

EMC Design Fundamentals

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EMC Certified by NARTE

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Outline

- ◆ Introduction
 - Importance of EMC
 - Problems with non-compliance
- ◆ Concepts & Definitions
- ◆ Standards
 - FCC, US Military, EU, RTCA
- ◆ Design Guidelines and Methodology
 - EM Waves, Shielding
 - Layout and Partitioning
 - Power Distribution
 - Power Conversion
 - Signal Distribution
- ◆ Design Process
- ◆ References and Vendors

Introduction

Importance of EMC

- ◆ Electromagnetic Compatibility (EMC) requires that systems/equipment be able to tolerate a specified degree of interference and not generate more than a specified amount of interference
- ◆ EMC is becoming more important because there are so many more opportunities today for EMC issues
- ◆ Increase use of electronic devices
 - Automotive applications
 - Personal computing/entertainment/communication
- ◆ Increased potential for susceptibility/emissions
 - Lower supply voltages
 - Increasing clock frequencies, faster slew rates
 - Increasing packaging density
 - Demand for smaller, lighter, cheaper, lower-power devices

Problems with Non-Compliance

- ◆ Product may be blocked from market
- ◆ Practical impact can be minor annoyance to lethal
...and everything in between

Annoyance,
Delays

Lost Revenue, Minor
Property Loss

Significant
Property Loss

Death or
Serious Injury

M i n o r

M a j o r

- AM/FM/XM/TV Interference
- Cell Phone Interference

- Critical communications Interference/Interruption
- Automated Monetary Transactions

- RADAR, Landing System Interruption
- Erroneous Ordnance Firing
- Improper Deployment of Airbags



Non-Compliance (continued)

- ♦ Fortunately, industry is well regulated and standards are comprehensive
- ♦ Major EMC issues are relatively rare
- ♦ For cost-effective compliance
 - EMC considered throughout product/system development

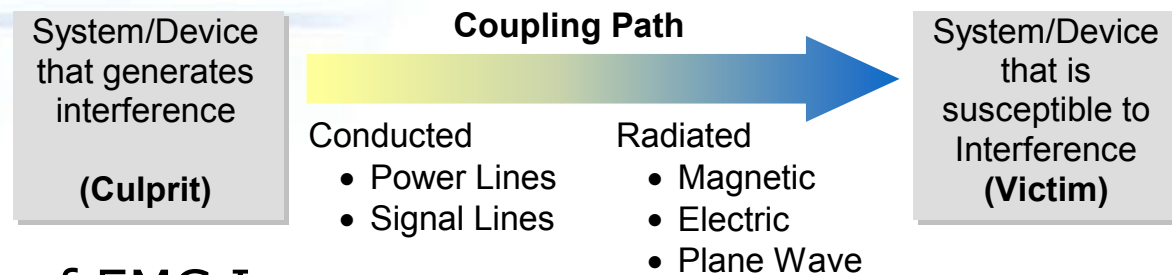
Concepts & Definitions

Concepts & Definitions

- ◆ Electromagnetic Interference (EMI)
 - Electromagnetic emissions from a device or system that interfere with the normal operation of another device or system
 - Also referred to as Radio Frequency Interference (RFI)
- ◆ Electromagnetic Compatibility (EMC)
 - The ability of equipment or system to function satisfactorily in its Electromagnetic Environment (EME) without introducing intolerable electromagnetic disturbance to anything in that environment
 - In other words:
 - Tolerate a specified degree of interference,
 - Not generate more than a specified amount of interference,
 - Be self-compatible

Concepts & Definitions, Continued

- ◆ For an EMC problem to exist:
 - System/Device that generates interference
 - System/Device that is susceptible to the interference
 - Coupling path



- ◆ Mitigation of EMC Issues
 - Reduce interference levels generated by culprit
 - Increase the susceptibility (immunity) threshold of the victim
 - Reduce the effectiveness of the coupling path
 - Combination of the above

Source (Culprit)	Coupling Path	Receiver (Victim)
Modify Signal Routing	Increase Separation	Modify Signal Routing
Add Local Filtering	Shielding	Add Local Filtering
Operating Freq Selection	Reduce # of Interconnections	Operating Freq Selection
Freq Dithering	Filter Interconnections	
Reduce Signal Level		

Standards

Some of the Institutes that Establish EMC Standards

- ◆ Federal Communication Commission (FCC)
- ◆ US Military
- ◆ European Union (EU)
- ◆ Radio Technical Commission for Aeronautics (RTCA)
- ◆ This lecture's main focus is on EMC Fundamentals, not
 - Electro Static Discharge (ESD)
 - Direct Lightning Effects
 - Antenna Lead Conducted Emissions/Susceptibility
 - RF Radiation Safety

FCC Part 15

Conducted Emissions			
	Frequency (MHz)	Quasi-Peak Limit (dBuV)	Average Limit (dBuV)
Class A	0.15 – 0.5	79	66
	0.5 – 30.0	73	60
Class B	0.15 – 0.5	66 to 56 *	56 to 46 *
	0.5 – 5	56	46
	5 – 30	60	50

*Decrease as logarithm of frequency

FCC Part 15

General Radiated Emission		
	Frequency (MHz)	Field Strength Limit ($\mu\text{V/m}$)
Class A (10 meters)	30 – 88	90
	88 – 216	150
	216 – 960	210
	above 960	300
Class B (3 meters)	30 – 88	100
	88 – 216	150
	216 – 960	200
	above 960	500

MIL-STD-461E

- ◆ Requirements for the Control of EMI Characteristics of Subsystems & Equipment

Req't	Description
CE101	Conducted Emissions, Power Leads, 30 Hz to 10 kHz
CE102	Conducted Emissions, Power Leads, 10 kHz to 10 MHz
CE106	Conducted Emissions, Antenna Terminal, 10 kHz to 40 GHz
CS101	Conducted Susceptibility, Power Leads, 30 Hz to 50 kHz
CS103	Conducted Susceptibility, Antenna Port, Intermodulation, 15 kHz to 10 GHz
CS104	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals, 30 Hz to 20 GHz
CS105	Conducted Susceptibility, Antenna Port, Cross Modulation, 30 Hz to 20 GHz
CS109	Conducted Susceptibility, Structure Current, 60 Hz to 100 kHz
CS114	Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz
CS115	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation
CS116	Conducted Susceptibility, Dampened Sinusoidal Transients, Cables & Power Leads, 10 kHz to 100 MHz
RE101	Radiated Emissions, Magnetic Field, 30 Hz to 100 kHz
RE102	Radiated Emissions, Electric Field, 10 kHz to 18 GHz
RE103	Radiated Emissions, Antenna Spurious and Harmonic Outputs, 10 kHz to 40 GHz
RS101	Radiated Susceptibility, Magnetic Field, 30 Hz to 100 kHz
RS103	Radiated Susceptibility, Electric Field, 10 kHz to 40 GHz
RS105	Radiated Susceptibility, Transient Electromagnetic Field

EU Standard Examples (Emissions)

Standard	Description
EN50081-1	Generic emissions standard for residential, commercial and light industrial environments.
EN50081-2	Generic emissions standard for industrial environment
EN55022	Limits and methods of measurement of radio disturbance characteristics of information technology equipment (Also known as CISPR-22)
EN55011	Industrial, scientific and medical (ISM) radio frequency equipment - Radio disturbance characteristics - Limits and methods of measurement (Also known as CISPR-11)
EN55013	Limits and methods of measurement of radio disturbance characteristics of broadcast receivers and associated equipment
EN55014-1	Emission requirements for household appliances, electric tools and similar apparatus
EN55015	Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment
EN61000-3-2	Limits for harmonic current emissions (equipment input current up to and including 16 A per phase)
EN61000-3-3	Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems

EU Standard Examples (Immunity)

Standard	Description
EN61000-4-2	Electrostatic Discharge
EN61000-4-3	Radiated Susceptibility Test
EN61000-4-4	Electrical Fast Transient/Burst Test
EN61000-4-5	Surge Test
EN61000-4-6	Conducted Immunity Test
EN61000-4-8	Power Frequency Magnetic Test
EN61000-4-11	Voltage Dips and Interruptions Test
EN61000-6-1	Immunity for residential, commercial and light-industrial environments
EN61000-6-2	Immunity for industrial environments
EN61547	Equipment for general lighting purposes — EMC immunity requirements
EN12016	Electromagnetic compatibility — Product family standard for lifts, escalators and passenger conveyors — Immunity

Standard Example - RTCA

- ◆ DO-160, Environmental Conditions & Test Procedures for Airborne Equipment

Section	Title	Notes
16	Power Input	115 VAC, 28 VDC and 14 VDC Power Voltage/frequency range, interruptions, surges
17	Voltage Spike	Power Leads Up to 600 V or 2x Line Voltage
18	Audio Frequency Conducted Susceptibility – Power Inputs	0.01 - 150 kHz or 0.2 - 15 kHz
19	Induced Signal Susceptibility	Interconnection Cabling E field and H Field 400 Hz – 15 kHz and spikes
20	Radio Frequency Susceptibility (Radiated and Conducted)	Conducted: 0.01-400 MHz Radiated: 0.1-2, 8 or 18 GHz
21	Emission of Radio Frequency	Power Lines: 0.15-30 MHz Interconnecting Cables: 0.15-100 MHz Radiated: 2-6,000 MHz
22	Lightning Induced Transient Susceptibility	Pin & Bulk injection, Pulse & Dampened Sine

