Understanding RFSoC Development and Integration Challenges

From experimentation to performance and power consumption, how engineers reduce costly design mistakes before production

A FIDUS SYSTEMS **WHITE PAPER**

The demand for high-performance RF systems continues to grow, driven by the need for faster, more reliable, and secure platforms for communications infrastructure and industrial applications. To satisfy the processing and I/O ambitions of manufacturers, engineers need the expertise and tools to deliver differentiated and novel designs with fewer issues in production.

The latest advances in combining processors, mixed-signal solutions, and FPGA technology, such as the **AMD Zynq® UltraScale+™ RFSoC** (Radio Frequency System On Chip), are the ideal pathway for meeting today's communications and industrial needs with reduced system complexity and risk. Combining powerful Arm® systems with FPGA processing, on-chip memory, and direct RF-sampling analog-to-digital converters (ADC) and digital-to-analog converters (DAC) onto a single SoC, these devices minimize the number of external components and reduce power consumption and footprint – the ideal architecture for evolving workloads.

This white paper helps system engineers and hardware designers understand the challenges of developing an RFSoC-based platform for high-performance RF applications. The paper will discuss different aspects of design and how the unique features of the Fidus RFSoC Development Platform, including integration, flexibility and high performance, make it the ideal solution to de-risk engineering projects that require adaptable, efficient, and powerful solutions.

BENEFITS OF RFSOC TECHNOLOGY

RFSoC devices meet the RF signal chain and form a complete signal processing system by combining high-speed ADCs and DACs, powerful processors, FPGA fabric, and memory on a single, monolithic device. RFSoC devices are highly programmable, allowing engineers to customize and optimize their designs to meet specific application needs.

