TEMPEST Low Emission Controlled Design

Volume 3A – Mechanical Design

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Last Updated: 2002

Based on the Texts:

- **TEMPEST, A Description and Approach**
- **Hardwire and Cable Design in Secure Communications**
- **TEMPEST Hardware Design**
- **TEMPEST Systems Engineering & Program Management**
- **INFOSEC Engineering**

Mechanical Design

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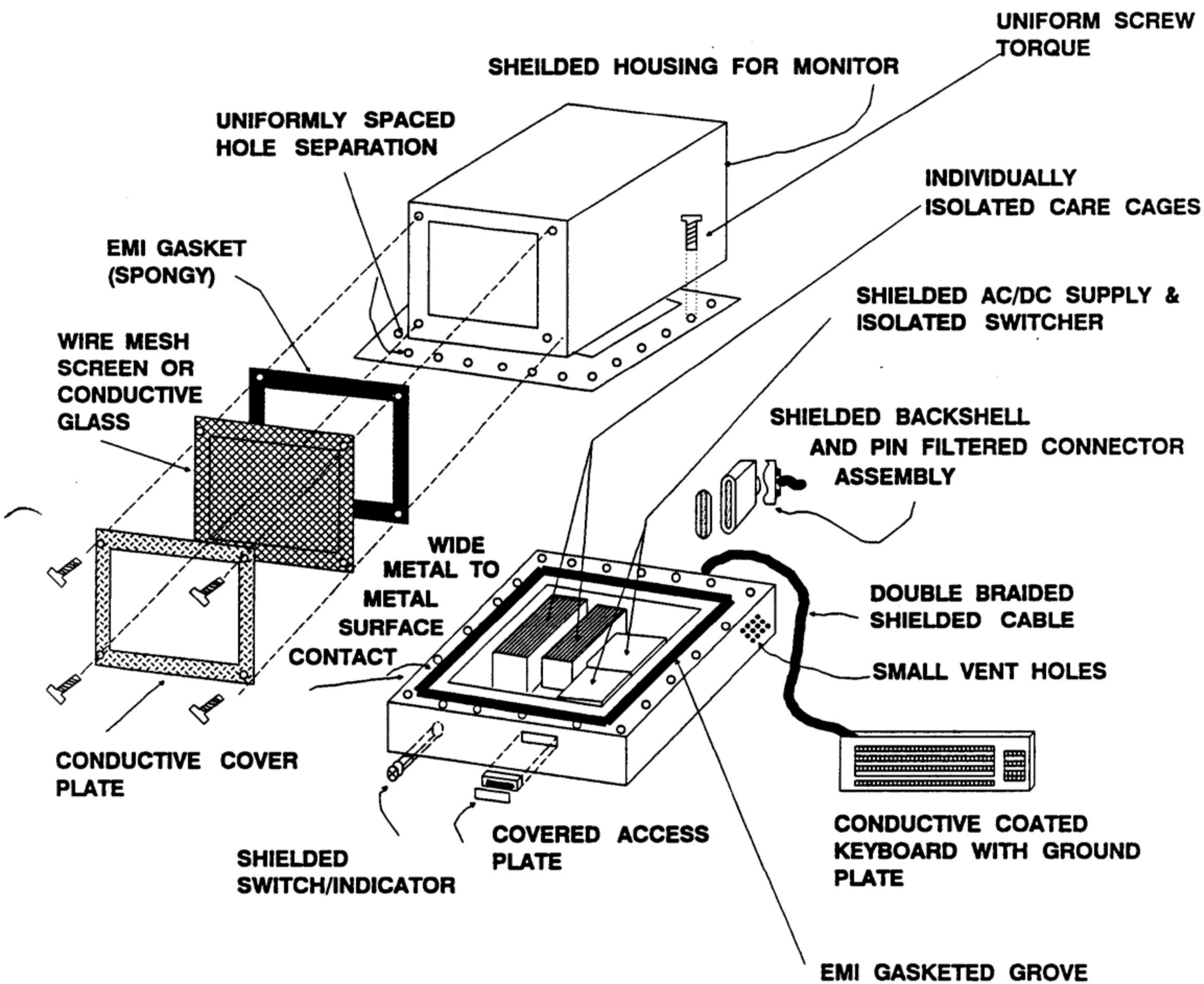
Contain at the Source

- The first level of emission protection is at the source itself
- The first level of isolation is at the pc card level.
- The power and ground system employed is almost as important in reducing emissions as through source attenuation.
- Once the signal radiates, box level control is used.

Box Level Mechanical Design

- Chassis provides overall outer shield
  - Chassis are dipped braised, die-cast, or conductive coated plastic
  - Monitors use conductive glass or mess screens
  - Vents employ waveguides
  - Covers are grooved and gasketed
  - Torquing requirements on screws
  - Internal partitions isolate emission sources


UNIFORM SCREW TORQUE
SHEILDED HOUSING FOR MONITOR
UNIFORMLY SPACED HOLE SEPARATION
INDIVIDUALLY ISOLATED CARE CAGES
EMI GASKET (SPONGY)
SHIELDED AC/DC SUPPLY & ISOLATED SWITCHER
WIRE MESH SCREEN OR CONDUCTIVE GLASS
SHIELDED BACKSHELL AND PIN FILTERED CONNECTOR ASSEMBLY
WIDE METAL TO METAL SURFACE CONTACT
DOUBLE BRAIDED SHIELDED CABLE
SMALL VENT HOLES
CONDUCTIVE COVER PLATE
CONDUCTIVE COATED KEYBOARD WITH GROUND PLATE
COVERED ACCESS PLATE
SHIELDED SWITCH/INDICATOR
EMI GASKETED GROVE

Coatings for Plastics

- Shielding
  - Zinc-Tin Spray
  - Nickel Filled Acrylic
  - Nickel Filled Polyurethane
  - Nickel Filled Aqueous Polymer
- Conductive Adhesives
  - Silver Epoxy
  - Copper Epoxy Copolymer

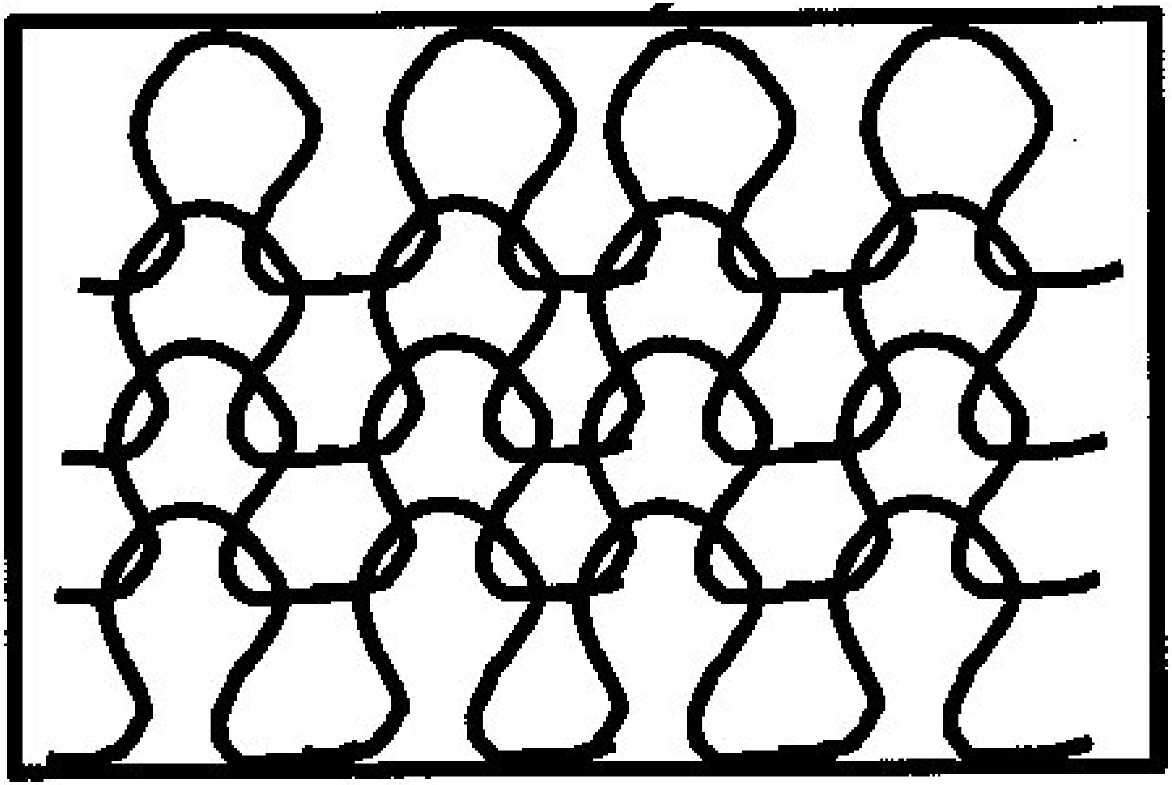
Problems With Coatings

- The biggest single concern with conductive coatings is their shielding effectiveness after extended high temperature and humidity exposure.
- If costs can be justified, only zinc-arc type coatings provide extended shielding after long term environmental exposure.

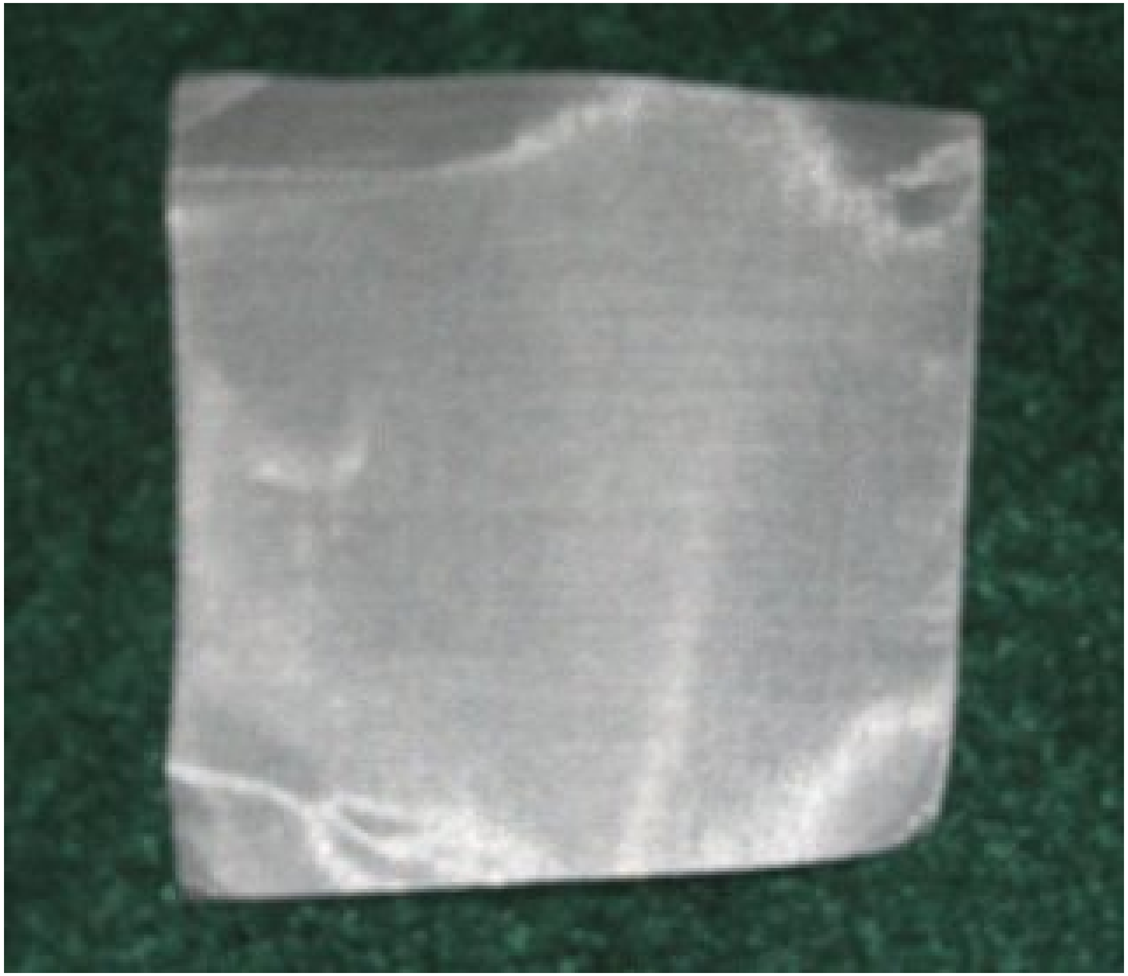
Conductive Paints

- Silver
  - Good conductivity
  - Conventional equipment
  - Resistive to flaking
  - Expensive
- Nickel
  - Good conductivity
  - Conventional equipment
  - Resists oxidation
  - Difficult to control uniform thickness

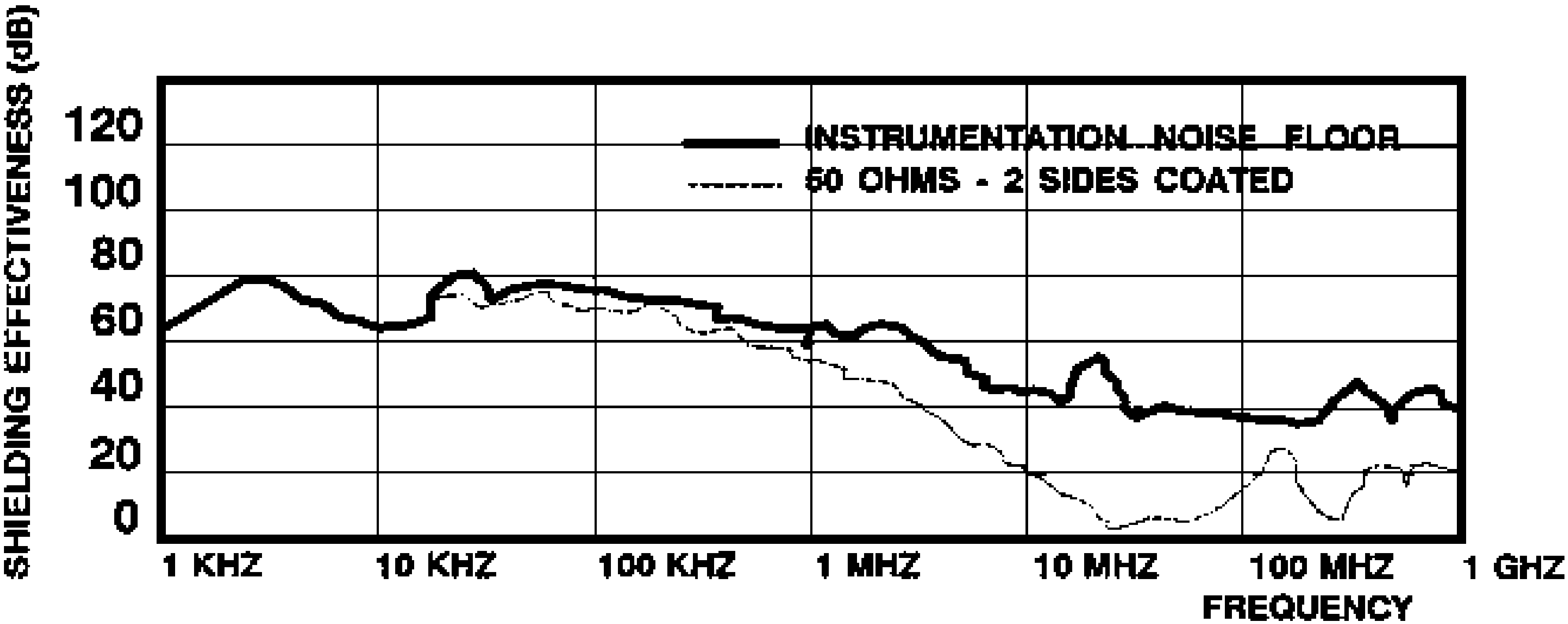
Conductive Knitted Wire Mesh



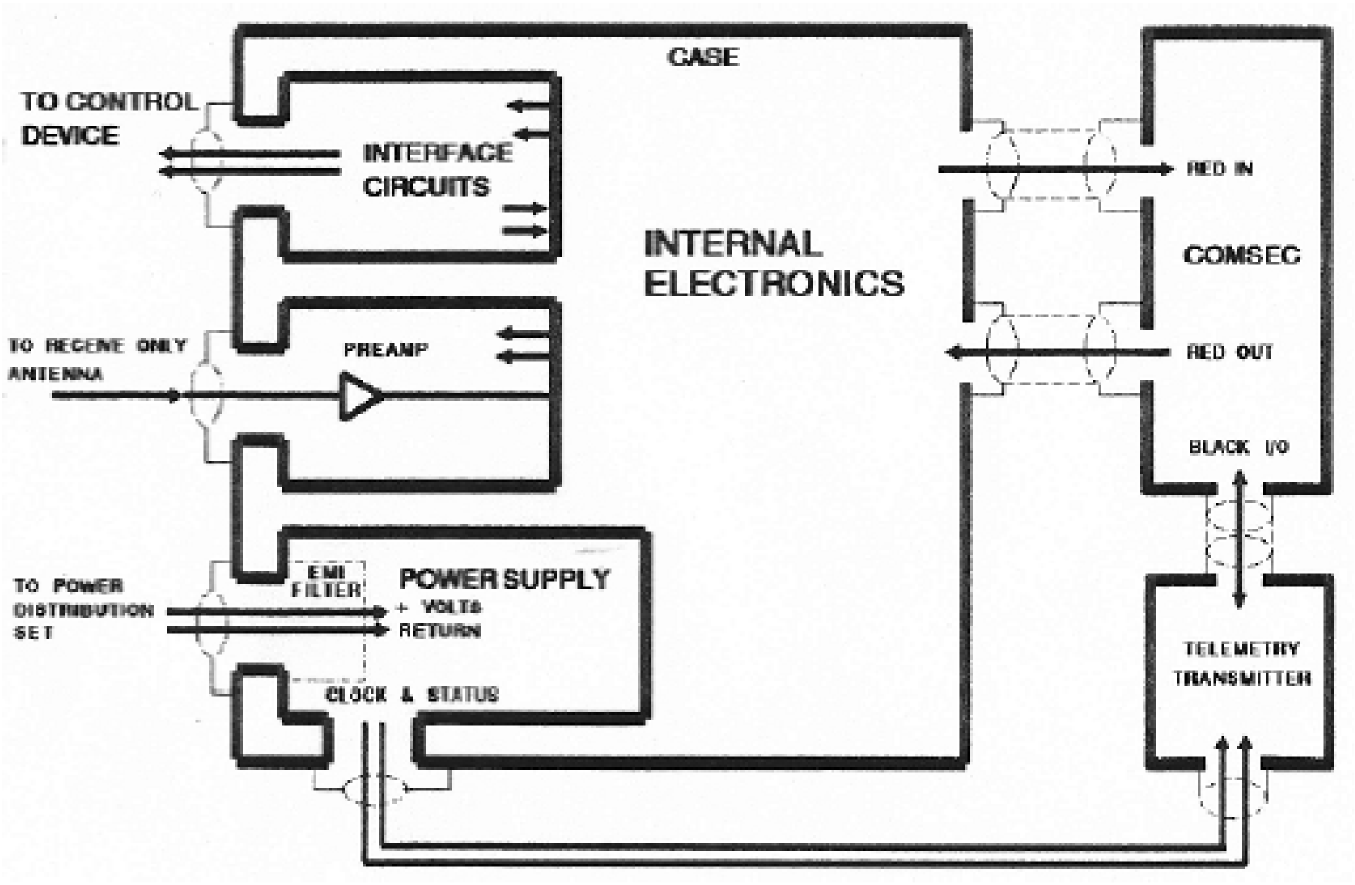
Thin Metal Mesh Screen



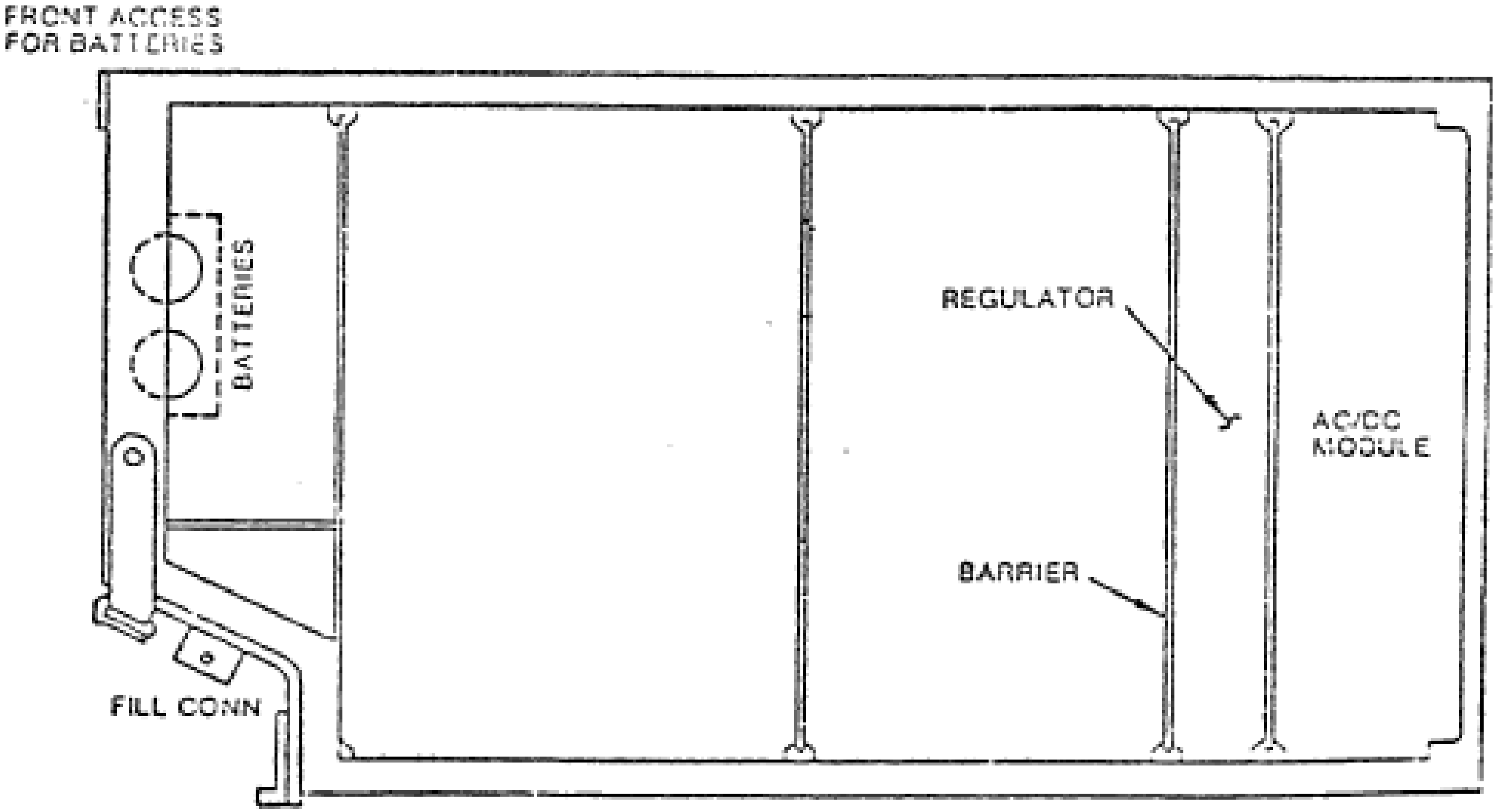
Shield Effectiveness of Glass To High Impedance Waves



