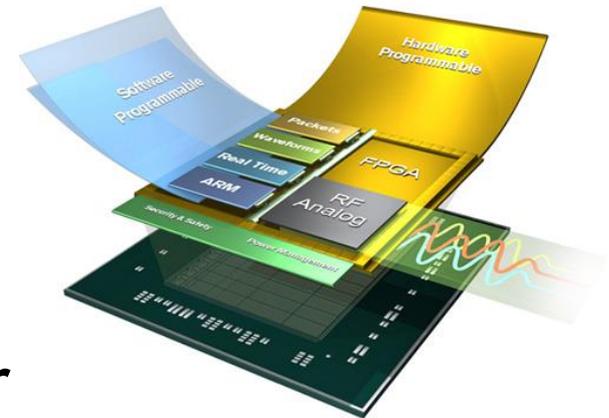


# Strategies for Deploying RFSoc Technology for SIGINT, DRFM and Radar Applications

*Rodger Hosking  
Pentek, Inc.*



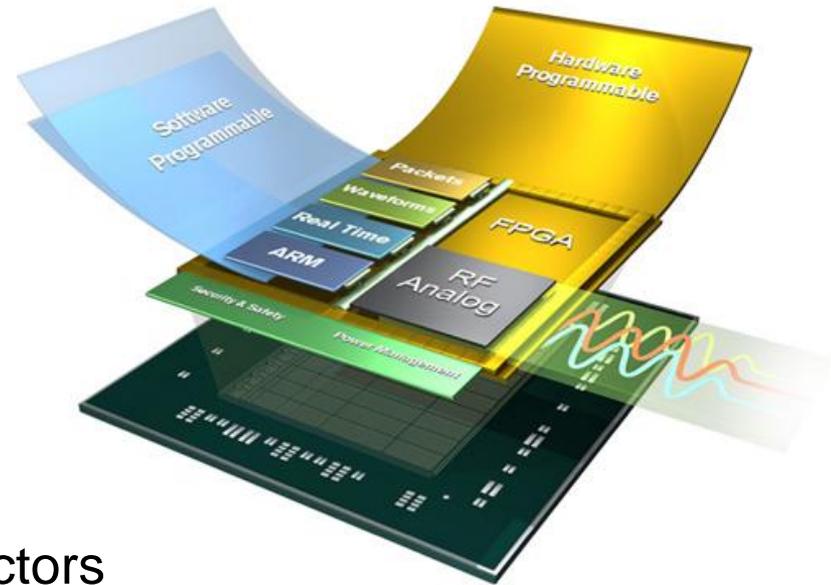
*WinnForum Webinar  
November 8, 2018*





# Topics

- Xilinx RFSoc Overview
- Impact of Latency on Applications
- RFSoc Market Opportunities
- RFSoc Design Challenges
- RFSoc Module Concept: QuartzXM
- Development Platforms for QuartzXM
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# February 2017: Xilinx Announced RFSoc

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

Overview   RF Sampling   Documentation   Developer Zone

White Paper   Press Release   IEEE Paper

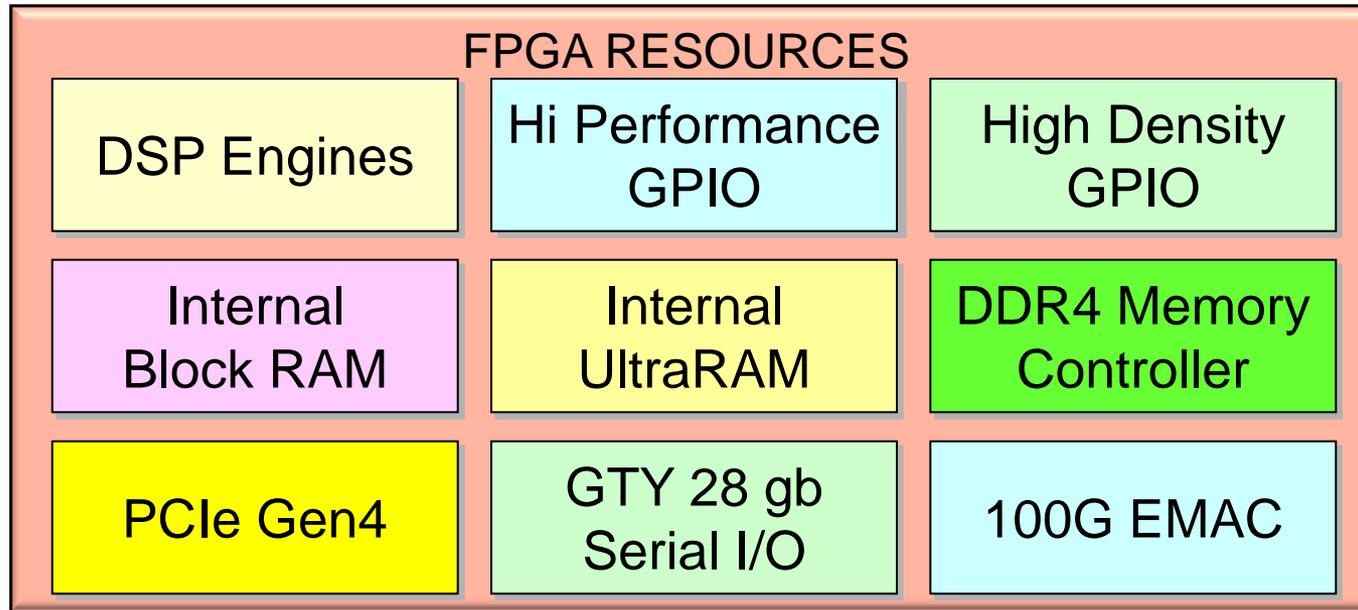
## RF Data Converters in an All Programmable MPSoC

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

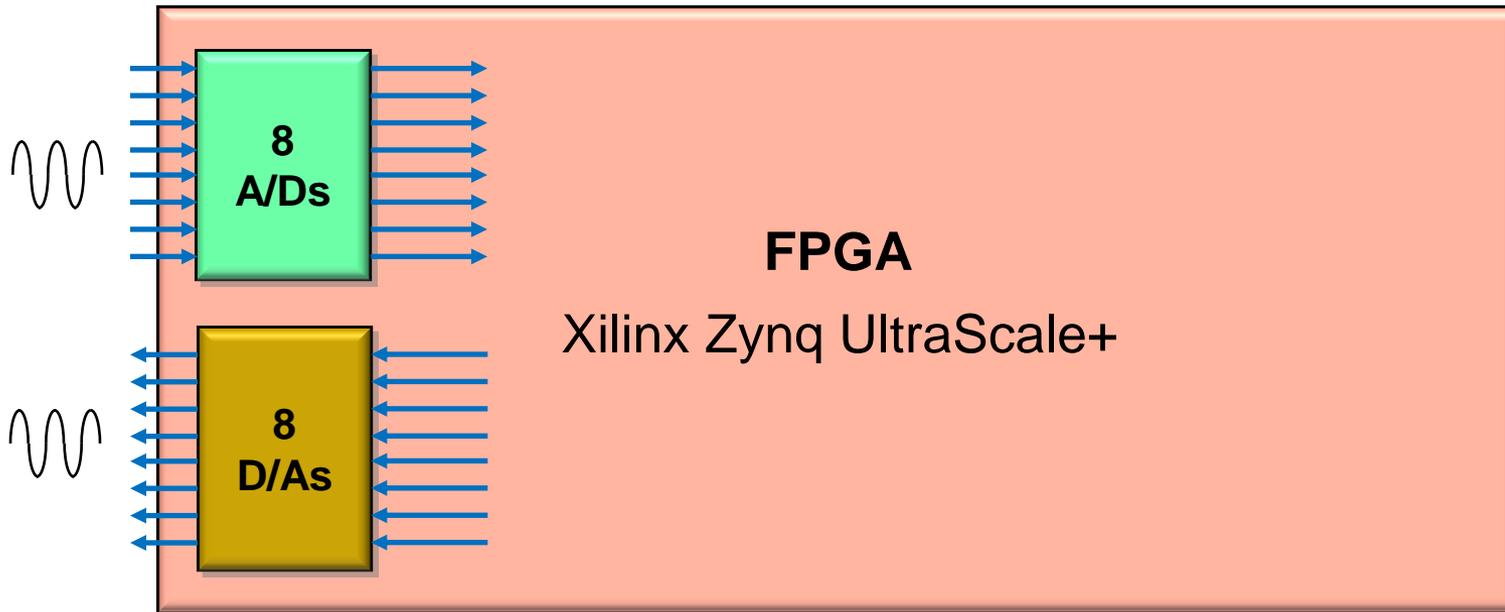


- Fast Internal Memory and Controller for External DDR4
- PCIe Gen4 System Interface
- Enhanced 28 gb GTY Serial I/O and MAC for 100 GbE



# Integrated Data Converters in the FPGA

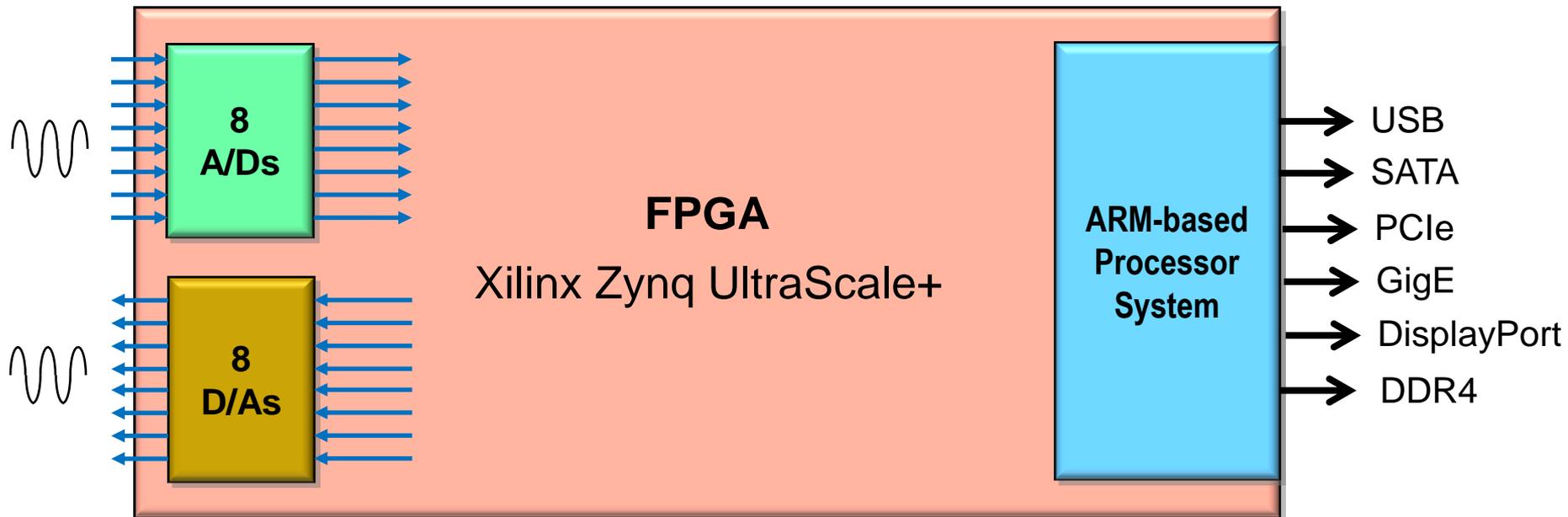
- A/Ds and D/As are connected directly to FPGA fabric
- Lowest latency parallel interfaces



