Electromagnetic Compatibility
(*EMC*)

Introduction about Shielding

Agenda

- *Shielding Effectiveness*
- Shielding Materials
- Shielding Integrity at Discontinuities
- Conductive Windows
- Conductive Coatings
- Cable Shielding
- Shielding Effectiveness Measurements
- Electrical Bonding

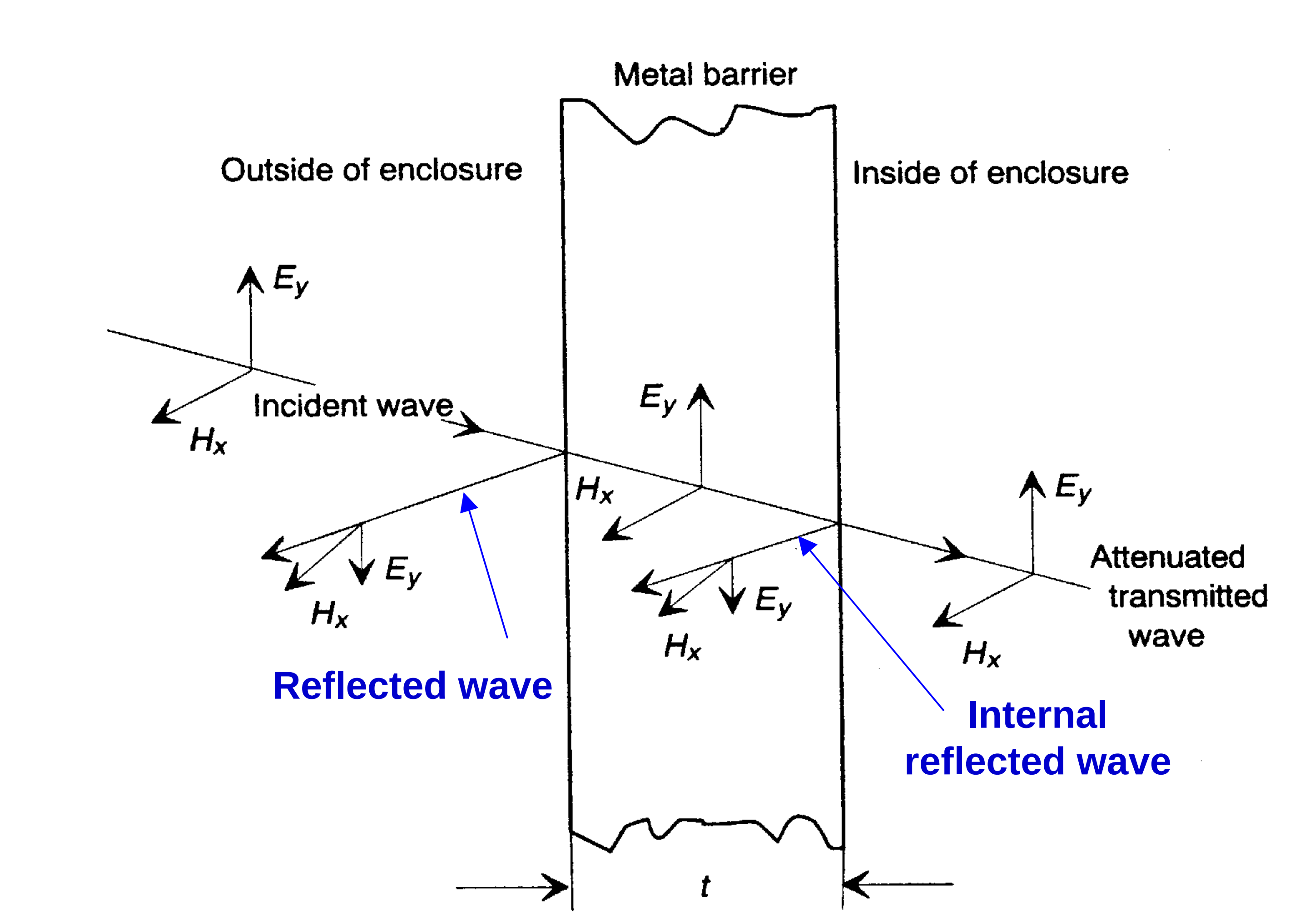
Shielding Effectiveness

- Shielding performance depends on a number of parameters such as frequency、distance of interference source、polarization of the fields、discontinuities in a shield、material of shield ...

Shielding Effectiveness

- Electromagnetic shielding is the technique that reduces or prevents coupling of undesired radiated electromagnetic energy into equipment.
- Shielding problems are difficult to handle because *perfect shielding integrity is impossible*.
  - Can’t be completely closed
- Shielding theory is based on transmission behavior through metals and reflection from the surface of the metal.
  - *Reflection loss R、Absorption loss A、Internal reflection loss IR*
  - Shielding Effectiveness <u>*SE= R + A + IR*</u>

Shielding Effectiveness



Shielding Effectiveness

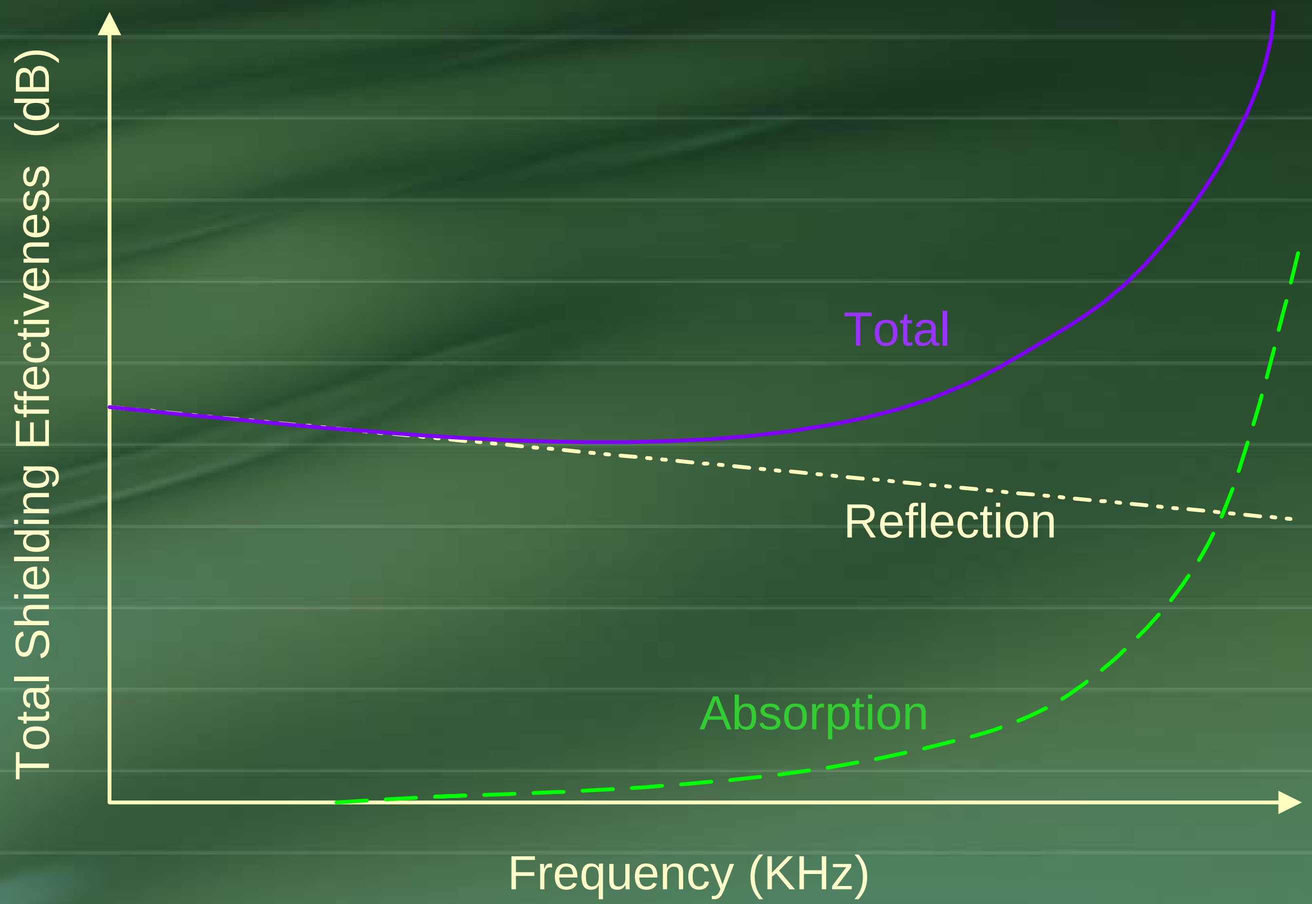
Shielded Thickness	1050 Å		12,500 Å		21,900 Å		219,600 Å	
Frequency	1MHz	1GHz	1MHz	1GHz	1MHz	1GHz	1MHz	1GHz
A	0.014	0.44	0.16	5.2	0.29	9.2	2.9	92
R	109	79	109	79	109	79	109	79
IR	-47	-17	-26	-0.6	-21	0.6	-3.5	0
SE	62	62	83	84	88	90	108	171

Shielding Effectiveness

- In summary ([1] p.178) ([2] Ch9-3)
  - *Absorption losses* increase with an increase in frequency of the electromagnetic wave (due to the decreasing skin depth), barrier thickness, and barrier permeability and conductivity.
  - *The reflection loss of E-field* increases with a decrease in frequency and a decrease in distance between the source and the shielding barrier.
  - *The reflection loss of H-field* increases with an increase in frequency and an increase in distance between the source and the shielding barrier.

