Power Integrity:
Challenges, best practices and test solutions for sensitive electronic designs

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SI → ? → PI
PI → SI
Power Supply Induced Jitter
Unexpected Noise – 2.8MHz POL

Switching Regulator Noise

Fundamental
Switching Frequency Noise Spectrum
Harmonics

Low Frequency Noise Spectrum

1kHz RBW
Noise Induced by a Single Logic Gate
Rogue Waves
Impedance is the Common Denominator
What is Power Integrity?

Power integrity (PI) is simply the assurance that power applied to a circuit or device is appropriate for the desired performance of the circuit or device.

This is not just about keeping voltages within limits!!!
The PDN Highway
A Simple Power Distribution Network (PDN)

Simple Power System

It's all about the load.
Resonances Degrade Performance

The Ideal PDN is Flat

Stability concerns exist at both the input and the output

PSRR - (S21)

VRM Impedance

Package

Decoupling
It Tells Us About Stability
NISM - In-System Test for Phase Margin

- Phase margin derived from Output Impedance
  - Accurate up to 65 degrees
  - Proven Accuracy

- It’s called ‘NISM’
  - Non-Invasive Stability Measurement

- And it’s available for R&S ZNL!!
- Performed using a simple cursor operation
- As accurate as a Bode plot and often accurate when a Bode plot isn’t

From 2-Port Impedance to Stability Margin
Stability from Output Impedance –
No Frequency Limits

Opamp Measurement
Works over all frequencies
What Power Rail Impedance Plots Tell Us

Motherboard measurement power on (red) and off (blue)

Flat=resistor
Rising=inductor
Falling=capacitor
How to Fix Poor Impedance

Minimize L and **MAXIMIZE** R

1. Determine L from resonance or 3dB point
2. Determine R from below resonant frequency
3. Set \( C = \frac{L}{R^2} \)
4. Set Cap ESR = R

Undersized output capacitor reveals the inductance resulting from the internal pole and slope compensation.
Reduced L (reduce filter inductor/raised Fsw)
Removed Ceramic output capacitors
Installed Tantalum capacitors
Impedance

2-Port – Ground Loop

- Due to the existence of a DC ground loop through the connecting cable braids, a 50Ω coaxial transformer is required for shunt-through measurements.
Low ESR caps must be mounted in a calibrated PCB for measurement.

The 2-port shunt-through method can easily measure capacitors with ESR below 1mΩ.
Five techniques for fast, accurate power integrity measurements
Power Rail Measurement Challenges
Lower rail voltages and smaller tolerances

Examples

<table>
<thead>
<tr>
<th>Rail Value</th>
<th>Tolerance</th>
<th>Need to measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3 V</td>
<td>1%</td>
<td>33 mV&lt;sub&gt;pp&lt;/sub&gt;</td>
</tr>
<tr>
<td>1.8 V</td>
<td>2%</td>
<td>36 mV&lt;sub&gt;pp&lt;/sub&gt;</td>
</tr>
<tr>
<td>1.2 V</td>
<td>2%</td>
<td>24 mV&lt;sub&gt;pp&lt;/sub&gt;</td>
</tr>
<tr>
<td>1 V</td>
<td>1%</td>
<td>10 mV&lt;sub&gt;pp&lt;/sub&gt;</td>
</tr>
</tbody>
</table>
1. Adjust viewing characteristics
1. Adjust viewing characteristics

Waveform intensity

Default – 50%

Adjusted to 90%
1. Adjust viewing characteristics

Infinite Persistance
1. Adjust viewing characteristics

Color Grading

- More easily identify pixels that are hit less frequently.
- See how often anomalies occur
2. Lower Noise
Several Factors Make It Difficult to Measure Small Signals

Consequences
- Large measurement deviation
- Measured $V_{pp} \gg$ Actual $V_{pp}$
- Can mask/hide anomalies

Signal (DUT)
Noise
Scope display

$V_{pp}$
2. Lower Noise

Choose signal path that has the lowest noise

Comparison of noise on 50 Ω and 1 MΩ paths on the R&S®RTO digital oscilloscope at increasing vertical sensitivities
2. Lower Noise

Use the most sensitive vertical scale

<table>
<thead>
<tr>
<th>Scale</th>
<th>Noise $V_{pp}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 mV/div</td>
<td>4.1 mV</td>
</tr>
<tr>
<td>2 mV/div</td>
<td>1.2 mV</td>
</tr>
</tbody>
</table>

All other settings are identical

Use the smallest V/div setting to get the most accurate measurement (lowest noise)
2. Lower Noise
Limit bandwidth

- Noise in time domain
- Distribution of noise in frequency domain

- 4 GHz bandwidth
- 200 MHz bandwidth
- 20 MHz bandwidth
2. Lower Noise
Choose the right probe

10:1 attenuation

$V_{pp} = 61 \text{ mV}$ 50% overstated

1:1 attenuation

$V_{pp} = 41 \text{ mV}$
2. Lower Noise

RT-ZPR20 & ZPR40 Power Rail Probe

- Designed uniquely for measuring small perturbations on power rails
- Active, single-ended probe
- Low noise with 1:1 attenuation
- Best in class offset compensation capability
- Built-in DC meter

