Testing for EMC Compliance:
MitigationTechniques

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Testing for EMC Compliance

- **Definitions**
  - Emissions
    - Energy generated by the electronic device's operation
  - Immunity
    - A measure of how immune a device is to external fields
  - Susceptibility
    - A measure of how susceptible a device is to external fields
  - Conducted
    - Energy transmitted primarily by a conductive medium
  - Radiated
    - Energy transmitted primarily by an electromagnetic field

Testing for EMC Compliance

- **Definitions (cont.)**
  - Electromagnetic Field
    - A general term for radiation from a current-carrying conductor. It is composed of both an electric field and magnetic field component.
  - Electric Field
    - The potential gradient's vector field quantity measured in volts per meter.
  - Magnetic Field
    - The current gradient's vector field quantity measured in amperes per meter.
  - Plane Wave
    - The electric and magnetic field vectors lie in the same plane and are independent of position in the plane

Testing for EMC Compliance

- **Definitions (cont.)**
  - Near Field
    - The distance to an EMI source whose distance is closer than $\lambda/6$ or $2d^2/\lambda$. Electric and magnetic fields must be considered separately.
  - Far Field
    - Distances from an EMI source greater than $\lambda/6$ or $2d^2/\lambda$. Beyond this distance, plane waves exist with a gradient of 1/r.
  - Cross-talk
    - The unintended electromagnetic coupling typically between wires of a cable and traces.

Testing for EMC Compliance

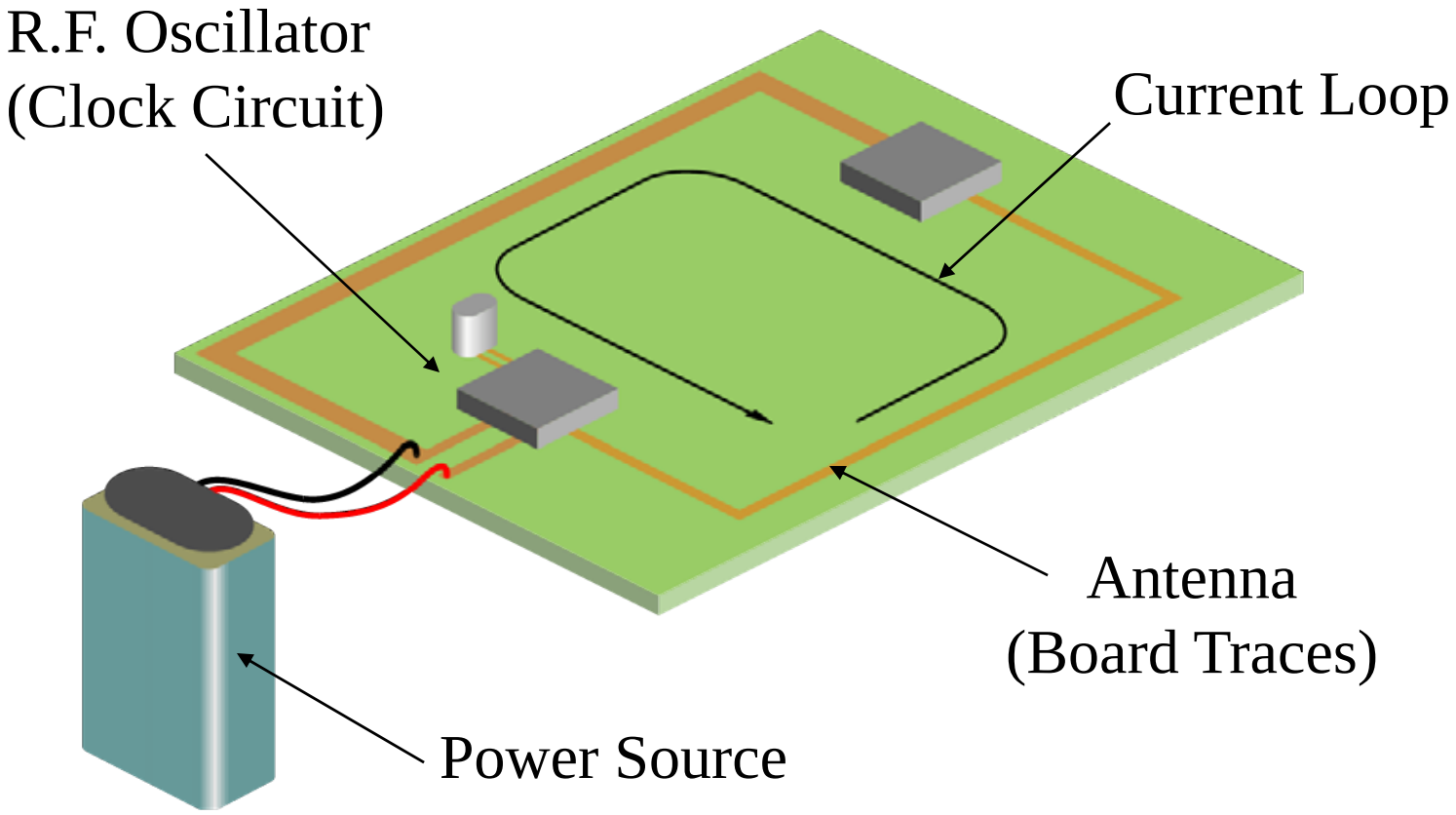
- Systematic Approach
  - Source
  - Coupling mechanism
  - Victim or receptor

For any EMI problem, there must be all three elements present.

Testing for EMC Compliance

Sources	Coupling Path	Receptor
Microprocessors	Radiated EM fields	Other logic circuits
Video drivers	Capacitance	Analog circuits
ESD	Inductance	Receivers
Power supplies	Conducted	Reset lines
Lightning	“Ground”	

Testing for EMC Compliance



Testing for EMC Compliance

- Solutions
  - PCB Design
  - Filtering
  - Cabling/Harnessing
  - Grounding/Bonding
  - Shielding

Testing for EMC Compliance

- Be like a Doctor

"*Prescription without diagnosis is malpractice*"

  - Diagnose First
    - Gather information
      - Ask questions
    - Make preliminary diagnosis
      - Eliminate least likely
      - Determine the most likely
    - Often times initial fixes won't work
    - There could be multiple contributors

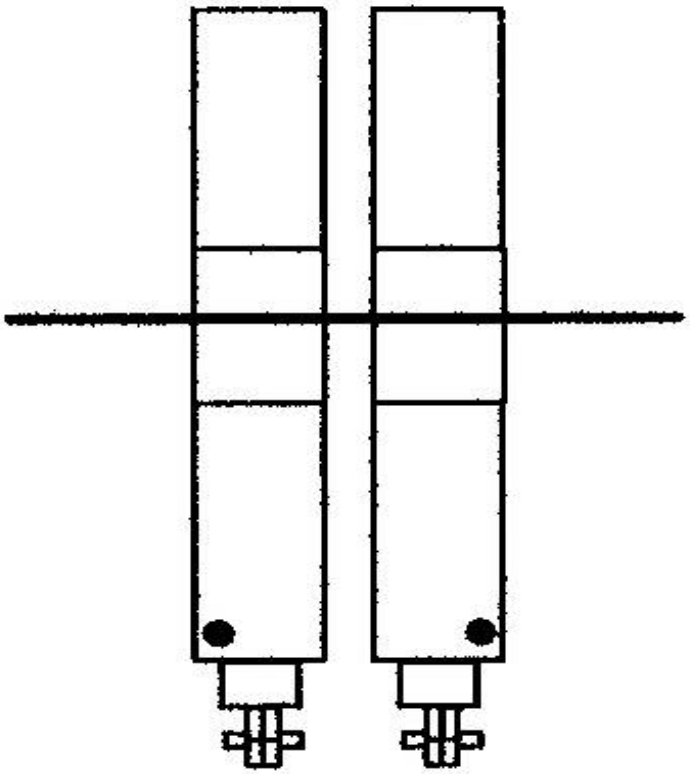
Testing for EMC Compliance

- Identify the Signal
  - Change bandwidth of receiver and observe changes
  - Change the span and “zoom in” on the signal
  - Change the sweep rate and observe signal
    - When you slow the sweep and the “spikes” get closer together, then you have a broadband, impulsive noise source

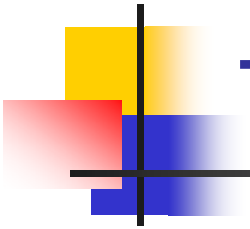
Testing for EMC Compliance

- Techniques for Emissions
  - “Piece of wire” or a screwdriver
  - Current clamp
    - Current magnitude and direction
      - “Directionality” of current flow
    - DM or CM ?
      - CM
        - Line-to-ground capacitors
        - Common mode inductors
        - For I/O cables, 5 uA max for Class B and 15 uA max for Class A
      - DM
        - Line-to-line capacitors
        - Series inductors

Testing for EMC Compliance



Using current clamps for “directionality”



