State-of-the-Art Synthetic Instrumentation
Built On NI FlexRIO and LabVIEW FPGA
Agenda

• What is a Virtual & Synthetic Instrument?
• How does NI FPGA fit in?
• The Flexibility of NI FlexRIO
• Applications
Technology trends in test

- Software--defined instrumentation
- Multicore/parallel test
- FPGA driven measurements
- Platform standardization
Technology Trend: Software-Defined Devices

Fixed Hardware Functionality  ➔  Software-based Personality
Industry Trend to Software-Based Systems

From the Department of Defense:

“Recent commercial technology allows for the development of synthetic instruments that can be configured in real time to perform various test functions….A single ‘synthetic’ instrument can replace numerous single function instruments thereby reducing the logistics footprint and solving obsolescence problems.”

– Report to Congress on the activities of the DoD Office of Technology Transition, February 2002
Virtual Instrumentation Defined

**Virtual instrument**
Software-defined system, where software based on user requirements defines the functionality of generic measurement hardware.

**Synthetic Instrument**
“A subset of virtual instruments that links a series of elemental hardware and software components with standard interfaces to generate signals or make measurements using numeric processing techniques”

Source: Synthetic Instrumentation Working Group
Trend Toward Software-Based Systems

“Software is the core of a SI test system. Since all of the previously discussed modules are generic by definition, it is the task of the software to define and control the hardware…”

Frost and Sullivan 2006 World Synthetic Instrumentation Test Equipment Report
Generic Synthetic Instrument Block Diagram
SIWG Approved Version

- **Digital to Analog Conversion**
- **RF Upconversion**
- **RF Signal Conditioning**
- **Analog Signal Conditioning**
- **Digital Signal Conditioning**
- **Analog to Digital Conversion**
- **RF Downconversion**
- **RF Signal Conditioning**
- **Software Algorithms**
- **CPU, DSP, FPGA, or Memory**
- **DUT Interface Switching**
- **Device Under Test**

**Internal Switching**
Key Technologies Driving SI Advancement

High-speed busses

PCIe Peer-to-peer

FlexRIO FPGA Processing

Converter Technology

Deep On-board Memory

Digital Down-converter

ADC

D/C

U/C

Digital Up-converter

High-speed busses

PCIe Peer-to-peer

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Synthetic/Virtual Instrumentation

“There will be a growing marketplace for tools that can be used by end users and system integrators to develop their own measurement algorithms.”

-Frost and Sullivan World Synthetic Instrument Test Equipment Market December-2006

LabVIEW Capability:

- FPGA
- FFT
- AM/FM/PM
- DSP
- Masks
- ASK, FSK, ...
- 32-bit µP
- Limits
- Filter design
- Dual-core
- ACP
- OFDM
- Real-time
- JTFM
- BER/MER
- DUC
- SINAD
- Order Analysis
- DDC
- THD
- Wavelet
- ...
- ...
- ...

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Technology Trend:  
*Field Programmable Gate Array (FPGA)*

- **What it is**
  - A silicon chip with unconnected logic gates

- **How it works**
  - Define hardware behavior in software

- **Advantages**
  - Fast, reconfigurable, reliable

- **Disadvantages**
  - Require HDL developer
Handling Complexity through Abstraction

System complexity vs Abstraction

- Machine code
- Assembly
- VHDL
- C
- C++
- C# (System Design Tools)
Preserving User Investment

Graphical System Design

- LabVIEW
- CVi
- Fortran 77
- Fortran 90
- C#
- Unix
- Dos
- Macintosh
- Linux
- Windows NT
- Windows 3
- Windows
- Windows 95
- Windows 98
- Windows CE
- Windows ME
- Windows CE.NET
- PocketPC
- Vista
- Windows XP
- AT
- NuBus
- Ethernet
- PCI
- USB
- PXI Express
- PCI Express
- DDE
- VBX
- OCX
- COM+
- OLE
- .NET
- ActiveX
- Visual Basic
- Visual C++
- Visual J++
- Visual Studio
- Visual Studio 2005
- Visual Studio.NET

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High-Level Design Models

Data Flow

C Code

Textual Math

1 $c = 0.285 + 0.013i$
2 $[X, Y] = \text{meshgrid}(x, y)$
3 $z = X + iY$
4 for $k = 1:30$
5 $z = z^2 + c$
6 end

Simulation

Graphical System Design Platform

LabVIEW

Desktop  Real-Time  FPGA  Microprocessors
LabVIEW FPGA

- Single-Board RIO
- CompactRIO
- Compact Vision System
- NI FlexRIO
- R Series DAQ
- PXI Timing & Synchronization
What is an FPGA?

