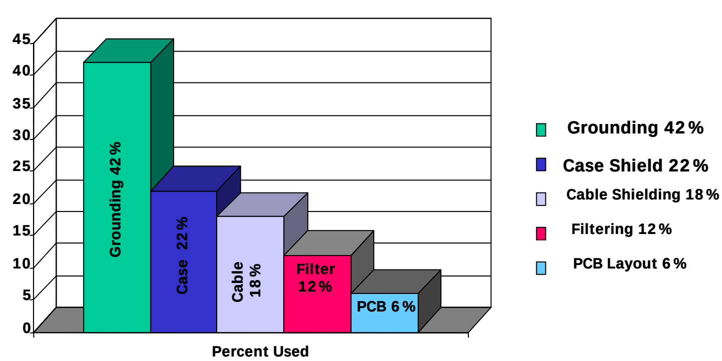
# Grounding Demystified



## Importance Of Grounding Techniques




- Categories of solutions applied for compliance.

# Ground Systems

- Grounding concepts take more time to understand than any other EMI concept because,
- Ground systems have diverse requirements and sometimes they appear conflicting.



# Examples:

1. Can we connect signal ground to chassis?
2. Should you connect the cable shield to chassis?
3. You must avoid a Ground Loop.

## What Is Grounding?

- Connecting all grounds in the system in a manner such that all of the objectives are met.
- What is ground?
  - Ground wire
  - Zero volts
  - Ground plane
  - Signal ground
  - Chassis ground
    - Conductive paint
    - A trace on PCB connecting chassis

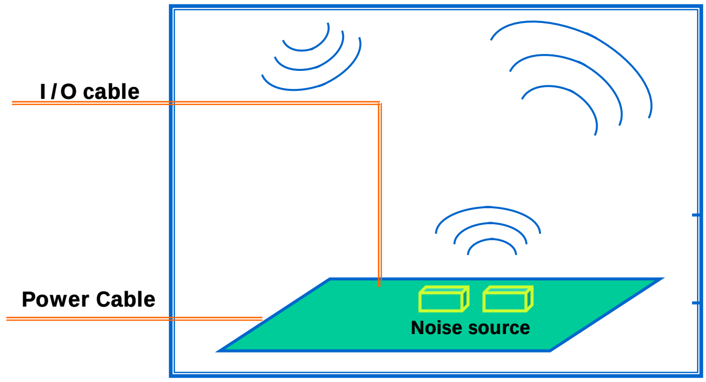


## Two Approaches to Limit the Noise

1. Stop the noise escaping the system
2. Stop at the circuit

- Often you use combination of the two.

## Noise Generation In a Digital System




- In a digital system noise is generated by circuits.

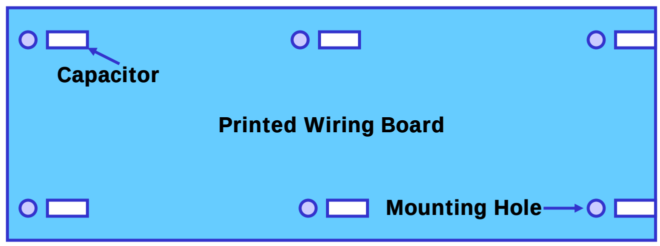


## Faraday Cage

- Faraday cage is the quiet RF reference.

- The chassis can be the Faraday cage if-
  1. It encloses the electronics.
  2. It is several times thicker than the skin depth.
  3. No conductor violates the Faraday cage.
  4. Large openings are avoided.

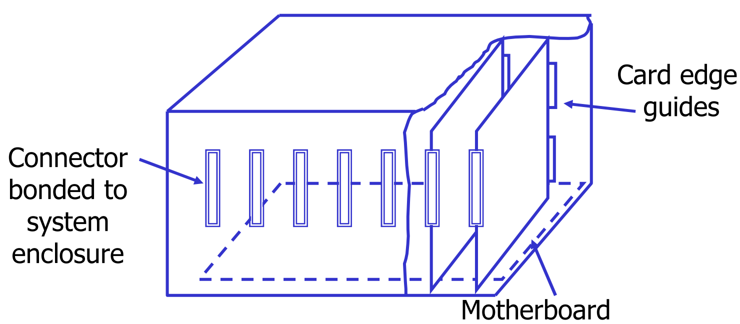
# Chassis Ground




- A direct low impedance connection to chassis is important.
- A low cost approach is to use the mother board mounting pads.
- Capacitive connection can be made to the signal ground at several points if single point ground is to be maintained.
- The effective capacitor leads must be short.

