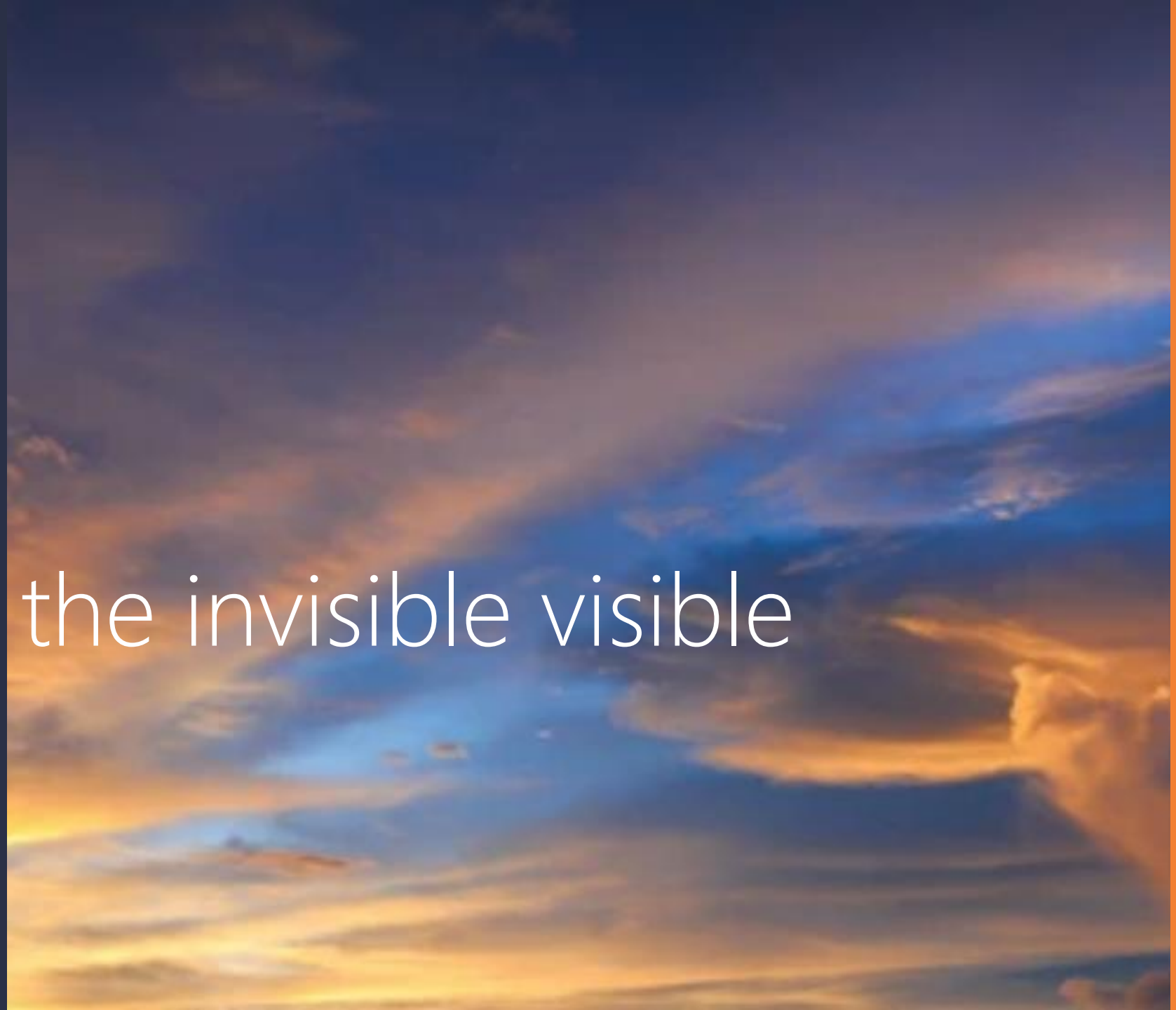
SPECTRUM CONTROL

We make the invisible visible



SPECTRUM CONTROL

The world's leading experts in controlling the electromagnetic spectrum

Our capabilities range from industry-leading EMI protection to advanced RF/microwave signal conditioning and processing. You can rely on our expertise to help you solve your electromagnetic spectrum challenges.

SPECTRUM CONTROL

A rich heritage and possibilities without limits

For more than 70 years Spectrum Control has led the way in developing reliable, high-performance technologies for powering and conditioning RF and microwave signals and protecting electronic equipment from electromagnetic interference. We continue to push out the limits of the possible today, innovating in material science, design, and manufacturing technologies.

SPECTRUM CONTROL

Leadership Team

Betsy Gifford
Chief Human Resources Officer

Ian Dunn
Chief Technology Officer

John Muller
Chief Growth Officer

Michael Armbrecht
Chief Financial Officer

Rich Sorelle
Chief Executive Officer

Focused Product Teams Led by Experts

Product Lines

TRx – High frequency, high-reliability transmit, receive modules for ground, airborne, and space-based AESAs
Lead = David Smith (UK)
Locations = Great Yarmouth, Milton Keynes
Products = TR modules, Hi-Rel Micro-E
NPI = QTRM
Value Proposition = High-frequency, high-rel manufacturing, GMIC expertise

OpenX – Next-gen open, interoperable analog and RF modules, subsystems, and solutions
Lead = Lorne Graves
Location = Frederick
Product Lines = Programmables & Subsystems, Power (PDUs)
NPI = OpenVPX Family of Tuners, Converters, Sources, and direct-to-digital receiver, exciters, AIUs, PDUs
Value Proposition = Unrivaled SWaP-C

RFx – Next-gen digitally-enabled, interoperable RF assemblies and modules
Lead = Jeff Miner
Locations = Delmar, Marlborough, Philadelphia
Products = Amps, Filters, IMAs, Micro-E, SAW
NPI = Switched Filter Bank
Value Proposition = Unrivaled, high-reliability design and manufacturing expertise 0 – 50 GHz

EMx – EMI Protection & Control Components
Lead = Jeff Chereson
Locations = Ann Arbor, Fairview, Frederick, State College, Mexico
Products = Coaxial Filters, Passive Coax, Power Filters & Modules
NPI = Custom connector references
Value Proposition = ceramic capacitor cost /reliability ratio

RELx – Extreme reliability micro-electronics, world-class design and manufacturing expertise
Lead = Dr. Byron Shulver (UK)
Locations = Great Yarmouth
Products = Micro-E design and manufacturing services for extreme reliability challenges
NPI = Optofire
Value Proposition = design, manufacturing, and testing to 250C

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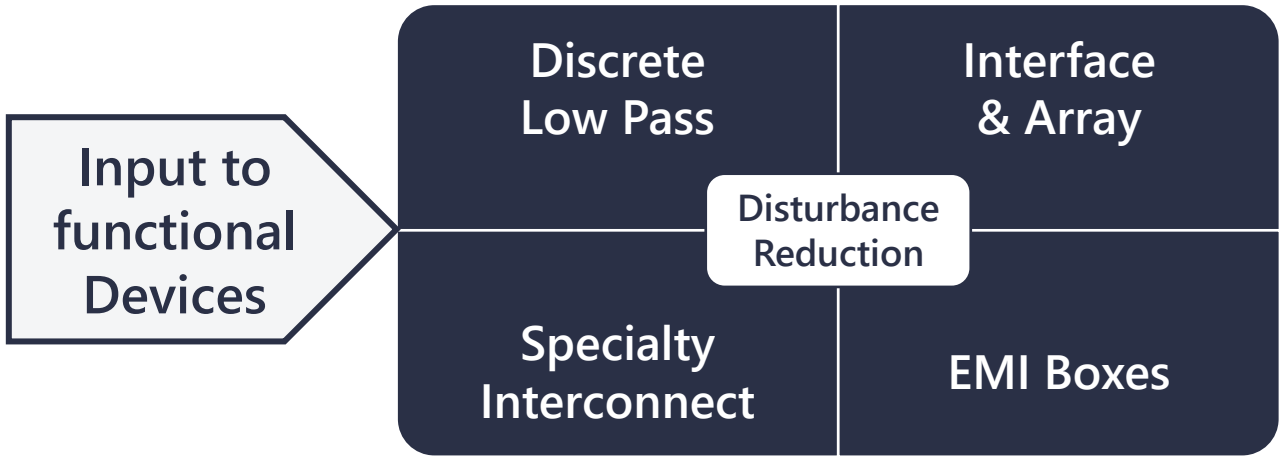
EMx EMI Solutions

Protecting the Electromagnetic Signals…

EMI Protection: conditioning signal and/or power, preventing electro-magnetic disturbances from affecting System performance.

EMC Testing

EMI Solutions



External Signal Disturbances

… that matter most to our Customers

EMx

Electromagnetic Compatibility (EMC)

EMC: the ability of systems, equipment or devices that use electromagnetic energy to operate in their intended environment without suffering unacceptable degradation or causing unacceptable degradation in other devices.

EMC Requires Proper:	Non-compliance Could Result In:
System layout	Poor signal integrity
Filtering	System failure
Shielding and grounding	Putting operators of system at risk

At Spectrum, we use words like **Emissions**, **Immunity**, **Compliance**, these words as the backbone of a company defending systems against EMI, not as a punchline …

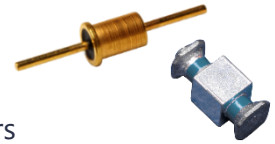
The 10 Commandments provide tools for EMC Compliance

Product Offering: Components

EMx

Board Mount

- Solder-in
- Surface Mount
- Multi-line Surface Mount
- Current Sense Transformers



Panel Mount

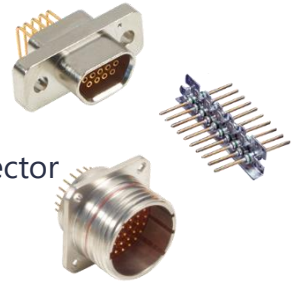
- Resin & Hermetically Sealed
- High Current/Voltage
- AC & DC Single Line FT

Chassis Mount

- Multi-section Catalog
- EMP/HEMP Filters
- Modular Configurable Filter

Interconnects

- Filter Plates & Arrays
- High Performance
- High Density
- 5G D-Sub
- Circular Filtered Connector
- Power Connector
- Rapid Mate Hot Shoe



Passive Coax: Attenuators & Terminations

- Fixed, High-Rel Attenuators
- Manual Step Attenuators
- 2-100W Terminations
- >75 Ohm Terminations
- Conductor Cooled Terminations
- Gain Equalizers