- Programmable Interconnects
- Logic Blocks
- I/O Blocks
Simplified FPGA Example

Implementing Logic on FPGA: \( F = \{(A+B)CD\} \oplus E \)

LabVIEW FPGA Code
Simplified FPGA Example
The number of HDL-savvy designers is expected to reach 200,000 by 2010.

-Wally Rhines
Mentor Graphics CEO
LabVIEW FPGA IP

Comparison

Boolean

Data Manipulation

Fixed-point & Integer Arithmetic
LabVIEW FPGA IP

Memory
- VI-Scoped Memory
- Memory Write
- Memory Read
- VI-Scoped FIFO
- FIFO Write
- FIFO Read
- FIFO Clear

Synchronization
- Occurrences
- First Call?
- Interrupt

I/O Integration
- I/O Node
- I/O Constant
- I/O Method
- I/O Property

Execution Structures
- For Loop
- While Loop
- Timed Structure
- Case Structure
- Flat Sequence
- Stacked Sequence
- Diagram Display
- Conditional Display
- Local Variable
- Global Variable
- Decorations
- Feedback Node

Timing
- Loop Timer
- Wait
- Tick Count
LabVIEW FPGA IP

Filters & Signal Analysis

Signal Generation

Non-Linear Systems

Data Manipulation

Linear Systems
LabVIEW FPGA IP Generators

Digital Filter Design Toolkit

Adaptive Filter Design Toolkit

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FPGA-Based Reconfigurable Hardware

• High-speed timing and synchronization
  ▪ Custom triggers, complex timing relationships….

• Custom digital protocols
  ▪ Interfacing, Bit Error Rate (BER) testing….

• In-line analysis
  ▪ Digital up/down conversion, data reduction, FFT’s…. 
Benefit of FPGAs in Test Systems

- **High Reliability** – Designs become a custom circuit
- **High Determinism** – Runs algorithms at deterministic rates down to 5 ns
- **True Parallelism** – Enables parallel tasks and pipelining and thus reduces test times.
- **Reconfigurable** – Create new and alter existing task-specific personalities
National Instruments FlexRIO

LabVIEW FPGA-Enabled Instrumentation
NI FlexRIO System Architecture

** NI FlexRIO Adapter Module**
- Interchangeable I/O
- Customizable by users
- Adapter Module Development Kit (MDK)

** NI FlexRIO FPGA Module**
- Virtex-5 FPGA
- 132 digital I/O lines
- 512 MB of DDR2 DRAM

** PXI Platform**
- Synchronization
- Clocking/triggers
- Power/cooling
- Data streaming
NI FlexRIO FPGA Modules for PXI

- Virtex-5 FPGA
  - LX30, LX50, LX85, LX110, SX50T, SX95T
- Direct access to FPGA I/O
  - 132 single-ended lines or 66 differential pairs
  - 400 Mbps single-ended
  - 1 Gbps differential
- 512 MB onboard DRAM
  - 2x 256 MB banks
  - 1.6 GB/s per bank
- Peer-to-peer streaming
  - 800 MB/s across PXI Express backplane
  - 16 simultaneous streams
- Adapter module required for IO
## FPGA Module Comparison

<table>
<thead>
<tr>
<th>Model</th>
<th>Bus/Form Factor</th>
<th>FPGA</th>
<th>FPGA Slices</th>
<th>FPGA DSP Slices</th>
<th>FPGA Memory (Block RAM)</th>
<th>Onboard Memory (DRAM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NI PXIe-7965R</td>
<td>PXI Express</td>
<td>Virtex-5 SX95T</td>
<td>14,720</td>
<td>640</td>
<td>8,784 kbits</td>
<td>512 MB</td>
</tr>
<tr>
<td>NI PXIe-7962R</td>
<td>PXI Express</td>
<td>Virtex-5 SX50T</td>
<td>8,160</td>
<td>288</td>
<td>4,752 kbits</td>
<td>512 MB</td>
</tr>
<tr>
<td>NI PXIe-7961R</td>
<td>PXI Express</td>
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<td>8,160</td>
<td>288</td>
<td>4,752 kbits</td>
<td>0 MB</td>
</tr>
<tr>
<td>NI PXI-7954R</td>
<td>PXI</td>
<td>Virtex-5 LX110</td>
<td>17,280</td>
<td>64</td>
<td>4,608 kbits</td>
<td>128 MB</td>
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<tr>
<td>NI PXI-7953R</td>
<td>PXI</td>
<td>Virtex-5 LX85</td>
<td>12,960</td>
<td>48</td>
<td>3,456 kbits</td>
<td>128 MB</td>
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<td>NI PXI-7952R</td>
<td>PXI</td>
<td>Virtex-5 LX50</td>
<td>7,200</td>
<td>48</td>
<td>1,728 kbits</td>
<td>128 MB</td>
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<td>NI PXI-7951R</td>
<td>PXI</td>
<td>Virtex-5 LX30</td>
<td>4,800</td>
<td>32</td>
<td>1,152 kbits</td>
<td>0 MB</td>
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</table>
## NI FlexRIO FPGA Modules for PXI Express

