Chapter 6
Grounding and Shielding

6.1 Outline of Grounding and Shielding

6.2 Noise ,Noise(Energy)Coupling Mechanism and prevention

6.3 Single point Grounding and ground loop

6.4 Filtering and smoothing

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6.9 General rules for design

Noise

- Noise is unwanted electrical activity coupled from one circuit to an other.
- 3 components:
  - A source
  - A coupling mechanism
  - A receiver

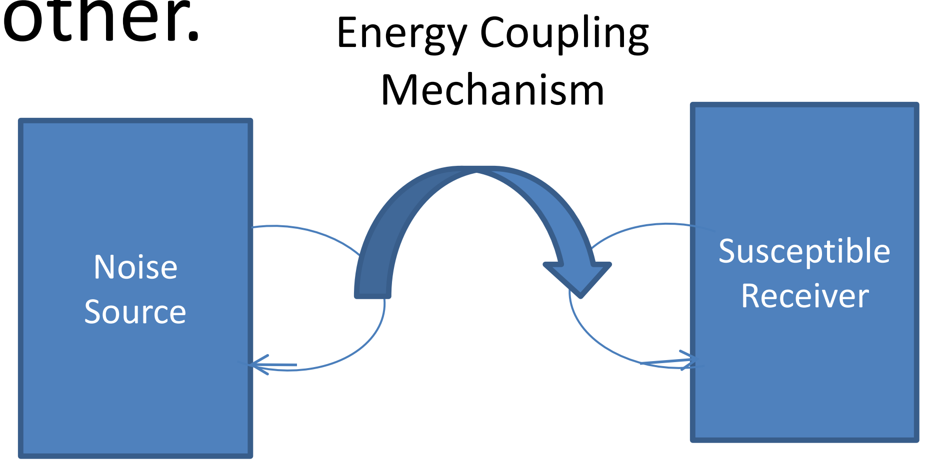


Fig. Block diagram of noise disrupting acircuit

Noise Sources

Noise sources generate either a periodic signal or transient pulse that disrupts other circuits.

Sources of noise: Power lines, Motors,

High voltage equipment (e.g. spark plug, igniter), Dischargers and sparks (e.g. lightning, static electricity), High current equipment (e.g. arc welder)

Energy Coupling Mechanism

Coupling Mechanism	Frequency Range	Comment
Conductive	DC to 10 MHz	Requires a complete circuit loop (really no upper limit to frequency)
Inductive	Usually> 3KHz	Larger loop area in circuit means greater self inductance and mutual inductance associated with heavy current (can get significant coupling from 50 Hz-60 Hz power).
Capacitive	Usually > 1 KHz	Greater spacing between conductors reduces coupling associated with high voltage (can get significant coupling from 50 Hz-60 Hz power).
Electromagnetic	Usually> 15 MHz	Needs antenna s greater than 1/20 of wave length in both the source and susceptible circuit.

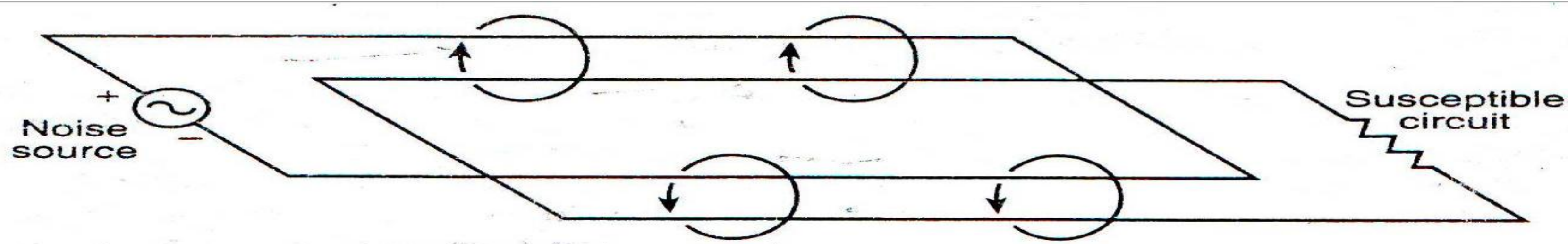


FIG. 6.6 Inductive coupling. Magnetic flux couples energy from the circuit of the noise source to the susceptible circuit.

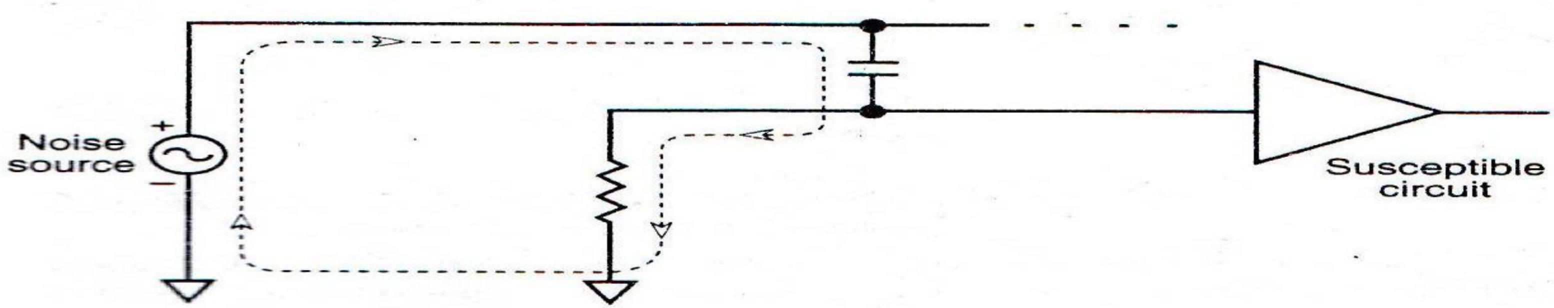


FIG. 6.7 Capacitive coupling. Coupling from stray capacitance completes the circuit of a noise source into a susceptible circuit.

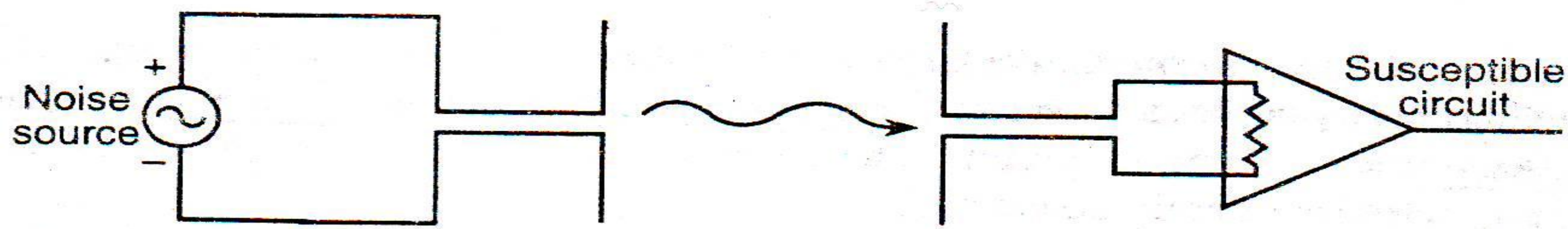


FIG. 6.8 Electromagnetic coupling. Radiated electromagnetic energy requires an antenna in both the noise and susceptible circuits. The antenna must be an appreciable portion of a wavelength, so such coupling is usually at high frequencies (> 15 MHz).

Susceptible Circuit

- Third component of noise is susceptible circuit.
- e.g. susceptibility include cross talk on inputs that leads to bit flips in digital logic, radio interference and static discharge that destroy components.
- Susceptibility can be traced by proper grounding and shielding.

Principle of Energy Coupling

- Current will flow in the path with low impedance.(frequencies > 3 KHZ or at audio range) $Z = \sqrt{(R^2 + |wL - 1/wc|^2)}$

- A Diagnostic ratio called Pseudo Impedance is used for frequencies above 3 KHZ.
- Pseudo Impedance is defined as

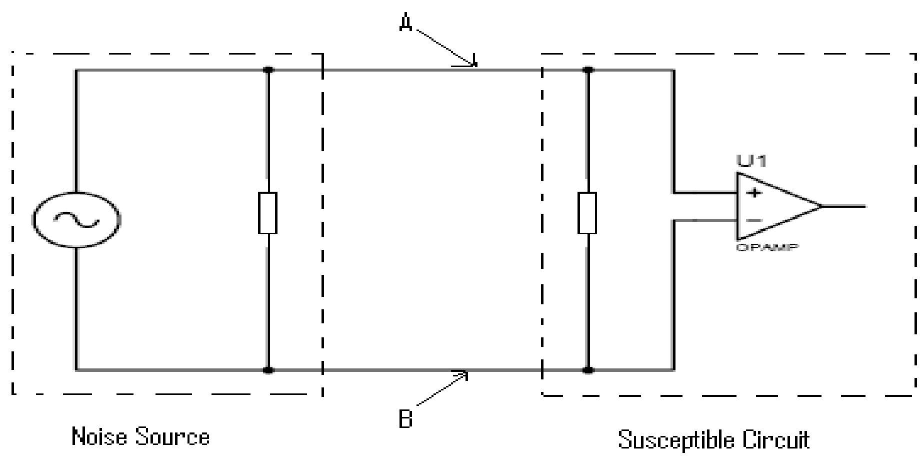
$$= (\mathrm{dv/dt})/(\mathrm{di/dt})$$

Pseudo impedance(γ)