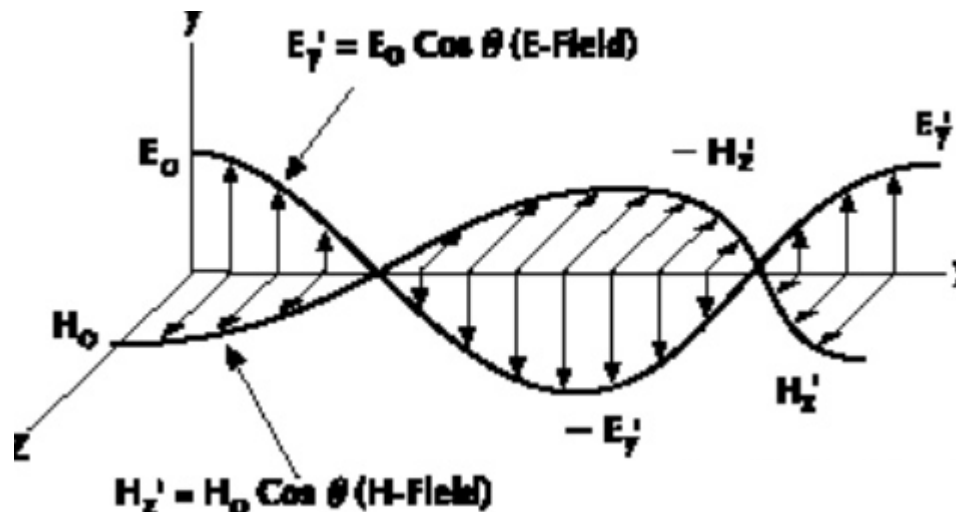
Standard Summary

- ♦ Numerous EMC standards exists
- ♦ Common Fundamental Theme
 - Conducted Emission Limits
 - Radiated Emission Limits
 - Conducted Susceptibility (Immunity) Limits
 - Radiated Susceptibility (Immunity) Limits

Design Guidelines and Methodology

Electromagnetic Waves

- ♦ Electromagnetic waves consist of two orthogonal fields
 - Electric, E-Field (V/m)
 - Magnetic, H-Field (A/m)
- ♦ Wave Impedance, $Z_W = E/H \, \Omega$



Electromagnetic Waves

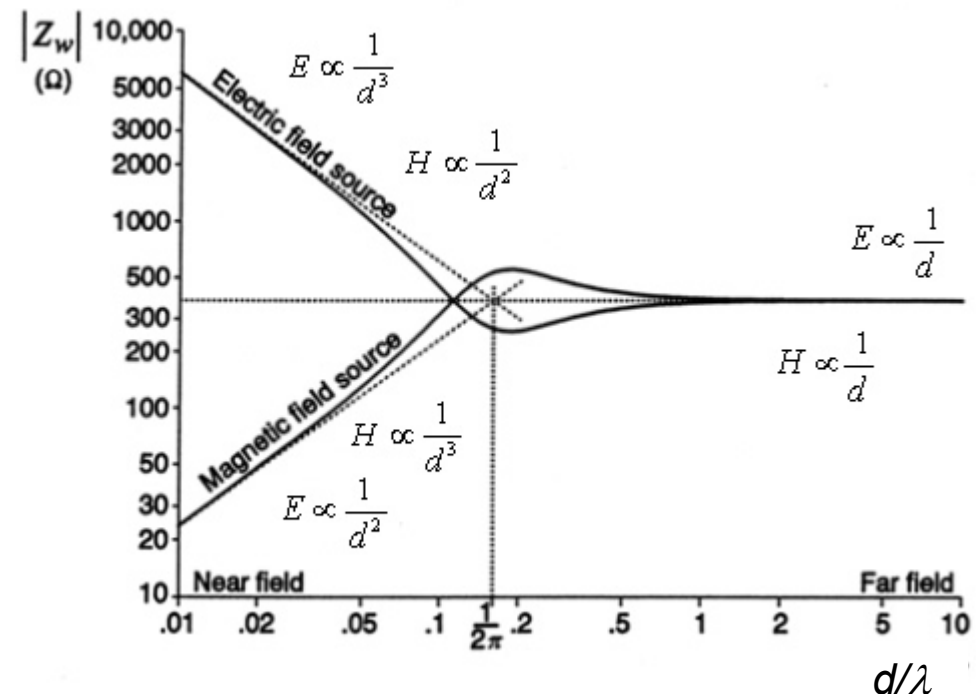
- ◆ E-Fields, high impedance, wire (dipole)
- ◆ H-Fields, low impedance, current loops (xformer)
- ◆ In far field, all waves become plane waves

$$d > \frac{\lambda}{2\pi}$$

Far Field for a Point Source

$$Z_w = \sqrt{\frac{\mu_0}{\epsilon_0}} = \sqrt{\frac{4\pi \cdot 10^{-7} \frac{H}{m}}{36\pi \cdot 10^{-9} \frac{F}{m}}} = 120\pi = 377 \Omega$$

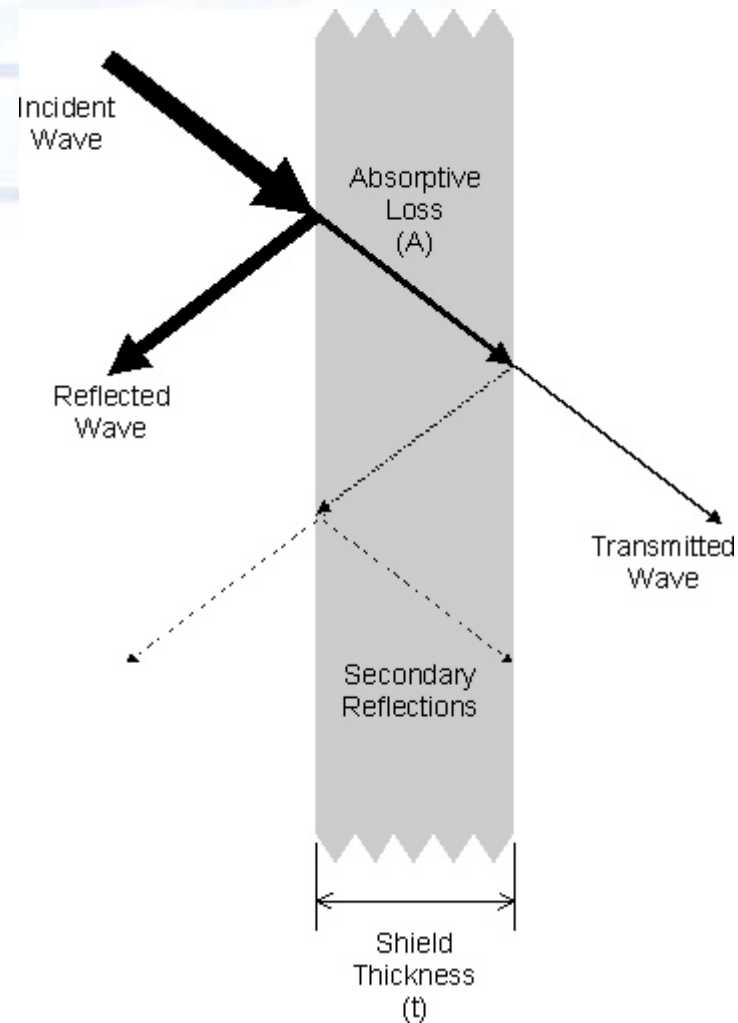
Impedance of Plain Wave



Shielding

- ◆ Enclosure/Chassis
 - Mechanical Structure
 - Thermal Path
 - Can form an overall shield (important EMC component)
 - Can be used as “first” line of defense for Radiated emission/susceptibility
- ◆ Some Applications Cannot Afford Overall Shield
 - Rely of other means of controlling EMC
- ◆ Enclosure material
 - Metal
 - Plastic with conductive coating
(Conductive paint or vacuum deposition)

Shielding Illustration



Shielding Effectiveness

- ♦ Shielding effectiveness (SE) is a measure of how well an enclosure attenuates electromagnetic fields

$$SE_{dB} = 20 \log_{10} \frac{E_{Inside}}{E_{Outside}}$$

- ♦ Theoretical SE of homogeneous material
 - Reflective losses, R
 - Absorption losses, A and
 - Secondary reflective losses, B (ignore if A > 8 dB)

$$SE = R + A + B \Rightarrow SE = R + A$$

SE Equations

$$R_h = 20 \log_{10} \left[\left(\frac{0.462}{r} \right) \sqrt{\frac{\mu_r}{f \sigma_r}} + \frac{0.136r}{\sqrt{\frac{\mu_r}{f \sigma_r}}} + 0.354 \right]$$

Magnetic Field Reflective Loss

$$R_e = 354 - 10 \log_{10} \left(\frac{f^3 \mu_r r^2}{\sigma_r} \right)$$

Electric Field Reflective Loss

$$R_p = 168 + 10 \log_{10} \left(\frac{\sigma_r}{\mu_r f} \right)$$

Plane Wave Reflective Loss

$$A = 0.003338 t \sqrt{\mu_r \sigma_r f}$$

Absorptive Loss

where:

t = Material thickness (mils)

μ_r = Material permeability relative to air

σ_r = Material conductivity relative to copper

f = Frequency (Hz)

r = Source to shield distance (inches)

SE Theoretical Examples

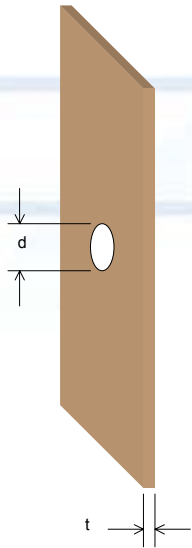
Freq (Hz)	Aluminum (60 mils)			Cold Rolled Steel (60 mils)			Copper (3 mils)		
	Magnetic (dB)	Electric (dB)	Plane (dB)	Magnetic (dB)	Electric (dB)	Plane (dB)	Magnetic (dB)	Electric (dB)	Plane (dB)
10k	58	>200	141	125	>200	>200	45	>200	129
100k	101	>200	165	>200	>200	>200	57	186	121
1M	>200	>200	>200	>200	>200	>200	74	162	118
10M	>200	>200	>200	>200	>200	>200	106	154	130
100M	>200	>200	>200	>200	>200	>200	184	193	188
1G	>200	>200	>200	>200	>200	>200	>200	>200	>200

- ♦ $r=12''$
- ♦ $\mu_r = 1$ (Aluminum), 180 (Cold Rolled Steel), 1 (Copper)
- ♦ $\sigma_r = 0.6$ (Aluminum), 0.17 (Cold Rolled Steel), 1 (Copper)

