

TitanMIMO-6

Sub 6 GHz Massive MIMO Testbed
PRODUCT SHEET



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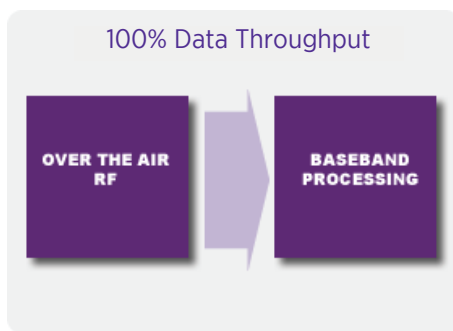
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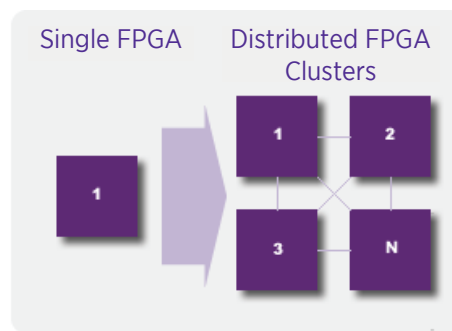
TitanMIMO-6

The only complete testbed that enables real-time, wideband, Massive MIMO research

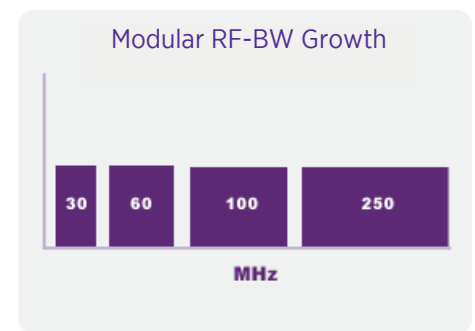
- Turnkey solution includes TDD + FDD capable radio heads with real-time baseband processing
- Up to 56 MHz OTA real-time baseband bandwidth
- Radio tunable up to 6 GHz
- Can support up to 1000 transceivers (or antenna elements)
- Truly scalable & upgradable
- Optional WiFi 5 GHz band antenna matrix
- Includes phase aligned RF clocks and common local oscillators synchronization system



Unrestricted data throughput channel aggregation, required for Massive MIMO baseband processing. Avoid standard backplane bandwidth restriction and undeterministic communication protocol.



Scalable baseband processing through modular approach and user-defined mesh topology. Benefits from the most advanced industry telecom standards (MTCA + ATCA + FMC).



Through the use of standard FMC radio head modules, the testbed is fully upgradable to next generation radio modules including wider bandwidth and tuning range. Radio modules can be replaced with IQ sampler (ADC/DAC) modules to support OTA real-time baseband bandwidth of up to 250 MHz (see TitanMIMO-X Series).

TitanMIMO-6 Solution

TitanMIMO 6 series Massive MIMO testbeds are scalable solutions that can meet any processing and channel count for real-time and very large antenna arrays research.

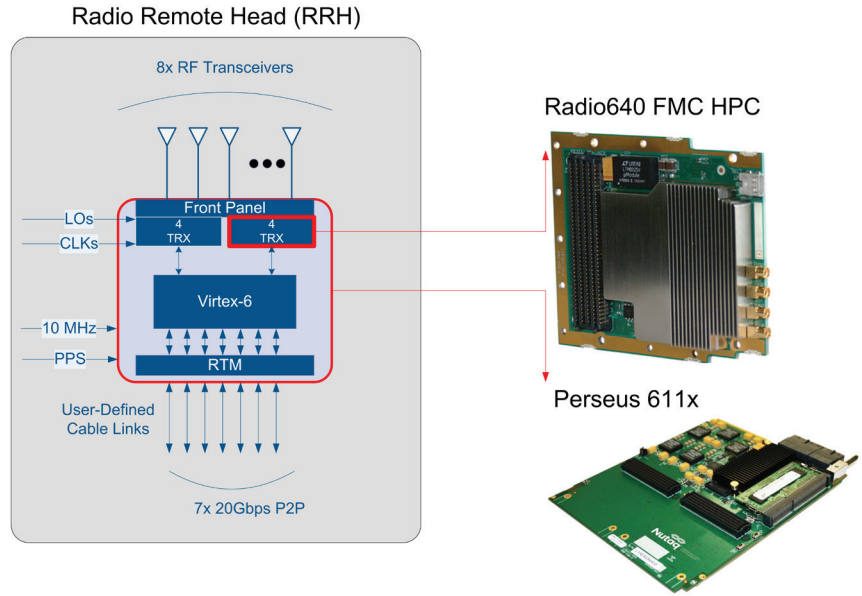
Why Testbed Implementation and Validation:

- Validate various waveform propagation schemes
- Optimize network deployment by balancing cost versus performance
- Validate interoperability scenarios
- Validate, optimize & develop analytic channel models
- Optimize TDD and RF calibration techniques

Testbed Main Components:

RRH (Radio Remote Head)

RRH includes Nutaq's second generation radio FMC module (Radio640x). The core technology of these radios consists of AD9361 agile RF transceiver ICs which provide all synchronization capabilities to implement large antenna system arrays that are accurately phased aligned (common LOs). The RRHs are based on radio carriers (Nutaq's Perseus 611X) that support 8x RF transceivers while providing a wide FPGA for pre/post-processing and 7x user-defined 20 Gbps P2P cable interfaces for channel aggregation or mesh-processing between multiple RRH or to Nutaq's octal Virtex-6 baseband core module (Kermode XV6). This powerful baseband processor unit offers tremendous FPGA processing capabilities (8x Virtex-6) and up to 32x user-defined 20 Gbps P2P cable interfaces for channel aggregation and mesh processing by stacking cards together to scale processing or channel count to very large numbers.

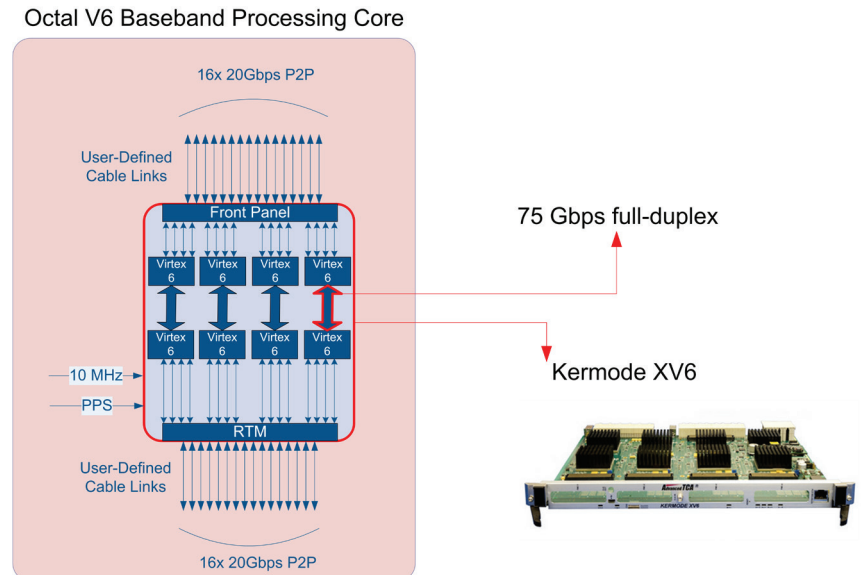


Octal V6 Baseband Core Module

This baseband processing module (Kermode XV6) provides tremendous processing capabilities through its on-board 8x Virtex-6 large FPGA (SX475T). The aggregation of all channels to a common central processing unit without real-time restriction or bandwidth compromise is one of the key features this module can provide. Additionally, each FPGA interfaces with two DDR-3 SDRAM SODIMM modules, capable of supporting up to 4 GBytes, for an aggregate memory capacity of 64 GBytes.

The Kermode-XV6 supports various user-defined interconnection modes with the RRH or between multiple baseband processors through its RTM interface (Rear Transition Module).

- 16x 20 Gbps full-duplex P2P cable connection on the Front Panel (typically interfacing with the RRH)
- 16x 20 Gbps full-duplex P2P cable connection on the RTM side (typically for interconnection between multiple Octal V6 Baseband Core Module)



System Synchronization

Radio Remote Heads (RRH)

Each Nutaq RRH includes two Radio640 FMC double-stack modules, each of which provides four TRX, giving a total of eight TRX per RRH. Each Radio640 has an onboard CLK & LO(s) but can also accept an external CLK/REF input as well as one or two external LO(s) inputs used for TDD or FDD topologies respectively.