- 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

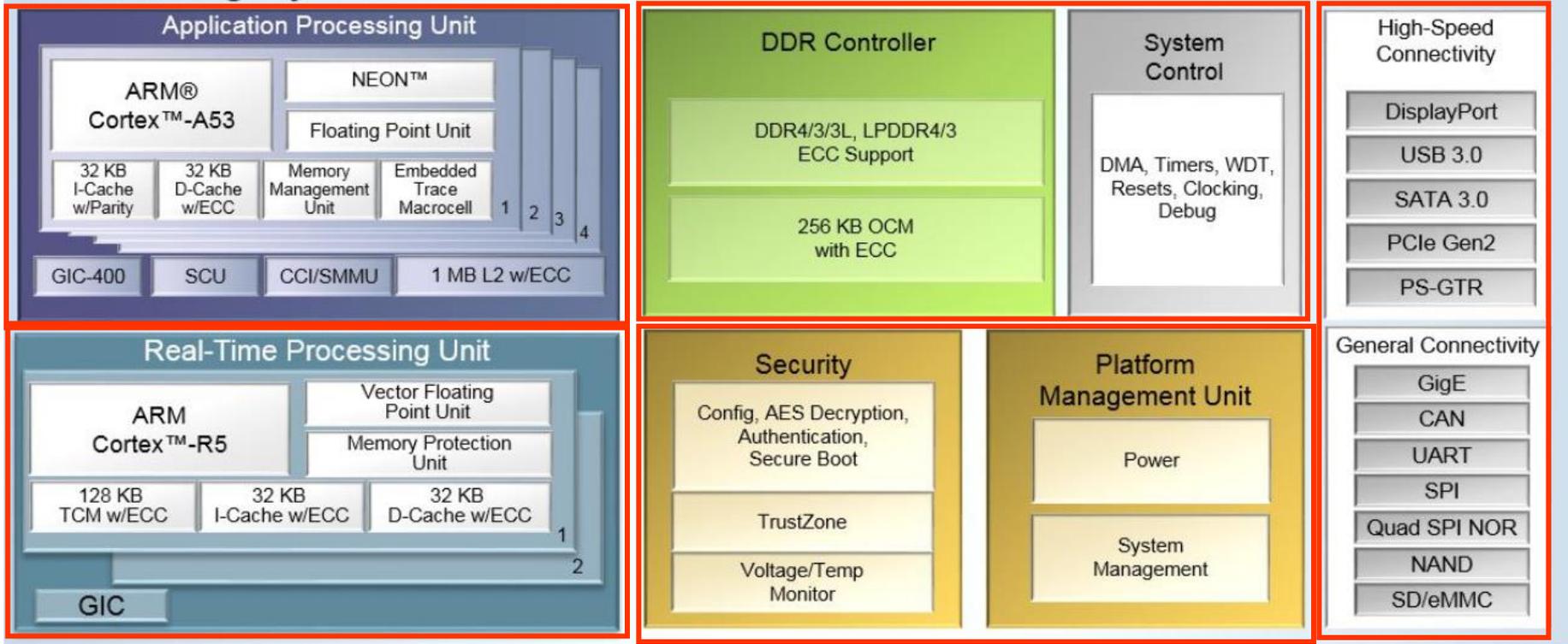




# ARM Based Processor System

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

## Processing System

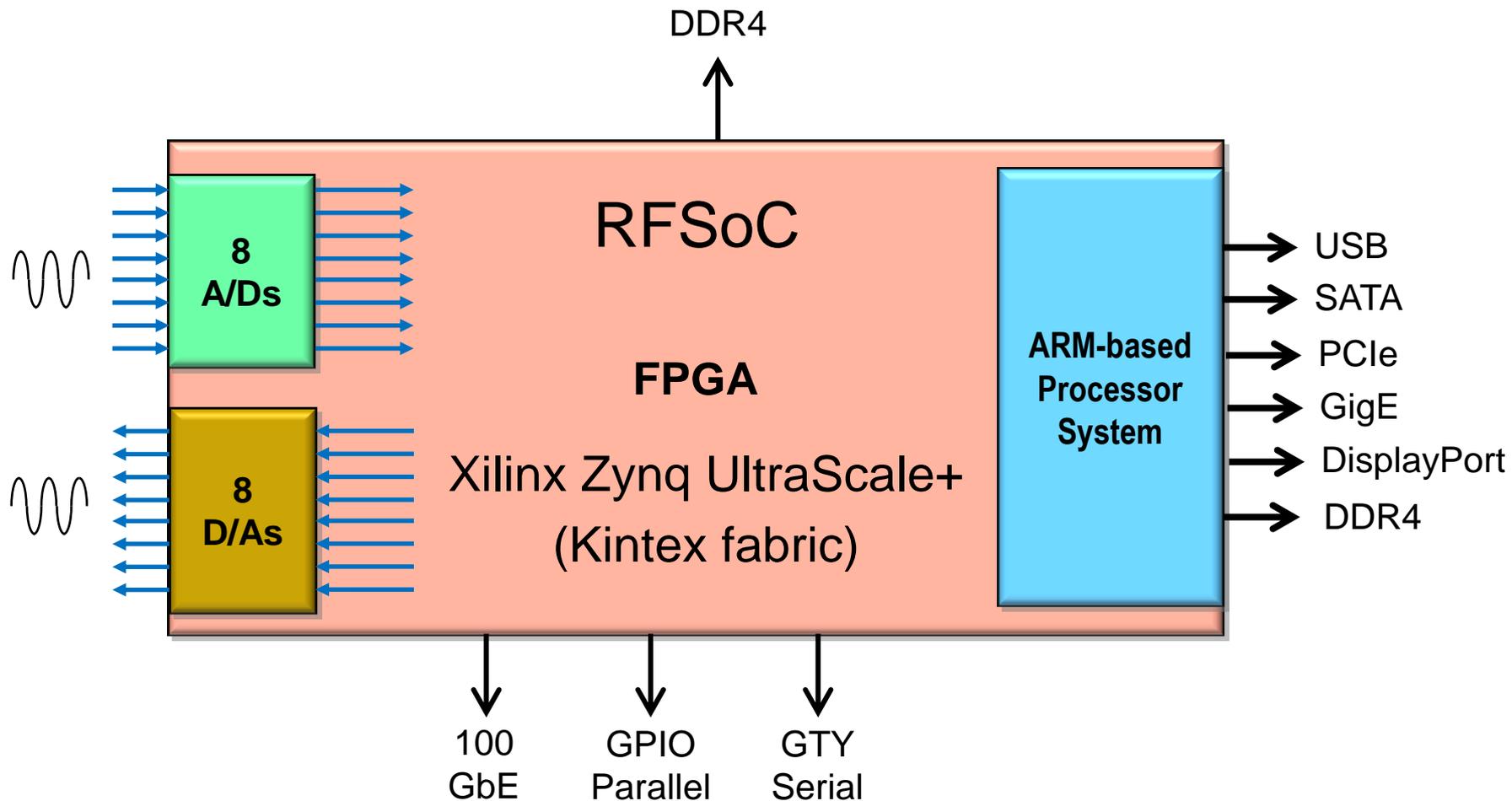


- DDR4 Memory Controller and System Controller
- Security Manager and Platform Management Unit
- High-Speed Connectivity and Processor I/O



# RFSoc – Complete RF System on Chip

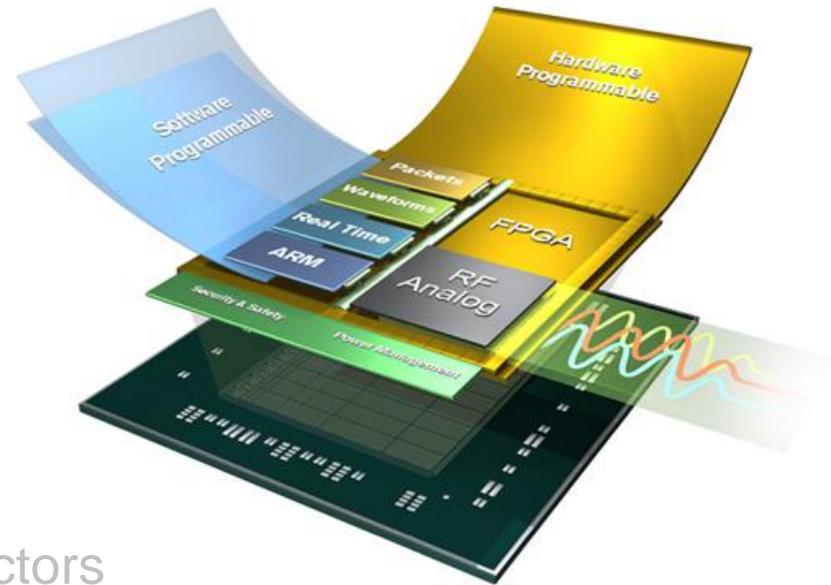
- Complete sub-system on a single monolithic chip!





# Topics

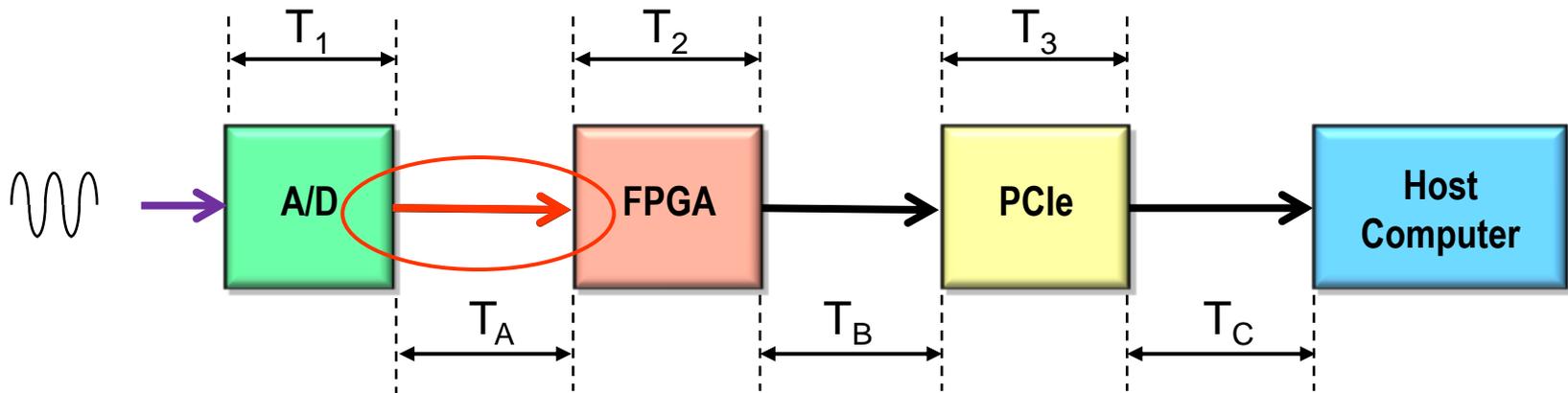
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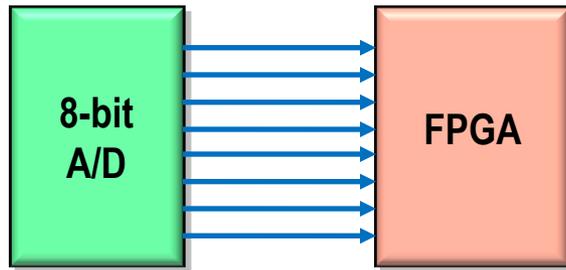
# What Is Latency?

- 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



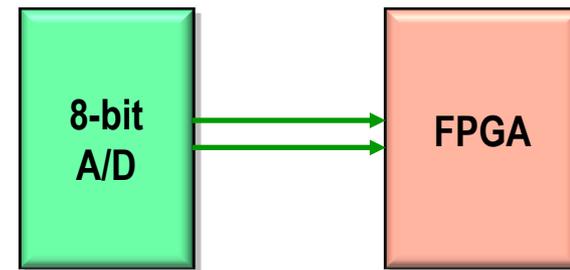
## Parallel connection (LVDS)

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

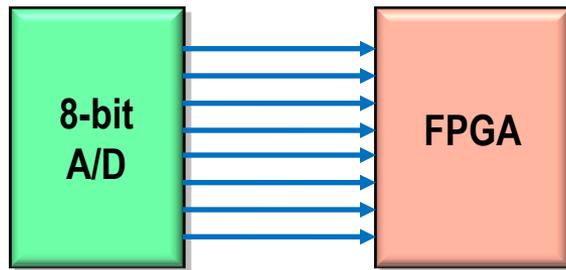
Con

- Serial protocol introduces latency
- Complex to implement

- The latest and fastest discrete data converters use JESD204B



# RFSoc – The Best of Both



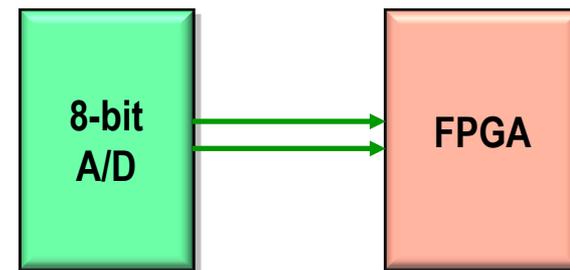
## Parallel connection (LVDS)

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

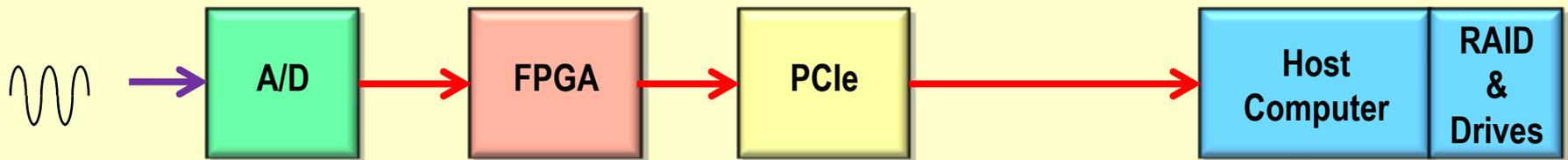
- ~~Complex to implement~~
- ~~Serial protocol introduces latency~~

- 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!



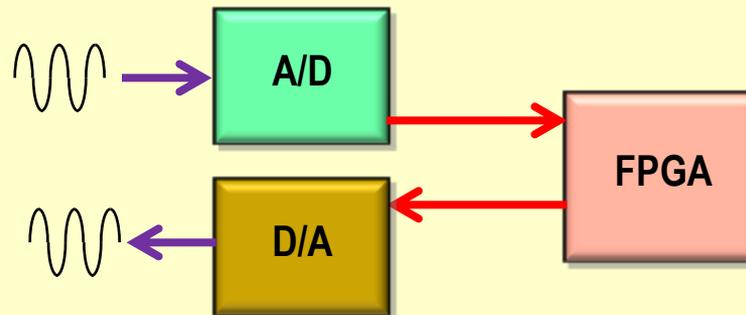
# Applications and Data Transfer Latency

Application not affected by latency - Recording



Latency introduced by JESD204B not a problem

Application affected by latency – Countermeasures



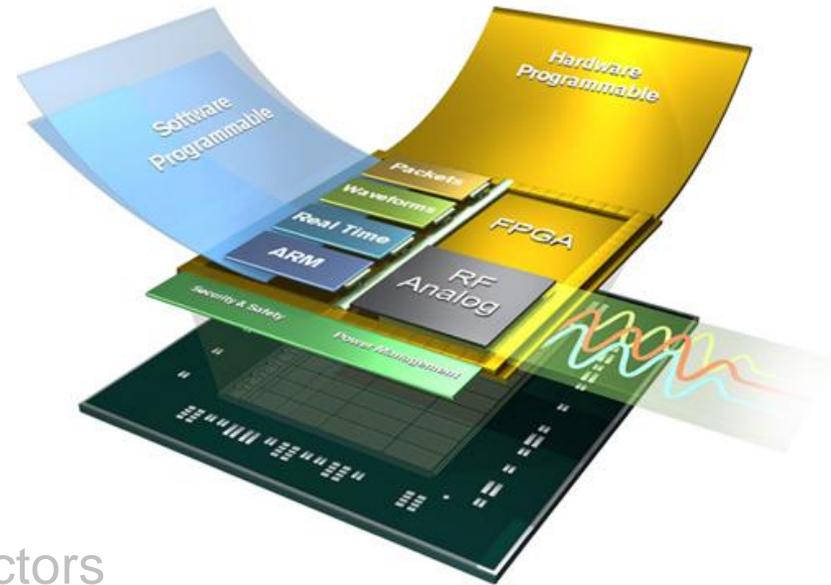
Latency introduced by JESD204B is a big problem!

- RFSoc Covers Applications for **ALL** Latency Requirements!



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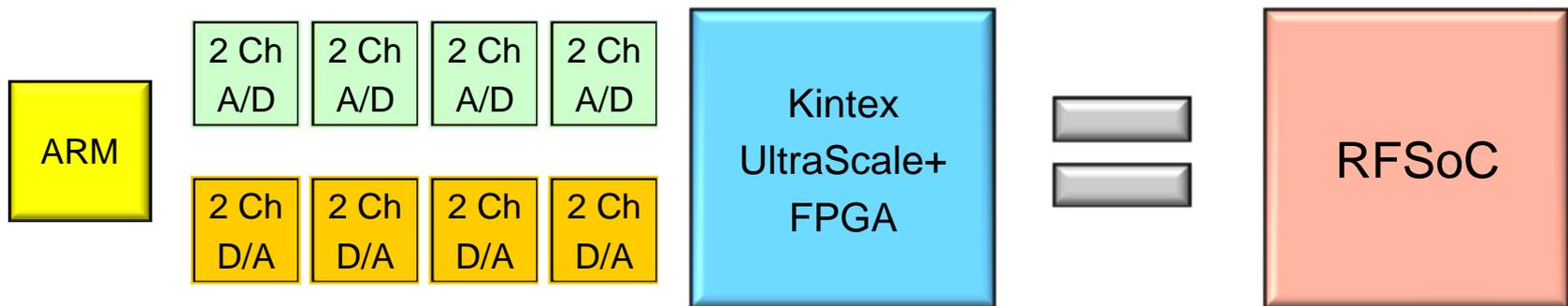
# RFSoc Market Opportunities

- 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?