Testing for EMC Compliance

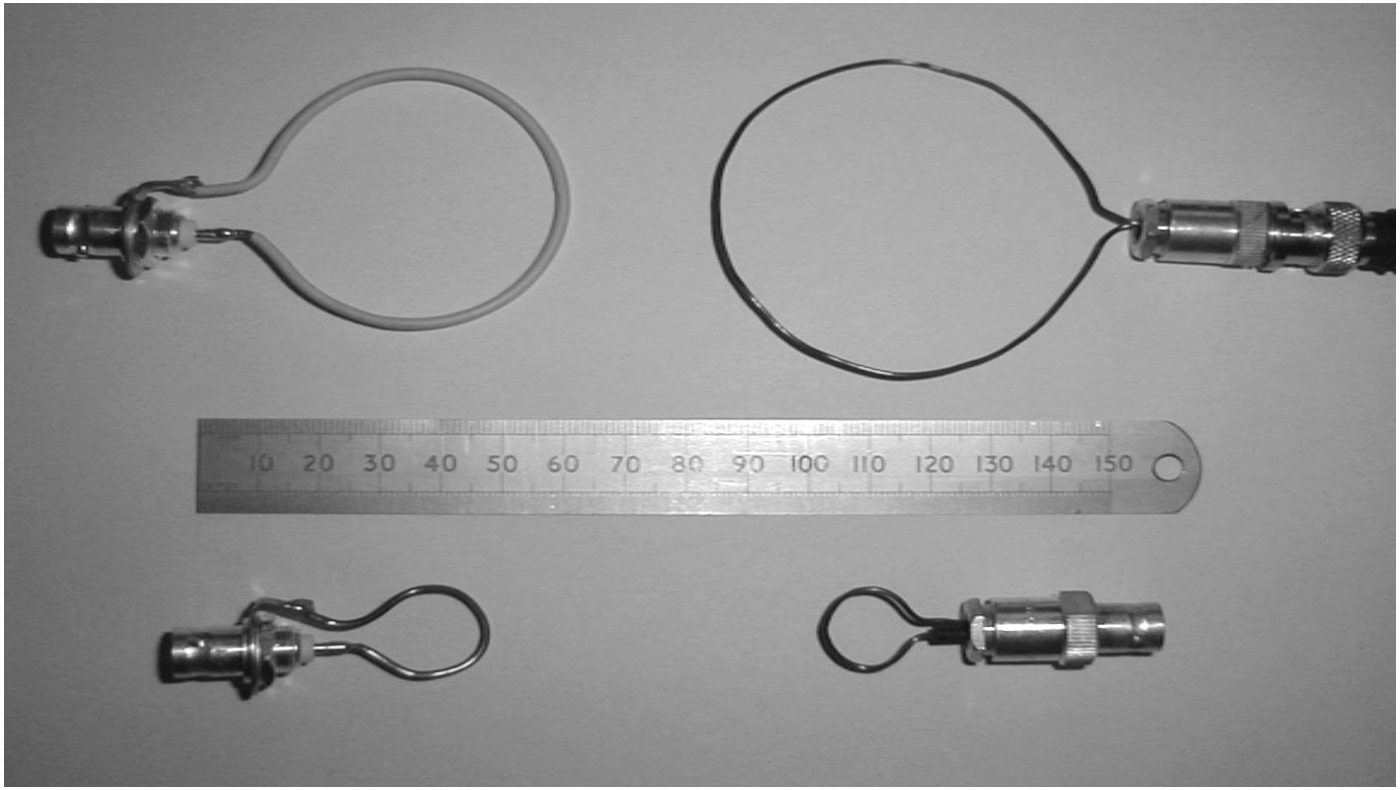
- Techniques for Emissions (cont.)
  - Radiated emissions below 200-300 MHz are typically cable related, while above this frequency, it is usually box related.
  - Near Field Probes
    - Slots, seams
    - PCB traces
    - No direct translation to antenna field strength
  - Oscilloscope
    - Ground noise
    - IC Noise / Power Supply Noise
  - Use AM radio as in inexpensive EMI/ESD sniffer

Testing for EMC Compliance

(Photo courtesy of Agilent)

(Photo courtesy of EMC Test, Inc.)

Testing for EMC Compliance



(Photo courtesy of *EMC Compliance Journal)*

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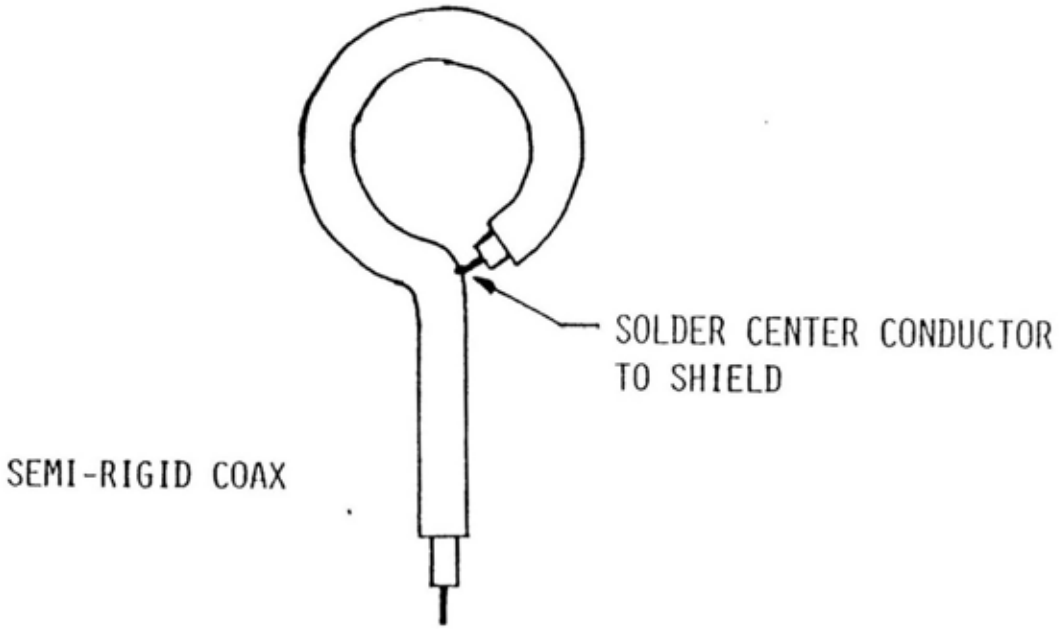

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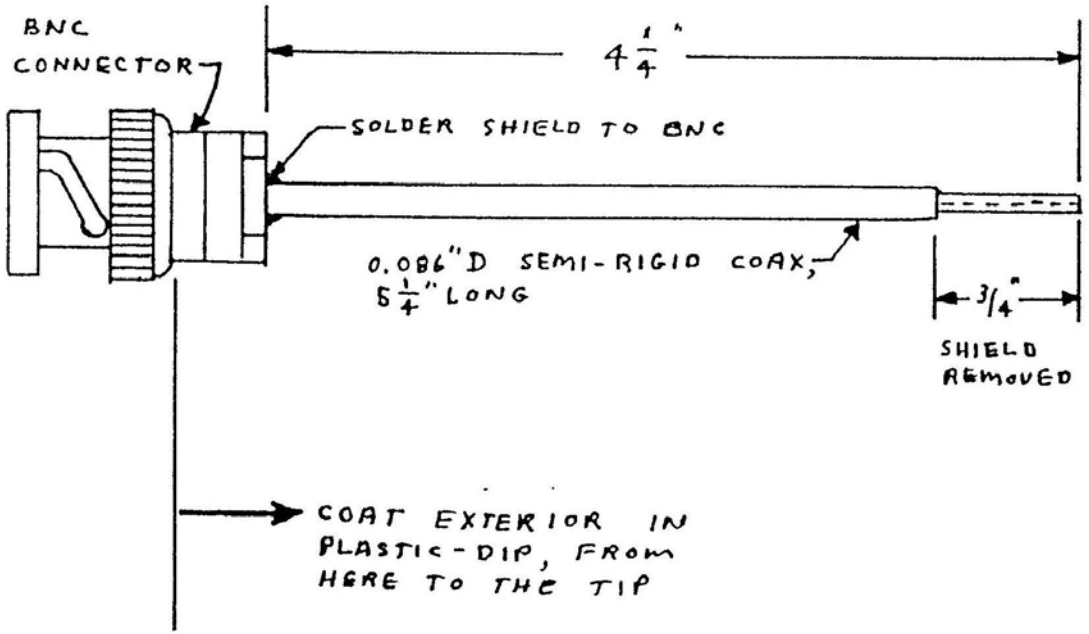


Testing for EMC Compliance

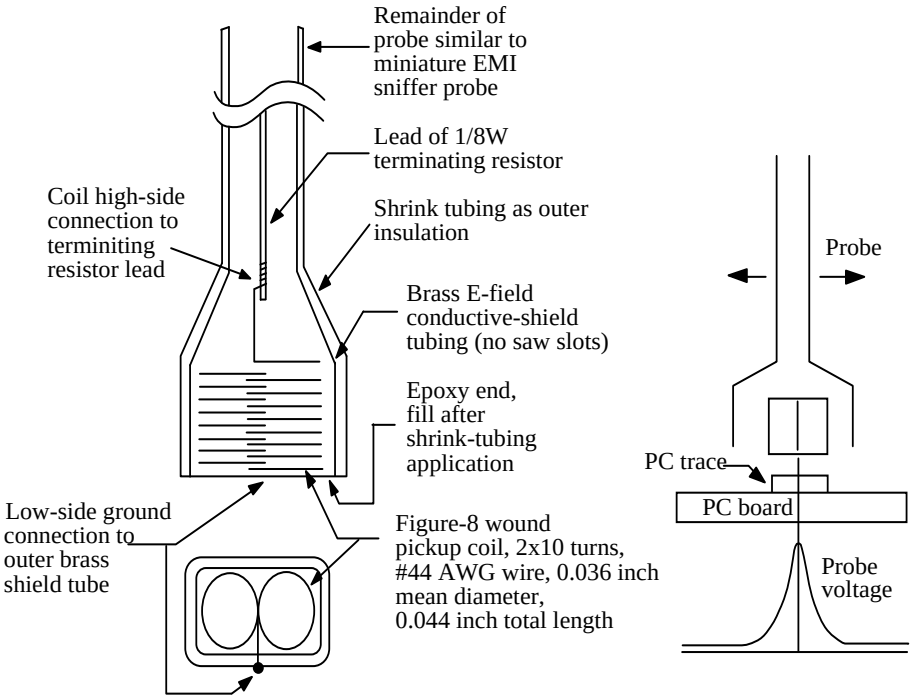
Couple of sources:

ETS-Lindgren

www.ets-lindgren.com

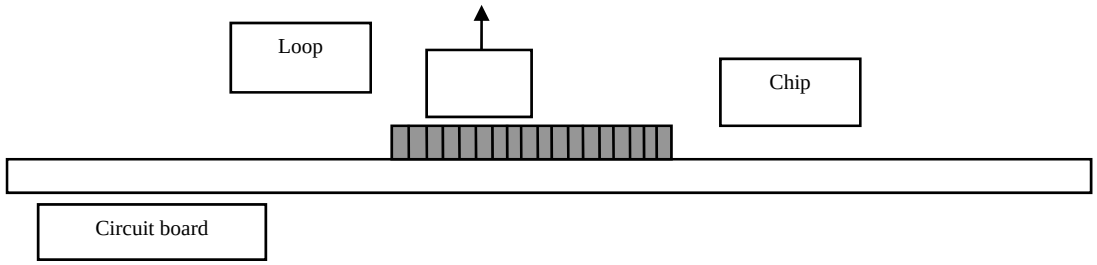
Magnetic Sciences

www.magneticsciences.com



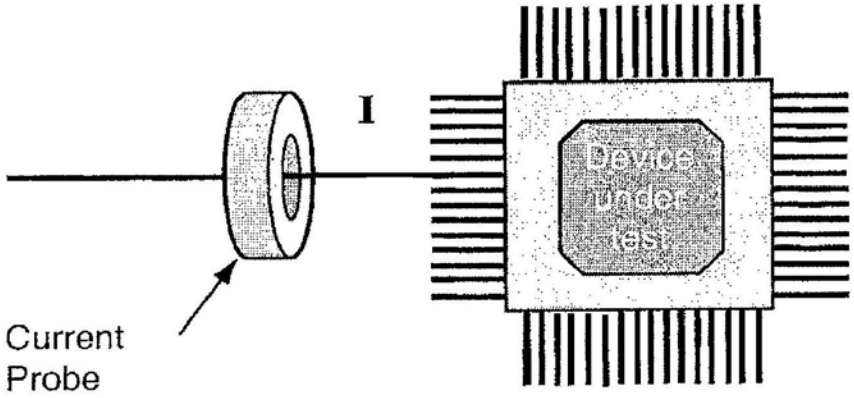
Ref: Mark Montrose, Edward Nakauchi, **Testing for EMC Compliance,** IEEE Press/Wiley, 2004.

