X-Band Hybrid Beamforming Phased Array Radar Development Kit

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Agenda

- X Band Dev System Platform
  - Overview
  - Building Blocks
  - Interconnects & Software

- Stingray: ADAR1000EVAL1Z
  - Overview
  - ADAR1000
  - ADTR1107

- XUD1A: ADXUD1AEBZ
  - Overview

- MxFE: EVAL-AD9081
  - Overview

- System Analog Phase Calibration
  - Null Power Method

- Future Work
Flexible X Band Prototyping/Development System

- Snap-On Antenna Board with 10 GHz Lattice Spacing
- Stingray 32-Channel Beamformer Board with T/R Modules and Lattice-Spaced Connectors
- XUD1a Up/Down Conversion Between X Band and C Band
- MxFE Evaluation Board Interfacing to the FPGA Board (ZCU102) and MATLAB

Applications: Phased Array Radar

- Full Signal Chain solution
  - Mix and Match Boards to Optimize
- Platform: Release CY3Q22
- Stingray: Limited Samples Now, release CY2Q22
- XUD1A: Limited Samples Now, release CY2Q22
- MxFE Eval: Released
Acceleration of Customer Design

- Provide customers with a complete beamforming system solution from Antenna to Bits
  - Beam forming ICs
  - Frequency conversion
  - LO generation
  - Amplifiers, attenuators, switches
  - Data converters
  - Power management

- Development kit will achieve TRL4 or TRL5 and accelerate customer design to TRL5 or TRL6
  - TRL4: Component and/or breadboard validation in laboratory environment
  - TRL5: Component and/or breadboard validation in relevant environment
  - TRL6: System/subsystem model or prototype demonstration in a relevant environment (ground or space)

- Form factor and scalability
  - Allow customers to bread board with low investment and risk
  - Provide building blocks for scalability

- Testbed available to customer for software development, beam calibration, test and debug
X-Band System: 32 Element Hybrid Beamforming

- Sub-Arrayed Architecture
  - 32 Elements Analog Domain (Magenta Circles)
    - Analog Phase Shift
    - Amplitude Adjustment
  - 4 Sub-Arrays: Digital Domain (Teal Rectangles)
    - 8 Elements per ADC/DAC
    - Digital Phase Shifters
    - Amplitude Adjustment

Hardware Requirements

<table>
<thead>
<tr>
<th>Component</th>
<th>32x Antennas</th>
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<tbody>
<tr>
<td>Stingray Brd</td>
<td>1x</td>
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<tr>
<td>XUD1a Brd</td>
<td>1x</td>
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<tr>
<td>MxFE Eval Brd</td>
<td>1x</td>
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<tr>
<td>Xilinx ZCU102</td>
<td>1x</td>
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AD9801 Eval Brd
- 4x, 16-bit DACs: 3 GSPS to 12 GSPS
- 4x, 12-bit ADCs: 1.5 GSPS to 4 GSPS

ADUD1a
- 8 – 12 GHz up converter and down converter

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X-Band GPIO Interconnects and Software

- Free and open-source software (FOSS): Linux drivers
  - Linux software drivers for all building blocks of the development kit with MATLAB as the glue that ties all the drivers together into a common software interface
    - This will allow the customer to use the drivers independently with any software platform
    - Provide a complete demo system with Matlab since it is the common language for most customers

- XUD1a has PMOD connectors
  - XUD1a + FMC Breakout + ZCU102

- Stingray has both PMOD and SDP-S
  - Stingray + PMOD + ZCU102
X Band Dev Kit Hardware Overview