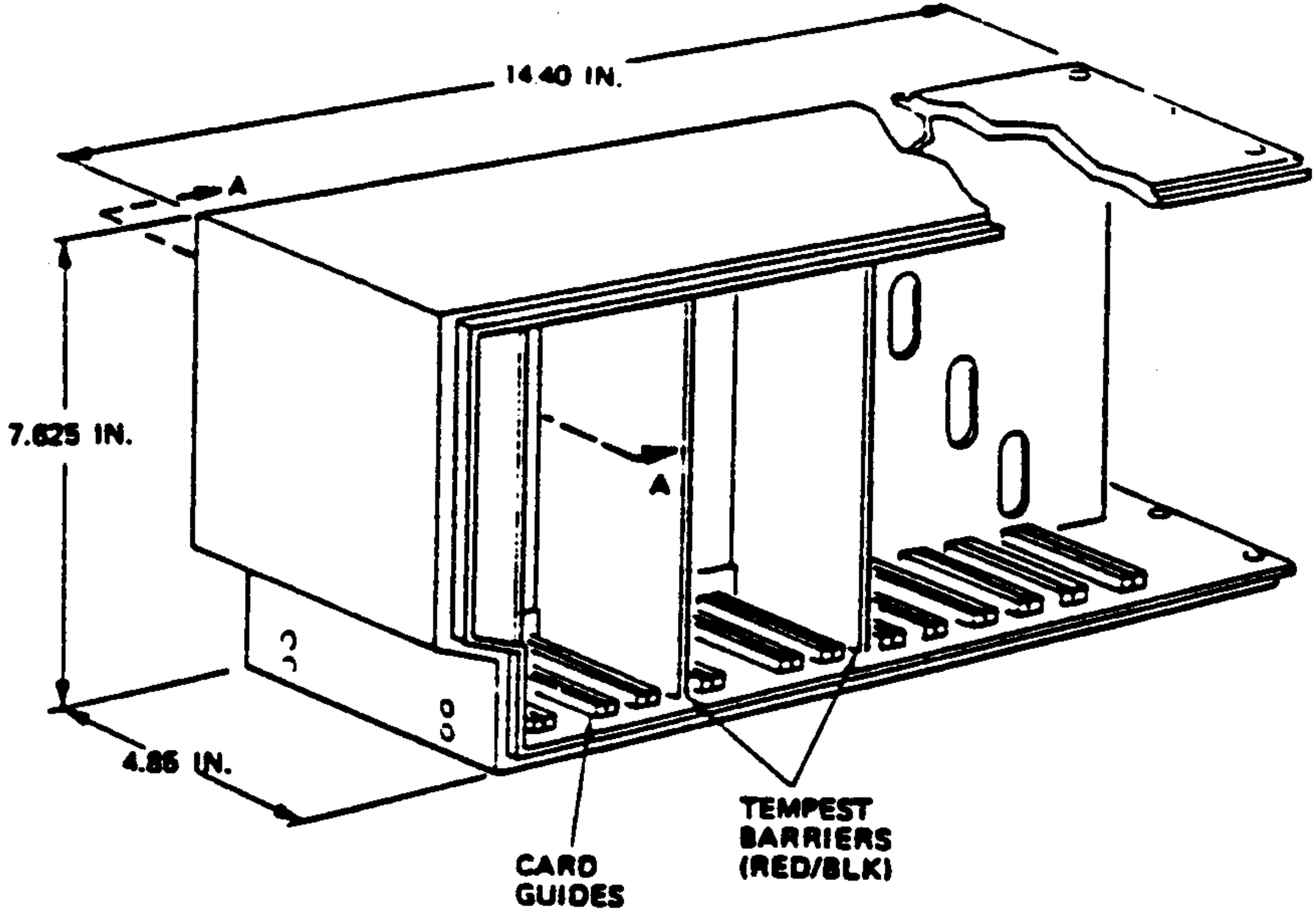
Internal Component Partitioning

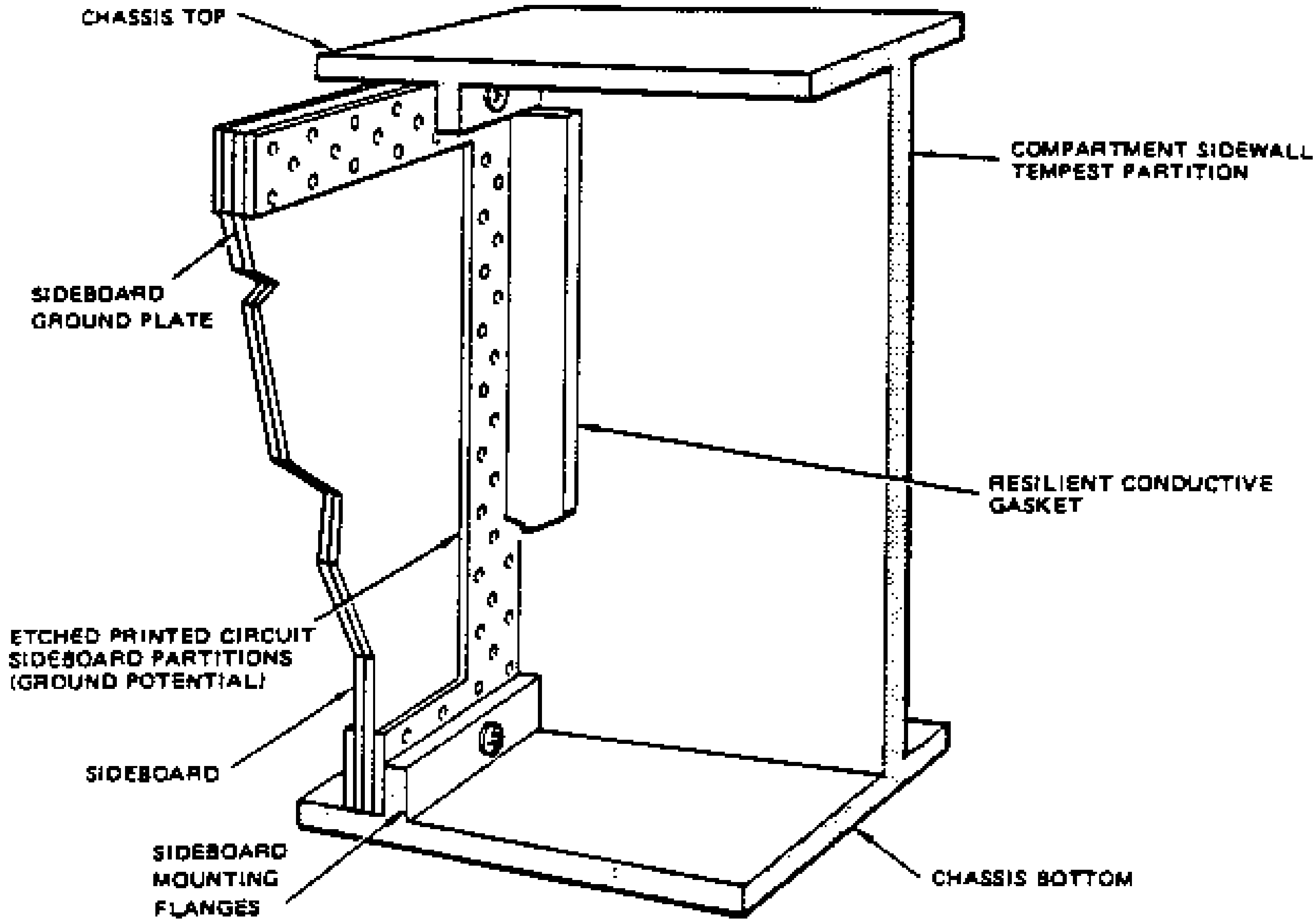


COMSEC Box Partition

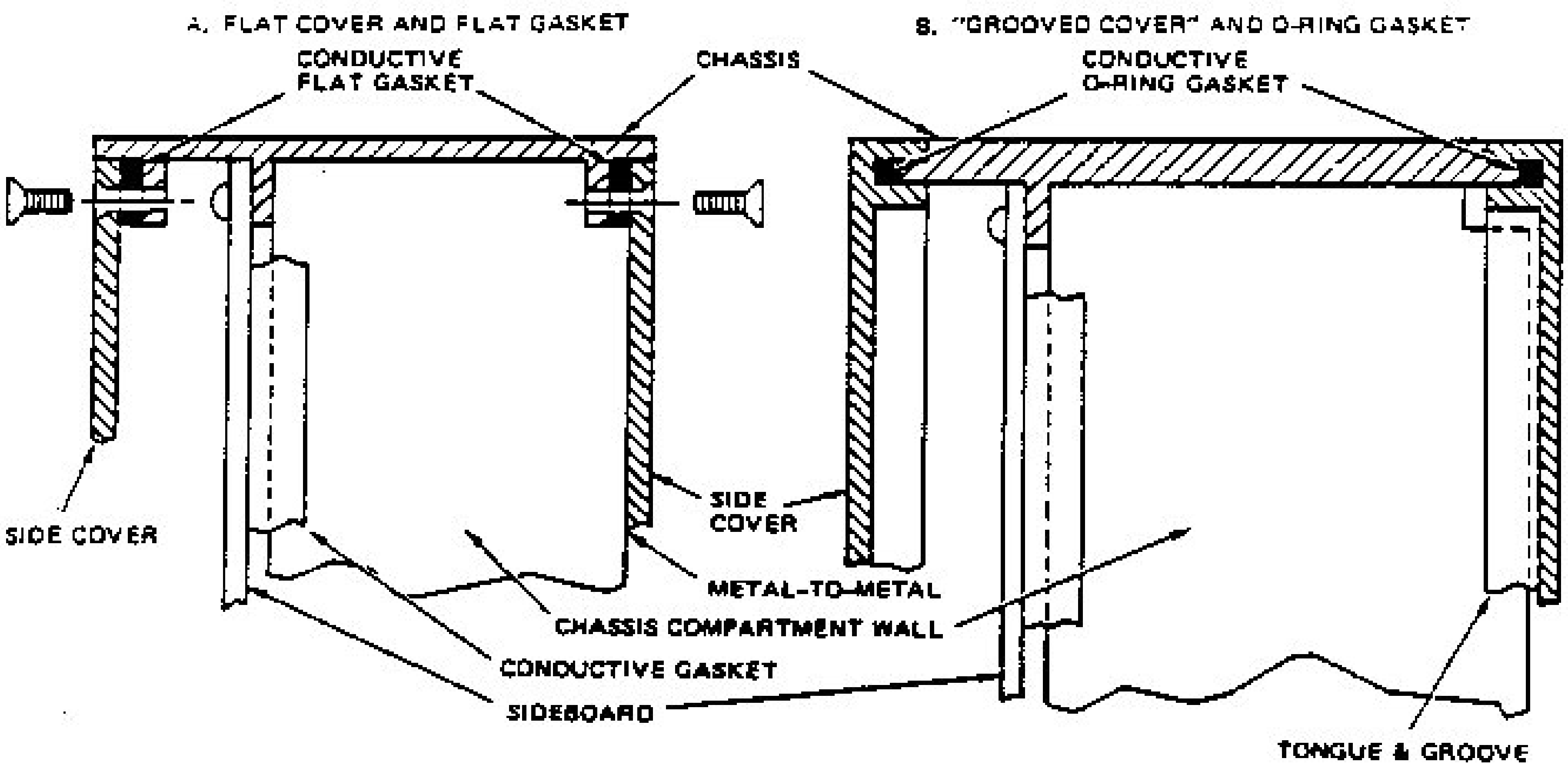


Dip-braised Assembly

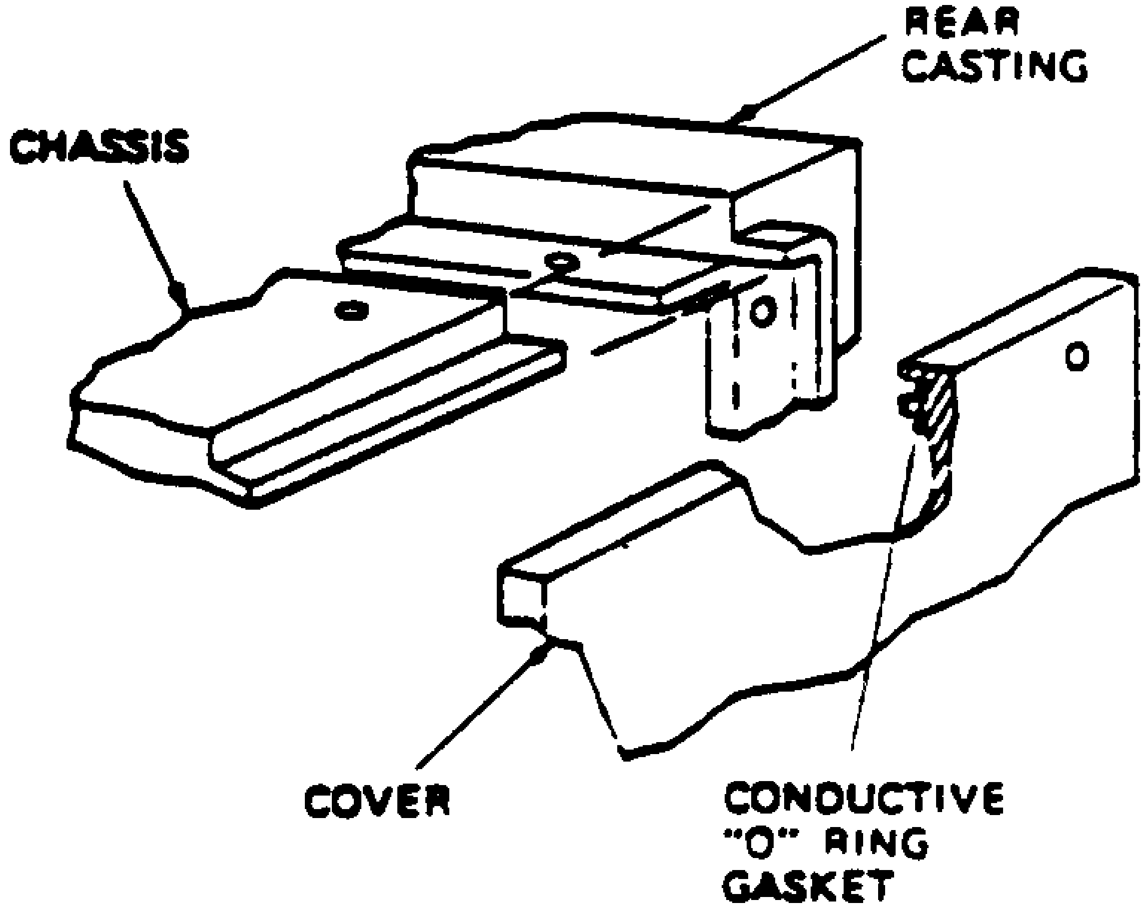



CHASSIS TOP
COMPARTMENT SIDEWALL TEMPEST PARTITION
SIDEBOARD GROUND PLATE
RESILIENT CONDUCTIVE GASKET
ETCHED PRINTED CIRCUIT SIDEBOARD PARTITIONS (GROUND POTENTIAL)
SIDEBOARD
SIDEBOARD MOUNTING FLANGES
CHASSIS BOTTOM

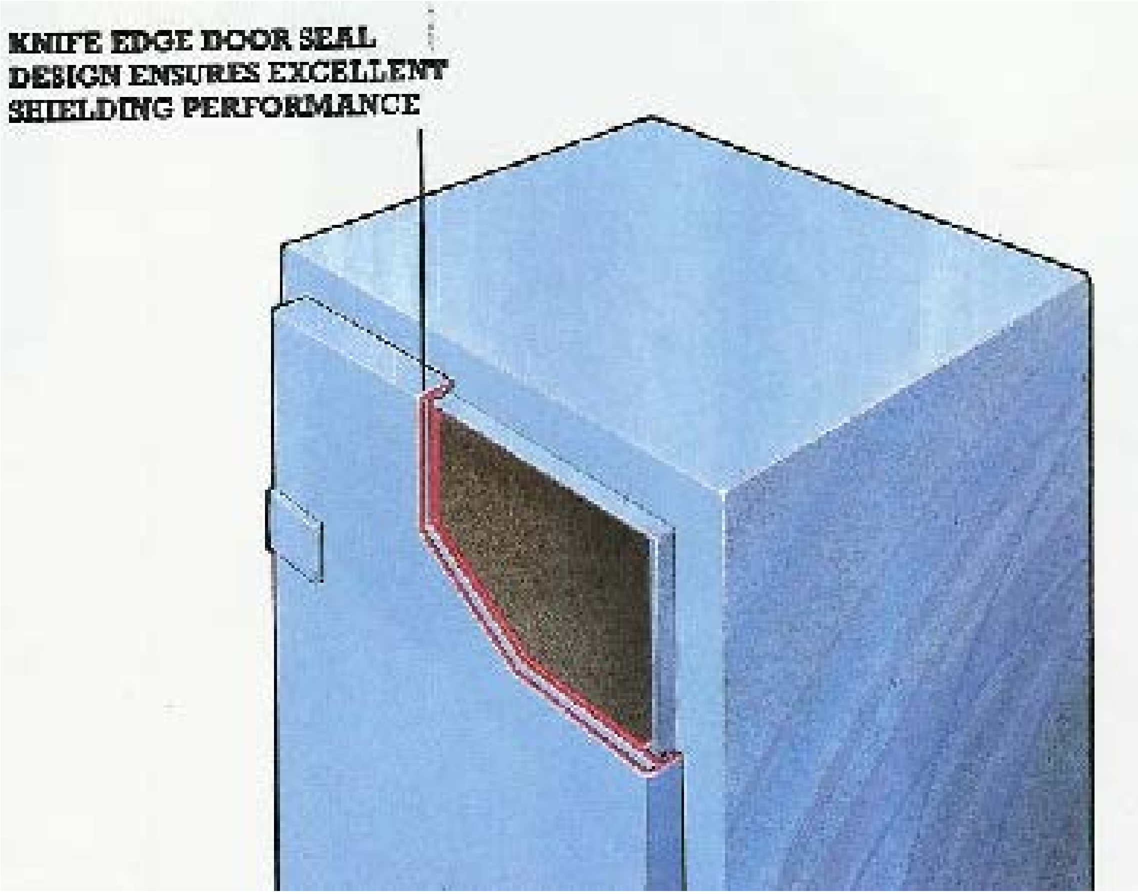
Assembly

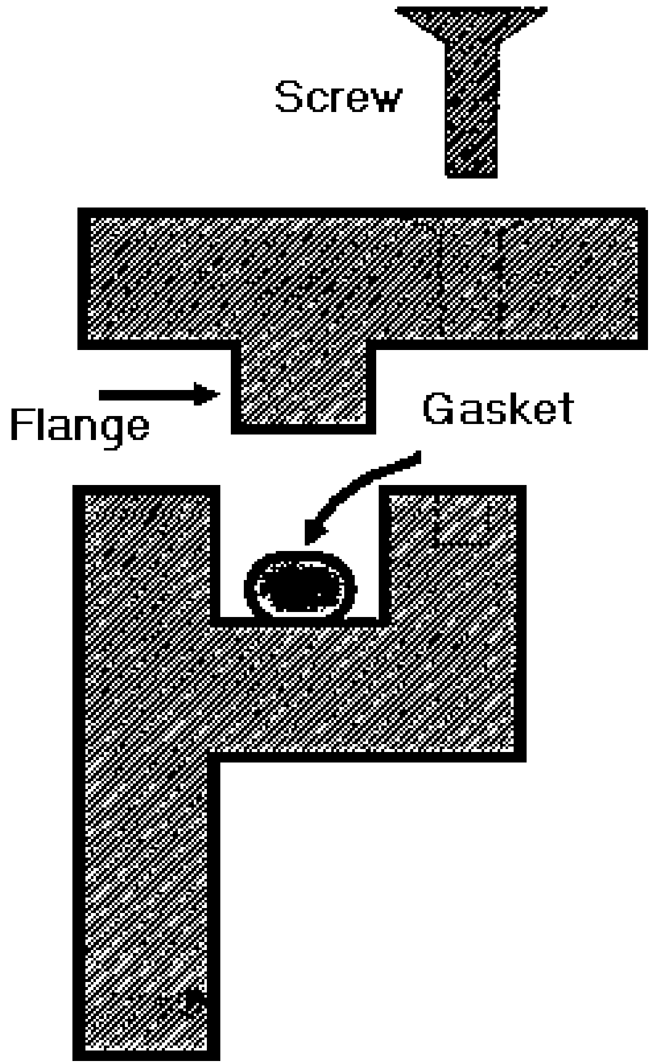


A. FLAT COVER AND FLAT GASKET
B. "GROOVED COVER" AND O-RING GASKET
CONDUCTIVE
FLAT GASKET
CHASSIS
CONDUCTIVE
O-RING GASKET
SIDE COVER
SIDE
COVER
METAL-TO-METAL
CHASSIS COMPARTMENT WALL
CONDUCTIVE GASKET
SIDEBOARD
TONGUE & GROOVE


REAR
CASTING
CHASSIS
COVER
CONDUCTIVE
"O" RING
GASKET

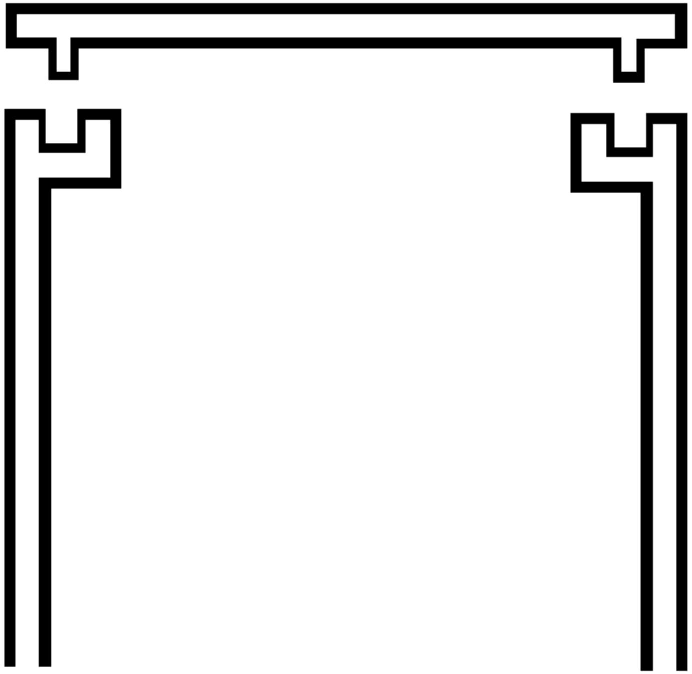
Knife Edge Lips Are Often Used on Larger Chasses





- Tongue and Grove with environmental and conductive gasket
- Note that the flange is slightly smaller then the grove

Grove as a Wave Guide



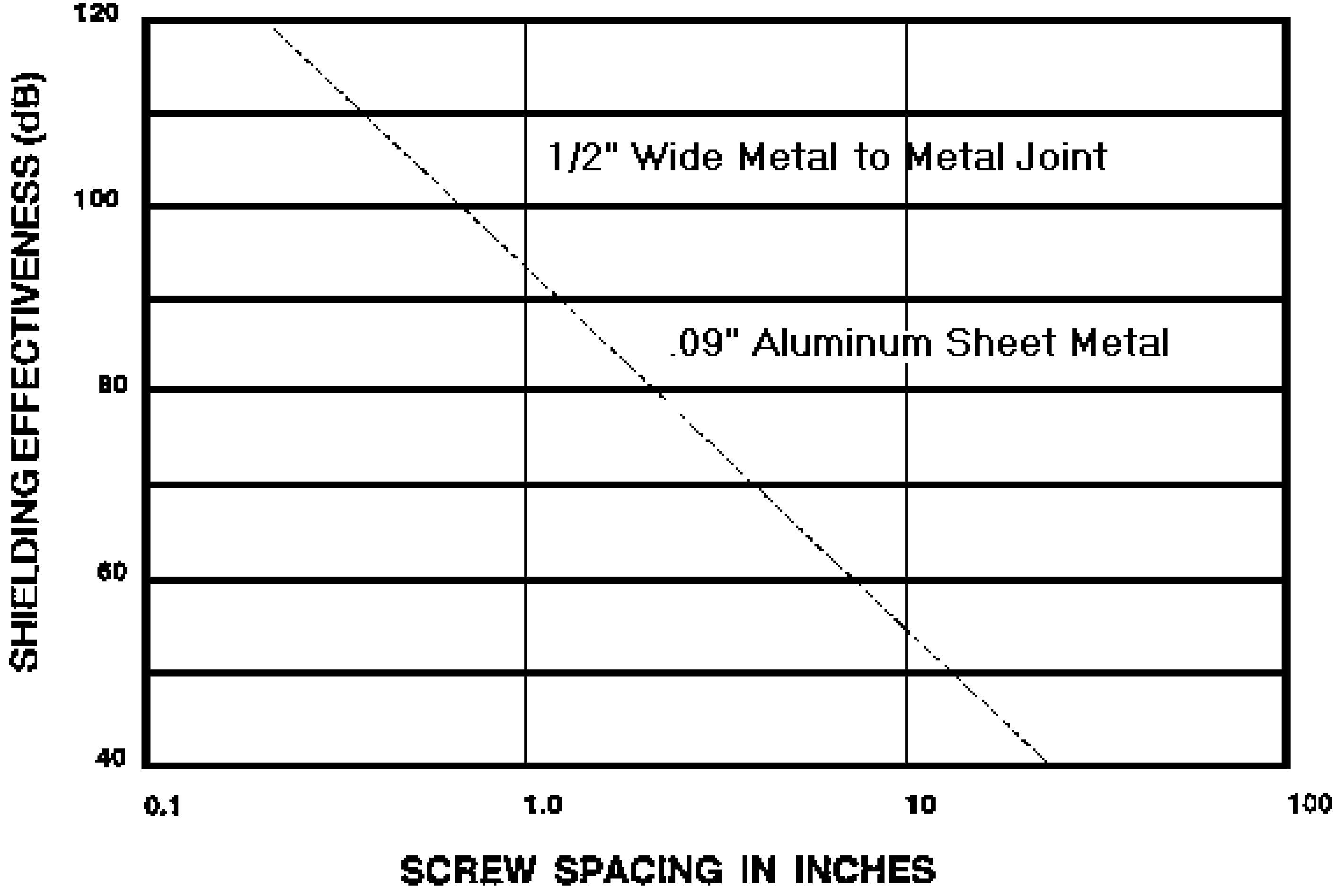
- In the absence of a gasket, the grove assembly acts as a wave guide to reduce, but not eliminate radiated leakages.

Problems During Paint Application

- Paint formulation can effect conductivity by a factor of 3.
- Paint should be applied in warm dry conditions with no forced drying.
- Sealing with paint will prevent pealing and flaking, but provides less protection against aging.

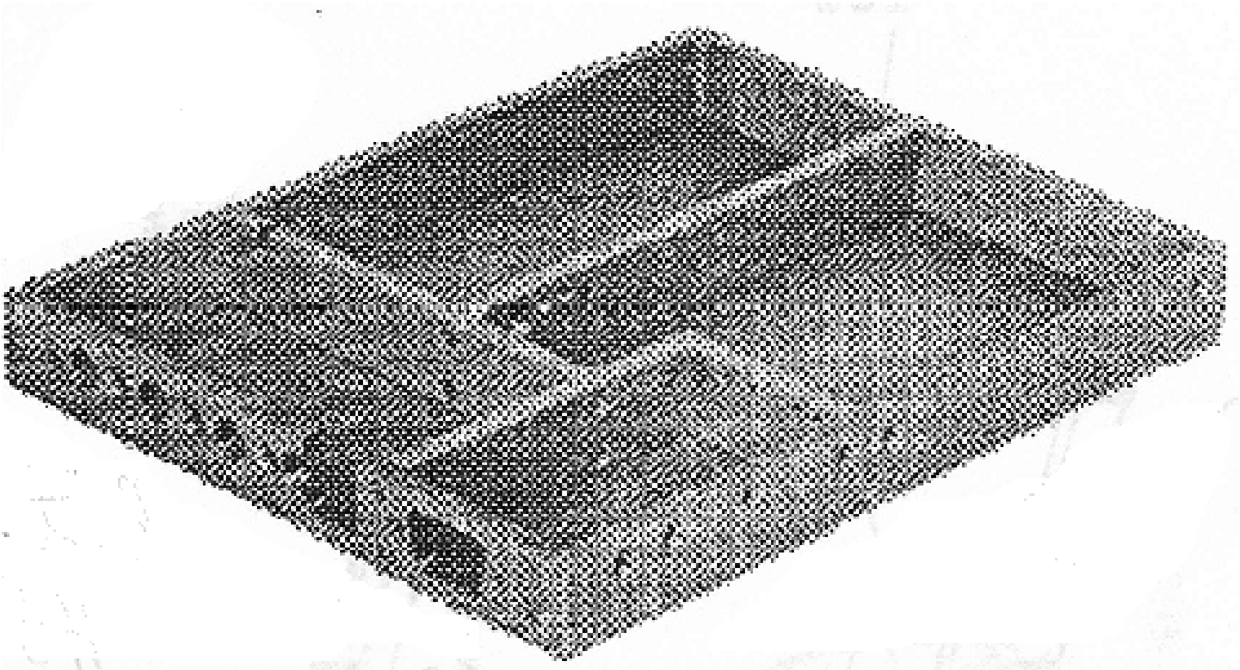
Screws

- While screws are the most common method of attachment, clamps are sometimes employed.
- Hinged assemblies are not recommended because of uneven torque.
- Screw spacing is the critical factor in leakage reduction.



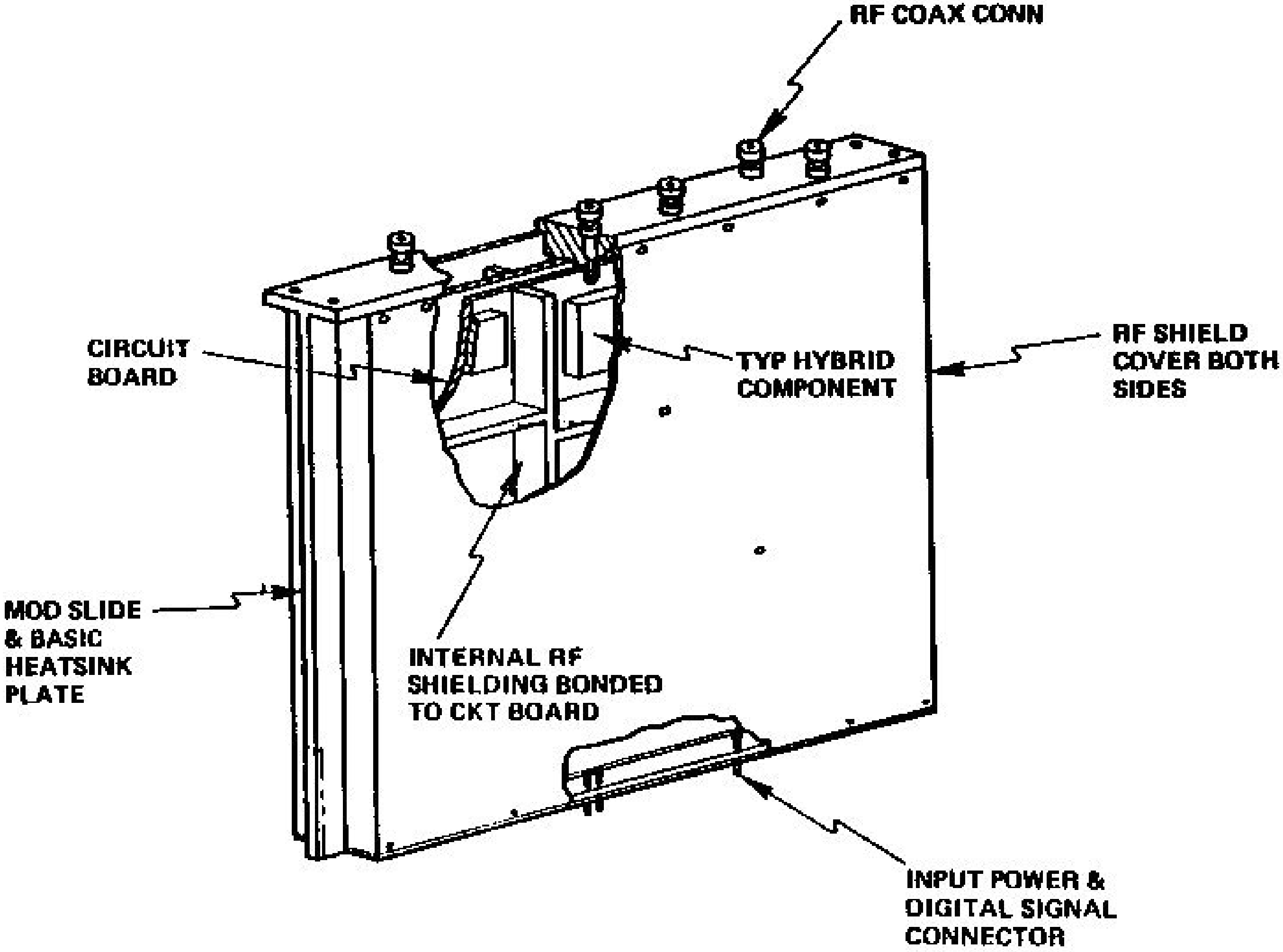
120
100
80
60
40
SHIELDING EFFECTIVENESS (dB)
1/2" Wide Metal to Metal Joint
.09" Aluminum Sheet Metal
0.1
1.0
10
100
SCREW SPACING IN INCHES

