Electromagnetic Compatibility (EMC)

IEEE Definition

Origin, control, and measurement of electromagnetic effects on electronic and biologic systems.

IEEE EMC Society Areas of Interest

- **EMC Standards:** Standards of good EMC engineering practice.
- **Measurement Technology:** Instrumentation and methods of measurement.
- **RF Noise Sources:** Studies of the origins and characteristics of electromagnetic emissions, both natural and man-made (but not designed to convey intelligence).
- **Equipment EMC:** Emissions and susceptibility of electronic equipment and components.
- **Systems EMC:** Emissions and susceptibility of electronic systems and subsystems.
- **Spectrum Utilization:** Utilization of the electromagnetic spectrum by, and frequency allocation of, signals designed to convey intelligence.
- **TEMPEST and EMP:** Electromagnetic considera-

tions of (i) secure communications and (ii) nuclear pulses.

- **Radiation Hazards:** Undesirable electromagnetic interactions with biological systems, fuel, and ordnance.
- **Walsh Functions:** Applications of orthogonal non-sinusoidal functions.

Course Objective

To cover the practical aspects of noise and interference suppression and control in electronic circuits for the engineer who is or will be involved in hardware design.

Course Level

Design oriented with a minimum mathematical complexity. Simplified models representing physical phenomena having physical meaning.

The Interference Problem

The operation of diverse circuits in close proximity gives rise to what is called EMI, which stands for Electromagnetic Interference (formerly called RFI which stood for radio

Radio Frequency Interference).

Examples

- Circuits for communications.
- Circuits for power distribution.
- Circuits for automation and control.
- Computers.

Effect of Circuit Size

As circuits become smaller, EMI problems become worse in general. Integrated circuits are particularly susceptible to EMI, especially LSI circuits.

Major Equipment Design Objective

Elimination (or avoidance) of EMI. This means that equipment should be designed so that it is not affected by noise nor is itself a source of noise.

Example of interference inside equipment:

Figure 1-1 shows how EMI can occur inside a radio receiver. There are four coupling mechanisms illustrated in the figure:

- Electric field coupling – caused by voltage difference between conductors.
- Magnetic field coupling – caused by current flow in conductors.
- Conductive coupling – noise coupled between components through interconnecting wires, e.g. through power supply and ground wires.
- Common impedance coupling – caused two or more currents flowing in the same impedance, e.g. in power supply and ground wires.

If the radio is free of these EMI sources, it will operate in the lab.

Example of interference when equipment is installed in the "real world": Figure 1-2 shows how external noise sources can interfere with the radio receiver when it is taken out of the lab. Some sources of noise:

- Electric field coupling from:
  - High-voltage power lines.
  - Broadcast antennas.
  - Communications transmitters.
  - Vehicle ignition systems.

  - Electric machinery.
- Conductive coupling through ac power lines.

Example of how equipment in the "real world" interferes with other equipment: Figure 1-3 shows how a radio can interfere with other equipment. Some examples are:

- Electric field coupling to:
  - Broadcast receivers.
  - Telephone lines.
  - Communications receivers.
- Conductive coupling through ac power lines.

Designing for EMC

Equipment should be designed to:

- Function properly in its intended electromagnetic environment, i.e. to be immune to EMI.
- Not be a source of pollution to that environment, i.e. not to be an emitter of EMI.
- Susceptibility tends to be self-regulating. For example, consumers will avoid purchasing it.
- Emission tends to not be self-regulating if the product is not affected by its own emissions. As a result, regulatory bodies impose standards to

control emissions.

Two Approaches for EMC Design

- *Crisis Approach:* Disregard EMC until the design is completed. Use “add-ons” to fix the problems as they arise during testing and field experience. Also called the “Band-Aid” approach. Tends to be expensive.
- *Systems Approach:* Consider EMC throughout the design. Anticipate all possible problems from the start. Thorough EMC test of final prototypes. More cost effective because EMC is designed into the product and not added on when problems later arise.

Example: Figure 1-4 illustrates how available techniques for EMC and cost vary with time during equipment development.

EMC Regulations

Those that affect the U.S. are primarily written by three agencies:

- The FCC or Federal Communications Commission.
- The U.S. Department of Defense (MIL-STD).
- The CISPR or International Special Committee on Radio Interference.

FCC

- Regulates the use of all licensed radio and wire communications.
- Three sections of FCC Rules are applicable to non-licensed electronic equipment.
  - Part 15.
  - Part 18.
  - Part 68.

FCC Rules Part 15

- States standards and requirements for RF devices, i.e. any device capable of emitting RF energy by radiation, conduction, or other means.
- Rf energy defined as any electromagnetic energy in the 10 kHz to 3 GHz range.
- Controls operation of low-power RF transmitters that do not require a license, e.g. garage door openers.
- Controls interference to RF communications services caused by other equipment that emits RF energy or noise, including digital electronics.

FCC Rules Part 18

- Specifies standards and operational conditions for industrial, scientific, and medical (ISM) equipment that uses RF for any purpose not intended for radio communications.

- ISM equipment includes medical diathermy equipment, industrial heating equipment, RF welders, RF lighting devices, and other non-communications devices.

FCC Rules Part 68

- Sets standards for equipment that connects to the telephone network
- Intended for the protection of the network from harm caused by equipment and its wiring.
- Harm to telephone network includes:
  - Electrical hazards to telephone company workers.
  - Damage to telephone company equipment.
  - Malfunction of telephone company billing equipment.
  - Degradation of telephone company services.
- Ensures compatibility of hearing aids and telephones.

FCC Part 15, Subpart J

- Written to control EMI generated by digital electronics.

- Places limits on radiated emission in the 30 MHz to 1 GHz band.
- Places limits on conducted emission on ac power lines in the 450 kHz to 30 MHz band.
- Regulations were result of increasing complaints of interference to radio and tv reception caused by digital electronics.

