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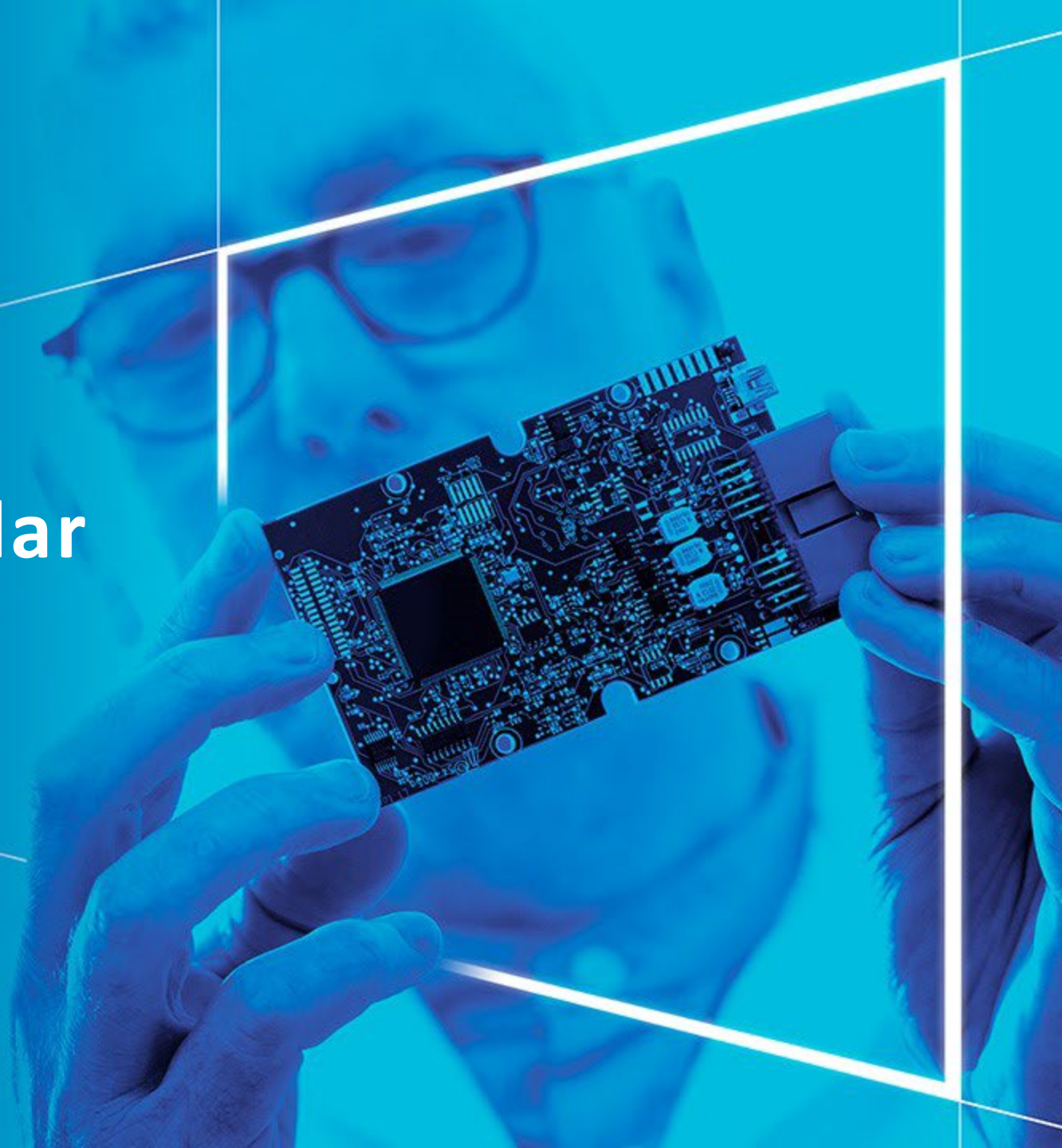
Direct RF Technology Transforms EW & Radar Defense Systems

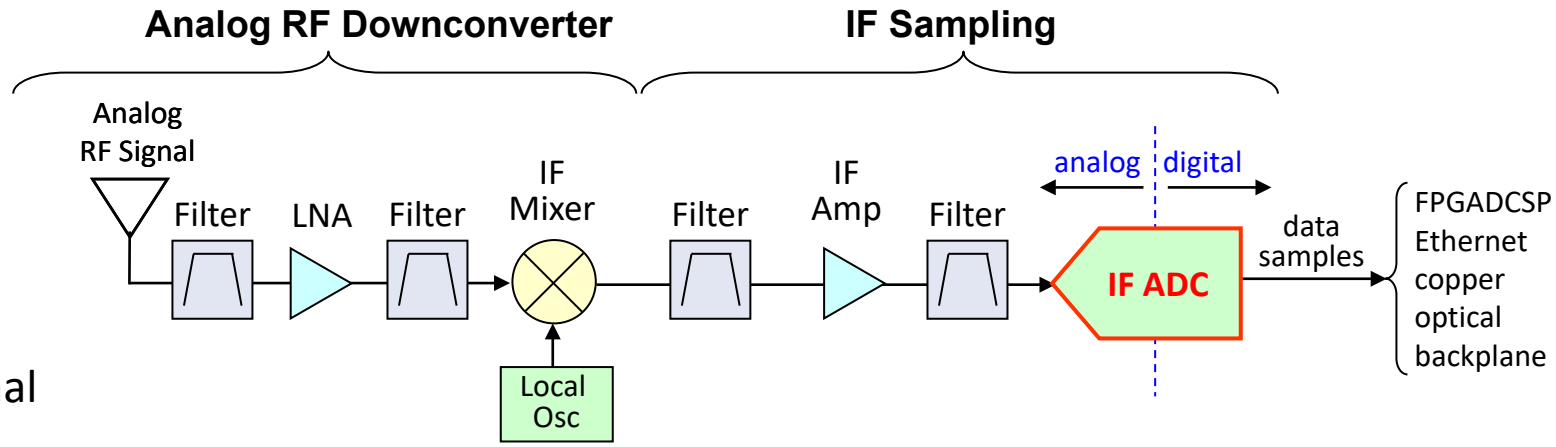


Rodger Hosking
Mercury / Saddle River

Embedded Tech Trends
January 22, 2024

Heterodyne IF Sampling vs. Direct RF Sampling Architectures

- Classic Heterodyne IF Architecture
  - Analog RF front-end includes bandpass filters, low-noise amp, mixer & local oscillator
  - IF (intermediate frequency) ADC digitizes the lower frequency IF signal



