



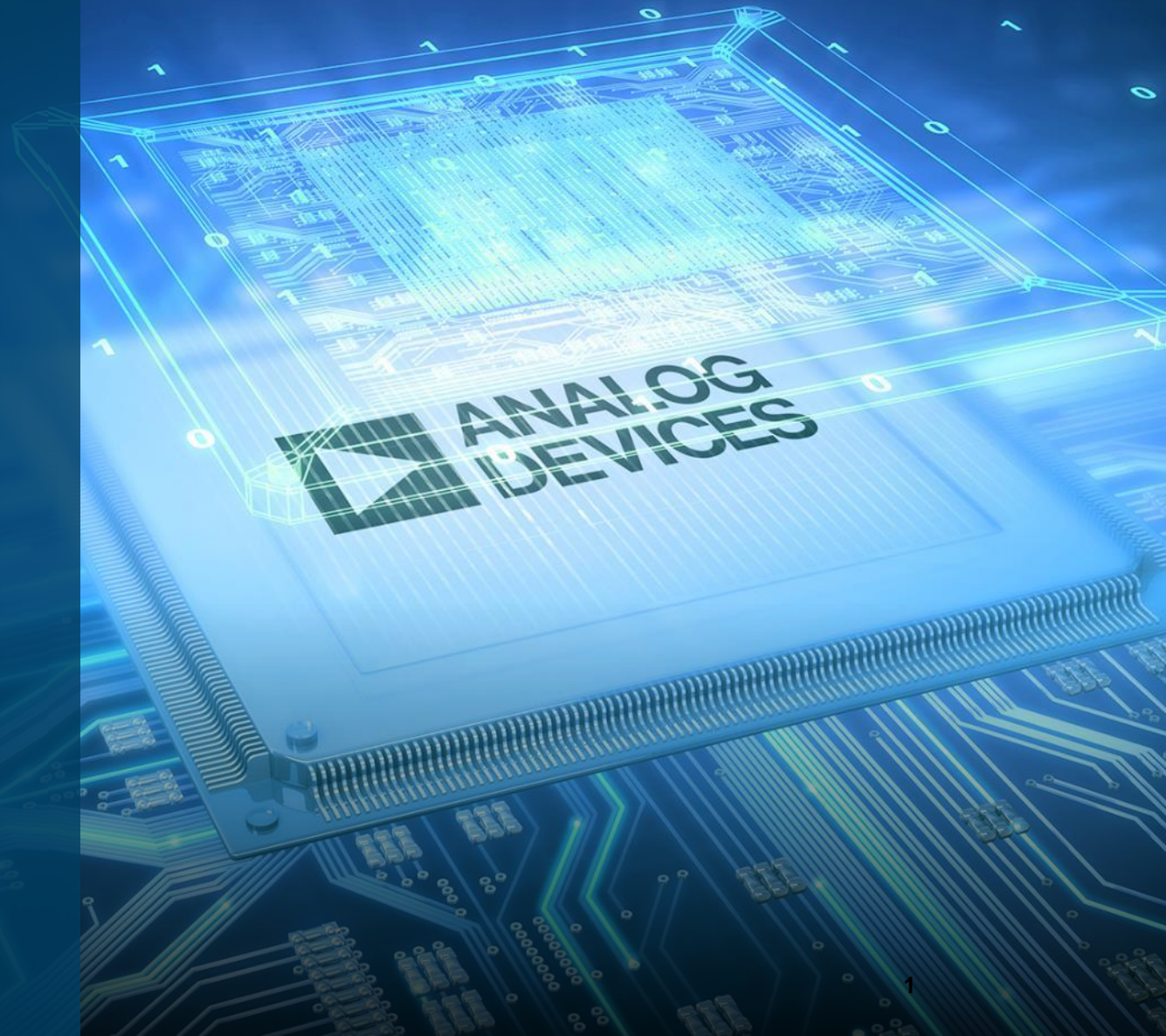
AHEAD OF WHAT'S POSSIBLE™

RF Technology for 5G mmWave Radios

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Director of Wireless Technology

09/27/2018



Agenda

- ▶ **Brief 5G overview**
- ▶ **mmWave Deployment**
 - Path Loss
 - Typical Link Budget
- ▶ **Beamforming architectures**
 - Analog
 - Hybrid
 - Digital
- ▶ **Bits-to-mmWave radio**
- ▶ **Q&A**

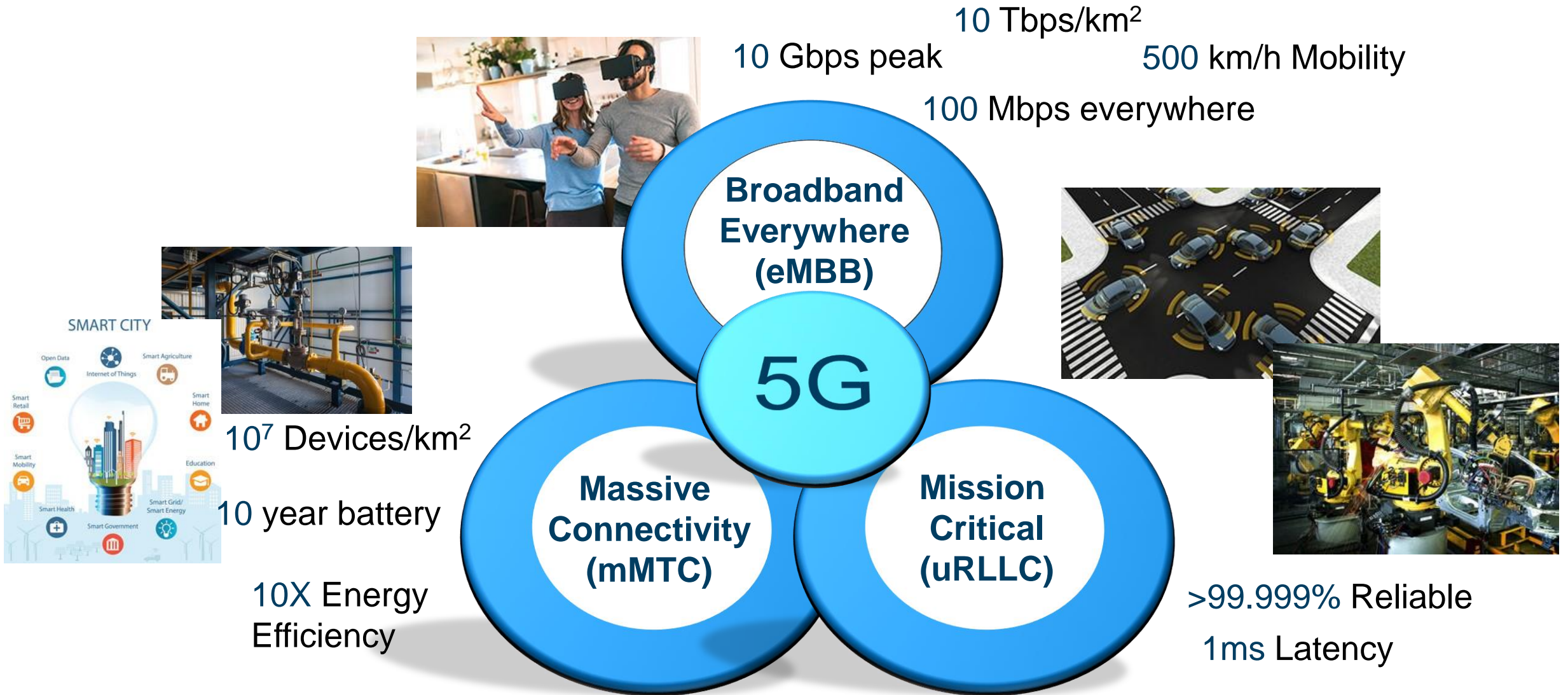
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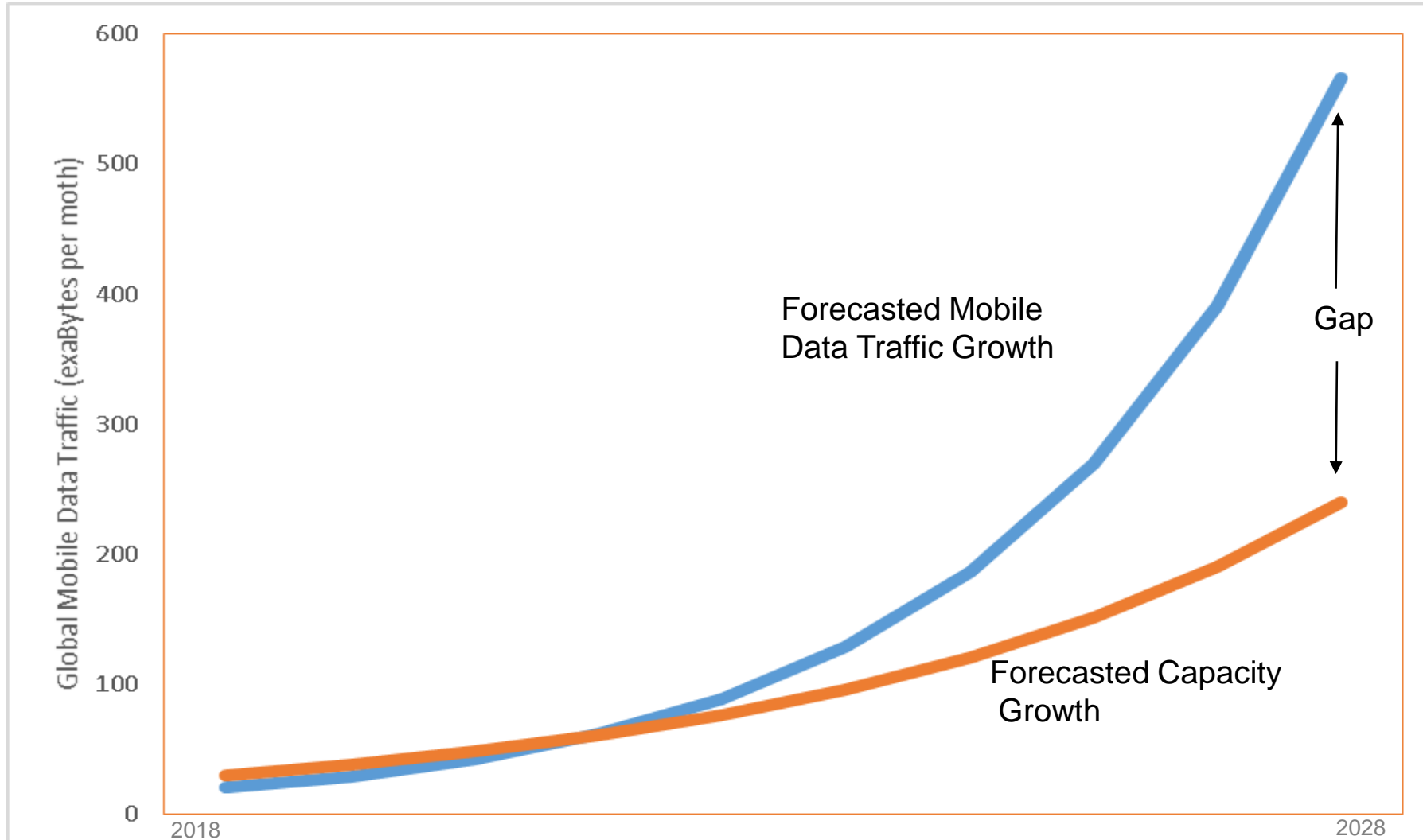
“Ericsson Mobility Report June 2018”