Passive Coax: DC Blocks

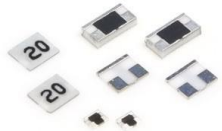
- High Voltage
- Broadband
- DC Blocking Attenuators, Terminations, Connectors
- 7003, 7006-1 DC Block

Passive Coax: Bias Tees

- General Purpose Bias Tees
- High Current Bias Tees
- Pulsed Bias Tees

Powerfilm

- Attenuators
- Resistors
- Terminations



World-Class Manufacturing Expertise

Ceramics, thin-film, thick-film in support of mission critical systems to suppress, eliminate electromagnetic interference and enhance the signal of interest

Safeguarding Mission-Critical Infrastructure

Electromagnetic Environmental Effects [E3] Solutions

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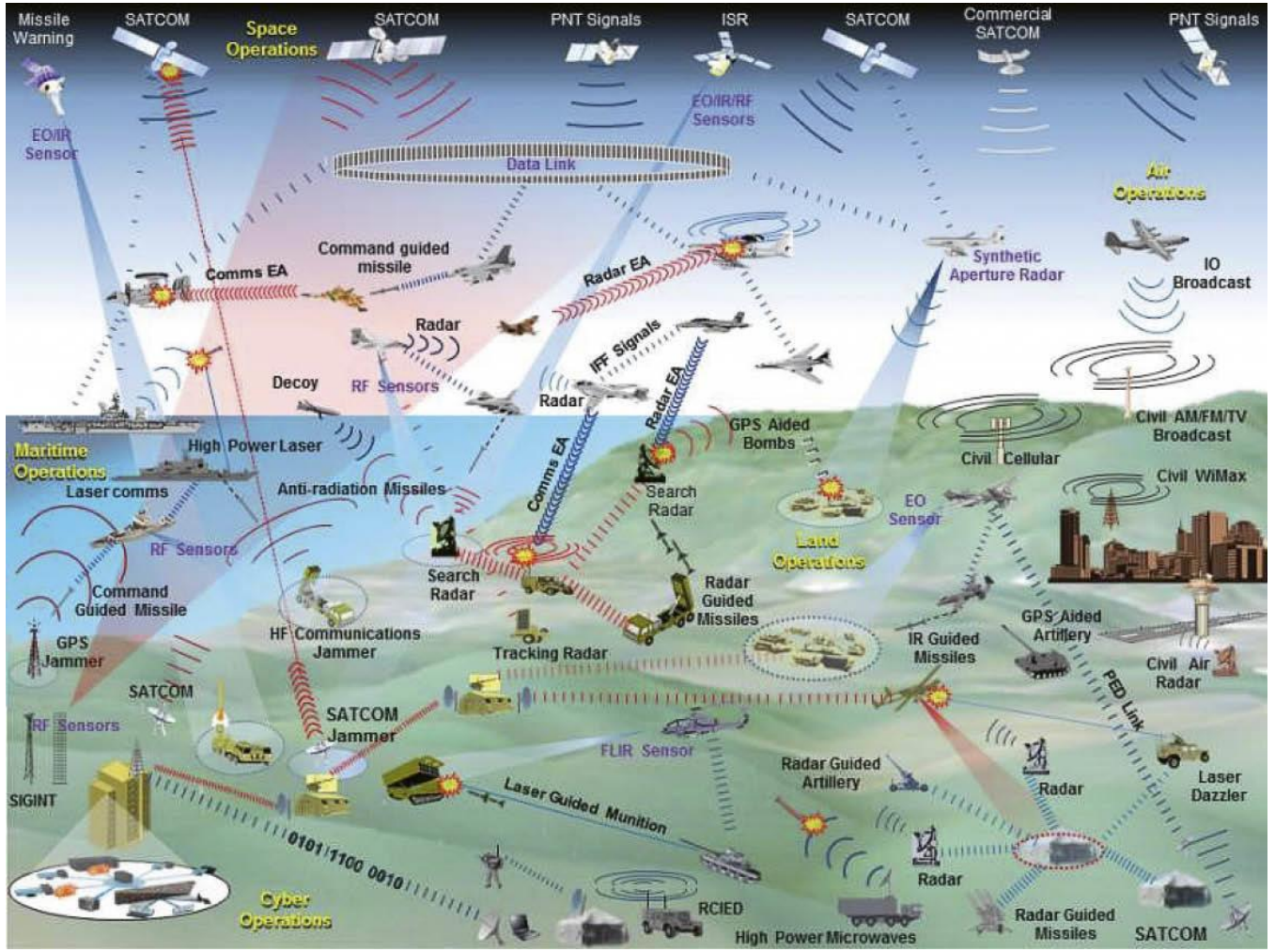
Environment Definitions

- P-static: Precipitation static
- ESD
- Lightning / DO-160
- MIL-STD 461 EMI/EMC
  - Conducted
  - Radiated
  - Broadband filtering
- HERO: Hazardous Electromagnetic Radiation to Ordinance
- HERF: High Energy Radio Frequency Weapon
- EMP/HEMP: Electromagnetic Pulse
- Background EME: Electromagnetic Energy
  - Natural
  - Artificial: telecom/wireless/5G, appliances or system noise
- Spurious Emission: unwanted effects like harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products



Prevent Emissions / Provide Immunity

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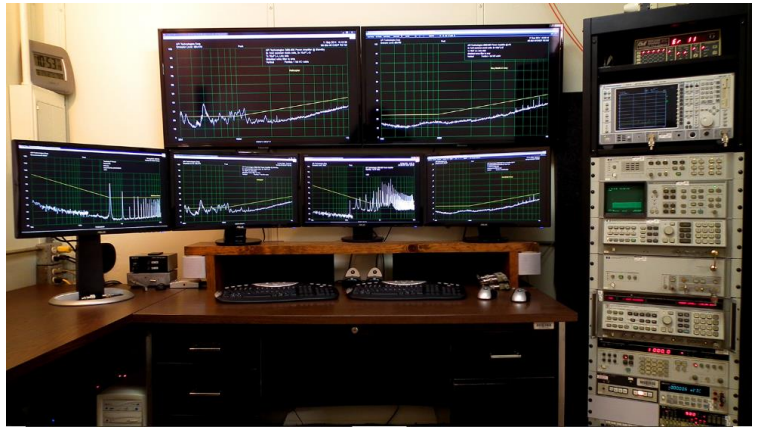
EMC Test & Design

- **Emissions:** measured by connecting a LISN, current probe or antenna to an EMI receiver
  - Desired frequency range is scanned, measuring the amplitude of the signal found
- **Immunity:** performed by connecting a LISN, current probe, or antenna to an RF amplifier instead of a receiver
  - Test is injecting instead of detecting, scanning the device under test for a response to energy being injected
- **Conducted:** measured directly through the wires and cables
- **Radiated:** measured via antenna



Immunity: Verifies the performance of a device when subjected to known high values of EMI

Emissions: The measure of amplitude and frequency of EMI generated by a device

EMC Test & Design

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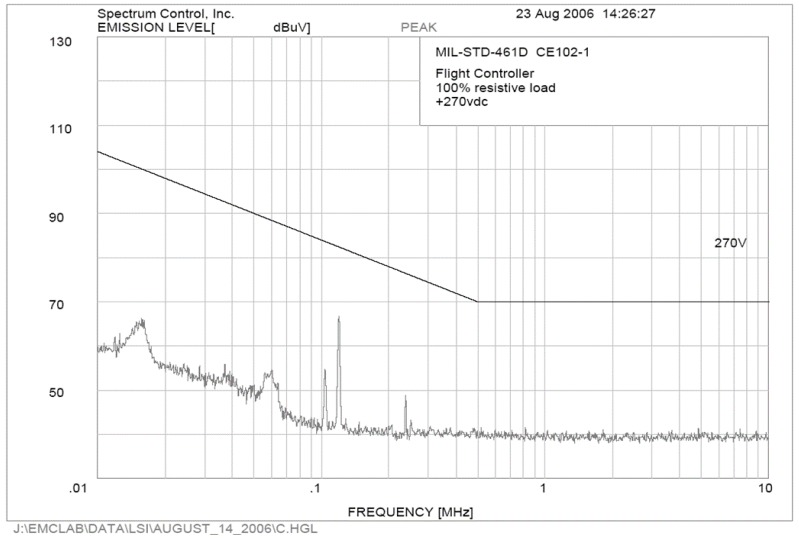
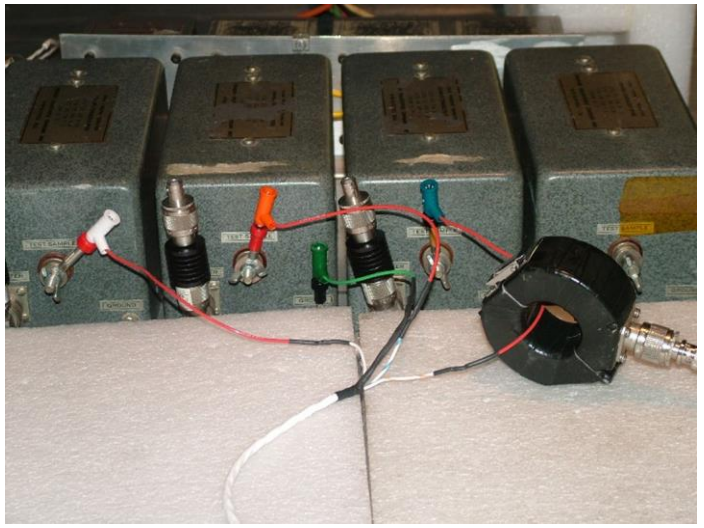
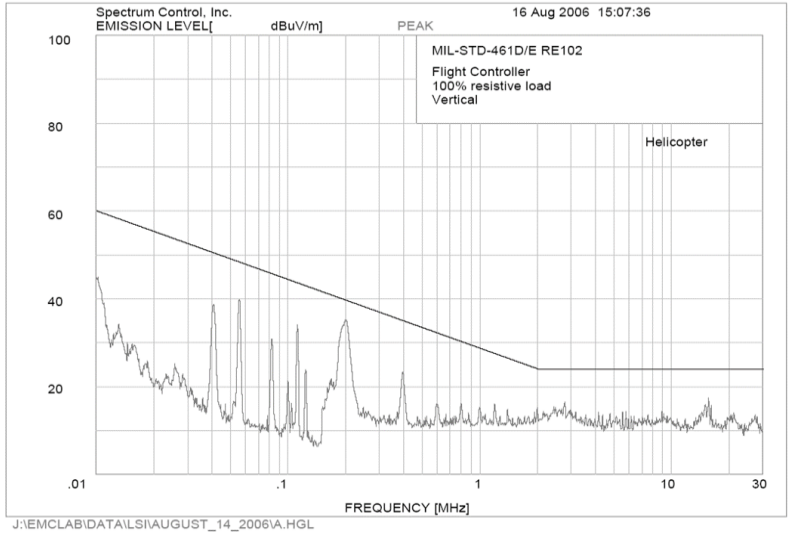
Conducted Emissions Test





Radiated Emissions Test



Noise Sources

Customer Noise Exposure / Emanation

Frequency Spectrum of Solutions

Frequency (MHz)-> / Source	Application	.001	.005	.01	.05	.1	.5	1	5	10	50	100	500	1000	5000	10000	20000
Connectivity	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O		
Power Harmonics	X	O	O	O	O	O											
Transient Energy	X			O	O	O	O	O	O	O	O	O	O	O			
Motor Noise	X			O	O	O	O	O	O	O	O	O	O	O	O	O	
Tempest Data				O	O	O	O	O	O	O	O	O	O	O	O	O	
Power Sources	X				O	O	O	O	O	O	O	O	O				
Transmitters	X					O	O	O	O	O	O	O	O	O	O	O	O
Digital Noise	X						O	O	O	O	O	O	O	O	O		

Symbol	Detail
X	Customer Application
O	Spectrum Control Solution

- What is cause, amplitude, frequency of disturbance needing a low pass filter?
- What real estate is available?
- What interface is required?
- What are power requirements?
- What is use environment?