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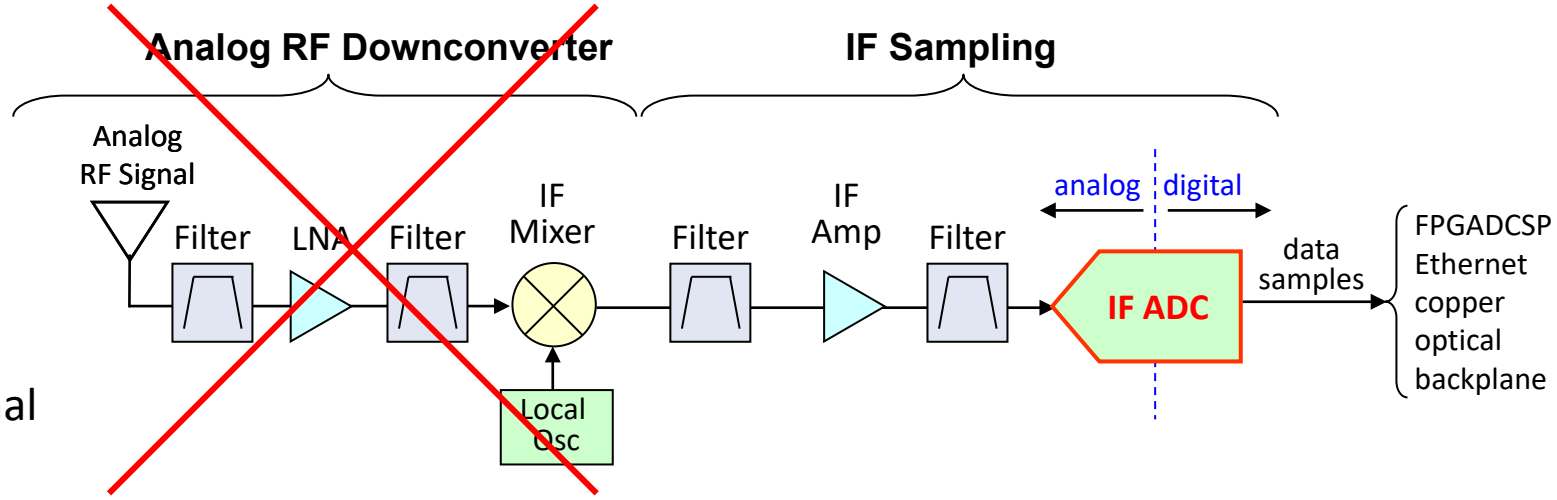
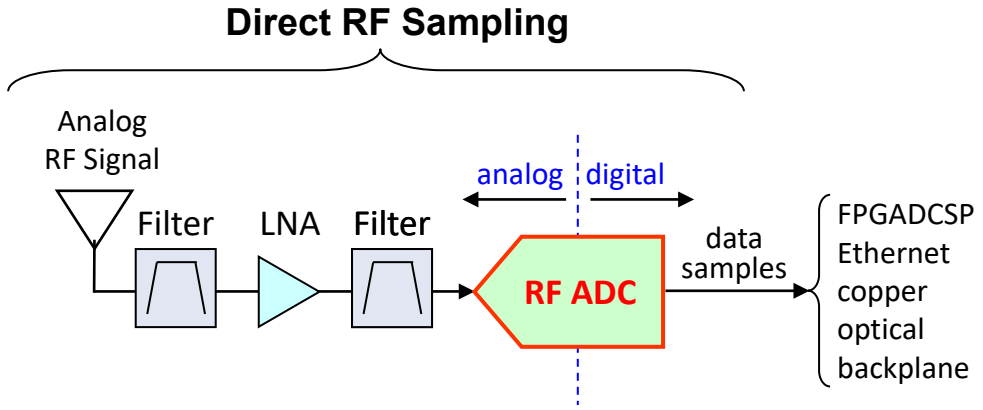
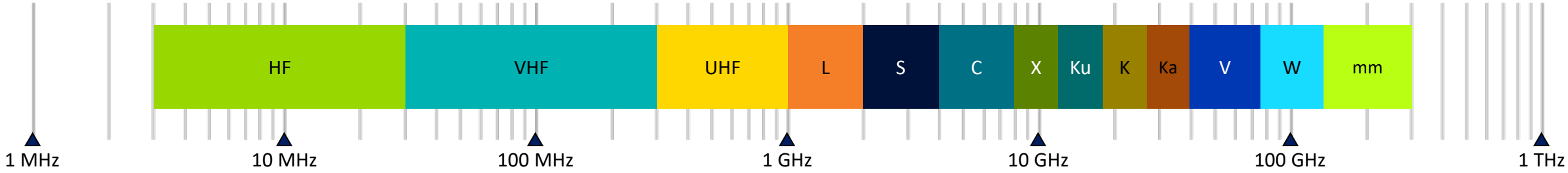


- Direct RF Architecture
  - Eliminates analog mixer & local oscillator for RF down conversion
  - Still includes front-end bandpass filters & low-noise amp
  - Wideband Direct RF ADC digitizes the RF signal directly
  - Reduces complexity, risk, cost/channel and SWaP
  - Boosts performance, latency, and channel density