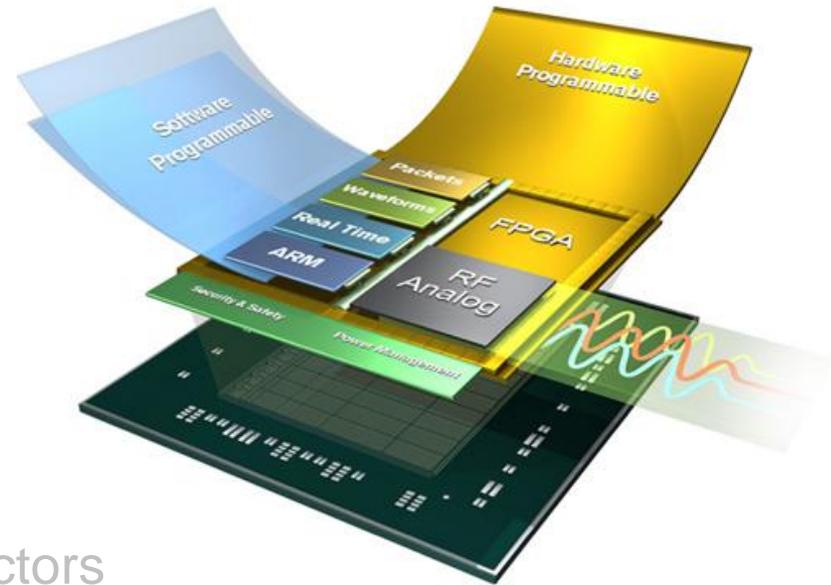
- Reduced size and footprint
  - About 50% less compared with discrete data converters, FPGA & processor
- Reduced power
  - About 30-40% total power savings
- Reduced cost
  - About 40-60% total cost savings
- Reduced latency
  - About 80-90% less delay than JESD204 data converters





# Topics

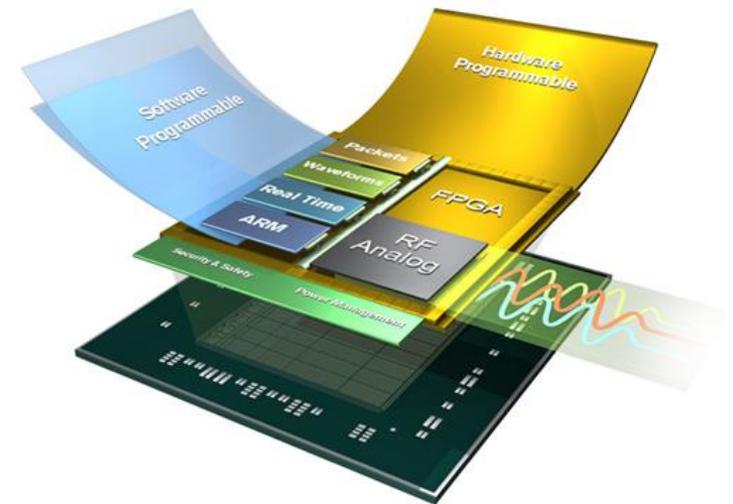
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# RFSoc: Board Level Design Issues

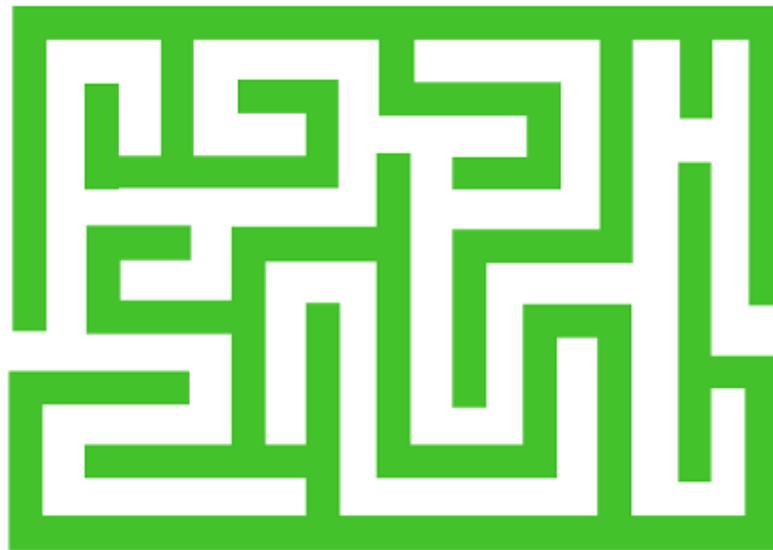
- RF Signal Integrity
  - 16 Analog RF Signals with GHz Bandwidths
  - Spurious digital signal pickup
  - Crosstalk between analog channels
  - Signal path integrity and impedance
- Gigabit Serial Links – 28 Gbit GTY
  - Signal path integrity and impedance
  - Bit error rate considerations
- Clock Management
  - 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

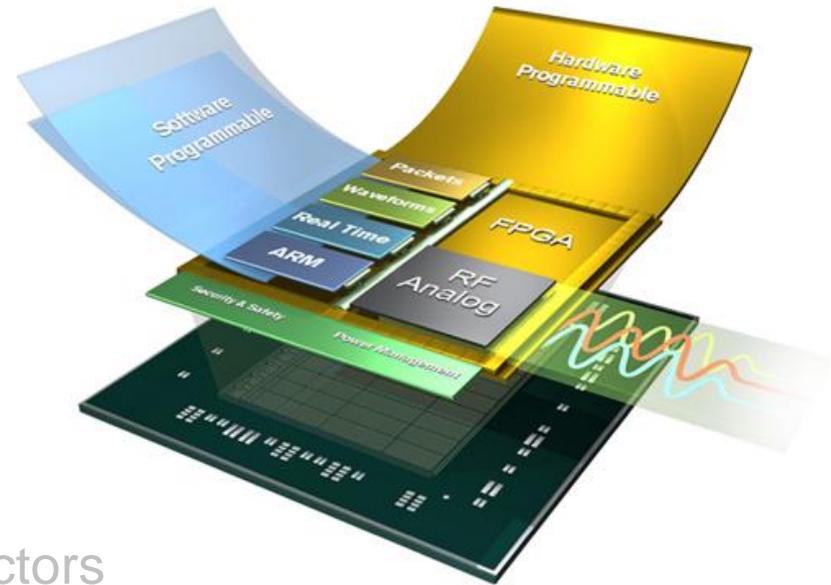
- What the shortest path from RFSoc chip to Deployed Product?
  - Hardware Strategies
  - FPGA Design Strategies
  - ARM Processor Software Development
- How can I get a running start?





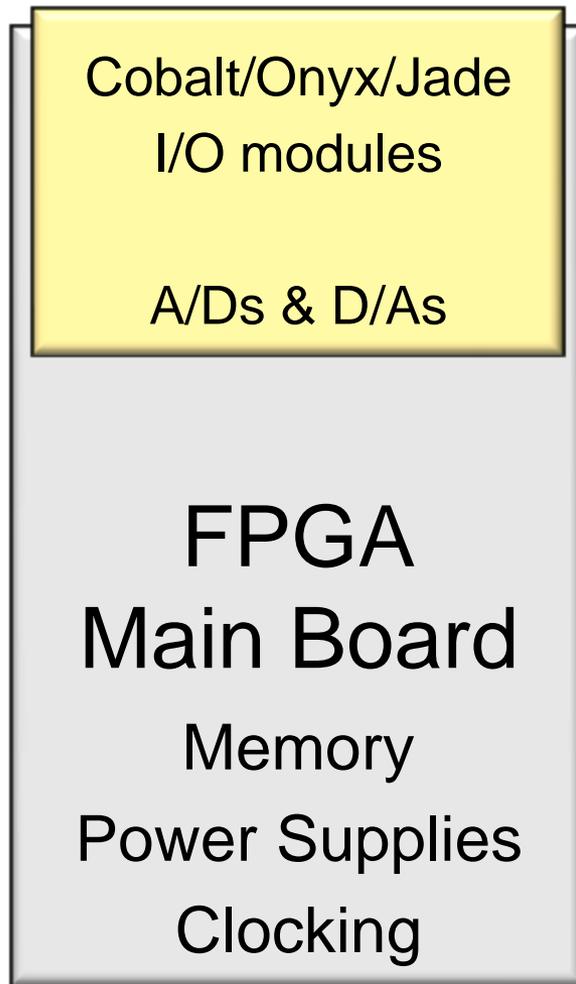
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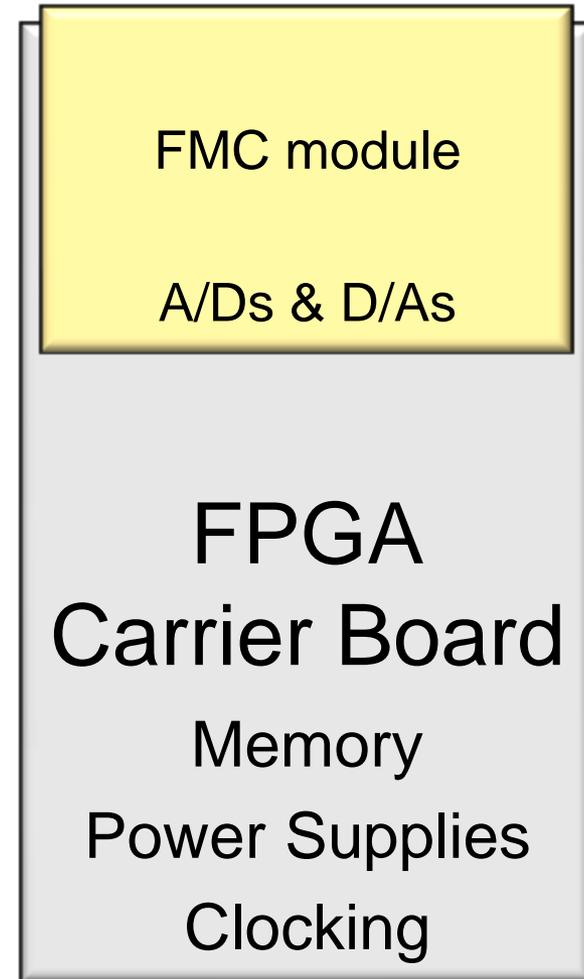