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Emission Sources

Common Contributors

- **Switch mode power supplies:** with typical operating frequencies between 20kHz and 2MHz, types of power supplies dominate the telecom industry
- **Computer or digital circuits:** the latest computers operate above 3GHz, but most lines in and out of the main board operate between 10kHz and 500MHz
- **Brushed DC motors:** generate broadband EMI from a few kHz to well beyond 1000MHz

Foxworthy Engineering:

- If you have a switching power supply …
  - You might need a filter.
- If you have processor or digital circuit …
  - You might need a filter.
- If you have a motor or actuator …
  - You might need a filter.

Passing emissions is no guarantee a device will pass immunity and vice versa

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Immunity

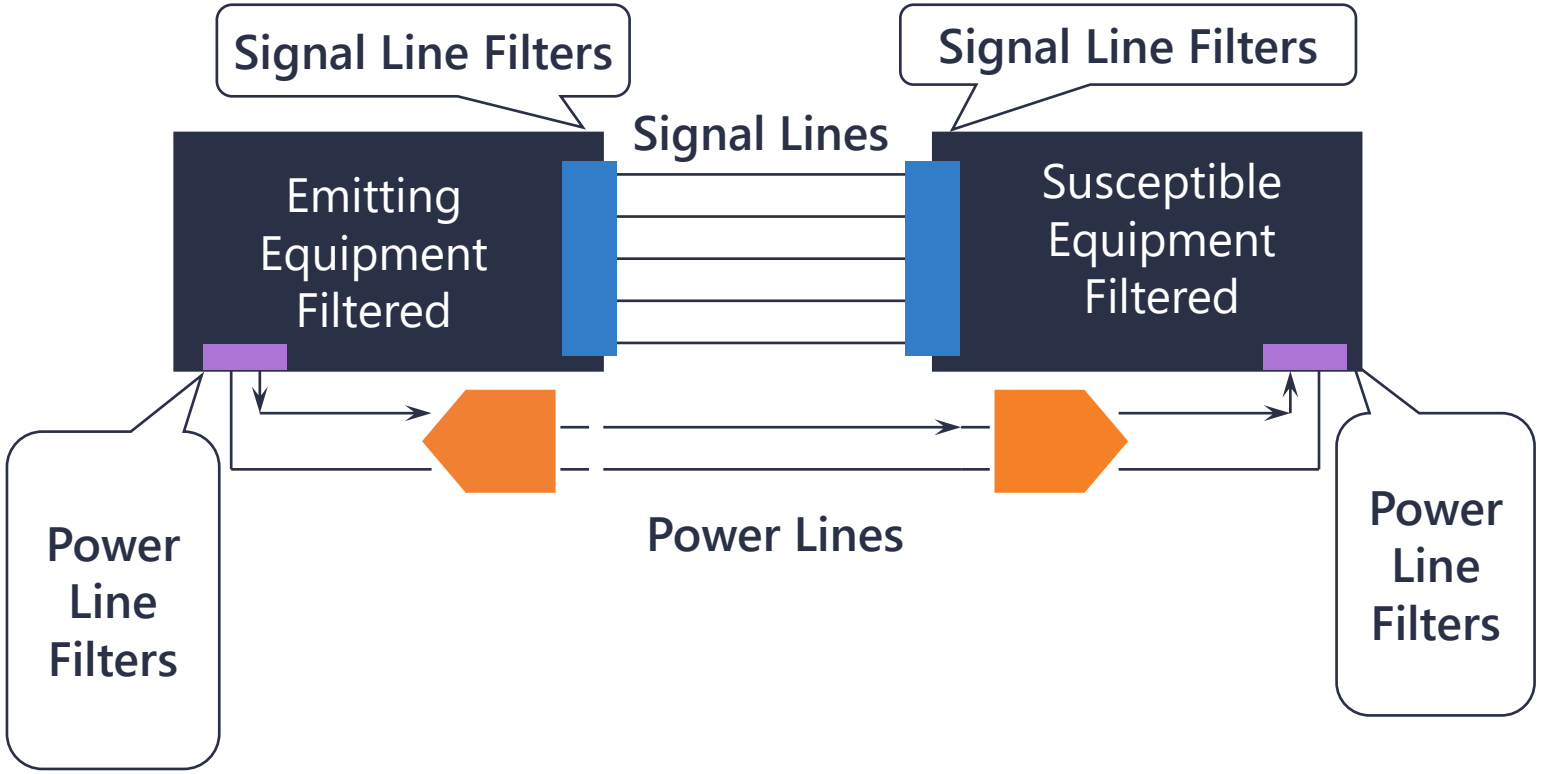
Sensitive Circuits

- **Sensors and sensor inputs:** temperature, pressure, vibration, position, humidity, gas analyzers, voltage and current monitoring circuits, etc.
  - These devices usually contain or feed operational amplifiers which are very sensitive to external RF transmitters
  - Sensor inputs rarely have emissions issues
- **Digital electronics:** usually handle higher levels of EMI than sensors but still have problems when used near RF transmitters greater than 10 watts. Some circuits have trouble passing emissions and immunity.
- **Switch mode power supplies and brushed DC motors:** rarely exhibit immunity failures

Passing emissions is no guarantee a device will pass immunity and vice versa

Mission Critical Equipment in an EMI Environment

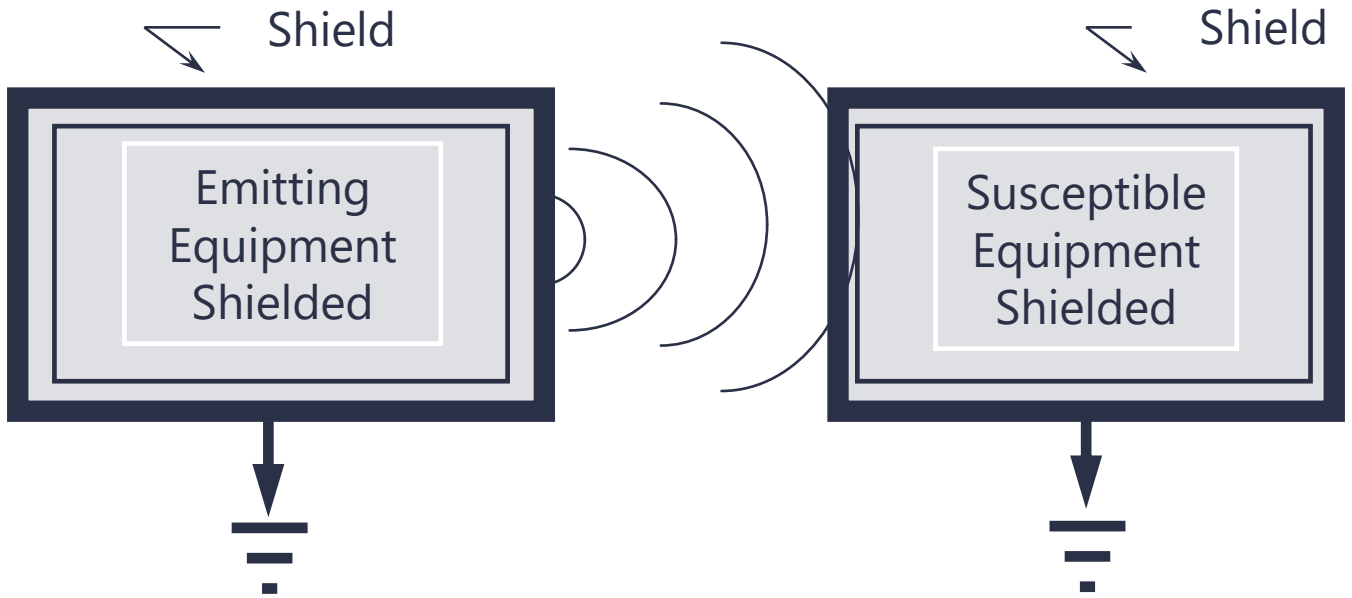
- Conducted Emissions
- Conducted Immunity [Susceptibility]