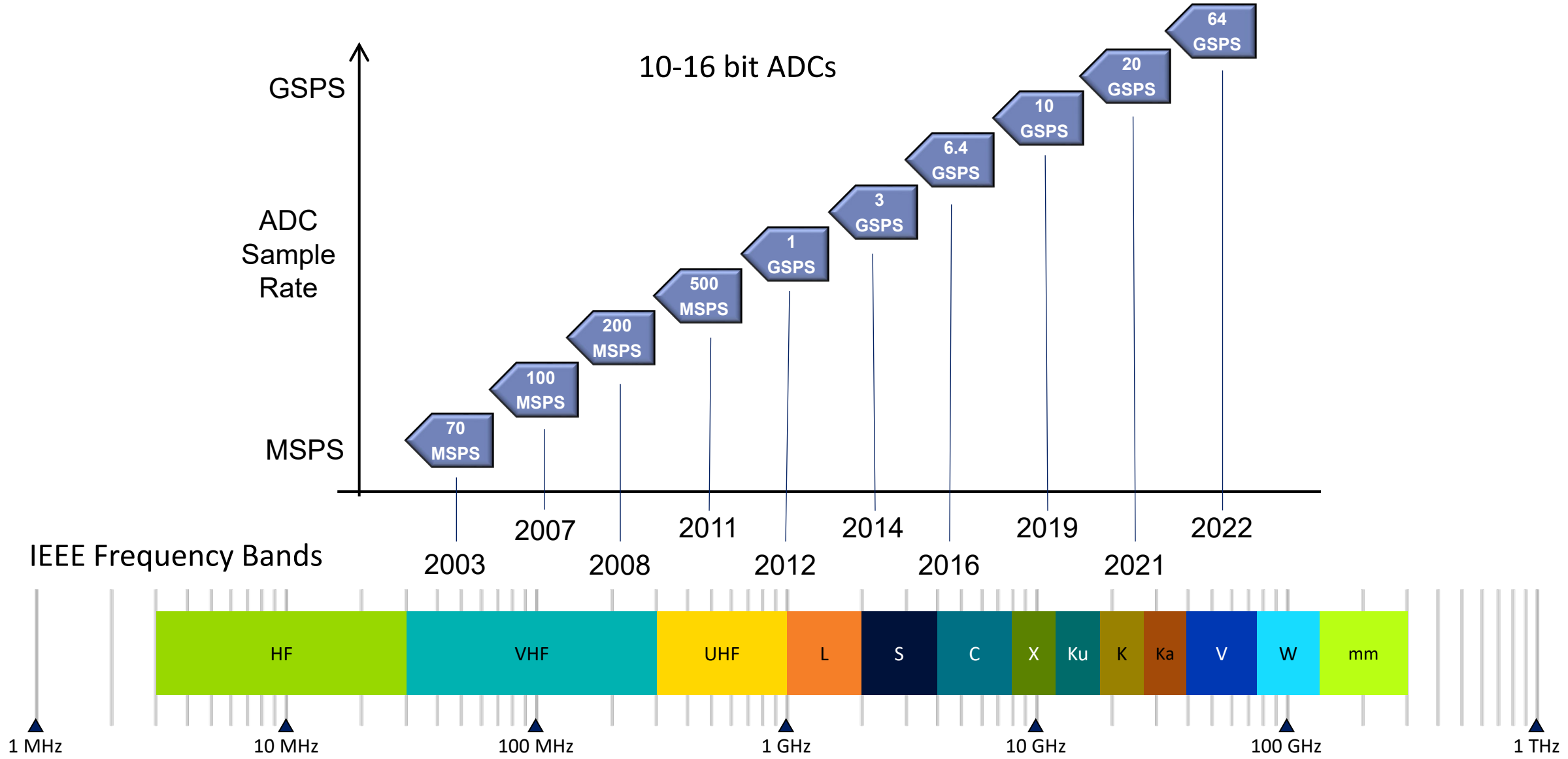


IEEE Frequency Band Definitions and Usage

Band	Frequency	Notes and Applications
HF	3–30 MHz	‘**H**igh **F**requency’; Coastal radar systems, over-the-horizon radar (OTH) radars
VHF	30–300 MHz	'**V**ery **H**igh **F**requency’; Very long range, ground penetrating
UHF	300–1000 MHz	'**U**ltra **H**igh **F**requency’; Very long range (e.g. ballistic missile early warning), ground penetrating, foliage penetrating
L	1–2 GHz	‘**L**ong’; Long range air traffic control and surveillance, monopulse radar, early warning radar, GPS
S	2–4 GHz	‘**S**hort’; Moderate range surveillance, terminal air traffic control, long-range weather, marine radar
C	4–8 GHz	‘**C**ompromise between **S** and **X** bands’ Satellite transponders, weather, long range tracking – Medium Extended Air Defense System (MEADS), ground penetrating radar
X	8–12 GHz	‘e**X**otic’, airborne radar; marine radar, weather, medium-resolution mapping and ground surveillance, battlefield and airport radar, short range tracking
Ku	12–18 GHz	‘frequency under **K** band, hence **u**’; High-resolution, also used for satellite transponders
K	18–24 GHz	‘from German **K**urz, 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	‘frequency above **K** band, hence **a**’; Mapping, short range, airport surveillance, photo radar, used to trigger cameras which take pictures of license plates of cars running red lights, operates at 34.300 ± 0.100 GHz
V	40–75 GHz	‘**V**ery, not to be confused with VHF’; Very strongly absorbed by atmospheric oxygen, which resonates at 60 GHz
W	75–110 GHz	‘**W**’ follow V’; Satellite communications, military radar tracking and targeting, non-military applications
mm	110-300 GHz	‘**mm**illi**m**eter’; Sometimes defined as 110 to 300 GHz, but more generally any frequency from 30 to 300 GHz

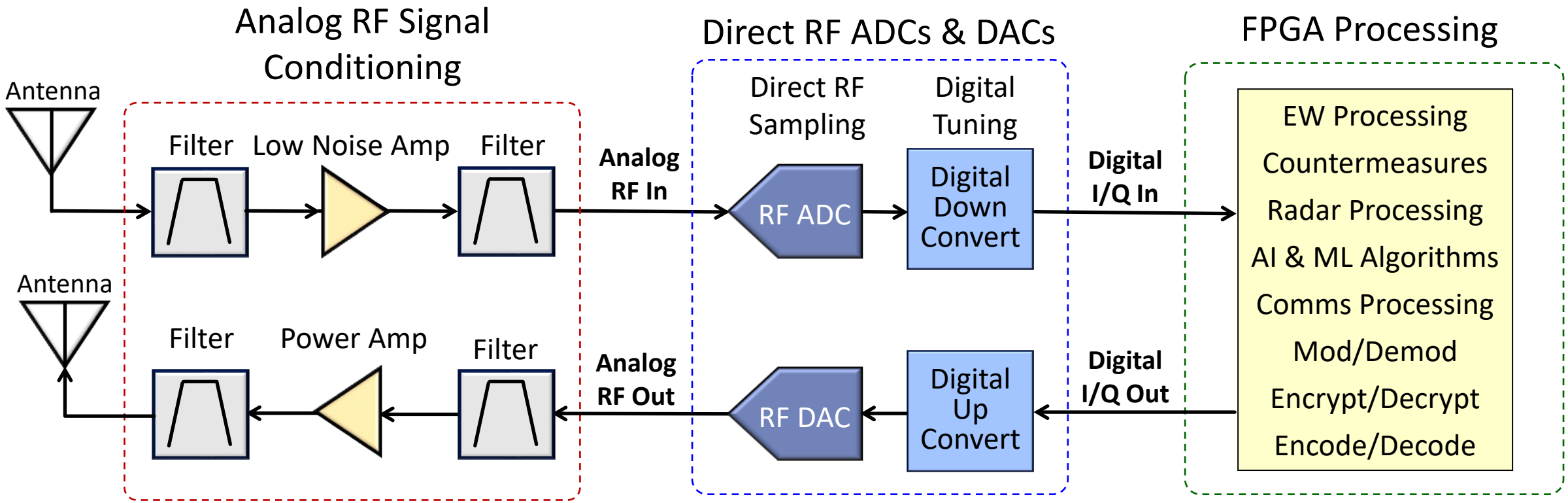


Advances in ADC Sampling Rates



Direct RF Transmit/Receive Basic Architecture

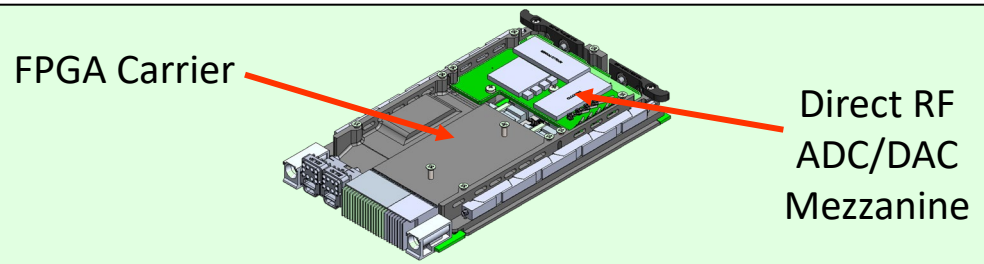
- Direct RF and FPGA technologies handle advanced, wideband, real-time tasks



