Software-Defined and Synthetic Instruments

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The Problem with Legacy Instrumentation
Historically, there is a unique set of instrumentation for a given lab.

Traditional labs often employ “box” instruments with *inflexible firmware* and *functionality*.

Obsolescence is a problem.

Software reuse is a problem.

Supporting new or *emerging* test requirements is a major issue.

The Challenge: Employ a new test and measurement paradigm.

- Software-Defined Instrumentation
- Synthetic Instrumentation
15,000 pieces of TMDE
# Modernization Alternatives

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extend: Replace with same instruments</td>
<td>• No Hardware or Software Changes</td>
<td>• Higher Downtime</td>
</tr>
<tr>
<td></td>
<td>• Low Risk, Simple</td>
<td>• Eventually the product will go out of support</td>
</tr>
<tr>
<td></td>
<td>• Least Expensive</td>
<td></td>
</tr>
<tr>
<td>Replace Obsolete Instruments Upgrade equipment</td>
<td>• Greater reliability</td>
<td>• Can Be Expensive</td>
</tr>
<tr>
<td>through emulation</td>
<td>• Faster test</td>
<td>• Risk measurement issues</td>
</tr>
<tr>
<td></td>
<td>• Lower cost of ownership</td>
<td>• Possible Requalification</td>
</tr>
<tr>
<td></td>
<td>• Minimum Hardware and Software Changes</td>
<td></td>
</tr>
<tr>
<td>Rehost/Migrate Modernize</td>
<td>• Greater Reliability</td>
<td>• Most Expensive</td>
</tr>
<tr>
<td></td>
<td>• Faster Test</td>
<td>• Greatest Risk</td>
</tr>
<tr>
<td></td>
<td>• Lowest cost of ownership (excluding acquisition cost)</td>
<td>• Maximum Hardware and Software changes</td>
</tr>
<tr>
<td></td>
<td>• Greatest future longevity</td>
<td></td>
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</tbody>
</table>
Synthetic Instrumentation Solution

- Solution Requirements
  - Reduce the amount of discrete instruments in inventory.
  - Existing experiments must be preserved.
  - Stem the tide of instrumentation obsolescence
- There is a need to evolve instrumentation.
  - SI offers a transformational technology
  - Incorporate SI technology into the lab Framework
- Require a standardized process to incorporate SI technology
Synthetic Instrumentation

Traditional Solution: >$500K, 72 ft³

SI Solution: <$150K, 0.67 ft³
Moore’s Law

“The complexity for minimum component costs has increased at a rate of roughly a factor of two per year... Certainly over the short term this rate can be expected to continue, if not to increase.”

“Cramming more components onto integrated circuits”, Gordon Moore, Electronics Magazine 19 April 1965
Moore’s Law

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- Increases by an order of magnitude approximately every 7.5 years
- Can be extended to performance of computing devices
- Can be extended to cost of computing devices
- Can be extended to the size of computing devices
What are the Expectations of Next-Generation Instrumentation – The “Moore” Machine
What are the Expectations – The “Moore” Machine
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What are the Expectations – The “Moore” Machine

*More Functionality*

*Reduced Cost*

*Smaller Footprint*

*Accelerated Delivery*
The Evolution of the Software-Defined Radio

Software-Defined Radios are related to Software-Defined and Synthetic Instruments

- Digital Radio (1970)
- Modular Radio (1988)
- Software Radio (1991)
The Evolution of the Software-Defined Instruments

Digital Radio → Modular Radio → Software Radio → Software-Defined Radio → Cognitive Radio


Software-Defined Radios are related to Software-Defined and Synthetic Instruments

SOFTWARE-DEFINED INSTRUMENT

DEVICE UNDER TEST → FREQUENCY CONVERSION → ADC → PROCESSING → DAC

FREQUENCY CONVERSION

1970
Digital Radio

1988
Modular Radio

1991
Software Radio

1995
Software-Defined Radio

1999
Cognitive Radio
A reconfigurable system that links a series of elemental hardware and **software components** with standardized interfaces to generate signals or make measurements using **numeric processing techniques**.
Synthetic Instrumentation: A Disruptive Technology

- Reduced Footprint
- Improved Measurement Time
- Reduced Cost
- Improved Performance

**TIME**

**PERFORMANCE**

- Measured SI Performance
- Predicted SI Performance
- TE performance required at the high end of the market
- TE performance required at the low end of the market

**Reduced Footprint**

**Reduced Cost**

**Improved Performance**

**Improved Measurement Time**
### Software-Defined and Synthetic Instrument Applicability

#### MEASUREMENT INSTRUMENTS
- Spectrum Analyzers
- Digital Storage Oscilloscopes
- Vector Signal Analyzers
- Vector Network Analyzers
- Phase Noise Testers
- Modulation Analyzers (VSA)
- Distortion Analyzers
- Frequency Counters
- RF Pulse Counters
- RF Power Meters
- Transmission Line Test Sets (VNA)
- Radio Test Sets
- RADAR Test Sets
- RFI Measurement Test Sets
- Data Communication Analyzers
- Digital Multi-Meters / Voltmeters
- DMM / Ammeters – Handheld
- Cable Testers - Handheld

#### STIMULUS INSTRUMENTS
- RF Signal Generators
- Vector Signal Generators (VSG)
- Pulse Generators
- RF Pulse Generators
- Sweep Generators
- Function Generators
- Arbitrary Waveform Generators
- BER Generators
- Bus Emulators

### CONCLUSION
Except for the “corner” cases, Synthetic Instruments can replace all traditional instruments

### SI Applicability LEGEND
- Applicable
- Maybe Applicable
- Not Applicable
Synthetic Instrument – An Example

- PROCESSOR
- 8-BIT FPGA
- 4-BIT ADC
- RF DOWN CONVERTER
Synthetic Instrument – An Example
Software-Defined Instrument Breakout Role
The FPGA

