Shielding Theory and Design
EMC Fundamentals

Definitions

• Electromagnetic Interference, (EMI)
  • The undesirable effect due to an electrical signal other than the desired signal

• Electromagnetic Compatibility, (EMC)
  • The ability to operate in an intended environment without being disturbed or disturbing other equipment

• Radio Frequency Interference, (RFI)
  • Interference to communication/radio bands

Emissions

• Energy generated by an electrical device’s operation
  • Conducted - Transmitted by a conductive medium
  • Radiated - Transmitted by an electromagnetic field

Immunity

• A measure of how resistant an electrical device is to external fields

Susceptibility

• A measure of how susceptible a device is to external fields
EMC Fundamentals

To have an EMI problem, three elements are necessary:

• Source
• Coupling path
• Receptor

The amount of emission “leakage” from an aperture depends upon three main items:

• The maximum linear dimension (not area) of the aperture
• The wave impedance
• The frequency of the source

Multiple Apertures

Reduction of shielding depends upon:

• The spacing between the apertures
• Operating frequency
• The number of apertures within $\lambda/2$

When apertures of equal size are placed close together (within $\lambda/2$), the shielding loss is approximately proportional to 20 times the log of the number of apertures.
To have an EMI problem, three elements are necessary:

- Source
- Coupling path
- Receptor

<table>
<thead>
<tr>
<th>Sources</th>
<th>Coupling Path</th>
<th>Receptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microprocessors</td>
<td>Radiated EM fields</td>
<td>Other logic circuits</td>
</tr>
<tr>
<td>Video drivers</td>
<td>Capacitance</td>
<td>Analog circuits</td>
</tr>
<tr>
<td>ESD</td>
<td>Inductance</td>
<td>Receivers</td>
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<td>Power supplies</td>
<td>Conducted</td>
<td>Reset lines</td>
</tr>
<tr>
<td>Lightning</td>
<td>“Ground”</td>
<td>Equipment</td>
</tr>
</tbody>
</table>
**MAXWELL EQUATIONS**

- Forms the building blocks of understanding electromagnetic theory by defining the relationship among charges, currents, magnetic and electric fields.
  - Gauss’s Law - There are + and - electric charges (flux) out of a surface proportional to the charge within the surface
  - Faraday’s Law - Any change in the magnetic environment of a coil will cause a voltage (emf) to be "induced" in the coil.
  - Ampere’s Law - A current flow creates a magnetic field.

- They are functions of three space variables (x,y,z) and time (t).

- They relate time-varying electric and magnetic fields to current and voltage.

*HyperPhysics is hosted by the Department of Physics and Astronomy*

[http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html](http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html)
A time varying electric field between two conductors represented as a capacitor.

A time varying magnetic field between two conductors represented by mutual inductance.

- A potential difference causes a current to flow which generates a magnetic field which, in turn, creates an electric field.
- For a time-varying field, we always have both an electric field and a magnetic field.

An RF voltage potential will cause a time varying current – generating magnetic field, developing a time varying transverse electric field, creating the electromagnetic field.
The Electromagnetic Wave

H-Field (magnetic)
E - Field (electric)
PW - Field (plane wave)
EF, HF, & Plane Wave

- The Electric Field (high impedance), Magnetic Field (low impedance), and Plane Wave (377 Ohm) are the three aspects of EMI/RFI wave propagation. Different shielding levels result from variations in wave impedance.

- Electric Field and Magnetic Field impedance change with separation distance.

- Plane Wave impedance is constant with separation distance.
Half-Wavelength Sized Emission

Full-Wavelength Sized emission

Equipotential Bands
Antenna Pattern Lobes
Typical Cross-Talk Problem

Digital Control Section

Sensitive Analog Section
Board Level Shielding

Metal shield soldered to P.C.B.

Digital Control Section
Sensitive Analog Section

P.C. Board grounding layer

Rayleigh-Helmholtz & Carson reciprocity theorem:

- Resolving radiated emission problems will also aid in resolving radiated immunity problems
Reciprocity - Emission and Immunity

Reciprocity

- Rayleigh-Helmholtz & Carson reciprocity theorem
  - Same frequency
  - Medium is linear, passive, and isotropic

- If a signal is applied and transmitted through antenna A and measured at another antenna B; an equal signal will be measured at antenna A if the same signal is transmitted through antenna B

- Basically means that resolving radiated emission problems will also aid in resolving radiated immunity problems
The Problem with a Partial Shield

Constructive interference makes signal stronger on this side.

