Chapter – 6
Grounding and Shielding

Grounding and Shielding

- Grounds & Shields improve safety and reduce interference from noise.
- Properly connected grounds reduce dangerous voltage differentials between instruments.
- Shields minimize interference from noise by reducing noise emission and noise susceptibility.

6.1 Outline for Grounding and Shielding Design

- Step 1: Understand the safety and noise issues for a product.
- Step 2: Know the possible mechanisms of energy coupling.
- Step 3: Define the necessary grounds and shields.

Safety

- Reduce the voltage differentials between external conductor surfaces.
- Usually the design is – conducted energy, low frequency (less than 1 MHz) and associated with power lines.
- Microwave energy is not a shock hazard but it does pose danger and demands especial attention to shielding.

Safety Ground

- Provides a path for the dangerous leakage currents and short circuits.
- Properly connected safety ground reduces voltage differential between external surfaces.
- Safety ground must be a permanent, continuous, low impedance conductor with adequate capacity that runs from the power source to load.
- Don't rely on a metallic conduct to form the conductive path for the safety ground, corrosion and breaks can open the circuit.
- Don't rely on building steel either because circulating currents can generate large and noisy ground potentials.
- A separate dedicated conductor will avoid these problems.

Three things to remember when to develop wiring for powering instruments:

- Consider the instrument and power mains as an integrated system.
- Always draw your ground scheme to understand the possible circuit paths.
- Don't blindly rely on building steel for a ground conductor.

6.2 Noise, Noise (Energy) Coupling Mechanism and Prevention

- Noise is unwanted electrical activity coupled from one circuit into another.
  - 3 components: A source, A coupling mechanism, and A receiver

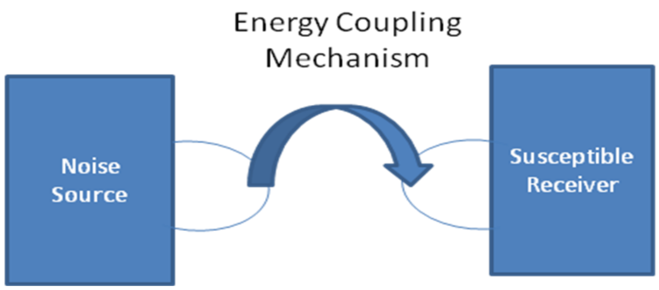


Fig: Block diagram of noise disrupting a circuit

Noise Sources

- Noise sources generate either a periodic signal or transient pulse that disrupts other circuits.
- There are many types of sources: 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

- Four mechanisms: Conductive, inductive, capacitive & electromagnetic

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.

- Conductive coupling → low frequencies, caused by incorrect grounding.
- Capacitive & inductive coupling → dominate at high frequencies
  - Changing magnetic flux can couple circuits.
  - The loop area of the circuit is the primary factor that determines the inductance and coupling.
  - Changing electric potentials can drive charge through stray capacitances.
  - Appropriate grounding, shielding and signal separation control the amount of capacitive coupling.

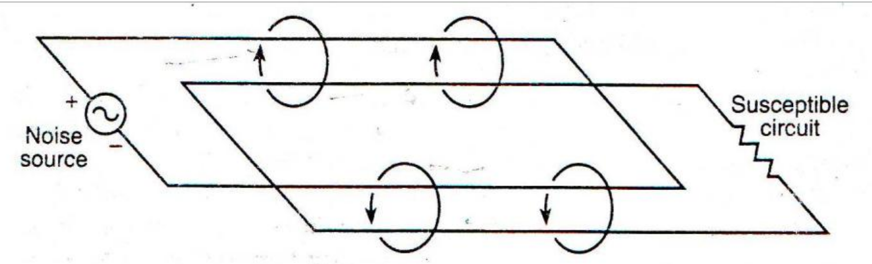


FIG. 6.6 Inductive coupling. Magnetic flux couples energy from the circuit of the noise source to the susceptible circuit.

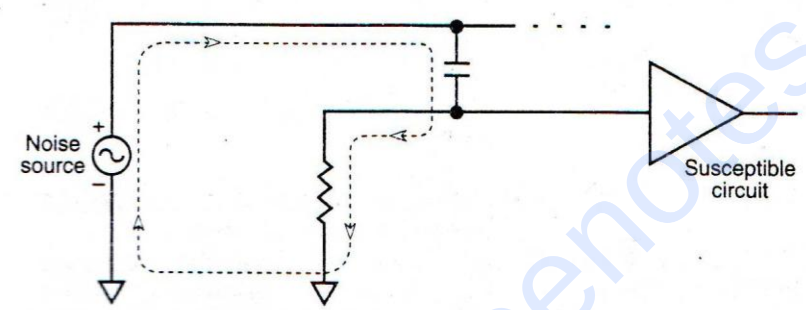


FIG. 6.7 Capacitive coupling. Coupling from stray capacitance completes the circuit of a noise source into a susceptible circuit.

- Electromagnetic coupling is a high frequency phenomenon.
- It requires a transmitting antenna in the source and a receiving antenna in the susceptible circuit. These antennas must be in appropriate fraction of the signal wavelength to couple effectively.

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 includes cross talk on inputs that leads to bit flips in digital logic, radio interference and static discharge that destroy components.
- Susceptibility usually can be traced by proper grounding (or return paths) or long signal lines that are not properly shielded.

Principle of Energy Coupling

- Current will flow in the path with low impedance, not necessarily lowest resistance.
- Consequently, charge follows the path of minimum inductive and maximum capacitive reactance for the lowest impedance.

  $$Z = \sqrt{(R^2 + [WL - (1/WC)]^2)}$$

  Where, Z = Impedance, R = Resistance, WL = Inductive reactance & 1/WC = Capacitive reactance
- For frequencies above 3 KHz, a useful diagnostic for determining the mechanism is the ratio of rate of change in voltage to the rate of change in current.
- For the special cases of sinusoidal signals or resistive loads, the ratio is impedance; otherwise, it is a pseudo impedance value.
- A Diagnostic ratio called Pseudo Impedance.
- Pseudo Impedance is defined as: $\gamma =$ (dv/dt)/(di/dt)
  - If $\gamma = 377$, @ high frequencies (> 20MHz) → Electromagnetic coupling.
  - If $\gamma < 377$, the value of di/dt > dv/dt i.e. large change in current → inductive coupling.
  - If $\gamma > 377$, the value of dv/dt > di/dt i.e. large change in voltage → 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.

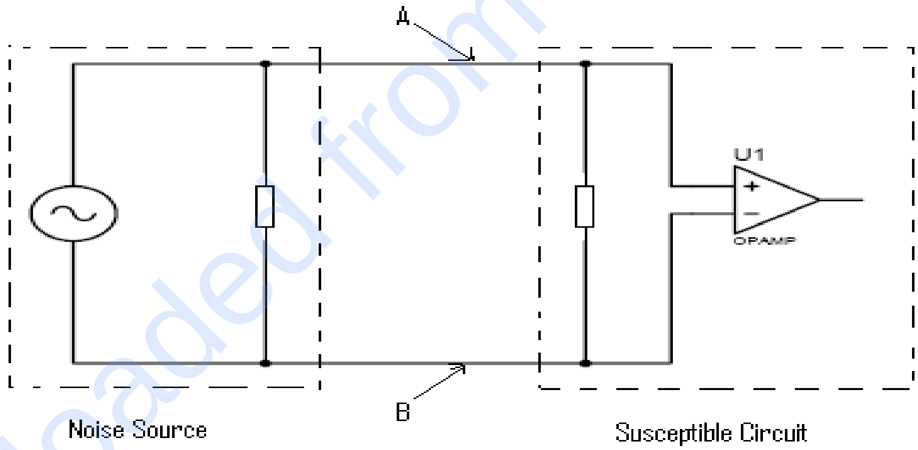


Fig: Conductive coupling. If either connection A or B is removed, the conductive noise is eliminated.

- Such connections are inadvertent and difficult to find; such connections are called Sneak circuits.
- A ground loop is a complete circuit that allows unwanted current to flow into the ground.
- Substantial current in a ground path (as opposed to a return path) can produce voltage differences across the ground resistance and raise the ground potential at the loads. Conversely, significant potentials in the ground can force unwanted current to flow between circuits.

- The use of high frequency and reduction of ground loop can reduce conductive coupling or conductive noise.

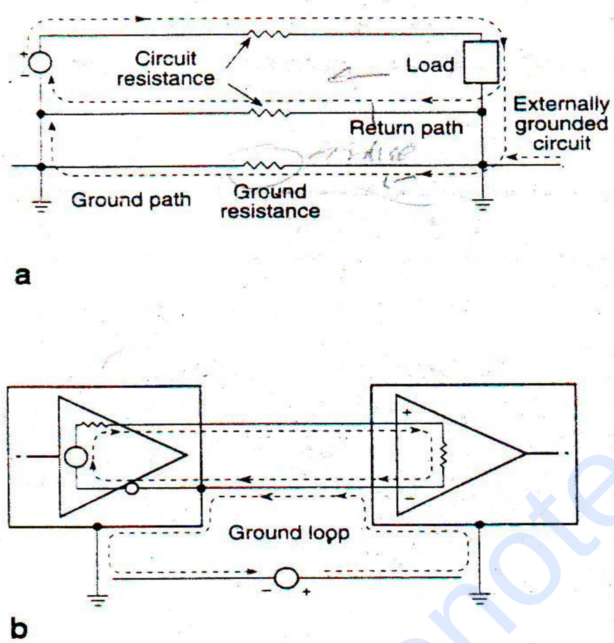


FIG. 6.10 A ground loop. Multiple ground connections can provide multiple return paths that cause significant current flow in the grounding structure, as shown in part (a). Ground potential causes currents in ground loops that unbalance circuits, as shown in part (b).