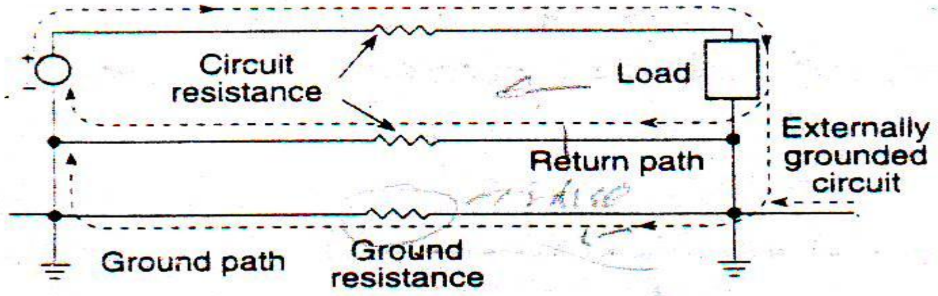
- If $\gamma=377$ Electromagnetic coupling
- If $\gamma< 377$,the value of di/dt > dv/dt so inductive coupling
- If $\gamma> 377$,the value of dv/dt > di/dt so capacitive coupling

Conductive Coupling

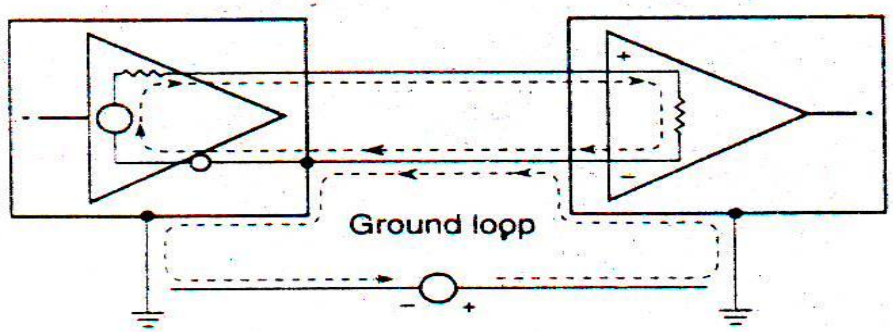
- Requires a connection between source and receiver that completes a continuous circuit.
- Conductive coupling usually occurs at lower frequencies and is often caused by incorrect grounding.
- Sneak circuit



- Fig: Conductive coupling. If either connection A or B is removed, the conductive noise is eliminated.



a



b

Fig. 6.10 A ground loop. Multiple ground connections can provide multiple return paths that cause significant current flow in the grounding structure, as shown in part (a). Ground potential causes currents in ground loops that unbalance circuits, as shown in part (b).

Inductive Coupling

- Inductive coupling mechanism requires a current loop that generates changing magnetic flux.
- A current transient creates the changing magnetic flux as: $\Phi = BA = \mu_0 nIA$

$$v = \frac{d\Phi}{dt} = A(\frac{dB}{dt}) = A\mu_0 n(\frac{di}{dt})$$

- The induced voltage in a magnetically coupled circuit is proportional to loop area and rate of change of current.

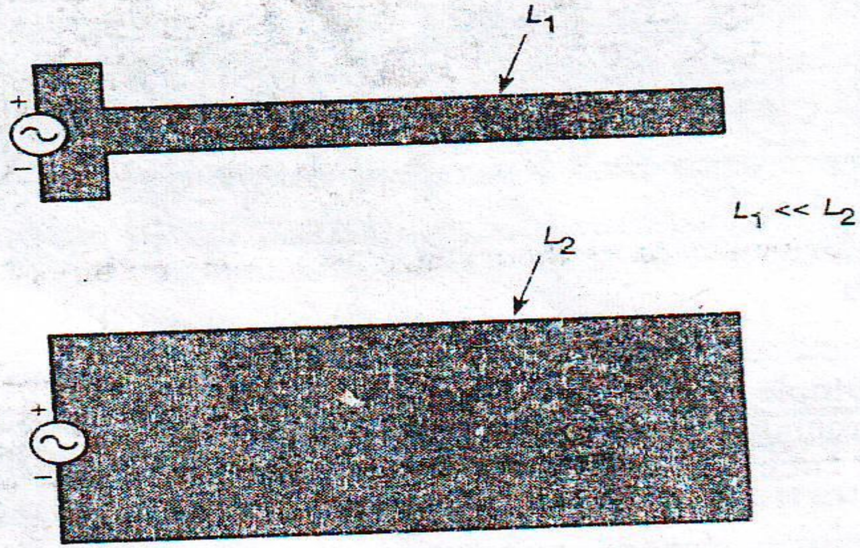


FIG. 6.11 Reducing loop area. Small loops of current have lower self-inductance and thus lower impedance.

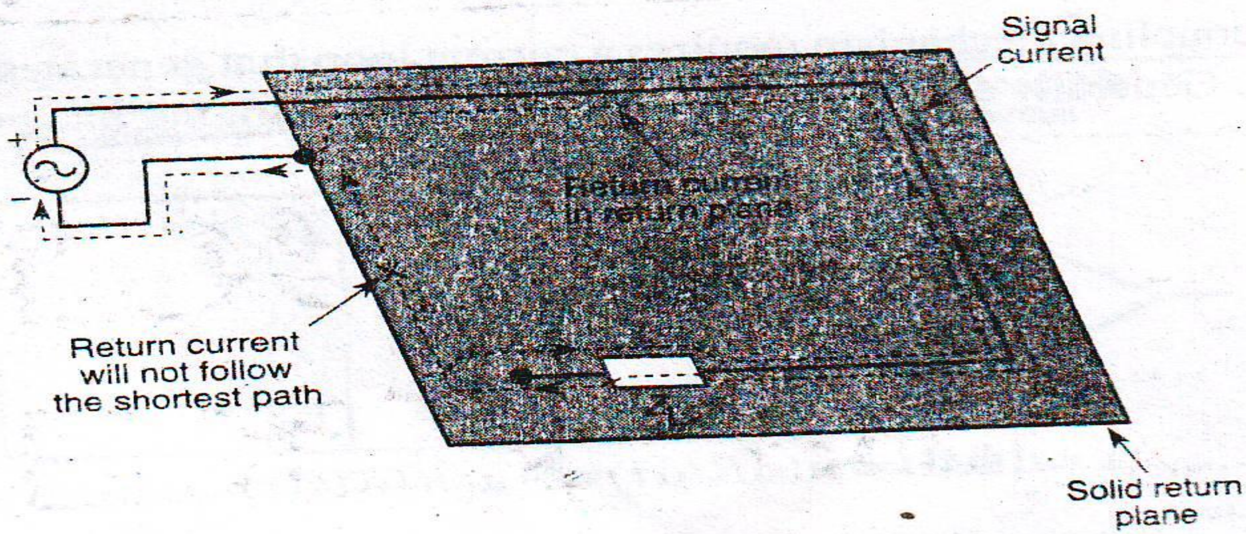


FIG. 6.12 Path of return current. Return current will follow the path of least impedance (in this case, the least self-inductance), not necessarily lowest resistance.

