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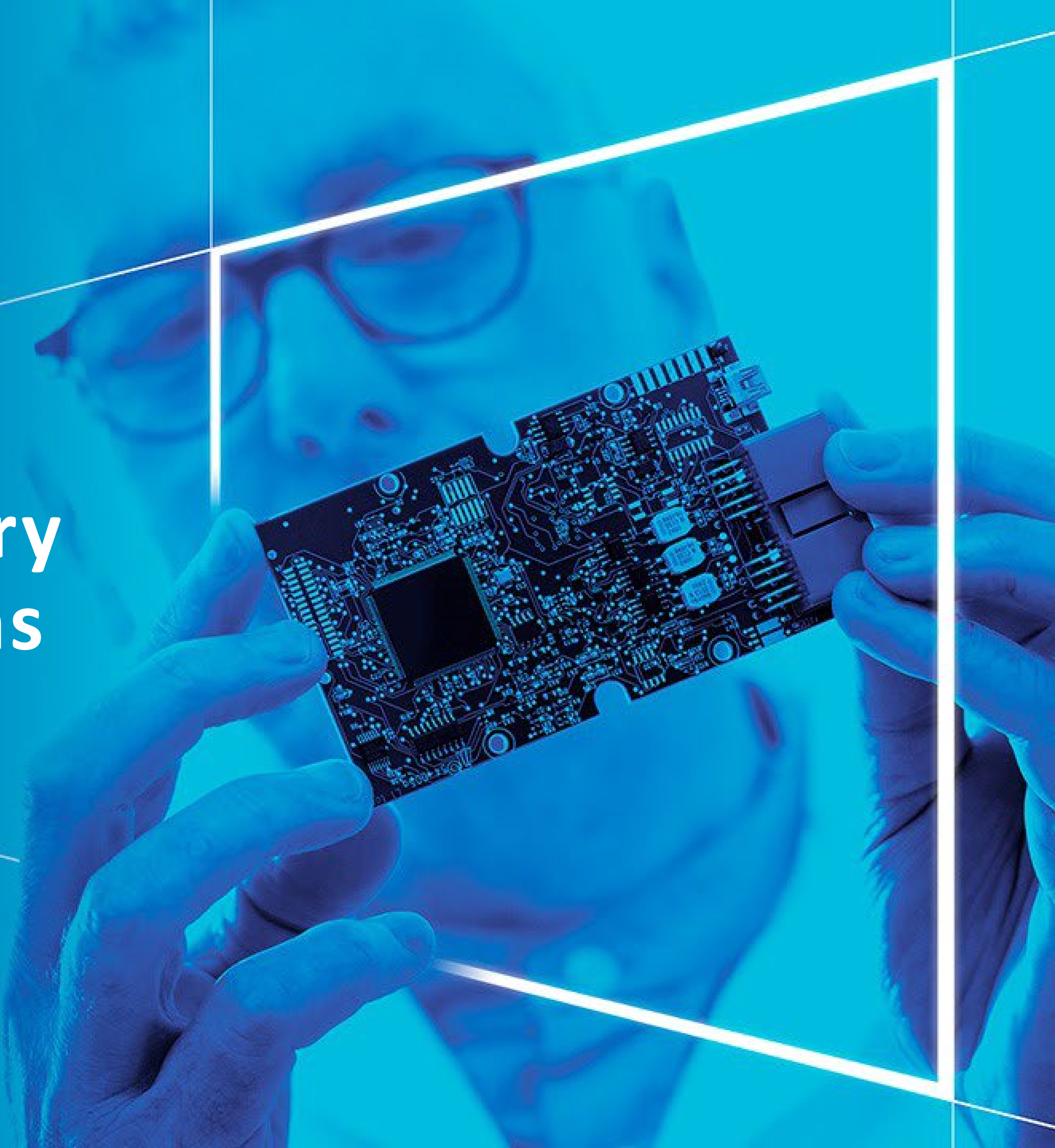
Direct RF Technology Revolutionizes Military EW and Radar Systems



Rodger Hosking
Mercury / Saddle River

Embedded Tech Trends
January 23, 2023

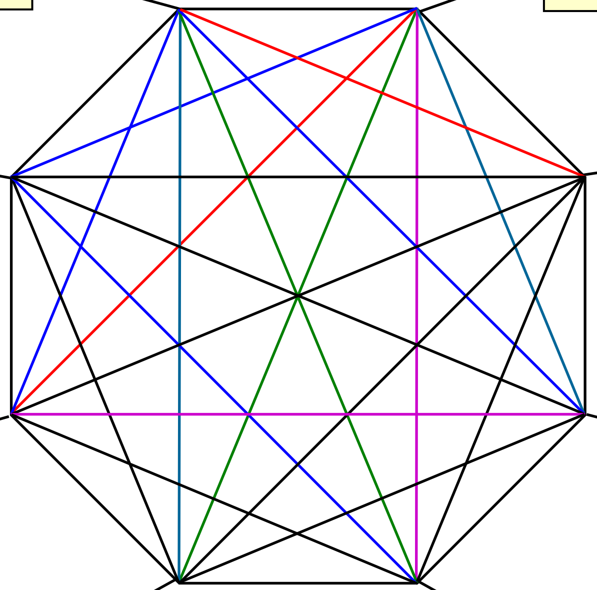
Critical Needs for Mil-Aero Radar and Electronic Warfare

