Smart Sensor ASIC for Nuclear Power Monitoring

David Kerwin, Aeroflex Colorado Springs
Ken Merkel, Aeroflex Colorado Springs
Olivier Rouxel, Dimac Red S.R.L.

www.aeroflex.com/HiRel
Presented at ANIMMA - June 2013
Outline: Smart Sensor ASIC

- Block Diagram
- Features
- Neutron Test Results
- Gamma Total Ionizing Dose (TID) Results
- Temperature Results
- Summary
Complete Instrumentation System:

- Includes circuitry to excite and precisely measure the response from 11 sensor types on 8 separate channels.
- Supported Sensors:
  - Resistance Thermometer, Thermocouple, Linear Variable Differential Transformer (LVDT), Strain Gauge/Load Cell, Inductive and Transformer-based Position, Absolute and Relative Pressure Sensors, Hall Effect Probe, Photodiode, Accelerometer, Tachometer, and other types of Sensors.
- Excitation generator includes a 14-bit digital-to-analog converter (DAC) with a high current, high-voltage differential output.
- Eight high-voltage differential signal inputs are provided, with configurable signal conditioning.
- 14-bit 45 kSps delta-sigma analog-to-digital converter (ADC)
UT08SC14ADV045HT Smart Sensor ASIC

Complete Instrumentation System:

- **Data I/O:**
  - Digital data word transmitted through a Low-Voltage Differential Signaling, Serial Peripheral Interface (LVDS SPI) port.
  - A second LVDS SPI port is used for configuration, control, parameter trim, and access to internal registers.

- **Clock Generation:**
  - A clock generator block generates the necessary internal clocks from a low-frequency reference.

- **Voltage Regulators:**
  - Internal regulators derive necessary supply voltages and references from +/-6V (Va6p and Va6n) and +3.3V (Vd3) power supply inputs.
UT08SC14ADV045HT Smart Sensor ASIC

▼ Complete Instrumentation System:

– Non-volatile Memory (NVM):
  ▼ Aeroflex Radiation Hardened One-Time Electrically Programmable Read-Only Memory (RH OTEP ROM) provides storage for reference trim data, configuration data, and user configurable program storage.

– Applications:
  ▼ Nuclear Power Instrumentation Monitoring
  ▼ Spacecraft Telemetry
  ▼ Radiation Oncology Equipment Motor/Motion Control
  ▼ Nuclear Waste Monitoring
# Key Performance and Environmental Parameters

<table>
<thead>
<tr>
<th>ASIC Specification</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Excitation Output</strong></td>
<td>14-bit DAC with differential voltage-mode output up to 20Vp-p, up to 140mA. Sine/square/triangle or arbitrary function outputs.</td>
</tr>
<tr>
<td><strong>Sensor Inputs</strong></td>
<td>8 multiplexed differential high-impedance user inputs; input range -5V &lt; Vin &lt; +5V</td>
</tr>
<tr>
<td><strong>Signal Channel</strong></td>
<td>Programmable gain range 0.18 to 100, 15 kHz bandwidth, includes anti-alias filter</td>
</tr>
<tr>
<td><strong>A/D Converter</strong></td>
<td>14-bit, 3rd-order delta-sigma, 45kSps</td>
</tr>
<tr>
<td><strong>Typical channel mismatch</strong></td>
<td>0.04% to 100°C, 0.07% to 200°C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operating Environment</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gamma Ray Total ionizing Dose (TID)</strong></td>
<td>100 krad(Si) at a dose rate of 2.8 mrad(Si)/sec</td>
</tr>
<tr>
<td><strong>Neutron Induced Upset (NIU)</strong></td>
<td>&lt; 1E-11 errors/bit/day</td>
</tr>
<tr>
<td><strong>Neutron induced Latch-Up (NIL)</strong></td>
<td>Immune (5E11 neutrons/cm², peak energy &lt; 2 MeV)</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>200 °C max. operating</td>
</tr>
</tbody>
</table>
Neutron Induced Upset (NIU) Test Results

- Five Smart Sensor ASICs were tested at Sandia National Laboratory (SNL) Annular Core Research Reactor (ACRR).
- Scan chains (≥ 95% coverage) were run at 2 MHz.
- Lowest operational supply voltages used (95% of nom.).
- Average neutron fluence: 6.9E11 n/cm²
- No scan chain errors before, during or after irradiation → No Neutron Induced Upset (NIU)
Neutron Induced Latch-Up (NIL) Test Results

- Five Smart Sensor ASICs were tested at Sandia National Laboratory’s ACRR Nuclear Reactor
- Used valve position detector (VPD) config. with max. output voltage swing (20V pk-pk), and highest operational supply voltages to test for latch-up.