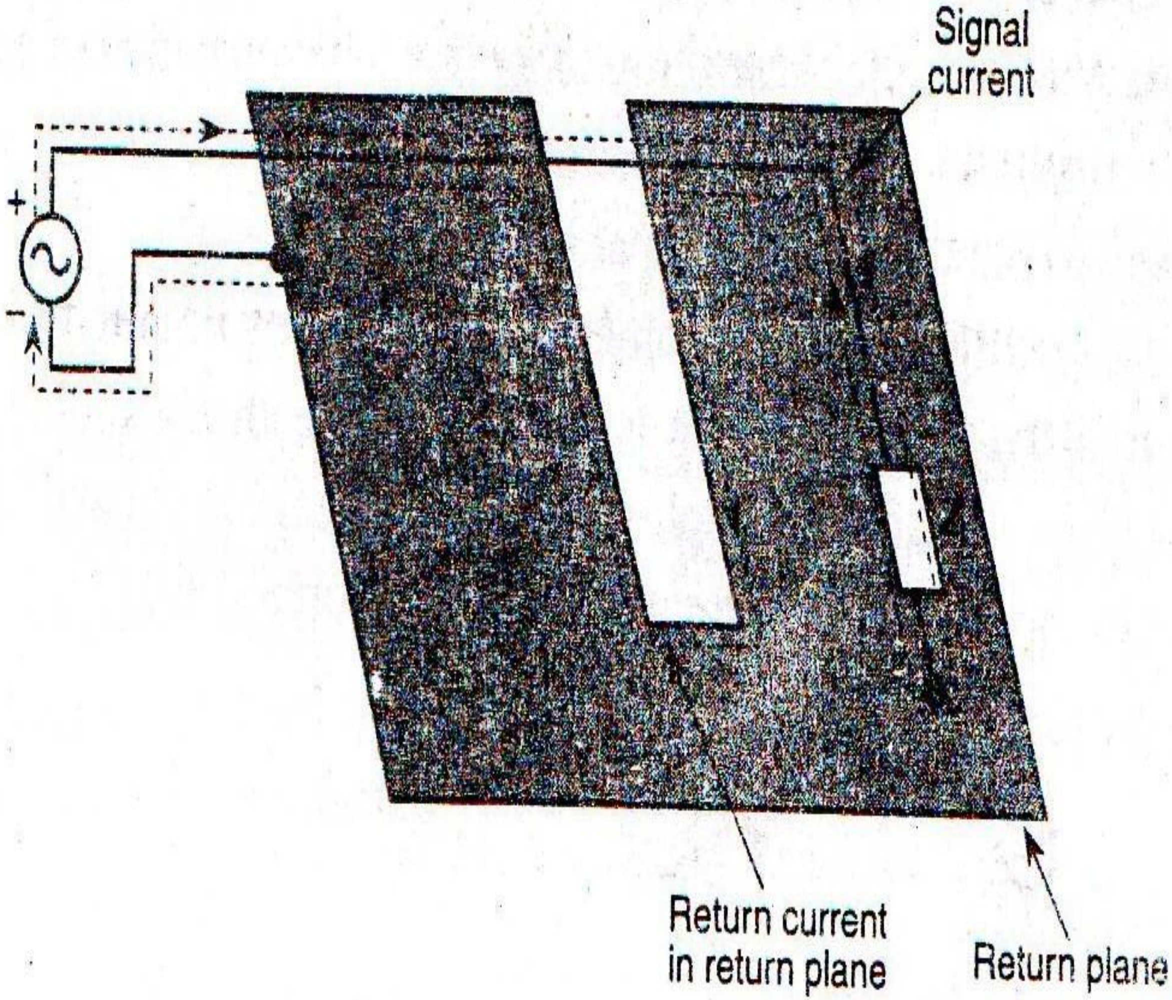


FIG. 6.13 A slot in the return plane increases the current loop area and the self-inductance.

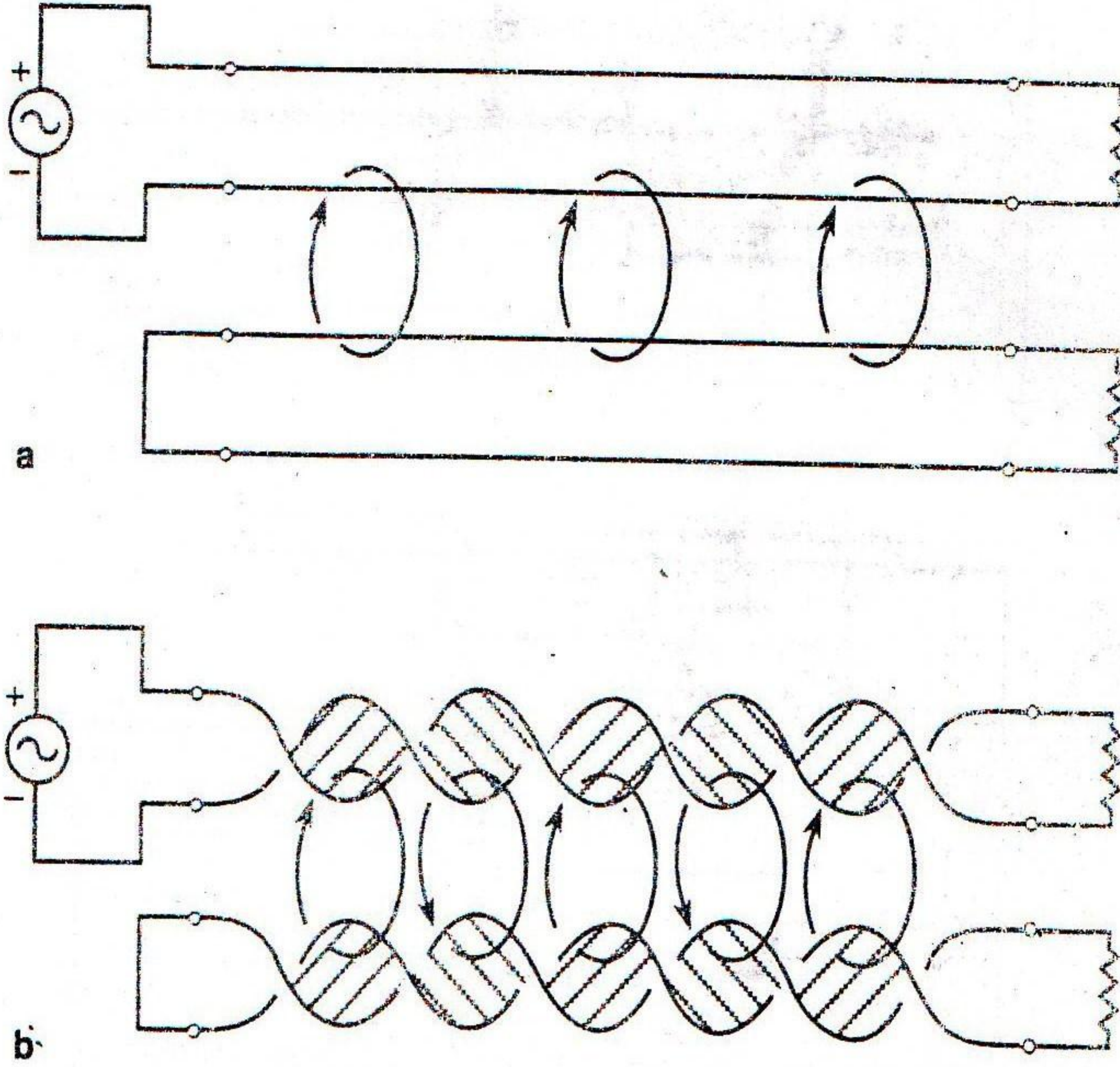


FIG. 6.14 Effect of twisted wire. (a) Straight wires create small loops that can couple magnetically. (b) Twisted wire eliminates the effective loop area of cables and magnetic coupling.

Capacitive Coupling

- Capacitive coupling mechanism requires both proximity between circuits and a changing voltage.
- It occurs when two conductors are placed at some distance apart and voltage level and frequency are changed.
- Capacitive coupling of noise becomes a factor for frequency above 1 KHz
- Capacitive coupling can be reduced with separation of conductors and approiate shielding.

