna >>> No EMI

Common issues leading to radiated emissions

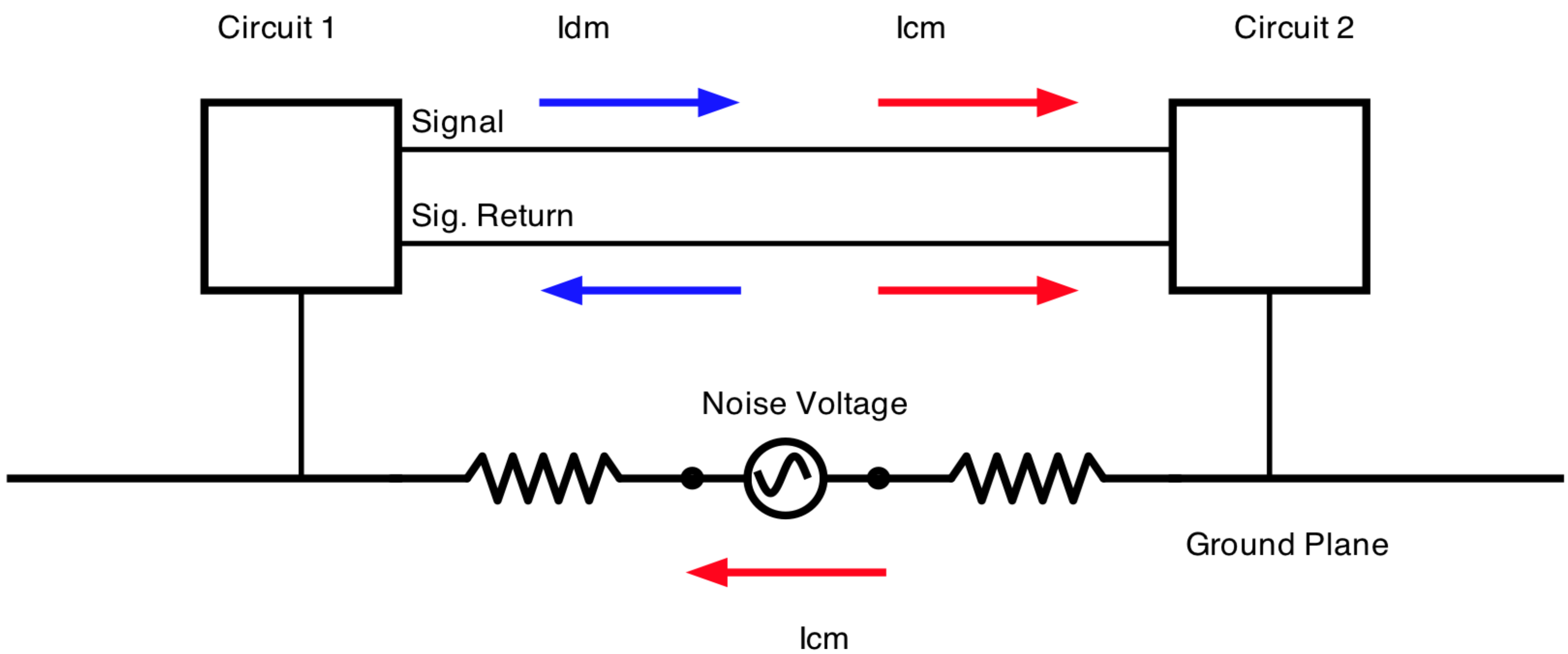
- Discontinuous return current paths
- Poorly-terminated I/O cable shields
- Slot radiation from enclosures
- LCD displays poorly bonded to the enclosure

All the above can cause radiated emissions and be susceptible from radiated RF sources and ESD.

Source - path - receptor model



Differential vs common-mode currents



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

Differential-mode emission equation (over reflecting surface)

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

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}

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

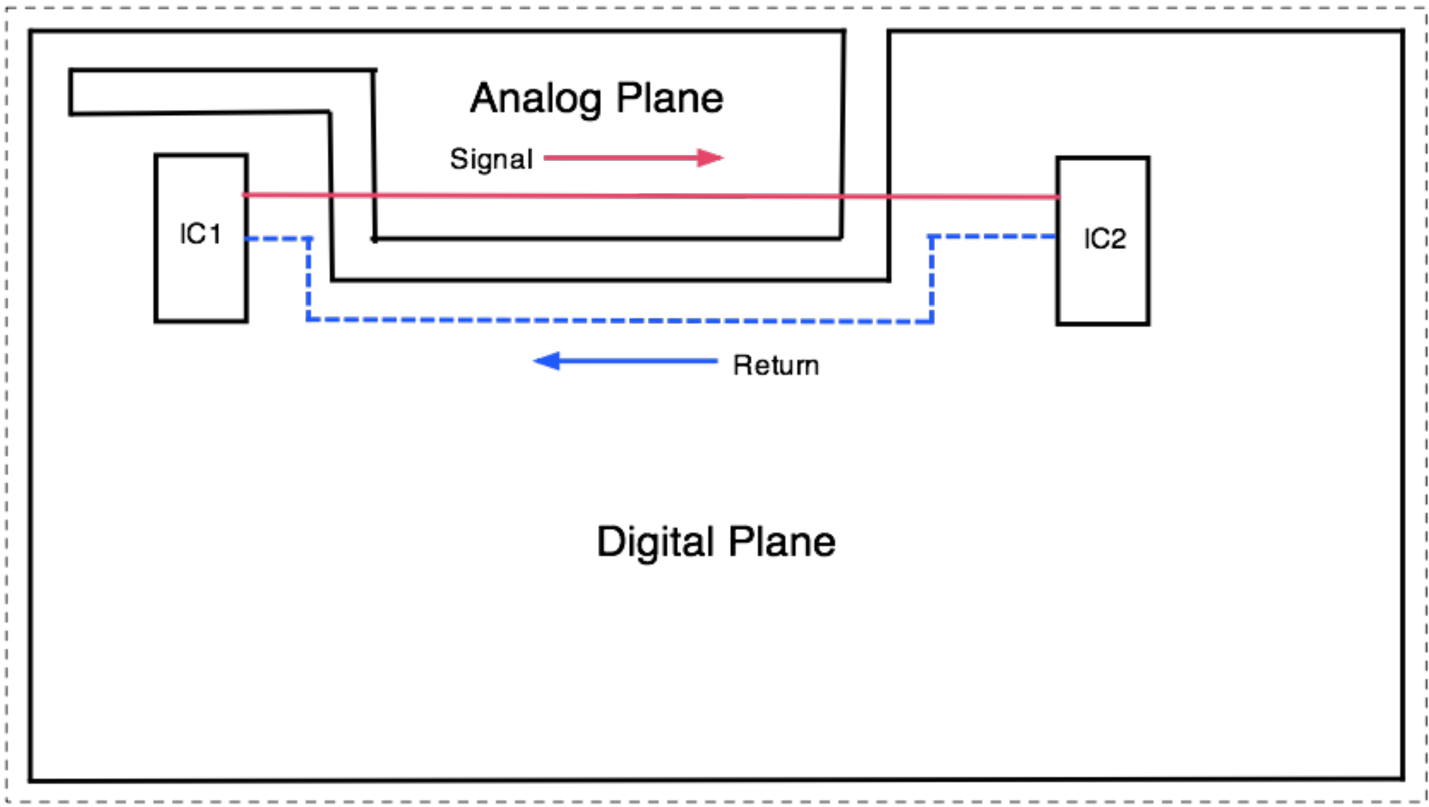
Assuming electrically short length, *(L< half wavelength)*.

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

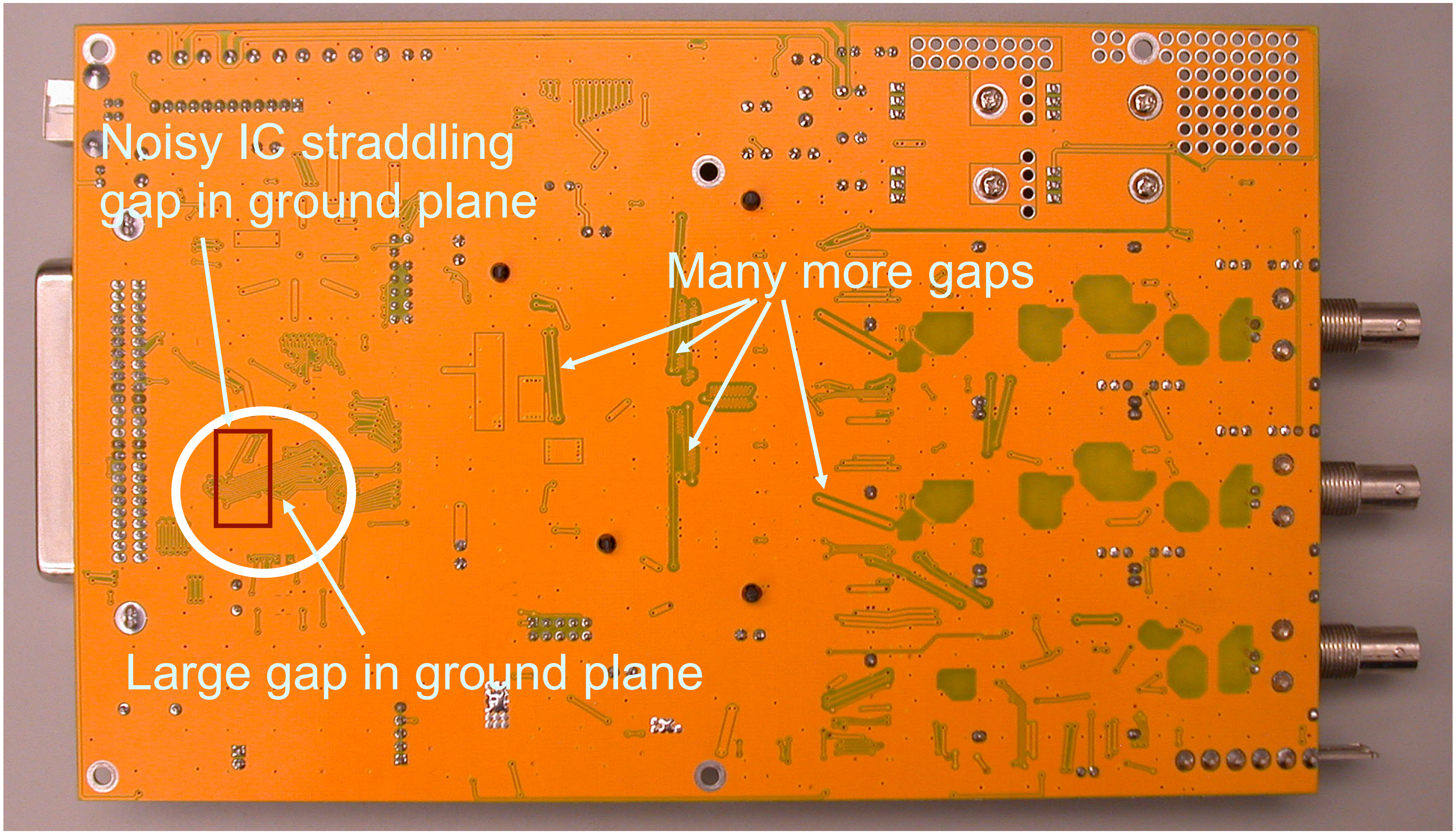
Note the relatively larger factor, 1x10^{-6}

Discontinuous return paths



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

Example: gaps in signal return plane



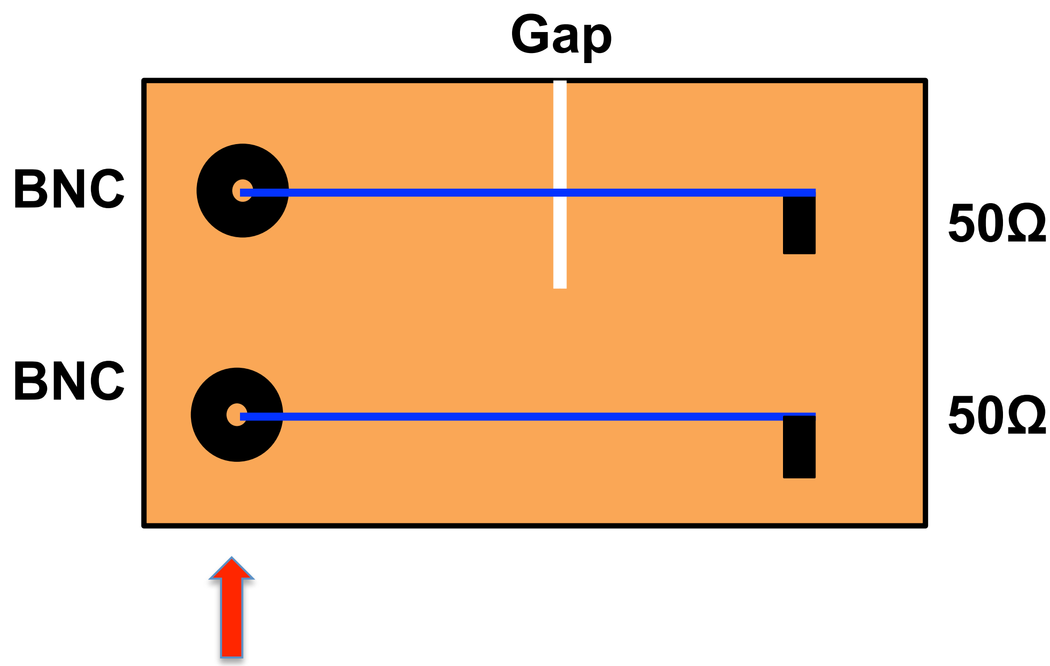
Temporary bridge with copper tape reduced emissions 17 dB!

