EMC and Wireless Systems

- Antenna basics and transmission lines.
- EMC of Electronic Modules.
- Communication channel parameters.
- EMC of communication systems.
- EMC Challenges / opportunities for the future.
Wireless System Antennas

- Typical schematic symbol for antenna is shown at left.
- This is used to represent a general antenna – additional information may be included based on application (such as “gain” attributes).
Antenna Purpose

- The antenna is connected to the end of the transmission line.
- Antenna is the method to transfer energy from the transmitter/receiver to the “medium” (air).
Antenna Basics

• Most wireless system antennas are designed to utilize the electric field component of E/M wave for communication.

• This type of antenna can be represented as an “open” capacitor.
Antenna Performance

- Antenna performance is generally a “reciprocal” process – if the antenna works well to transmit a signal, it will work well on receiving a signal.
Electrical and Physical Size

- Many antennas are physically constructed to be a specific length corresponding to the signal wavelength.
- Typical antennas are multiples of $\frac{1}{4}$ of a wavelength, for “resonant” conditions.
Electrical Model of Antenna Parameters

- An antenna can be represented just like any other type of electrical component.
- Can be expressed as a complex impedance load:
  \[ Z_{\text{ant}} = R_r + jX \text{ (ohms)} \]

Where:

- \( R_r \) is the “Radiation Resistance” (a derived value describing how effective the antenna is in transferring power to/from the medium)
- \( jX \) is the value of the sum of the reactance (due to series inductance and capacitance).
Description of Antenna Parameters

- $R_r$ of ¼ wavelength antenna (typically called a monopole) is about 37 ohms.
- Antenna reactance is the “$jX$”, and is the same as a series resonant circuit.
  - When the antenna length is physically shorter than ¼ wavelength, $jX$ is negative and antenna “looks” capacitive.
  - When “$jX = 0$” the antenna is “resonant”.
Antenna / Transmitter Interface

- Antenna ("E-field" antenna shown) is connected to the transmitter via a transmission line.
- Objective is to send/receive power/signal with minimal loss from/to transmitter/receiver.
Transmission Line Types

- "Coaxial" cable consists of an inner conductor and an outer conductor *that also functions as a shield*. 
- "Twin Lead" consists of two identical conductors and is a "balanced" cable.
Transmission Line Model

- Electrical representation of a transmission line consists of distributed inductance, capacitance, and resistance.
  - Is a result of cable geometry, and conductor material.
  - Transmission line impedance determined by values of the equivalent circuit.
Transmission Line Metrics

• Transmission lines are characterized in terms of impedance, and is a function of a per-unit length of inductance (L), capacitance (C), and resistance.
  – A simplified expression for impedance is (neglecting resistance of the conductors) is $Z = (L/C)^{1/2}$.
  – Note that $Z$ does not depend on the length of line.

• Example: RG-58 cable has a specified capacitance of 23 pf/ft, $Z= 50$ ohms, and “TV Twin lead” has a specified capacitance of 4.5 pf/ft, $Z=300$ ohms.
EMC of Electronic Modules

• Early boards used “stick lead” components - now use many surface mount devices (SMD).
• Conductors are created by on the surface of the printed (PCB) circuit board layers.
PCB Properties – “Parasitics”

• Every conductor (“trace”) on a PCB has real characteristics of:
  – Resistance: Determine by trace conductivity.
  – Capacitance: Determined by spacing to other traces and dielectric of board.
  – Inductance: Determined by the geometry of the current loop.
PCB Properties - Capacitance

- Traces have coupling due to electric fields.
- Maximum coupling occurs between largest areas ("plates of a capacitor").
- Largest area typically called "Ground Plane".
PCB Properties - Inductance

- Energy is stored in magnetic field around conductor.
- Magnetic Flux lines can couple to adjacent conductors (similar to a transformer).
- Trace length and width determines the geometry of the flux lines (determines the current loop area).
Representation of PCB Parasitic Inductance and Capacitance

- Inner and outer layer traces can have coupling to each other.
- Current return planes may be placed on the outside of the board.
A “transmission line” is represented by any pair of wires or conductors.

Goal is to characterize impedance of line.

Evenly Distributed \( R, L, G \) & \( C \) – \( Zo = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \)
Current Paths on PCB’s

• All currents return to their source.
• PCB traces exhibit impedance \((R + jX)\).
• Current Paths:
  – At low frequency - path of least \(R\).
  – At high frequency – path of least \(Z\).
• For traces containing high frequency located over a return plane – current return minimizes loop inductance.
Typical PCB Parasitic Values

- Capacitance between traces/conductors:
  - Approximately 3 pF / inch.
  - Dependent upon trace separation.

- Inductance of a trace:
  - Approximately 15 nH / inch.
  - Can vary by ½ to 2 times, dependent upon current loop geometry.
PCB “Crosstalk”

- Occurs when energy from traces couple to other traces.
- May be due to capacitance, inductance, or combination of both.
  - Capacitance coupling result of parallel traces.
  - Inductive coupling result of trace loops in same planes.
- Can occur from same layer, or different layers.
Components and PCB’s

- “Ideal” and “Real” components may have very different characteristics in high speed circuits.
- Traditional resistor (shown below) is represented by only resistance.
Resistor Actual Impedance!

Impedance of a 50-Ohm Resistor

EMC and Wireless Systems
“Ideal” and “Real” components may have very different characteristics in high speed circuits.

Traditional capacitor (shown below) is represented by only capacitance.
Capacitor Actual Impedance!