In order to synchronise all radios, Nutaq provides uSync CLKs & LOs 19" rackmount modules to accomplish these tasks. The uSync systems are specifically designed to ensure phase coherency between all CLKs as well as all LOs and are even stackable to scale for clocking very large systems

A common time base

On top of synchronising radio heads for beamforming applications, the uSync CLK module allows CLK disciplining to an external reference or embedded GPS.

The user selected reference can then be distributed on all RRH and octal V6 baseband processor cores to ensure precise time-based communication between all FPGAs within the system, through the use of VITA49 communication protocols.

Through the uTCA/ATCA backplane, the PPS and 10 MHz time signals are distributed to ensure a deterministic communication system.

User-defined cabled link topologies



Nutaq RRHs and Octal V6 Baseband Core modules are interconnected using cabled link technology that supports multiple communication topologies and which are user-defined, adaptable and scalable to multiple baseband processing schemes. This provides the TitanMIMO testbed with almost infinite flexibility and reduces risks associated with fixed solutions that can't be adapted and can't scale (see next section model examples).

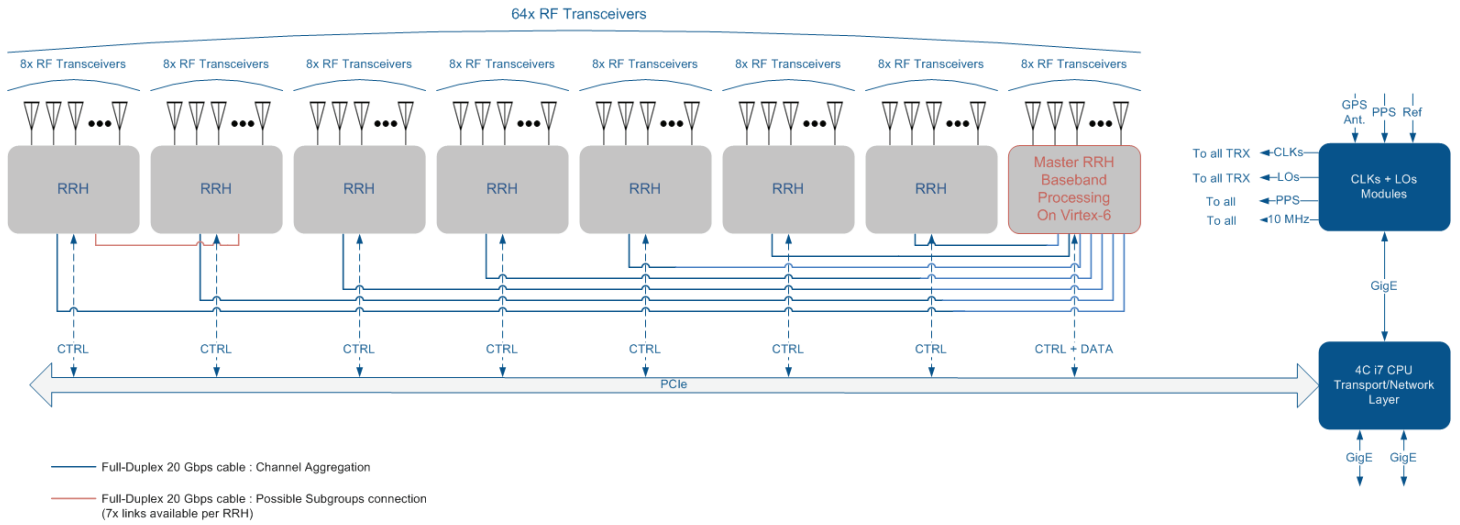
These 20 Gbps full-duplex links per cable are offered over Mini-SAS physical interfaces (Nutaq selected these interfaces due to their small form factor, available high speed rate and low cost compared to existing SFP-type interfaces). Each of the Mini-SAS connection are directly interfaced to 4x Virtex-6 FPGA's full-duplex high speed MGT (Multi-Gigabit Transceiver) interface.

These physical interfaces can support multiple protocol layers. Provided with TitanMIMO development software are high-speed and low-latency Aurora-4x protocol (20 Gbps) full duplex interface supported per cable link. Customers may use these physical interface to support other telecom standard such as CPRI protocol for validating scenarios that are much closer to final deployment scenarios. These Mini-SAS cable links can be offered in either copper or optical versions, allowing the RRHs to be located far from the baseband processing.