Demo - gap in return plane

High-frequency traces crossing gaps in the return plane can lead to:

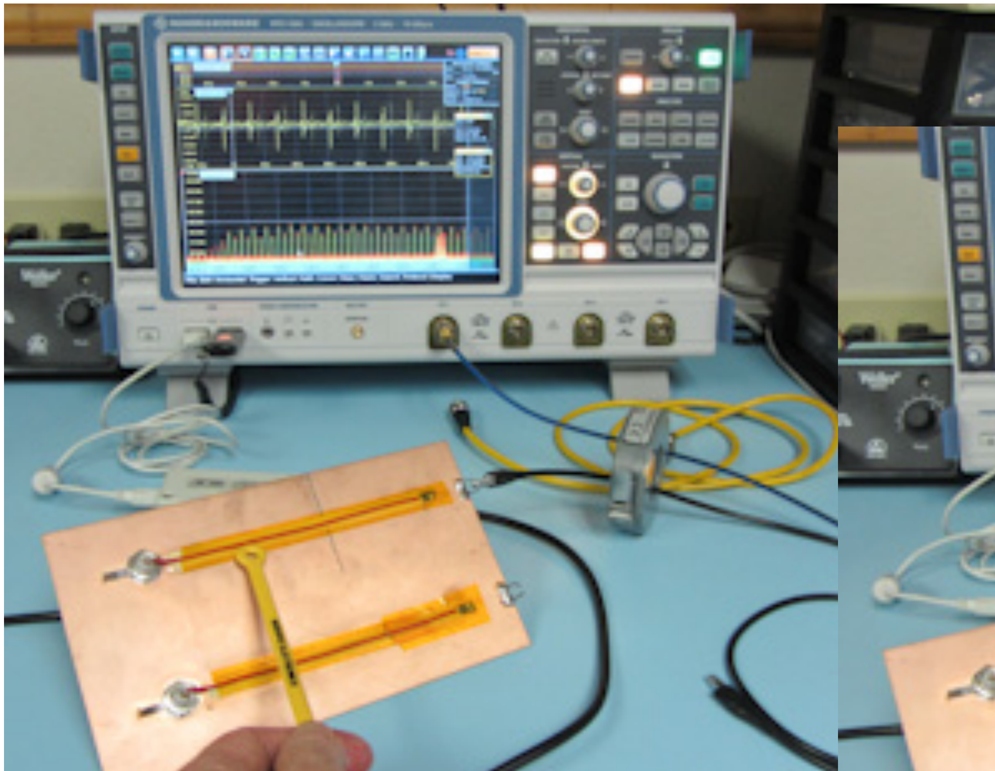
- An increase in radiated emissions
- An increase in radiated susceptibility
- An increase in ESD susceptibility

We'll use a loop probe to measure & compare the signal level along a transmission line with- and without a slot cut in the signal return plane.

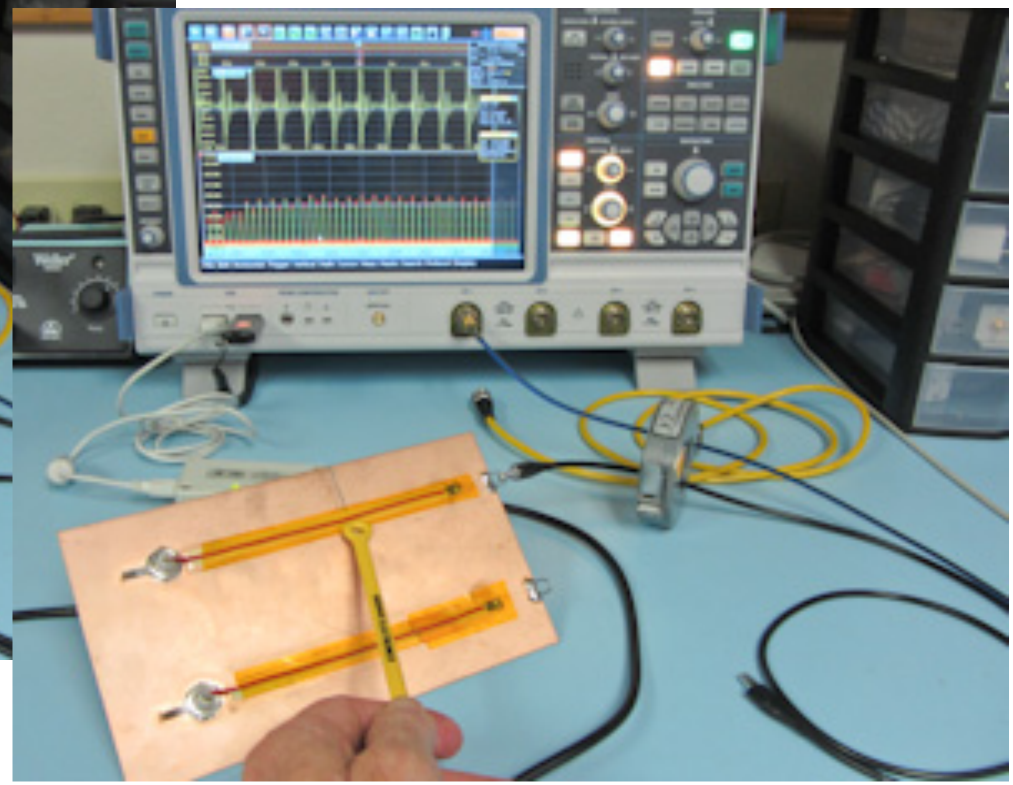


Injecting 3V, 2ns pulse train into either the gapped or un-gapped trace. Simulation of a high speed digital signal. The gap is 5 cm long.

Demo - gap in return plane



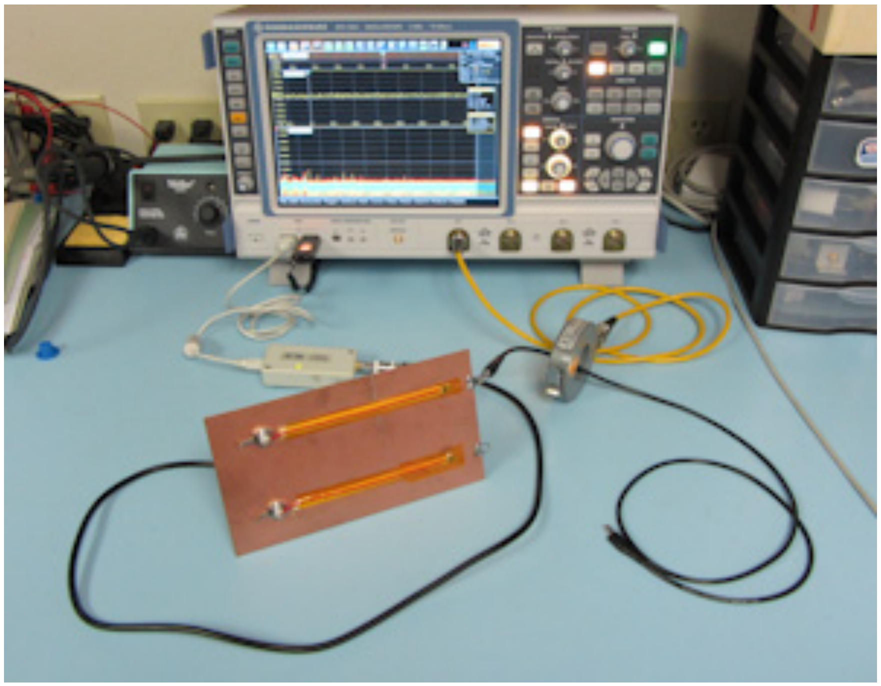
Near gap…

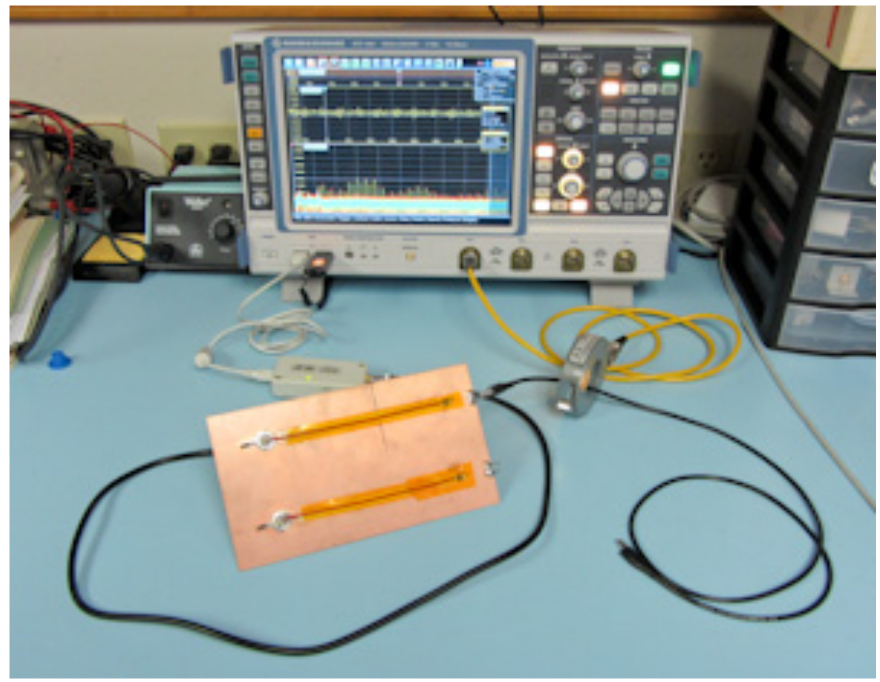


At gap…

Demo - gap in return plane

Measuring the HF currents in our "I/O cable" (1m long clip-lead), which is connected to the return plane.

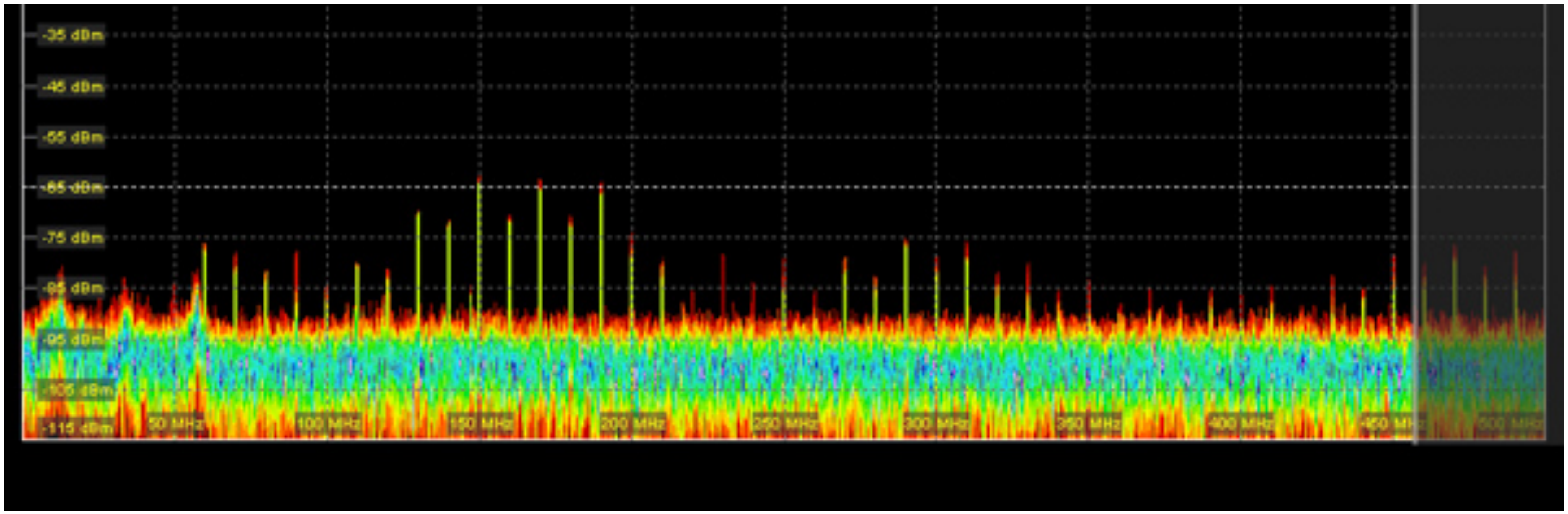




Driving the un-gapped trace (very little harmonic signals)

Driving the gapped trace (+10 to 20 dB incr.) (with resonances at 150 and 300 MHz)

