The Future of Digital RFICs

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Engineer, Analog Devices
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@robinlgetz
Seeing the Unseen
https://eventhorizontelescope.org/
Analog Devices
Connecting the Physical and Digital Worlds

Physical World → Power → Digital World

Sense → Measure → Interpret → Connect → Analyze
Communications
LTE Base Station Radio Architecture ~ 2013
Base Station Radio Architecture Evolution ~ 2016

~2013

AD9361
RF Agile Transceiver

~2016

McLaurin et al.,
RFIC 2016

RX Sub-System
(Monolithic)

PA

Antenna Port

LNA

Balun

ADC

Digital Core
Decimation
Prog. IC
DC-Offset
QEC
Tuning
AGC
RSSI

6-12GHz LC PLL

-2

ADC

ARM micro-controller

RX2

RX1

RFIC 2016

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Single Carrier to Full Band

Single-carrier LTE
Modest dynamic range requirements 65nm 2T2R single-carrier ZIF TRX
Single Carrier to Full Band

**Single-carrier LTE**

- Modest dynamic range requirements
- 65nm 2T2R single-carrier ZIF TRX

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**GSM/LTE multi-carrier**

- Need ~ 50dB SFDR improvement for multi-carrier GSM
- ~30dB SNR improvement
- ~ 8X digital content

65nm 2T2R multi-carrier GSM/LTE ZIF TRX
More Antennas to Multi-bands

Massive MIMO

30dB higher dynamic range than single carrier but far more (64 or more) antennas.

Power-efficient PA linearization

Need higher channel density and power optimized

28nm 4T4R ZIF TRX with DPD
More Antennas to Multi-bands

Massive MIMO
30dB higher dynamic range than single carrier but far more (64 or more) antennas.
Power-efficient PA linearization
Need higher channel density and power optimized

28nm 4T4R ZIF TRX with DPD

Multi-band
Similar to multi-carrier but over much wider bandwidth

28nm 4T4R RF converter
Evolution

28nm 4T4R ZIF TRX with DPD

28nm 4T4R RF converter
Digital Enables New System Level Capabilities

Mayer et al., RFIC 2016
Digital Enables New System Level Capabilities

Mayer et al., RFIC 2016

System with Central DPD
Digital Enables New System Level Capabilities

Mayer et al., RFIC 2016

System with Transceiver DPD

Digital Predistortion (DPD) improves PA efficiency:

- 2/3 the FPGA size
- 110W savings per 64T64R system
Recombinant Innovation

- Existing technologies are unique combinations of three elements.
  - The objects are hardware and software.
  - The ideas are an understanding of how to interact with those objects.
  - The people are those who know the ideas and objects. Their experiences give them the tacit knowledge that makes the ideas and objects work effectively together.

- Innovators are no smarter, no more courageous than the rest of us – they are simply better connected. They find ways to exploit the networked landscape. So they are able to innovate continuously by seeing and making connections between people, ideas, and objects from across the broader landscape.
Curiosity Meets Empowerment

“Discover yourself here. Try out different careers and roles. The outpouring of support is empowering.”

Cristina, Field Sales Engineer
Lia, Field Applications Engineer
Sarah, Marketing Engineer
https://careers.analog.com/

- Sales: 11 openings
- Engineering: 136 openings
- Facilities: 1 opening
- Finance: 1 opening
- Human Resources: 1 opening
- Information Systems: 16 openings
- Legal: 1 opening
- Materials/Logistics: 3 openings
- Operations: 11 openings

- United States: 65
- India: 22
- Philippines: 17
- Ireland: 12
- China: 8
- Romania: 5
- Germany: 3
- Great Britain: 1
- Italy: 1
- Japan: 1
- Taiwan: 1
Technologies for Today’s and Tomorrow’s Innovations

- Autonomous Transportation and Machines
- Automotive Electrification
- 5G and Next-Gen Connectivity
- Digital Health
- Industry 4.0 and Smart Energy
- Immersive Consumer Experiences
## Commitment to Innovation