Impedance of a 0.01-μF Capacitor

EMC and Wireless Systems
Components and PCB’s

- “Ideal” and “Real” components may have very different characteristics in high speed circuits.
- Traditional inductor (shown below) is represented by only inductance.
Inductor Actual Impedance!
Critical part of PCB is the ability to supply required power to circuit.

Digital device switching process can have significant power/current demands.

Switching currents can have high speed content.

Important to supply required current in required time.
PCB Power Distribution

- Power distribution system consists of three (3) main sections:
  - A – The power source.
  - B – The parasitic capacitance.
  - C – The parasitic inductance.
Goal is to be able to provide power when required, for the time required.

If power source is located away from digital device, series inductance may be too high.

Solution is to locate energy storage devices (capacitors) physically near devices requiring energy.

Locating capacitors is known as “decoupling”.
PCB Summary

- PCB is a critical part of electronic systems and its design / layout issues can:
  - Affect system functionality.
  - Prevent meeting signal processing requirements ("Signal Integrity").
  - Result in not meeting EMC requirements.
PCB Summary - Continued

• Component selection and placement important to PCB’s performance:
  – Not all components are created equal!
  – Need to understand component parasitic elements.

• Proper attention to both PCB AND COMPONENT SELECTION can help assure a successful product!
Three (3) types of propagation can occur: (1) Surface (ground), (2) Reflection (sky wave), (3) Space wave (line of sight).

Each type is typically a function of signal frequency (highest frequencies are line of sight).
**E/M Wave “Polarization”**

- Transmitter and receiver antenna polarization refers to the E field vector orientation.
- A monopole on a typical wireless device uses vertical polarization.
Electromagnetic Frequency Bands

- Much of today’s communication occurs from MF to UHF.
- MF/VHF/UHF used for broadcasting.
- UHF is used for handheld and mobile devices (phones, Wi-Fi).
Communication “Link Budget”

• The “link budget” determines the received-signal power for a line-of-sight communication link:

\[ Pt + Gt - L + Gr = Pr \]

Where:

- \( Pt \) = Signal power at transmitter output, in dBm
- \( Gt \) = Transmitter antenna gain, in dBi
- \( L \) = Propagation loss, dB
- \( Gr \) = Receiver antenna gain, in dBi
- \( Pr \) = Signal power at the receiver input, in dBm
Free-Space Propagation Loss ("Friis") Equation

- Allows determination of the expected minimum propagation path loss for "free space" conditions.
- Propagation Loss (in dB) = 20 log \(\frac{4\pi r}{\lambda}\)
  
  Where: \(r\) = distance, \(\lambda\) = signal wavelength
“Rayleigh Effects” on Propagation Loss

- The communication path can be significantly affected by objects in the line-of-sight.
- Typically expressed as: $\text{dB} = 40 + n \log (r)$, where $r$ is the path distance, $n$ is a function of wavelength.
Comparison of Friis to Rayleigh Effects

• For a transmitter / receiver system operating on 2.4 GHz, and with a range of about 5 km in free-space, due to Rayleigh Effects, this same signal would have a range of about 226 *meters*!  
  – Typical path loss impact due to various objects:  
    • Trees, 10 to 20 dB  
    • Walls, 10 to 15 dB  
    • Floors, 10 to 30 dB  

• Therefore, it is important to understand when to apply Free-Space or Rayleigh conditions to determine communication link performance.
Benefit of Digital Modulation Methods

- Digital systems can provide robustness to EMC issues in the communication link by error detection and correction methods as well as through bit-error-rate (BER) parameters.

- If a higher BER can be accommodated, this may allow minimal link budget values.

- Goal is an acceptable balance of transmitter / receiver specifications (such as sensitivity, signal to noise ratio), path loss, and BER.
“EMC” of Communication Systems

• The EMC of communication systems can be significant due to the “coexistence” challenges.
• Low level signals from distant devices may be not be received and high power systems may interfere.
Impact Upon “Link Budget”

- Link budget calculations can be significantly affected by interference sources.
- Can affect both the “channel” and the receiver performance.
Wireless System EMC - Summary

• The proliferation of wireless systems can result (ironically) in the demand for more immune/robust systems.

• System compatibility can be evaluated by understanding the basics of EMC as applied to other technologies.

• By understanding how antennas, transmission lines, and electromagnetic fields interact, the analysis of wireless system EMC can be accomplished.
Methods to Assure EMC

- EMC testing may be conducted on any systems containing electrical/electronic components (photos courtesy of ETS-Lindgren).

EMC and Wireless Systems
Applications of EMC Testing

- EMC testing may be done on any size component or system.
- EMC is important for systems designed for space exploration…..and….
..EMC Is Important for Earth Based Systems!

Zune 80 passes FCC!

by Conrad Quilty-Harper, posted Oct 30th 2007 at 4:12AM

The new Zune 80 has hit and passed the FCC and its rigorous series of emissions tests. Unfortunately you won’t see the usual slightly beat up shots in the documents this time: just a series of charts and plenty of data about "radiated emissions." Microsoft made sure to request that the FCC hold back from posting external / internal photos, the user manual, schematics, antenna specification, and well, anything interesting at all. At least any Zune fans out there can sleep safe at night knowing that when they pick up their own Zune 80, it won't burn their hand off in a blast of radiation.
EMC Challenges and Opportunities For The Future

- Understand the system’s intended use, application, parameters, and specifications.
- Perform an evaluation of system location with other devices present (and future plans).
- Know the applicable standards and regulations.

- In summary: An understanding of the basics of E/M and technology can provide the key to an effective and efficient EMC program that will enhance a product’s reputation and performance!