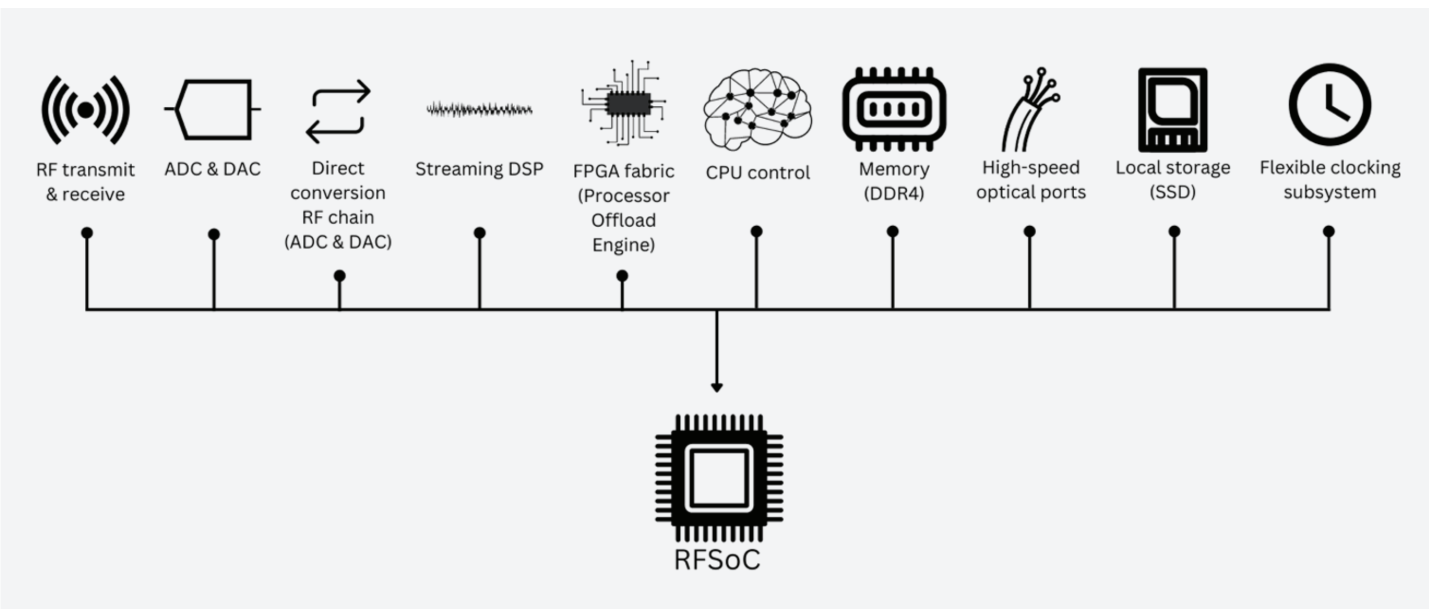

Figure 1: RFSoC technology combines multiple functions onto one device

Real-world applications of RFSoC devices are numerous, including 5G wireless communication systems, software defined radios (SDR), aerospace and defence systems, and autonomous vehicles. In these systems, RFSoC devices help engineers program application-specific features and address complex RF issues such as signal distortion, interference, and noise while balancing the need for increased signal processing capability with reduced power consumption and footprint.

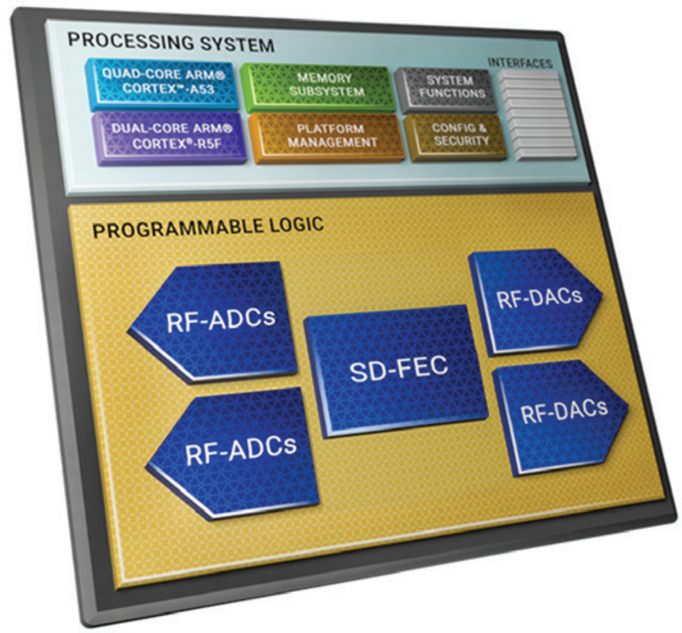

Figure 2: Components of the Zynq® UltraScale+™ RFSoC (Source: AMD)

CHALLENGES IN RFSOC DESIGN AND DEVELOPMENT

Hardware engineers face many challenges when integrating RFSoC devices with peripheral components, such as ensuring signal integrity and preserving the signal to/from the antenna and from/to the FPGA. This requires careful synchronization between data conversion channels, trace routing, and impedance matching as well as a board design that minimizes noise and thermal issues.

For example, in communication applications that involve multiple channels, engineers must consider several aspects of design:

Timing synchronization: To properly synchronize multiple channels, it is necessary to ensure alignment between the timing of signals in each channel. Timing synchronization is critical to avoid inter-symbol interference, crosstalk, and other types of interference that can degrade signal quality.

Frequency synchronization: In addition to timing, frequency synchronization is essential to avoid frequency drift, which can cause errors and distortion in the received signals.

Phase synchronization: It is important to ensure the proper in-phase alignment of signals in each channel, to avoid phase errors that can cause interference and distortion in the received signals and degrade overall system performance.

Channel equalization: To compensate for variations in channel response, it may be necessary to implement channel equalization techniques to ensure that the received signals are of uniform quality across all channels.

Data alignment: In addition to signal synchronization, it is necessary to align the data in each channel. This can involve techniques such as packet synchronization, framing, and bit synchronization to ensure that the data in each channel can be processed correctly.

Engineers can use advanced techniques, such as adaptive filtering, digital signal processing (DSP), and synchronization algorithms, to address these design aspects and ensure communication systems are reliable, predictable, and meet stringent performance requirements. These techniques are well suited for implementation in the FPGA fabric of the RFSoC.