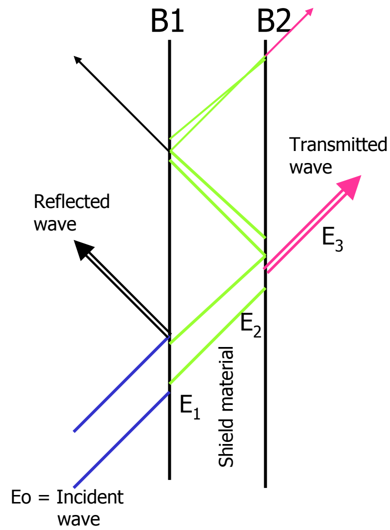


# Connection To Chassis




- Another economical way to make chassis connection is by means of connector body- such as D connectors.
- DIN connectors are available with shield and spring contacts for easy and reliable contact to the chassis.
- Power line filter body should also be used for chassis connection.

## Wave Propagation Through A Shield




- $E_0$ = Incident field strength
- $R_1$ = Reflection loss at $B_1$ = 20 log ($E_0$ /$E_1$ )
- A = Absorption loss = 20 log ($E_1$ /$E_2$ )
- $R_2$ = Reflection loss at $B_2$ = 20 log ($E_2$ /$E_3$ )
- Total shielding effectiveness
- = $E_0$ /$E_3$ = $R_1$ x A x $R_2$ x $C_m$



## Absorption Loss

- Absorption loss occurs due to induced currents
- The field decays with distance (d) traveled
- The decay is exponential, and is dependent on skin depth $\delta$
- Skin depth depends on
  - $\mu$= Permeability
  - $\sigma$= conductivity
  - $\omega$= Angular frequency of the wave

- $\delta = \sqrt{2/(\mu\omega\sigma)}$

## Grounding Considerations

- System performance: system must perform reliably.
- Safety of personnel: minimize electrical shock hazard.
- AF noise emissions and susceptibility.
- RF noise emissions and susceptibility.
- ESD immunity.

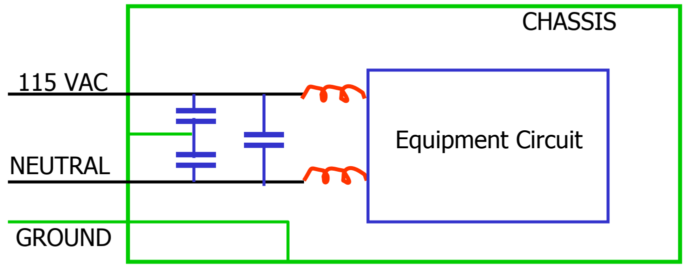
- Generally, the noise emission and noise susceptibility approaches are similar.



## Grounding For Personnel Safety

- The main concern is that the metal enclosure remain at “safe” potentials.
- So it should be connected to the green wire ground of the power cord by “reliable” means.

# Grounding For Safety




- Safety ground wire is connected to the chassis.
- EMI filter capacitors are limited by leakage current
  -UL 1950 or IEC 950 - 3.5 mA
  -Medical devices - in micro-amps.



# Ground Definitions

## --- Based on Purpose :

- General - Equipotential reference surface.
- EMC - Low effective impedance path for the return.
- ESD - Surface that can source or sink large amount of charge without changing its potential.
- Safety - Conductor providing a path for currents to flow during a circuit fault.

## Ground Design Objectives For EMC

- Minimize Cross- talk.
- Minimize Emissions.
- Minimize Susceptibility.

- One must consider signal characteristics as well as allowable noise levels when designing a grounding scheme.