Aluminum Housing

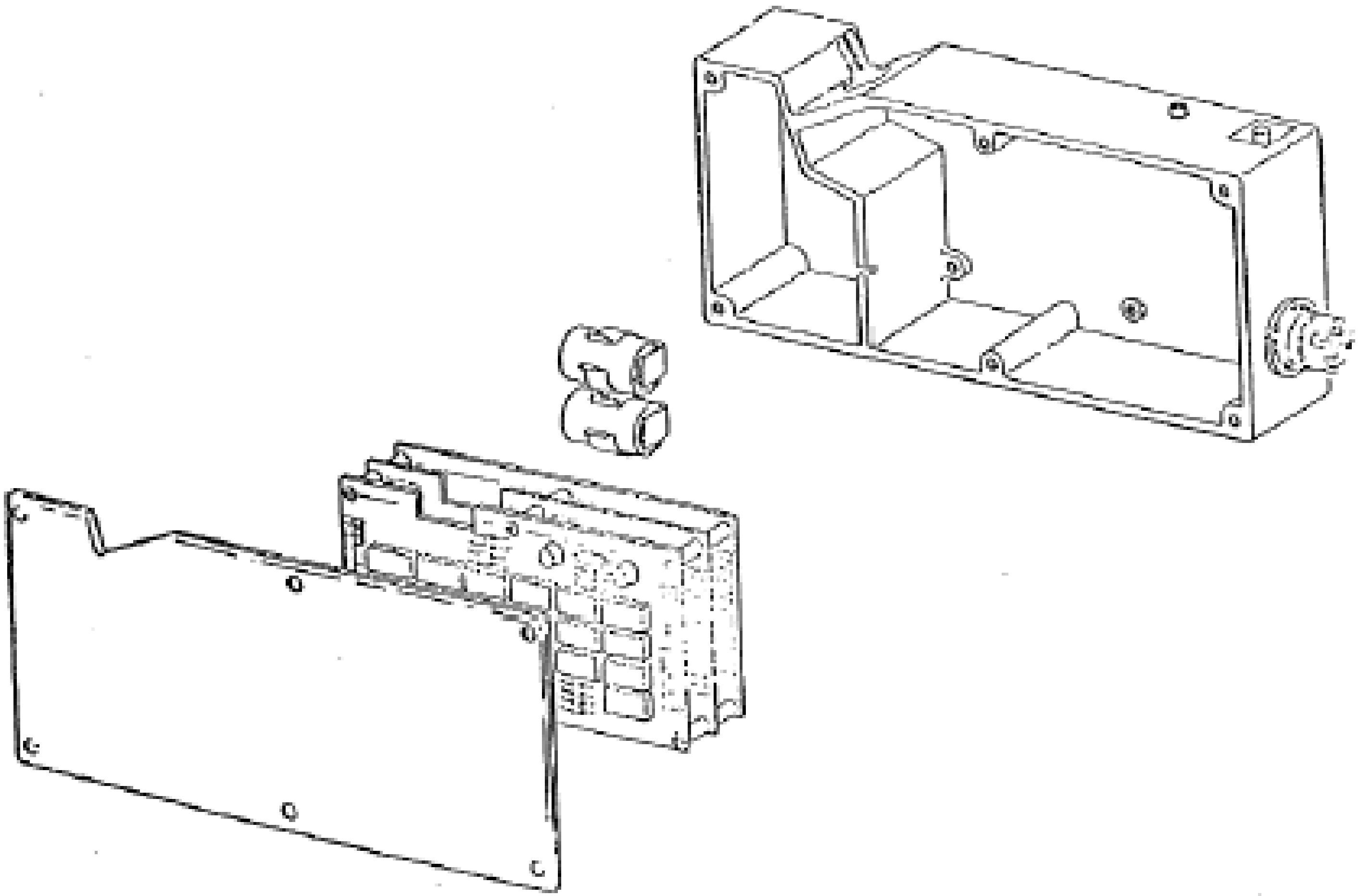


Note: Nickel coating required for shielding

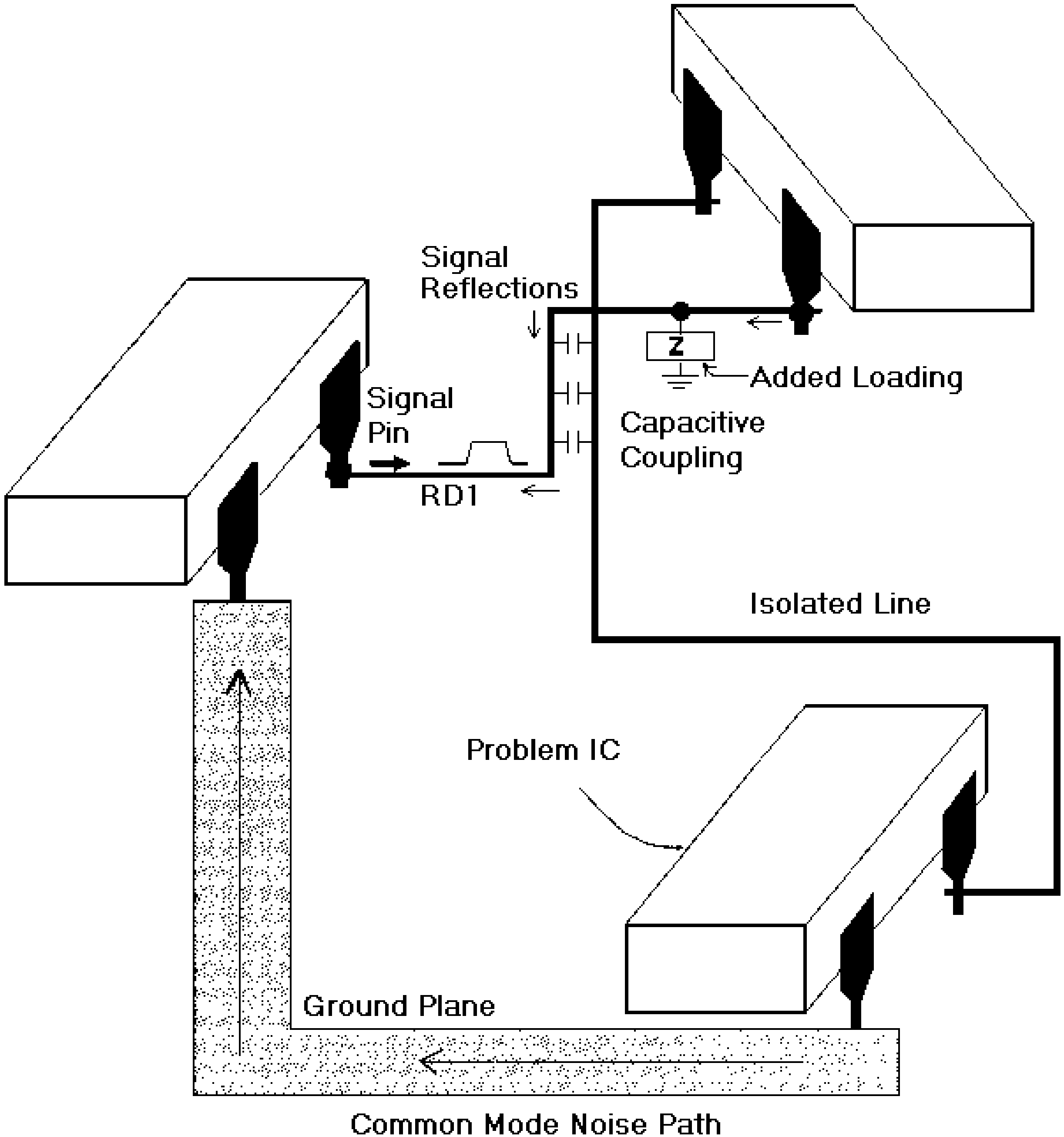
Encapsulated Card



KEY Fill Device Packaging

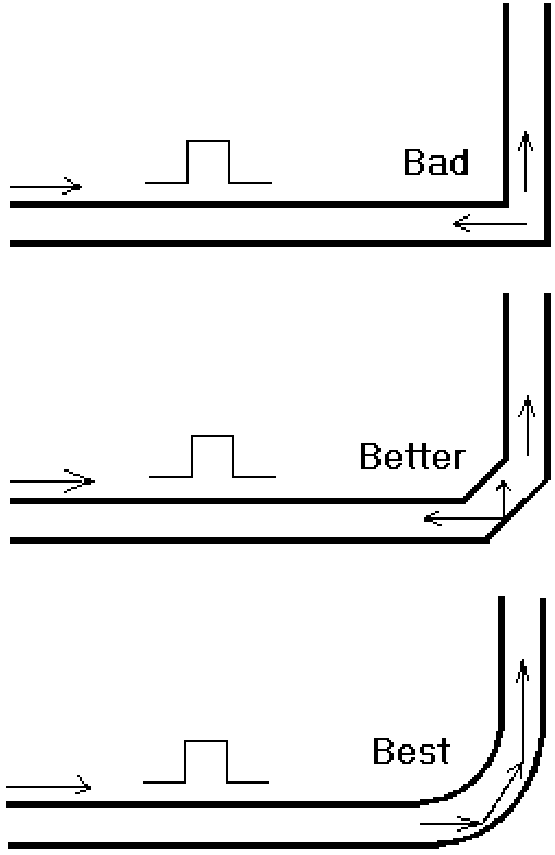


PC Cards & Backplanes



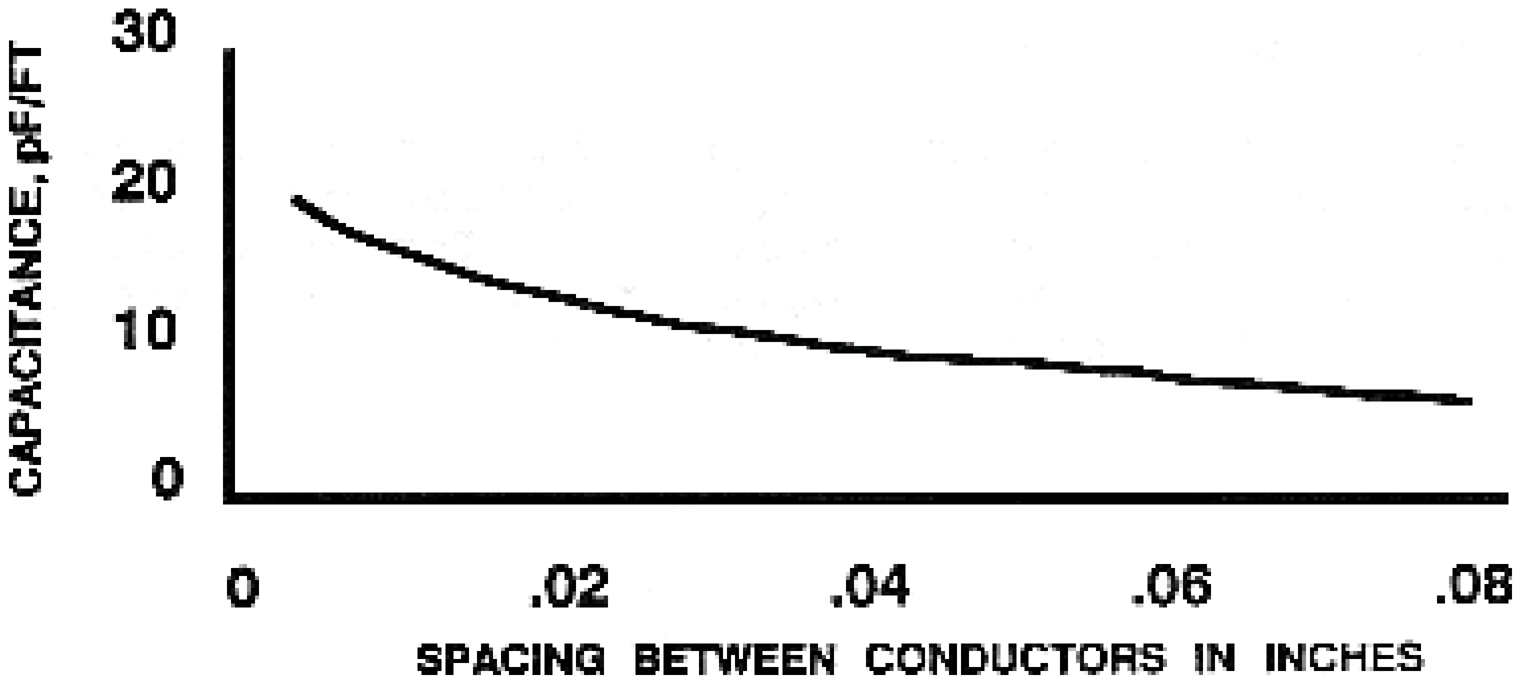
- Potential coupling due to impedance mismatch.

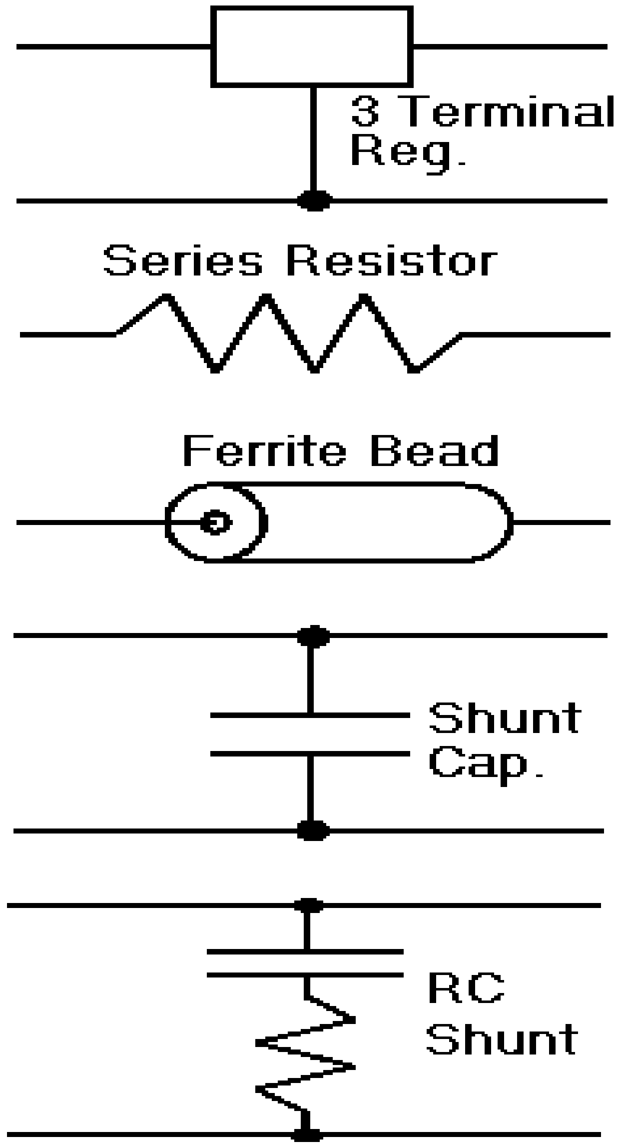
PC Board Rubber-banding



- Sharp edges appear as impedance mismatches to high frequency emissions.

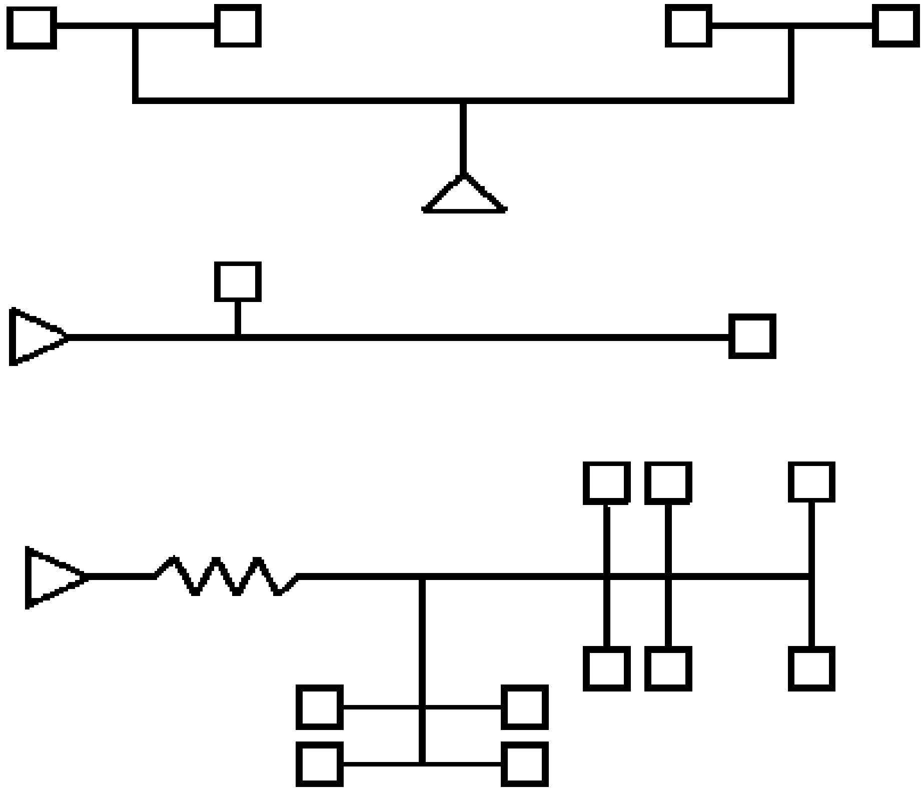
Capacitive Coupling to Adjacent Traces





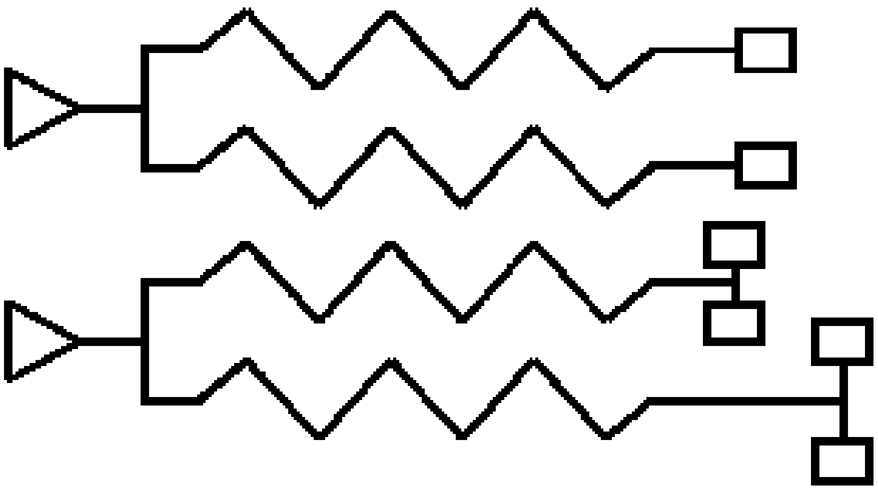
- Most common damping approaches on a trace.

Bad High Frequency Distribution Schemes



- Without damping, variations of these schemes are likely to enhance trace emission problems.

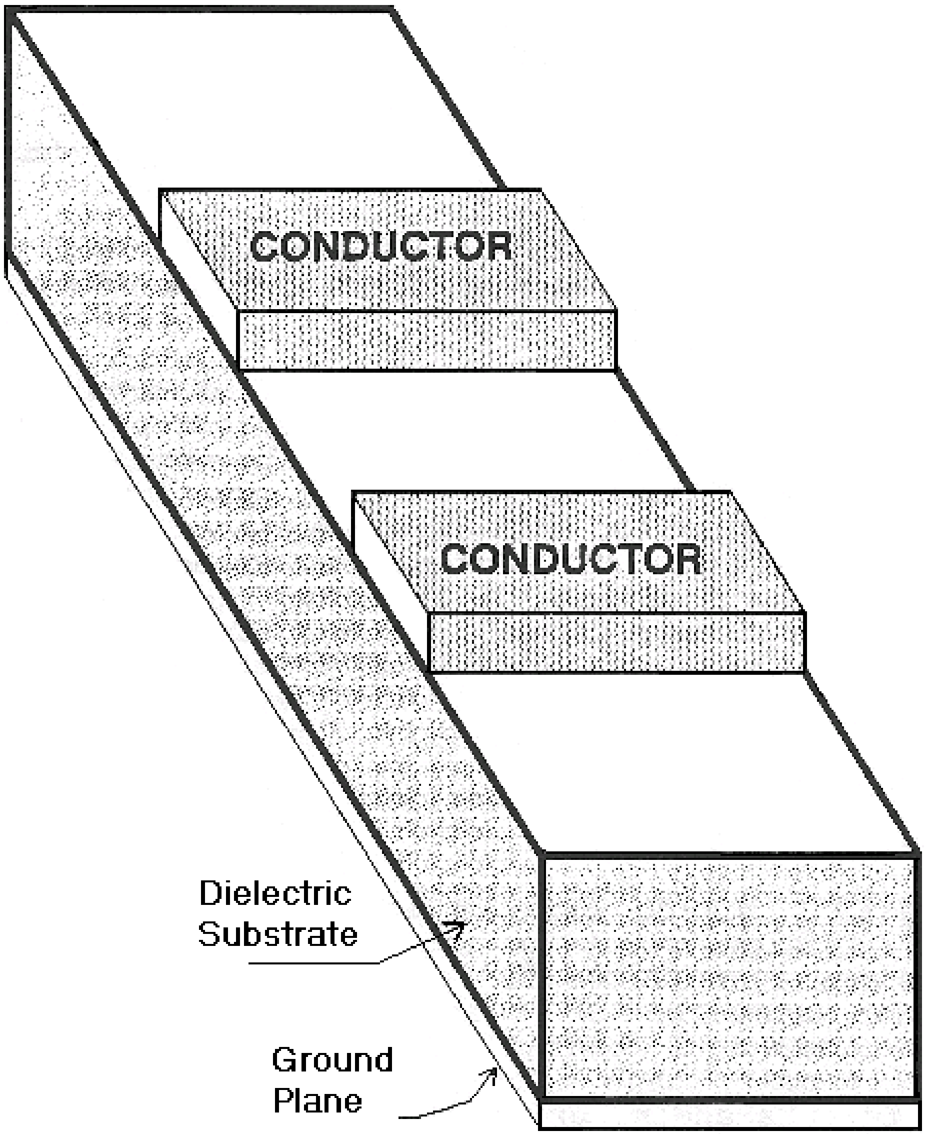
Good High Frequency Distribution Schemes



- Upper is the ideal distribution for a driver and load.
- Lower is very good approach.

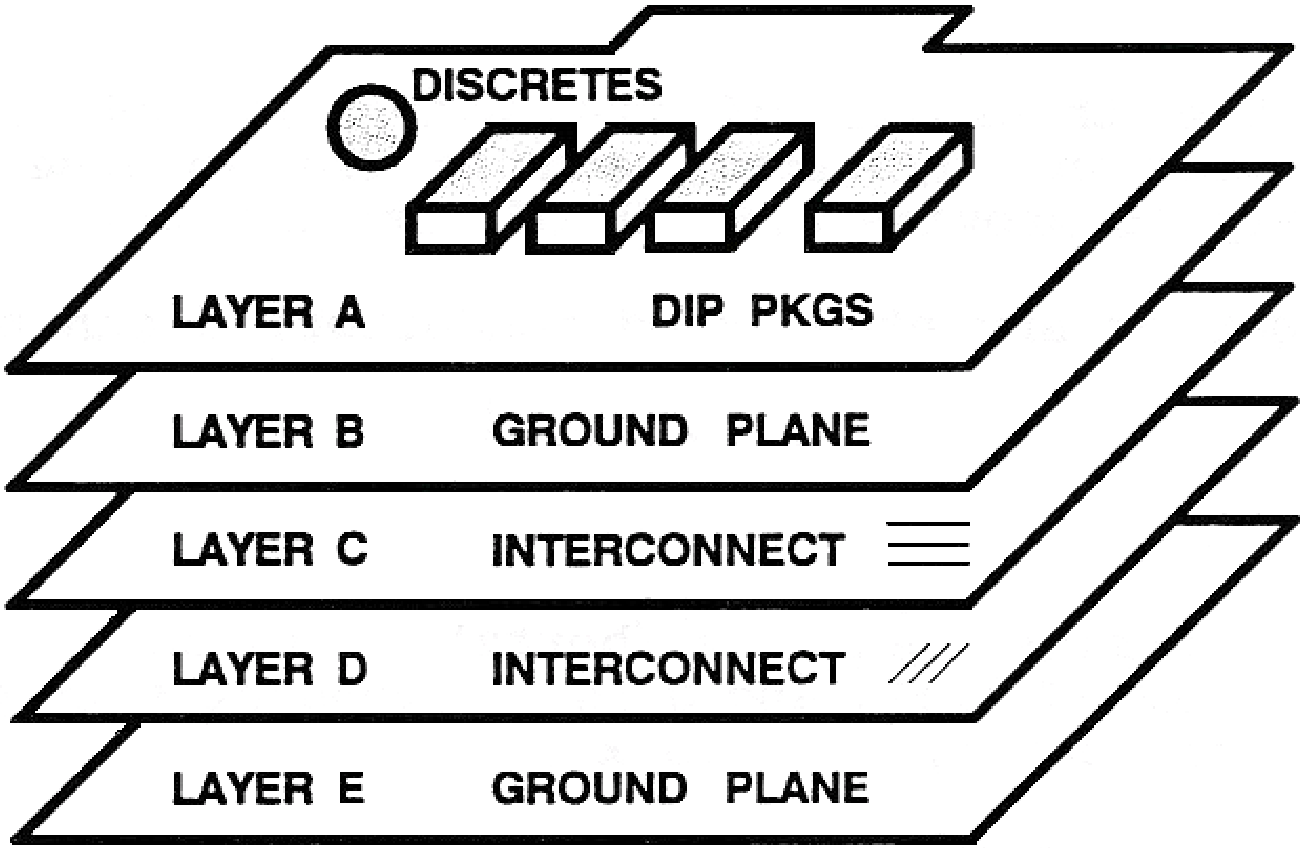
Microstrip Transmission Lines

- Technique developed as a means of providing high frequency isolation on circuit boards.
  - Allows uniform characteristic impedance on the microstrip transmission line.
  - Circuit traces located above a ground plane will produce much less radiated energy then circuits with no ground plane on the card.
- Sandwiching the circuit traces between outer layer ground planes is the most effective means of reducing emissions without changing the systems circuit design.

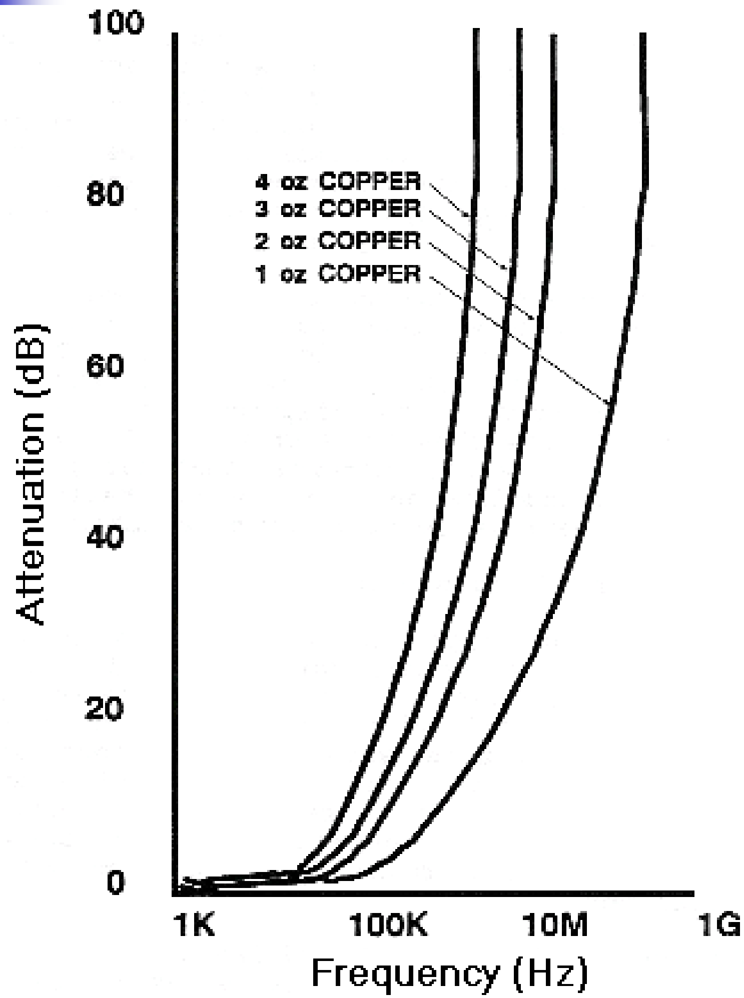


Microstrip transmission line format.

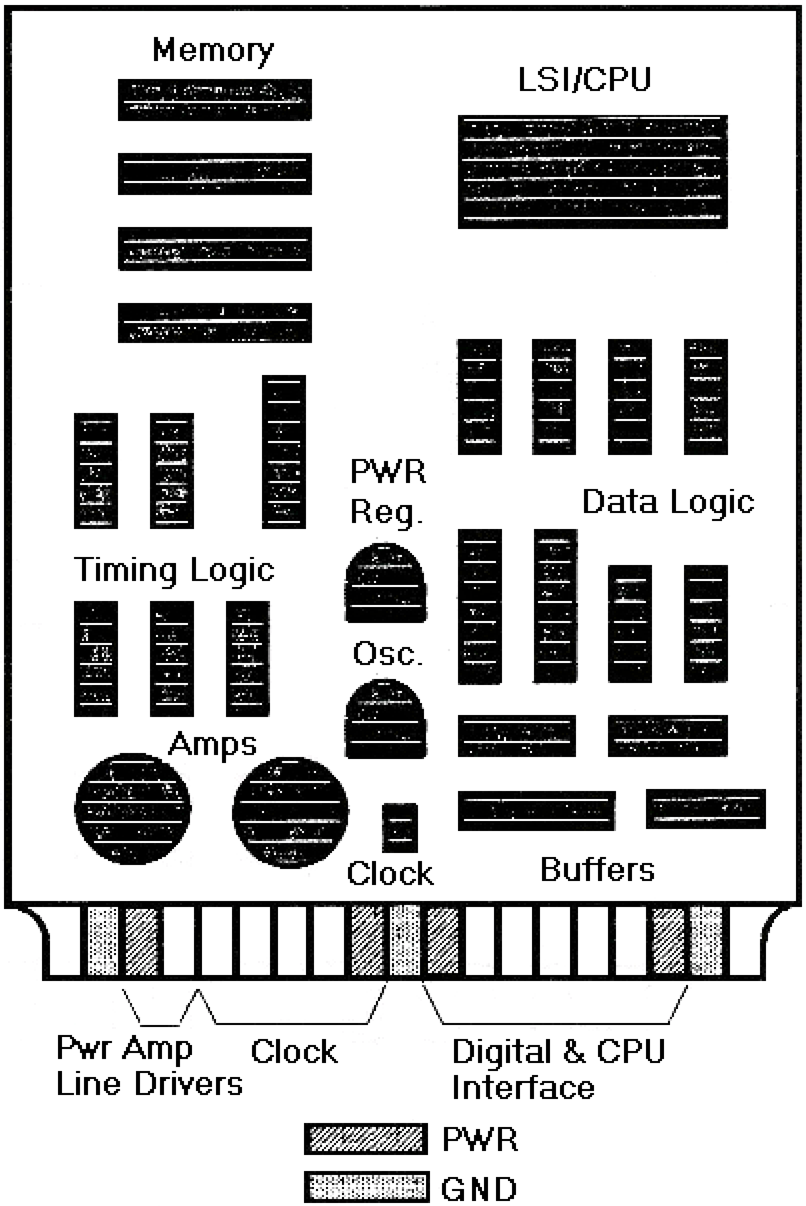
Typical PC Board Sandwich Configuration



Ground Plane Thickness



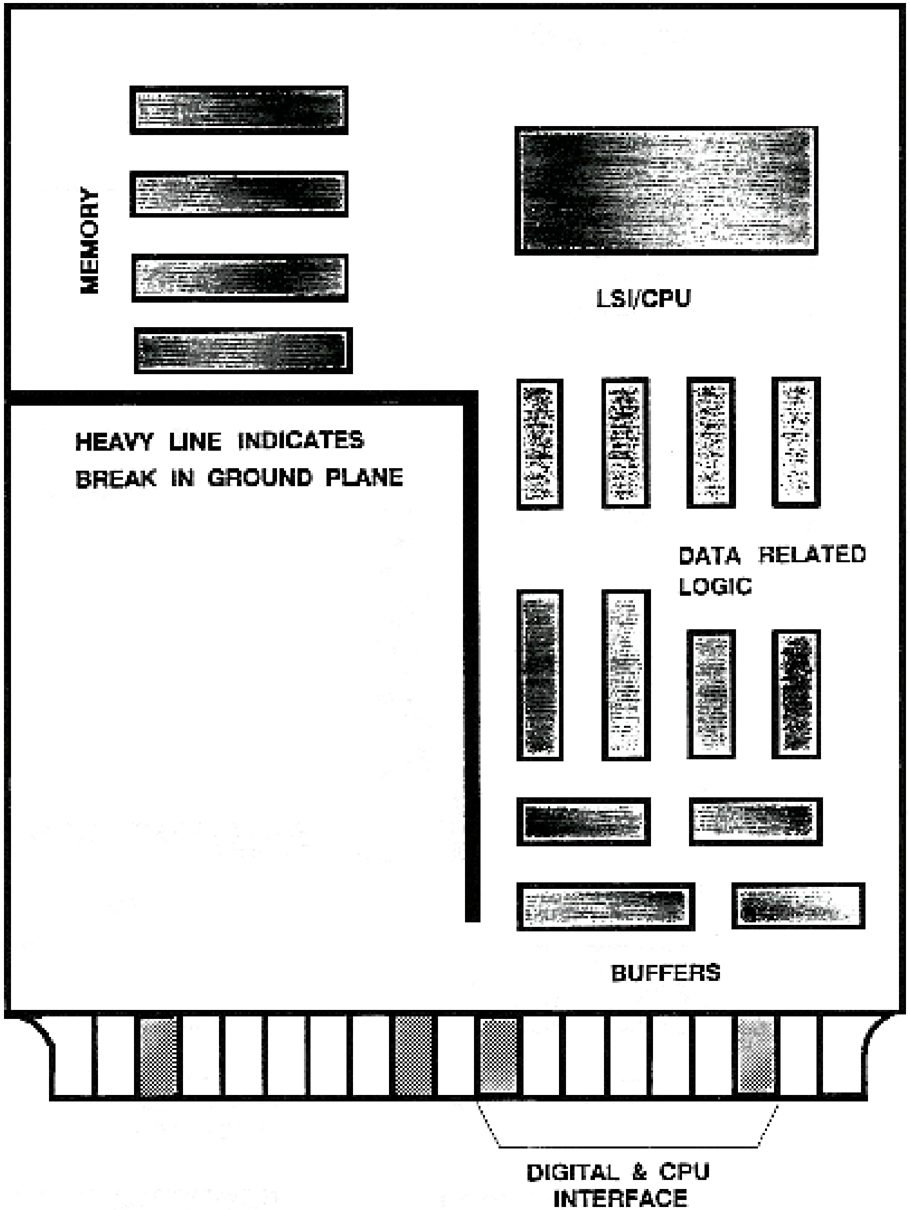
- Traces reflect the damping associated with using copper ground planes of various thickness.
- Note no attenuation below 1 MHz for any thickness.



- Typical PC board layout.
- Note pattern of keeping noise generators towards middle and separating power from signals.

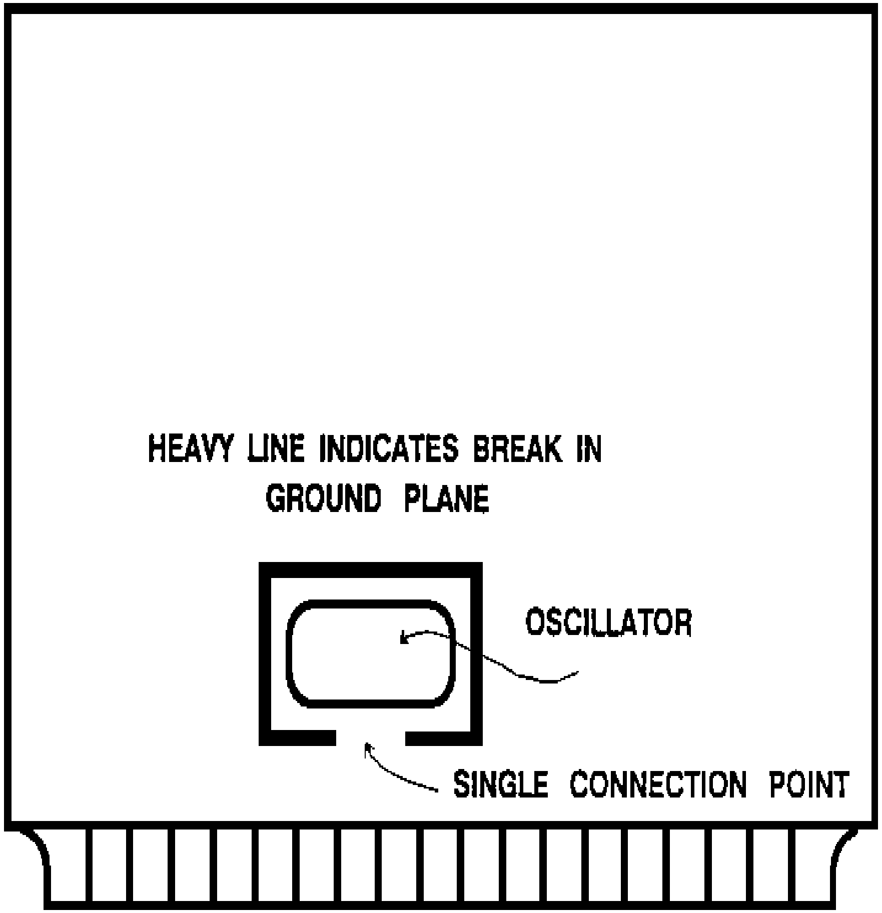
Broken Ground Planes

- Regardless of board layers, short interconnect traces and isolation through circuit nesting are preferred.
- While most standard multilayer applications promote the use of an unbroken ground plane, unless a sandwich configuration is to be used, there are instances when breaking the ground plan is extremely beneficial to the TEMPEST designer.



