Improve Device Performance Using Power Integrity Test Tools

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Power Integrity (PI)

**WHAT ARE WE TALKING ABOUT**

**Power Integrity:** The study of the *conversion*, *delivery* and *consumption* of DC power in an electronic system. *Kenny Johnson, Keysight*

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Product Functional Reliability α Quality of the system power

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ADS 3D model of power distribution network (PDN) for simulating power integrity
Why is Power Integrity critical to your design
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**WHY?**

- Moore’s Law: transistors on an integrated circuit will double every two years.
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WHY? POWER AND CURRENT DENSITY

- Operating voltages are decreasing to reduce power and/or in support of finer pitch IC processes.

![Diagram showing voltage tolerances and power savings over time.](image-url)
• Power supply noise causes clock/data jitter

Example 1:

Switching Threshold Variation

Input

Output

Jitter

Example 2: CPU/APU/µ

Variations in core voltages cause variations in propagation delay through the gates of the processor.

Decrease of gate propagation delay

Increase of gate propagation delay

Power Supply Tolerances

Jitter

Jitter

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Switching loads can cause high frequency supply noise with content easily exceeding 1GHz.

Power rails must be stable from DC to the BW of the switching current.
• PDN is likely to be the biggest conducting structure.
• PDN is likely to carry high current.
• PDN is likely to have high frequency noise.
A well designed PDN will maintain a stable voltage (within tolerance) from DC to the bandwidth of the switching current (typically above 1GHz).

This will help:
- Optimize power consumption
- Minimize switching noise (SSN—simultaneous switching noise)
- PSIJ (dropped bits, missed clock …)
- Minimize EMI problems

Therefore, one the primary validation tasks is measuring power rail quality.
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**PDN THEORY AND MODELING**

\[ Z_{\text{target}}(f) = Z_{PDN}(f) < \frac{V_{\text{Ripple}}}{I(f)} \]

\[ I_{\text{transient}} \sim (1/2)^*I_{\text{max}} \]

\[ I_{\text{peak}} = P_{\text{max}}/V_{dd} \rightarrow Z_{\text{target}}(f) = \frac{2^*(V_{dd})^2*(\text{ripple}\%)}{P_{\text{max}}} \]
PDN Impedance

PDN Impedance measurement at IC position.

DC-DC converter

Large decoupling capacitor
Middle and Small size capacitor

Feedback loop

Middle and Small size capacitors
PCB plane Capacitor and Inductance

PDN Impedance(Ω)

PDN Impedance measurement at IC position.

Log Freq(Hz)

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SIGNIFICANCE OF DC POWER

Compromise the flow and the system malfunctions

Battery
3.7V
5V
Docking Station
12V

Processor & WiFi
2.5V
5V
1.8V/1.1V/0V

Memory
5V
1.8V/1.1V/0V

Sensors
12V

1.8V/1.1V/0V

Common carotid arteries
Internal carotid artery
External carotid artery
Internal jugular vein
External jugular vein
Vertebral arteries
Subclavian artery
Subclavian vein
Cephalic vein
Axilla
Atrial artery
Thoracic artery
Suprarenal veins
Intercostal veins
Descending aorta
Brachial artery
Basilic vein
Median cubital vein
Cephalic vein
Radial artery
Ulnar artery
Palmar digital veins
Digital artery
Pulmonary arteries
Pulmonary veins
Heart
Celiac trunk
Hepatic veins
Renal veins
Renal artery
Gonadal artery
Common iliac artery
Common iliac vein
Internal iliac artery
Internal iliac vein
External iliac artery
External iliac vein
Gluteal superior veins
Pronal vein
Pronal artery
Popliteal vein
Popliteal artery
Small saphenous vein
Anterior tibial artery
Popliteal artery
Peroneal artery
Anterior and posterior tibial veins
Dorsal venous arch
Dorsal digital veins
Power Sequencing
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ADDED COMPLEXITY—POWER SEQUENCING

Power Sequence Specification
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POWER MANAGEMENT IC (PMIC)

- Battery Voltage Monitor
- Temperature Sensor
- Battery Charger
- Camera Flash/Torch
- I²C/PMBus Interface
- Backlight Driver
- ADC
- Audio CODEC
- Power Manager
- Sequencer
- Dynamic Voltage Scaling
- Smart Power Selector
- Buck 1
- Buck 2
- Buck N
- LDO 1
- LDO 2
- LDO N

Remote Sensing on POL

Battery

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PMIC IS THE TRAFFIC OFFICER
Power Integrity Test Flow
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Typical Test Flow

- Power Good
- Power Up/Down Sequence
- Power Rail Quality
- Current Consumption, Energy Efficiency
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POWER-GOOD USING MXR DVM
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TYPICAL TEST FLOW

Power Good

Power Up/Down Sequence

Power Rail Quality

Current Consumption, Energy Efficiency
PMIC Testing

POWER SEQ.—EX. 8 RAILS, PERSISTENCE & DIGITAL

Digital Persistence
- No analog information
- No statistics (run/run variations)

Issues
- Uncertainty
- Time consuming
- Not repeatable/human error

Infinite Persistence
- No 'count' of occurrences
- Manually place markers to determine pass/fail

Issues
- Uncertainty
- Time consuming
- Not repeatable/human error

Mask Test
- Failures clearly identified
- Number of pass/fail measured
- Mask represents specification tolerances

Issues
- Only one mask available
PMIC Testing

POWER SEQUENCE TESTING—MASK ON EVERY CH.

