EMI Shielding, Gasketing and Filtering

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Outline

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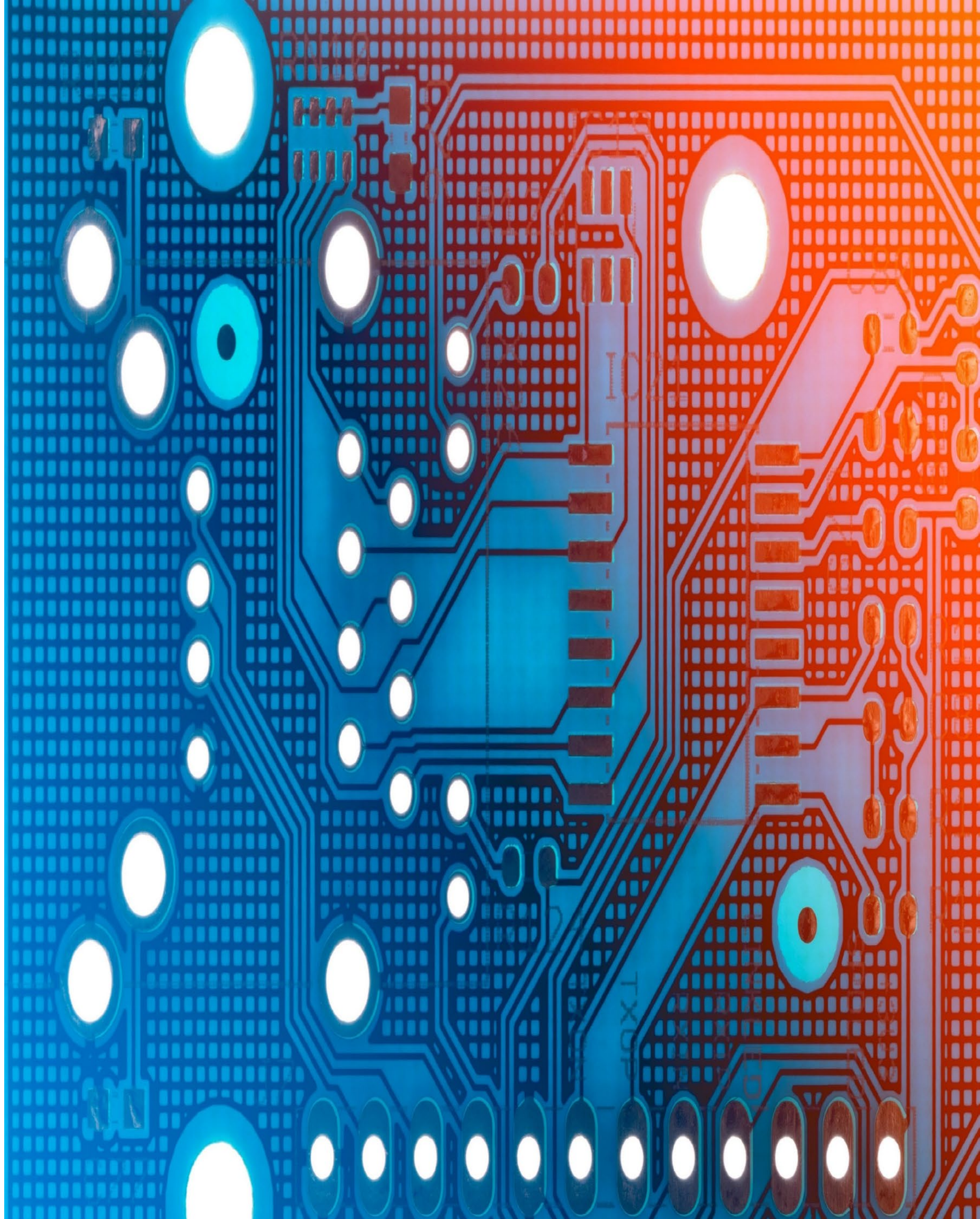
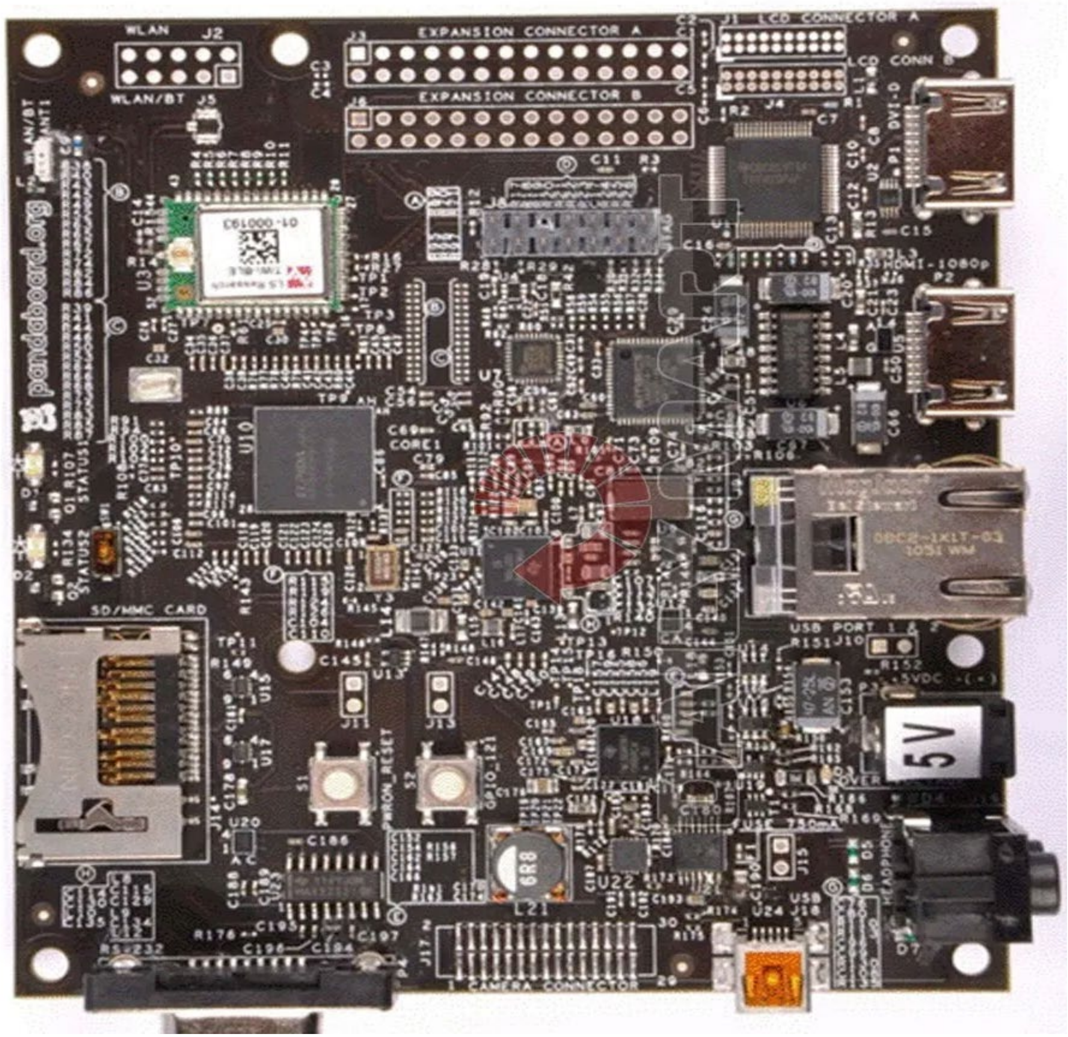
Wrap Up



Printed Circuit Board



Electromagnetic Interference (EMI)

What is Electromagnetic Interference?

- Electromagnetic interference (EMI) is the coupling of signals from one system to another.