Inductive Coupling

- An Inductive coupling mechanism requires a current loop that generates changing magnetic flux.
- Generally, a current transient creates the changing magnetic flux, as follows:

  Φ = BA = $\mu_0 nIA$

  Then,

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

  Where, Φ = Magnetic Flux
  B = Magnetic field
  A = Loop area
  μ_0 = Permeability of free space
  n = Number of turns in the loop
  i = Current
  v = Voltage
- The induced voltage in a magnetically coupled circuit is proportional to the time rate of change of current and loop area.
- Reducing the loop area will reduce the inductive reactance of a circuit.
- For frequencies above 3 MHz, (dv/dt) / (di/dt) << 377Ω
- Generally, the load impedance is large, while the source impedance is small.

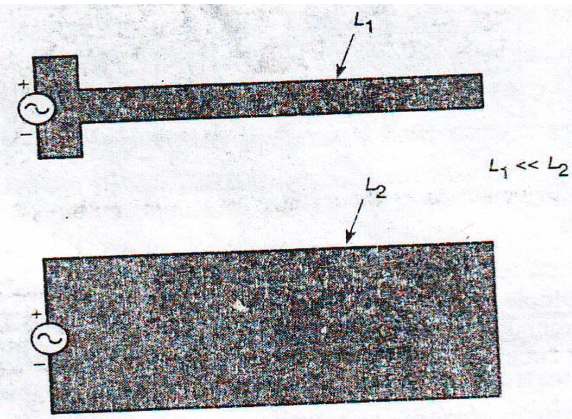


FIG. 6.11 Reducing loop area. Small loops of current have lower self-inductance and thus lower impedance.

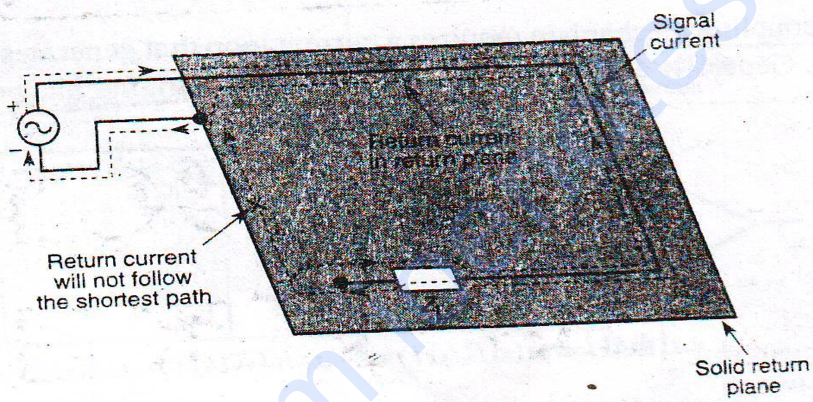


FIG. 6.12 Path of return current. Return current will follow the path of least impedance (in this case, the least self-inductance), not necessarily lowest resistance.

- Current follows the path of lowest impedance, not necessarily lowest resistance. Therefore, current will follow the path of minimum inductive reactance; this means the current will minimize loop area in a circuit.
- A slot in the ground plane of a circuit board will increase the loop area of a circuit; below figure shows this; so avoid such slots.

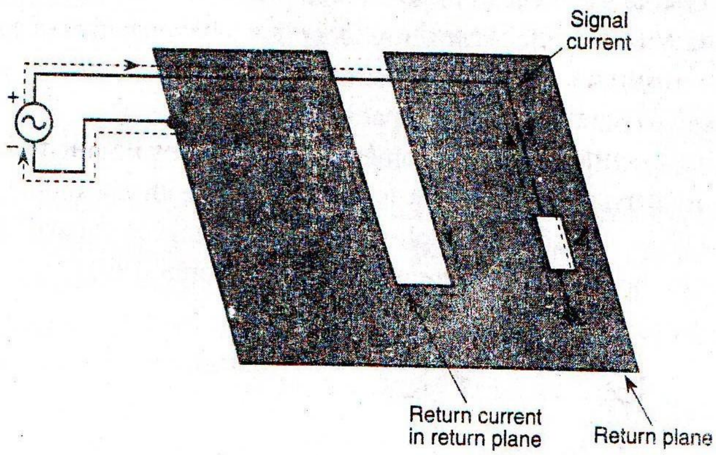


FIG. 6.13 A slot in the return plane increases the current loop area and the self-inductance.

- The long, straight wires encompass significant loop area that provides an inductive reactance. Twisting the pairs of signal and return lines together eliminates the loop area and the mutual inductive coupling between circuits.

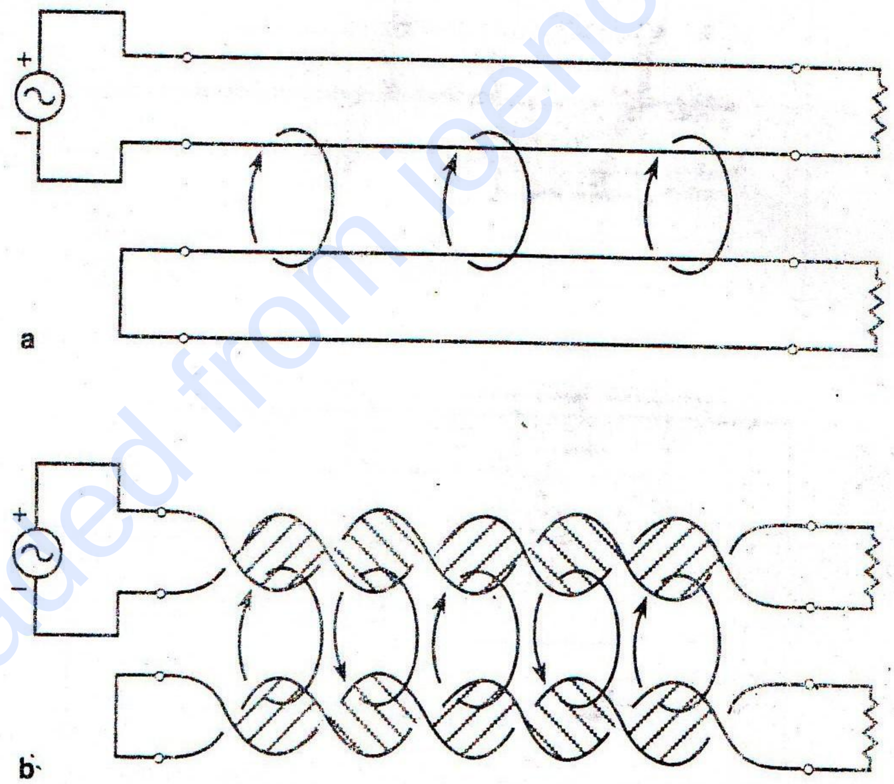


FIG. 6.14 Effect of twisted wire. (a) Straight wires create small loops that can couple magnetically. (b) Twisted wire eliminates the effective loop area of cables and magnetic coupling.

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
- Generally, the total circuit impedance is high; i.e. both the source and load impedance are large.
- (dv/dt) / (di/dt) >> 377Ω
- Capacitive coupling can be reduced by separation of conductors and appropriate shielding.

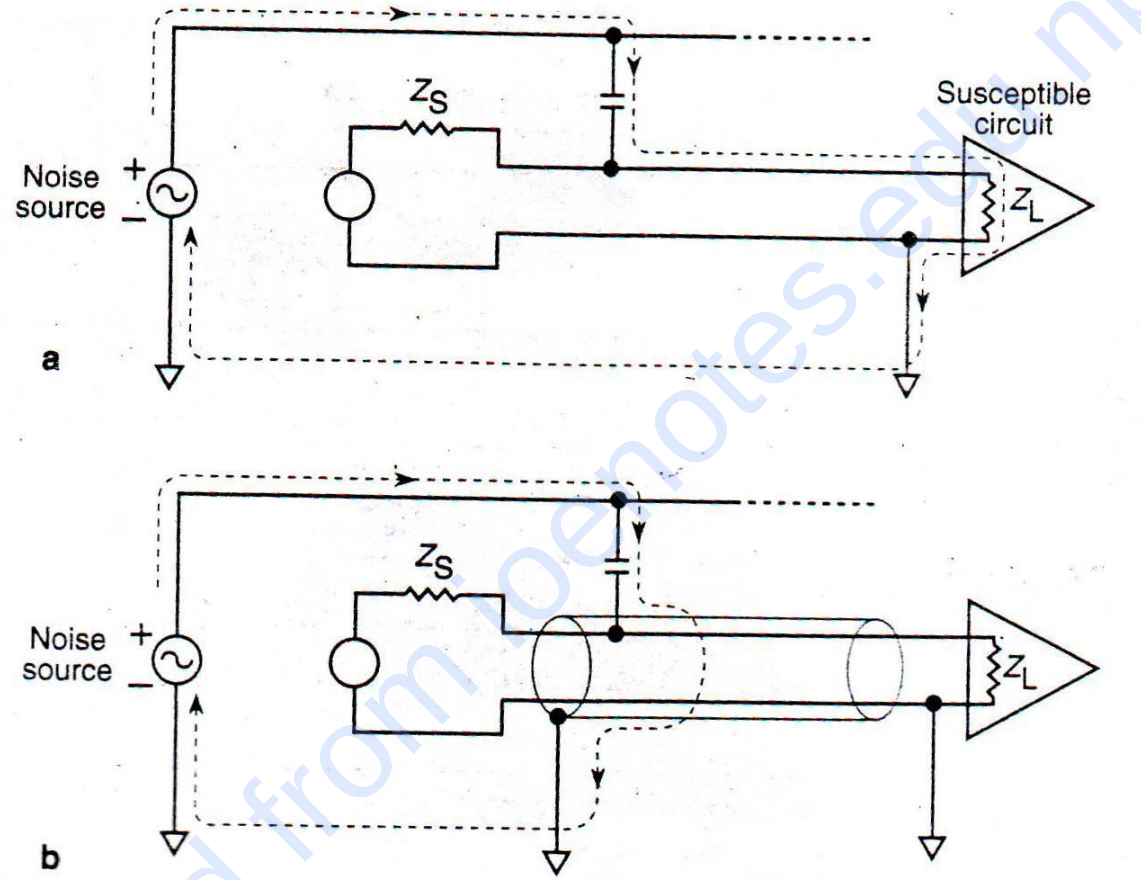


Fig. 6.15 Effect of shielding. (a) Without the shield, stray currents can disrupt susceptible circuits. (b) A properly connected shield can divert capacitively coupled current from susceptible circuits.