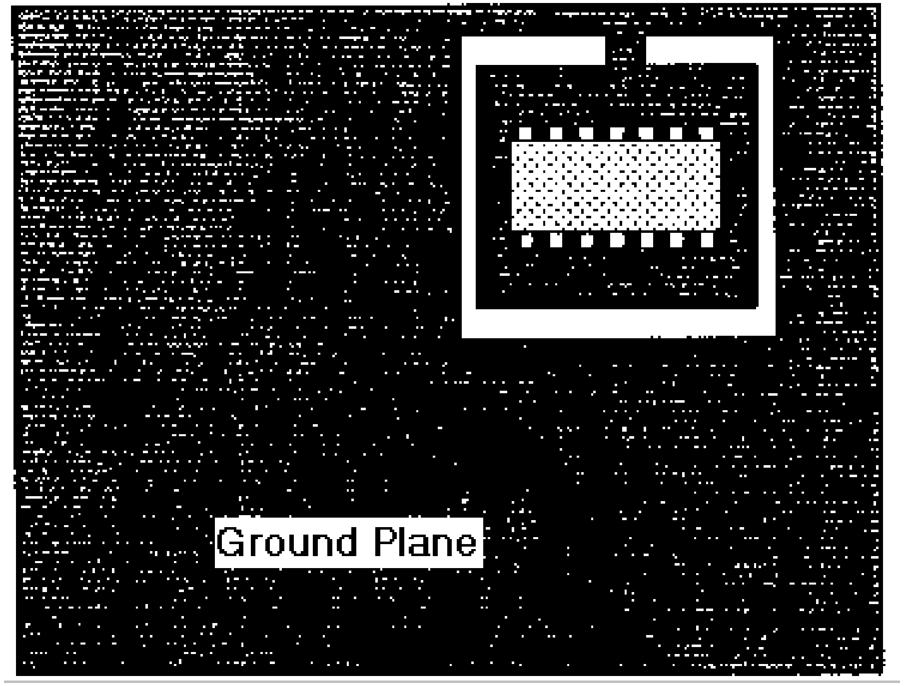
- Data logic nest showing signal ground isolation from power ground.

Oscillator Noise



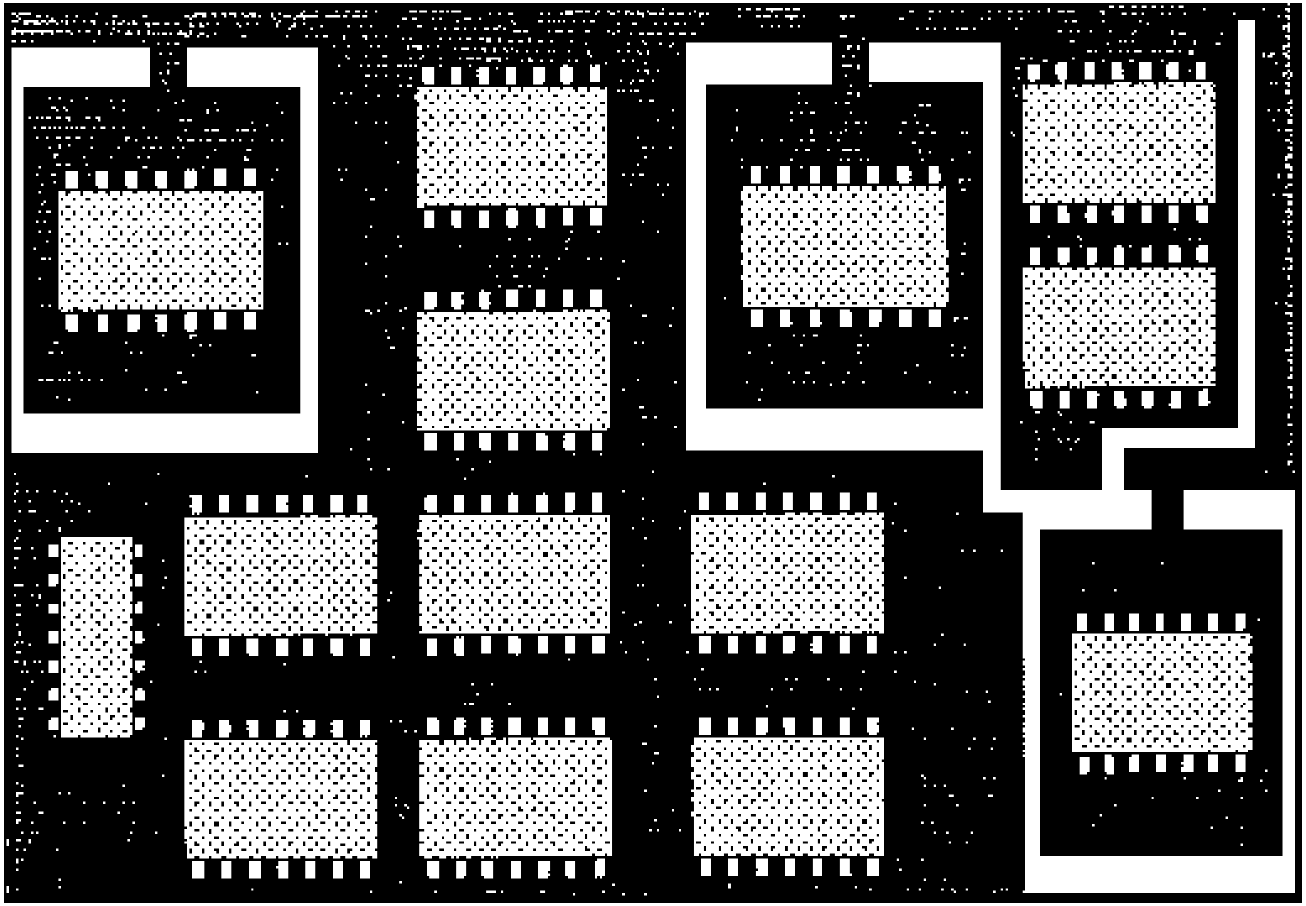
- Technique for reducing oscillator induced ground noise.

When You Control the Design



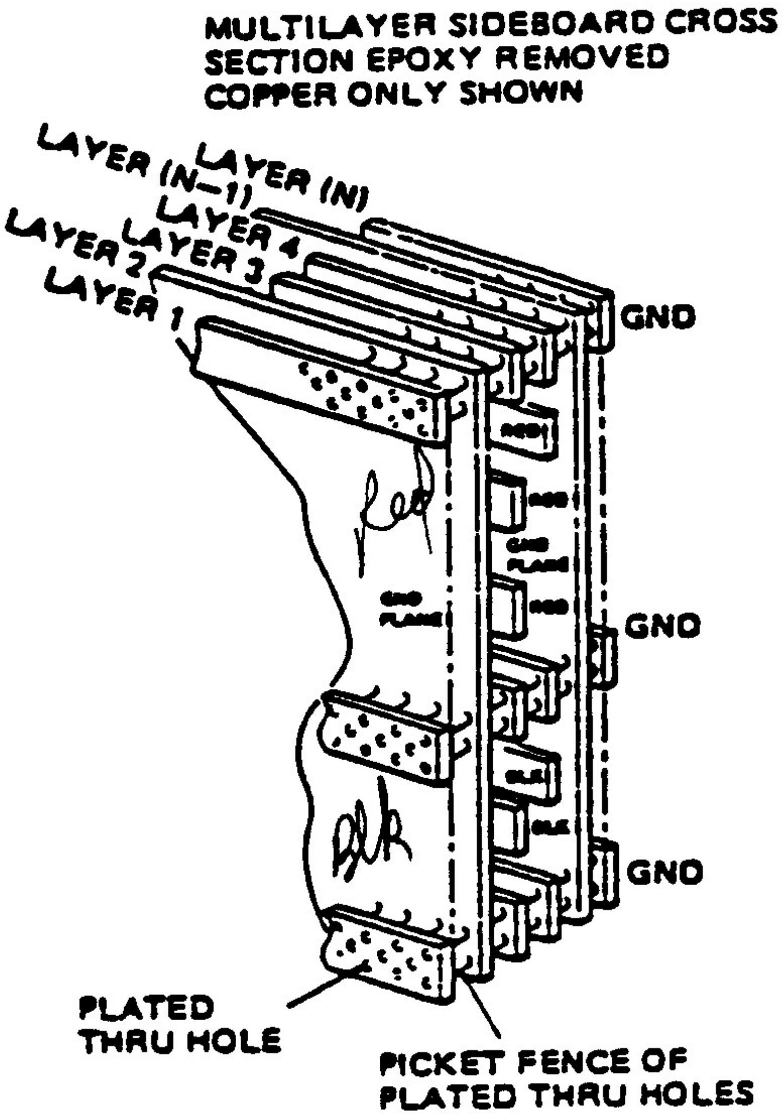
- Locate the signal source near the card interface connector during board layout.
- Place a ground plane under the IC with the conductive connection to the ground plane at only one point

Isolated Ground Plane Branching

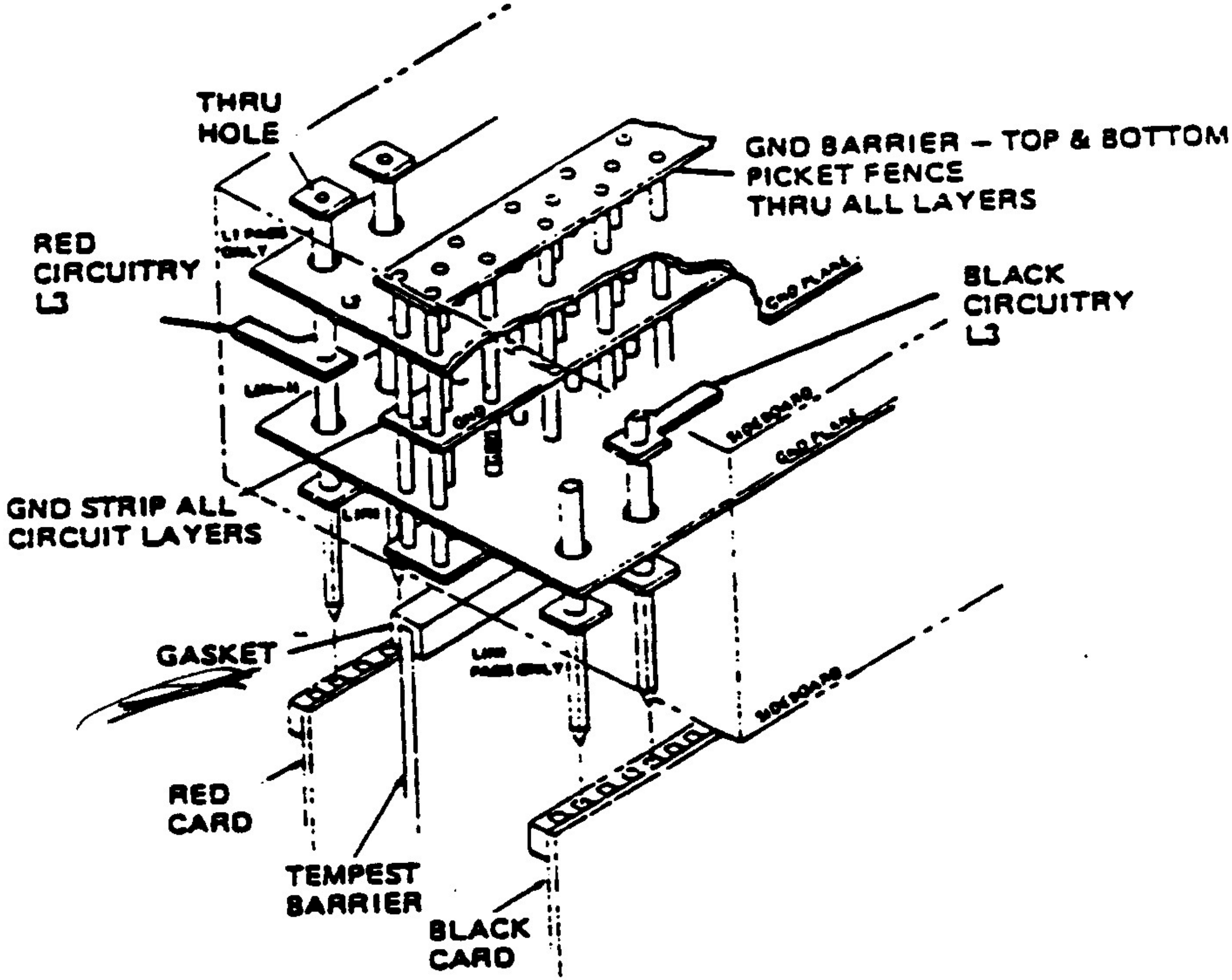


PC Board Layout Rules

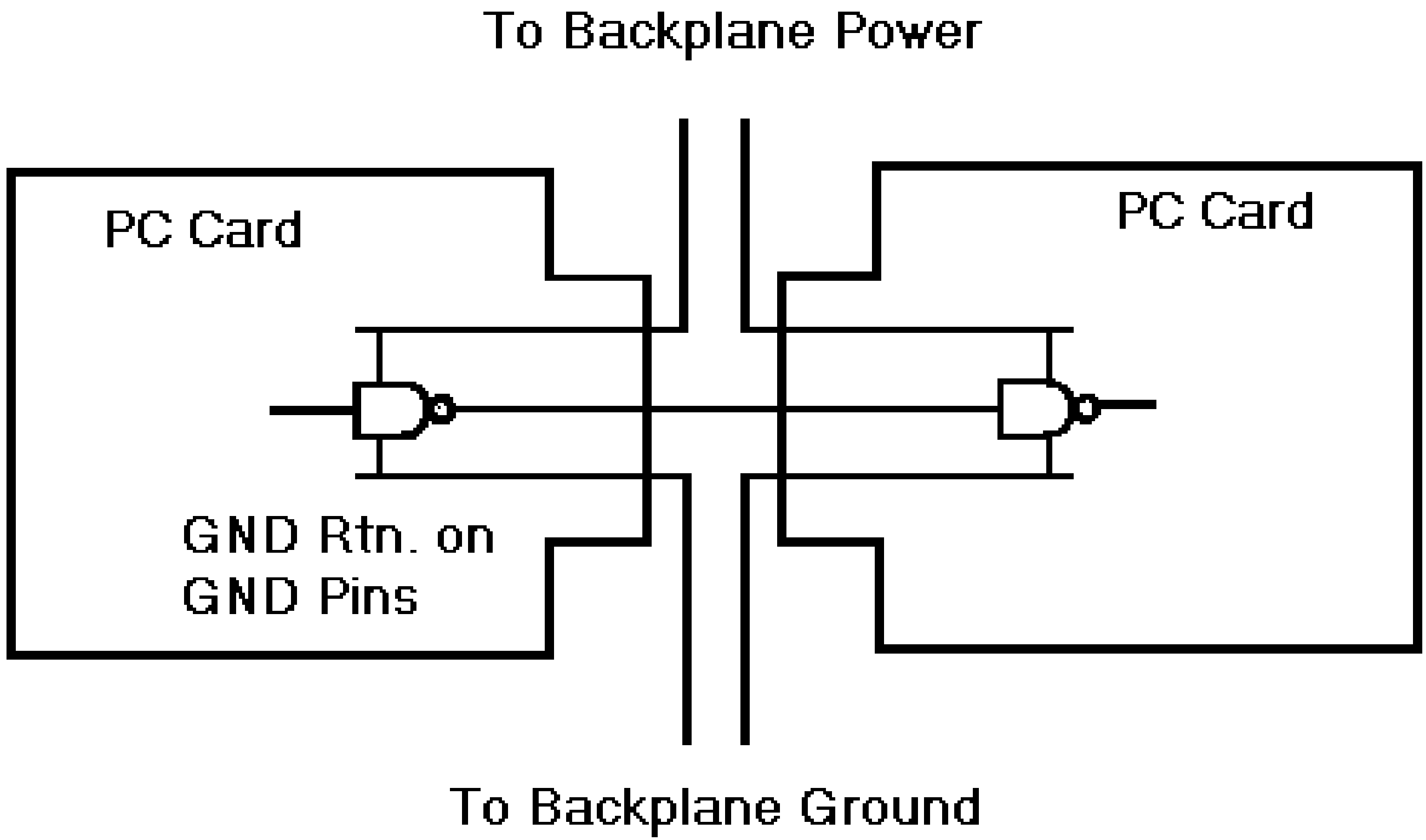
- Maximum isolation achieved using a picket fence.
- Inter-trace coupling greatly reduced using ground traces between each signal trace.
  - Isolated ground planes or controlled grounds can also eliminate inter-trace coupling.
- Avoid ground return loops on the card.
- Use ground planes with breaks to control emissions.



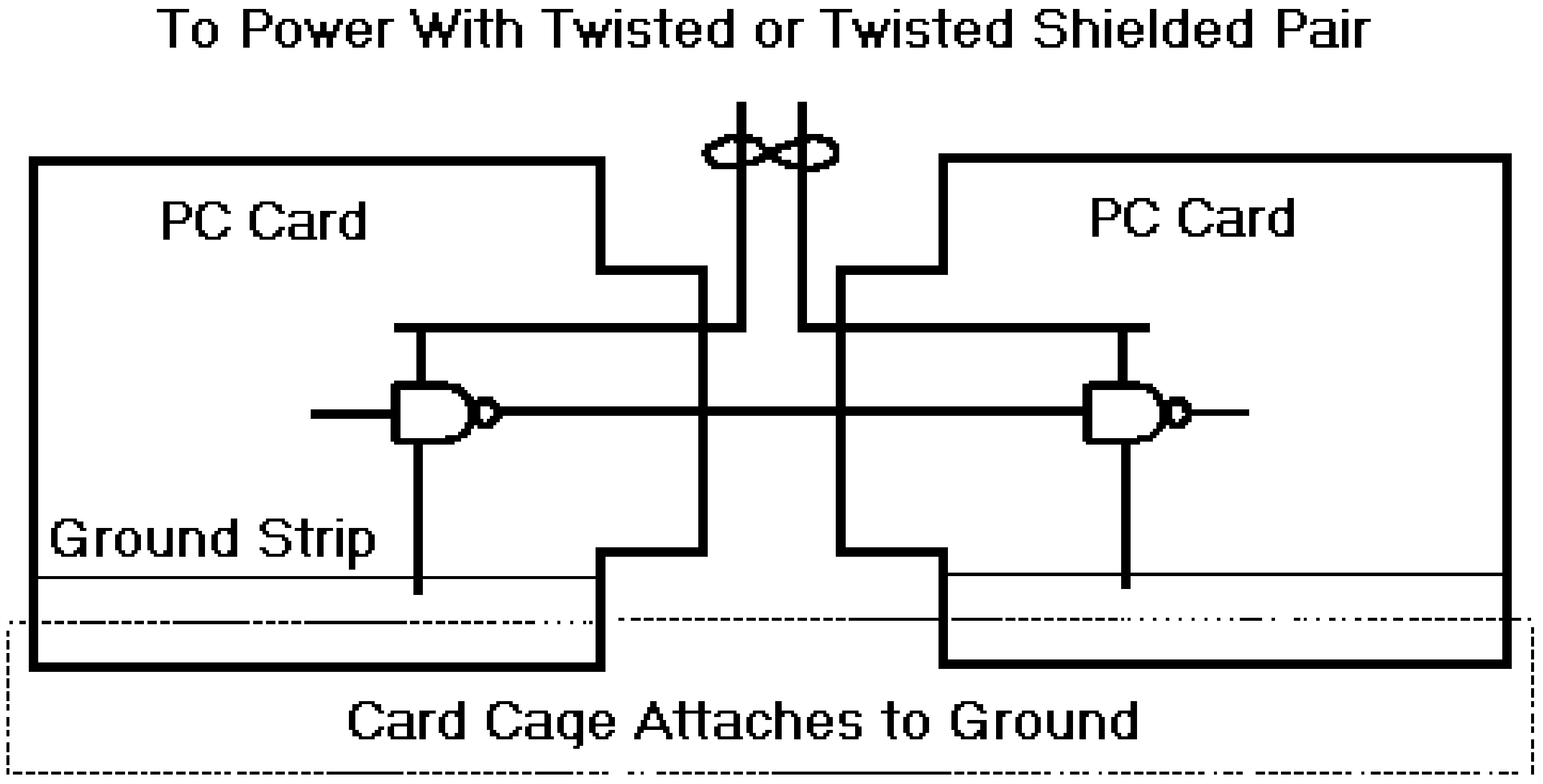
- The picket fence pc-board configuration creates isolation between signal lines with different emission controls to be placed on the same board.


THRU HOLE
GND BARRIER – TOP & BOTTOM
PICKET FENCE
THRU ALL LAYERS
RED CIRCUITRY L3
BLACK CIRCUITRY L3
GND STRIP ALL CIRCUIT LAYERS
GASKET
RED CARD
TEMPEST BARRIER
BLACK CARD