Four Popular Direct RF Packaging Architectures

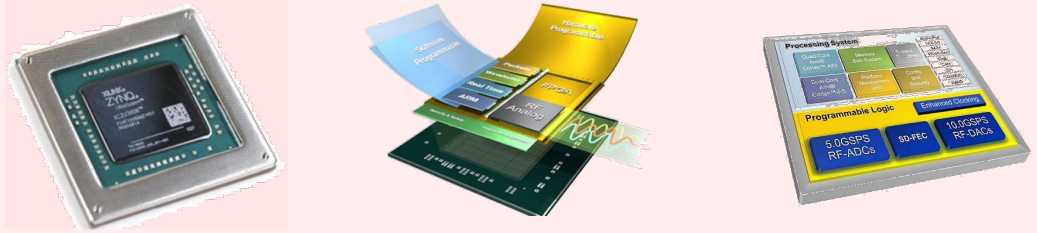
Carrier/Mezzanine Card

- Discrete FPGA Carrier Card
- Discrete ADC/DAC Mezzanine



System-on-Chip – SoC

- Monolithic FPGA and Direct RF ADC/DACs

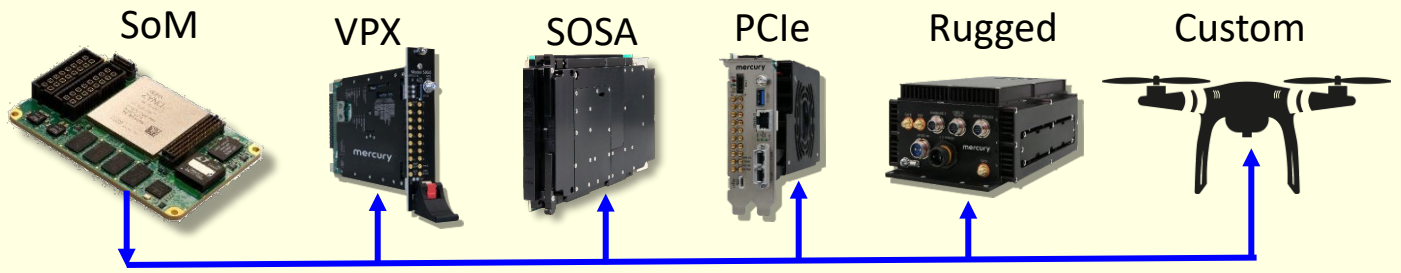


System-in-Package – SiP

- Multi-chip Modules (MCMs)
- FGPA die + Direct RF ADC/DAC chiplets

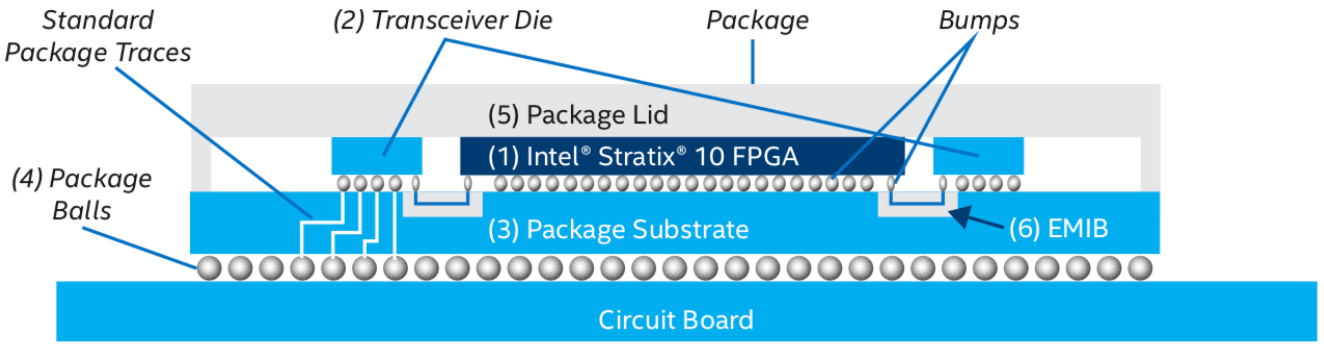
System-on-Module – SoM

- FGPA + Direct RF ADC and DAC
- Accelerates product family breadth
- Speeds & lowers risk for custom designs

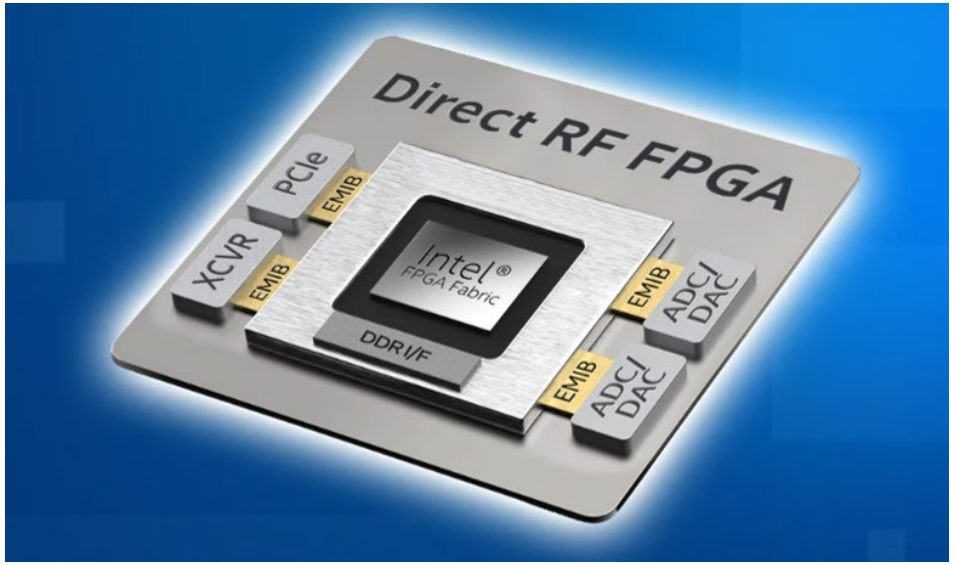


System-in-Package Technology for Direct RF FPGAs

- MCMs allow heterogenous combinations of different die in a single package to address application-specific functions
- EMIB (Embedded Multi-die Interconnect Bridge) standard
- FPGAs are connected to transceiver die (ADCs & DACs) available as “chiplets”
- Intel and Mercury 2.5D MCM fabrication facilities are fully on-line in the U.S.