Electromagnetic Coupling

- Electromagnetic coupling or radiative coupling becomes a factor only when the frequency of operation exceeds 20 MHz.
- f < 200 MHz, cables are primary sources and receivers for electromagnetic coupling.
- f > 200 MHz, PCB traces begin to radiate & couple energy.
- Generally, the length of conductor must be longer than 5% of the bandwidth i.e. l > ʎ/20.
- Pseudo impedance factor between 100Ω and 500Ω.
  (dv/dt) / (di/dt) = 377Ω
- The frequency of signal must be reduced.
- Use magnetic plate shielding.

6.3 Single Point Grounding and Ground Loop

Grounding

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

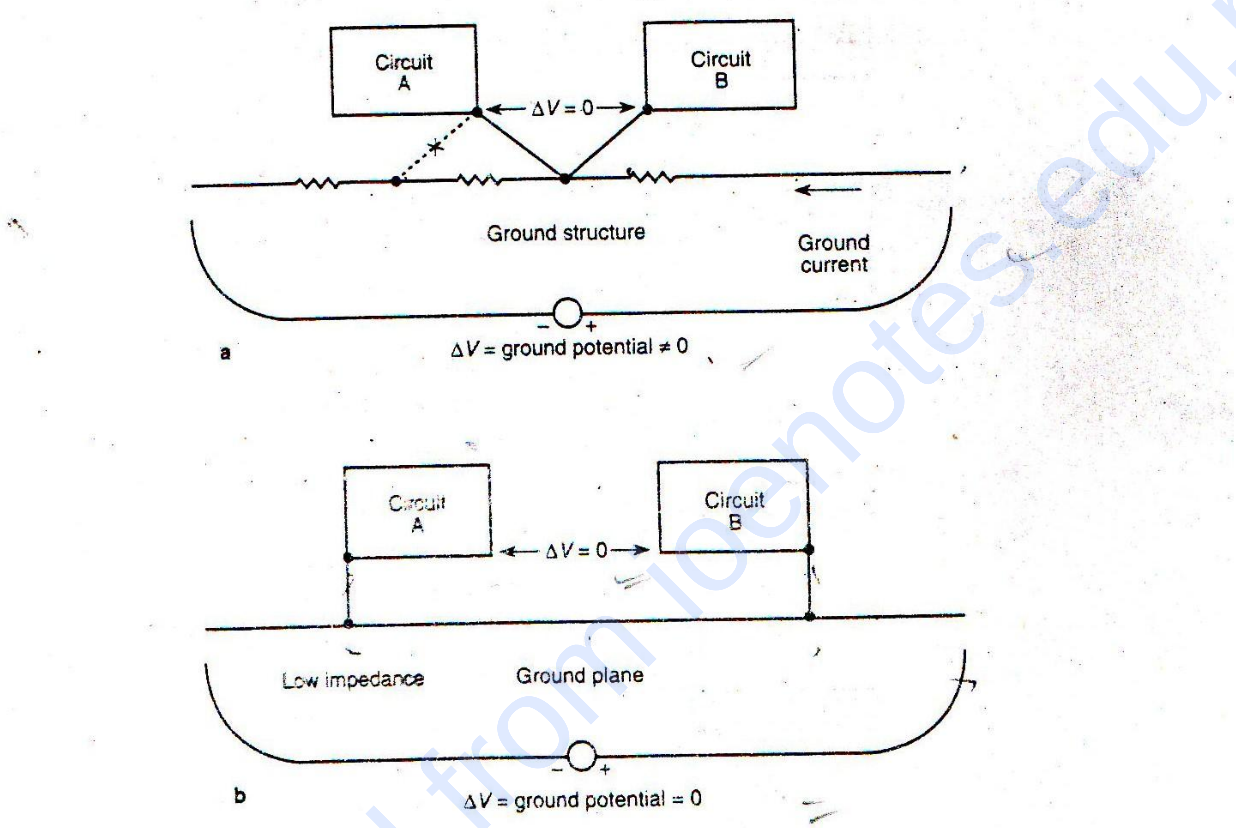


FIG. 6.16 Two grounding configurations. For safety and for signal reference, reduce the potential difference between the ground connections of circuit, instrument, or chassis. (a) Single-point ground. (b) Multipoint ground with low-impedance ground structure.

- Often designers use the return conductors as a signal reference.

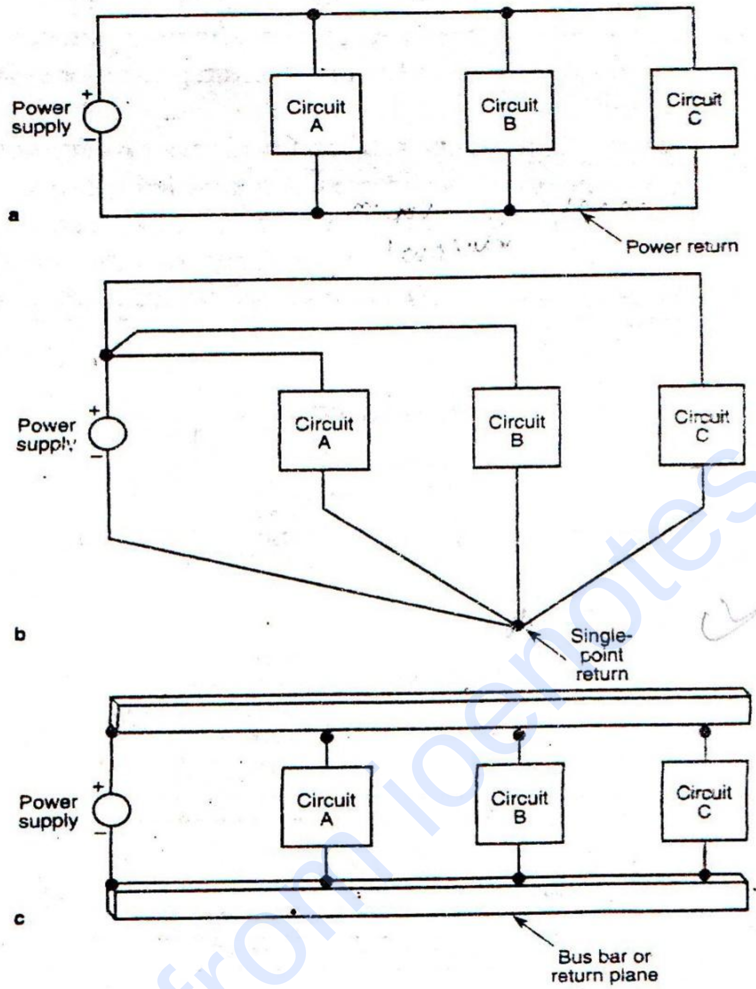


FIG. 6.17 Three return configurations. (a) Series return connection. (b) Single-point return. (c) Multipoint return.

Safety Grounding

- Seeks to reduce the voltage differentials between exposed conducting surfaces.
- Should have many connections between the exposed conducting surfaces.

Signal Referencing

- Seeks to reduce the voltage differentials between reference points.
- Should have one connection between reference points at low frequency.
- In either case, ground is not the return path for a signal. Both safety and signal grounds nominally conducts current.

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

Single Point Grounding

- The separate ground conductors isolate the noise in the return paths of the separate circuits because the single point reference connection does not complete any ground loops between circuits.
- Most appropriate low-current, low-frequency (< 1 MHz) applications.
- The ground conductor should be a short strap to reduce high-frequency noise and unsafe voltages.

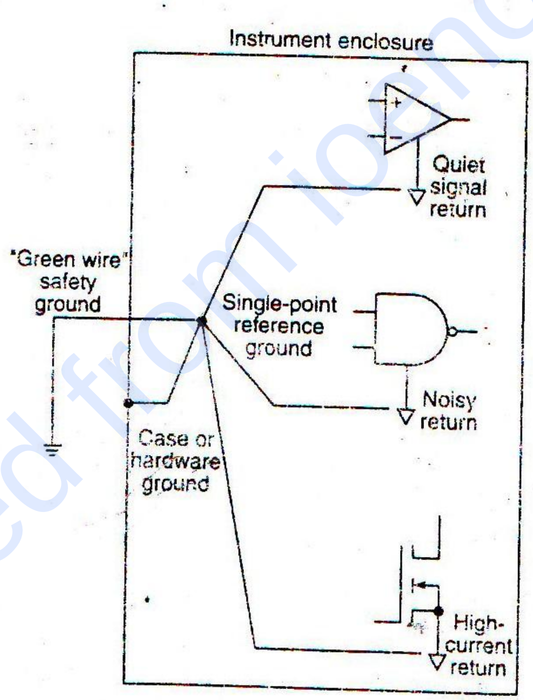


FIG. 6.18 Single-point grounding. Connecting grounds to returns in parallel and then to a single point isolates noise within an instrument. The ground conductors should not carry significant current; that is the function of the return conductors.