Interference from Computers

- Reported to interfere with almost all radio services, particularly those below 200 MHz, including:
  - Police radio.
  - Aeronautical radio.
  - Broadcast services.
- Contributing factors:
  - Prolification of digital equipment, particularly in the home.
  - Increasing computer speeds, causing EMI problems that didn't occur with slower computers.
  - Production economics which replace shielded steel cabinets with cheaper plastic cabinets.

FCC Definition of a Computing Device

- Any electronic device that generates and uses timing pulses in excess of 10,000 pulses per second and uses digital techniques.
- Why 10 kHz? Because harmonics extend to much higher frequencies.
- Two classes of devices.
  - Class A – Intended for commercial, industrial, or business use.
  - Class B – Intended for home use. More likely to be used close to radio and tv receivers. Limits are about 10 dB more restrictive than Class A devices.
- Devices cannot be legally advertised without the statement that *the device is subject to FCC rules and will comply with the rules prior to delivery*.
- Personal computers and peripherals must be FCC *certified* before they can be marketed.

Radiated Emission Certification Tests

- Must be made on a complete system with all cables connected.
- Figure 1-5 shows the test fixture for radiated emission tests.

- Tables 1-1 and 1-2, respectively, specify maximum class A and B emission limits.
- Figure 1-6 compares the Class A and B limits, where the Class A limits are extrapolated to a 3-m distance.
  - Class B limits are lower by about a factor of 3 (about 10 dB).

Conducted Emission Certification Tests

- Emissions conducted onto ac power lines and radiated from the lines are the primary cause of interference below 30 MHz
- Figure 1-7 shows the test fixture for conducted emissions
- Measurements must be made with a line impedance stabilization network (LISN) to isolate the EMI receiver from the ac line
- Table 1-3 specifies Class A and B conducted emission limits

International Harmonization

- CISPR formed in 1934 to determine limits on EMI
- Europe adopted the CISPR limits
- U.S. is a voting member of the CISPR and FCC has been pressured to adopt its limits

- Figures 1-8 and 1-9 compare the FCC and CISPR limits for radiated and conducted emissions.

Military Standards

- More stringent than FCC limits
- Cover 30 Hz to 40 GHz range
- Measurement techniques require shielded room, whereas FCC requires an open field
- Figure 1-10 summarizes the MIL-STD requirements

Typical Noise Path

- Figure 1-11 shows three necessary elements for a noise path
  - Noise source
  - Coupling channel
  - Receptor
- Three ways to break a noise path
  - Suppress the source
  - Desensitize the receiver
  - Eliminate transmission through the coupling channel

Example of a Noise Path

- Figure 1-12 illustrates a low-level circuit near a dc motor housed in a shield
- Sparks between the motor brushes and armature cause noise on the motor control lines
- Noise radiates to the low-level circuit
- Breaking the coupling channel is only option
  - Suppress noise conduction out of the shield
  - Suppress noise radiation from the leads

Use of Network Theory

- Solving Maxwell's equations for an exact analysis is difficult
- *Electric circuit analysis* is used to obtain approximate solutions
- Assumptions in analyzing a circuit
  - All electric fields are confined to the interior of capacitors
  - All magnetic fields are confined to the interior of inductors
  - Circuit dimensions are small compared to a wavelength. (At 300 MHz $\lambda \simeq 1$ m.)
- Noise coupling channels are modeled as equivalent

lumped component networks

Electric Field Coupling

- Figure 1-13 illustrates E-field coupling between a source and a grounded circuit
- Coupling channel modeled by a capacitor

Magnetic Field Coupling

- Figure 1-14 illustrates B-field coupling between a current carrying conductor and another conductor
- Coupling channel modeled by a transformer

Methods of Noise Coupling

- Conductive coupling – noise coupled on a conductor, e.g. power supply leads, ac power lines, etc.
- Common impedance coupling – when currents from two or more circuits flow through the same impedance.
- Figures 1-15 and 1-16 illustrate common impedance coupling
- Electric and magnetic field coupling
  - In the near field, E and H field coupling are treated separately
  - In the far field, coupling is treated as a plane wave

coupling

Miscellaneous Noise Sources

- Galvanic action
  - Contacts between dissimilar metals generate noise voltage in presence of moisture
  - Figure 1-17 illustrates how corrosion can occur which can cause failure
  - Minimized by using contact materials close to each other in galvanic series
  - Table 1-5 gives galvanic series
- Electrolytic action
  - Corrosive action between metal contacts cause by current flow. Can occur between identical metals in contact when moisture is present.
- Triboelectric effect
  - Noise cause by a charge that appears on dielectric surfaces when they are flexed
  - Flexing a cable can induce triboelectric noise
- Conductor Motion
  - Caused by wired moving through any magnetic field
  - Signal cables should be secured with cable clamps

Methods of Noise Reduction Covered in Course

- Shielding
- Grounding
- Balancing
- Filtering
- Isolation
- Separation and Orientation
- Circuit Impedance Level Control
- Cable Design
- Cancellation Techniques