PROCESSING
- Signal Processing
- Data Processing
- Display Processing
- Control Processing
## FPGA Performance Evolution

<table>
<thead>
<tr>
<th>Maximum Capability</th>
<th>Virtex-4 Family</th>
<th>Artix-7 Family</th>
<th>Kintex-7 Family</th>
<th>Virtex-7 Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logic Cells</td>
<td>200K</td>
<td>215K</td>
<td>478K</td>
<td>1,955K</td>
</tr>
<tr>
<td>Block RAM</td>
<td>10K</td>
<td>13 Mb</td>
<td>34 Mb</td>
<td>68 Mb</td>
</tr>
<tr>
<td>DSP Slices</td>
<td>192</td>
<td>740</td>
<td>1,920</td>
<td>3,600</td>
</tr>
<tr>
<td>Peak DSP Performance</td>
<td>24</td>
<td>929 GMAC/s</td>
<td>2,845 GMAC/s</td>
<td>5,335 GMAC/s</td>
</tr>
<tr>
<td>Transceivers</td>
<td>6.6 Gb/s</td>
<td>16</td>
<td>32</td>
<td>96</td>
</tr>
<tr>
<td>Peak Transceiver Speed</td>
<td></td>
<td>6.6 Gb/s</td>
<td>12.5 Gb/s</td>
<td>28.05 Gb/s</td>
</tr>
<tr>
<td>Peak Serial Bandwidth (Full)</td>
<td></td>
<td>211 Gb/s</td>
<td>800 Gb/s</td>
<td>2,784 Gb/s</td>
</tr>
<tr>
<td>PCIe Interface</td>
<td></td>
<td>x4 Gen2</td>
<td>x8 Gen2</td>
<td>x8 Gen3</td>
</tr>
<tr>
<td>Memory Interface</td>
<td></td>
<td>1,066 Mb/s</td>
<td>1,866 Mb/s</td>
<td>1,866 Mb/s</td>
</tr>
<tr>
<td>I/O Pins</td>
<td>896</td>
<td>500</td>
<td>500</td>
<td>1,200</td>
</tr>
</tbody>
</table>

Let’s Look at how we can use the FPGA in High Performance Synthetic Instruments
The PXIe FlexRIO: User-Defined Instrument

- PXIe-7965R
  - Virtex-5 SX95T FPGA
  - 512 MB DDR2
  - Supports FAM
  - Supports P2P streaming
  - LabVIEW FPGA compatible

- PXIe-7975R
  - Kintex-7 FPGA
  - 2 GB DDR3
  - High-speed data streaming to host at 1.6 GB/s
  - Supports FAM
  - Supports P2P streaming
  - LabVIEW FPGA compatible
The FlexRIO Adapter Module
Solving the Data Transport Bottleneck

### Example FAMs

<table>
<thead>
<tr>
<th>P/N</th>
<th>FAM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>5791</td>
<td>TRANSCEIVER</td>
<td>100 MHZ</td>
</tr>
<tr>
<td>5792</td>
<td>RECEIVER</td>
<td>200 MHZ</td>
</tr>
<tr>
<td>5793</td>
<td>TRANSMITTER</td>
<td>200 MHZ</td>
</tr>
<tr>
<td>5781</td>
<td>ADC/DAC</td>
<td>100 MSPS</td>
</tr>
<tr>
<td>5782</td>
<td>TRANSCEIVER</td>
<td>250 MSPS</td>
</tr>
<tr>
<td>5731</td>
<td>ADC</td>
<td>400 MSPS, 14-BIT</td>
</tr>
<tr>
<td>5771</td>
<td>ADC</td>
<td>3 GSPS, 8-BIT</td>
</tr>
<tr>
<td>5772</td>
<td>ADC</td>
<td>1.6 GSPS, 12-BIT</td>
</tr>
<tr>
<td>AT-1120</td>
<td>ADC</td>
<td>2 GSPS, 14-BIT</td>
</tr>
<tr>
<td>6581</td>
<td>DIGITAL I/O</td>
<td>200 MBPS, 54 CH</td>
</tr>
<tr>
<td>6583</td>
<td>DIGITAL I/O</td>
<td>300 MBPS, 32 LVDS</td>
</tr>
<tr>
<td>6587</td>
<td>DIGITAL I/O</td>
<td>1 GBPS, 20 LVDS</td>
</tr>
</tbody>
</table>

Diagram:
- **NI-5731**
- **DIRECT I/O**
- **FPGA**
- **ANALOG**
- **ADC**
- **PCIe**
- **RESULT**
- **HOST**
- **PCle-8135**
- **PXle-7975R**
- **PXle-5797R**
The Vector Signal Transceiver

CONCLUSION
The FPGA is the Breaking Out Role for Synthetic Instruments
Summary

- Synthetic Instruments will replace many classic “box” instruments in classes and labs that traditionally use the standard “rack-n-stack” test equipment.
- The FPGA is critical to fielding high performance Synthetic Instruments.
- Synthetic Instruments will evolve toward embedded instrumentation.
Conclusion

• A methodology for mitigating instrumentation obsolescence was presented.
  • Enhancing laboratory equipment sustainability via inserting test equipment functionality employing synthetic instrumentation technology.
• SI technology represents a major paradigm shift in current support equipment hardware & software sustainability approaches.
• It will have a profound impact on the process of supporting and maintaining legacy equipment now and into the future.
• The subject methodology was validated at Tobyhanna Army Depot.
• The proof-of-concept demonstration validated the concept of replacing legacy COTS instruments with synthetic instrument technology.
Thank You!

Questions