SE Practical Considerations

- ♦ SE is typically limited by apertures & seams
 - Removable Covers
 - Holes for control/display components
 - Holes for ventilation
 - Holes for connectors
- ♦ Mitigation of apertures and seams
 - Minimize size and number of apertures and seams
 - Use gaskets/spring-fingers to seal metal-to-metal interface
 - Interfaces free of paint and debris
 - Adequate mating surface area
 - Avoid Galvanic Corrosion
 - Use of EMI/conductive control/display components

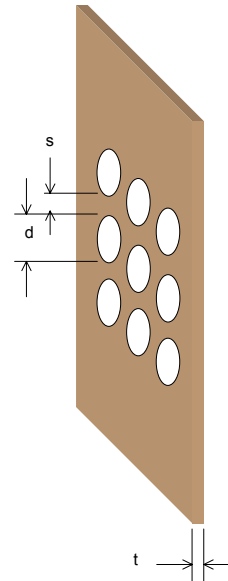
Holes/Apertures $d > t$



◆ Single Hole

If $\frac{\lambda}{2} < d$ $SE \approx 0dB$

If $\frac{\lambda}{2} > d$ $SE \approx 20\text{Log}_{10} \frac{\lambda}{2d}$



◆ Multiple Holes

If $s < \frac{\lambda}{2} > d$ and $\frac{s}{d} < 1$

$SE \approx 20\text{Log}_{10} \frac{\lambda}{2d} - 10\text{Log}_{10} n$

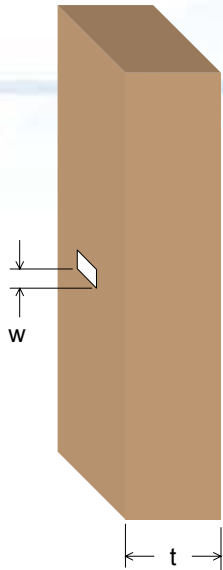
where:
 t = Material thickness
 n = Number of Holes
 s = edge to edge hole spacing

Notes:

1. d is the longest dimension of the hole.
2. Maximum SE is that of a solid barrier without aperture.

Holes/Apertures $d < t$ ($w < t$)

- Behaves like a waveguide below cutoff



$$\lambda_c = 2w \quad \text{Cutoff wavelength}$$

$$\alpha = \frac{2\pi}{\lambda_c} \sqrt{1 - \left(\frac{f}{f_c}\right)^2} \quad \text{Absorption factor of WG below cutoff}$$

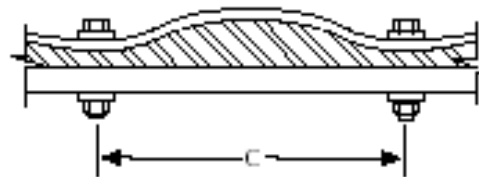
$$\alpha = \frac{2\pi}{\lambda_c} = \frac{\pi}{w} \quad \text{For frequencies well below cutoff}$$

$$A = 8.686\alpha t = 27.3 \frac{t}{w} \quad \text{Absorption loss}$$

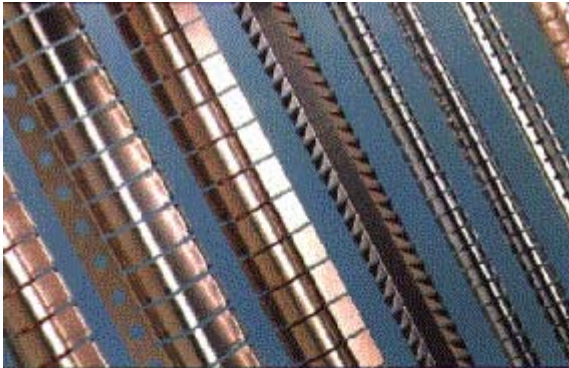
t/w	Loss
8	>200
6	164
4	109
2	55

Enclosure Seams

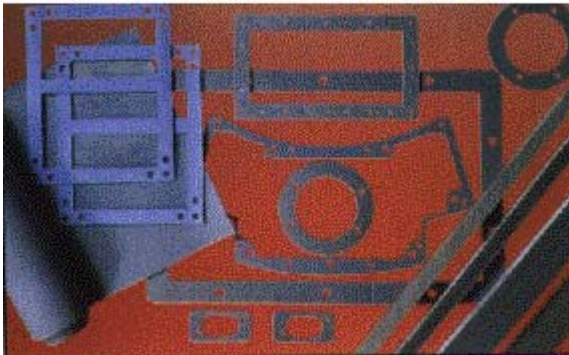
- ◆ SE can be limited by the failure of seams to make adequate contact
 - Contact area must be conductive
 - Adequate cross-section of overlap
 - Adequate number of contact points
- ◆ Gasketing helps ensure electrical contact between fasteners



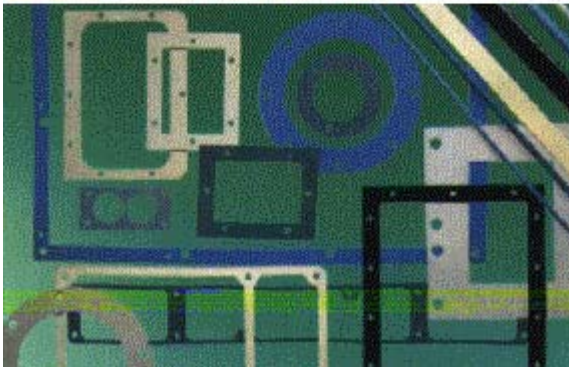
Gasketing Examples



- ◆ Fingerstock (≈ 100 dB @ 2GHz)
 - Large Selection (shape, size, plating)
 - Wide mechanical compression range
 - High shielding effectiveness
 - Good for frequent access applications
 - No environmental seal



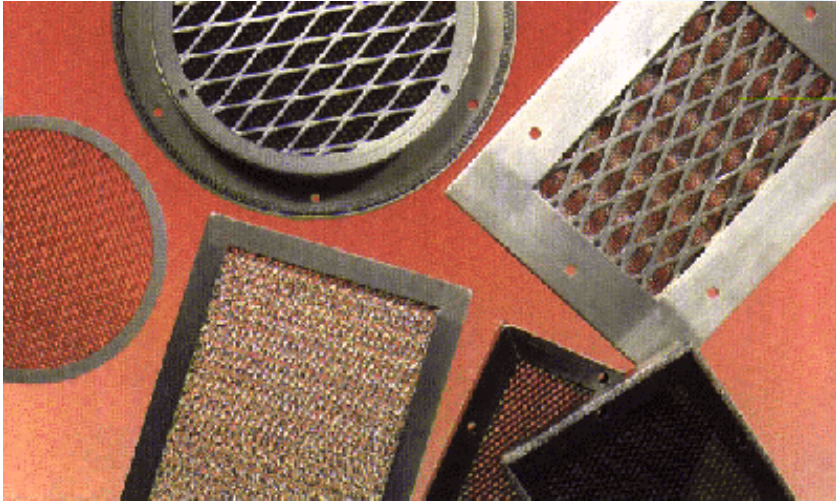
- ◆ Oriented Wire (≈ 80 dB @ 2GHz)
 - Provides both EMI and Moisture Seal
 - Lower SE than all-metal gaskets
 - Sponge or Solid Silicone, Aluminum or Monel
 - Mechanically versatile – die cut



- ◆ Conductive Elastomers (≈ 80 dB @ 2GHz)
 - Provides both EMI and Moisture Seal
 - Lower SE than all-metal gaskets
 - Mechanically versatile – die cut or molded

Courtesy of Tecknit

Panel Components

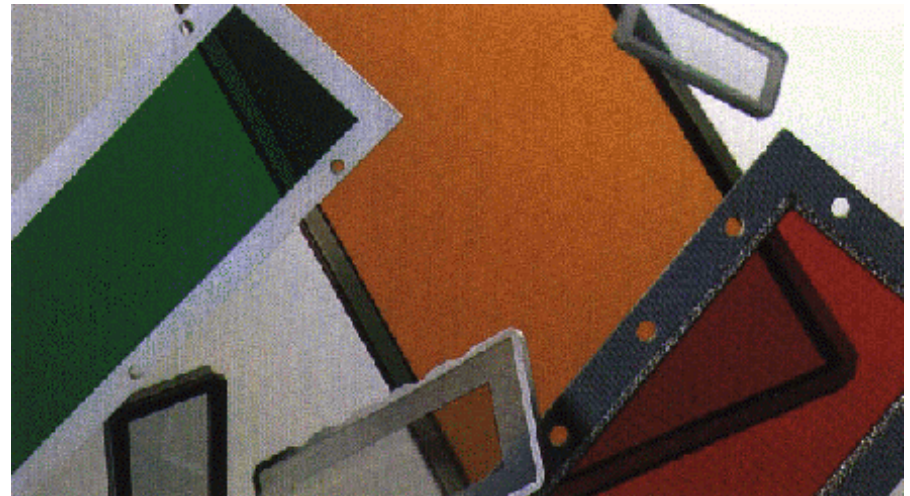


Air
Ventilation
Panels



EMC Switch
Shield

Shielded
Windows



Courtesy of Tecknit

Galvanic Series

- ◆ Galvanic Corrosion
 - Two dissimilar metals in electrical contact in presence of an electrolyte