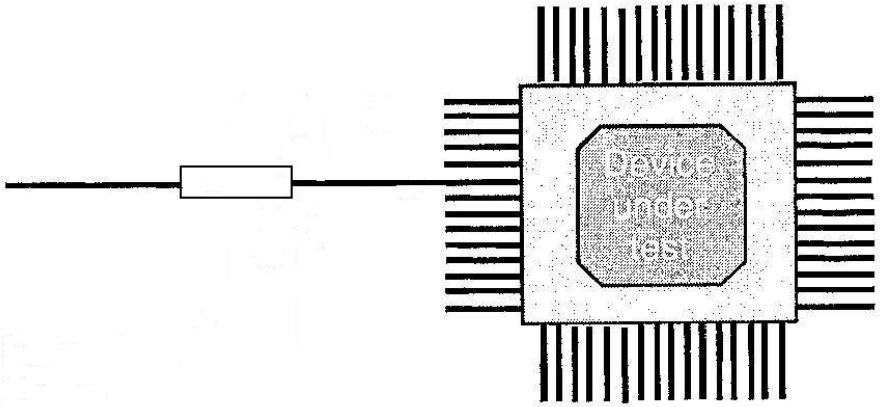
Testing for EMC Compliance



ASIC Testing – Use of Loop Probe

Testing for EMC Compliance





ASIC Testing

Testing for EMC Compliance

- Techniques for Emissions (cont.)
  - To make an LISN
    - Add a ferrite of about 5-6 turns on the power source side and tape about 1 to 1.5 meters length of power wires to the groundplane
    - Use a current probe on the EUT side
      - I (dBuA) = V (limit in dBuV) – $Z_{transfer}$ of an LISN (dBohms)
  - I/O cable noise
    - Measure Icm1 and Icm2 individually and then together (Icm1 + Icm2)
      - If (Icm1 + Icm2) is greater than either individually, then it is crosstalk
      - If (Icm1 + Icm2) is less than either individually, then it is common impedance

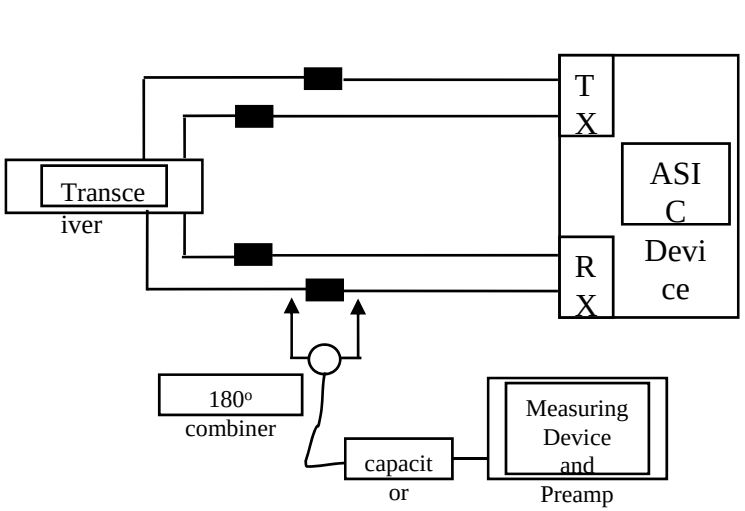
Testing for EMC Compliance

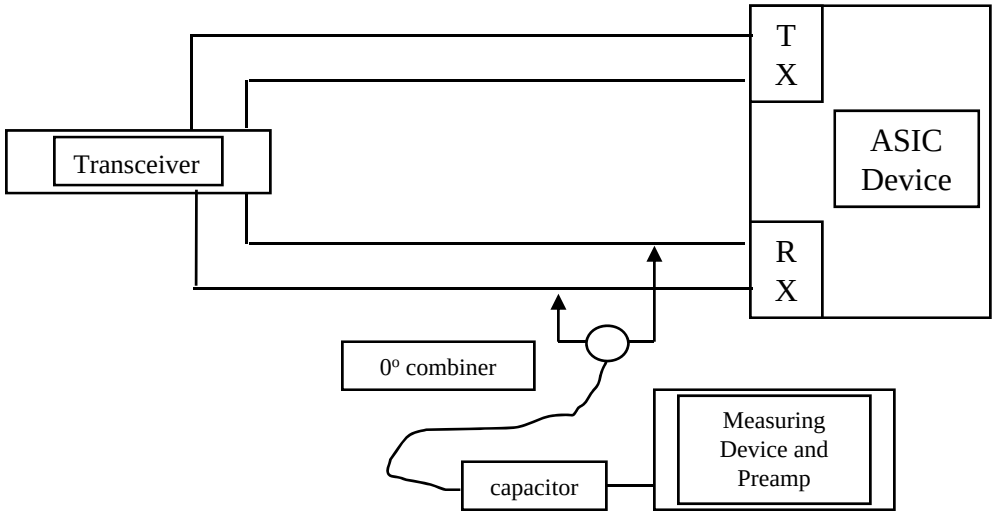
Cantenna (Directional Waveguide Antenna)

Testing for EMC Compliance

- Techniques for Emissions (cont.)
  - Differential probe - Fischer Custom Communications (FCC-BCP-2)
    - www.fischercc.com

Testing for EMC Compliance





ASIC Testing – Use of Differential Probe

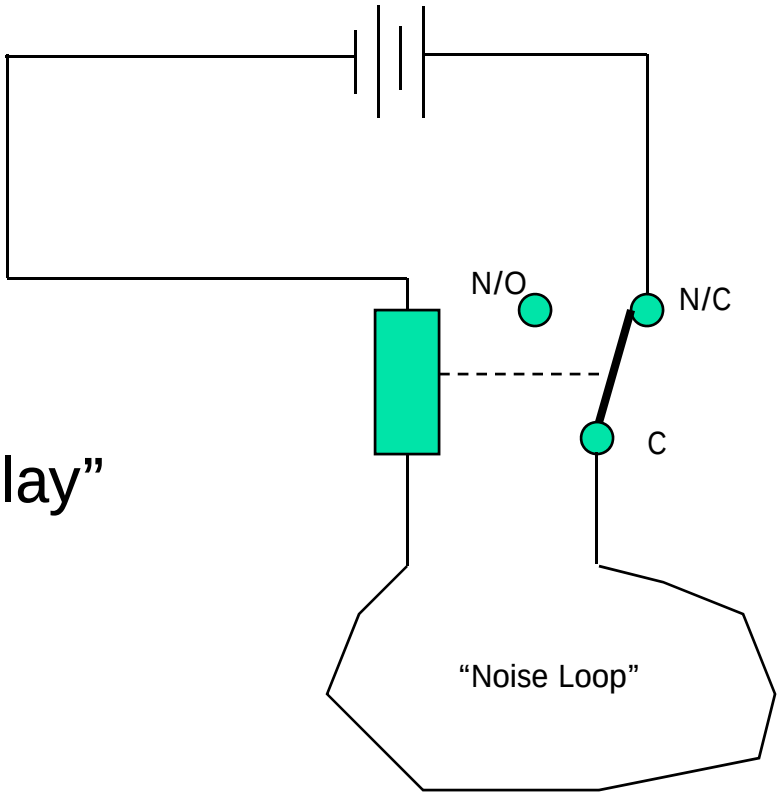
Testing for EMC Compliance

- Techniques for Immunity
  - Hand-held radios
  - “Chattering relay”
    - Wired in a self oscillating mode
  - Small loop
    - Signal generator & 1-5 W amplifier
    - Signal Injection
  - ESD Gun
    - Can simulate ESD, EFT, RI
      - A Capacitive Clamp
        - 50 cm of foil around cable (100pF)

Testing for EMC Compliance

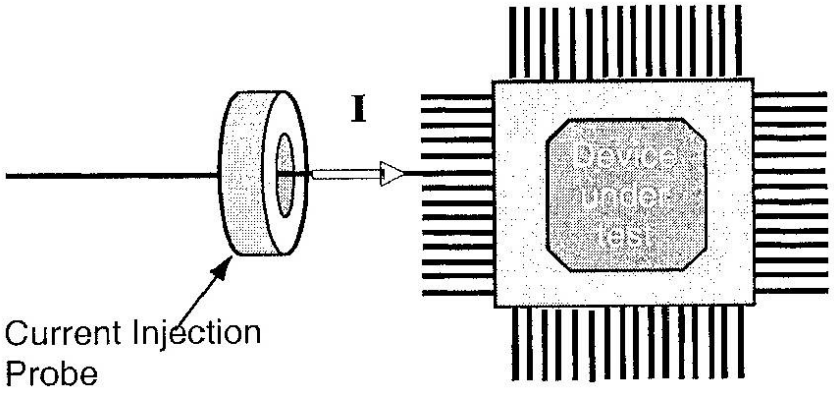
- Techniques for Immunity (cont.)
  - Current Injection Probe
    - About 10 watts is good for 1-3 volts
  - Use EFT generator or ESD generator to simulate power bus noise problems
    - Couple through a capacitor of about 0.01 uf
    - Use a loop probe
    - Can simulate “hot swap” noise problems
    - Use bias-tee network on DC lines