Higher Signal Bandwidths
- Better range & feature resolution
- Multiple target detection
- Detailed target ID & classification

Multi-Radio Acquisition
- Single shared wideband antenna
- Signal distribution over network
- Improves new tech insertion

Acquisition at the Edge
- Eliminates long RF cables
- Optical data links extend distance
- Improves signal integrity & SWaP

Higher Signal Complexity
- Target detection & exploitation
- Reduces interception & noise
- Improves countermeasures



Lower Signal Latency
- Reduce all system delays
- Critical for countermeasures
- Improves adaptive tracking

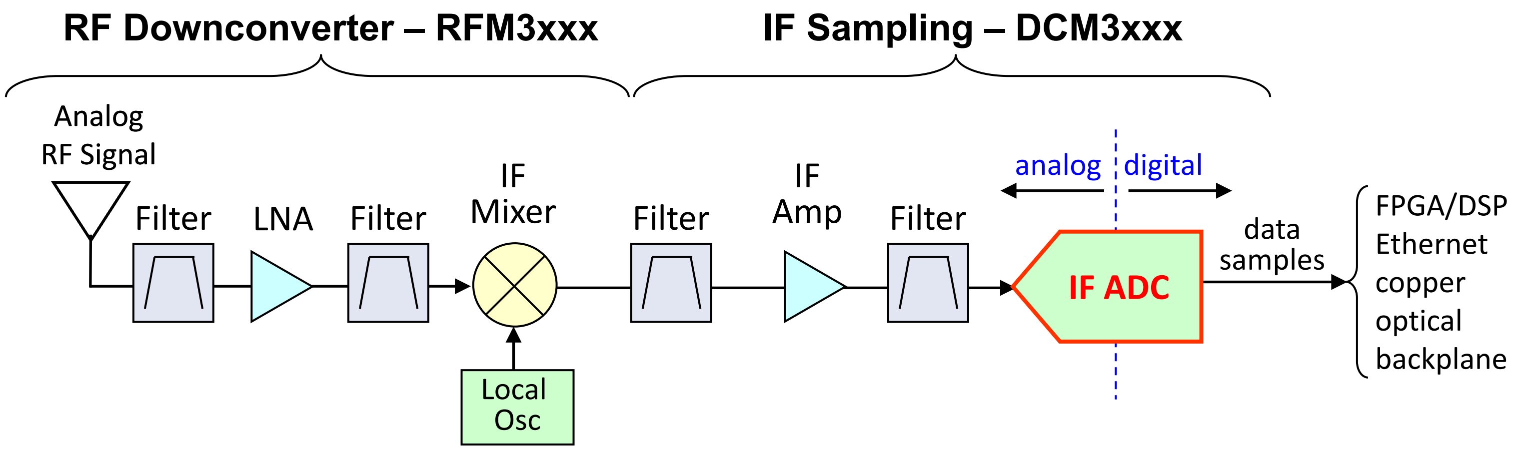
Phased Arrays (AESA)
- Electronically steer beam pattern
- Multiple agile target tracking
- SWaP gains vs. rotating dish

Heterogeneous Computing
- DSP, FPGA, GPU, RISC, AI, ML
- High-Level Portable Tools
- Higher Performance Levels

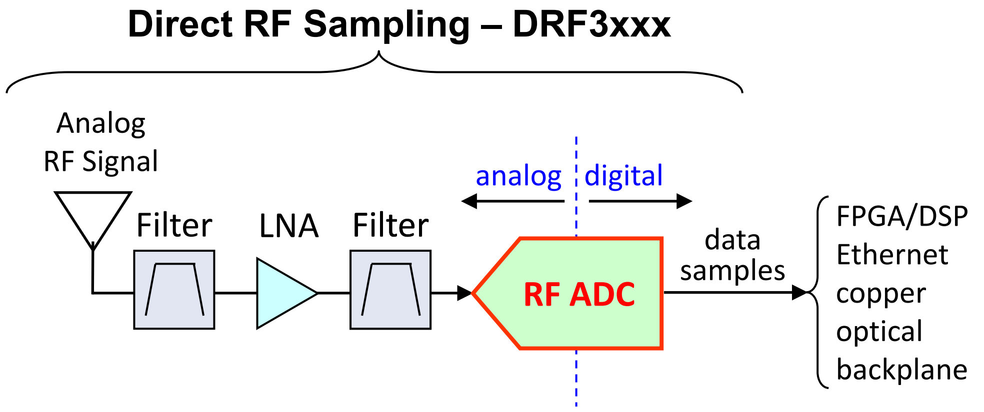
“Stare” Mode Capability
- Capture a wide frequency span
- Improves diverse target detection
- Superior to scanning sweeps

IF Sampling vs. Direct RF Sampling Architectures

- Heterodyne Architecture
  - Front-end includes bandpass filters, low-noise amp, mixer and local oscillator
  - IF ADC digitizes a lower frequency IF signal