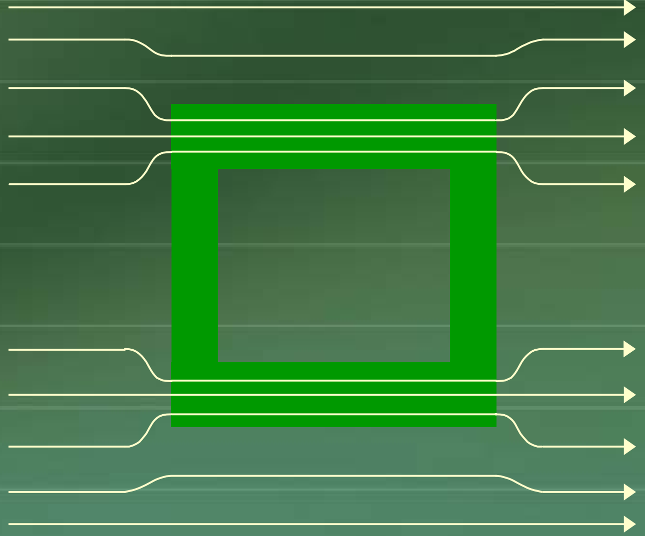
Shielding Effectiveness

Plane Waves in Far Field



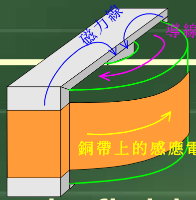
Shielding Effectiveness

- In the near field, since both the absorption and reflection losses are small for magnetic fields at low frequencies, the total shielding effectiveness is low.
- Protection against low-frequency magnetic fields can be achieved *only by providing a low-reluctance (high permeability μ_r) magnetic shunt path to divert the field around the circuit being protected.*
  - μ_r decreases with frequencies and thickness of shield, and it is related with field strength.



Shielding Effectiveness

◆	電場干擾	磁場干擾	
		高頻磁場	低頻磁場
防治原則	以*高導電性*材料做屏蔽，並接地	利用封閉的金屬屏蔽導體上產生的磁場感應電流，其產生的反向磁通與雜訊源輻射相互抵消；或減少迴路面積避免引入感應電流	以*高導磁性*材料做屏蔽



- The inductive current in a electromagnetic field *is direct proportioned to* the high-frequency of electromagnetic field, so it is the conductive material that is used to shield the high-frequency electromagnetic field.
- A high-frequency electromagnetic field will make a high μ_r material saturated, so it is used just under low-frequency electromagnetic field.

Shielding Materials

Metal	Relative Conductivity (σ_r)	Relative Permeability @ 150kHz (μ_r)	Absorption Loss @ 150kHz (dB/mm)
Silver	1.05	1	52
Gold	1.00	1	51
Copper-Annealed	0.97	1	50
Copper-Hard Drawn	0.70	1	42
Aluminum	0.61	1	40
Magnesium	0.38	1	31
Zinc	0.29	1	28
Brass	0.26	1	26
Cadmium	0.23	1	24
Nickel	0.20	1	23
Phosphor-Bronzer	0.18	1	22
Iron	**0.17**	**1000**	**650**
Tin	0.15	1	20
Steel, SAE 1045	0.10	1000	500
Beryllium	0.10	1	16
Lead	0.08	1	14
Hypernick	0.06	80,000	3500
Monel	0.04	1	10
Mu-Metal	0.03	80,000	2500
Permalloy	0.03	80,000	2500
Steel, Stainless	0.02	1000	220

Conductivity of copper=5.8×10^{7} mhos/m

Permeability of air $=4\pi \times 10^{-7}$ henry/m

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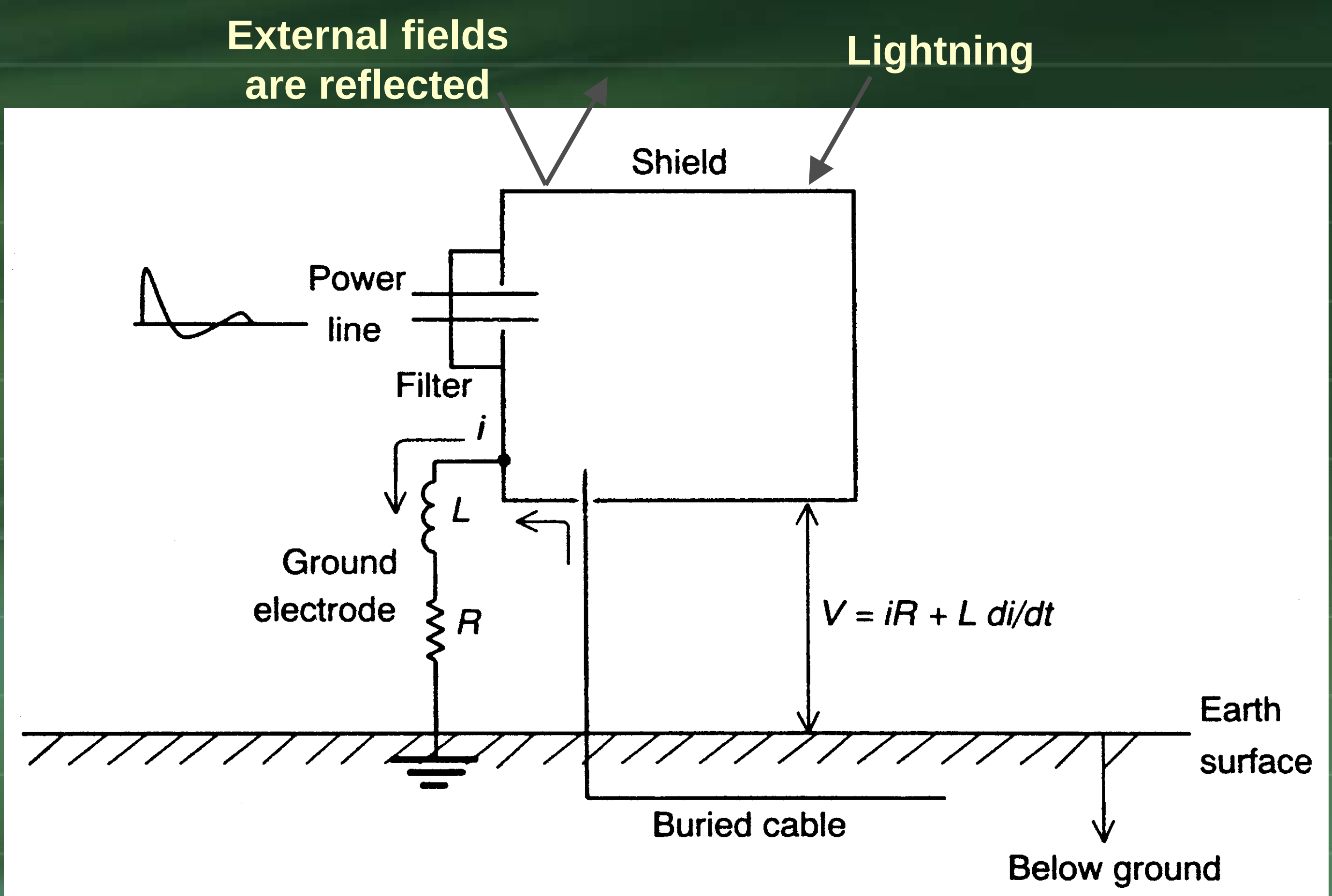
- Shielding Theory and Effectiveness
- Shielding Materials
- *Shielding Integrity at Discontinuities*
- Conductive Windows
- Conductive Coatings
- Cable Shielding
- Shielding Effectiveness Measurements
- Electrical Bonding

