EMI

- What are the repercussions
- What applications are prone to EMI
- Know what specifications apply to you
- Types of filters
- Basic circuits of “Low Pass” filters
- I/O impedance & selection criteria
- Propagation Modes & Methods of suppression
- Timing impact
What are the repercussions?

- Cause catastrophic system failure in avionics equipment, or a piece of medical instrumentation may provide a false vital sign on a patient's condition.

- This electrical energy could simply cause poor quality reception, & possible dropped calls and other system deteriorating.
What applications are prone to EMI?

- Microcell Repeaters
- RF Amplifiers
- Linear Power Amplifiers
- Digitally Tuned Oscillators
- Switching Power Supplies
- Frequency Synthesizers
- Medical Electronics
- Automotive Controls
Standards & Specifications

North America

- FCC Part 15- Telecommunications Industry
- FDA Regulations: Medical Industry
- Mil - STD- 461 and DO160: Military and Aerospace Industry
Standards & Specifications Cont’d.

European Regulations
European Directive 89/336/ EEC: Regulation for all electronic devices and electrical equipment used in Europe. All products imported to the European community must conform to these regulations.

Generic Emissions
- EN 50081-1: Residential, Commercial, & Light Industrial
- EN 50081-2: Industrial Environment

Specific Emissions
- EN 55011: Conducted & Radiated for Industrial, Scientific & Medical
- EN 55014: Conducted & Radiated for Household Appliances
- EN 55022: Conducted & Radiated for Information Technology Equipment
- EN 60555-2/3: Harmonics & Voltage Fluctuations in Household Equipment. Deals with Power Factor Corrections
Standards & Specifications Cont’d.

European Regulations Cont’d

Generic Immunity

- EN 50082-1: Residential, Commercial, & Light Industrial
- EN 50082-2: Industrial Environment

Specific Immunity

- EN 61000-4-1: Basic Immunity document, not a specific test
- EN 61000-4-2: ESD, Electrostatic Discharge
- EN 61000-4-3: Radiated RF Fields, radiated immunity
- EN 61000-4-4: EFT, Electrical Fast Transients, AC mains and I/O cable conducted immunity.
- EN 61000-4-5: Surge, AC mains conducted immunity
- EN 61000-4-6: Conducted RF Fields
- EN 61000-4-8: Power frequency magnetic field immunity
- EN 61000-4-9: Pulsed magnetic field immunity
- EN 61000-4-10: Damped Oscillatory field immunity
- EN 61000-4-11: Voltage dips, interruptions, and variations
Methods of Suppression

- PCB Layout
- Shielding & Grounding
- Filtering
Types of Filters

- **High Pass**
  - Frequency $f_0$
  - StopBand

- **Band Reject**
  - Frequency $f_0$
  - StopBand

- **Band Pass**
  - Frequency $f_0$
  - StopBand

- **Low Pass**
  - Frequency $f_0$
  - StopBand
The Basic Circuits of Low Pass Filters Using a 50 ohm Source & 50 ohm Load

**Single Element Filter**
- **Insertion Loss vs Frequency**
- **20 dB per Decade**

**“L” Section**
- **“L” Section**
- **2 Element Filters**
- **40 dB per Decade**

**Pi**
- **“T” Section**
- **3 Element Filters**
- **60 dB per Decade**
The Basic Circuits of Low Pass Filters
Using a 50 ohm Source & 50 ohm Load

4 Element Filters
Ideal Characteristics

Insertion Loss vs Frequency

2 X “L” Section

80 dB per Decade

Double Pi

100 dB per Decade

Double “T”
# I/O Impedance & Selection Criteria

<table>
<thead>
<tr>
<th>Input Impedance (Zi)</th>
<th>Output Impedance (Zo)</th>
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</thead>
<tbody>
<tr>
<td><strong>High</strong></td>
<td><strong>High</strong></td>
</tr>
<tr>
<td></td>
<td>Feedthru</td>
</tr>
<tr>
<td></td>
<td>Pi</td>
</tr>
<tr>
<td></td>
<td>Double Pi</td>
</tr>
<tr>
<td></td>
<td><strong>Low</strong></td>
</tr>
<tr>
<td></td>
<td>“L” Section</td>
</tr>
<tr>
<td></td>
<td>2 X “L” Section</td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td><strong>High</strong></td>
</tr>
<tr>
<td></td>
<td>“L” Section</td>
</tr>
<tr>
<td></td>
<td>2 X “L” Section</td>
</tr>
<tr>
<td></td>
<td><strong>Low</strong></td>
</tr>
<tr>
<td></td>
<td>Coil</td>
</tr>
<tr>
<td></td>
<td>“T” Section</td>
</tr>
<tr>
<td></td>
<td>Double “T”</td>
</tr>
</tbody>
</table>
Propagation Modes