To illustrate the enormous throughput capacity and flexibility of the TitanMIMO-6 series, for each RRH, consisting of 8x TRXs, only one of the seven available 20 Gbps links is required to support the entire data rate of the all eight TRXs in sustained real-time operation. This assumes no decimation/upconversion within the RRH's FPGA, i.e. in bypass-mode. The remaining 6x links are therefore available for other interconnection topologies.

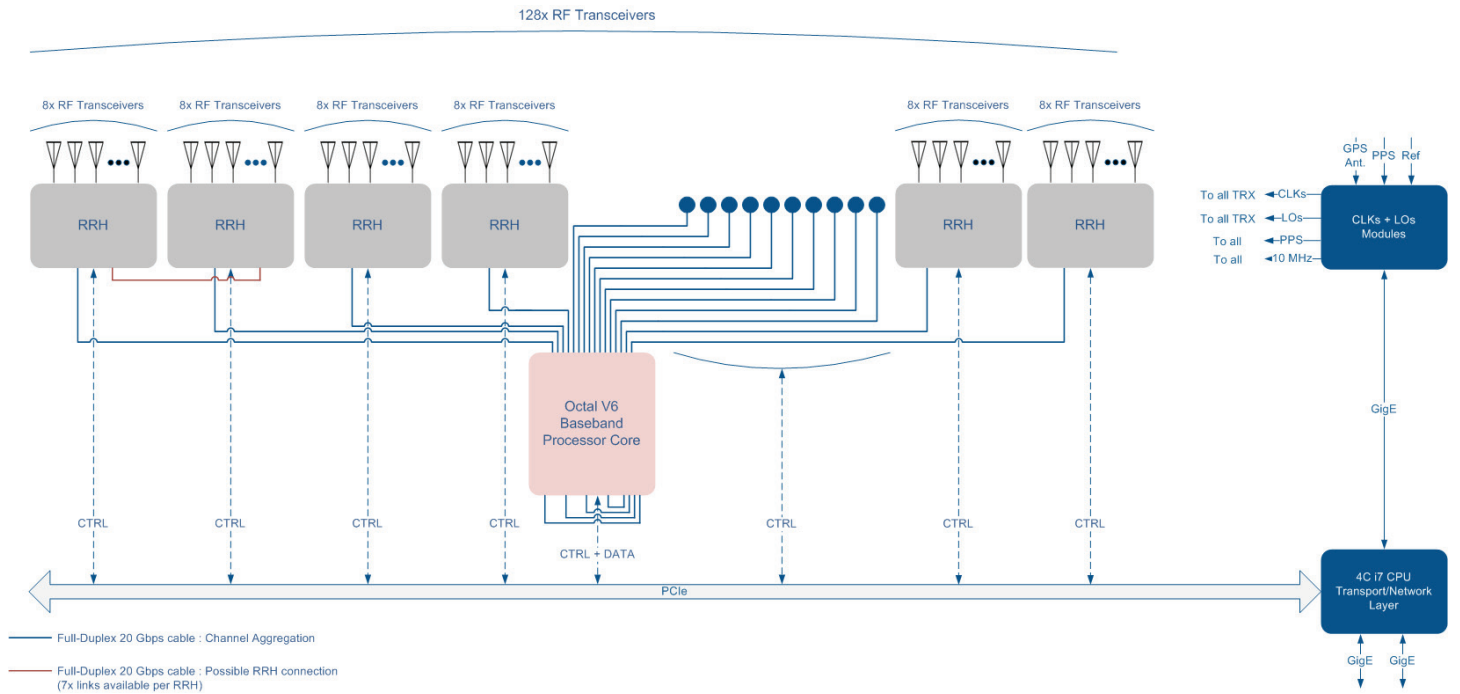
Configuration Examples

TitanMIMO-6S 64 TRX