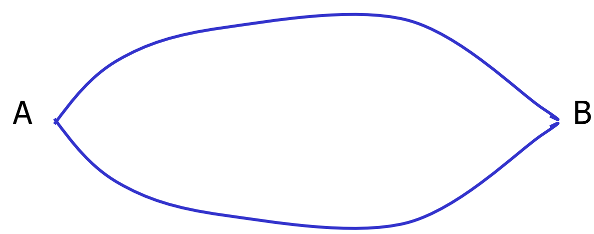


## Ground System Considerations

- There are four important circuit characteristics to be considered during the design of ground system:

1. Frequency of signal: Digital signal is broadband.
2. Effective Impedance of path: not the resistance.
3. Current Amplitude: The voltage drop is proportional to the signal current.
4. Noise voltage threshold: The noise level that a circuit can withstand or generate.

## Avoid a Ground Loop




- If a ground connects point A to B, it should not have an alternate path.

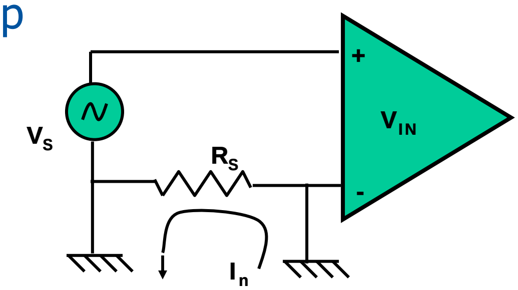


## Ground Loop

$I_n$= Induced noise current

$V_n$=Noise voltage

$V_n = I_n \times R_s$

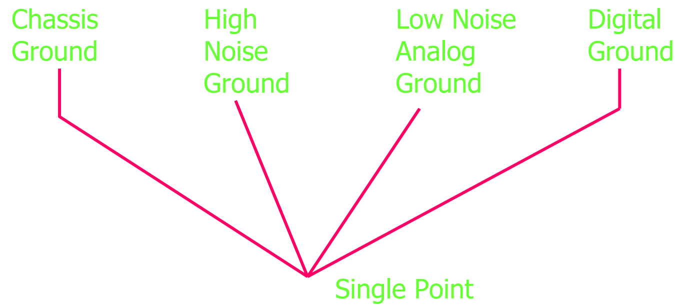



- Definition : A ground circuit allowing ground currents to flow in a loop causing two problems.

1. Induced noise voltage: magnetic coupling causes induced current resulting noise voltage.
2. The return current may take a path further away from the signal current and create a radiating loop.

# Low Frequency Grounds

-Separated According to Circuit Noise Levels

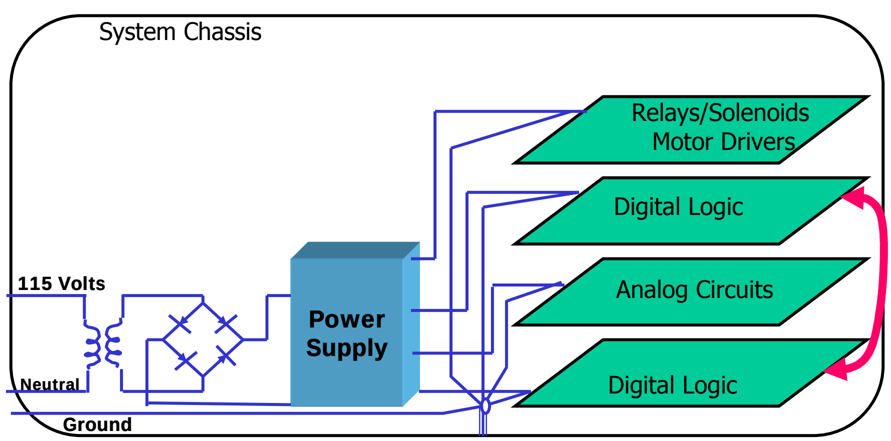



- Chassis ground normally carries no current.
- This arrangement avoids ground loops.
- Noise coupling by conduction is avoided.
- Chassis is connected to power ground for safety.
- It carries current only in fault condition.



# Typical Single Point Grounding

-for Low Frequency




- This grounding is inadequate for RF signals between the boards.

