Testing for EMC Compliance:
Approaches and Techniques

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Outline

- Discuss EMC Basics & Physics
- Fault Isolation Techniques
- Tools & Techniques
- Correlation Analyzer

Emulex Corporation

- **Headquarters: Costa Mesa, CA**
  - **500+ employees worldwide**
  - **Sales offices in UK, France, China**
- **22 years experience in storage/networking technologies**
- **Major investments in emerging technologies:**
  - **Next generation storage networking, driver-based management, embedded switching**

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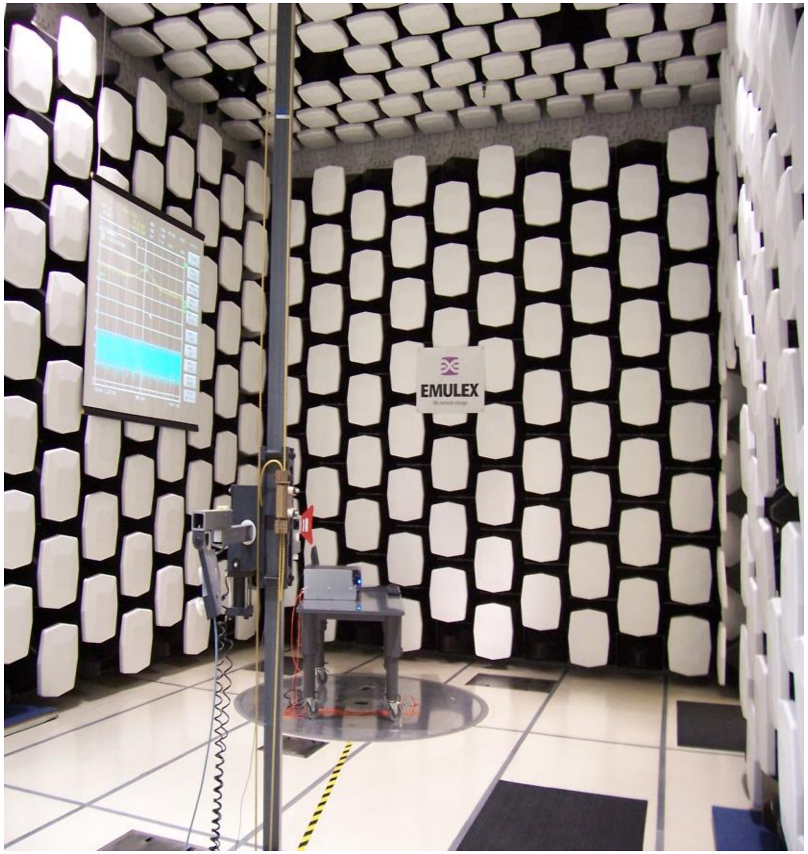
Typical Host Bus Adapters

- HBA
  - Managed “Smart” Digital Diagnostics
  - Large onboard contexts cache and buffer credits for superior performance and scalability
- Compatibility
  - Windows, Linux, NetWare, Solaris, AIX, HP-UX
  - OEM custom drivers

EMC Capabilities



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Testing for EMC Compliance

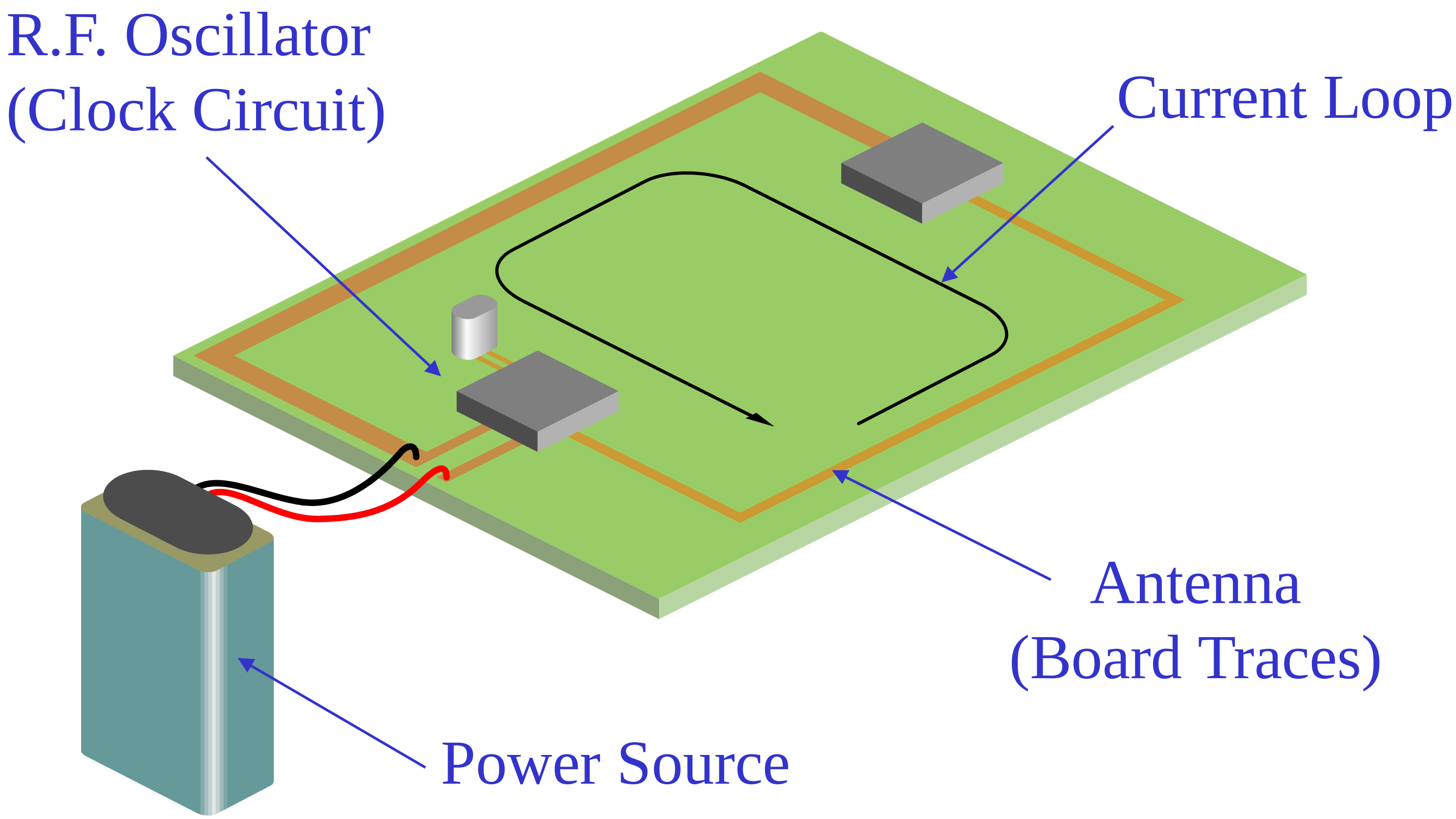
- **Systematic Approach**
  - **Source**
  - **Coupling mechanism**
  - **Victim or receptor**