Radiated Emissions

- Emitting Equipment
- Susceptible Equipment
Methods of Suppression

Radiated Emissions - Shield

- Emitting Equipment Shielded
- Susceptible Equipment Shielded
Propagation Modes

Conducted Emissions

Emitting Equipment

Susceptible Equipment

Signal Lines

Power Lines
Methods Of Suppression

Conducted Emissions - Filters

Signal Line Filters

Emitting Equipment Filtered

Susceptible Equipment Filtered

Signal Lines

Power Lines

Power Line Filters
Propagation Modes

Radiated Conducted

Emitting Equipment

Susceptible Equipment

Peripheral Equipment

Signal Lines
Methods of Suppression

Radiated Conducted-Shield / Filters
Propagation Modes

Conducted Radiated

Emitting Equipment

Peripheral Equipment

Susceptible Equipment
Methods of Suppression

Conducted Radiated - Filter / Shield

- Emitting Equipment Filtered
- Peripheral Equipment
- Filters
- Susceptible Equipment Shielded
The further along in the design cycle, the more challenging & more costly the solution.

Consult and ask questions from the go, it may save you a considerable sum of money in design time and components.
The Ten Commandments of Electromagnetic Compatibility
Ten Commandments of Electromagnetic Compatibility

1. Create control plan and tabulate all known frequencies and waveshapes to predict EMI profile.

2. Filter Power Lines at immediate entry point.

3. Filter all I/O lines and signal lines with selected tailored passband response filters.

4. Design all modules to have an aluminum stiffener backplane under P.C board that bonds to printed circuit commons.

5. Use multilayer boards wherever possible to contain fast rise time energy.
Ten Commandments of Electromagnetic Compatibility

6. Monitor Surface resistively of plating on all metal finishes to maintain less than 3 milliohms per square centimeter R.

7. Install ferrite cores / beads over input power lines and signal lines, coax lines etc. to minimize common mode emissions.

8. Twist all pairs of wires at 18 turns per foot to minimize magnetic pickup.

9. Shield and wiper ground / bond all backplanes and interfaces to modules.

10. Close or interbond all apertures and gaps longer greater than Lambda (wavelength) / 20.
Ten Commandments of Electromagnetic Compatibility

1. Create control plan and tabulate all known frequencies and waveshapes to predict EMI profile.
### 1992 European EMC Standards

Emission Standards: EN 55 022 Class B (Conducted Emission Radiated Emission)

<table>
<thead>
<tr>
<th></th>
<th>Freq Range</th>
<th>Limits</th>
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<tbody>
<tr>
<td><strong>Radiated</strong></td>
<td>30 - 230 MHz</td>
<td>30 dB µV/m @ 10 m</td>
</tr>
<tr>
<td></td>
<td>230 - 1000 MHz</td>
<td>37 dB µV/m @ 10 m</td>
</tr>
<tr>
<td><strong>Conducted</strong></td>
<td>0.15 - 0.5 MHz</td>
<td>66 → 56 dBµV quasi pk</td>
</tr>
<tr>
<td></td>
<td></td>
<td>56 → 46 dBµV ave</td>
</tr>
<tr>
<td></td>
<td>0.5 - 5 MHz</td>
<td>56 dBµV quasi pk</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46 dBµV ave</td>
</tr>
<tr>
<td></td>
<td>5 - 30 MHz</td>
<td>60 dBµV quasi pk</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 dBµV ave</td>
</tr>
</tbody>
</table>
Time Domain

- **AMPLITUDE**
  - A
  - A/2

- **TIME**
  - Tr = 5 ns
  - T = 100 ns
  - 4.08 MHz = f_o

- **Formulas**
  - \[ f_o = \frac{1}{T_o} = 245 \text{ nSECOND} \]

- **Pulse**
  - 100 ns PULSE @ 4.08 MHz
  - 5 nano second Risetime
Frequency Domain