Shielding Integrity at Discontinuities

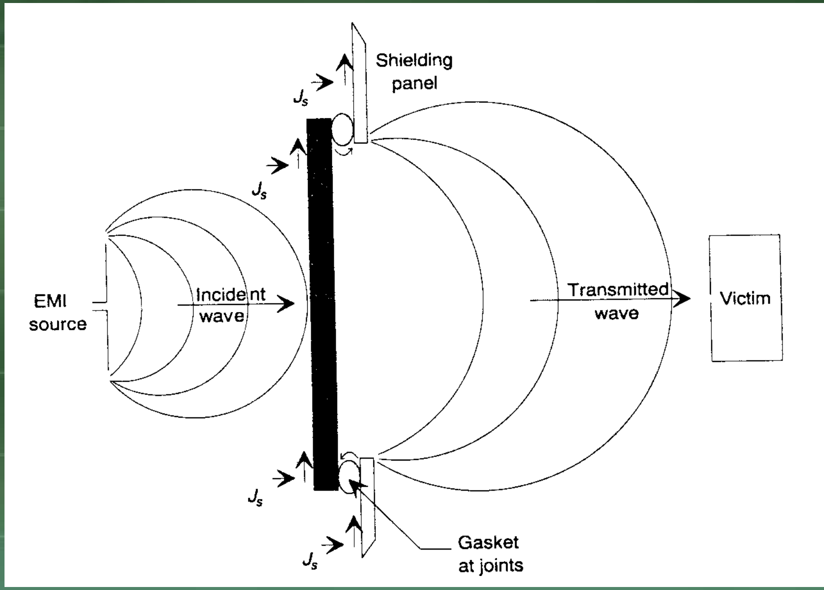
- Material of the shielding box is invariably a good conductor.
  - *All external fields are reflected by the walls*
  - *All currents or charges induced on the outside surface remain on the outside surface*, because the skin depth in a good conductor is extremely small.
- The intrinsic shielding effectiveness of the material is of less concern than the leakage through seams, joints, and holes.
- Common types of discontinuities
  - Slots in the weld seam gaps between shielding panel joints、ventilation hole (通風孔) …

Shielding Integrity at Discontinuities



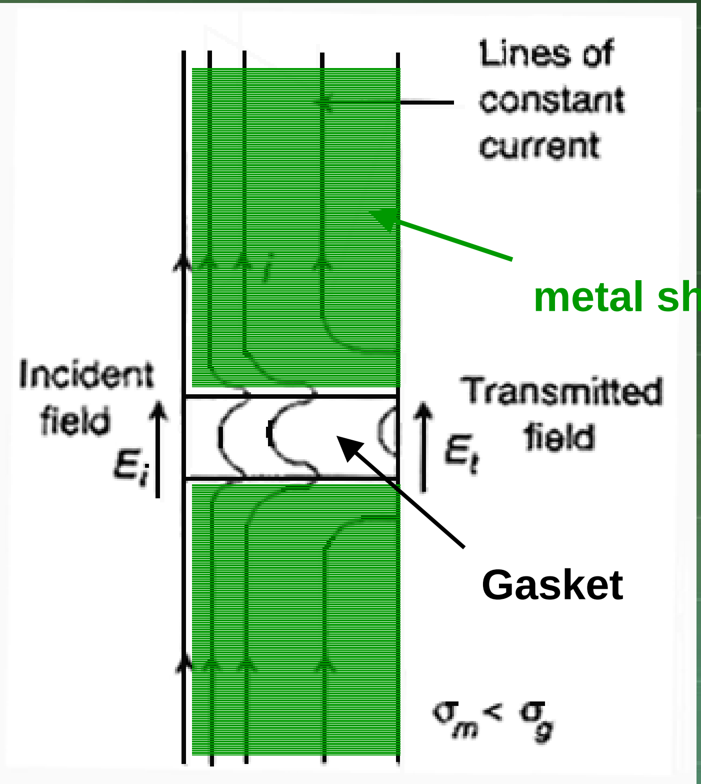
Shielding Integrity at Discontinuities

- The leakage of electromagnetic energy in a metallic enclosure is dominated not by physical characteristic of metal, but by the size, shape, and location of discontinuities.
  - *When the size of these discontinuities is equal to their resonant values, shielding effectiveness at corresponding frequencies will be very low.*



Shielding Integrity at Discontinuities

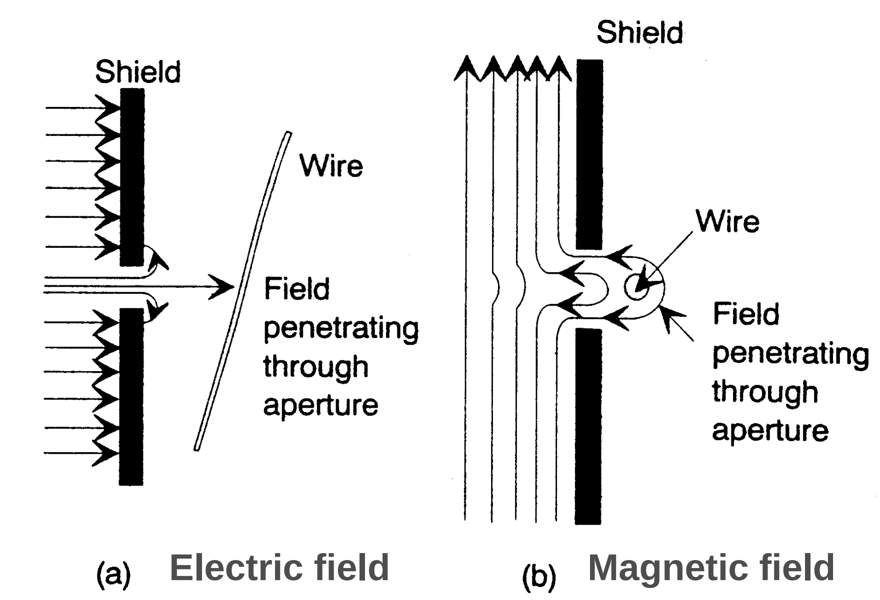
- Effects of discontinuity at a joint with jointing material gasket (襯墊), which is different from shield wall
  - The induced currents flow on the opposite of the enclosure and *result in a decrease*.

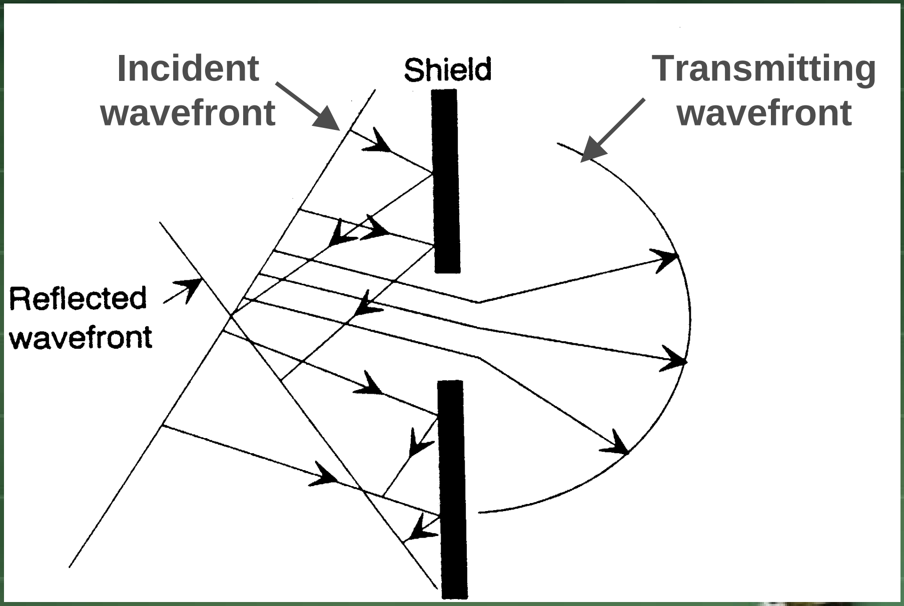


Shielding Integrity at Discontinuities

Single Aperture

- Aperture is smaller than wavelength
- Aperture is larger than wavelength



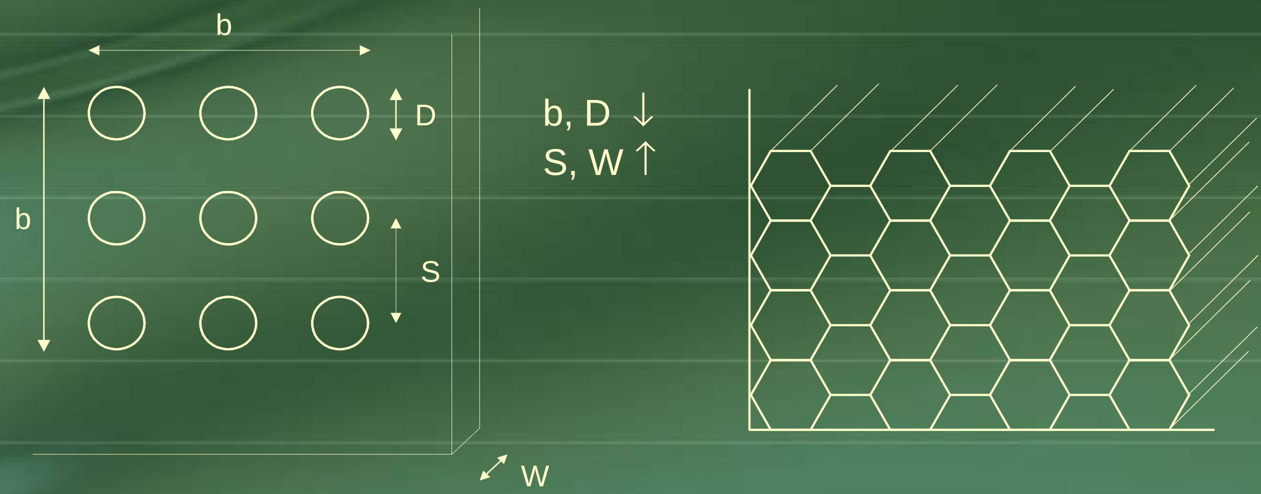


For holes in thin barriers, a good rule to follow in general design is to avoid openings larger than $\lambda/50 \sim \lambda/20$ at the highest frequency of operation.