- There are three components to creating an EMI: the source, path, and receiver.

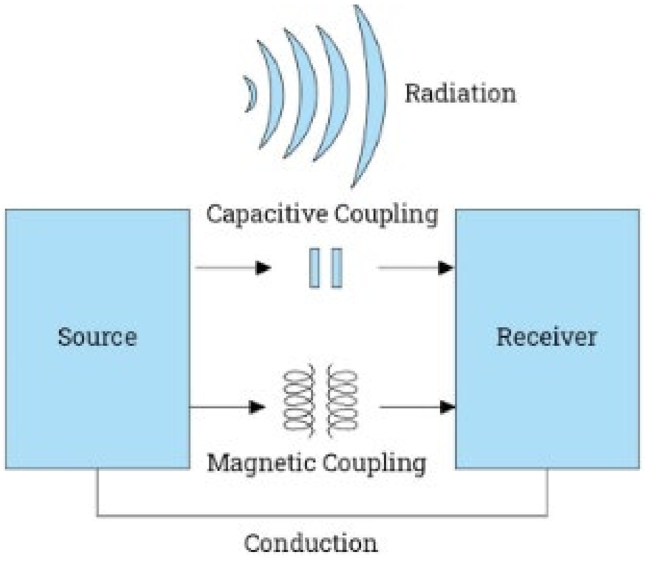


Image Source: IQSDiectory.com

☞ *Electromagnetic interference is a problem for most electronics since it can decrease the performance of the circuit or even cause it to fail.*

Modes of Electromagnetic Interference

- **Conducted EMI**: This is caused by the presence of a conductive path between two circuits where stray signals or currents can travel.
  - Common-mode
  - Differential-mode

- **Radiated EMI**: Radiated EMI propagates through the open space between the source and the receiver.

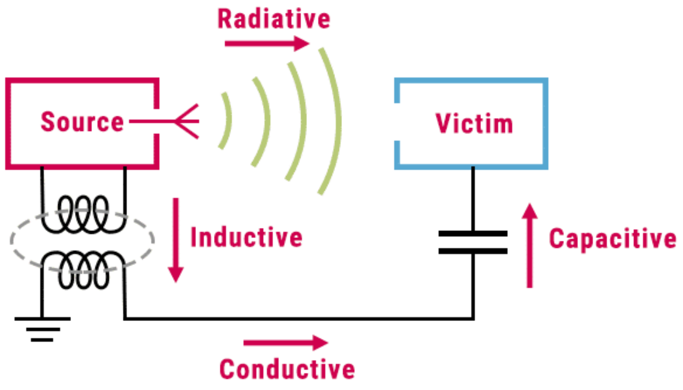


Image Source: Colin Zauner, kebamerica.com

Modes of Electromagnetic Interference

- **Capacitive EMI:** This occurs between two conductors in a system that has very close proximity, typically less than a wavelength apart.

- **Magnetic EMI:** Signal transfer is done by creating a current across another conductor through electromagnetic induction.

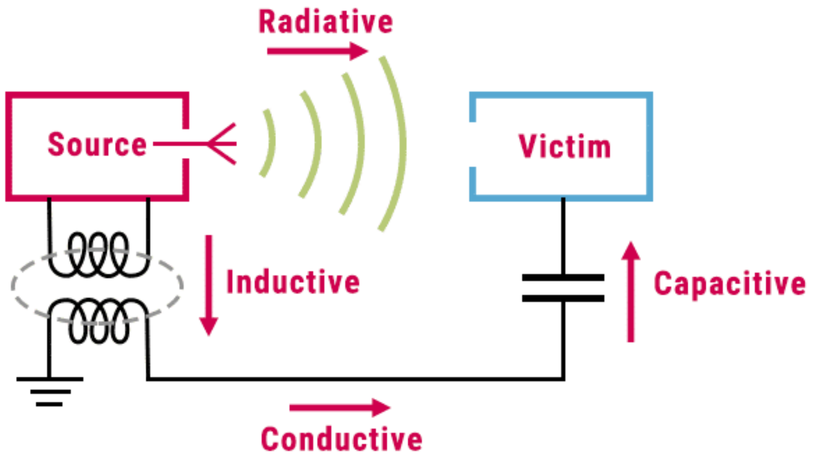


Image Source: Colin Zauner, kebamerica.com

EMI Shielding

What is EMI Shielding?

- EMI Shielding reduces RF field amplitudes propagating in free space by blocking fields with a barrier made of conductive and/or magnetic materials.
- Electromagnetic interference, or radio frequency interference (RFI), is a problem for most electronics since it can decrease the performance of the circuit or even cause it to fail.
- Shielding is achieved by using a conductive (metallic) enclosure that absorbs EMI being transmitted through air. This is commonly called as Faraday cage.
- Shielding can be all metallic enclosure if protection down to low frequencies is not needed.
- For higher frequency protection (>30MHz), almost any thin metallic material is adequate.

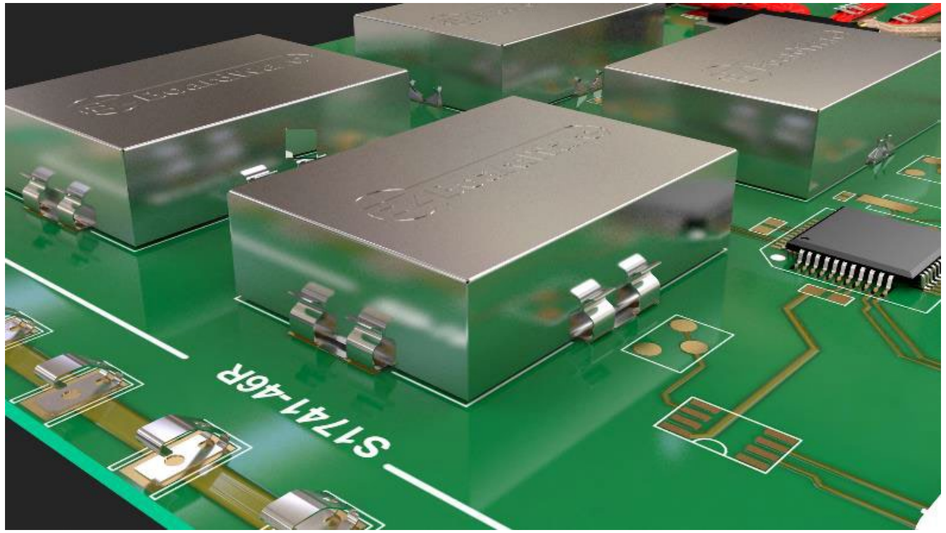


Image Source: Harwin

EMI Shielding

- Shielding performance will be affected with excessive slots, openings or cable penetrations.
- The amount of field reduction depends on material used, thickness, size of the shielded volume, the RF frequency and impedance of the field impinging on the shield compared to shield impedance.
- Metallic foil or plaited braid to shield equipment wires.
- Shielding on PCBs typically consists of a PCB with a ground plane built into it, and a metal box placed over the sensitive or transmitting elements.
- In devices such as audio speakers, an inner metallic casing would be used to successfully block EMI produced by nearby transmitting devices