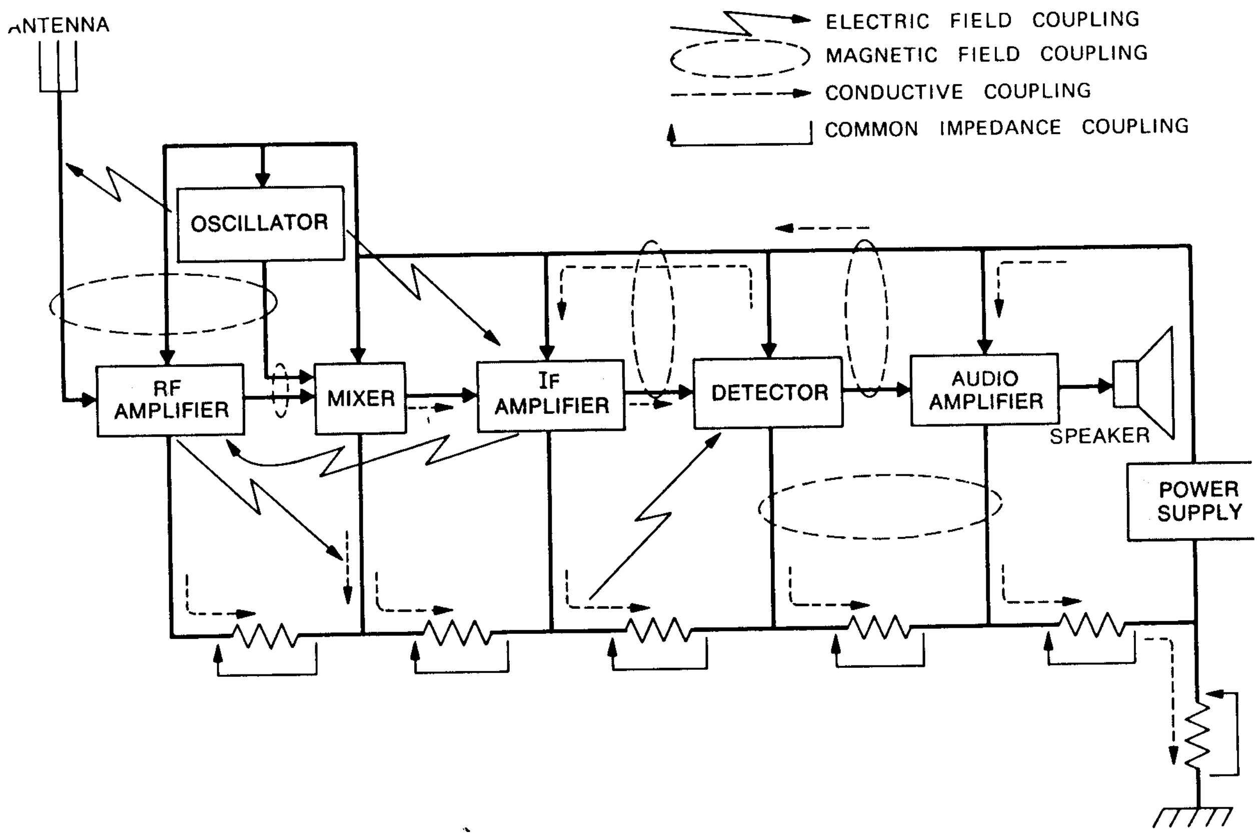

Figure 1-1. *Within equipment, such as this radio receiver, individual circuit elements can interfere with one another in several ways.*

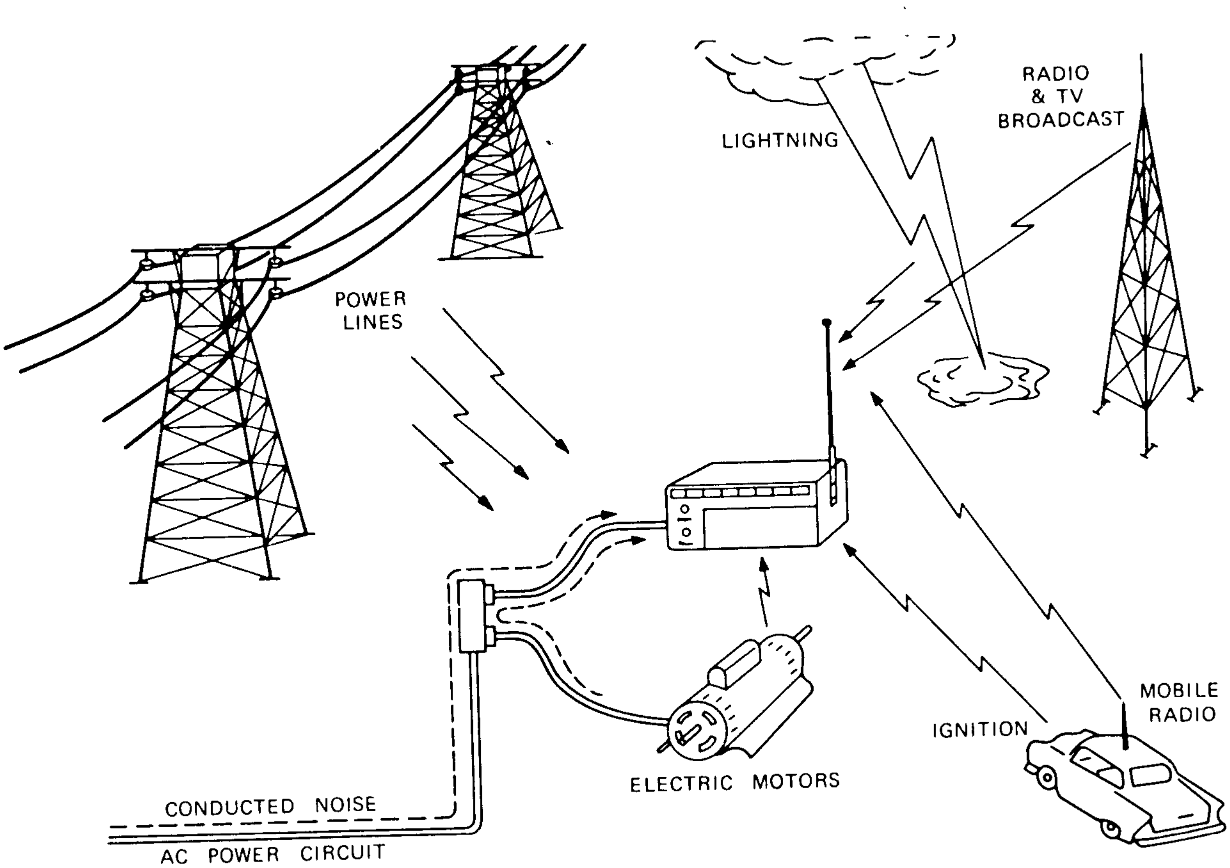

Figure 1-2. *Outside of the laboratory, electronic equipment such as this radio is subjected to a variety of electromagnetic noise sources. Careful design is required to guarantee compatibility with the environment.*