Shielding Integrity at Discontinuities

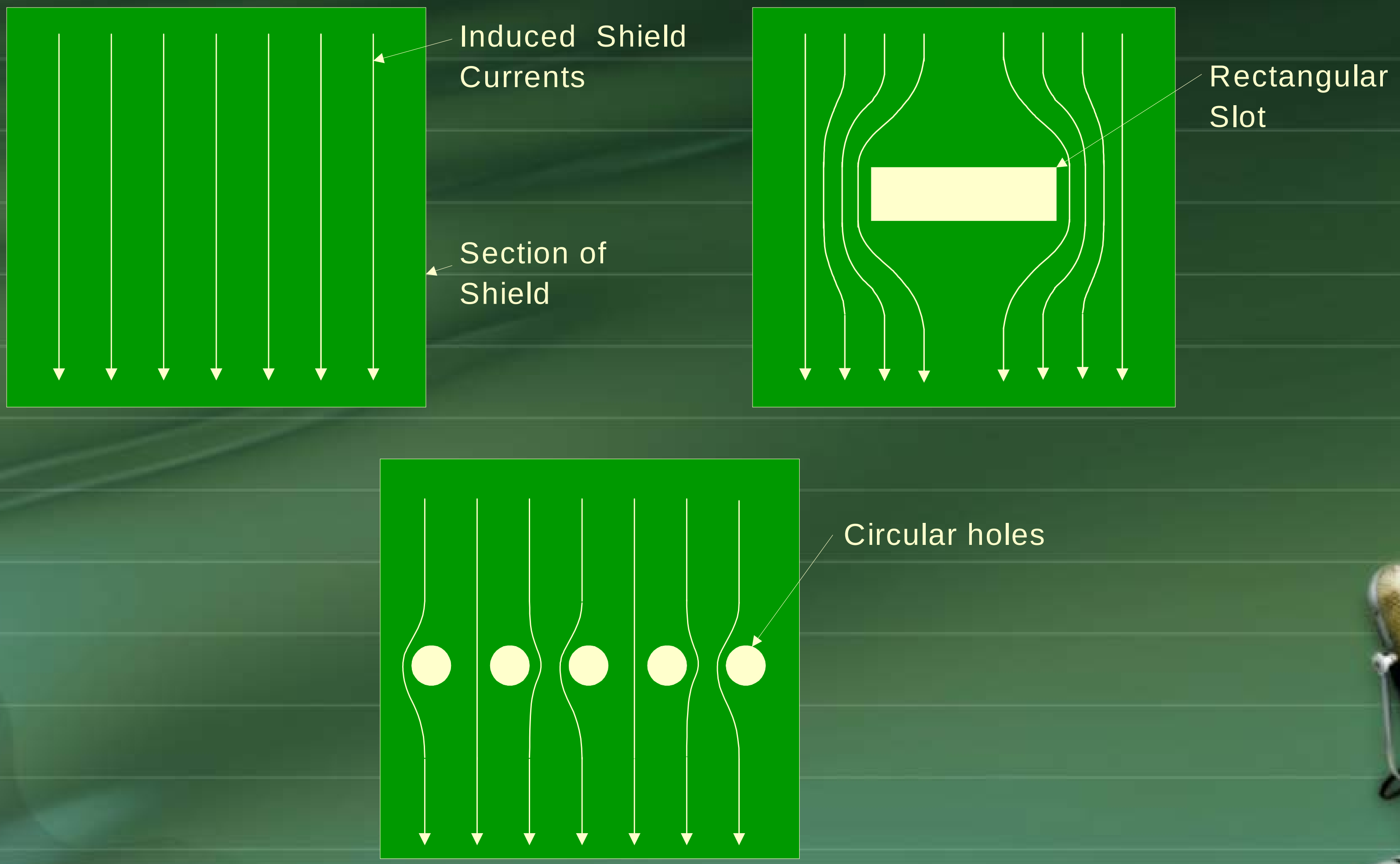
Multiple Apertures

- For proper air circulation, there are several apertures of the same size on one shield well usually.
  - Apertures are either *circular* or square geometries, and arranged in square lattice(晶格).
  - Total effectiveness of shielding by this arrangement depends on the *space* between any two adjacent apertures, the *wavelength*, and the *total number* of apertures.



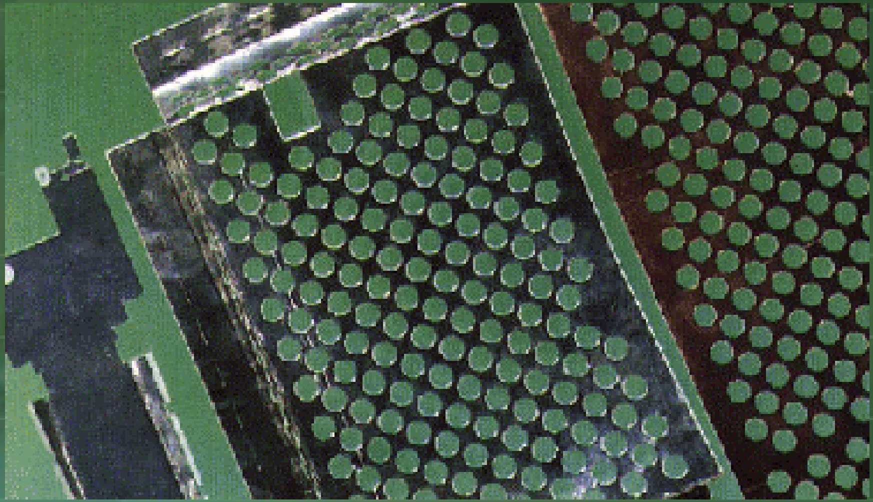
Shielding Integrity at Discontinuities

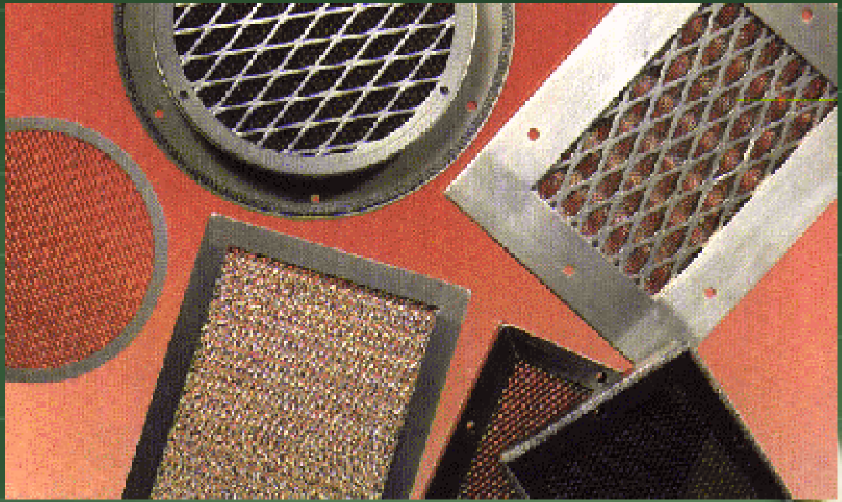
How discontinuities affect the induced shield current