Galvanic Series Table

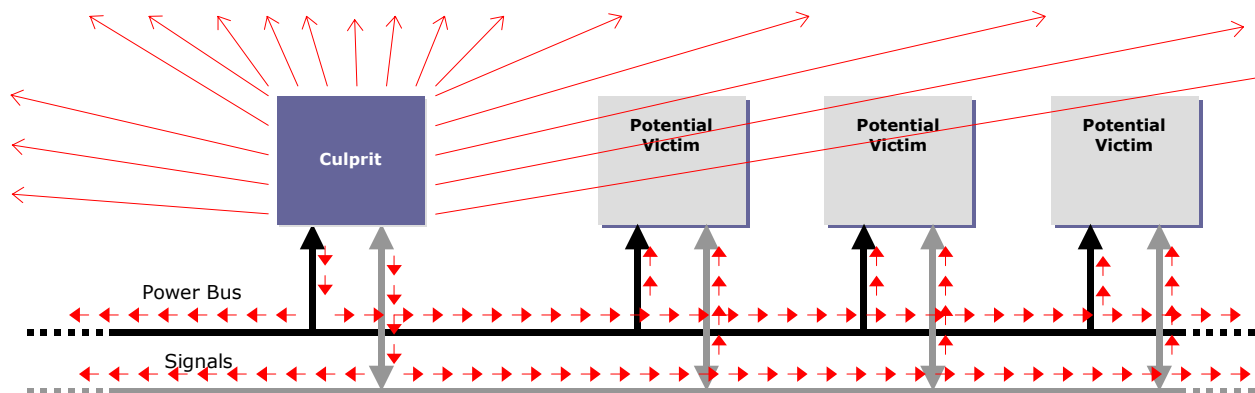
Metallurgical Category	Anodic Index (V)
Gold , Wrought Platinum, Graphite Carbon	0.00
Rhodium Plating	0.10
Silver, High-Silver Alloys	0.15
Nickel , Nickel-Copper Alloys, Titanium, Titanium Alloys, Monel	0.30
Beryllium Copper, Low Brasses or Bronzes, Silver Solder, Copper, Ni-Cr Alloys, Austenitic Corrosion-Resistant Steels, Most Chrome-Moly Steels, Specialty High-Temp Stainless Steels	0.35
Commercial Yellow Brasses and Bronzes	0.40
High Brasses and Bronzes, Naval Brass, Muntz Metal	0.45
18% Cr-type Corrosion Resistant Steels, Common 300 Series Stainless Steels	0.50
Chromium or Tin Plating, 12% Cr type Corrosion Resistant Steels, Most 400 Series Stainless Steels	0.60
Tin-Lead Solder , Terneplate	0.65
Lead, High-Lead Alloys	0.70
Wrought 2000 Series Aluminum Alloys	0.75
Wrought Gray or Malleable Iron, Plain Carbon and Low-Alloy Steels, Armco Iron, Cold-Rolled Steel	0.85
Wrought Aluminum Alloys (except 2000 series cast Al-Si alloys), 6000 Series Aluminum	0.90
Cast aluminum Alloys (other than Al-Si), Cadmium Plating	0.95
Hot-Dip Galvanized or Electro-Galvanized Steel	1.20
Wrought Zinc, Zinc Die Casting Alloys	1.25
Wrought and Cast Magnesium Alloys	1.75
Beryllium	1.85

Galvanic Series Notes

- ◆ For harsh environments
 - Outdoors, high humidity/salt
 - Typically design for < 0.15 V difference
- ◆ For normal environments
 - Storage in warehouses, no-temperature/humidity control
 - Typically < 0.25 V difference
- ◆ For controlled environments
 - Temperature/humidity controlled
 - Typically design for < 0.50 V difference
- ◆ Mitigation of Galvanic Corrosion
 - Choosing metals with the least potential difference
 - Finishes, such as MIL-C-5541, Class 3 *using minimal dip immersion*
 - Plating
 - Insulators, as electrically/thermally appropriate

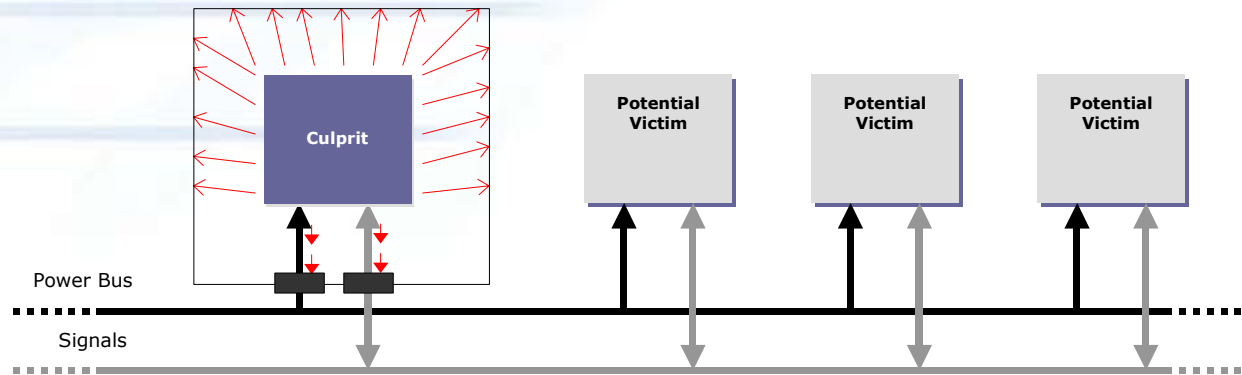
System Partitioning/Guidelines

- ♦ Minimize interconnections between WRAs/LRUs
- ♦ Minimize the distribution of analog signals
- ♦ Control interference at the source

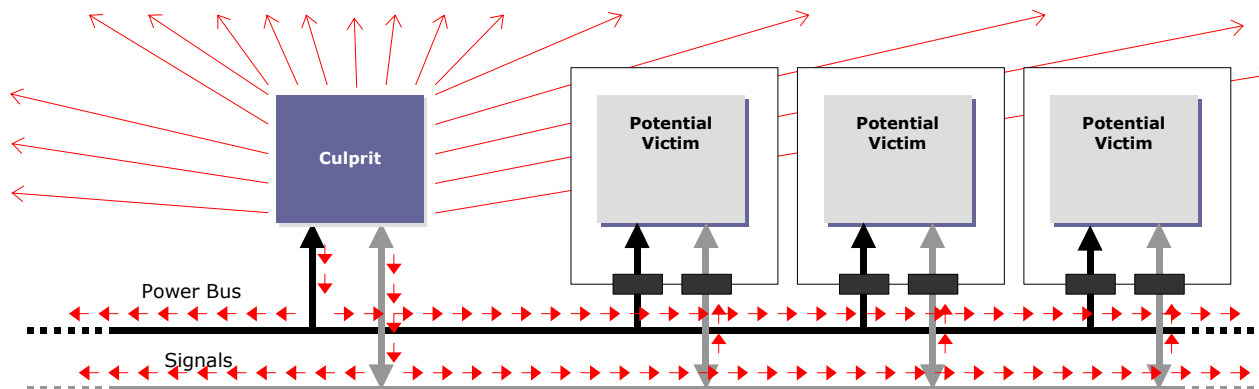


Control Interference at the Source

- ◆ Preferred Approach – Shield/Filter the Source (Culprit)



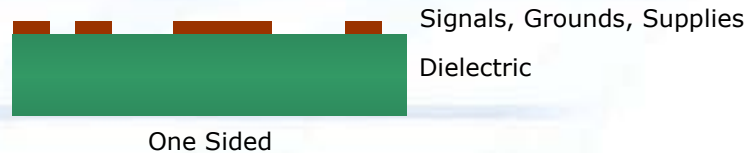
- ◆ Alternate Approach – Shield/Filter Potential Receivers (Victims)



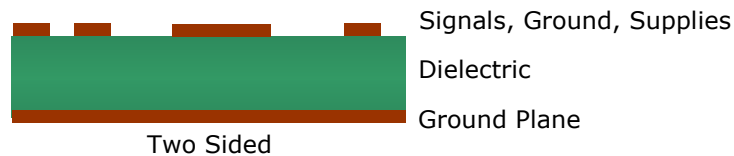
CCA Layout and Partitioning

- ◆ Layout is 3 Dimensional
 - Component placement (X & Y)
 - Signal and Power Routing (X & Y)
 - PWB Stack Up (Z)
- ◆ Dedicate layer(s) to ground
 - Forms reference planes for signals
 - EMI Control (high speed, fast slew rate, critical analog/RF)
 - Simpler impedance control
- ◆ Dedicate layer(s) to Supply Voltages
 - In addition to dedicated ground layers
 - Low ESL/ESR power distribution

One and Two Layer



- Inexpensive
- Difficult to control EMI without external shield
- Difficult to control impedance

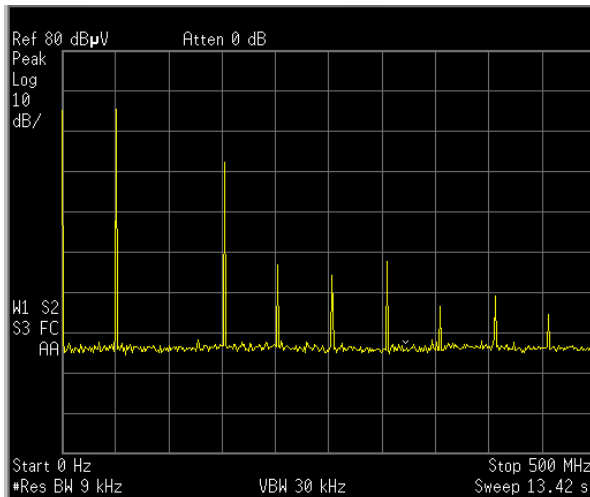


- Inexpensive (slightly more than 1 sided)
- EMI mitigation with ground plane
- Impedance control simplified with ground plane