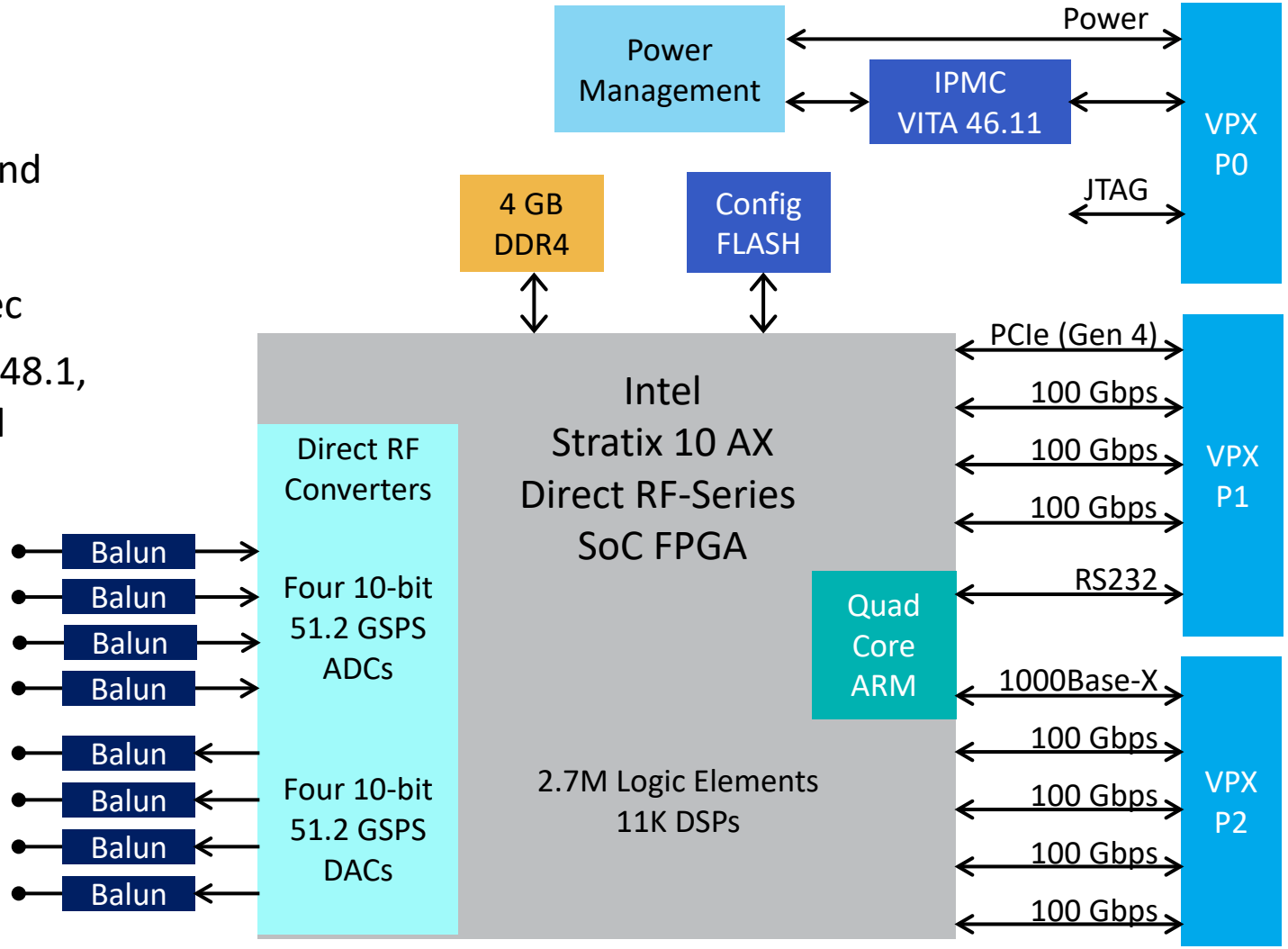


- Intel Altera **Stratix 10AX** Direct RF FPGA MCM
  - Eight 10-bit 64 GS/s ADCs & DACs
  - Direct RF Inputs/Outputs: Up to 36 GHz
  - ADC & DAC connections: Parallel EMIB
  - Six PCIe Gen3 x8 deliver 75 GB/s



Intel Direct RF System-in-Package VPX Board Example

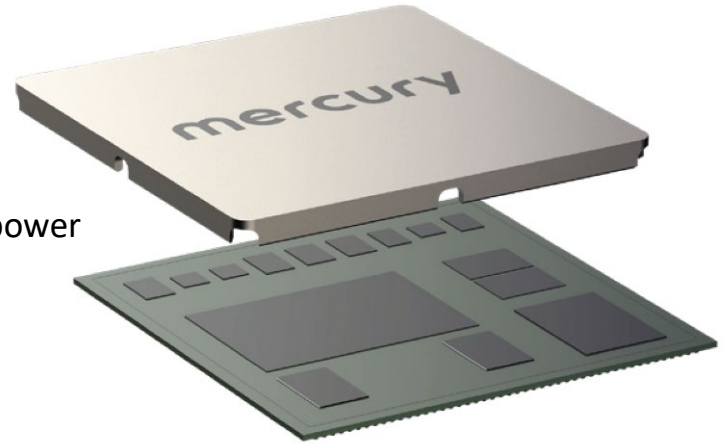
- Mercury DRF3182 3U OpenVPX Direct RF Board
  - Intel Stratix 10AX Direct RF FPGA
  - Four 10-bit 51.2 GS/s ADCs & DACs
  - Direct RF digitization across 2 - 18 GHz band
  - 4 GB DDR4 SDRAM
  - Eight Gen3 x 4 Data plane ports: 64 GB/sec
  - VITA 65 with VITA 46.0, 46.3, 46.6. 46.11, 48.1, 48.2 (REDI),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