Amplitude

Frequency Domain

Slope = 20 dB/decade

Slope = 40 dB/decade

Frequency in MHz

\[ \frac{1}{\pi T} \quad \frac{1}{\pi T_r} \]
## 4.08 MHz Expected Harmonics

<table>
<thead>
<tr>
<th>$n^a$</th>
<th>FREQ.</th>
<th>$n^a$</th>
<th>FREQ.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f = 1$, $\pi T = 3.183$ MHz</td>
<td>4.08</td>
<td>$40 \text{ dB/decade}$</td>
<td>21</td>
</tr>
<tr>
<td>100 dBμV</td>
<td></td>
<td>2</td>
<td>8.16</td>
</tr>
<tr>
<td>20 dB/decade</td>
<td>3</td>
<td>1224</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1632</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>2040</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>2448</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>2856</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3264</td>
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<td></td>
<td>9</td>
<td>3672</td>
<td>29</td>
</tr>
<tr>
<td>10</td>
<td>4080</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>11</td>
<td>4488</td>
<td></td>
<td>31</td>
</tr>
<tr>
<td>12</td>
<td>4896</td>
<td></td>
<td>[65 \text{ dBμV}, \quad f = 2 \pi \frac{1}{T}, \quad f = 127.32 \text{ MHz}]</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>5304</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>5712</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>6120</td>
<td>34</td>
</tr>
<tr>
<td>77 dBμV, $f = 1$, $\pi T = 63.662$ MHz</td>
<td></td>
<td>35</td>
<td>142.80</td>
</tr>
<tr>
<td>40 dB/Decade</td>
<td>16</td>
<td>6528</td>
<td></td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>6936</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>7344</td>
<td></td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>7752</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>8160</td>
<td>[60.65 \text{ dBμV}, \quad 40 \text{ dB/decade}, \quad \text{(-16.35 dB)}]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>41</td>
</tr>
</tbody>
</table>

etc.

37 dBμV | 156 | 636.62

Frequency List
Ten Commandments of Electromagnetic Compatibility

2. Filter Power Lines at immediate entry point.
COMMON PENETRATION PATHS INTO EQUIPMENT

- INSULATED WIRE
- INSULATED, UNGROUNDED CABLE SHIELD
- GROUND CONDUCTOR
Wrong Power Filter Installation

DENOTES COUPLING FROM NOISY CIRCUITS BACK TO LINE

CABINET

POWER INPUT

LINE FILTER

INPUT POWER LINE FROM NOISY COUPLING
Correct Filter Installation

- CABINET
- LINE
- CLEAN LINE FILTER
- INPUT POWER LINE
- BACK TO CIRCUITS FROM NOISY COUPLING

DENOTES COUPLING FROM NOISY CIRCUITS BACK TO LINE

POWER INPUT

CLEAN LINE

LINE FILTER
3. Filter all I/O lines and signal lines with selected tailored passband response filters.
Chip Cap vs. Tubular
1000pF PI-Style vs. C-Style

Typical Insertion Loss
Chip Results Actual

Spectrum Control, Inc.
10,000pF Chip Cap Filter Plate
(Plate tested in a coaxial test fixture)
L-Section Filters

Insertion Loss (dB)

Frequency

1KHz 10KHz 100KHz 1MHz 10MHz

Decade

0 20 40 60

L-Section Feedthru
40dB/Decade Ideal Insertion Loss

20dB/Decade Ideal Insertion Loss

40dB 40dB(total)

20dB

Feedthru “C”

40dB
Pi-Section Filters

- **“Pi Section”**
  - 60 dB/Decade

- **“L-Section”**
  - 40 dB/Decade

- **Ideal Feedthru “C”**
  - 20 dB/Decade

---

**Graph Details**

- **Y-axis:** Insertion Loss (dB)
- **X-axis:** Frequency
  - 1KHz
  - 10KHz
  - 100KHz
  - 1MHz
  - 10MHz
Ten Commandments of Electromagnetic Compatibility

4. Design all modules to have an aluminum stiffener backplane under P.C board that bonds to printed circuit commons.
ALUMINUM GROUND PLANE FASTENED TO PRINTED CIRCUIT BOARD

- ALUMINUM GROUND PLANE
- CONTACTS/BUSHINGS (MANY PLCS.) TO COMMON GROUND OF BOARD (BRIDGES TO ALUMINUM GROUND PLANE)
- EDGE CARD CONNECTOR OR FILTER
- CIRCUIT BOARD
- FRONT PANEL

Panel Front Circuit Board

SPECTRUM CONTROL, INC.
5. Use multilayer boards wherever possible to contain fast rise time energy.
MULTILAYER PC BOARD PROVIDES I/O ISOLATION FROM POWER GROUND
LAYER 3 SERVES AS Vcc COMMON
Ten Commandments of Electromagnetic Compatibility

6. Monitor Surface resistively of plating on all metal finishes to maintain less than 3 milliohms per square centimeter R.
SURFACE RESISTIVITY OF PLATING

<table>
<thead>
<tr>
<th>PLATING</th>
<th>8oz. Milliohms</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIN</td>
<td>.75 .77 .71 .8 .74</td>
</tr>
<tr>
<td>YELLOW CHROMATE</td>
<td>17 11 7 10 12 11</td>
</tr>
<tr>
<td>UNPLATED EDGE</td>
<td>1.6 1.8 2.0 2.2 1.7 1.8</td>
</tr>
</tbody>
</table>
Ten Commandments of Electromagnetic Compatibility