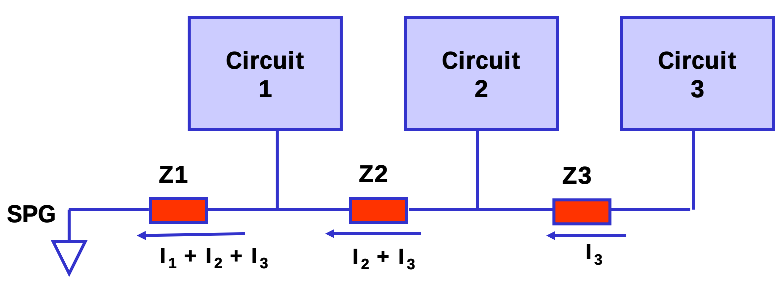
# Ground Systems For Signal Currents

- Single point ground
  - Series or Parallel ground connection
- Multi- Point Ground
  - When signal spectrum contains high frequency energy.
- Multi- Point AC Ground
  - When low frequency and high frequency is present.

- These ground systems are selected based on the frequency of signal and noise.

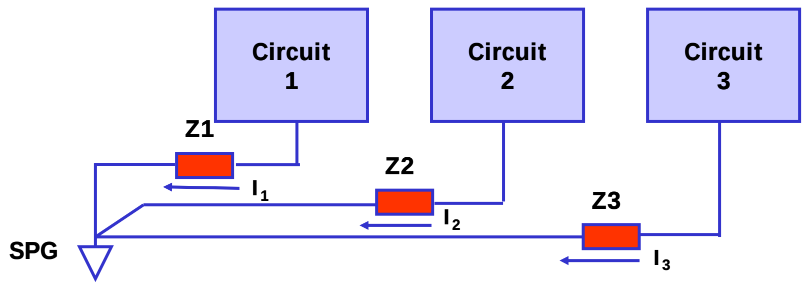


# Series Ground Connection




- Question :
  - when do you connect ground in this manner?

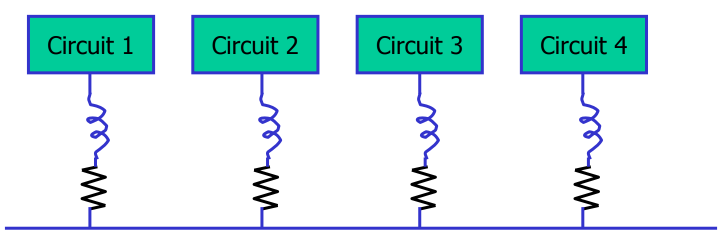
# Parallel Ground Connection




- Q: When do you connect ground in your system in this manner?

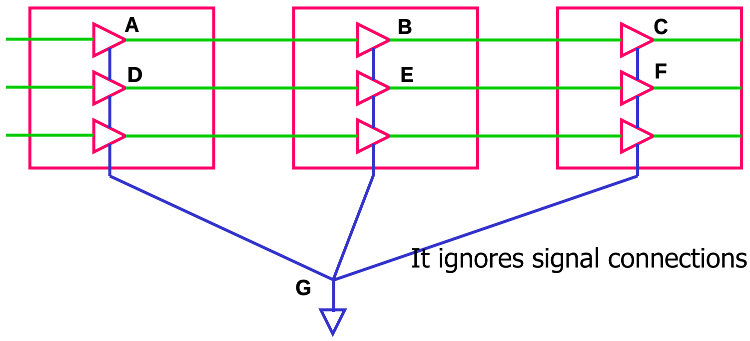


# Multi-point Ground Connection




- Definition: circuits are connected to a reference ground plane at several different points by low impedance connections.
- The low impedance, single reference ground replaces the SPG, when we add a ground plane on the PWB.

