Designing MIL Systems that Employ High Speed Data Systems

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IEEE EMC Rocky Mountain Chapter

June 20, 2003

Past Interference Problems between aircraft and cars

picture courteously of Mr. Dale Eggen taken by his father

Introduction

- Many new Military designs are employing high speed data buses
  - DVI,
  - Serdes,
  - Fibre Channel,
  - IEEE 1394 (Firewire), and
  - Ethernet.
- MIL-STD-461E, RE102, external limits
- RS103 at 200 V/m
  - 13,000 V/m may also be imposed.

Digital Visual Interface, DVI

- Stimulate the widespread adoption of digital displays for high-performance desktop and mobile PCs
- Transition Minimized Differential Signaling (TMDS).
  - DVI supports two TMDS links
  - 1.6 GB/sec

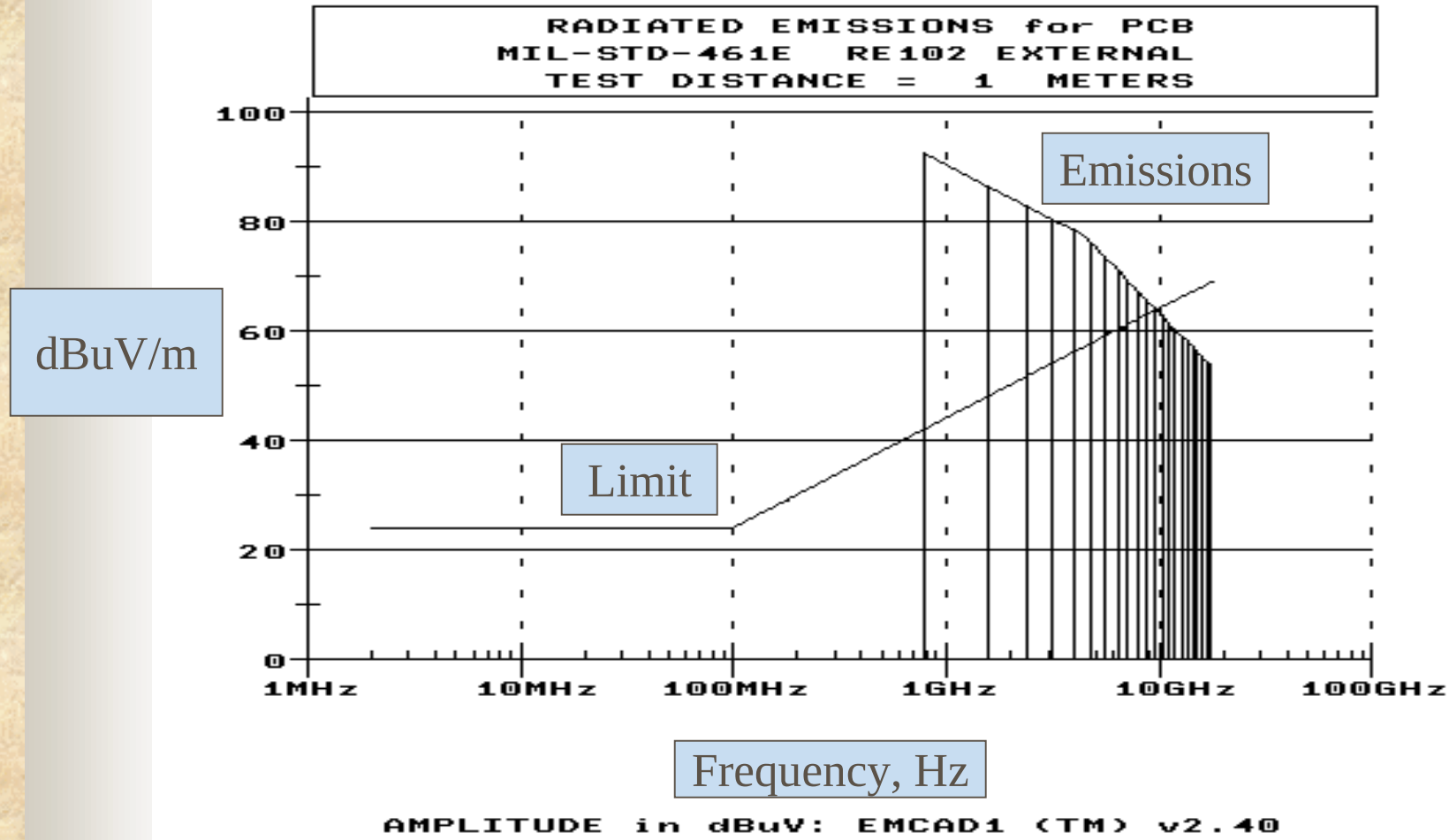
DVI vs. Analog

Display Type	Graphics Adapter	System Output	Monitor Interface	Display Interface
Analog CRT	Digital-to-Analog	Analog	Analog	Analog
Analog Flat Panel	Digital-to-Analog	Analog	Analog-to-Digital	Digital
Digital CRT	Digital	Digital	Digital-to-Analog	Analog
Digital Flat Panel	Digital	Digital	Digital	Digital

DVI Properties

- Risetime = 75 to 140 picoseconds
- Clock rates Vs. Data rate = 800 MHz/1.6 GHz
- Amplitudes = 3.3V peak to peak
- Trace lengths = typical 8 to 12 inches
- Impedance
  - 100 ohms trace to trace,
  - 50 ohms trace to ground plane
- Trace widths = 5 to 8 mils
- Height above ground = 5 to 8 mils
- Dielectric constant of PCB = 4.3

Predicted Radiated Emissions, PCB (based on EMCad™)



Predicted Radiated Emissions, PCB (based on EMCad™) Assumptions

- Microstrip, for stripline deduct 14 dB
- Amount of case shielding needed to contain the PCB emissions
- Maximum single aperture for –14 dB at 10 GHz or 0 dB at 5 GHz is about 1.2 inches
- Maximum single aperture for 36 dB at 800 MHz is 0.12 inches (Approximately 1/8 inch)
  - Based on 1” yielding 0 dB at 6 GHz.

DVI Cabling Choices

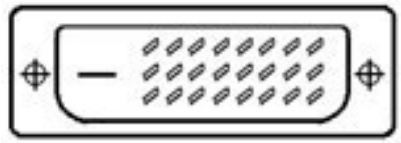
- Commercial choice is six Twisted shielded pairs, gross shielded
- MIL work may use coax and transmit signal “single ended”.
- Usually takes two coax cables to equal one differential pair.

Typical commercial DVI Connector Pin-out

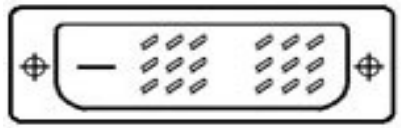
PIN	Signal Assignment	PIN	Signal Assignment	PIN	Signal Assignment
1	Data 2-	9	Data 1-	17	Data 0-
2	Data 2+	10	Data 1+	18	Data 0+
3	2/4 shield	11	1/3 shield	19	0/5 shield
4	Data 4-	12	Data 3-	20	Data 5-
5	Data 4+	13	Data 3+	21	Data 5+
6	DDC Clock	14	+ 5 V pwr	22	Clk Shield
7	DDC Data	15	+5 V grd	23	Clk +
8	No Connect	16	Hot plug D	24	Clk -