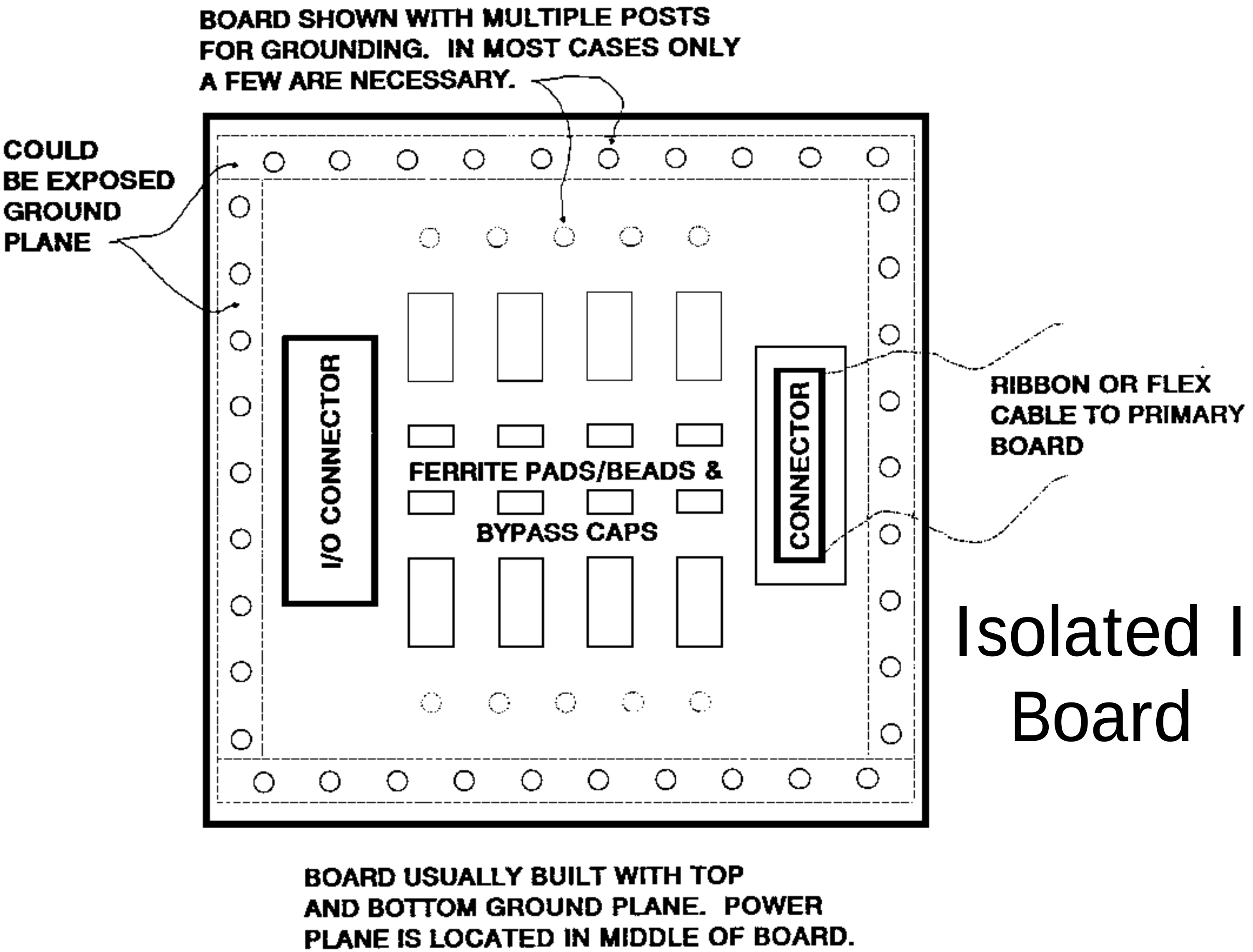
Power & Ground for PC Card Mounting



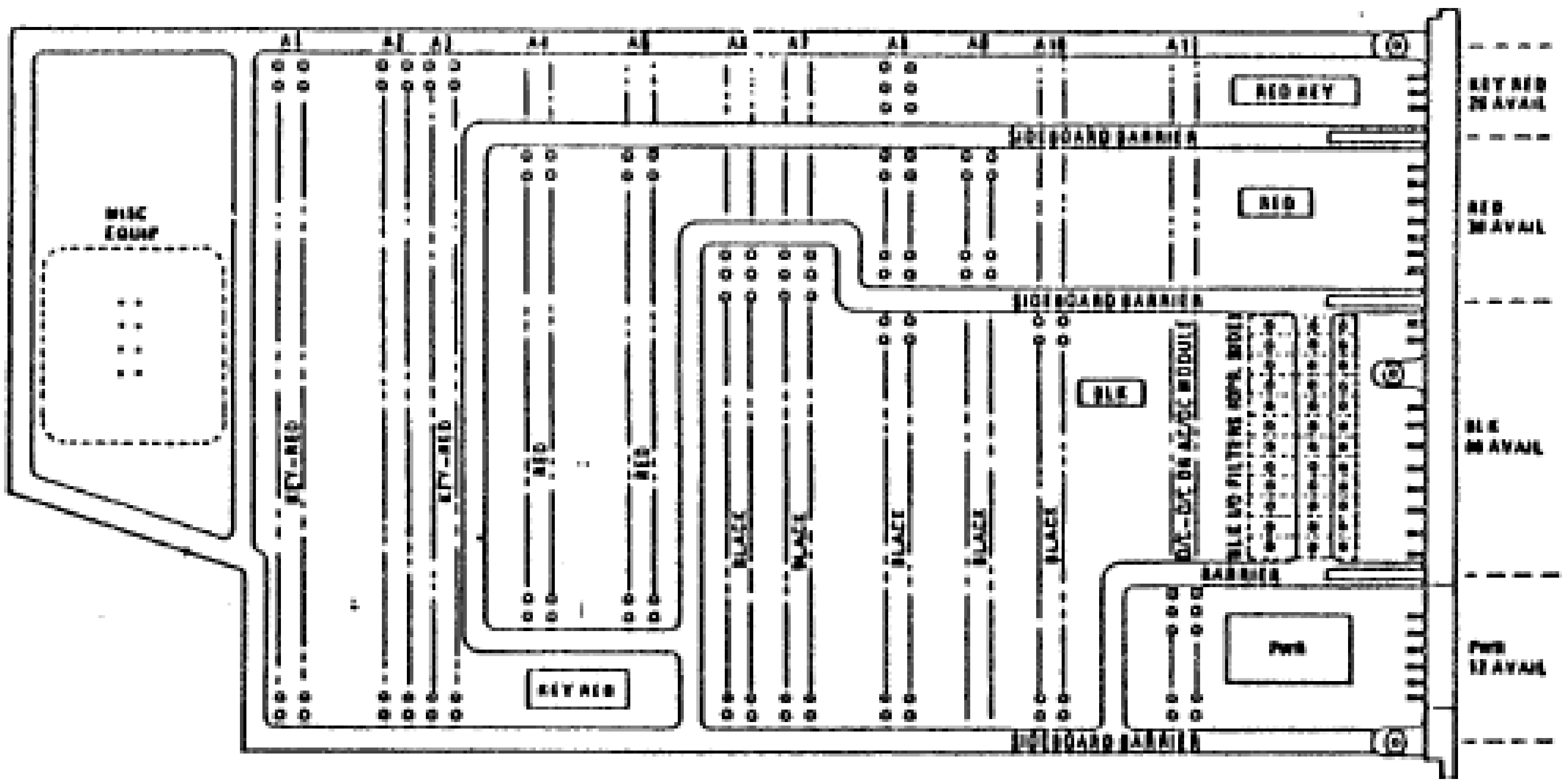
Power & Ground With TSP Power



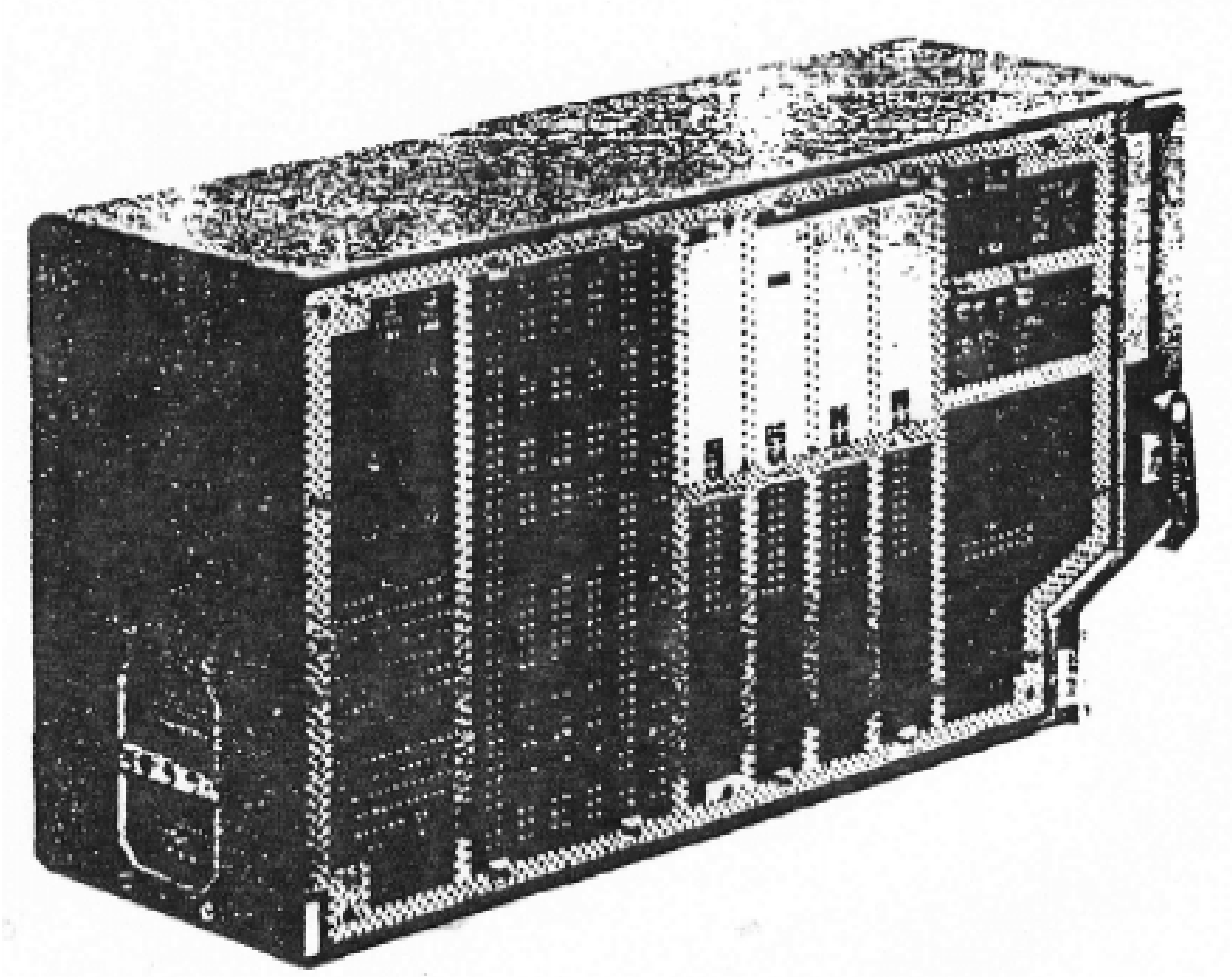
Isolated I/O Board

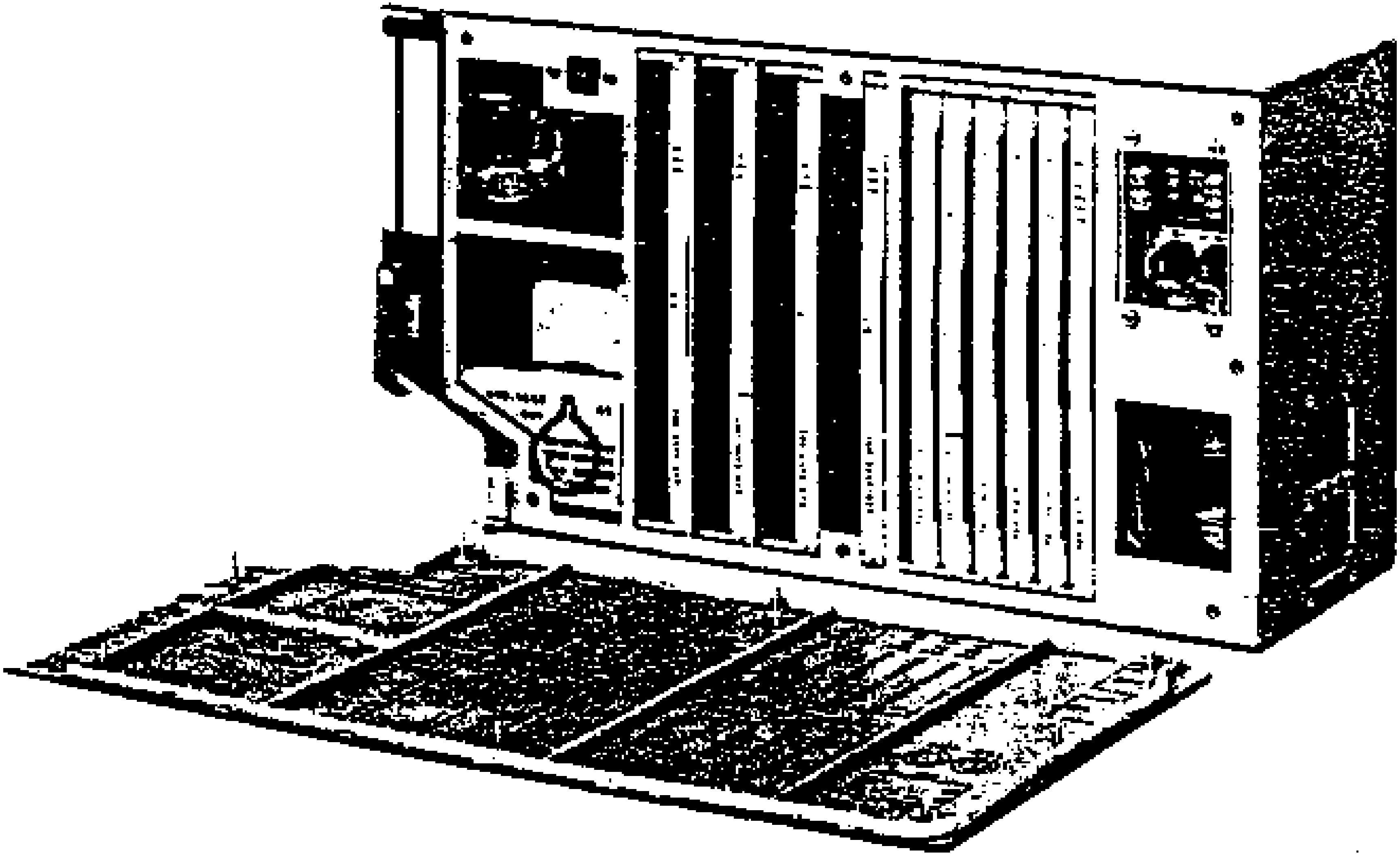


Sideboard With Ground Barriers

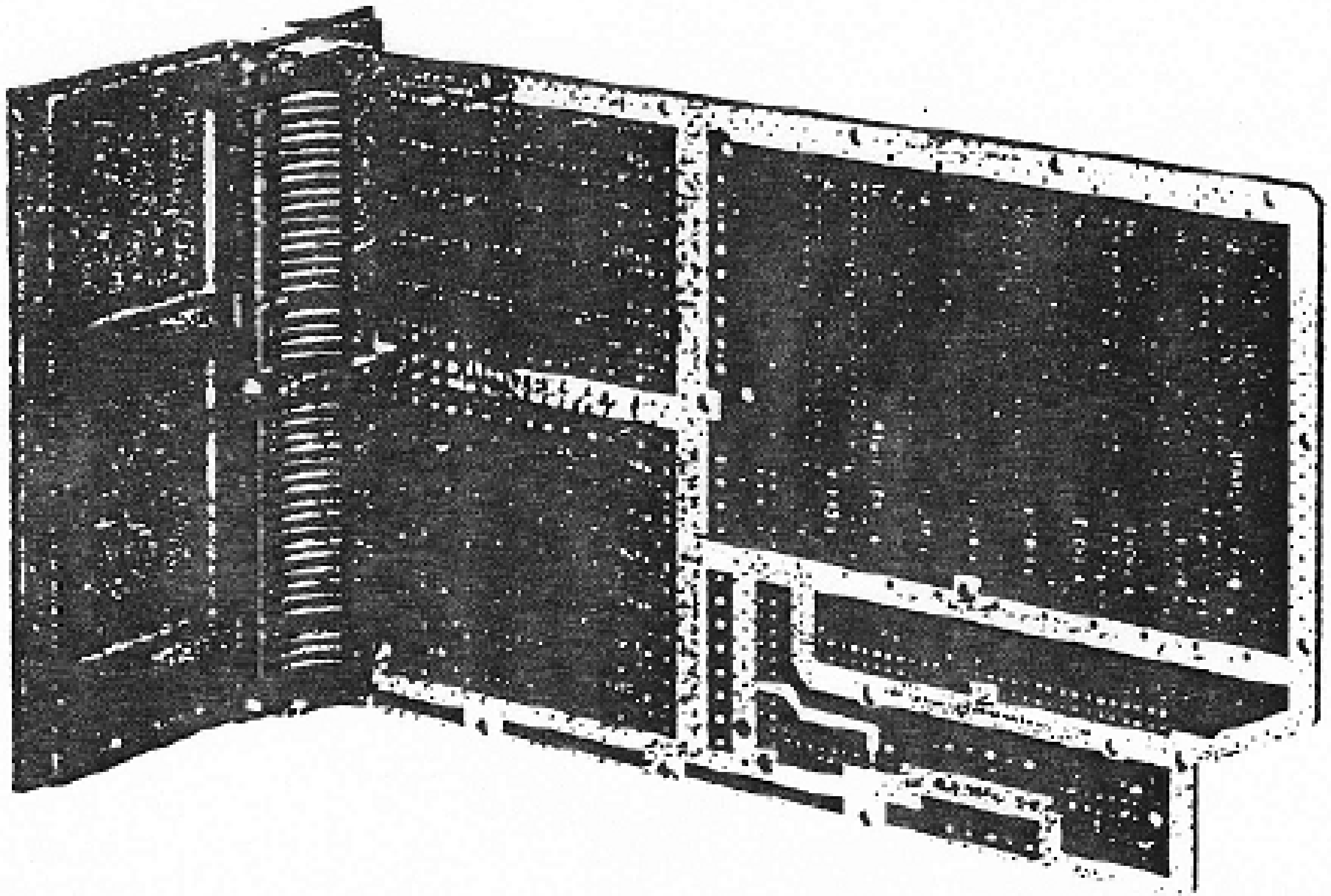


Mounted Sideboard





Sideboard With Connector



Gaskets & Mechanical Suppression Techniques

Shield Discontinuities

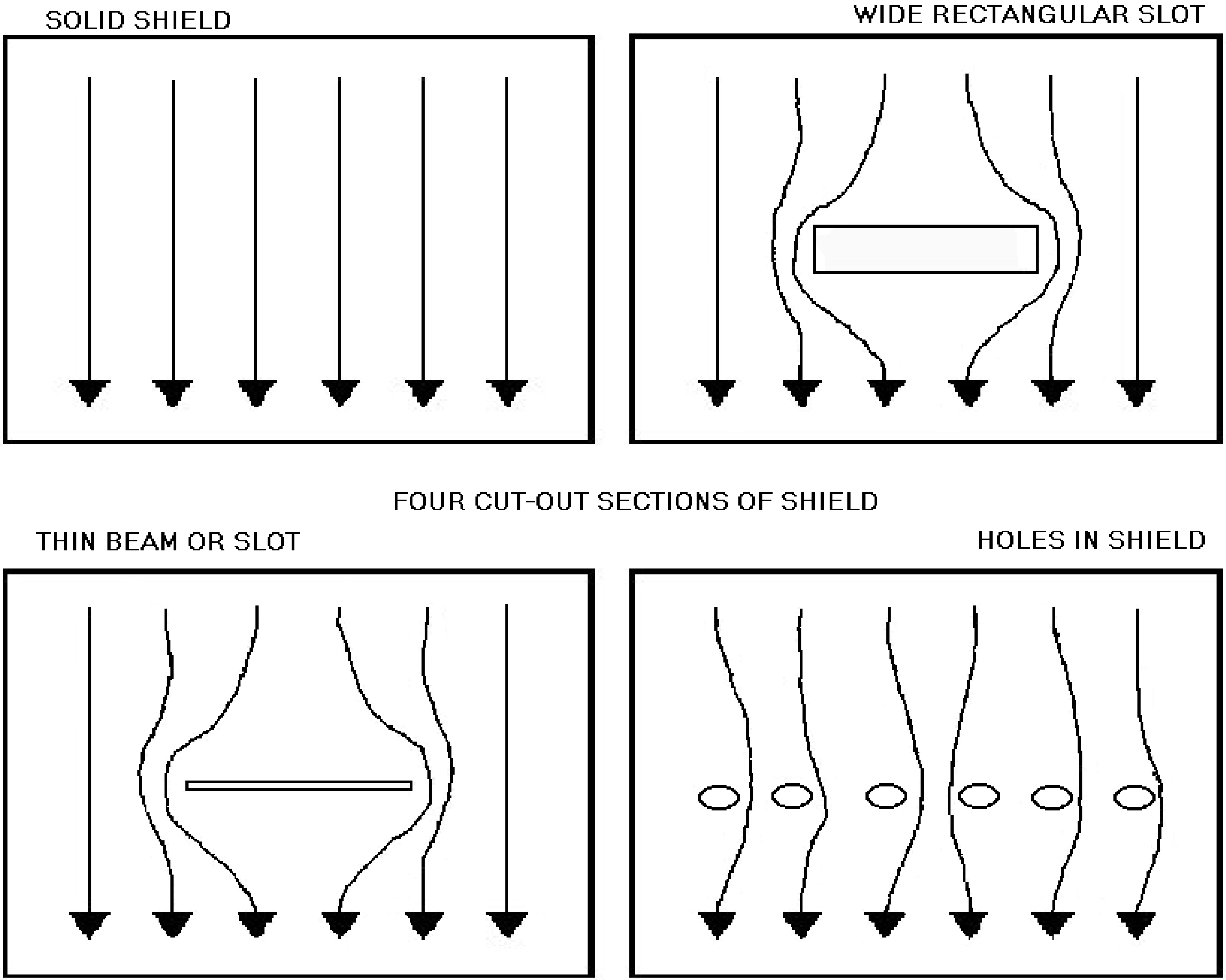
- Discontinuities more significant to shielding effectiveness than the direct shielding provided by the container walls.
- Maximum discontinuity dimension, not area, is the most significant factor in determining the leakage in the direct radiated path.

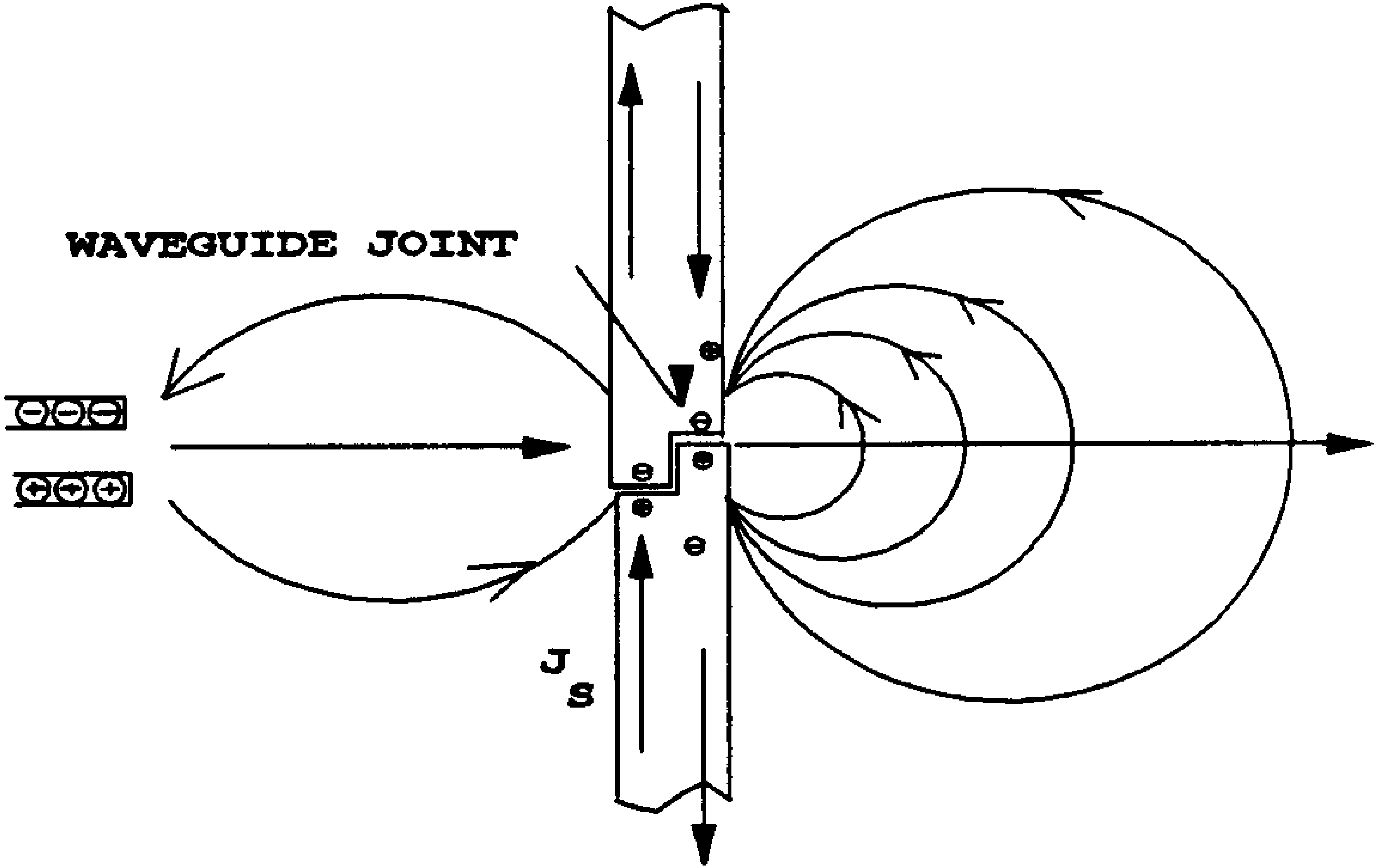
Leakage Factors

- Three factors determine the amount of direct radiated leakage through a shield discontinuity.
  - The maximum linear dimension of the opening
  - The propagating wave impedance
  - The frequency of the noise source

Slot Antennas

- Noise fields induce current flow in a shield
- The shield currents cause oscillations that generate additional fields.
- These new fields, reduced by resistive heating, reduce the initial field current and original field as measured at some region in space.
- For reduced oscillation to occur, the currents must be allowed to flow undisturbed.
  - The farther the current is forced to detour, the greater the decrease in shielding effectiveness.


SOLID SHIELD
WIDE RECTANGULAR SLOT
FOUR CUT-OUT SECTIONS OF SHIELD
THIN BEAM OR SLOT
HOLES IN SHIELD

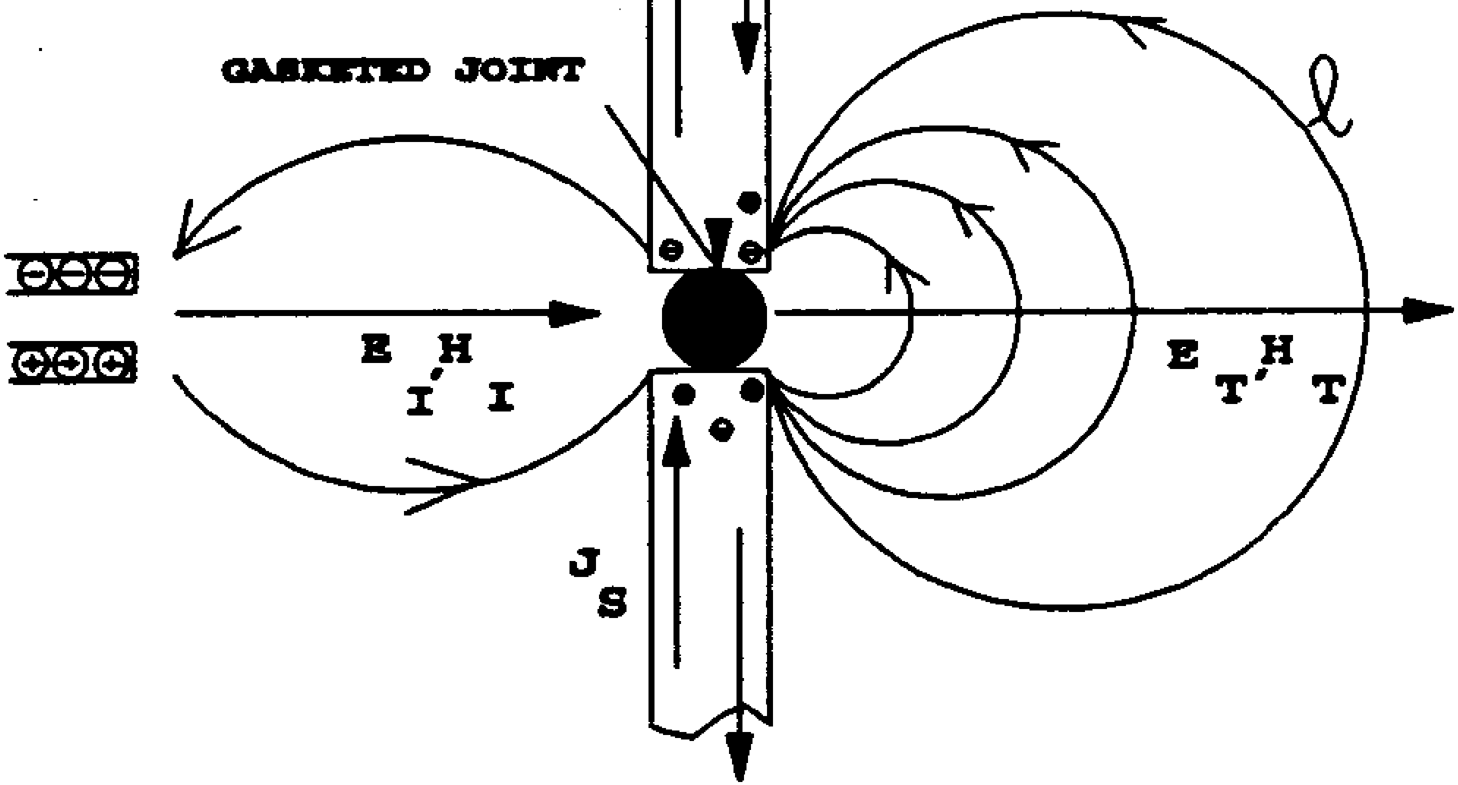


WAVEGUIDE JOINT
J
S

$$\bar{E}_T \approx \frac{Z_T J_S}{\ell}$$

Z_T Joint Transfer Imped.

J_S Surface Current Density



Metal Mesh Gaskets

- Good attenuation properties while lacking in environmental protection.
- Often used in conjunction with an outer rubber gasket to provide the moisture seal.
- Over compressing results in “flattening” the sharp edges or metal wires causing loss of the low impedance bond.

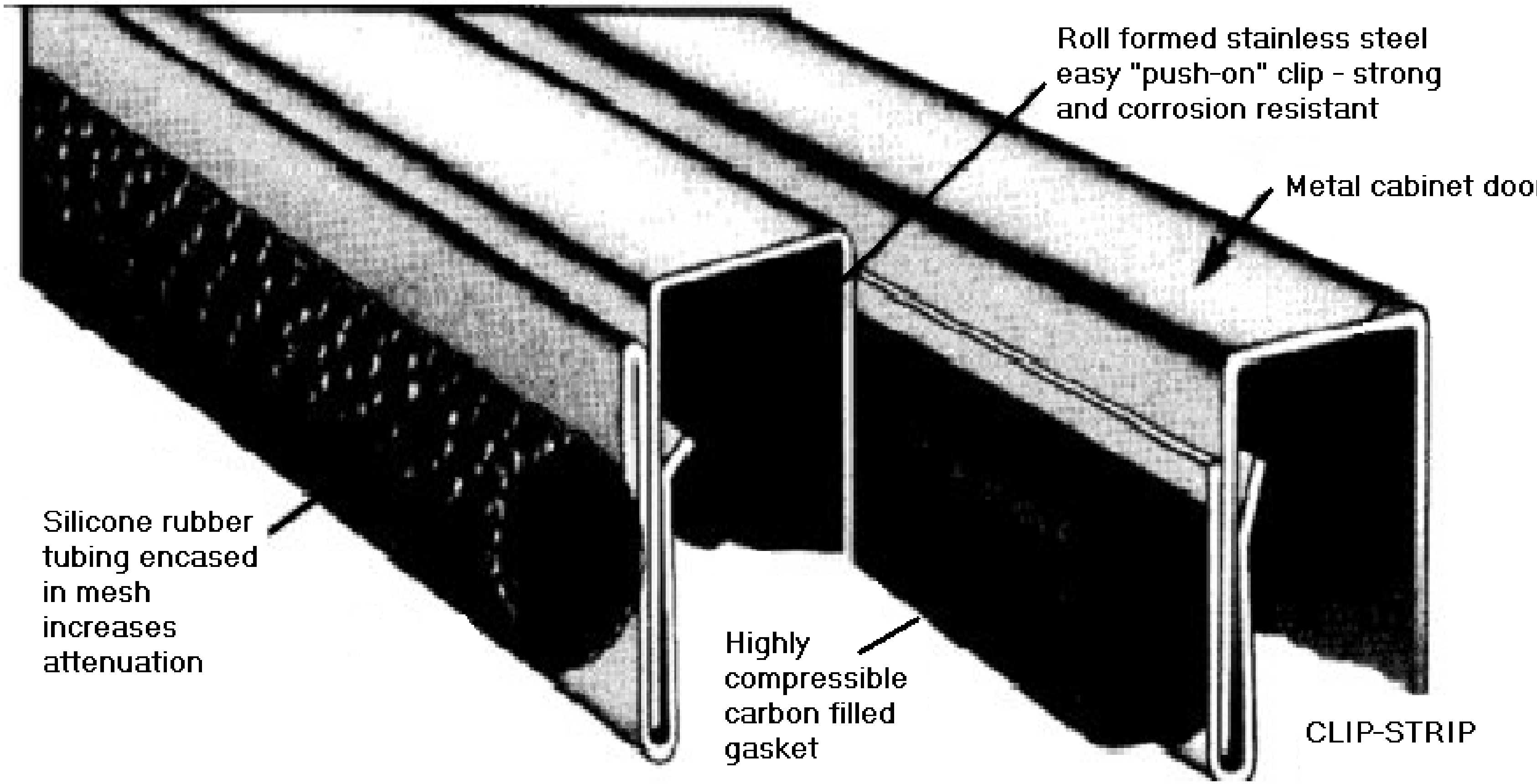
Conductive Elastomers

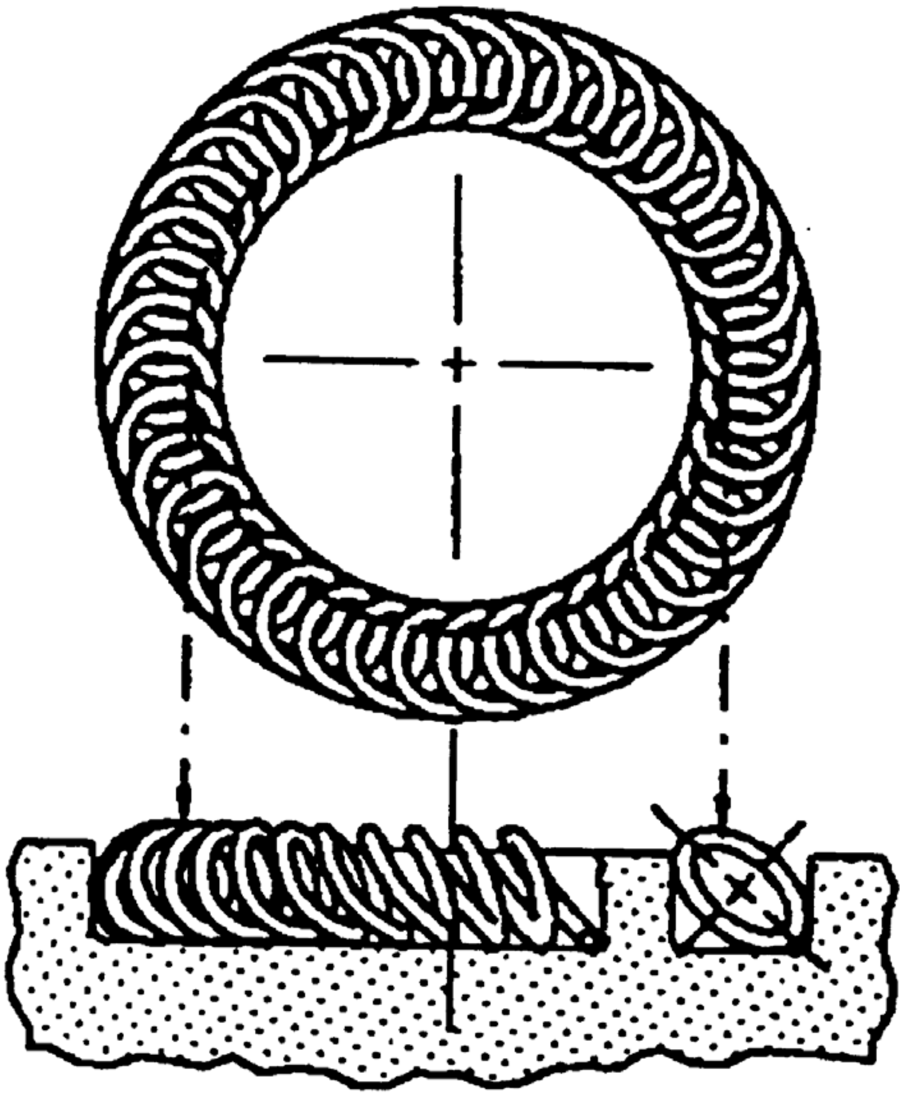
- Used to provide a conductive gasket under conditions where rubberized gaskets for moisture sealing are necessary but room is limited.
- Corrosion resistant silver encased in rubber exhibits longer life and greater shielding than other techniques.

Extruded Dual Elastomer

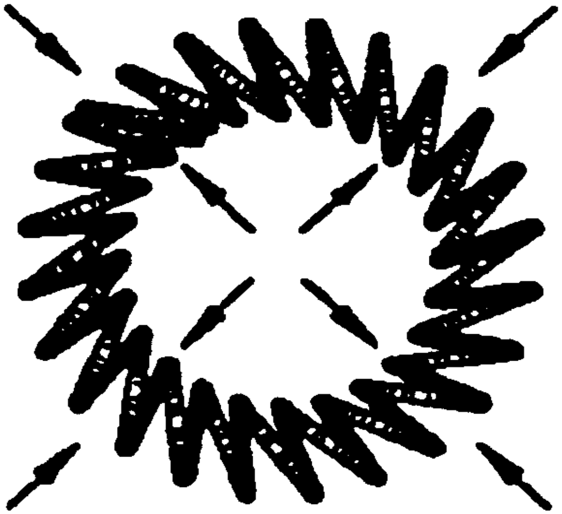
- Consists of a continuously extruded high-strength nonconductive silicone rubber coated with a thin conductive silver-filled rubber.
- Since it's free of conductive filler material, the elastic inner core can maintain its resistance after multiple compressions.

Mesh Covered & Carbon Filled Gaskets

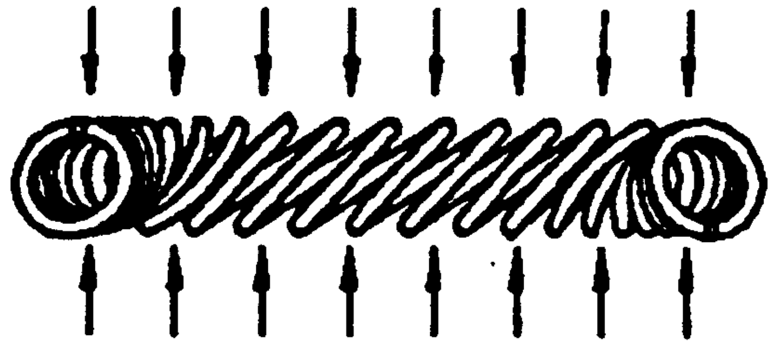




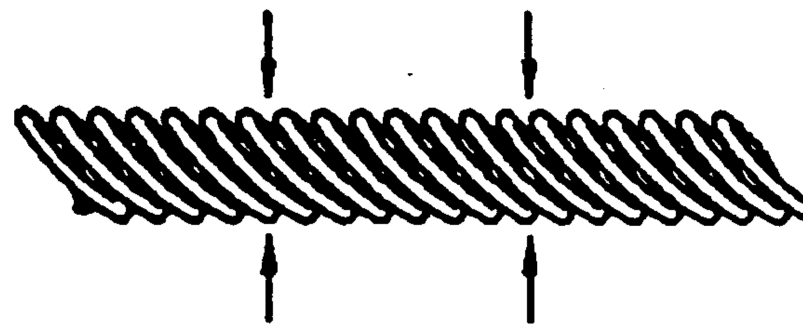
- Canted-Coil spring gasket
- The more points that make metal to metal contact, the higher the attenuation.