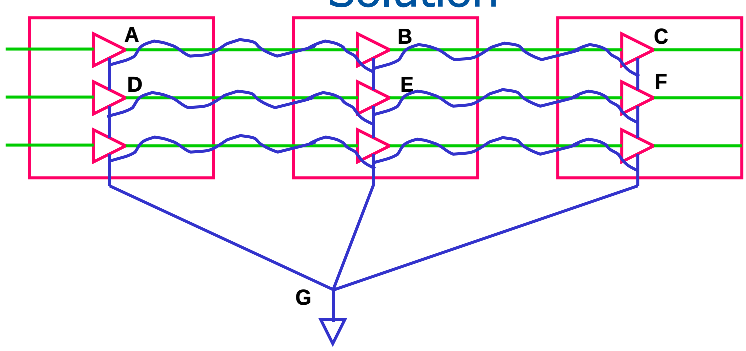
## Problem With SPG




- With the SPG, the signal circuit has magnetic loop coupling:
  - These are formed by signal conductors and all ground paths returning through SPG. The coupling increases with frequency.

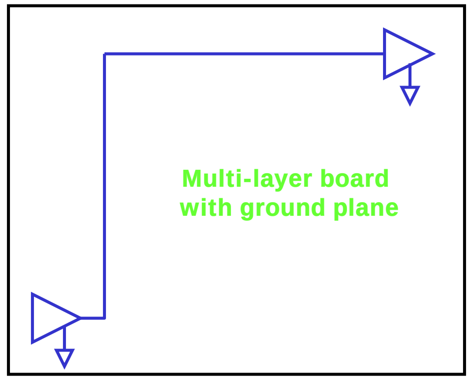


## Solution




- Provide ground paths close to the signal connections.
- This parallel path can be: (a) Twisted conductor with each signal (b) coaxial cable shield or (c) a conductor in the ribbon cable.
- Should you worry about the ground loop? Not for RF designs.

# What Is The Return Current Path?

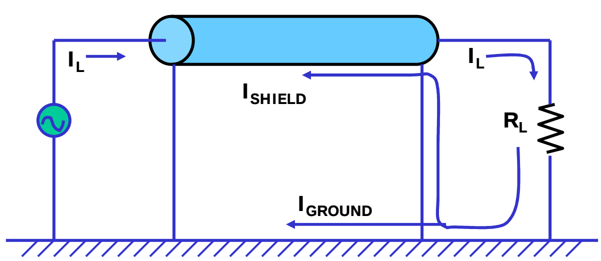



- Choices:
  - Return current takes path of the lowest resistance.
  - Return current is distributed inversely proportional to the resistance of each path.
  - Return current takes path of the lowest impedance.

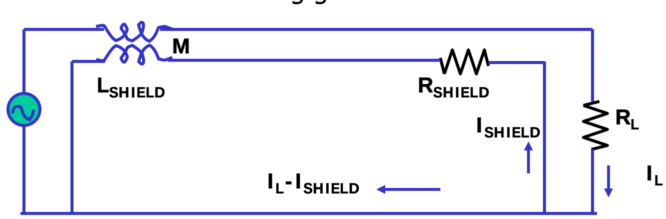


# Return Current Division

- Current is divided : (1) shield and (2) ground plane.




Equivalent Circuit- Assuming ground resistance = 0

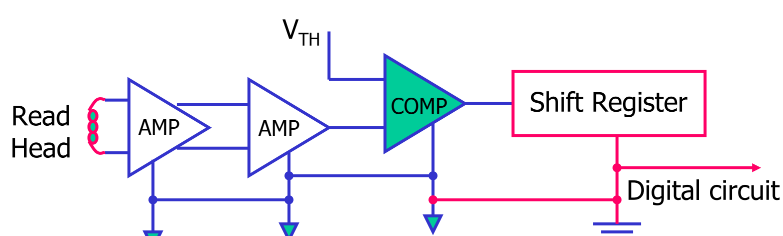


## Single Point Or RF Grounding

- Grounding scheme is chosen according to requirements. The RF and AF requirements are not contradictory.
- When low (audio) frequency and high (RF) frequency protection is required, use multi- point AC ground with only one DC connection.
- Separate grounds according to signal levels - since induced noise can affect signal only if ground loop is part of the signal circuit.