The following sections explain further challenges that engineers must consider when building RFSoC-based systems.

RF system performance

One of the primary design challenges for RF systems is performance. High-speed data converters require careful consideration of clocking (optimal sample rate selection, phase noise, etc.) and synchronization to ensure the accurate capture of received signals or production of transmitted signals. Meeting these constraints requires careful planning, design and layout, including:

- **FPGA resource utilization:** RF systems require a large amount of FPGA resources, such as logic elements, memory blocks, and DSP blocks, to implement the signal processing and RF functions.
- **Real-time processing:** Processing RF signals requires the implementation of strict timing characteristics and constraints, such as clock frequency, low clock jitter, setup time, and hold time, to avoid timing violations and ensure correct data processing.
- **System integration:** Components must work together seamlessly, including the RF front-end, power management, software drivers, and control interfaces, to meet overall functional and performance requirements.
- **Design verification:** Ensuring functional and performance requirements are met involves extensive design verification using techniques such as test planning, test benching, simulation, regression (e.g., UVM) and in-lab hardware testing, integration, and validation.

Power consumption

RF components can consume significant amounts of power, which can lead to thermal issues affecting performance and overall system reliability. An efficient power regulation and distribution solution paired with upfront thermal considerations ensure the system remains within acceptable operating temperatures and power budgets, including:

- **Power integrity:** Mixed-signal systems require a clean and stable power supply through all components for optimal performance, requiring the power distribution network to minimize voltage drops, noise, and crosstalk through a combination of techniques, such as decoupling value optimization and location.
- **Power efficiency:** High-performance applications must balance the need for large amounts of peak power with the desire to consume as little average energy as possible, especially for applications that are power limited (e.g., eco-friendly systems) or portable.
- **Thermal management:** RFSoC systems can generate significant amounts of heat due to the high-density integration of processing and RF circuits, necessitating effective and carefully provisioned thermal management solutions, such as heat sinks and fans, and in some cases, liquid cooling.

Signal integrity

As RF components operate at high frequencies, improper design and insufficient validation can lead to signal distortion, reduced signal-to-noise ratio, and increased bit error rates – affecting overall system performance and quality.

Engineers must employ techniques to minimize noise and ensure proper signal routing, including:

- **Component integration:** The RFSoC, ADC, DAC, and other signal processing components require expert implementation to optimize performance and differentiate the solution.
- **High-speed data transfer:** Given high-speed transmission across the system, signal integrity must be ensured by optimizing the layer stack and routing to minimize noise, crosstalk, and distortion to prevent errors in data streams.
- **Power and ground noise:** Due to high-speed digital and analog circuits coexisting on the same platform, the design of power and ground distribution is critical to ensure signal quality.
- **Electromagnetic interference:** RF systems are susceptible to electromagnetic interference (EMI) from external sources so shielding techniques, such as component separation, ground planes, shields, and filters, must be chosen and implemented to maintain signal integrity.

HOW FIDUS HELPS

Fidus has the skills to maximize the performance-to-cost ratio of your high-speed RF projects through proper pre-production modeling and constraints. We can help select the right tools and have the knowledge to build system models and interpret results to achieve first-pass success – that's why 95% of our customers come back.

Visit our website **www.fidus.com** to learn more about our signal and power integrity services.

PCB layout

PCB layout is an essential step when integrating an RFSoC with high-speed signal processing components and the design challenges include:

- **High-speed signal routing:** Maintaining signal quality and performance requires layout design techniques that minimize signal distortion, noise, and crosstalk between lines and components.
- **Impedance matching:** Ensuring maximum power transfer and signal quality requires the design of transmission lines, vias, and connectors to match the characteristic impedance of the signals and preservation of signal integrity.
- **Ground plane design:** Maintaining signal integrity requires a well-designed ground plane that is continuous, has low impedance across a wide bandwidth, and properly connected to the ground pins of all components.
- **Thermal management:** PCB layout must optimize thermal management, such as using thermal vias or heat sinks, to dissipate heat and prevent overheating.
- **Power distribution:** A well-designed power distribution network, including power traces, planes, and a careful selection and placement of capacitors ensures a stable, clean, and responsive power supply to components with minimal voltage drops, ripple, and ringing.

