BLUE DANUBE™

Blue Danube Systems Active Antenna System for 3D-Beamforming Open-Radio Units (O-RUs)

July 8, 2021

U.S.-based Active Antenna RU Company: Overview

BLUE DANUBE™

Breaktrhough architecture for low-cost phased-arrays

3D-Beamforming Active-Antenna Radio Units and massive MIMO for cellular

Locations

Santa Clara, CA

New Providence, NJ

Funding to Date

$70M

Since 2013

Key Investors

Sequoia Capital
Silver Lake
Northgate
AT&T
In-Q-Tel

US Patents

33

32 Issued & Allowed
1 Pending

Employees

33

9 PhD | 13 MS

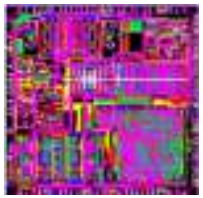
Revenue Markets

Wireless Telecom
Defense/Intelligence
Disaster Recovery
HAPS

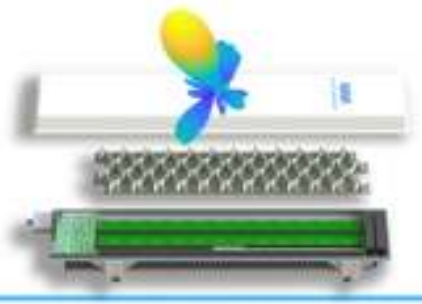
Blue Danube Technology and Product Offering Summary

BLUE DANUBE™

Semiconductor IC & RF Subsystem Design



3D Beamforming Open-Radio Unit (O-RU)



Software (RIC-based Cognitive BF)

Low Cost, Coherent mMIMO

BeamCraft™

Network-wide deployment at low cost

+

Advanced AI/ML Optimization

BeamMaster™

Same HW as baseline, no tower touch

Disruptive Hardware Solution Enables Software Value Capture

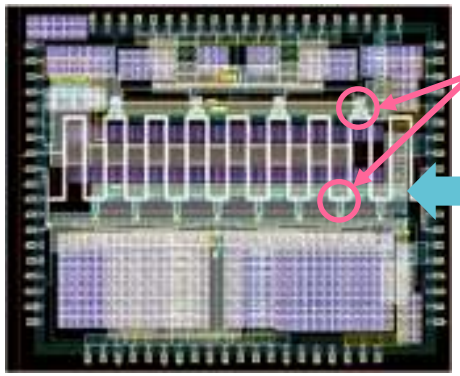
Technology Genesis Via NSF-SBIR Support (2009) for Clock Synchronization

BLUE DANUBE™

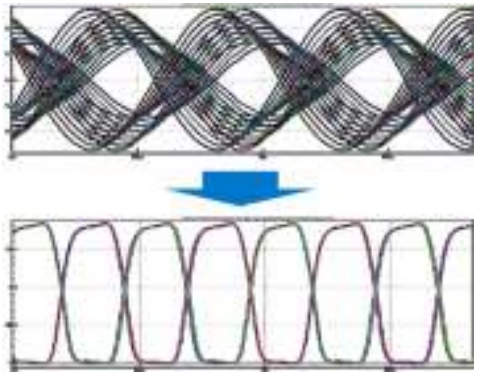
Original Concept | (2006)

GHz Serial Passive Clock Distribution in VLSI Using Bidirectional Signaling

Synchronization Test Chip | (2009)



Actual (Bi-Directional) Signals at Taps



Processed Synchronized Signals

- 2006 breakthrough concept minimized multi-GHz clock skew for application to large VLSI chips
- **Validated in 2009 via 180 nm TSMC CMOS test chip (pre-Series-A, NSF-SBIR funded)**

Bidirectional Signaling Breakthrough Enables:

- First Ultra Low-Cost Phased Arrays
- Better Massive MIMO: Digital & Hybrid
- Blue Danube Coherent Massive MIMO
- O-RAN Beamforming Cat-A/Cat-B O-RUs

Blue Danube BeamCraft™ Product Portfolio

BLUE DANUBE™

1.7-2.6 GHz

96 antenna elements
4 columns x 12 rows

FIRST & FIELD-PROVEN PRODUCT

BeamCraft™ 500/550

Single Active Band
FDD 4T4R
4 Programmable beams
CPRI
1x160W or 1x80W

B1, B2/25, B3, B4/66, B7, B70

+optional passive low band

BeamCraft™ 600/650

Dual Active Band
FDD+FDD/FDD+TDD 2x4T4R
8/16 Programmable 3D beams
CPRI/ORAN Category A and B*
2x80W