Disadvantages

- Conductors longer than 5m (16 ft) are susceptible to high-frequency ground noise. (A braided cable may reduce impedance at high frequencies by increasing the skin effect; that is, current tends to flow along the surface, and braided cable has a large surface area).

- Conductors longer than 30m (100 ft) or those conducting high fault currents are unsafe. The inherent impedance of the conductor will cause large potential differences exist between the instrument and ground.
- ADC is one application that needs a single point ground for signal referencing separate references can generate noisy ground loops.

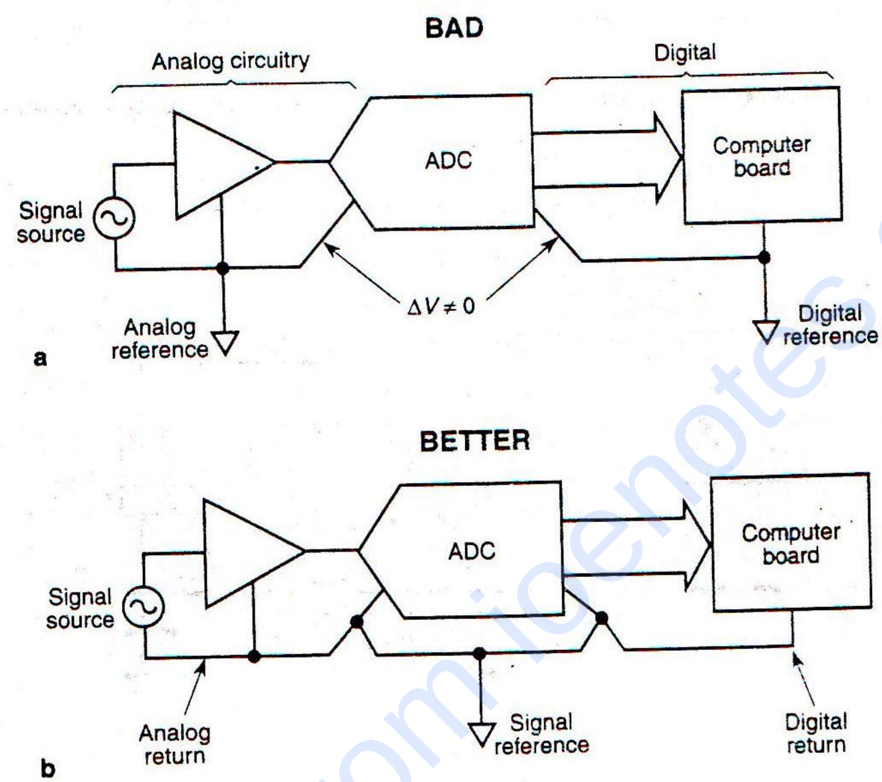


FIG. 6.19 Reducing noise from the signal reference. Tie the analog and digital references together near the ADC. (a) Separate references can lead to large loops of current. (b) A single-point reference eliminates large loops; usually an uninterrupted ground plane suffices.

Ground Plane or Grid

- A ground plane within a circuit board is better for high frequency (> 100 KHz) operation.
- Likewise, a ground grid is better for high frequency or high fault currents, because it has lower impedance than a single cable.

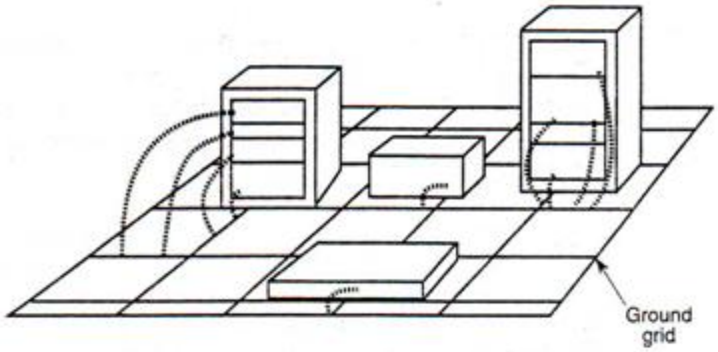


FIG. 6.20 A ground grid. Such grounding is appropriate for high-frequency operation or high-fault currents.

Ground Loop

- A ground loop is a complete circuit that comprises a signal path and part of the ground structure.
- It arises whenever multiple connections to ground are physically separated.
- External currents in the ground structure generate potential differences between the ground connections and introduce noise in the signal circuit.

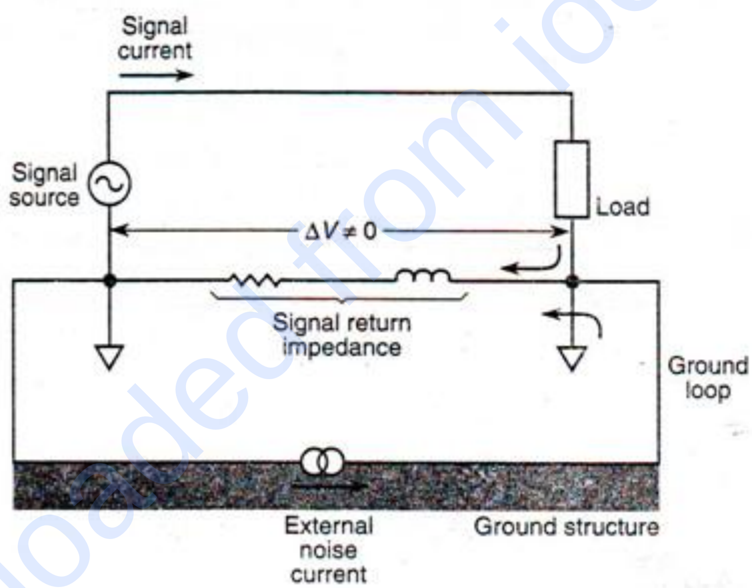


FIG. 6.21 A ground loop. It occurs when a circuit makes multiple connections to the ground conductor or structure.

- Generally, the problem arises at low frequencies (< 10 MHz); high frequencies follow the path of minimum impedance that can avoid higher impedance ground loops.
- Ground loops are a particular problem in systems that have low level signal circuits and multipoint grounds separated by large distances.
- Either circuit balance or signal isolation can eliminate noise from ground loops.

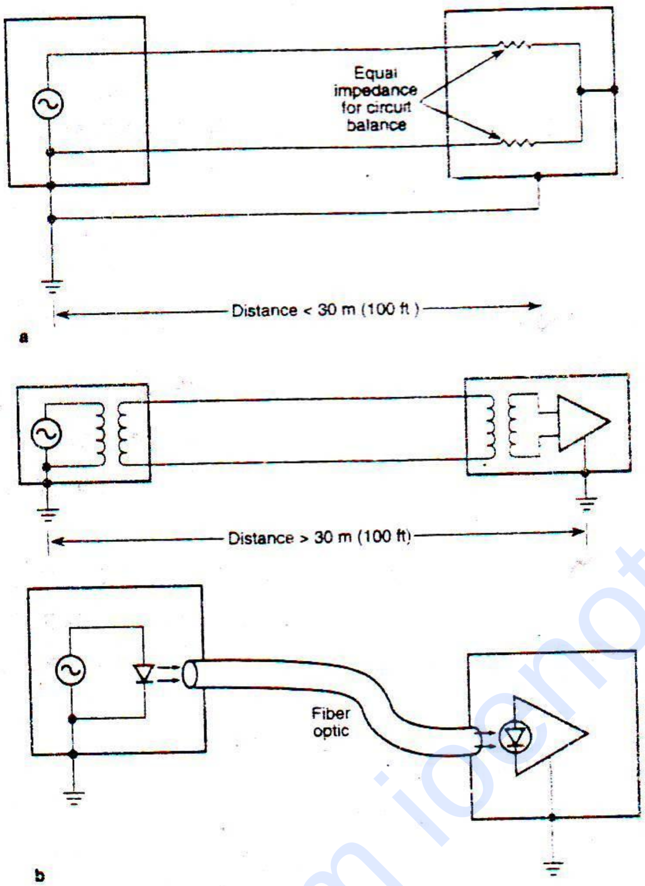


FIG. 6.22 Eliminating ground noise. Circuit balance or isolation removes problems from ground noise. (a) For short distances, a balanced transmission line and single-point grounding reduce noise and safety concerns. (b) For long distances, an isolated signal transmission allows multiple safety grounds while eliminating ground loops.

- For safety, coordinate the routing of power and signal to reduce noise introduces by the ground structure.