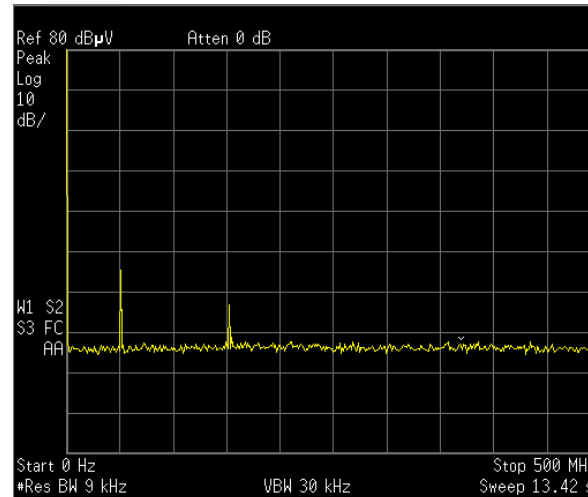
Radiation Example, 50 MHz Clock



- ◆ Adding ground plane reduces emission of fundamental ≈ 40 dB



No Ground Plane

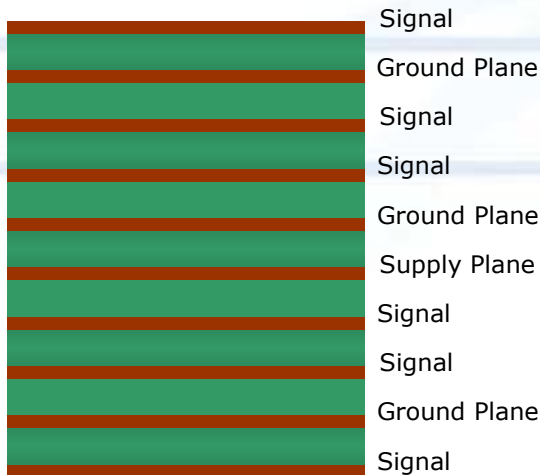


With Ground Plane
(Micro-Strip)

PWB: 2" x 6" x 0.060" (FR4)
Trace: 5" x 0.050"
E-Field Probe Spacing: 2"
(Emco 7405-004)
Source: 50 MHz, 4 ns rise/fall,
3 Vp

Multi-Layer Stack Up Examples

1



High Speed Digital PWB

- High Density
- Ten Layers
- Two Micro-Strip Routing Layers
- Four Asymmetrical Strip-Line Routing Layers
- Single Supply Plane
- Two Sided

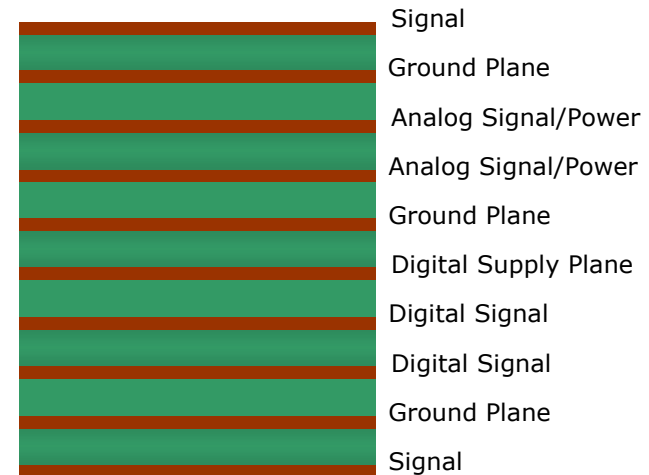
2



High Speed Digital PWB

- Moderate Density
- Six Layers
- Two Micro-Strip Routing Layers
- Two Buried Micro-Strip Routing Layers
- Single Supply Plane
- Two Sided

3

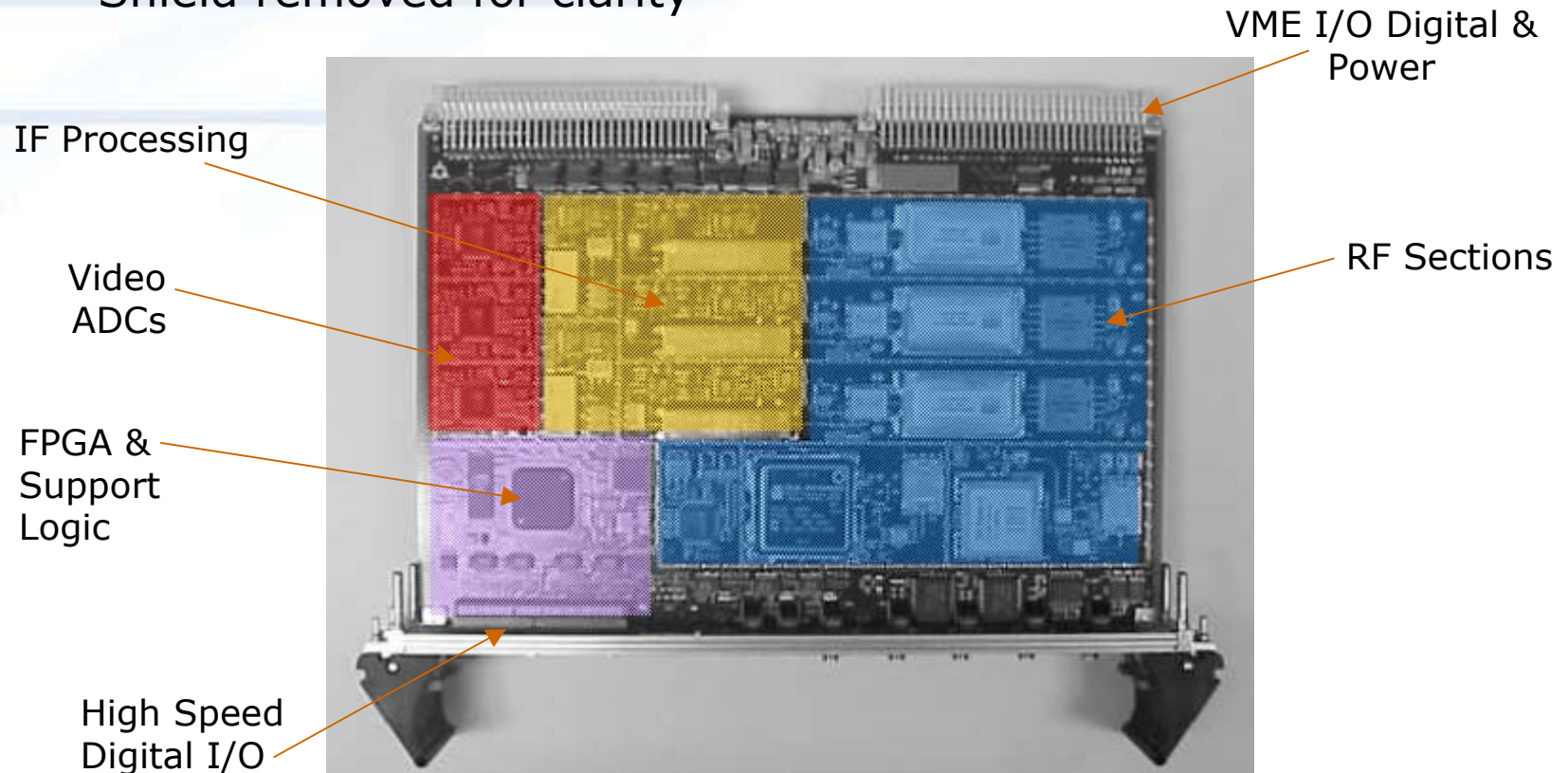


Mixed Analog/RF/Digital PWB

- Moderate Density
- Ten Layers
- Two Micro-Strip Routing Layers
- Four Asymmetrical Strip-Line Routing Layers
- Single Digital Supply Plane
- Analog supplies on inner layers
 - Routing Clearance Considerations
 - Improved isolation
- Two Sided

PWB Example

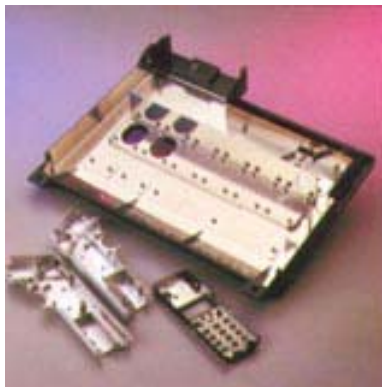
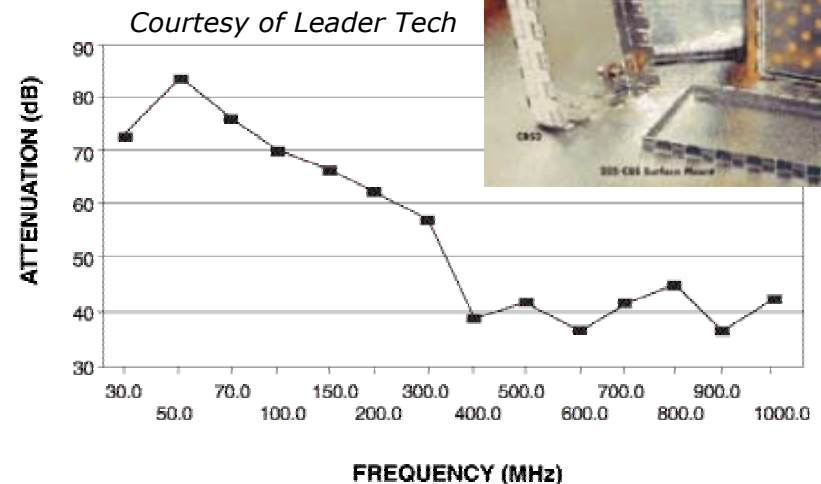
- ♦ Three Channel, L-Band VME Receiver
 - Shield removed for clarity



CCA Level Shielding

- ♦ Used in conjunction with PWB ground plane(s)
- ♦ Supplement shielding of overall enclosure or instead of overall enclosure
- ♦ Isolate sections of CCA
 - Local Oscillators, Front Ends, High Speed Digital, Low Level Analog (audio, video)

Metal CCA Shield Examples



Metalized Plastic Shield Examples

Courtesy of Mueller

COTS Power Supply Selection

(AC/DC Power Converters)

- ◆ **EMC Selection Considerations**
 - AC Input EMC Specification Compliance
 - Radiated emission/immunity compliance
 - Open frame, enclosed, stand-alone
 - Hold-Up Time
 - DC to AC Noise Isolation
 - DC to DC Noise Isolation (Multi-output)
 - DC to DC Galvanic Isolation (Multi-output)
- ◆ **Non-EMC Selection Considerations**
 - Safety compliance
 - Size & weight
 - Efficiency
 - Line/Load/Temperature Regulation
 - Operating/Storage Temperature Ranges