# Traditional Modular Designs



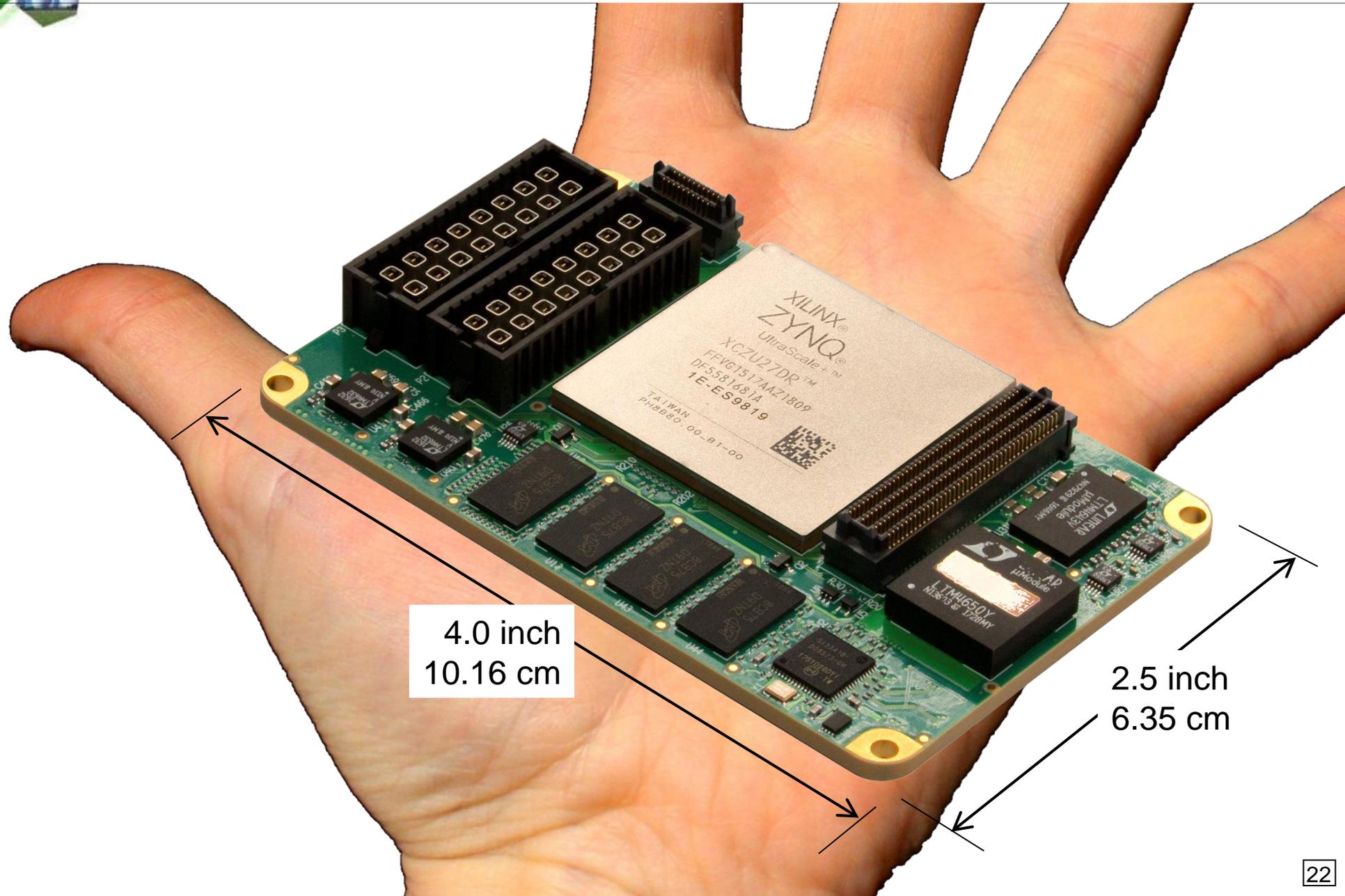
XMC Products



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

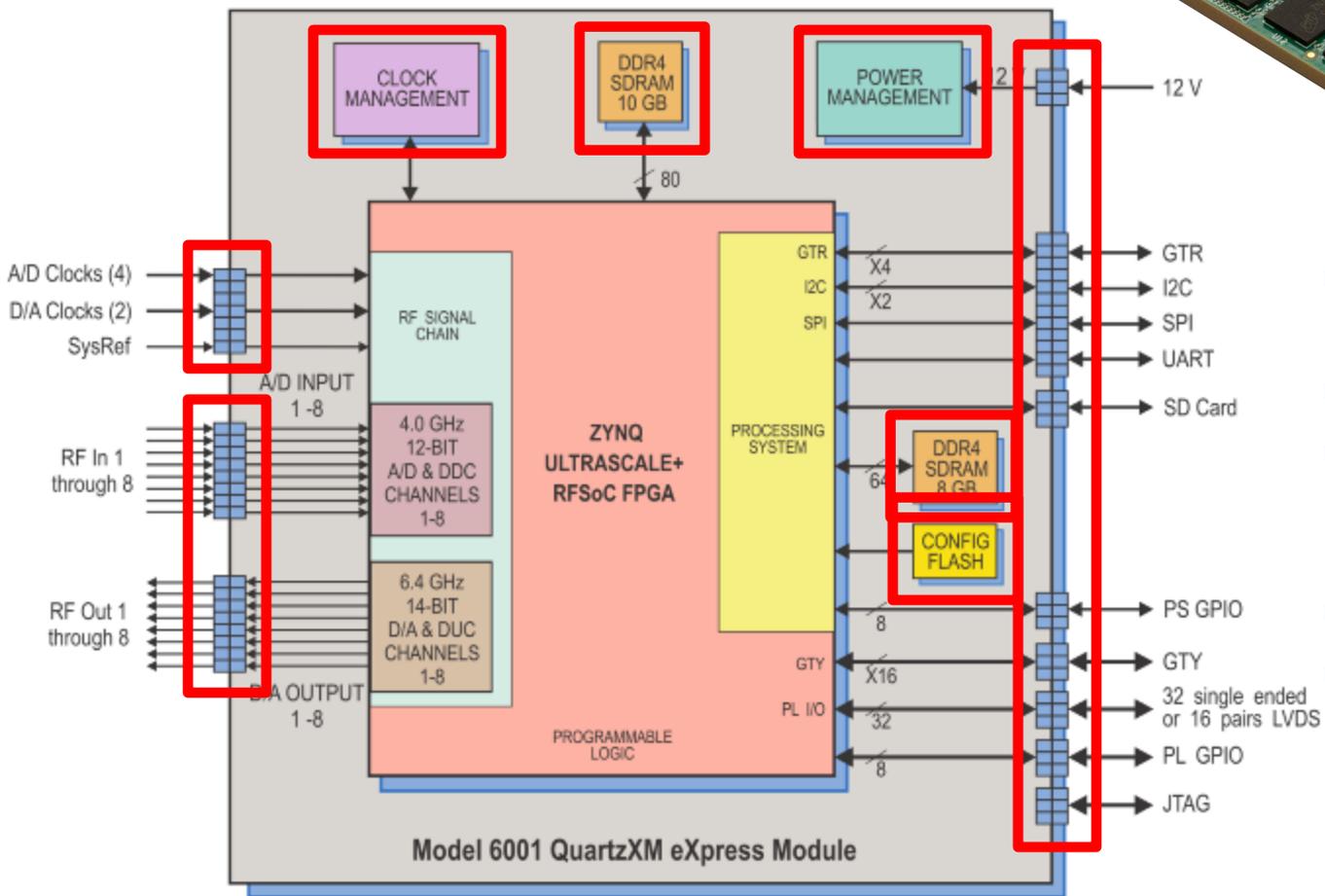
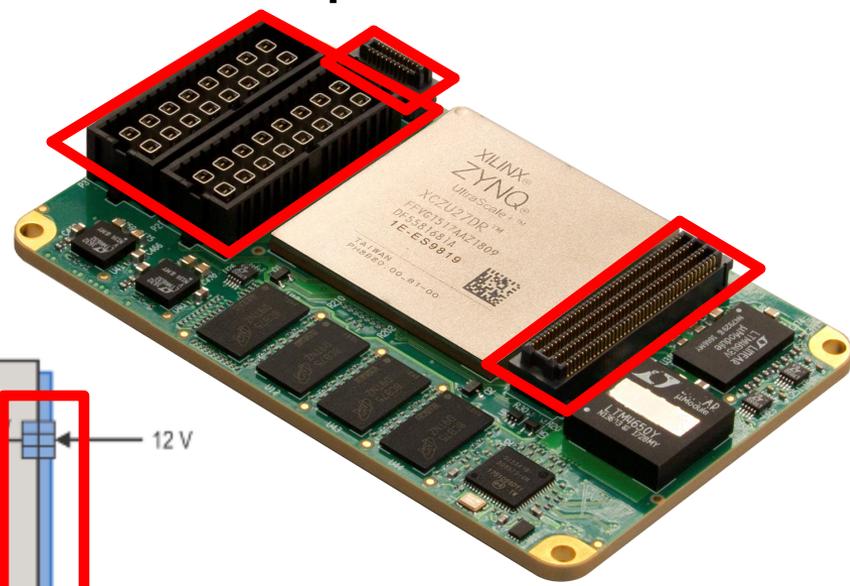


- Some technical details:
  - 28 layer PCB
  - Over 4000 drilled holes
  - Uses advanced PCB fabrication techniques including: *sequential lamination, backdrilling, blind and buried vias, etc.*
  - Supports 28Gbps GTY serial interfaces



# Model 6001 – QuartzXM eXpress Module

- Contains all the infrastructure circuitry to support the RFSoc

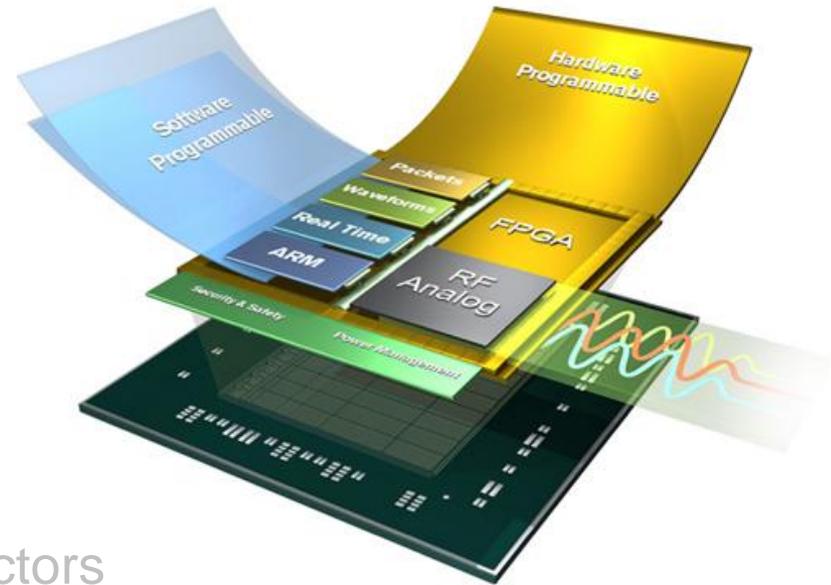


- Power supplies and power management
- Clock management
- DDR4 SDRAM for both the FPGA fabric and processors
- Configuration FLASH
- Connectors for bringing ALL RFSoc signals to a carrier board



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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



Photo: Elma

## ■ 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



Photo: SV Microwave

## ■ 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

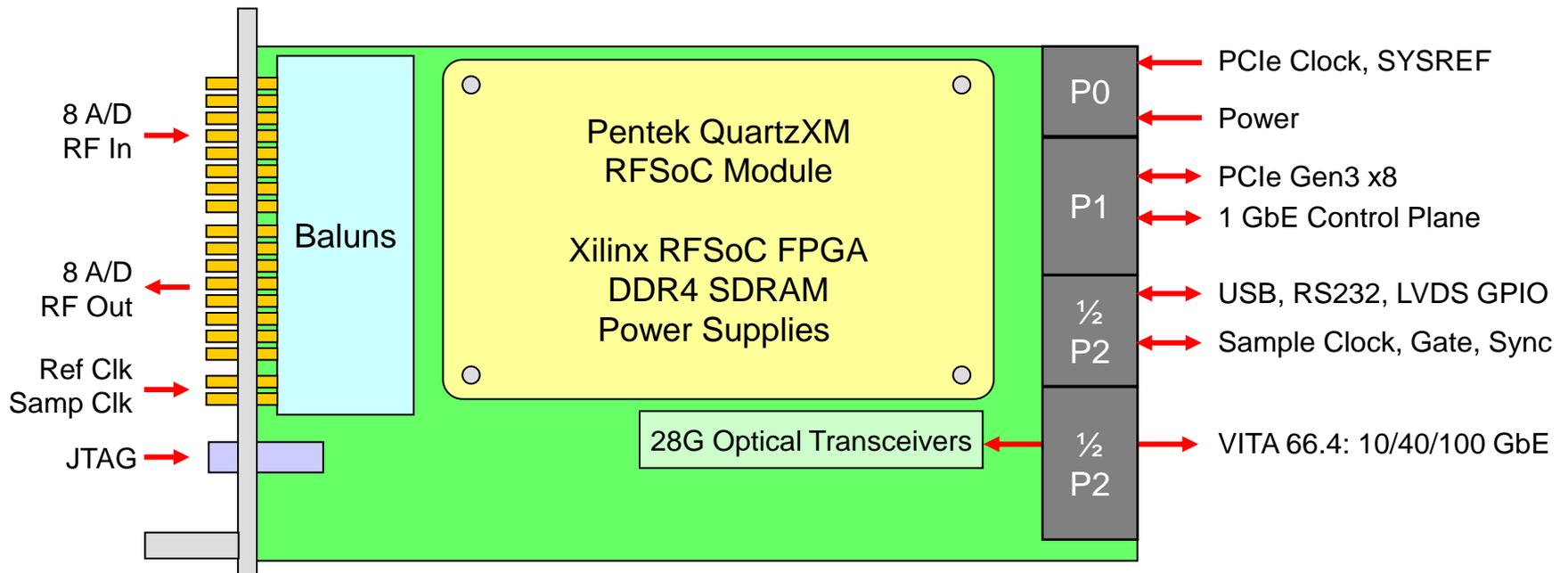


Photo: TE Connectivity



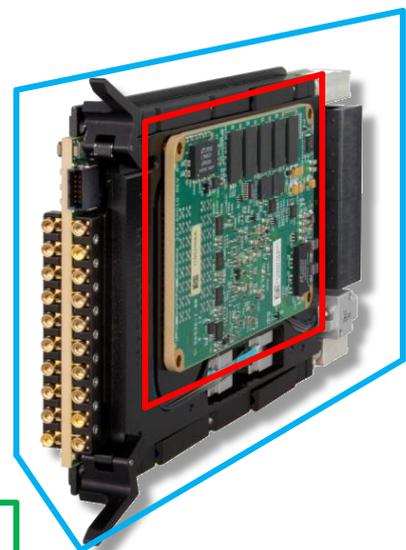
# QuartzXM on 3U VPX – Front Analog I/O

- 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

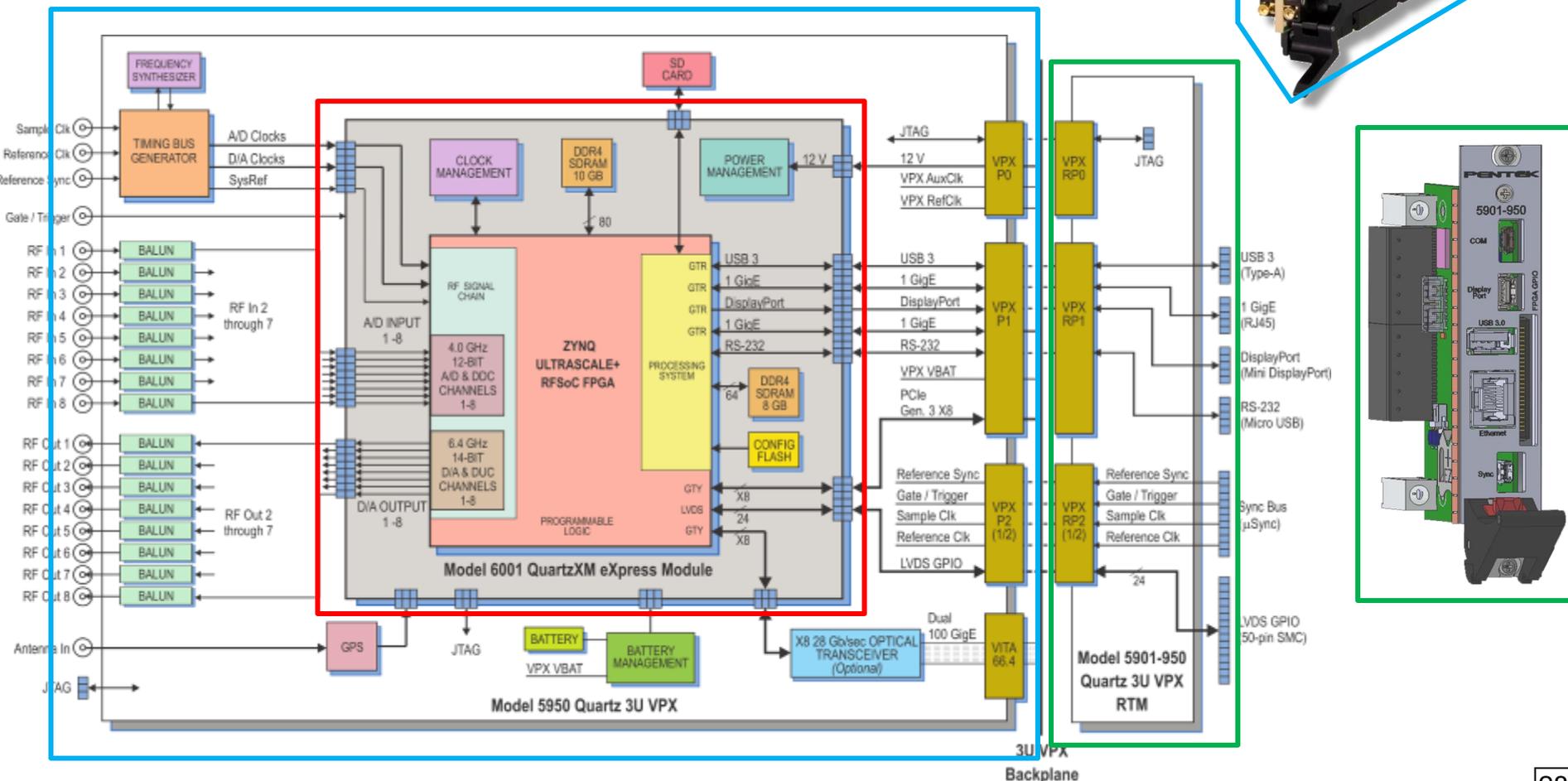




# Model 5950 Quartz 3U VPX



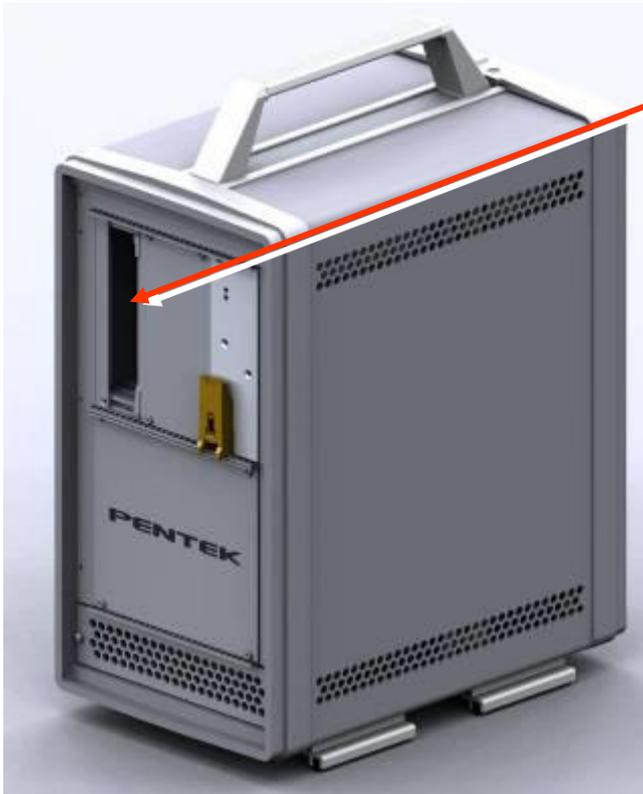
- 3U VPX Carrier provides Coaxial RF Front Panel I/O
- Rear Transition Module provides ARM processor I/O
- Air- and Conduction-cooled Versions