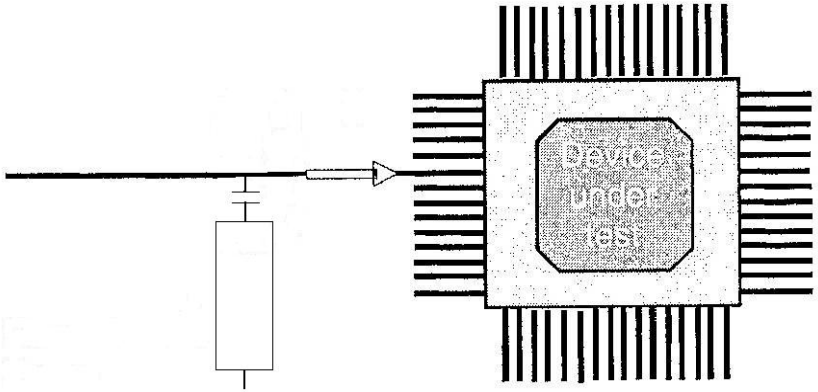
Testing for EMC Compliance



"Chattering Relay"

Testing for EMC Compliance





Testing for EMC Compliance

- Minimal Requirement for Lab Setup
  - As quiet as possible ambient
  - Noise-free power main
  - Ground plane (reference for power)
  - Test Equipment

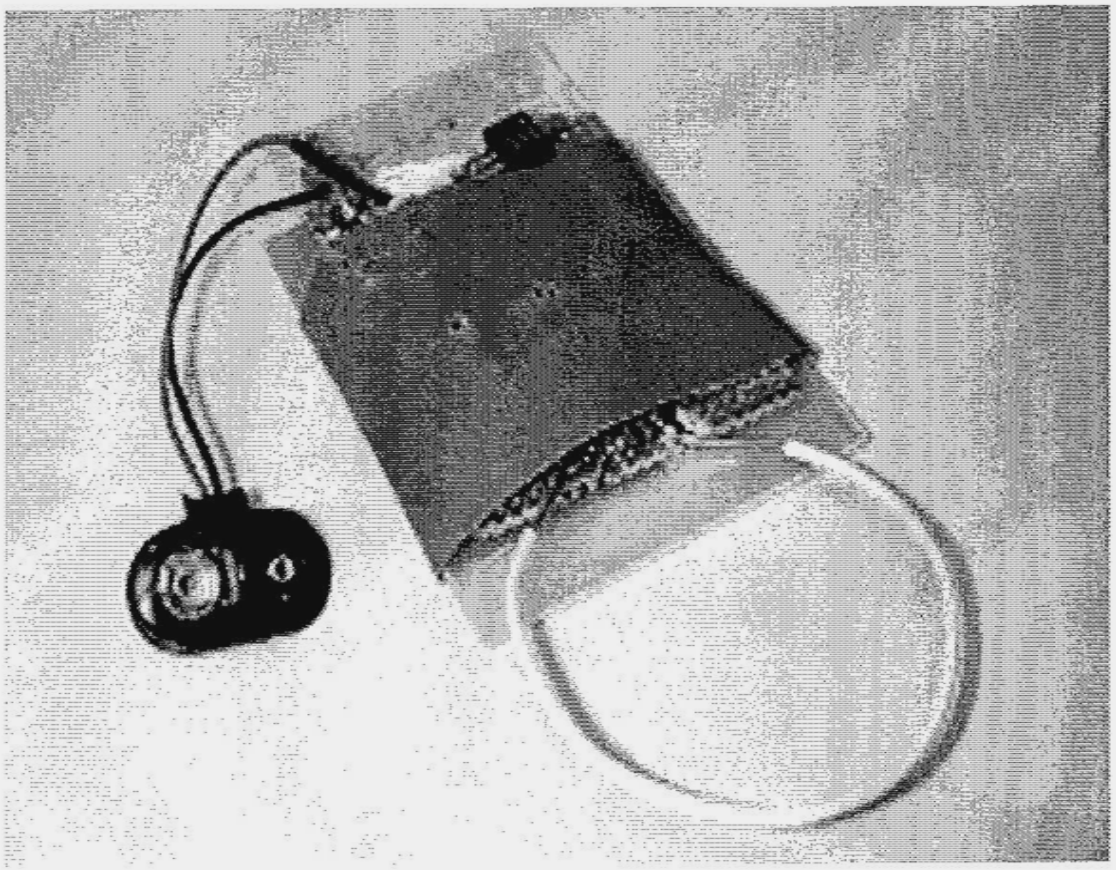
Testing for EMC Compliance

- Test Equipment
  - Spectrum analyzer/receiver
    - Balanced differential probe
    - Sniffers
  - LISN
  - ESD simulator
  - Signal generator
  - Low Level Power Amplifier
  - Hand-held radios
  - Network analyzer
  - Correlation analyzer

Testing for EMC Compliance

- Typical Sequence of Testing
  - Locate PCB “hot spots”
    - Near-field probes/differential probes
  - Emissions measurement of open PCB
    - If emissions over the regulatory limit are less than SE of enclosure, then PCB will likely be okay
  - Shielding effectiveness (SE) of enclosure
    - Make a battery operated oscillator
    - Put inside the enclosure
    - Measure amplitudes and re-measure without the enclosure
    - Use differential probe across seams or apertures
  - Analyze leakages in the enclosure
  - Common Mode Cable Currents

Testing for EMC Compliance



Wyatt/Chaney, RF Design Magazine, January 1991

Testing for EMC Compliance

- “Bag of Tricks”
  - Aluminum foil
  - Conductive tape and gaskets
  - Braid and “zippertubing”
  - Ferrites
  - Power line filters
  - Components
    - Small capacitors
    - Resistors
    - Inductors

Testing for EMC Compliance

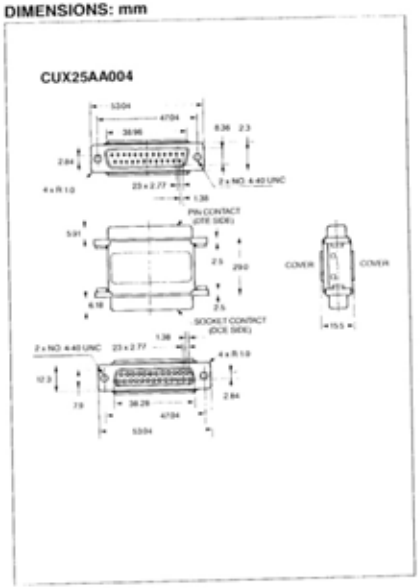
EMI FILTER CONNECTORS
MALE/FEMALE IN-LINE 'D' CONNECTOR

muRata

CUX25AA004

Murata Electronics has developed this in-line male/female 'D' connector specifically to reduce EMI in existing equipment. It is designed to be placed in the signal lines directly at the equipment without requiring any equipment modification or alteration.

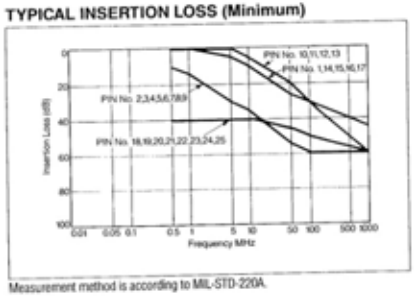
DIMENSIONS: mm



SPECIFICATIONS

Parameter	Rating		Note
WV	50VDC		—
DWV	125VDC		—
IR	50MΩ min.		50VDC/1 min.
Oper. Temperature	0°C to 70°C		—
Storage Temperature	−25°C to +85°C		—
Capacitance (PIN No.)	2, 3, 4, 5, 6, 7, 8, 9	3,000pF min.	
	1, 14, 15, 16, 17	2,700pF min.	
	10, 11, 12, 13	1,200pF min.	
	18, 19, 20, 21, 22, 23, 24, 25	1,200,000pF min.	

TYPICAL INSERTION LOSS (Minimum)



Measurement method is according to MIL-STD-220A.

Testing for EMC Compliance

'LOSSYLINE' FLEXIBLE FILTER

The "LossyLine" Flexible Filter is a new and unique filter for microwave EMI suppression up to 100GHz. It is wire-like in form and unlike other filters, absorbs and dissipates EMI, thus eliminating characteristic problems of conventional types of EMI filters, such as, mismatch, reflection, necessity for grounding and high VSWR.

Two to five inch lengths of the "LossyLine" Flexible Filter usually provide the required attenuation. When compared with conventional filtering methods, the "LossyLine" Flexible Filter is substantially lower in cost. No special fittings, connectors or housings are necessary. The Flexible Filter can also be installed in series or employed in conjunction with existing harnesses or cables.

CAPCON, INC.
147 West 25th Street
New York, N.Y. 10001
212-243-6275

Testing for EMC Compliance

456 CAPACITIVELY DECOUPLED RF CONNECTORS

These products are protected by U.S.Patent # 4,772,223.

Amphenol's 456 Series of RF connectors provides capacitive decoupling between the connector body and the mounting panel. EMI on the coaxial shield is shunted to the chassis ground through capacitors, while not affecting the DC and power supply frequencies. This reduces ground loop problems and provides a mechanism to harmlessly dissipate ESD to chassis ground.

The RF parameters of these connectors are the same as their non-filtered counterparts. Filtering does not affect the signal contact, but only the shell-to-ground connection. Capacitively decoupled RF connectors are intermateable and interchangeable with standard non-filtered versions.

Mechanical Data:

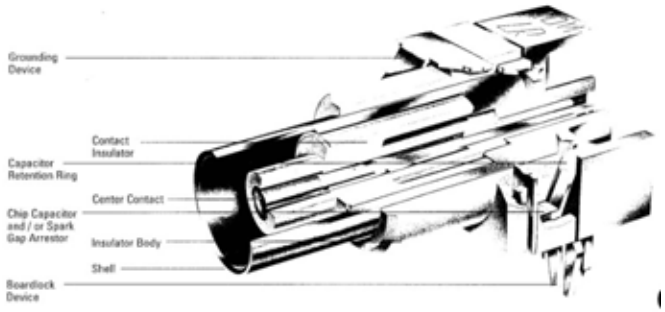
Shell:	Zinc Diecast or Brass; Nickel plated
Insulator Body:	Thermoplastic
Contact Insulator:	Noryl or Teflon
Center Contact:	Phosphor Bronze or Beryllium Copper; Gold plated (456-107S is silver plated)
UL File # :	E135615
CSA File # :	LR68598

Filter Performance:

Capacitance		10,000 pF
Working Voltage		200 VDC
DWV		600 VDC (1000VDC for Rear Mt)
Filter Insertion Loss (dB) (per MIL-STD-220 @ 25°C and no load)	1 MHz	4
	5 MHz	16
	10 MHz	18
	30 MHz	25
	50 MHz	30
	1000 MHz	30

* Other capacitance values are available. Consult the factory for details.