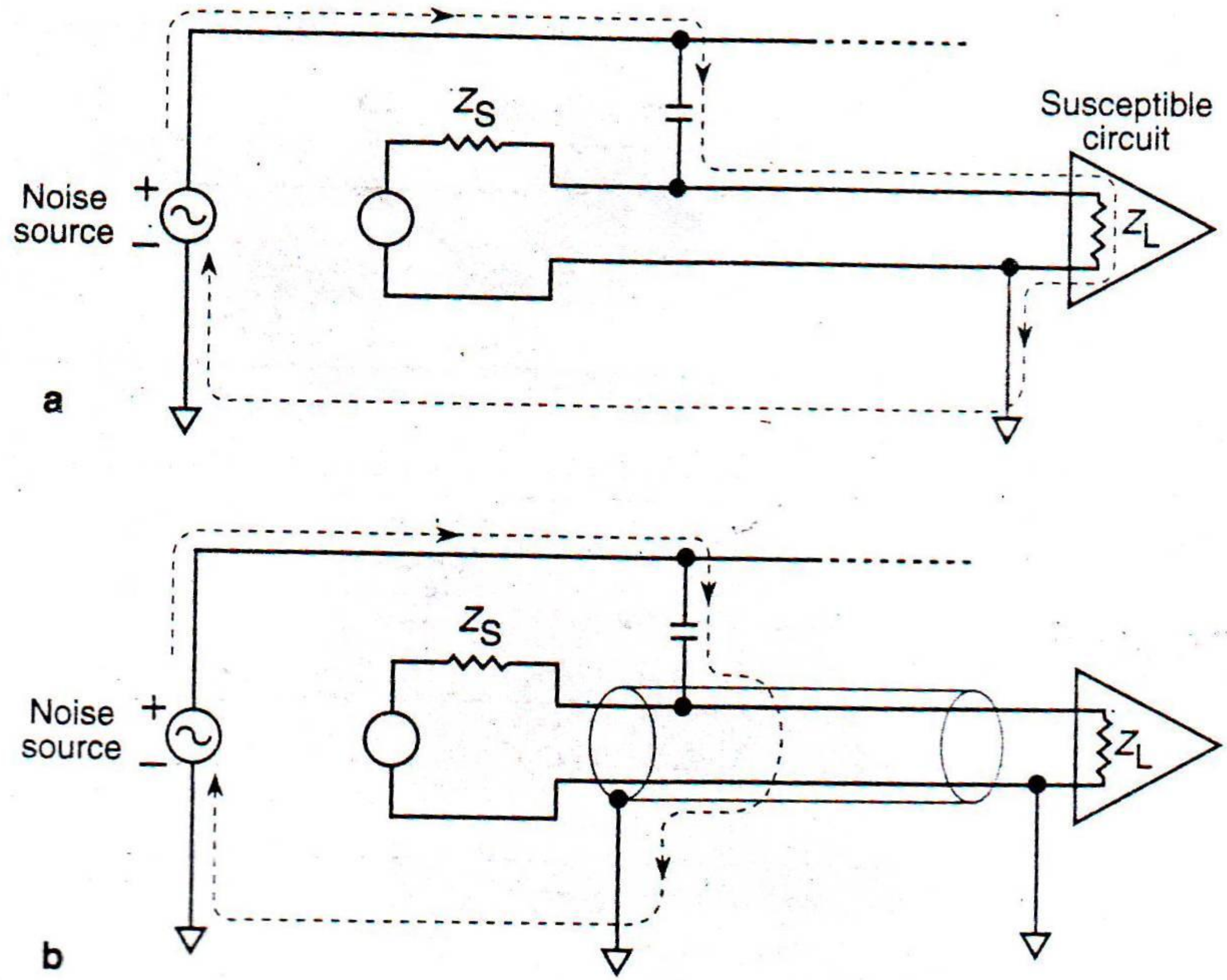


FIG. 6.15 Effect of shielding. (a) Without the shield, stray currents can disrupt susceptible circuits. (b) A properly connected shield can divert capacitively coupled current from susceptible circuits.

Electromagnetic Coupling

- Electromagnetic coupling becomes a factor only when the frequency of operation exceeds 20 MHz.
- <200 MHz, cables are sources and receivers and > 200 MHz, PCB traces acts like that.
- Generally length of signal conductors must be longer than 5% i.e. $l > \lambda/20$
- The frequency of signal must be reduced.

Review This

Examples on Noise coupling Mechanism

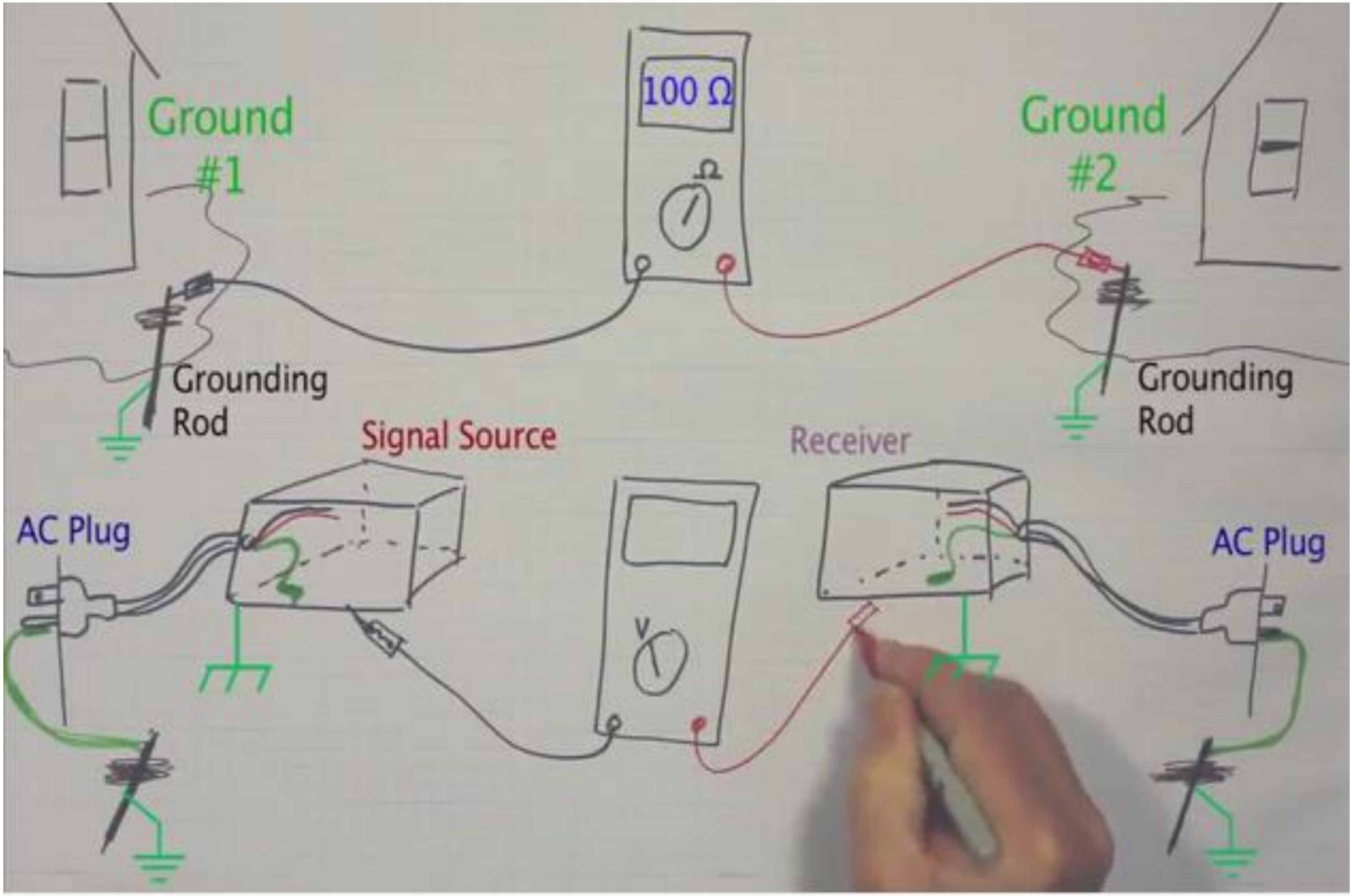
- P.N.188,216 ,Fowler

Grounding

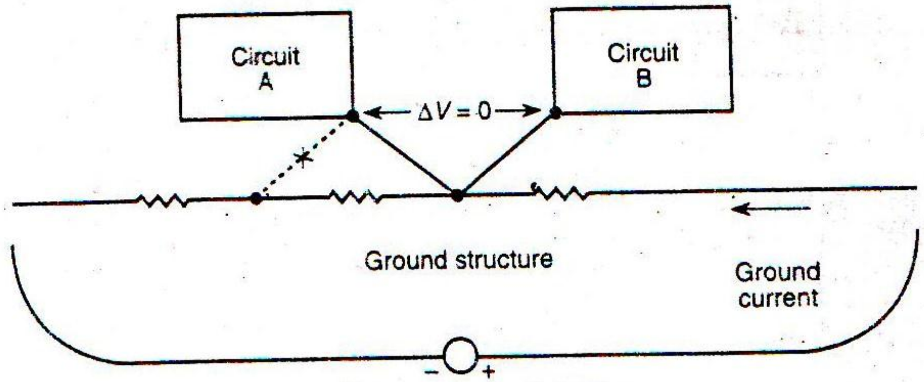
- Grounding provides safety and signal reference
- General principle is to minimize the voltage differential between your instrument and a reference point i.e. $\Delta V = 0$ between instruments.
- Use the return conductors as a signal reference.

Table 6.2 Ground and return symbols

Symbol	Function	Application
	Safety ground	A connection to an electrical ground structure like building steel or an isolated ground wire
	Signal ground	A connection to a chassis that does not normally conduct current
	Signal return	A conductor that sustains return current for signal or power



100 Ω
Ground
#1
Ground
#2
Ω
Grounding
Rod
Grounding
Rod
Signal Source
Receiver
AC Plug
AC Plug
V



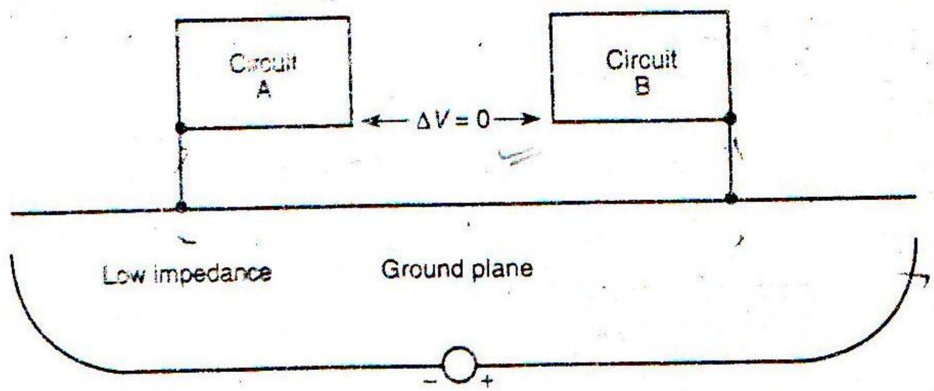


FIG. 6.16 Two grounding configurations. [For safety and for signal reference, reduce the potential difference between the ground connections of circuit, instrument, or chassis.] (a) Single-point ground. (b) Multipoint ground with low-impedance ground structure.