Shielding Integrity at Discontinuities

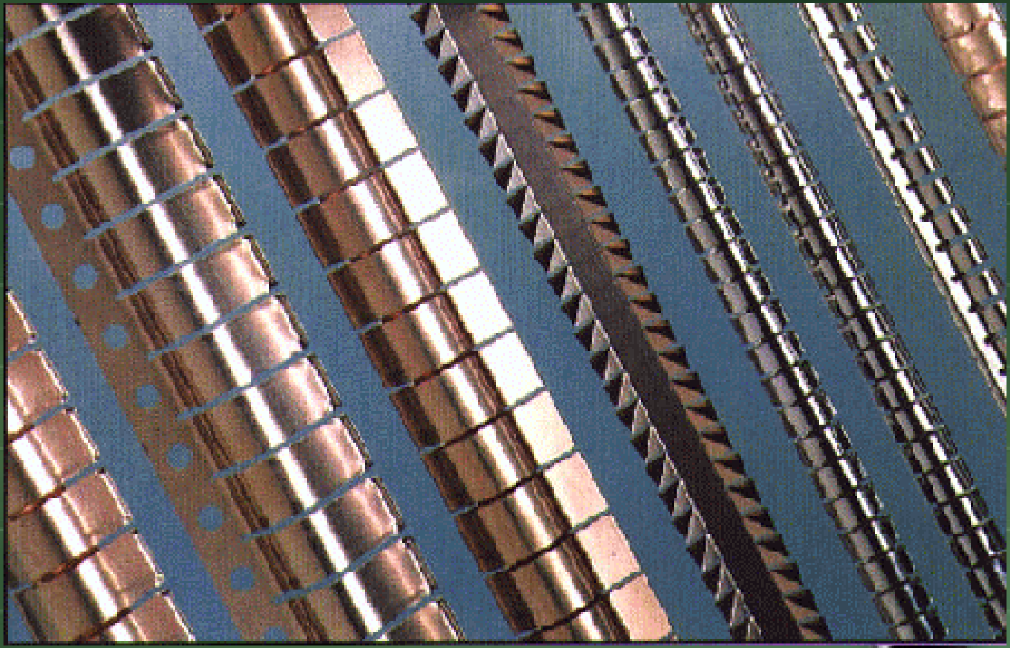
Shielding Laminates





Shielding Integrity at Discontinuities

Beryllium Copper Finger-stock



Shielding Integrity at Discontinuities

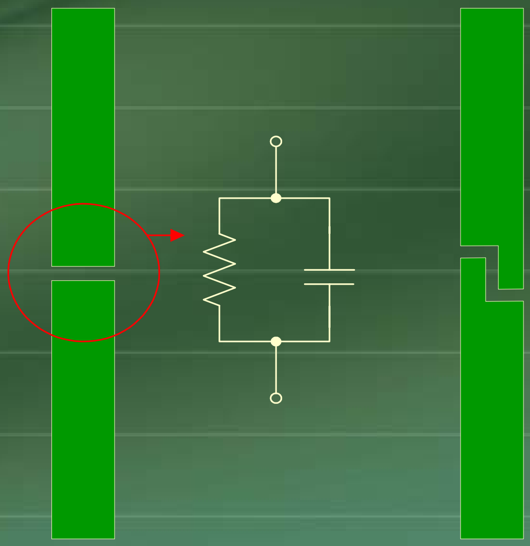
Seams

- Shielding effectiveness is limited by the failure of seams to make current flow in the shield.
  - The ability to create a low-contact resistance across the joint.
- Contact resistance is a function of the materials, the conductivity of their surface contaminants, and the contact pressure.
  - Conductive contact
  - Seam overlap
  - Using conductive gaskets
    - Typically effectiveness is the order of 80~100dB

Shielding Integrity at Discontinuities

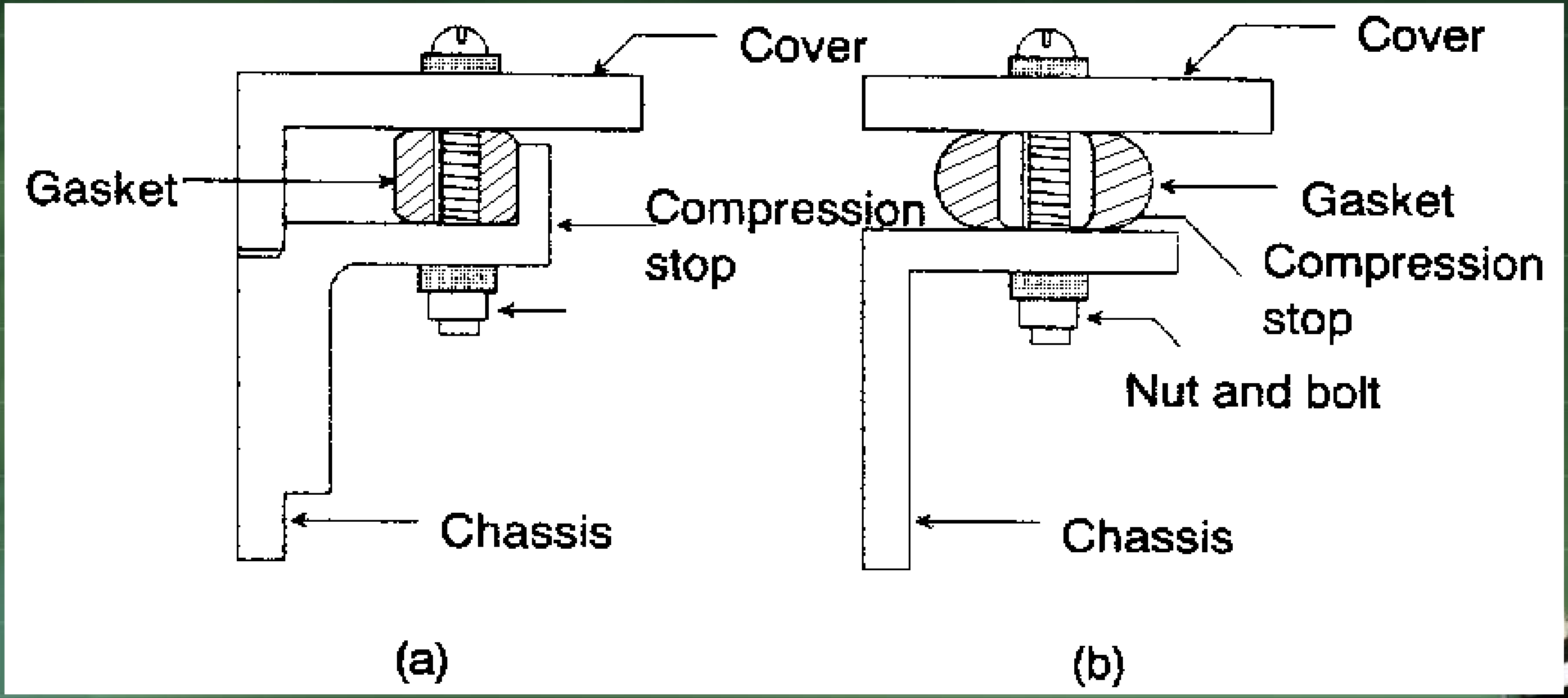
Seams

- The impedance across a seam consists of a resistive and a capacitive component.
- An overlap on a seam can be helpful to reduce seam impedance with frequency, due to the increasing capacitor component.



Shielding Integrity at Discontinuities

Conductive Gaskets



Built-in compression stop

Washer type compression stop

Conductive Windows

- Transparent(透明的) Conductive Coatings
  - It is vacuum deposited(真空沉積) onto optical substrates (plastic or glass).
  - Since the deposited film thickness is in micro-inches, there is very little absorption loss, and *the primary shielding comes from reflection loss.*
    - *Hence very good conductors are used. – gold*
  - Trade-off between thinness for transparency and thickness for shielding effectiveness
    - Typical surface resistivities range 10~20Ω per square, with optical transmission 70~80%
- Wire Mesh Screens
  - Optical transparency 65~98% is better than conductive coating 60~80%
- Mounting of shielding window is as important as material of the window itself.

Conductive Coatings

- When electronic systems are packaged in enclosures of nonconductive material, these enclosures must be treated with a conductive coating.
  - Silver(銀), nickel(鎳) for EMI；carbon for ESD
    - Low resistivities is better for EMI shield, but high resistivities is useful against ESD.
  - Typically effectiveness is 60dB and above

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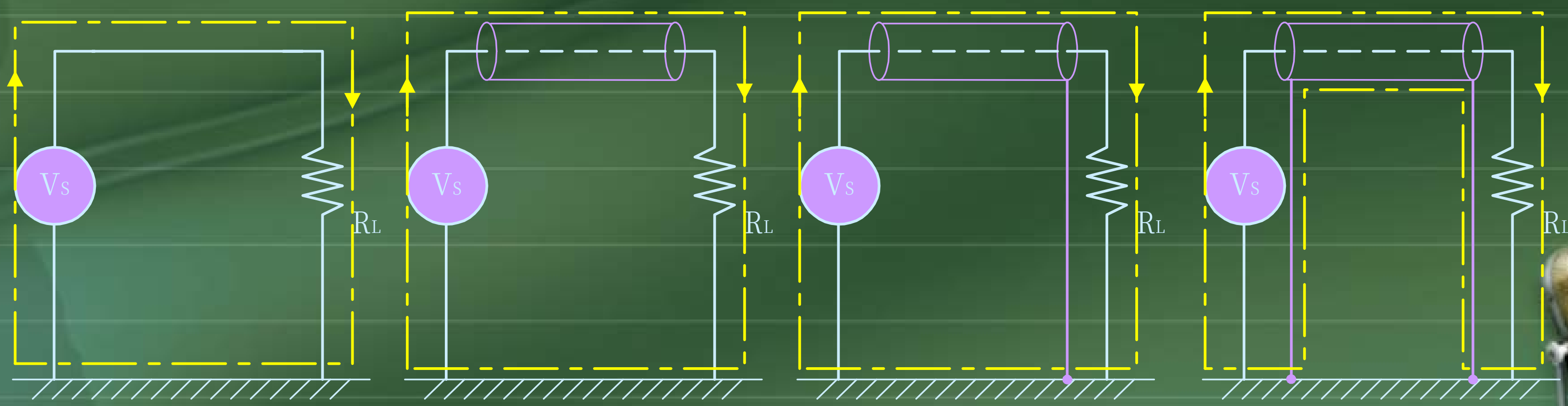
Cable Shielding