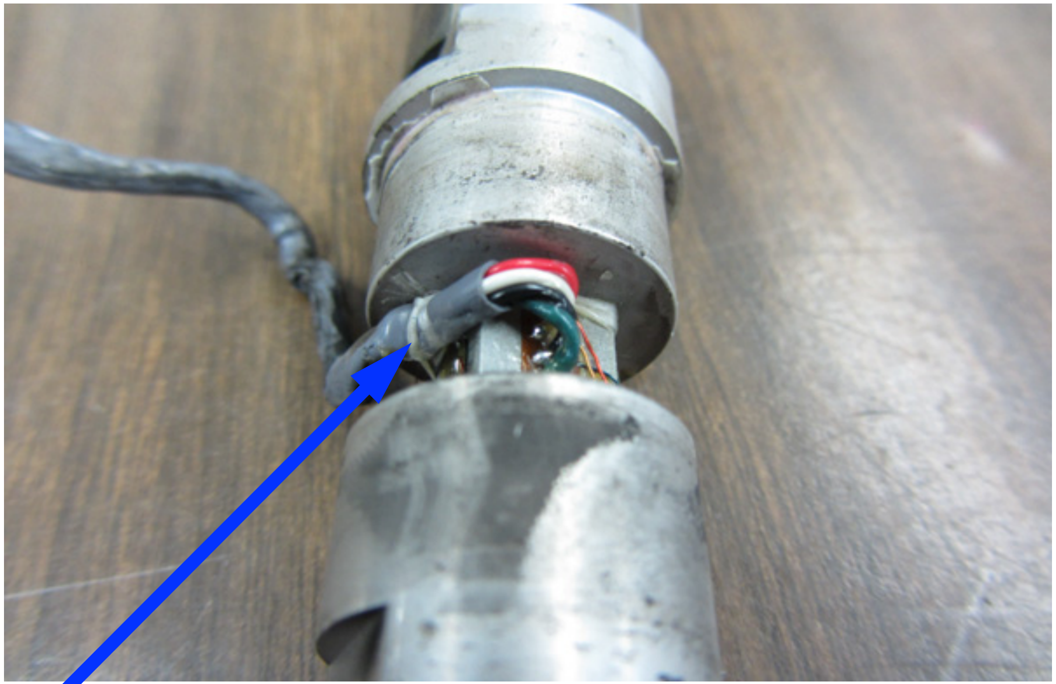
Demo - gap in return plane

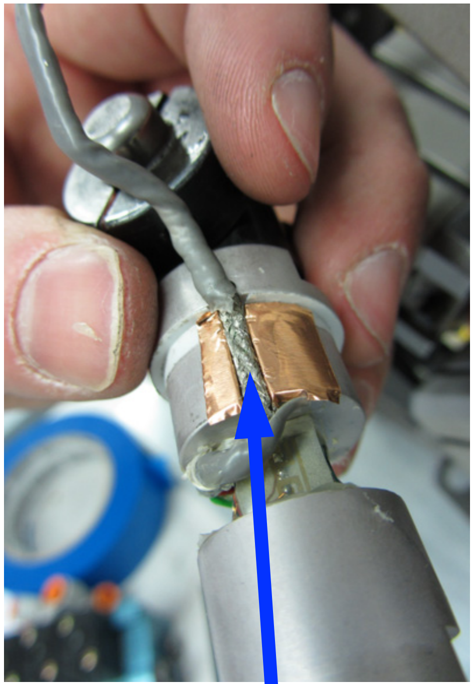


Common-mode currents measured in the 1m cable (-85 dBm = 22 dBuV >> 42 dBuV/m at 150 MHz and a 3m test distance). A Fischer F-33-1 current probe was used.

NOTE: FCC Class B limit = 43.5 dBuV/m! Barely passing!

Poor cable shield bonding to chassis

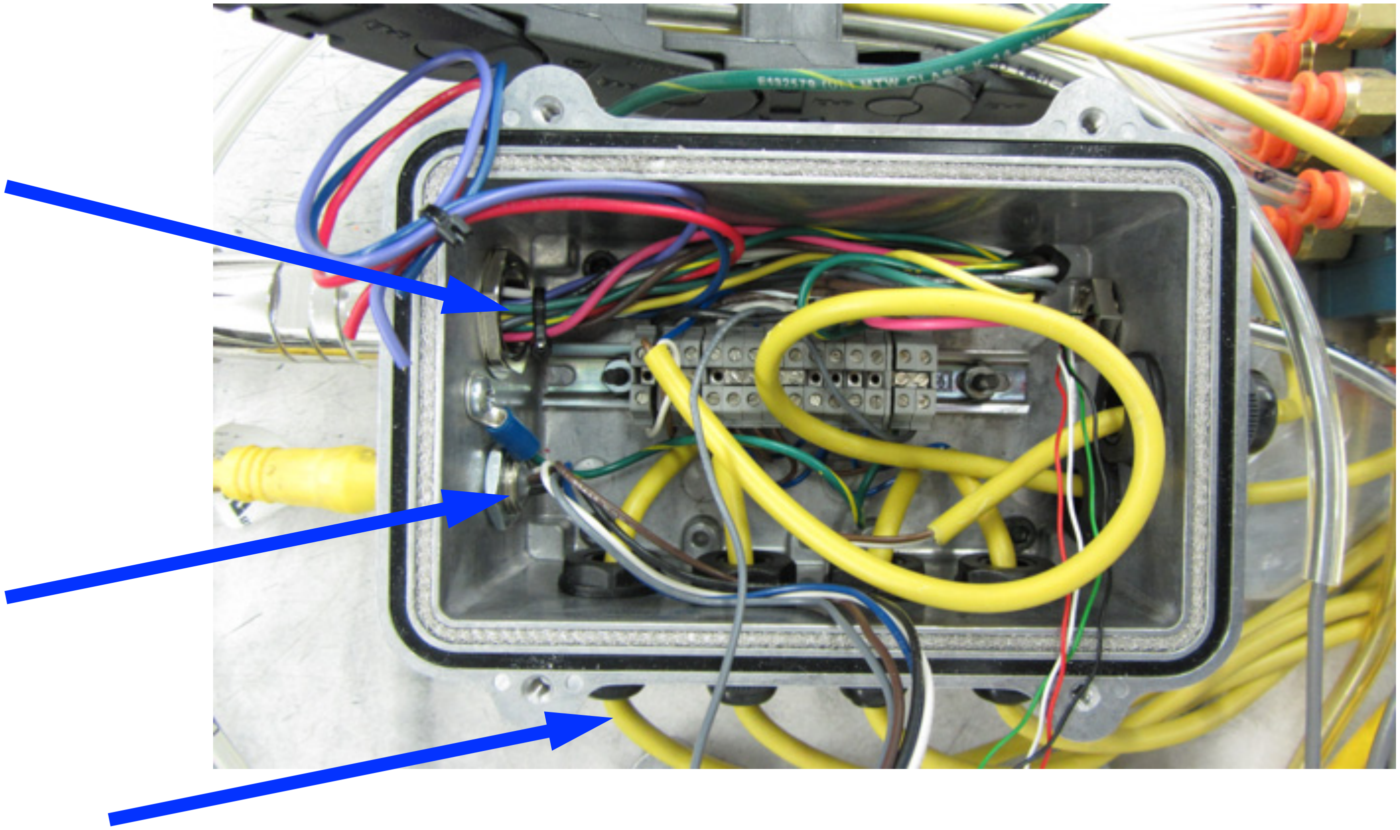




Poor cable shield bonding – cable shield disconnected.

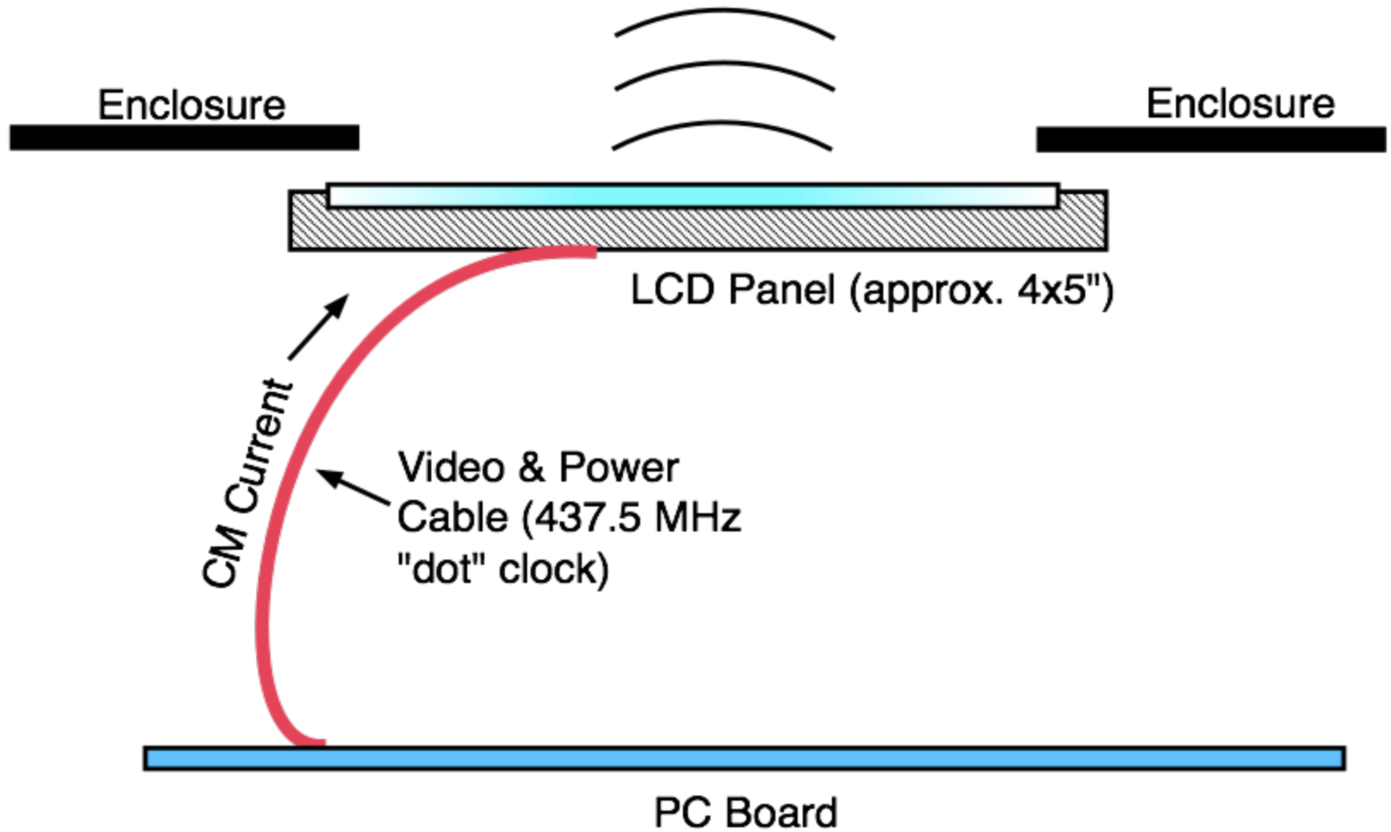
Good cable shield bonding – cable shield connected to chassis.

Poor cable shield bonding to enclosure



Multiple cables are penetrating through metal enclosure.

LCD emissions

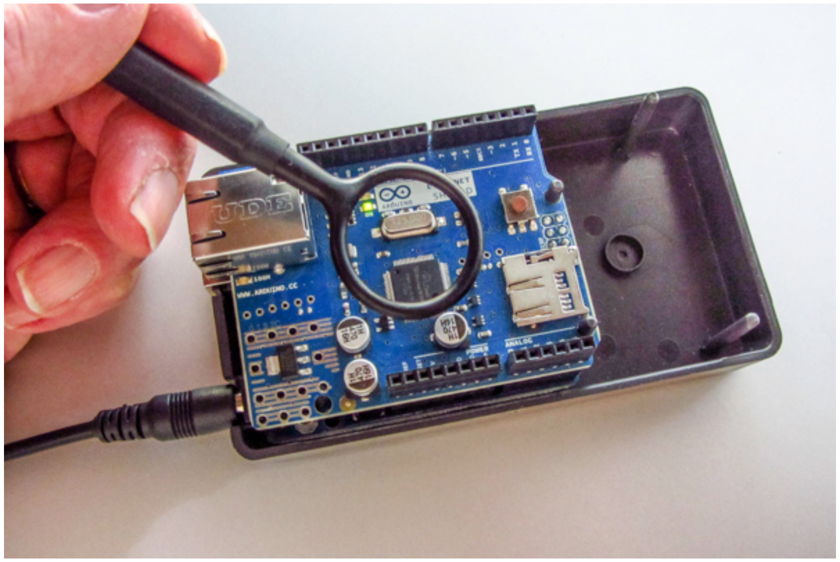


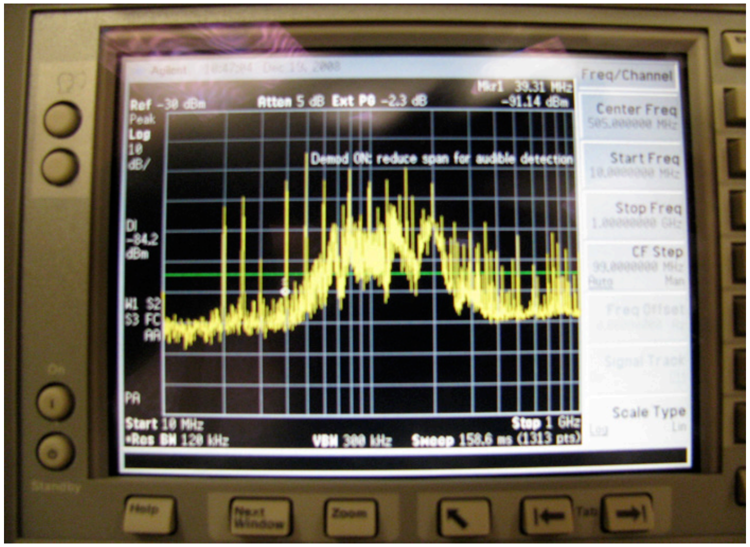
Display cable radiates and excites the metal LCD housing.