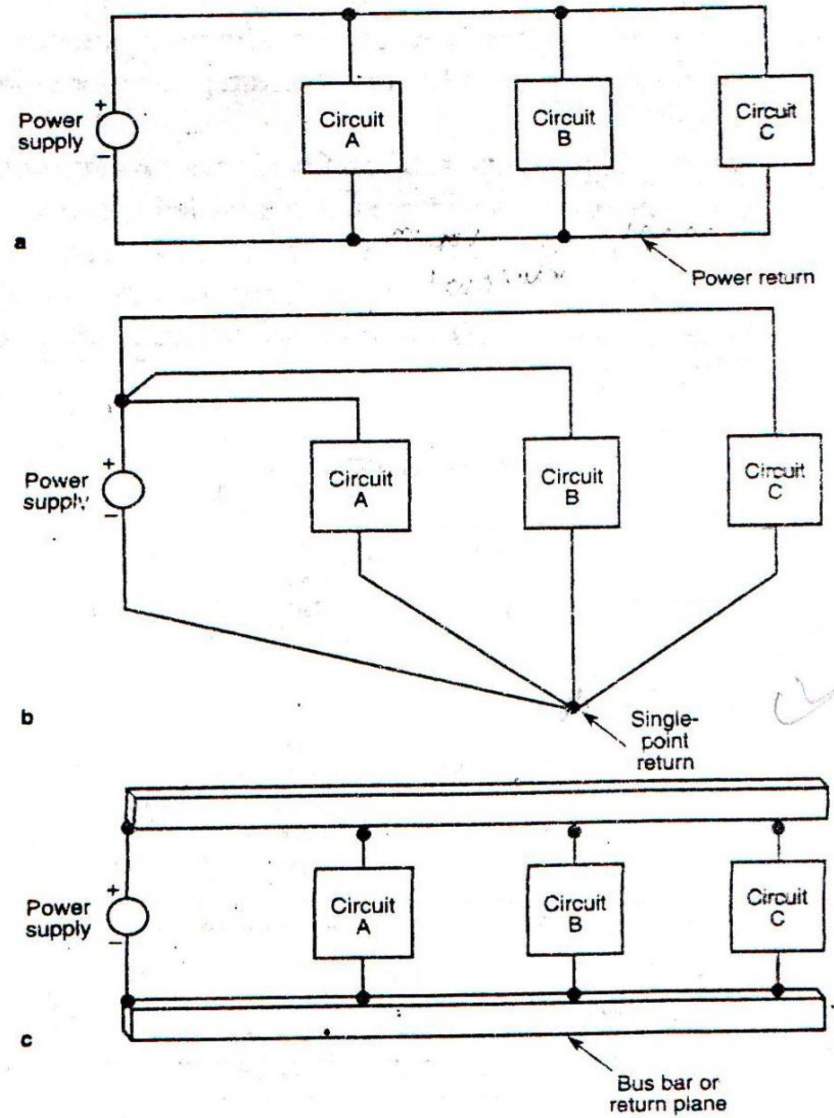


FIG. 6.17 Three return configurations. (a) Series return connection. (b) Single-point return. (c) Multipoint return.

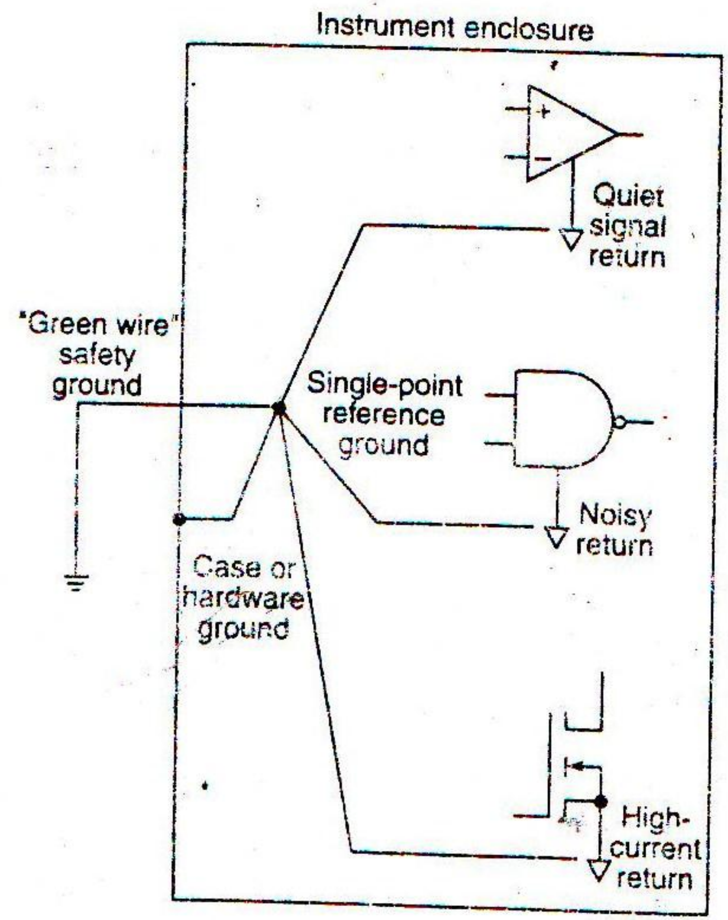


FIG. 6.18 Single-point grounding. Connecting grounds to returns in parallel and then to a single point isolates noise within an instrument. The ground conductors should not carry significant current; that is the function of the return conductors.

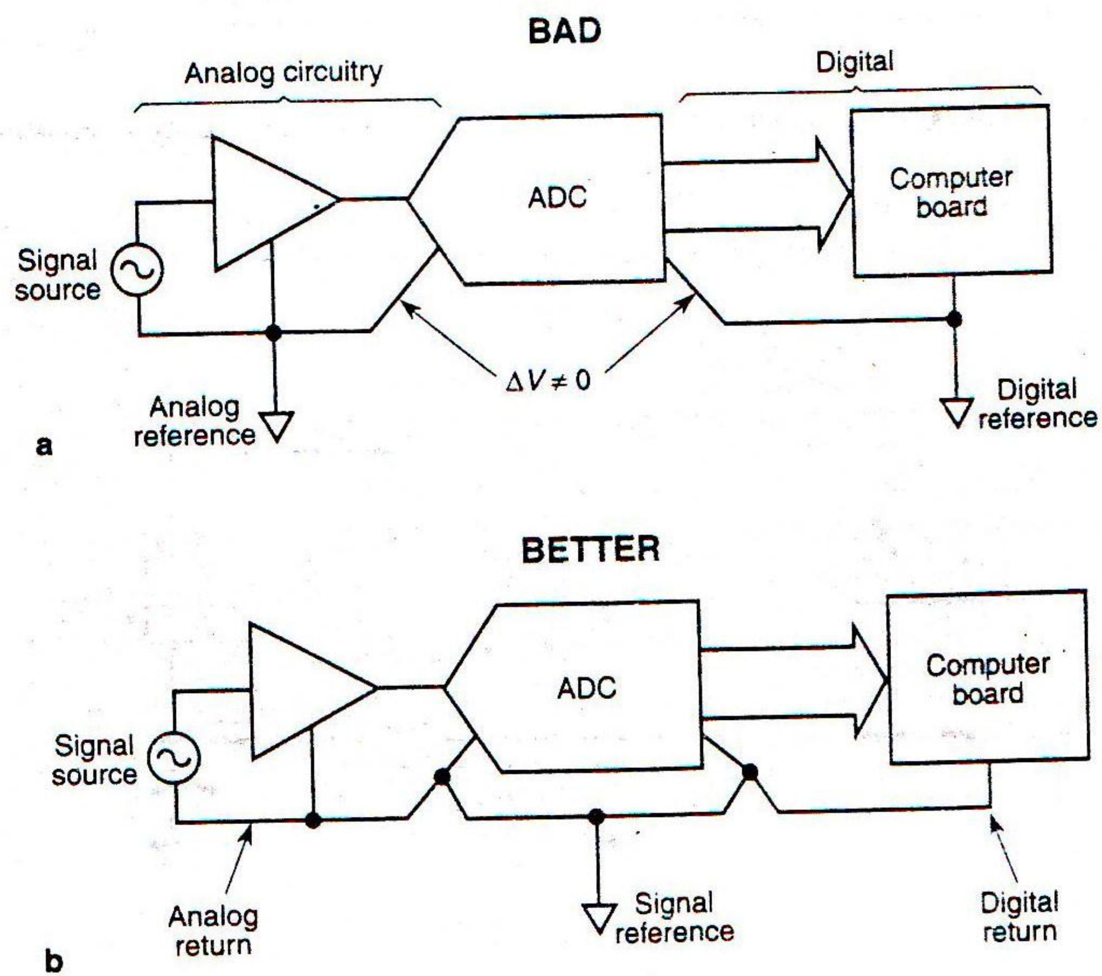


FIG. 6.19 Reducing noise from the signal reference. Tie the analog and digital references together near the ADC. (a) Separate references can lead to large loops of current. (b) A single-point reference eliminates large loops; usually an uninterrupted ground plane suffices.

