Demystifying Automotive EMC Applications: Filtering and Decoupling Strategies

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ABSTRACT

Automotive EMC is a unique subset in the field of EMC that has both stringent requirements and cost-reduction pressures. Most automotive products require low-cost innovative approaches to meet OEM requirements. This presentation will highlight several automotive products/applications and detail proven low-cost strategies for filtering and decoupling by answering two questions:

- What are we trying to do?
- Are we following fundamental EMC concepts?
Review – What is dB?

dB level is a logarithmic way of expressing power and voltage ratios.

<table>
<thead>
<tr>
<th>dB level</th>
<th>power ratio</th>
<th>dB level</th>
<th>voltage ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$X_{dB} = 10 \log_{10} \left( \frac{X}{X_0} \right)$</td>
<td></td>
<td>$X_{dB} = 20 \log_{10} \left( \frac{X}{X_0} \right)$</td>
</tr>
<tr>
<td>-30 dB</td>
<td>1/1000 = 0.001</td>
<td>-30 dB</td>
<td>$\sqrt{1/1000} = 0.03162$</td>
</tr>
<tr>
<td>-20 dB</td>
<td>1/100 = 0.01</td>
<td>-20 dB</td>
<td>$\sqrt{1/100} = 0.1$</td>
</tr>
<tr>
<td>-10 dB</td>
<td>1/10 = 0.1</td>
<td>-10 dB</td>
<td>$\sqrt{1/10} = 0.3162$</td>
</tr>
<tr>
<td>-3 dB</td>
<td>1/2 ≈ 0.5</td>
<td>-3 dB</td>
<td>$\sqrt{1/2} = 0.7071$</td>
</tr>
<tr>
<td>3 dB</td>
<td>1.995 ≈ 2</td>
<td>3 dB</td>
<td>$\sqrt{2} = 1.414$</td>
</tr>
<tr>
<td>10 dB</td>
<td>10</td>
<td>10 dB</td>
<td>$\sqrt{10} = 3.162$</td>
</tr>
<tr>
<td>20 dB</td>
<td>100</td>
<td>20 dB</td>
<td>$\sqrt{100} = 10$</td>
</tr>
<tr>
<td>30 dB</td>
<td>1000</td>
<td>30 dB</td>
<td>$\sqrt{1000} = 31.62$</td>
</tr>
</tbody>
</table>

The conversion for decibels is often simplified to: "+3 dB means two times the power and 1.414 times the voltage", and "+6 dB means four times the power and two times the voltage".
dB to Impedance (ohms) Conversion

\[ |\text{Insertion Loss}| = 20 \log_{10} \left( \frac{|\text{Impedance}|}{25 \Omega} \right) \]
Characteristic Impedance of a Basic Capacitor

\[ Z_0 = R + j \omega L - j \frac{1}{\omega C} \]
What to expect from a component

Ideal Cap

Real Cap

Mounted Cap in Circuit
Magnitude & Phase (Smith Chart Evaluation)

\[ Z_0 = \left( \frac{R + jwL}{G + jwC} \right)^{1/2} \]

- **Real Axis**
- **Imag. Axis**

**Inductive**

**Capacitive**

ESR
Magnitude & Phase (Smith Chart Evaluation)
What are we trying to do?

- We want to understand the influence of parasitics on decoupling and filtering components from a system EMC perspective.

- This will allow better control of system:
  - Model/predict circuit behavior
  - Design more effective circuits
  - Properly locate components
  - Use fewer components
  - Reduce costs
  - Reduce development times
Are we following fundamental EMC concepts?

- As EMC Engineers we are really System Engineers looking at and identifying current loops.
- Minimizing and controlling current loops involves identifying parasitics and paths caused by parasitics.
- Parasitics can be broken into 2 categories within a System:
  - Packaging (mounting) parasitics
    - Pad geometries
    - Via locations and numbers
    - Trace routing
    - PCB plane depth
    - Location of components
  - Inherent (component) parasitics
    - Component technology
    - Physical component geometry
    - Current loop
# Loop Area and SRF of a Leaded Capacitor

<table>
<thead>
<tr>
<th>Capacitor Type And Value</th>
<th>Total Lead Length (mm)</th>
<th>Self Resonant Frequency (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Disk Capacitor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>470 pF &amp; 0.01 uF</td>
<td>25.4</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>12.7</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>6.35</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>151</td>
</tr>
<tr>
<td><strong>Monolithic Capacitor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>470 pF &amp; 0.01 uF</td>
<td>25.4</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>12.7</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>6.35</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>190</td>
</tr>
</tbody>
</table>

Slide courtesy of Jastech-EMC, LLC.
Mounting (packaging) Parasitics of Surface Mount Technologies on a PCB

- Mounting (packaging) geometries such as:
  - Location of vias-to-pads
  - Number of vias
  - Trace connection
- change parasitics in the current loop.