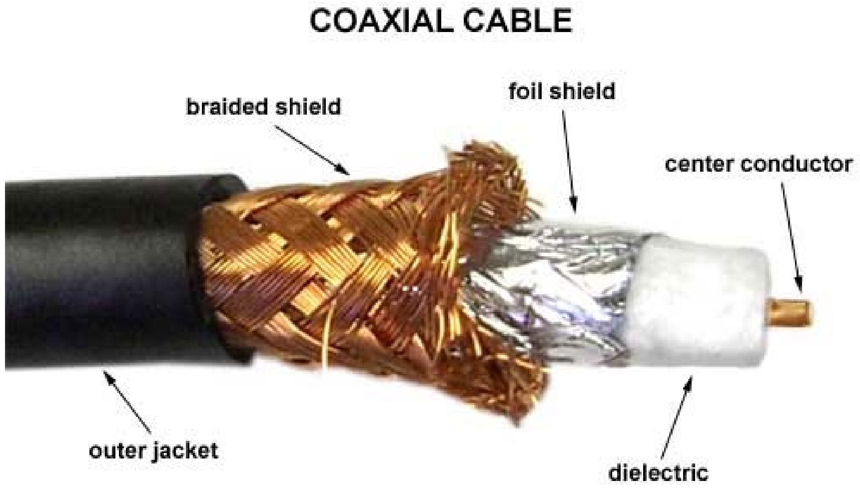


Image Source: Cablewholesale.com

Ref: Harwin

Shielding Effectiveness

- Shielding Effectiveness

$$SE\ (dB) = R + A + B$$

  R: Reflection Loss
  A: Absorption Loss (function of frequency and material)
  B: Loss due to multiple reflections (usually very small)

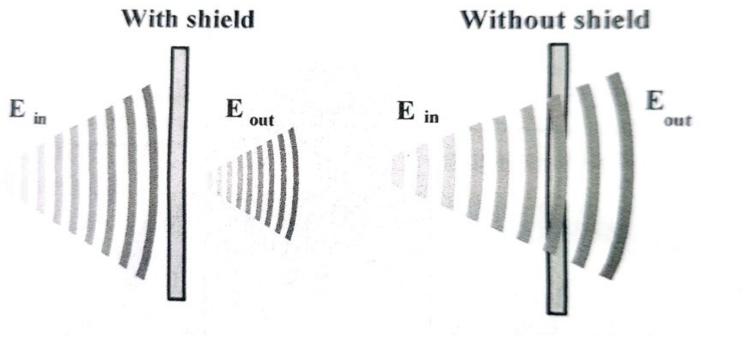
- If the reflected wave phase adds with the incident wave, total RF intensity internal to the system would increase.

- Impedance of the free space:

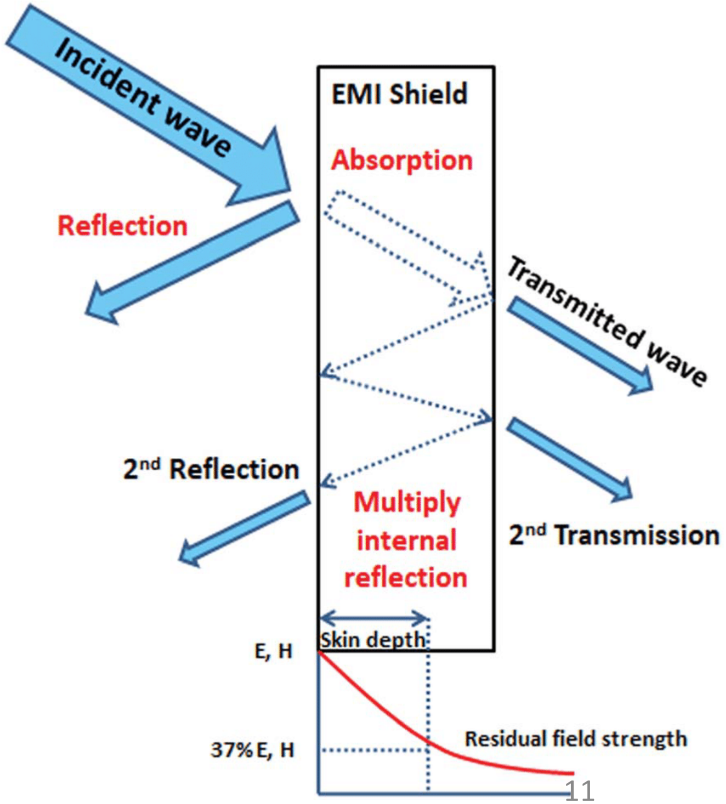
$$Z = \frac{E}{H} = \sqrt{\frac{\mu_o}{\varepsilon_o}} = 377\Omega$$

- Impedance mismatch between free air and the metallic barrier causes reflections at the boundary.

- The remaining field not reflected at the boundary is either absorbed internally or passes through, depending on thickness of the metal layer.



Ref and Image Source: Mark Montrose, "EMC Made Simple"



Shielding Effects

- A perfectly conducting enclosure that surrounds a given volume prevents anything within that volume from electrically coupling to anything outside that volume. This type of enclosure is called a Faraday cage.

- A metallic sphere of high conductivity will eliminate any internal electric field because induced charges on one side tend to generate electric field that cancels the original field from the other side.

- Magnetic field attenuation can be achieved by means of a boundary condition made of magnetic material combining high permeability with sufficient thickness to attract the material's magnetic field by providing a low reluctance path.

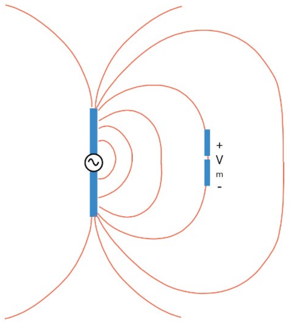


Fig: Electric Field Coupling without shielding
Image source: learnemc.com

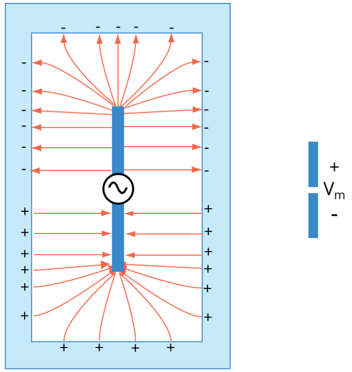


Fig: Electric Field Shielding
Image source: learnemc.com

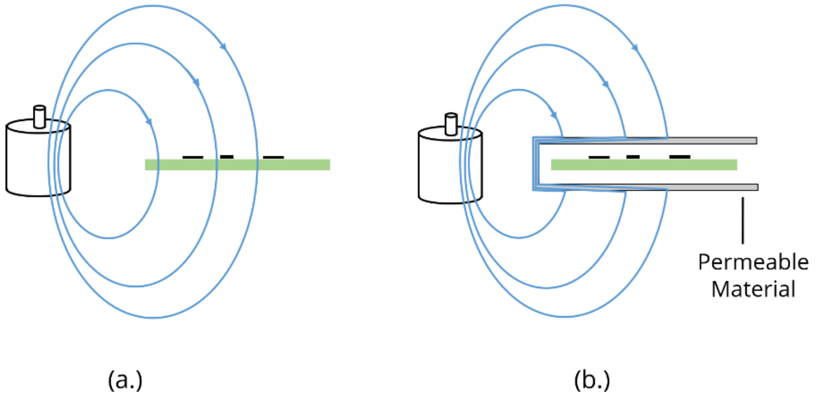


Fig: a) Magnetic field coupling b) Magnetic Field Shieling by using high permeability material
Image source: learnemc.com

Ref: Mark Montrose, "EMC Made Simple", Montrose Compliance Services
Ref: www.learnemc.com

Shielding Effects

- Alternatively, a thin shield made of a conductive material with low permeability can provide some level of effective shielding for magnetic fields only if there is adequate skin depth presented by thickness, frequency and conductivity of the shield material.

- Alternating magnetic field will induce eddy currents in the barrier provided the shield has adequate conductivity.

- Eddy currents will themselves create an alternating magnetic field of equal and opposite orientation inside the closed volume. This effect will increase as frequency increases resulting in high shielding effectiveness at higher frequencies.