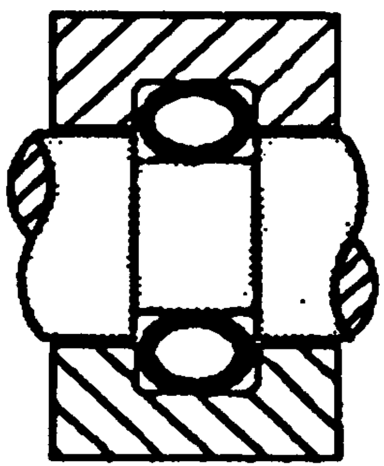
RADIAL SPRING



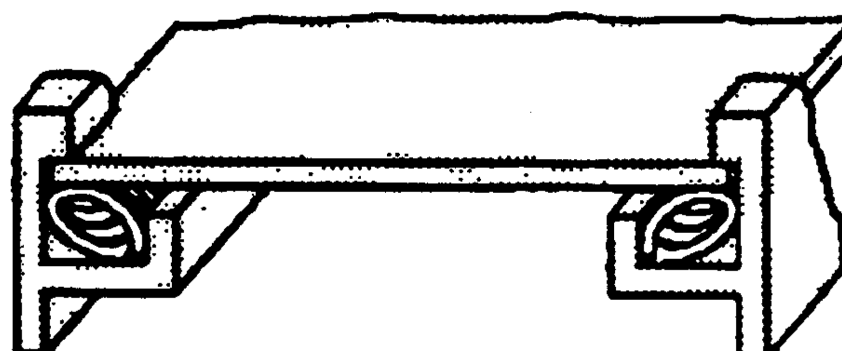
AXIAL SPRING



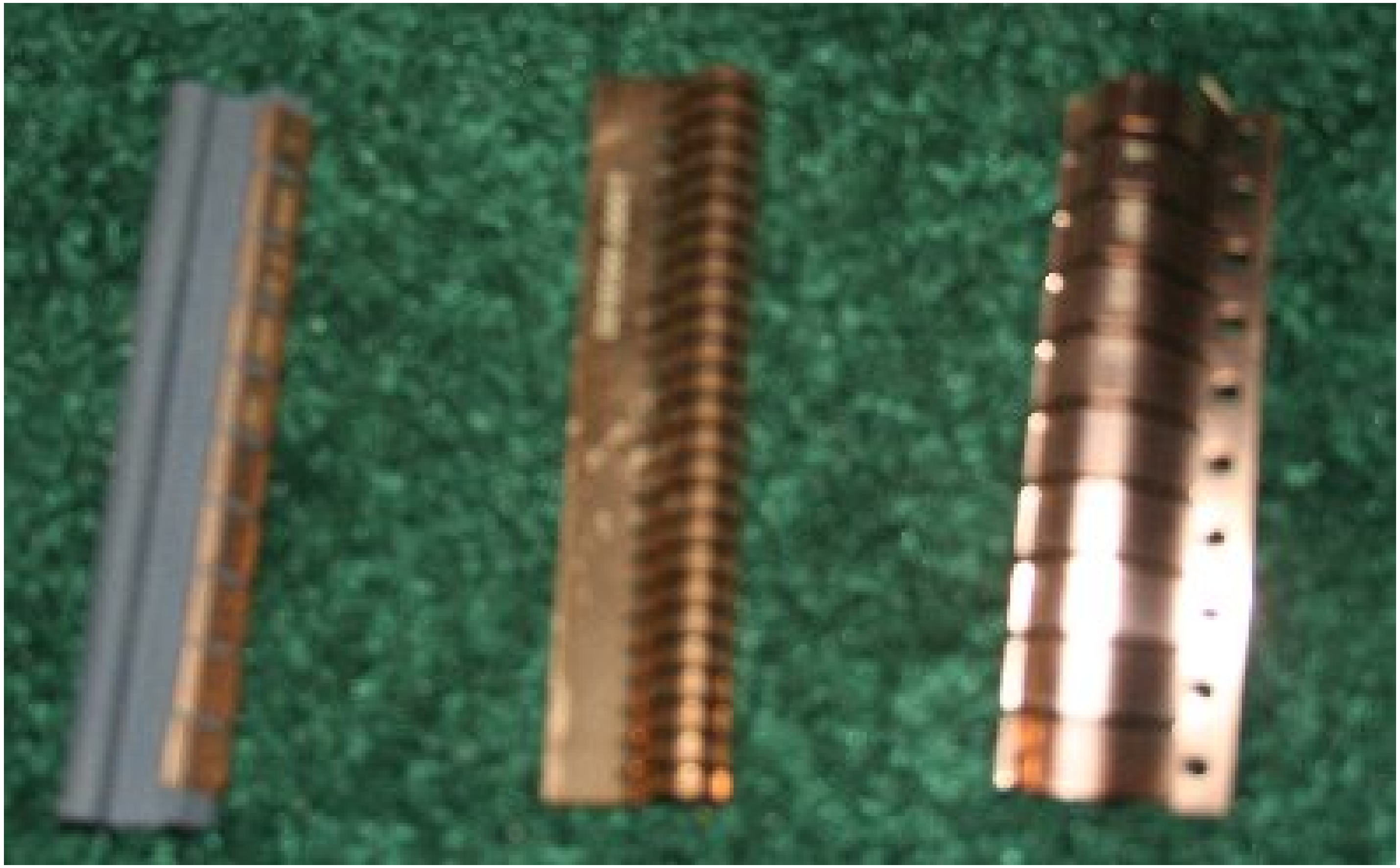
LENGTH OF SPRING

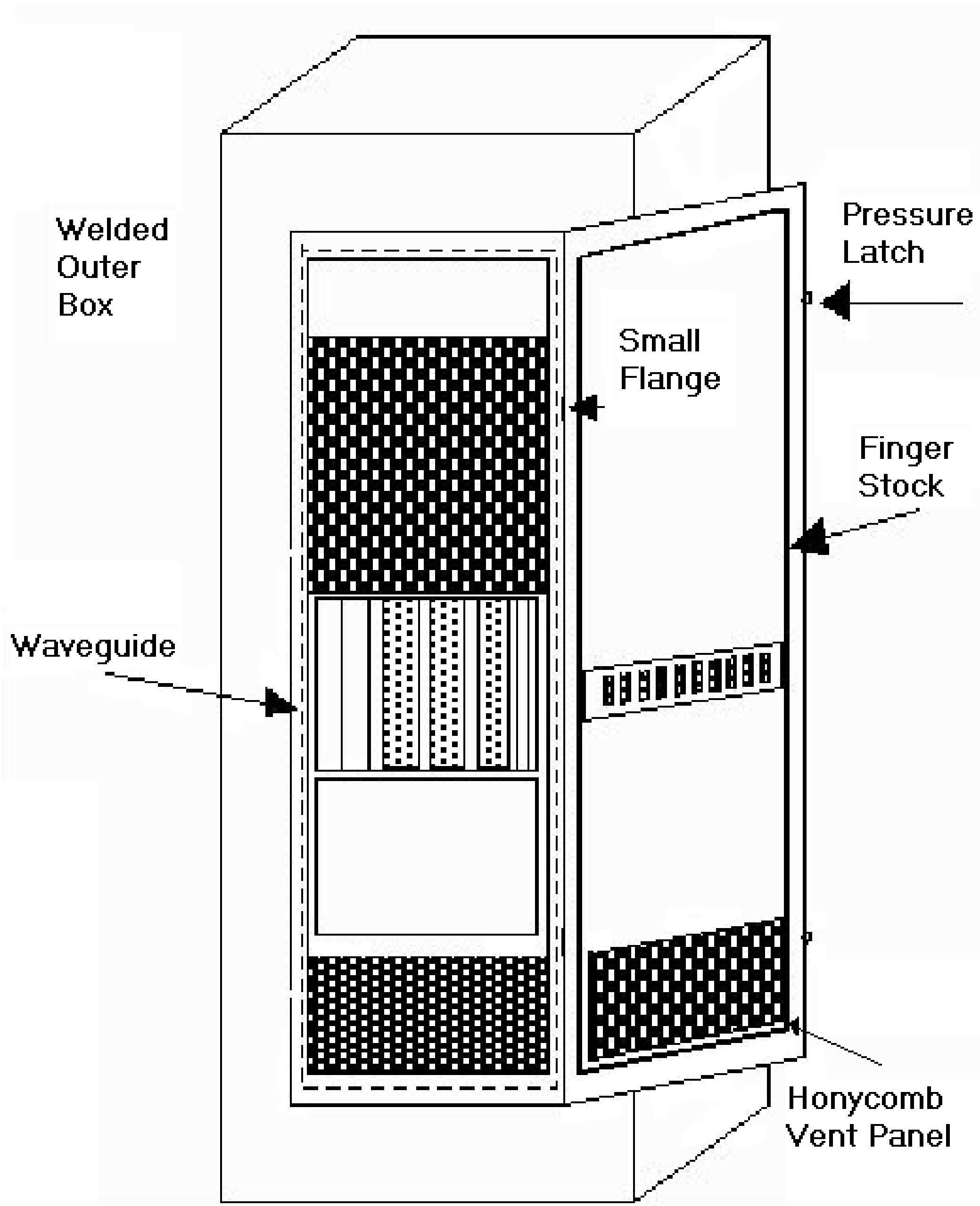


FOR GROUNDING SHAFTS



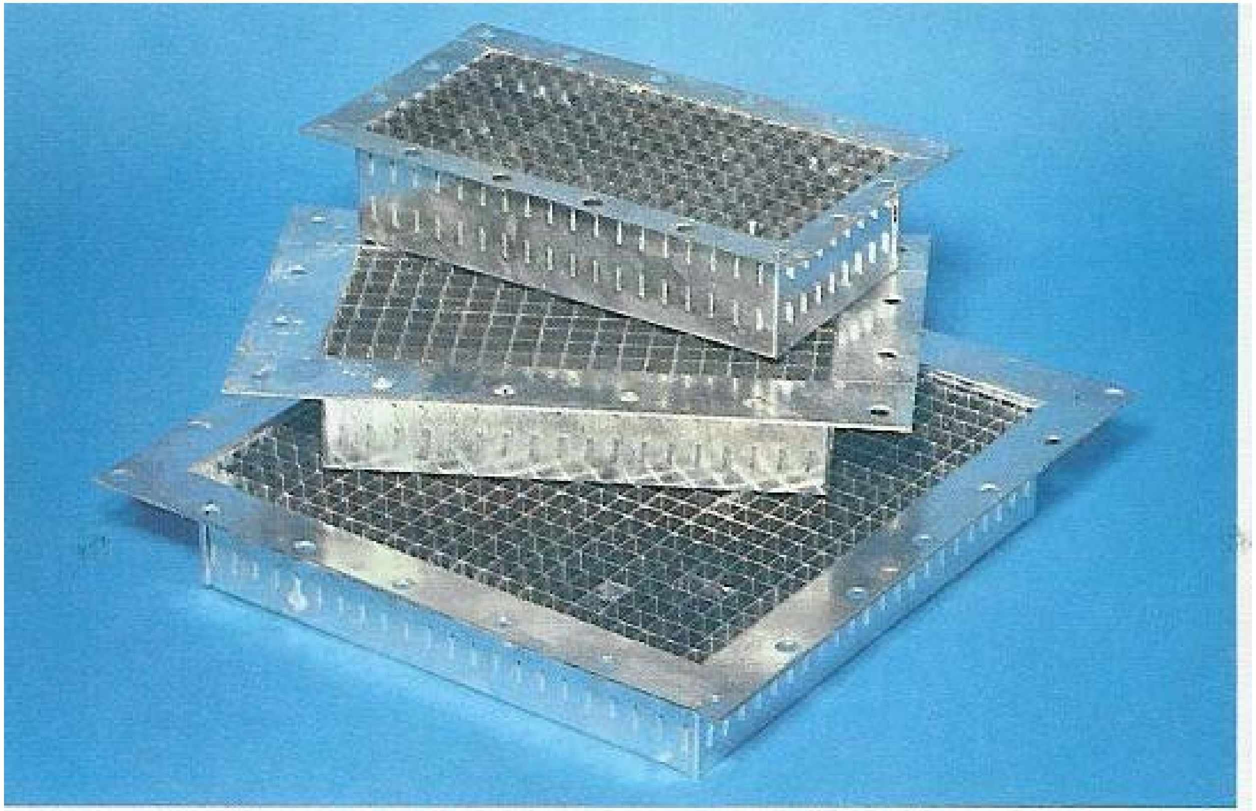
Beryllium Copper Fingerstock



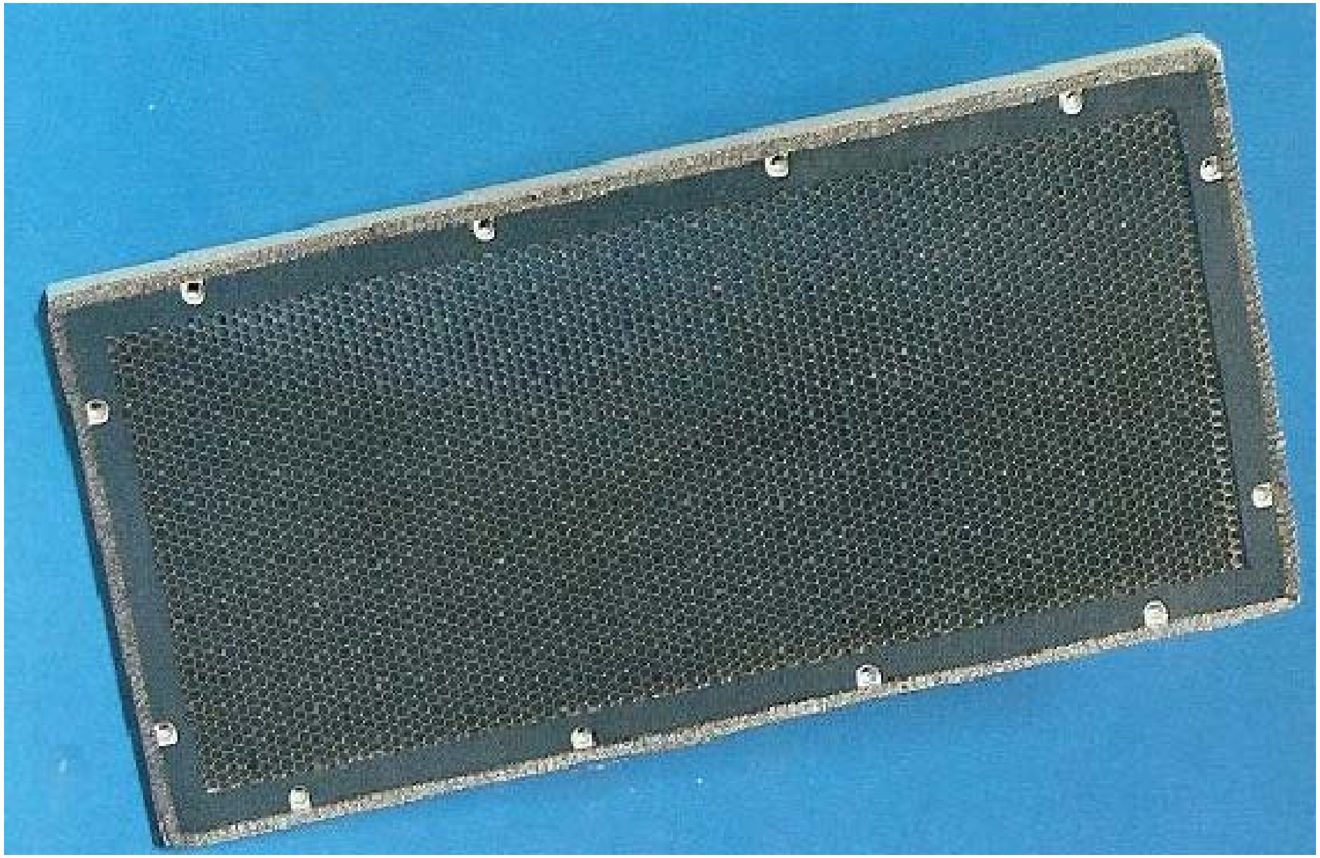


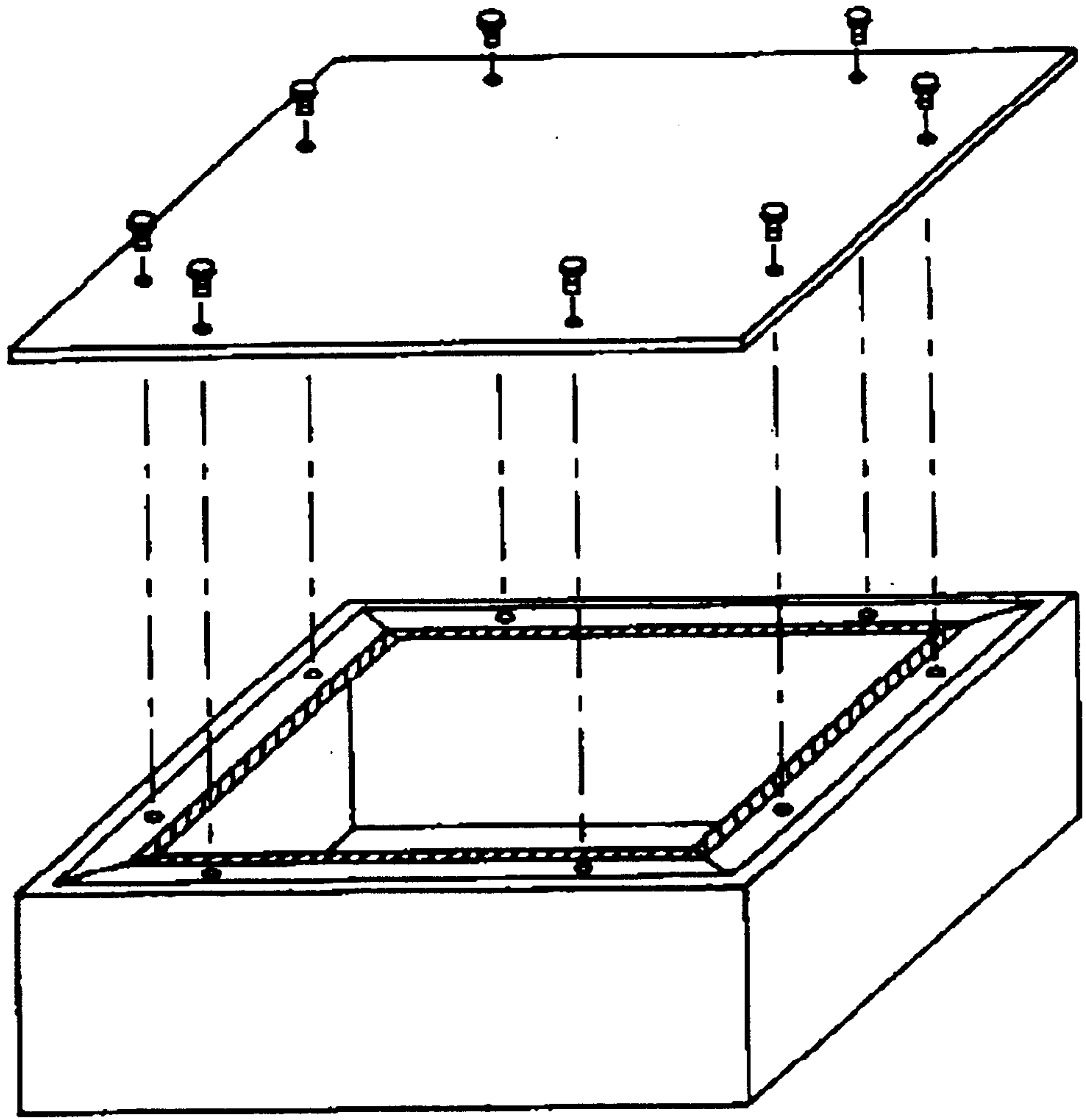
- Highly emission suppressed workstation or rack with finger stock on door.

Waveguide Vents



Honeycomb Panel





General Gasket Comparisons

Type	Attn. DB	Compression Force	Compression Set	Cost
Dual Elastomer	110	Low	None	Mod.
Elastomer	90-100	High	7-15%	High
Clad Foam	60-80	Low	15-20%	Mod.
Mesh	90-100	High	12-20%	Mod.
Bery. Copper	100	Medium	1-2%	High

Gasket Attenuation Comparison in DB

Frequency	Wire Mesh	Bery. Copper	Silver Elast.
10 KHz H-field	30	55	35
10 KHz E-field	100	120	100
10 MHz	100	140	100
1 GHz	90	100	100
10 GHz	Unmeas.	105	100

General Guidelines

- Permanently mounted cover plate on indoor box with no environmental problems and low compression.
  - Soft metal gasket with screw down top.
- Permanently mounted cover plate on sensitive emission indoor/outdoor box with no EMP problems and high compression.
  - Silver filled elastomer mounted in a grooved wave guide and screw secured to a rigid metal top.

General Guidelines

- Access plate on military box with uneven joints and frequent opening and closing.
  - Elastomer with regular replacement on rigid metal cover with compression latch assembly (if allowed)
- Hinged door with wave guide controls on sensitive emission cabinets.
  - Beryllium Copper finger stock with pressure latch assembly and honeycomb vent panel.

General Guidelines

- Removable cover plate on low compression indoor/outdoor box.
  - Sponge elastomer (disposable) on flat metal edge; bent welded metal box assembly
- Removable cover plate on low compression indoor box with high shielding effectiveness requirement.
  - Wire mesh on bent welded metal box assembly.

Shielded Wires, Cables & Connectors

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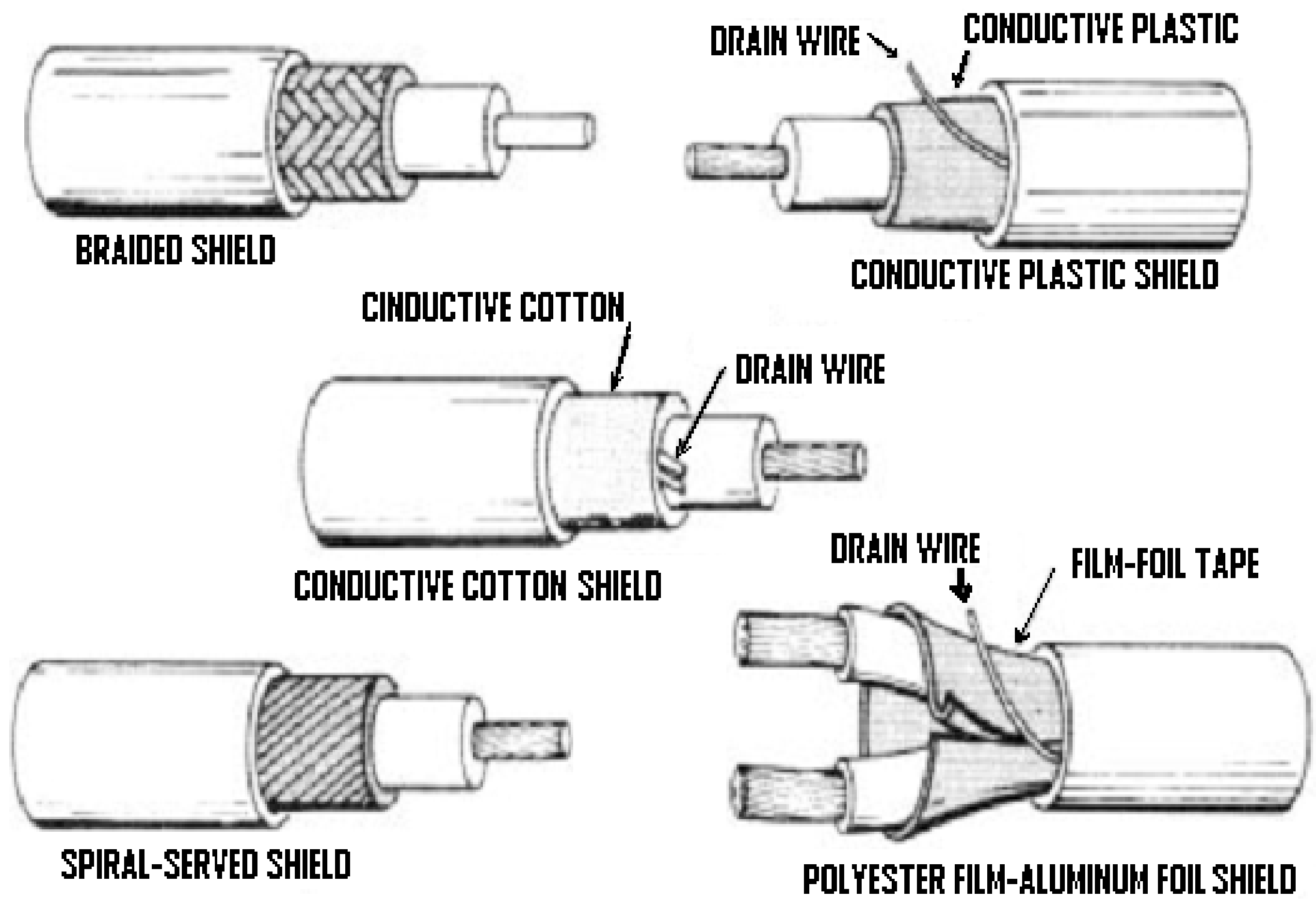
Last Updated: 2002

Advantages of Shielding

- Shielded conductors permit the transmission of low level signals, at high impedance levels, through areas where excessive interference voltages would be induced into low impedance conductors by low frequency magnetic fields, or in areas where sensitive information must be sent.
    - Shields on wires act the same as room shields, the continuous enclosure acts as a Faraday cage barrier to radiated fields.

Examples of Shielding Types

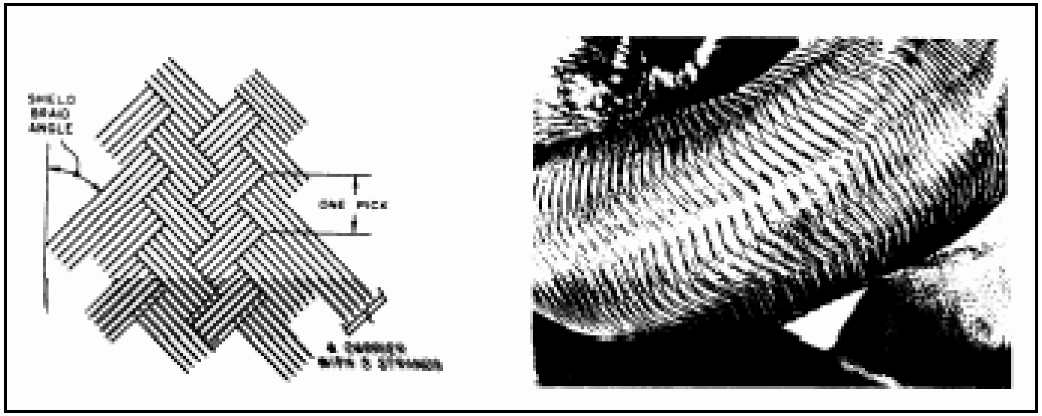


Comparison of Shielding Types

Table 4.1
Relative Shielding Characteristics

	Copper	Copper Cond.	Alum. Cond.	Textile	Mylar Plast.
Shield Effect. Audio Frequencies	*Good*	*Good*	*Fair*	*Excel.*	*Good*
Shield Effect. Radio Frequencies	*Good*	*Poor*	*Poor*	*Excel.*	*Poor*
Percent of Coverage	*60-95%*	*90-97%*	*100%*	*100%*	*100%*
Termination Method	*Comb & Pigtail Pigtail*		*Drain Wire*	*Drain Wire*	*Drain Wire*

Zippertube & Braided Shield



Twisting or Magnetic Shielding

- The magnetic shielding effectiveness of ordinary non-ferrous shielding materials is considerably lower than that of ferrous materials below approximately 100 KHz
- Twisted wiring, even without a shield, provides the most effective isolation from low frequency magnetic fields.

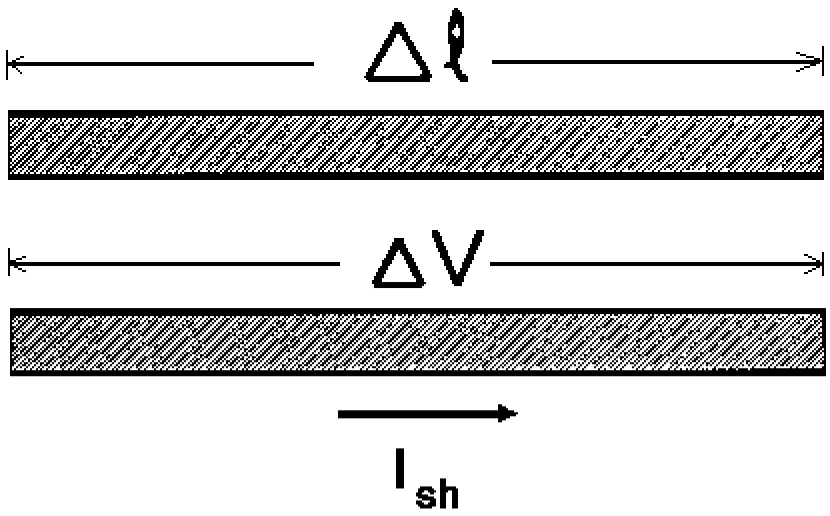
Proper Application

- Twisted wire is normally used in low frequency low impedance circuits that are located in areas associated with high magnetic field problems.
- Shielded wire is normally used in high frequency high impedance circuits associated with electric field problems.

Flexibility vs. Weave Angle

- Shielding effectiveness can be improved by making the shield more dense, but that reduces the flexibility of the shield.
  - Small diameter shields can be made with a small weave angle, but on large diameter cables the weave angle must be large to maintain flexibility.
  - An alternative construction involves two overlapping layers of braid.
    - Using two similar layers of braid will reduce the resistance of a single braid by a factor of two (and double the weight of the shield), and can reduce the transfer inductance by a much greater factor.

