Strategies for Deploying RFSoC Technology for SIGINT, DRFM and Radar Applications

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Topics

- Xilinx RFSoC Overview
- Impact of Latency on Applications
- RFSoC Market Opportunities
- RFSoC Design Challenges
- RFSoC Module Concept: QuartzXM
- Development Platforms for QuartzXM
- QuartzXM Migrates to Other Form Factors
- FPGA IP Development Strategies
- ARM Software Development Strategies
- Summary
February 2017: Xilinx Announced RFSoC

“Xilinx Unveils Disruptive Integration and Architectural Breakthrough for 5G Wireless with RF-Class Analog Technology”

RF Data Converters in an All Programmable MPSoC

Xilinx has integrated multi-giga-sample RF data converters into its 16nm MPSoCs devices for the industry’s first All Programmable RFSoC. This eliminates the need for discrete ADCs and DACs and enables next-generation radio and RF communication systems to scale for power, footprint, and channel density requirements.
Xilinx UltraScale+ FPGA Resources

- 16 nm FPGA Fabric – Logic Cells, DSP Engines, Block RAM, etc.
- Advanced Real-Time Digital Signal Processing Engines
- Extensive General Purpose I/O for Peripherals

<table>
<thead>
<tr>
<th>FPGA RESOURCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSP Engines</td>
</tr>
<tr>
<td>Hi Performance GPIO</td>
</tr>
<tr>
<td>High Density GPIO</td>
</tr>
<tr>
<td>Internal Block RAM</td>
</tr>
<tr>
<td>Internal UltraRAM</td>
</tr>
<tr>
<td>DDR4 Memory Controller</td>
</tr>
<tr>
<td>PCIe Gen4</td>
</tr>
<tr>
<td>GTY 28 gb Serial I/O</td>
</tr>
<tr>
<td>100G EMAC</td>
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</tbody>
</table>

- Fast Internal Memory and Controller for External DDR4
- PCIe Gen4 System Interface
- Enhanced 28 gb GTY Serial I/O and MAC for 100 GbE
Integrated Data Converters in the FPGA

- A/Ds and D/As are connected directly to FPGA fabric
- Lowest latency parallel interfaces

- 8 A/Ds: 12-bit, 4 GHz with integrated Digital Downconverters
- 8 D/As: 14-bit, 6.4 GHz with integrated Digital Upconverters
ARM Processor Resources

FPGA
Xilinx Zynq UltraScale+

ARM-based Processor System

8 A/Ds

8 D/As

USB
SATA
PCIe
GigE
DisplayPort
DDR4
ARM Based Processor System

- Application Processor: Four 64-bit ARM Cortex-A53 cores
- Real-Time Processor: Two ARM Cortex-R5 real time cores

- DDR4 Memory Controller and System Controller
- Security Manager and Platform Management Unit
- High-Speed Connectivity and Processor I/O
RFSoC – Complete RF System on Chip

- Complete sub-system on a single monolithic chip!
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What Is Latency?

- Time delay through the system from input to output
- Includes delays within each element
- Includes delays in the links between each element
- Data converter links are becoming a critical limiting factor!
Parallel vs. Serial Converter Interfaces

Parallel connection (LVDS)
Pro
- Simple
- Low latency

Con
- Limited speed
- Many lines to route on PCB

Serial connection (JESD204B)
Pro
- Can handle high speed A/Ds
- Fewer lines to route on PCB

Con
- Serial protocol introduces latency
- Complex to implement

- The latest and fastest discrete data converters use JESD204B
RFSoC – The Best of Both

**Parallel connection (LVDS)**
- **Pro**
  - Simple
  - Low latency
- **Con**
  - Limited speed
  - Many lines to route on PCB

**Serial connection (JESD204B)**
- **Pro**
  - Can handle high speed A/Ds
  - Fewer lines to route on PCB
- **Con**
  - Complex to implement
  - Serial protocol introduces latency

- **RFSoC Uses Internal Parallel Data Converter Interfaces**
  - Simplest Interface and Low Latency
  - Internal connections handle high data rates
  - Internal connections reduce PCB trace count

- **Eliminates All the Cons!**
Applications and Data Transfer Latency

Application **not** affected by latency - Recording

Latency introduced by JESD204B not a problem

Application affected by latency – Countermeasures

Latency introduced by JESD204B is a big problem!