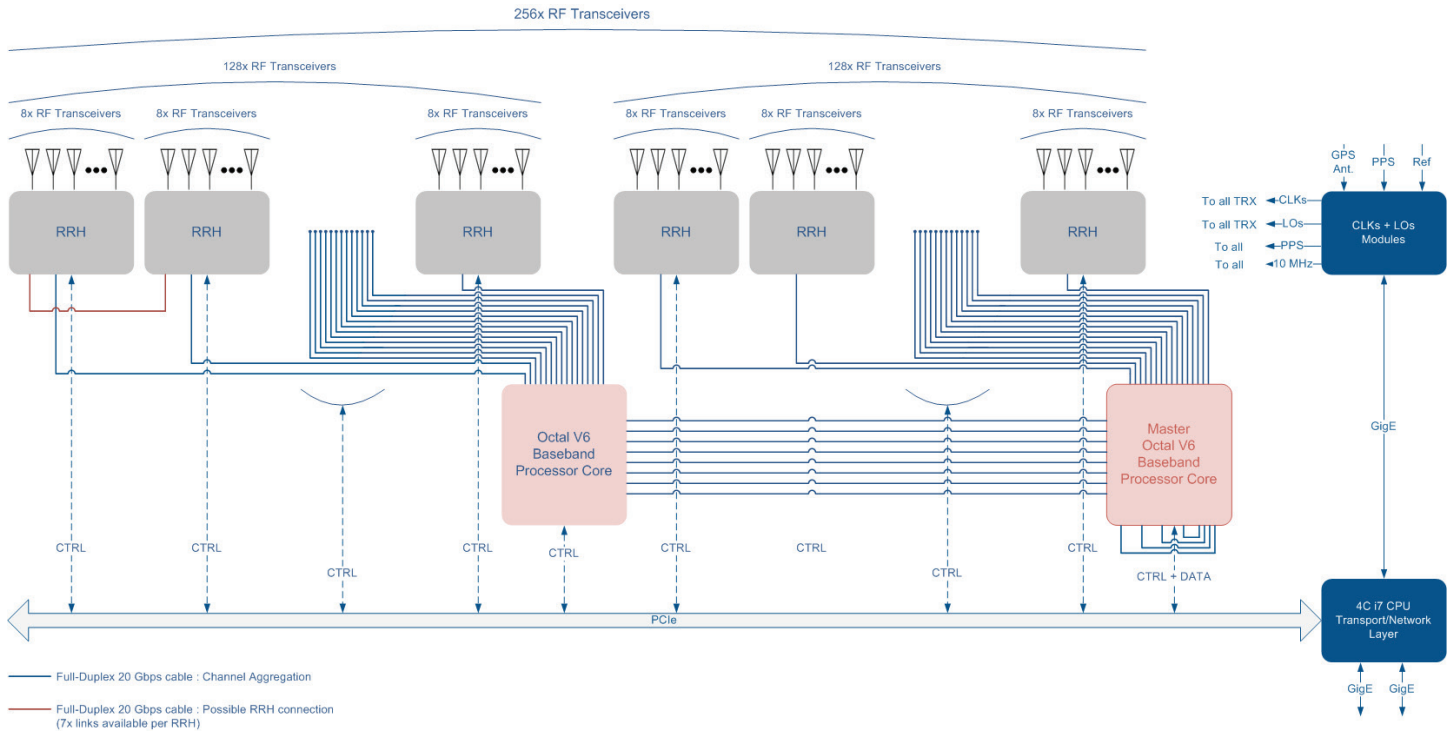
Note: A low cost 64 transceiver testbed built combining 8x RRH and aggregating all channels to a master RRH for baseband processing.

TitanMIMO-6D 128 TRX



Note: A 128 transceiver testbed built combining 16x RRH and aggregating all channels to a master octal V6 baseband processing core.

TitanMIMO-6D 256 TRX



Note: A 256 transceiver testbed built combining 32x RRH and aggregating all channels to 2x octal V6 baseband processing core where a master core does the final aggregation.