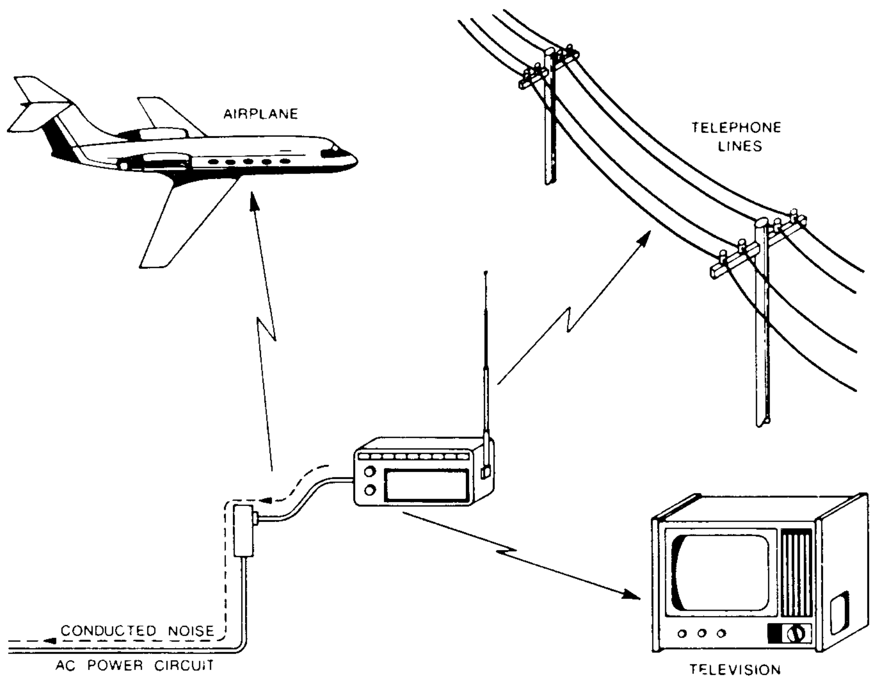

Figure 1-3. *Electronic equipment such as this radio can emit noise that may interfere with other circuits. Consideration of noise during equipment design can avoid these emissions.*

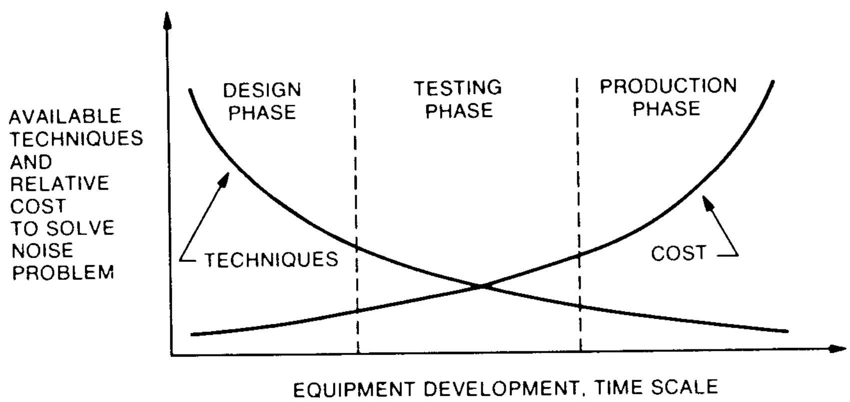

Figure 1-4. *As equipment development proceeds, the number of available noise-reduction techniques goes down. At the same time the cost of noise reduction goes up.*

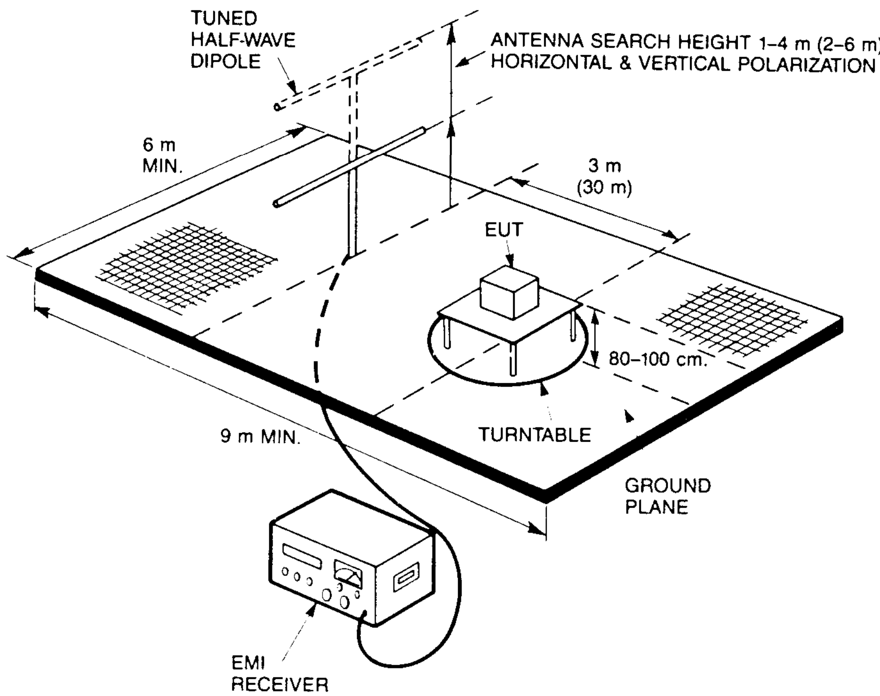

Figure 1-5. *Open field test site for FCC radiated emission test. Equipment under test (EUT) is on the turntable.*