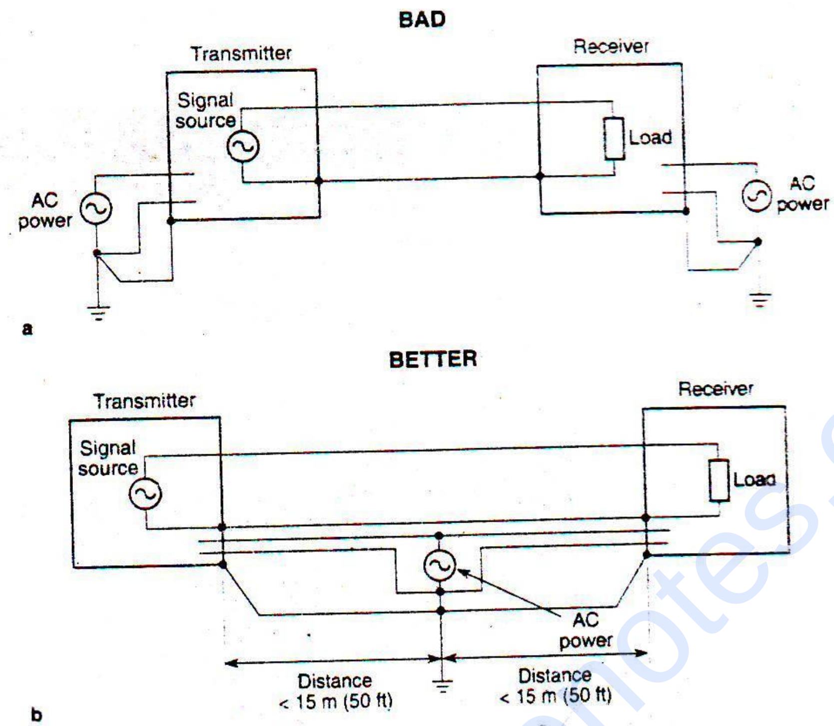


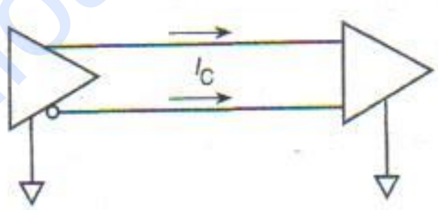
FIG. 6.23 Coordinated routing of power, signal, and safety ground. (a) Separate grounds and power, while safe, introduce noise. (b) For short distances, a coordinated routing of power and ground maintains safety and reduces noise.

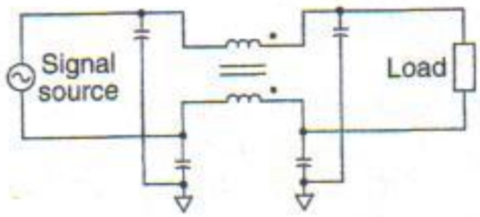
6.4 Filtering and Smoothing

Filtering

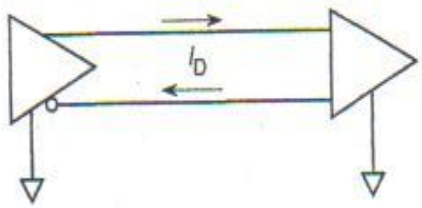
- Only filtering reduces conductive noise coupling.
- A filter can either block or pass energy by three criteria.
    a) Frequency
        - LPF passes low frequency energy and rejects high frequency energy
        - HPF passes high frequency energy and rejects low frequency energy

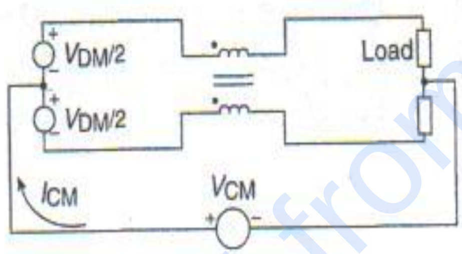
    b) Mode (Common or Differential)
        - Common-mode noise injects current in the same direction in both the signal and return lines. Filter diverts common mode noise current to ground.





- Differential-mode noise injects current in opposite directions in the signal and return lines. Filter blocks common mode currents while passing differential mode current.





c) Amplitude (Surge suppression)
- Amplitude selective filters reduce large transients or spikes e.g. surge suppressors.

- Time-average filter → Implemented in software, reduce the effect of noise on data within a signal.
- Time-synchronous filter → Stop running at periodic disturbance e.g. periodic switching in power supply.

Minimize Bandwidth
- A low-pass filter reduces high frequency emissions and susceptibility for signal applications.
- Filtering input signals may improve the noise immunity of the circuit.
- Sharp edges on pulses will have large Fourier coefficient. Slowing the rise and fall times of pulse edge will reduce the bandwidth of signals.

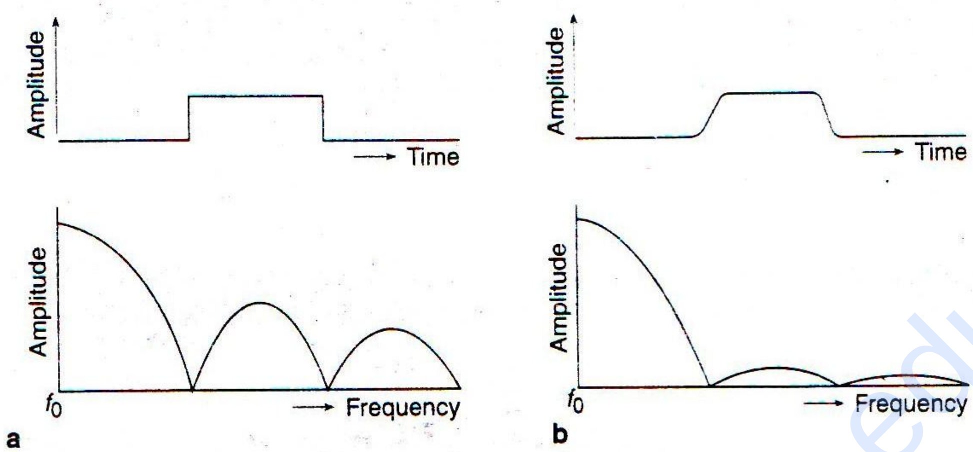


FIG. 6.26 Spectral content of square and rounded pulses. The faster the rise time on a pulse edge, th greater the amplitudes of the harmonics and the greater the potential for noise coupling. (a) Faste edges create greater harmonics. (b) Slower edges reduce the harmonic content.

- Filtering clock signal to reduce the high-frequency harmonics is one area where we may significantly reduce noise interference. But be careful not to violate the minimum skew rate required by the logic circuits.

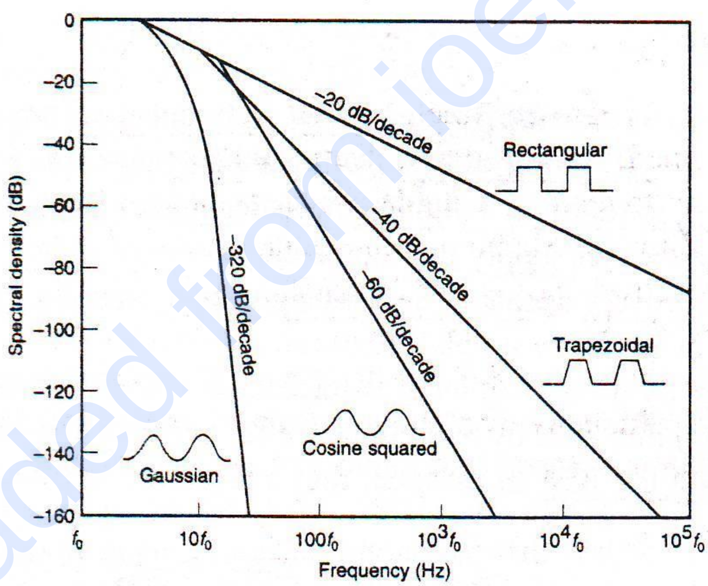


FIG. 6.27 Spectral content of pulse shapes. Pulse shape defines the harmonic content of a signal and its potential for radiating electromagnetic interference. f_0 = fundamental frequency. (Adapted from Brewer, 1991.)

6.5 Decoupling Capacitors and Ferrite Beads

Ferrite Beads

- Ferrite beads provide one form of filtering based on frequency.
- A ferrite bead is a magnetically permeable sleeve that fits around a wire. It presents inductive impedance to signals that attenuates high frequencies.

- Ferrite beads are best suited to filter low level signals and low current power feeds to circuit board.
- 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.

Decoupling and Bypass Capacitors

- They provide Filtering based on frequency
- They filter and smooth out the spikes in DC power of ICs
- During a logic transition, a momentary short circuit from power to return in a digital device demands a large current transient. A decoupling capacitor can supply the momentary pulse of current and effectively decouple the switching spike from the power supply.
- They reduce the impedance of power supply circuit.
- Inductance in the power supply attenuates the effect of switching current transients by producing large voltage spikes.
- Decoupling capacitor provides this demand for shorter time.
- Mitigate the effect of inductance by reducing effective loop area between Power supply and the ICs.

$$Z0 = \sqrt{(R^2 + [WL - (1/WC)]^2)}$$

- Reduce impedance of power supply
- If you arbitrarily make the decoupling capacitor too large, you will move the resonance frequency of the supply inductance and decoupling capacitor down into the range of operation of your circuit and cause excessive ringing in the supply.
- Also, large capacitors have larger parasitic inductances than smaller decoupling capacitors.