Solution: bond the LCD housing to the enclosure in multiple points.

Troubleshooting radiated emissions

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

Identifying emission sources & propagating structures

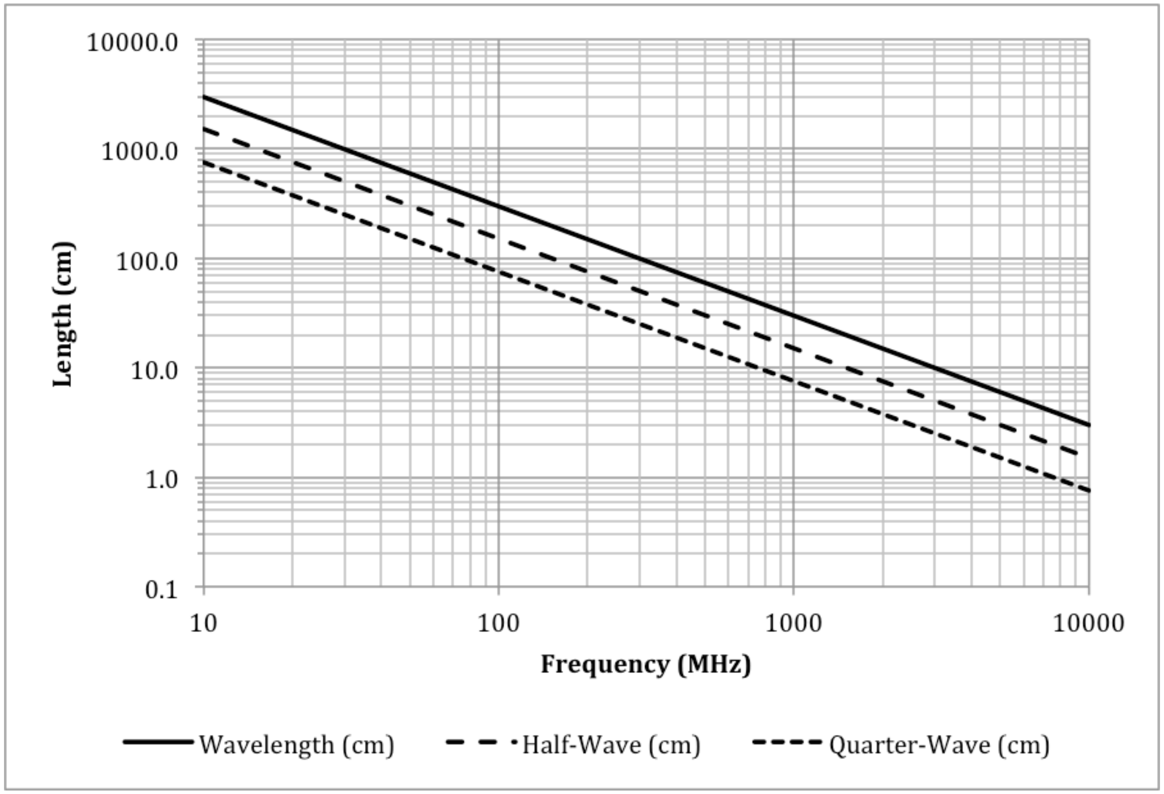
Near field scanning using a probe can help identify potential sources, but…

…does the structure really cause radiated emissions?

- Is it an efficient antenna?
- You need to measure the structure length and compare against the wavelength for a half-wave dipole antenna
- Then, confirm using a close-spaced receiving antenna

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

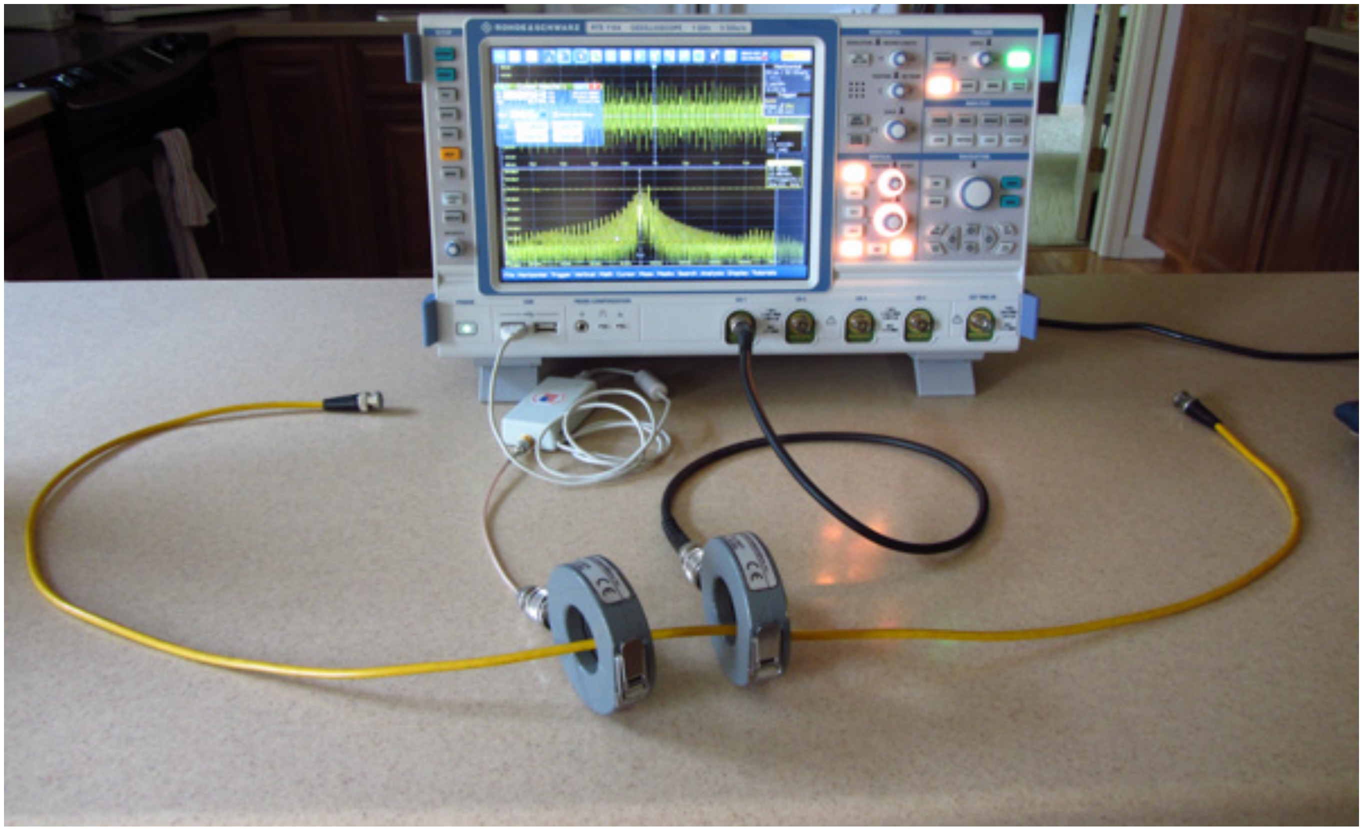
Wavelength versus length



As a metallic structure approaches 1/2 wavelength (or multiple), it becomes an efficient antenna.

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

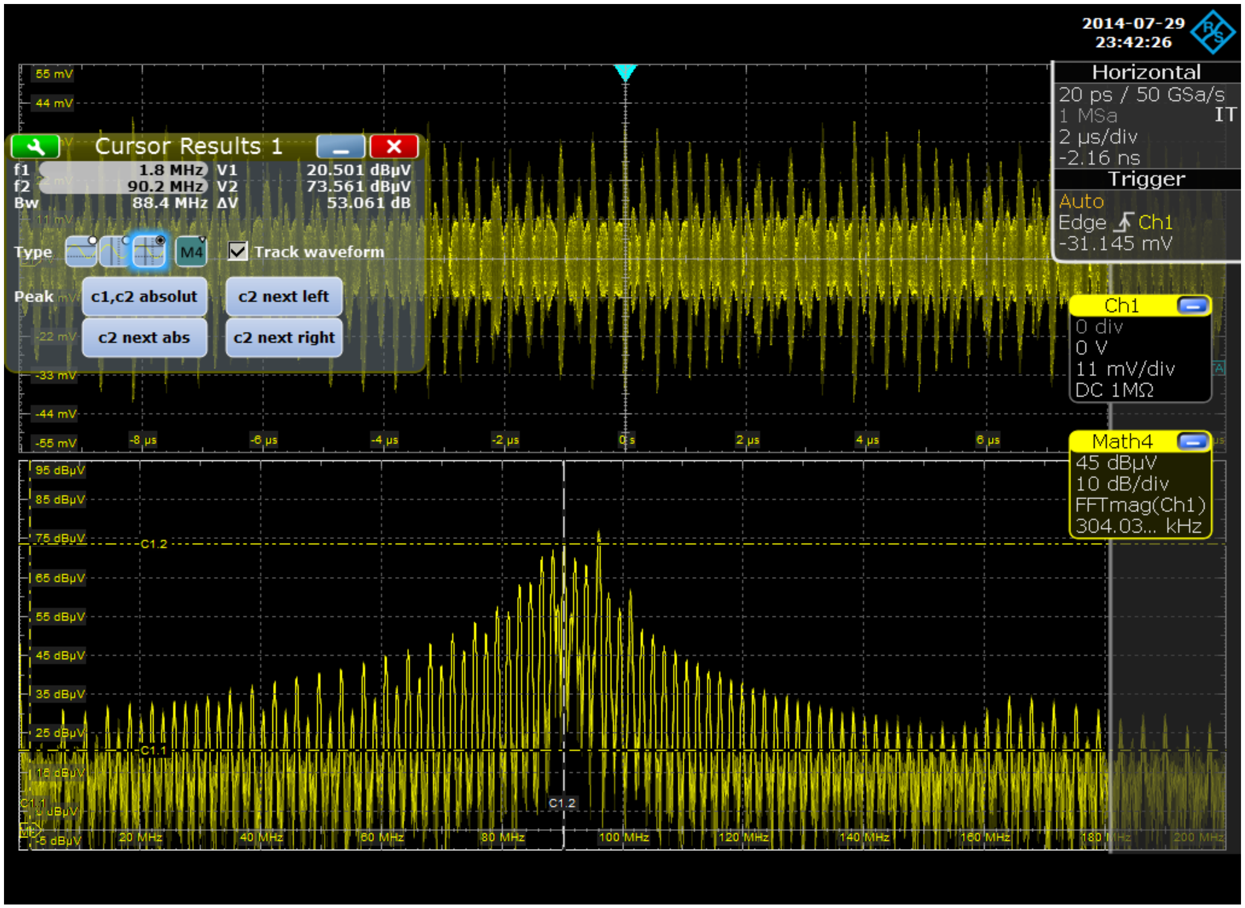
Measuring cable resonance



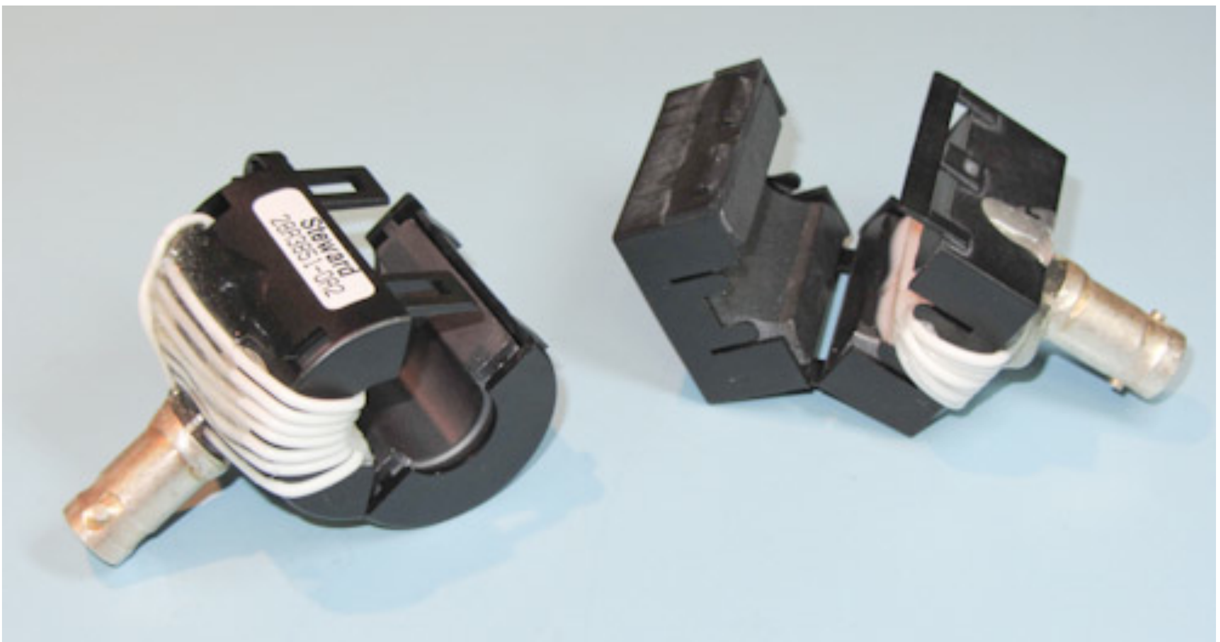
Use a harmonic comb generator and current probes to measure cable resonance.