<table>
<thead>
<tr>
<th>Founded</th>
<th>1965</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headquarters</td>
<td>Norwood, MA</td>
</tr>
<tr>
<td>Employees</td>
<td>~15,000</td>
</tr>
<tr>
<td>Countries</td>
<td>20+</td>
</tr>
<tr>
<td>Products</td>
<td>~45,000 SKUs</td>
</tr>
<tr>
<td>Customers</td>
<td>125,000</td>
</tr>
<tr>
<td>Publicly Listed</td>
<td>NASDAQ:ADI</td>
</tr>
<tr>
<td>Design Centers</td>
<td>~45</td>
</tr>
<tr>
<td>Global Manufacturing</td>
<td>U.S. (Massachusetts, California, Washington), Ireland, Philippines</td>
</tr>
</tbody>
</table>

Over 4700 patents and $4 billion R&D investment in the past 10 years.
ADI at GNU Radio Conference 2019
https://www.analog.com/gnu

► Monday
- 11:15-11:45
  - Mega Hertz, Mega Samples, Mega bits, Mega Confusing
- 15:45-16:15
  - Determining Optimized Radio settings for specific waveforms

► Tuesday
- 14:00-14:30
  - The Future of Digital RFICs
- 16:30-17:00
  - Building a radio with ADALM2000 (m2k) and spare parts

► Wednesday
- 10:30-11:00
  - gr-iio: Nuances, Hidden Features, and New Stuff
- 13:30-17:00
  - ADALM-PLUTO Workshop (Discovery Room)
  - Multichannel phase coherent transceiver system with GNU Radio interface

► Thursday
- 11:00-11:30
  - Enabling Precise Timing Control in SDRs
- 13:30-17:00
  - ADALM-PLUTO Workshop (Discovery Room)
GNU Radio Demos

- **ADRV9009-ZU11EG 4 Rx, 4 Tx Phase Coherent System on Module**
  - A complete multi-transceiver system will 4 transmit and 4 receive fully phase aligned will be demonstrated. This is a single system-on-module (SOM) solution, ideal for phased array applications and is even expandable so multiple SOMs can be synchronized together to build large channel count systems.

- **ADALM2000 Ring Oscillator for HF Radio Reception**
  - Powered with GNU Radio and with a few external components, the ADALM-2000 (M2K) can be turned into a direct sampling or direct conversion SDR RF receiver. This demo will introduce a simple LNA, active mixer and PLL frontend circuits for the M2K and show how they can be controlled from the GNU Radio flowgraph.

- **ADALM-PLUTO Fosphor (FFT done inside FPGA)**
  - A hardware-accelerated implementation of everyone’s favorite out-of-tree module gr-fosphor. Inspired by the RFNoC variant, this version has been specifically designed for the ADALM-PLUTO.

- **Enabling AD9361 Fast Frequency Hopping with GR-IIO**
  - Learn how custom IP cores can be created and controlled through the ADI ecosystem leveraging both IIO and GNU Radio, enabling high-speed control over the fast frequency hopping mode of the AD9361 transceiver.
ADRV9009 : Released ~2018

- Dual transmitters
- Dual receivers
- Dual input shared observation receiver
- Maximum receiver bandwidth: 200 MHz
- Maximum tunable transmitter synthesis bandwidth: 450 MHz
- Maximum observation receiver bandwidth: 450 MHz
- Fully integrated fractional-N RF synthesizers
- Fully integrated clock synthesizer
- Multichip phase synchronization for RF LO and baseband
- clocks
- JESD204B datapath interface
- Tuning range (center frequency): 75 MHz to 6000 MHz
Next Generation RFSOM: ADRV9009-ZU11EG

- Dual ADRV9009 + Expandable daughterboard
  - 4T and 4R or 8T and 8R (with daughterboard)
- Xilinx Ultrascale+ ZU11EG
  - 653K logic cells
  - 2,928 DSP slices
- 4 GB DD4 ECC for PS
- 2x 2 GB banks dedicated for PL
- SFP+, QSFP+, USB3, PCIe 3.0 x8
- Available Q1 2019
Analog Devices RF SOM (System on Module)

Production Ready Module, MIL-202 qualified (projected)

ADRV9009-ZU11EG RF SOM : $7999

- Processor
  - Quad Core ARM Cortex A53 (1.5 GHz each)
  - L1 cache : 32 KB Instruction, 32 KB Data
  - L2 cache : 512 KB
- Processor
  - Dual ARM R5 (600 MHz each)
  - L1 cache : 32 KB Instruction, 32 KB Data
  - 128KB Memory per core
- GPU : Mali-400 MP2 up to 667MHz
  - L2 Cache 64KB
- FPGA
  - Kintex Ultrascale+ Fabric
  - 653k Logic Cells
  - 52.7 Mb Block RAM
  - 2,928 DSP Slices
  - Vivado license required
- 2 Banks of 2 Gbyte (x32) DDR4 for PL (Radio)
- 128 Mbyte SPI Flash
- MicroSD Card (lockable)