Vendor IP

Engineers must have deep knowledge of vendor IP and industry standards to develop creative and efficient solutions without compromising performance or compliance. There is also a cost associated with using IP, either by licensing from the device vendor or leveraging a third-party company's expertise. Often, the needed IP is not available and must be created to suit the application.

HOW FIDUS SUPPORTS RFSOC DEVELOPMENT & INTEGRATION

To provide start-up companies, large multi-nationals, research facilities, and development labs with the capabilities necessary to experiment with and prove out high-performance RF system designs, Fidus combines its extensive experience in design services with the Zynq® UltraScale+™ RFSoC customizable radio, memory, control, and data transfer cards in its RFSoC Development Platform. With a proven RFSoC at its core, Fidus can customize and manufacture this platform to suit the needs of any research lab and development workbench, enabling that spark of innovation and reducing design errors and integration issues before production.

Figure 3: Front view of the Fidus RFSoC Development Platform

Unlike most development and evaluation kits, which limit components and capabilities to a narrow set of use cases, the Fidus RFSoC Development Platform includes a range of I/O, control, and storage options to prove out any type of RF application, at any scale. Combined with Fidus design services, the RFSoC Development Platform is a comprehensive, flexible solution that enables engineers and software developers to experiment, prototype, and get ahead of productization.

BENEFITS OF THE FIDUS RFSOC DEVELOPMENT PLATFORM

As a proven springboard for manufacturers across industries, the Fidus RFSoC Development Platform allows engineers to experiment, test, and validate their RF system designs to resolve issues and failures before production.

Partnered with Fidus design services, each platform is customized to manufacturing needs, offering:

- Extensive control and flexibility over the RF workbench for rapid experimentation and prototyping.
- Multiple devices and modules combined into one enclosure, including the Zynq® UltraScale+™ RFSoC, memory, storage, programmable clocking, data transfer, and control cards.
- Access to skills and experience ranging from FGPA design and verification to DSP techniques and best practices.
- Full rights to developed IP.
- Reduced time to market by proving out designs before costly errors in production.

FIDUS RFSOC DEVELOPMENT PLATFORM FEATURES	
AMD RFSoC, XCZU49DR-2FFVF1760	
Reference design included	
Radios	Up to 4 slots, including custom-designed cards: • RC1: Quad Channel, TX/RX, 2.4/5.8 GHz • RC2: Dual Channel, TX/RX, 24 GHz
Memory	• One (1), PS DDR4 bank, 32 GByte, 64-bit, RDIMM • Two (2), PL DDR4 banks, 64 GByte, 64-bit, RDIMM
Storage	• M.2 NVMe PCIe Gen2 x2/x4, 2280, PS, 1 TByte • Dual QSPI • eMMC • SecureDigital
Programmable clocking	• Multi-channel clock generator • Jitter attenuator • IEEE1588/SyncE sub-system
Data transfer	• QSFP28, 100 Gbps • 1 GE RJ45 Port • SuperSpeed, USB3.0, Micro-AB • Four (4), Samtec® AcceleRate® Ports
Control	• UART-over-USB, 2.0, MicroAB • JTAG-over-USB, 2.0, MicroAB • Four (4) USB2.0, TypeA e.g., Mouse/Keyboard • DisplayPort 1.2a Source Port

