Ultra-Low SWaP Chip-Based Digital Beamforming Antenna Arrays for Space Networks: AI-Enhanced, Anti-Jam, and DIFI-Compliant

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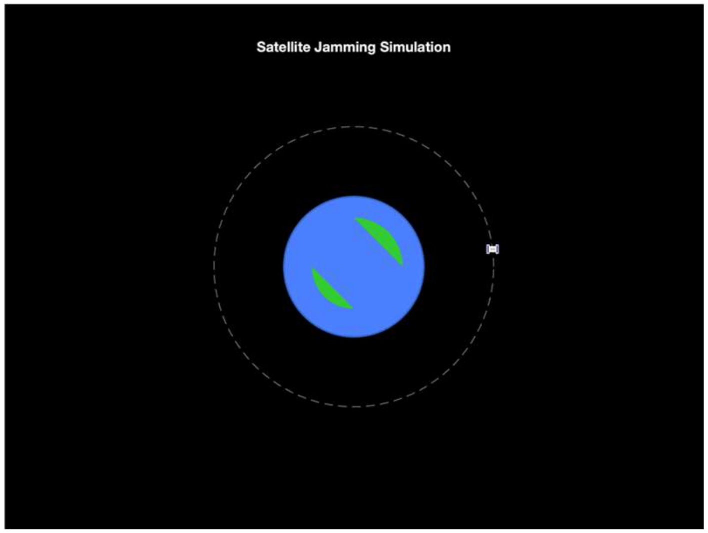
Outline

- NEXT's ASIC Advantage
  - 10× SWaP reduction compared to FPGA-based phased arrays
  - Radiation-hardened SoCs purpose-built for space environments
- AI-Enhanced Beamforming
  - Adaptive, jammer-resilient, and predictive beam steering
  - Real-time optimization for contested and dynamic space networks
- Integrated DIFI Interface
  - Native Digital IF interoperability for seamless system integration
  - Eliminates bulky external hardware and reduces lifecycle cost
- Scalable Space-Grade Platforms
  - From ultra-compact CubeSat tiles to multi-thousand-element gateway arrays
  - Dual-band, multi-beam architectures supporting future satellite payloads
- Mission Impact
  - Compact, efficient, and resilient antenna systems
  - Enabling the next generation of LEO and multi-orbit communications

Future Satellite Payload Needs

Emerging Threat Environment

- Proliferation of ground-based jamming systems
- Sophisticated multi-vector interference attacks
- Need for autonomous threat mitigation



Performance Requirements

- Ultra-high data rates (500+ Gbps)
- Multi-mode communication flexibility
- Real-time adaptive beam steering

Market Reality: Next-generation satellites will demand jammer-resilient operation

- Standardized DIFI interface accelerates adoption across heterogeneous payloads

Jammer Resilience Techniques

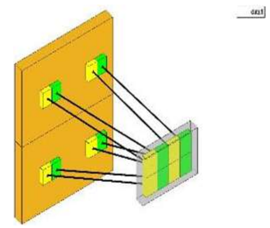
Adaptive Digital Beamforming (ADBF)

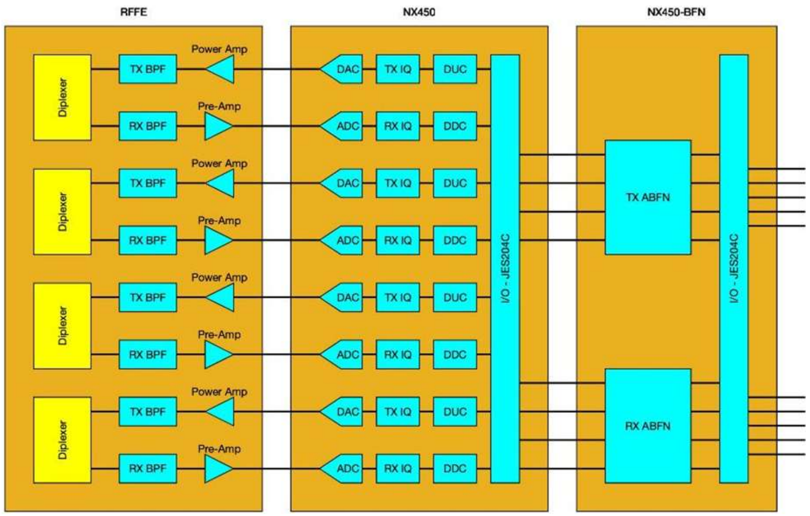
- 60+ dB jammer suppression capability through adaptive nulling and spatial filtering
- DIFI transport allows resilient beamformed outputs to be routed flexibly across networks

RX Dynamic Range

- 70+ dB over >4 GHz instantaneous bandwidth
- Superior dynamic range prevents receiver saturation under intense jamming, improves receiver sensitivity to prevent nonlinear distortion from masking low amplitude signals of interest

Combined Impact: 10x improvement in jammer resilience compared to conventional systems

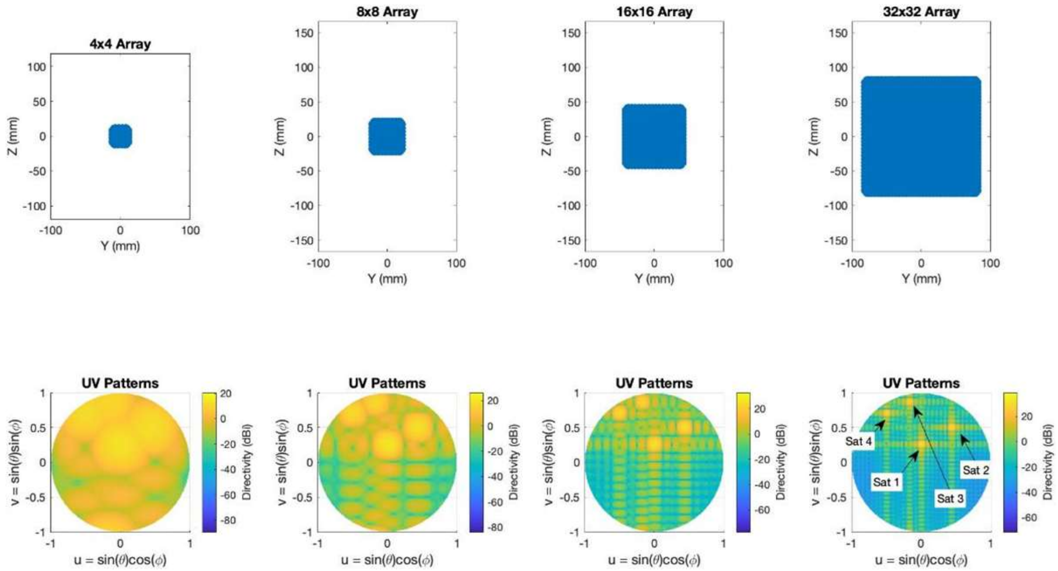




Example Configuration: 2x2 T/R Subarray Block Diagram

Adaptive Digital Beamforming (ADBF)

- Adaptive Spatial Filtering
  - Combined analog null-steering and digital beamforming achieve >60 dB jammer suppression without ADC saturation.
- Real-time beam steering: Sub-millisecond response to jammer detection
- Multiple null placement: Simultaneous suppression of 8+ jammers
- Sidelobe control: -45 dB sidelobe suppression prevents jammer entry
- Coherent processing: Full exploitation of array gain and directivity
- Key Advantage: Software-defined flexibility allows rapid adaptation to evolving threat scenarios
- DIFI transport allows resilient beamformed outputs to be routed flexibly across networks