Table 1-1 FCC Class A Radiated Emission Limits

Frequency (MHz)	Measuring Distance (m)	Field Strength (μV/m)
30–88	30	30
88–216	30	50
216–1000	30	70

Table 1-2 FCC Class B Radiated Emission Limits

Frequency (MHz)	Measuring Distance (m)	Field Strength (μV/m)
30–88	3	100
88–216	3	150
216–1000	3	200

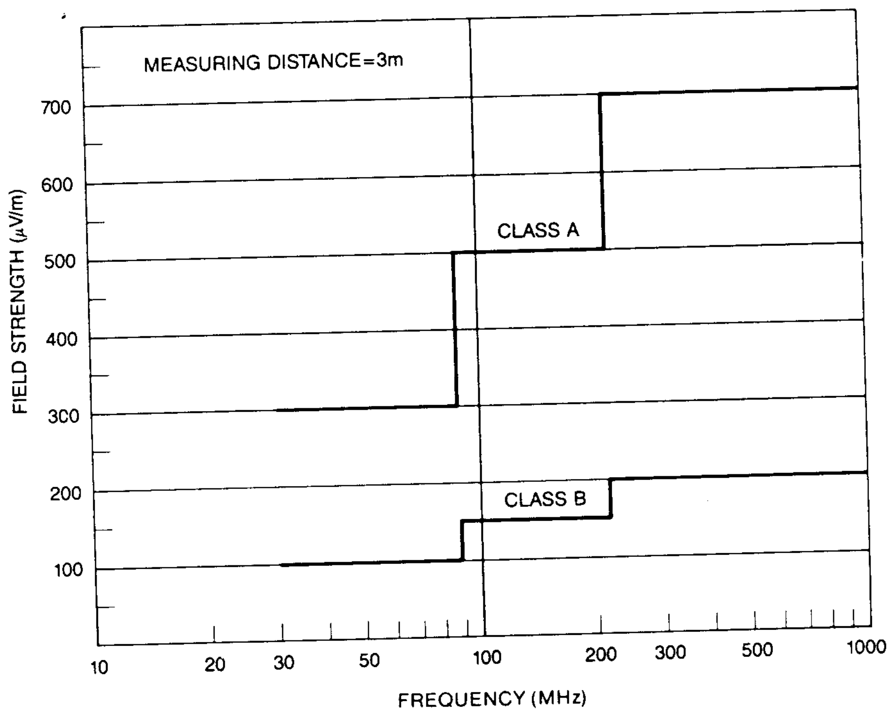

Figure 1-6. *FCC Part 15, Subpart J radiated emission limits measured at a distance of 3 m.*

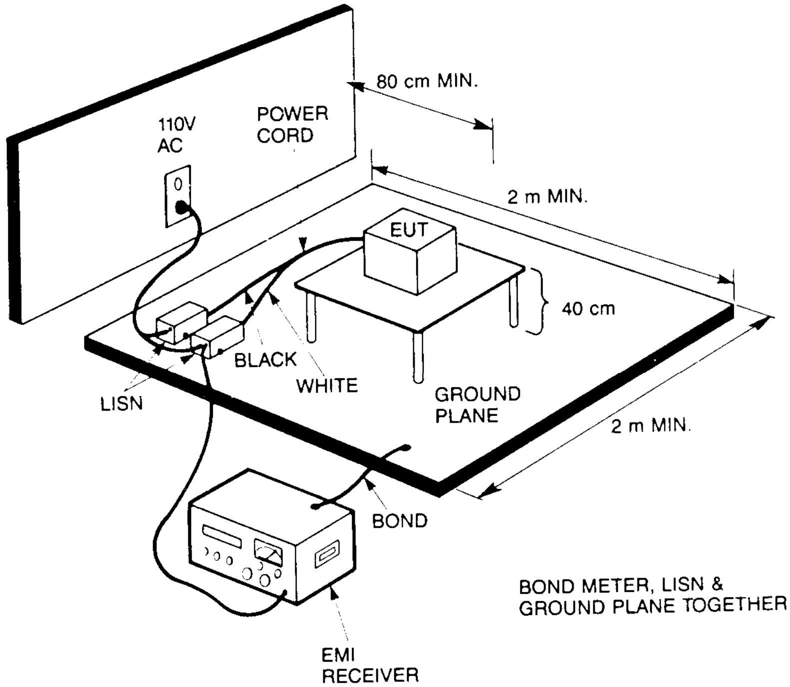

Figure 1-7. Test setup for FCC conducted emission measurements.