- 12 V Power Supply (included w ZCU102)
- ZCU102
- MxFE (Powered from FMC)
- XUD1a
- STINGRAY
- HPC 1 FMC & Ribbon Cable
- FMC & Raiser
- INTERPOSER BOARD
- 1x PMOD Ribbon Cable
- 2x PMOD Ribbon Cable (included w Stingray)
- Ethernet UART JTAG Linux Image
- 8x SMA Male to SMPM Male RF Cables
- 4x SMA Male to SMPM Male RF Cables
- 8x SMA Male to SMPM Male RF Cables
- 4x 1x2 SMA Power Splitter Female-Female (w g Z22PD-04203-4-)
- 32 x SMPM Bullet
- 10 Element (4x4)
- 10 G Hz Antenna Board (2x)
- 8x SMA Male to SMPM Male RF Cables
- XUD PMOD
- FMC Riser
- 12V Supply
- External LIO SMA
- 21 SMA Power Splitters
- 16 GB SD Card with Linux Image
- FMC Ribbon
- 12V Supply
- Stingray PMODs
- Stingray PMODs
- XUD PMOD
- Ethernet
- DisplayPort
- JTAG UART
Stingray
Stingray
X/Ku Band Phased Array RF Prototyping Board

- A 32-Channel Analog Phased Array RF Prototyping board consisting of 8xADAR1000 and 32xADTR1107

- RF
  - RF IN, RF OUT (no frequency translation)
  - Separate RFIO for Each Beamformer IC
  - Lattice Spacing = 590mils/15mm (10 GHz)
  - SMPM Connectors
  - Stand-Alone RF Detector/ADC for Calibration

- Power Management
  - 12V DC Power Input
  - Integrated Power Management and Protective Sequencing

- Control
  - PMOD and SDP Connectors for Programming

- Thermal Management
  - Component-Side Heatsink with Cut-Outs for Access to RF I/O connectors

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ADAR1000: 8-16 GHz, 4-Channel X/Ku Band Beamformer

- Half Duplex Solution for Pulsed Radar
- 360° phase adjustment range, 2.8° phase resolution
- ≥31 dB gain adjustment range, ≤0.5 dB gain resolution
- Memory for 121 pre-stored beam positions
- Adjustable bias modes
- 3 or 4 wire SPI Interface
- Integrated gate bias and control for external Tx/Rx modules
- Four 30 dB power detectors
- Integrated temperature sensor
- Integrated 8-bit ADC for power detectors and temperature sensor
ADTR1107 6-18 GHz 0.3 W T/R Module

- Transmit PA
  - Gain: 22 dB
  - PSAT: 25 dBm
  - Bias: 5V/220 mA

- Receive LNA Gain: 18 dB
  - NF: 2.5 dB
  - PSAT: 16 dBm
  - PINMAX: 20 dBm
  - Bias: 3.3V/80 mA(self biased)

- Directional Coupler
  - Coupling Factor: 18 - 23.5 dB

- Glue-less interfacing with the ADAR1000

- Additional 10W/50W modules currently in design
Building Larger Arrays

3D Rendering of Stacked Boards for Larger Arrays

- Limited to two arrays in vertical stacking
- No limit in horizontal extension
- Power Supplies can be “daisy chained”.
  - Two Boards per power supply.
- Maintain 10 GHz lattice spacing while scaling element count
Stingray OTA Testing

Example Rx Bench Setup

- Single Tx antenna fed from signal generator (CW)
- 4x4 Rx antenna array feeding ½ of the Stingray board (4 ADAR1000s)
- ADAR1000 RF outputs combined using external combiner and fed into on-board RF detector for completely self-contained scalar measurements

No tapering

Hanning taper
XUD1a
**XUD1a**

**X-Band/C-Band Up & Down Converter**

- **A General-Purpose Quad-Channel Up & Down Converter**
- **RF**
  - RF Frequency 8 GHz to 12 GHz
  - SMA Connectors
  - IF Frequency 4.2 GHz to 6.3 GHz
  - SMPM Connectors
  - Four Transmit Channels
  - Four Receive Channels
    - High Gain
    - Low Gain
  - Isolating Cages
- **LO**
  - External LO
  - Internal PLL/VCO: ADF4371
    - 8 GHz to 32 GHz
    - External Reference up to 500 MHz
- **Power Management**
  - 12V DC Power Input
  - Integrated power management
- **Control**
  - PMOD Connector for Programming
  - Compatible Interposer Board with PMOD, SDP, and FMC Connectors for Programming