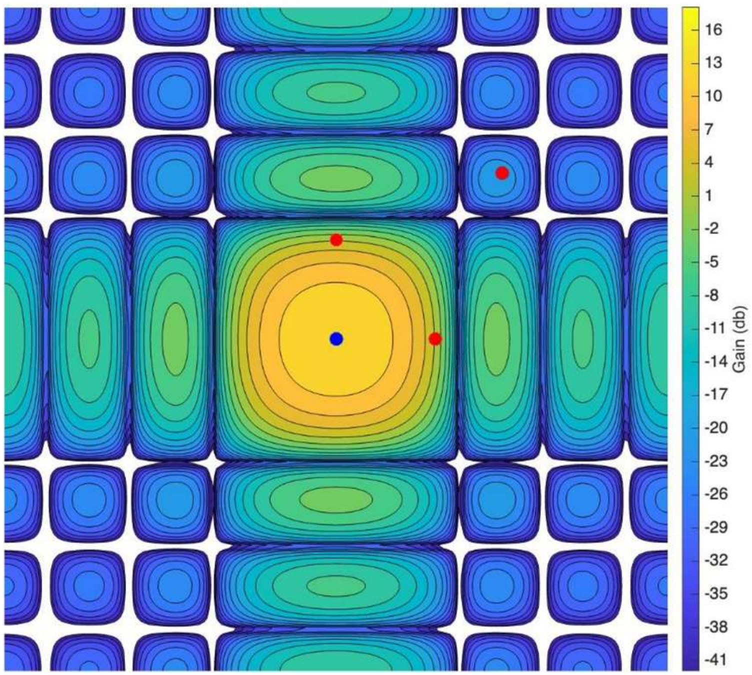


Example Array UV Beam Patterns

Adaptive Digital Beamforming (ADBF)

Non-Adaptive Beamsteering

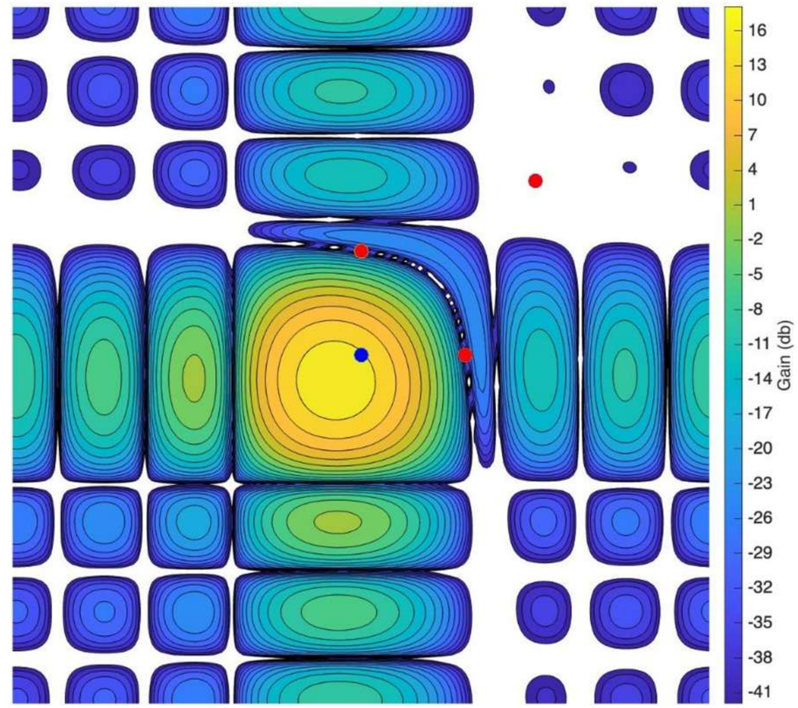
Comet Ku64



Non-Adaptive Beamsteering relies on narrow antenna array pattern to point to SOI (blue dot) and attenuate jammers/interference (red dots)

Adaptive Beamforming / Nulling

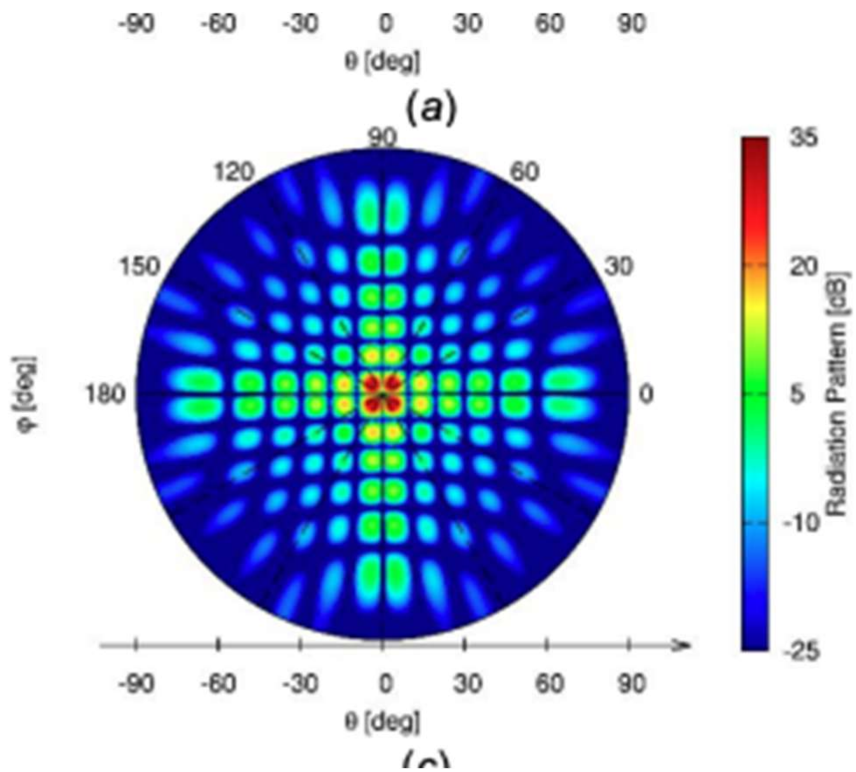
Comet Ku64



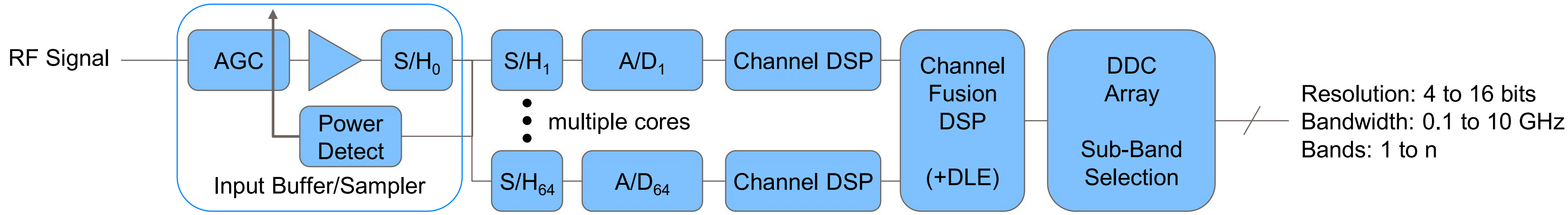
Adaptive Digital Beamforming maximizes the SINR by placing nulls on the jammers/interference (red dots) while maintaining the SOI (blue dot) within the main lobe.

AI Enhanced ADBF

1. Orbital Motion Prediction
    - LSTM networks predict satellite positions
    - Proactive beam steering before handovers
    - Reduced tracking lag and improved continuity
2. Deep Learning Interference Classification
    - Distinguishes between satellite, ground, and atmospheric interference
    - Adaptive mitigation strategies for each interference type
    - Real-time spectral and spatial feature analysis
3. Reinforcement Learning Optimization
    - Deep Q-Network learns optimal beamforming policies
    - Adapts to changing orbital geometry automatically
    - Maximizes SINR while minimizing interference
4. Predictive Beamforming
    - Computes future optimal weights based on predicted positions
    - Enables seamless beam handovers between satellites
    - Reduces service interruptions during orbital transitions
5. Real-time adaptation to changing link conditions
    - AI/ML for configuration of receiver sensitivity, dynamic range, bandwidth, center frequency
    - Based on current RF signal conditions, jamming, interference
6. DIFI enables AI-driven adaptive signals to interoperate seamlessly with ground and space systems.