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Shielding Effects

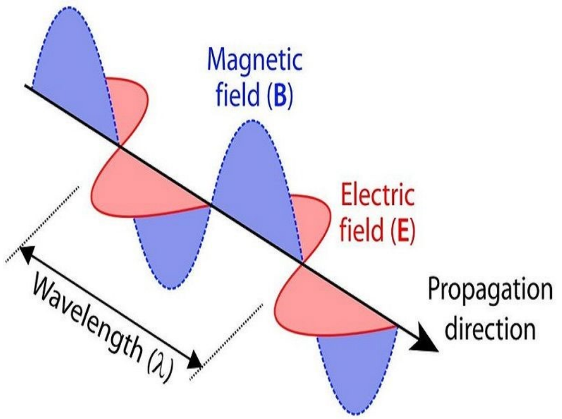
- Low frequency magnetic fields are more difficult to shield.
- Shields based on induced current principle can be effective at power line frequencies (50/60Hz).
- Any opening in the shield will limit its effectiveness. Apertures have high frequency resonances and can act as transmitting antennas.
- It is essential that any openings be arranged in such a manner to minimize any disturbance in the current propagation.

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Near Field and Far Field Condition

- Plane wave conditions in free space $\left(\frac{E}{H} = Z_o = 377\Omega\right)$ appear when the distance from the radiation source is several wavelengths away $(d \geq \frac{\lambda}{2\pi})$. This is the far-field region.

- The amplitude of E-field and H-field decrease in the far-field as 1/r.



- In the near-field region, the ratio between E and H is complex and varies with distance from the source.

- A higher impedance antenna source, such as dipole, will produce a near field dominated by E, while a lower impedance antenna such as a current loop will yield a near field dominated by H.

- In the near field, shield must be designed separately for both electric and magnetic field components.

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Reflection Losses in the Shield Barrier

- Reflection loss is the ratio of impinging wave impedance to barrier impedance.
- The barrier impedance is a function of conductivity, permeability and frequency. This combination describes skin depth.
- Materials with high conductivity such as copper and aluminum have higher E-field refection loss than lower conductivity metal such as steel.
- Reflection loss is high for electric fields in near field. Conversely, H-field impedance is low in the near field and thus low magnetic field reflection loss.
- Reflection loss is relatively high for high frequency magnetic fields.

$$Z_0 = \sqrt{\frac{\mu_o}{\varepsilon_o}} = 377\Omega \qquad Z_s = \sqrt{\frac{2\pi f \mu_r \mu_o}{\sigma}} \qquad R(dB) = 20\log\left(\frac{Z_o}{4 * Z_s}\right)$$

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Reflection Losses in the Shield Barrier

- In the near field, electric field has higher reflection loss.
- Reflection loss of the electric field decreases with frequency until separation distance is $\frac{\lambda}{2\pi}$.
- Reflection loss of the magnetic field increases with frequency before the loss begins to decrease at the same rate as the plane wave.
- At a distance $r = \frac{\lambda}{2\pi}$, both electric and magnetic field reflection losses merge

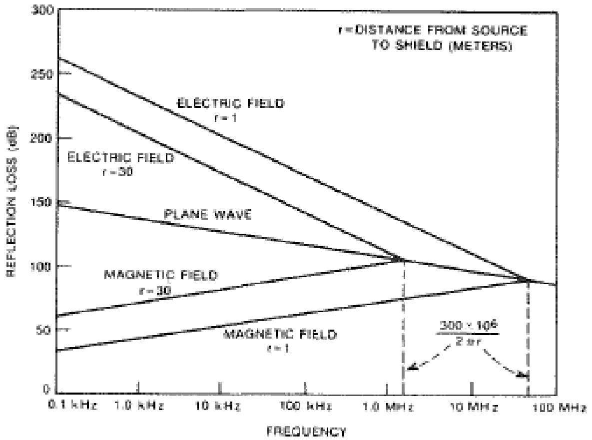
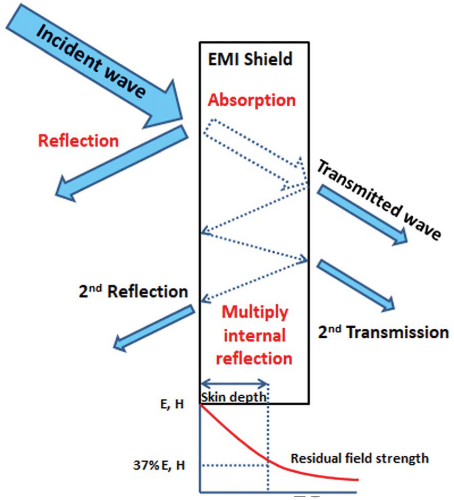


Fig: Reflection loss in a copper shield relative to frequency

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Absorption Losses in the Shield Barrier

- Absorption loss is the loss within the shield barrier caused by the dissipation or conversion of electromagnetic energy into heat.
- Absorption loss increases with frequency, barrier thickness, barrier permeability and conductivity.
- Absorption loss is related to skin depth. Steel has higher absorption loss than copper.
- At high frequencies, absorption becomes the dominant mode increasing exponentially with the square root of frequency. In 30-100MHz range, it is greater than reflection loss.
- At low frequency: reflection loss; at high frequency: absorption loss.



$$E_1 = E_o e^{-\frac{t}{\delta}} \qquad H_1 = H_o e^{-\frac{t}{\delta}} \qquad A = 20\frac{t}{\delta}\log(e) \qquad \delta = \sqrt{\frac{2}{\omega\mu\sigma}} = \sqrt{\frac{1}{\pi f \mu\sigma}}\, meters$$

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Apertures in the Shield Barrier

- Apertures allow a radiated field to propagate from one side to the other causing an emission.

- When currents are induced into the shield, they generate scattered fields which counteract the incident field, to satisfy the boundary condition related to the total electric field tangent to the barrier.

- In a perfect conductor, the total electric field is zero if there are no disruptions to the current flow.

- If there are slots in the barrier, current flow is disrupted and shielding effectiveness is reduced.

- If we orient the slot in parallel to the direction of the induced current the opening will have much less effect on shielding effectiveness.

- For small holes (size < λ/2π), fields cannot propagate and hence preferred by distributing on all sides.

For $l < \lambda/2$ $$SE = 20\log\left(\frac{\lambda}{2l}\right)$$ l is the maximum linear dimension of the opening

Ref: Mark Montrose, "EMC Made Simple", Montrose Compliance Services

Apertures in the Shield Barrier

- Normally, at high frequencies, the openings in EMI shields act as slot antennas. To avoid this slot antenna effect in EMI shield openings, a dimension for the aperture is calculated, above which it serves as a slot antenna.

- Ideal dimension of the slots: λ/20 to give 20dB of SE. $SE = 20\log\left(\frac{\lambda}{2l}\right)$

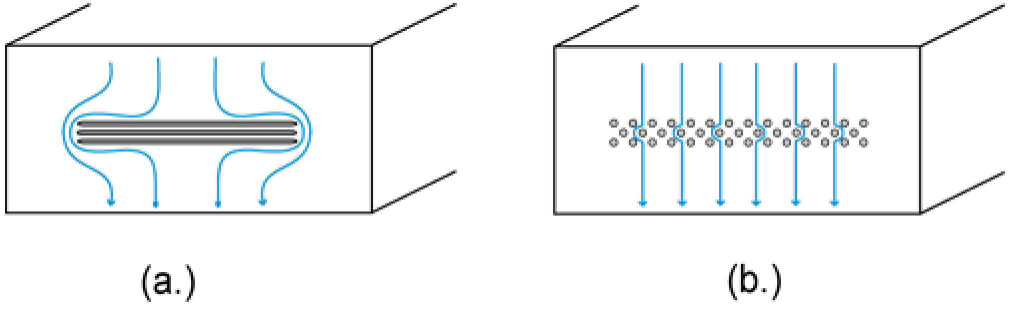


Fig: RF current distribution in a) large openings and in b) small openings
Image Source: learnemc.com