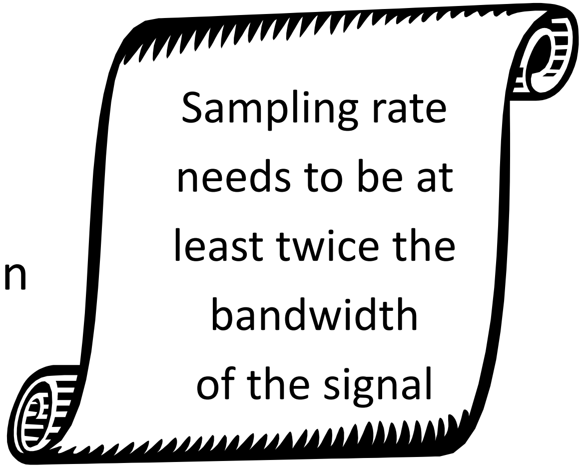
- Direct RF Architecture
  - No mixer or local oscillator for down conversion
  - Still includes front-end bandpass filters and a low-noise amp
  - Wideband RF ADC digitizes the RF signal directly
  - Reduces complexity, risk, cost/channel and SWaP
  - Boosts performance, latency, and channel density

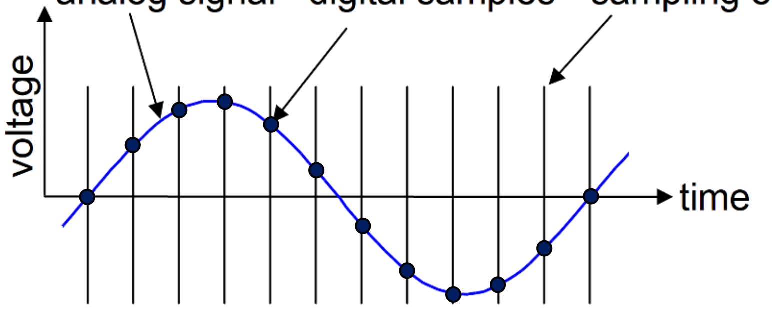


Principles of Signal Sampling

- Continuous real world analog signals are sampled at a given constant rate
- Each digital sample is the value of the instantaneous voltage at sample time
- Nyquist Theorem states that this sample stream represents all signal information ***provided*** the sampling rate is at least twice the signal bandwidth
- Analog-to-Digital converters (A/Ds or ADCs) perform the sampling and digitization
- Higher signal bandwidths require higher sample rate ADCs
- Digital samples are usually sent to a DSP
- DSP performs the operations on the digital ADC samples required for specific radio receiver functions