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”	Equipment

Testing for EMC Compliance



Testing for EMC Compliance

- **Coupling Mechanisms**
  - **Conduction**
    - **Noise is transmitted through power, signal or ground conductors**
  - **Radiation**
    - **Noise is transmitted through air**
    - **Distance is greater than a wavelength**
  - **Crosstalk**
    - **No direct connection and is transmitted through electric or magnetic fields**

Testing for EMC Compliance

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

The Physics of it All

MAXWELL EQUATIONS

- **Forms the building blocks of understanding the electromagnetic phenomena.**
  - **Gauss's Law - There are + and - electric charges and no magnetic charges.**
  - **Faraday's Law - A changing magnetic field cutting across a closed loop generates a current flow.**
  - **Ampere's Law - A current flow creates a magnetic field.**

Testing for EMC Compliance

MAXWELL EQUATIONS (cont.)

- **A time varying electric field between two conductors can be represented as a capacitor.**
- **A time varying magnetic field between two conductors can be represented by mutual inductance.**

AN RF VOLTAGE POTENTIAL WILL CAUSE A TIME VARYING CURRENT GENERATING A TIME VARYING MAGNETIC FIELD WHICH, IN TURN, DEVELOPES A TIME VARYING TRANSVERSE ELECTRIC FIELD. THIS IS AN ELECTROMAGNETIC FIELD.

Testing for EMC Compliance

Fault Isolating

- Be like a Doctor
  - 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

- 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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Testing for EMC Compliance

- **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**

Testing for EMC Compliance

- 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

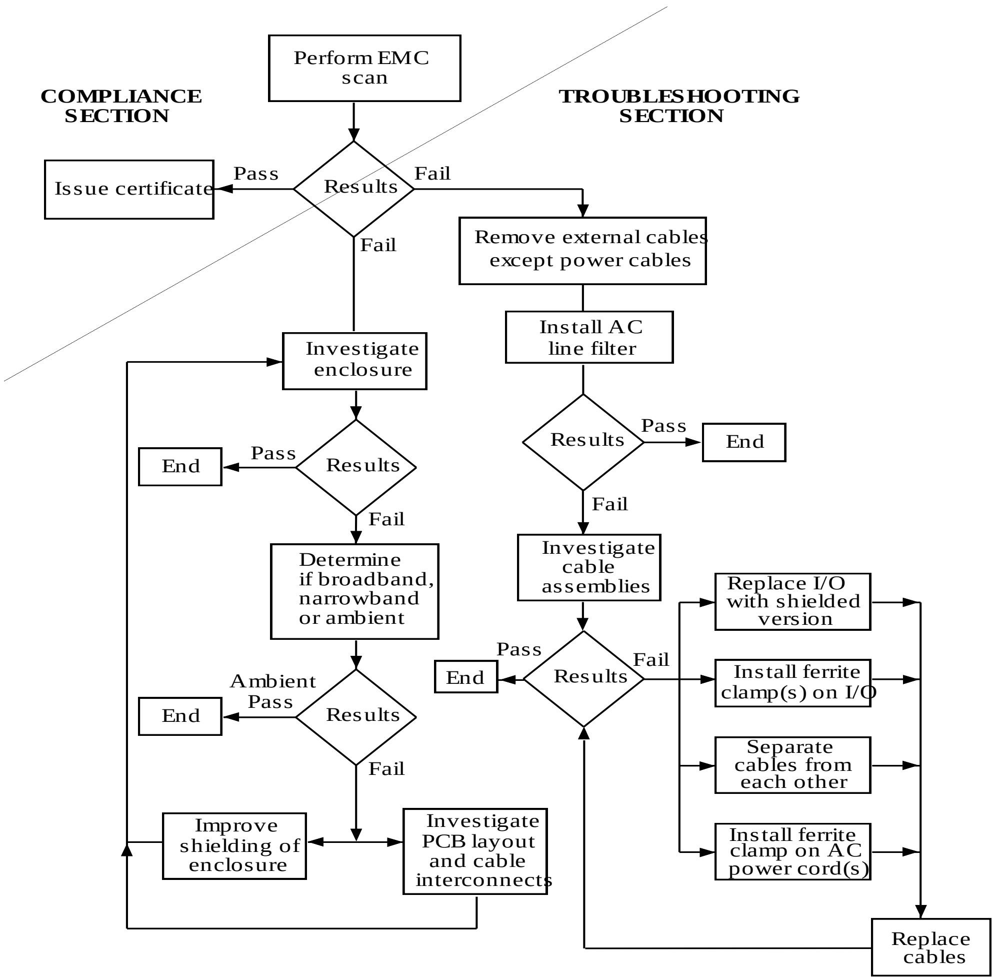

Figure 8.4 Flow chart for emissions testing and troubleshooting.