Transfer Impedance

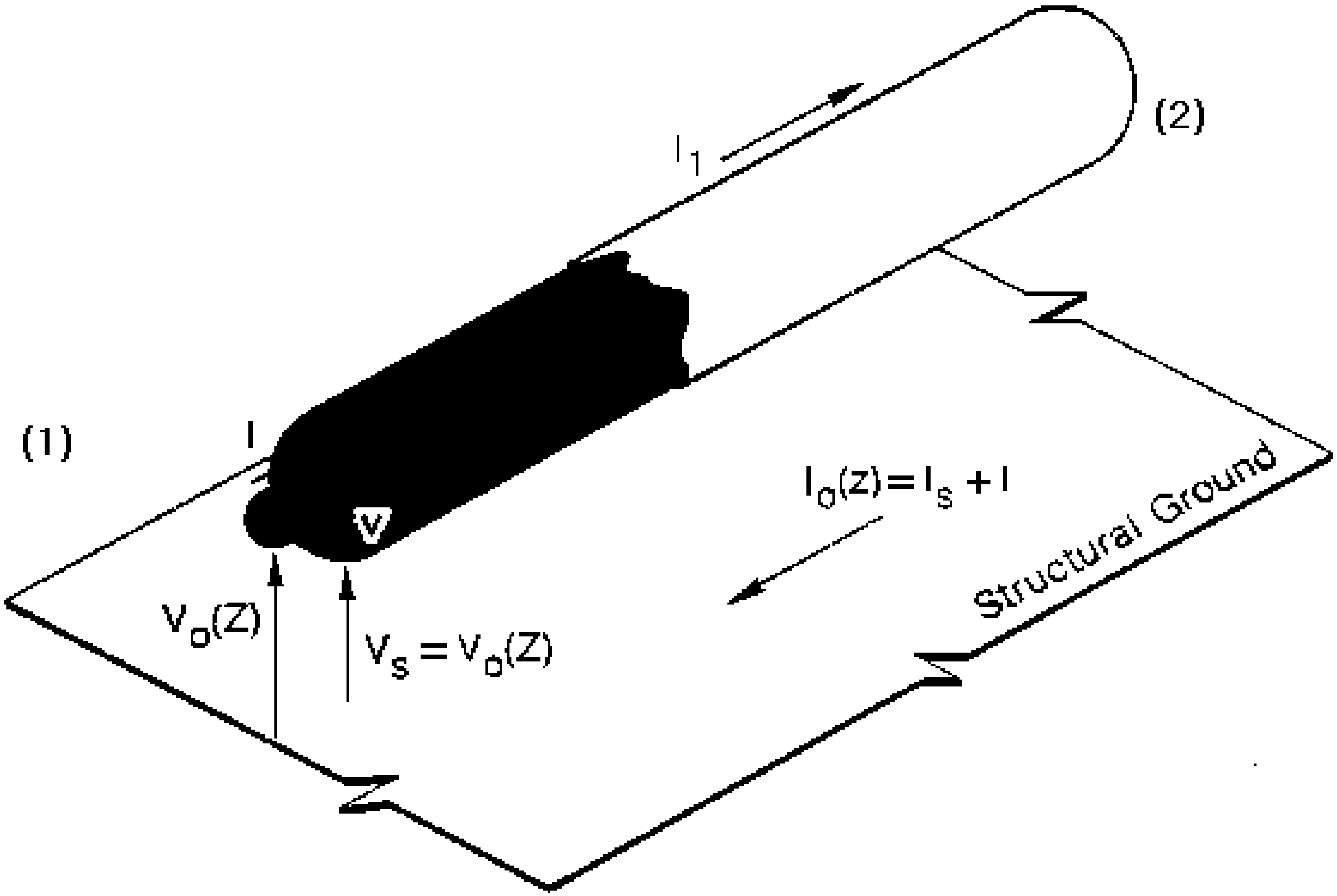


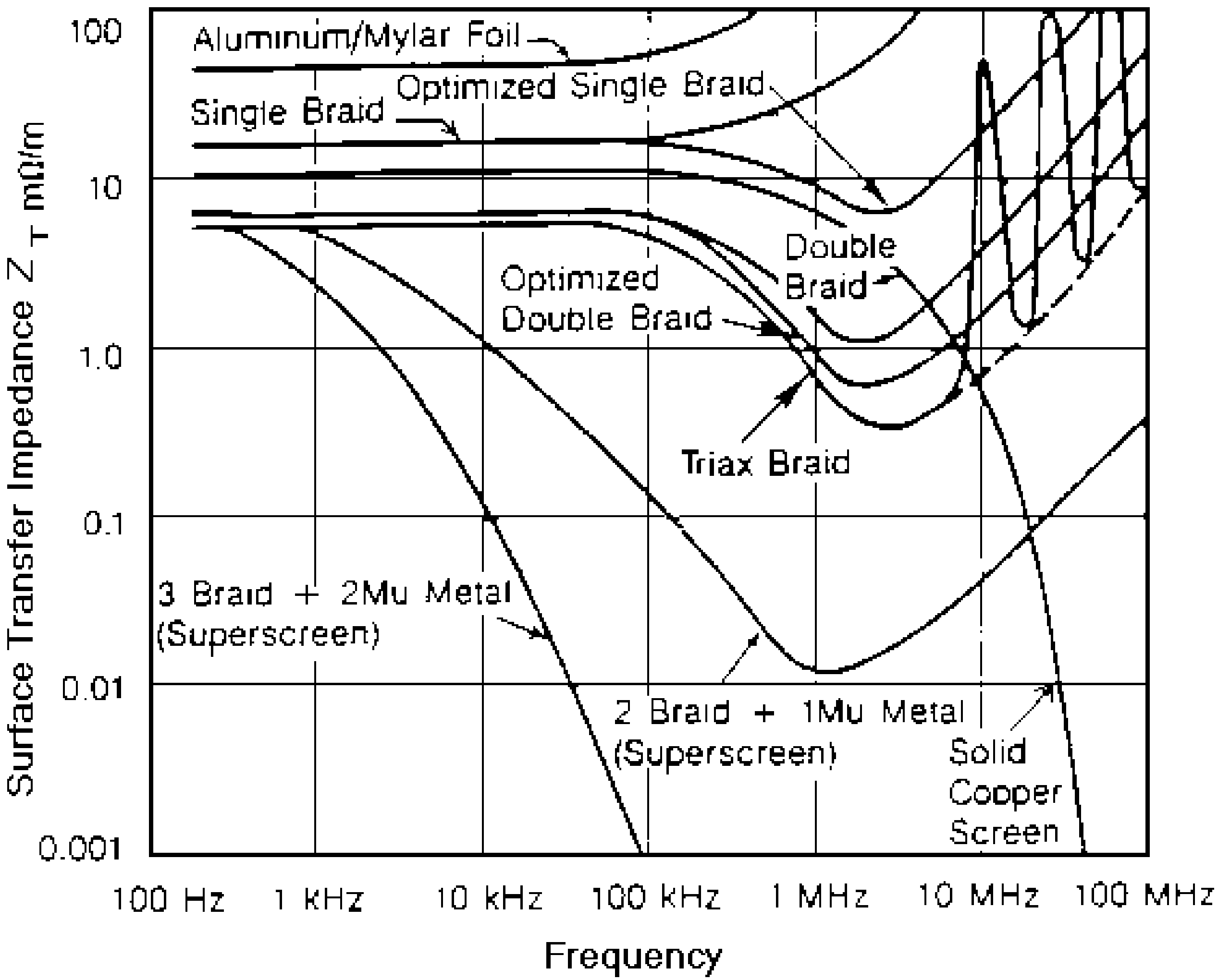
Appx. Correlation to SE

$$SE \approx 36 - 20\log\left(\frac{Z_T\Omega}{m\ell_m}\right)$$

- Ratio of shield inner voltage to shield outer current.
- Easier to measure then shielding effectiveness.

Shielded Cable Analysis





Representative values of Surface Transfer Impedance.

Limitations of Shielded Conductors

- For low frequency isolation, shields must be connected to the structural ground plane at only one end to prevent the flow of current through the shield as a result of small differences in the voltage potential of the ground plane at each end of the shield.
  - The shield and center conductor form a one-turn coaxial transformer.
  - Interference or problem causing currents flowing through the shield induce an interference voltage in the center conductor.

Emission Control Issues

- The one end shield grounding philosophy conflicts with the requirements for high frequency shielding.
- Emission controlled radiated problems result from high frequency signal leakage.
- Ground loop emission coupling problems occur when shields are connected at both ends.

Be Careful

- Any potential appearing on the shield as a result of capacitive coupling from other conductors, or as a result of voltage drops due to interference ground currents flowing through the shield will be both radiated and capacitive coupled into the cable's center conductor.
  - The shield must be connected to the structural ground plane through extremely short jumpers at many points along its length in order to prevent the existence of an ungrounded length of shield greater than one-tenth wavelength long at the highest frequency of interest

Minimum Practical Cable Length

- It is impossible to achieve worthwhile signal radiation improvement factors unless the twisted or shielded portion of the cable is at least an order of magnitude longer than the total untwisted or unshielded cable length.
  - System interconnection cables must be considered in conjunction with the related internal cables of the assemblies.
  - Most wiring wholly internal to an assembly does not involve long enough conductors to provide a useful improvement factor.

Shielded Wire Design Guidelines

- For good E field reduction
  - Minimize the length of the center conductor extending beyond the shield
  - Provide a good ground for the shield
- A shield grounded at one end has no effect on the magnetic induced current (and voltage) in that conductor

Shielded Wire Design Guidelines

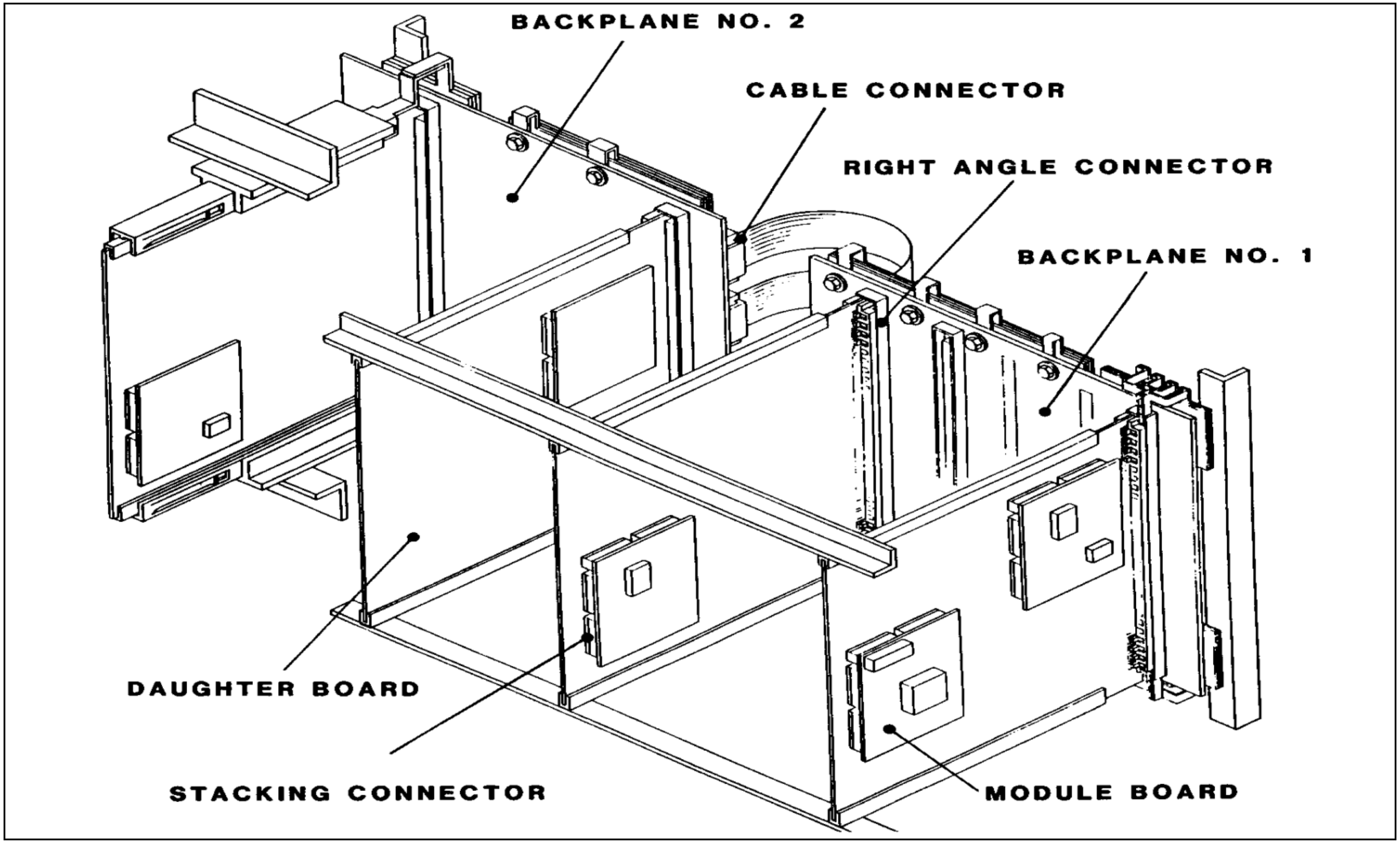
- To prevent H field radiation from a conductor from forming a ground return loop between both ends, the conductor should be shielded and the shield should be grounded at both ends.
- Braided shields should be terminated uniformly (circumferentially) around the braid at the connector for best isolation.

Shielded Wire Design Guidelines

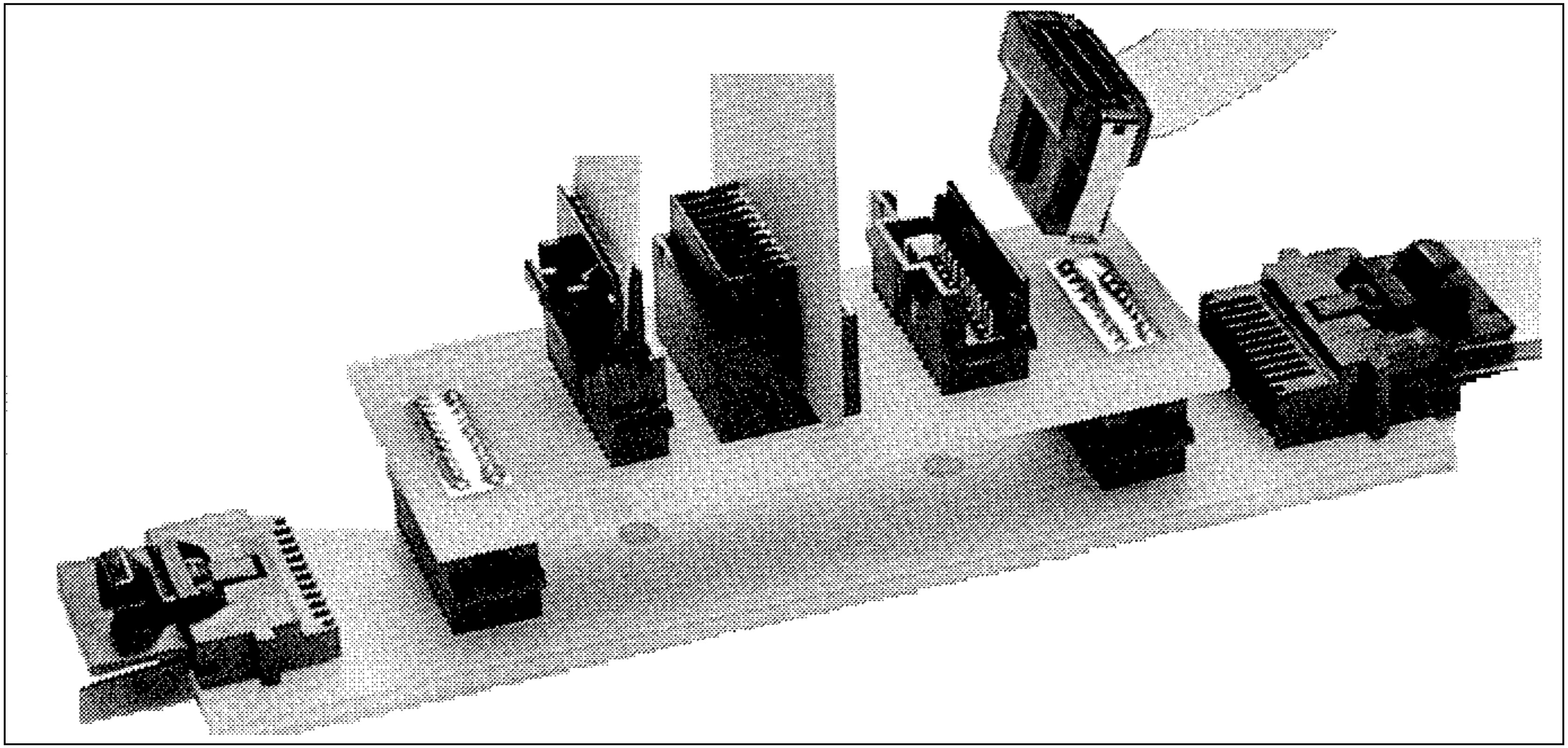
- For maximum noise protection at low frequencies, the shield should not be one of the signal conductors.
  - One end of the circuit must be isolated from ground
  - At low frequencies, large noise currents are induced in ground loops

Cable Terminations & Connectors

Box Level Connector Assemblies



Board Level Connectors



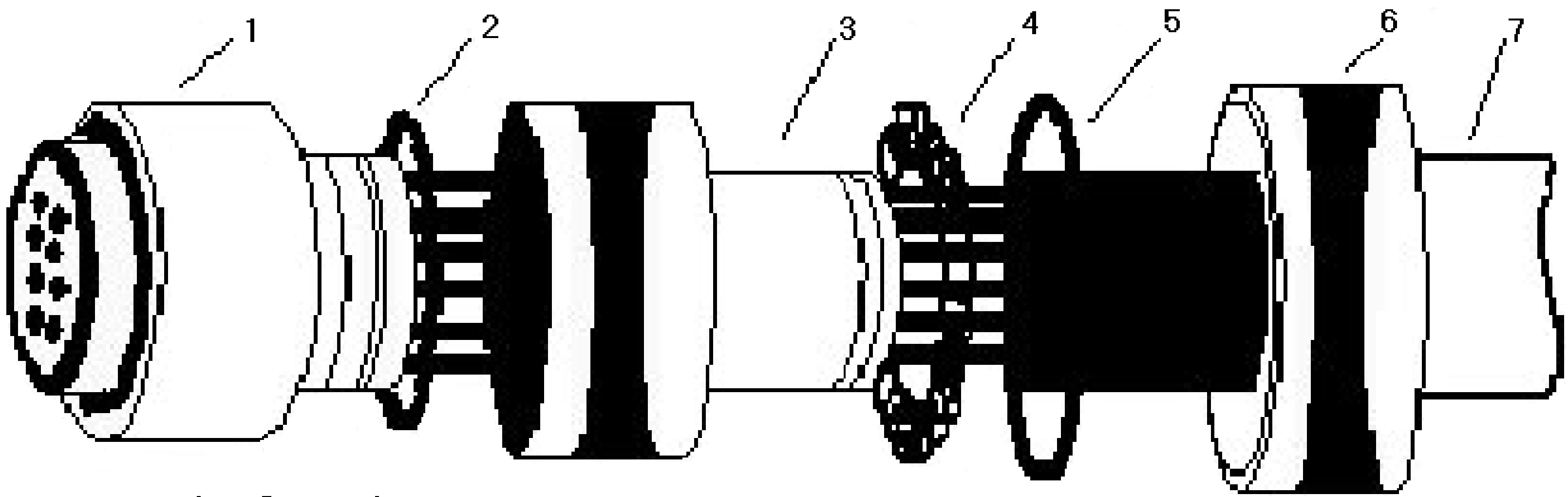
Using Commercial Connectors

- In order to maintain the needed emission control, while also increasing signal throughput, a large number of signal pins are sometimes used as ground connections.
- Another approach to maintain control has been to carefully control the dimension, spacing, and dielectric properties of the connector/pin assembly.

Problem With Commercial Connectors

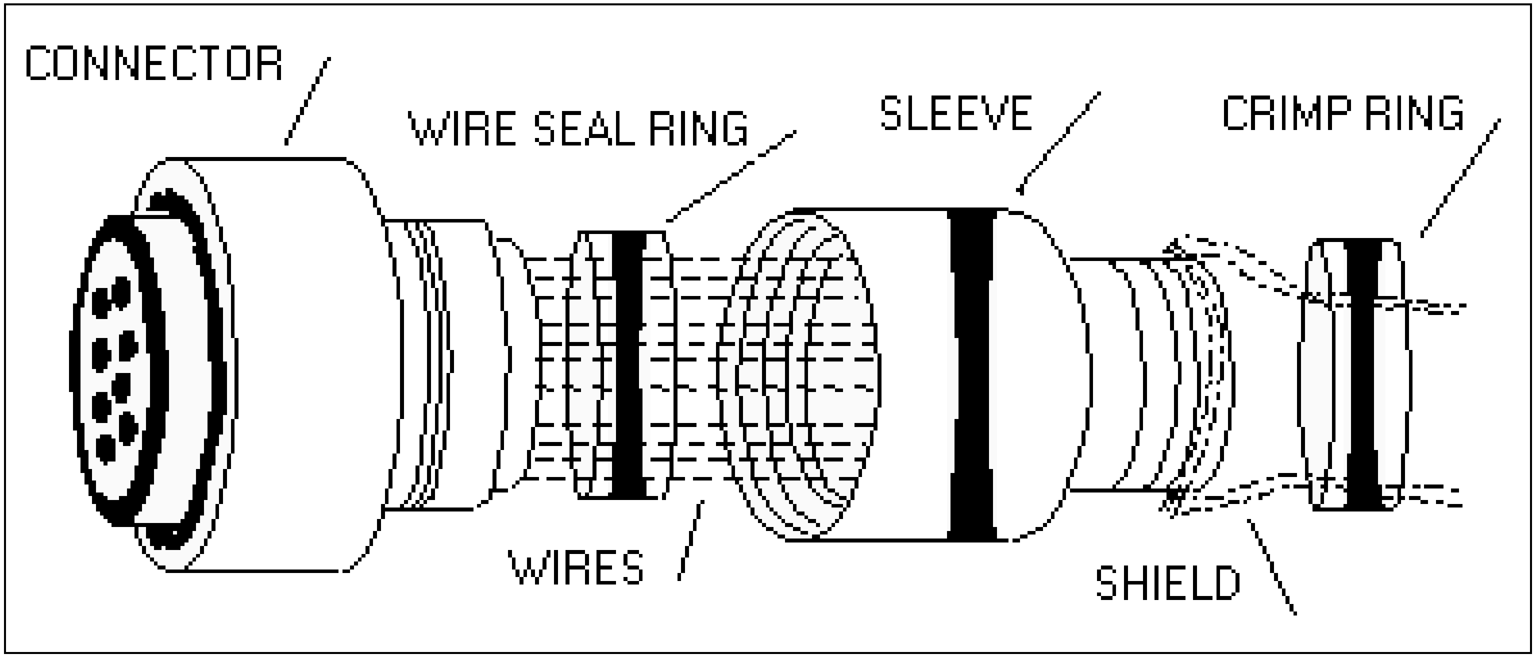
- While each of these techniques enhance the ability of a cable and connector combination for signal transmission, the same approaches also work to reduce the escape secure emissions from the assembly.
- However, since the design thrust is on cross channel coupling reduction, even the best crosstalk noise reduction techniques can be compromised if outside signals can couple into the cable system.

Standard Protected Cable Connector

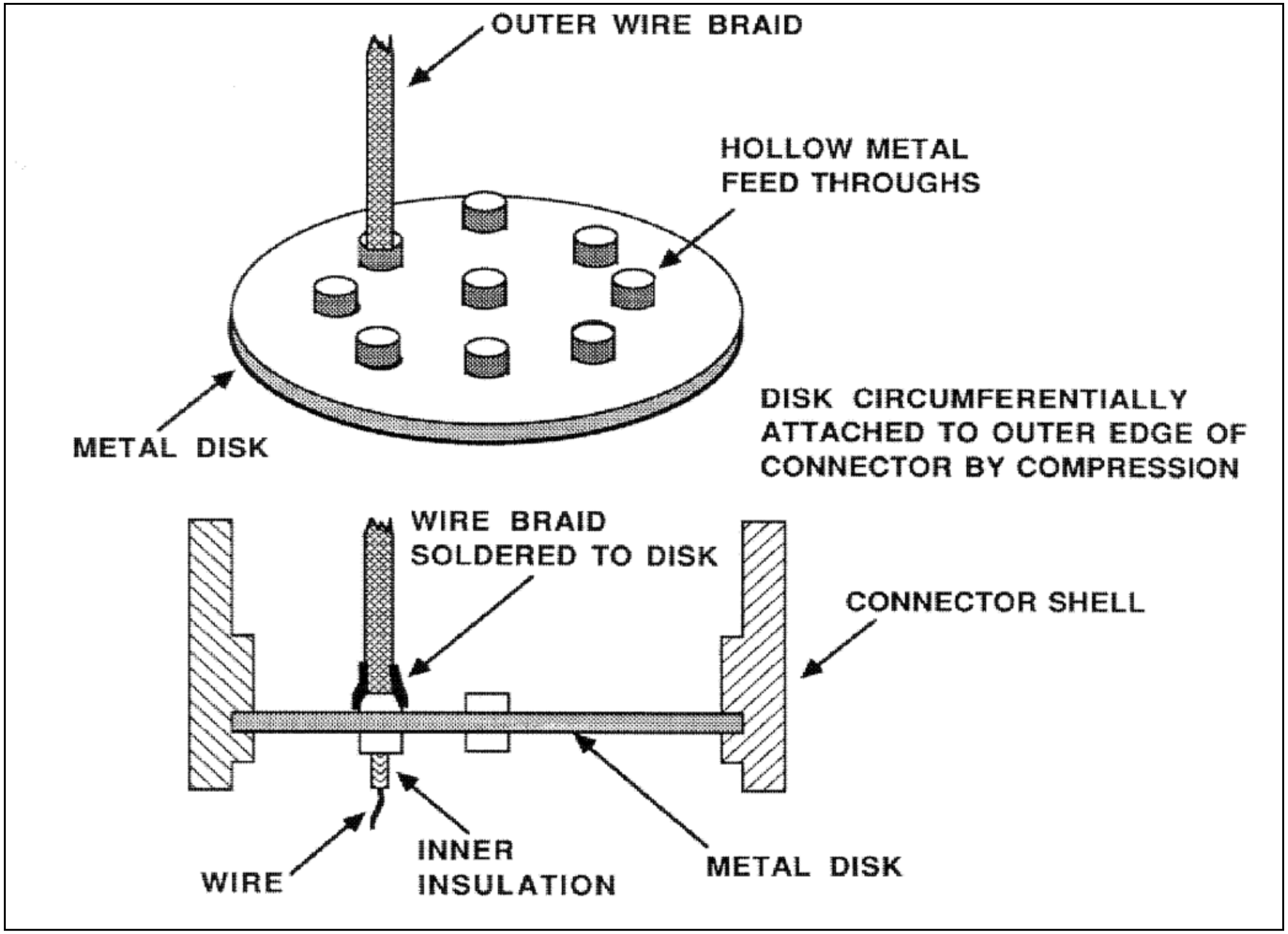


1. Connector
2. Environmental Seal
3. Adapter
4. Compressible Iris
5. Collar
6. Lock Nut
7. Outer Cable

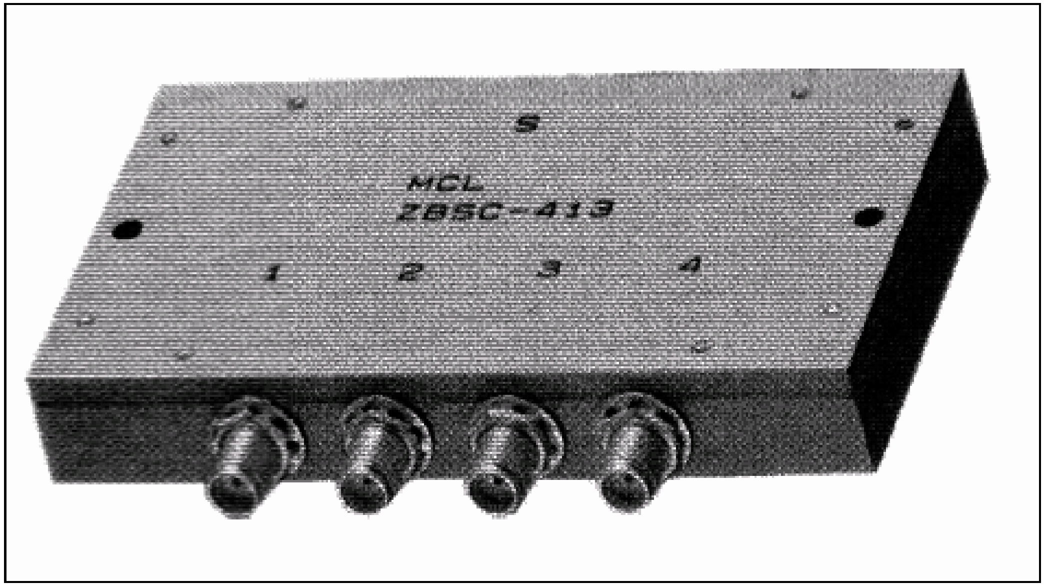
Shield Termination to Connector Using Crimping



Disc Type Shield Termination

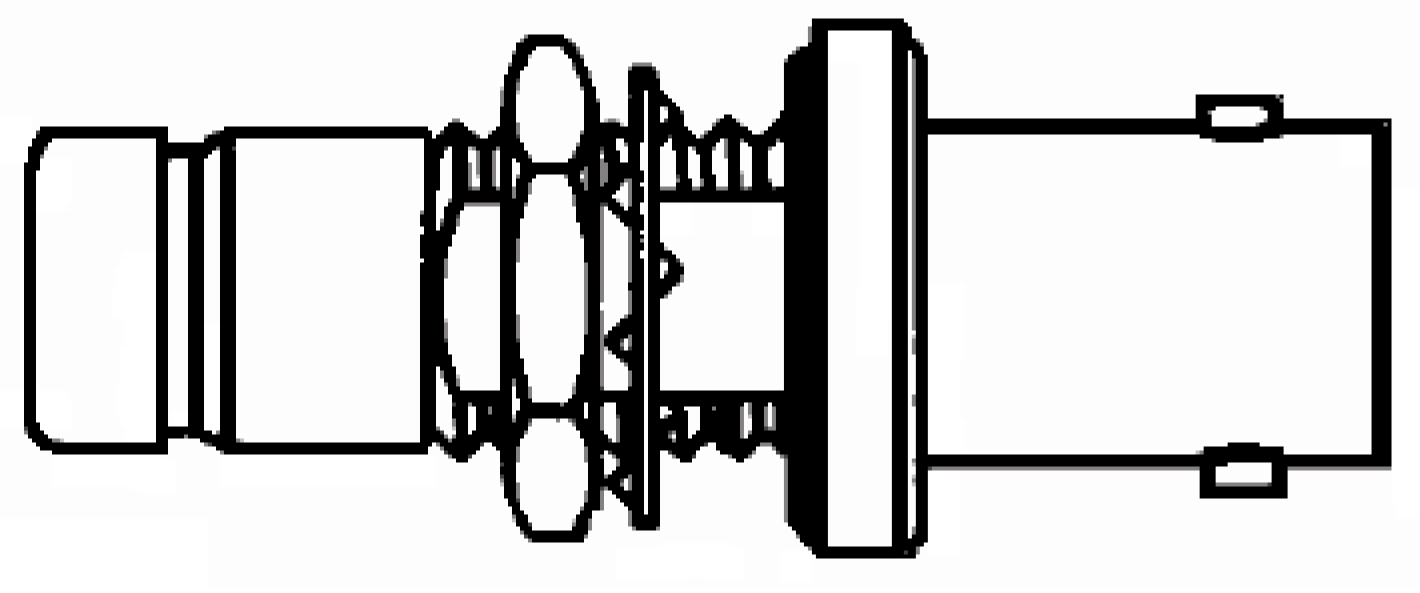


SMA Coaxial Connectors



- Related to frequency, the available operating frequency range decreases as the connector size increases.

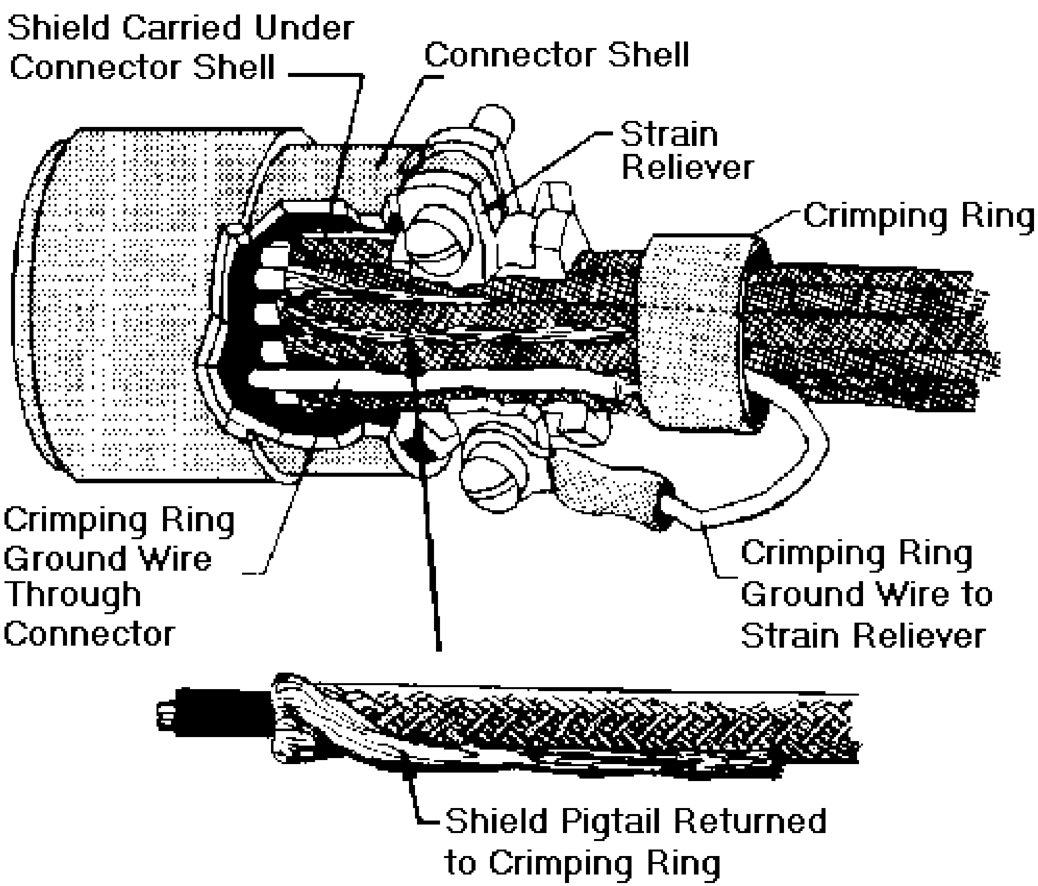
Typical Bulkhead Feedthrough & Grounding Connector



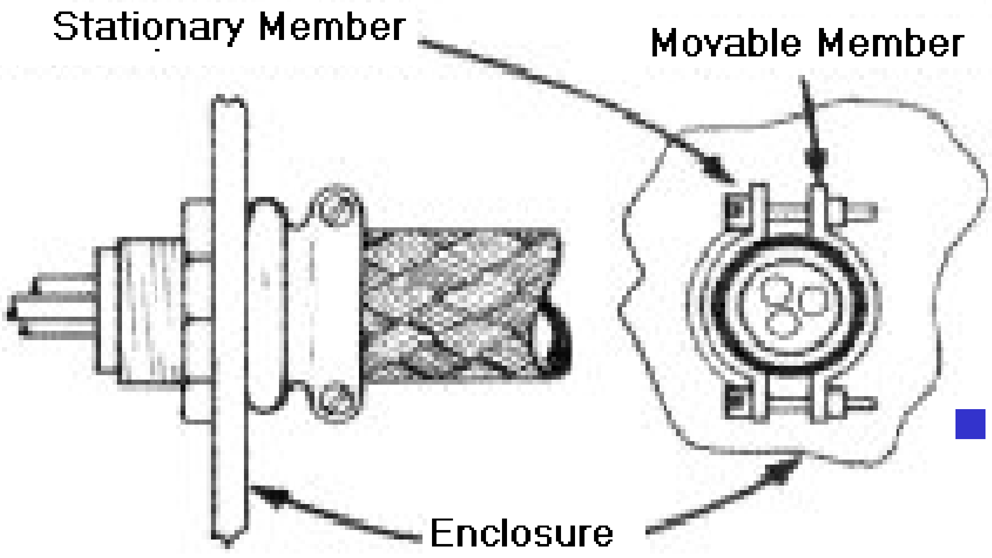
Shield Braids

- Shielding effectiveness is dependent on the existence of a low impedance shield return to an efficient ground plane.
- Long shield ground return conductors convert the shielded wires into unintentional coupling capacitors or transformers (due to inductance) at higher frequencies.
- Braids should be considered as an extension of the shielding structure and must be connected directly to the nearest primary ground structure.