- RFSoC Covers Applications for **ALL** Latency Requirements!
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RFSoC Market Opportunities

- **Radar**
  - Multi-function Phased Array Radar (MPAR) initiative combines U.S. weather and radar networks
  - Common Module beamformer for DARPA Arrays Commercial Time Scales (ACT) program

- **EW and Countermeasures**
  - Low latency DRFM applications

- **Communications**
  - SATCOM and Military / Airborne Radios

- **SIGINT**
  - Monitoring, Interception, and Analysis

- **5G Wireless & Cable Remote PHY**
  - Remote radio head for Massive-MIMO, wireless backhaul, and fixed wireless access
  - Implements DOCSIS 3.x PHY Spectral Efficiency requirements for distributed broadband digital networks
How Does RFSoC Change the Market?

- **Reduced size and footprint**
  - About 50% less compared with discrete data converters, FPGA & processor

- **Reduced power**
  - About 30-40% total power savings

- **Reduced cost**
  - About 40-60% total cost savings

- **Reduced latency**
  - About 80-90% less delay than JESD204 data converters
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RFSoC: Board Level Design Issues

- **RF Signal Integrity**
  - 16 Analog RF Signals with GHz Bandwidths
  - Spurious digital signal pickup
  - Crosstalk between analog channels
  - Signal path integrity and impedance

- **Gigabit Serial Links – 28 Gbit GTY**
  - Signal path integrity and impedance
  - Bit error rate considerations

- **Clock Management**
  - Data Converter Sample Clocks
  - FPGA Fabric and Gigabit Serial Links

- **Power Supply Requirements**
  - RFSoC chip requires 13 different power supplies
  - Analog supplies must be extremely clean

- **Thermal Management**
  - Air- or conduction-cooling provisions
Design Strategies for RFSoC

- What is the shortest path from RFSoC chip to Deployed Product?
  - Hardware Strategies
  - FPGA Design Strategies
  - ARM Processor Software Development
- How can I get a running start?
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Traditional Modular Designs

- **Cobalt/Onyx/Jade**
  - I/O modules
  - A/Ds & D/As

- **FPGA Main Board**
  - Memory
  - Power Supplies
  - Clocking

- **FMC module**
  - A/Ds & D/As

- **FPGA Carrier Board**
  - Memory
  - Power Supplies
  - Clocking

- **XMC Products**

- **FMC Products**
QuartzXM: RFSoC eXpress Module

4.0 inch
10.16 cm

2.5 inch
6.35 cm
Benefits of the QuartzXM eXpress Module

- Mezzanine module simplifies and speeds RFSoC product designs
- Connectorizes & preserves integrity of RF and gigabit serial signals
- Generates all 13 RFSoC power supplies from a single +12V input
- Includes FLASH and DDR4 memories for FPGA & ARM processor
- Maintains PCB constraints for bypassing, filtering, & geometries
- Includes clock management and health monitoring facilities
- Excellent path for addressing SWaP requirements

Some technical details:
- 28 layer PCB
- Over 4000 drilled holes
- Uses advanced PCB fabrication techniques including: sequential lamination, backdrilling, blind and buried vias, etc.
- Supports 28Gbps GTY serial interfaces
Model 6001 – QuartzXM eXpress Module

- Contains all the infrastructure circuitry to support the RFSoC
- Power supplies and power management
- Clock management
- DDR4 SDRAM for both the FPGA fabric and processors
- Configuration FLASH
- Connectors for bringing ALL RFSoC signals to a carrier board
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VPX Standards for Embedded Systems

- **VITA 66.x Optical Backplane I/O**
  - Several full- and half-width blind-mate optical connector types
  - Provides high bandwidth data paths between boards and chassis

- **VITA 67.x Coax Backplane I/O**
  - Several multi-position connector types – up to 12 coax signals
  - RF signal bandwidths to 40 GHz
  - Eliminates front panel signal cables