# 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

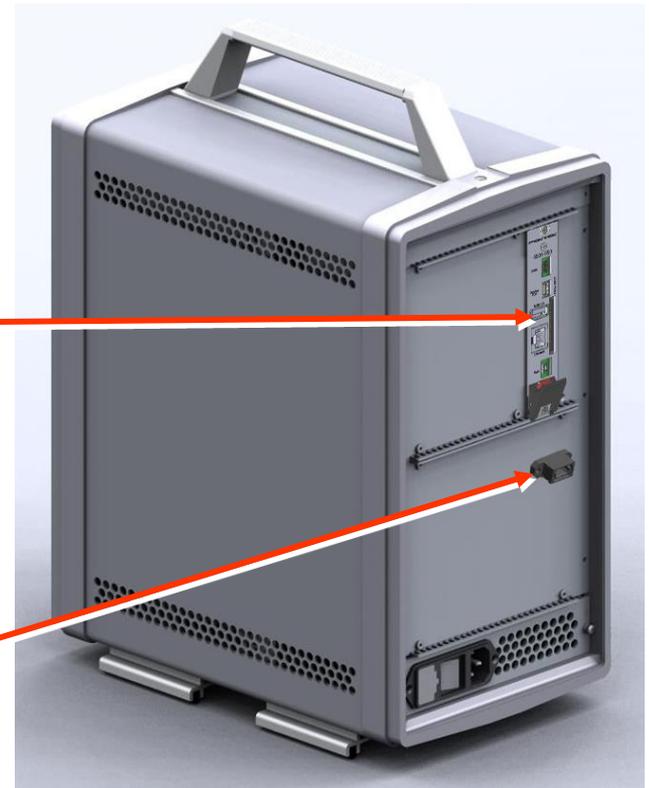


Front

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)



Rear



# Single Slot Development Chassis Strategies

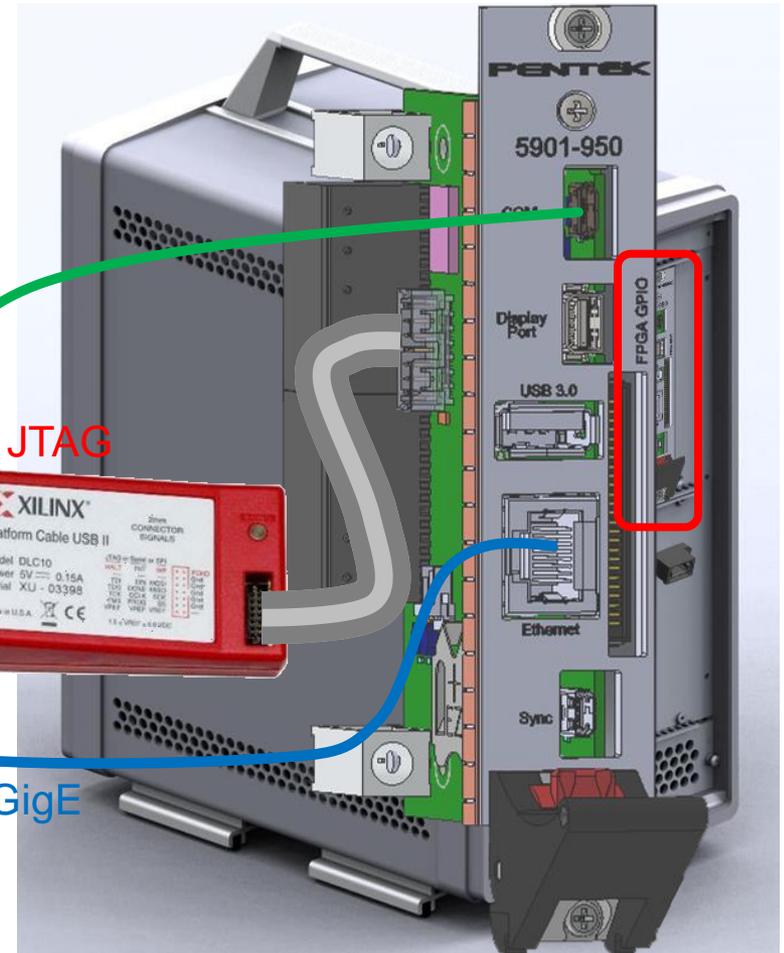


Customer's PC

RS-232  
(USB)

JTAG

1 GigE

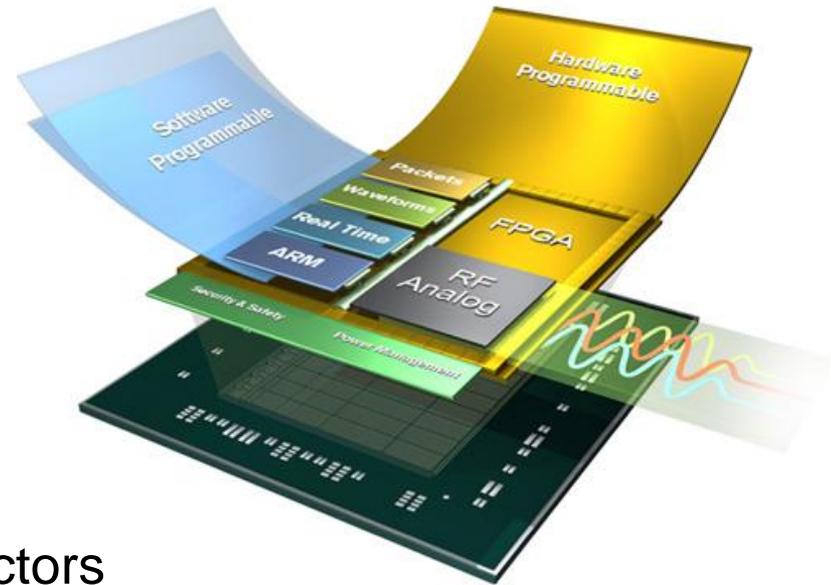


Rear



# Topics

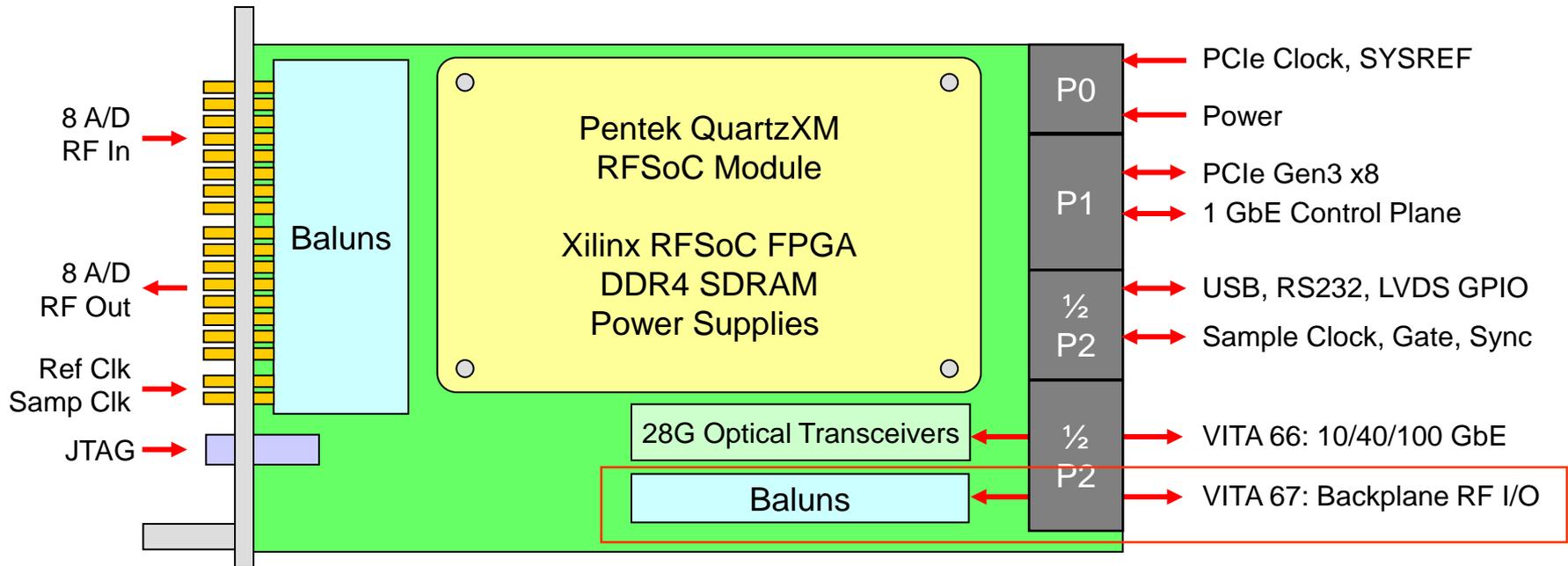
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# QuartzXM for 3U VPX – Backplane RF I/O

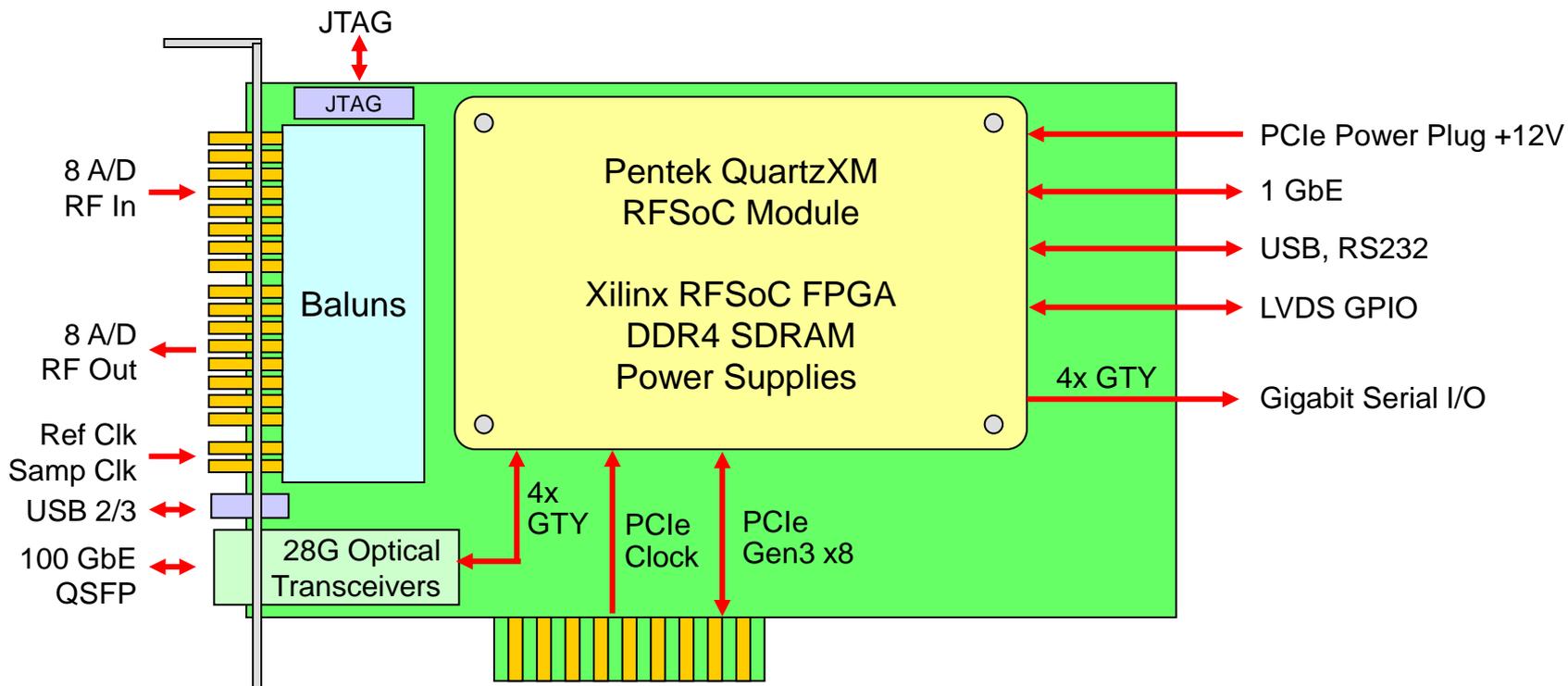
- Similar to Model 5950 except analog RF I/O connects through backplane
- VITA 67 defines several possible RF backplane connector formats
- Simplifies system integration and maintenance tasks
- Improves reliability by eliminating cables





# 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





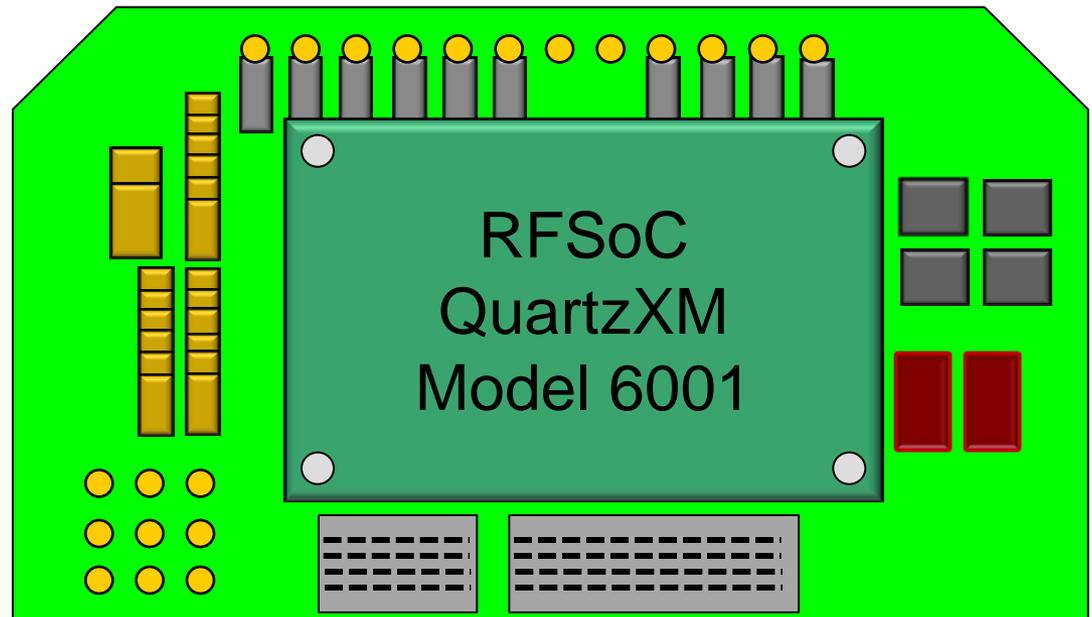
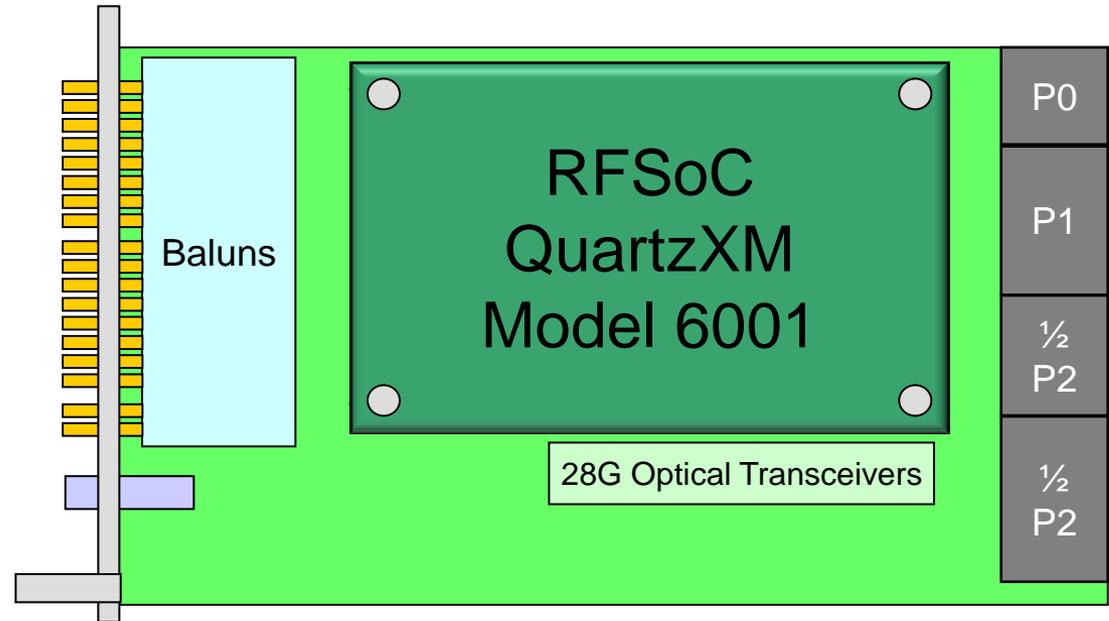
# Migrating QuartzXM to Custom Platforms

