Layout-Based Chip Emission Models Using RedHawk

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Introduction

Microcontroller power integrity models serve two requirements:

- Chip/package design evaluation and improvement
- Printed circuit board design evaluation and improvement
Introduction

- Microcontroller power integrity models for PCB design evaluation...
  - provide noise profiles from chip activity
  - are pin-accurate
  - fill the gap left by IBIS models
  - must cover all noise coupling paths
We distinguish among 6 types of noise coupling:

- **Galvanic noise coupling:**
  - Origin = Core activity → Noise visible on core supply
  - Origin = I/O activity → Noise visible on I/O supply

- **Noise crosstalk:**
  - Origin = Core activity → Noise visible on I/O supply
  - Origin = I/O activity → Noise visible on core supply
  - Origin = Core activity → Noise visible on I/O signals
  - Origin = I/O activity → Noise visible on I/O signals
Emission Test Setup

- Emission measurements follow BISS specification:
  - Conducted emission → IEC 61967-4 (150Ω method)
  - Radiated emission → IEC 61967-2 (Mini-TEM cell method)
  - Combi test board for both tests
  - Test patterns provide scaling of core and I/O activity
Emission Measurement Results

- 4 of the 6 cases are considered in our study
- Microcontroller behaviour seen as follows:
  - Significant core noise from clock system (case 1)
  - Low crosstalk of core noise to I/O supply (case 3)
  - Significant I/O noise from switching pads (case 2)
  - Significant crosstalk of I/O noise to core supply (case 4)
For IC and PCB design validation and optimization, the conducted emission provides more useful information than the radiated one.

Emission measurement results are documented by voltage over frequency spectra.

PCB simulation results using the IC emission model (ICEM) are correlated with measurement results for 4 out of the 6 cases.

A good model quality is indicated by good agreement of simulation and measurement results.
We use the following setup:

- Board design
  → Sigrity Speed2000

- Package design
  → AutoCAD → MCM

- Chip design & activity
  → Apache RedHawk → Spice
Model validation happens in several steps:

- Impedance simulation vs. measurement of bare PCB
  → PCB model ok

- Impedance simulation vs. measurement of PCB with empty package
  → Package model ok

- Impedance simulation vs. measurement of fully assembled PCB
  → Component models ok

Now we are ready for microcontroller noise simulations
Microcontroller Emission Model

- Generic ICEM is built from current sources and pin impedances
- Various tool approaches have been started in the past:
  - IC-Emit (INSA)
  - NEMO and EXPO (Infineon)
  - XcitePI (Sigrity)
  - RedHawk CPM (Apache)
- All these approaches differ in the grade of accuracy:
  - The ideal ICEM should be based on the full chip/package layout data
  - Due to the IC complexity, the first attempts used layout partitioning and estimated current signatures
  - Today, layout extraction and activity simulation allow the generation of realistic accurate models
Apache Chip Power Model (CPM) uses the following IC design data:
- DEF files
- LEF files of std. cells, memories, IPs
- LIB files of std. cells, memories, IPs
- GDS files for memories and IPs
- Technology files
- Signals SPEF/DSPF
- Timing data from STA
- Apache Power Library (APL) of std. cells, memories, IPs (auto-char. from SPICE simulations)
- Design constraints of power supply & chip activity (toggle rates or VCD)
- Package model

Microcontroller under test:
- 130nm CMOS process, 7 metals
- Size 7938 µm x 7876 µm
- 612k Instances
- 10k Filler cells
- 289k Decap cells
Chip Power Model: Construction

- The Apache CPM is an important step towards a full ICEM:
  - Gate-level noise profiles by pre-characterization including supply voltage stepping allow realistic switching scenarios
  - Layout extraction of resistance, capacitance, self and mutual inductance allows dynamic voltage drop and inter-domain noise coupling
  - Switching activity is controlled by VCD patterns or vectorless assumptions, distinguishing between glue logic and clock tree
Chip Power Model: Configurations

■ Configuration 1
- Chip Power Model contains all VDD & VSS pads with:
  - Characteristic impedances
  - Core activity current sources
  - Pre-characterized I/O current source connected to chip I/O power supply
- This model is lacking on-board charge/discharge currents from pad driver

■ Configuration 2
- Consists of configuration 1 plus additional IBIS model of pad driver
- This model supports on-board charge/discharge currents from pad driver
Simulation Result Case 1

- Core noise to core supply coupling is simulated with very good matching to measurement.
- This was expected since the CPM is generated from core layout data and thus reflects the coupling path very well.

![Conducted Emissions at VDDC, Core active, I/Os inactive](image)
Simulation Result Case 4

- I/O noise to core supply coupling is simulated with good matching to measurement.
- This was expected since the CPM is generated from core layout data and thus reflects the coupling path very well.

![Conducted Emissions at VDDC, Core and I/Os active](image)

**Case (4)**

- Simulation with IBIS
- Simulation w/o IBIS
- Measurement
Simulation Result Case 2

- I/O noise to I/O supply coupling shows bad matching to measurement.
- This was expected since the CPM per se is unable to stimulate the I/O signal trace on the PCB, thus it lacks high frequency noise.
- Good RF correlation was achieved by adding the pad driver IBIS model.
- 160 MHz mismatch will be addressed by improved CEM pad models.
Conclusion

- 6 noise coupling cases are needed for full IC emission characterization
- Validation of chip emission models are done by measurement correlation
- Emission measurement setup (PCB, package, chip) must be modelled
- Model validation starts with PCB, then IC package, last chip
- PCB and package models have been proven to be accurate
- EDA tools are unable to achieve good simulation accuracy for all 6 cases
- Together with IC vendors, chip emission models must be improved
- Remaining cases 3, 5, 6 are addressed by RedHawk CEM release