- Shielding effectiveness of cable shield installation depends on
  - The nature of the electromagnetic interference
  - The type of terminations at the two ends



Connecting wire without shield

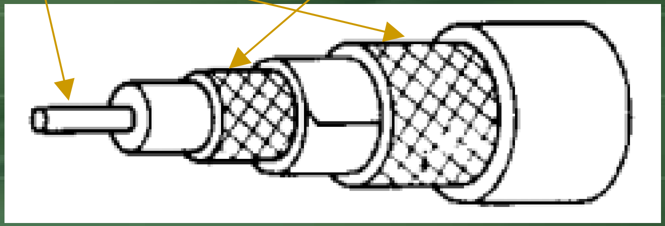
Cable shield without grounding

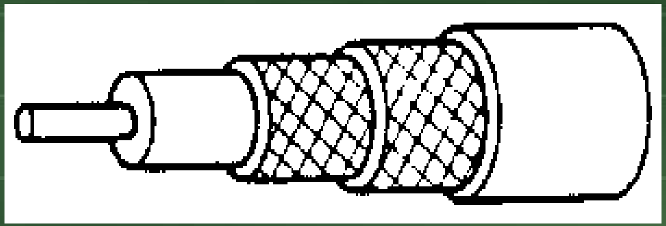
Cable shield grounded (Grounded at one end)

Cable shield grounded and current in shield (Grounded at two end)

Cable Shielding

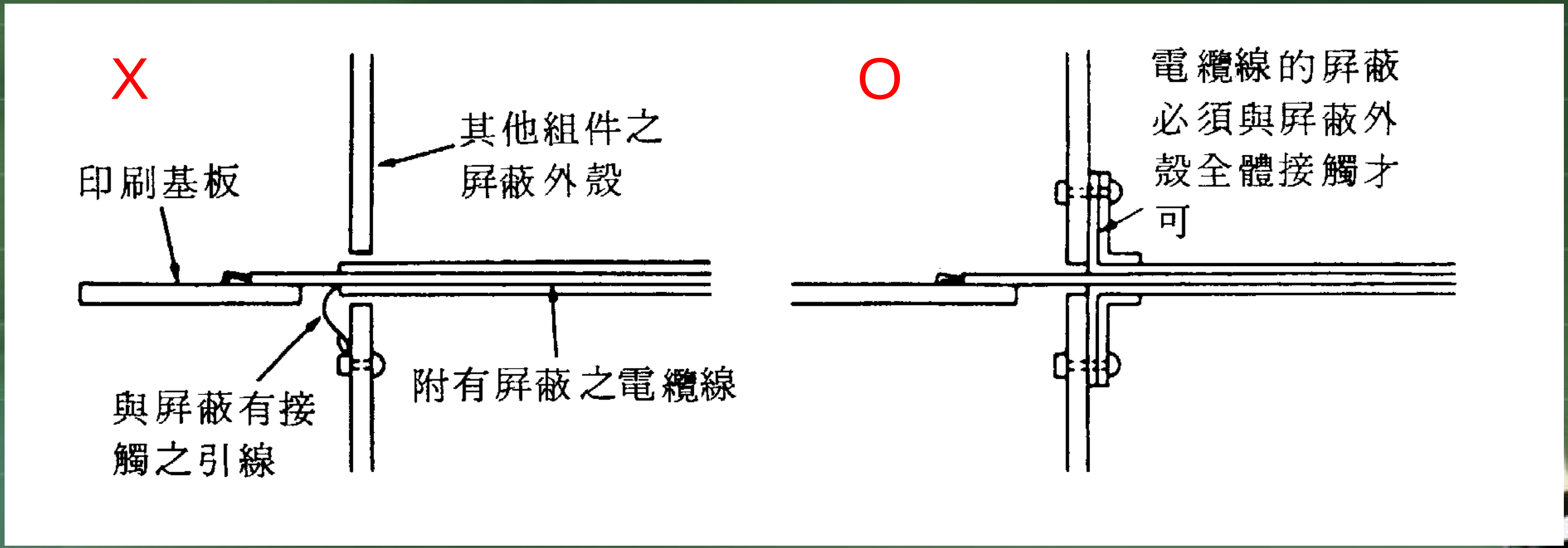
- *At high frequencies*, a coaxial cable containing three isolated conductors is used.
  - Center conductor、inner surface of the shield conductor、outer surface of the shield conductor





  - *Skin effect causes the signal current flows on the inside surface of the shield, and the noise current flows on the outside, and therefore there is no common impedance.*

Cable Shielding



Cable Shielding

- A measurement of shielding effectiveness in terms of the *transfer impedance of the cable shield* is often preferred.
  - The definition of shielding effectiveness using the ratio of fields before and after the shield, or ratio of voltage induced without and with shield are not convenient.
    - Since it is difficult to measure the field inside a cable shield, and the voltage measured at either end of the line depends on the type of termination and the degree of impedance mismatch at the ends of the line and the line losses.

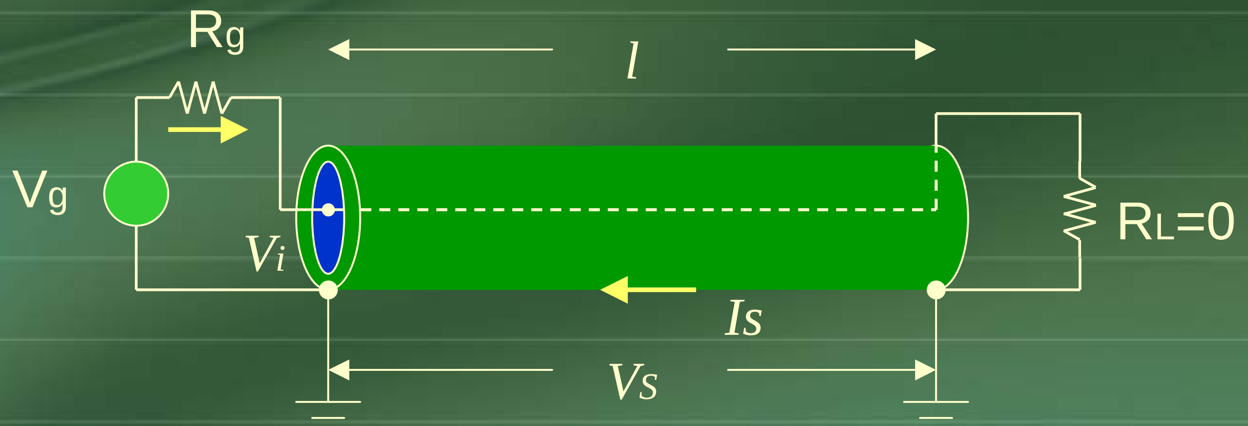
Cable Shielding

Transfer Impedance of Cable Shield

- The transfer impedance of a cable shield：

$$Z_t = \frac{V_S}{I_S} = \frac{1}{I_S}\left(\frac{dV_i}{dl}\right) \quad (\Omega / m)$$

- Lower *Zt* results from a better shielding.