## ■ Development Strategy

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

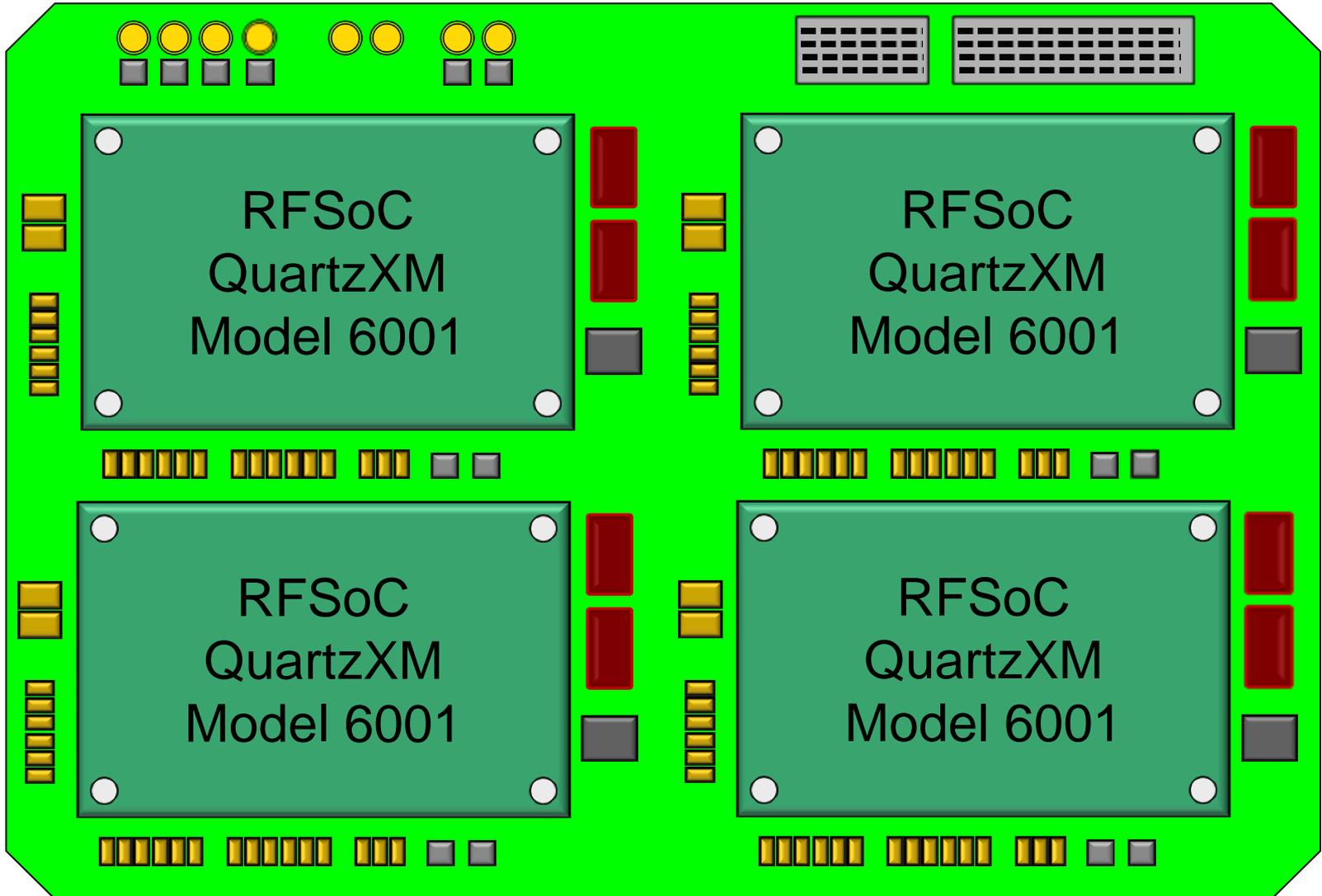
## ■ Custom Carrier

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



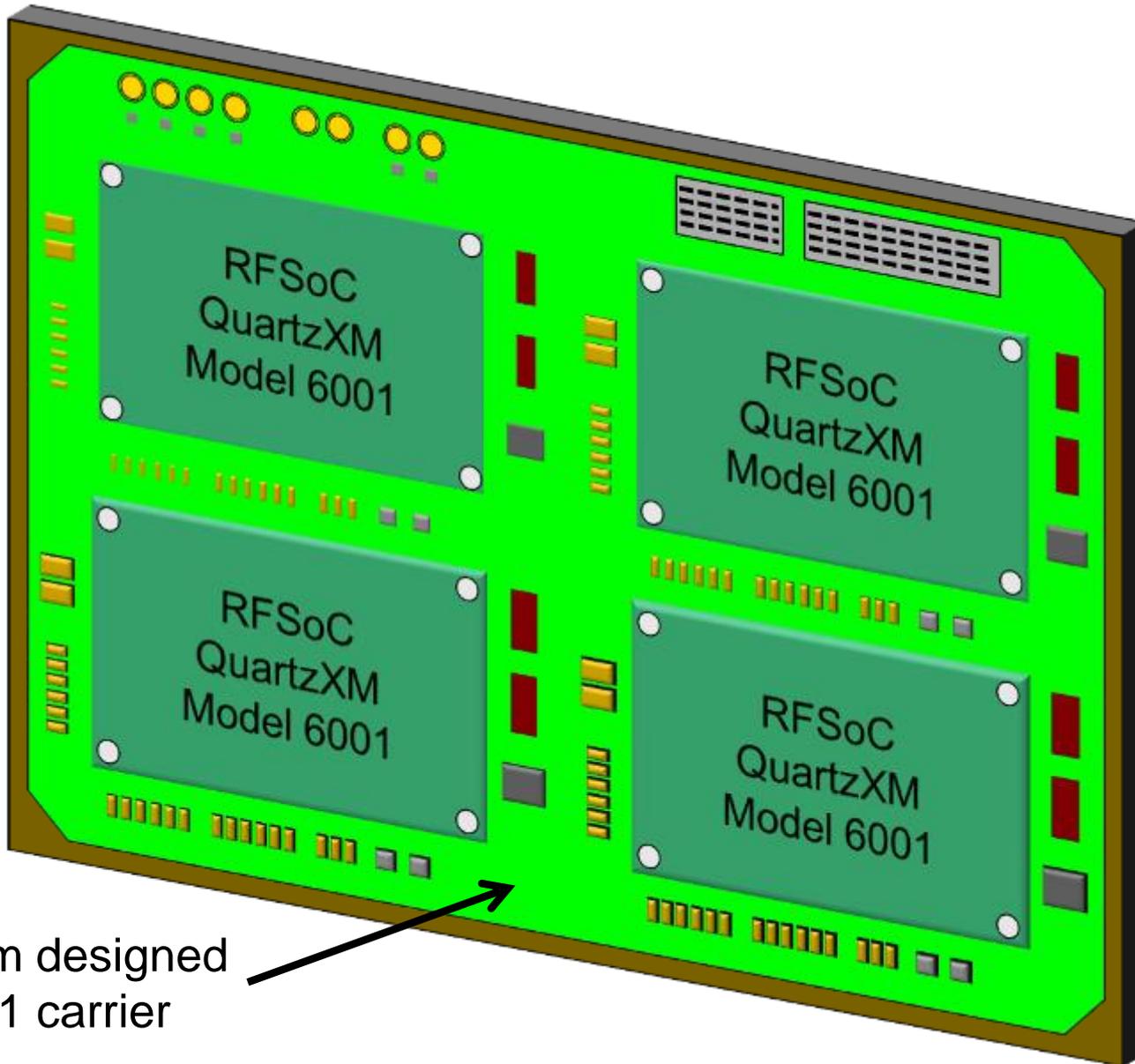


# Custom RFSoc SoM Solutions





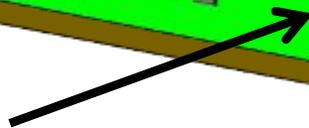
# Custom RFSoc SoM Solutions



Customer's  
8 x 4 antenna  
array



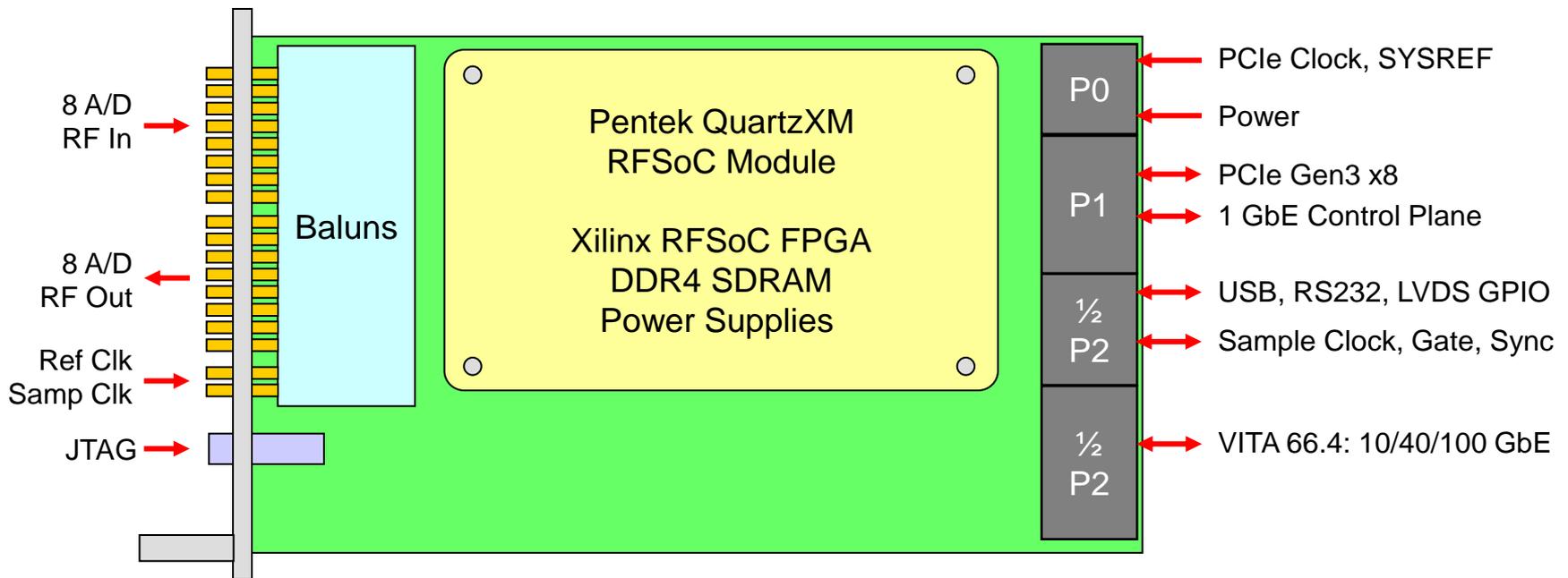
Custom designed  
6001 carrier





# Small Form Factor Remote Box

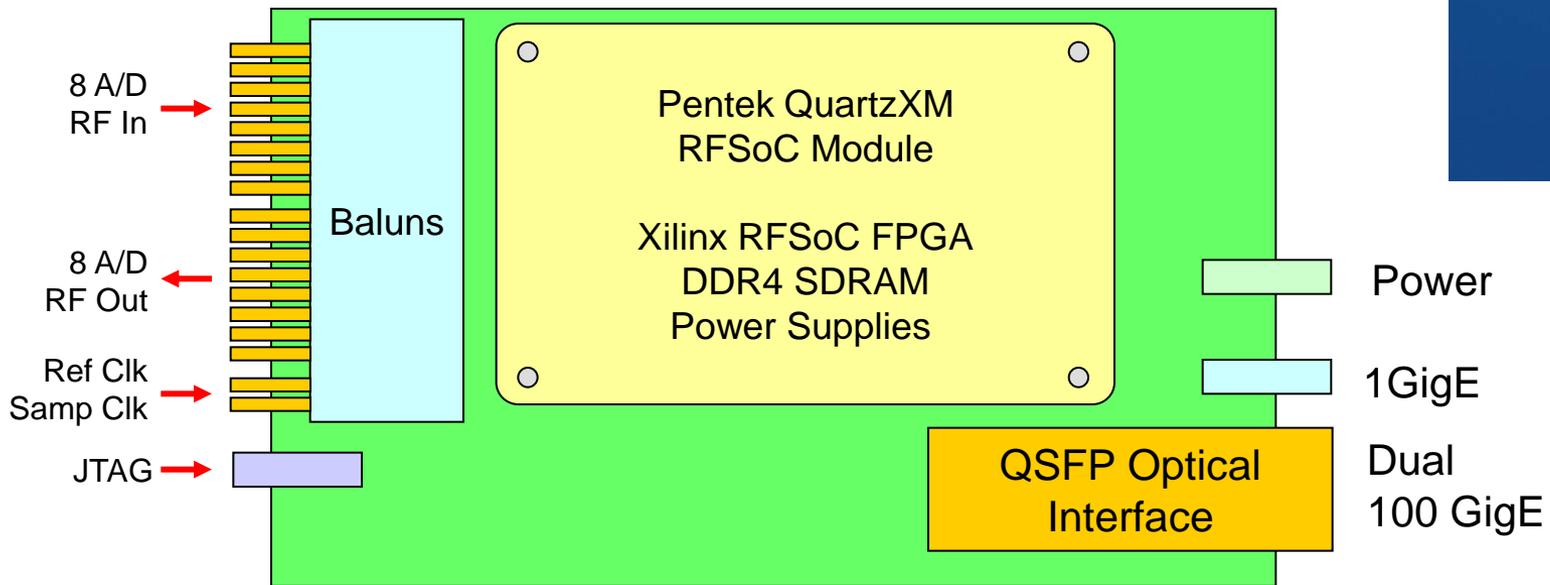
- Create or adapt a carrier for the QuartzXM module
- For example, start with the Model 5950 3U VPX board
- Modify the board to remove VPX connectors & hardware