Typical DVI Commercial Connector, single link

Typical DVI Commercial Connector, single link



DVI/D Dual Link



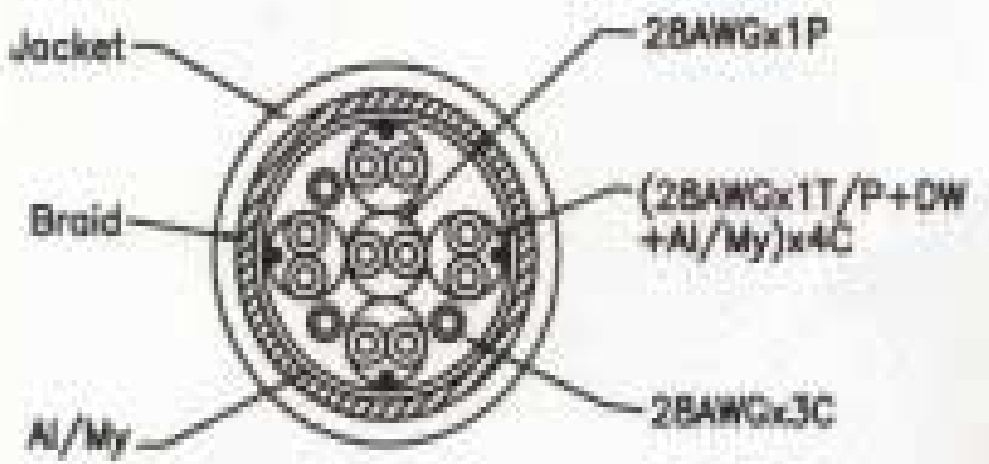
DVI/D Single Link

DVI/I Analog/Digital

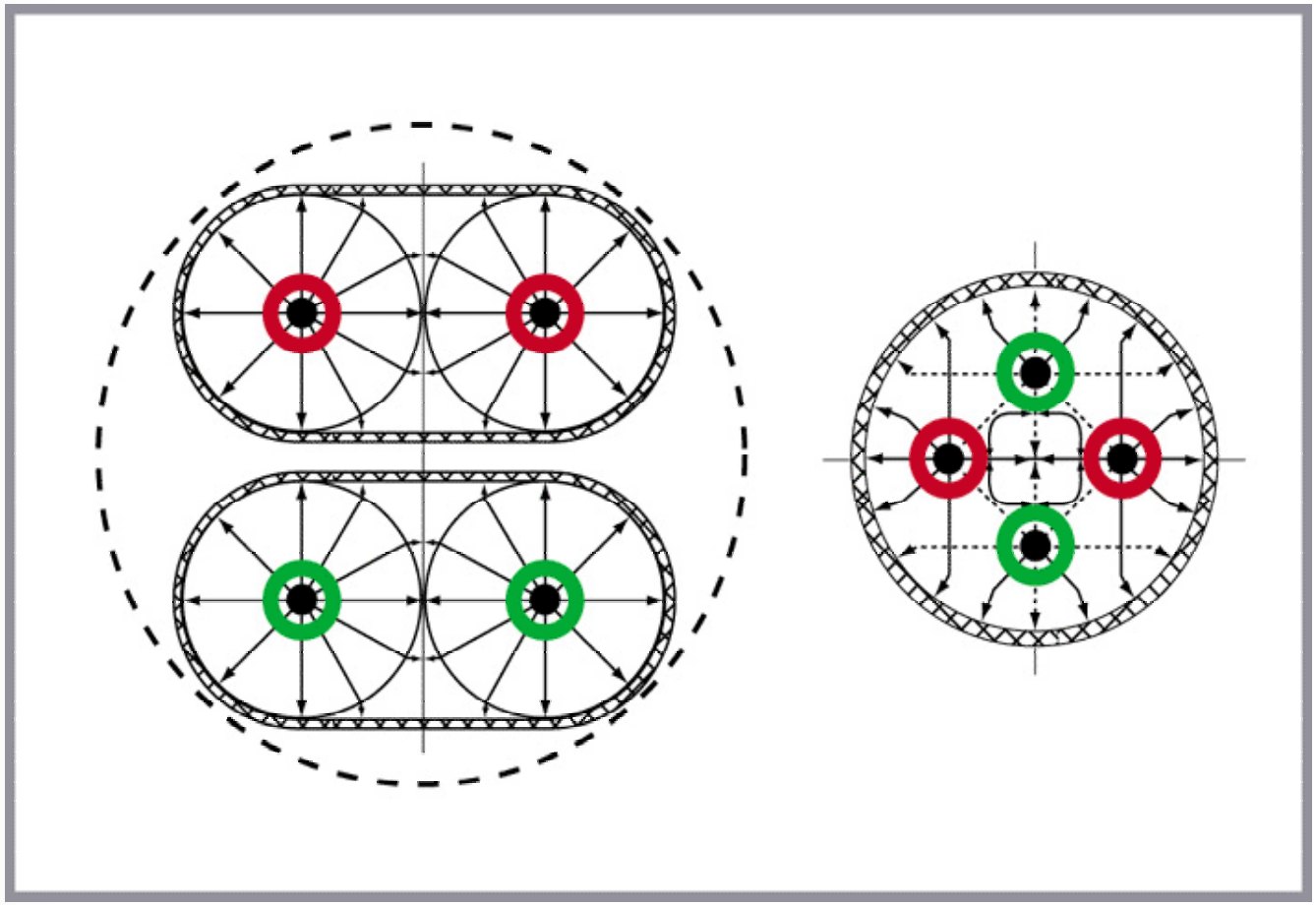
DVI/A Analog

Typical DVI Commercial Cable

NOTE:1.Cable Specification:
UL20276 [(28AWG*1T/p+DW+AL/MY)*4C
+28AWG*1P+28AWG*3C] +AL/MY+BD
Jacket Color : PMS Black 3U 2X



DVI MIL Cable Twinax vs. Quadax



DVI Quad Connectors from Gore

DVI Quad Connectors

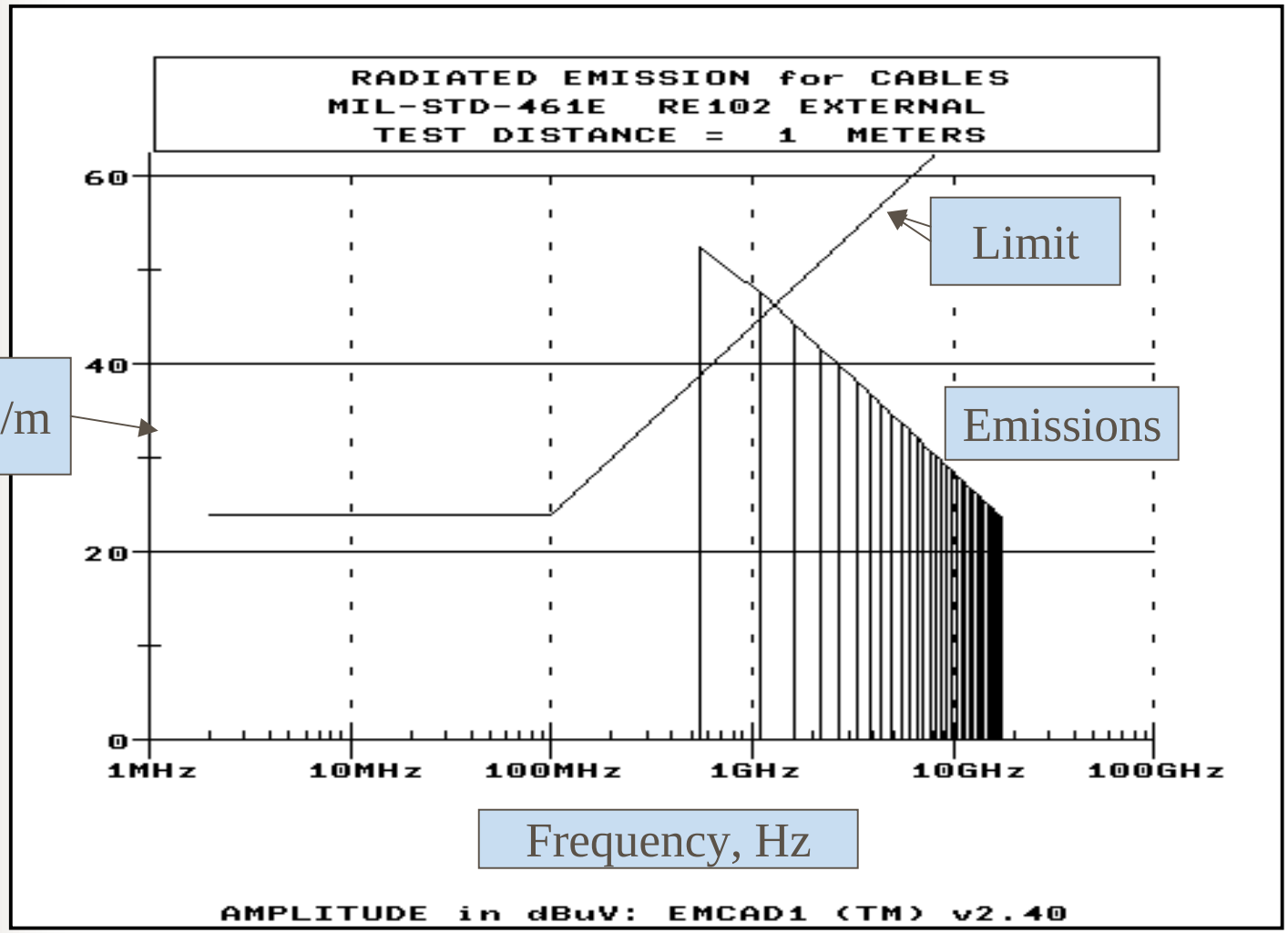
Inserts for size 11 MIL-C-38999 connectors provide optimized performance in the smallest possible connector package.

Insert configuration maintains quad geometry through the connector interface

Improved Z° match minimizes reflections for clean eye patterns

Standard size 22D contacts for high reliability and ease of use
Series 3 coupling provides enhanced EMI performance

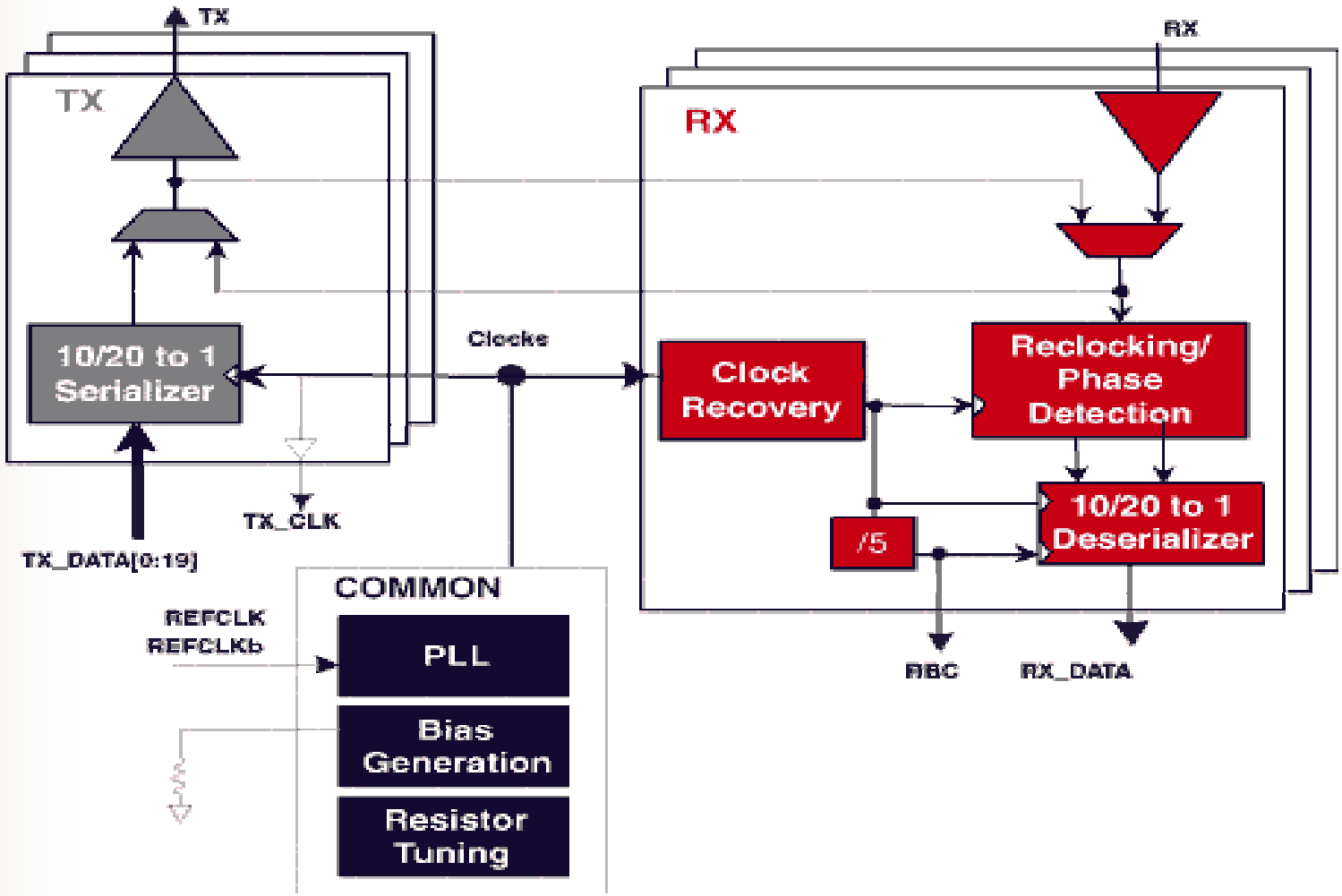
DVI Signals from coax



What is SerDes?