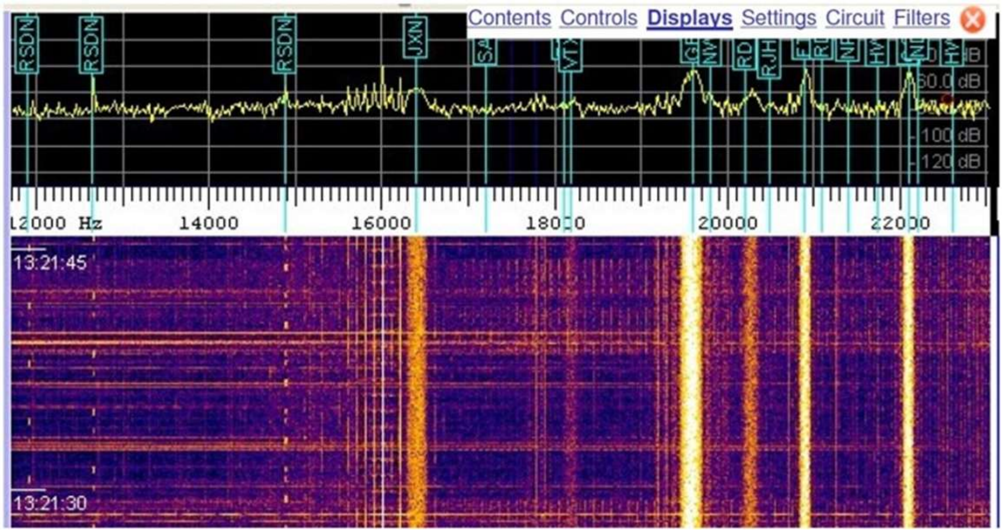
Adaptive Dynamic Range via Configurable Data Conversion



- On-the-Fly Data Conversion Reconfiguration:
  - Dynamically switch IN MICROSECONDS between high-res/narrowband and low-res/wideband modes to match mission needs via core averaging and interleaving customizations to efficiently meet high and low bandwidth mission requirements
  - Direct RF sampling multistage ADC core architecture with selectable resolution and multi-core interleaving and/or averaging to achieve optimal power efficiency vs noise density supporting 4-bit to 16-bit operation
  - Digital Down Conversion (DDC) support multiple simultaneous bands of independent resolution, bandwidth, and frequency
- 70+ dB SFDR Performance:
  - Digital Linearity Enhancement (DLE) linearization allows capture of weak signals alongside strong interferers without distortion.
- Jammer-Tolerant Automatic Gain Control (AGC)
  - Adaptive input scaling mitigates overload of high power jammers with sub-microsecond reaction times
- High-Reliability Rad-Hard by Design:
  - Space-grade reliability with multi-core redundancy and continuous fault checking

RF Sensing & Cognitive Adaptive Modem

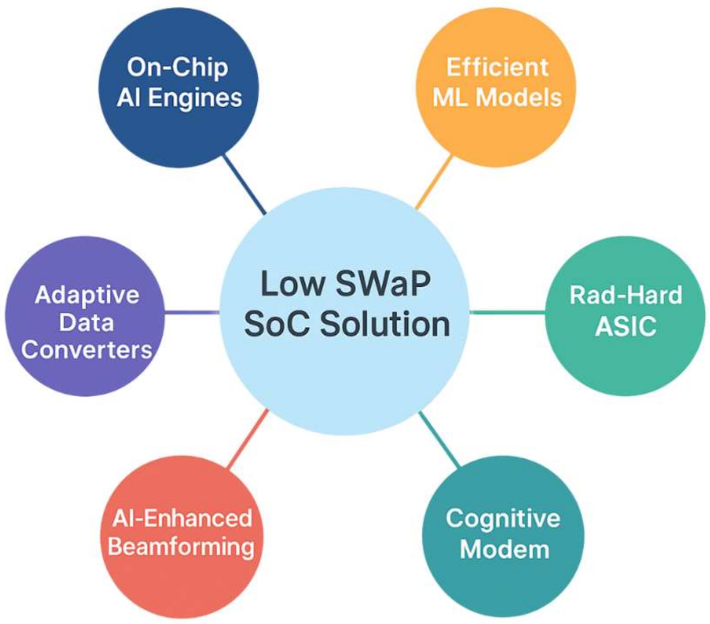
- Real-Time Spectrum Sensing:
  - On-chip RF scanner detects jammers, anomalies, and unauthorized emitters using spare ADC resources or dedicated sensing paths.
- Rogue Signal Detection:
  - Anomaly detection algorithms identify unexpected or illicit transmissions (e.g., enemy jammers or pirate signals).
- Modem Agility:
  - Waveforms adapt on the fly—auto-switching modulation, code rate, bandwidth, or hopping to maintain link quality under jamming.
- Waveform Shaping:
  - Supports standard satcom formats (e.g. QPSK, DVB-S2) with AI-driven real-time optimization.
- Autonomous Jamming Avoidance:
  - Embedded ML detects jammer signatures and autonomously reconfigures beamformer, bandwidth, and frequency in a closed-loop response.
  - Spectrum sensing enables real-time hopping and subcarrier nulling (OFDM/DMT) to dodge interference within waveform.
  - Feedback loop between sensing and modem enables closed-loop resilience without operator intervention.



Real-Time Spectrum Sensing:
Modulation Recognition Power Spectral Displays

Embedded AI/ML for Resilient Space Communications

- On-Chip AI Engines:
  - Dual RISC-V cores and DSP blocks execute trained models for signal classification and decision-making at the edge.
- Efficient ML Models:
  - Rule-based logic and decision trees for fast jammer detection
  - Compact CNNs for modulation/interference recognition
  - Anomaly detection (SVMs, autoencoders) for unknown threats
  - Spectrum clustering to map usable channels
- Radiation-Hardened AI:
  - Lightweight models optimized for space—low power, minimal memory, ECC-protected, and SEU-tolerant.
- System-on-Chip Integration:
  - RF sensing, beamforming, and AI control merged into a single rad-hard chip—replacing racks of radios with a compact, space-ready ASIC.



NEXT ASICs vs FPGAs

Our semiconductor IP foundation and SoC integration allows us to build lower SWaP+C digital beamforming antenna solutions

- APUs, Antenna Processor Units
  - Direct RF-sampling transceivers (i.e. NXA1)
- BPUs, Beam Processor Units
  - Software defined beam processors (i.e. NXB1)
- Integrated DIFI eliminates bulky FPGA-based interface cards, reducing SWaP by 10×

	FPGA	NEXT
Software Configurable	Yes	**Yes**
Platform	FPGA	**ASIC**
SWaP	>10X	**1 (normalized)**
Cost	>10X	**1 (normalized)**

Custom Phased Array Panel

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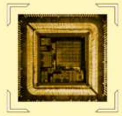
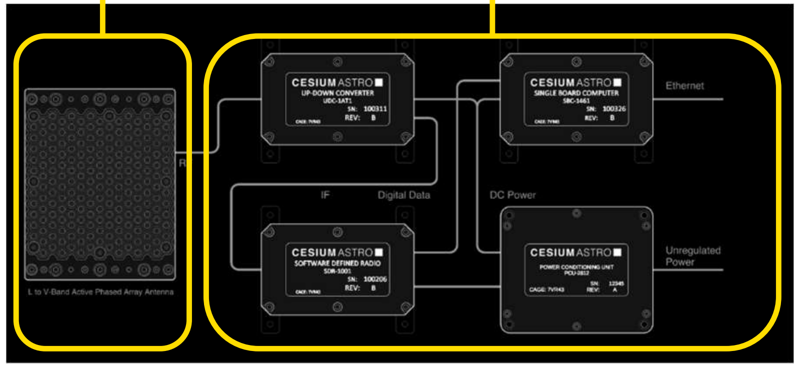