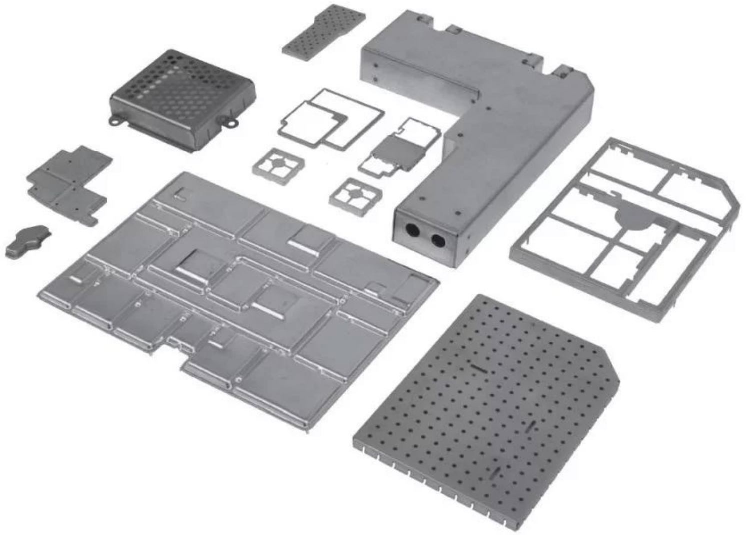


Fig: EMI Shielding Parts
Image source: Laird, DuPont

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Gaskets

Gaskets

- Gaskets make a low impedance connection between two conductive surfaces to ensure undesired RF energy does not enter, leave or penetrate an enclosure or shield barrier.

- An ideal shield barrier is a continuous seal between two mating surfaces with no apertures or openings.

- Gaskets are used for temporary or semi-permanent sealing applications between joints of metallic structures

- Examples:
  - Securing access doors to enclosures, cabinets or equipment
  - Mounting cover plates
  - Mounting honeycomb covers to enclosure cabinets
  - Securing parallel members of equipment housing to a frame structure using machine screws.

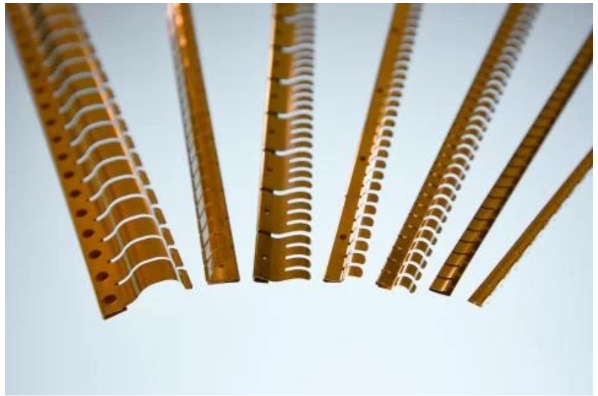


Fig: Finger Stock Gaskets
Image source: Laird, DuPont

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Types of Gaskets

- **Aluminum Foil**: Excellent for electric fields but poor for magnetic field.
- **Knitted Wire Mesh**: Tin-plated, copper-clad or steel knitted wire mesh. Cost effective for low cycling applications. Designed for enclosure joints, door contacts, cables. Mesh can penetrate plating on metals and useful over a broad frequency range.
- **Oriented Wire Mesh**: Oriented array of wires of aluminum are impregnated into a solid or sponge silicone. Designed for military, industrial and commercial applications. Good for environmental sealing, repeated opening and closing of access doors using high compression forces. Can penetrate through plating on metals.
- **Conductive Elastomer**: Provides high SE up to 120dB at 10GHz. High corrosion resistance. Conductive fillers include, but not limited to: Carbon, passivated aluminum, silver plated aluminum/copper/glass/nickel, nickel coated carbon. etc.

Fig: Conductive Elastomers
Image source: Laird, DuPont

Fig: Knitted Wire Mesh
Image source: knittedwiremesh.net

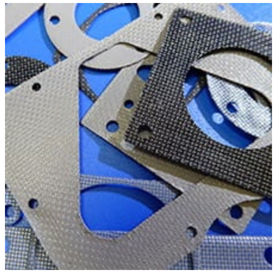


Fig: Oriented Wire in Silicone Gaskets
Image source: silram.co.il

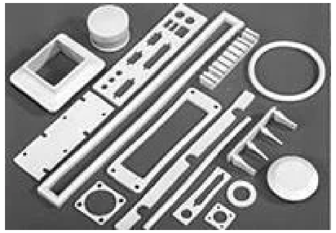


Fig: Silver filled Liquid Silicone coated gasket
Image Source: Laird, DuPont

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Types of Gaskets

- **Metal Strips:** Tin-plated beryllium copper installed between to flat surfaces such as a metal case and its top cover. BeCu is highly conductive, corrosion resistant spring material. Tin plating is added to the surface to lower contact resistance to other metal.

- **Conductive Coating**: Silver, nickel or copper applied to a surface to enhance conductivity and provide good level of shielding effectiveness.

- **Conductive fabric over foam**: Low-cost material. Ideal for applications that require low compression force but still need high conductivity and shielding attenuation. Conductive cloth offers very small size stitching of metallized nylon fibers.

- **EMI Tapes:** Thinner, conductive tapes of nickel/copper metallized fabric (with conductive PSA).

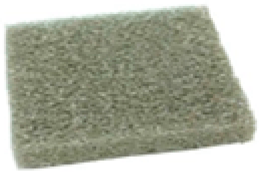


Fig: Conductive Foam Gaskets
Image source: Laird, DuPont

Fig: Fabric over Foam Gaskets
Image source: Laird, DuPont

Fig: EMI Tapes
Image source: Laird, DuPont

Fig: Conductive Fabric
Image source: Laird, DuPont

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services, Laird DuPont

EMI Filters

EMI Filters

- An EMI filter is a passive device to suppress EMI present on both signal and power transmission lines.

- Filters protect from EMI as well as EMC. They include components to suppress both common and differential mode noise.

- Factors to consider when choosing a filter:
  - Insertion loss
  - Impedance
  - Power handling capability
  - Signal distortion
  - Tunability
  - Cost
  - Weight
  - Size

Fig: Single Phase Filters, Corcom N Series
Image source: TE Connectivity

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Insertion Loss in EMI Filters

- Filters have high reactive, discrete components relative to the impedance of a transmission line.

- Filters look like a high value resistor for low frequency signals and an inductor for high frequency signals.

$$H(f) = \frac{V_L(f)}{V_S(f)}$$

- Insertion Loss is the reduction of signal power resulting from the insertion of a filter in the transmission line

$$IL = 10\log\left(\frac{P_t}{P_r}\right)$$

Pt: power transmitted to the load without filter
Pr: power transmitted to the load with filter loss

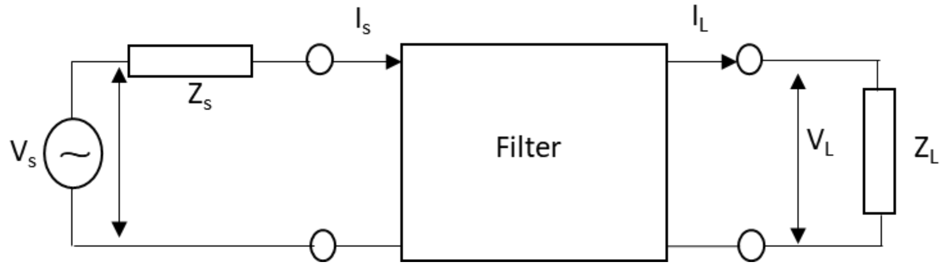


Fig Transfer function of a Filter

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Filter Configurations

- Discrete: Symmetrical filters (bi-directional)
- Series Inductor: T- Filter
- Shunt Capacitor: π – Filter
- Asymmetrical: L- Filter