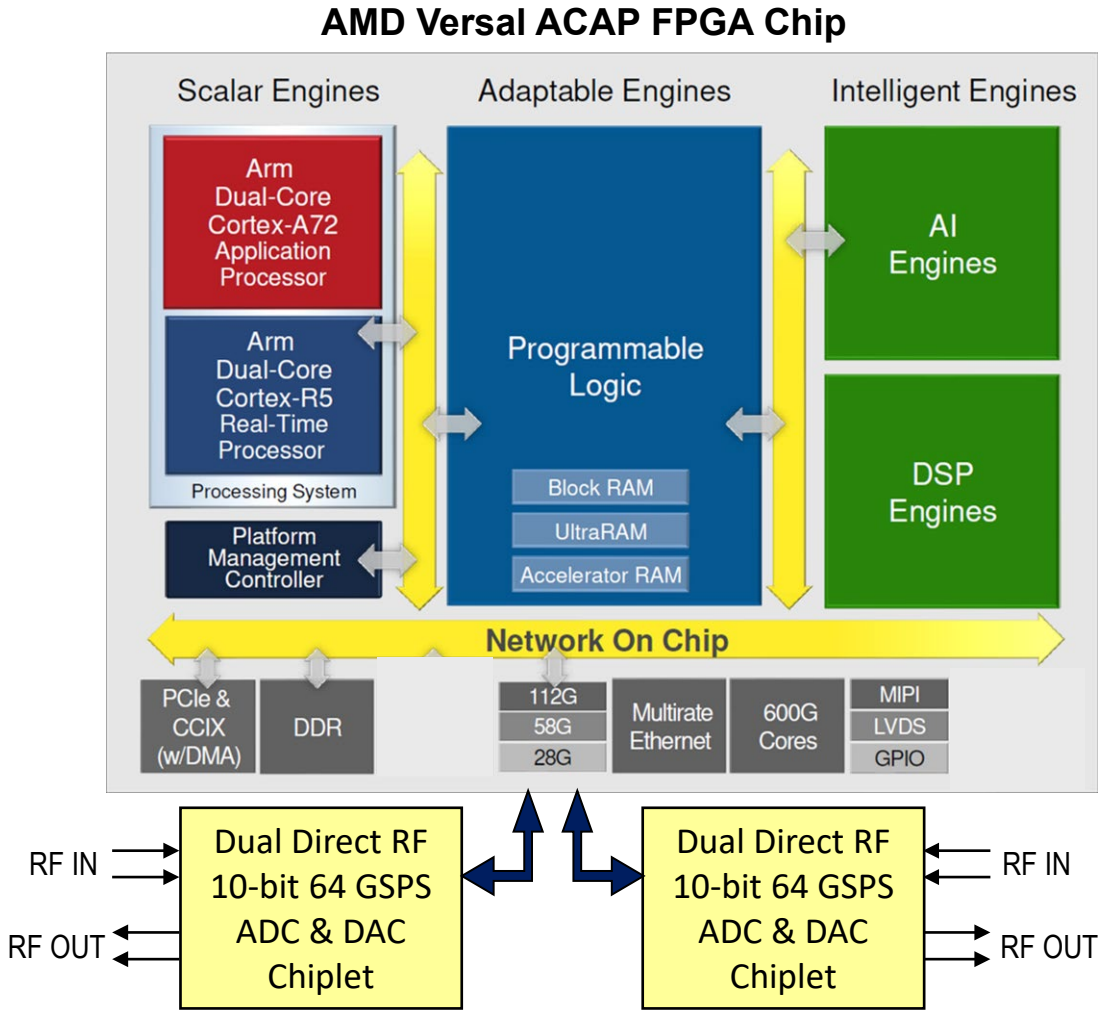


AMD Versal Direct RF System-in-Package

- Mercury RFS1140 RFSiP (System-in-Package)
  - AMD Xilinx VC1902 Versal ACAP FPGA
  - Heterogenous Processors: Fabric, Vector, AI & ML
  - Four Jariet 10-bit 64 GSPS 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 Mercury's DMEA-accredited facility

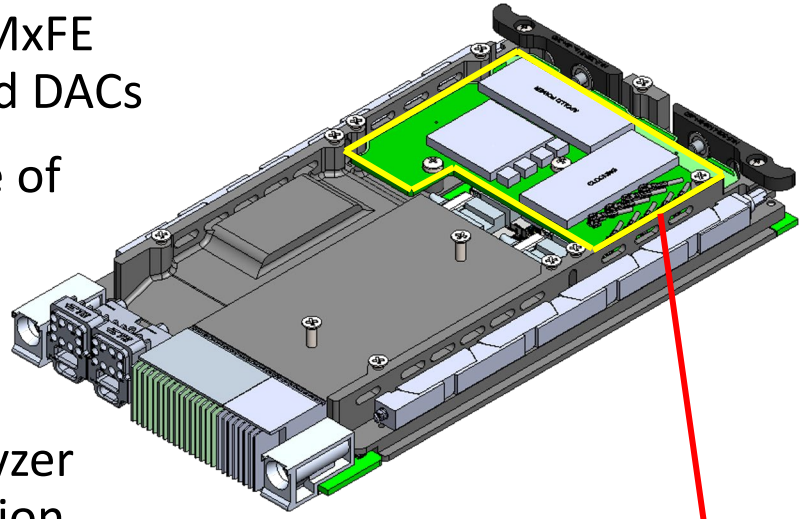
50 x 50 x 5 mm
with integrated power





AMD Versal ACAP HBM FPGA board + Direct RF Mezzanine Example

- Four ADI Apollo MxFE 20 GSPS ADCs and DACs
- Direct RF Capture of 2–18 GHz signals
- Multiple DDCs & DUCs
- On-chip FFT analyzer for energy detection
- 40 GigE & 10 GigE
- PCIe Gen 4 x4
- Two 100 GigE optical interfaces
- 3U SOSA Aligned



Intel Agilex 9 Direct RF FPGAs

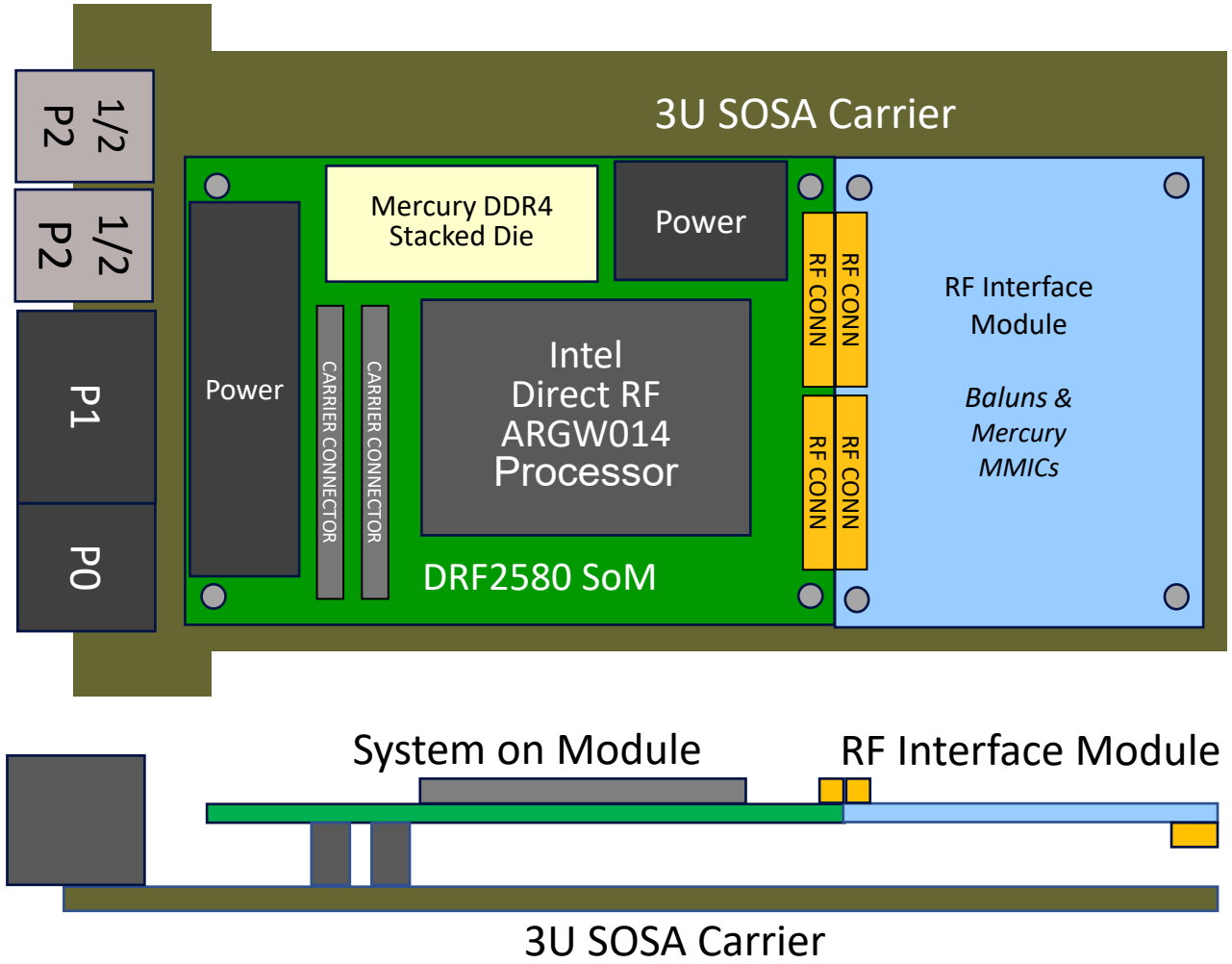
- Introduced in 2023
- Agilex 9 FPGA fabric using Intel 10nm SuperFin process
- Four or Eight 64 GSPS 10-bit ADCs & DACs
- Digitizes RF signals to 36 GHz
- Instantaneous bandwidth to 32 GHz
- 56 Gbaud PAM-4 Serial Transceivers
- EMIB interface from FPGA to chiplets
- AIB (Advanced Interconnect Bus) wide parallel bus reduces power and latency
- Mercury is one of six early access partners