- ADRV9099 RF Transceiver
  - 245.76 MSPS Rx (200 MHz Bandwidth)
  - 491.52 MSPS Tx (450 MHz Bandwidth)
  - 491.52 MSPS Observer (450 MHz Bandwidth)
  - 128-tap FIR Filters for equalization
  - Multi-chip phase synchronization for RF LO and baseband clocks
  - 75 – 6000 MHz tuning range
  - 2 Rx, 2 Tx, 2 Tx Monitor (per device)

- Power Modules (2x16A, 1x40A)
  - 12V input
- 4 Gbyte DDR4 + ECC for Processors
- 128 Mbyte SPI Flash
- USB 2.0 (OTG Controller + Phy)
- 4 x GTR share among:
  - PCIe® Gen2 x4,
  - 2x USB3.0,
  - SATA 3.1,
  - DisplayPort,
- 4x Tri-mode Gigabit Ethernet
  - 1 x 10/100/1000 Ethernet Phy
- 2xUSB 2.0
  - 1 USB 2.0 Phy
- 2x SD/SDIO
  - 1x MicroSD Card (lockable)
  - 2x UART,
  - 2x CAN 2.0B,
  - 2x I2C,
  - 2x SPI,
- 4x 32b GPIO
  - 24 x GTH (12.5 Gb/s)
  - 2x 100G Ethernet MAC/PCS w/RS-FEC
  - PCI Express® Gen 3 (x16)
  - External JESD204B ADRV9009 Devices

- Full Linux based reference design
- Fully integrated and tested system
- Common connector: HPC FMC
- Digital I/O pins:
  - U.FL connectors : 15
Multi-SOM Sync
scalable up to 8 cards x 8 channels = 64 Rx, 64 Tx
Size comparison
To Scale (as good as you can get in powerpoint)

<table>
<thead>
<tr>
<th>Size Comparison</th>
<th>51 x 30 mm</th>
<th>100 x 62 mm</th>
<th>109.14 x 69.55 mm</th>
<th>150 x 94 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>15.3 cm²</td>
<td>62 cm²</td>
<td>75.9 cm²</td>
<td>141 cm²</td>
</tr>
</tbody>
</table>

ADALM-PLUTO
ADRV9009-ZU11EG
ADRV9364-Z7020
ADRV9361-Z7035
Epiq Solutions
Sidekiq Z2
Sensing Technology Landscape (ADI have solutions in these areas)

**RANGE/DISTANCE**

**SPECS**

- **24GHz Chipset**
  - FOV 120 degree
  - Accurate at long range
  - 60cm @ 150 M
  - Works well in Harsh Environment
  - Scalable Designs

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**POS/NEG**

- **Lidar 16 Point TIA**
  - 16 Pixel Image
  - Narrow FOV
  - Accurate over longer ranges
  - 5cm at 40M
  - Ambient Light Rejection
  - Interference Cancellation
  - Sensitive to Outdoor Environment

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**APPS**

- **Road-Railway Sensors**
  - Intelligent Lighting
  - Building Security – Occupancy Detection
  - Surveillance – IP Network Camera

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- **LIDAR**
  - CCD Sensor, VGA Depth Image
  - Wide FOV
  - Accurate at short Ranges
  - 5cm at 5M
  - Frame Rate 10-60Hz
  - 3D Scanning
  - Navigation
  - People Counting
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- **RADAR**
  - Wide FOV
  - Accurate at short Ranges
  - 5cm at 5M
  - Frame Rate 10-60Hz
  - 3D Scanning
  - Navigation
  - People Counting
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- Good up to 7 GHz
- SMA input connector
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- SMA input connector
- Visit analog.com/DC2870A-KIT

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- SMA input connector
- Visit analog.com/EVAL-AD8302-ARZ

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- SMA input connector
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  - Circuit I & II Lab Activities
  - Electronics I & II
  - Electronics I & II Lab Activities
  - Online Teaching Materials
  - Virtual Classroom - Questions and support for courseware and modules.

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Communications exercises and text
Power electronics
Fast prototyping

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