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- *Shielding Effectiveness Measurements*
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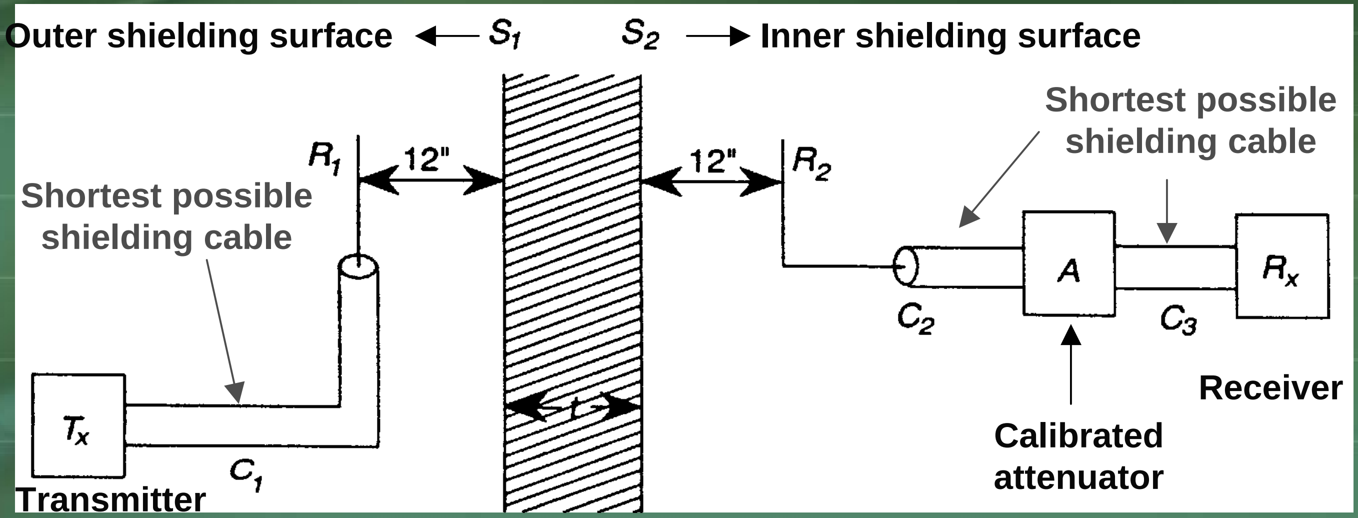
Shielding Effectiveness measurements

- MIL-STD-285
- The Coaxial Holder Method
- The Dual TEM Cell Method
- Time-Domain Method

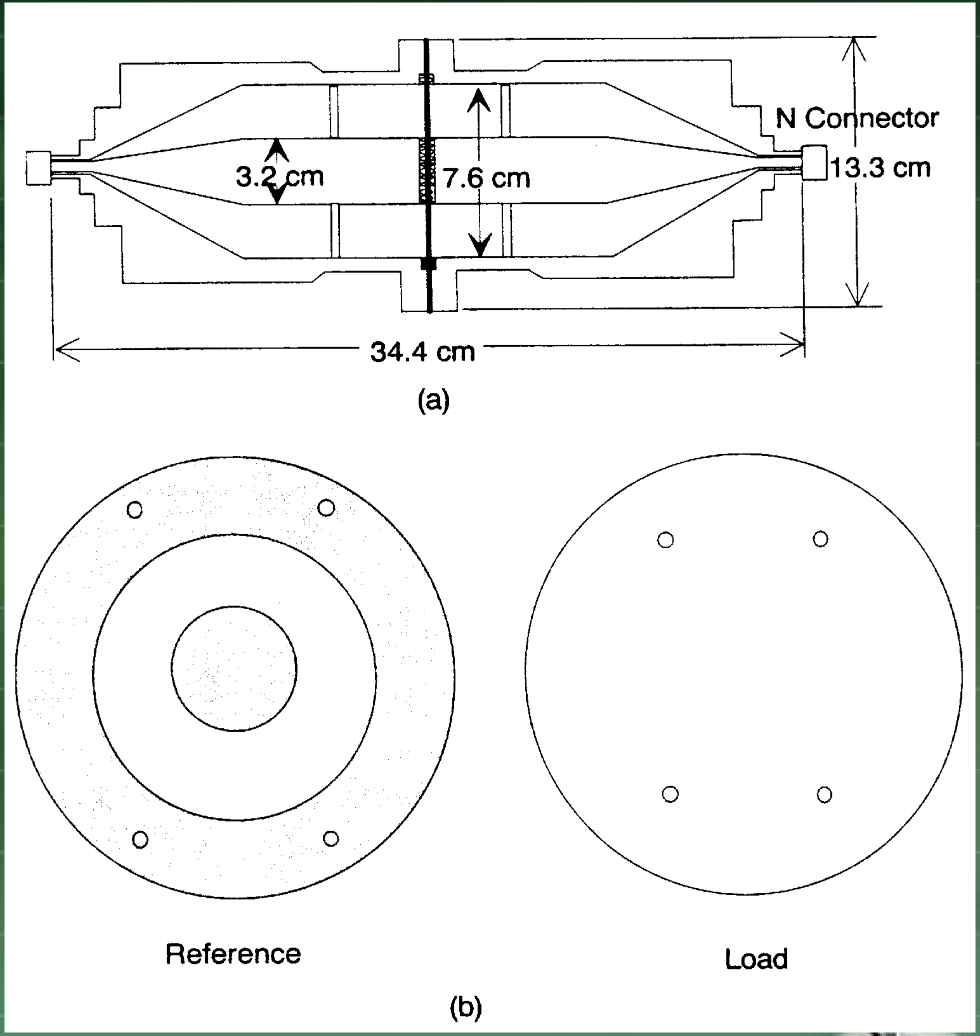
Shielding Effectiveness measurements

- MIL-STD-285
  - Measure the increase of the dB attenuation on the receiver, which reads the reference when the shield wall is remove.
    - Low-impedance magnetic field shielding：150~200kHz
      - Tx and Rx antennas are 12-in diameter loops.
    - High-impedance electric field shielding：200kHz,1MHz,18MHz
      - Tx and Rx antennas are 14-in rod antennas.



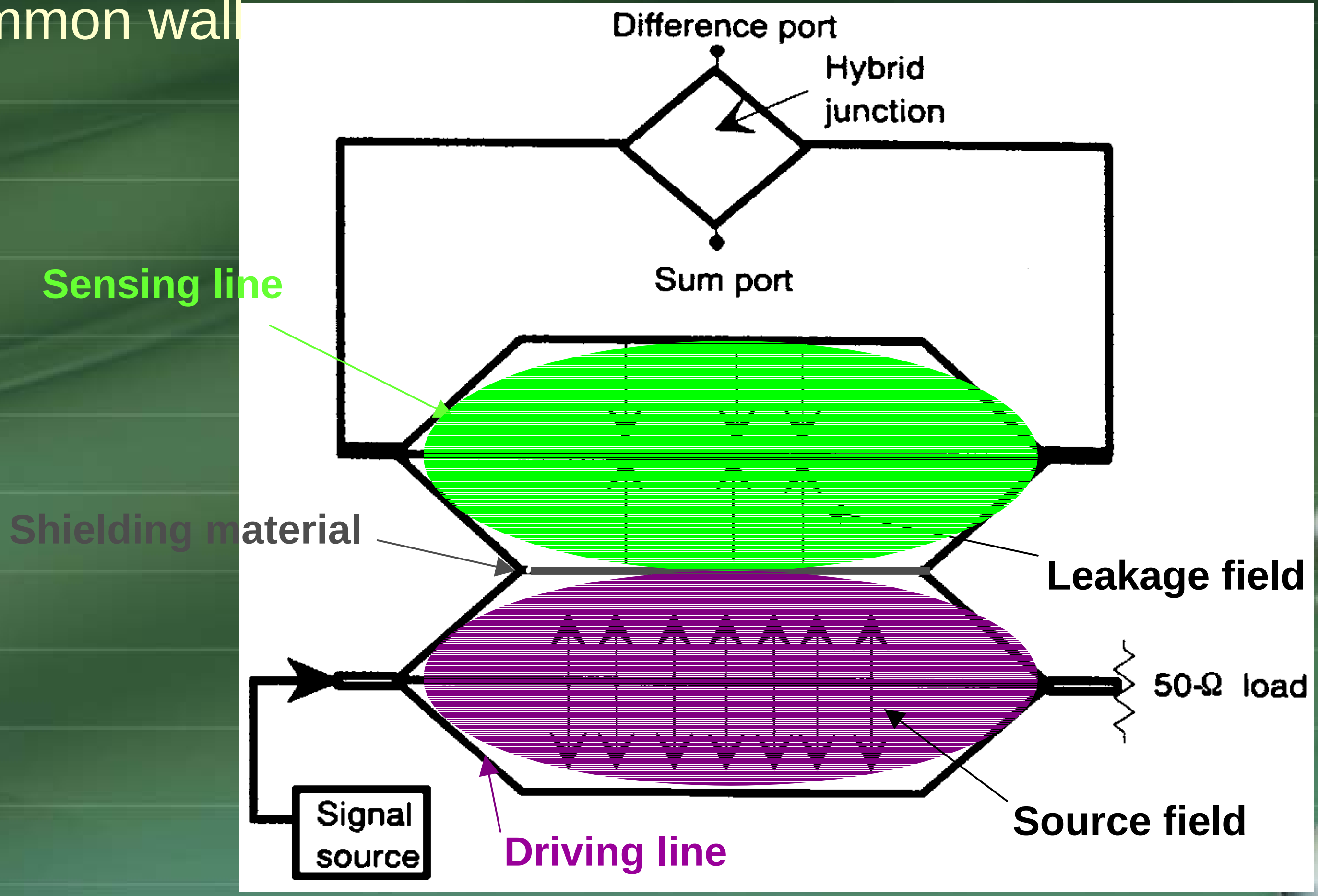
Shielding Effectiveness measurements

- The Coaxial Holder Method
  - Far-field testing is possible
  - An expanded section of 50Ω coaxial line like TEM cell, which is disassembled at the center to allow the insertion of an annular(環) reference or a circular disk test sample.