NEXT SoCs
- NXA1
- NXB1

Single-Panel Integration

NEXT SoC replaces hardware modules at 10X lower SWaP



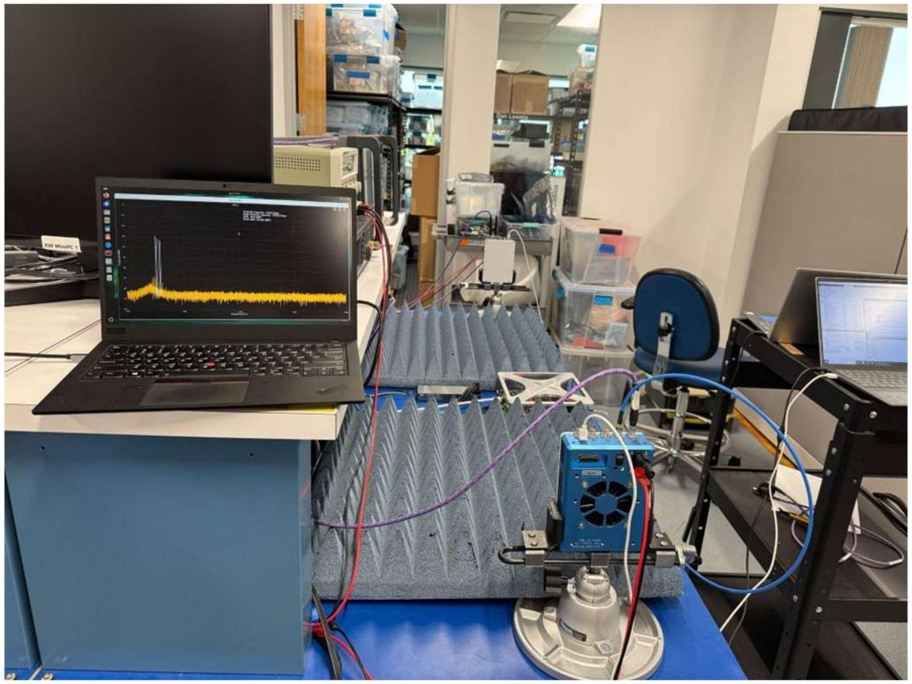
example: CesiumAstro modular antenna

RF Panel

Multiple Hardware modules

Full Antenna System Solutions

- NEXT is partnering with Extreme Waves to provide full end-to-end antenna systems replacing FPGAs with SoCs



NEXT Semiconductor
Direct RF RX+TX SoC
Integrated Digital Beamforming

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Extreme Waves (XW)
RF Antenna Panels

Full system demo showcasing a 28-GHz flat panel array with up to 4-GHz waveforms at our shared lab facility in San Diego

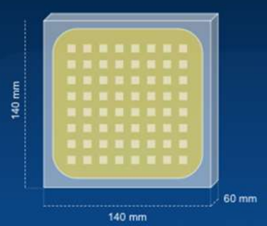
NEXT Antenna Roadmap

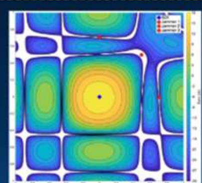
Platform	NX-Comet™	NX-Photon™	NX-Nebula™	NX-Aurora™	NX-Quasar™	NX-Zenith™	NX-TerraKu™	NX-TerraKa™
Type	Tile	Tile	Tile	Panel	Gateway	Aggregator	Terminal	Gateway
Elements	64	256	512	768	1024	2048	1024	4096
Frequency Band(s)	Ku	Ka	Ka	Ku + Ka	Q/V	Ku + Ka + Q/V	Ku	Ka
RX Band (GHz)	10.7–12.7	17.7–21.2	17.7–21.2	10.7–21.2	37–51	10.7–51	10.7–12.7	17.7–21.2
TX Band (GHz)	14.0–14.5	27.5–31.0	27.5–31.0	14.0–31.0	37–51	10.7–52	14.0–14.5	27.5–31.0
Application	LEO Satellite	LEO Satellite	LEO Satellite	LEO Satellite	LEO Satellite	LEO Satellite	Terrestrial	Terrestrial
Size (cm)	14 × 14	12 × 12	17 × 17	24 × 24	16 × 16	34 × 34	60 × 40	100 × 100
Weight (kg)	0.7	1.2	2.5	4.5	5.8	12	3.5	22
Est. Power (W)	20	45	90	140	220	350	65	400

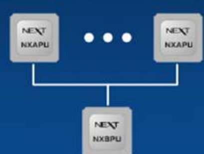
NEXT SEMICONDUCTOR

Product Brief: Comet-Ku64™

Ultra-Compact Ku-Band Phased Array Antenna with Integrated Digital Beamforming for LEO SmallSats







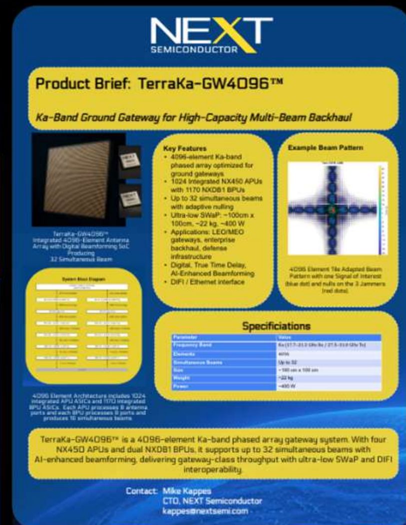
Key Features

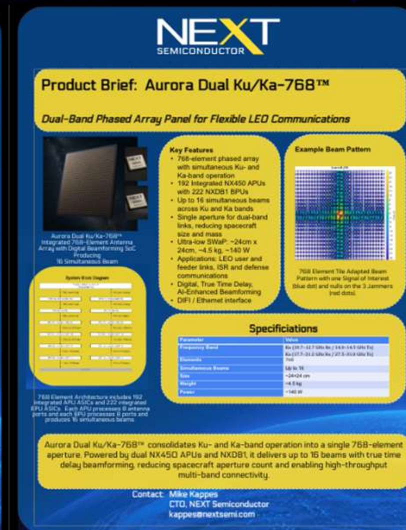
- 64-element electronically steerable Ku-band phased array
- Integrated NX212 Antenna Processor (APU) and NXDB1 Beam Processor (BPU)
- Up to 16 simultaneous beams with adaptive nulling and anti-jam capability
- Ultra-low SWaP (<1 kg, ~20 W typical)
- CubeSat-compatible 14×14 cm form factor
- Applications: LEO CubeSats, tactical smallsat constellations, ISR payloads, IoT networks

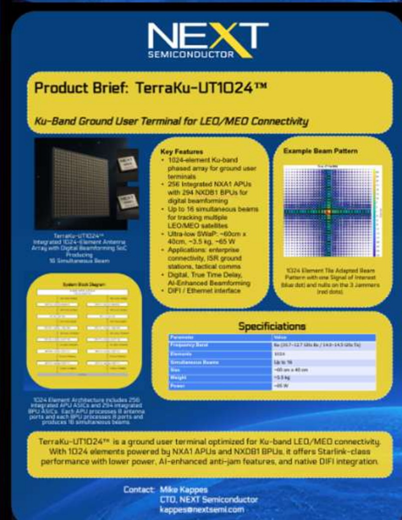
Specifications

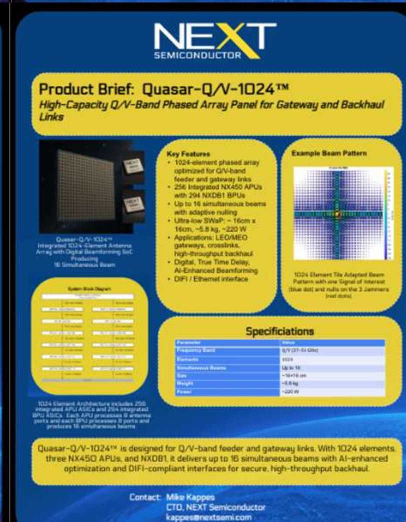
Parameter	Value
Frequency Band	Ku [10.7–12.7 GHz Rx / 14.0–14.5 GHz Tx]
Elements	64
Simultaneous Beams	Up to 16
Size	14×14 cm
Weight	0.7 kg
Power	20 W

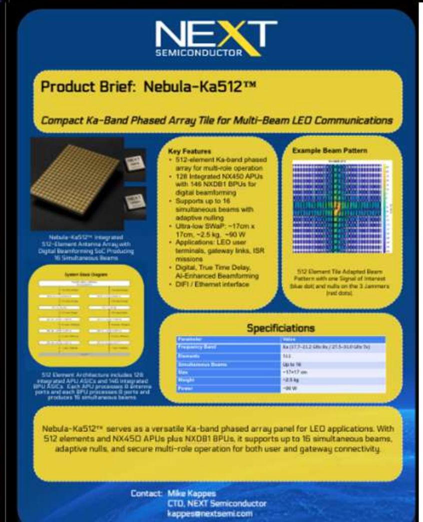
The Comet-Ku64™ is NEXT Semiconductor's most compact chip-based phased array antenna, optimized for CubeSat and smallsat platforms. Integrating the NX212 APU and NXDB1 BPU, it delivers fully digital beamforming with up to 16 simultaneous Ku-band beams in a form factor under 1 kg and 20 W. By combining low SWaP with native DIFI-compliant outputs, Comet-Ku64 enables small spacecraft to achieve secure, high-capacity multi-beam communications traditionally reserved for larger satellites.