<table>
<thead>
<tr>
<th></th>
<th>LX110 (PXI-7954R)</th>
<th>SX95T (PXIe-7965R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slices</td>
<td>17,280</td>
<td>14,720</td>
</tr>
<tr>
<td>Logic Cells</td>
<td>110,592</td>
<td>94,208</td>
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<tr>
<td>CLB Flip-Flops</td>
<td>69,120</td>
<td>58,880</td>
</tr>
<tr>
<td>Distributed RAM (Kbits)</td>
<td>1,120</td>
<td>1,520</td>
</tr>
<tr>
<td>Block RAM/FIFO with ECC (36 Kbits ea.)</td>
<td>128</td>
<td>244</td>
</tr>
<tr>
<td>Total Block RAM (Kbits)</td>
<td>4,608</td>
<td>8,784</td>
</tr>
<tr>
<td>Digital Clock Managers (DCM)</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Phase Locked Loops (PLL)</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>DSP48E Slices</td>
<td>64</td>
<td>640</td>
</tr>
</tbody>
</table>
PXI-7831R versus PXI-7952 Project

PXI-7831R

PXI-7952

New
NI FlexRIO Adapter Module

- Analog
  - ADCs, DACs, clocks
- Digital
  - Buffers, transceivers, serializers, deserializers
- Card edge connector
- Defines I/O for LabVIEW FPGA
NI FlexRIO Adapter Module Options

NI Modules
- Complete integration with LabVIEW FPGA
- R Series-like experience

Third-Party Modules
- Expands NI I/O breadth
- Custom and application-specific modules

Custom Modules
- Requires PCB and HDL design work
- Supported through MDK
NI FlexRIO Adapter Module
NI Adapter Modules

• Complete Integration with LabVIEW FPGA and NI FlexRIO

• No HDL experience required
NI 6581
High-Speed Digital Adapter Module

- 100 MHz digital I/O
- 54 single-ended channels
- Selectable voltage levels
  - 1.8, 2.5, 3.3 V (5 V compatible)
- External DIO voltage reference
  - 1.8 to 5.5 V
- Configurable by connector
NI 6581 LabVIEW Code

When in this state, we sample a single 24-bit data value from the connector and push this data into the FPGA-to-Host DMA FIFO.

When triggered mode, we continually monitor the sample count to determine when to stop acquiring new data. We need to stop acquiring when the sample count reaches the "Samples Per Trigger" value.
NI 6585
200 MHz LVDS Digital Instrument

- 200 MHz digital I/O
- 32 / 42 LVDS channels
- 200 Mbps SDR, 300 Mbps DDR

PXI-6585R
High Speed Hardware Compare (BERT)
NI 5781 Baseband Transceiver Module

- Dual 100 MS/s, 14-bit inputs
- Dual 100 MS/s, 16-bit outputs
- 2 Vpp differential range
- 1 Vpp single-ended range
- 40 MHz bandwidth
- Interface to Ettus Research RF daughter boards
NI 5752 Digitizer Module for NDT Applications

- 32 ch, 50 MS/s, 12-bit
- TI AFE5801 ADC w/ variable gain amplifiers and ADC
- 2 Vpp, 100 Ω differential inputs with AC coupling
- Built-in antialias filters
- 16 DO w/ per-channel phase control that can be coupled to pulser arrays
NI 5761 High Speed Digitizer

- 4 channel, 14-Bit, 250 MS/s
- 500 MHz bandwidth
- 8 DIO
- AC- and DC-coupled versions
NI 6584 RS-485/RS-422 Adapter Module

- Up to 16 Mbits/s data rates
- 16 channels
- Half or Full Duplex
- 100 Ohm terminated or no termination options
NI 1483 Camerlink Module