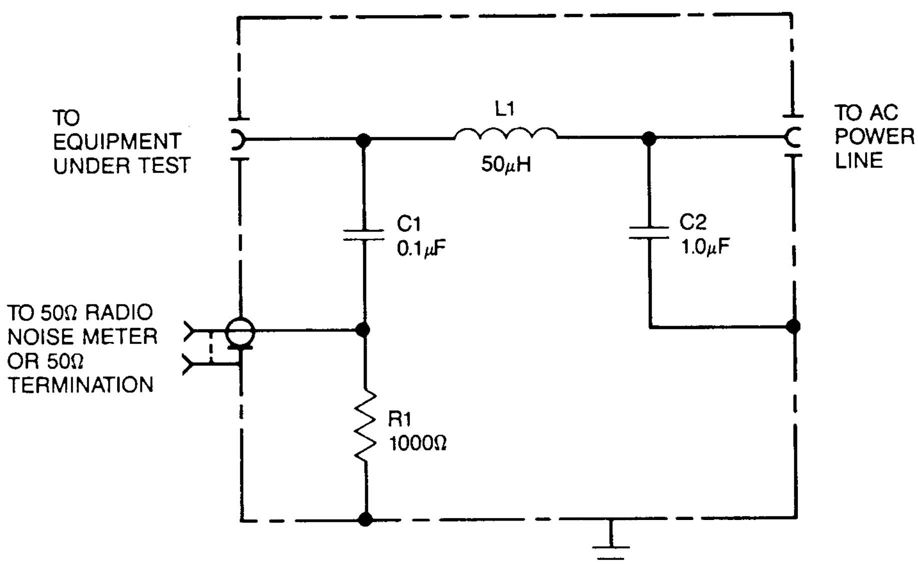

Figure F-4. *Circuit diagram of LISN to provide the impedance of Fig. F-2.*

Table 1-3 FCC Conducted Emission Limits

Frequency (MHz)	Class A (μV)	Class B (μV)
0.45–1.6	1000	250
1.6 –30	3000	250

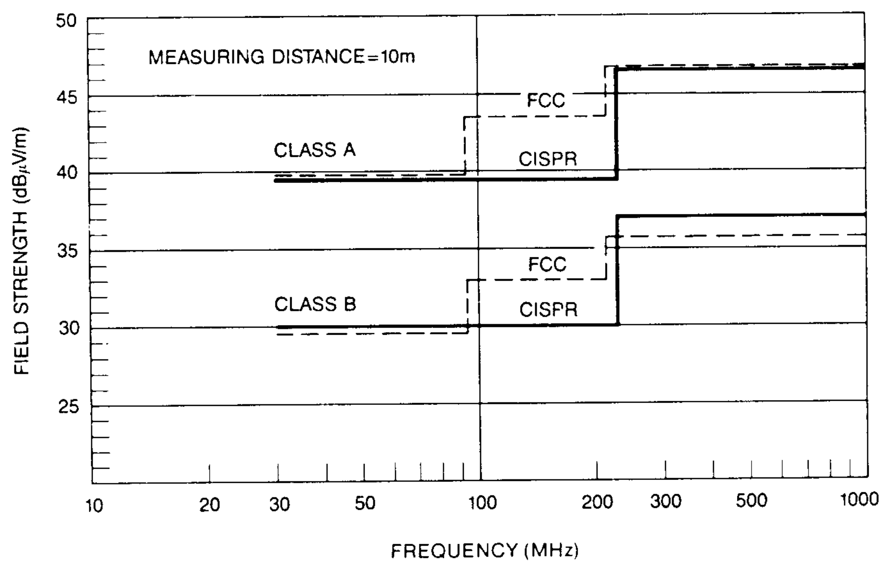

Figure 1-8. *FCC Part 15, Subpart J and CISPR, Publication 22, radiated emission limits measured at a distance of 10 m.*

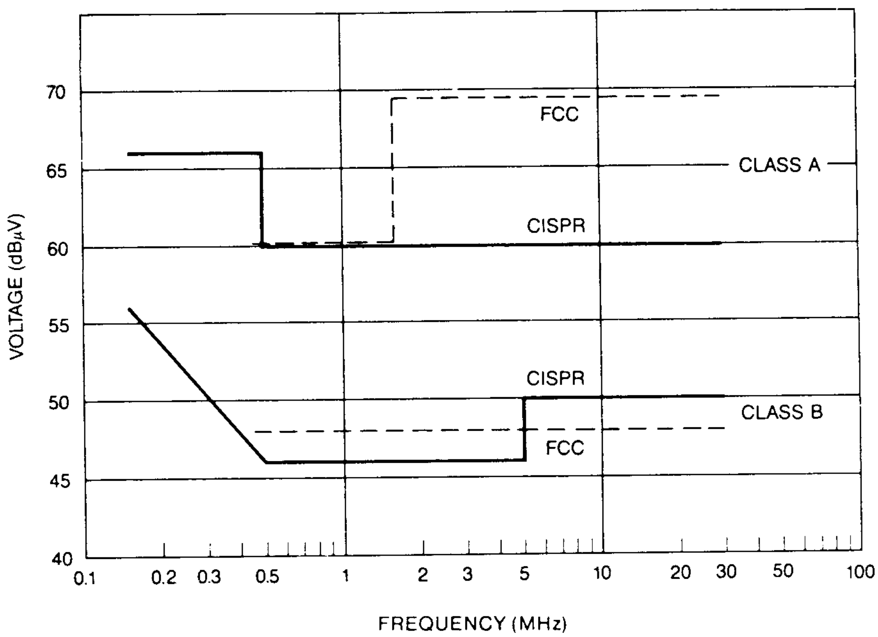

Figure 1-9. *FCC Part 15, Subpart J and CISPR, Publication 22, narrowband conducted emission limits.*