ARGW014
Intel Agilex 9
4 ADCs, 4 DACs
10 bits at 64 GSPS
1,437 logic elements
9,020 multipliers

ARGW027
Intel Agilex 9
8 ADCs, 8 DACs
10 bits at 64 GSPS
2,693 logic elements
17,056 multipliers

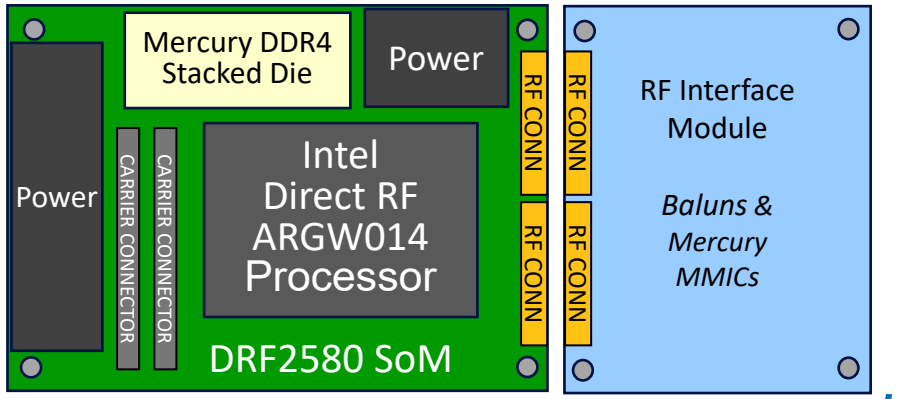
Intel Agilex 9 Direct RF System-on-Module Architecture

- Mercury's first Agilex 9 family is based on the DRF2580 System on Module (SoM)
- RF Interface Module provides flexibility for application specific RF front ends
- Carriers are available in standard form factors including 3U SOSA and PCIe, and small form factor enclosures
- SoM and RF Interface modules are available separately for custom carriers
- A design package enables unique carriers to be designed by customers
- SoM highly optimizes both RF and digital signal integrity to speed custom form factor system designs



Intel Agilex 9 Direct RF System-on-Module Product Family Example

DRF2580 SoM
w/ ARGW014

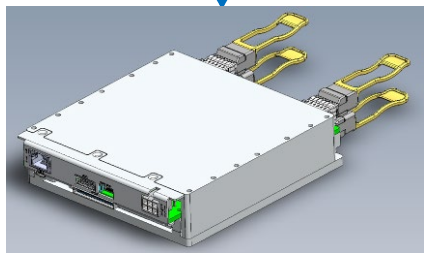


- Flexible form factors
- Flexible RF interfaces
- Simplifies development
- Supports custom designs
- Next SoM features ARGW027