- PCB Trace
- Radiated field with no shielding.
- Improvement on the shielded side.
- Radiated field with shielding on one side.

Reflections
Shielding Material
(Graphical Representation)

Note: If $A \geq 6$ dB then $B = 0$

ABSORPTION:
$$A \text{ (dB)} = 3.338 \times t \left( \mu r \sigma r F \right)^{1/2}$$

PLANE WAVE REFLECTION:
$$R_P \text{ (dB)} = 108.1 - 10 \log \left( \frac{\mu r F}{\sigma r} \right)$$

WHERE:
- $t =$ Thickness in mils
- $\mu r =$ Relative permeability
- $\sigma r =$ Relative conductivity
- $F =$ Frequency (MHz)
R.F. Current flowing through a conductor is non-uniform.

Current density is highest at the surface, and becomes exponentially smaller with depth into the conductor.

The parameter quantifying this occurrence is called ‘Skin Depth’ (δ).
Definition of Skin Depth

\[ \delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \]

where:

- \( f \) = Frequency (Hz)
- \( \sigma \) = Conductivity (Siemens)
- \( \mu \) = Permeability (of material relative to air)

Each skin depth equals approx 37% of the amplitude of the propagating wave through the material.

Skin effect increases as frequency and amplitude of the losses increase therefore at higher harmonic frequencies there is a greater degree of heating in a conductor.
Skin Depth v.s. Frequency
For Common Shielding Materials

Material Dominates
Holes Dominate

Smaller is Better

Frequency (Hz)
Skin Depth (mm)
Copper
Mild Steel
Aluminum
Stainless Steel
## Common Shielding Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Typical Uses</th>
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<tbody>
<tr>
<td>Magnetic Alloys</td>
<td>CRT’s, Coils, Transformers</td>
</tr>
<tr>
<td>Mild Steel</td>
<td>Computers, Telecom Racks</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Avionics, Portable Equipment</td>
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<tr>
<td>BeCu</td>
<td>Shielding gaskets</td>
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<tr>
<td>Stainless Steel</td>
<td>Snap-In Covers, Grounding Strips</td>
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<tr>
<td>Flame Spray Coatings</td>
<td>Plastic Housings</td>
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<tr>
<td>Metallic Plating</td>
<td>Small Plastic Housings</td>
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<tr>
<td>Filled Plastics</td>
<td>ESD Shielded Housings</td>
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<tr>
<td>Conductive Paint</td>
<td>Architectural, Plastic Housings</td>
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</tbody>
</table>
Holes (apertures) within a shielded enclosure
Shield Aperture Leakage

- The amount of leakage from an aperture depends upon three main items:
  - The maximum linear dimension (not area) of the aperture
  - The wave impedance
  - The frequency of the source
Current Flow Around a Slot

Fringing field. A fraction of the current radiates across the slot instead of going around it.

Area of high current density. Impedance is higher here.
Shielding Effectiveness = 20 \log_{10} \left( \frac{\lambda}{2L} \right)

\lambda = \text{Wavelength} = \frac{C}{F}
F = \text{Frequency}
C = \text{Speed of Light} = 3 \times 10^8 m/sec
L = \text{Longest Dimension}
Multiple Apertures

Reduction of shielding depends upon:
- the spacing between the apertures
- the frequency
- the number of apertures

When apertures of equal size are placed close together (within $\lambda/2$), the shielding loss is approximately proportional to 20 times the log of the number of apertures.
Aperture Attenuation Modeling Program
We saw the need for a software design tool to assist engineers in the initial shielding design stage of their electronic product.

A modeling program that we can input the products’ frequency of concern, aperture size, and quantity of apertures for connectors and/or heat management of the shield or enclosure.

An output indicating approximate but conservative shielding levels prior to expensive radiated emission and/or susceptibility testing.