Nyquist Theorem

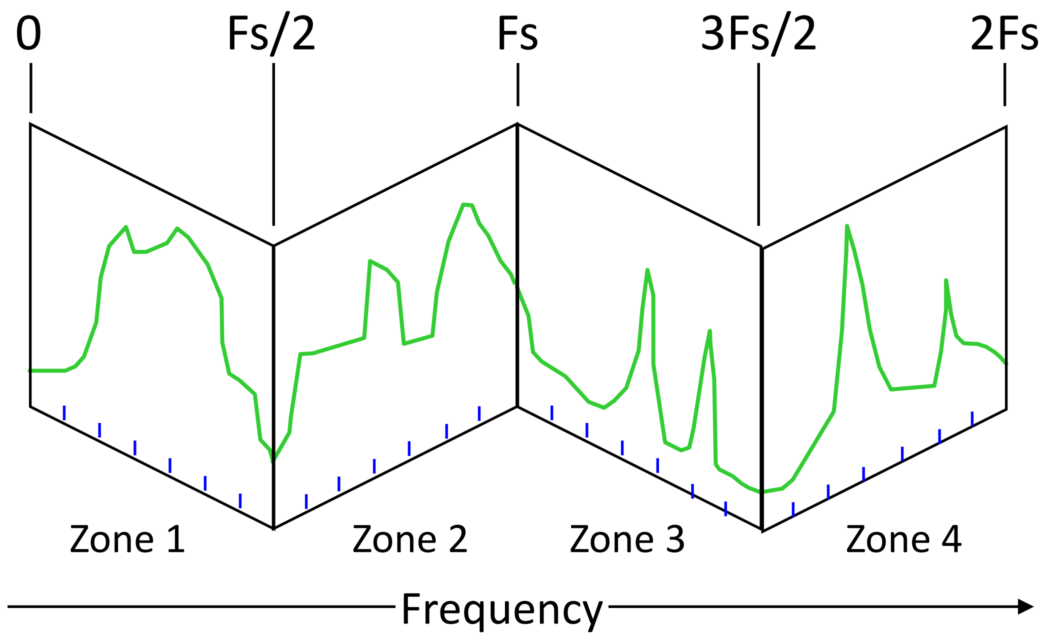


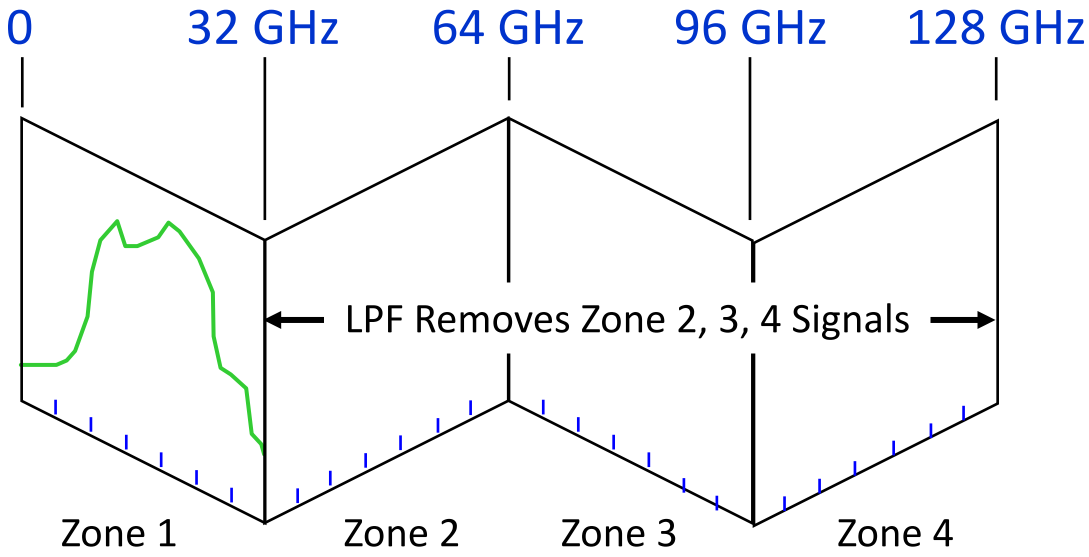


Harry Nyquist
1889 - 1986

Direct RF and Nyquist

- Plot frequency of RF input on fan fold paper to see Nyquist "zones" after sampling at Fs
- Nyquist Theorem dictates that all input signals must fall within a single zone
- To preserve signals in zone 1, we must remove all signals above zone 1, otherwise they will alias or "fold into" and corrupt signals in zone 1
- Done with a low pass filter before the ADC
- For example, if Fs = 64 GS/s, zone 1 covers DC to 32 GHz frequency span
- So, we need a 32 GHz low pass filter
- Filters are almost always needed to satisfy Nyquist
- Amplifiers are always needed to boost weak antenna signals

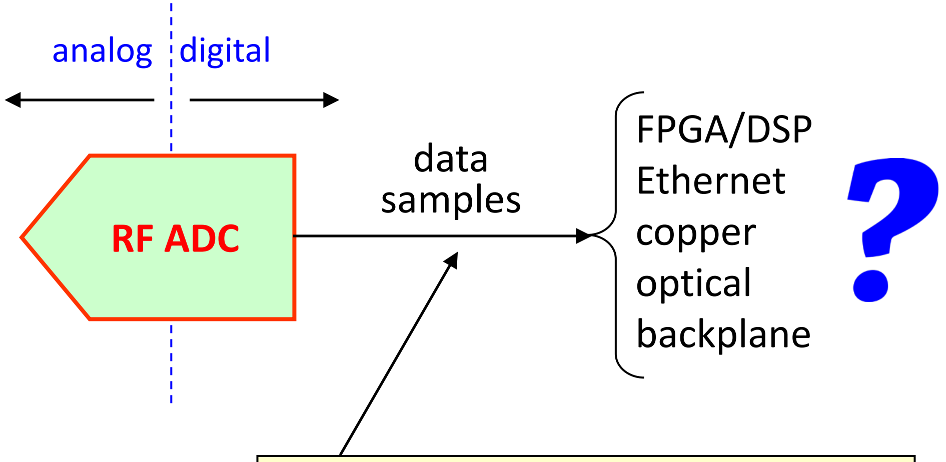




Direct RF and System Interfaces

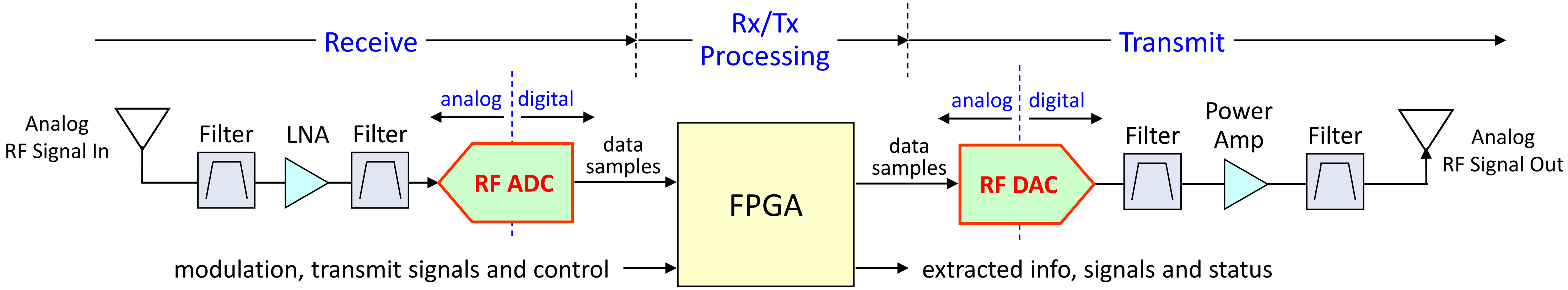
- Each RF ADC channel generates a lot of data!
  - E.g., single channel 10-bit 64 GS/s = 80 Gbytes/s
- How can RF ADCs avoid system data bottlenecks?
- How can RF ADCs even connect directly to an FPGA?