B1, B2/25, B3, B4/66, B7, B70
B38, B40, B41

+optional passive low band

BeamCraft™ 700/750

Single Active Band
FDD/TDD 8T8R
8/16 Programmable 3D beams
CPRI/ORAN Category A and B*
1x160W

B1, B2/25, B3, B4/66, B7, B70
B38, B40, B41

+optional passive low band

3.5 GHz

128 antenna elements
8 columns x 8 rows

BeamCraft™ 300 CBRS

Single Active Band
TDD 8T8R / 16T16R
8/16 Programmable 3D beams
CPRI/ORAN Category A and B*
10W

B48 CBRS

PRIMARY 3.5 GHz FOCUS

BeamCraft™ 300

Single Active Band
TDD 8T8R / 16T16R
8/16 Programmable 3D beams
ORAN Category A and B*
200W

B42/B43 N77/N78

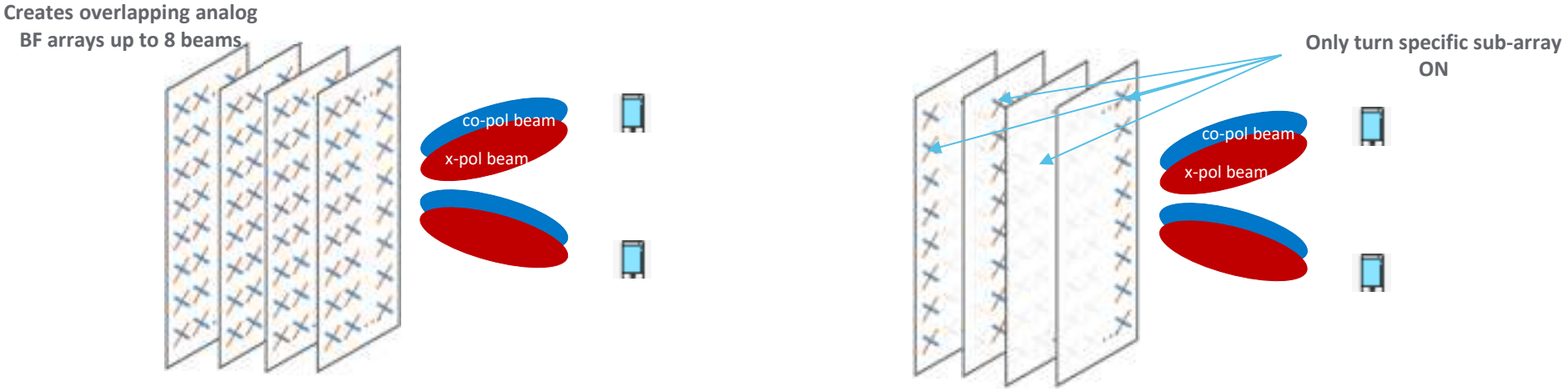
BeamCraft™ 300 FD

Single Active Band
TDD 32T32R / 64T64R
FD-MIMO
ORAN Category B
200W

N77/N78

**SW configurable to support either ORAN Category A or B operation*
Timing & availability depending on customer commitment and partners' product roadmap

Unique Beamforming RU Field Proven for Analog and Digital BF



- Multiple beams with analog beamforming (4 x 2T2R, 2x 4T4R, 2 x 8T8R, 8 CSI-RS beams for 5G-NR)
  - Full-connection or overlapping array model for higher-order sectorization
- Analog + Digital Beamforming (8T8R, 16T16R, 32T32R, 64T64R)
  - Sub-array beamforming for massive MIMO
- Digital Beamforming
  - Unique synchronization and calibration support for future use cases (higher cost)

Multiple Successful Commercial LTE Network Deployments | Summary

BLUE DANUBE™

SHENTEL

Suburban/Rural Virginia (2016-)

BBU NOKIA

Delivered HD streaming over 3+ miles

2.5x Capacity Increase	10x Video Streaming

CONFIDENTIAL

Dense Urban Mexico City (2018)