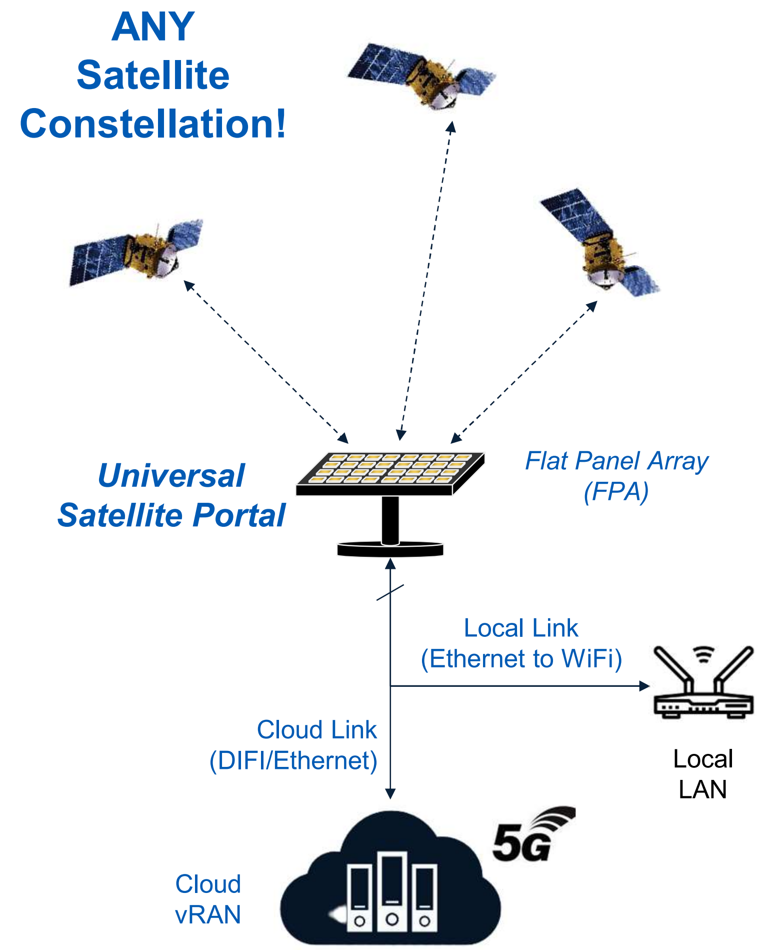




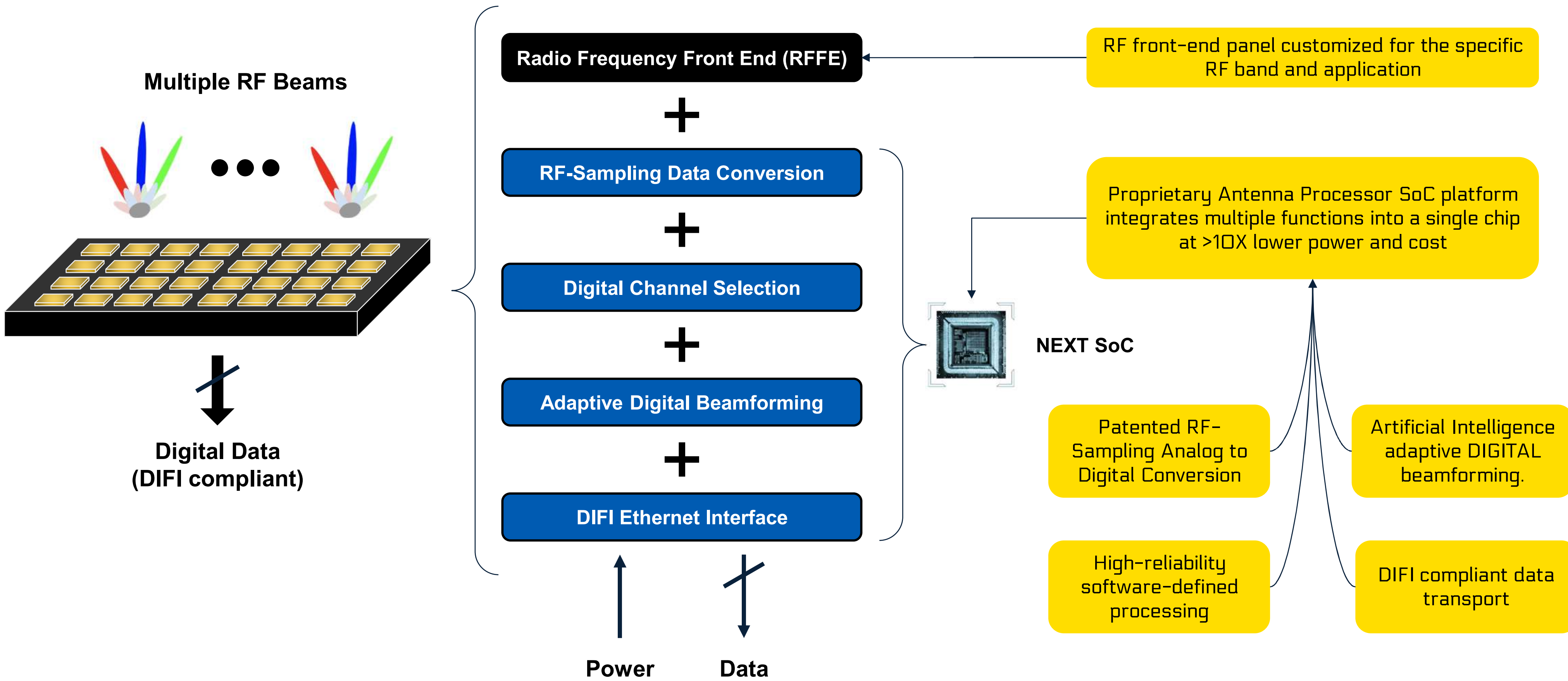
Universal Satellite Portal Opportunity

- A USP translates signals from satellites into secure digital packets for internet traffic
  - Enables "Global WiFi" networks
  - Enables Virtual 5G Networks (V-RAN)
  - Uses the new DIFI transport protocol

- A USP enables virtual networks running on software to leverage low-cost data center processing and global satellite connectivity



SoC-Enabled Antenna Technology



DIFI-Enabled Interoperability in NEXT Phased Arrays

- Native Digital IF Interface
  - Fully aligned with DIFI (Digital IF Interoperability Consortium) standard
- Direct On-Chip Packetization
  - Digitized I/Q streams packetized at the source, transported over Ethernet
- Simplified Architecture
  - Eliminates bulky external FPGAs and proprietary interfaces
- Plug-and-Play Interoperability
  - Seamless integration with other DIFI-compliant systems and networks
- SWaP & Cost Advantages
  - Reduced hardware complexity, lower power consumption, and faster deployment
- Enhanced Flexibility
  - Beamformed signals easily shared, routed, or processed across multi-orbit and ground systems

SUMMARY

- Growing demand for high-throughput, electronically steerable antennas with low SWaP for LEO constellations and multi-orbit networks
- NEXT's Antenna Processor Units (APUs) and Beam Processor Units (BPUs) offer JAMMER-RESILIENT, radiation-hardened, true time delay, adaptive digital beamforming with adaptive data conversion
- NEXT solutions mitigate SWaP+C limitations of traditional phased arrays with CUSTOM SoCs delivering 10× power efficiency in LEO payloads and gateways
- Scalable platforms: from 64-element Ku-band CubeSat tiles to multi-thousand-element dual-band LEO gateway panels
- DIFI-Compliant Digital IF Interface: On-chip Ethernet packetization enables interoperability, reduces external hardware, and simplifies integration