Testing for EMC Compliance

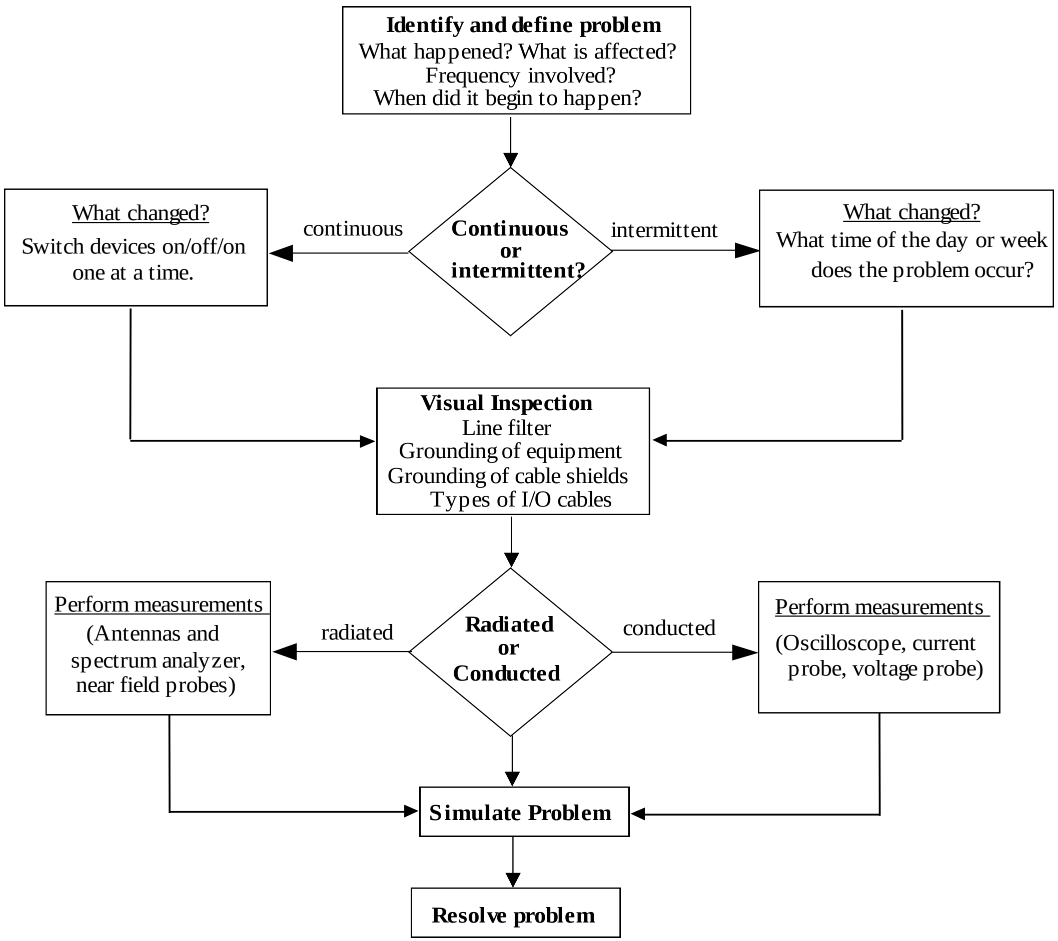

Figure 8.5 Systematic approach to detecting and locating problems

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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?**

Testing for EMC Compliance

- 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.

Testing for EMC Compliance

- **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**

Testing for EMC Compliance

- **Inside the Box**

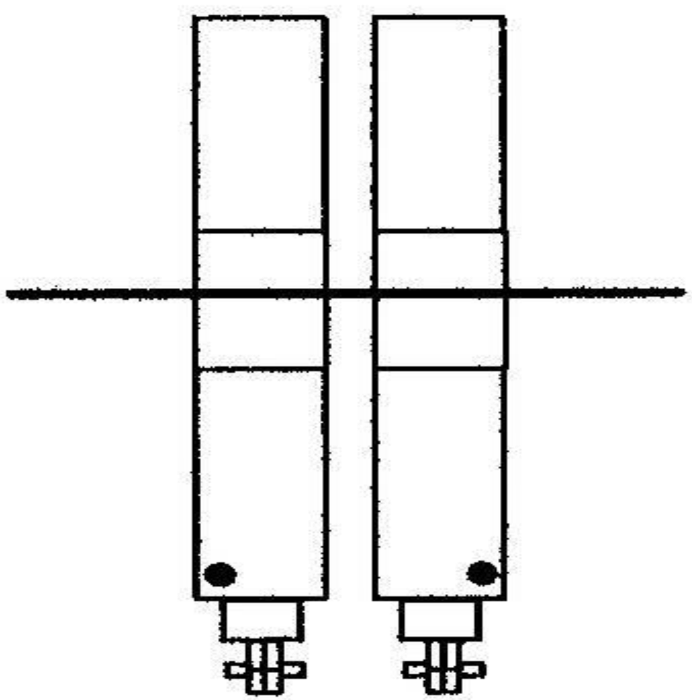
  If enclosure fixes are unacceptable, then turn to inside the box.

  - **Check cable routing**
  - **Check grounding**
  - **Circuit board**

Testing for EMC Compliance

- Techniques for Emissions
  - "Piece of wire" or a screwdriver
  - Current clamp
    - Current magnitude and direction
      - "Directionality" of current flow
      - Measure cable, Icm1, and second cable, 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
    - 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

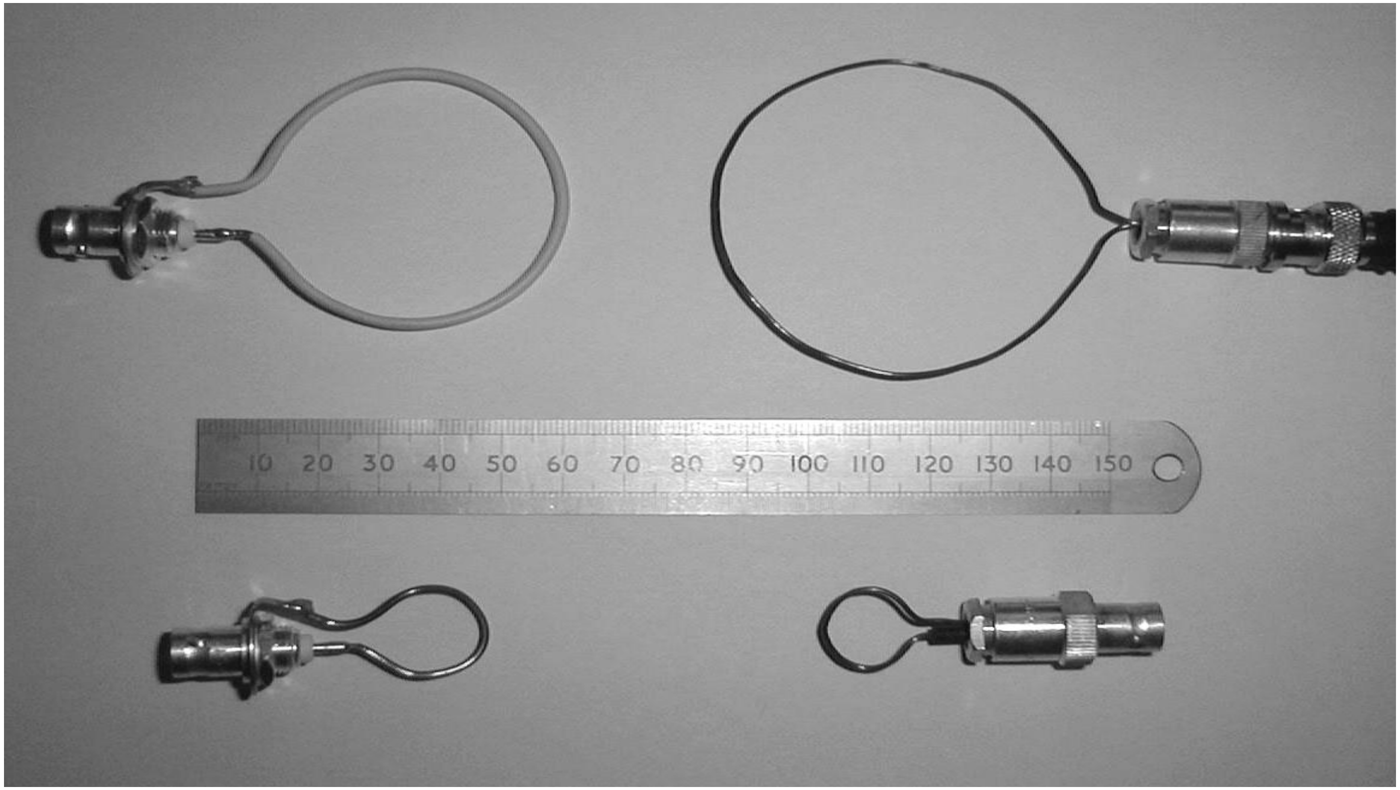
- Techniques for Emissions (cont.)
  - Radiated emissions below 200-300 MHz are typically cable related, while above this frequency, it is usually box related.
  - Near Field Probes
    - Slots, seams
    - PCB traces
  - Oscilloscope with differential probe
    - Ground noise / Cable noise
    - IC Noise / Power Supply Noise
  - Use AM/FM 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)*