1.Filtering

- Filtering reduce conductive noise coupling, a filter can either block or pass energy by three criteria:
  - Frequency
  - Mode (common or differential)
  - Amplitude (surge suppression)

Minimize bandwidth

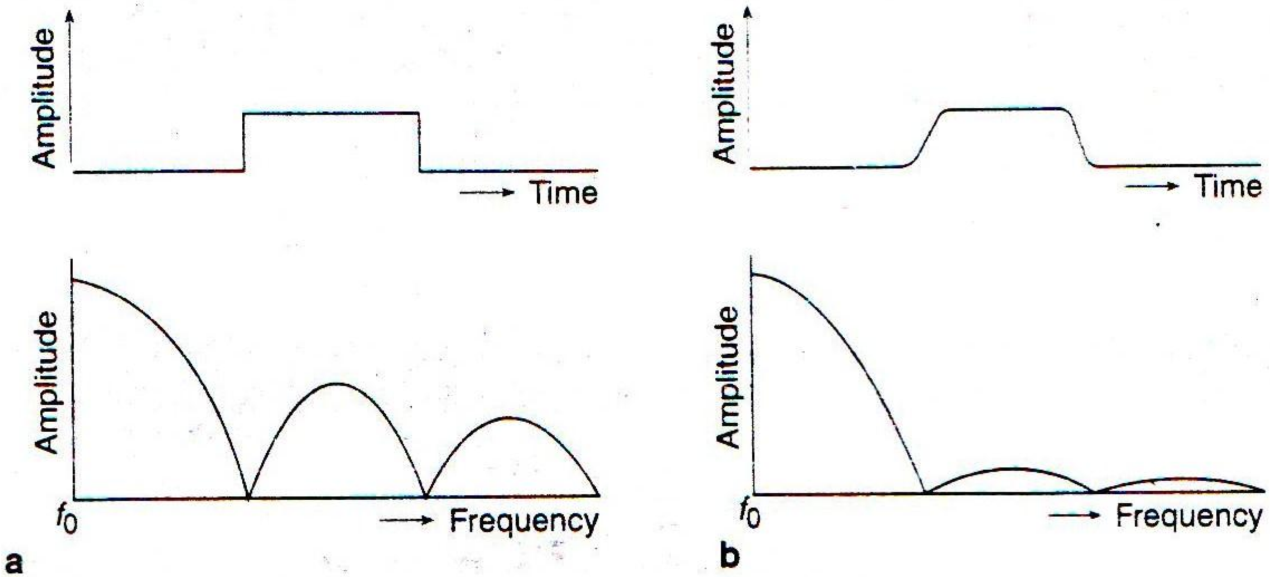


FIG. 6.26 Spectral content of square and rounded pulses. The faster the rise time on a pulse edge, th greater the amplitudes of the harmonics and the greater the potential for noise coupling. (a) Faste edges create greater harmonics. (b) Slower edges reduce the harmonic content.

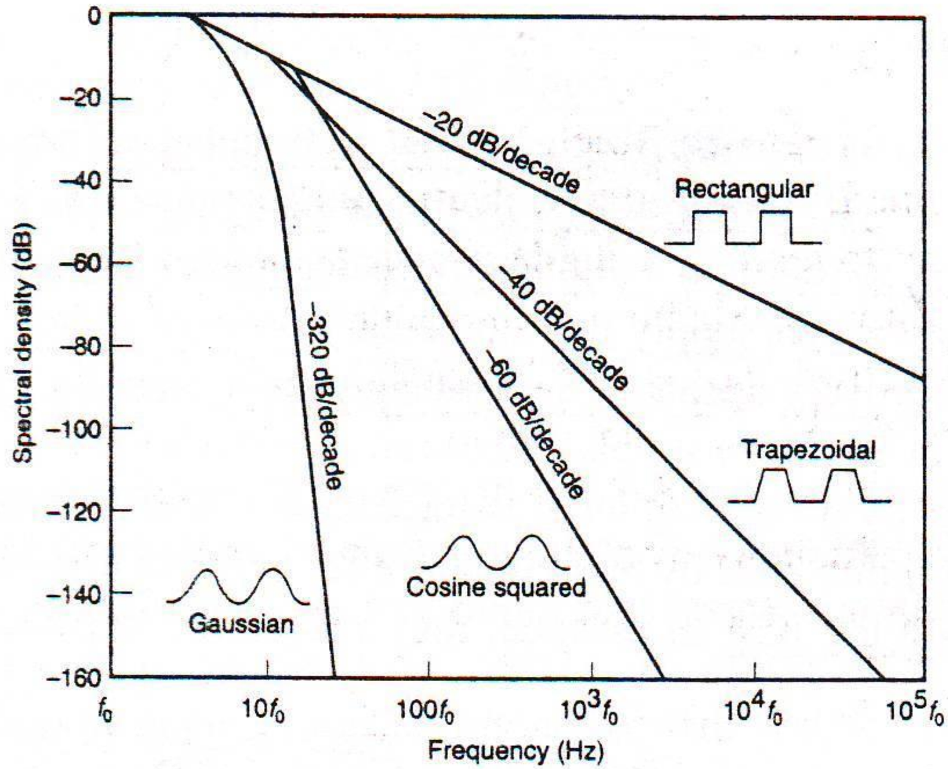


FIG. 6.27 Spectral content of pulse shapes. Pulse shape defines the harmonic content of a signal and its potential for radiating electromagnetic interference. f_0 = fundamental frequency. (Adapted from Brewer, 1991.)

Ferrite beads

- A **ferrite bead** is a passive electric component used to suppress high frequency noise in electronic circuits.
- It is a specific type of electronic choke. Ferrite beads employ the mechanism of high dissipation of high frequency currents in a ferrite to build high frequency noise suppression devices.
- The ferrite bead is effectively an inductor with a very small Q factor.
- For a simple ferrite ring, the wire is simply wrapped around the core through the center typically 5 or 7 times. Clamp-on cores are also available, which can be attached without wrapping the wire at all.

- It is a magnetically permeable sleeve that fits around a wire.
- It presents inductive impedance to signals that attenuates high frequencies.
- Best suited to filter low level signals and low current power feeds to circuit boards.

Decoupling and Bypass Capacitors

- They provide Filtering based on frequency
- They filter and smooth out the spikes in DC power of ICs
- Inductance in the power supply accentuate the effect of switching current transients by producing large voltage spikes.
- Mitigate the effect of inductance by reducing effective loop area between Power supply and the ICs.
- Reduce impedance of power supply

  $Z_0 \approx 0\Omega = \sqrt{R^2 + [\omega L - (1/\omega C)]^2}$

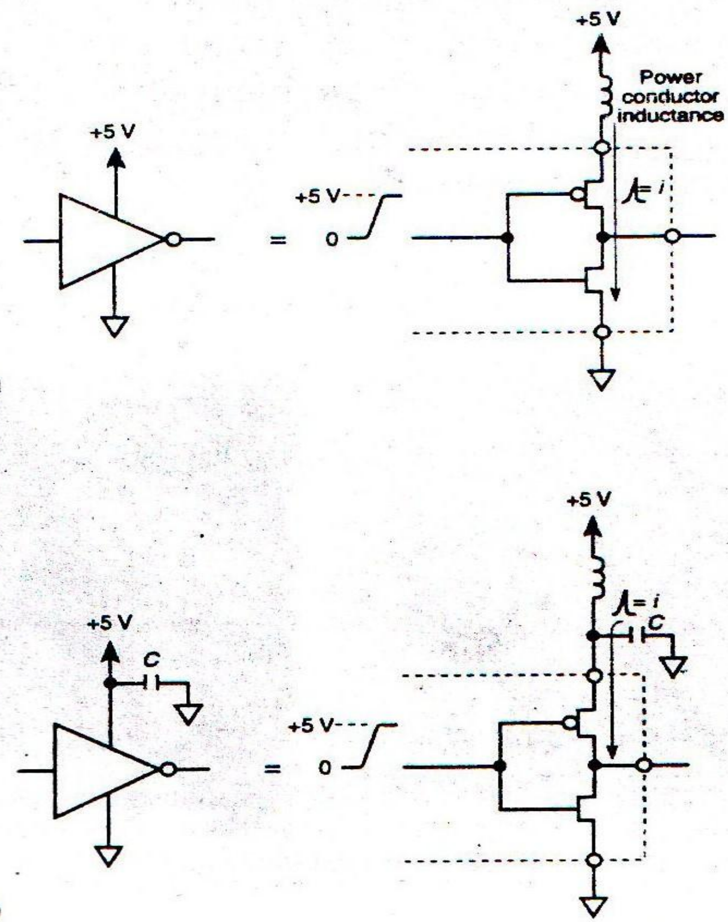


FIG. 6.29 Decoupling, or bypass, capacitors. They filter current transients when transistors switch within a digital logic gate. (a) As input voltage changes logic level, both transistors turn on, momentarily producing a short circuit and drawing a current pulse from the DC power source. (b) A decoupling capacitor can supply the current pulse and reduce the transient propagated through the DC power supply.