456 SERIES CONSTRUCTION



Testing for EMC Compliance

- “Bag of Ideas”
  - For an electromagnetic problem, the distance must be greater than a wavelength away
  - Conducted
    - Requires a conductive connection
  - Inductive coupling is caused by di/dt and low impedance circuits
    - Induced noise is in series
  - Electric field coupling is caused by dv/dt and high impedance circuits
    - Induced noise current is in parallel

Testing for EMC Compliance

- "More Bag of Ideas"
  - Measure noise voltage at both ends of victim circuit
  - If V_S / V_L is about 1, then capacitive coupling
    - Reduce load at one end; if voltage drops, then probably capacitive coupling
  - If V_S / V_L = Z_S / Z_L, then magnetic coupling
    - Reduce impedance at far end; if voltage increases at other end, then magnetic coupling

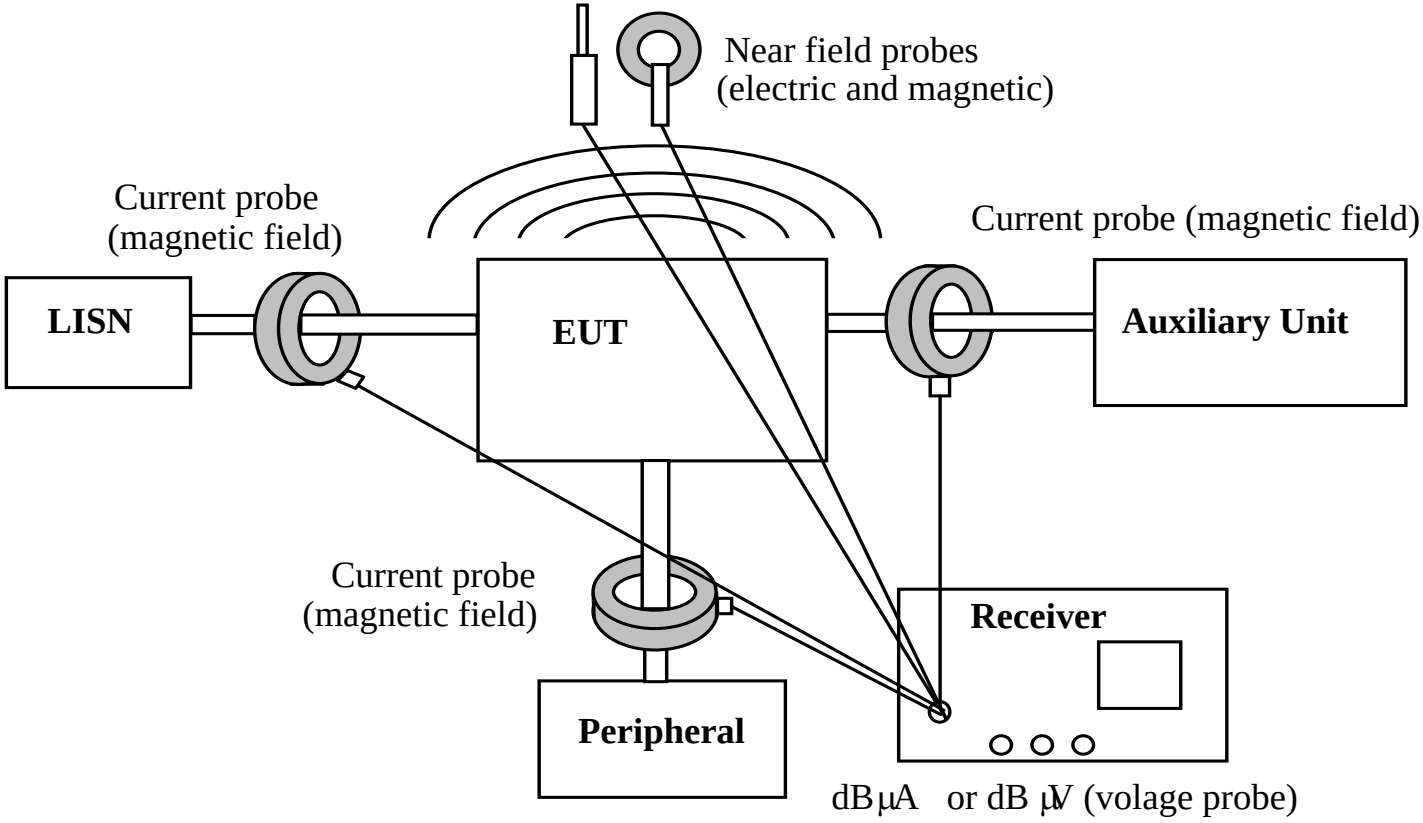
Testing for EMC Compliance

- “More Bag of Ideas”
  - Hand or Body Affects Level
    - Aluminum Foil to augment effects
    - Body is dielectric and conductive
      - Electric field or capacitive
  - Body is reflective and absorptive
    - Electromagnetic
  - Wire / Screwdriver Effect
    - Locates “hot spots”
  - Series Resonant Probe
  - Pin Probe

Testing for EMC Compliance

- "Even More Bag of Ideas"
  - Reverse probe reference or drive source line from other end
    - Polarity reversal indicates possible inductive coupling
  - Disconnect load
    - If problem still persists, then it is voltage related and possibly capacitive coupled
    - If problem goes away, then it is current related and possibly inductive coupled
  - Observe polarity of signal
    - Vertical: vertical hanging cables or horizontal aperture
    - Horizontal: horizontal cables or vertical aperture

Testing for EMC Compliance



Alternate RE testing setup

Testing for EMC Compliance

1. Clamp probe around the cable and measure the amplitude of the harmonic in question
2. Convert to current: I (dBuA) = V (dBuV) – ZT (dBW)
3. Plug into emission equation:

E (V/m) = 1.26x10-6(f L I) / R

where f is in Hertz, L is cable length in meters,
I is in amperes and R is in meters
L is either actual length or maximum of c/4f

Testing for EMC Compliance

EXAMPLE

1. Measured 33.5 dBuV on the analyzer at 100 MHz of a 5 meter cable
2. Convert to current: I (dBuA) = 33.5dBuV – 15dBW = 18.5 dBuA
3. Plug into emission equation:

L = c / 4(100MHz) = 0.75 meters

I = 8.4 uA

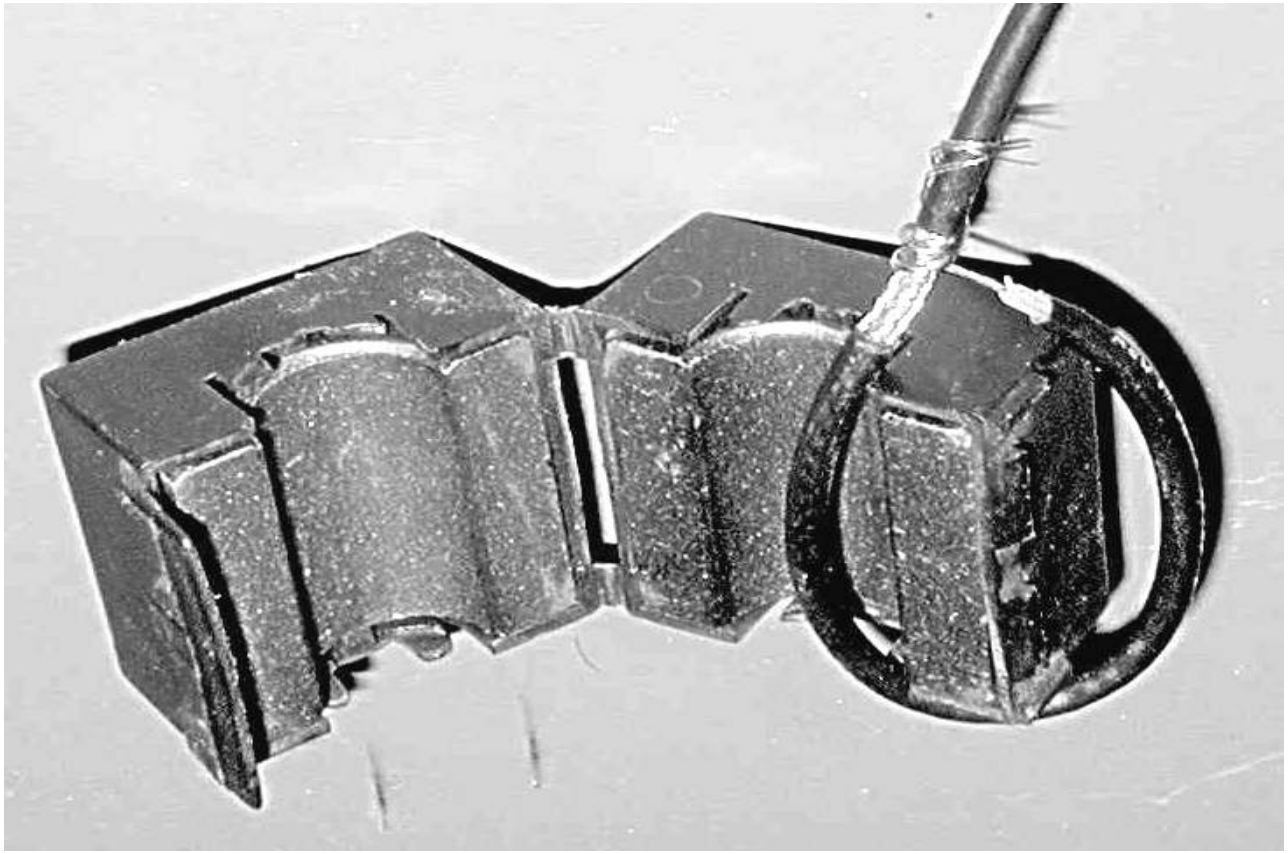
E (V/m) = 1.26x10-6(f L I) / R @ 3 m

= 2.65 x 10-4 V/m = 265 uV/m

= 48.5 dBuV/m

For FCC Class B at 100 MHz measured at 3 meters, the limit is 43.5 dBuV/m. We are potentially 5 dB over. Notice that it doesn't much current to exceed the limit.