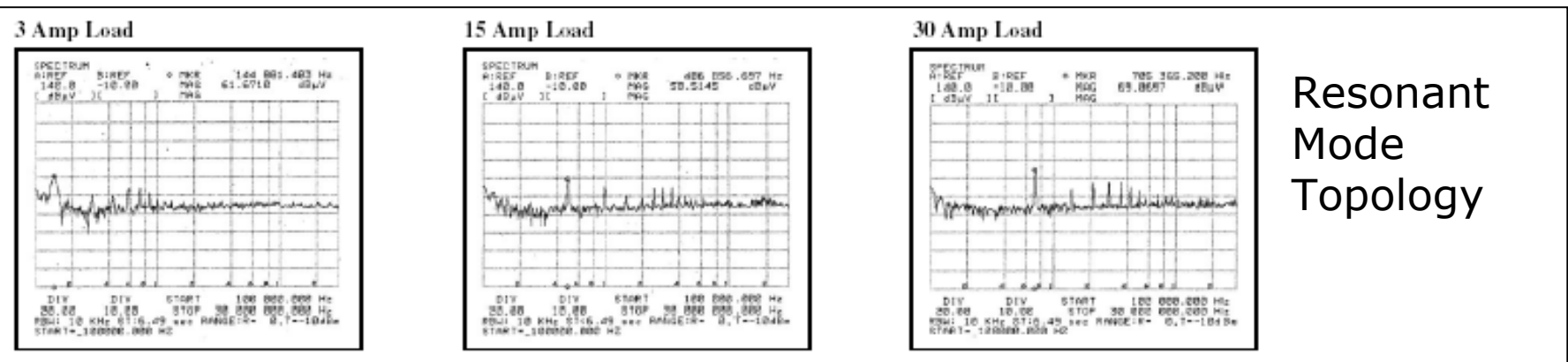
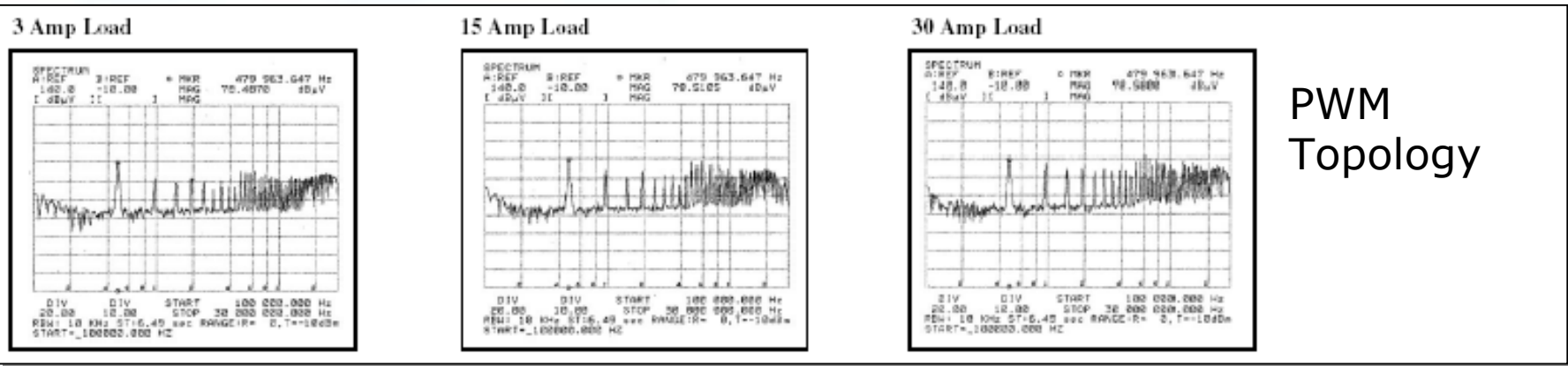
DC/DC Converter Design/Selection

- ◆ Small Converters at CCA Level
 - Local regulation in critical applications
 - Generate unavailable voltages (3.3 to 1.25 VDC for FPGA core)
 - Many complete COTs solutions available (Vicor, Interpoint, etc.)
 - Many discrete solutions available (Linear Tech, National, etc.)
- ◆ Linear
 - Inherently Quiet
 - Provide noise isolation, input to output
 - Typically much less efficient (depends on $V_{In} - V_{Out}$ difference)
 - Three terminal devices provide no Galvanic isolation
- ◆ Switching
 - Can be configured for Galvanic isolation
 - Typically noisier than Linear (however mitigation options exist)
 - Pulse Width Modulation, Controlled di/dt and dV/dt
 - Pulse Width Modulation, Spread Spectrum
 - Resonant mode (zero current switching)

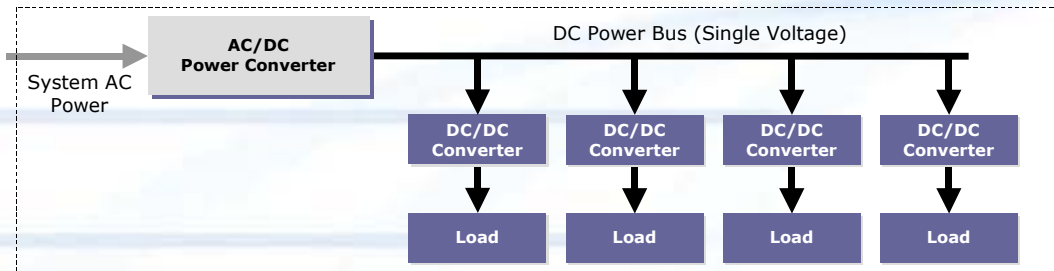
PWM, Resonant Mode Comparison

- ♦ Resonant Mode Vs PWM
 - 48 VDC Input, 5 VDC Output
 - 100 kHz to 30 MHz, Input Noise

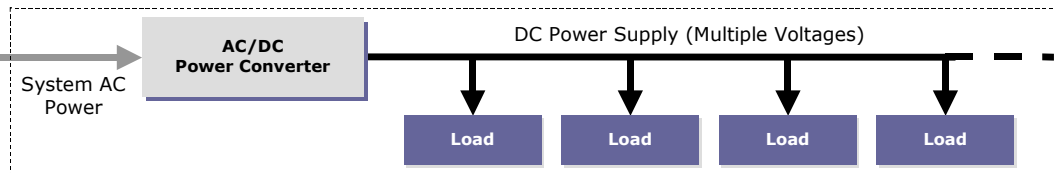
Courtesy of Vicor



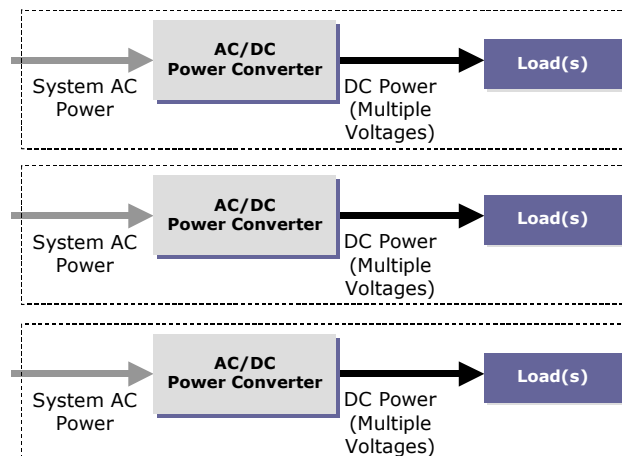
Power Distribution – System Level



- ◆ **Distributed DC**
 - One Primary Converter
 - Multiple Secondary Converters at each load
 - Typical Application: Large ground based system



- ◆ **Direct DC**
 - One Primary Converter for all loads
 - Typical Application: Home Computer



- ◆ **Separate Primary**
 - One AC/DC Converter per unit
 - Typical Application: RADAR System housed in multiple units

Power Distribution Examples



AN/APS-147 LAMPS RADAR
(Separate Primary Distribution)

Multiple Access
Beamforming
Equipment
(Distributed DC)



Courtesy of Dell

Personal Computer
(Direct DC Distribution)



Power Distribution Comparison

Architecture	Load Ground Loops	Load Reg	Power Effic	Load Iso	Notes
Distributed DC	+	+	-	+	Only one Converter is directly exposed to input.
Direct DC	-	-	+	-	May not be practical on large systems with heavy current demands and/or tight regulation requirements
Separate Primary	x	x	+	x	

- ◆ Legend:
- "+" Advantage
- "-" Disadvantage
- "x" Neutral

Signal Distribution

- ◆ Avoid routing analog signals over long distances in harsh environments, but if unavoidable:
 - Differential
 - Amplify at source and attenuate/filter at destination
- ◆ Inter-Unit (LRU or WRA)
 - Digital preferred over analog
 - Differential preferred over single ended
 - Minimize number of interconnects

Cable Shields

- ◆ Shields of external interconnecting cables
 - Essentially extensions of the chassis enclosure
- ◆ Shielding Effectiveness and Transfer Impedance
 - Properties of material
 - Degree of coverage
 - Geometry
- ◆ Shields are an important part of EMC design, especially in systems that require compliance to EMP and/or Indirect Lightning Effects

Cable Shield Termination

- ◆ Maintaining quality SE and Transfer Impedance depends on effective termination of shields at both ends
 - 360 Degree Backshells
 - If high frequency isolation is needed, avoid using long leads to terminate shields



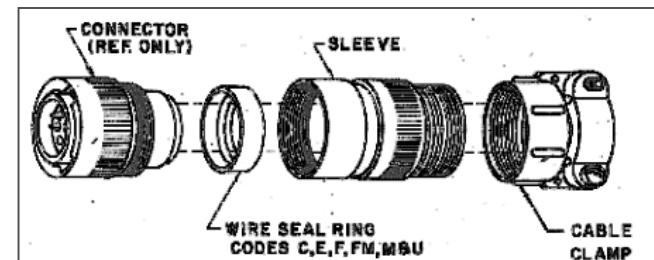
Coax Shield Terminated with Excessive Lead Length