Ref: http://edn.com/electronics-blogs/the-emc-blog/4423597/Measuring-resonance-in-cables

1.3m cable (88.4 MHz resonance)



DIY current probes



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

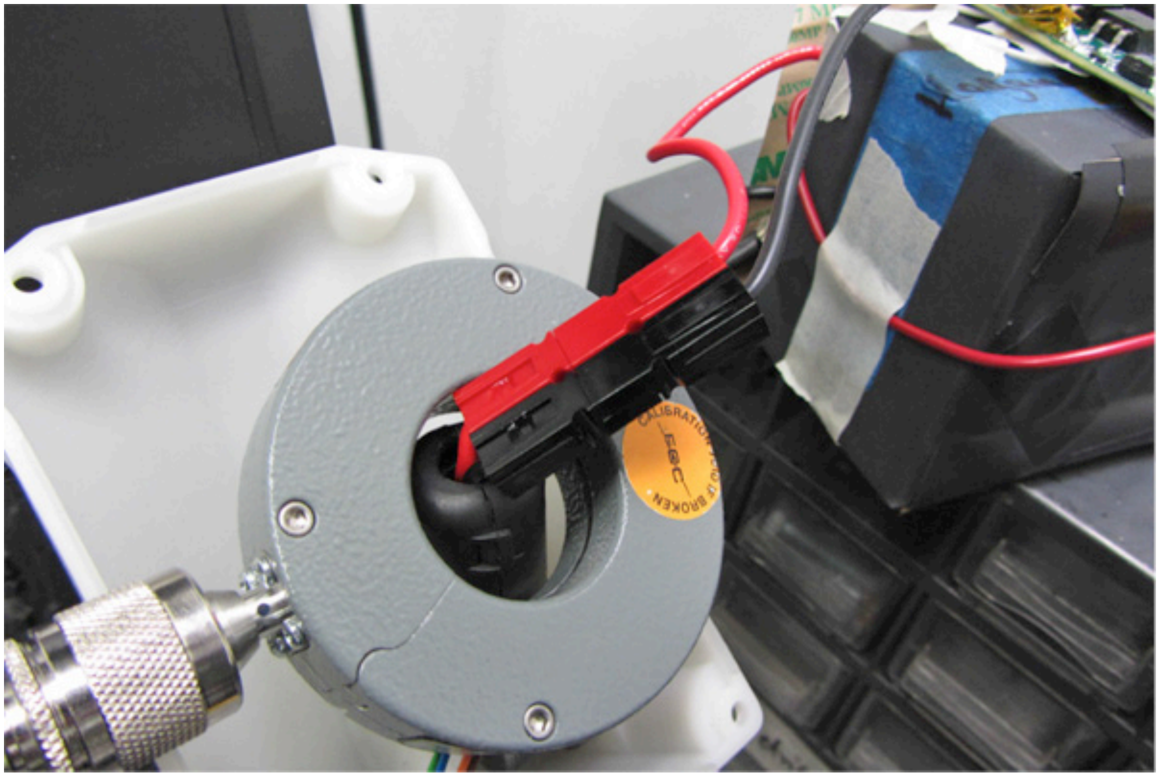
7 turns #22 Teflon insulated.

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/

Commercial current probes



Use a current probe to measure common mode currents on cables.

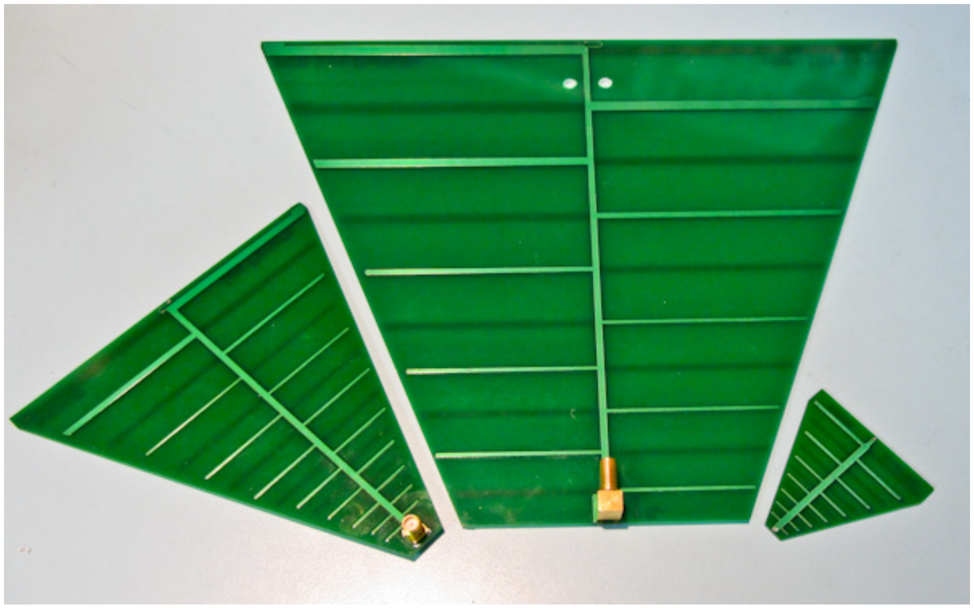
This may be used to estimate the E-field at some distance from the cable.

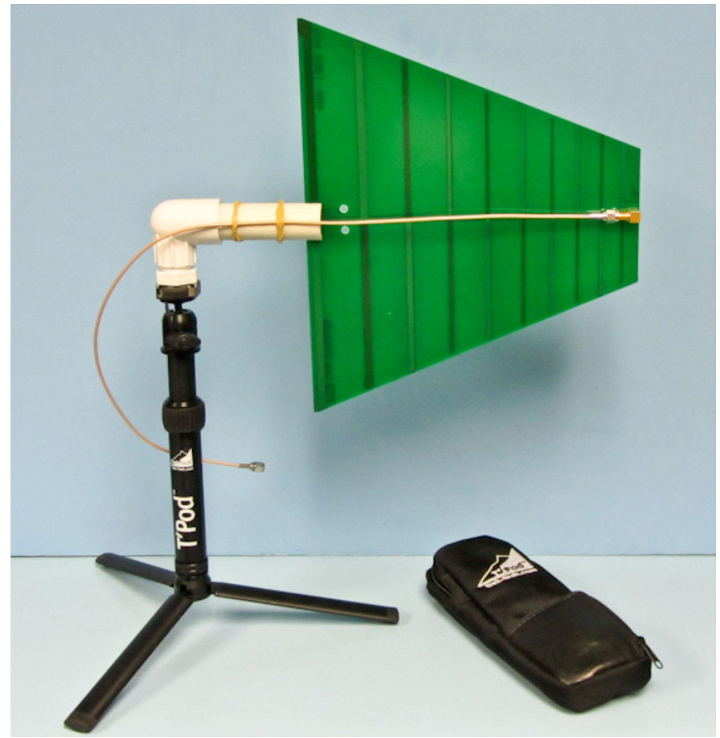
For more information, refer to the article.

Commercial current probe from Fischer Custom Communications (1 to 250 MHz).

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

PC board antennas for emissions



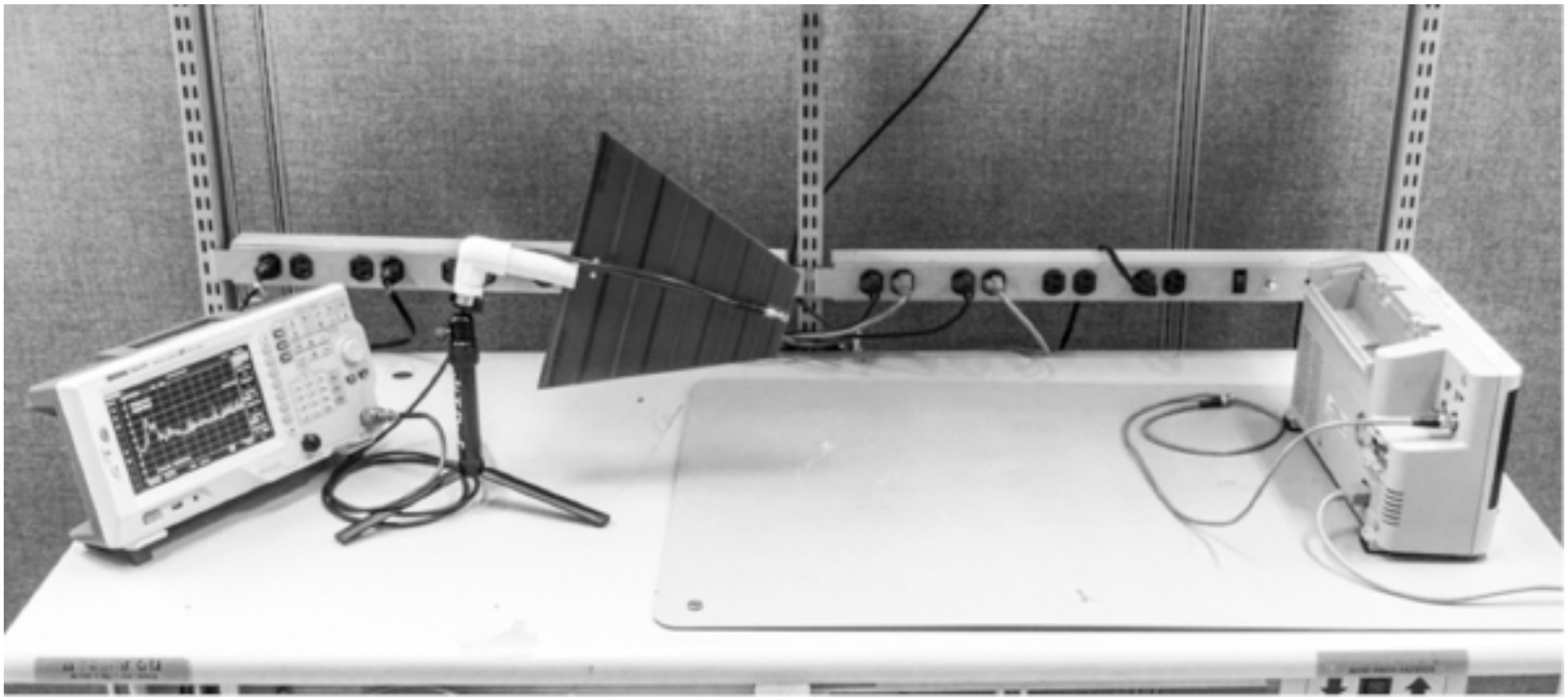


PC board log periodic antennas (ranging from 400 MHz to 11 GHz shown). Approximate gain is 6 dB. Available from www.wa5vjb.com/. Cost ranges from $7 to $28.

