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Building mmWave Communication and Sensing Systems: Moore Than Chips

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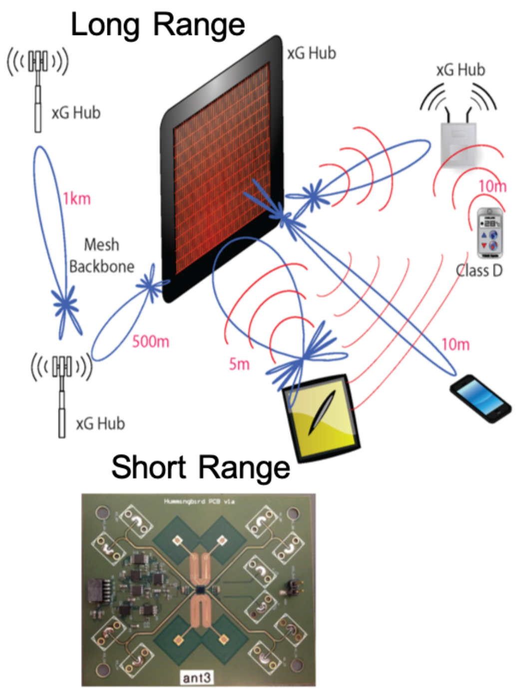
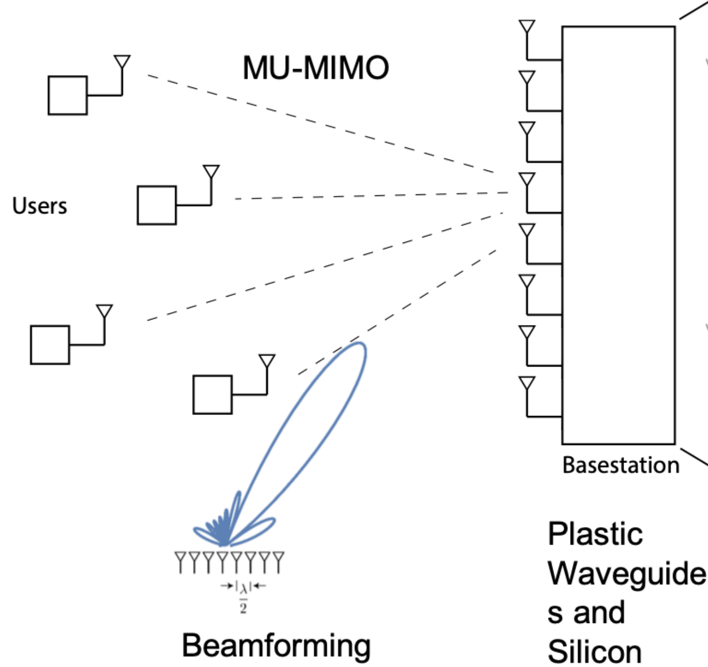
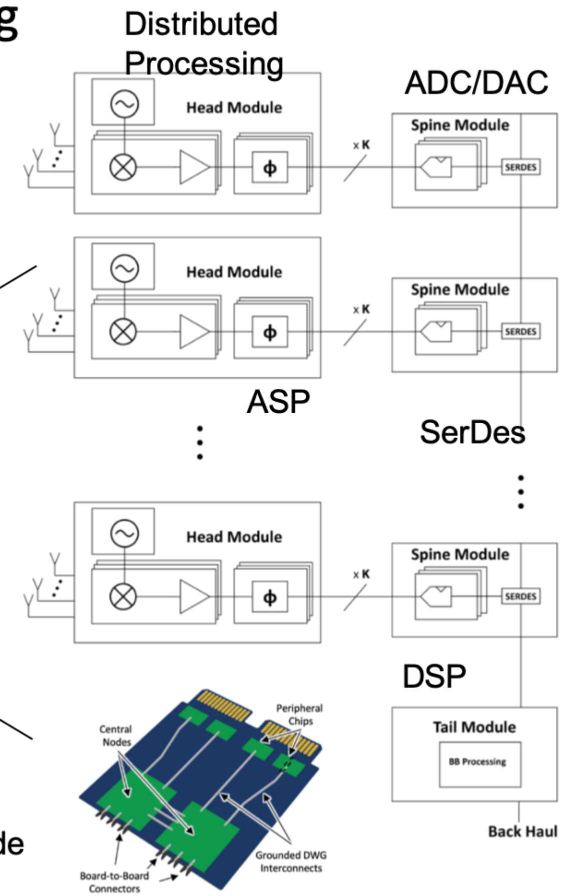
The Big Picture