EMI: electromagnetic disturbances that affects system performance

Mission Critical Equipment in an EMI Environment

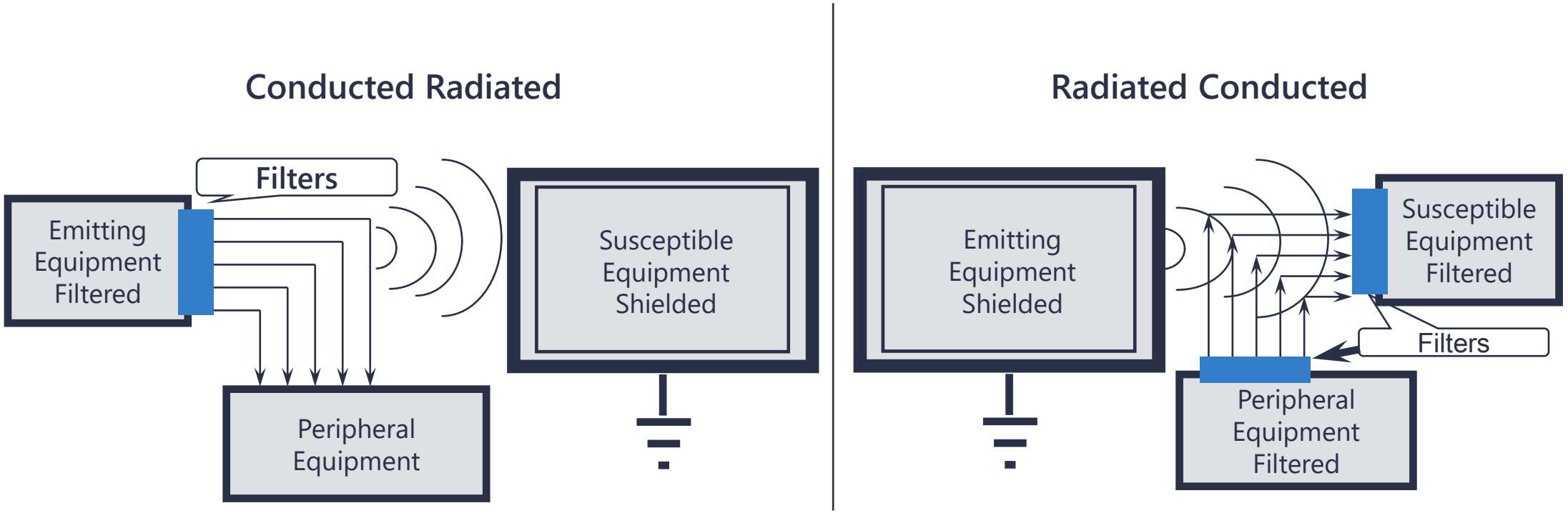
- Radiated Emissions
- Radiated Immunity [Susceptibility]



EMI: electromagnetic disturbances that affects system performance

Mission Critical Equipment in an EMI Environment

- Hybrid sources
- Conducted radiated and radiated conducted
- Filter and shield



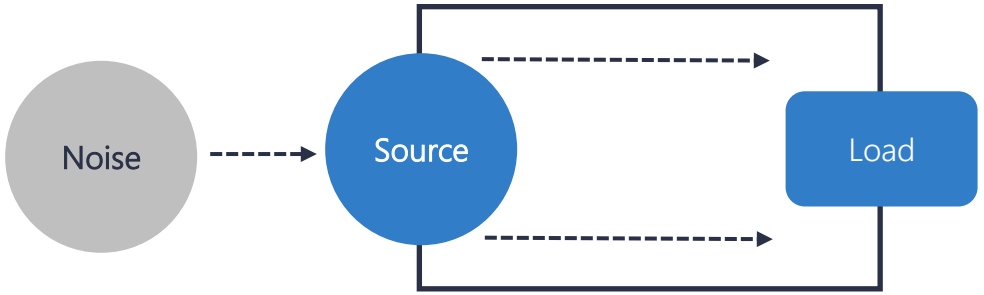
EMI: electromagnetic disturbances that affects system performance

Noise Types

Dual Line Filter

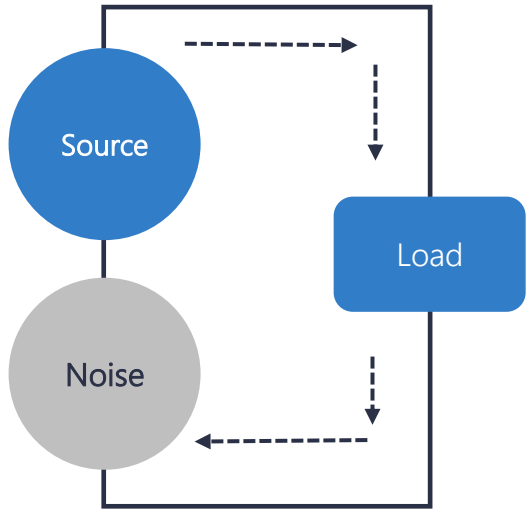
Common Mode

- Signal or noise that flow in the same direction on a pair of lines
- Typical sources
  - Stray parasitics
  - Radiated energy
- Typical fixes
  - Feedthrough capacitors (coaxial)
  - Common mode chokes



Differential Mode

- Signal or noise that flows in opposite directions on a pair of lines
- Typical sources
  - Power line harmonic noise
  - Noise source in proximity to one line (vs both)
- Typical fixes
  - Series differential components
  - Across line capacitance



EMI: electromagnetic disturbances that affects system performance

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10 Commandments of EMC Design

1. Know your EMI profile and specifications you need to meet
2. Filter at immediate entry point to system
3. Design filter for I/O and signal lines with response tailored to the application
4. Match and balance system impedances
5. Shielding: shield noise emitting or noise susceptible modules and devices, modules, circuit boards, interfaces (ground layer)
6. Grounding: provide adequate grounding to boards and modules including multilayer board ground planes to isolate power from signal circuits for EMI paths. Material surface finishes and plating's designed for low resistivity: 3milli-ohm / sq cm.
7. Ferrite cores for common mode emissions around input power, signal, coaxial lines, etc. for common mode emissions
8. Twisted pairs at 18 turns / foot to minimize magnetic pick-up
9. Keep all apertures to less that lambda/20
10. Use correct transient suppressors for transient speed, power, and parasitics

Electromagnetic compliance requires filtering, shielding/grounding & system layout disciplines

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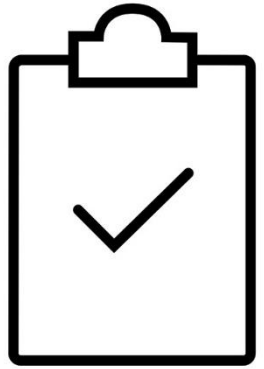
#1 - Noise Profile & Specifications

Know your EMI profile and specifications you need to meet

Governing Specifications

Geography	Specification	Industry
North America	MIL-STD-461	Military
North America	DO-160	Aviation
North America	FDA	Medical
North America	FCC	Telecom
North America	CISPR 25	Automotive
International	EU Directive 89/336/EEC	Residential/Industrial
International	UK MOD	Military/Aerospace



MIL-STD-461E Test Plan Scenario

#	Test	Type	Frequency Range
1	CE102	Conducted Emissions	10KHz – 10MHz
2	RE102	Radiated Emissions	10KHz – 18GHz
3	CS114	Conducted Susceptibility	10KHz – 200MHz
4	RS103	Radiated Susceptibility	10Khz – 40GHz

#2 - Filter Placement

Filter at immediate entry point to system

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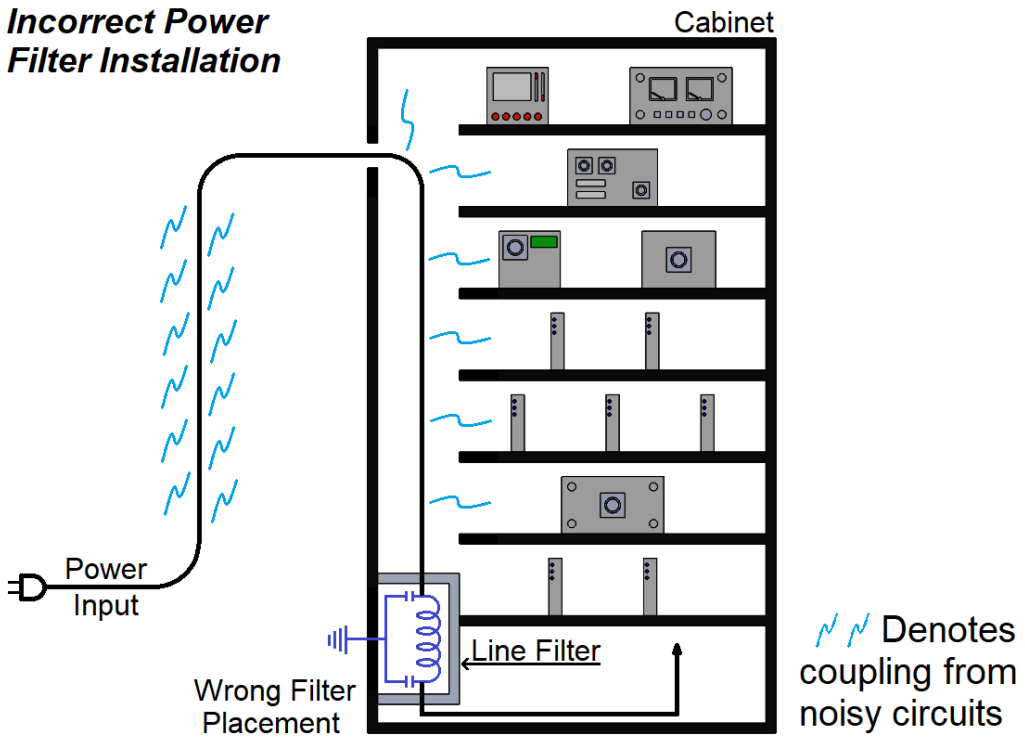