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

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

Bench top RE troubleshooting test



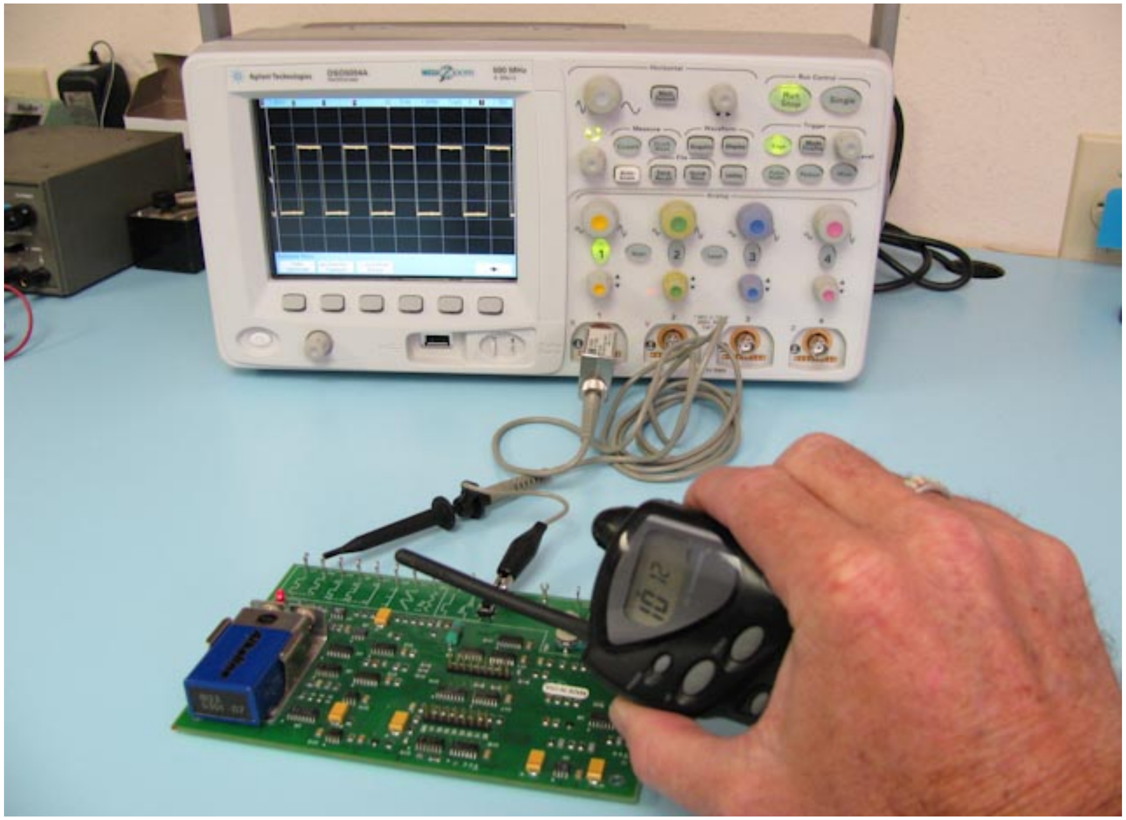
Ref: http://edn.com/electronics-blogs/the-emc-blog/4430335/Troubleshooting-EMI-on-your-bench-top

Radiated emission pre-compliance test

3m test range set up in an office.

Troubleshooting radiated immunity

License-free 2-way radios



By using an small FRS (Family Radio Service) transmitter at about 465 MHz, many radiated immunity issues may be discovered.

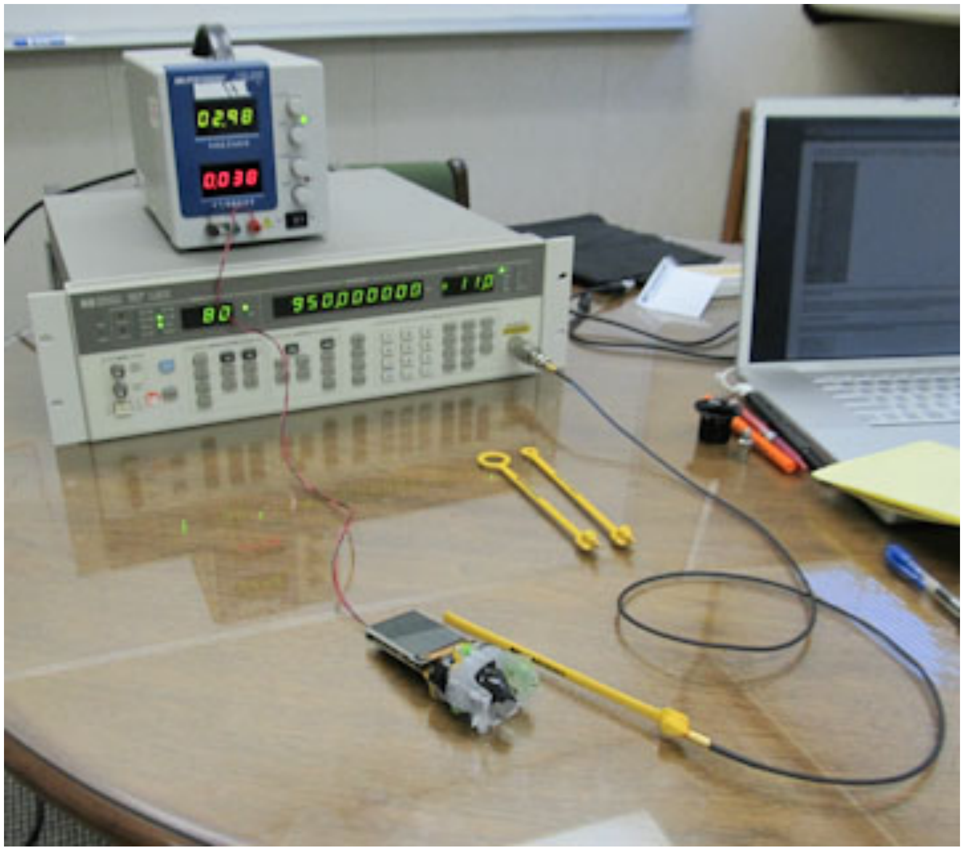
License-free 2-way radios (V/m)

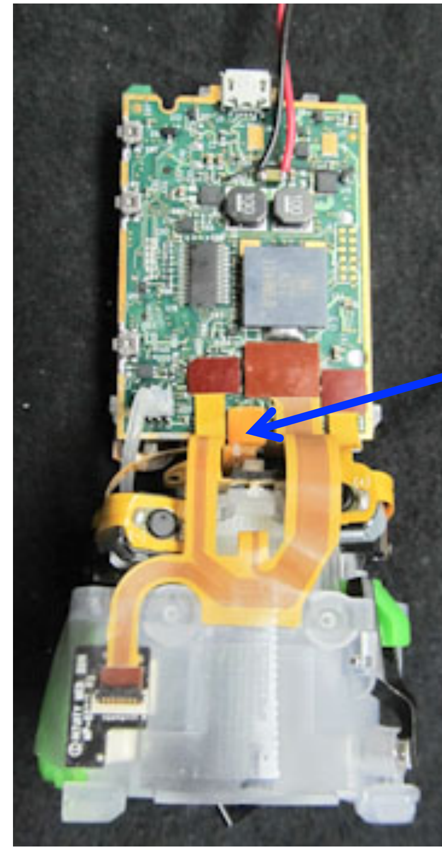
Device	Approx Freq	Max Power	Approx V/m at 1m
Citizens Band (HT)	27 MHz	4W	3
FRS	465 MHz	0.5W	2
915 MHz FHSS	915 MHz	0.5	3
3G Mobile CDMA Phone*	850 / 1900 MHz	300 mW, peak	Too small to measure

Chart of measured E-fields in V/m

* At two inches, the mobile phone registered 0.5 to 2 V/m

Setup for radiated immunity





The only sensitive cable!

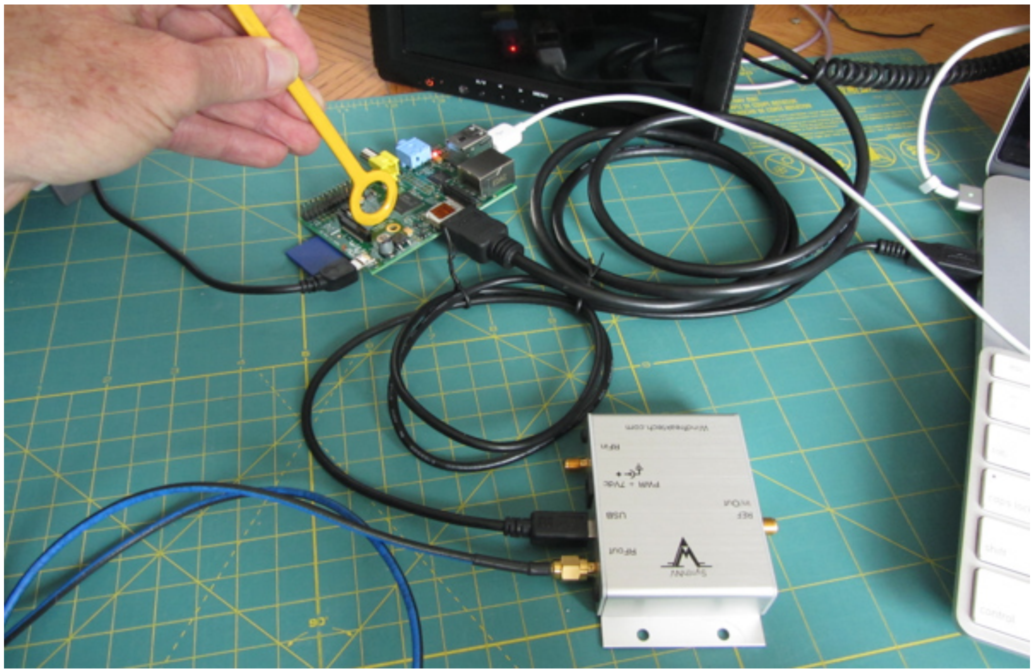
Helped client set up radiated susceptibility simulation with RF signal generator driving an H-field probe. Using the smallest loop probe determined the most sensitivity at flex cables.

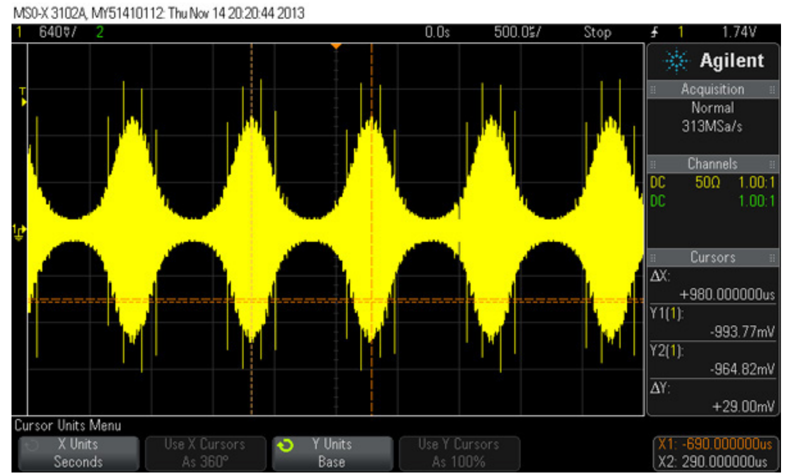
RF synthesizer with AM/pulse modulation

Here's another moderate-cost PC-controlled RF synthesizer. This one produces up to +19 dBm from 35 to 4400 MHz (in 1 kHz steps) and also includes AM and pulse modulation, along with network analyzer and power meter features.

Available from: : Windfreak Technology, www.windfreaktech.com. See the review article here: http://www.edn.com/electronics-blogs/the-emc-blog/4424843/Review--Windfreak-Technologies-SynthNV-RF-generator--Part-1-

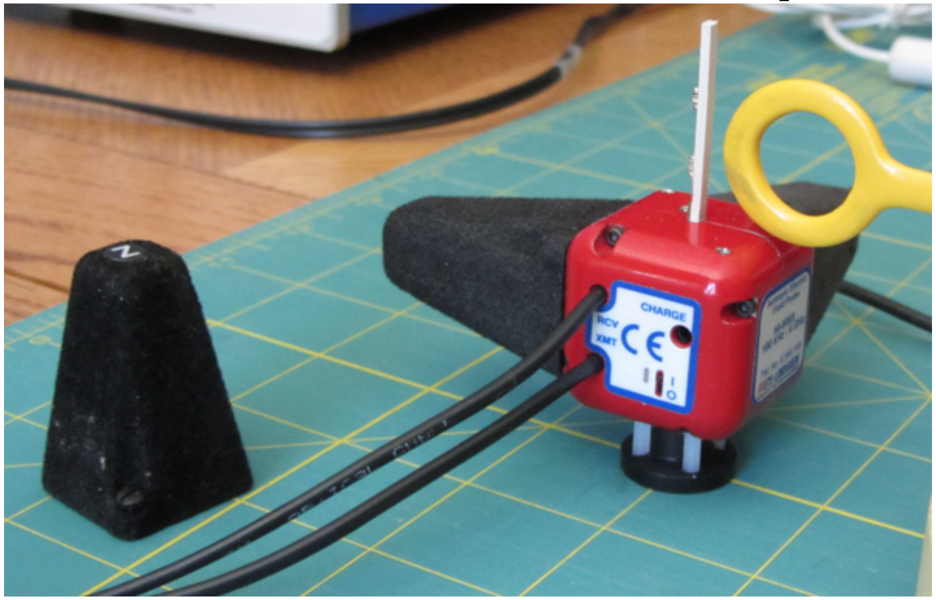
RF synthesizer with AM/pulse modulation

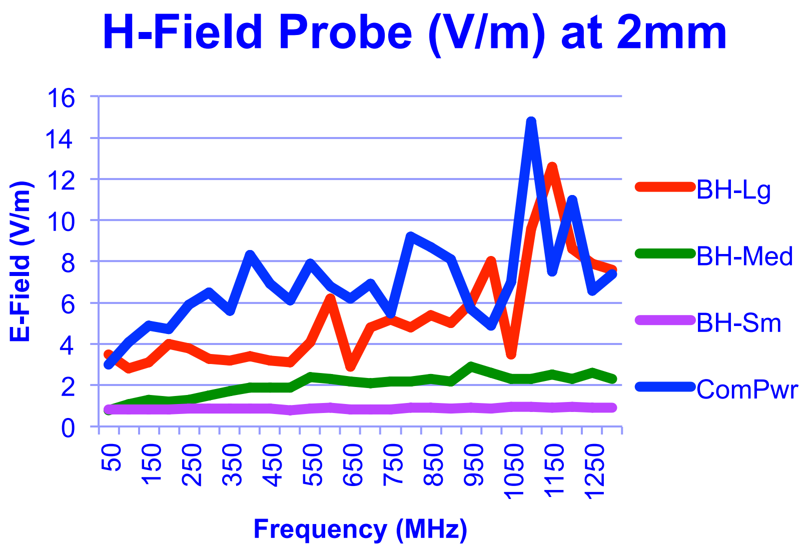




Using the Windfreak Technologies “SynthNV” to test radiated immunity.