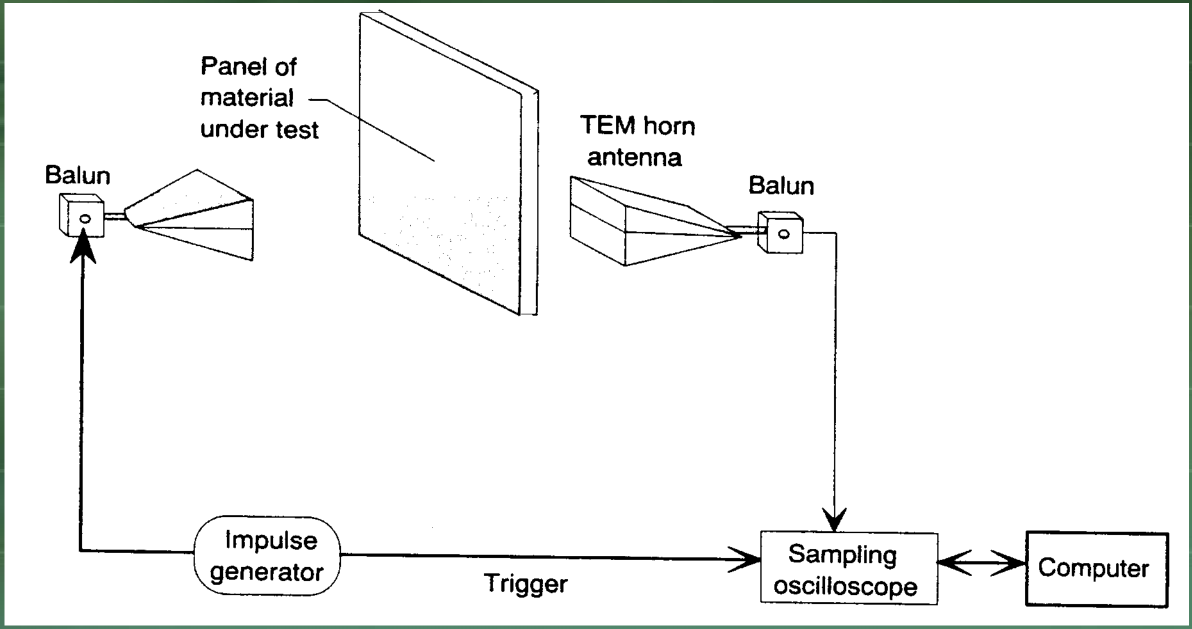
Shielding Effectiveness measurements

- Dual TEM Cell Method
  - Using one cell to drive another through aperture in a common wall



Shielding Effectiveness measurements

- Time-Domain Method
  - There are limitations on the shielding measurements in the far field using coaxial holders and dual TEM cells.
  - In time-domain method, unwanted signal paths to the receiving antenna are eliminated by time gating.
    - The upper frequency limit of this measurement can be controlled by reducing the pulse width of the signal.



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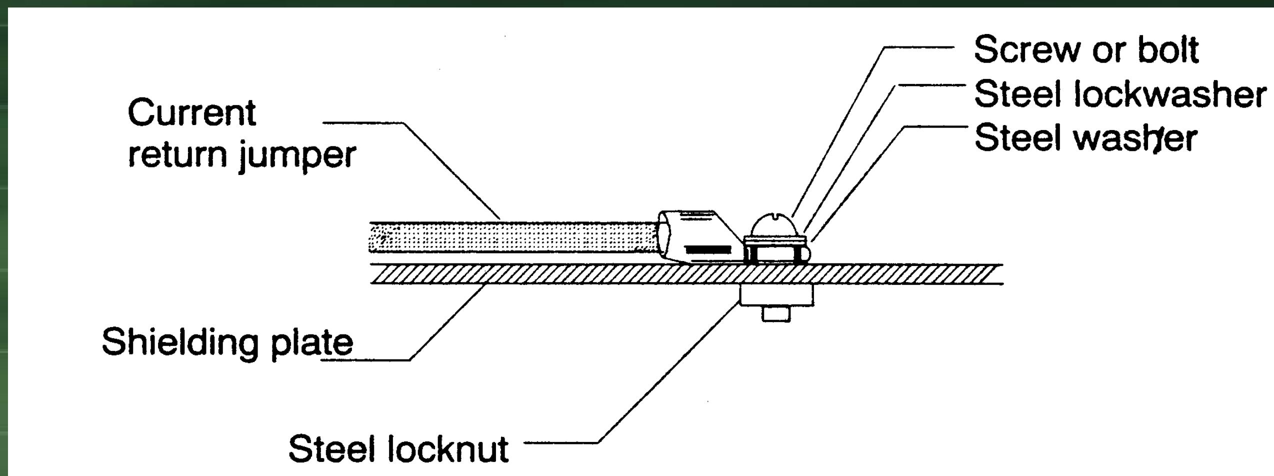
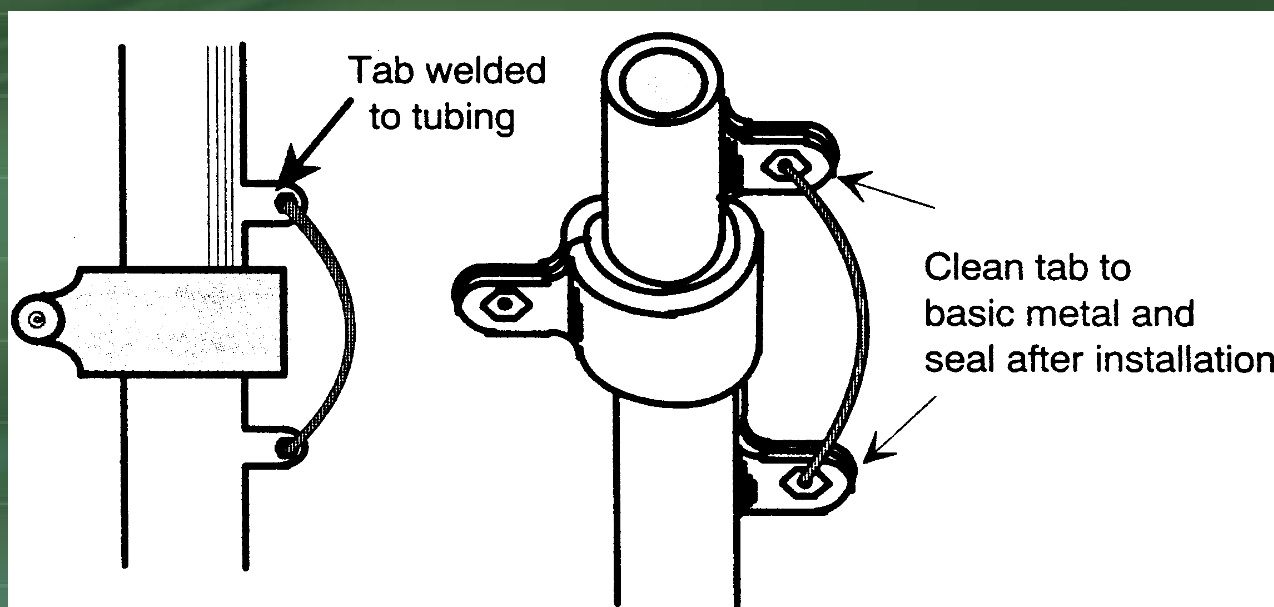
Electrical Bonding

- The interconnections of electrical bonding should be made so that the mechanical and electrical properties of the current path are determined by the connected members and not by the joints.
- Bonding can be made by
  - Joining two metallic items or surfaces through the process of welding(焊接).
  - Metallic interfaces through fasteners(扣栓) or by direct metal-to-metal contact.
  - Bridging two metallic surfaces with a metallic bond strap.

Electrical Bonding





Summary

- Shielding effectiveness is relative to frequency、distance from interference source、polarization of the fields、discontinuities in a shield、material of shield…
- Numbers of discontinuities should be as few as possible, and size of discontinuities should be as small as possible.
- A completely surrounding shield can be at any potential and it still provides a effectiveness shielding. However, the shield is not a complete enclosure, so it has to be grounded.
- A good electrical bonding has to be also a good electrical shield.
- A shield grounded at one or more points shields against electric fields.
- Any shield in which noise currents flow should not be part of the signal path. Use a shielded twisted pair or a triaxial cable at low frequencies.
- At high frequencies a coaxial cable acts as a triaxial cable due to skin effect.