5G: A Flexible Network for the Future



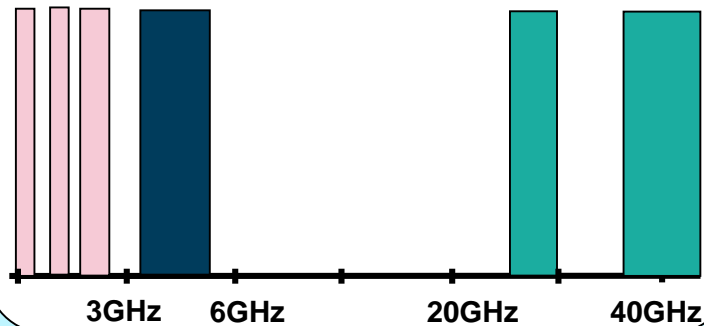
Global Mobile Data Growth Continueswith no end in sight



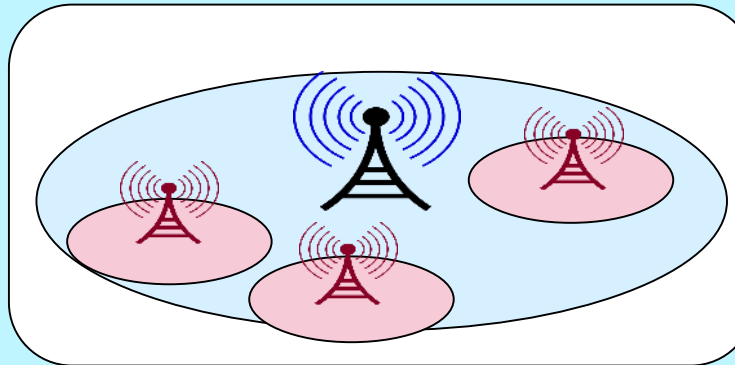
$$\text{Capacity (b/s/area)} = B \times N \times \eta$$