- FPGA image processing
- Base, Medium, and Full Camera Link cameras
- Supports up to 10-tap, 80-bit images at 20 to 85 MHz pixel clock frequency
- 4 TTL I/O channels, 2 optically isolated inputs, and 1 quad encoder input
NI FlexRIO Partner Modules

• Expand I/O breadth into custom and niche applications
• Available as “catalog” products through NI Alliance Partners
• National Instruments recommended modules evaluated by NI R&D
• Current list available on ni.com/flexrio
IEEE 1394b Adapter Module for NI FlexRIO

- 800 Mbps on 3 ports
  - 2.4 Gbps total bandwidth
- Physical layer implemented in adapter module
- CLIP Node to implement IEEE 1394 protocol
- LabVIEW FPGA code for image processing
NexFrontier NF1208 PMU Module

- 8 channels
- 100 MHz digital vectors
- Per-channel, per-cycle direction control
- Per-pin parametric measurement unit (PPMU)
- Dynamic load of ±12 mA
- Support for STIL IEEE 1450-1999 events
Prevas Gigabit Ethernet Simulator

- Two PHY connections (RJ45)
- 10M/100M/1000Mbps rates
- Generate and analyze Ethernet traffic in real time
- Fault injection and channel simulation
IRS Multi-Gigabit Module

- Xilinx Virtex-5 LX20T FPGA on adapter module
- Implement common and custom multi-gigabit protocols
- Customization by IRS required
SET ARINC 429 Module

- 16 Tx or Rx channels
- Low (12.5 kbps) and high-speed (100 kbps) operation
- Receiver voltage threshold
- Transmit output voltage
- 4 digital outputs
Custom Modules

Custom Front End

Xilinx Virtex-5 FPGA

CLIP

CLIP

CLIP

Socketed CLIP

LabVIEW FPGA VI

Socketed CLIP

Socketed CLIP

DRAM Memory

DRAM Memory

PXI Bus
NI FlexRIO Adapter Module Development

Hardware
- PCB
- Firmware
- LabVIEW FPGA

Software
- API
- Application
- Examples

Mechanical
- PCB
- Connectors
- Thermal

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NI FlexRIO Adapter Module

- 6 W power – electrical and thermal limit
- 3.3 V (1 A) and 12 V (200 mA) rails
- 400 Mbps (single-ended), 1 Gbps (differential) I/O
- I²C EEPROM for module identification and user-defined storage
- NI mechanical enclosures

<table>
<thead>
<tr>
<th></th>
<th>1.2 V</th>
<th>1.5 V</th>
<th>1.8 V</th>
<th>2.5 V</th>
<th>3.3 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVTTL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>LVCMOS</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>LVDCI</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>LVDS</td>
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<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>
NI FlexRIO Adapter Module Development Kit (MDK)

- CAD files (for PCB outline and gold finger cell)
- Detailed drawings
- Hardware documentation
  - Pin descriptions and power options
- Software documentation
  - CLIP development
  - Using adapter modules in LabVIEW FPGA
  - Identification protocol
  - Example TBC, VHDL, UCF, and XML files
- Metal adapter module enclosures
  - 1 windowed enclosure and 3 blank enclosures
  - Additional enclosures purchased separately
Application Areas

- Communications
- Semiconductor
- Protocol-Aware ATE
- Hardware-in-the-Loop
- Custom Protocols
- Custom Measurements
Software-Defined Radio (SDR)

- Use common hardware to implement radio components in software
- Relevant adapter modules:
  - NI 5781 Baseband Transceiver – 100 MS/s 14-bit 2-ch. ADC, 100 MS/s 16-bit 2-ch. DAC

Module 2 of 5: FlexRIO for Test
Spectral Monitoring and Signal Intelligence

- Use both high dynamic range and high bandwidth ADCs to monitor a large frequency range with the ability to “zoom in” on specific signals with higher dynamic range
- Relevant adapter modules:
  - NI 5771 8-bit 3 GS/s ADC*
  - NI 5761 14-bit 250 MS/s 4-ch. ADC
  - NI 5762 16-bit 250 MS/s ADC*

*Unreleased
Semiconductor Validation – Protocol-Aware ATE

• Use NI FlexRIO to provide fast, deterministic response to an IC (DUT), rather than static pattern generation
• Hardware-in-the-loop (HIL) for semiconductor
• Relevant adapter modules:
  ▪ NI 6581 100 MHz DIO module
  ▪ NI 6585 200 MHz LVDS DIO module
  ▪ Protocol-specific modules (422, 485, I²C, I²S, SPI)
  ▪ Customer-developed board or IC interfaces
Protocol-Aware ATE