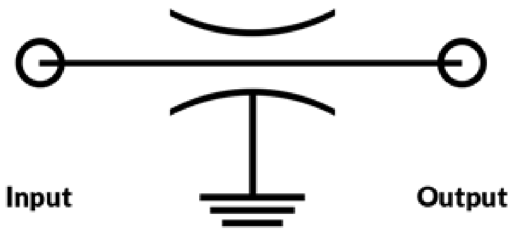


Fig: Feedthrough filter
Image Source: passive-components.au

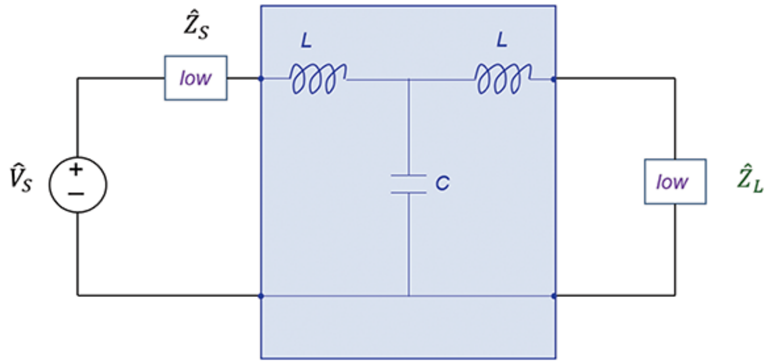


Fig::T-filter

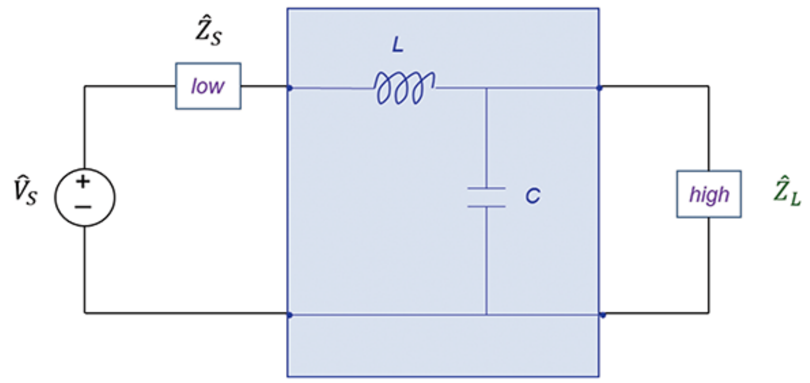


Fig::LC-Filter

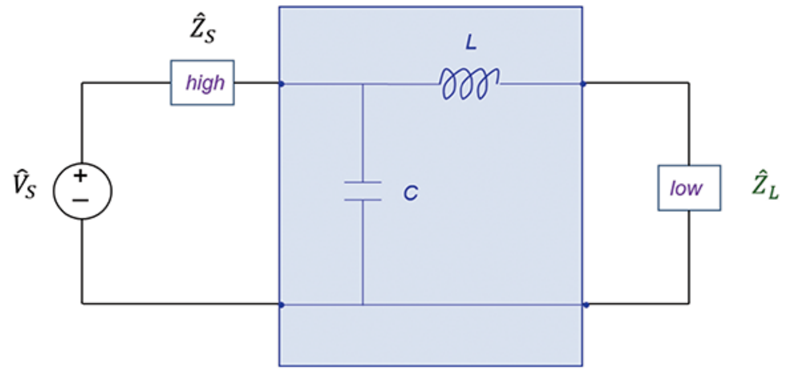


Fig::CL-Filter

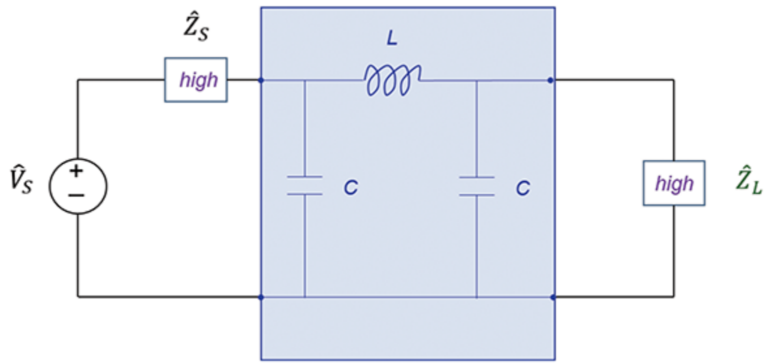


Fig::π-filter

Image Source: Incompliance Magazine

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Common-Mode and Differential-Mode Filters

- Common Mode Filters:
  - Common-mode noise is undesired RF energy created because of an imbalance within any transmission line system.

  - A common mode filter is an electrical filter that blocks high frequency noise common to two or more data or power lines while allowing the desired DC or low-frequency signal to pass. Common mode filters are used in the inputs to switching power supplies.

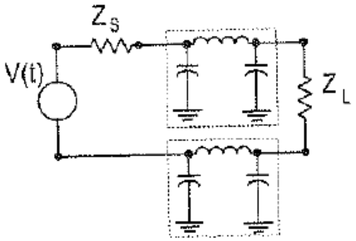
  - To filter common-mode noise, a shunt capacitor is generally required.

  - A common-mode filter does not affect differential mode noise since the shunt capacitor is located across two conductors carrying the same RF noise and is thus invisible to differential mode interference.

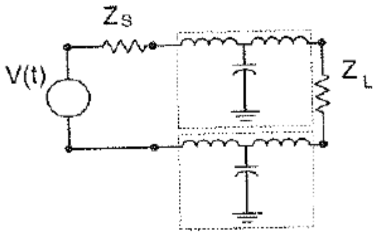
Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Common-Mode and Differential-Mode Filters

- Common Mode Filters:
  - There are two ways to design the filter. One way is to put the inductor and resistor in series with every line.
  - The other way is to wrap all lines on a common core and wire them in opposite directions such that only undesired common mode current is attenuated.
  - Important aspect is connecting the capacitor to earth ground in the “Y” configuration.
  - If earth ground is not present, a series choke, or resistor can be added to absorb the undesired RF energy.

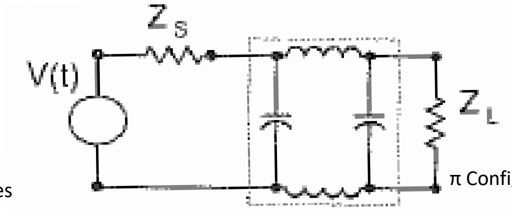


π Configuration

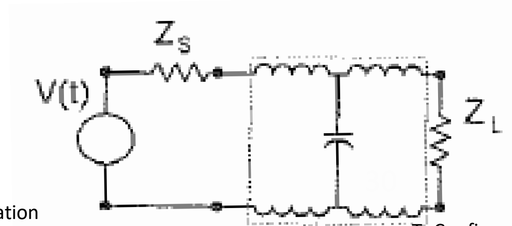


T- Configuration

- Differential Mode Filters:
  - These are installed within a signal line and sometimes within the return path without any connection to earth ground.
  - When differential mode filtering is required in AC power line filters, line to line capacitors and a discrete inductor can be used.