- The effect on the system is:
  - Shifting SRF
  - Shifting resonances
  - Over-all performance
Mounting (packaging) Parasitics of SM Technologies on a PCB
Mounting Parasitics in PCB

- PCB geometries such as plane stack-up and plane depth add to the current loop of components in a circuit.

- Below shows the difference when the upper most dielectric thickness is varied (3, 6, & 12 mils) between the component and uppermost plane.
Multiple Components Used to Construct EMI Filter

- Each Multi-Layer Ceramic Capacitor (MLCC) measured individually
- Total (5) MLCC = 0.398uF
- X2Y® total capacitance value = 0.44uF
- Note: package size differences

Multi-Layer Ceramic Capacitor (MLCC) cumulative measured
- Total (5) MLCC = 0.5uF
- X2Y® total capacitance value = 0.44uF
- Note: package size differences

Measurements made on 50ohm Coplanar PCB with Ground Plane.
Analysis of Components to System Performance – Mounted (package) Parasitics

The following slides discuss mounted (package) parasitics. Looking specifically at the 3 L(s):

- Loop
- Leads
- Location
Motor Filter Example #1

Automotive washer pump motor

Radiated Emissions 100MHz - 1GHz

Frequency

Power Leads #1

Power Leads #2
Motor Filter Example #2

Automotive convertible top motor
Connector Filter Example

![Connector Filter Example Image]
Initial Filter Results – Automotive Load Box

Temporary Filter Solution
30 MHz – 200 MHz

Typical Filter Solution
200 MHz – 300 MHz

Attend the Technical Paper presentation:
Thursday, August 03, 2006
2006 IEEE EMC Symposium
Automotive EMC (TH-PM-SS)
1:30 - 5:30 pm

Automotive Product
Load Box Tester
CISPR 25 – Radiated

X2Y® Filter Solution
30 MHz – 200 MHz

X2Y® Filter Solution
200 MHz – 300 MHz

For other application information: visit our website www.x2y.com
Connector Filter Example

Automotive product load box
PCB Filter Example – What NOT to do
Example – What NOT to do
PCB Filter Example – What NOT to do

Good Layout

BAD Layout
Analysis of Components to System Performance – Inherent (component) Parasitics

Basic Capacitor Characteristic Impedance is:

\[
Z_o = R + j \omega L - j \frac{1}{\omega C}
\]

- 3 parasitics to look at:
  - Capacitance
  - Inductance
  - Resistance
Automotive CANBus Common-Mode-Choke (CMC) Filter

EMI Filter Elements:
- CMC (ZJYS81R5-2PL51T-G)

Tx – blue
Rx – Red
CANH – Green
CANL – Pink
Automotive CANBus Capacitive Filter

EMI Filter Elements:
- X2Y [47pF]
- Tx – blue
- Rx – Red
- CANH – Green
- CANL – Pink
Instrumentation Amplifier (IN-Amp)
Common Mode Rejection Ratio (CMRR)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>X2Y® 10nF</th>
<th>Discrete film 10nF + 220pF + 220pF</th>
<th>Common Mode Choke</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC offset shift</td>
<td>&lt;0.1μV</td>
<td>&lt;0.1μV</td>
<td>360μV</td>
<td>Referred to input</td>
</tr>
<tr>
<td>Common mode rejection</td>
<td>91dB</td>
<td>92dB</td>
<td>69dB</td>
<td></td>
</tr>
</tbody>
</table>
Inherent Component Parasitics
(Component Technologies)

- Capacitance is needed to supply energy.
- As frequency increases, the effect the internal inductance increases. Thus the capacitive energy is reduced from the circuit.
- Less inherent inductance means the less capacitance a component needs to supply energy to the circuit.
- MLCC Technology needs 10 to 20% of the capacitance value compared to surface mount electrolytic or tantalum.

Comparison of MLCC Technology

What works? What doesn’t?

Things to consider:

- Standard MLCC – Package Size
- Reverse-Aspect-Ratio (RAR) [Low-Inductance Caps]
- Ultra-Low Inductance Capacitor Technology
Smaller is better – 0603 has less inductance than 0805, 1206, 1812.

To meet total capacitance requirements typically small caps increase the number of caps needed. (Package size limits number of layers.)