EXTRA SLIDES

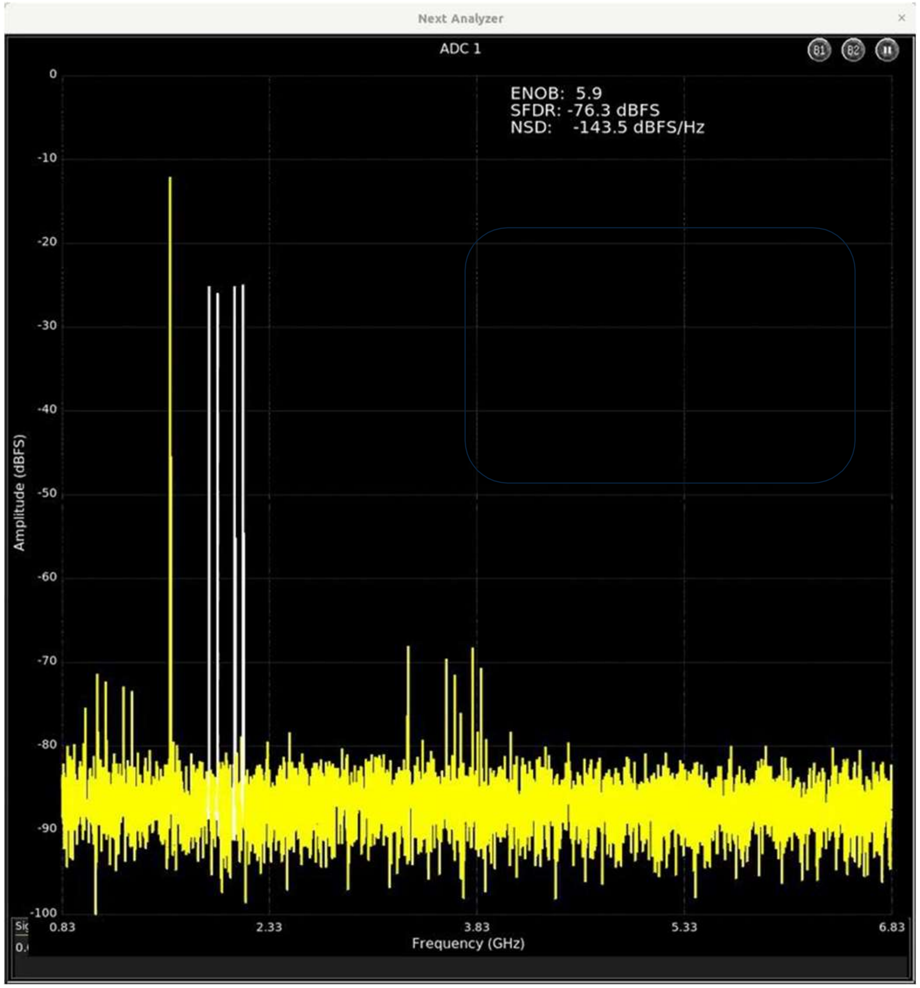
NEXT PATENT PORTFOLIO *

- Autonomous Beamforming SoC with Embedded AI
- AI-Integrated SoC for Cognitive Beamforming & Jammer Mitigation
- AI-Driven Adaptive Data Converter System
- Jammer-Resilient Phased Array with Self-Healing Beamforming
- Autonomous Jam-Resilient Cognitive Beamforming SoC

*Patents Pending

Jammer Resilience with High Rx Dynamic Range

- NEXT is demonstrating an unprecedented jammer insensitive wideband transceiver capability using our NX450 SoC
- Proprietary and Patented Digital Linearity Enhancement (DLE) uses efficient DSP algorithms to reduce nonlinear distortion (intermodulation and harmonic distortion)
  - Provides strong spurious free dynamic range (SFDR) even in the presence of large amplitude jamming signals, which would otherwise induce large distortion spurs and obscure low amplitude signals of interest
  - Performance verified in rad hard testing

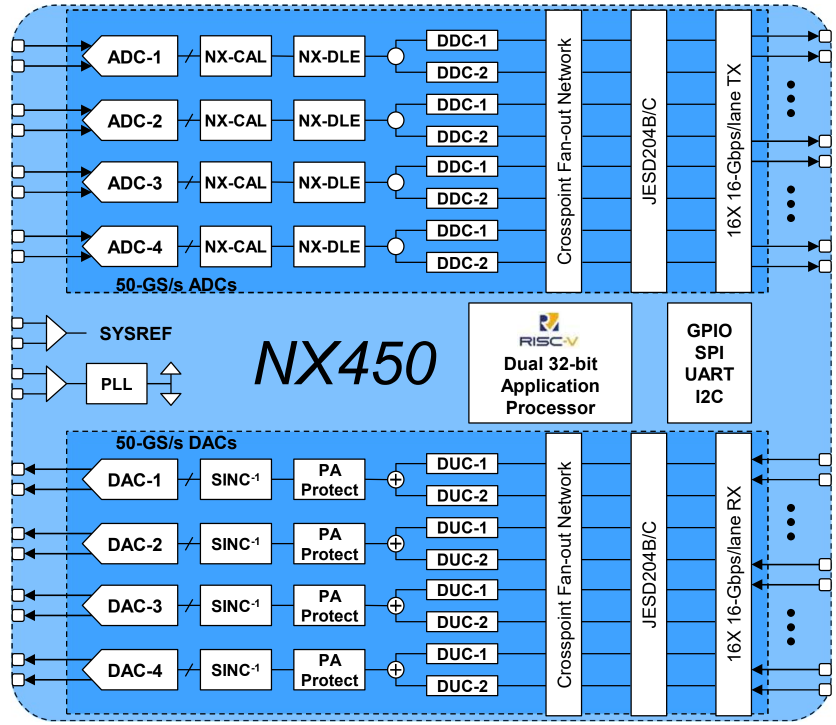


NX450 : 4x50G Antenna Processor Unit

NX450: 4-ch, 50-GS/s Antenna Processor Unit (APU)

- Direct RF-Sampling up to 20-GHz
- In active use, TRL-7
- **Radiation hardened to 20 k-rad**

- Key Features:
  - 20-GHz Full Power Bandwidth (RF bandwidth)
  - 4-channel, 50-Gsps Analog-to-Digital Conversion (ADC)
    - -145 dBFS/Hz Noise Density, 85-dB SNR/MHz
  - 4-channel, 50-Gsps Digital-to-Analog Conversion (DACs)
    - -145 dBFS/Hz Noise Density, 85-dB SNR/MHz
  - 32-lanes 16-Gbps long-reach SerDes
  - Integrated channel selection DDC/DUC
  - Fast frequency hopping capability
  - Embedded, dual 32-bit RISC-V processors
  - 5.5 x 6.0mm die, GlobalFoundries 12LP



FCBGA PACKAGE

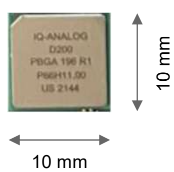
Prototypes available NOW

NX212 : 2x12G Antenna Processor Unit

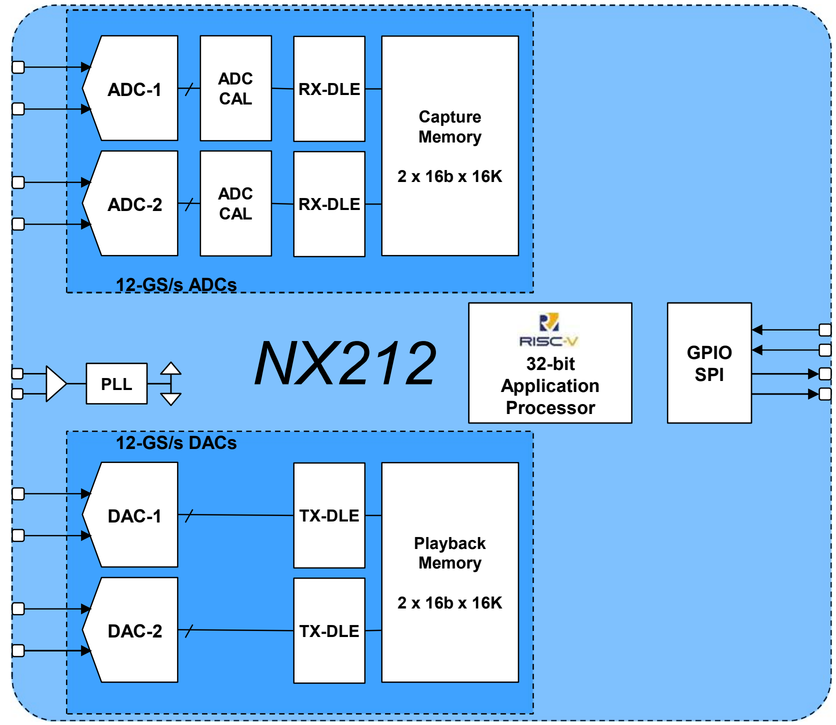
NX212: 2-ch, 12-GS/s Antenna Processor Unit (APU)