Unassembled 360 Degree Backshell for D Connector



Circular D38999 Mil Connector with 360 Degree Backshell



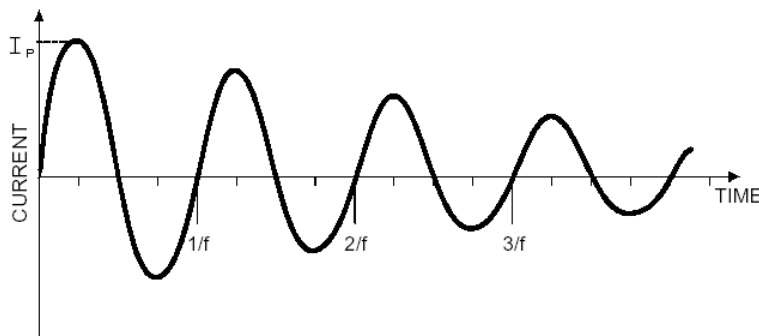
Exploded View of 360 Degree Backshell for D38999 Connector

Shield Example

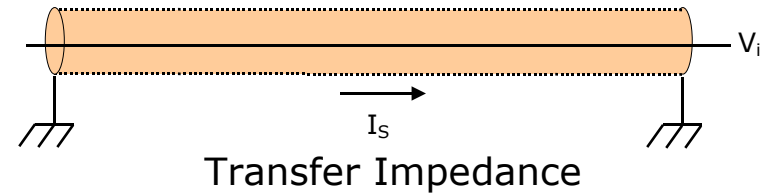
95% Coverage Double Copper Shield				
Frequency (Hz)	Shielding Effectiveness			Xer Z (Ω/m)
	Magnetic (dB)	Electric (dB)	Plane Wave (dB)	
1 k	0	100	100	
10 k	16	100	100	0.0080
100 k	36	100	100	0.0080
1 M	70	100	100	0.0014
10 M	90	90	90	0.0011
100 M	90	90	90	0.0060
1 G	80	80	80	
10 G	60	60	60	

Transfer Impedance Example

CS116 of MIL-STD-461E Example
10 A at 10 MHz



$$Z_T = \frac{V_i}{I_s} \quad (\Omega \text{ per meter})$$

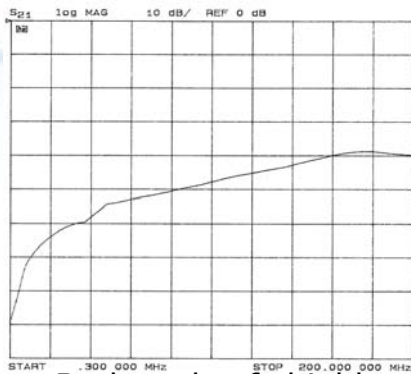


$$V_i = I_s Z_T l = (10 A) \left(0.0011 \frac{\Omega}{m} \right) (2m) = 22mV$$

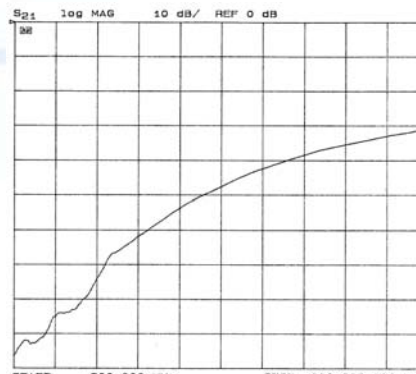
Induced Voltage of 22 mV is well below damage/upset threshold of most logic families.

Coupling Example #1, 0.3-200 MHz

- ◆ Two Parallel Lines, One shielded, One unshielded
 - 0.5" Over Ground Plane, 10" Long, Separated by 2"
 - Shielded Line has 0.5" exposed



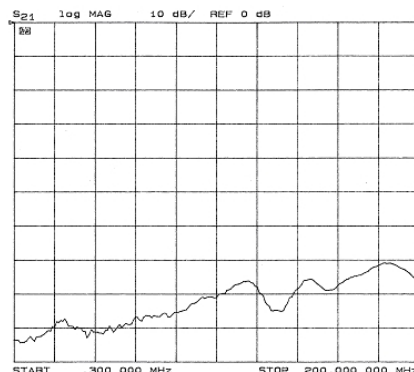
Both ends of shield ungrounded



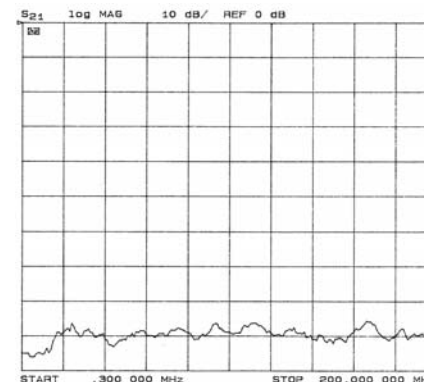
Both ends of shield grounded with 3" loop (60 nH)



Both shielded ends grounded with 1" loop (19 nH)



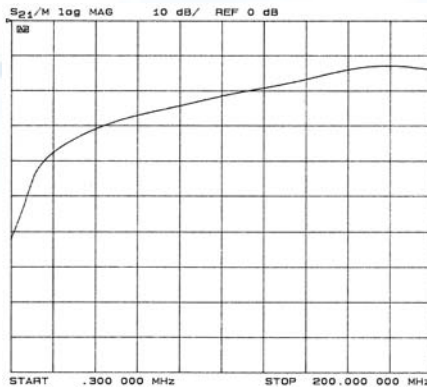
Both ends of shield directly grounded



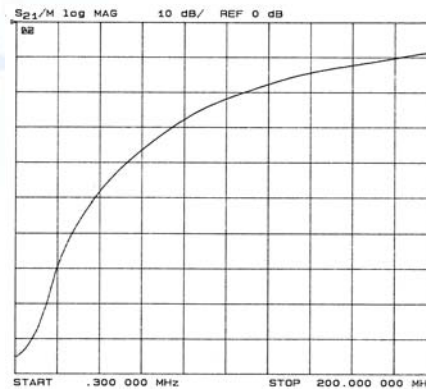
Continuous shield with both ends of grounded directly

Coupling Example #2, 0.3-200 MHz

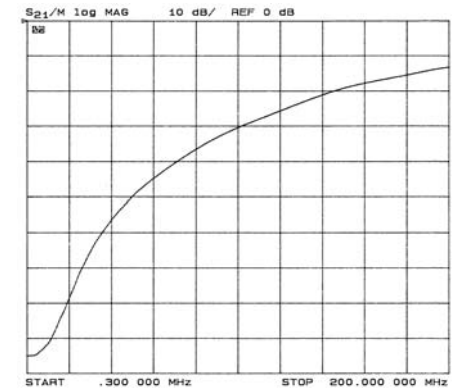
- ◆ Two Parallel Lines, One shielded, One unshielded
 - 0.5" Over Ground Plane, 10" Long, Separated by 0.5"
 - Shielded Line has 0.5" exposed



Both ends of shield ungrounded



Both ends of shield grounded with 3" loop (60 nH)



Both shielded ends grounded with 1" loop (19 nH)



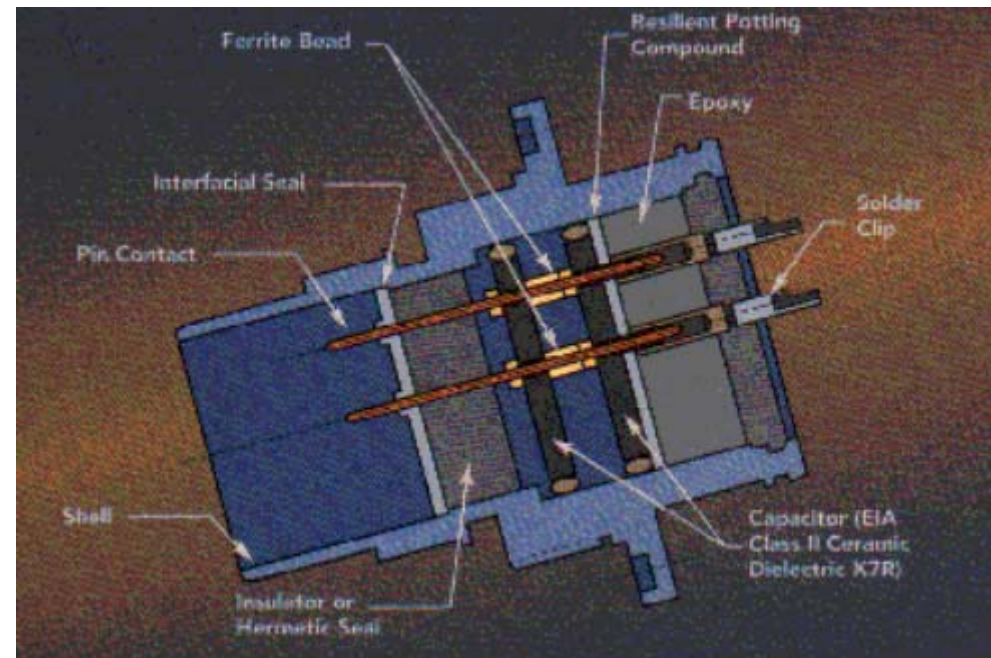
Both ends of shield directly grounded



Continuous shield with both ends of grounded directly

Filter Connectors

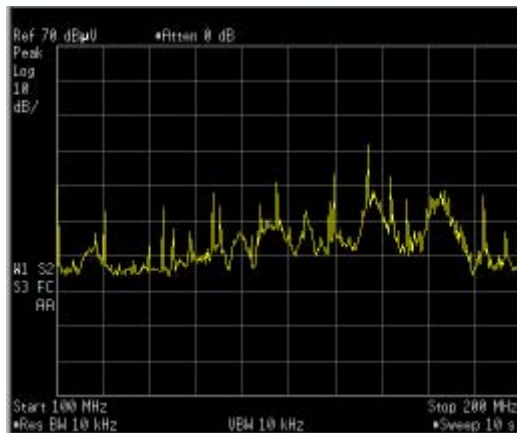
- ◆ Applications for connectors with integral filtering and/or transient suppressors
 - Shields not permitted on interconnection cables
 - Isolation needed between assemblies (WRAs, LRUs)
- ◆ Filtering effectiveness is typically much better than discrete filters
 - Parasitics
 - Interconnection Coupling (between filter & connector)