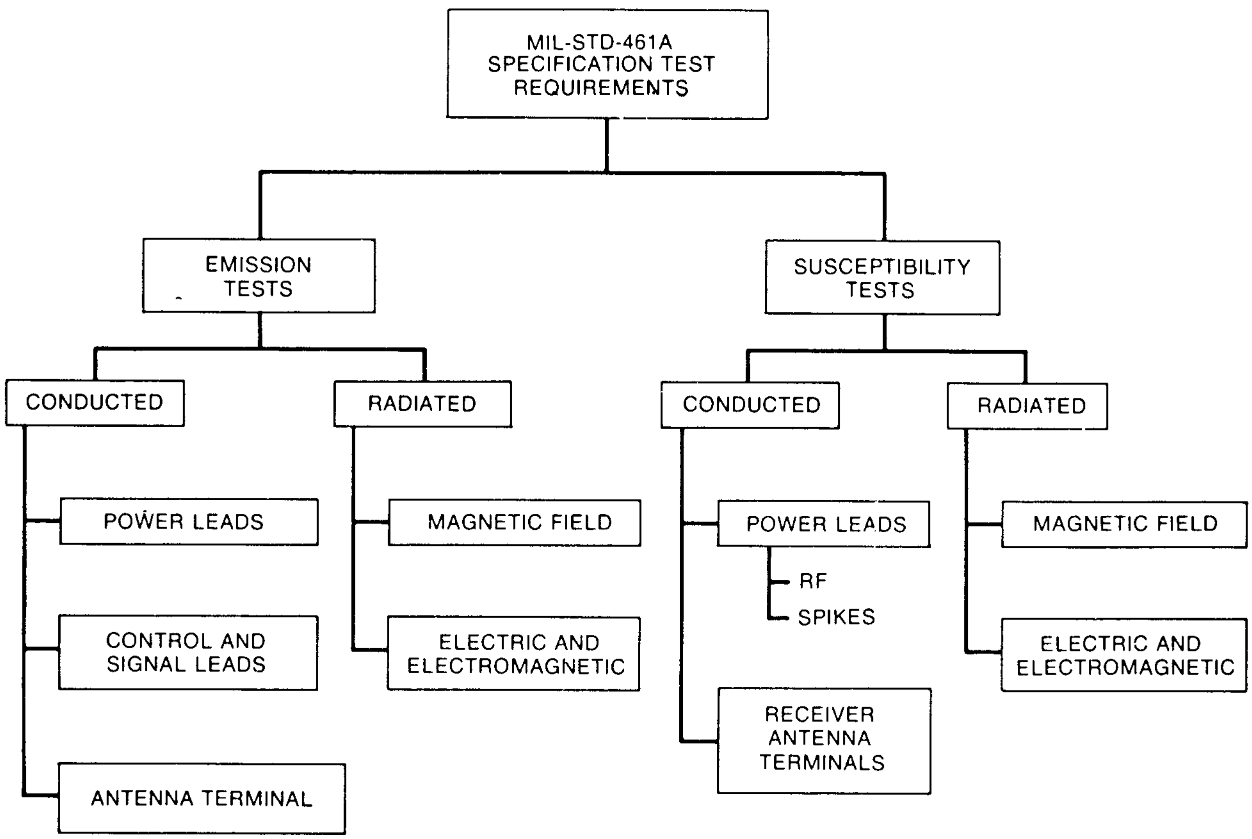

Figure 1-10. *Military specifications cover both the emission of noise and the susceptibility to it. In both cases tests of conducted and radiated noise are specified.*

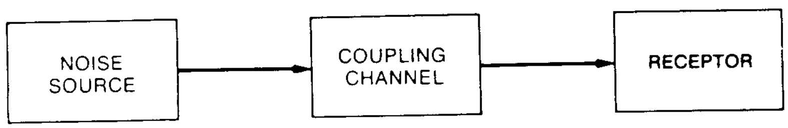

Figure 1-11. *Before noise can be a problem, there must be a noise source, a receptor that is susceptible to the noise, and a coupling channel that transmits the noise to the receptor.*

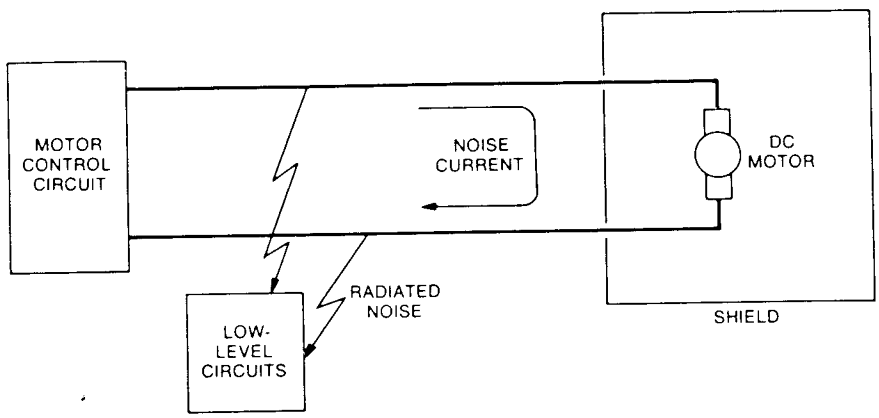

Figure 1-12. *In this example the noise source is the motor, and the receptor is the low-level circuit. The coupling channel consists of conduction on the motor supply leads and radiation from the leads.*

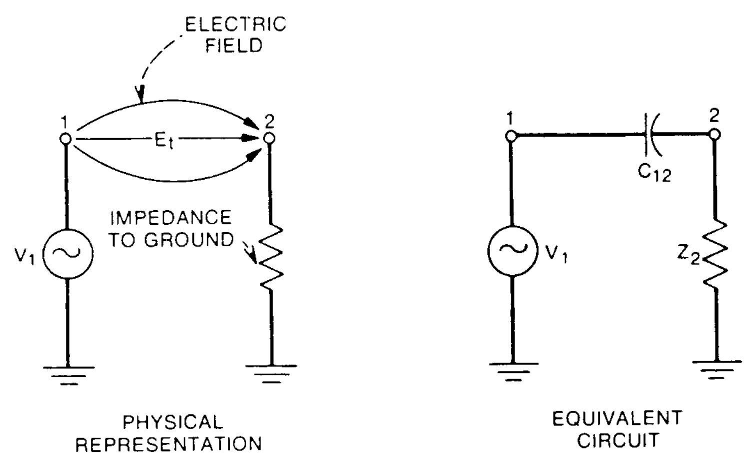

Figure 1-13. *When two circuits are coupled by an electric field, the coupling can be represented by a capacitor.*