- SerDes stands for serializer/deserializer
- SerDes typically uses 10 to 1 or 20 to 1
- Signal is converted from parallel to serial

SerDes Concept



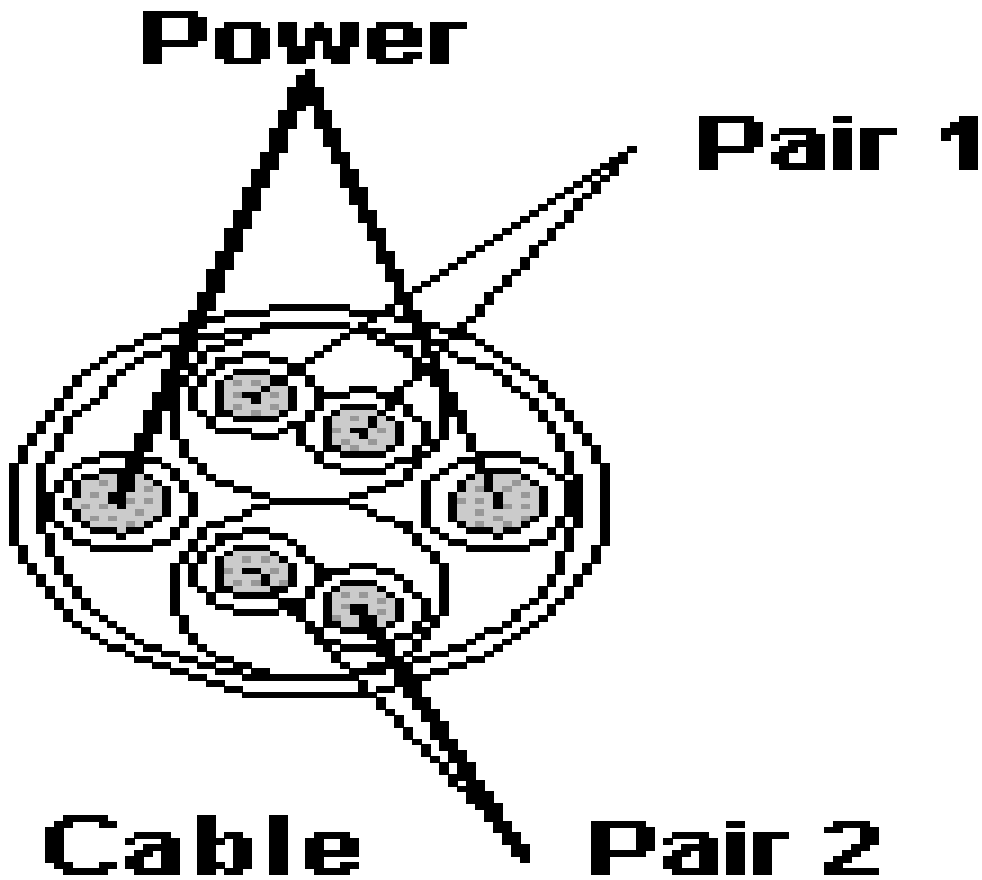
What is Firewire?

- IEEE 1394a"wire" is good for 400 Megabits per second over 4.5 meters
- IEEE 1394b extend the rate to 800 - 3200 Megabits over 4.5 meters copper
- 28 AWG signal pairs with 40 twist/meter, 13 per foot.
- Apple = *FireWire*. Others companies use names, such as *i.link* and *Lynx*

Firewire commercial connectors

Firewire commercial cable

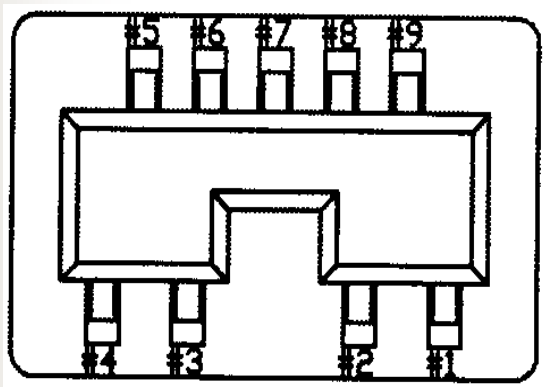
The Firewire has two

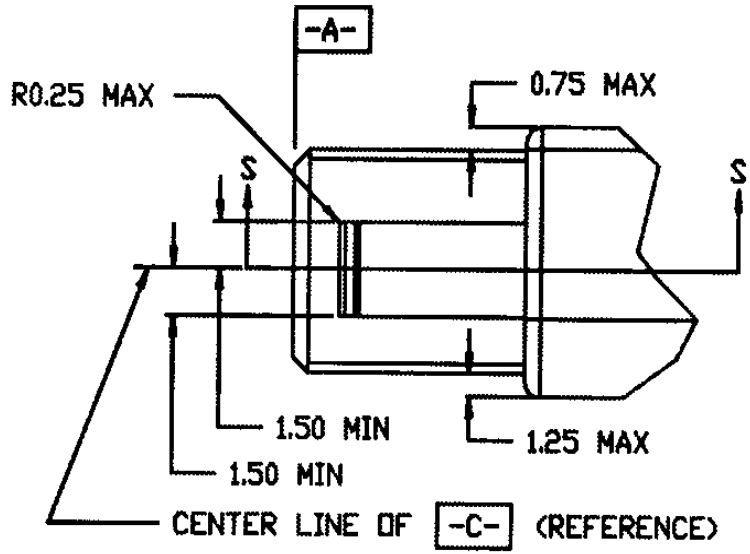


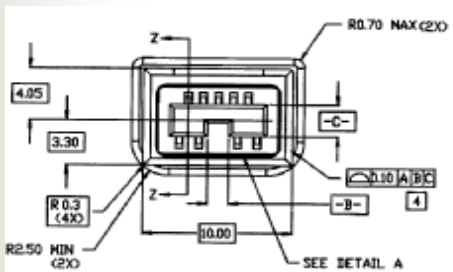
IEEE 1394 A EMC Issues

- Need to DC float connect shell from case
  - Problem for case shielding
- Need to AC symmetric shield terminate shell to case using 1000 pF capacitors
- Must meet the Lambda/40 rule
- Must filter the DC lines if used

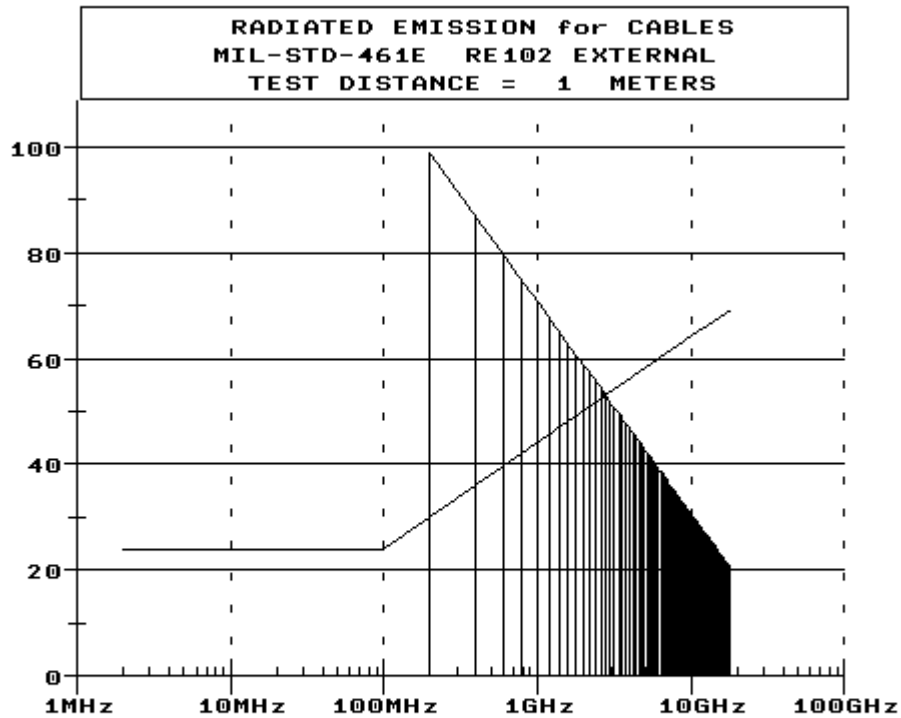
IEEE 1394B Connectors - not the same as “a”