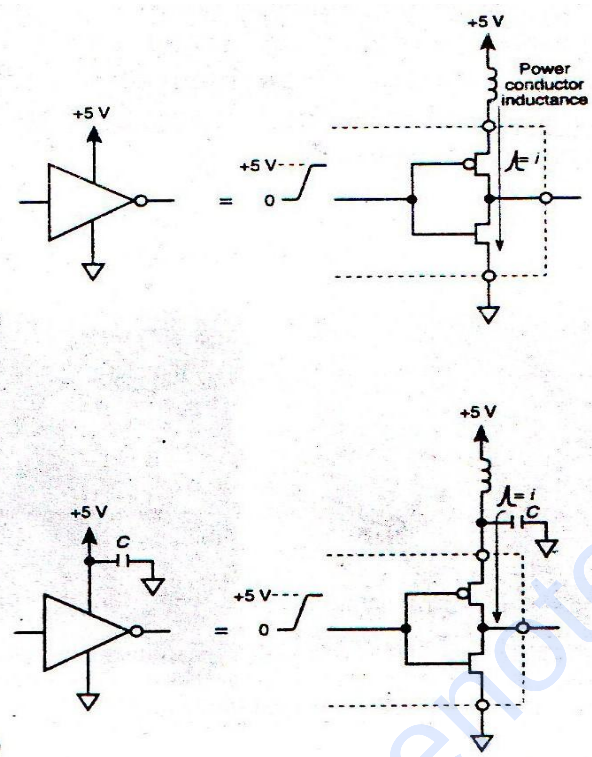


FIG. 6.29 Decoupling, or bypass, capacitors. They filter current transients when transistors switch within a digital logic gate. (a) As input voltage changes logic level, both transistors turn on, momentarily producing a short circuit and drawing a current pulse from the DC power source. (b) A decoupling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

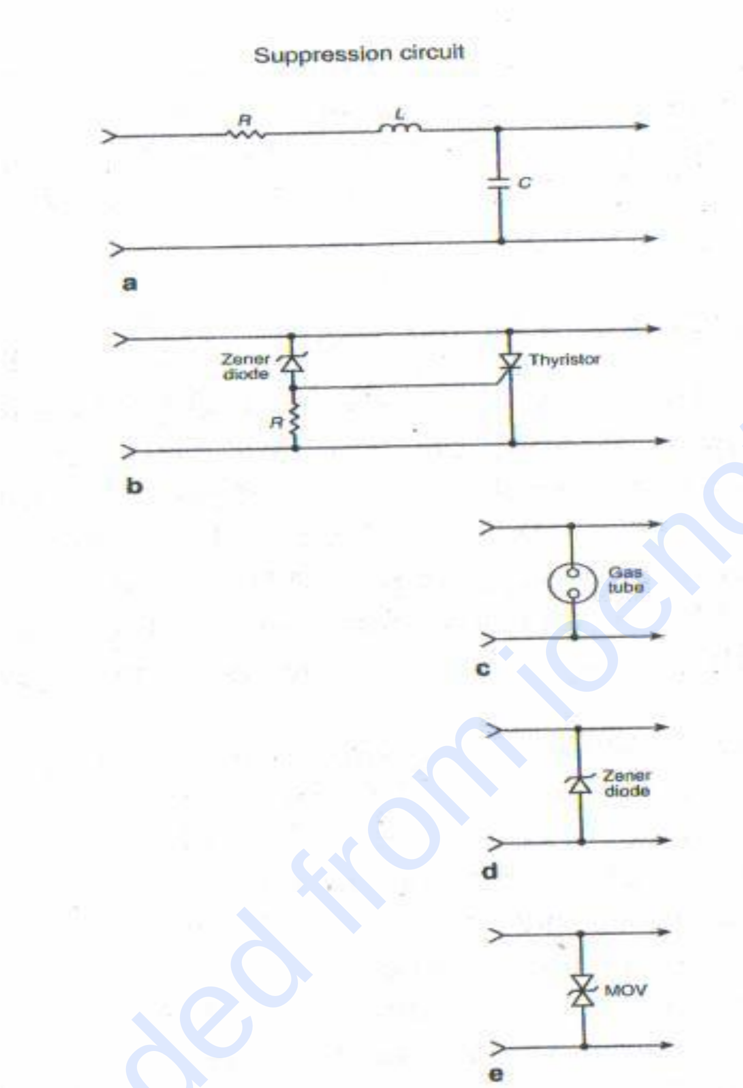
6.6 Line Filters, Isolators and Transient Suppressors

Line filters and Isolators → Mode basis
Transient Suppressor → Amplitude basis

- Common mode filters for AC power lines diverts noise to ground, but beware of polluting the signal reference ground with noise.
- An optoisolator can eliminate common mode noise by interrupting the conductive path.
- A differential mode filter has to separate noise from signal by criteria other than current direction; a low pass filter is an example of differential mode filter that uses frequency as the selection criterion.
- Transient → Machinery switching on or off produces transients through inductive "kick". The opening or closing of switches changes the load current instantaneously and generates a sizable voltage across the line inductance that affects the other loads.
- Transient protection can take one of four approaches: filter, crowbar (thyrister), arching discharge, or voltage clamp (zener diode or metal-oxide varister i.e. MOV).
  1. **Filter:** It removes the high frequency components of the energy associated with the sharp edge of a spike. Consequently, the peak of the spike is flattened.
  2. **Crowbar (thyristor):** It detects an over voltage and short circuit current until the input voltage is cycled off and on again.
  3. **Arching discharge:** It occurs across gap into a gas tube. The initial breakdown of the gas requires a fairly high voltage; but once the arc is established, the holding

voltage is much lower. It is used in telephone circuits to suppress surge caused by lightning.

4. **Voltage clamp (Zener):** It shorts the excess energy to prevent an overvoltage condition. Fast, more cost, low current capacity than MOV (Metal oxide varister).



6.7 Different kinds of Shielding Mechanism

Shielding

- Shielding either prevents noise energy from coupling between circuits or suppresses it.
  - Magnetic flux – inductive shielding
  - Electric field – capacitive shielding
  - Electromagnetic wave propagation – electromagnetic shielding

Inductive Shielding

- It is concerned with Self-inductance and Mutual inductance.
- It reduces noise coupling by reducing or rerouting magnetic flux.

- The most effective inductive shielding minimizes loop area, separating circuits and reducing the change in current help, while metal or magnetically permeable enclosures place a distant third in usefulness.
- Magnetic noise depends on loop area and current in the emitting and receiving circuits.
- Coaxial cable has minimal loop area and may be preferable for high frequencies (> 1MHz) because it provides both capacitive shielding and controlled impedance.
- Always pair signals with return, otherwise, we will not gain any inductive shielding.

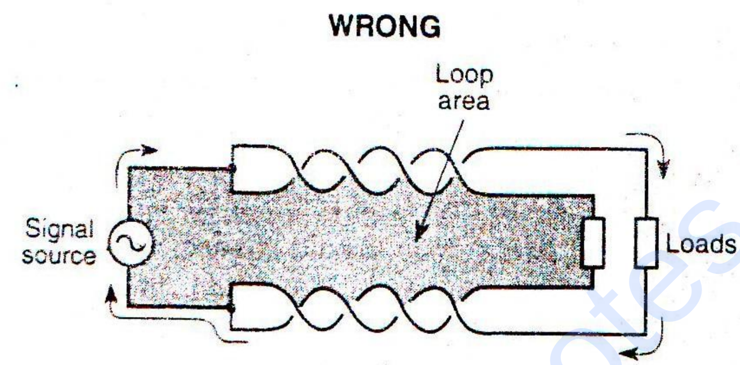


FIG. 6.32 Incorrect application of twisted-pair wire. A large loop area still exists.

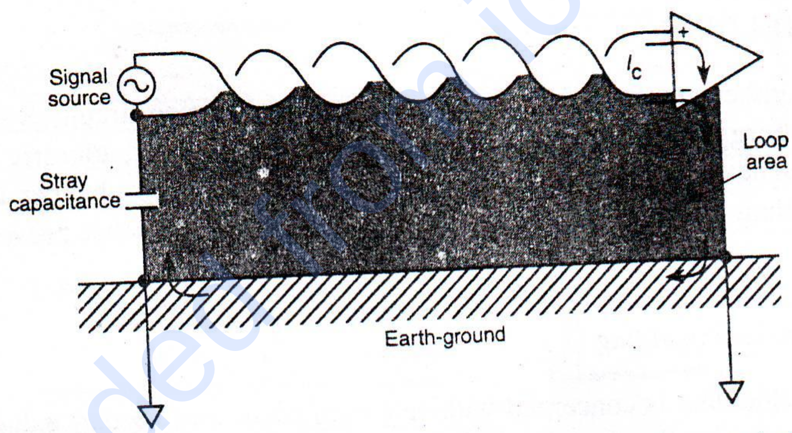


FIG. 6.33 Twisted-pair cable. Twisting the wire and running it close to the ground will reduce the common-mode current, I_C, by reducing the loop area for inductive coupling.

- On circuit boards,
  - Make sure that the return path is always under the signal conductor to minimize loop area.
  - Avoid slots in ground plane, which increase the loop area of signal path.
- Enclosures provide magnetic shielding by allowing eddy currents to reflect or absorb interference energy. These enclosures are heavy, expensive and frequency dependent, but sometimes they are only solution.

Capacitive Shielding

- Capacitive shielding reduces noise coupling by reducing or rerouting the electrical charge in an electric field.
- Capacitive shields shunt to ground charge that is capacitively coupled.
- Capacitive coupling provides a path for the injection of noise charges.
- At low frequencies (< 1 MHz), connect a capacitive shield at one point if the signal circuit is grounded. Multiple connections can form ground loops.
- Capacitive shielding can be improved by reducing:
  - Noise voltage and frequency
  - Signal impedance
  - Floating metal surfaces
- Conversely, multiple ground connections are necessary for high frequencies (> 1 MHz). Stray capacitance at the ungrounded end of a shield can complete a ground loop.
- Therefore, we should ground both ends of a long (relative to wavelength) shield.
- A mutual enclosure can be an effective electrostatic shield (transformer), or faraday shield to prevent capacitive coupling.