A graph of aperture attenuation (dB) vs. frequency (MHz).
**APERATURE ATTENUATION MODELING PROGRAM**

**Shielding Effectiveness for apertures (holes) in a shield**

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Wavelength (λ)</th>
<th>1/2 wavelength (λ/2)</th>
<th>Holes</th>
<th>Hole size</th>
<th>Hole Attenuation Calculation</th>
<th>Shielding Effectiveness</th>
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<tbody>
<tr>
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<td>5.5014</td>
<td>2.5607</td>
<td>5</td>
<td>0.040</td>
<td>74.7148</td>
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<td>5.3649</td>
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<td>5</td>
<td>0.040</td>
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<td>68.8695</td>
<td>13.9754</td>
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**Shielding Effectiveness for apertures (slots) in a shield**

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Wavelength (λ)</th>
<th>1/2 wavelength (λ/2)</th>
<th>Slots</th>
<th>Slot size</th>
<th>Slot Attenuation Calculation</th>
<th>Shielding Effectiveness</th>
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<tbody>
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<td>4</td>
<td>1.000</td>
<td>26.4759</td>
<td>12.9412</td>
</tr>
</tbody>
</table>

**Holes** — **Slots**

Follow the 3 steps below to calculate Shielding Effectiveness of holes and/or slots for printed circuit board shields. The shaded areas are variable, all other cells are protected. The holes usually represent air vent holes, slots usually represent folded metal corners or fence stand-off areas. If an aperture is an irregular shape use it's largest length for (l in.)

1. Enter from 1 (minimum), to 10 (maximum), the frequencies of interest in a MHz format for holes and/or slots in the spreadsheet below.
   **Note:** Because of the calculation used for wavelength, always use MHz in the frequency column, i.e. 6 GHz is 5000 MHz etc....

2. Enter the number of holes and/or slots within the calculated 1/2 (1/2 wavelength) circular area for each frequency entered.

3. Enter the hole and/or slot maximum diameter or length.

Recommendation: In general a slot or hole size should not exceed 0.02 x 1/4 of the highest frequency (λ in.) of concern. As for all mathematical models, final radiated testing prior to new product release or final redesign is necessary for valid EMC compliance.

[Image of graph showing shielding effectiveness for holes and slots]

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(877) MAJR PRO Toll Free
An important aspect of a shielding effectiveness modeling:

- To verify theoretical shielding calculation error with a radiated emission of a shielded product under test
- Analyze results
- Adjust calculations to reduce shielding error based on analysis of the actual test
- Keep in mind that even though important to reduce errors every radiated set-up is unique and incorporates its own anomalies such as reflections, resonances, coupling, VSWR losses, etc…
Antenna 2, Far Field Circuit Isolation
Specific transceiver technologies for the cellular industry

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Circuit Isolation (dB)</th>
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<tbody>
<tr>
<td>1500</td>
<td>0</td>
</tr>
<tr>
<td>1600</td>
<td>10</td>
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<tr>
<td>1700</td>
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<td>2400</td>
<td>90</td>
</tr>
<tr>
<td>2500</td>
<td>100</td>
</tr>
</tbody>
</table>

Dynamic Range Level
- Pin Mount
- Pin Mount (half pins)
- Surface Mount
- Surface Mount (half tabs)
- Surface Mount (corners soldered)

PCB Shield Measurement

- GPS 1575.42
- TDMA / GSM 1850 - 1990
- WCDMA 1920 - 2170
- Bluetooth 2402 - 2480

Frequency (MHz)

60 dB
43 dB
Aperture Attenuation Program

<table>
<thead>
<tr>
<th>Test Factor</th>
<th>Aperature</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>40</td>
</tr>
</tbody>
</table>

- Factor of 1 = 1.7 dB
- Factor of 5 = 8.46 dB
- Factor of 10 = 15 dB

Shielding Effectiveness Graph of Aperature Effects for an Enclosure or Printed Circuit Board Shield
### Shielding Effectiveness for apertures (holes) in a shield