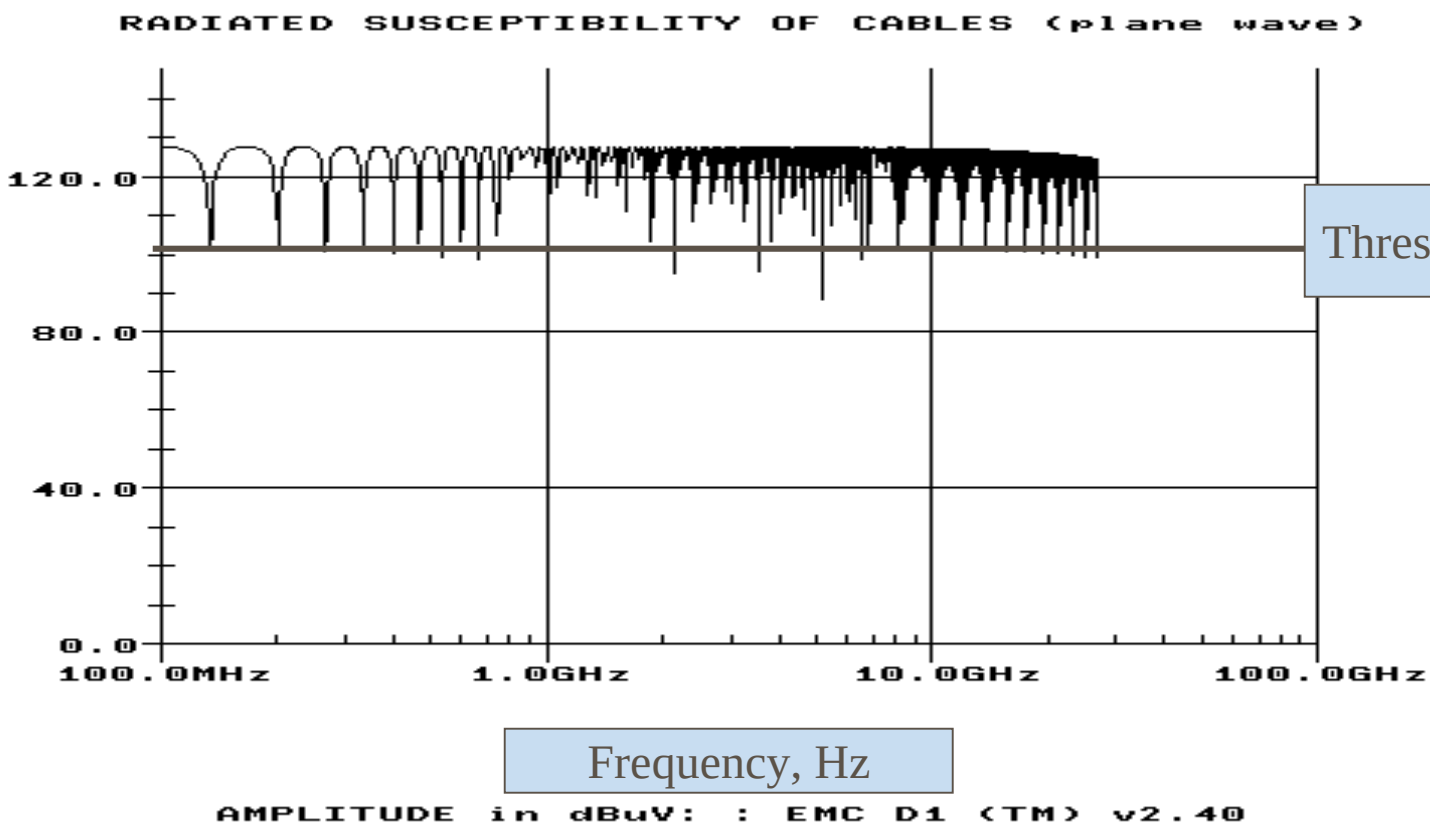




RE102 Emissions from 200 MHz



RS103 Hardening requirements for firewire



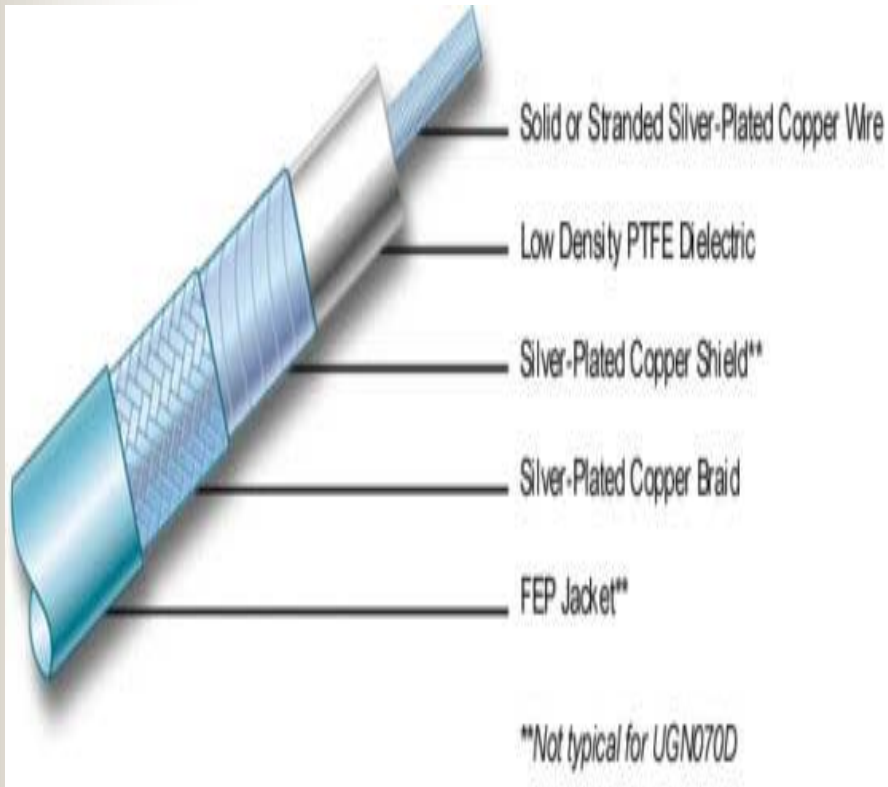
RE102 vs. RS103

- Above about 1 GHz, more cable shielding needed for RS103 than RE102
- RS103 > 27 dB @ 200 V/m
- EME ship > 63 dB @ 13,000 V/m (3-4 GHz)

Single-ended high speed

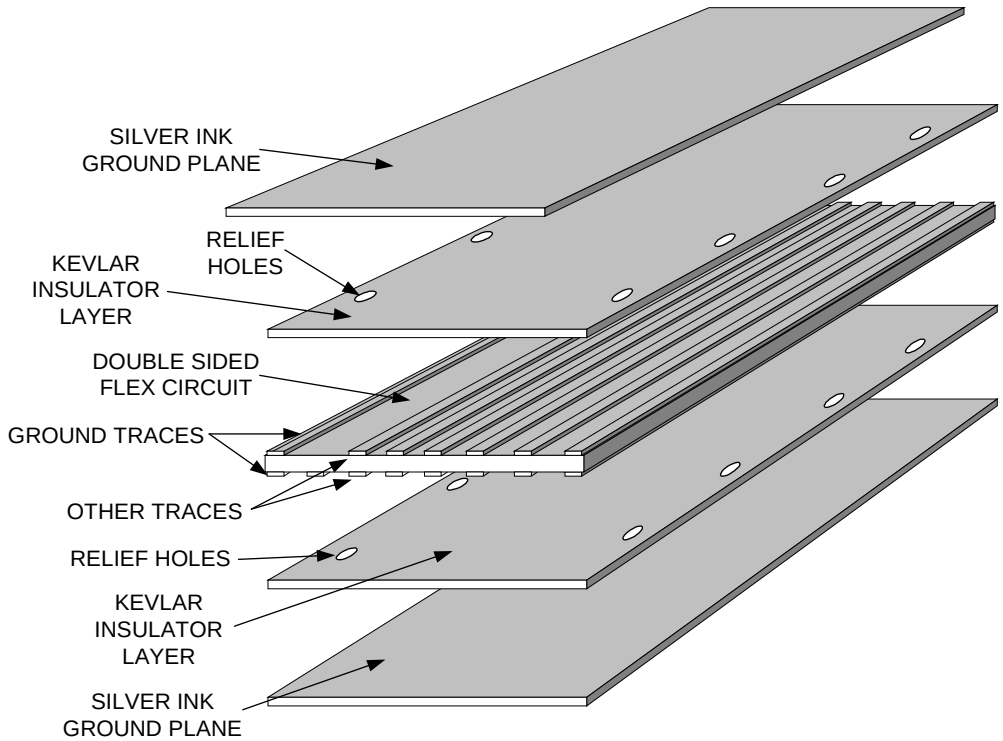
- Mil designs prefer coax instead of twinax cables
- Send high speed singles single-ended
  - Loose common mode rejection resulting in more shielding
  - Typically use transformer to convert differential to single-end and back again.

DVI Radiated Emission Analysis – Based on EMCad™ Analysis – SE # 2, Cable Required, Micro-Coax model UFF092F (100 dB @ 1 GHz)



- Center Conductor
  - silver-plated copper wire
- dielectric constant 1.4 to 1.7
- Silver-plated copper tape – Inner shield
- Silver-plated copper wire – outer shield
- 100 dB @ 1 GHz

Internal Flex needed to contain High Speed Signals



GROUNDING/REFERENCING

- A good ground system must be designed, not left to chance.
- Digital systems because of their inherent high threshold levels (≥100 mV) may be chassis referenced at both ends.
- Analog systems that have operational bandwidths 0 - 10 MHz or less benefit from circuit isolation from chassis.
- Grounding schemes must maintain case shielding integrity.

GROUNDING/REFERENCING (cont'd.)

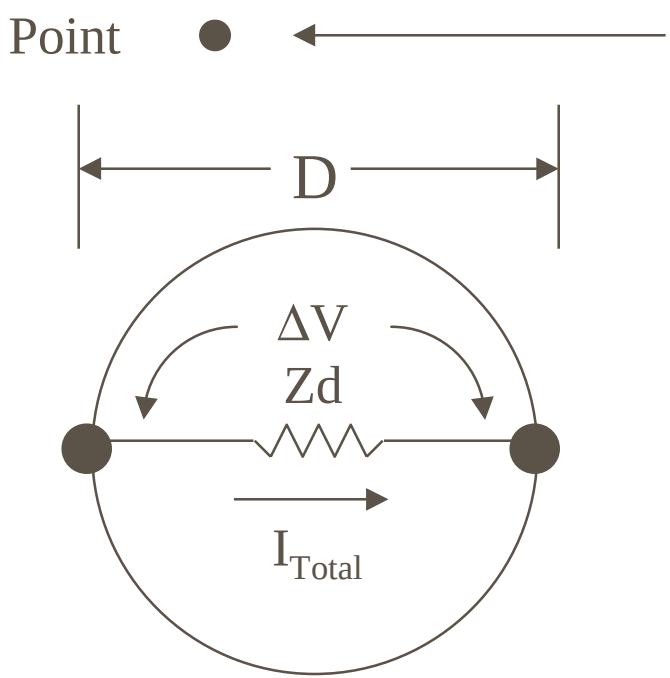
- The best approach is a hard reference to chassis at each unit with the interlacing I/O cable becoming the circuit isolator between same.

- The exception to this rule would be for analog or signaling circuits which cannot be easily isolated by a common inductance between the center conductor and its return.

- However, leaving a ground system to be developed by each design entity is not recommended.

SINGLE POINT OR REFERENCE CONCEPT

Single point grounding cannot exist

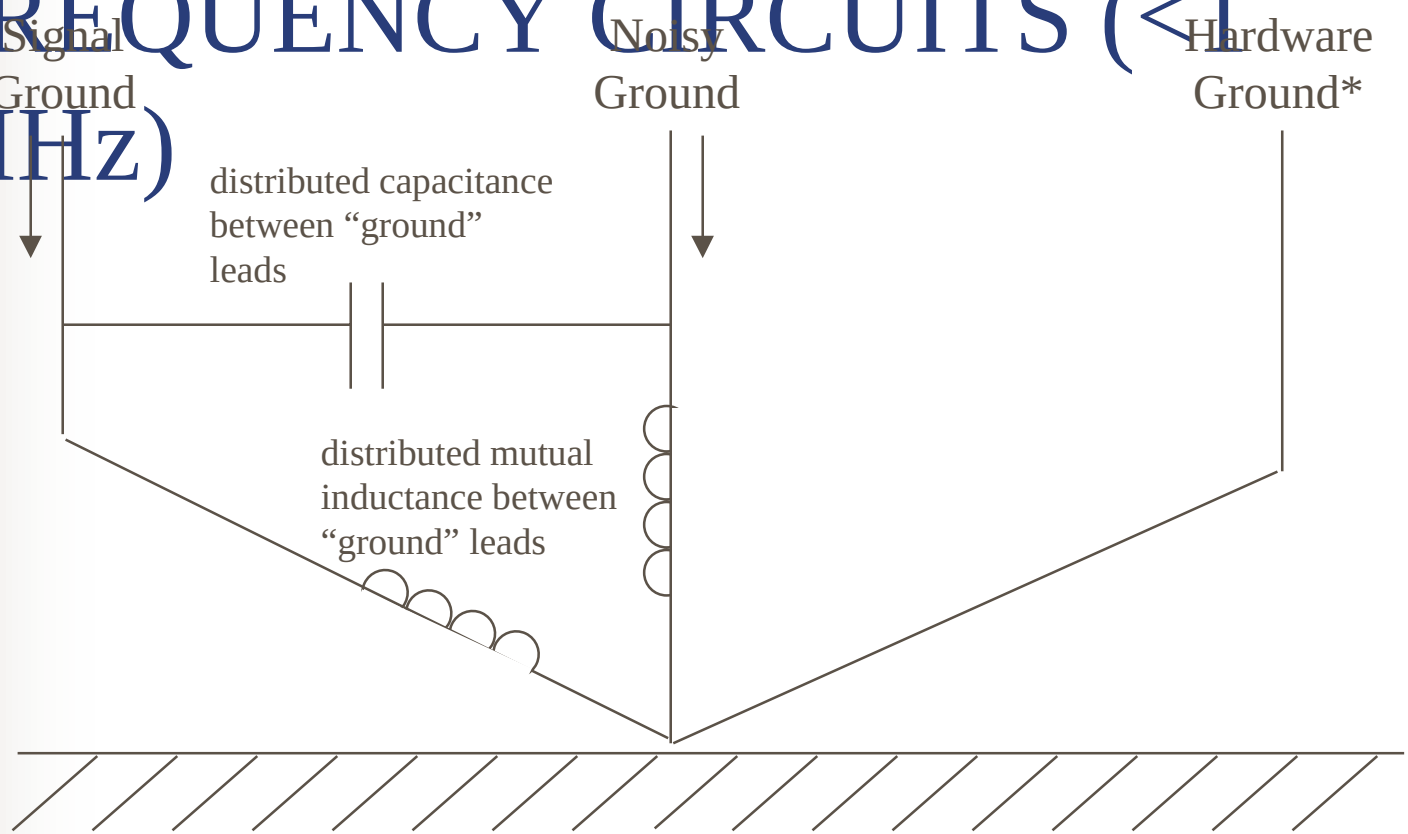


No dimensions, therefore no way to terminate wires together

Ground reference area of diameter "D"
$I \times Z_d = \Delta V$
that is below all circuit threshold values referenced to ground.