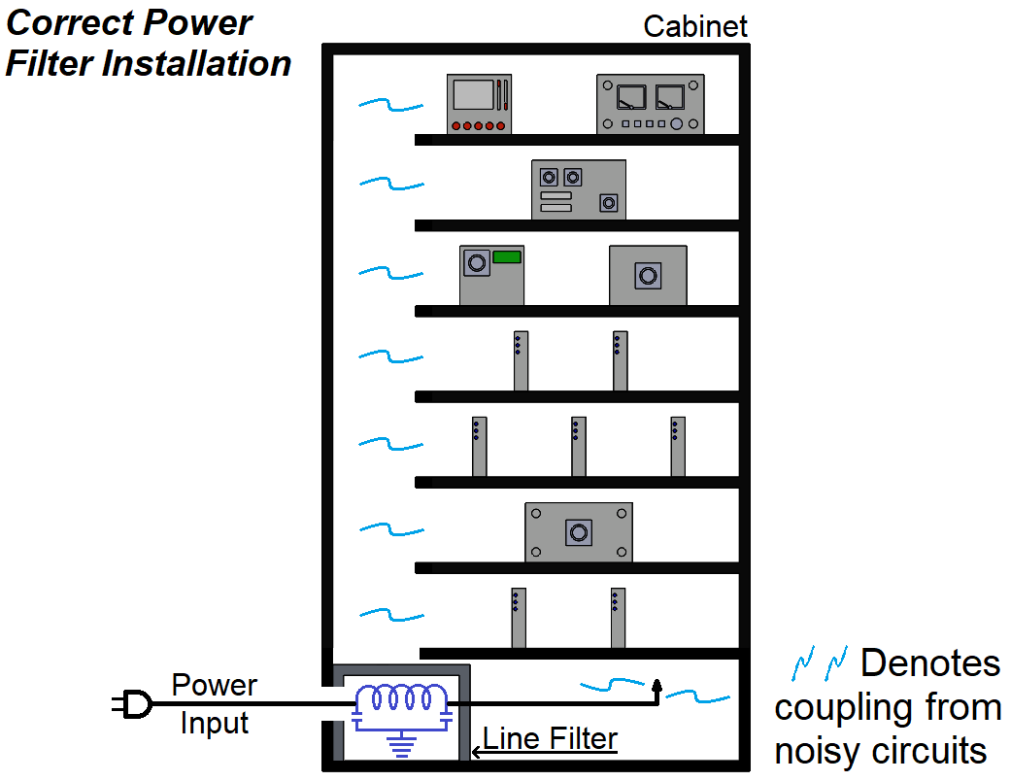

#3 - Filter Design & Selection

Design filter for I/O and signal lines with response tailored to the application

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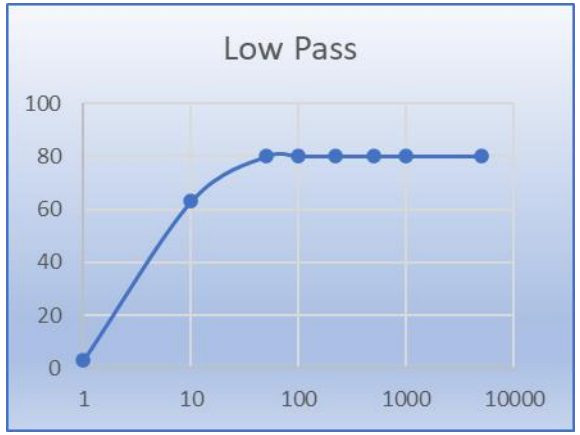
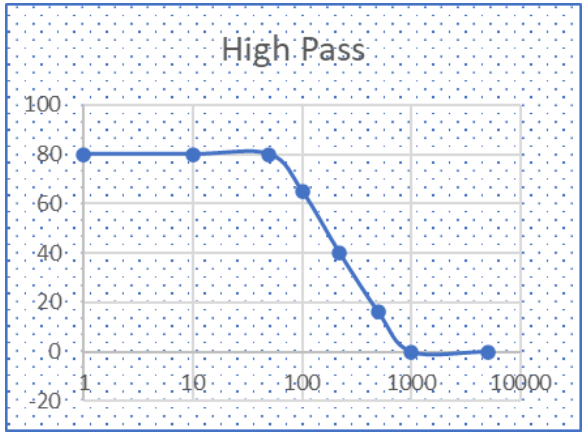
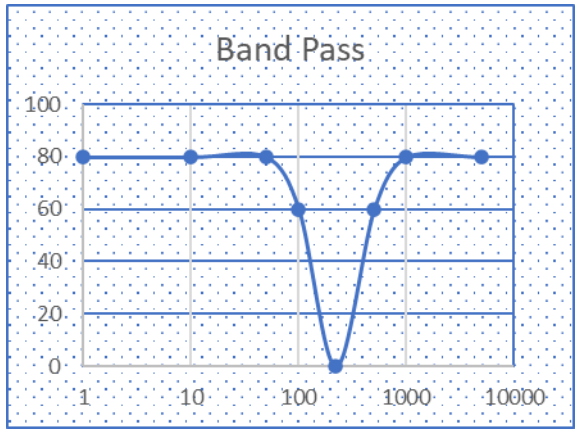
- Low Pass Filters are the most common filter type to solve EMC issues
- Harmonics:
  - Cause almost all EMC emissions problems
  - Switch mode power supplies, computer/digital circuits and DC brushed motors all generate harmonics.
  - The 3rd, 5th, 7th odd harmonics are the hardest to filter. They are highest in energy and are closest to the fundamental frequency

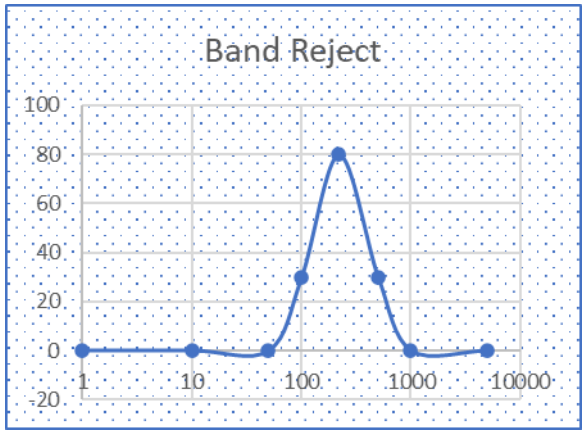
Frequency [MHz]	Harmonic	High energy Harmonics
4	1	Fundamental
8	2	
12	3	X
16	4	
20	5	X
24	6	
28	7	X
32	8	
36	9	
4000	1000	

Filter Types









#3 - Filter Design: Insertion Loss

Design filter for I/O and signal lines with response tailored to the application

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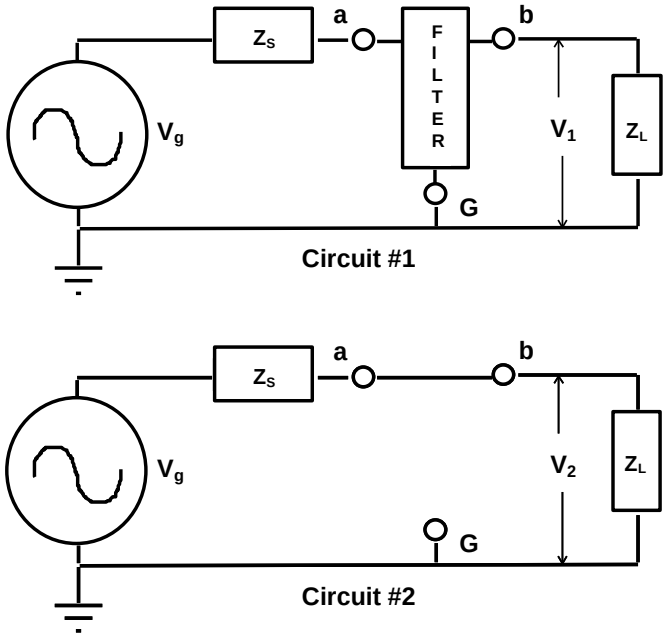
IL is the ratio of output Voltage before and after insertion of a filter

Per MIL-STD-220:

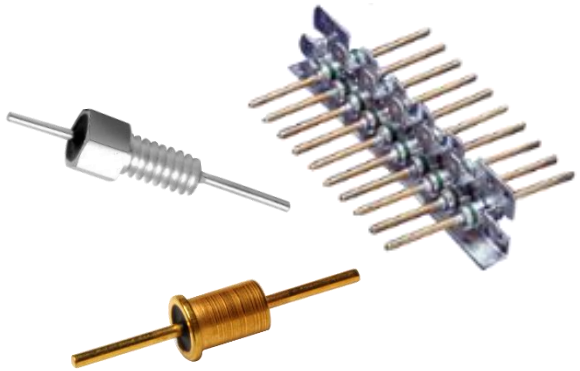
- ILdB = 20 Log (V1/V2)
- Using S-Parameters:
  ILdB = 20 Log Mag(S21)

(Where ZS = ZL = 50 Ohms)



IL (dB)	Voltage Ratio
100	1:100,000
80	1:10,000
60	1:1000
40	1:100
20	1:10
6	1:2
3	1:1.1414
1	1:1

3dB is termed cut-off or half power, or where V1=[V2]/1.414



When specifying IL, 80 dB is still the practical output from an RF test set-up

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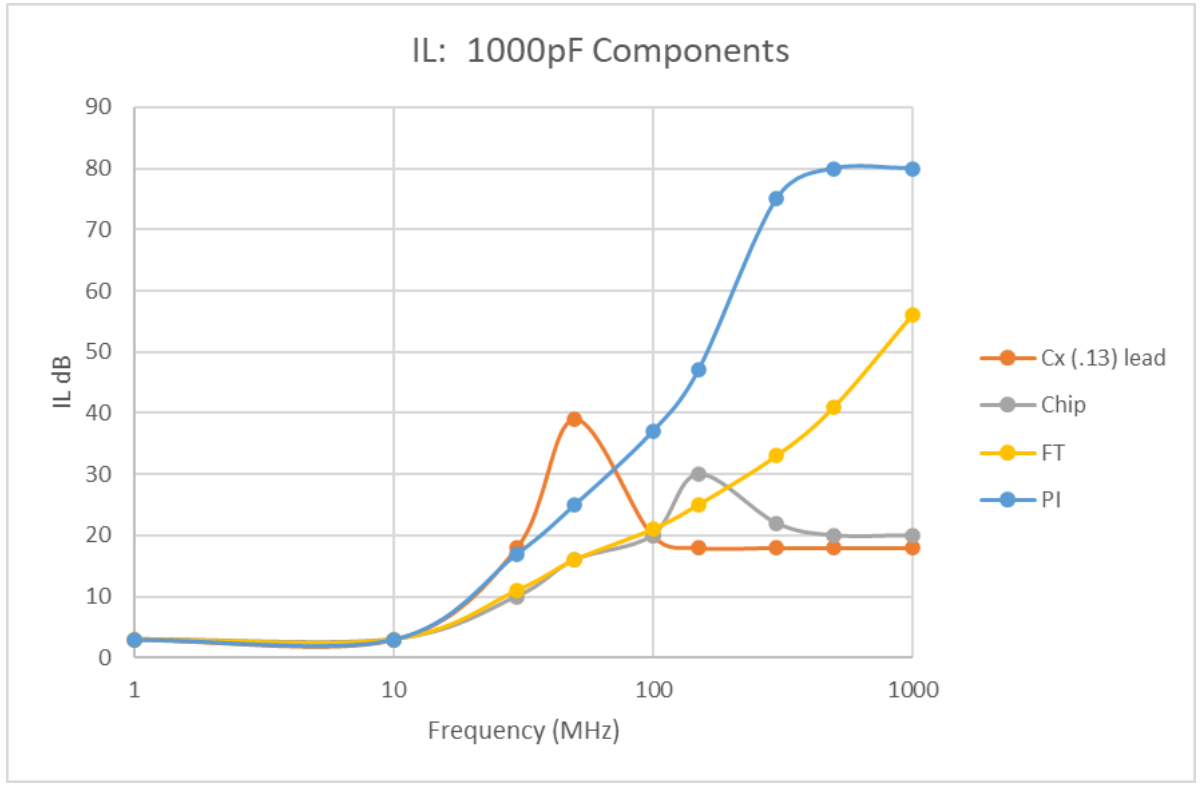
#3 - Filter Design & Performance

Design filter for I/O and signal lines with response tailored to the application

- Solutions curve comparison
  - 50-ohm source
  - 50-ohm load
- Coaxial Pi
- Coaxial feedthrough "C"
- Chip capacitor
- Leaded capacitor



The slope of the coaxial Pi filter and coaxial feedthrough filter perform similar to "pure" simulated model.