Measured field level from H-field probes

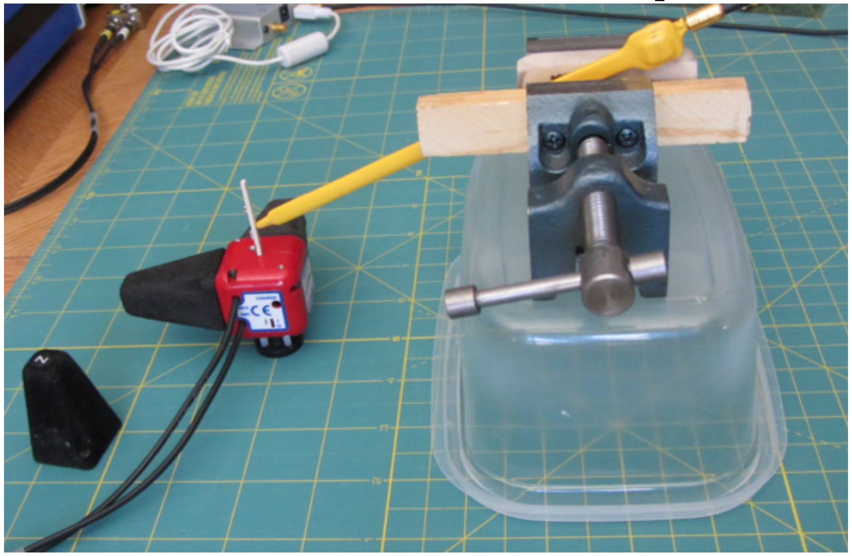


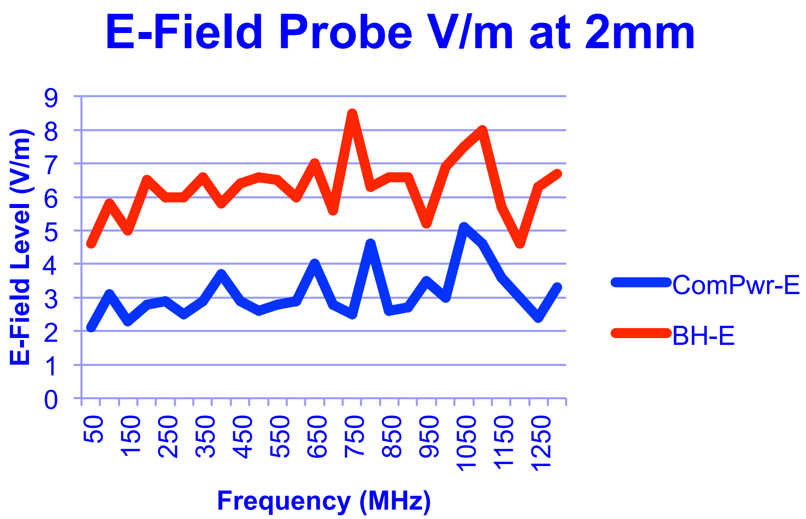


An ETS-Lindgren field sensor was used to measure the levels from several probes*. The probes were driven by the TPI synthesizer at +17 dBm output with the probe about 2mm from the sensor antenna (to try and duplicate the field level when probing circuit traces.

*Beehive Electronics and Com-Power H-field probes were used.

Measured field level from E-field probes

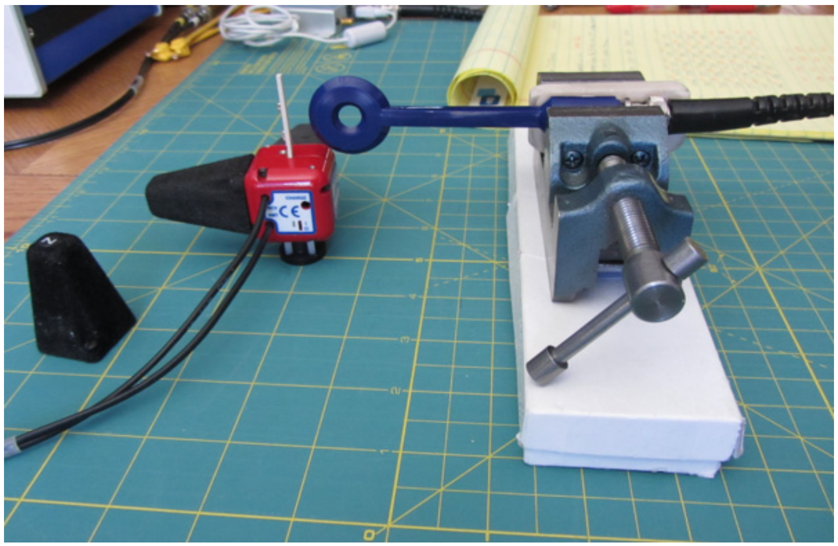


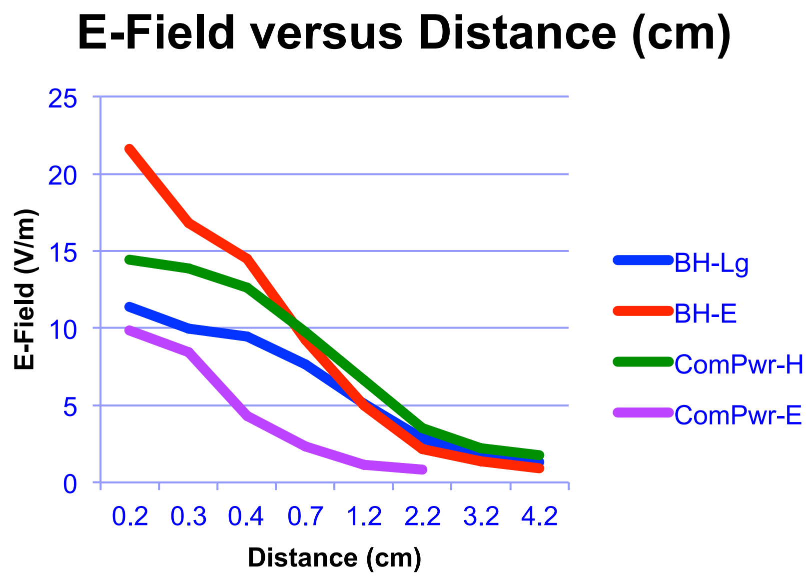


An ETS-Lindgren field sensor was used to measure the levels from several probes*. The E-field probes were driven by the Windfreak SynthNV synthesizer at +19 dBm output with the probe angled to match a realistic coupling and about 2mm from the sensor antenna (to try and duplicate the field level when probing circuit traces.

*Beehive Electronics and Com-Power H-field probes were used.

Field level versus distance (cm)





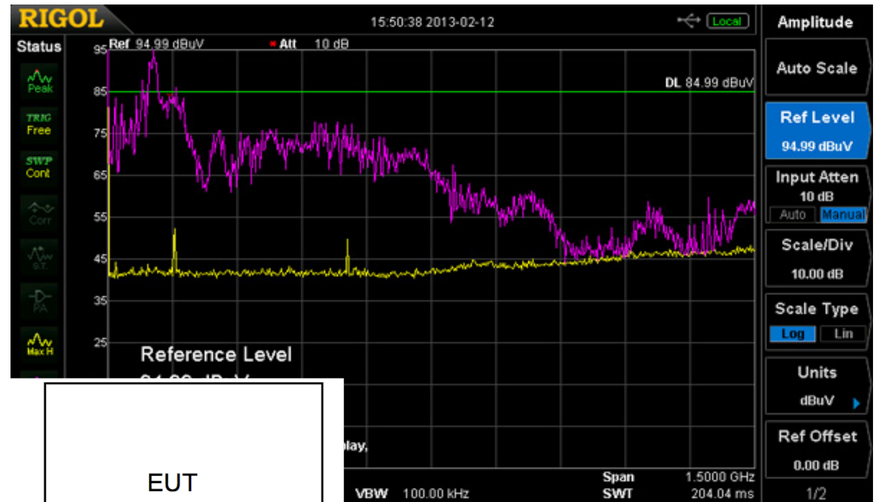
To investigate just how localized the field actually was, each probe* was measured at increasing distances from the field sensor. The closest the probe could get to the sensor antenna element was 2 mm.

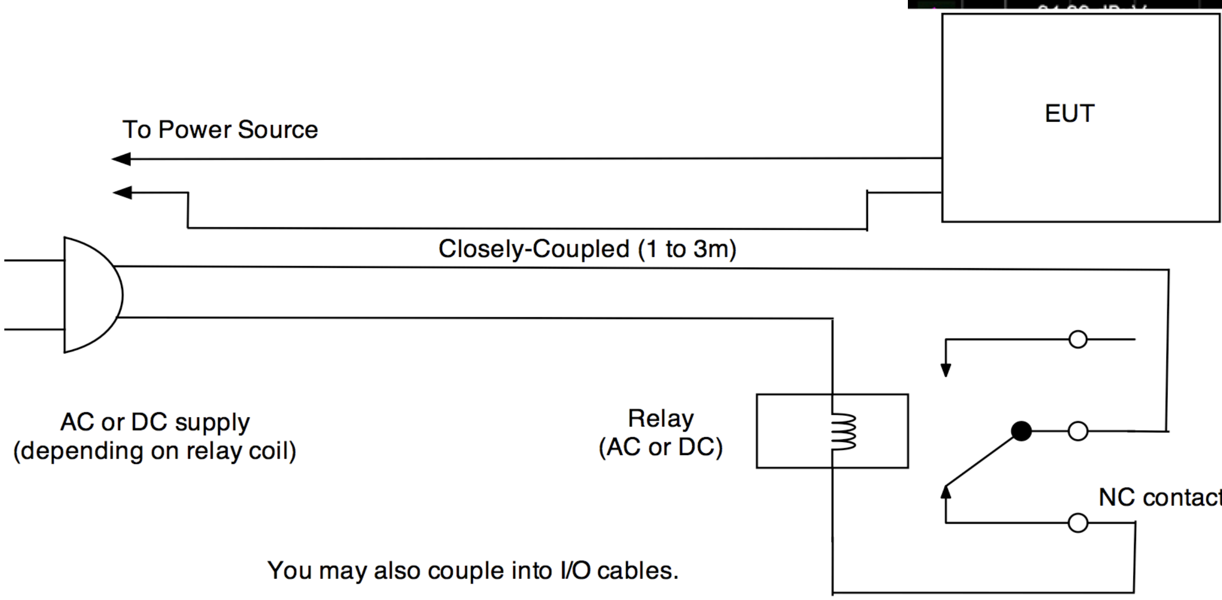
*Beehive Electronics and Com-Power H-field probes were used.

Radiated immunity – “chattering relay”

All components are available at Radio Shack.

Holding the line cord near a short antenna on the spectrum analyzer produced an average of 70 dBuV from 9 kHz to 1 Ghz.