- Direct RF-Sampling up to 10-GHz
- Prototype demonstration

- Key Features:
  - 10-GHz Full Power Bandwidth (RF bandwidth)
  - 2-channel, 12-Gsps Analog-to-Digital Conversion (ADC)
    - -155 dBFS/Hz Noise Density, 95-dB SNR/MHz
  - 2-channel, 12-Gsps Digital-to-Analog Conversion (DACs)
    - -155 dBFS/Hz Noise Density, 95-dB SNR/MHz
  - 128k sample depth capture/playback memory
  - 2.5 x 3.0mm die, TSMC 16FFC



BGA PACKAGE



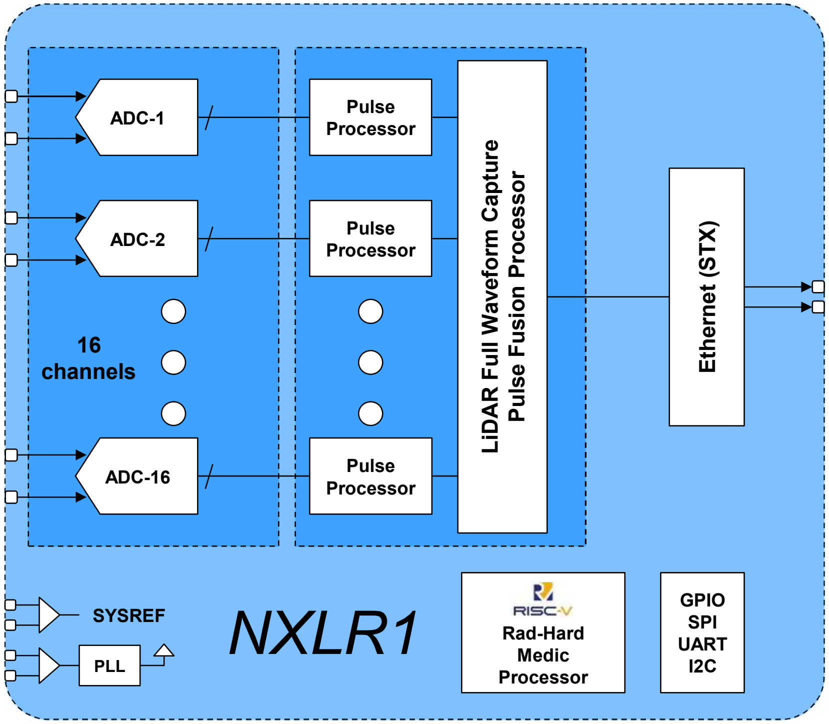
Prototypes available NOW

NXLR1 : LIDAR Processor Unit

16-channel LIDAR Processing Unit (LPU)

- Complete single chip sensor solution
- Interfaces to multi-sensor fusion central AI processor

- Key Features:
  - <5W total power consumption
  - Unique direct sampling analog interfaces to ROIC
  - 16-channel 2-Gsps Analog-to-Digital Conversion (ADC)
  - Embedded low jitter PLL and clock management
  - Embedded pulse and pulse fusion digital processing
  - AEC-Q100 Grade 1



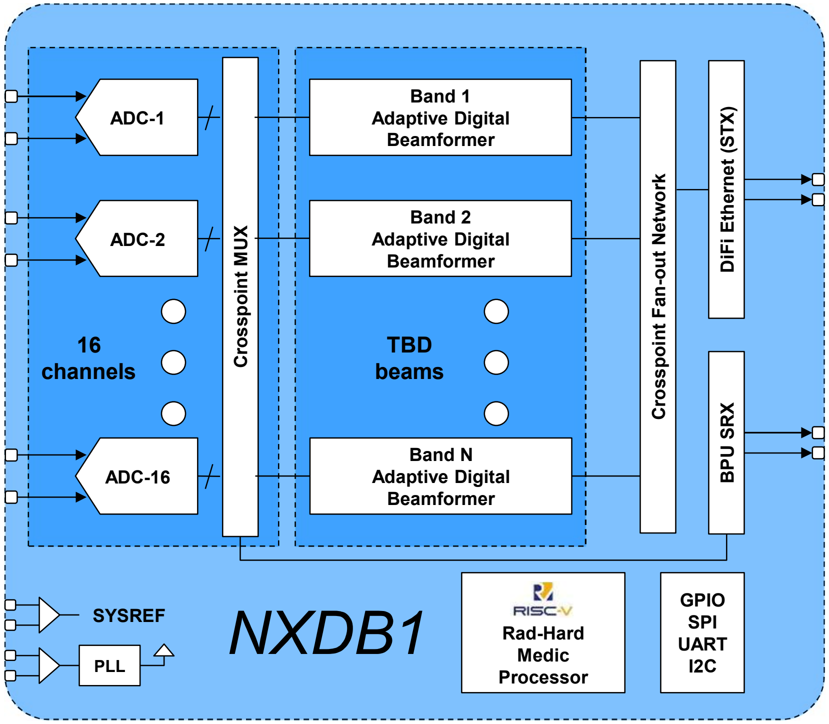
Prototypes available
Q1-26

NXDB1 : Digital Beam Processor

16-channel Beam Processing Unit (BPU)

- Sole source custom ASIC for defense satellite sensor platform

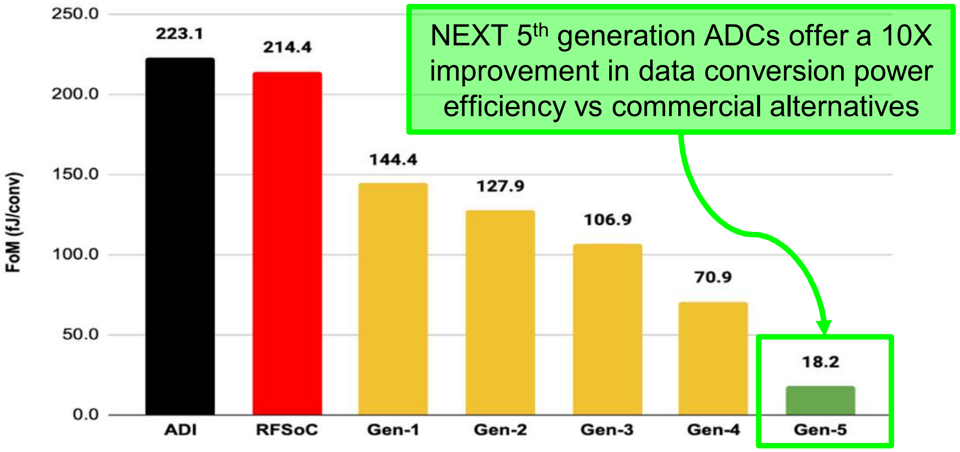
- Key Features:
  - 10-GHz Full Power Bandwidth (RF bandwidth)
  - 16-channel, 4-Gsps Analog-to-Digital Conversion (ADC)
  - TBD independent digital beams with adaptive beamforming
  - Embedded rad-hard RISC-V control processor
  - DIFI Standard Compliant Ethernet backhaul



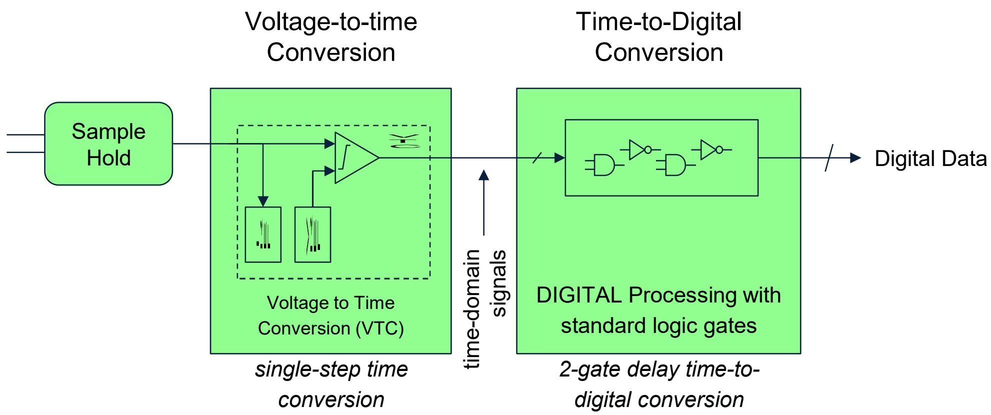
Prototypes available Q4-26

Technology Comparative Analysis

	ADI	RFSoC	NX212
Noise Density (dBFS/Hz)	-151.5	-150.3	**-155.0**
ENOB in 100-MHz	11.6	11.5	**12.2**
SNR in 100-MHz	71	70	**75**
Power (mW)	1300	513	**74**
Figure of Merit (fJ/conv)	223.1	214.4	**18.2**
Noise Figure (dB)	23.5	24.7	**18.0**