Testing for EMC Compliance



(Photograph courtesy of Cortland Richmond)

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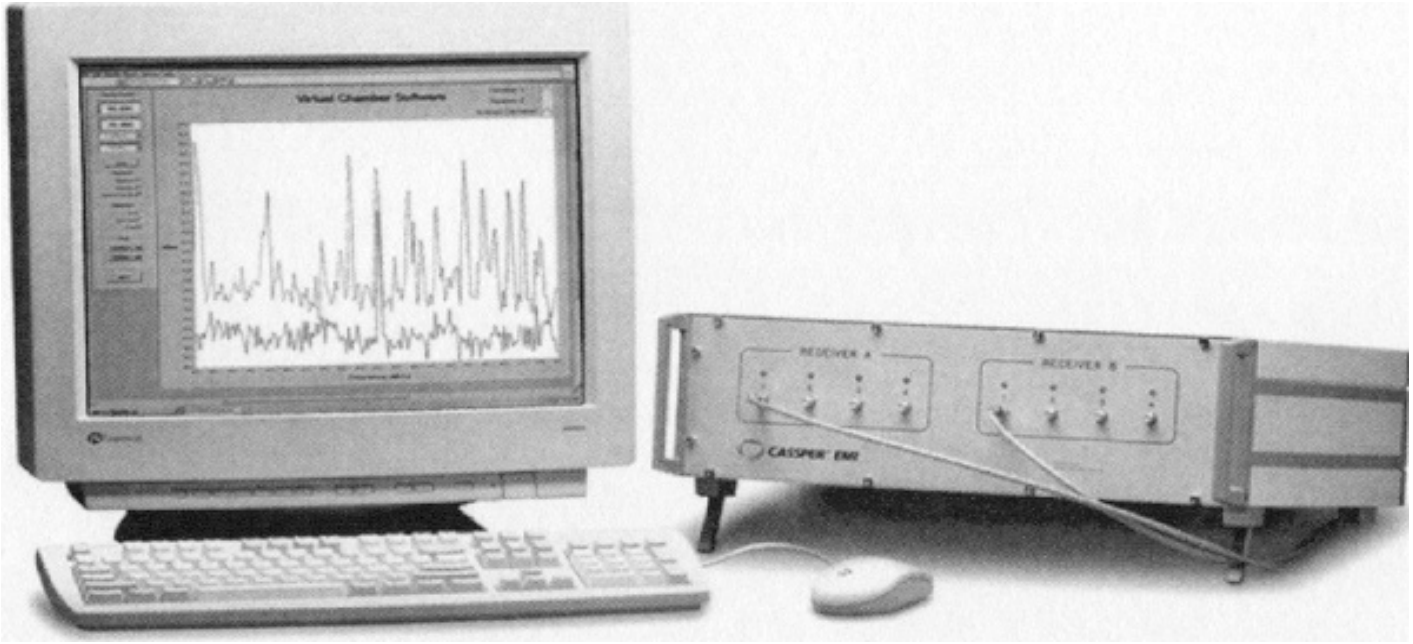
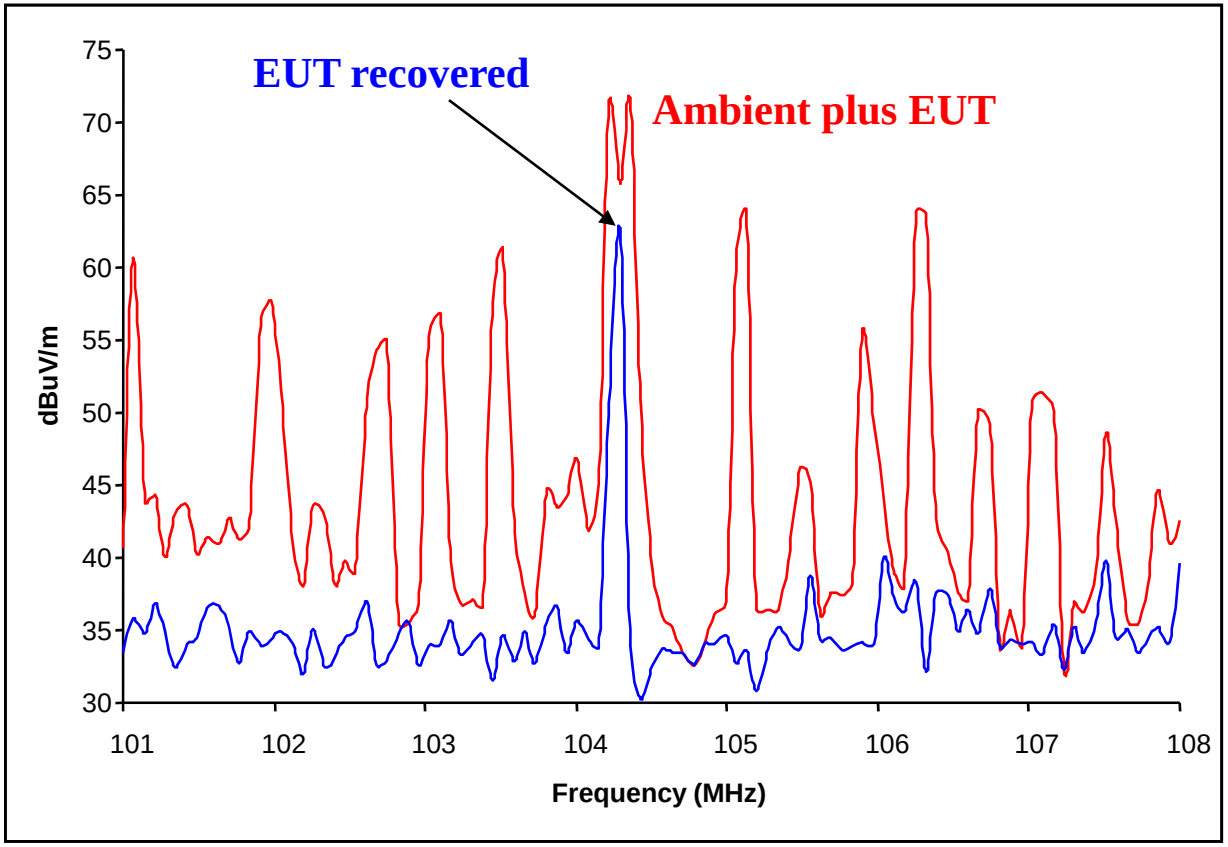


Correlation analyzer (Photo courtesy of SARA Inc.)

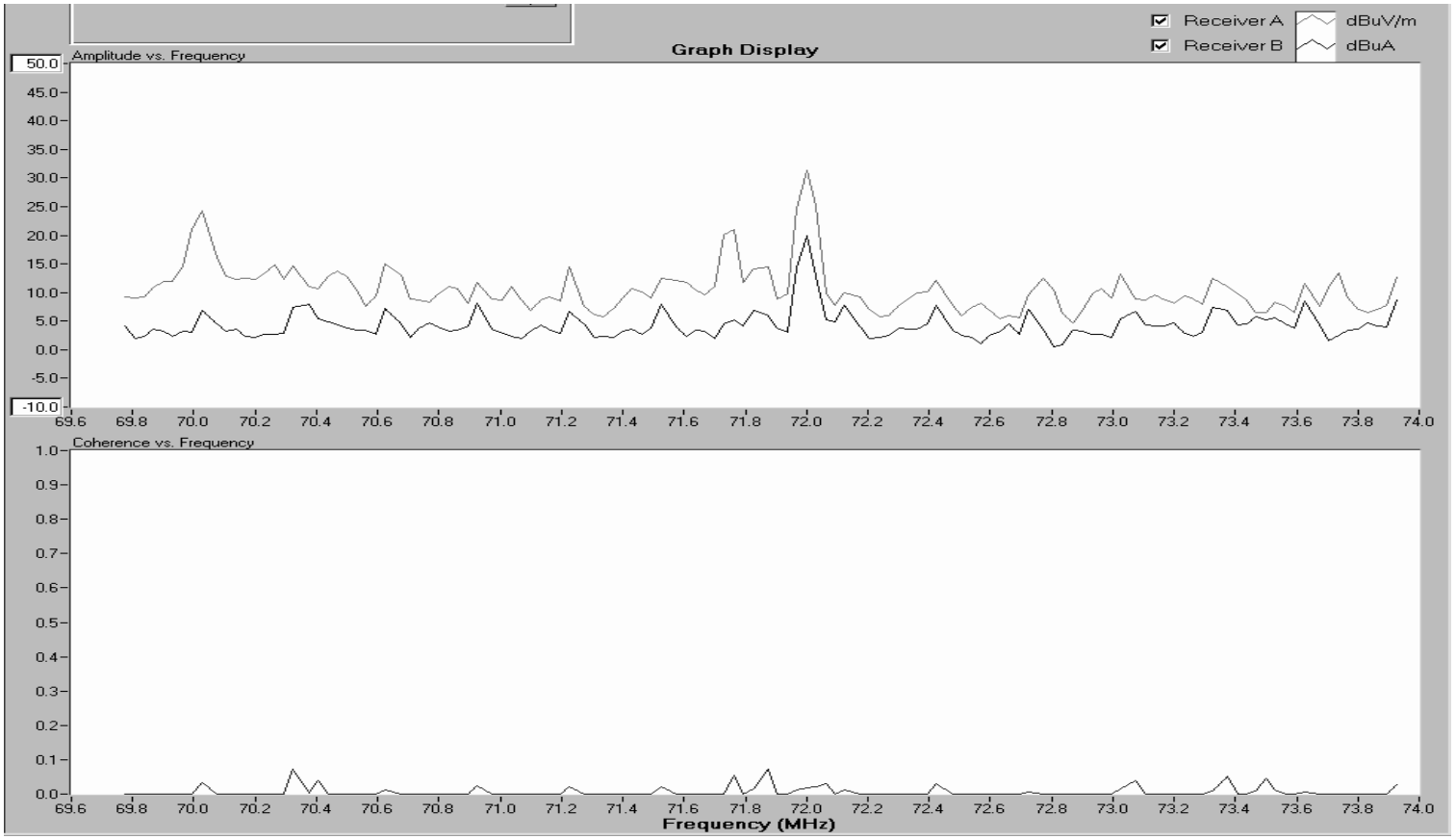
Testing for EMC Compliance



(Photo courtesy of SARA Inc.)