$$BW = \frac{1}{\pi t_r} = \frac{300\ MHz}{t_r\ nsecs}$$

SEPARATE GROUNDS SHOULD BE USED FOR LOW FREQUENCY CIRCUITS (<1 MHz)

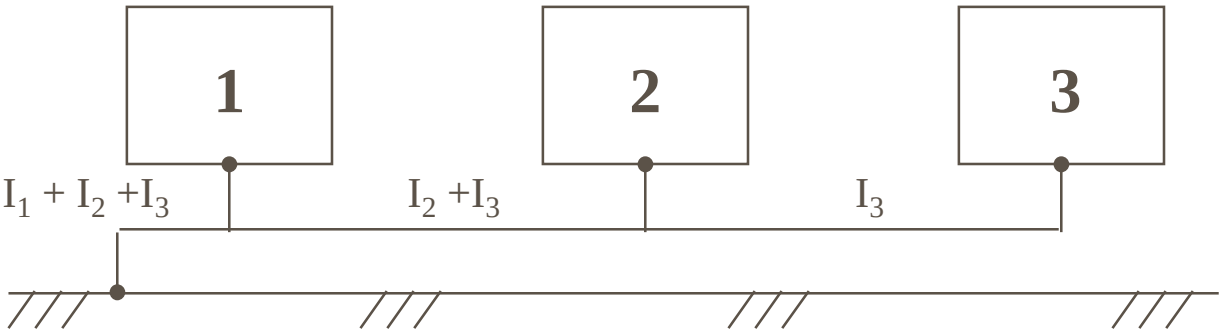


* AC power ground (green wire) should be connected to hardware ground (within 1.5 inches of case entry)

SINGLE POINT GROUNDS

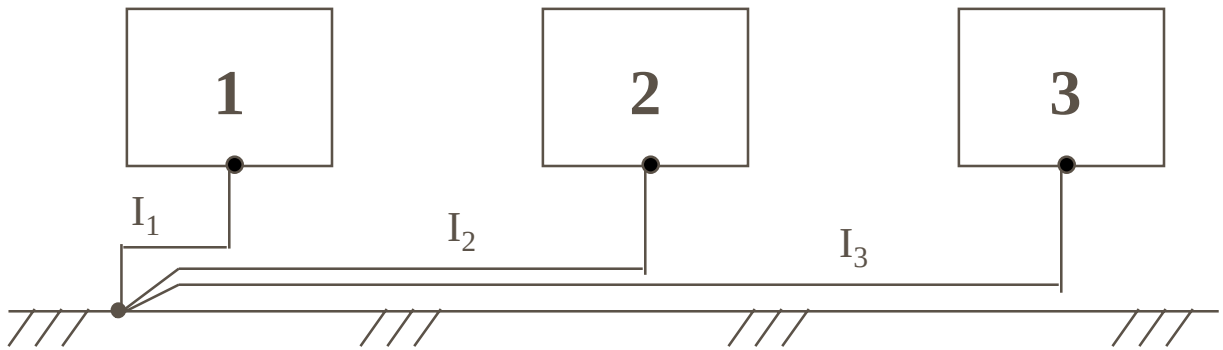
1A. Series

Signal Current Loop Control?

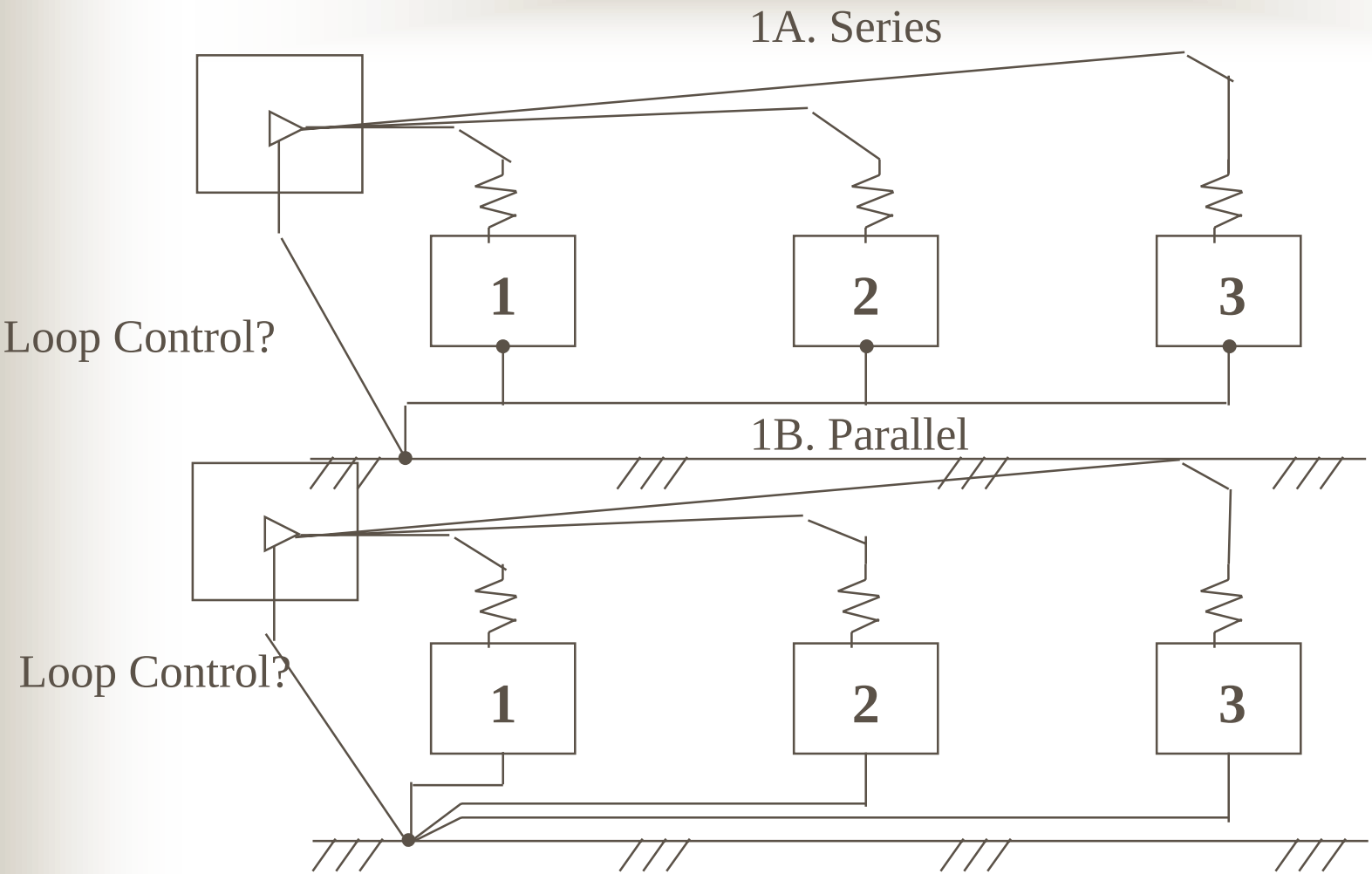


1B. Parallel

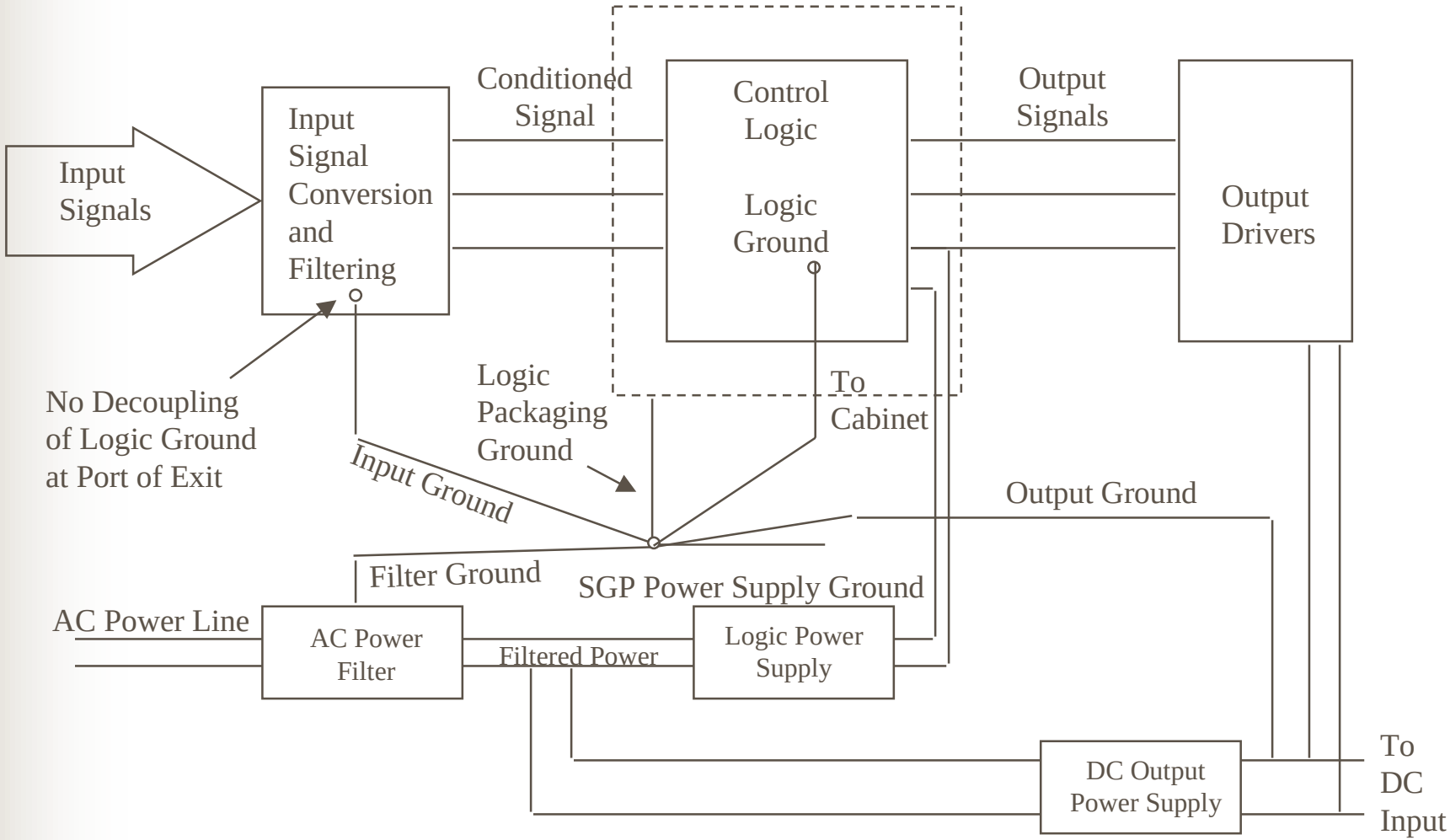
Signal Current Loop Control?