- Strategies to manage extreme data rates
  - Use digital down-converters within the ADCs to extract smaller frequency bands tunable across entire 32 GHz frequency span
  - Process data in a local FPGA to extract only the required information
  - Use a local FPGA to split the input data stream into multiple output streams to different destinations



Interfaces	Xfer Rate
1 Ch 64 GS/s 10-bit ADC	80 GB/s
PCIe Gen4 x 16	32 GB/s
PCIe Gen4 x 8	16 GB/s
100 Gb Ethernet	12 GB/s
PCIe Gen3 x 8	8 GB/s

Direct RF Transceiver System – FPGA + RF ADC + RF DAC

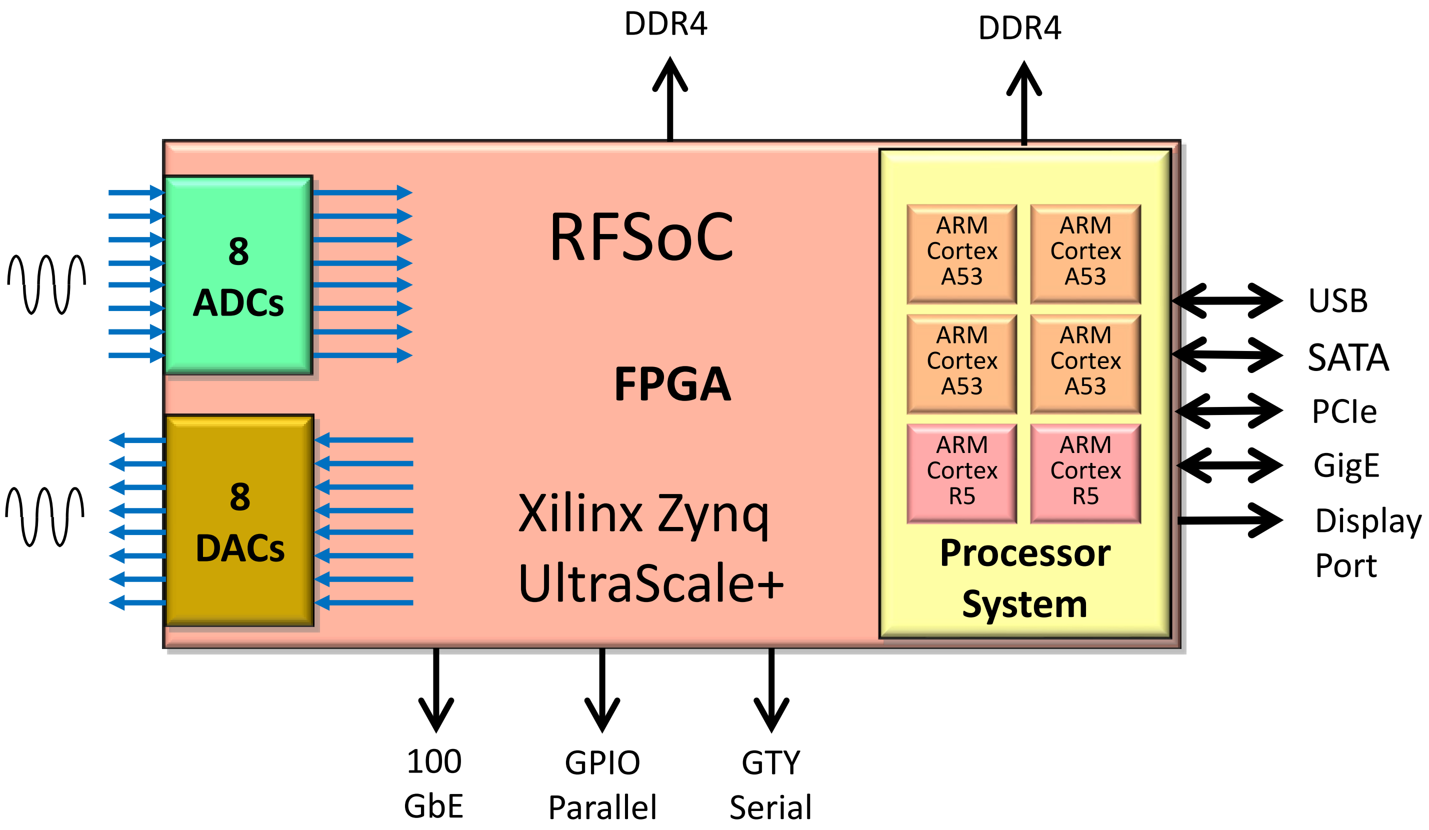


- Same Nyquist Theorem Constraints as ADCs
  - Signal Bandwidth and Frequency
  - Sampling Rate
  - Anti-aliasing and reconstruction Filters

- Direct RF: Ideal for Phased Array Transceivers
  - Same antenna elements often used for Rx and Tx
  - Direct RF with both ADCs and DACs simplifies design
  - Simplifies channel phase coherency
  - Multi-channel Direct RF devices improve SWaP-C