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Wavelength (l in.)</th>
<th>1/2 Wavelength (l/2 in.)</th>
<th>Holes</th>
<th>Hole size within l/2 (l in.)</th>
<th>Hole Attenuation Calculation</th>
<th>Shielding Effectiveness of holes (dB)</th>
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</thead>
<tbody>
<tr>
<td>1000</td>
<td>11.8028</td>
<td>5.9014</td>
<td>20</td>
<td>0.200</td>
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### Shielding Effectiveness for apertures (slots) in a shield

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Wavelength (l in.)</th>
<th>1/2 Wavelength (l/2 in.)</th>
<th>Slots</th>
<th>Slot size within l/2 (l in.)</th>
<th>Slot Attenuation Calculation</th>
<th>Shielding Effectiveness of slots (dB)</th>
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<tr>
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<td>0.400</td>
<td>3.3779</td>
<td>12.9412</td>
</tr>
</tbody>
</table>

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e-mail: sales@majr.com
Honeycomb Ventilation Panels
Attenuation of Plated Honeycomb Shielding Panels

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Field</th>
<th>Alum H/C Chromate Plating (dB)</th>
<th>Alum H/C Nickel Plating (dB)</th>
<th>Alum H/C Tin Plating (dB)</th>
<th>Steel H/C Tin Plating (dB)</th>
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</tr>
<tr>
<td>1 GHz</td>
<td>PW</td>
<td>35</td>
<td>90</td>
<td>90</td>
<td>100+</td>
</tr>
</tbody>
</table>
Attenuation of Shielding Panels

Ventilation Aperatures

- Honeycomb
- Perforated metal
- Screening
- 6.0 inch opening

Frequency

- 10 kHz
- 100 kHz
- 1 MHz
- 10 MHz
- 100 MHz
- 1 GHz

Shielding Effectiveness

- 120
- 110
- 100
- 90
- 80
- 70
- 60
- 50
- 40
- 30
- 20
Shielding Products and Materials

MAJR Products Corporation

An internationally recognized manufacturer of Shielding Products

Offering:
EMI/RFI Honeycomb Ventilation panels
Shielded windows
Knitted wire mesh gaskets
Multicon oriented wire gaskets
Conductive fabric gaskets
Board Level Shields
EMC Consulting
Fingerstock gaskets
Conductive Elastomer
Die-Cut gaskets
Grounding washers
Thermal materials
Ferrites and RF Absorber

www.majr.com
REFERENCES

Acknowledgment for partial assembly of this presentation: Ron Brewer, Gary Fenical, Ed Nakauchi, and Bill Stickney

ELECTRONIC SYSTEM DESIGN: INTERFERENCE AND NOISE CONTROL TECHNIQUES

DIGITAL DESIGN FOR INTERFERENCE SPECIFICATIONS
R. Kenneth Keenan - Pinellas Park, FL: TKC, 1983

DECOUPLING AND LAYOUT OF DIGITAL PRINTED CIRCUITS
R. Kenneth Keenan - Pinellas Park, FL: TKC, 1985

INTERFERENCE CONTROL IN COMPUTERS AND MICROPROCESSOR BASED EQUIPMENT
Michel Mardiguian - Gainesville, VA: Interference Control Technologies, 1984

NOISE REDUCTION TECHNIQUES IN ELECTRONIC SYSTEMS

ELECTROMAGNETIC WAVES

EMC HANDBOOK VOL III EMI CONTROL METHODS AND TECHNIQUES

EMI CONTROL IN THE DESIGN OF PRINTED CIRCUIT BOARDS AND BACKPLANES

ANSI/IPC-D-275: DESIGN STANDARD FOR RIGID PRINTED BOARDS AND RIGID PRINTED BOARD ASSEMBLIES, SEP 1991
Institute for Interconnecting and Packaging Electronic Circuits - Lincolnwood, IL

IPC-D-316: DESIGN GUIDE FOR MICROWAVE CIRCUIT BOARDS UTILIZING SOFT SUBSTRATES, NOV 1994
Institute for Interconnecting and Packaging Electronic Circuits - Lincolnwood, IL

IPC-D-317A (DRAFT): DESIGN GUIDELINES FOR ELECTRONIC PACKAGING UTILIZING HIGHSPEED TECHNIQUES, JAN 1995
Institute for Interconnecting and Packaging Electronic Circuits - Lincolnwood, IL
Thank you:

Questions or Comments

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