BBU HUAWEI

Huawei could not provide equivalent solution

2.7x Capacity Increase	2x Volume Increase

CONFIDENTIAL

Providence, RI USA (2020-now)

BBU SAMSUNG

Eliminated need for small cells, closed loop demonstration

2.1x Capacity Increase	1.9X Throughput Increase

CONFIDENTIAL

Dense Urban Mumbai (2019)

BBU SAMSUNG

Extreme traffic load, volume & revenue increase

2.5x Capacity Increase	3x Volume Increase

CONFIDENTIAL

Honolulu, HI USA (2019-now)

BBU ERICSSON

Most challenged OpCo market, avoid new/expensive sites

2.3x Capacity Increase	2 – 3x Signal at Key Sites

CONFIDENTIAL

Extended Metro USA (TBD)

BBU O-RAN

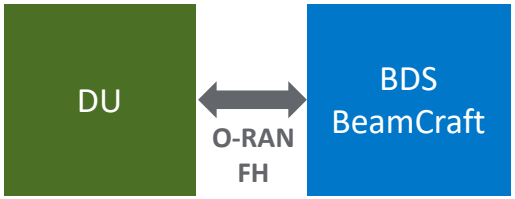
Site minimization and TCO savings for greenfield network

Deployment Flexibility	Accelerated TTM

Current Connectivity to RU for Commercial Evaluation with OEM DU

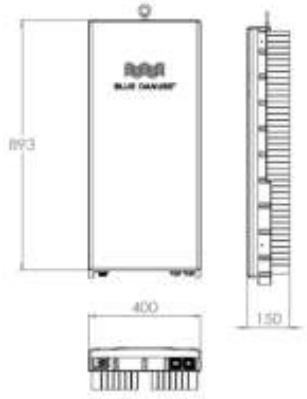
Commercial Evaluation with direct RF connection similar to DAS and Beam control over Local LAN

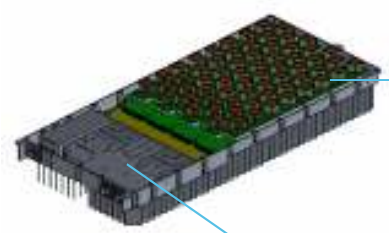
Closed Fronthual Problem



OpenRAN Fronthaul enables Open-Radio Unit interoperability with Open-DU

5G-NR 3.5GHz 8T8R/16T16R Modular Product Design

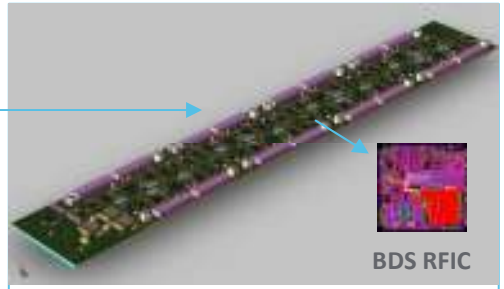




200W UNIT
Volume: 54 L, Weight: 24 KG

Frequency	3-4.2 GHz
TX power	200w (320w†)
DC power	850w (1100w†)
Beamwidth	12° Az, 9° El
Steering	+/-45° Az, +/-7.5° El
Array	8 x 8, dual polarized
Ports	8T8R / 16T16R

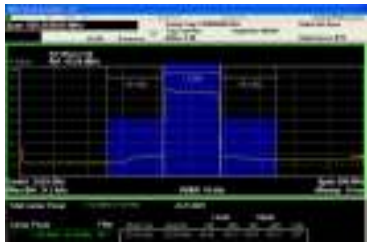
† future 320W variant, 250mm depth



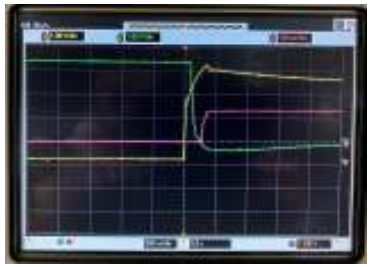
RF FRONT-END MODULE (2x8)

DFE WITH ORAN 7.2 LOW-PHY

Transmitter dynamic range using 3GHz RFIC



TDD waveforms showing ~400ns switching



Small, light form factor with low power consumption supporting O-RAN fronthaul and Category A and B beamforming modes