B = available bandwidth N = number of cells/area η = spectral efficiency

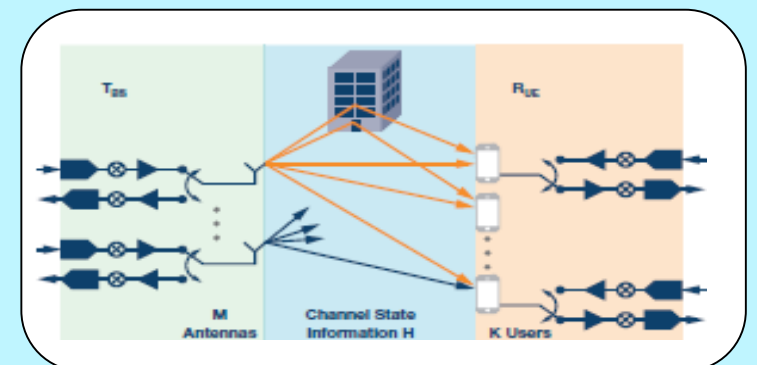
C-band + mmWave



Small Cells

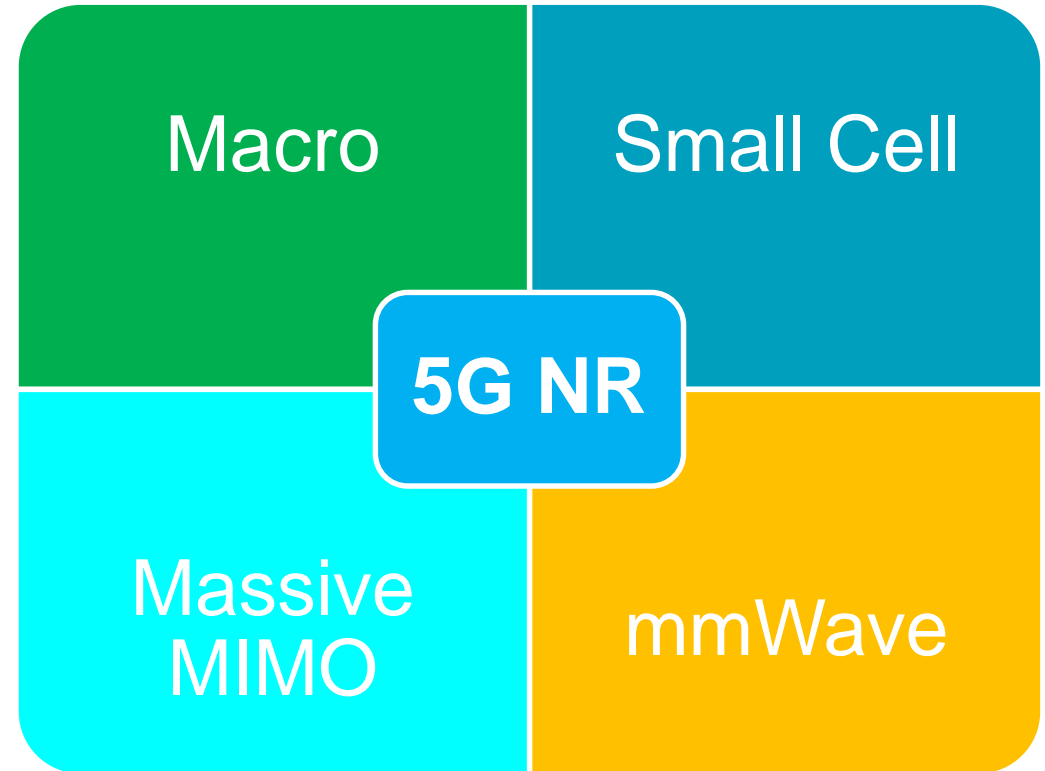


Massive MIMO

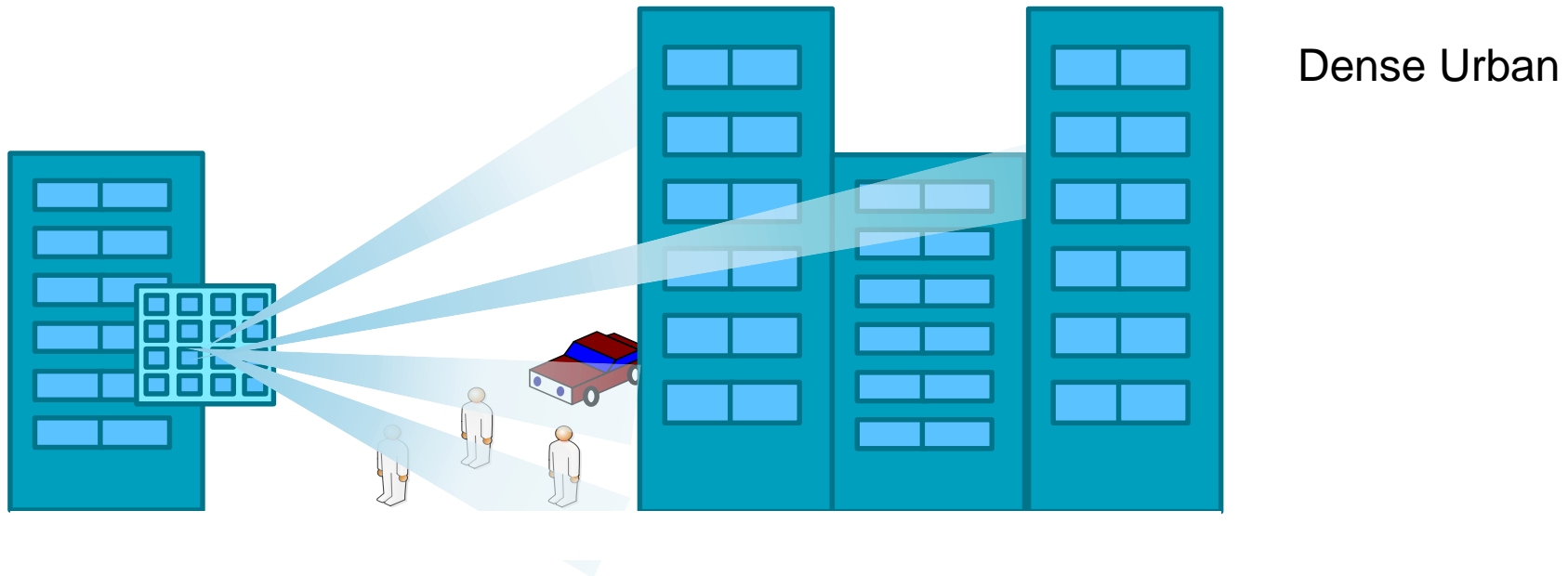


5G NR for the Basestation Radio

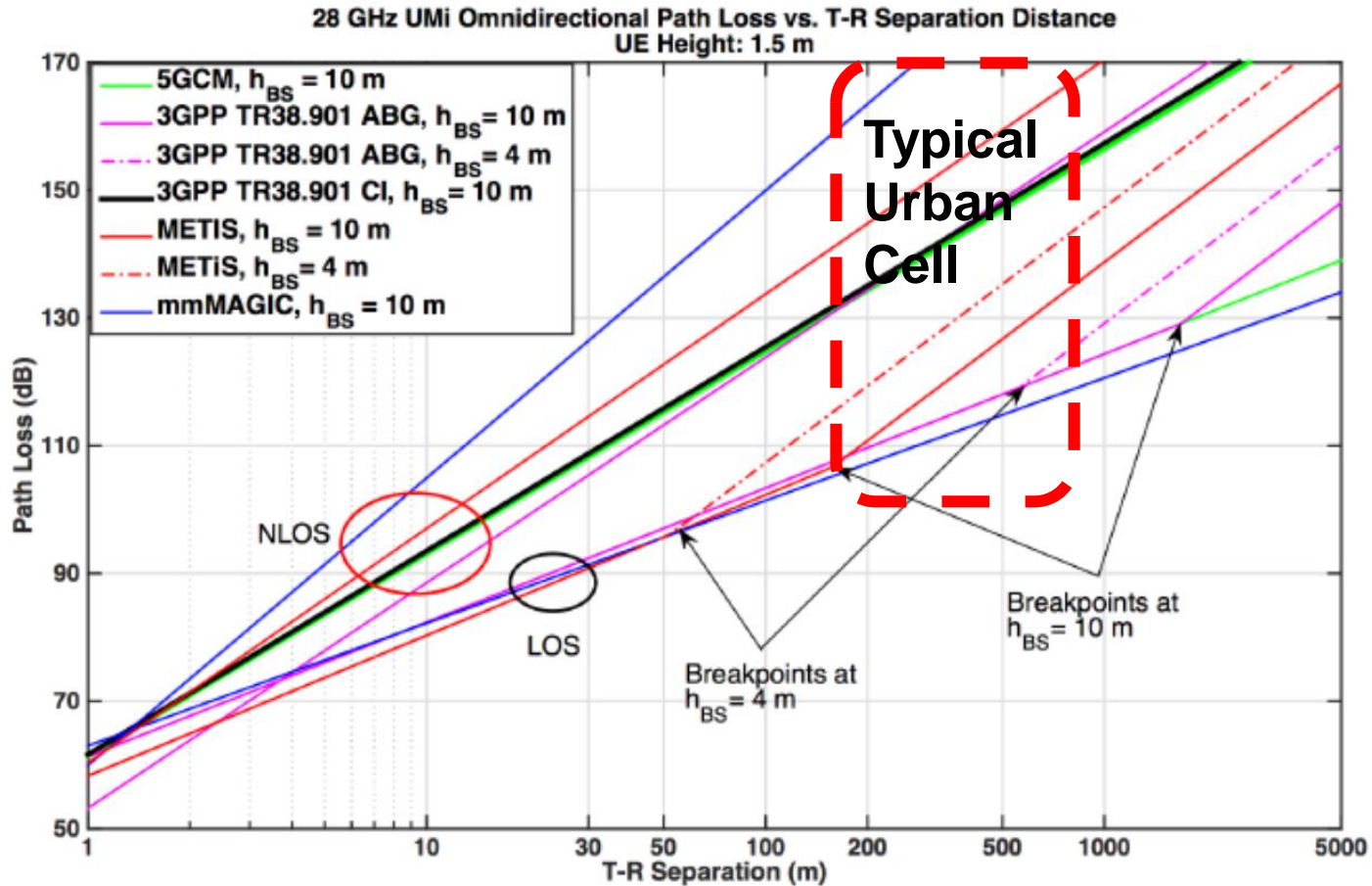
- ▶ 5G NR radio expected to be initially deployed in new spectrum
 - Below 6GHz: Carrier BW of 5 MHz to 100 MHz
 - Above 6GHz: Carrier BW of 40 MHz to 400MHz
- ▶ NR waveform will be very similar to LTE (CP-OFDM)
 - ▶ Flexible numerology
- ▶ Beamforming will be prevalent above 2GHz



5G mmWave Deployment Scenarios



Path Loss



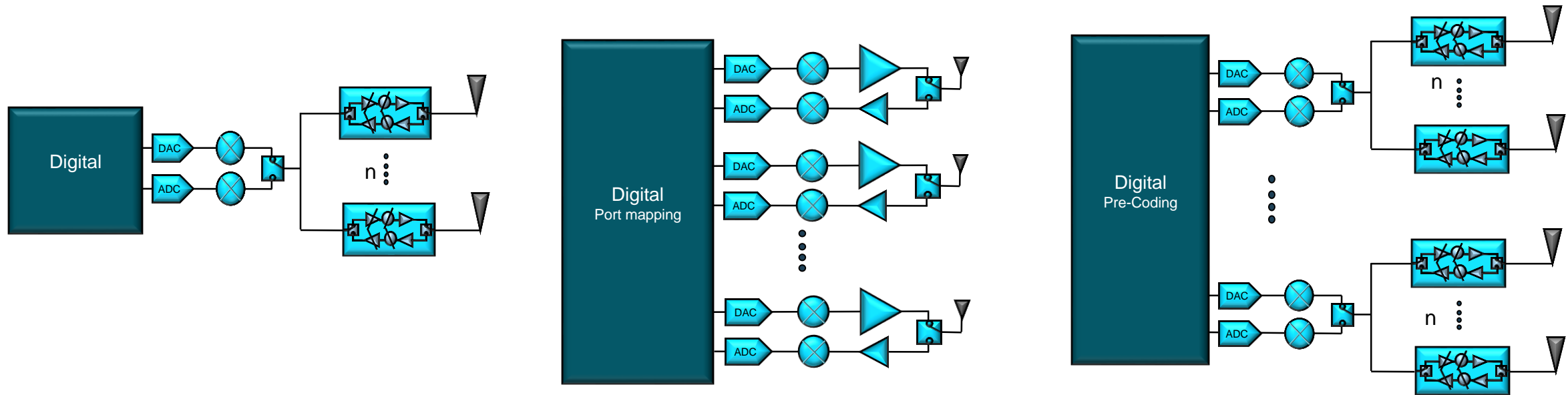
Reference: T. S. Rappaport et al, "Overview of Millimeter Wave Communications for Fifth-Generation (5G) Wireless Networks—with a focus on Propagation Models," in IEEE Transactions on Antennas and Propagation, Special Issue on 5G, Nov. 2017

Link Budget Example

Assumptions	BTS	CPE
Power per PA	9dBm	1 dBm
Number of PA	256	64
Number of antennae	256	64
Gain per element	5dB	5dB
Front end loss	2dB	2dB

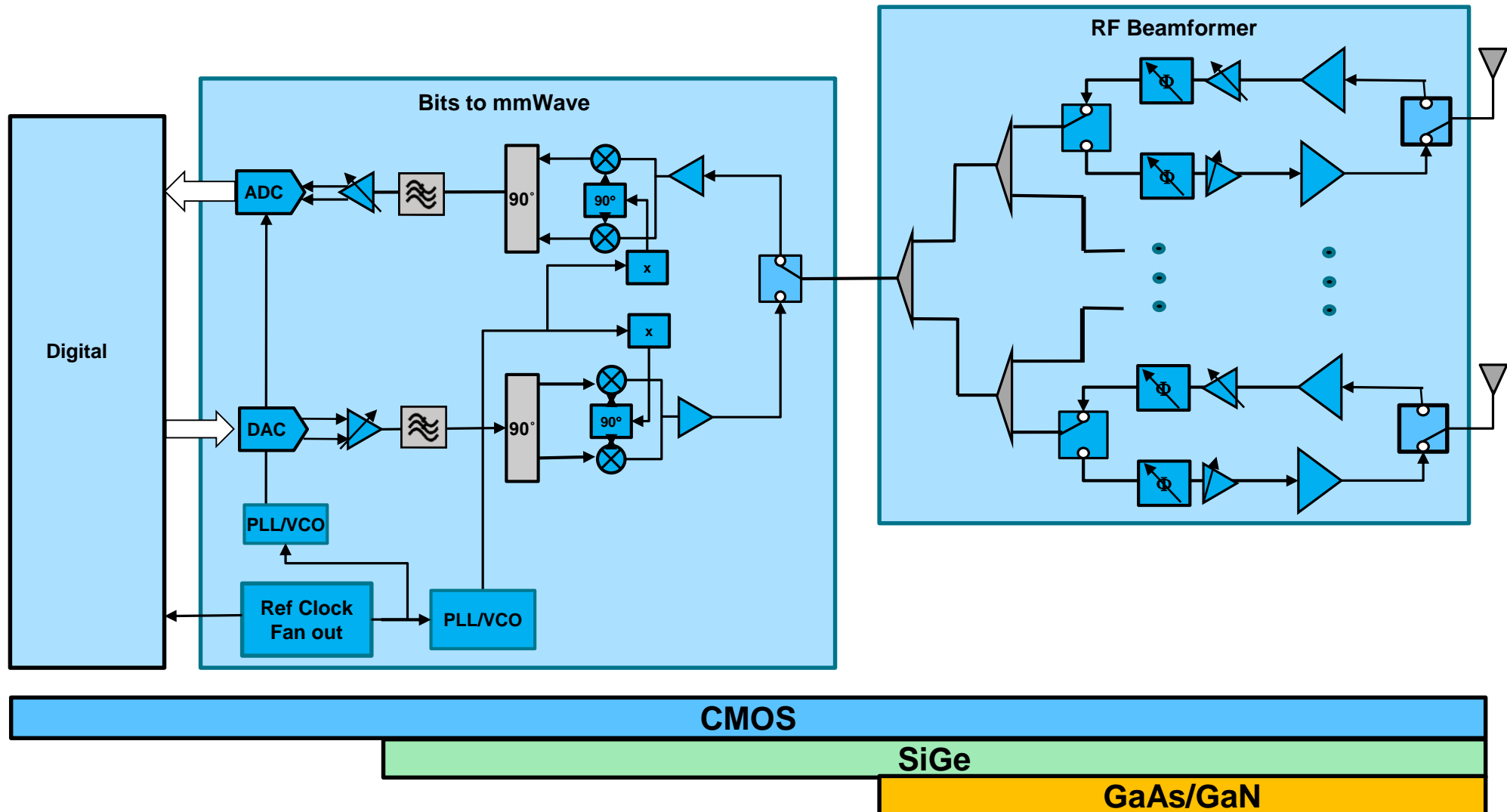
Link Budget 200m link @ 28GHz	Downlink (Access Point)	Uplink (CPE)
Total Conducted PA power	+33dBm	+19 dBm
Antenna Gain	27 dB	21
TX EIRP	60 dBm	40dBm
Path Loss	135dB	135 dB
Received Power	-75dBm	-95 dBm
Thermal noise floor	-85 dBm	-85dBm
RX Noise Figure	5dB	5dB
SNR per RX element	5dB	-15dB
RX Antenna Gain	21dB	27dB
RX SNR after beamforming	+26dB	+12dB