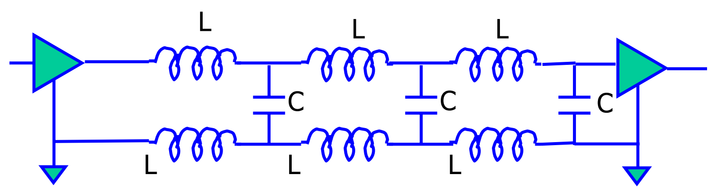


## Ground and Signal Go Together




- Keep ground with the signal when connecting different circuits.
- Ground is the return path for the signal and power current.
- This rule is very important - when we are breaking ground loop.

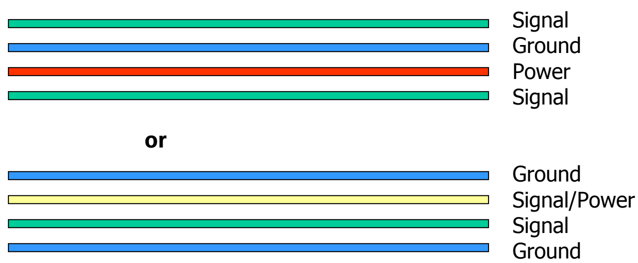
## Transmission Line




- Distributed parameters, and characteristic Impedance.
- Reflections can be controlled by controlling the impedance.
- The transmission lines used in practice are not ideal. For example, the distributed parameters include resistors attenuating the propagating signal.

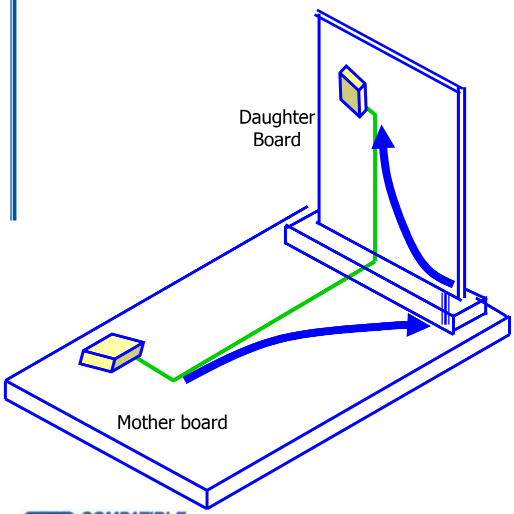


## Layer Stacks For Four Layer PCB




- Would it help to put the ground layers on the outside surface?
- How useful are high frequency signals embedded into the ground and power planes?

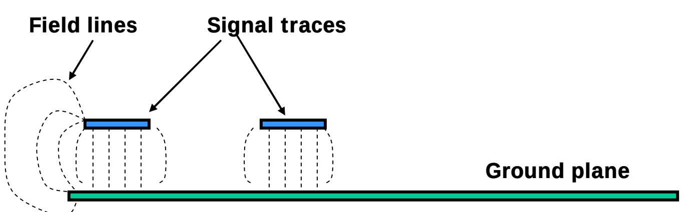
# Large Loops In Signal Return Paths




- Even with a ground plane in the PWB, a large loop in the signal path can exist.
- A return pin far away from signal pin will cause a loop.
- Large loops in signal return paths can be avoided by using distributed grounds.

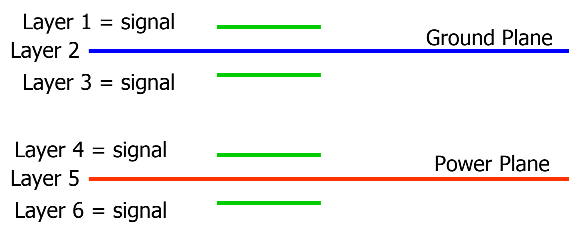


# Layout Near Board Edge




- Fringing near edge changes the characteristic impedance of the signal.
- This can result in ringing and additional radiation for high frequency signals.
- The advantages of the ground plane may be lost completely, if traces are laid outside the ground plane boundary.

# Six Layer Board




- The ground layer is two and power plane is five.
- The distance between signal layers and the reference planes should be maintained constant, say X.
- The distance between layer three and four > 3X.

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# Summary

- Chassis ground is important for RF.
- Consider Signal loop more important than ground loop – look at ground as return path.
- Transmission line is your goal when you add ground and power planes on PCB.

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