Test Vectors

Standard ATE Model

System Emulation or Protocol Intelligence

Protocol-Aware Communication

Input

Output

Routine pre-defined in test software

Intelligence embedded into FPGA hardware

Image courtesy of Verigy
Protocol-Aware ATE

“The missing item is the programmable logic that would be used for the emulation. This logic would primarily consist of FPGAs and would reside between the ATE pin electronics and the rest of the ATE pin, which is the vector memory, pattern/timing generators, and formatters.”

Evans, Andrew, “The New ATE – Protocol Aware,”
2007 International Test Conference (ITC)
High-Speed Digital

- Use NI FlexRIO’s 66 Gpbs (8.25 GB/s) of I/O bandwidth to interface with high-speed digital ICs
- Relevant adapter modules:
  - Future HSDIO modules (16-ch. 1 Gbps, etc.)
  - Customer-developed, application-specific modules
HIL and Custom Protocols

• Use an NI FlexRIO adapter module to implement the physical layers of common communication protocols
• Use the FPGA to define MAC layer and above for custom protocols and real-time, low-latency communication
High-Performance Silicon with Fast Time-to-Market

- Build an NI FlexRIO adapter module with the latest DACs, ADCs, SERDES, and other ICs to get the latest / highest-performance measurement capabilities
- Evaluate and characterize semiconductor devices before incorporating them into your design
- Perform analysis which cannot be done on the host (e.g. Sparkle code search)
- Custom-developed modules or vendor supplied “evaluation boards”
- NI 5771 featuring the National Semiconductor ADC08D1500
Custom Measurements and Triggering

- Use the FPGA on NI FlexRIO to perform custom triggering, measurements, data reduction, and processing
- Common applications include Nondestructive Test (NDT), complex analog triggering, custom digital triggering
- Most general-purpose use case
P2P Streaming Instruments

PXIe-5122 Digitizer
- Dual-channel
- 14-bit, 100 MS/s
- 100 MHz bandwidth
- 400 MB/s streaming to PXI Express FlexRIO

PXIe-5663 VSA
- 10 MHz to 6.6 GHz
- 16-bit, 150 MS/s
- 50 MHz bandwidth
- 250 MB/s streaming to PXI Express FlexRIO

PXIe-5622 IF Digitizer
- 16-bit, 150 MS/s
- 3-250 MHz bandwidth
- 60 MHz bandwidth DDC
- 300 MB/s streaming to PXI Express FlexRIO, I/Q or time domain
Example Application: Frequency Domain Trigger

NI-RFSA Data
PXI Trigger
P2P Stream
Application Areas - Summary

- Software-Defined Radio (SDR) and communications
- Spectral Monitoring and Signal Intelligence
- Semiconductor evaluation
- Semiconductor validation (protocol-aware ATE)
- High-speed digital
- Protocols for HIL systems
- Highest performance DACs, ADCs, and other silicon
- Custom measurements, triggering, and data reduction
Adapter Module Ecosystem

- 100 MHz TTL
- 200 MHz LVDS
- CameraLink
- 1 Gbps LVDS
- RS-485, 422, I²C, SPI
- 1394b
- DigRF
- 8 channel PMU
- 3 GS/s, 8-bit ADC
- 250 MS/s, 16-bit ADC
- 250 MS/s, 14-bit, 4 channel ADC
- 50 MS/s, 12-bit, 32 channel ADC
- 100 MS/s 16-bit output, 14-bit input dual channel transceiver
- PXI Express FlexRIO
Trend Toward Software-Based Systems

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Key Technologies Driving SI Advancement

- **High-speed busses**
  - PCIe to PCIe
  - PXIe
  - FlexRIO FPGA

- **Software-defined Instrumentation & DSP**

- **Converter Technology**
  - ADC
  - DAC
  - PCIe Peer-to-peer

- **Deep On-board Memory**
  - Digital Up-converter
  - Digital Down-converter

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Virtual Instrumentation

- GSM Tester
- WLAN Tester
- Spectrum
- Radio Tester
- Power Meter
- RFID Tester

All in one PXI platform!

- Multi-Protocol UUT

Traditional Instrumentation

- Lower cost
- Higher performance
- Smaller size
- Flexibility
- Easy upgrades
- User-defined

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