- Basestation MU-MIMO ←→ Handset with Beamforming
- Applications: Sensing, Imaging, and Comm
- Short range (~cm) links to long range (~km)







Plastic Waveguides and Silicon Photonics

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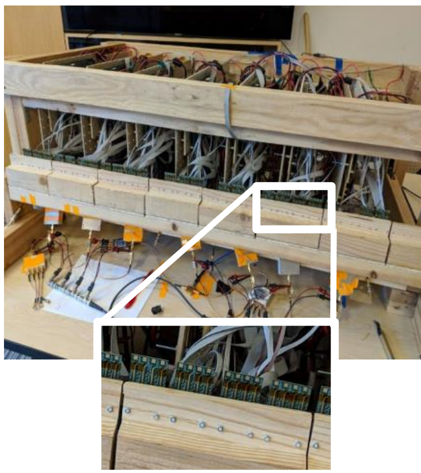
Berkeley Projects

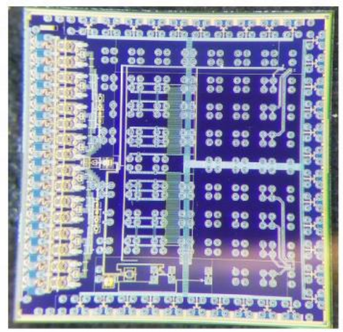
- **Hydra** – E-Band mm-Wave Massive MIMO
- **Hummingbird** –100 Gbps @120 GHz
- **Berkeley MIDAS** – Mining Digital mm-Wave MIMO
- **ComSenTer** – MU-MIMO > 100 GHz
- **All of these projects are leveraging early NSF funding**