π Configuration



T- Configuration

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Types of Filters

- Low Pass Filter
- High-Pass Filter
- Band-Pass Filter
- Band-Reject Filter

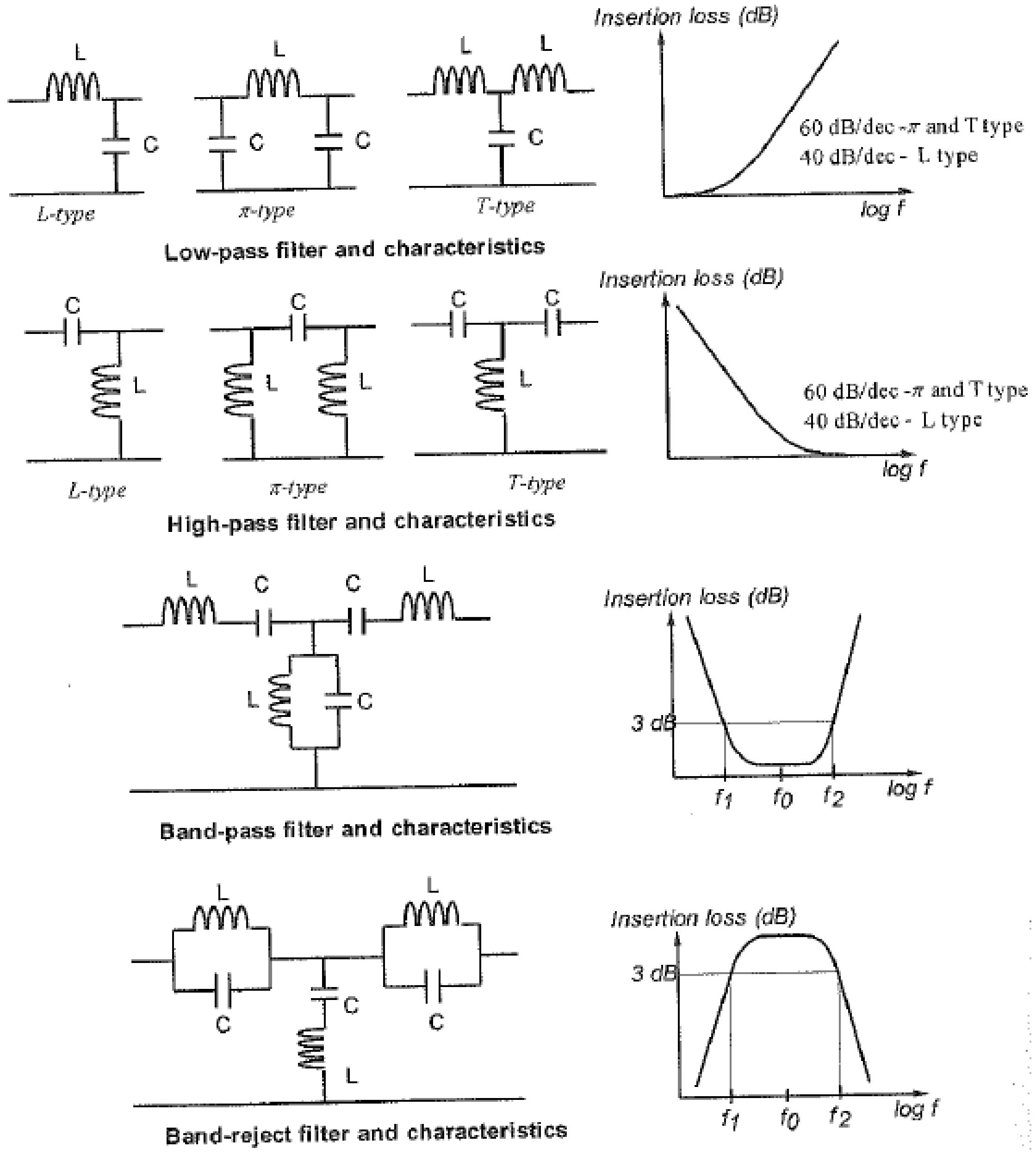


Fig Transfer function of a Filter

Ref: Mark Montrose, “EMC Made Simple”, Montrose Compliance Services

Signal Integrity Wrap Up

Important Design Guidelines for Signal Integrity

- Use controlled impedance traces.
- Ideally, all signals should use low-voltage planes as their reference planes.
- If different voltage planes are used as signal references, there should be tight coupling between them, such as thin dielectric and low inductance capacitors between different voltage planes.
- Use proper termination strategies
- Keep the time delay of stubs less than 20% of the rise time of the fastest signals.
- Place the terminating resistors as close to the package pads as possible.

Ref: Eric Bogatin, “Signal and Power Integrity Simplified”, Prentice Hall

Important Design Guidelines for Signal Integrity

- Follow the return path of each signal and keep the width of the return path at least 3 times the width of the signal trace.
- Route signal traces around rather than across return path discontinuities.
- When rise times are less than 150ps, minimize the loop inductance of the terminating SMT resistors or consider using integrated or embedded resistors.
- Vias generally look capacitive. Minimize the capture pads and increase the antipad clearance diameter to make the via look transparent.
- Route all differential pairs with a constant differential impedance.
- Avoid all asymmetries in a differential pair.

Ref: Eric Bogatin, "Signal and Power Integrity Simplified", Prentice Hall

Important Design Guidelines for Signal Integrity

- If delay line must be added on one leg of a differential pair, add it near the beginning of the trace and keep the traces uncoupled in this region.

- In general, route differential pair traces with as tight a coupling as practical.

- For any board level differential pairs, there will be significant return current in the planes, so avoid all discontinuities in the return path.

- To minimize cross talk, keep the spacing between adjacent signal traces at least twice their line width.

- If you have to cross a gap in the return path, only use differential pairs. Never cross a gap with single ended signals routed close together.

Ref: Eric Bogatin, “Signal and Power Integrity Simplified”, Prentice Hall

Important Design Guidelines for Signal Integrity

- For surface traces, keep the coupled lengths as short as possible and use as much solder mask as practical to minimize far-end cross talk.
- Use the lowest dielectric constant laminate so the dielectric spacing to the return plane can be kept to a minimum for the same target impedance.
- In a tightly coupled microstrip bus, the deterministic jitter can be reduced by keeping the spacing at least twice the line width.
- For isolations in excess of -60dB, use stripline with guard traces.
- If you use a guard trace, make it as wide as possible with vias to short the ends to the return path.

Ref: Eric Bogatin, “Signal and Power Integrity Simplified”, Prentice Hall

Important Design Guidelines for Signal Integrity

- Minimize ground bounce by making the return paths in any package or connector as short and wide as possible.

- Minimize ground bounce in the power plane by bringing it closer to the return plane.

- Minimize ground bounce in the signal return paths by bringing the signal path as close to the return path as acceptable.

- Avoid using shared return paths in connectors and packages.

- When assigning leads in a package or connector, reserve the shortest leads for the ground paths and space the power and ground leads uniformly among the signal paths, or closest to the signal paths that will carry a lot of switching current.

Ref: Eric Bogatin, “Signal and Power Integrity Simplified”, Prentice Hall

Important Design Guidelines for Signal Integrity

- All no-connect leads or pins should be assigned as ground-return conditions.

- If a signal changes reference planes, the reference planes should be as closely spaced as possible. If you use a decoupling capacitor to minimize the impedance of the return path, select it and design it for lowest loop inductance.

- If many signal lines are changing reference planes, space the signal path vias as far as possible, rather than clustering them all in the same location.

- If a signal switches reference layers, and the planes are at the same voltage level, place a via between the return planes as close to the signal via as possible.

- Use chip-scale packages than the larger packages.

Ref: Eric Bogatin, “Signal and Power Integrity Simplified”, Prentice Hall

Power Integrity Wrap Up

Important Design Guidelines for Power Integrity

- Minimize the loop inductance between power and ground paths.
- Allocate power and ground planes on adjacent layers with as thin a dielectric material as possible.
- Get the lowest inductance between the planes by having a high dielectric constant material between the planes.
- Use as many power- and ground-plane pairs in parallel as possible.
- Route the same currents far apart and opposite currents close together.
- Place each power via as close as practical to a ground via. If it is not possible to get them at least within a pitch equal to their length, there will be no value in proximity.

Ref: Eric Bogatin, “Signal and Power Integrity Simplified”, Prentice Hall

Important Design Guidelines for Power Integrity

- Route the power and ground planes as close as possible to the surface where the decoupling capacitors are mounted.