Testing for EMC Compliance

- Techniques for Immunity
  - Hand-held VHF/UHF 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 a Bias-Tee Network or a capacitor
  - Use EFT generator or ESD generator to simulate power bus noise problems
    - Couple through a capacitor of about 0.01 or 0.001 uf
    - Can simulate “hot swap” noise problems

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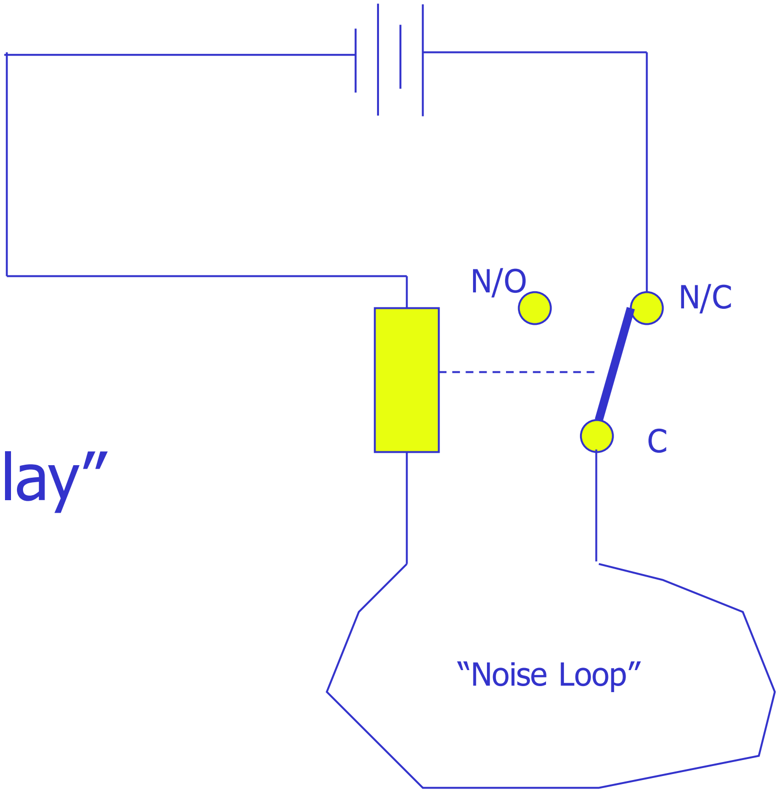
Testing for EMC Compliance

"Chattering Relay"



Testing for EMC Compliance

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

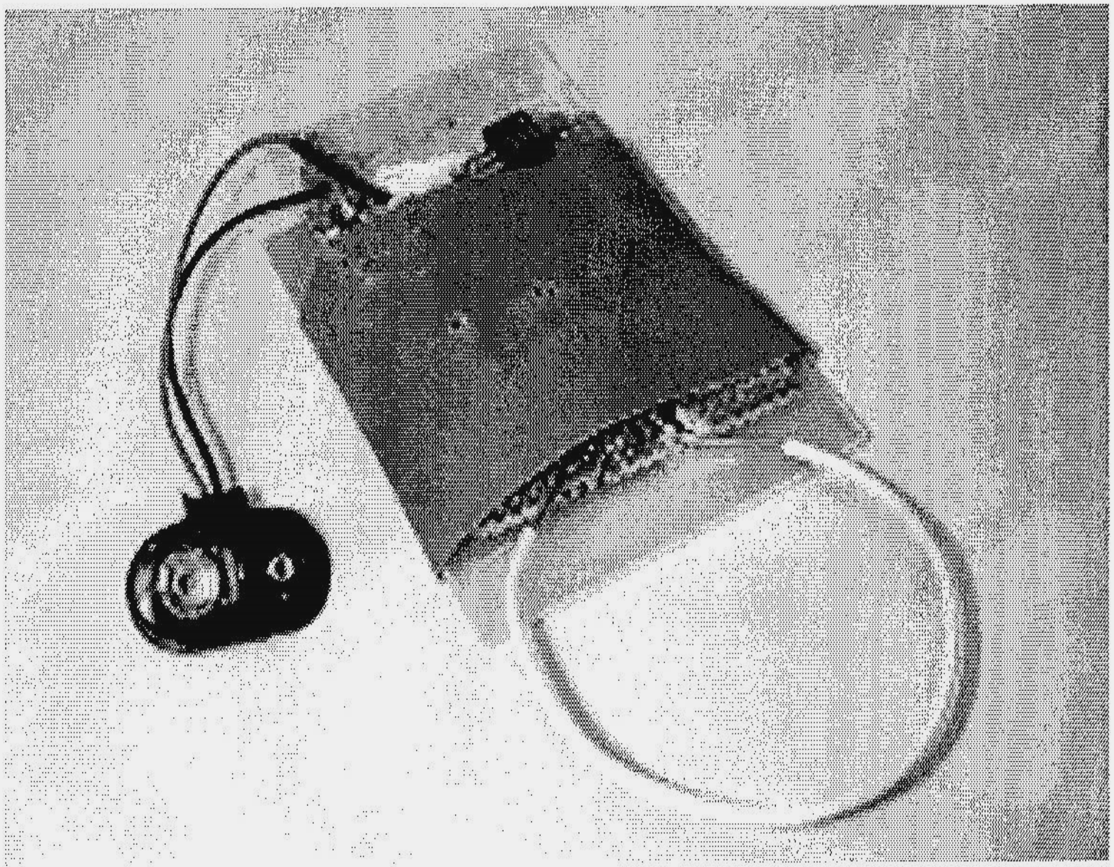
Testing for EMC Compliance

- Test Equipment
  - Spectrum analyzer/receiver
    - Balanced differential probe
    - Current probe
    - Near field probes
  - 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
  - Emissions measurement of open PCB
    - If emissions 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
  - Analyze leakages in the enclosure
  - Common Mode Cable Currents