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MxFE Eval Brd
AD9081: Quad 16B 12GSPS RFDAC and Quad 12B 4GSPS RFADC

- Configurable sampling rate schemes
  - 4, 16-bit DACs: 3 GSPS to 12 GSPS
  - 4, 12-bit ADCs: 1.5 GSPS to 4 GSPS
- RF synthesis and sampling up to 7GHz
- Tx Signal bandwidth support up to 1.6 GHz; N’=12 (4T)
- Signal processing blocks supporting multiband
  - Transmit: 8 DUC paths shared by 4 DACs
  - Receive: 8 DDC paths shared by 4 ADCs; optional 48 tap programmable filter per ADC; or 192 taps total
- Signal monitoring/peak detection for AGC (Rx); PA protection (Tx)
- Timing adjustments for QEC optimization (Rx) and configurable transmit signal placement
- Flexible on-chip PLL for clocking, multi-chip synchronization
- Total Power depends on digital configuration and converter sample rate
  - 8W to 10W typical
- 15x15 324 ball thermally enhanced BGA

*Integrated Hardened DSP on DAC/ADC ICs Improves Wideband Multichannel Systems*

System Phase Calibration
TX: Channel to Channel Analog Phase Alignment

- Analog Phase adjustment using the ADAR1000 Beamforming IC
- Phase calibration obtained using the null power method
  - Establish reference channel (fixed phase)
  - Sweep other channel phase, $\theta$, and find null power
  - Add 180 degrees phase to null power for max power phase
  - Repeat for all channels within a cell
TX: Cell to Cell Analog Phase Alignment

- Analog Phase adjustment using the ADAR1000 Beamforming IC
- Phase calibration obtained using the null power method
  - Establish reference cell (fixed phase)
  - Sweep other cell phase, \( \phi \), and find null power
  - Add 180 degrees phase to null power for max power phase
    - Repeat for all cells
- Reference Channel: Channel 1 of each cell
TX Analog Phase Calibration Data

- Null Power Method Plots
  - Channel to Channel Phase Difference
    - ± 90 degrees
    - Test Cabling Not Calibrated Out
  - Cell to Cell Phase Difference
    - ± 15 degrees
    - Test Cabling Not Calibrated Out

- Phase Alignment Verification
  - Element Power Gain Calculated vs Measured Tightly Coupled
RX Digital Phase Calibration

- AD9081 Programmable NCO Phase Offsets
- Phase Aligned Channels Improves Spurious Free Dynamic Range Performance
RX Digital Amplitude Equalization

- AD9081 Dual-Real 96 Tap Programmable Finite Impulse Response Filters (pFIRs)
- Enables amplitude equalization across desired frequency range

Future Work
Future Work

- MATLAB Toolbox for System Level Control
- Full System Characterization
- Over The Air Testing
  - Anechoic Chamber for Pattern Measurement
  - Potential Collaboration with Multiple Customers
- Refine System Calibration
  - Potential Collaboration with Multiple Customers
More Information
More Information

- X Band Dev Kit Product Page Coming Soon
- X Band Dev Kit Wiki: www.wiki.analog.com/x-band-dev-kit
- Stingray Part Number: ADAR1000EVAL1Z
- XUD1A Part Number: ADXUD1AEBZ
- XUD1A User Guide Wiki: https://wiki.analog.com/resources/eval/user-guides/xud1a
- MxFE Eval Board Part Number: AD9081-FMCA-EBZ
- ADAR1000 Product Page: www.analog.com/ADAR1000
- ADTR1107 Product Page: www.analog.com/ADTR1107
- AD9081/MxFE Product Page: www.analog.com/AD9081
- ADEF System Platforms Engineer Zone: www.ez.analog.com/adef-system-platforms
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THANK YOU