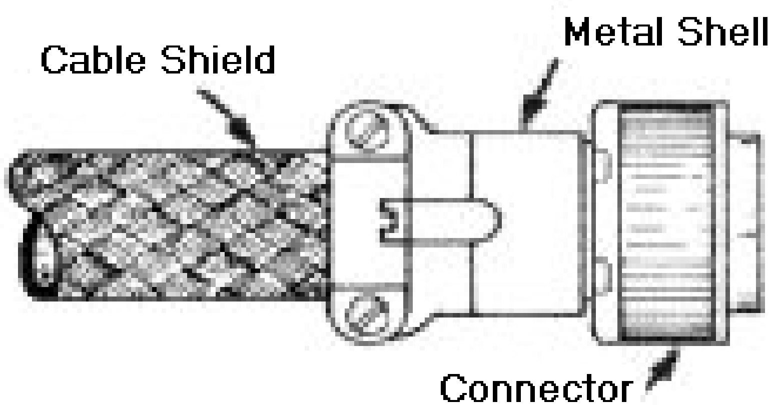
Braid Shield Attachment Using Crimping



- Notice in this case the shield is crimped completely around the conductor.

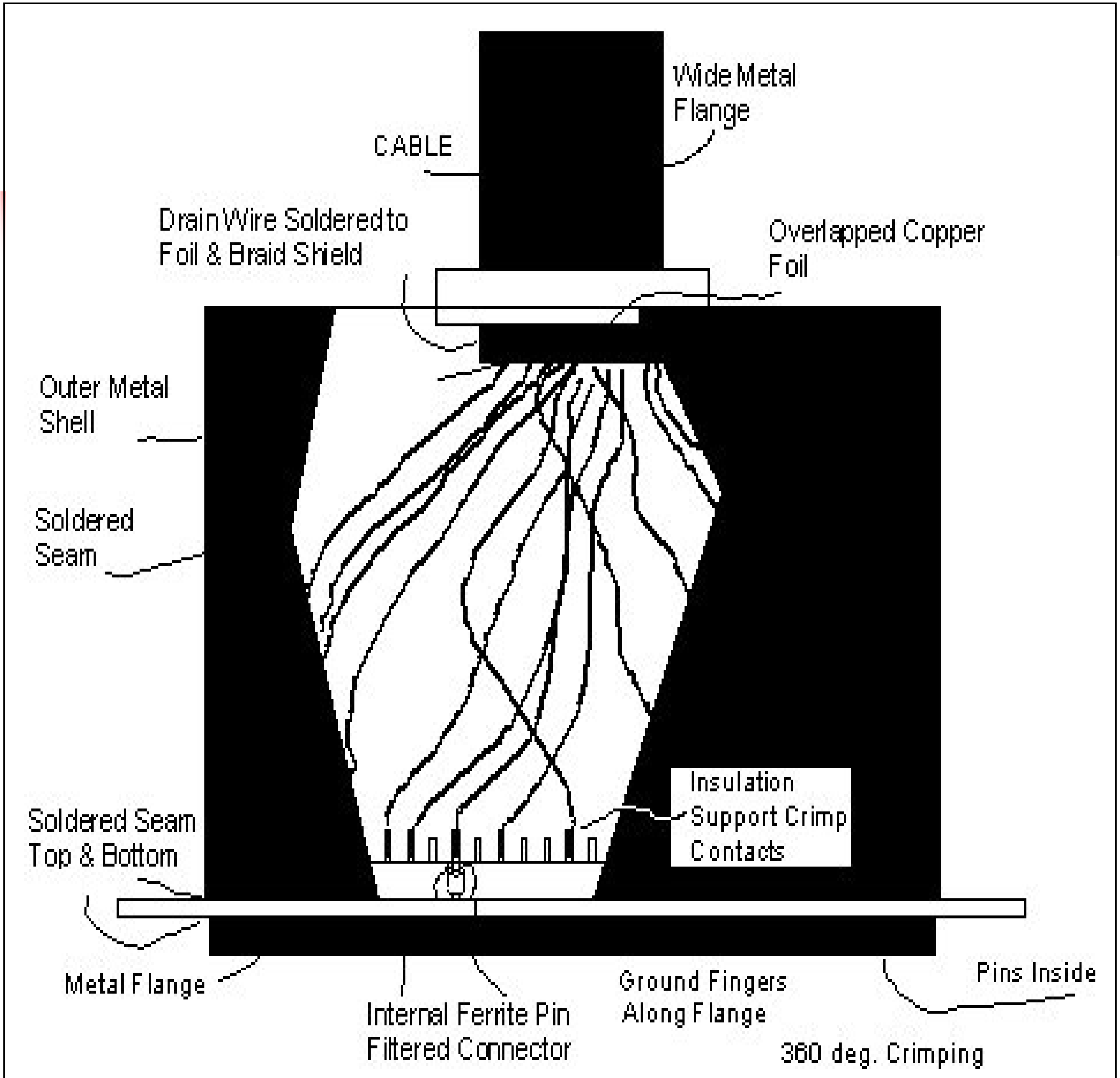


Box Connector



Grounding of Multi-pin Connector

- In this case the braid is clamped to ground on the connector assembly.

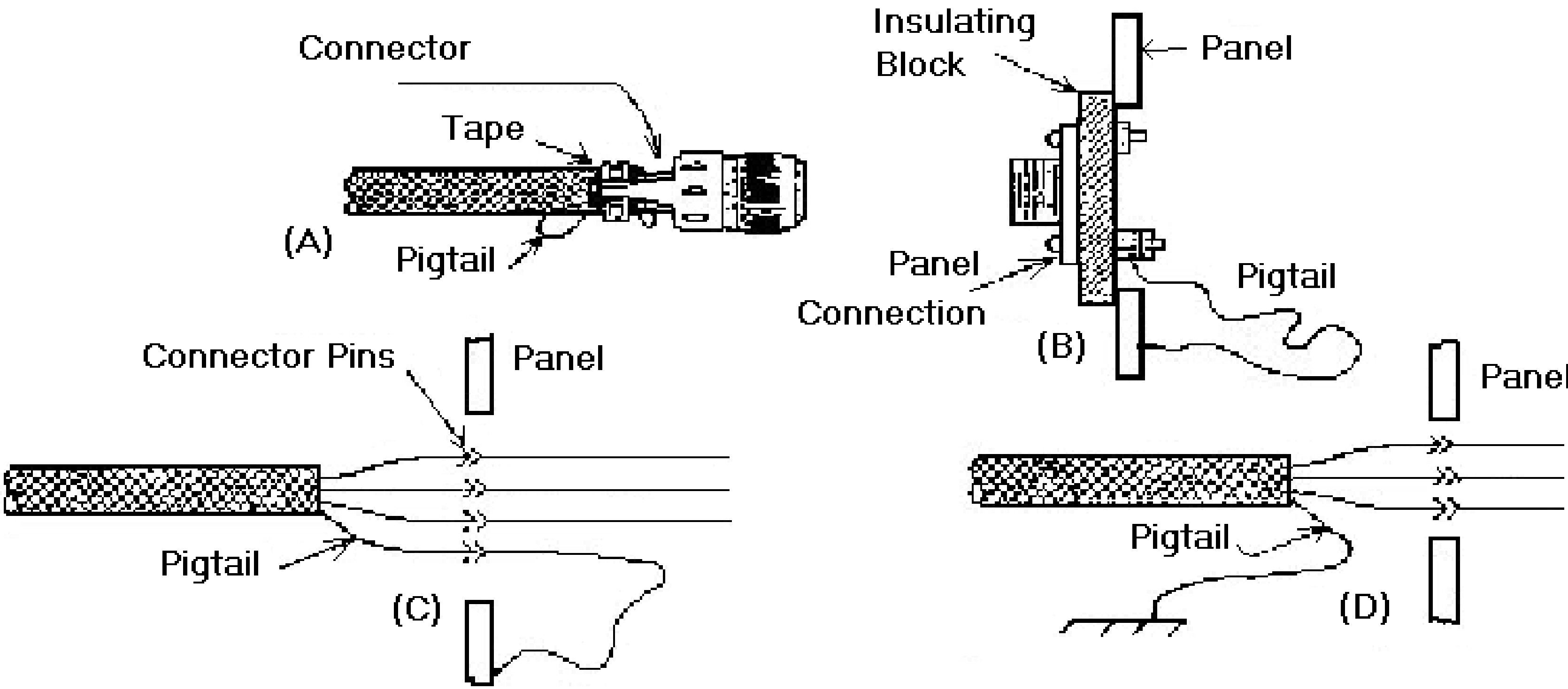


Drain wires and ground fingers used in computer type connector.

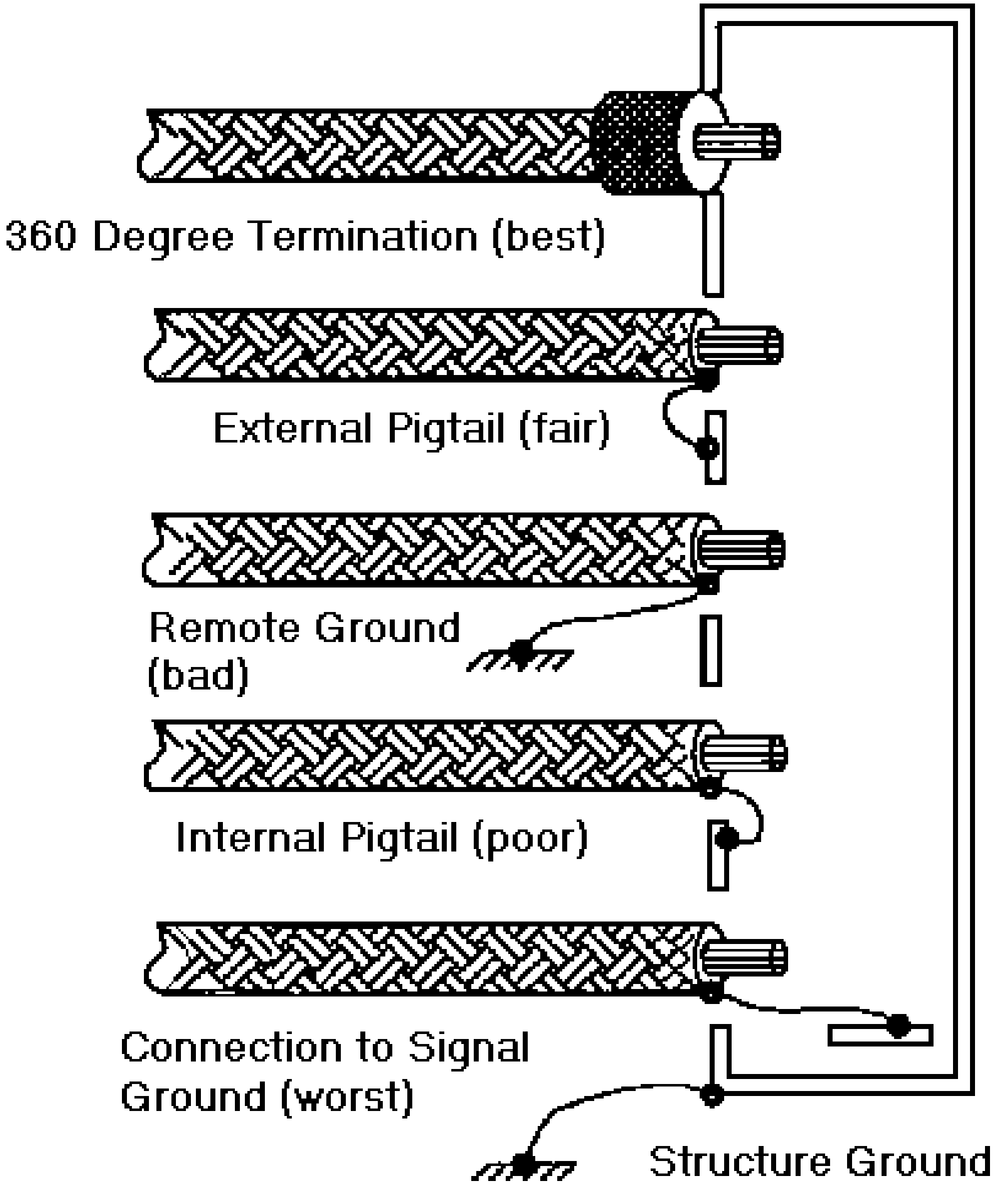
Pigtail Grounding

- The inductance of a typical pigtail will not be significantly different even if it is twisted and not straight.
- Regardless of approach specified, pigtails have little application in the emission controlled environment.
  - They negate the low impedance connection required between the shield and first ground reference.

No Pigtails Allowed



(A) Pigtail Connection to Backshell
(B) Pigtail Grounding to Panel Connector
(C) Shield Carried on Connector Pin
(D) Shield Grounded to Remote Plate



- Various pigtail shield terminations plus a good 360 degree termination.

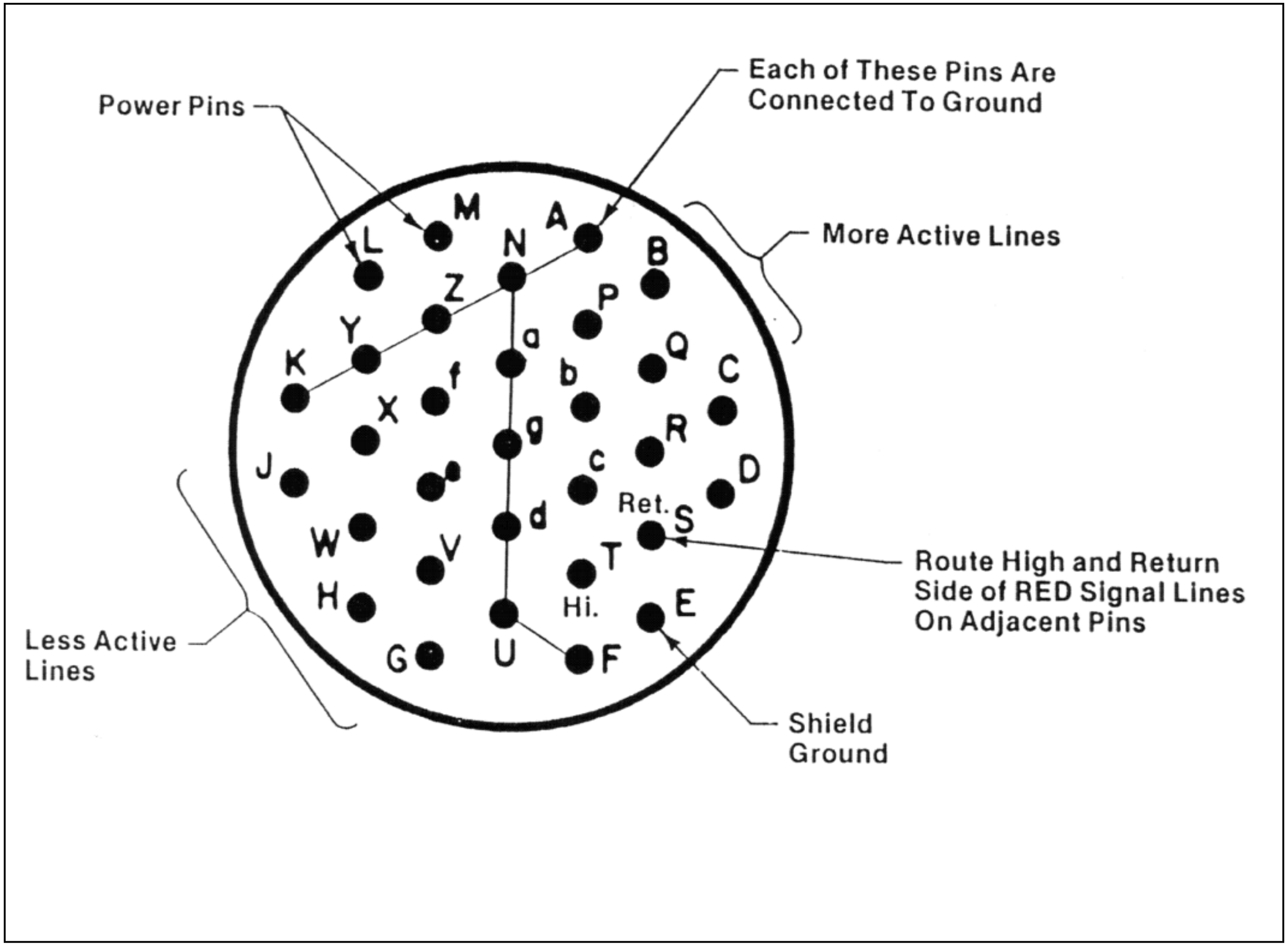
General Cable Termination and Connector Guidelines

- Cabling penetrating the case should be shielded and the shield terminated in a peripheral bond to the case at the point of entry.
- Cable shield grounds should be maintained separate from any signal grounds or circuitry grounds.
- Cable shields should be bonded peripherally to adapter and connector shells
  - Cable shields should not be "pig-tailed off" and run through on connector pins.

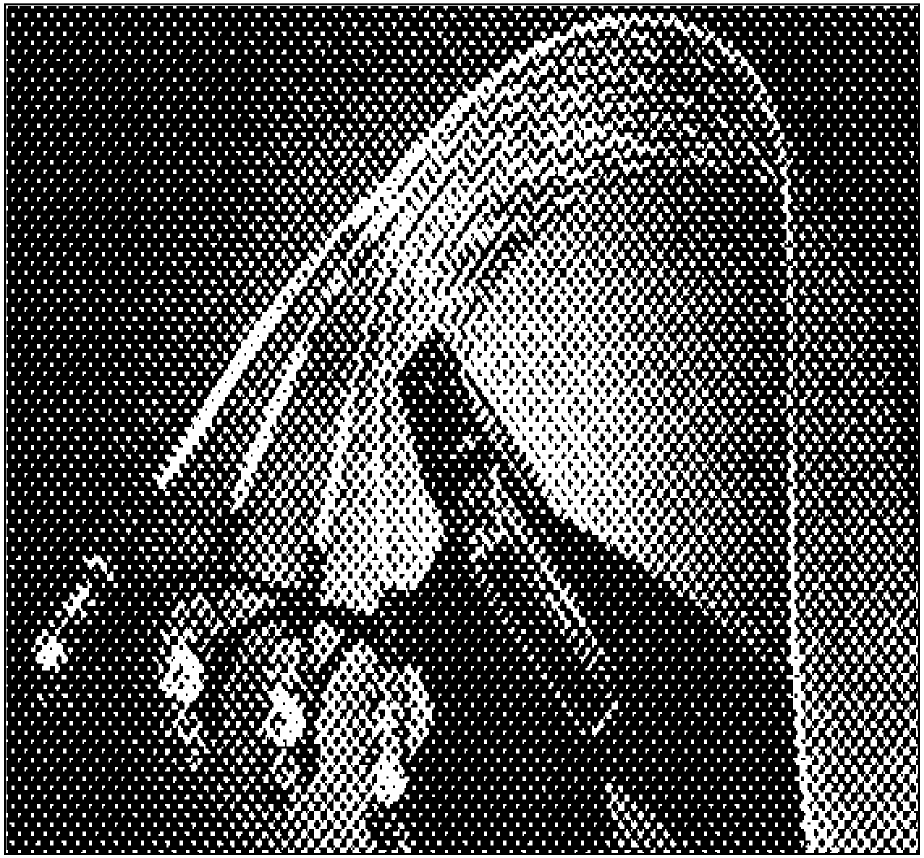
General Cable Termination and Connector Guidelines

- Connectors should be of the type which make peripheral shield (shell) ground before the pins mate during the process of connection.
  - The pins should disconnect before the shield (shell) separates.
- Pins of connectors leading to electronic circuitry should be, wherever possible, female.
  - Otherwise, they should be recessed male pins so as to exclude contact with any portion of the shell of the mating connector or with operator fingers.

Connector Pin Isolation

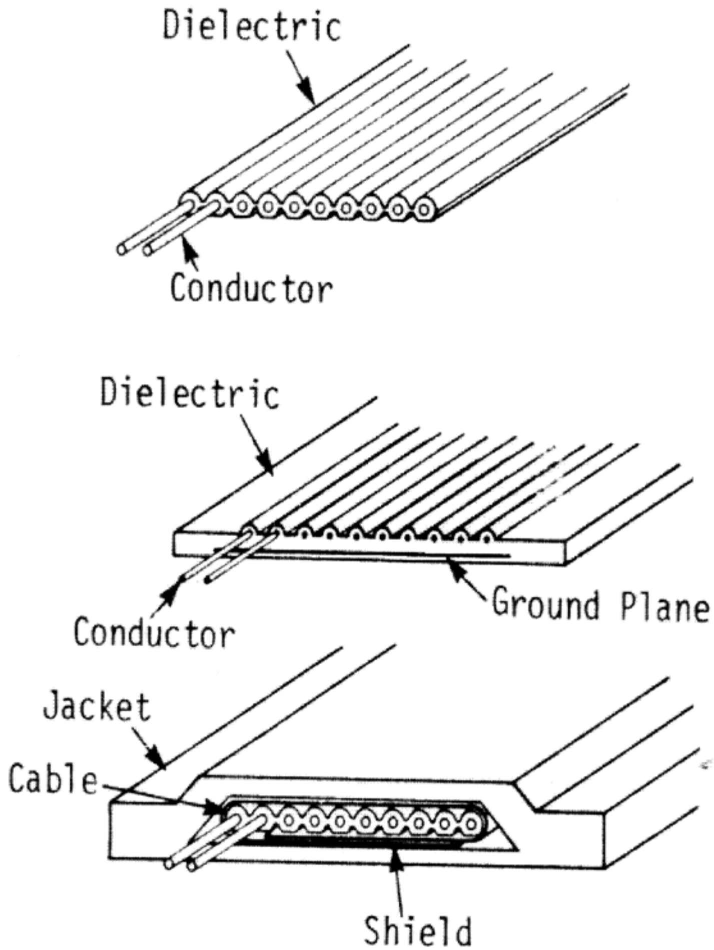


Flat Wire Cables



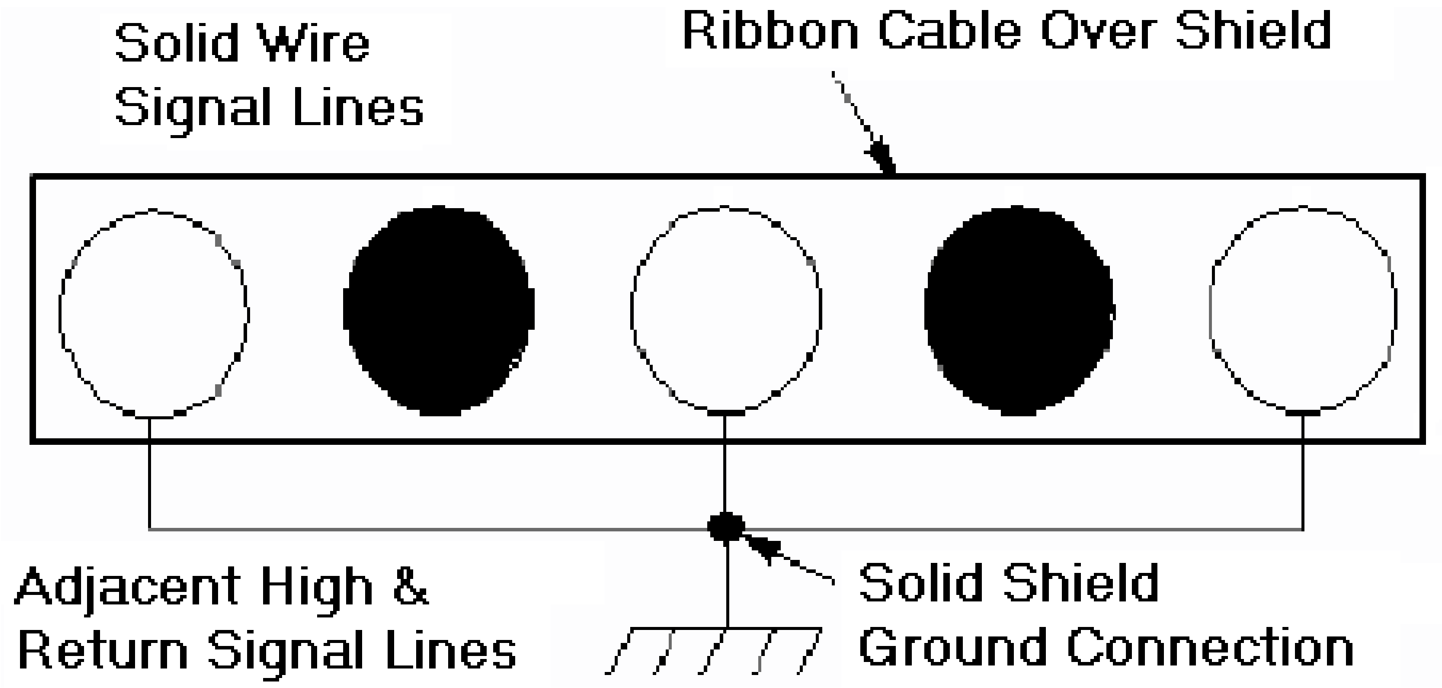
- The biggest problem with flat wire cable is crosstalk.
- Individual wires maintain uniform parallel capacitive and inductive coupling paths.

Typical Ribbon Cable Designs

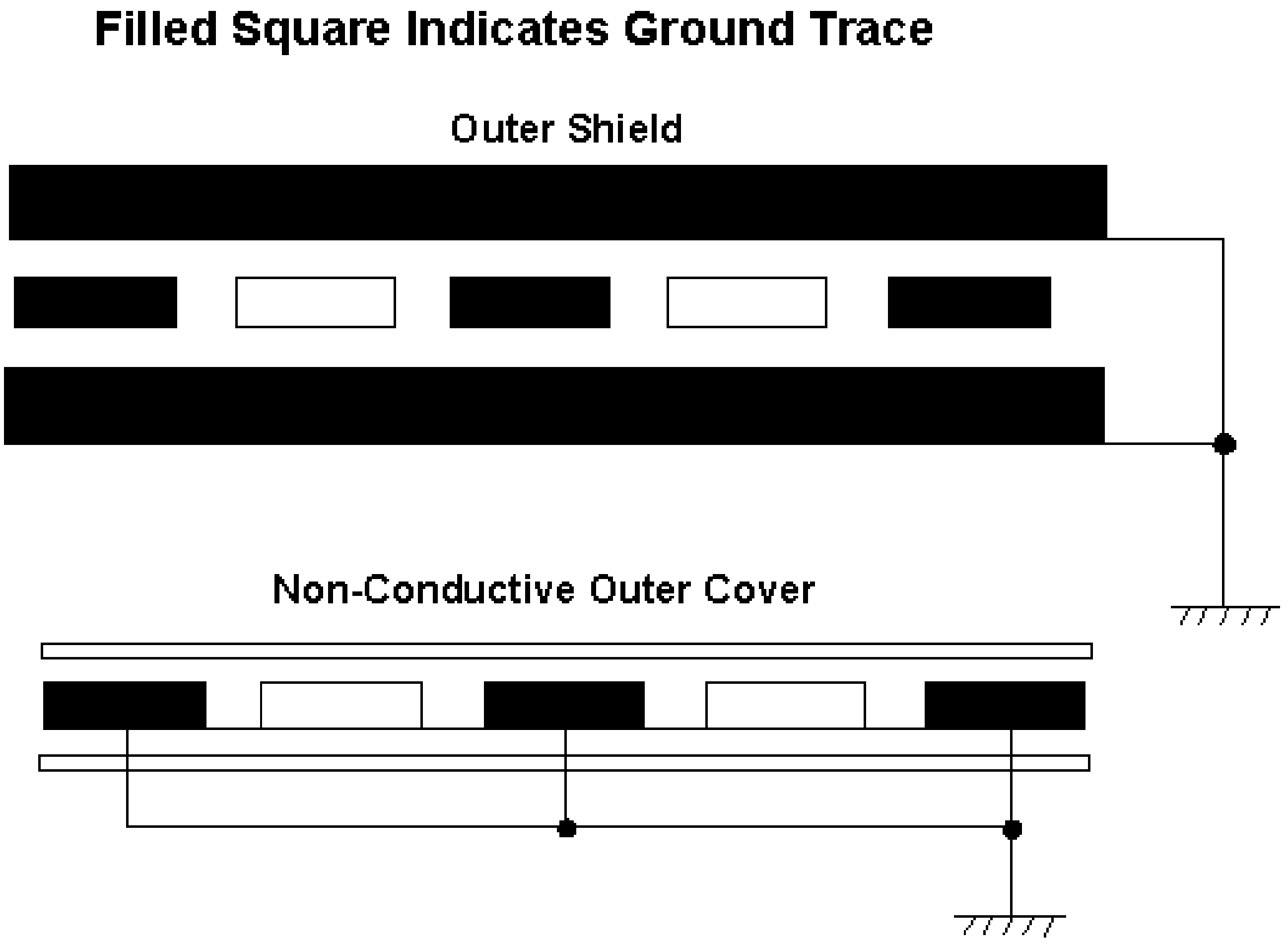


- While coupling is often controllable inside an individual shielded box, the use of ribbon cables in composite aircraft applications represents a severe controlled emission issue.

Alternate Grounding of Ribbon Wires in Cable



Stripline Flexprint



Crosstalk Controls

- Use shielded twisted pair cables if possible.
- If a flat cable is used, run reference lines between signal lines.
  - This approach can be improved if the reference lines are larger then the signal lines.
- Minimize printed circuit line and cable lengths.
- Route switching lines away from quiet lines.
- Use as many reference pins as possible in printed circuit board and cable assembly connectors.
  - Assign and isolate connector pins to take advantage of maximum isolation and separation.