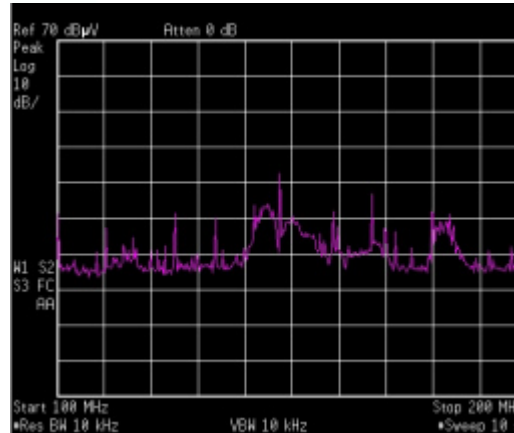
Courtesy of G&H Technology

Discrete Filter vs. Filter Connector

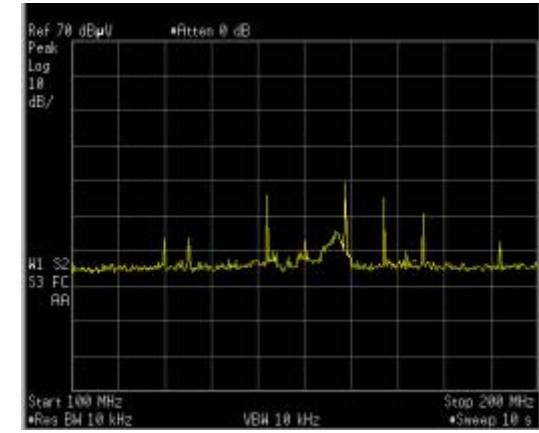
- ◆ Portable RADAR System, I/O Cables Unshielded
- ◆ RADAR Headset cable interferes with 100 - 200 MHz Communication band



Baseline



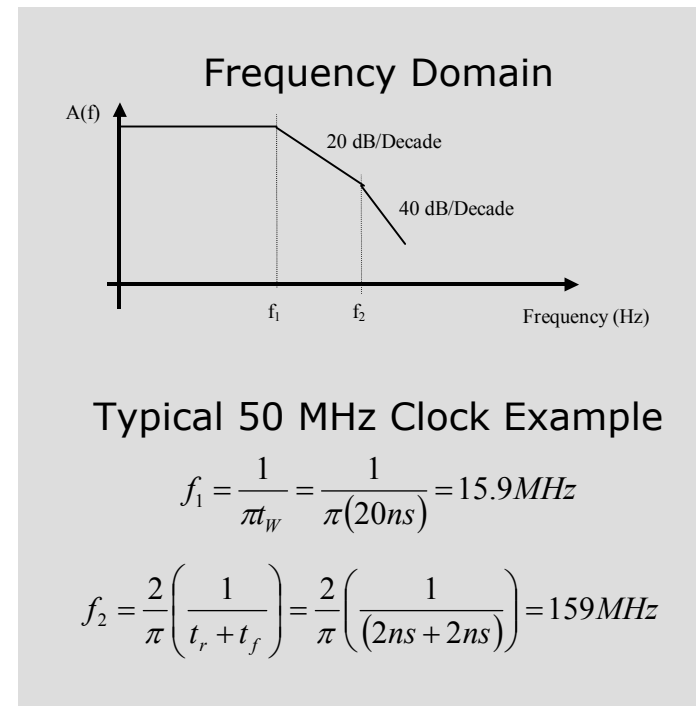
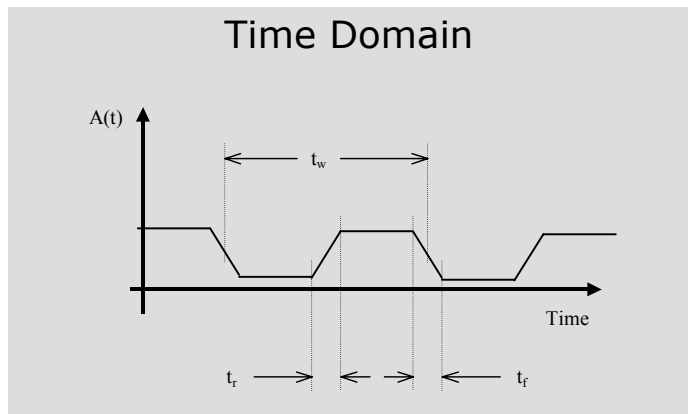
Discrete LC Filter at
Connector
(1nH, 8200p)



Filter Connector
(1nH, 8000 pF)

Signal Spectra & Filter Connectors

- ◆ Come in many types and filter capabilities
 - Filter Topologies: Pi, C, LC
 - Various cutoff frequencies
 - In some cases, not larger than standard non-filtered version
- ◆ Selection Considerations
 - Spectrum of Signals
 - Source/Sink Capability of Driver
 - Source/Load Impedances
 - Cable effects



EMC Design Process

Design Process

- ◆ Starts with a System/Device Specification
 - Describes the applicable EMC Requirement(s)
- ◆ Develop and Implement an EMC Control Plan
 - Details EMC Requirements and clarifies interpretation
 - Lists applicable documents
 - Defines management approach
 - Defines the design procedures/techniques
 - EMC design is most efficiently accomplished when considered early in the program
- ◆ Process Example
 - Intended for large system
 - Can easily be tailored for smaller system or a single device.

EMC Design Flow Diagram

System/Device
Specification

- EMC Engineer may need to be involved with SOW and/or specification prior to contract award.

Generate
EMC/EMI
Control Plan

- Cull EMC Requirements from System/Device Specification and clarifies interpretation
- Summarize applicable documents, specifications and standards
- EMC Program Organization and Responsibilities
- Defines design procedures and techniques

Mechanical Design

Electrical Design

System Design

Chassis/
Enclosure

- Shielding
- Material Selection
- Gasketing
- Covers

Bonding
and
Grounding

- Single vs. Multi Point Ground
- Chassis component bonding

Hardware
Partitioning and
Location

- System functional allocation
- Separation of analog, RF, digital and power

PWB Layout
and
Construction

- Micro-strip, stripline
- Number of layers
- Ground layers
- Separation of analog, RF, digital and power

Power
Conversion and
Distribution

- Conversion Topology
Linear, Resonant, PWM
- Connector Selection
Filter/Non-Filter
- Filter location/type

Signal
Distribution

- Single Ended, Differential
- Logic Family
- Connector Selection
Filter/Non-Filter
- Filter location/type
- Cable harnessing and shielding
- Signal Spectrum

Typical EMC Engineer's Involvement

♦ Prepare EMC Section of Proposal	<i>Pre-Award</i>
♦ Contract/SOW Review and Recommendations	
♦ Interference Prediction	<i>Design</i>
♦ Design Testing	
♦ Interference Control Design	
♦ Preparation of EMC Control Plan	
♦ Subcontractor and Vendor EMC Control	
♦ Internal Electrical and Mechanical Design Reviews	
♦ EMC Design Reviews with the Customer	
♦ Interference Testing of Critical Items	
♦ Amend the EMC Control Plan, as Necessary	
♦ Liaison with Manufacturing	<i>Manufacture</i>
♦ In-Process Inspection During Manufacturing	
♦ Preparation of EMC Test Plan/Procedure	<i>Test</i>
♦ Performance of EMC Qualification Tests	
♦ Redesign and Retest where Necessary	
♦ Preparation and Submittal of EMC Test Report or Declaration	

References

References

- ♦ "New Dimensions in Shielding", Robert B. Cowdell, IEEE Transactions on Electromagnetic Compatibility, 1968 March
- ♦ "Alleviating Noise Concerns in Handheld Wireless Products", Tony Armstrong, Power Electronics Technology, 2003 October
- ♦ "Electromagnetic Compatibility Design Guide", Tecknit
- ♦ "Metals Galvanic Compatibility Chart", Instrument Specialties
- ♦ "EMI Shielding Theory", Chomerics
- ♦ "Shield that Cable!", Bruce Morgen, Electronic Products, 1983 August 15
- ♦ "Interference Coupling - Attack it Early", Richard J Mohr, Electronic Design News, 1969 July
- ♦ "Simplified Method of Analyzing Transients in Interference Prediction" H.L. Rehkopf, Presented at the Eighth IEEE Symposium of EMC, San Francisco, CA, 1966
- ♦ "Electronic Systems Failures & Anomalies Attributed to EMI" NASA Reference Publication 1374

Committees and Organizations

- ♦ Comité Internationale Spécial des Perturbations Radioelectrotechnique (CISPR)
- ♦ Federal Communication Commission (FCC), www.FCC.gov
- ♦ European Union, www.Europa.eu.int
- ♦ Radio Technical Commission for Aeronautics (RTCA)
www.RTCA.org
- ♦ National Association of Radio & Telecommunications Engineers (NARTE), www.NARTE.org

Gasket and Shielding Vendors

- ◆ www.Chomerics.com  
- ◆ www.LairdTech.com 
- ◆ www.Tecknit.com 
- ◆ www.Spira-EMI.com 
- ◆ www.WaveZero.com 
- ◆ www.LeaderTechInc.com 

Backshell Vendors

- ◆ www.SunBankCorp.com
- ◆ www.TycoElectronics.com



Filter Connector Vendors

- ◆ www.GHtech.com



- ◆ www.SpectrumControl.com



- ◆ www.Amphenol-Aerospace.com



- ◆ www.EMPconnectors.com



- ◆ www.Sabritec.com

