Welcome

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The Effect of Digital Noise on RF Receiver Sensitivity in Modern Smart-Phones Applications

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Agenda

Review of EMI/EMC basic definitions
Modern Smart phones and its design challenges
Investigation of digital-to-RF interference via EM simulations
A case study: Digital noise on Wi-Fi receiver sensitivity
Conclusion
Quick Review on EMI/EMC Definitions

EMI (Electro-magnetic Interference):

• Electromagnetic emissions from a device or system that cause another device or system to behave in an undesired manner, also referred to as Radio Frequency Interference (RFI)

EMC (Electro-magnetic Compatibility):

• The ability of a device or system to function satisfactorily in its electromagnetic environment with other electronic systems and not produce or be susceptible to interference
Two Types of Interferences

**Conducted**
- Power Lines
- Signal Lines

**Radiated**
- Magnetic
- Electric
- Planewave

Source (Culprit, emitter) → Transfer (Coupling Path) → Receptor (Victim, Receiver)
Why EMI/EMC becomes more important?

Increasing complexity and integration of electronic systems cause more issues with EMI/EMC

• Smaller and lower-power devices
• Increasing clock frequencies, faster slew rate
• Increasing packaging density

Increasing product weight and cost pressure

• Increased use of lower cost material
• Decreased use of good shielding due to lighter product designs

Physically debugging EMI/EMC issues in reverberant or anechoic chambers is time-consuming and costly
Common Characteristics of Modern Smart Phones

Very small form factor
• More compact/slim PCB

High trace routing density

Ever increasing clock speed and data rate
• DDR, HDMI, USB 3, SATA etc.

Complex multi-band and multi-mode designs
• WIFI, BT, GPS, GSM, UMTS, LTE etc.

Mixed RF/Analog and high-speed digital contents
Design Challenges of Smart Phones for EMI Compliance

Increased digital to RF interference

- Need to isolate digital and RF circuits from each other
- Need to mitigate digital to RF noise interference

Increased shared grounds

- Limited number of ground layers available on board

Smaller grounding area

Increased proximity effects
Problem Statement

“When the device is turned on and loading contents (involving CPU and DDR together), the Wi-Fi receiver sensitivity is affected!”
Understanding DDR2 Clock Signal in Frequency and Time Domain

Clock Frequency : 266MHz
Data Rate : 533Mbps

Clock contains high frequency components around 2.45GHz, which may act as the noise source.

Rise/Fall: 0.31ns and 0.26ns respectively
EM Simulation Technologies

FEM (Finite Element Method)
- Frequency Domain EM
- 3D Arbitrary Structures
- Full Wave EM Simulation
- Direct, Iterative Solvers
- Multiport simulation at no additional cost
- High Q

MoM (Method of Moments)
- Frequency Domain EM
- 3D Planar structures
- Full Wave and Quasi-Static
- Dense & Compressed Solvers
- Multiport simulation at no additional cost
- High Q

FDTD (Finite Difference Time Domain)
- Time Domain EM
- 3D arbitrary structures
- Full Wave EM simulations
- Handles much larger and complex problems
- Simulate full size cell phone antennas
- EM simulations per each port
- GPU based hardware acceleration

Best for EMI/EMC problems
EMPro FDTD Technology

Full 3D, Time Domain

Preparing a 3D structure:

- Complete simulation domain segmented using E and H fields as unknowns
- Boundary conditions to truncate simulation domain

Time stepping algorithm

- Alternating update of E and H field at each mesh cell, progressing in time until steady state time domain is reached
- No matrix solve
- Use FFT to obtain broadband S-parameters
Faster FDTD Simulation with GPU Acceleration

Simulation is multi-threaded on GPU cores
The speedup scales with # of GPU cards used
3~40 times typical simulation speed improvement
EM simulation Approaches to EMI

Perform S-parameter analysis with a broadband source at locations of suspected EMI sources and receptors

• Understand the frequency selectivity of PCB across broad frequency range

Find hot spots on PCB layers at the frequency of interest

• Pinpoint the areas for de-coupling capacitor locations and potential noise coupling path

Perform time-domain analysis with an actual digital CLK

• Understand the time-domain noise builds-up as time progresses
High frequency component of DDR clock noise may interfere with Wi-Fi, Bluetooth, and Antenna

S-parameter analysis technique will provide insight on the board’s frequency selectivity to DDR noise
Detailed S-parameter (Network) Analysis Setup

**Board’s Frequency Selectivity Response**

- **Apply 50-ohm load for collecting S-parameter**
- **Apply a broadband source**

**Clock Signal (Broadband Input)**

**Wi-Fi**

**Bluetooth**

**DDR**

**CPU**

**Ant**

**PCB**
Approach 2: Hot Spot Analysis

Find hot spots
Place de-caps

This example is from the paper, “Using CUDA Enabled FDTD Simulations To Solve Multi-Gigahertz EMI Challenges” by Davy Pissoort, Cheng Wang, Hany Fahany, and Amolak Badesha
Approach 3: Time-Domain Analysis with Differential Clock Signals

Excite the differential line at CPU BGA balls for DDR2 directly with time domain clock signal to understand time-domain behavior of PCB.
Result of Network Analysis: DDR to RF

Network analysis can reveal the board’s frequency susceptibility to DDR noise

![Network analysis graph](image-url)

**Plot Legend**
- Light Green: Wi-Fi
- Magenta: RF Ant
- Dotted Blue: Bluetooth
The frequency response of DDR2 to Wi-Fi, BT, and RF Ant proves the clock noise couples more to Wi-Fi than others.
Results of Hot Spot Analysis

Performed single frequency steady state analysis, which was at 2.45GHz

Various planar sensors were located on different PCB layers

Plot and investigate the conduction currents from the planar sensors for any hot spots
Result of Time Domain Simulation

Noise voltages are time-dependent and keep increasing due to multiple paths available for coupling.
Possible Approaches for EMI Reduction

Shielding/grounding improvement for reduced radiation

De-coupling capacitor placement

Apply advanced packaging technology such as PoP (Package on Package) that combines CPU and DDR in a single package

Courtesy of TI
Effect of Shielding on Radiation at 2.45GHz

Proper shielding could reduce the radiation approximately 3.8dB
Effect of Shielding on Radiation at 2.45GHz

Azimuth Cut Radiation Plot

Direction of Reduction

Radiation Plot Without Shielding

Radiation Plot With Shielding
Effects of De-caps on Hot Spots

Without De-caps placement

With De-caps placement

Reduced Hot Spots
Effect of De-caps on Radiation at 2.45GHz

De-caps could reduce the radiation approximately 1.5 dB
Conclusion

Digital signal (including clocks) noise to RF may reduce the receiver’s sensitivity unexpectedly.

PCB’s network analysis through EM simulations provides a great insight and potential ways to reduce digital to RF noise coupling.

With a proper shielding and the use of de-caps, EMI can be significantly reduced, for example, 5dB as shown in this case study.
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Q&A

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Nine videos covering 3D drawing, FEM simulation, FDTD simulation, Python scripting, etc
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