# Small Form Factor Remote Box

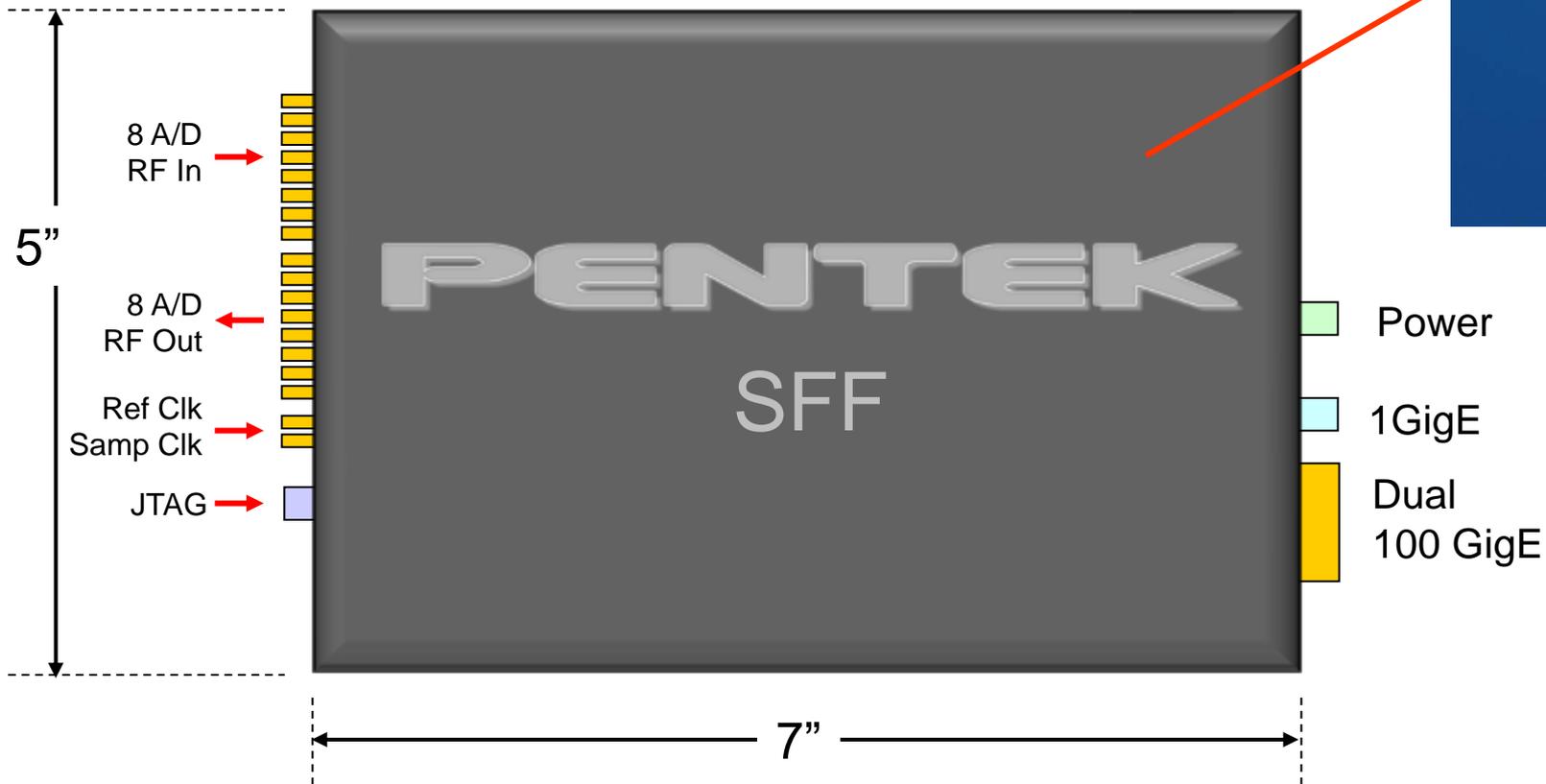
- Add connectors appropriate for the application





# 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





# Model 4801 Carrier Design Package

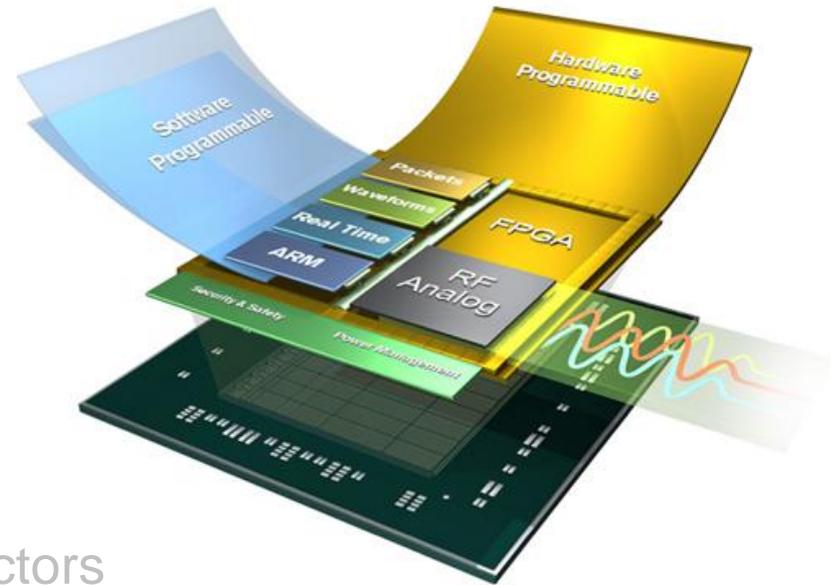
- Documentation needed for a customer to design his own carrier
  - Pin definitions and electrical specifications of all signals on the QuartzXM
  - 3D mechanical models
  - Thermal profiles of the module and components
  - Carrier reference design schematics
  - PCB stack-up recommendations
  - PCB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

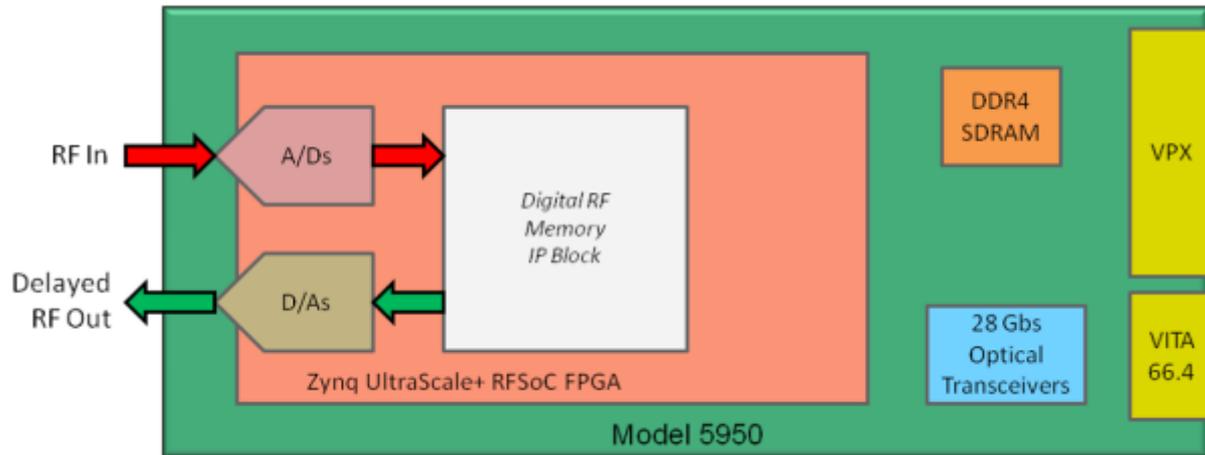
## ■ Pentek Navigator FDK for RFSoc

- 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

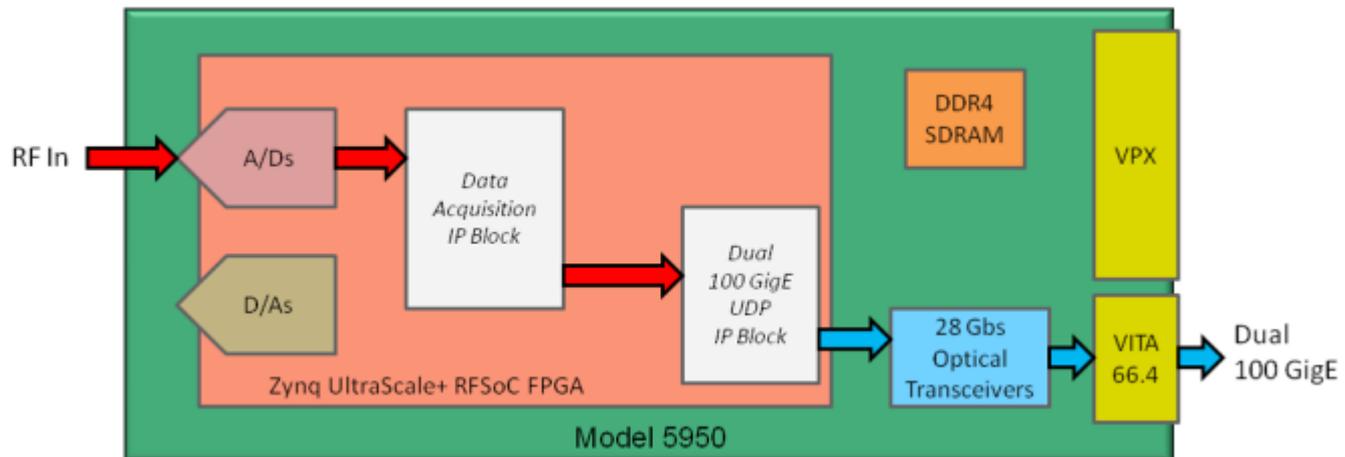


# Included RFSoc Starter Applications

## Digital RF Memory with Programmable Delay



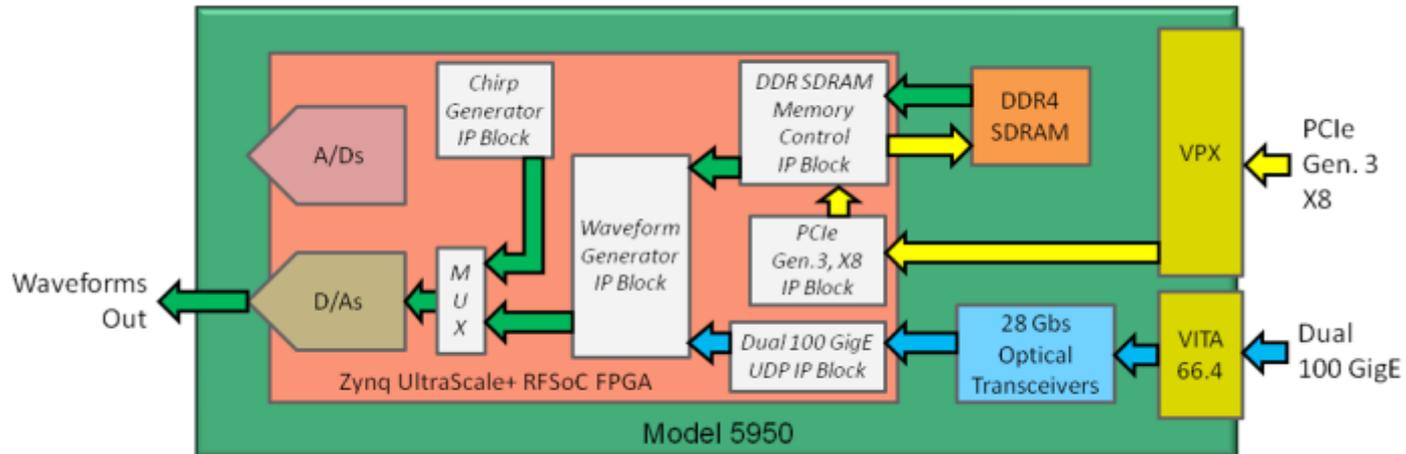
## A/D Acquisition Engine to 100 GbE Optical Streaming



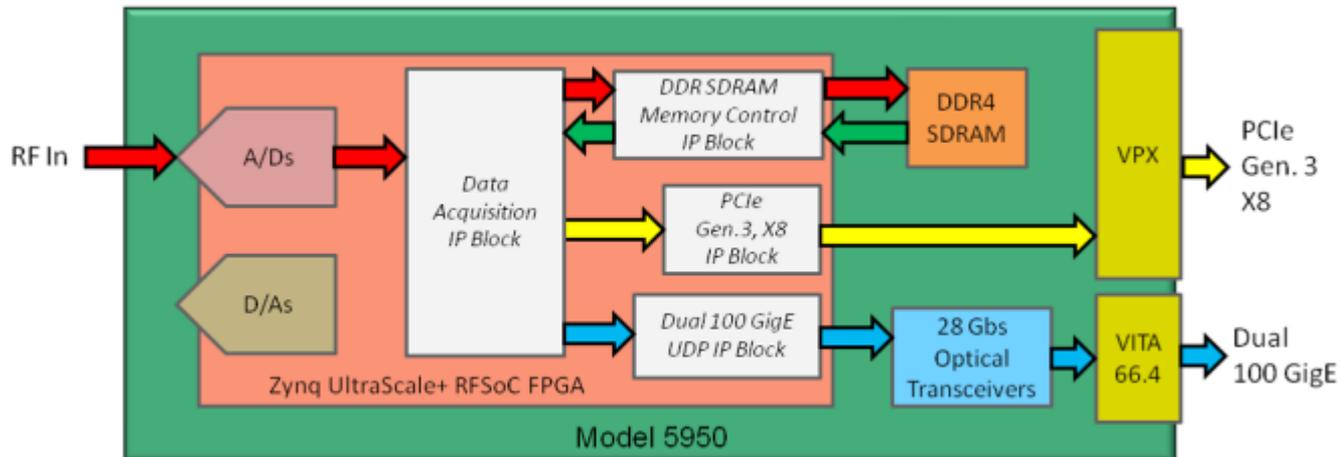


# Included RFSoc Starter Applications

## Waveform Generator from Memory, PCIe, or 100 GbE



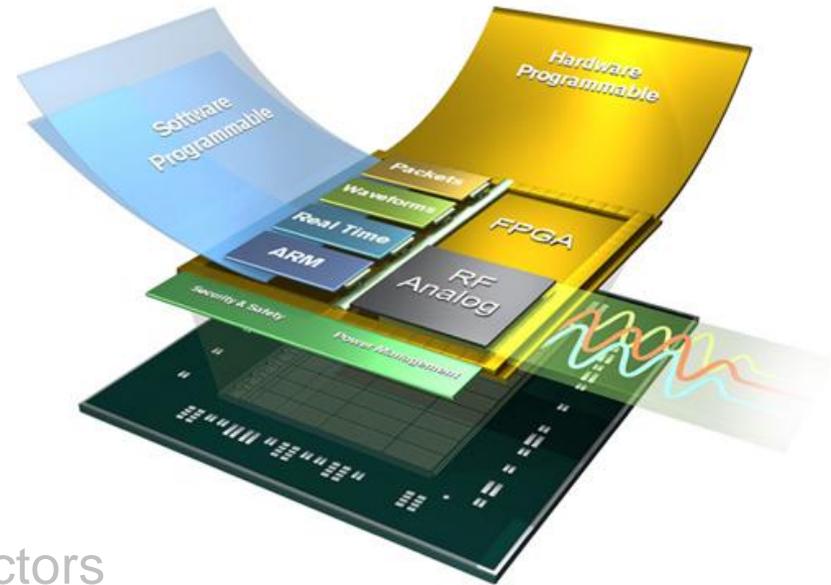
## Multi-mode Acquisition to Delay Memory, PCIe, or 100 GbE