Mask for every channel
• Saves time
• Eliminates uncertainty
• Complete test report in one screen shot

Automask
• Saves time
• Simple and easy mask setup
PMIC Testing

POWER SEQUENCE TESTING—MASK ON EVERY CH.
PMIC Testing

POWER SEQUENCE TESTING—ΔTIME MEASUREMENTS
PMIC Testing

POWER SEQUENCE TESTING—ONE PAGE REPORT.
PMIC Testing

PROTOCOL DECODE AND ANALYSIS—SPMI EXAMPLE
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**Typical Test Flow**

- **Power Good**
- **Power Up/Down Sequence**
- **Power Rail Quality**
- **Current Consumption, Energy Efficiency**

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POWER RAIL QUALITY

DC/DC Converter

Keysight Power Rail Probe

21.6mV_{pp}

(67% Larger)

‘Regular’ Probe

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KEYSIGHT POWER RAIL PROBES FOR MXR-SERIES

- Keysight invented the Power Rail probe and their use with oscilloscopes
- Optimized for measuring the quality of power rails

N7020A
2GHz

N7024A
6GHz
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D9010POWA POWER INTEGRITY ANALYSIS APP

- Helps you understand power rail noise sources and power rail noise effects

Power Rail, before (with switching loads) & after (effects of switching loads removed)

Data Line before (with the effects of power rail noise) & after (effects of power rail noise removed).
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D9010POWA POWER INTEGRITY ANALYSIS APP
Power Integrity

D9010POWA POWER INTEGRITY ANALYSIS APP

Before (w/switching loads)

After (app removed effects of switching loads)

Original (clk/data off)
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D9010POWA POWER INTEGRITY ANALYSIS APP

1.10V Supply with 115mV$_{pp}$ Noise (±5%)
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D9010POWA POWER INTEGRITY ANALYSIS APP

Original Signal

PSIJ Removed
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D9010PWRA—POWER ANALYSIS APPLICATION

- Automated, time saving analysis of switch mode and linear power supplies
- 20 measurements

‘Setup Wizard’ provides clear directions.

Type of analysis
Input measurements

Measurement
Power quality
- Real power
- Apparent power
- Reactive power
- Power factor
- Crest factor
- Phase angle

Current harmonics
Inrush current
Switching loss
Rds(on)
Vce(sat)
Slew rate
Safe operating area
Output ripple
Turn-on time
Turn-off time
Efficiency
Transient response settling time
Power supply rejection ratio (PSRR)
Control loop response (gain and phase)
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**POWER SUPPLY REJECTION RATIO -- PSRR**

- PSRR is a measure of how well a DC-DC converter can reject noise on the input from getting to the output.

\[
\text{PSRR} = 20 \log\left(\frac{\text{Ripple}_{\text{IN}}}{\text{Ripple}_{\text{OUT}}}ight)
\]

- PSRR is a measure of how well a DC-DC converter can reject noise on the input from getting to the output.
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POWER SUPPLY REJECTION RATIO -- PSRR

PSRR = 20Log( Ripple_{IN} / Ripple_{OUT} )
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CONTROL LOOP RESPONSE (BODE)
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TYPICAL TEST FLOW

Power Good

Power Up/Down Sequence

Power Rail Quality

Current Consumption, Energy Efficiency
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CURRENT CONSUMPTION, ENERGY EFFICIENCY

DC/DC Converter

Keysight High-sensitivity Current Probe (N2820A/21A)

“Regular” Clamp-on Current Probe

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HIGH-SENSITIVITY CURRENT PROBES

• N2820A-Series Current Probes
  • High Sensitivity
  • High Dynamic Range
  • $R_{\text{SENSE}}$: 1mΩ to 1MΩ

Minimum Current: 100nA
Maximum Current: >100A's
Dynamic range: 20,000:1

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**SUMMARY**

MXR With:
- Built-in Digital Volt Meter (standard feature).

MXR With:
- Simultaneous mask testing on every channel and automatic mask generation (standard feature).

MXR With:
- 2Ghz & 6GHz Power Rail Probes (N7020A, N7024A)
- PI App-D9010POWA
- Power App-D9010PWRA
  - PSRR, etc.

MXR with:
- High-sensitivity current probes (N2820A, N2821A)

**Power Good**

**Power Up/Down Sequence**

**Power Rail Quality**

**Current Consumption Energy Efficiency**