SINGLE POINT GROUNDS



POOR SINGLE REFERENCE GROUNDING BECAUSE OF LARGE EXPOSED LOOP AREAS

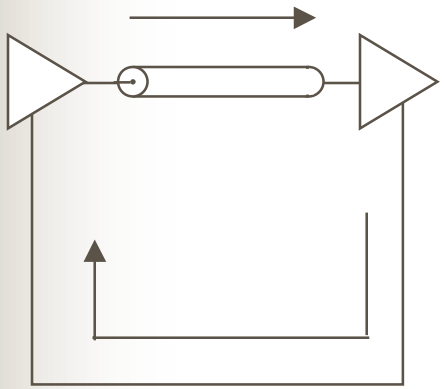


POOR SINGLE REFERENCE GROUNDING

- This viewgraph was taken from literature and was titled "The Proper Way to Ground".
  - One can see that the conditioned signals transferring from the input conversion to the control logic could not possibly be transmitted if the only signal return was through the single ground point (SGP).
  - This is because each of the 3 lines shown would form 3 concentric loop areas that would crosstalk.

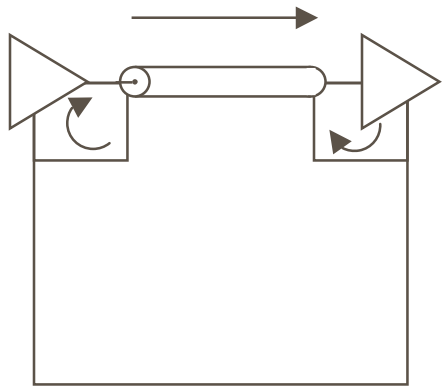
PROPER APPLICATION OF TRANSMISSION LINES TO SINGLE-ENDED CIRCUITS

Bad



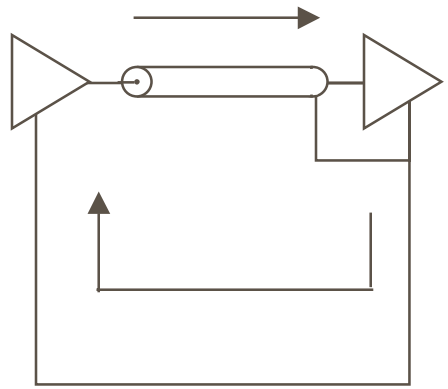
No Shield
Large Enclosed Area

Preferred



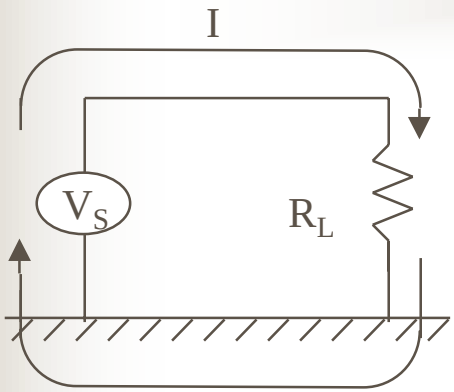
Shield Area
Both Ends of Chassis
Grounded - Significant
Reduction in Loop Area

Bad

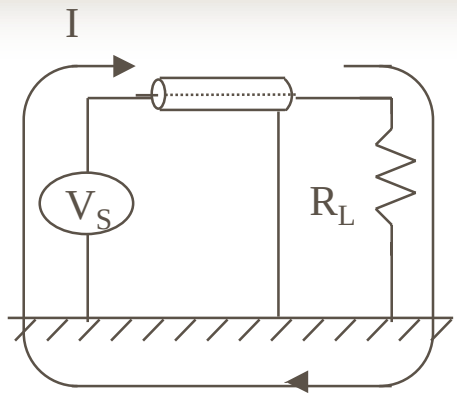


Shield Added
One End Chassis
Grounded - No
Reduction in
Loop Area

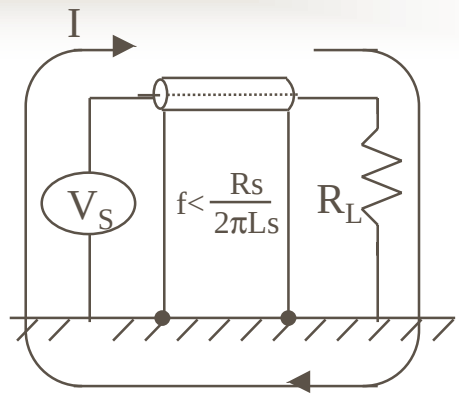
EFFECT OF SHIELD ON LOOP AREA



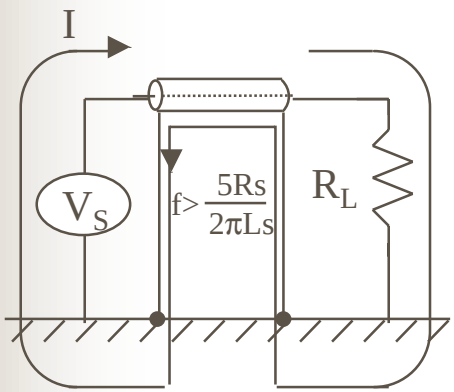
No Shield
Large Enclosed Area



Shield Added
One End Grounded
Large Enclosed Area



Shield Added
Two Ends Grounded
Large Area



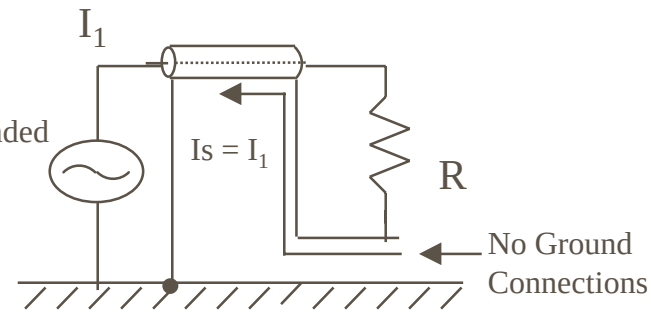
Shield Added
Two Ends Ground
Reduced Area

$$f\ (\text{cut-off}) = \frac{Rs}{2\pi Ls}$$

$$\text{or } 2\pi f = \frac{Rs}{Ls}$$

$$\omega c = \frac{Rs}{Ls}$$

Circuit Not Grounded
At One End
Reduced Area



Notes:
Rs = Shield Resistance
Ls = Self Inductance of Shield

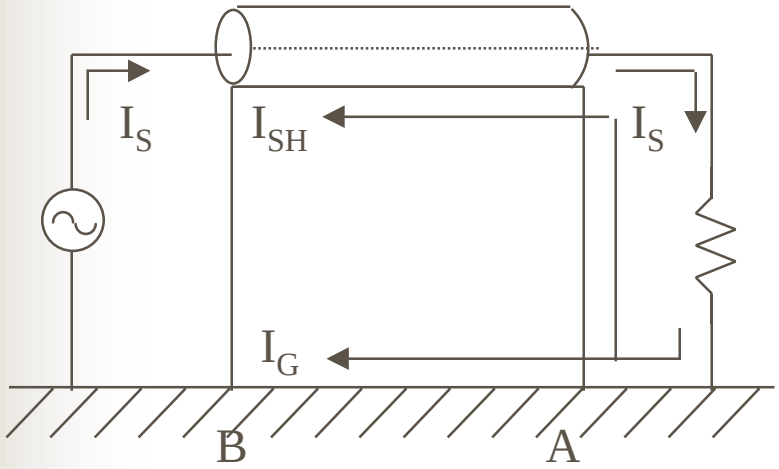
MEASURED VALUES OF SHIELD CUT-OFF FREQUENCY (F_C)

CABLE	IMPEDANCE (Ω)	CUT-OFF FREQUENCY (kHz)	FIVE TIMES CUT-OFF FREQUENCY (kHz)	REMARKS
Coaxial Cable				
RG-6A	75	0.6	3.0	Double Shielded
RG-213	50	0.7	3.5	
RG-214	50	0.7	3.5	Double Shielded
RG-62A	93	1.5	7.5	
RG-59C	75	1.6	8.0	
RG-58C	50	2.0	10.0	
Shielded Twisted Pair				
754E	125	0.8	4.0	Double Shielded
24Ga.	---	2.2	11.0	
22Ga.[1]	---	7.0	35.0	Aluminum-Foil Shield
Shielded Single				
24Ga.	---	4.0	20.0	

1 One pair out of an 11 pair cable (Belden 8775).

From: "Noise Reduction Techniques in Electronic Systems", by H.W. Ott, 2nd ed. (1988) by Bell Telephone Laboratories Inc., Reprinted by permission of John Wiley & Sons, Inc.