Model Comparison Chart

Model	RF Tuning Range	OTA Real-Time BW	# TRX Channels	# RRH Nodes (Perseus 611x)	# Octal V6 Baseband Processor Cores (Kermode XV6)	# Virtex-6 FPGAs
TitanMIMO-6S 64x	0.07 to 6 GHz	Up to 56 MHz	64	8	0 (baseband processing implemented on master RRH)	8
TitanMIMO-6D 64x			64	8	1	16
TitanMIMO-6D 128x			128	16	1	24
TitanMIMO-6D 256x			256	32	2	48
TitanMIMO-6D Nx			User-defined. Up to 1000 TRX channels possible			

Massive MIMO Reference Design

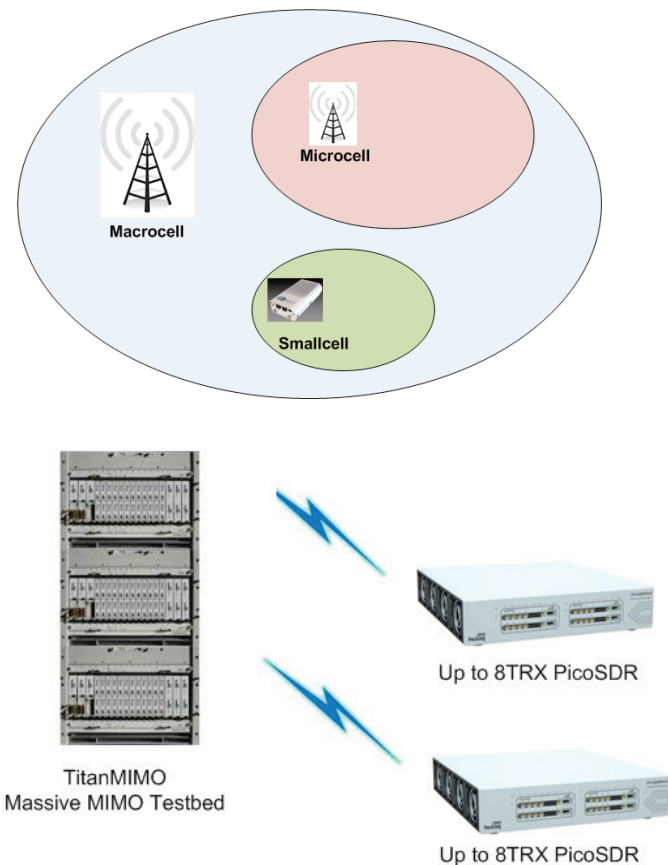
As part of the TitanMIMO-6 system, a reference design is provided which enables developers to rapidly implement Massive MIMO applications without dealing with TRX calibration, data communications issues, data synchronization, using the right set of APIs etc.

The reference design supports the data transfer, aggregation, and control of all radio channels. It also provides the automatic calibration from radio nodes, through to the central baseband processing engine, and back to the radio nodes.

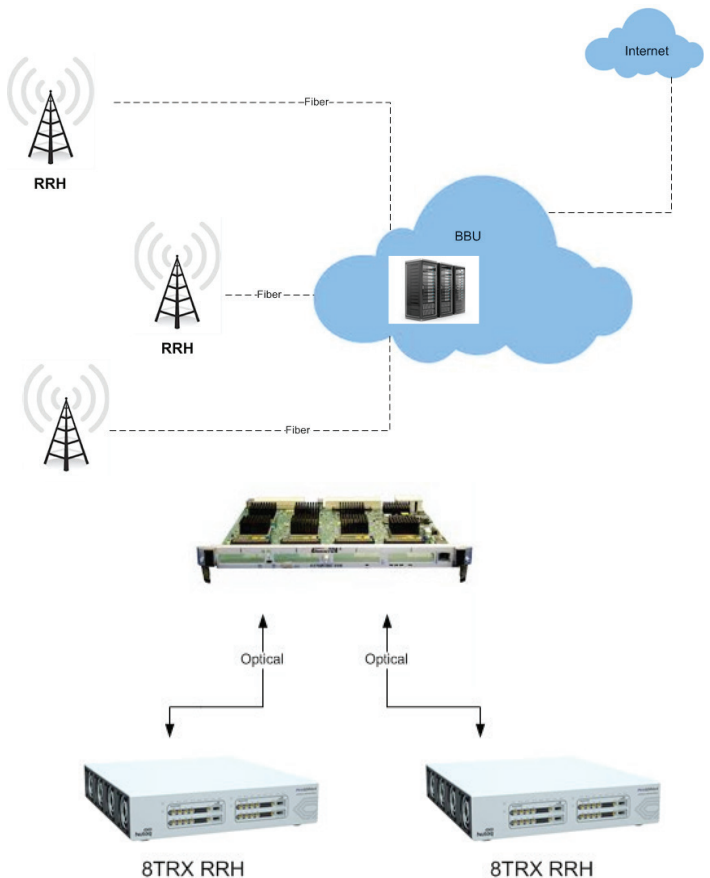
HetNet, MU-MIMO and CRAN Testbed Ready

Nutaq's SDR systems (PicoSDR) can be combined with the TitanMIMO system to build up complete HetNet, MU-MIMO or CRAN testbed solutions involving both BTS and UE, enabling the evaluation of interoperability behavior for various deployment scenarios.