- Use multiple vias to the same power or ground pad but keep the vias as far apart as possible.

- Use vias as large in diameter as practical when routing to power or ground planes.

- Use double bonding on power and ground pads to minimize the loop inductance of the wire bonds.

- Use as many power and ground connections from the chip and from the package as possible.

- Try to keep the PDN impedance as flat as possible and below the target impedance.

Ref: Eric Bogatin, “Signal and Power Integrity Simplified”, Prentice Hall

Important Design Guidelines for Power Integrity

- Use chip-interconnect methods that are as short as possible, such as flip-chip rather than wire-bond.

- Use package leads as short as possible, such as chip-scale packages rather than QFP packages.

- Keep all surface traces that run between the pads of the decoupling capacitors and their vias as short and wide as possible.

- Use as small a body size for a decoupling capacitor as possible to minimize the length of all connections from the capacitor pads to the power and ground planes.

- Place as much decoupling capacitance as possible on the chip itself.

- Use differential pairs for I/Os.

Ref: Eric Bogatin, “Signal and Power Integrity Simplified”, Prentice Hall

EMI/EMC Wrap Up

Important Design Guidelines to Minimize EMI

Strategy: Reduce the voltage that drives common currents, increase the impedance of the common current paths, and use EMI shields and filters when needed

- Minimize ground bounce.
- Keep all traces at least five-line widths from the edge of the board.
- Route traces in stripline when possible.
- Place the highest speed and highest current components as far from the I/O connections as possible.
- Place the decoupling capacitors close to the chips to minimize the spread of high-frequency current components in the planes.

Ref: Eric Bogatin, “Signal and Power Integrity Simplified”, Prentice Hall

Important Design Guidelines to Minimize EMI

- Keep power and ground planes on adjacent layers and as close together as possible.
- Use as many power- and ground-plane pairs as possible.
- Use ground planes as surface layers, where possible.
- Know the resonant frequency of all packages and change the package geometry if there is an overlap with a clock harmonic.
- Avoid signals switching different voltage reference planes in a package. This will drive package resonances.
- Add ferrite filter sheets to the top of packages if they might have a resonance.
- Minimize asymmetry in a differential pair.

Ref: Eric Bogatin, “Signal and Power Integrity Simplified”, Prentice Hall

Important Design Guidelines to Minimize EMI

- Use common signal choke filter on all differential pair connections.

- Use a common-signal choke filter around the outside of all peripheral cables.

- When connecting shielded cables, try to keep the shield as an extension of the enclosure.

- Minimize the inductance of the shielded cable connections to the enclosure. Use a coaxial connection right from the end of the cable and to the enclosure.

- Equipment bays should not penetrate the integrity of the enclosure, only interconnects need to break the enclosure integrity.

- Keep aperture diameters significantly smaller than a wavelength of the lowest frequency radiation that might leak. More and smaller holes are better than fewer and larger holes.

Ref: Eric Bogatin, “Signal and Power Integrity Simplified”, Prentice Hall


Questions
Answers

Jitter

What is Jitter?

- Jitter is the uncertainty of when the crossing point of the signal's bit state will occur at the receiver.

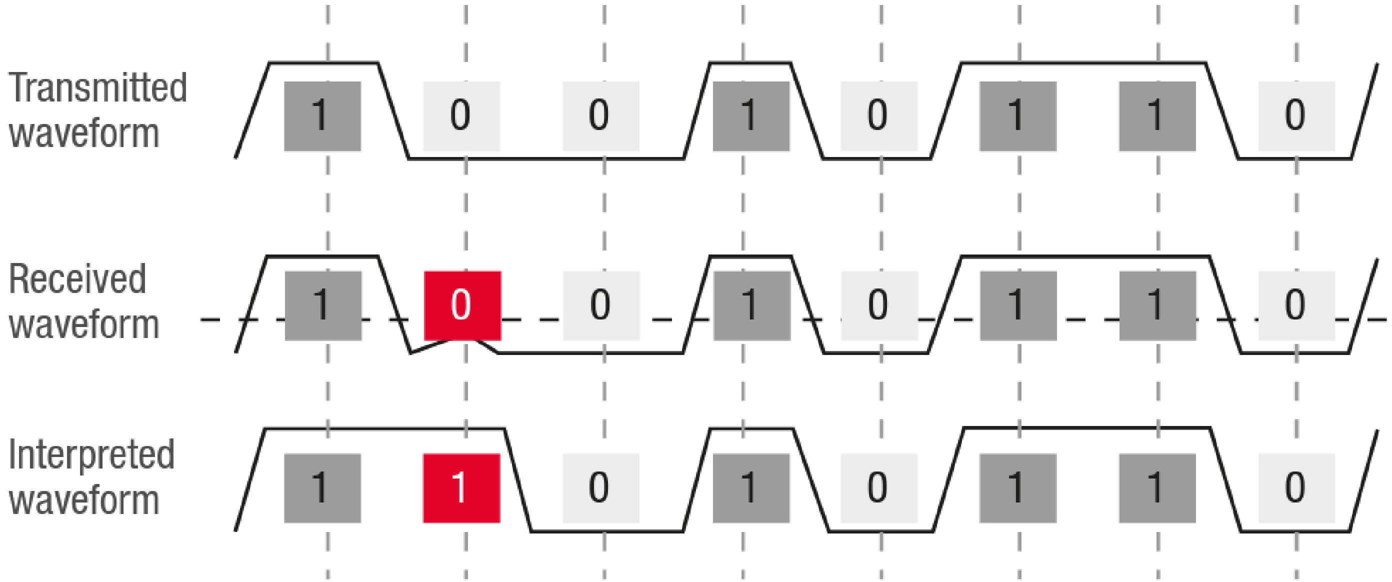
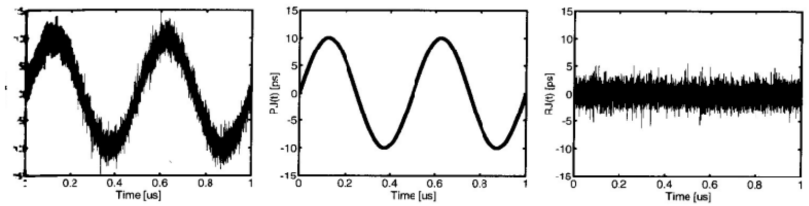


Image Source: Keysight

Ref: Eric Bogatin, "Signal and Power Integrity Simplified", Prentice Hall

Types of Jitter

Total Jitter Time Waveform



$$TJ(t) = PJ(t) + RJ(t)$$

Image Source: Jose E, Schutt, Illinois ECE Dept

- Jitter effects can be divided into two major categories:
    - Deterministic Jitter
    - Random Jitter

- Deterministic Jitter
    - Periodic Jitter: Mainly caused by switching power supplies and clocks leaking into the signal
    - Data-dependent Jitter: Caused by ISI, duty cycle distortion (DCD) which affects when the receiver detects the state of the bit.
    - Bounded Uncorrelated Jitter: Caused by Crosstalk

- Random Jitter (Unbounded Jitter)
    - Caused by thermal noise (electron flow within semiconductor), shot noise (electron and hole noise governed by bias current), pink noise (spectrally related to 1/f)

Ref: TI Application Notes

Ways to Reduce Jitter Effects

- Deterministic jitter can be corrected by equalization at the receiver, pre-distortion (pre-emphasis) at the driver, or a combination of both.
- Random Jitter will continue to increase within a given sample time.
- It becomes an issue as transmission rates increase, unit interval decreases, which allows less time for a bit to stabilize.
- Equalization cannot remove random jitter and may need re-timer device to “re-clock” the data.
- The effect of re-clocking removes all jitter with a slight penalty in delay through the device.

Ref: Eric Bogatin, “Signal and Power Integrity Simplified”, Prentice Hall