Testing for EMC Compliance



Wyatt/Chaney, RF Design Magazine, January 1991

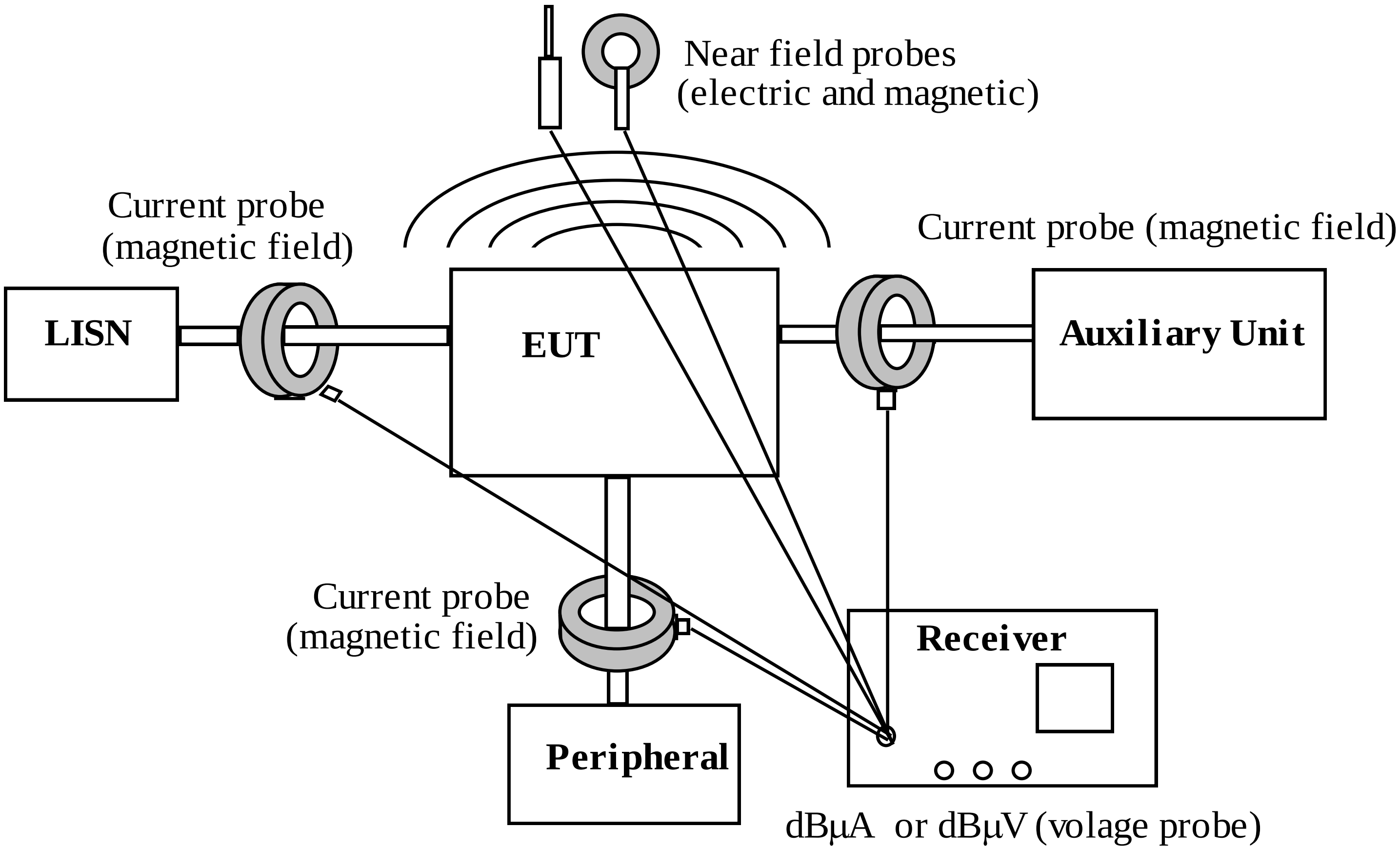
Testing for EMC Compliance

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

Testing for EMC Compliance

- “Bag of Concept Tricks”
  - For an electromagnetic problem, the distance must be greater than a wavelength away
  - 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
  - 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

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: $I\ (dBuA) = V\ (dBuV) – Z_T\ (dB\Omega)$
3. Plug into emission equation:

$$E\ (V/m) = 1.26 \times 10^{-6} (f\ L\ I) / R$$

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

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EXAMPLE

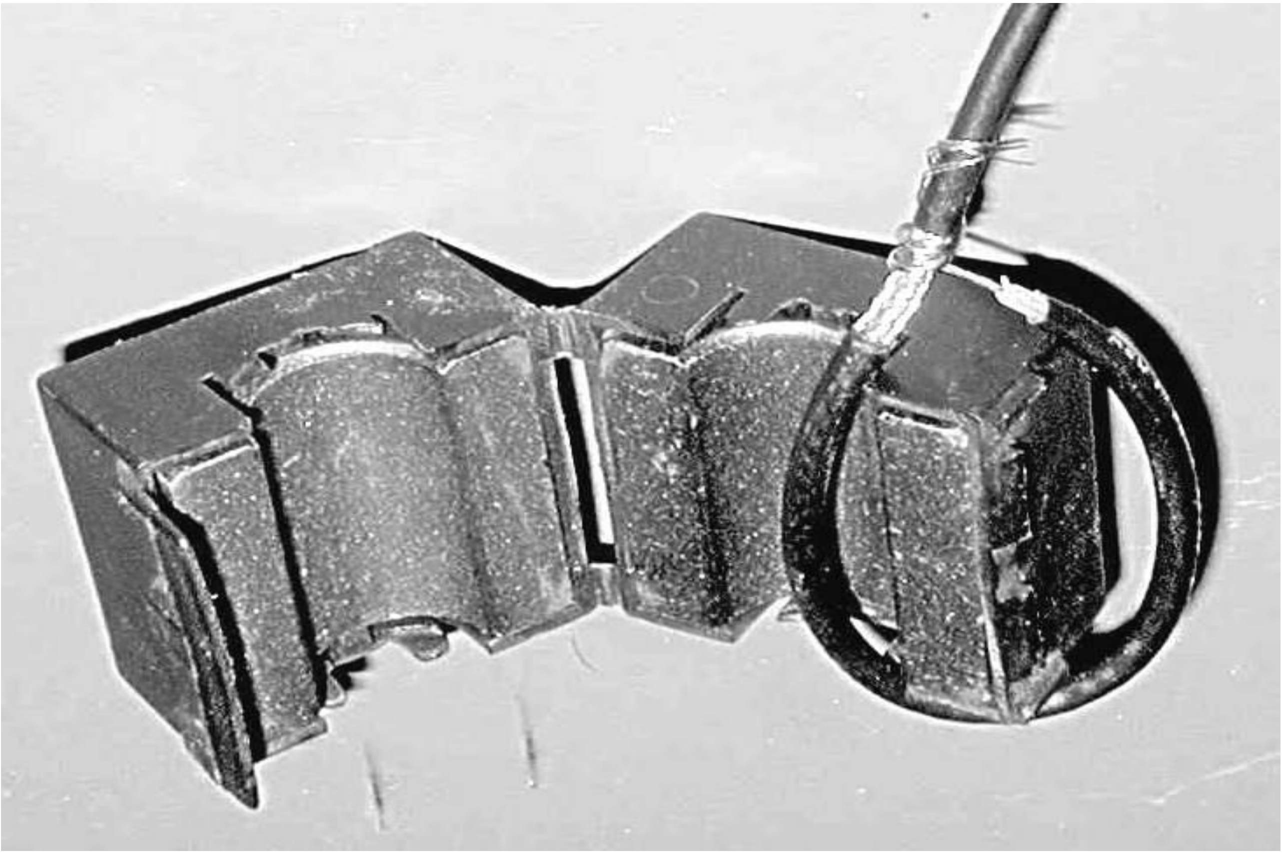
1. Measured 33.5 dBuV on the analyzer at 100 MHz of a 5 meter cable
2. Convert to current: $I\ (dBuA) = 33.5dBuV - 15dB\Omega = 18.5\ dBuA$
3. Plug into emission equation:

$$L = c / 4(100MHz) = 0.75 \text{ meters}$$
$$I = 8.4\ uA$$

$$E\ (V/m) = 1.26 \times 10^{-6} (f\ L\ I) / R$$
$$= 2.65 \times 10^{-4}\ V/m$$
$$= 48.5\ dBuV/m$$

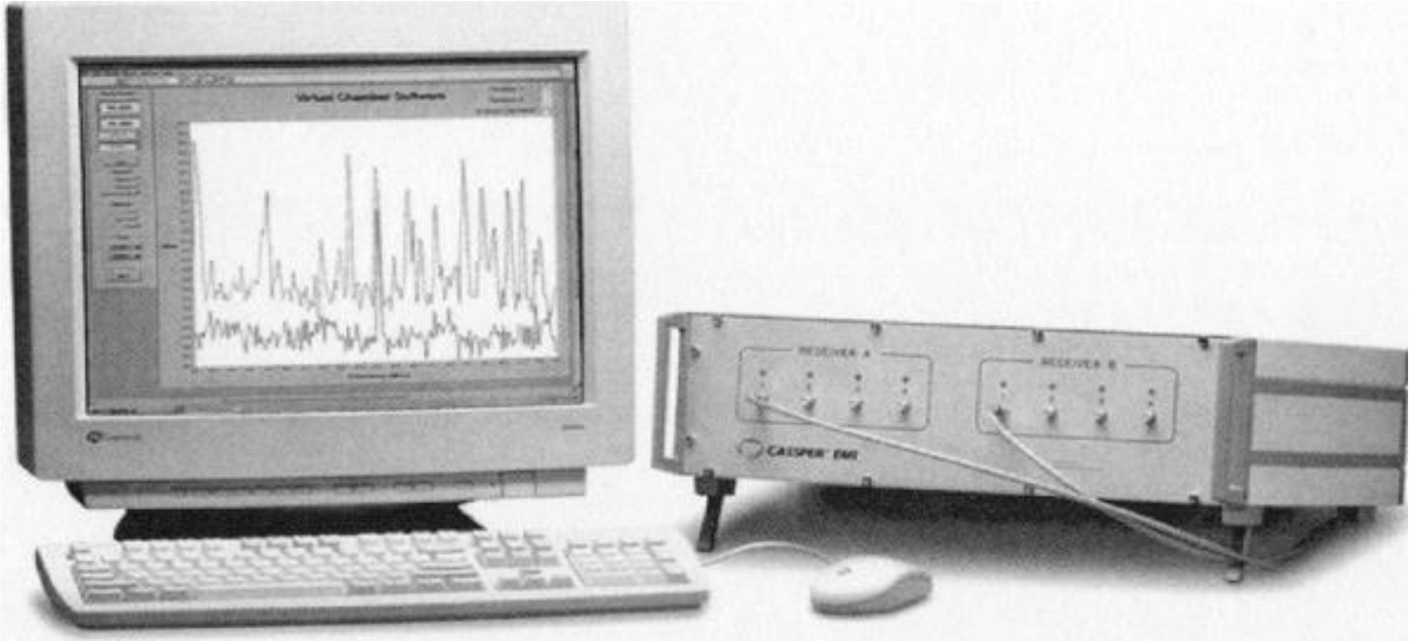
For FCC Class B at 100 MHz measured at 3 meters, the limit is 43.5 dBuV/m. We are potentially 5 dB over. Notice that it doesn't take much current to exceed the limit.