Filter Selection includes construction in addition to circuit design

#3 - Filter Design & Selection

Design filter for I/O and signal lines with response tailored to the application

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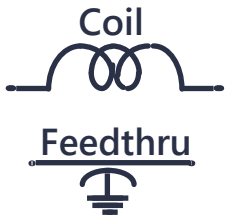
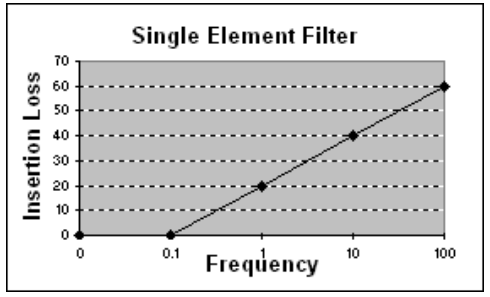
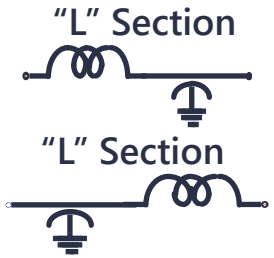
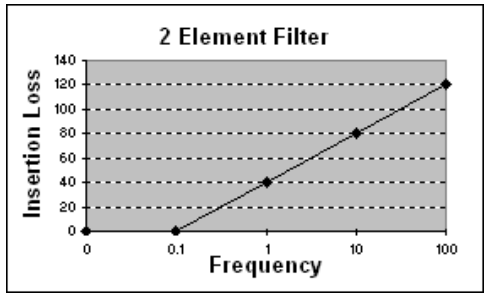
Different types of Low Pass Filters



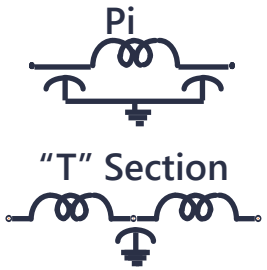


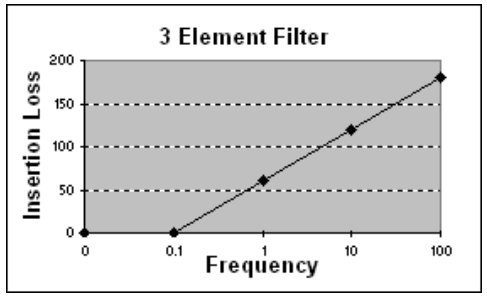
20 dB per Decade





40 dB per Decade





60 dB per Decade

Slope = n x 20 dB/dec

Type	"n"	Slope dB/dec	
C	1	20	
L	2	40	Directional
Pi	3	60	
T	3	60	
Double L	4	80	Directional
Double Pi	5	100	
Double T	5	100	

#4 - Impedance Matching & Balancing

Match and balance system impedances

Common Design Considerations

- Low impedance looking into high impedance
- High impedance looking into low impedance
- Impedance balancing on differential pairs
  - Balance pairs to avoid creating additional differential issues from common mode interference
- Impedance of high-speed digital signals
  - Can't filter in traditional methods – signal / integrity distortion
  - Example: Ethernet, USB, HDMI
  - Common mode ferrite sleeve – post design

Input Impedance (Zi)	Output Impedance (Zo)		
		High	Low
	High	Feedthru Pi Double Pi	"L" Section 2 X "L" Section
	Low	"L" Section 2 X "L" Section	Coil "T" Section Double "T"

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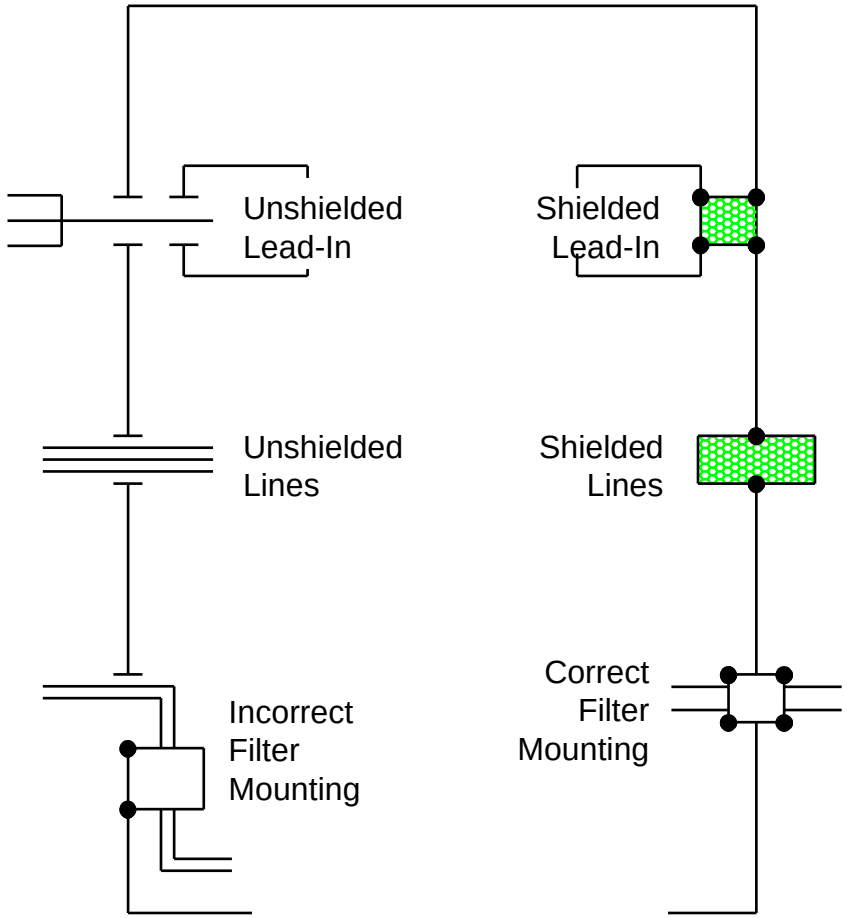
#5 – Shielding

Shield noise emitting or noise susceptible modules and devices, modules, circuit boards, interfaces (ground layer)

Cabling Scenarios



Improper

Proper

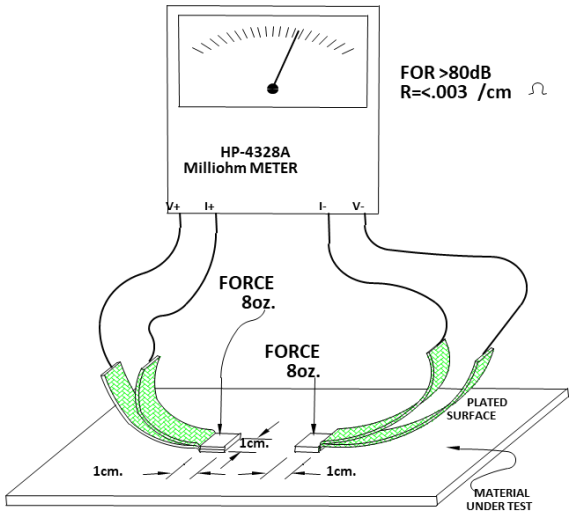
Other Common Mistakes

- Insulated wire passing ungrounded through chassis
- Shielded wire passing through chassis ungrounded
- Ground on outside of chassis then passing through chassis

#6 - Grounding & Surface Conductivity

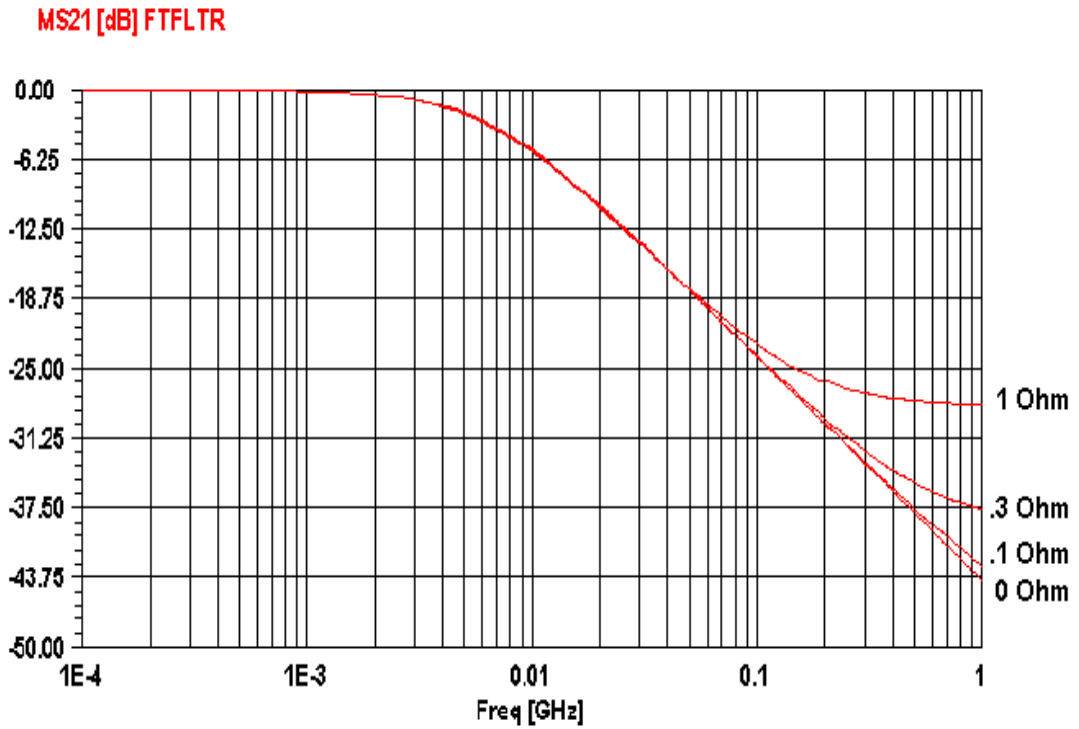
Provide adequate grounding to boards and modules including multilayer board ground planes to isolate power from signal circuits for EMI paths. Material surface finishes and plating's designed for low resistivity: 3milli-ohm / sq cm.