Beamforming Architectures



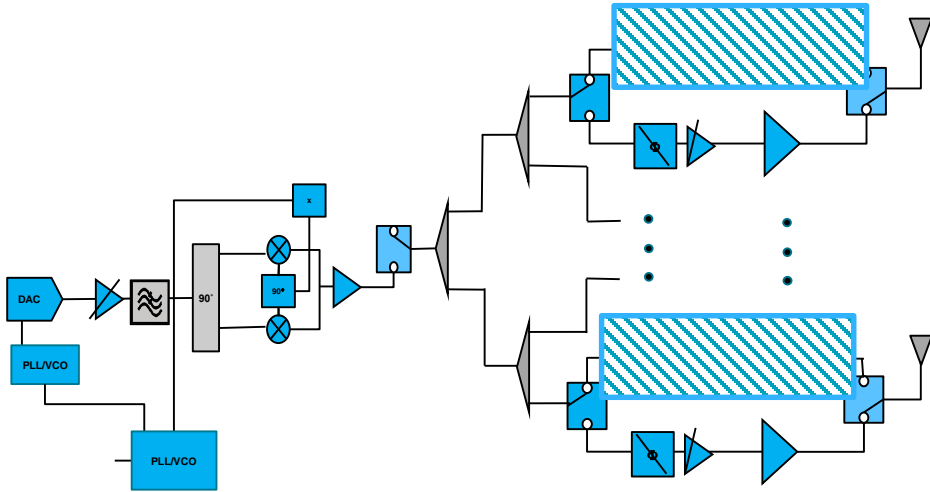
Analog Beamforming	Digital Beamforming	Hybrid Beamforming
Beam formed by weighting RF paths	Beam formed by weighting digital paths	Beamforming a combination of analog and digital
Low power/complexity	Highest power / complexity	Moderate power/complexity
Good for coverage	Highest capacity / flexibility	Compromise between analog and digital
Single beam – single data stream	Frequency selective beamforming	Best choice with existing technology

Analog Beamformer



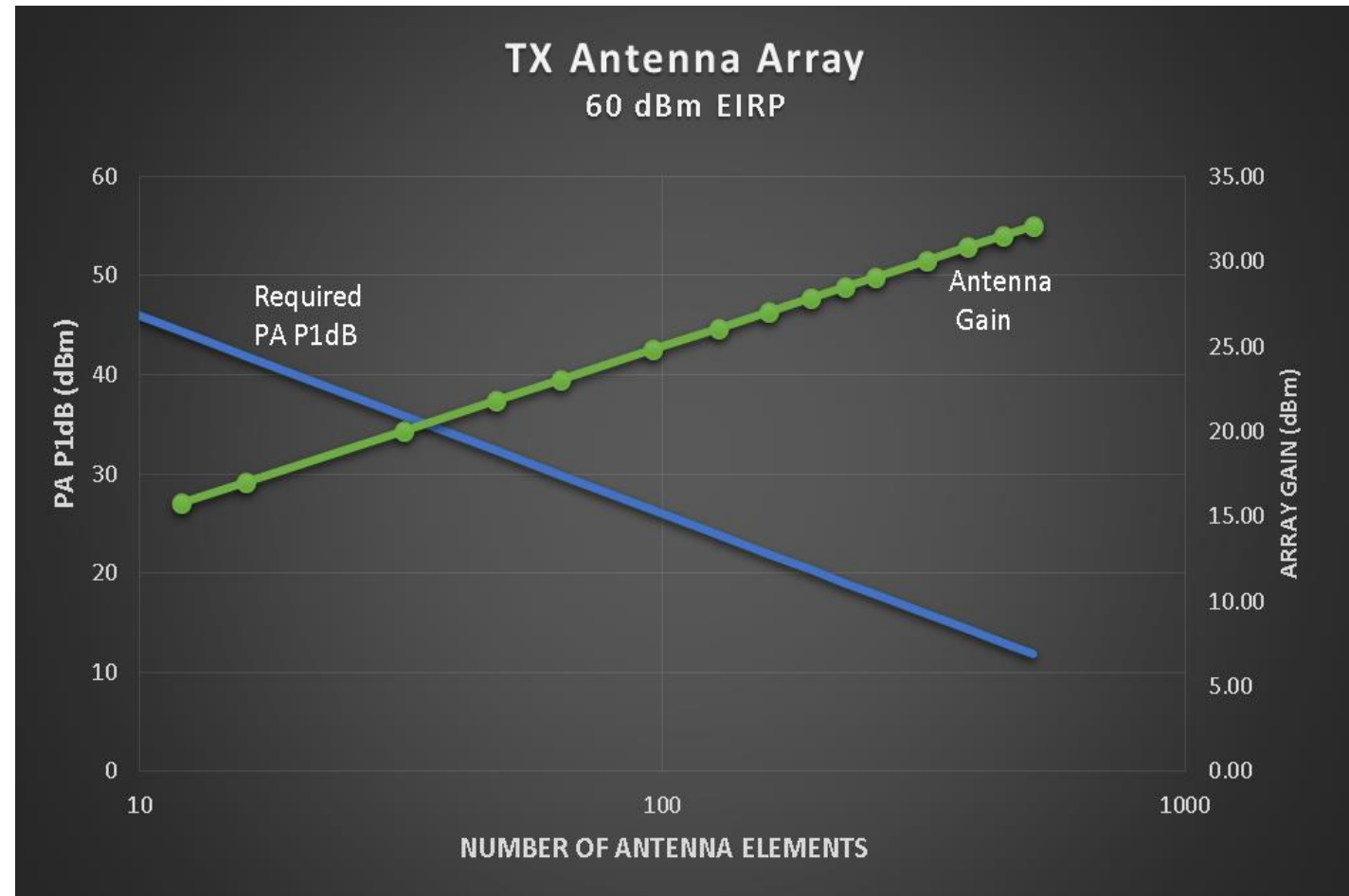
Analog Beamformer

TX Array Gain and PA Output Power vs Array Size at Fixed EIRP



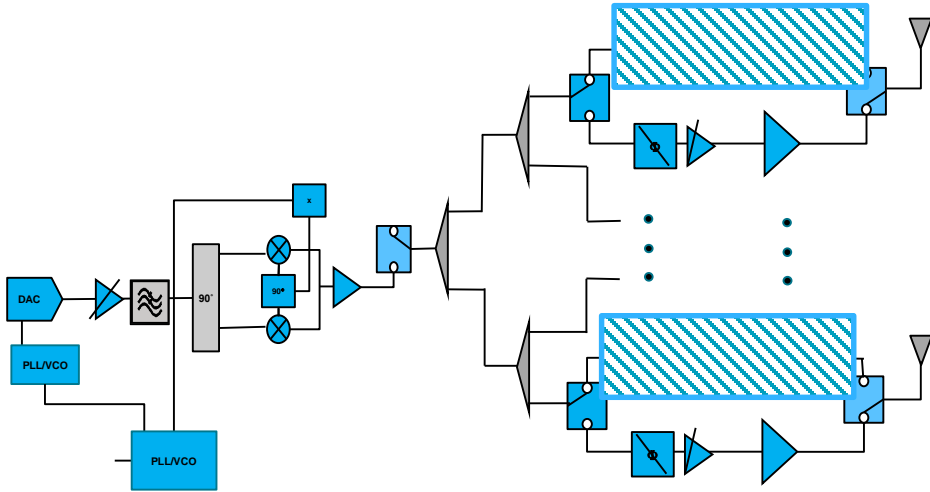
Assumptions:

- 60dBm EIRP per beam
- 800MHz BW
- PAPR =9 dB
- 2dB switch loss



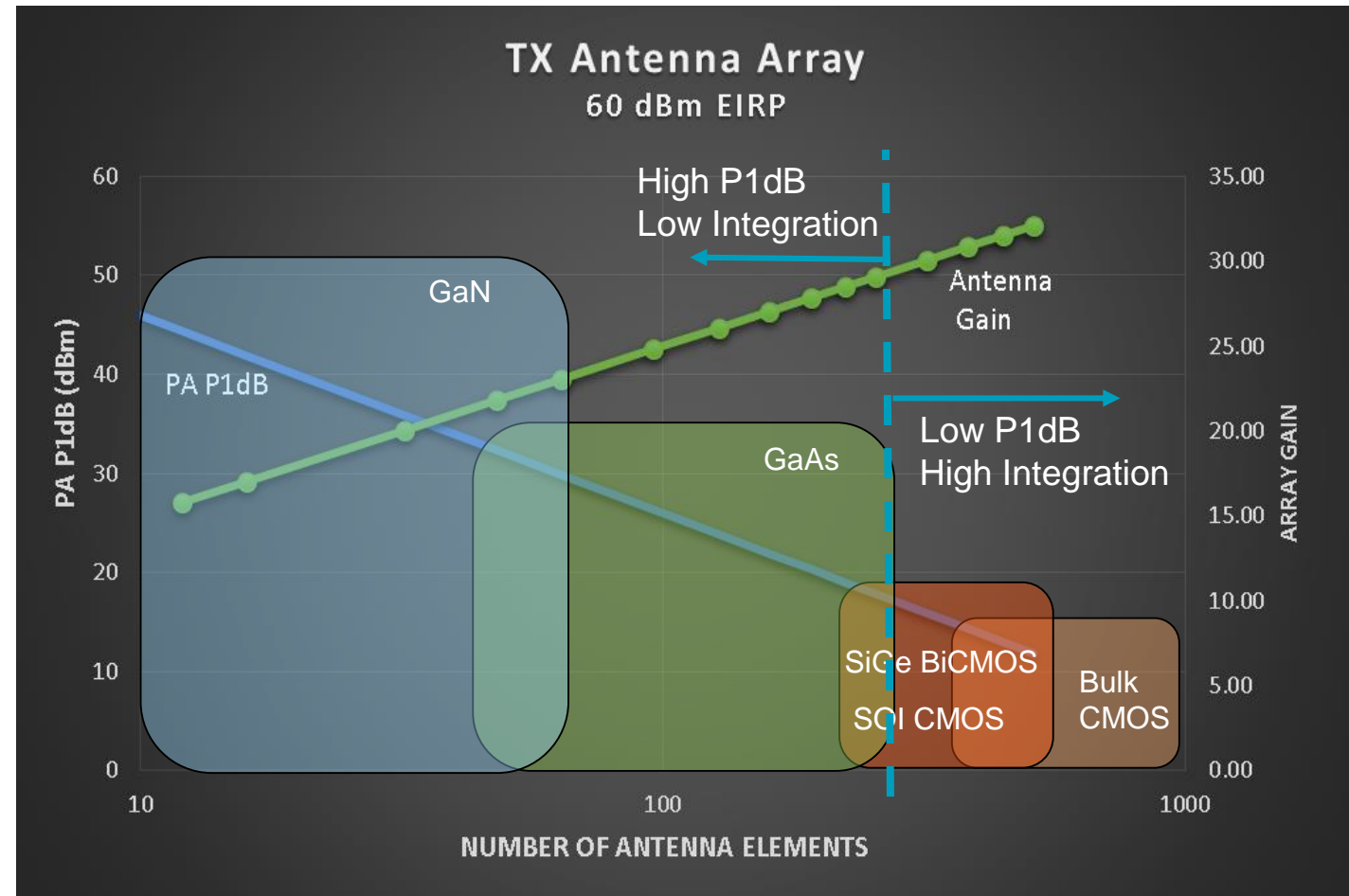
Analog Beamformer

TX Array Gain and PA Output Power vs Array Size at Fixed EIRP



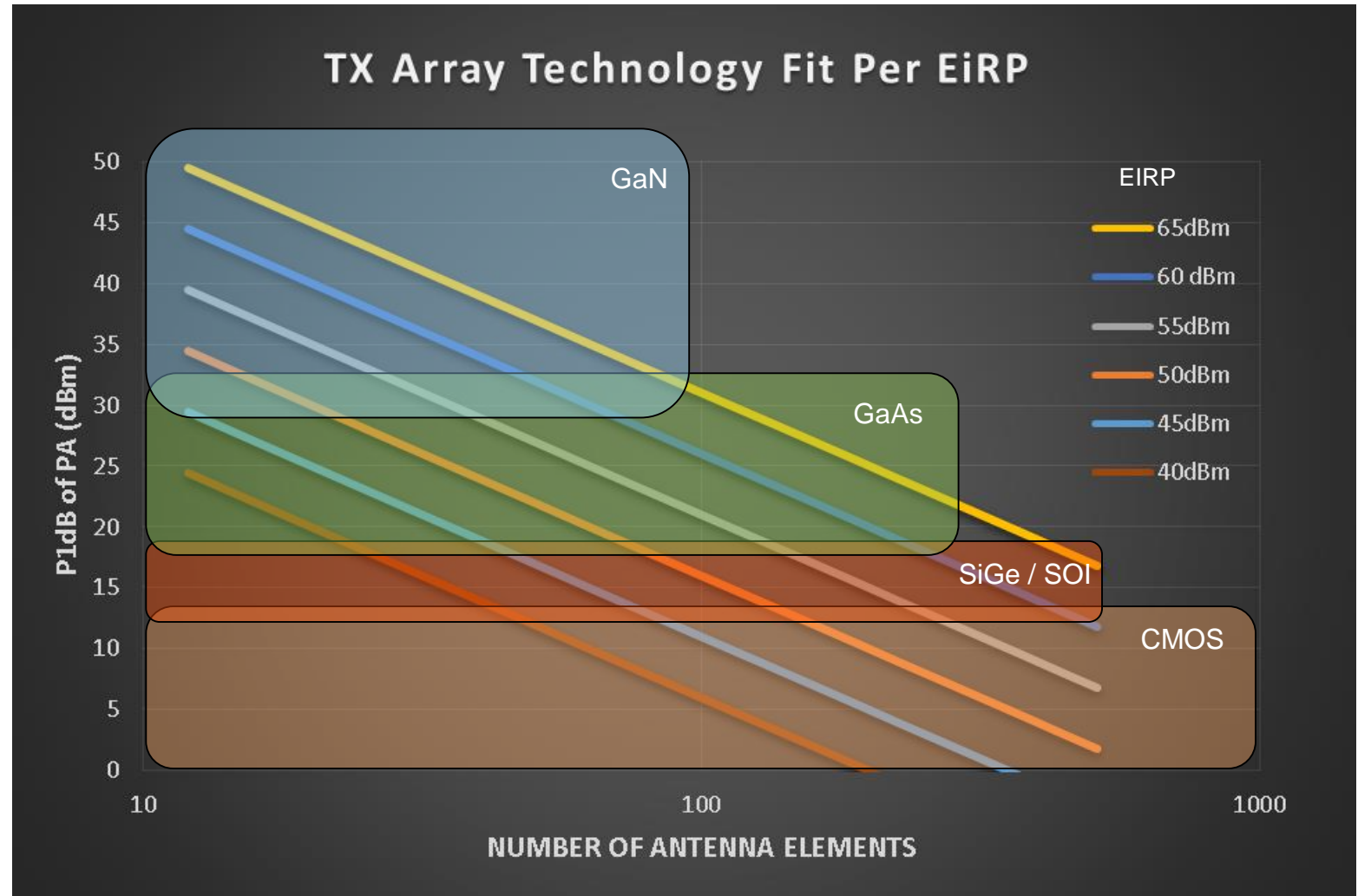
Assumptions:

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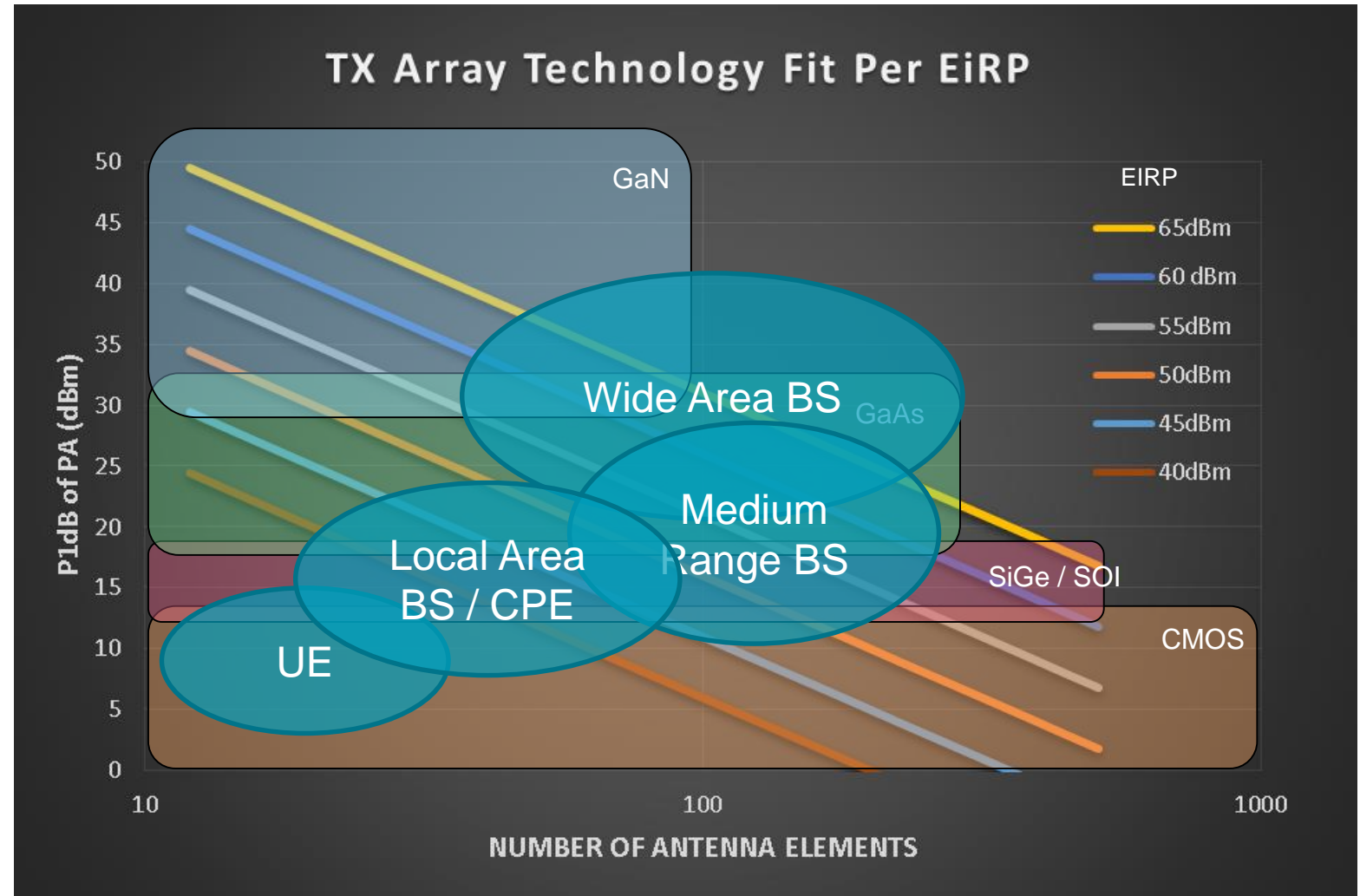
Technology Fit Per Radio Form Factor

- Higher EIRP pushes PA technology toward III-V
- Lower EIRP allows for highly integrated silicon based solutions
- Larger array allows for the use of silicon PAs
- Larger array adds complexity and cost