Testing for EMC Compliance



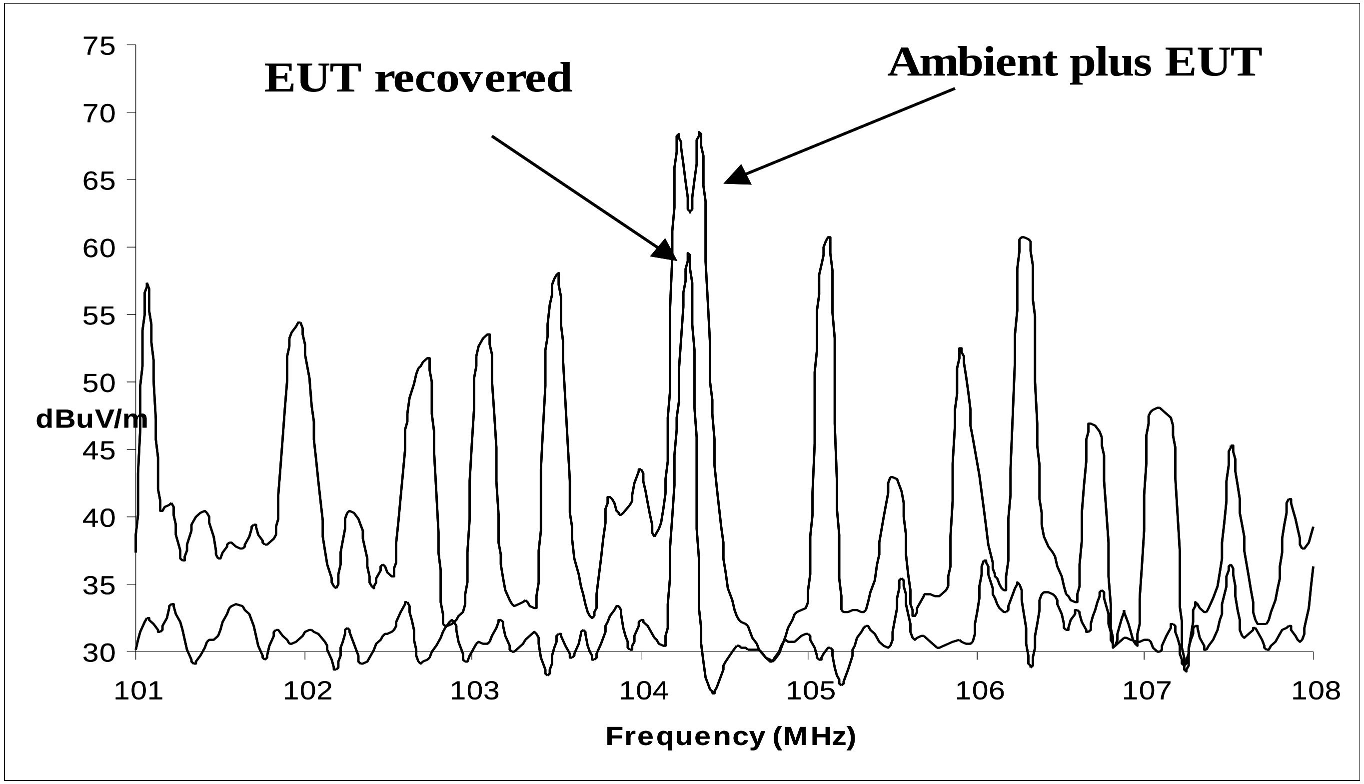
(Photograph courtesy of Cortland Richmond)

Testing for EMC Compliance



Correlation analyzer (Photo courtesy of SARA Inc.)

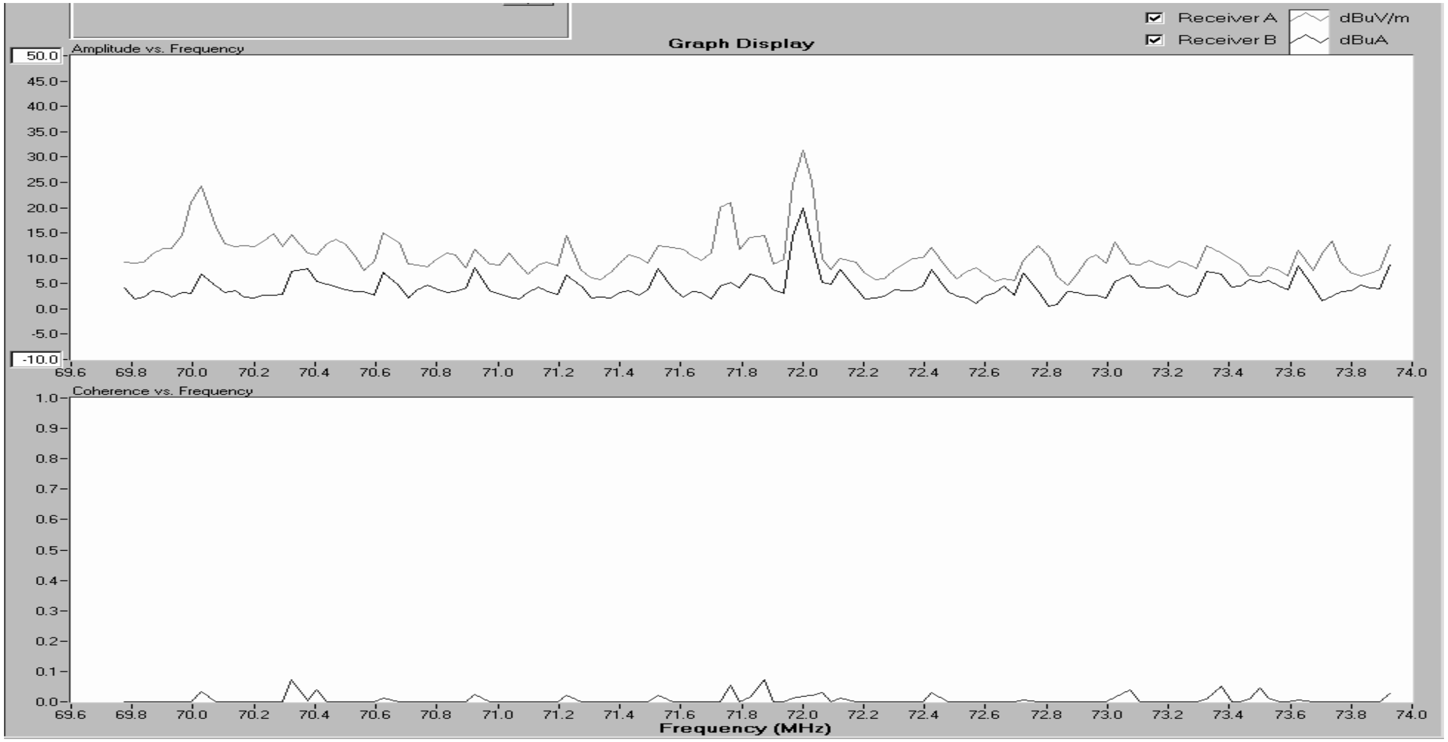
Testing for EMC Compliance



(Photo courtesy of SARA Inc.)