Massive MIMO HetNet testbed



CRAN optional testbed scheme



Record & Playback

Each RRH (8 TRXs) is equipped with a 4 GB SDRAM FPGA memory, which allows for recording of the full signal bandwidth, as shown in the example below:

- Eight RF channels sampled at 122.88 MSPS.
- Each sample has 2 Bytes.
- Therefore 1966.08 MBps throughput are needed to record all 8 TRX at full speed to the SDRAM (8 x 122.88 MSPS x 2 Byte/Sample = 1966.08 MBps).
- Maximum SDRAM throughput: 5700 MBps.

Thus, the record/playback FPGA module provided within each RRH enables record or playback for all channels of the entire Massive MIMO testbed. A maximum of 250 Mega-Samples per channel can be recorded to the SDRAM (4 GB divided by 8 channels divided by 2 Bytes per channel). This translates to a total recording of 2 seconds (or a continuous playback) for all channels of the testbed at full rate (122.88 MSPS). Additionally, synchronous record (or playback) of all channels can be performed through the time based control of each RRH (see synchronization section above).

Record & Playback Operating Modes		
Single Shot	Normal	Continuous
Record: Fill up memory from RF, stop, then download data to PC.	Record: Fill up memory, stop, download data to PC, then re-arm trigger.	Playback: Upload file, playback memory in a continuous loop.
Playback: Upload file, playback from memory to RF	Playback: Upload file, playback from memory to RF	
Record & Playback Trigger Modes		
External	FPGA based	Time-based software
An external trigger for each 4x4 MIMO subsystem is available	The trigger signal can be defined by user logic within the FPGA of each 4x4 MIMO subsystem	The trigger signal can be sent from the central processor unit using time based events

High Speed Real-Time Data Exchange (RTDEx) with embedded CPU (4C i7)

Nutaq RTDEx IP core provides an extensive framework to exchange data with the embedded host device for transport layer implementation through the PCIe or GigE links with the highest bandwidth and lowest latency possible. On both interfaces (FPGA & CPU), DMA engines initiates data transfer at very high

speed through simple API calls, enabling the channel aggregates processed in the last FPGA in the baseband processing chain to send/receive the demodulated data to the embedded CPU at up to 10 Gbps.

HOST - FPGA Streaming	GigE	PCIe 4x (Gen 1)
Data Throughput	1 Gbps	10 Gbps
True Data Throughput (no overhead)	~ 900 Mbps	~ 6.4 Gbps
Roundtrip Latency (4KB, send&receive)	~ 1 msec	~ 200 - 300 μsec

TitanMIMO-6 Specifications

General System Specifications

	TitanMIMO-6S	TitanMIMO-6D
Total # RF Channels (TRX)	Up to 64 TRX	Scalable up to 1000 TRX* (128 TRX per Octal V6 BB Core)
# 8 Channels (TRX) group RRH	Up to 8 RRH	Up to 96 RRH* (16x per Octal V6 BB Core)
RF Tuning Range	0.07 to 6 GHz	
Real-Time OTA RF BW	Up to 56 MHz	
System Throughput at Central Baseband Processing	140 Gbps (Master RRH)	Up to 2 Tbps (320 Gbps per Octal V6 BB Core)
Sustained System Throughput at Central Baseband Processing (w/o overhead)	112 Gbps (Master RRH)	Up to 1.5 Tbps (256 Gbps per Octal V6 BB Core)
Central Baseband Processor Technology	Up to 8x Xilinx Virtex-6 FPGAs	Up to 144x Xilinx Virtex-6 FPGAs (24x per Octal V6 BB Core)*
CPU Master Controller	Intel 4C i7	
Network Remote Interface	2x GigE	
Form Factor	MTCA.4	MTCA.4 + ATCA
System Size	12U Rackmount**	26U Rackmount**
Power, Cooling & Shelf Management	Yes	
Radio Control Interface	PCIe 4x	
RF-to-Baseband Reference Design	Yes	
Record/Playback Tools	Yes	
RF Phase Synchronization Mode	Phase Coherent	
Radio IQ-Imbalance & DC-Offset Calibration	Auto	