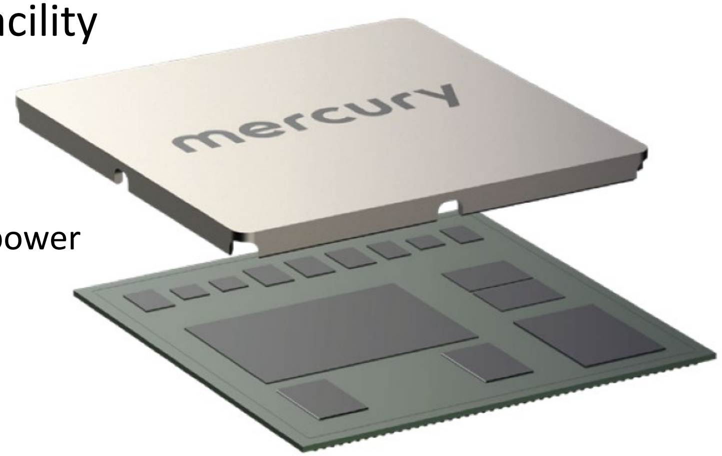
Monolithic Direct RF RFSoC Transceiver with ADCs, DACs and FPGA

- AMD Xilinx RFSoC Gen 3
  - Eight 5 GS/s 14-bit ADCs
  - Direct IF input signals: DC to 6 GHz
  - Instantaneous BW: >2 GHz
  - Eight 9 GS/s 14-bit DACs
  - UltraScale+ FPGA Fabric
  - Two 100 GbE Interfaces: 25
  - Two DDR4 SDRAM Ports
  - Four ARM Cortex A53s
  - Two ARM Cortex R5s
  - ADC/DAC to FPGA connections: Parallel silicon lanes
  - Very low latency: 50 nsec



Multi-Chip Module Transceivers with FPGAs and Direct RF Data Converters

- Mercury RFS1140 RFSiP (System in Package)
  - AMD Xilinx VC1902 Versal ACAP FPGA
  - Heterogenous Processors: Fabric, Vector, AI & ML
  - Four Jariet 10-bit 64 GS/s ADCs & DACs
  - Direct RF Inputs/Outputs: Up to 36 GHz
  - Instantaneous BW: >4 GHz
  - Four PCIe Gen4 x8: 64 GB/s
  - Onshore design and manufacturing at a DMEA-accredited facility



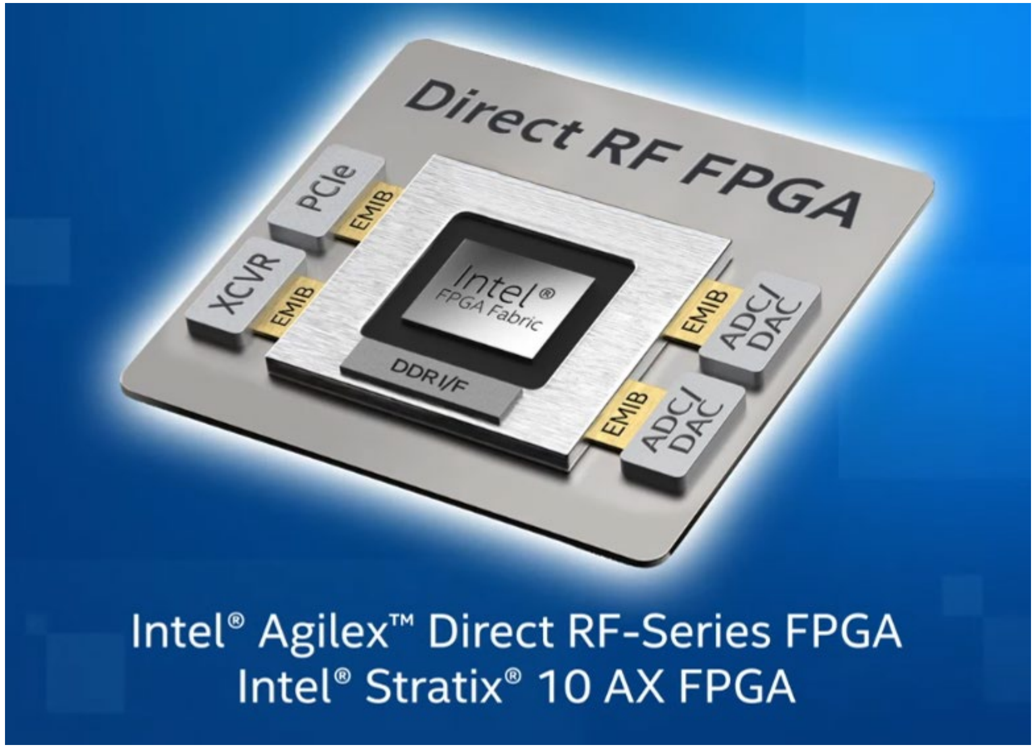
50 x 50 x 5 mm
with integrated power

- Chiplets & Standardized Interconnects
  - A “chiplet” is a silicon die containing specialized functions like ADCs, DACs, system interfaces, optical I/O, encryption, etc.
  - Open Industry standard interconnects like EMIB and AIC define connections between FPGAs and chiplets
  - Enables MCMs to combine an FPGA with diverse collection of peripheral chiplets to address application-specific functions
  - Dramatically shortens design cycles and costs
  - Fabrication facilities are now on-line in the U.S.