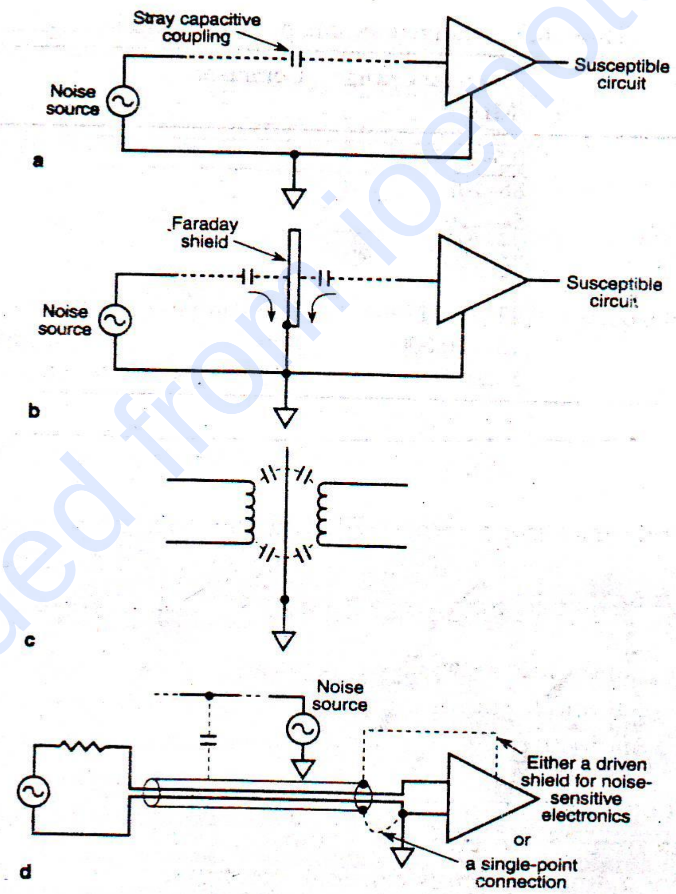


FIG. 6.34 Capacitive shielding. Capacitive coupling provides a path for the injection of noise charges, while an appropriately placed shield prevents the coupling between circuits by shunting charge to ground. (a) Outline of capacitive coupling. (b) Proper placement of a shield to shunt noise charge. (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

- Electromagnetic shielding reduces emissions and reception.
- Emission sources: Lightning, Discharges, Radio and TV transmitters, High-frequency circuits.
- Electromagnetic Interference (EMI) always begins as conductive (current in wires) becomes radioactive, and ends as conductive (fields interact with circuitry).
- Several techniques can reduce EMI:
    - Reduced bandwidth (longer wavelength)
    - Good layout and signal routing
    - Shielded enclosures
- As shielded enclosure should ideally be a completely closed conducting surface. Effective enclosure is one that has watertight metallic seams and openings. Openings include cooling vents, cable penetration with slots larger than a fraction of a wavelength (> λ/20), push buttons, and monitor screens that can leak electromagnetic radiation.
- Similarly, cable shields must seal completely around each connector.

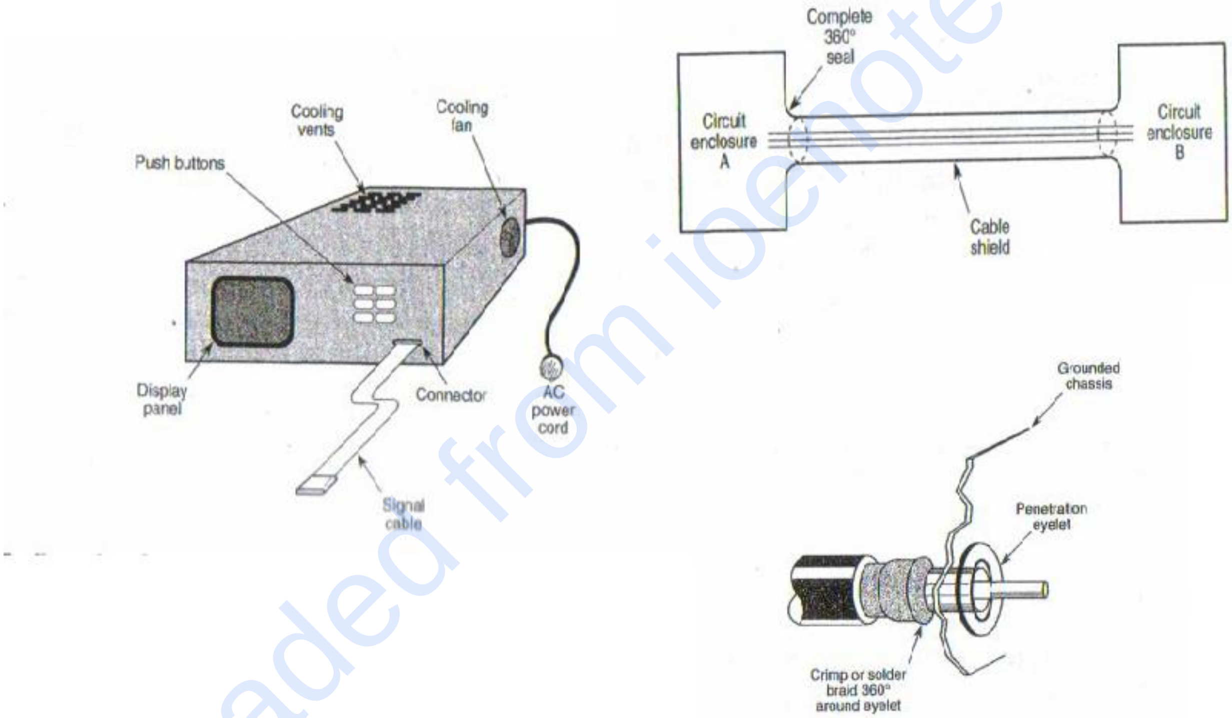


Fig: Shielded enclosure and cable shield

Some Practical Applications
Twisted Pair Cable

- Effective up to 1 MHz, lossy at higher frequencies
- Cheaper and mechanically more flexible
- Single ground connection to both the shield and return line provides best attenuation of the 50 KHz noise.

Coaxial Cable

- Have low loss and less variance in characteristic impedance from DC to very high frequencies (> 200 MHz).
- A pigtail connection from the shield to ground presents a loop inductance that increases impedance with frequency. Thus, high frequencies (> 10 MHz) demand a complete 360^{o} seal of the shield at both ends.

Ribbon cable

- Ribbon cable is ubiquitous in instrumentation.
- It is suitable for low frequency operation << 1 MHz
- We should pair each signal with a return conductor or use a return plane for low-level signals or higher frequencies.

EM leakage through openings of conducting enclosure can be reduced by:

- Seams must be soldered, welded or overlapped
- Penetration such as vents and cables need appropriate filters and shields. A honeycomb matrix invents, acts as a waveguide to filter electromagnetic radiation.

6.8 Protecting Against Electrostatics Discharge

- Electrostatic discharge (ESD) is a discharge at very high voltage and very low current that readily damages sensitive electronics.
- ESD can range from hundreds to tens of thousands of volts. Any instrument containing integrated circuits is susceptible.
- ESD transfers electrical charge in three stages: pickup, storage and discharge.
- Usually mechanical rubbing between dry, insulated materials transfers the charge from source to storage. Often the storage medium is person, who then unwillingly delivers the damaging discharge.
- Proximity or physical contact discharges the charge from storage.
- Several conditions including humidity, speed of the activity, and material affect the charge transfer.
- The discharge waveform of ESD has a fast rise time and short duration. The below figure illustrates sample waveform for simulating ESD while testing products.

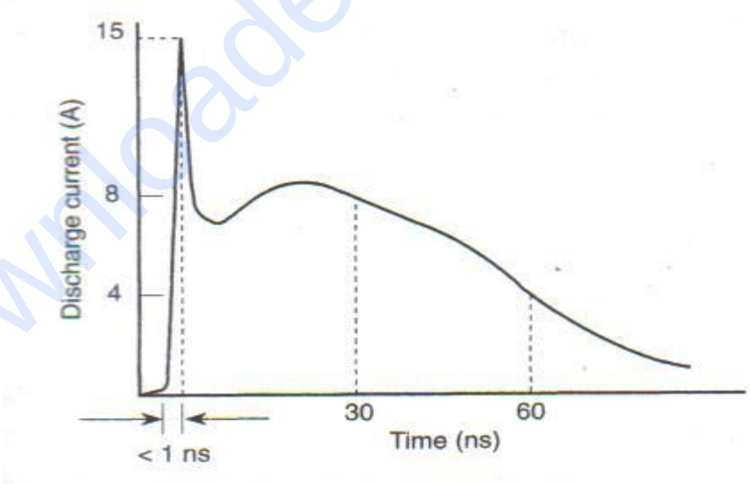


Fig: Discharge waveform at 4 kv

- Several schemes including grounding, shielding and transient limiters can protect circuits from ESD.
- Input gates are the most susceptible to damage, so we should use surge-limiters on input lines as shown in below figure.