2. Shielding

- Prevents noise energy coupling
  - Magnetic flux – inductive shielding
  - Electric field – capacitive shielding
  - Electromagnetic wave propagation – electromagnetic shielding

Inductive Shielding

- Self inductance
- Mutual inductance
- Reduce or reroute magnetic flux
- Magnetic noise depends on loop area and current in the emitting and receiving circuits
- Minimize loop area, separate circuits, reduce current change
- Coaxial cable minimal loop
- Twisting signal and return conductors

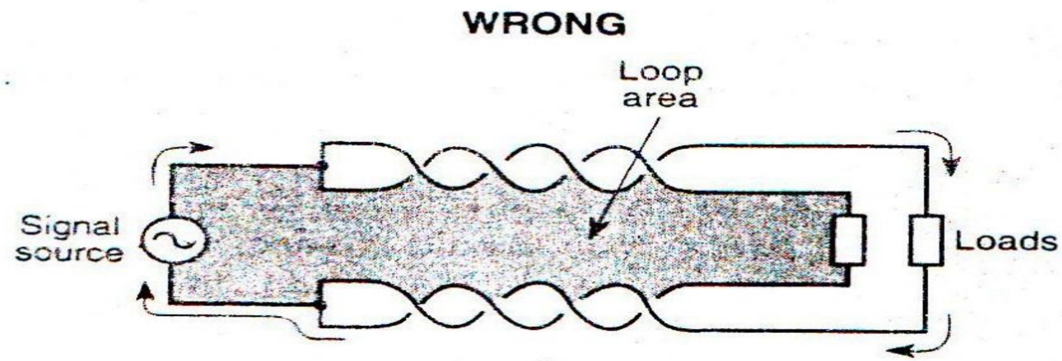


FIG. 6.32 Incorrect application of twisted-pair wire. A large loop area still exists.

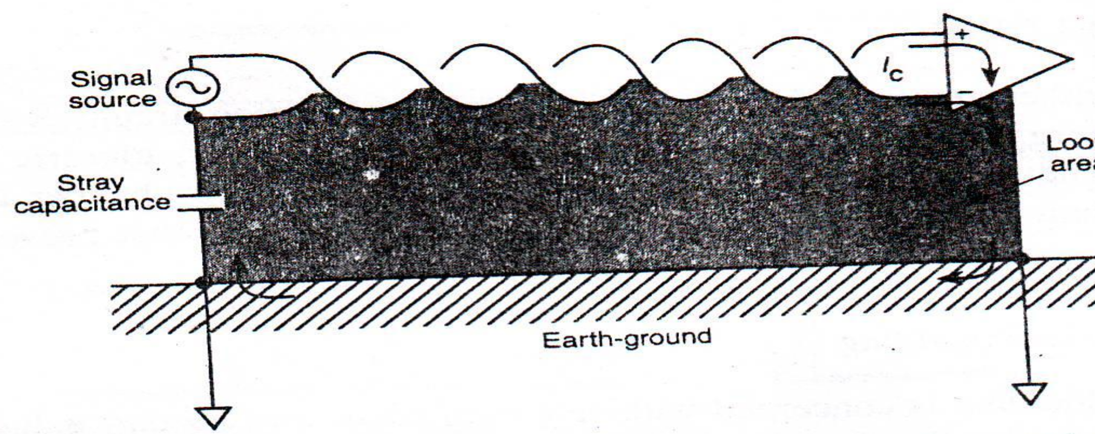


FIG. 6.33 Twisted-pair cable. Twisting the wire and running it close to the ground will reduce the common-mode current, I_C, by reducing the loop area for inductive coupling.

Capacitive Shielding

- Reduce or reroute electrical charge
- Capacitive coupling provides a path for the injection of noise charges

- Reduce :
  - Noise voltage and frequency
  - Signal impedance
  - Floating metal surfaces

- Faraday shield
- Shielded transformer

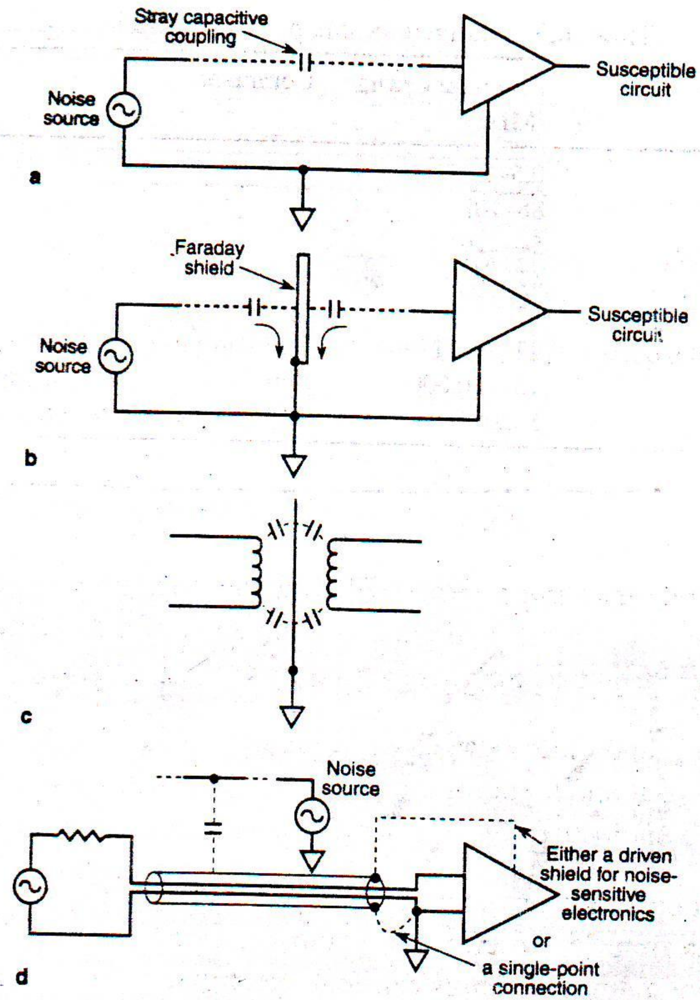


Fig. 6.34 Capacitive shielding. Capacitive coupling provides a path for the injection of noise charges, while an appropriately placed shield prevents the coupling between circuits by shunting charge to ground. (a) Outline of capacitive coupling. (b) Proper placement of a shield to shunt noise charge. (c) A shielded transformer prevents capacitive coupling between windings. (d) A cable shield usually should be connected at only one place to prevent coupling or shunt charge.

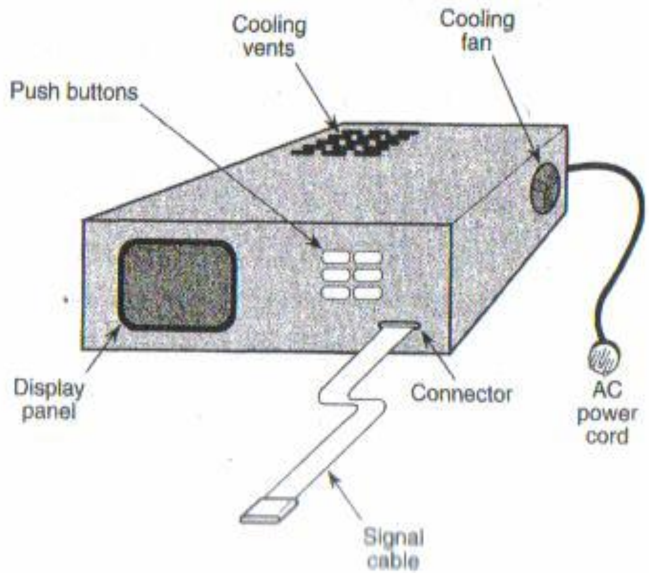
Electromagnetic Shielding

- Reduce emissions
- Emission sources:
  - Lightning
  - Discharges
  - Radio and TV transmitters
  - High-frequency circuits

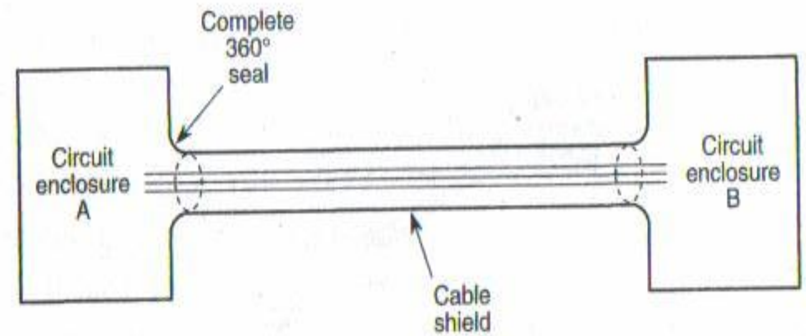
- Electromagnetic interference (EMI)
- Begins conductive
- Becomes radioactive
- Ends conductive
- Reduce EMI
  - Reduced bandwidth
  - Good layout
  - Shielded enclosures

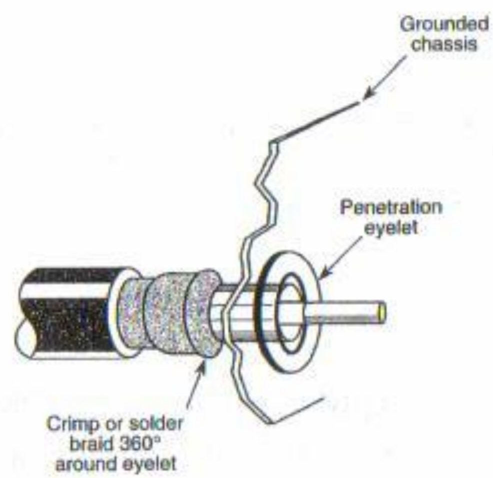
Electromagnetic Shielding (2)