DIVISION OF CURRENT BETWEEN SHIELD AND GROUND PLANE



Subscript $_{SH}$ = Shield

Mesh Equation Inside Loop

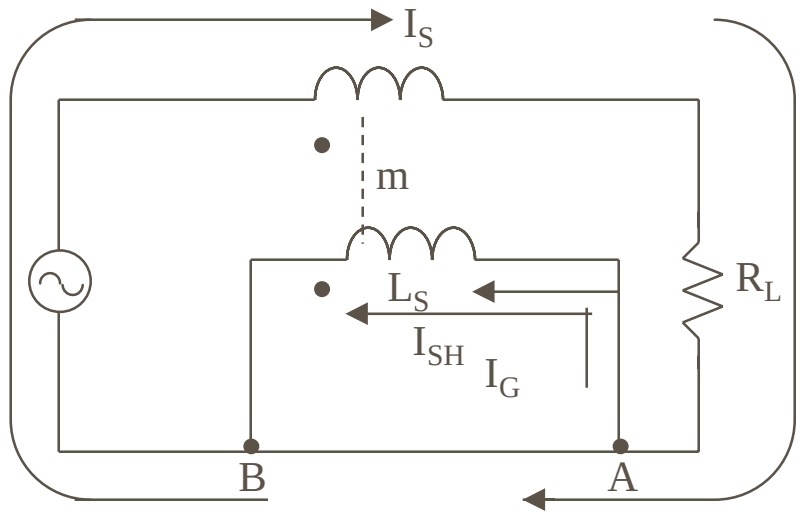
For $\omega >> \omega_c$

$$0 = I_S (j\omega L_S + R_L) - I_{SH} \quad (j\omega m)$$

$$I_S = I_{SH} \left(\frac{j\omega}{j\omega + R_S/L_S} \right) = \left(\frac{j\omega}{j\omega + \omega_c} \right) I_{SH}$$

At $\omega >> \omega_c$ all current returns on shield

At $\omega << \omega_c$ all current returns through ground

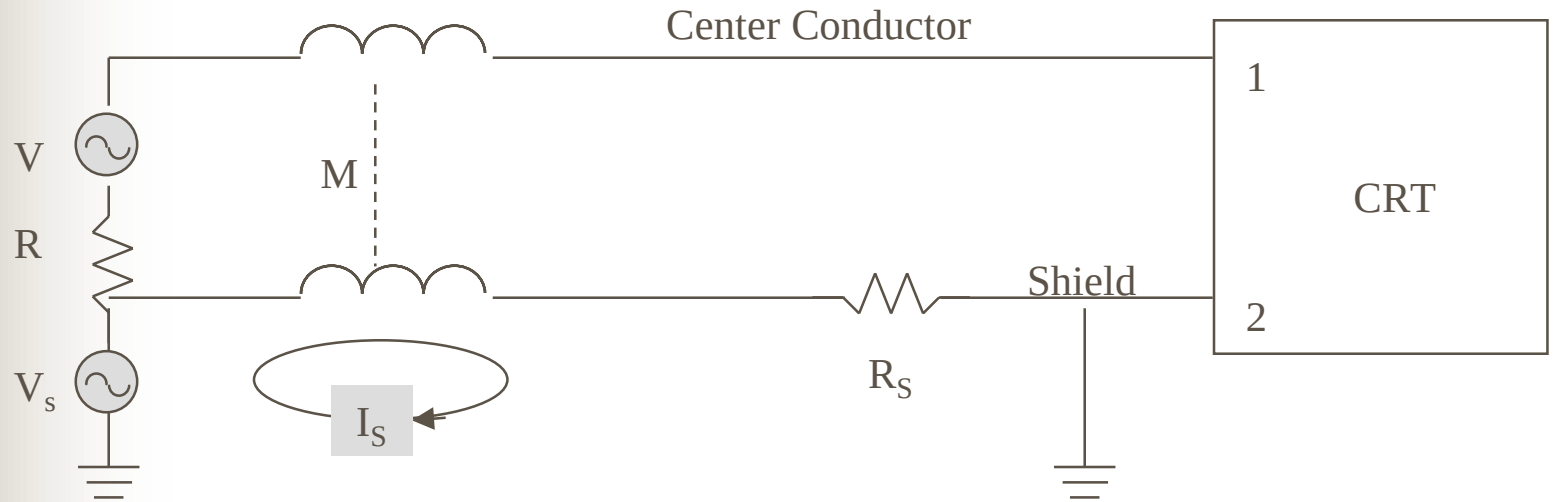


$$I_G = I_S - I_{SH}$$

$$\omega_c = \frac{R_L}{L_S}$$

GROUND LOOP

If shielded current is allowed to flow and the shield is one of the signal conductors, a noise voltage will be generated due to the I-R drop in the shield.



$V_{12} = -j\omega M I_S + j\omega L_S I_S + R_S I_S$

Since $M = L_S$ (self inductance)

Then $\boxed{V_{12} = R_S I_S}$

Therefore: Avoid shield being a signal conductor

1. Use shielded twisted pair
2. Use triaxial cables

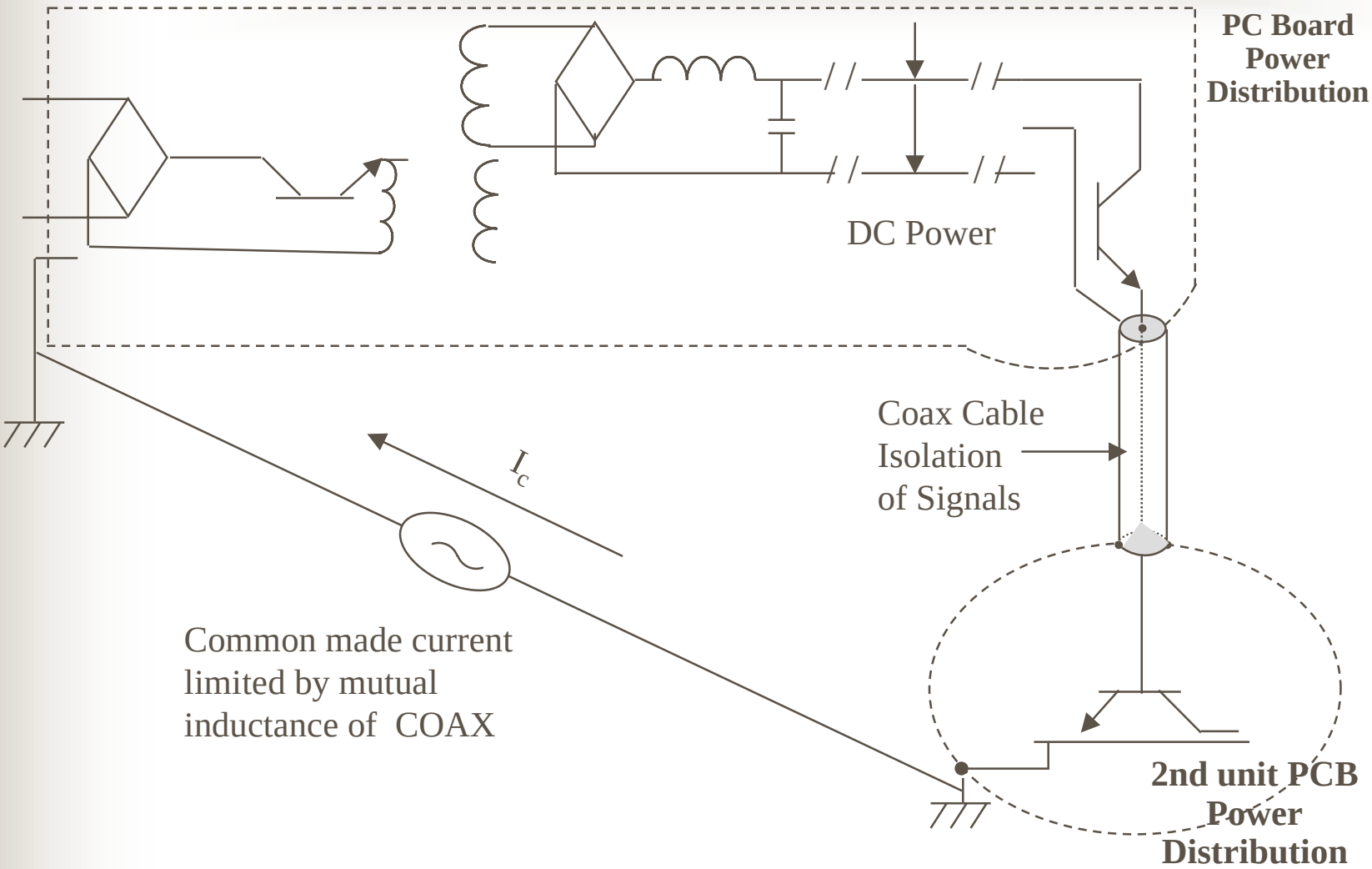
} Low frequency

3. At high frequencies (>1 MHz) coax acts as triax due to skin effects

GROUNDING SCHEMES

- Subdivide as follows:
  - AC power grounding: safety
  - DC power distribution: 3.3V, +5, + 12V, etc.
  - Signal reference
    - Analog
    - Digital
    - Discrete
    - Video
- AC power green/yellow isolated from DC by transformer
- DC power isolated from signal in transmission bandwidth by transmission line effect of interconnect cable (i.e., coax, twisted pair, tri-lead, GSG ribbon cable, or 3M style ground plane ribbon cable

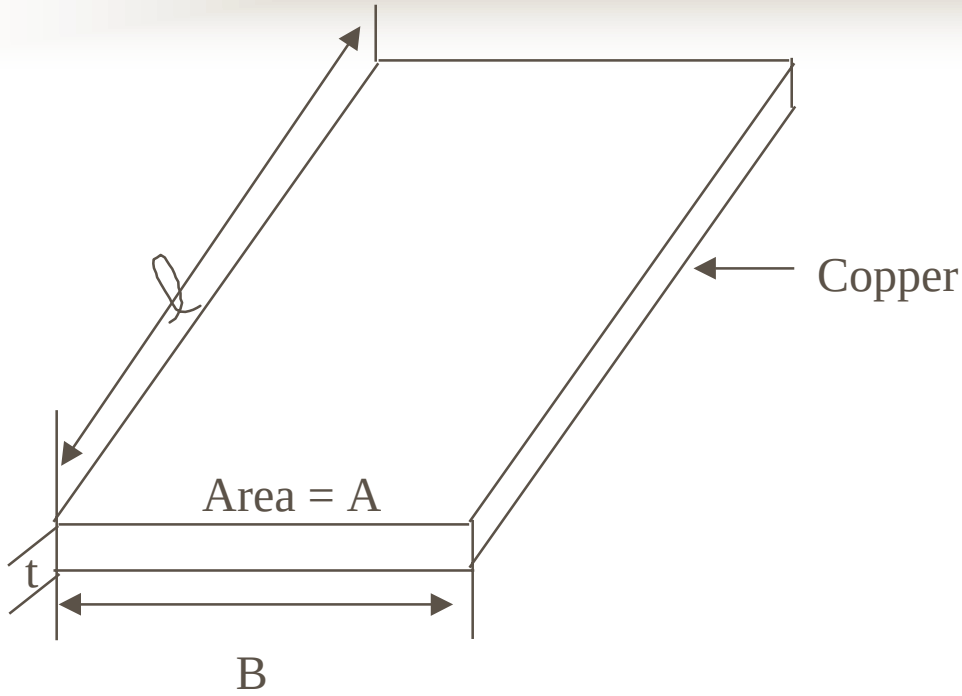
COAX AS GROUND LOOP SUPPRESSOR



COAX AS GROUND LOOP SUPPRESSOR

- This is a schematic of the isolation achievable through the signal cable.
  - The common mode current IC is inhibited by the mutual inductance, hence the isolation quality of the coax signal cable.