Testing for EMC Compliance

Source 1



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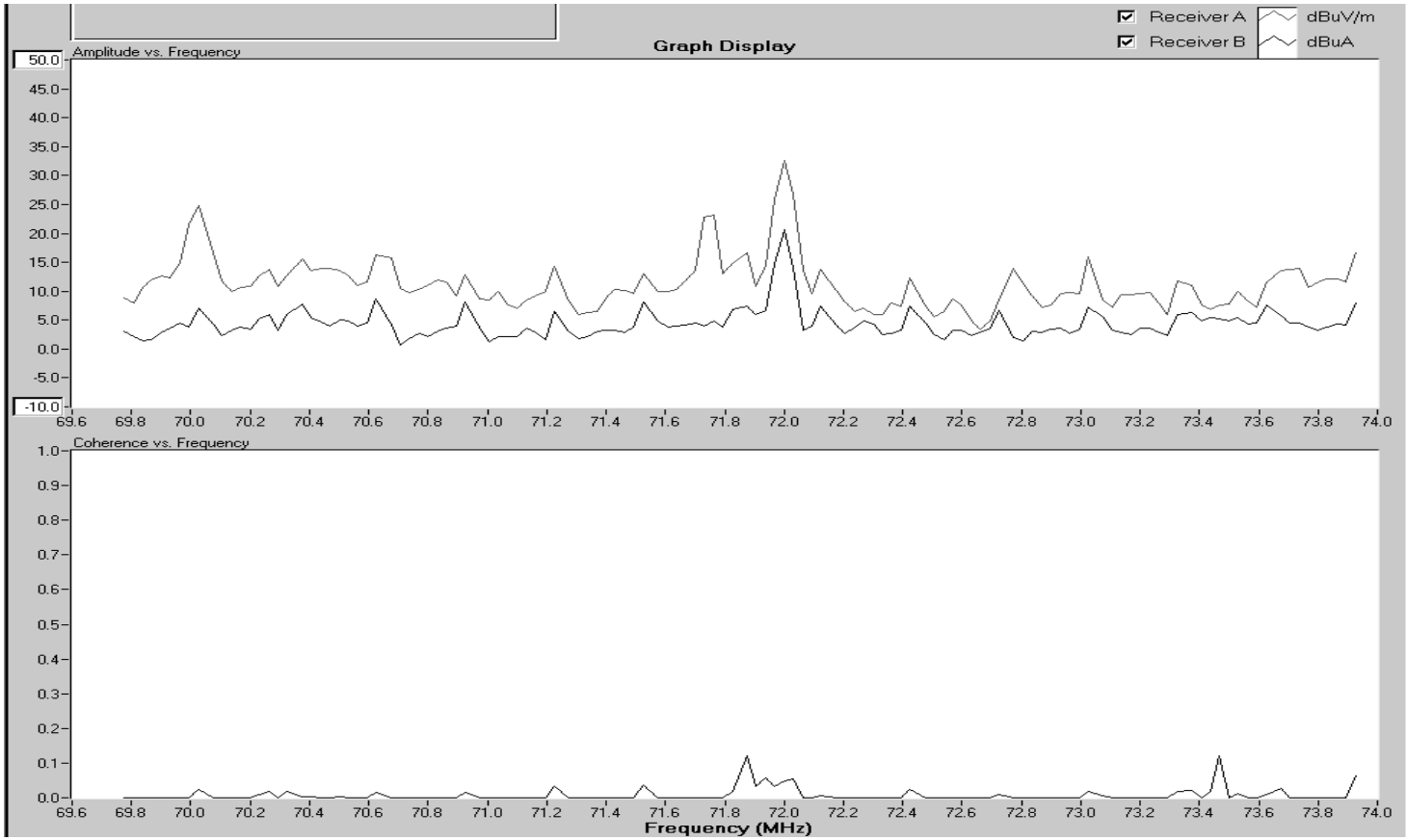
Source 2



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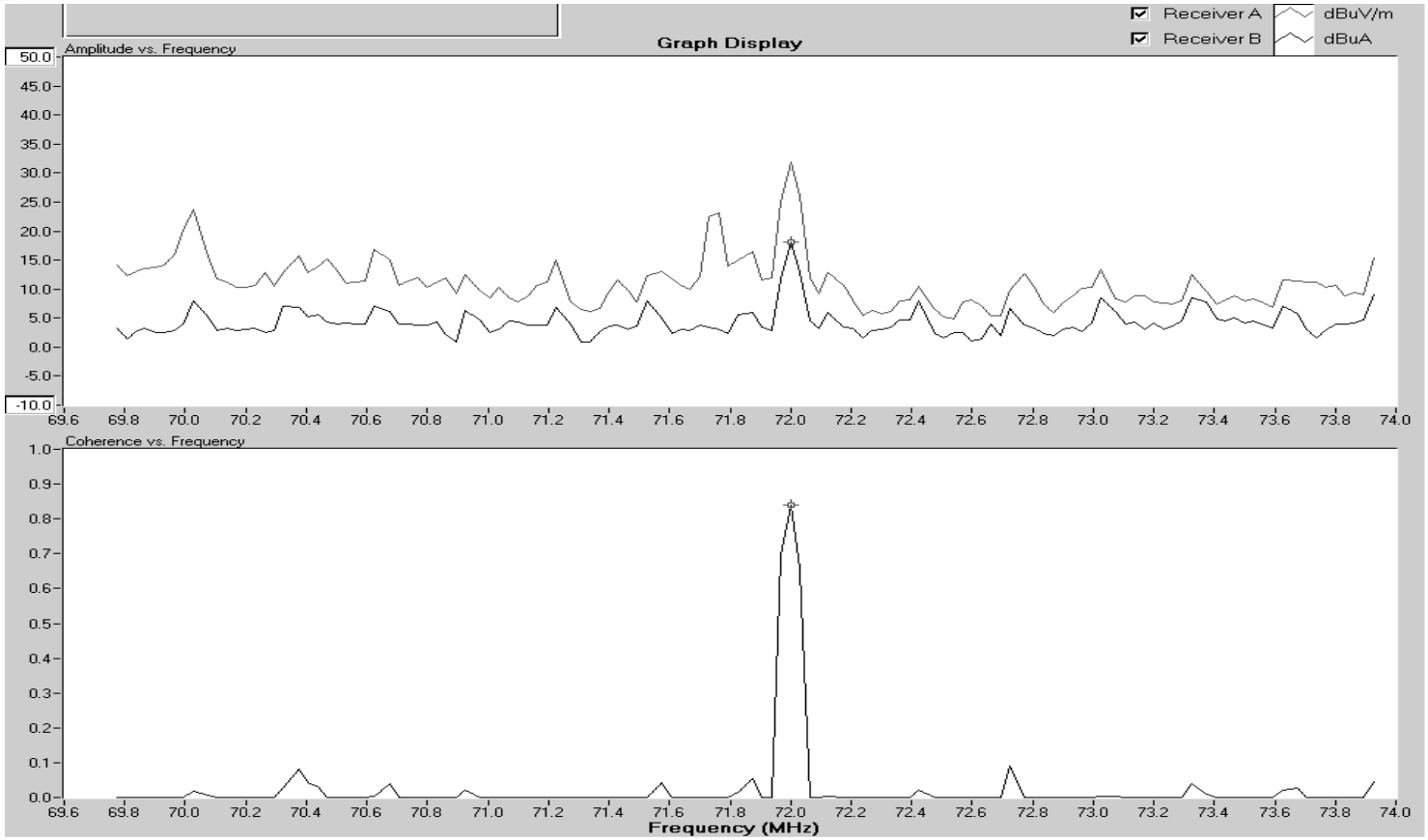
Source 3



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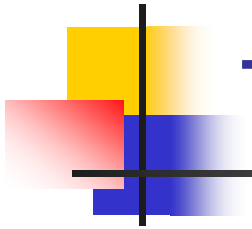
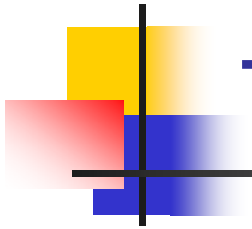


Testing for EMC Compliance

Leave all the fixes in place no matter what the effect.

Solve the problem.

THEN remove fixes one at a time.



Testing for EMC Compliance

- **A Step-By-Step Procedure**

Testing for EMC Compliance

STEPS

A. IDENTIFY & DEFINE THE PROBLEM(S)

B. RADIATED EMISSION PROBLEM ?

- YES: Shut down as many devices as possible
  - Does problem disappear ?
    - Yes: Turn back on devices sequentially until problem returns
      - With source identified, check on possible coupling paths
      - Go to “perform measurement” step
    - No: Problem is probably not related to a source within the “system”
      - Check on other possible “outside” sources and coupling paths
      - Go to “perform measurement” step
- NO: Continue on to appropriate problem area

Testing for EMC Compliance

STEPS (cont.)

- Disconnect external cable(s) from the suspect device one at a time
  - If noise has gone away, then the last cable(s) was the source
    - Go to “perform measurement” step
    - Go to next step
  - If noise is still present, then power cord is radiating
    - Go to “perform measurement” step
    - Go to next step

Testing for EMC Compliance

STEPS (cont.)

- For power cord, insert additional filtering
  - CM
    - line-to-ground capacitors
    - common mode inductors
  - DM
    - line-to-line capacitors
    - series inductor
- For other cables:
  - Shield
    - wrap in conductive tape, foil, Zippertubing™
  - 360º grounding of shield
  - Filter
    - clamp-on ferrite
    - series filtered gender changer connector

Testing for EMC Compliance

STEPS (cont.)

- If not power cord or cables, then radiation is from box (usually at higher frequencies i.e. >200 MHz)
  - Rotate or relocate source from apertures
  - Press on the seams with your hand
  - Cover the seam with foil or conductive tape
  - Wrap in conductive material (like a turkey)
    - If problem disappears, then design or redesign shielded box
    - If problem is still present, then there is another sources (i.e. support equipment, ambient)

Testing for EMC Compliance

STEPS (cont.)

- Work on enclosure design to locate the "leakage(s)"
  - Perform measurements
  - Are seams well connected (conductive coating)
- Work at the circuit level or internal packaging level
  - Perform measurements
- After reducing level, put all cables back in place

LEAVE ALL EMI FIXES IN PLACE UNTIL THE PROBLEM IS SOLVED AND ONLY THEN START TO REMOVE FIXES ONE AT A TIME.