Multi-Chip Module Transceivers with FPGAs and Direct RF Data Converters

- Intel Altera Agilex Direct RF FPGA
  - Eight 10-bit 64 GS/s ADCs & DACs
  - Direct RF Inputs/Outputs: Up to 36 GHz
  - ADC & DAC connections: Parallel EIB
  - Quad Core ARM
  - 58Gb PAM4 Transceivers
  - PCIe Gen4 Interfaces

- Intel Altera Stratix 10AX Direct RF FPGA
  - Four 10-bit 64 GS/s ADCs & DACs
  - Direct RF Inputs/Outputs: Up to 36 GHz
  - ADC & DAC connections: Parallel EMIB
  - Six PCIe Gen3 x8: 75 GB/s



Direct RF Transceiver Open Architecture Board Example

- Mercury DRF3182 3U OpenVPX Direct RF Board
  - Intel 14 nm Altera Stratix 10AX Direct RF FPGA
  - Four 10-bit 51.2 GS/s ADCs & DACs
  - Direct RF digitization across 2 - 18 GHz band
  - 2753 logic elements
  - Quad ARM core processor
  - 4 GB DDR4 SDRAM
  - Eight Gen3 x 4 Data plane ports: 64 GB/sec
  - VITA 65 with VITA 46.0, 46.3, 46.6. 46.11, 48.1, 48.2 (REDI)
  - VITA 49.2 VITA Radio Transport Protocol

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Direct RF Coverage of IEEE Frequency Bands

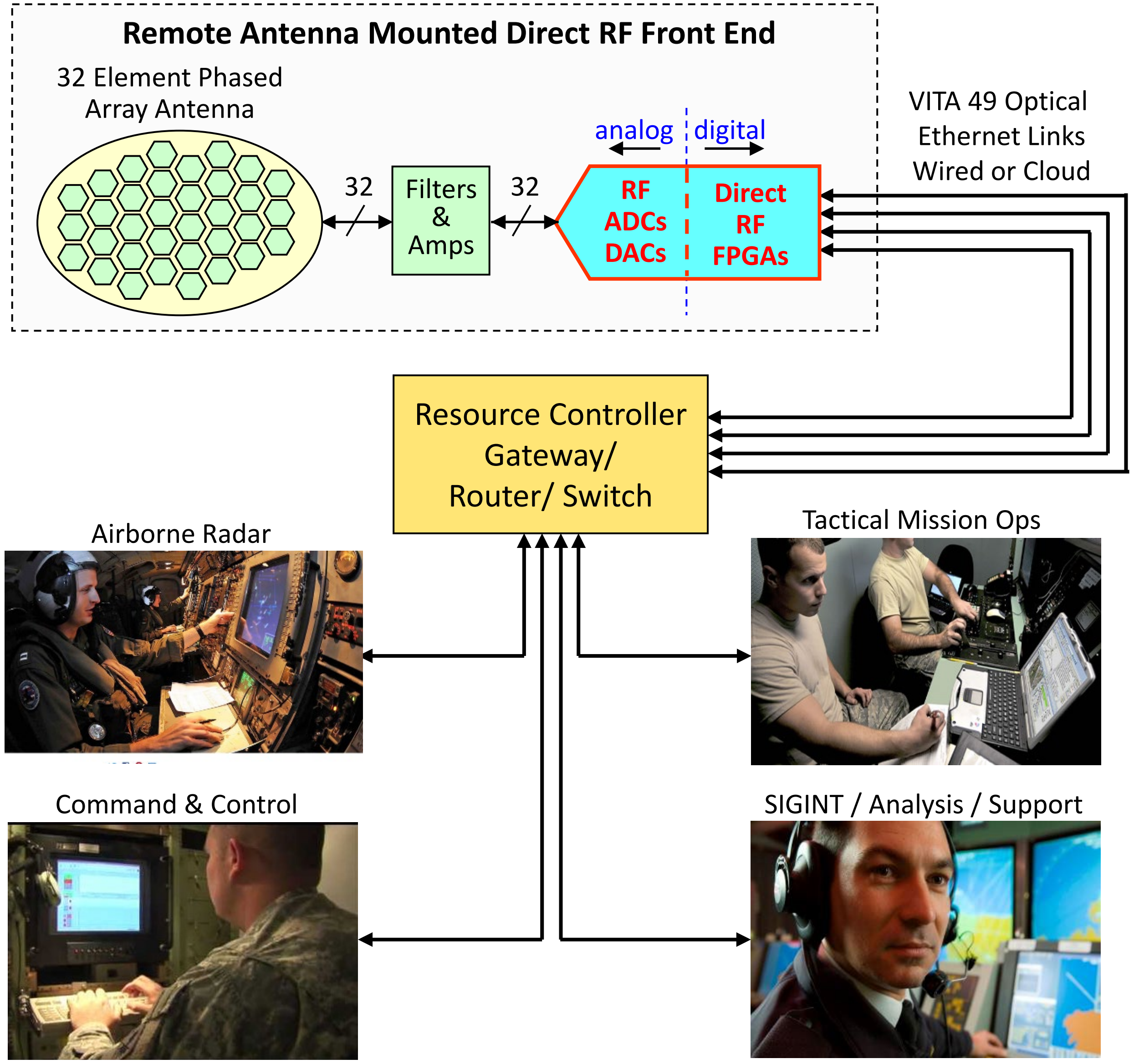
64 GS/s
Direct RF ADC
Coverage
(to 36 GHz)