- No Neutron Induced Latch-Up (NIL) observed!
  - Average neutron fluence: 6.8E11 n/cm²

- Worst case results:
  - Supply current increased +6.7% (+6V power supply). All other current increases ≤ 1.5%
    - All supplies returned to pre-irradiation values after removal from reactor
  - Variation in sine wave replication was +/- 0.034%

- Signal chain integrity demonstrated during NIL test and measurement
Neutron Induced Latch-Up (NIL) Test Results

- A 60 Hz sine wave was generated and measured at the SPI-C port.
- No noticeable increase in power supply currents during irradiation.
- Sine wave measurement used 768 samples taken at $f_{\text{clock}} = 46.08$ kHz.
- The figure overlays the maximum and minimum excursions of the sampled sine wave in blue. Y-axis in units of integer LSBs for the internal 16-bit ADC. X-axis in units of time for a single 60 Hz sine wave with a 16.7 msec period.
- (Sine wave “glitches” artifact of look up table entries in EXCGEN, not NIU or NIL.)
Gamma TID Results – Standard Dose Rate

- Quiescent current (Iddq) was measured on 5 ICs following stepped-dose irradiation to 300 krad(Si) using standard dose rate (SDR) gamma irradiation (169 rad(Si)/sec) at Aeroflex Colorado Springs.

- Iddq measured at low and high power supply settings following SDR irradiation: +/- 6V => +/- 5.7 or +/- 6.3V, and 3.3V => 3.14 or 3.47V.

- No increase in Iddq up to a total ionizing dose (TID) of 300 krad(Si).

- Demonstrates excellent control of MOSFET subthreshold leakage in SDR gamma radiation.

*Iddq Results to 300 krad(Si) SDR*
Gamma TID Results – Low Dose Rate

**Iddq Results to 100 krad(Si) LDR**

- Iddq was measured at Aeroflex RAD on 5 ICs following stepped-dose irradiation to 100 krad(Si) using low dose rate (LDR) gamma irradiation at 10 mrad(Si)/sec.
- Iddq measured at low and high power supply settings following SDR irradiation: +/- 6V => +/- 5.7 or +/- 6.3V, and 3.3V => 3.14 or 3.47V.
- No increase in quiescent current in TID up to 100 krad(Si).
- Demonstrates excellent control of MOSFET subthreshold leakage in gamma radiation at LDR.
Temperature Results

- Three ASICs subjected to an Extended Abnormal Temperature (EAT) ramp for up to 960 hrs as defined below
- Complete characterization test performed at intervals marked by *
- Post-ramp results. All units passed all tests at room temperature (RT) and at low and high supply extremes. No functional failures observed at any temperature or at RT following thermal ramp exposure
- Parametric performance at high temperature generally tracks voltage reference.

* Bench MT evaluation at temperature, start and final test not shown
Temperature Sweep Results

- Comprehensive characterization performed over $20 \leq T \leq 200 \, ^\circ C$
- Absolute measurement accuracy $\sim 1\%$ at $180 \, ^\circ C$, and $\sim 5\%$ at $200 \, ^\circ C$
  - Tracks bandgap reference
  - Same reference used for excitation generator and ADC
- Relative/ratiometric error is $\leq 0.1\%$ over entire temperature range
- Differential input leakage current $< 10\, nA$ at $200 \, ^\circ C$
Summary

Smart Sensor ASIC

- Specifically designed for Nuclear Power Radiation Environment:
  - > 100 krads(Si) in both Standard (SDR) and Low Dose-Rate (LDR) Gamma Radiation Environment
  - High Tolerance to Neutrons:
    - Neutron Induced Latch-Up (NIL) Immune
    - No Neutron Induced Upset (NIU)
  - High Temperature operation up to 200 °C

- High Functionality, Performance and Reliability in a Single ASIC:
  - 8 sensor inputs
  - 14-bit ADC
  - Programmable Gain
  - 20Vpp DAC Output for sensor excitation