GROUND PLANE IMPEDANCE

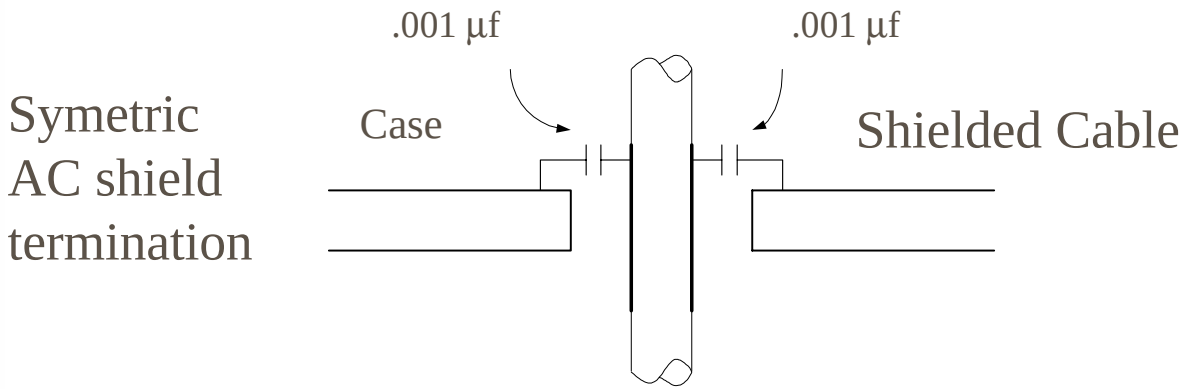


Total Impedance Consists of:

1. DC resistance
2. Inductance effect
3. Skin effect
4. Standing wave impedance (transmission line effect)

CONCLUSIONS

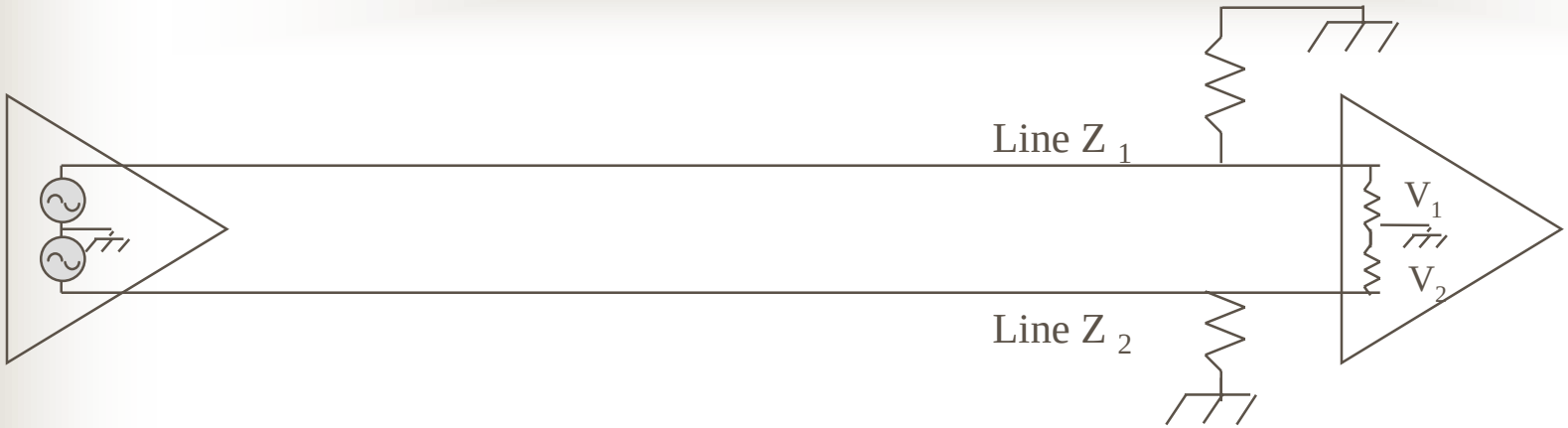
- Single reference ground is the only acceptable scheme
- This creates apparent ground loop problems
- Isolation is required if ground loop is excessive
- All I/O cables routed between shielded equipment enclosures must have outer shield grounded at both ends preferably symmetrically

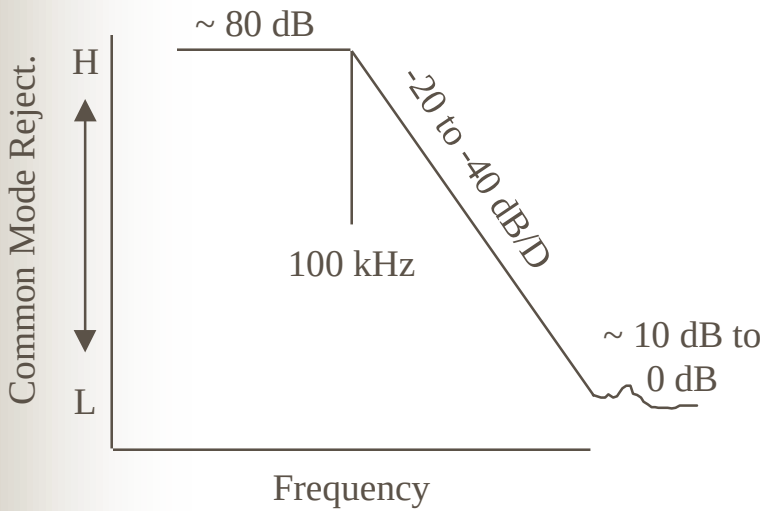


ISOLATION SCHEMES

- Differential Circuits
- Optic Couplers
- Isolation Transformers
- Coax Cables and/or Twisted Shielded Pair
- Fiber Optics
- Except for the last two schemes, the above concepts do not work for controlling emissions or rejecting ESD and E-Field radiation.

DIFFERENTIAL DRIVERS





Good to about 5 MHz (i.e. >20dB).

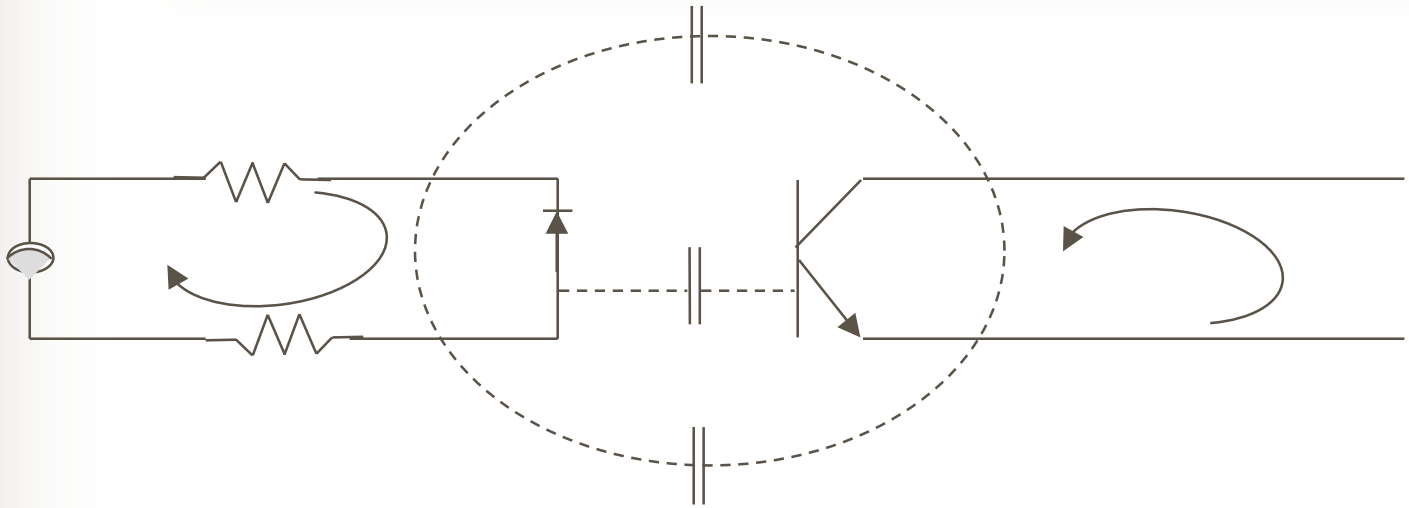
Cause of high frequency common reduction is:

1. Unbalance in common mode Z in high frequency.
2. Unbalance in connectors.
3. Unbalance in twisted pairs in internal route.
4. Unbalance in PC board traces.
5. Unbalance in twisted shielded pairs.

Radiation from differential drivers is 2X single ended drivers (line to ground).

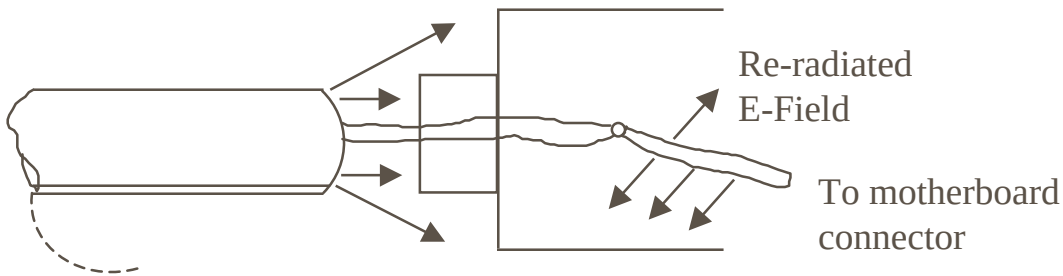
Major external threat is 5-200 MHz range where common mode isolation is least.

OPTIC ISOLATORS

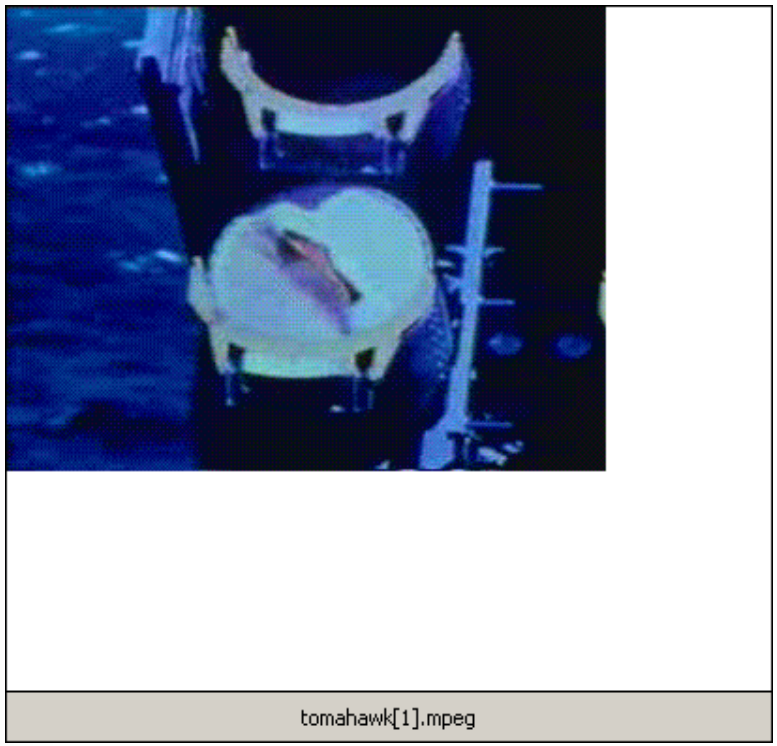


Mutual Couple

1. Isolation limited by harness and connector coupling
2. To work without external cable shield they need to be located within 1.5" of case entry
3. If used, then need separate PC board connectors



Tomahawk Cruise Missile



- Changes allows programming in minutes today
- Future: allow programming in flight
- May need great bandwidth to accomplish