Band	Frequency	Wavelength	Notes and Applications
HF	3–30 MHz	10–100 m	Coastal radar systems, over-the-horizon radar (OTH) radars; 'high frequency'
VHF	30–300 MHz	1–10 m	Very long range, ground penetrating; 'very high frequency'
P	< 300 MHz	> 1 m	'P' for 'previous', applied retrospectively to early radar systems; essentially HF + VHF
UHF	300–1000 MHz	0.3–1 m	Very long range (e.g. ballistic missile early warning), ground penetrating, foliage penetrating; 'ultra high frequency'
L	1–2 GHz	15–30 cm	Long range air traffic control and surveillance; 'L' for 'long'; monopulse radar, early warning radar
S	2–4 GHz	7.5–15 cm	Moderate range surveillance, Terminal air traffic control, long-range weather, marine radar; 'S' for 'short'
C	4–8 GHz	3.75–7.5 cm	Satellite transponders; a compromise (hence 'C') between X and S bands; weather; long range tracking – Medium Extended Air Defense System (MEADS), ground penetrating radar
X	8–12 GHz	2.5–3.75 cm	Missile guidance, airborne radar; marine radar, weather, medium-resolution mapping and ground surveillance; battlefield and airport radar; short range tracking.
Ku	12–18 GHz	1.67–2.5 cm	High-resolution, also used for satellite transponders, frequency under K band (hence 'u')
K	18–24 GHz	1.11–1.67 cm	From German *kurz*, meaning 'short'; limited use due to absorption by water vapor, so Ku and Ka were used instead for surveillance. K-band is used for detecting clouds by meteorologists, and by police for detecting speeding motorists. K-band radar guns operate at 24.150 ± 0.100 GHz.
Ka	24–40 GHz	0.75–1.11 cm	Mapping, short range, airport surveillance; frequency just above K band (hence 'a') Photo radar, used to trigger cameras which take pictures of license plates of cars running red lights, operates at 34.300 ± 0.100 GHz.
mm	40–300 GHz	1.0–7.5 mm	Millimeter band. The frequency ranges depend on waveguide size.
V	40–75 GHz	4.0–7.5 mm	Very strongly absorbed by atmospheric oxygen, which resonates at 60 GHz.

Credit: Institute of Electrical and Electronic Engineers

Direct RF Transceiver Remote Acquisition/Generation at the Edge

- Shared Direct RF Acquisition and Generation
  - One remote antenna captures multiple bands across wide frequency span for different applications
  - Wideband digitized signals are delivered over optical links or via the cloud using VITA 49 protocol
- Resource Controller and Gateway
  - Connects users to radios using VITA 49 links
  - LAN, Internet, or Secure Wireless Networks
- Diverse Group of Users
  - Radar Countermeasures/Monitoring/Support
  - Tactical mission operations, SIGINT, analysis
  - Command center merging battlefield intelligence
- Flexible Modes
  - Precise synchronization supports direction finding, array steering and diversity reception



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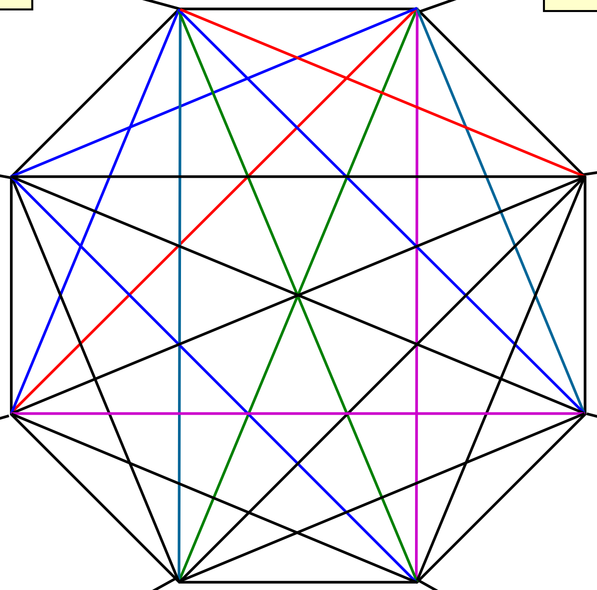

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Benefits and Tradeoffs of Direct RF Technology

Direct RF Benefits

- Reduces the number of platform antennas
- Reduces analog circuitry and system complexity
- Improves reliability and reduces maintenance
- Allows continuous wideband monitoring
- Accommodates extreme frequency hopping
- Reduces cost per channel
- Reduces latency for EW & countermeasures
- Improves channel density and SWaP
- Supports edge sensors and phased-array antennas
- Direct RF FPGAs use heterogeneous processors
- Supports complex wideband modulation
- Improves new technology insertion and reusability

Direct RF Tradeoffs

- Challenging signal data rates require faster interfaces
- First devices are expensive - will improve with new device and packaging technology, volume, competition, and adoption
- Strong interferer signals can impact dynamic range but can be mitigated with tunable filters

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Mercury Products for RF and Microwave – Complete Signal Chain Solutions

- Tunable MMIC Filters
- RF Filters/Amplifiers
- Board Level Products
- RF Tuners/Transmitters
- Solid State Power Amps
- Microelectronic Components
- System-in-Package
- Multi-Chip Modules
- Radiation-Tolerant Modules
- Mixed-Signal Modules
- Microwave Frequency Converters
- Integrated Microwave Assemblies
- FPGA, Analog IO Boards
- RF & Microwave Transceivers
- Signal Sources
- Clock Modules
- Amplifiers
- Active RF & Microwave Components
- Passive RF Components
- Space-Qualified Components

THANKS FOR ATTENDING TODAY!

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