- **VITA 65.0 & 65.1 OpenVPX - 2017**
  - Most popular MIL-AERO standard for deployed systems
  - Major enhancements reflect widespread use and adoption of OpenVPX
  - New Card, Slot and Backplane Profiles
  - Radial Backplane Clock distribution ensures precision timing and synchronization across boards
  - Provision for a 100 MHz reference clock
  - New definitions of combinations of VITA 66.x optical and VITA 67.x coaxial backplane I/O

Photo: SV Microwave

Photo: Elma

Photo: TE Connectivity
QuartzXM on 3U VPX – Front Analog I/O

- Model 5950 3U VPX Carrier for QuartzXM
- Open Architecture Form Factor Supporting Industry Standards
  - VITA 65.1 OpenVPX
  - VITA 66.4 Optical Serial Backplane I/O
- Complete functional sub-system on one 3U VPX module
- Scales easily to support high-channel count systems
- Synchronization across multiple modules

![Diagram of QuartzXM on 3U VPX]
Model 5950 Quartz 3U VPX

- 3U VPX Carrier provides Coaxial RF Front Panel I/O
- Rear Transition Module provides ARM processor I/O
- Air- and Conduction-cooled Versions
3U VPX Single Slot Development Chassis

- Low-cost chassis includes backplane, power supply, & cooling
- Model 5950 3U VPX RFSoC installed & tested
- Model 5901 Rear-Transition Module installed & tested
- Optional MTP Optical connector for dual 100GbE

Model 5950 3U VPX Front Panel
(RF I/O, clocks, timing, etc.)

Model 5901 Rear Transition Module
(ARM Processor I/O, FPGA LVDS I/O)

MTP Optical I/O
(Dual 100 GbE)
Single Slot Development Chassis Strategies

Customer’s PC

Rear

RS-232 (USB)

JTAG

1 GigE
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QuartzXM for 3U VPX – Backplane RF I/O

- Similar to Model 5950 except analog RF I/O connects through backplane
- VITA 67 defines several possible RF backplane connector formats
- Simplifies system integration and maintenance tasks
- Improves reliability by eliminating cables
QuartzXM on PCIe Carrier for PC Platform

- Allows RFSoC development tasks in a low cost PC platform
- Perfect for software and FPGA development seats
- Perfect for continuation engineering and support
- Supports deployed applications for benign environments
Migrating QuartzXM to Custom Platforms

- Development Strategy
  - Start with standard open-architecture product like 5950
  - Develop software and IP for custom form factor application

- Custom Carrier
  - Use Pentek Quartz Carrier Design Package
  - Pin definition, design rules, layout guidance and design review
  - Attach QuartzXM Module
  - Keep 5950 as a development platform
Custom RFSoC SoM Solutions

RFSoC QuartzXM Model 6001

RFSoC QuartzXM Model 6001

RFSoC QuartzXM Model 6001

RFSoC QuartzXM Model 6001
Custom RFSoC SoM Solutions

Customer’s 8 x 4 antenna array

Custom designed 6001 carrier
Small Form Factor Remote Box

- Create or adapt a carrier for the QuartzXM module
- For example, start with the Model 5950 3U VPX board
- Modify the board to remove VPX connectors & hardware
Small Form Factor Remote Box

- Add connectors appropriate for the application
Small Form Factor Remote Box

- Install it within a suitable SFF sealed enclosure
- Mount the unit on a mast near the antenna
- Complete 8-channel RF transceiver sub-system

- **RF In**
- **8 A/D**
- **RF Out**
- **Ref Clk**
- **Samp Clk**
- **JTAG**
- **5”**
- **7”**
- **Power**
- **1GigE**
- **Dual 100 GigE**
Model 4801 Carrier Design Package

- Documentation needed for a customer to design his own carrier
  - Pin definitions and electrical specifications of all signals on the QuartzXM
  - 3D mechanical models
  - Thermal profiles of the module and components
  - Carrier reference design schematics
  - PCB stack-up recommendations
  - PCB design guidelines and routing rules
  - Operating system and bootstrap guidelines
  - Additional electrical and mechanical engineering guidance