Hydra Development Steps

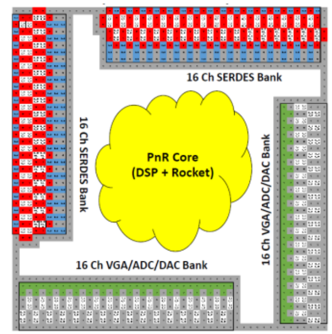
E-Band COTS demonstrator



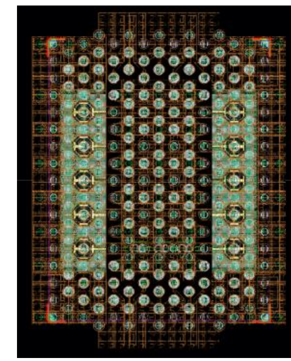
Plug in
E-band “head” radio ASIC



Plug in
baseband “spine” ASIC



Plug in
140GHz radio ASIC



2018 | 2019 | 2020

Leveraged NSF Funding

ComSenTer Funding

DARPA Craft Funding

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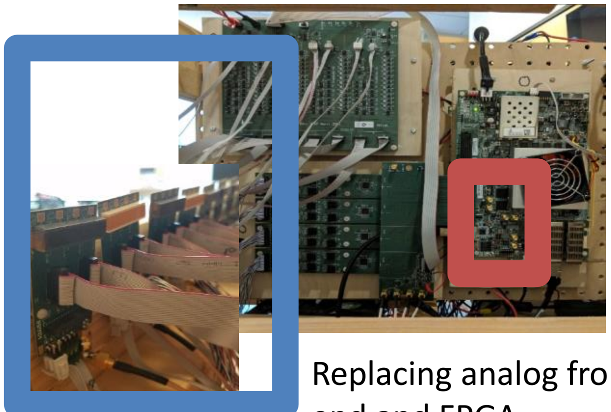
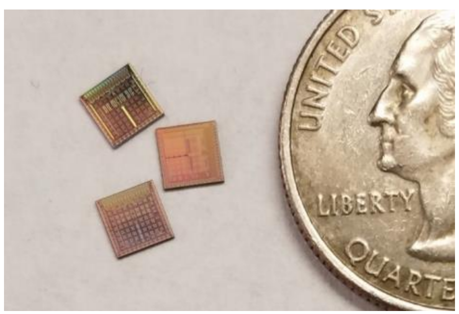
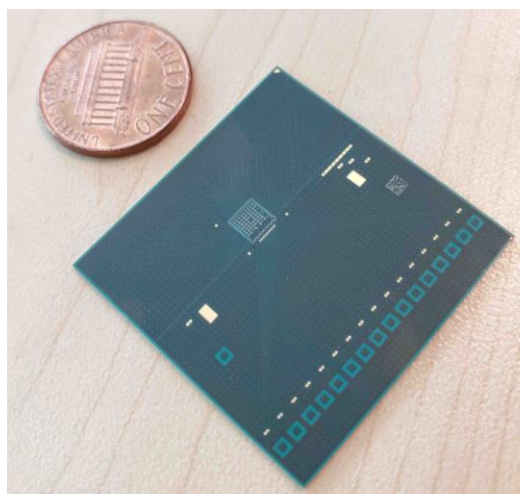
10X Power Savings with ASICs



Replacing analog front end and FPGA beamformer processing





Hydra Head ASIC Simulated Power Budget

	TOT PDC	**PDC/USER**
RX front-end	190 mW	12 mW
LO gen+distr	210 mW	13 mW
BB beamformer	600 mW	37 mW
BB output buff	500 mW	30 mW
TOT	**1.5 W**	**92 mW**

Power Consumption:

16 W → 1.5 W

>10x power reduction

Signal BW:

250 MHz → 2 GHz

x8 bandwidth increase

HUMMINGBIRD – 100 Gb/s @ 120 GHz

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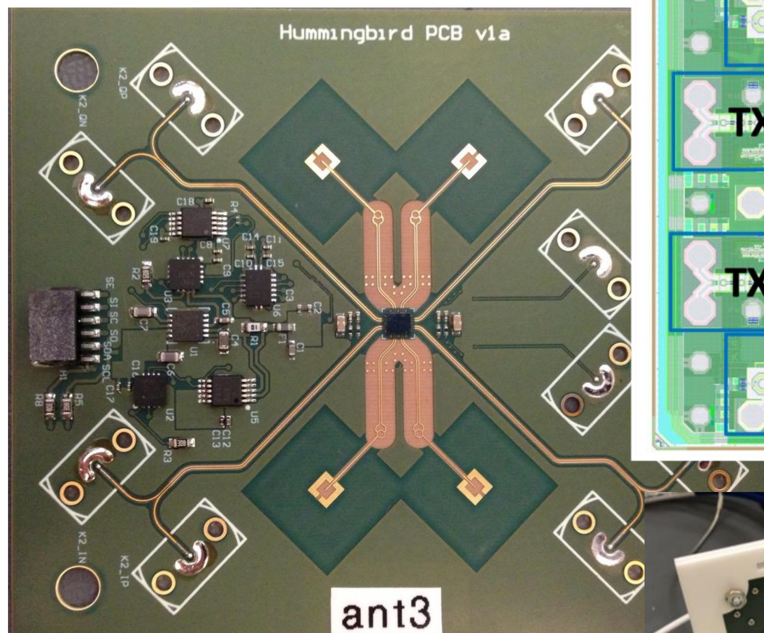
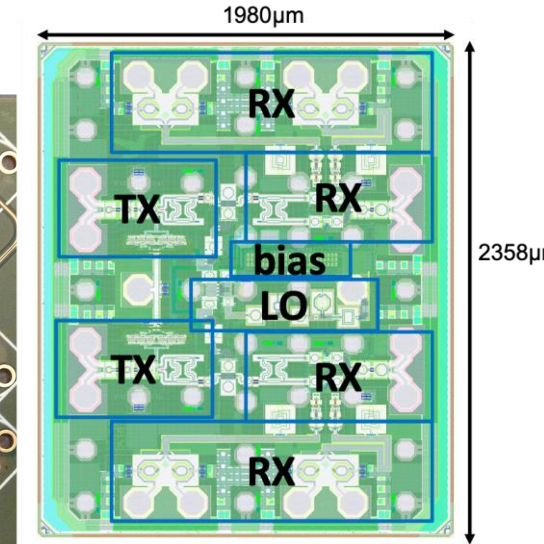
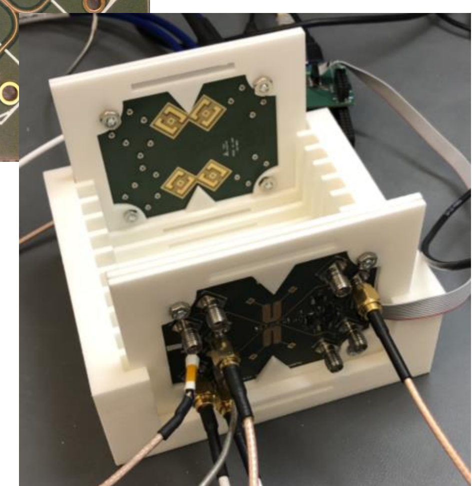
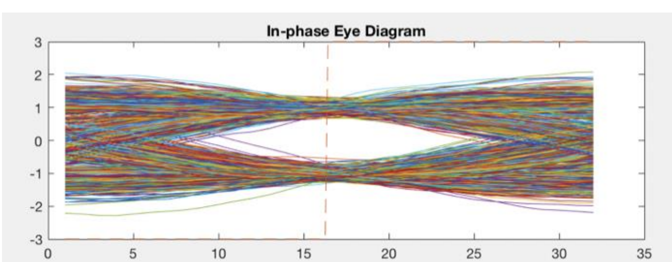
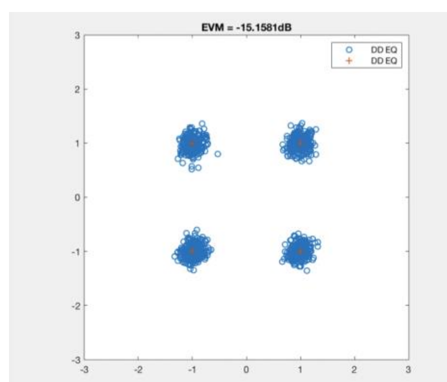
- RX only: 297mW/chip @ 50Gb/s/channel
- TX only: 271mW/chip
- **Full link: *5.7pJ/bit*** @ 100Gb/s dual-channel
- Measurement: 40Gbps @ 6cm distance
    - BER < 1E-3
    - EVM = -15.2dB
- Expect to double this rate with dual polarization
- Will be testing 16-QAM and possibly 64-QAM modes this summer