Larger number of caps require more vias & greater distance from IC. (More PCB space)
Std vs. RAR vs. Ultra-Low MLCC Technology

| Component | Configuration | Performance
|-----------|---------------|--------------
| 0508      | 4 Via         |              
| 0603      | 6 Via         |              
| 0612      | 4 Via         |              
| X2Y®      | 6 Via         |              

- 0508 100nF
- 0603 100nF
- 0612 100nF
- X2Y® 0603 56nF

Frequency (MHz)
Internal Parasitics Affecting other Components

Measurements made on 50ohm Coplanar PCB with Ground Plane.

(2) MLCC 1206 100nF (End-to-End)
(2) MLCC 1206 100nF (Side-by-Side)
X2Y 1206 100nF
What would a component with 1/10\textsuperscript{th} inherent parasitics over standard MLCCs offer us?
Ultra-Low Inductance Capacitor Replacement of Low- and Mid-freq Caps

Note: X2Y 0603 capacitive values greater than 0.4uF currently under development.
Check List – Are we following fundamental EMC concepts?

- Impedance Value @
  - DC
  - Frequency of Interest
  - Across Frequency Spectrum

- Break-down of Z values and Inherent Parasitic Values @
  - DC
  - Frequency of Interest
  - Across Frequency Spectrum
  - Over Temperature
  - DC Bias
  - Aging
  - Cross-talk attenuation
  - DC Loss

- Component Model
  - Valid over the frequency spectrum
  - Valid for environmental factors

- System Parasitic Values
  - Parasitic relationship to other circuit elements
  - Parasitic relationship to packaging (mounting) parasitics
  - Predictable Lead/Lag
  - Location of component(s)
  - Current Loop
  - Break-down Impedance (parasitic - C, L, & R)

- How impedance measured:
  - 50 ohm system?
  - Test fixture used
# Example of a System Cost/Build-of-Materials (BOM)

<table>
<thead>
<tr>
<th>Cost/Build-of-Materials (BOM)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of cap</strong></td>
</tr>
<tr>
<td><strong>Number of vias</strong></td>
</tr>
<tr>
<td><strong>Placement Cost</strong></td>
</tr>
<tr>
<td><strong>PCB real-estate</strong></td>
</tr>
<tr>
<td><strong>Number of layers for routing</strong></td>
</tr>
<tr>
<td><strong>Assembly time</strong></td>
</tr>
<tr>
<td><strong>Number solder joints</strong></td>
</tr>
<tr>
<td><strong>Number via drills</strong></td>
</tr>
<tr>
<td><strong>Number pick-and-place machines</strong></td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
</tr>
<tr>
<td><strong>Number of attachments</strong></td>
</tr>
<tr>
<td><strong>solder joints</strong></td>
</tr>
<tr>
<td><strong>Number of vias</strong></td>
</tr>
<tr>
<td><strong>Number of components</strong></td>
</tr>
</tbody>
</table>
Questions/More Information

For more information, contact Jim Muccioli or Dale Sanders:

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phone: 248-489-0007
e-mail: x2y@x2y.com

Look for App Notes, tech papers, and more information @

www.x2y.com

or sign-up for:

Cost Effective EMI Suppression Techniques for DC Motors Course

June 25, 2007
Instructor:
Jim Muccioli

For more information:

www.jastech-emc.com
Biography

- **James Muccioli** – Chief Technology Officer with X2Y Attenuators, LLC for the past 8 years and has over twenty-five years of specialized experience in EMC design, analysis and testing, both with Daimler Chrysler, United Technologies, and Jastech-EMC Consulting. He has taught EMC courses at Lawrence Technical University and the University of Michigan-Dearborn as well as seminars through Jastech-EMC Consulting, LLC (www.jastech-emc.com). He is inventor or co-inventor of 19 Patents while at Daimler Chrysler and numerous adaptations on the X2Y® Technology. He holds a BSEE and a MSEE degrees from the University of Michigan. Currently he is Chairman of the SAE Integrated Circuit EMC Task Force and an active member of SAE J-1113/J-551 EMC committees as well as a NARTE certified EMC and ESD engineer. He has served on the Board of Directors for the IEEE EMC Society and received an IEEE Fellow in 1998 for contributions to integrated circuit design practices to minimize EMI.

- **Dale Sanders** – Applications Engineer with X2Y Attenuators, LLC for the past 4 years. His responsibilities include specialized component testing, high frequency fixture design, application prototyping, and technical review/consulting on products for EMC compliance. He holds a BSEE from the University of Michigan-Dearborn where he helped construct the EMC Lab facility. He is an active member of the IEEE EMC Society as well as associate member of the SAE EMR committee. He has published numerous technical papers and articles at symposiums and in trade journals as well as a technical presenter for workshops.