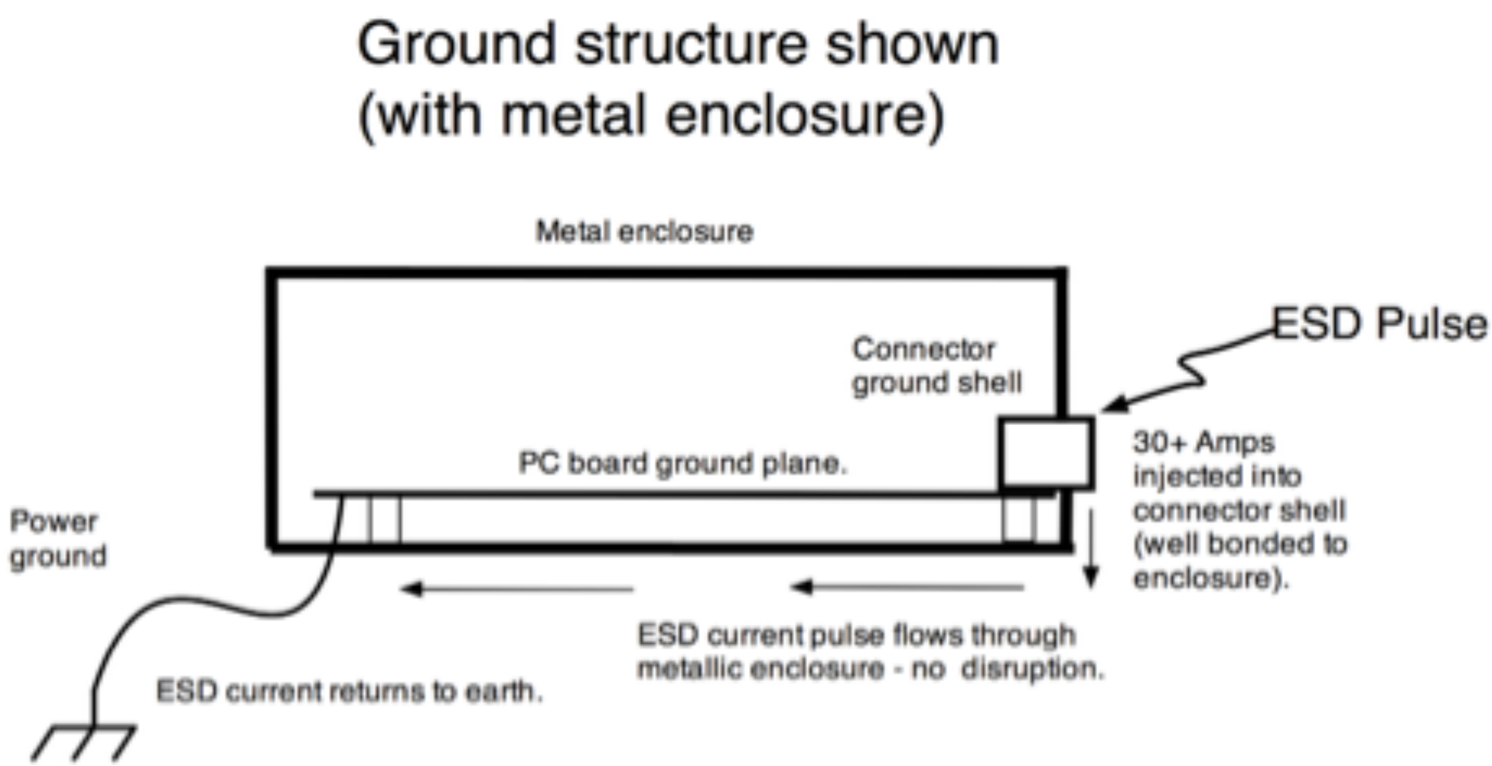


Troubleshooting ESD

Typical ESD waveform

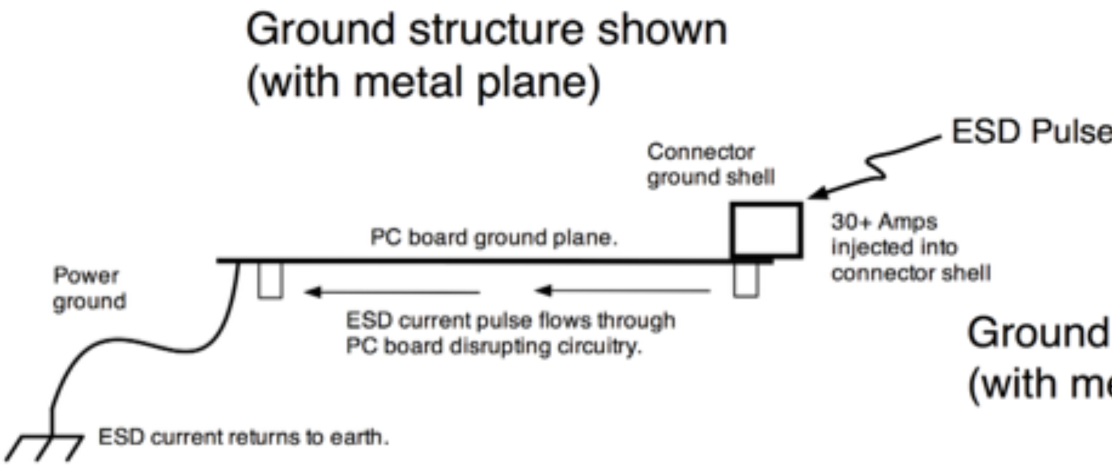
As measured using an Agilent 6 GHz BW oscilloscope and ESD verification fixture.

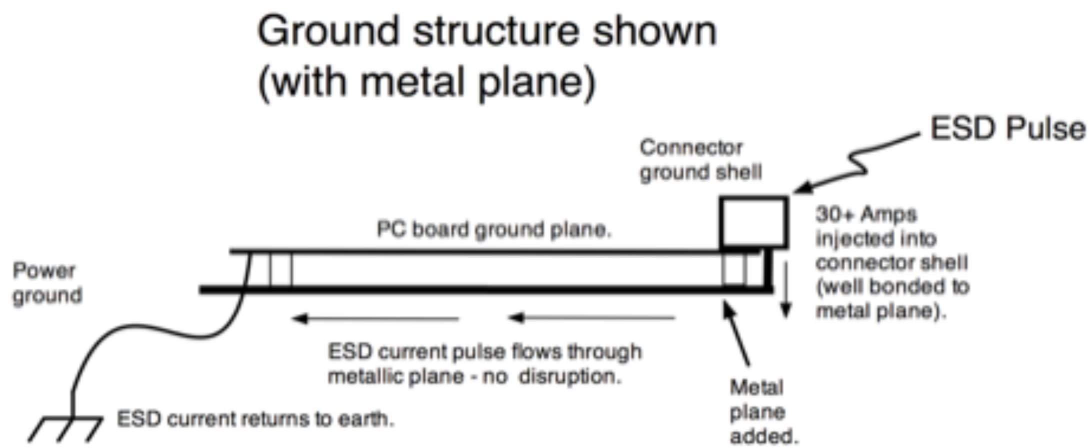
Electrostatic discharge - shield



The very best protection from ESD discharges is to use a shielded enclosure and ensure all I/O connectors are well bonded to the enclosure.

Electrostatic discharge – divert, filter & transient protect

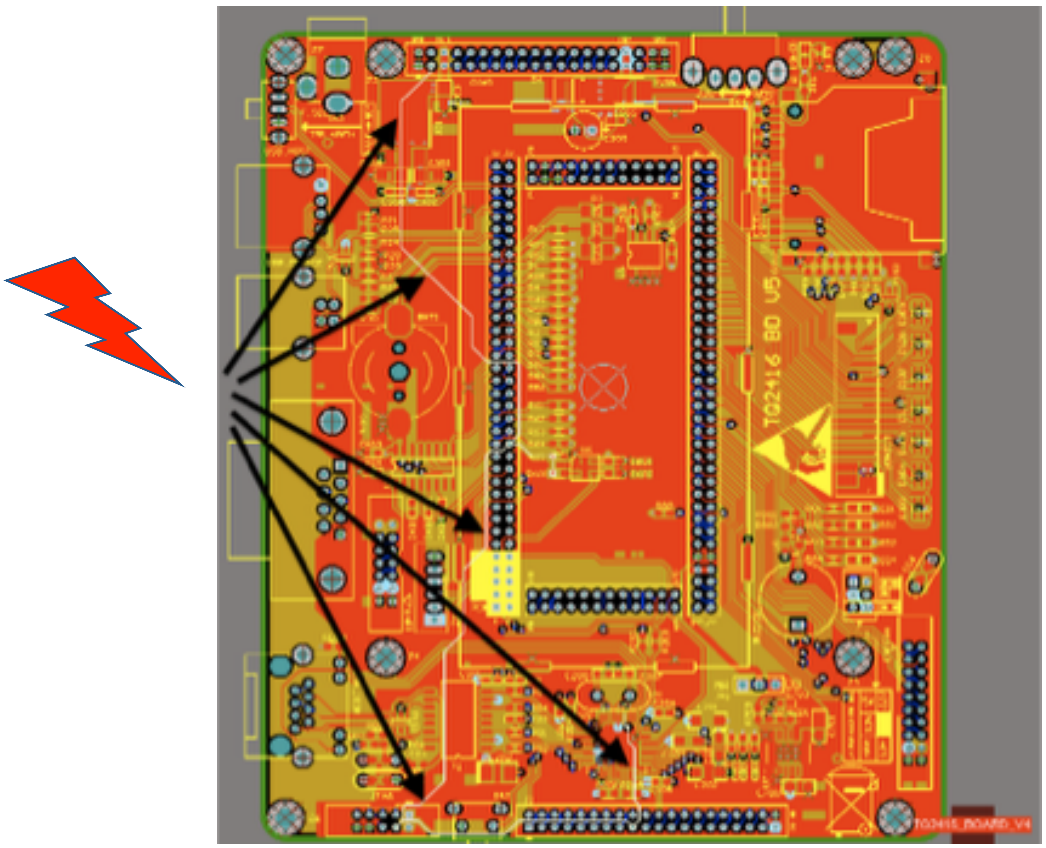




Identify the path of ESD current and then design an alternate (safer) path around your electronics (diversion).

Alternatives include common-mode filters and transient protection.

CPU reset lines



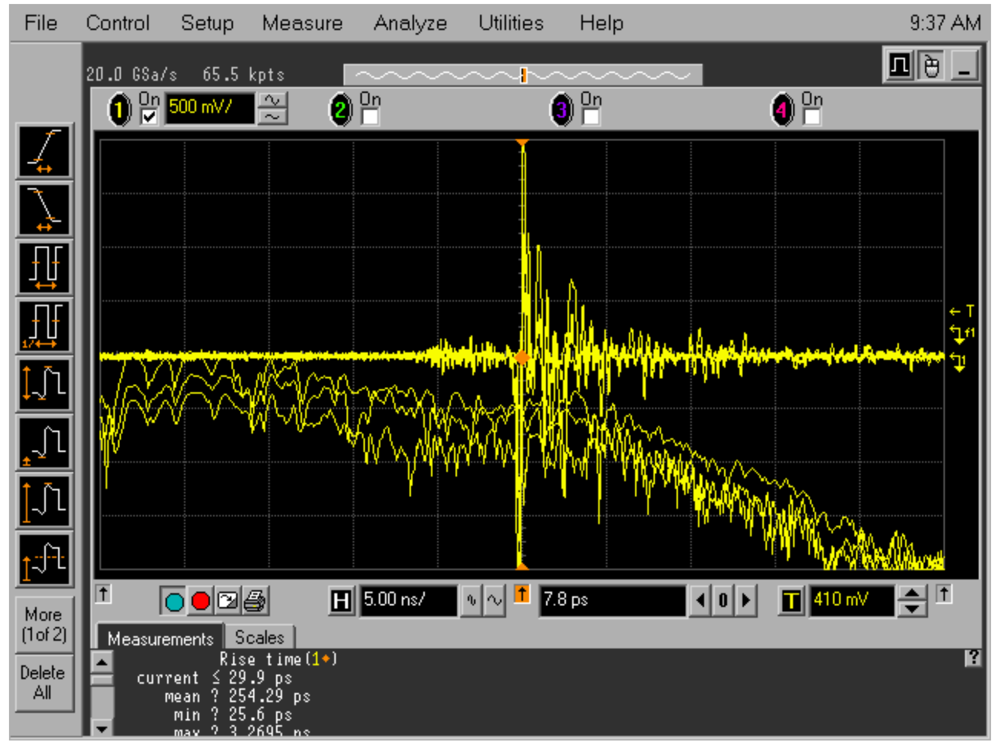
ESD coupling to processor reset line. Reduce length and filter at CPU.

ESD event detector

An inexpensive portable AM radio tuned off-station can detect ESD events (clicking) from a long distance away. This is useful for troubleshooting potential ESD issues.

An inexpensive ESD generator

500 mV/div, 6 GHz BW, <30 ps!



Jiggling a few coins inside a ZipLok bag will produce rise times of 30 to 500 ps at several volts!

Idea courtesy, Doug Smith, http://www.emcesd.com

Inexpensive ESD simulator

The Coleman lighter is unique that the butane has a separate control switch to allow the gas to flow. Cut the metal shroud back with a Dremel tool to expose the tip and connect a length of grounding wire. Pulling just the trigger produces about 4-6 kV.

Summary

Most EMC problems can be traced to poor PC board design which causes common-mode currents, faster-than-necessary edge rates, poorly bonded cable shields, poorly routed cables leading to high frequency coupling, and/or poorly designed product enclosures.

•The spectrum analyzer is the instrument of choice when it comes to measuring or troubleshooting EMC issues. It is also invaluable for pre-compliance testing.

•An oscilloscope is also useful for measuring edge rates, ringing on waveforms and measuring noise voltages in ground planes and power busses. Some, such as the R&S RTE 1104 are sensitive enough (1mV/div) for low-level spectral analysis.

•Simple DIY or low-cost probes and equipment may be made or purchased, which are useful for troubleshooting the top three EMC issues – radiated emissions, ESD and radiated/conducted immunity.

•When troubleshooting EMC problems, identifying the path of current – *especially return currents* – is the key to solving EMI issues.

For more information…

www.emc-seminars.com

The EMC Blog (on EDN.com)

Buy the book!

Call “The EMC Doctor” at (719) 310-5418 or ken@emc-seminars.com

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