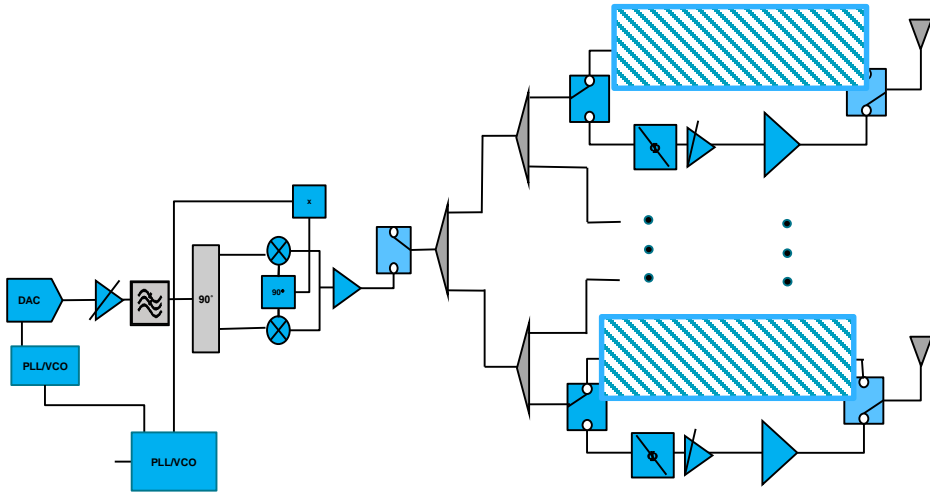


Technology Fit Per Radio Form Factor

- UE is clearly in CMOS technology domain
- CPE spans CMOS and SiGe BiCMOS
- Low power access point spans CMOS, SiGe BiCMOS and GaAs
- High power Basestation spans GaAs and GaN

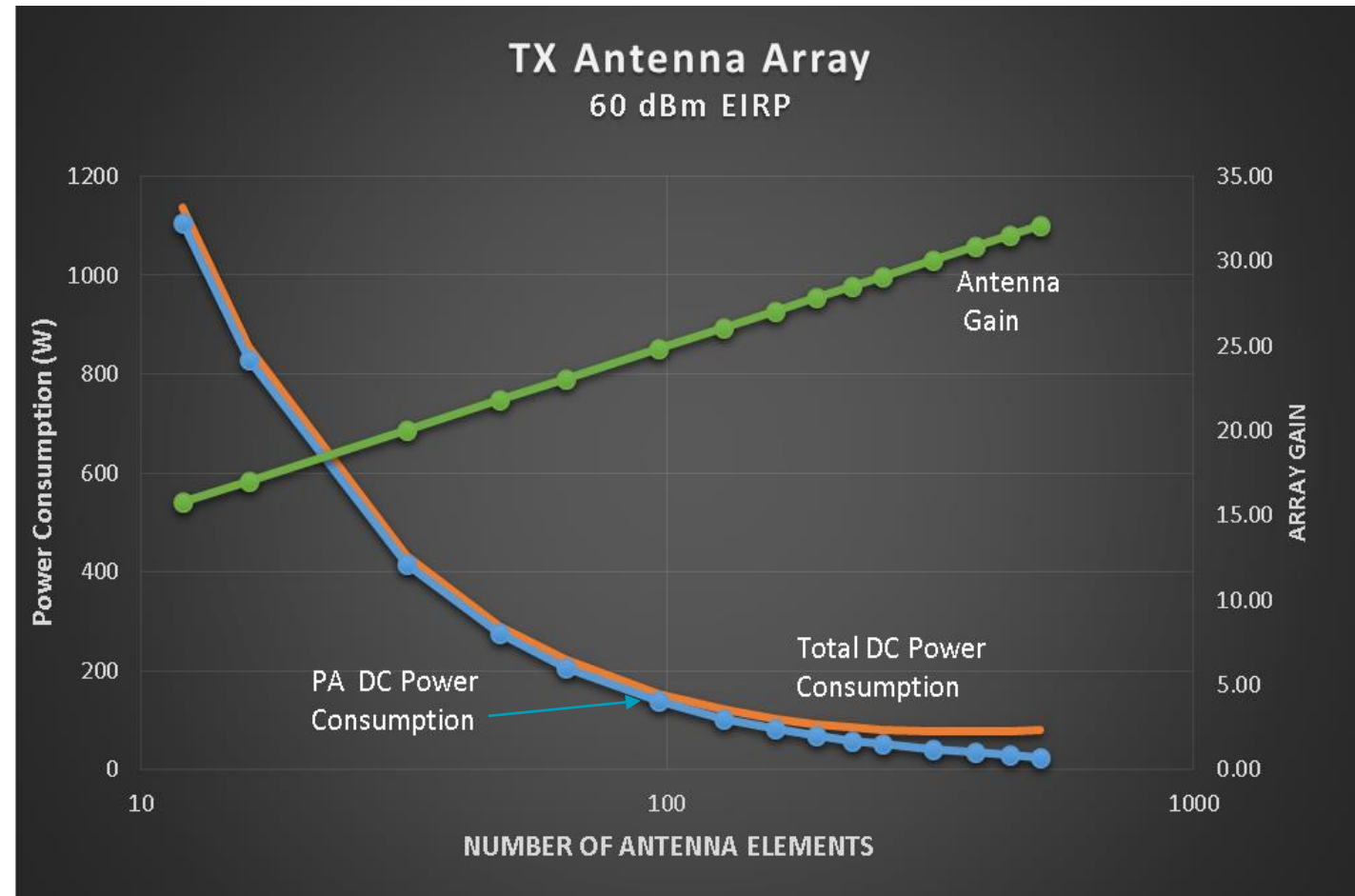


Analog Beamformer Power Consumption



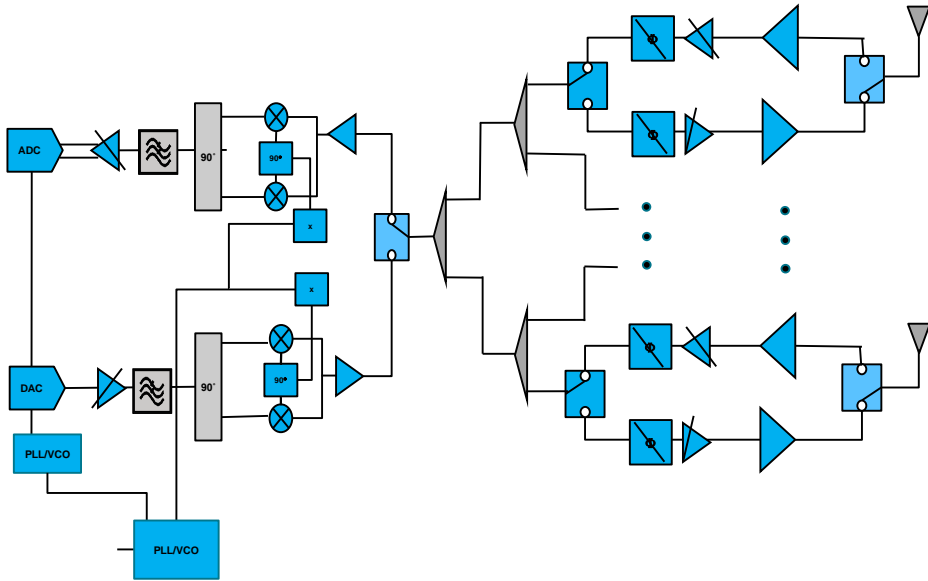
Assumptions:

- 60dBm EIRP per beam
- PAPR = 9 dB
- 2dB switch loss
- PA Peak PAE – 30%
- Core PAE - 13%