3U SOSA Aligned

PCIe

Rugged Enclosure

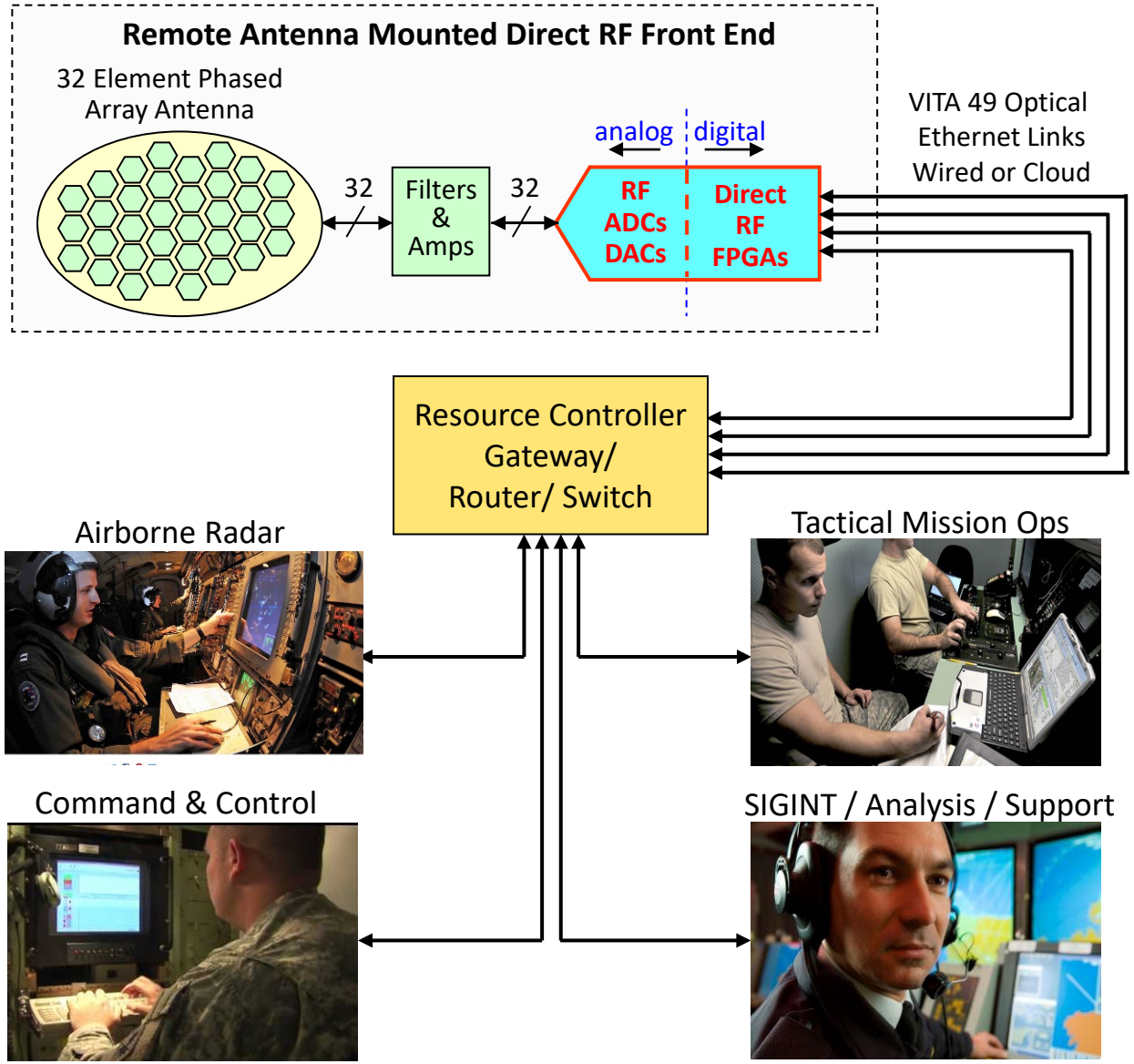


Sub-System

Custom Carriers enabled with 4806 carrier design kit

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



Direct RF Benefits for Mil-Aero Radar and Electronic Warfare

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

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

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

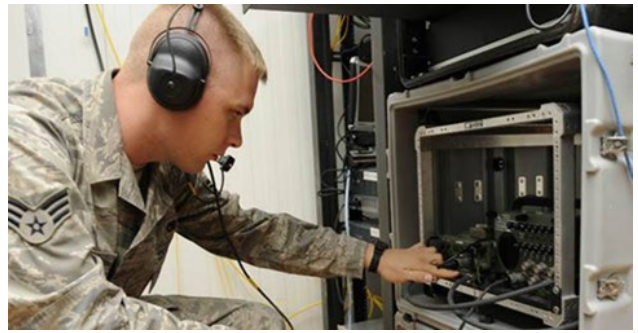
Heterogeneous Computing
- DSP, FPGA, GPU, RISC, AI, ML
- High-Level Portable Tools
- Higher Performance Levels

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

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

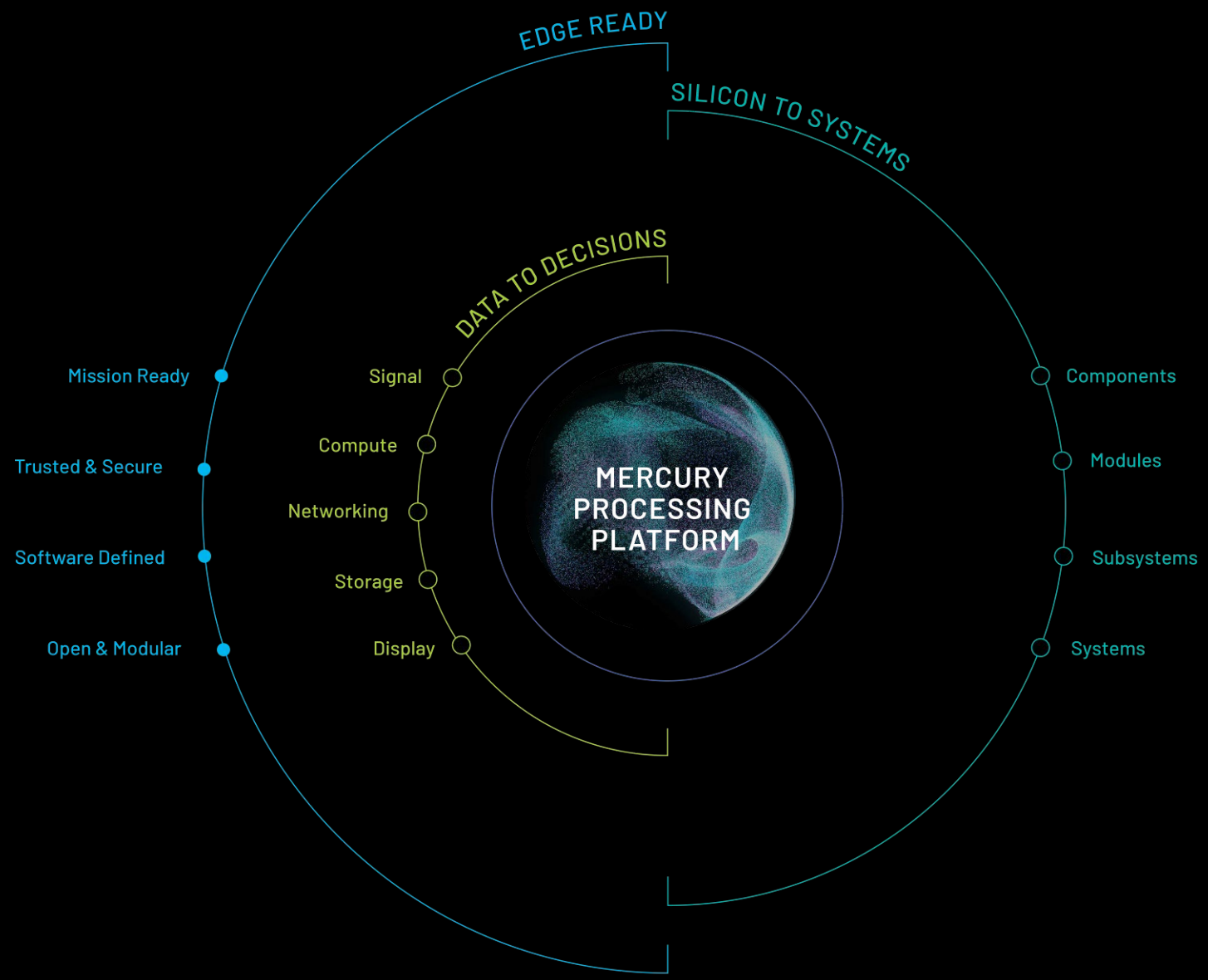
Phased Arrays (AESA)
- Electronically steer beam pattern
- Multiple agile target tracking
- SWaP gains vs. rotating dish

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



Mercury Processing Platform Solutions for RF and Microwave

- 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



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