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STEPS (cont.)

C. CONDUCTED EMISSION PROBLEM ?

- Perform measurements on power lines
  - Power factor correction (PFC) circuitry
  - Filter placement (breadboard outside of EUT)
  - Wire in an isolated secondary power supply
    - This also works for a suspected radiated problem
  - Insert additional filtering
    - CM
      - Line-to-ground capacitors
      - Common mode inductors
    - DM
      - Line-to-line capacitors
      - Series inductors

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STEPS (cont.)

D. IMMUNITY PROBLEMS ?

- Understand what the circuit or system does or is doing and how does it get into that state.
  - Any correlation ?
    - Yes: Victim or receptor identified - check on possible coupling paths
      - Go on to “perform measurement” step
    - No: Force a failure condition

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STEPS (cont.)

- "Forced Error" Technique
  - Hand-held Radios
  - Chattering Relay
  - Near Field Loop
    - Signal Generator / 1W or 2W Amplifier
  - Electrostatic Discharge Gun
    - Radiated immunity
    - Electrical Fast Transient (EFT)
    - Conducted immunity
- If linear circuit, apply square wave input through a coupling capacitor
  - Large overshoots indicate poor stability
  - Parasitic oscillations
- CASSPER

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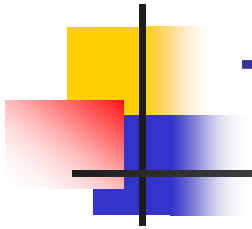
STEPS (cont.)

- Perform measurements
  - Current clamp
    - Current direction/magnitude
    - DM or CM
    - Cables including power cord(s)
  - Near field probes
    - Slots, seams
    - Apertures
    - PCB Traces
  - Oscilloscope
    - Ground noise
    - Power supply noise

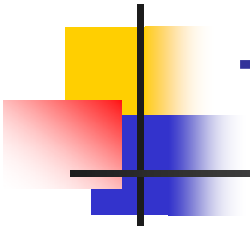


Testing for EMC Compliance

- In Final Summary

Testing for EMC Compliance

- Four Key Questions
  - What are the symptoms?
    - Equipment issues
      - What is the problem?
      - When was it first noticed?
      - What else is wrong?
  - What are the likely causes?
    - Environmental issues?
    - ESD?
    - Power disturbances?



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- Four Key Questions (continued)
  - What are the constraints?
    - System issues
    - Cost?
      - Cost of failure not just cost of component
    - Board modifications?
  - How will you know if it is fixed?
    - Establish a goal
    - Method of verification

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- Specific Questions for Emission Problems
  - What is the frequency of the noise?
  - Is it continuous or intermittent?
  - Does the noise happen in relation to another event such as when a printer is printing or data is transferring?
  - Is it cable or enclosure ?

Testing for EMC Compliance

- Specific Questions for Immunity Problems
  - What is the error or fault that is observed?
  - Is it cable or enclosure related?
  - Is it a radiated or conducted effect?
  - Isolate circuitry or subassemblies

Testing for EMC Compliance

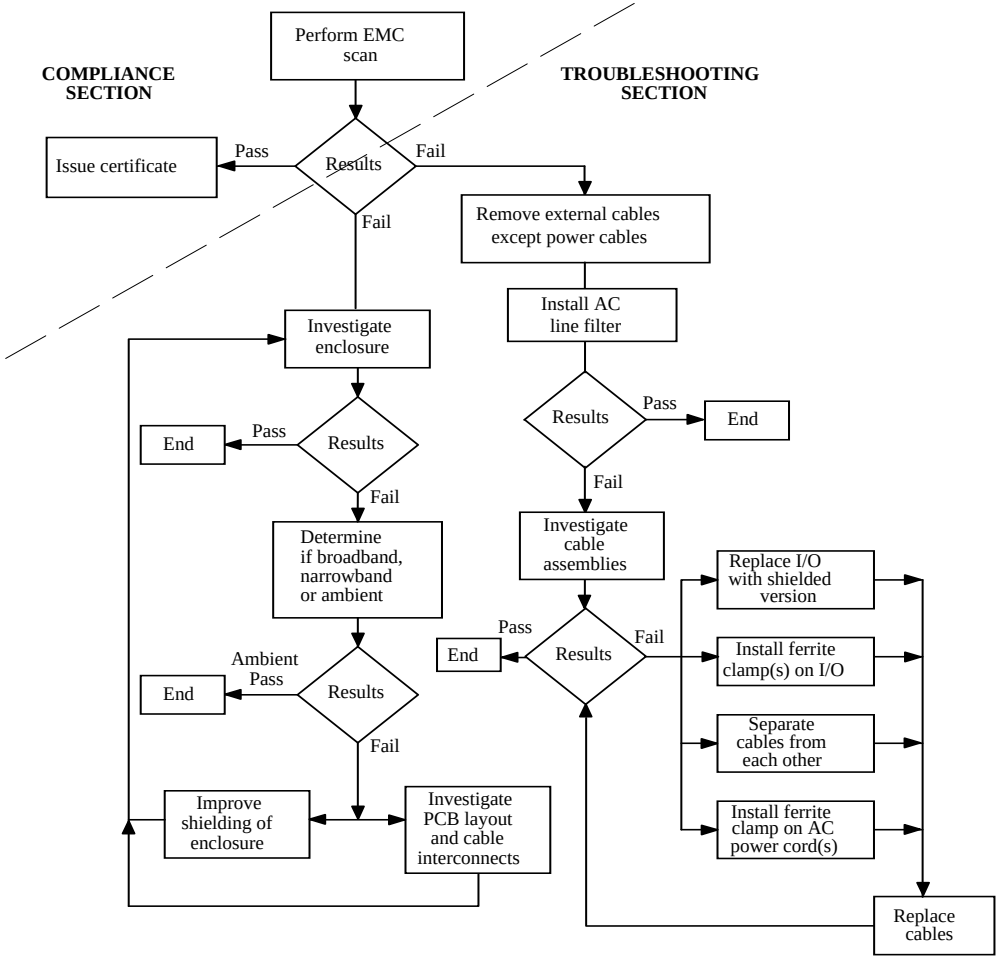

Figure 8.4 Flow chart for emissions testing and troubleshooting.

Testing for EMC Compliance

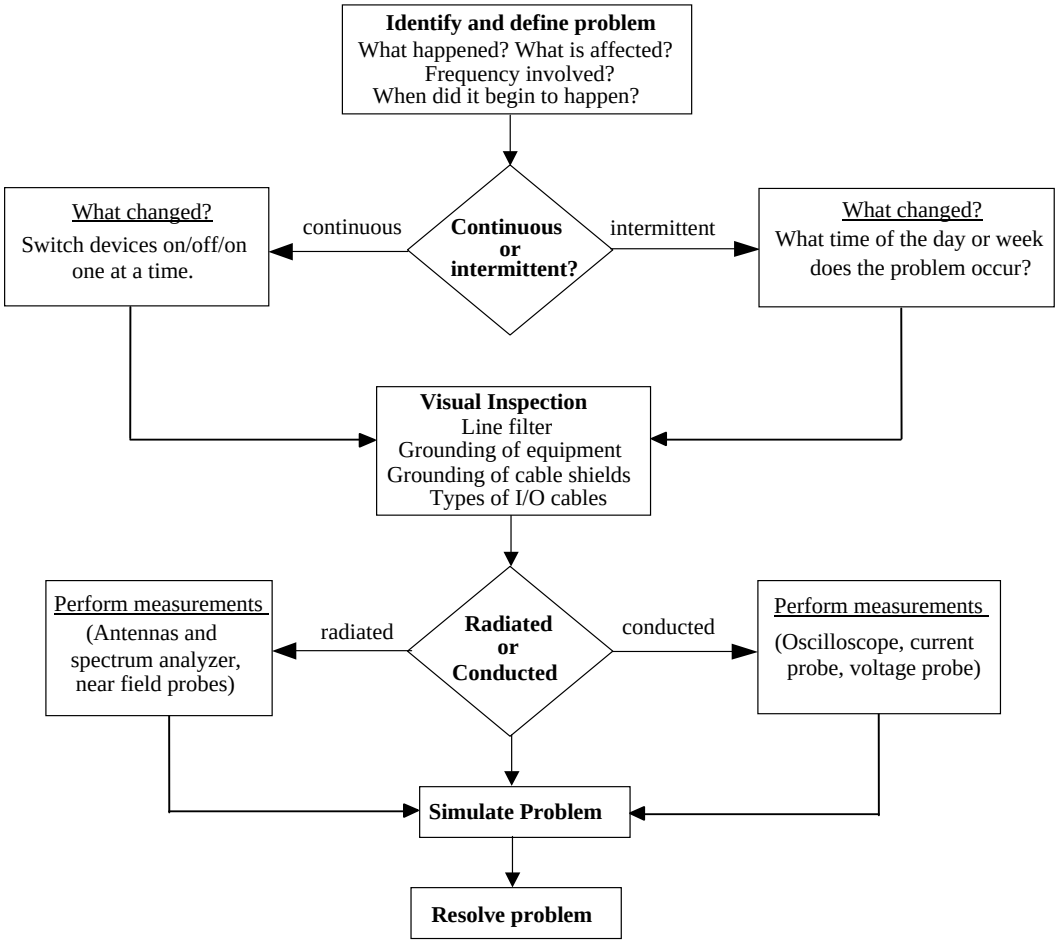

Figure 8.5 Systematic approach to detecting and locating problems

Testing for EMC Compliance

- Perform a Visual Inspection

Many times a visual inspection can lead to a starting point.

  - Are there unclosed seams or openings?
  - Are the cables shielded or filtered?
  - Are the cable connectors good?
  - What is the grounding scheme?
  - Is the circuit board multilayer?
  - Are internal cables placed for minimizing coupling?

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- Board Fixes
  - Circuit board “changes” are most appropriate early in the design stage.
  - Circuit board “fixes” are most appropriate when you cannot re-lay the board.

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- Outside the Box
  - Disconnect cables and peripheral devices
  - Use ferrites or aluminum foil for cables that cannot be disconnected
  - Start with a “minimum configuration” system
  - One at a time, re-connect cables and peripherals and solve individually

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- Inside the Box

If enclosure fixes are unacceptable, then turn to inside the box.

  - Check cable routing
  - Check grounding
  - Circuit board

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