- Carrier Design Package purchase requires an NDA
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FPGA Design Strategies for RFSoC

- **Xilinx Vivado Tool Suite**
  - Vivado IP Integrator
    - Graphical Design Entry Tool
  - Vivado AXI-4 IP Library Modules
    - Standardized for compatibility
  - Vivado High-Level Synthesis
    - Generates RTL from C & C++
  - Vivado Simulator
    - Design Verification
  - TCL Tool Command Language
    - Scripting language

- **Pentek Navigator FDK for RFSoC**
  - Complete Vivado Project Folder
    - All files included ready for development
  - Full AXI-4 Compliant IP Library
    - Full IP Source code included
  - Pentek FPGA Resource Modules
    - DMA controllers, triggering & gating
    - Timing & synchronization
    - 100 GbE engines
  - Factory Installed RFSoC Applications
    - Radar & Data Acquisition
    - Waveform Generation
Included RFSoC Starter Applications

Digital RF Memory with Programmable Delay

A/D Acquisition Engine to 100 GbE Optical Streaming
Included RFSoC Starter Applications

Waveform Generator from Memory, PCIe, or 100 GbE

Multi-mode Acquisition to Delay Memory, PCIe, or 100 GbE
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FPGA Design Strategies for RFSoC

▪ Xilinx Vivado Tools for RFSoC
  • Xilinx RFSoC ARM SDK
    ▪ Complete Integrated Design Environment (IDE) interfaces to Vivado FPGA tools
    ▪ Multi-processor hardware/software co-debug capabilities
    ▪ Editor, compilers, build tools, flash memory management
    ▪ Libraries and device drivers
    ▪ Xilinx Software Command Line Tool (XSCT) for scripting
  • Xilinx PetaLinux
    ▪ Linux OS for ARM Processor
    ▪ Linux Tools and Utilities

▪ Pentek Navigator BSP for RFSoC
  • Navigator command processor
    ▪ RFSoC ARM command processor application executes high-level API commands from PCIe or Ethernet
  • Powerful Tool Suite
    ▪ Initialization and control of all FPGA IP
    ▪ Delivery of all operational parameters
    ▪ High-Level C-Language Libraries
    ▪ Full C Source Code Provided
    ▪ Numerous Program Code Examples
    ▪ Device Drivers for Windows & Linux
  • Signal Viewer Utility
    ▪ Displays acquired signals on virtual spectrum analyzer and oscilloscope
Flexible API Command Processing

- ARM Processor on QuartzXM runs the Pentek Navigator QuartzXM API Command Processor
- Accepts API commands across Ethernet
- Accepts API commands across PCIe bus
- Flexible options for different system architectures
Model 5950 3U VPX PCIe Interface can be configured as a Root Complex

- Model 5950 can replace the SBC to save a system card and slot space
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RFSoC Deployment Strategies

- **Xilinx RFSoC Offers Extreme Integration**
  - A/D, D/A, FPGA, ARM Processor, Flexible I/O
  - Low Latency for wideband RF signals

- **Pentek QuartzXM Simplifies System Design**
  - Small footprint for high density applications
  - Complete RFSoC infrastructure with DDR4, clock management, & power supplies
  - High performance RF and digital connectors

- **Xilinx Vivado Tools**
  - FPGA development tools
  - ARM processor OS and development tools

- **Pentek Navigator FDK and BSP Tools**
  - API command processor for ARM
  - Factory installed FPGA IP modules for timing, DMA controllers, PCIe, memory controllers
  - FPGA IP AXI-4 library functions
  - Four starter application examples installed

- Speeds development cycles, saves costs
Thank you! For More Information……

- Visit [www.pentek.com/RFSoC](http://www.pentek.com/RFSoC)
- Data Sheets
  - Model 5950 3U VPX RFSoC Board
  - Model 6001 RFSoM Module
- Whitepaper
  - Xilinx’s Zynq UltraScale+ RFSoC
- Pentek Pipeline Summer 2018
  - Strategies for Deploying RFSoC
- Live Signal Acquisition Video
  - Shows A/D acquisition using ARM-based API Command Processor