*More TRX, RRH and FPGA resources available by combining large baseband processor cards (Kermode XV6)

**Dimensions may differ depending on MTCA/ATCA chassis provided

RRH (Perseus 611x + Radio640x) Specifications

	TitanMIMO-6S	TitanMIMO-6D
FPGA	1x Virtex-6 LX550T/SX475T	
64 bit DDR3 SDRAM SODIMM Memory	4 GB	
RTM (Rear Transition Module)	28 GTX (7x Aurora-4x / Mini-SAS)	
CTRL Interfaces	PCIe-4x or GigE	
Form Factor	AMC Full-Size (MTCA.4)	
# RF Channels (TRX) per RRH	8	
# FMC HPC Site	2	
TRX RF Range	70 - 6000 MHz	
TRX Mode	TDD and FDD	
4 TRX Subgroup On-Board CLK & Sync mode	Onboard 30.72 MHz + LO + PLL	
4 TRX Subgroup External CLK & Sync mode	CLK, PPS, TRIG and LO(s) inputs	
Receiver Baseband Configurable Low-Pass Filter	RF channel bandwidths from 200 KHz to 56 MHz	
Receiver NF	10 dB	
Receiver P1dB (Sub 4 GHz)	-40 dBm	
Receiver P1dB (4 - 6 GHz)	-40 dBm	
Receiver IMD3 (Sub 4 GHz)	-50 dBc	
Receiver IMD3 (4 - 6 GHz)	-40 dBc	
Receiver SFDR	50 dBc	
Receiver Gain Control Range	70 dB	
Transmitter P1dB (Sub 4 GHz)	15 dBm	
Transmitter P1dB (4 - 6 GHz)	10 dBm	
Transmitter Carrier Leakage	-45 dBc	
Transmitter Unwanted SSB Suppression (Sub 4 GHz)	-50 dBc	
Transmitter Unwanted SSB Suppression (4 - 6 GHz)	-45 dBc	
Transmitter IMD3 (Sub 4 GHz)	-50 dBc	
Transmitter IMD3 (4 - 6 GHz)	-45 dBc	
Transmitter 2nd Harmonic	-40 dBc	
Transmitter 3rd Harmonic	-50 dBc	
Gain Control	50 dB	
LTE typical class	Home eNB / Local area eNB	

Octal V6 Baseband Processor Core (Kermode XV6) Specifications

	TitanMIMO-6S	TitanMIMO-6D
FPGA	N/A (Baseband implemented on master RRH)	8x Virtex-6 SX475T
64 bit DDR3 SDRAM SODIMM Memory	N/A (Baseband implemented on master RRH)	32 GB (4 GB per FPGA)
RTM (Rear Transition Module)	N/A (Baseband implemented on master RRH)	64 GTX (16x Aurora-4x / Mini-SAS)
Front Panel (FP)	N/A (Baseband implemented on master RRH)	64 GTX (16x Aurora-4x / Mini-SAS)
# FMC HPC Site	N/A (Baseband implemented on master RRH)	4
CTRL Interfaces	PCIe-4x* or GigE	
Form Factor	N/A (Baseband implemented on master RRH)	ATCA
Maximum Baseband Throughput (FP)	N/A (Baseband implemented on master RRH)	16x 20 Gbps = 320 Gbps
Maximum Expansion Throughput (RTM)**	N/A (Baseband implemented on master RRH)	16x 20 Gbps = 320 Gbps

*60 GTX (15x Aurora-4x / Mini-SAS) at RTM if PCIe-4x interface used

**More TRX, RRH and FPGA resources available by combining large baseband processor cards (Kermode XV6)

CLK & LOs Module Specifications

	TitanMIMO-6S	TitanMIMO-6D
GPS Disciplined Option	Yes	
Phase Coherent CLK to all RRH	Yes (2x per RRH)	
Phase Coherent LOs to all RRH	Yes (2x per RRH TDD, 4x per RRH FDD)	
Reference mode	Onboard / External	

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