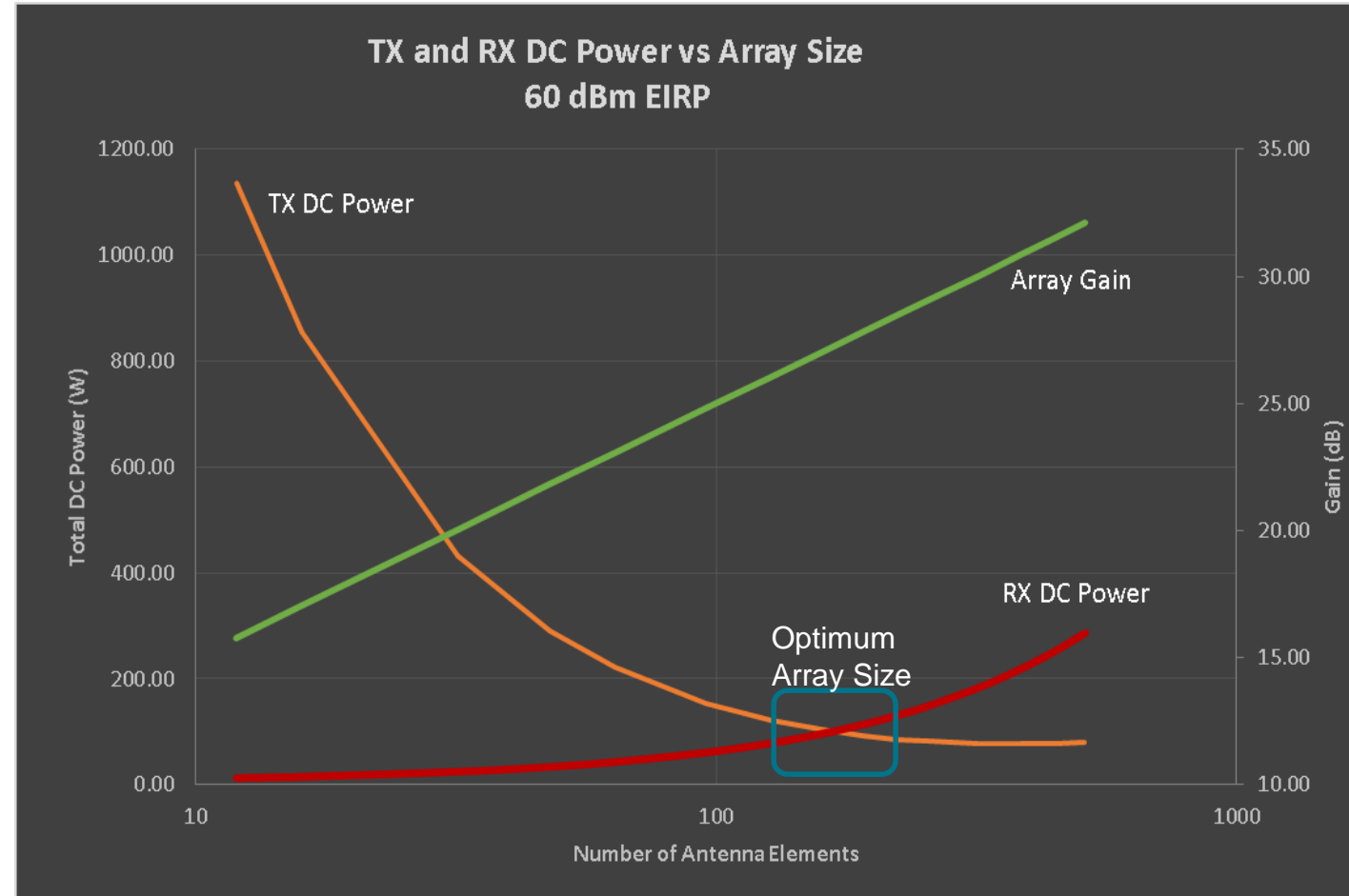


Analog Beamformer Power Consumption

TX and RX DC Power Consumption vs Array Size at Fixed EIRP



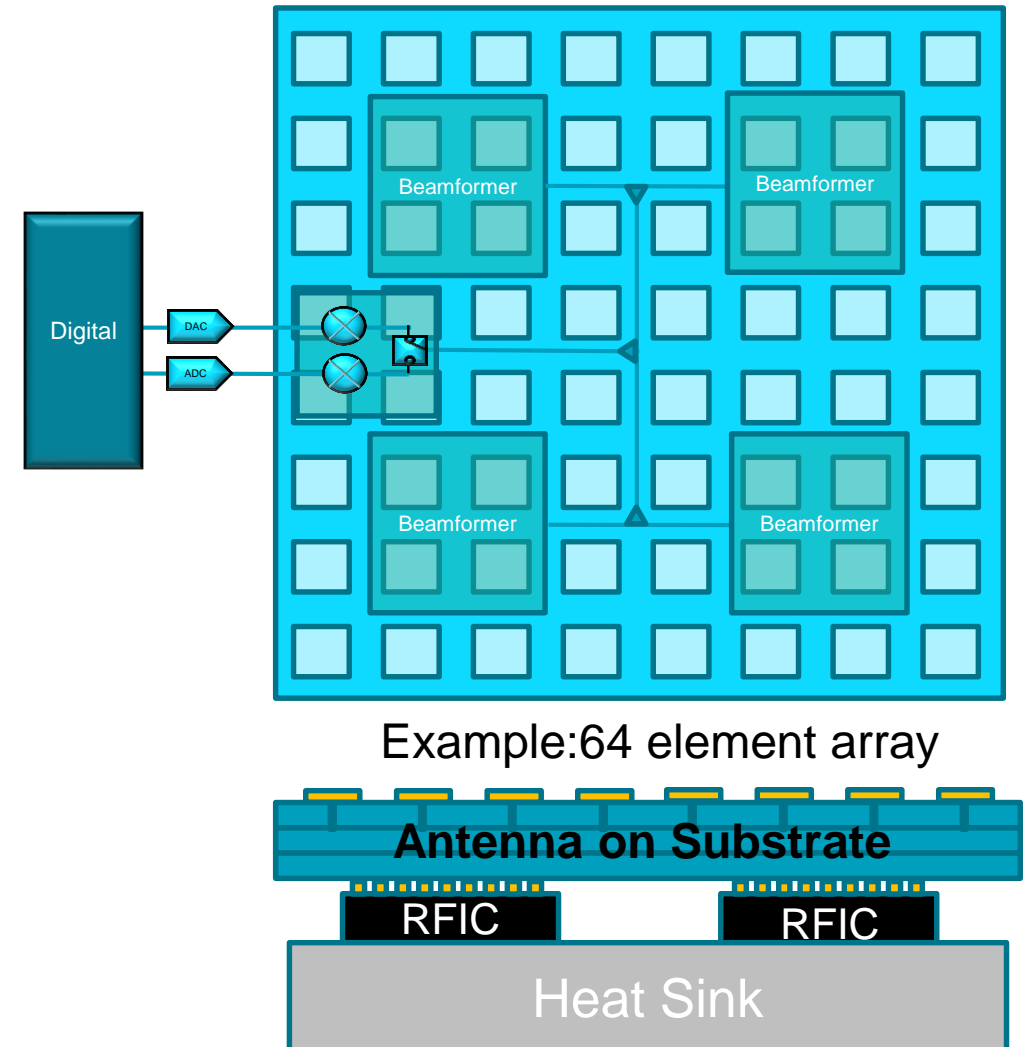
- Overlay TX and RX power consumption
- Optimum array size is 128 to 256 elements
- TX power consumption ~ 80 -100W



High Integration Beamformer Assembly

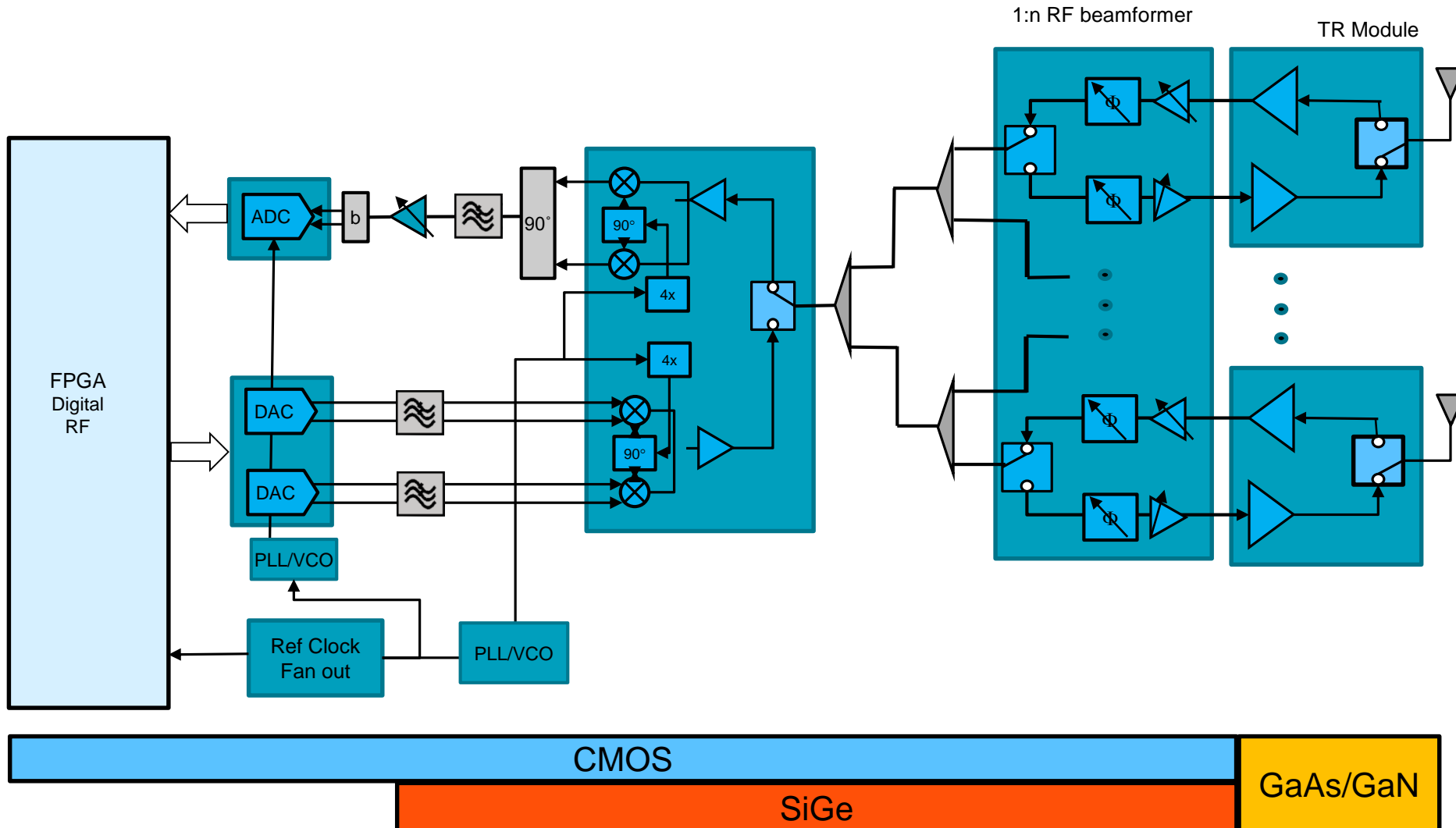
Antenna on Substrate

- Compact implementation
- Supports wide range of beamforming in both vertical and horizontal
- Scalable for higher EIRP
- Thermal challenges
- Difficult to implement front end filters