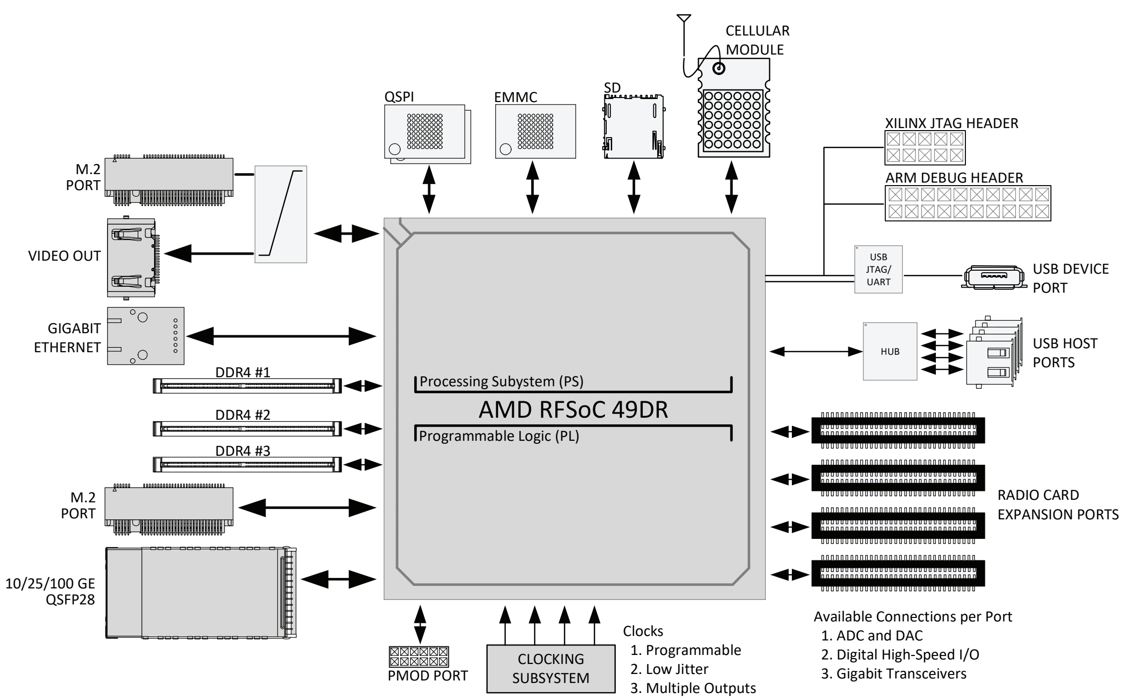

Figure 4: Fidus RFSoC Development Platform block diagram

A FLEXIBLE SOLUTION FOR RF DEVELOPMENT AND BEYOND

RFSoC-based systems offer manufacturers a competitive advantage by enabling the delivery of high-performance products with a significantly smaller bill-of-materials, reduced footprint, and much less power consumption. While RFSoC systems are already paving the way towards the future of wireless applications, manufacturers must adopt the right tools and expertise now to differentiate and de-risk their engineering efforts.

Fidus is a leading provider of design and engineering services, specializing in complex electronic systems, offering a range of solutions based on the Zynq® UltraScale+™ RFSoC. As a proven foundation for RF system design, the Fidus RFSoC Development Platform helps engineers accelerate their development process and reduce risk. Through this platform, engineers benefit from pre-existing IP, simulation models, and reference designs that reduce the time and effort required for custom development and validation.

Figure 5: The Fidus RFSoC Development Platform

Additionally, the Fidus team of experienced engineers can provide expert guidance and support throughout the design process, helping to optimize systems for performance and reliability.

Interested in de-risking and accelerating your next RF system design project? **Contact Fidus today**.

20+
years experience
Collaborating with smart teams is what fuels us every day.

3,000+
successful projects
Your unique challenges are our obsession.

400+
customers
Extending your team with our expertise brings designs to market faster.

95%
repeat customers
Customers love to work with us, again and again.

ABOUT FIDUS

Fidus Systems, founded in 2001, specializes in leading-edge electronic product development with offices in Ottawa and Waterloo, Ontario, and San Jose, California. Our hardware, software, FPGA, verification, wireless, mechanical and signal integrity teams work to innovate, design and deliver next-generation products for customers in emerging technology markets. Fueled by 20+ years' experience and creativity, along with our collaborative and process driven approach, we turn complex challenges into well-designed solutions. And with over 400 customers and 3000+ completed projects, we have the expertise to be a seamless extension of your team, providing a clear focus and commitment to getting designs and prototypes to market faster. Once you start working with us, you'll trust us like one of your own. Our hallmark is transparency. Our guiding principle is first time right.

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