7. Install ferrite cores / beads over input power lines and signal lines, coax lines etc. to minimize common mode emissions.
Ferrite Beads
Ferrite Bead Filtering

- Select bead Z at Fo from Data Steward type 25 is 170 ohm @ 100MHz = Zf
- Determine

\[
\frac{Z_{source}}{Z_{load}} = \frac{100}{500} = 0.2 \quad \text{ohm}
\]

\[
20 \log \left( \frac{Z_{source}}{Z_{load}} + Z_{source} \right)_{\text{LOAD}} = 20 \log \left( \frac{100}{170 + 100 + 500} \right) = 2.16 \text{ dB}
\]

\[
20 \log \left( \frac{Z_{source}}{Z_{load}} + Z_{source} \right)_{\text{LT}} = 20 \log \left( \frac{100 + 15.41}{170 + 100 + 15.41} \right) = 7.86 \text{ dB}
\]
COMPARING MATERIALS
BO562-200

IMPEDANCE (Ohms)

FREQUENCY (MHz)
Impedence vs. DC Bias
Common vs. Differential Mode

![Graph showing Impedence vs. DC Bias between Common and Differential Mode.](image-url)
### Impedance vs. Frequency

#### 25B0562-2

<table>
<thead>
<tr>
<th>Property</th>
<th>Frequency Range MHz</th>
<th>Initial Permeability (μ)</th>
<th>Saturation Flux Density (B_s) Gauss</th>
<th>Residual Flux Density (B_r) Gauss</th>
<th>Coercive Force H_c</th>
<th>Curie Temperature (T_c) °C</th>
<th>Volume Resistivity (ρ) Ohm-Centimeters</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 Material</td>
<td>100 - 500</td>
<td>125</td>
<td>3650 @ 10 Oe</td>
<td>2600</td>
<td>1.6</td>
<td>≥ 225°C</td>
<td>10^8</td>
</tr>
<tr>
<td>28 Material</td>
<td>30 - 300</td>
<td>850</td>
<td>3350 @ 10 Oe</td>
<td>2200</td>
<td>0.4</td>
<td>≥ 175°C</td>
<td>10^5</td>
</tr>
<tr>
<td>29 Material</td>
<td>30 - 300</td>
<td>600</td>
<td>3300 @ 10 Oe</td>
<td>1500</td>
<td>0.35</td>
<td>≥ 165°C</td>
<td>10^9</td>
</tr>
</tbody>
</table>
Ten Commandments of Electromagnetic Compatibility

8. Twist all pairs of wires at 18 turns per foot to minimize magnetic pickup.
<table>
<thead>
<tr>
<th>Circuit</th>
<th>Relative Susceptibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0dB (REF.)</td>
</tr>
<tr>
<td>B</td>
<td>-2dB</td>
</tr>
<tr>
<td>C</td>
<td>-5dB</td>
</tr>
<tr>
<td>D</td>
<td>-49dB</td>
</tr>
<tr>
<td>E</td>
<td>-57dB</td>
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<tr>
<td>F</td>
<td>-64dB</td>
</tr>
<tr>
<td>G</td>
<td>-64dB</td>
</tr>
<tr>
<td>H</td>
<td>-71dB</td>
</tr>
<tr>
<td>I</td>
<td>-79dB</td>
</tr>
</tbody>
</table>

VALUES GIVEN ARE FOR CIRCUITS 1 INCH ABOVE GROUND PLANE
9. Shield and wiper ground / bond all backplanes and interfaces to modules.
SHIELD BACKPLANE WIPER GROUND CARD

- Shielded Interface Cables
- Metal Shield
- Ground Braid to Metal Shield
- Back Plane Printed Circuit Board
- Filtered Connector
- Card Guide
- Card Ground Wipers

Spectrum Control, Inc.
Ten Commandments of Electromagnetic Compatibility

10. Close or interbond all apertures and gaps longer greater than Lambda (wavelength) / 20.
GAP (4"")

FREQ.  Max. Gap
120 MHz  4.92"
600 MHz  0.98"
1.5G Hz  0.394"
3.0 GHz  0.197"

\[
\frac{3 \times 10^8 \times 39.37}{\text{FREQ.}} = \lambda \\
\frac{\lambda}{20} = \text{Aperture Max.}
\]

simplified

\[
\frac{591}{F \text{ MHz}} = \text{Max. Gap Inches}
\]
Spectrum Control Contacts

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Tel – 866-281-0288
E-mail – showers@spectrumcontrol.com