# 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





# FPGA Design Strategies for RFSoc



## ■ Xilinx Vivado Tools for RFSoc

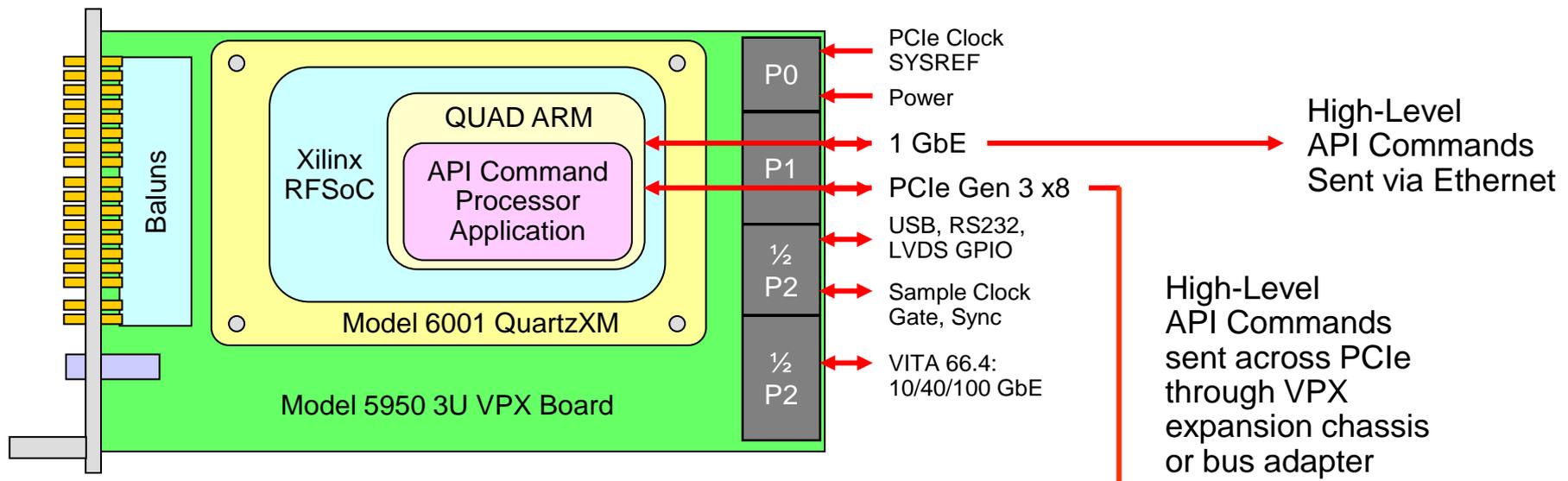
- Xilinx RFSoc ARM SDK
  - Complete Integrated Design Environment (IDE) interfaces to Vivado FPGA tools
  - Multi-processor hardware/software co-debug capabilities
  - Editor, compilers, build tools, flash memory management
  - Libraries and device drivers
  - Xilinx Software Command Line Tool (XSCT)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

## ■ Pentek Navigator BSP for RFSoc

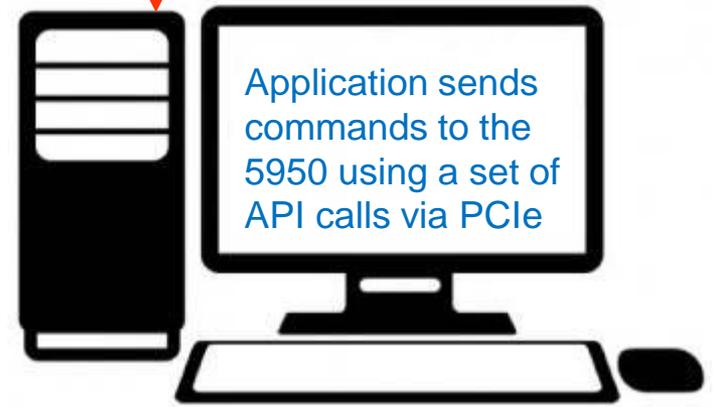
- Navigator command processor
  - RFSoc ARM command processor application executes high-level API commands from PCIe or Ethernet
- Powerful Tool Suite
  - Initialization and control of all FPGA IP
  - Delivery of all operational parameters
  - High-Level C-Language Libraries
  - Full C Source Code Provided
  - 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

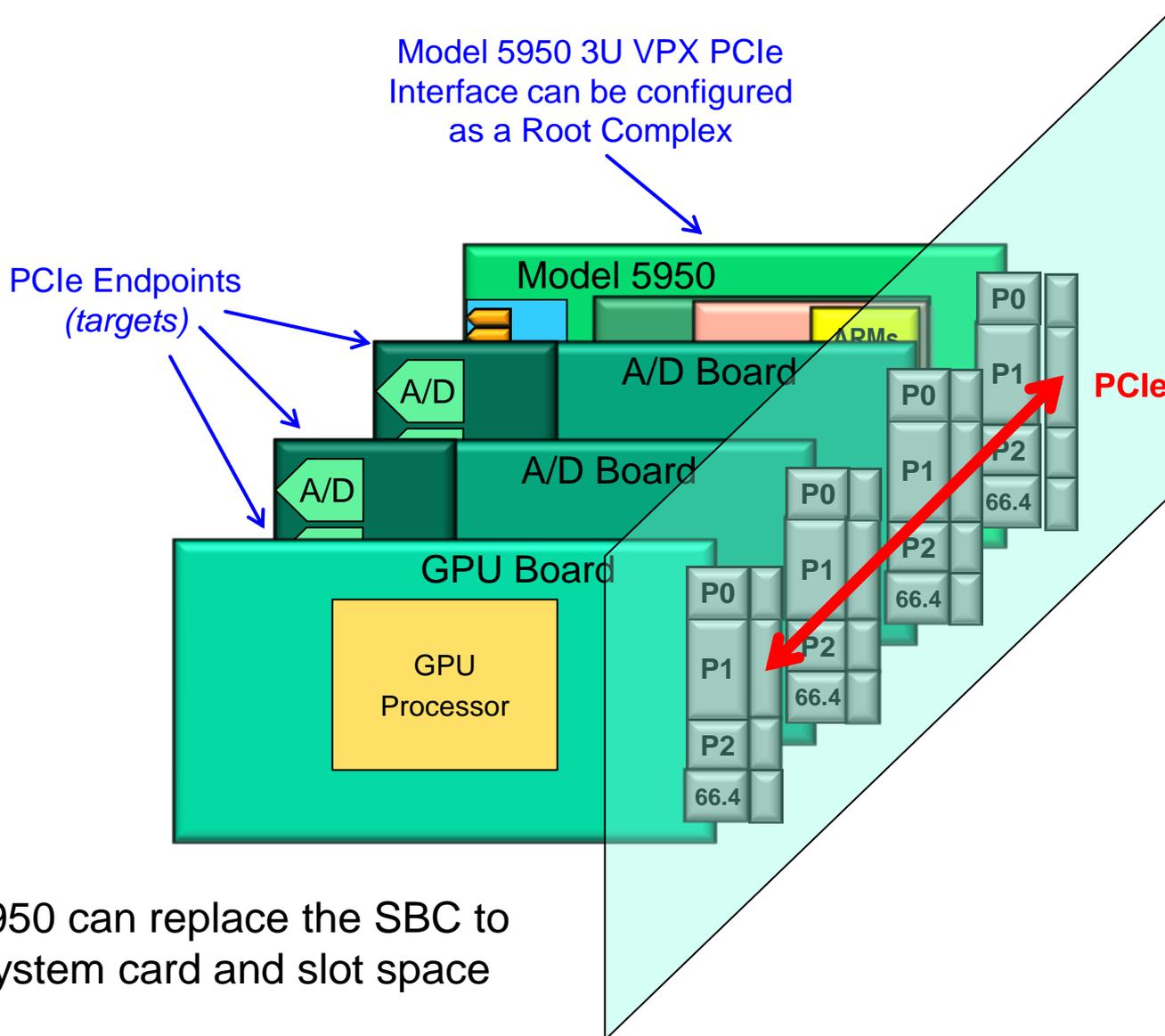


- ARM Processor on QuartzXM runs the Pentek Navigator QuartzXM API Command Processor
- Accepts API commands across Ethernet
- Accepts API commands across PCIe bus
- Flexible options for different system architectures





# Multiboard 3U VPX System Architectures

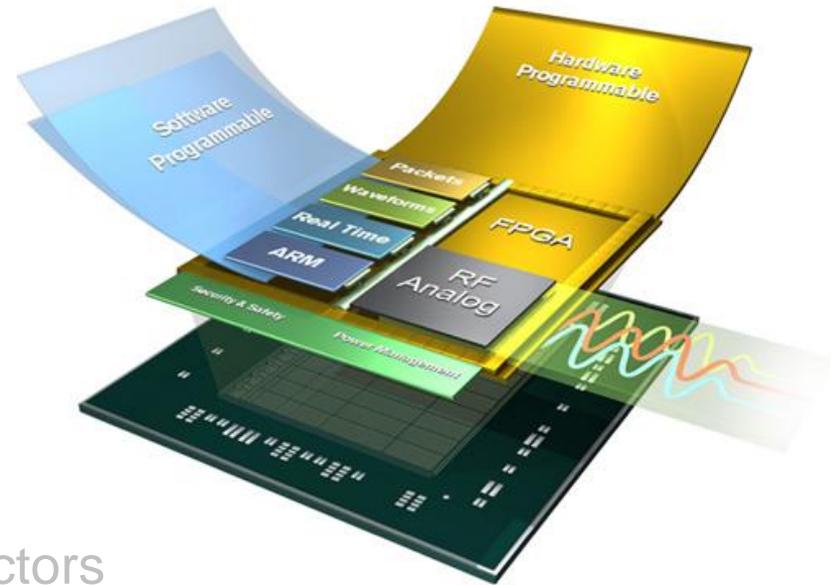


- Model 5950 can replace the SBC to save a system card and slot space



# Topics

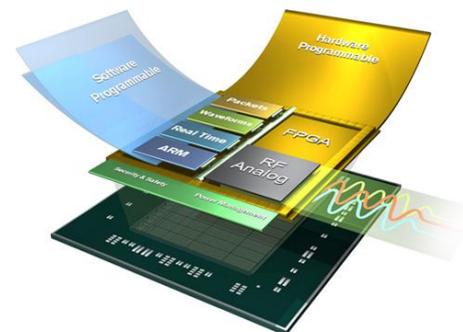
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# RFSoc Deployment Strategies

- 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 RFSocM 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

**Model 5950** 8-Channel A/D & D/A Zynq UltraScale+ RFSoc Processor - 3U VPX

**General Information**

The Quartz Model 5950 is a high performance 3U VPX board based on the Xilinx Zynq UltraScale+ RFSoc FPGA. The RFSoc integrates eight RF-class A/D and D/A converters into the Zynq's multiprocessor architecture, creating a multichannel data conversion and processing solution on a single chip. The Model 5950 brings RFSoc performance to 3U VPX with a complete system on a board.

**A/D Converter Stage**

The front end acquires analog RF or RF

**Model 6001** 8-Channel A/D & D/A Zynq UltraScale+ RFSoc Processor - QuartzXM

**General Information**

The Quartz Model 6001 is a high performance Quartz Express Module (QuartzXM) based on the Xilinx Zynq UltraScale+ RFSoc FPGA. The RFSoc FPGA integrates eight RF-class A/D and D/A converters into the Zynq's multiprocessor architecture, creating a multichannel data conversion and processing solution on a single chip.

The Model 6001 has been designed to bring RFSoc performance to a wide range of

**Features**

- Support UltraScale
- 18 GB of DRAM
- On-board PCI Exp. interface
- LVDS or Zynq UI (customer)
- Optima interface (optional)
- Dual 10 interface
- Compact VITA as VITA-46, VITA-49, VITA-50 (Customer Specific)
- Ruggedized and conduction cooled
- Includes a complete IP functions and applications

**Features**

- Unique QuartzXM Module enables in custom form factor
- Supports Xilinx UltraScale+ RFSoc
- 18 GB of DRAM
- LVDS connected Zynq UltraScale+ custom IO
- GTF connector for serial communication
- Ruggedized and conduction cooled
- Includes a complete IP functions and applications

**Strategies for Deploying Xilinx's Zynq UltraScale+ RFSoc**

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**In This Issue**

- Feature: Using terms like "disruptive" and "breakthrough" to describe new technology can sound like advertising hype, but in the case of RFSoc, such a description is true. Our feature article explores how to best use the advantages of this technology.
- Product Focus: [Quartz Model 5950](#).
- Product Focus: [Jade Model 7180](#).
- With Pentek's New Jade Architecture: [Come a New Documentation Architecture.](#)

**What is RFSoc?**

RFSoc, or more properly Zynq UltraScale+ RFSoc, is based on Xilinx's prior family, the Zynq UltraScale+ MPSoC. The MPSoC is a system-on-chip architecture that includes up to four ARM Cortex-A53 application processors and two ARM Cortex-R5 real-time processors integrated into the UltraScale+ programmable logic. This solution offers the software programmability and flexibility of a processor with the hardware programmability and performance of an FPGA in a single IC.

RFSoc builds on the MPSoC foundation and adds eight 4-GSPS 12-bit A/Ds, each equipped with programmable Digital Downconverters (DDCs) and eight 6.4-GSPS 14-bit D/AAs, each equipped with Digital Upconverters (DUCs). While other A/D and D/A configurations are available, we'll consider the eight A/D and eight D/A configuration for the rest of this article. Figure 1 shows the similarity between the MPSoC and RFSoc.

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Live Signal Acquisition: Quartz Model 5950 and Model 6001 RFSoc boards