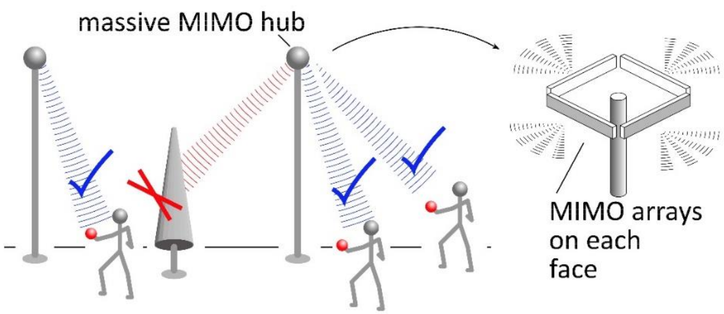


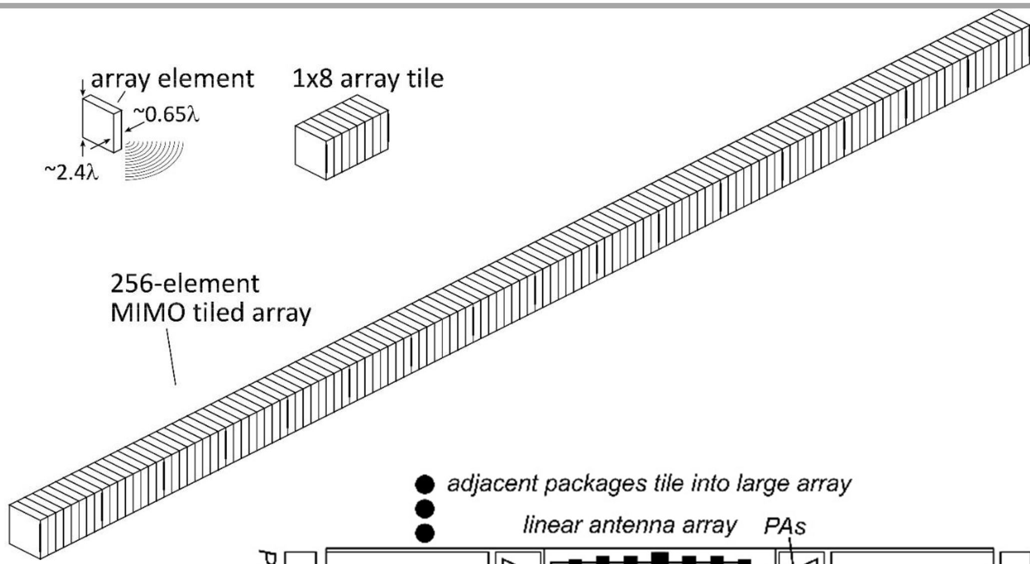


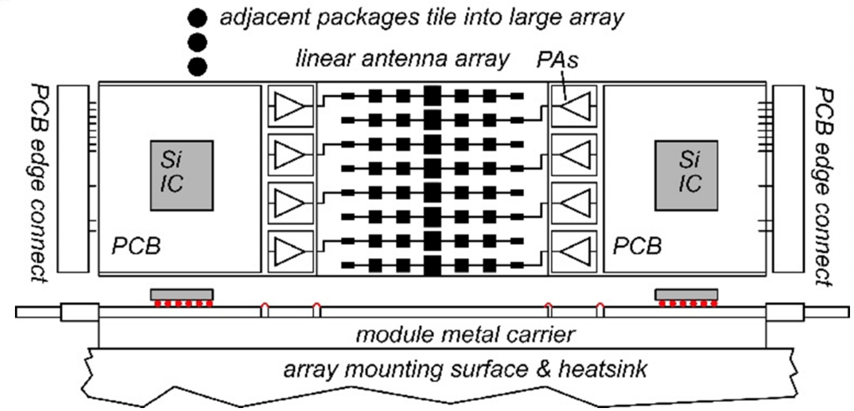


NSF Funded Research

MU-MIMO Demo at 140 GHz



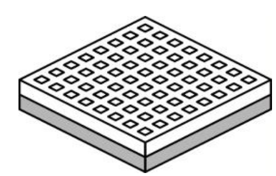




Collaboration between Berkeley, UCSB (Rodwell/Buckwalter), and UCSD (Rebeiz)

1 Tb/s spatially-multiplexed 140GHz base station

- 128 users/face, 4 faces. 16 dB_m PAs, F=3dB LNAs
- 1024 total users @ 1 user/beam, 1,10 Gb/s/beam;
- 225, 100 m range in 50mm/hr rain with 20dB total margins



Handset:
8 × 8 array
(9×9mm)

Why (More) Research is Needed

- Today's 5G systems are expensive, bulky, and power hungry
  - → Densification requires smaller form factor, compatibility with Solar, wireless backhaul
  - → Fully connected arrays allow higher spatial multiplexing with pencil sharp beams reducing form factor (compare with multi-panel solutions today)
- Packaging and testing mm-wave systems is very difficult and can dominate costs (silicon IC front-ends a "solved" problem … not really !)
- ADCs/DACs improving everyday but moving data around very expensive. Need to rethink architectures for signal processing

Explosion in mm-Wave and Challenges

- Need front-end IC's that are more general purpose in terms of frequency of operation, bandwidth, and architecture
  - 5G bands from 24 GHz all the way to 90 GHz
  - Operation above 100 GHz a new opportunity and presents even greater challenges
- Beam search, acquisition, and tracking not a solved problem
- The most expensive real-estate is the PCB in your phone. Can't squeeze more antenna arrays for new bands / applications
  - Need to combine applications (sensing, radar, comm) and address antenna problem