Enabling Differentiation and Accelerating Open vRAN

BLUE DANUBE™

Blue Danube RF Coherent 3D Beamforming

- 3GPP and ORAN compliant beamforming operation
- Supporting subarrays and full aperture grid of beams
- Beam refinement and optimization through RIC-based beam management

High performance, cost-effective active antenna system for 2 & 3.5 GHz FDD and TDD bands

Simplified implementation of DU software algorithms

Hardware cost synergies for DU/CU differentiation

Unique content enabled by HW independently or in collaboration with DU/CU

Blue Danube RF Coherent Massive MIMO

RAN DU/CU Application

Virtualization and Orchestration (NFVI Layer)

DU/CU Edge x86 HW

BeamMaster Network AI

VNF

VNF

Virtualization and Orchestration (NFVI Layer)

Data Center x86 HW

RIC-based Beam Management

Product & Service Availability Jan-2022

BLUE DANUBE™

BeamCraft™ Open-RU Products

FDD

BeamCraft™ FDD 2GHz

FDD 1.7-2.6GHz
- 96 active antenna elements
- 4T4R/2x4T4R/8T8R

Single and Dual-band
+ passive low band column

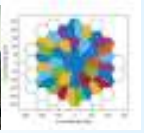
TDD

BeamCraft™ TDD 2/3.5GHz

TDD 2/3-4.2GHz
- Up to 256 active antenna elements
- 4T4R/8T8R/16T16R

Single and Dual-band
+ passive low band column

HAPS & Military

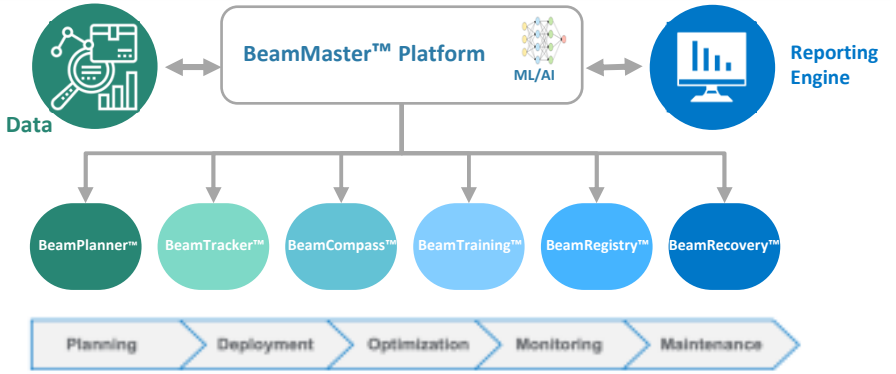


national spectrum consortium

- **HAPS >100 Km LTE Range test validated with BeamCraft RU**
- Integrated x86-BBU/CPRI
- Airship flight targeted for July
- Extensible to 5G over Satellite
- Engaged with NSC and DoD on sensing, DoA and spectrum sharing

BeamMaster™ Suite | Software

- BeamMaster is an RF automation platform that optimizes HDAAS deployments by flexibly customizing 3D Beam patterns for improved coverage, capacity and interference control



BeamPlanner™	Comprehensive RF planning & site selection with interference simulation models
BeamTracker™	Intelligent traffic-sensing software assists in direction finding and hotspot detection
BeamCompass™	Automated site preparation and accurate installation directionality calibration
BeamTraining™	AI-driven sector and network beamforming optimization
BeamRegistry™	KPI Dashboard for monitoring, reporting, and beam inventory
BeamRecovery™	Self-healing network troubleshooting

Unique U.S.-designed and manufactured Active Antenna OpenRAN RU

BLUE DANUBE™

Flexible Solution Meeting Current and Future Operator Requirements

3D-Beamforming 8T8R SU-MIMO Operation

- >3dB higher beamforming gain compared to passive four-column antenna
- Better 5G-NR coverage and higher data throughput

FDD available today
TDD Jan 2022

Capacity Enhancement with 8T8R Grid-of-Beams

- Full aperture beamforming with 3GPP Grid-of-Beams method enables MU-MIMO for increased capacity
- Software upgrade over same O-RU

>4x SU-MIMO Capacity

Technology scalable to higher digitization

- Supports 16T16R mMIMO RU configuration
- Higher digitization to >32T32R based on market demand and performance

16T16R available Jan 2022

Thank You

Confidential