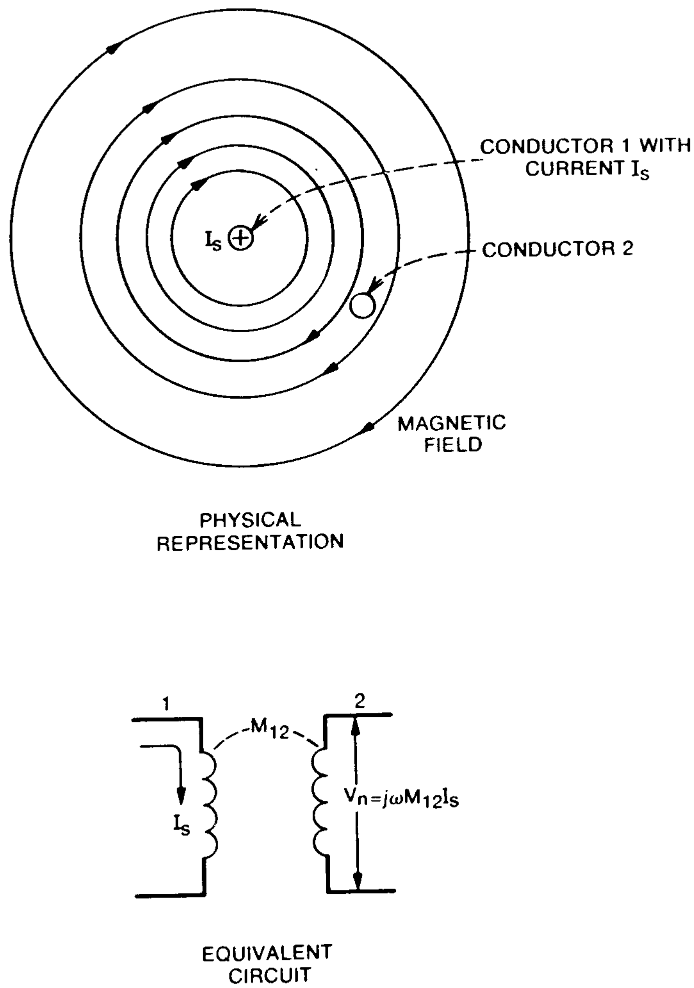

Figure 1-14. *When two circuits are coupled by a magnetic field, the coupling can be represented as a mutual inductance.*

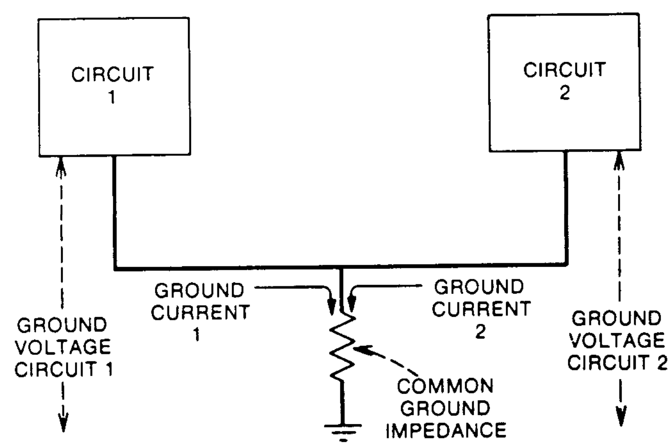

Figure 1-15. *When two circuits share a common ground, the ground voltage of each one is affected by the ground current of the other circuit.*

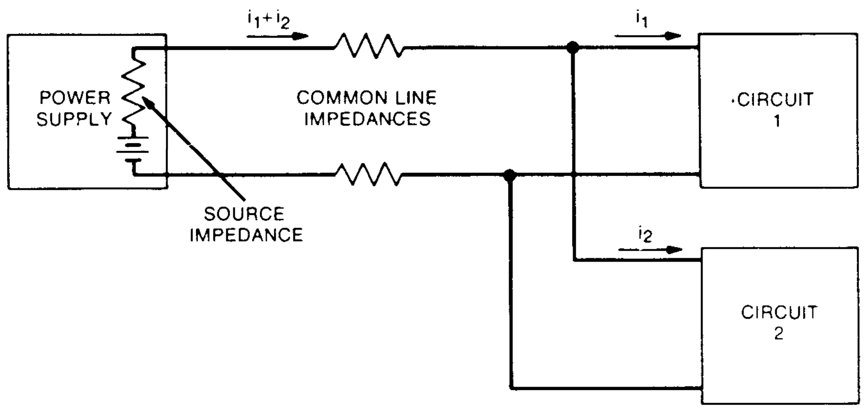

Figure 1-16. *When two circuits use a common power supply, current drawn by one circuit affects the voltage at the other circuit.*

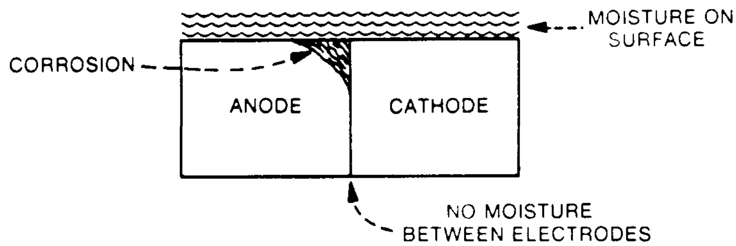

Figure 1-17. *Galvanic action can occur if two dissimilar metals are joined and moisture is present on the surface.*

Table 1-5 Galvanic Series

ANODIC END
(Most susceptible to corrosion)

Group I	1. Magnesium		13. Nickel (active)
			14. Brass
	2. Zinc		15. Copper
	3. Galvanized steel		16. Bronze
Group II	4. Aluminum 2S	Group IV	17. Copper-nickel alloy
	5. Cadmium		18. Monel
	6. Aluminum 17ST		19. Silver solder
			20. Nickel (passive)[a]
	7. Steel		21. Stainless steel (passive)[a]
	8. Iron		
Group III	9. Stainless steel (active)		22. Silver
	10. Lead-tin solder	Group V	23. Graphite
	11. Lead		24. Gold
	12. Tin		25. Platinum

CATHODIC END
(Least susceptible to corrosion)

[a]Passivation by immersion in a strongly oxidizing acidic solution.