Ground Resistance of Platings



PLATING	8oz. Milliohms					
TIN	.75	.77	.71	.8	.74	
YELLOW CHROMATE	17	11	7	10	12	11
UNPLATED EDGE	1.6	1.8	2.0	2.2	1.7	1.8

IL vs Ground Resistance: 1000pF filter

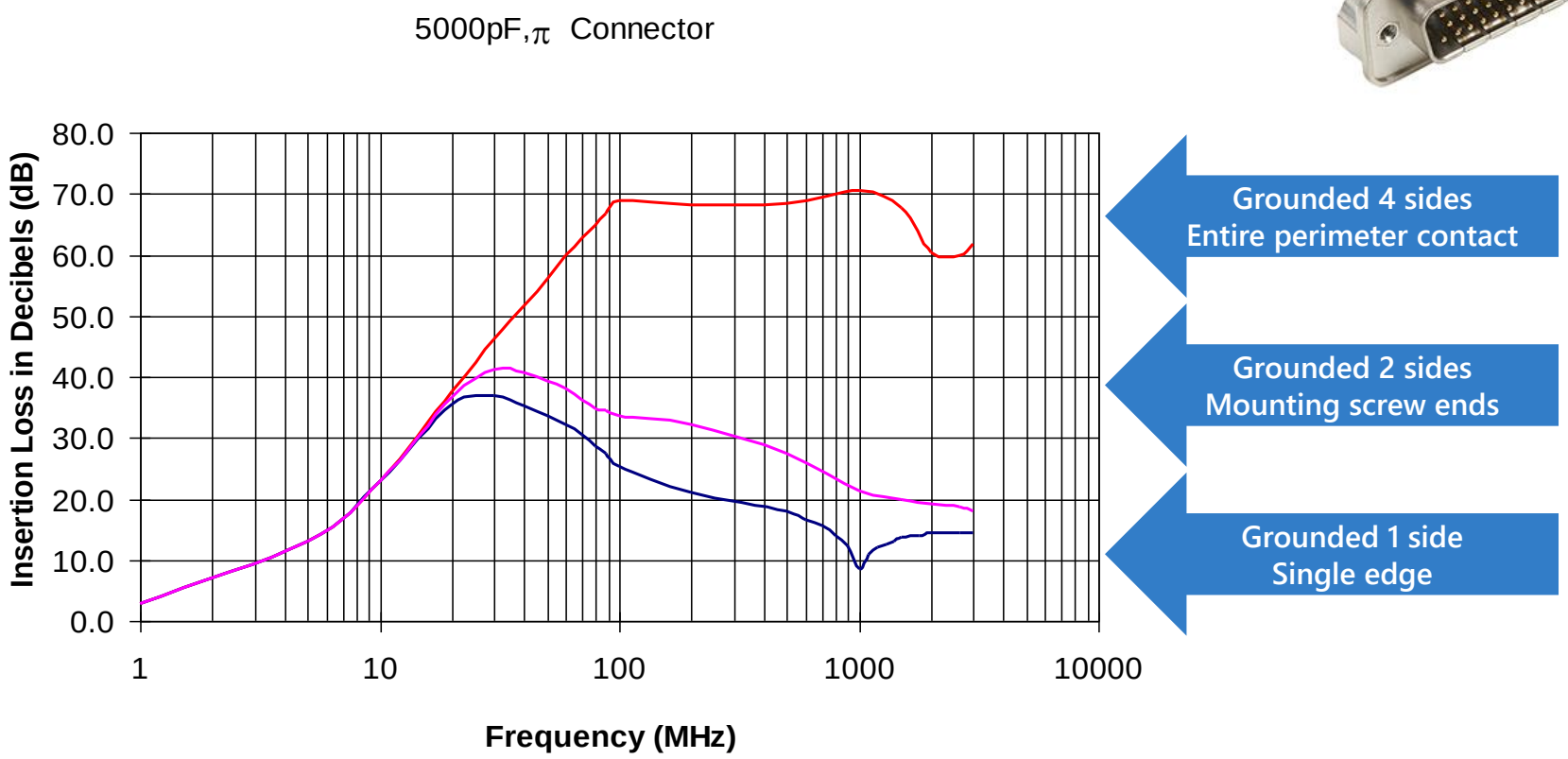


Surface material selection is important

#6 - Grounding Effects

Provide adequate grounding to boards and modules including multilayer board ground planes to isolate power from signal circuits for EMI paths. Material surface finishes and plating's designed for low resistivity: 3milli-ohm / sq cm.

Filtered Connector Grounding Scenarios



Even with proper filter placement interface grounding is important

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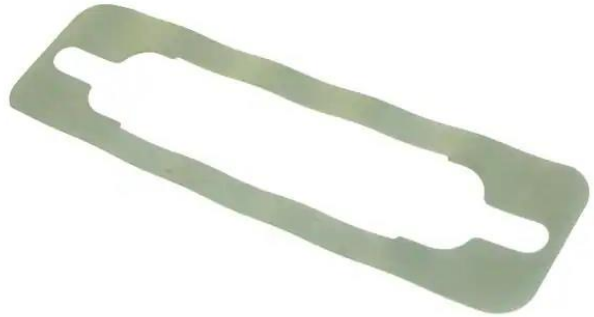
#6 - Grounding & Shielding Notes

Provide adequate grounding to boards and modules including multilayer board ground planes to isolate power from signal circuits for EMI paths. Material surface finishes and plating's designed for low resistivity: 3milli-ohm / sq cm.

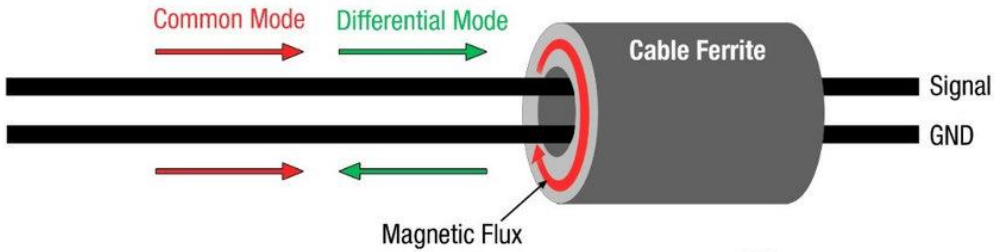
- Add ground plane on multi-layer boards to isolate digital from power circuits
- Isolate signal grounds from power grounds
- Avoid long ground connections and traces to avoid ground loops
- Provide as many points of contact to substantial ground planes
- External power returns with dedicated wiring *[Avoid power return through chassis]*
- Separate Input and Output (I/O) cables to avoid coupling *[Bundling]*
- Avoid combining I/O and power in same connector

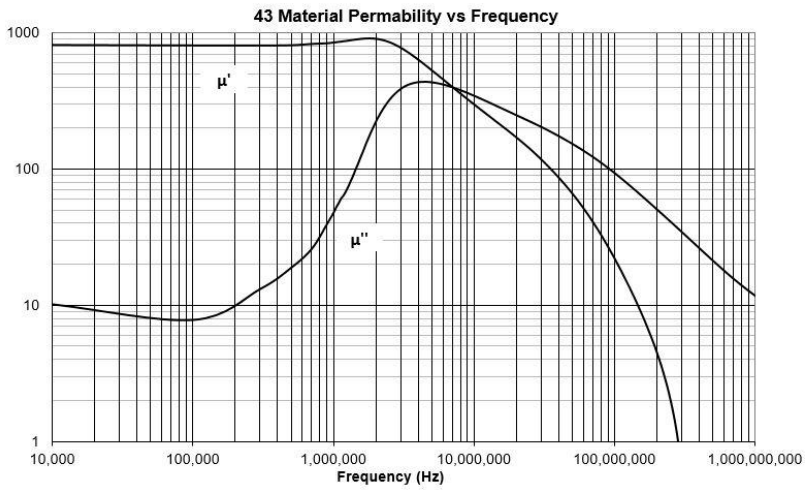


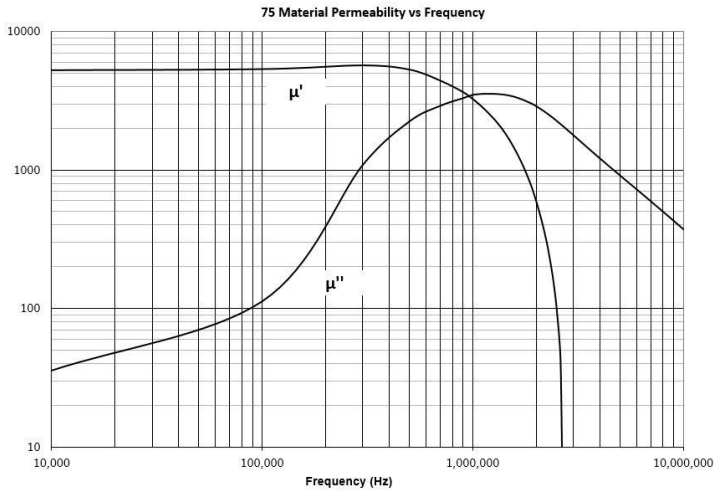
#7 - Common Mode Technique: Ferrite Beads

Ferrite cores for common mode emissions around input power, signal, coaxial lines, etc. for common mode emissions

- Ferrite beads / sleeves
- Most commonly applied in a common mode configuration
- Ferrite materials have a Real and Loss component (complex permeability u")
- Loss component is beneficial at frequencies above cross over in EMC applications







Ferrite Beads work best in common mode configuration

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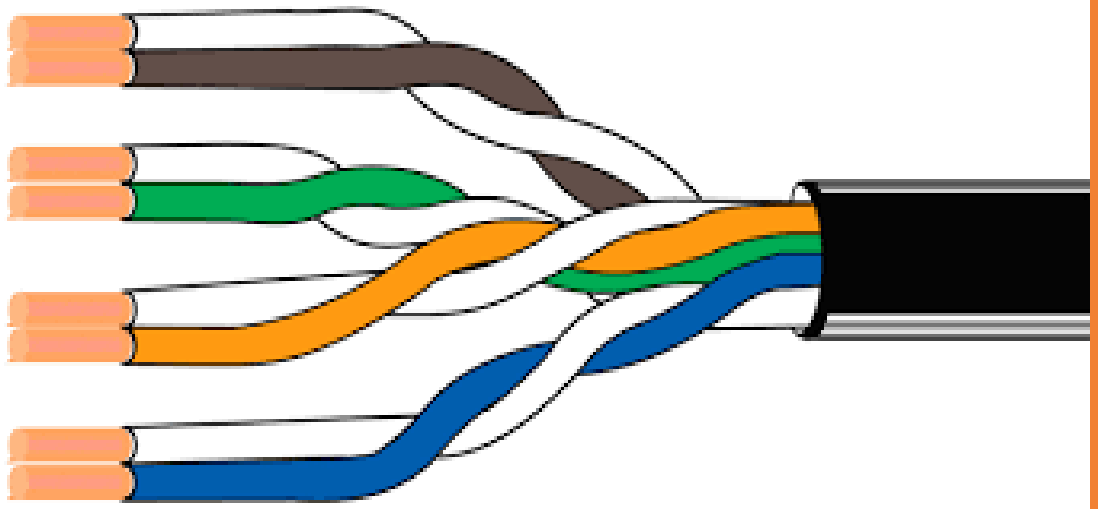
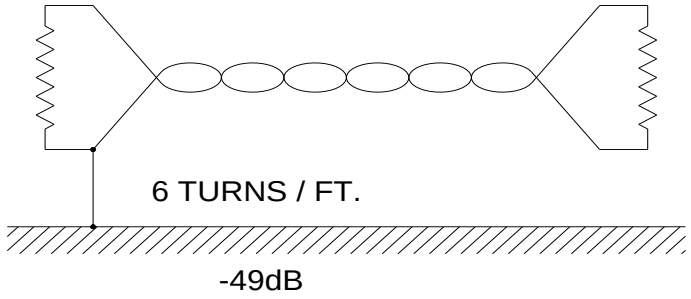
#8 - Common Mode Technique: Twisted Pair