Shielded enclosure



Cable shield





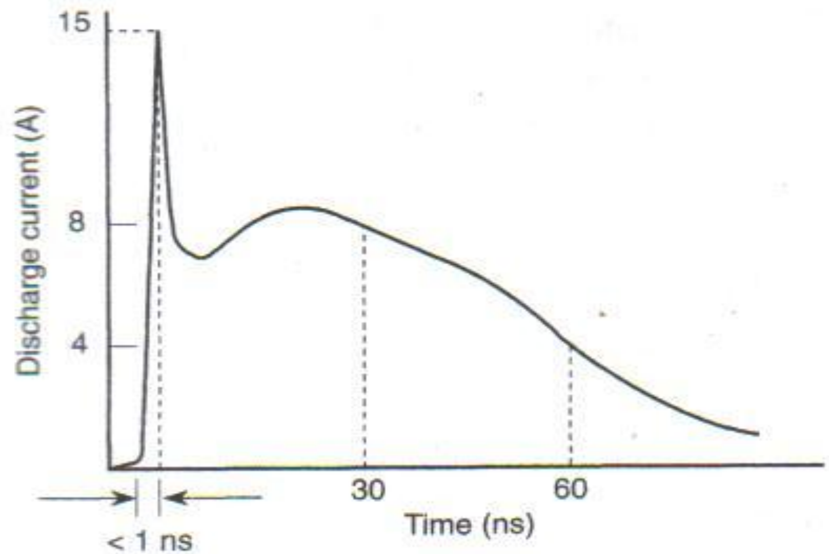
3. Electrostatic discharge

- High voltages low current
- Integrated circuits is susceptible if not protected
- ESD stages: pickup, storage, discharge

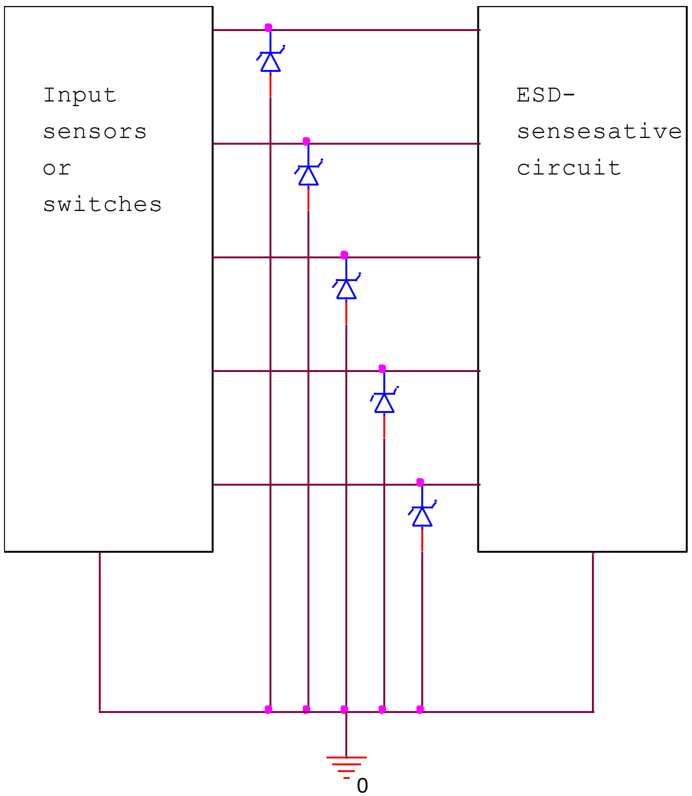
Protecting Against Electrostatic Discharge

Sources of ESD:

- Work Surface: Waxed, painted or varnished surface
- Floors: Sealed concrete, waxed, finished wood
- Clothes: Virgin cotton, wool, non-conductive shoes
- Chairs: Finished wood, fiber glass
- Packing and Handling: Common plastic bags, wraps, envelops. Common bubble pack and foam. Common plastic tray and box
- Assembly, cleaning, testing and repair: Spray cleaners, solder iron with ungrounded tips, heat guns and blowers.



Preventing Damage



Checklist for an ESD-safe work area

- Wear a wrist ground strap
- Discharge static before handling devices
- Keep parts in original container
- Minimize handling of components
- Pickup devices by their bodies
- Never slide a semiconductor over any surface
- Use antistatic containers for storage
- Clear all plastic, vinyl, Styrofoam from work area

General Rules of Design

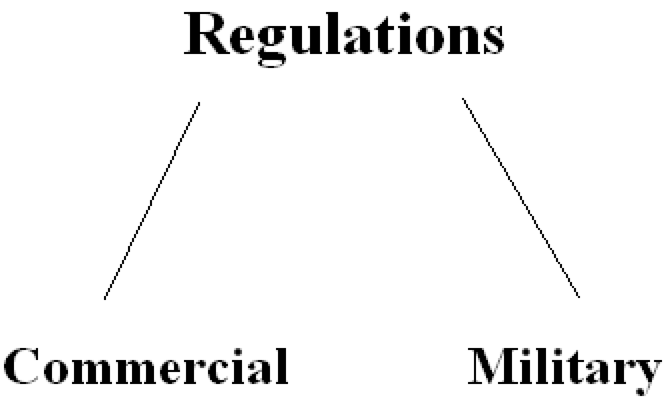
- When design and develop product, must include grounding and shielding. Also need to follow these general guidelines.
  - System Characterization
  - Standards
  - Procedure (good design technique)

System Characterization

- Establish the following
  - Grounding options
  - Source and load impedance
  - Frequency bandwidth
- Determine possible coupling mechanism
- Diagram the topology of circuit paths and reduce the loops
  - Ground loops
  - Inductive loops in signal and power circuits

Standards

- Have to meet or surpass the limits of emission or susceptibility in both conducted and radiated environments.



Procedure

- Good design techniques for grounding and shielding have a few basic rules:
  - Reduce Frequency bandwidth
  - Balance currents
  - Route signals for self shielding: a return (ground) plane, short traces, decoupling capacitors
  - Add shielding only when necessary

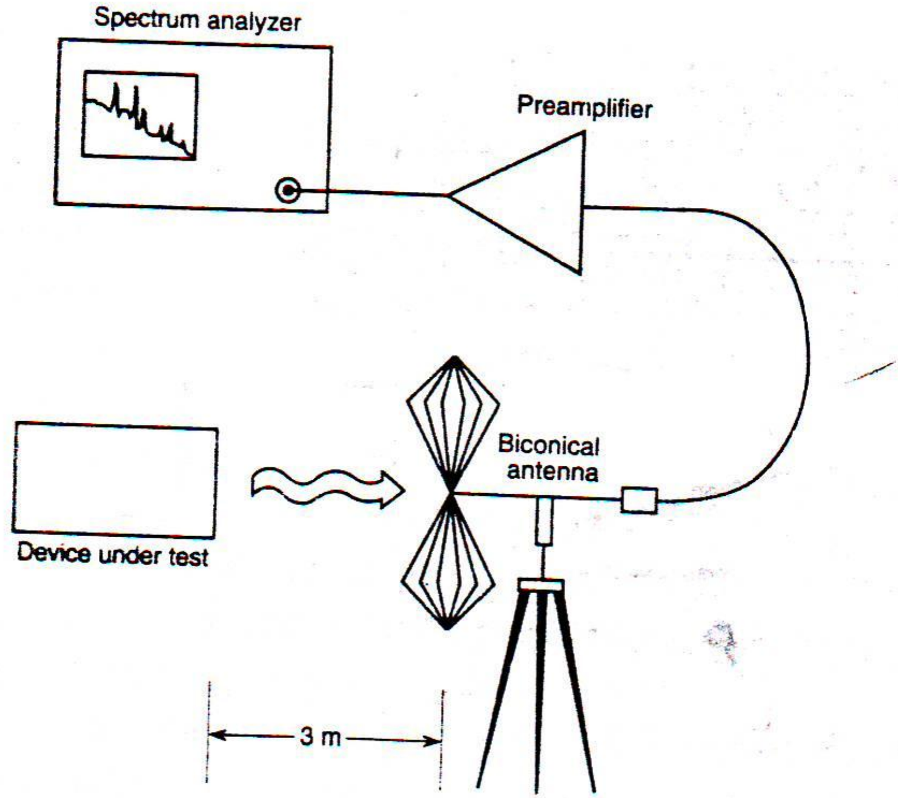


FIG. 6.47 Measuring radiated EMI with an appropriate antenna by positioning the device under test for maximum emissions.

References:

- K. R.Fowler, Electronic Instrument Design-architecting for the life cycle, Oxford University Press, Inc., 2010.
- H. Aryal, "Instrumentation II," haryal4@gmail.com, Kathmandu, 2010.