<table>
<thead>
<tr>
<th>Key Specifications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Attenuation</td>
<td>1:1</td>
</tr>
<tr>
<td>ZPR20 BW</td>
<td>2 GHz(*)</td>
</tr>
<tr>
<td>ZPR40 BW</td>
<td>4 GHz(**)</td>
</tr>
<tr>
<td>Browser BW</td>
<td>350 MHz</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>±850 mV</td>
</tr>
<tr>
<td>Offset Range</td>
<td>&gt; ±60 V</td>
</tr>
<tr>
<td>ZPR20 Noise Scope (RTO)</td>
<td></td>
</tr>
<tr>
<td>Scope + Probe Noise</td>
<td></td>
</tr>
<tr>
<td>(at 1 GHz, 1mV/div)</td>
<td></td>
</tr>
<tr>
<td>ZPR20 Noise Scope (RTO)</td>
<td>107 µV AC&lt;sub&gt;rms&lt;/sub&gt;</td>
</tr>
<tr>
<td>ZPR40 Noise Scope (RTO)</td>
<td>120 µV AC&lt;sub&gt;rms&lt;/sub&gt;</td>
</tr>
<tr>
<td>Input Resistance</td>
<td>50 kΩ @ DC</td>
</tr>
<tr>
<td>R&amp;S ProbeMeter</td>
<td>Integrated</td>
</tr>
<tr>
<td>Coupling</td>
<td>DC or AC</td>
</tr>
</tbody>
</table>

(*) 2.4 GHz typical 3 dB point
(**) 4.0 GHz typical 3dB point
3. Achieve sufficient offset

DC blocks
Eliminate low freq visibility

With ZPR20
see low freq DC changes
3. Achieve sufficient offset
Probes with built-in offset

R&S®RT-ZPR20 power rail probe with ±60 V built-in offset for zooming in on a wide range of DC power rail standards
4. Evaluate switching and EMI

Frequency domain view

$V_{pp}$ with statistics

High BW shows coupled sources

1.9 GHz coupling

2.4 GHz coupling

High BW shows coupled sources
5. Accelerate measurement time
Update rate impact on speed of power integrity measurements

Comparison of the R&S®RTO and R&S®RTE update rate with other oscilloscopes in the industry (log scale):

Impact of measurements, memory depth increases, and the use of an FFT on the update rate of the R&S®RTO oscilloscopes (log scale):
Conclusion

- Choosing a scope with low noise is critical to accurate power integrity measurements.
- Coupling the scope with a 1:1 probe with built-in offset, high bandwidth, high DC impedance and an integrated R&S®ProbeMeter delivers superior capability and measurements.
- Understanding and correctly setting a number of oscilloscope attributes such as vertical scaling and bandwidth limit filters increases the accuracy of results.
- Adding frequency domain view enables users to quickly isolate coupled signals.
- Fast update rates let users test power rails more quickly.
R&S Scope Portfolio
Oscilloscope Innovation. Measurement Confidence.

Support for power integrity

RTH1000
60 MHz … 500 MHz
HANDHELD

RTC1000
50 MHz … 300 MHz

RTB2000
70 MHz … 300 MHz

RTM3000
100 MHz … 1 GHz

RTA4000
200 MHz … 1 GHz

RTE1000
200 MHz … 2 GHz

RTO2000
600 MHz … 6 GHz

RTP
4 GHz … 8 GHz

Performance
Bandwidth

RTH1000
1000

RTC1000
2000

RTB2000
3000

RTM3000
4000

RTA4000
BENCH

RTE1000
LAB

High Performance

ROHDE & SCHWARZ
Accurate PDN Impedance Measurements
Measure PDN Impedance with R&S®ZNL

- Reflection setup

- Shunt-transmission setup
Reflection setup

\[ \Gamma = \frac{Z_L - 1}{Z_L + 1} \]

\[ \Gamma = \frac{b_1}{a_1} = S_{11} \quad b_2 = 0 \]

Measurement
Reflection setup

\[ Z_L = Z_1 \cdot \frac{1 + S_{11}}{1 - S_{11}} \]

\[ Z_1 = Z_{PORT} + Z_{PROBE} \]

or

50 Ω

if calibrated @ measurement plane
Shunt-Transmission setup

\[ Z_0 \overset{\text{def}}{=} Z_1 = Z_2 = 50\Omega \]

\[ Z_L = \frac{50}{2} \cdot \left( \frac{S_{21}}{1 - S_{21}} \right) \]
Shunt-Transmission setup

\[ Z_L = 25 \cdot \left( \frac{S_{21}}{1 - S_{21}} \right) \]

Best impedance dynamic range (mΩ ~ kΩ)

\[ Z_{PDN \ target} \approx \frac{V_{L \ noise}}{I_{L \ worst-case}} \]

Low (nom. V supply * ripple %)

High (worst transient)
Shunt-Transmission setup
R&S® ZNL – Comprehensive PDN testing… Easy
Power Integrity:
Challenges, best practices and test solutions for sensitive electronic designs

Please contact the presenters by email if you have any questions or comments

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Thank You

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