NEXT Digital Data Conversion

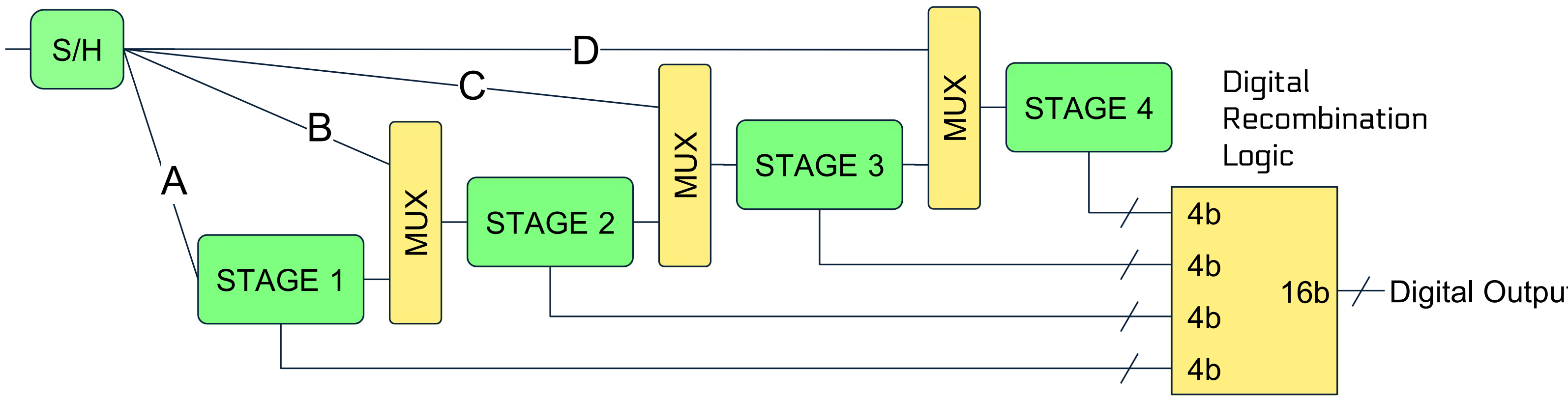


$$I = C*(dV/dT)$$

					NEXT Digital Data Conversion	
		AMD	**ADI**	**Socionext**	**NEXT-1**	**NEXT-2**
Technology	nm	16	16	7	16/12	16/12
Sample Rate	Gsps	4.0	12.0	24.0	12.0	16.0
NSD	dBFS/Hz	-150.3	-151.0	-147.3	-149.0	-153.5
Noise Figure	dB	24.7	24.0	24.6	24.0	19.5
SNR (1-MHz)	dB	90.3	91.0	87.3	89.0	93.5
ENOB (1-MHz)	bits	14.7	14.8	14.2	14.5	15.2
Power/channel	mW	513	850	750	480	490
Area/channel	mm2	1.04	2.64	0.90	0.12	0.18
Power/bit	fJ/conv	**214**	**189**	**181**	**135**	**71**
Area/bit	mm2*fJ/conv	**223**	**499**	**163**	**16**	**13**

- 4X Faster Core
  - 4-Gsps peak core rate vs 1-Gsps for ADI-Apollo and 500-Msps for RFSoC
  - Single-step voltage-to-time conversion, 2-gate delay time-to-digital conversion
- Digital processing of analog signals = “Digital Data Conversion”
- State of the Art Figure of Merit with scaling benefits as manufacturing technology improves

Configurable Data Conversion

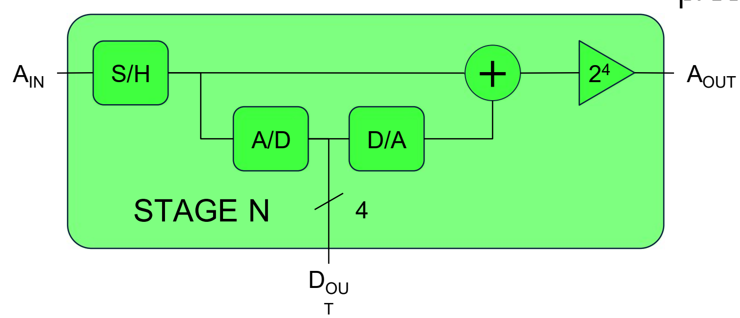


Each core operates at rates up to 1-Gsps and can be configured for 4-bit to 16-bit resolution

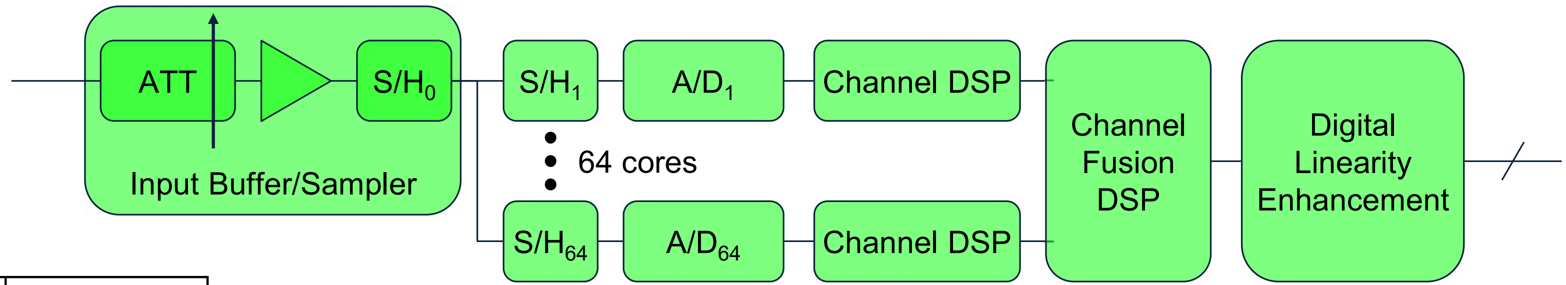
Pipelined 4-bit/stage architecture with bypass muxes

MODE	Stage 1	Stage 2	Stage 3	Stage 4	Final	NSD (dBFS/Hz)	Power/Gsps (mW)
A	4b	4b	4b	4b	16b	-145	15.6
B	-	4b	4b	4b	12b	-142	11.0
C	-	-	4b	4b	8b	-136	5.5
D	-	-	-	4b	4b	-130	2.8

Each core stage processes 4-bits



Configurable Data Conversion Example



Benefit	Averaging	Interleaving
Noise	10*log(N)	10*log(N)
Bandwidth	Fs/2	N*Fs/2
Jitter	none	10*log(N)

Averaging and interleaving both reduce overall noise, while interleaving also increases the sampled bandwidth and reduces the impact of clock jitter

Target Requirements

RF Input Frequency (MHz)	NSD Rqmt (dBFS/Hz)
100	-161
500	-161
1,500	-159
3,000	-158
5,500	-151
10,000	-146
20,000	-146

Optimized Configuration / **Effective Performance**

MODE	Core NSD (dBFS/Hz)	Averaged Cores	Interleaved Cores	Sample Rate (GS/s)	NSD (dBFS/Hz)	Power (mW)
A	-145	16	4	4.0	-163.1	1014
B	-142	4	16	16.0	-160.1	751
C	-136	8	8	8.0	-154.1	365
D	-130	1	64	64.0	-148.1	222

The ADC can be software configured to operate in multiple resolution and sample rate modes.

An optimal set of modes shown here address the specific target requirements with optimal power efficiency

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