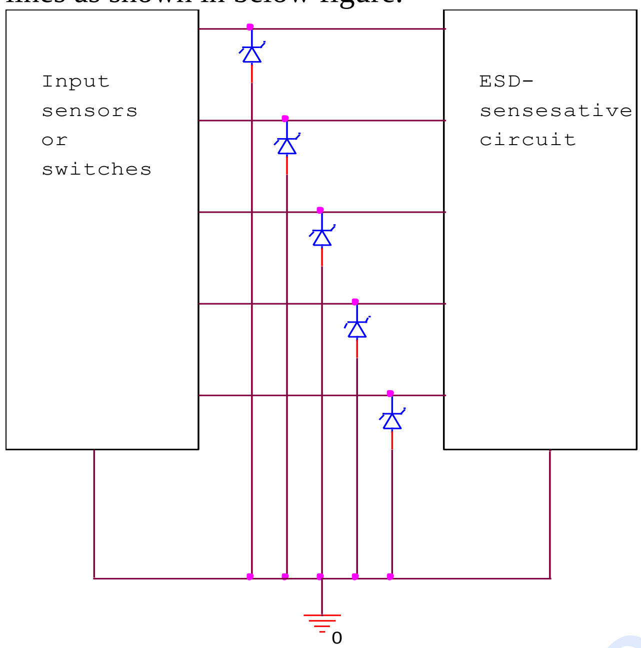


Fig: Preventing damage by shunting high voltage transients away from circuits with zener diodes or MOVs

- Generally zener diodes and MOVs are used to limit surges. Zener diodes tend to turn on faster, while MOVs are cheaper and handle large peak current.
- For prevention, we need to eliminate the activities and materials that create high static charge control methods including the following.
    - Grounding
    - Protective handling
    - Protective material
    - Humidity
- Checklist to make work areas less prone to ESD
    - Use a "static-free" workstation, and wear a wrist ground strap
    - Discharge static before handling devices
    - Keep parts in original container
    - Minimize handling of components
    - Pickup devices by their bodies, not their leads
    - Never slide a semiconductor over any surface
    - Use conductive or antistatic containers for storage and transport of components
    - Clear all plastic, vinyl, Styrofoam from work area

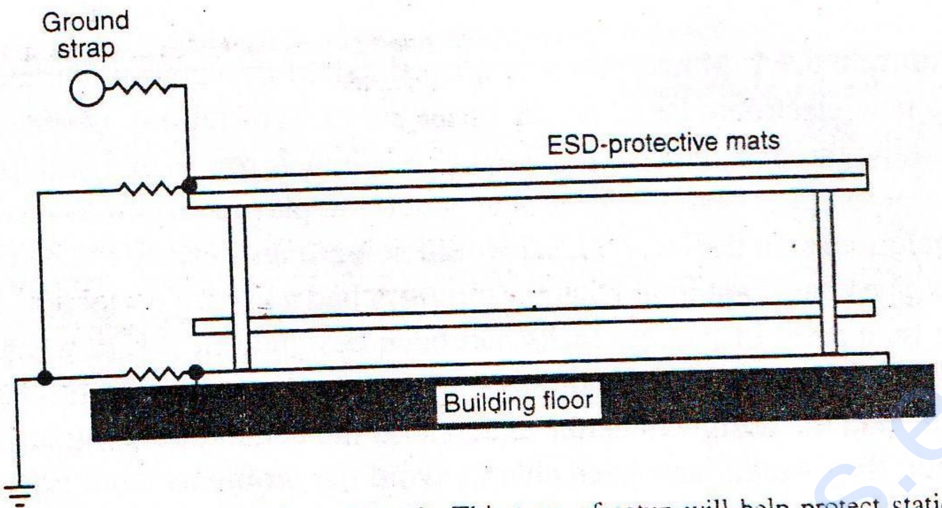


FIG. 6.43 Typical ESD-grounded workbench. This type of setup will help protect static-sensitive components.

6.9 General Rules for 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

- Undoubtedly encounter regulations and standards whatever market, product will compete in.
- Have to meet or surpass the limits of emission or susceptibility in both conducted and radiated environments.
- Regulations types may be commercial or military

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

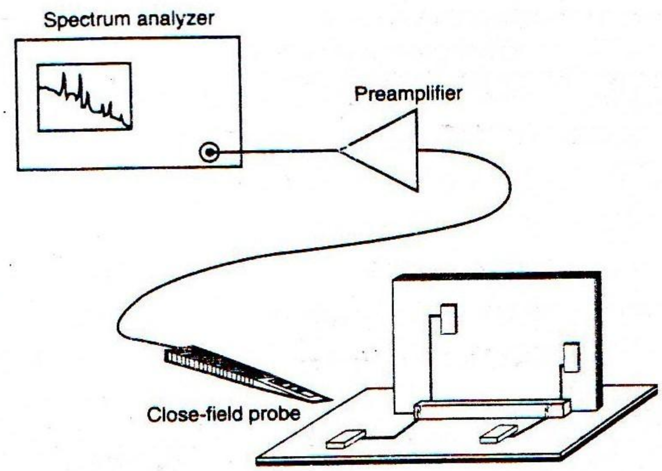


FIG. 6.45 Use of close-field probe to detect individual components, circuits, or shields that are radiating EMI.

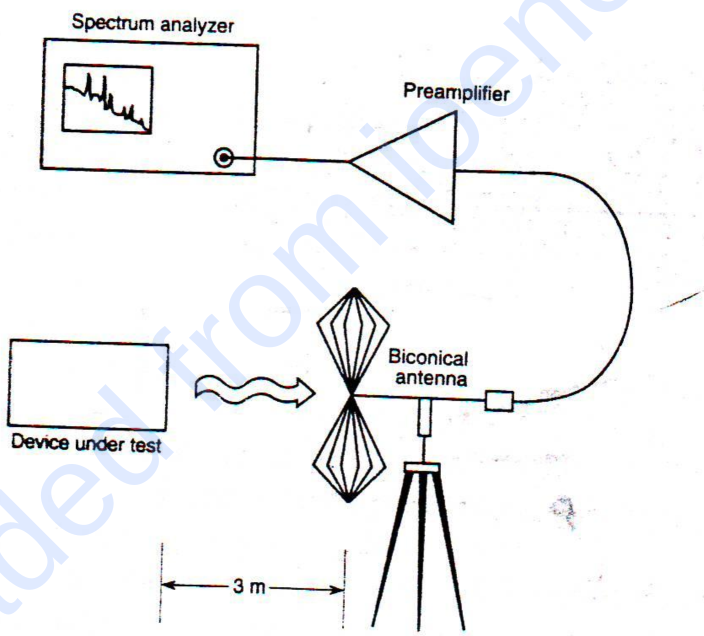


FIG. 6.47 Measuring radiated EMI with an appropriate antenna by positioning the device under test for maximum emissions.

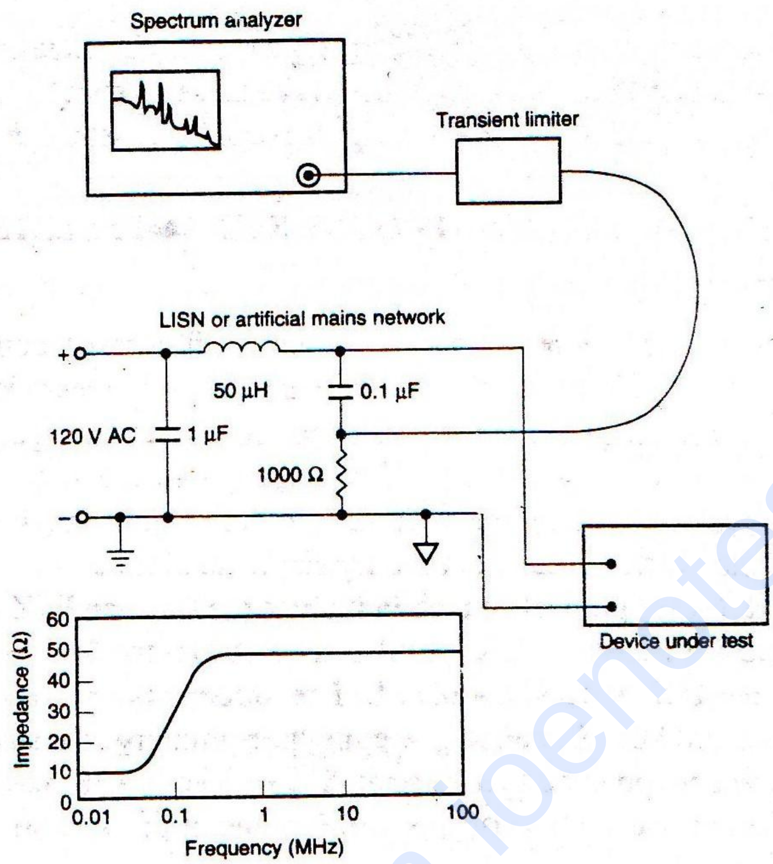


Fig. 6.46 Measuring conducted EMI by powering the device under test through a line impedance stabilization network (LISN). The LISN, or artificial mains network, isolates the test circuit from emissions conducted from the input power mains. The transient limiter presents damage to the spectrum analyzer when the LISN is switched into use.

Case Study

- Enclosure Design
- Enclosure Testing
- Option Module Design
- Circuit Suppression Design
- Printed Circuit board Design
- Power Supply Filtering
- System Design
- Acknowledgements

Be important Noted:

- Example 6.5.1, Example 6.5.2, Example 6.8.1.1, Example 6.9.1