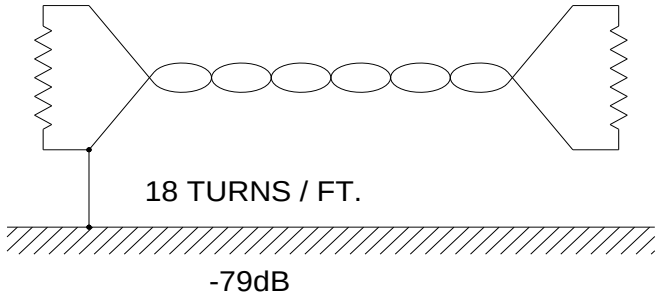
Twisted pairs at 18 turns / foot to minimize magnetic pick-up

Twisted Pairs

- Field Cancellation
- Differential Voltage: same on both wires
- Dielectric Constant: changes with tighter twist
- Field cancellation & cross talk reduction
- Better isolation from outside influences
- Makes wire equal distance from noise source
- Reduced dielectric losses



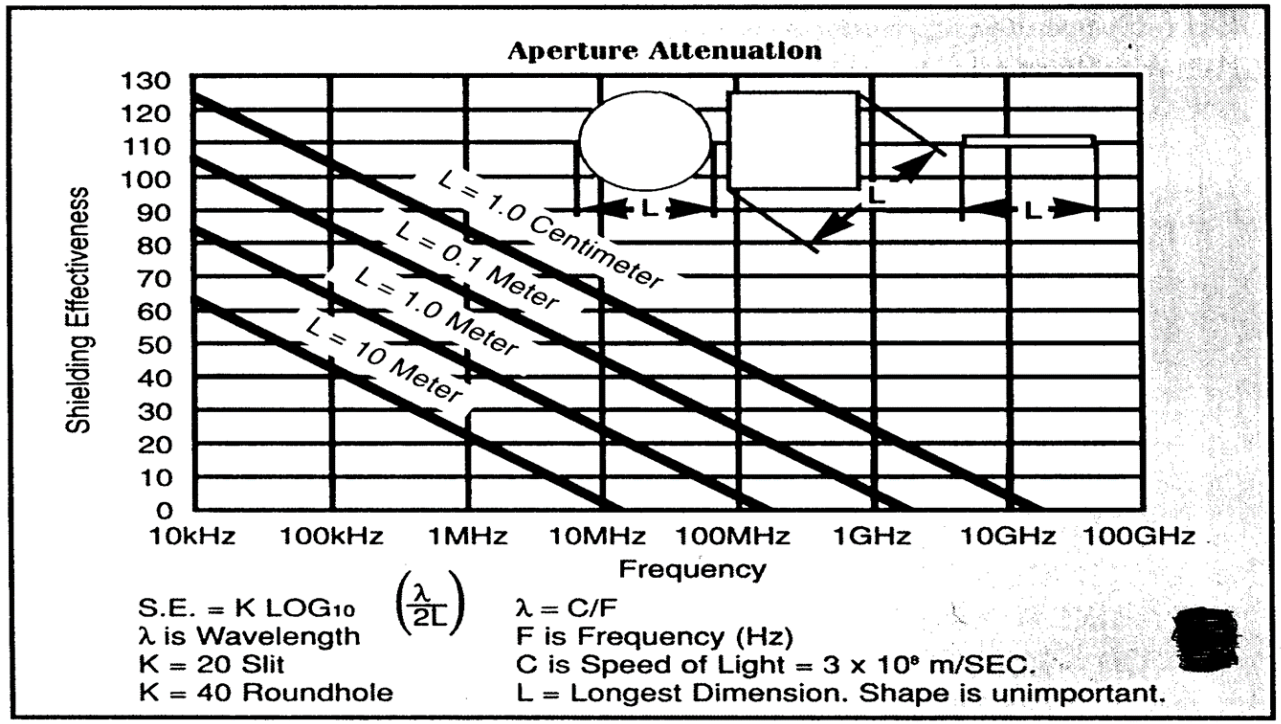


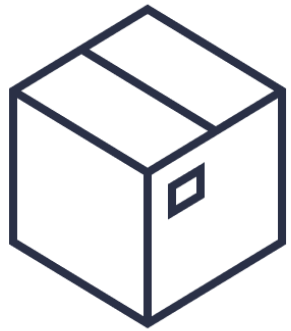


#9 - Openings & Apertures

Keep all apertures to less that lambda/20

Aperture Design & Chassis Openings Survey





Frequency	Maximum gap
120MHz	4.92 inch
600MHz	0.98 inch
1.5GHz	0.394 inch
3GHz	0.197 inch

Equation:
[(3x10^8)*39.4] / (f) = lambda
Lambda / 20 = aperture max.
Simplified 591/f(MHz) = aperture max. inches

Depending on frequency of operation, openings in chassis affect EMC compliance

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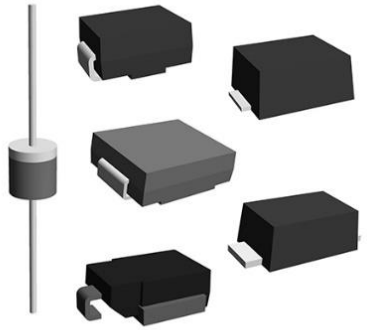
#10 – Transients

Use correct transient suppressors for transient speed, power, and parasitics

- Use correct suppressor for application
- Common types of transients
  - ESD
  - Lightning
  - EMP/HEMP

GDT

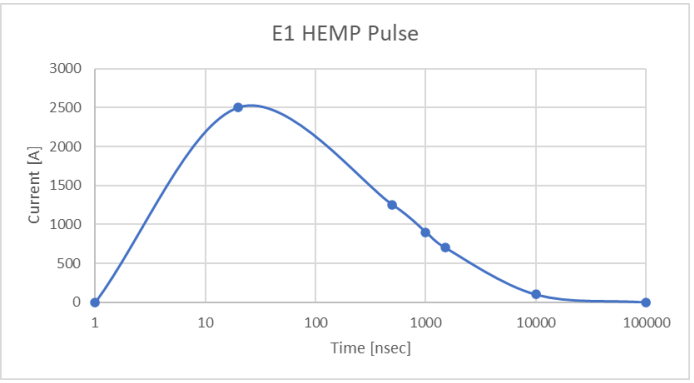
MOV



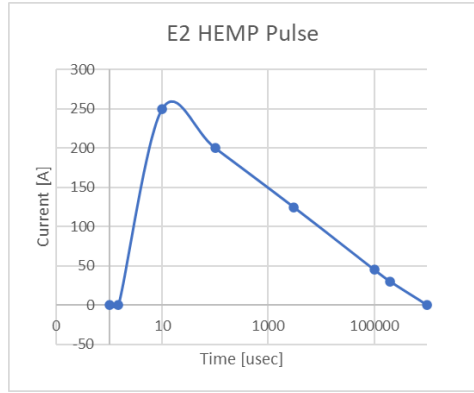
TVS

Style	Relative Energy Capability	Speed	Parasitic
Diode	Low	Fast	Med
Varistor	Med	Med	High
Gas Discharge Tube	High	Slow	Low

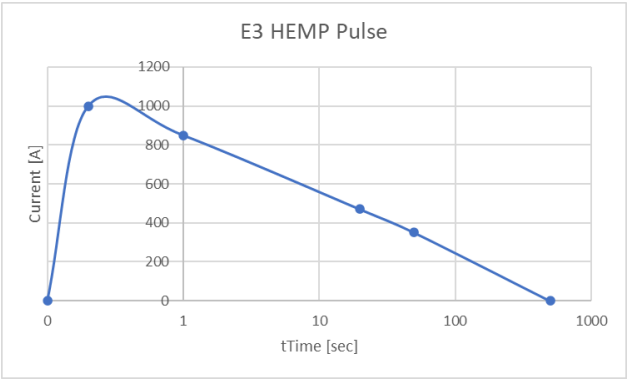
Typical Transient Curves



E2 Pulse Energy similar to Lightning Strike



E3 Pulse Long Duration



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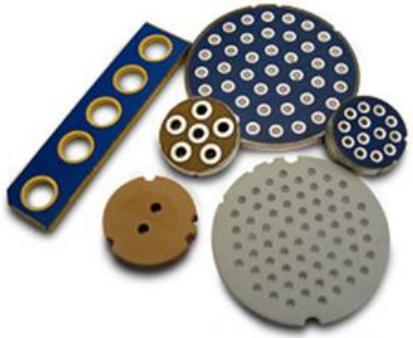
Technology & Solutions

- USA-designed and manufactured in our State College, PA facility
- Solid-wall and embedded technologies for commercial and high-performance military applications
- Largest offering of EMI capacitor sizes and configurations (cylindrical and rectangular geometries)
- Multiple termination materials (F.O.S., Silver, Gold, Nickel, Copper) for specific customer requirements
- Coated ceramics available for high voltage and transient requirements

Discoidal



Planar

Tubular

Coaxial ceramic capacitors key to high frequency performance

Recent & Scheduled Filter Launches

EMx

Dual Line Hermetic

- Packaged in a standard MIL-PRF-15733 style package
- Two circuits in that package size

EMSEC & MIL-STD 461 - Single Phase Power Entry

- Meet requirements of MIL-PRF-15733
- In 5, 10, 15, 20A current ratings

Space Grade

- Meets requirements of MIL-PRF-28861 B+ Level
- Up-screened to meet higher reliability requirements

Transient Protection

- Power entry EMP/HEMP filters
- Power entry transient protection – Lightning & DO-160

Thank You! Questions?

Key Take-Aways

System Layout

Filtering

Shielding & Grounding

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