Testing for EMC Compliance

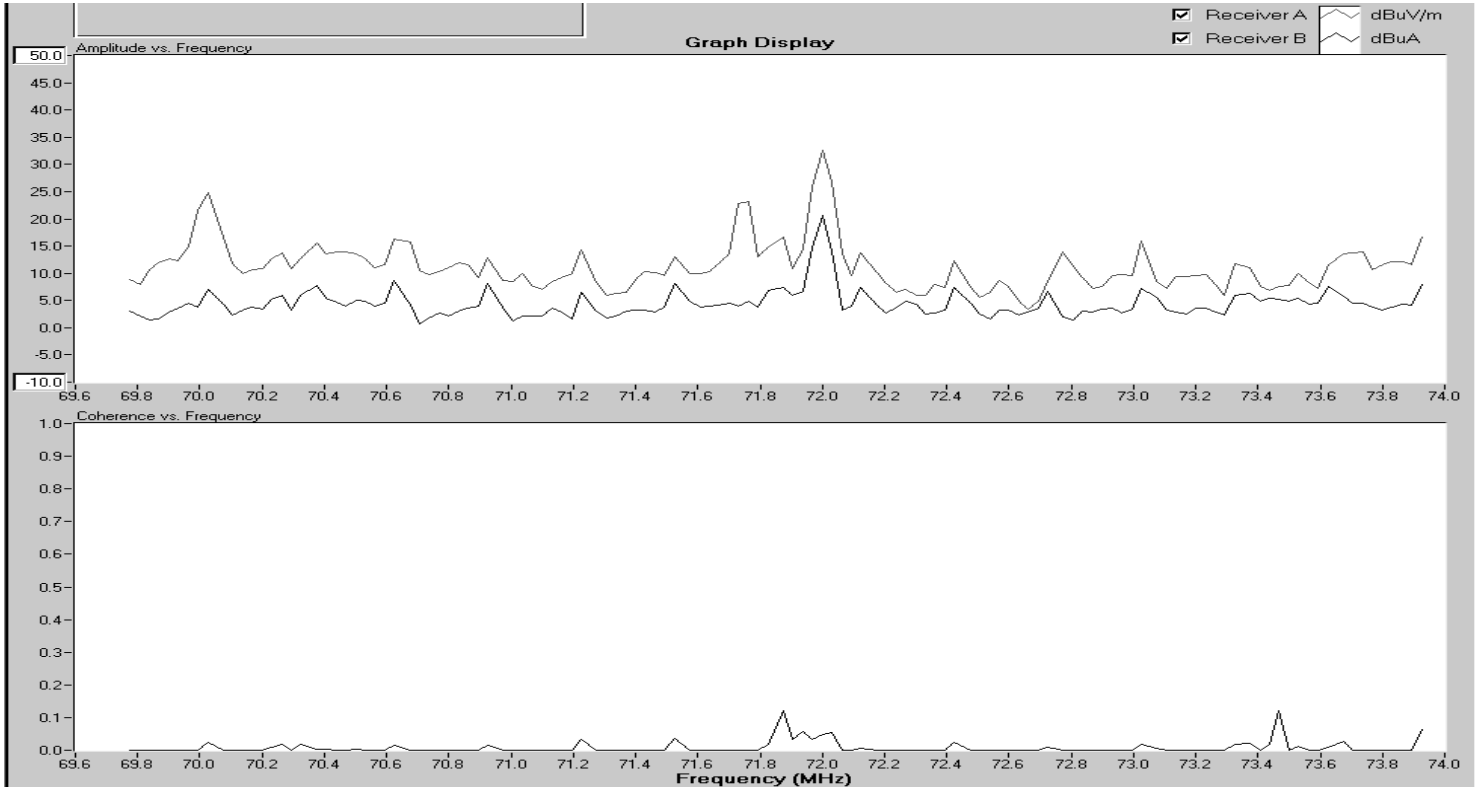
Source 1



(Courtesy of SARA Inc.)

Testing for EMC Compliance

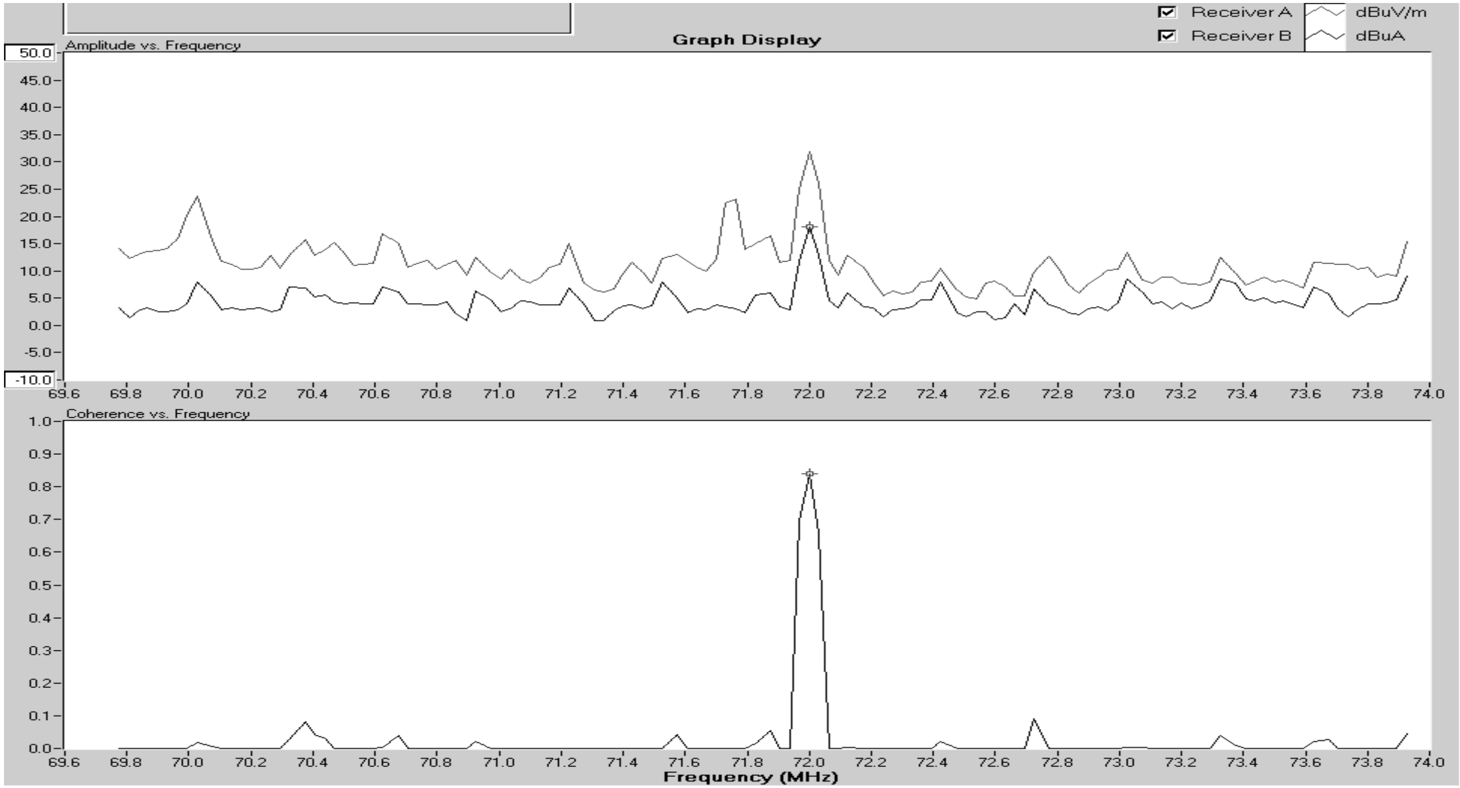
Source 2



(Courtesy of SARA Inc.)

Testing for EMC Compliance

Source 3



(Courtesy of SARA Inc.)

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.