Semi-Integrated Analog Beamformer

Integrated Beamformer with TR Module



Semi-Integrated Analog Beamformer

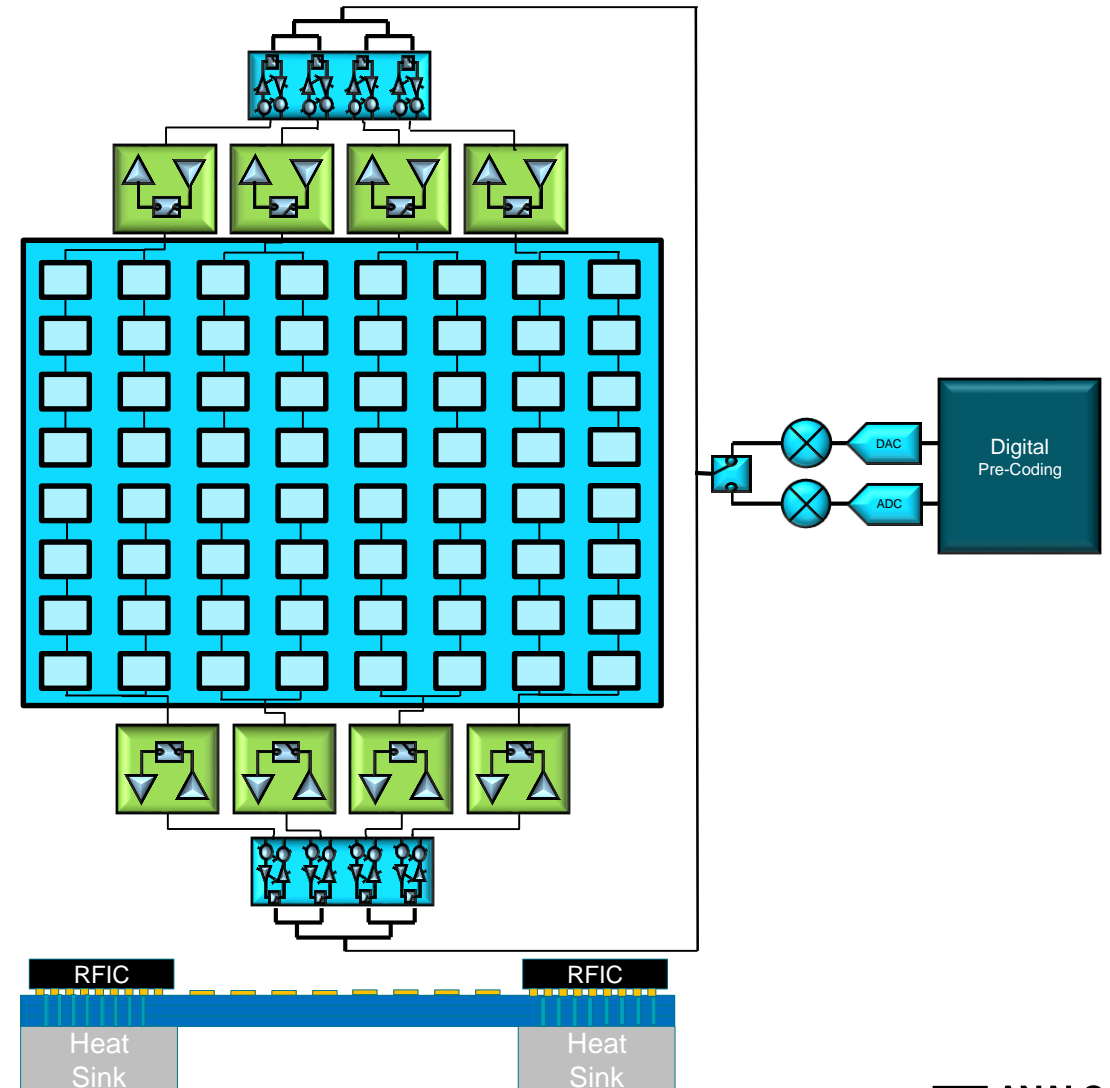
- Opt to drive a sub-array with each PA to leverage the array gain

Pros:

- 8X less PAs and beamformer ICs
- Planar implementation
- Printed front end filters possible
- Conventional thermal management
- Scalable for very high EIRP

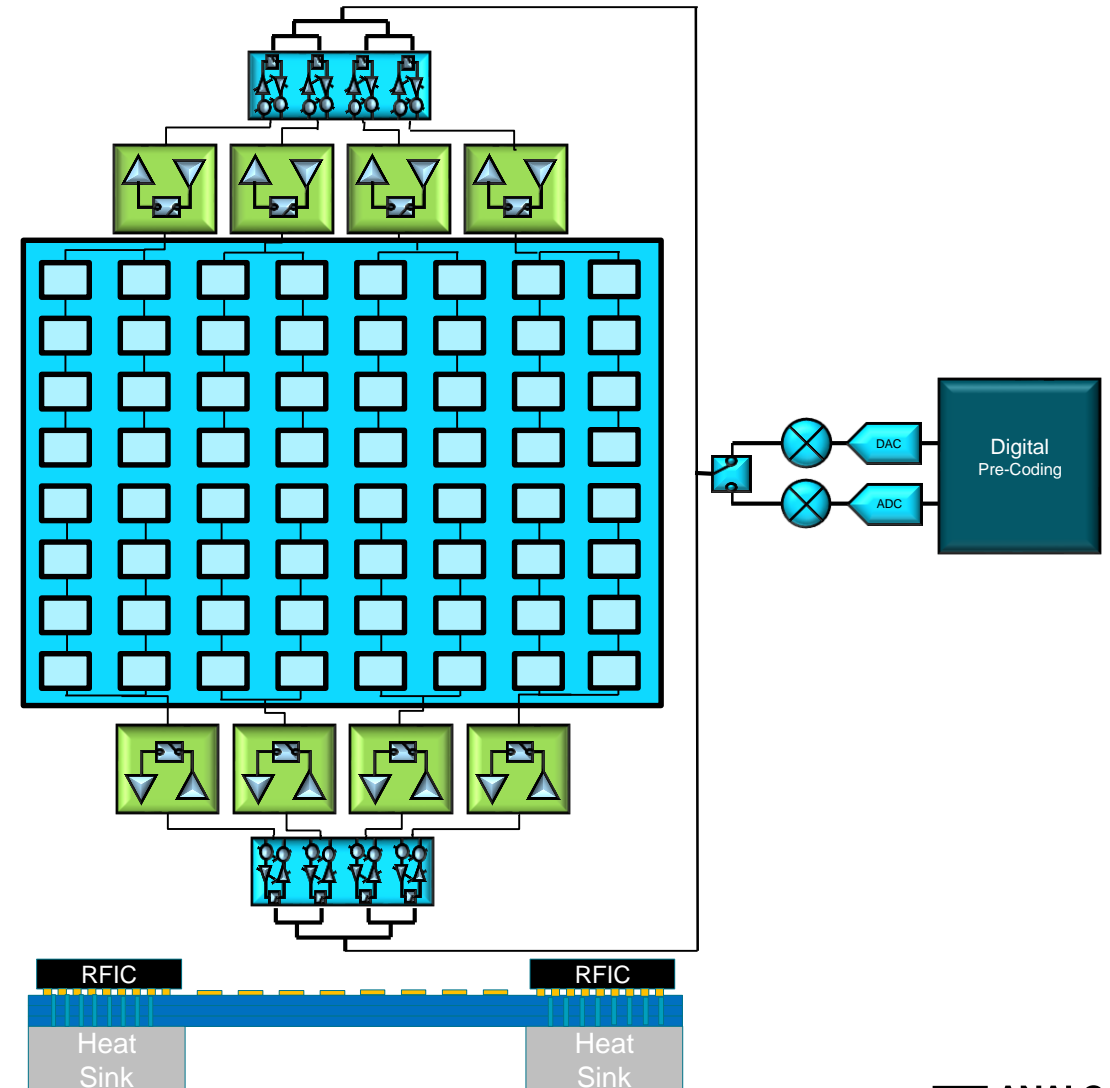
Cons:

- Reduced scanning capability



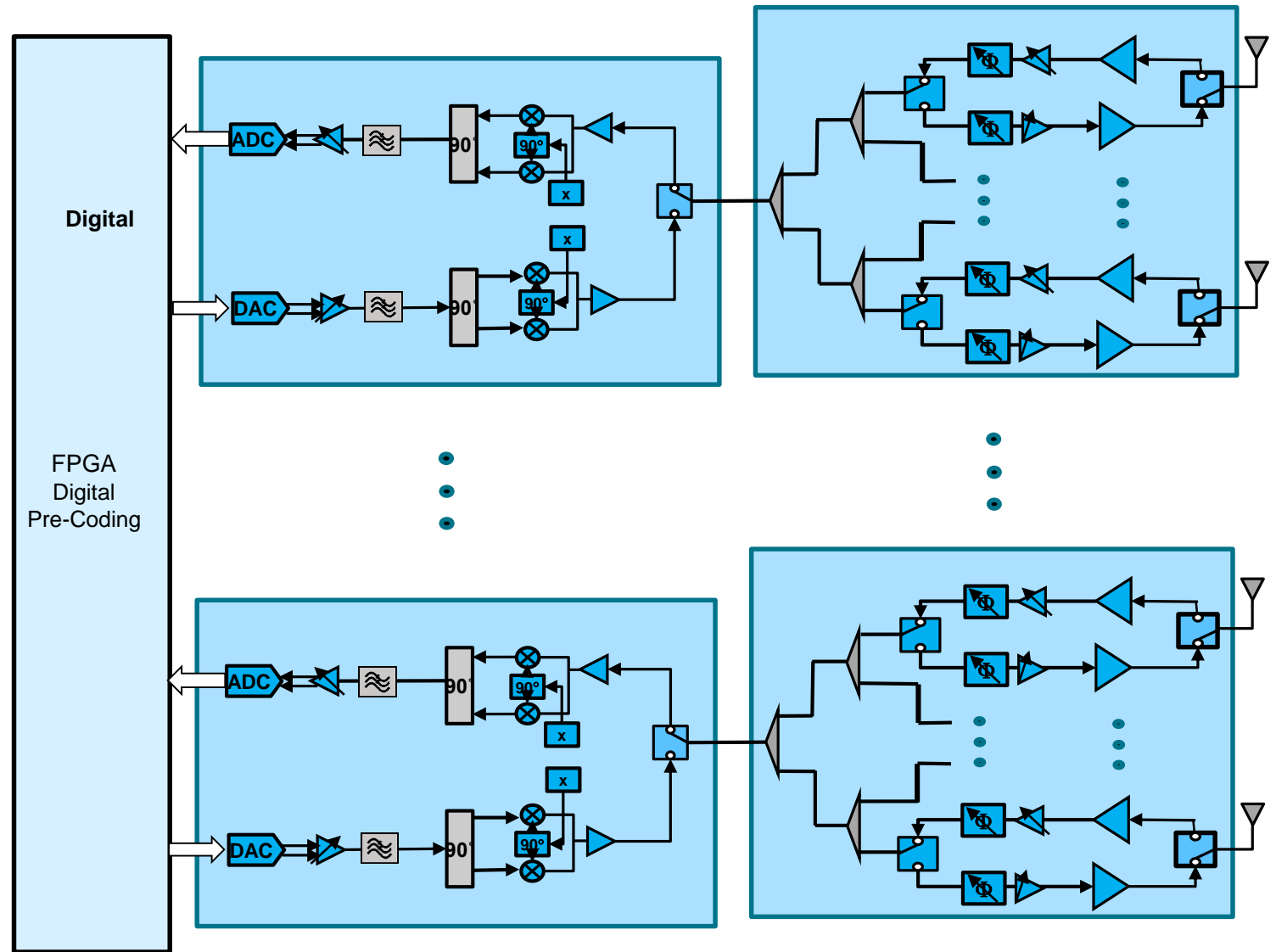
Semi-Integrated Analog Beamformer

- For EIRP = 60 dBm optimum DC power consumption achieved with 128 elements for single beam
- PA output power is 24dBm (suitable for GaAs or GaN)



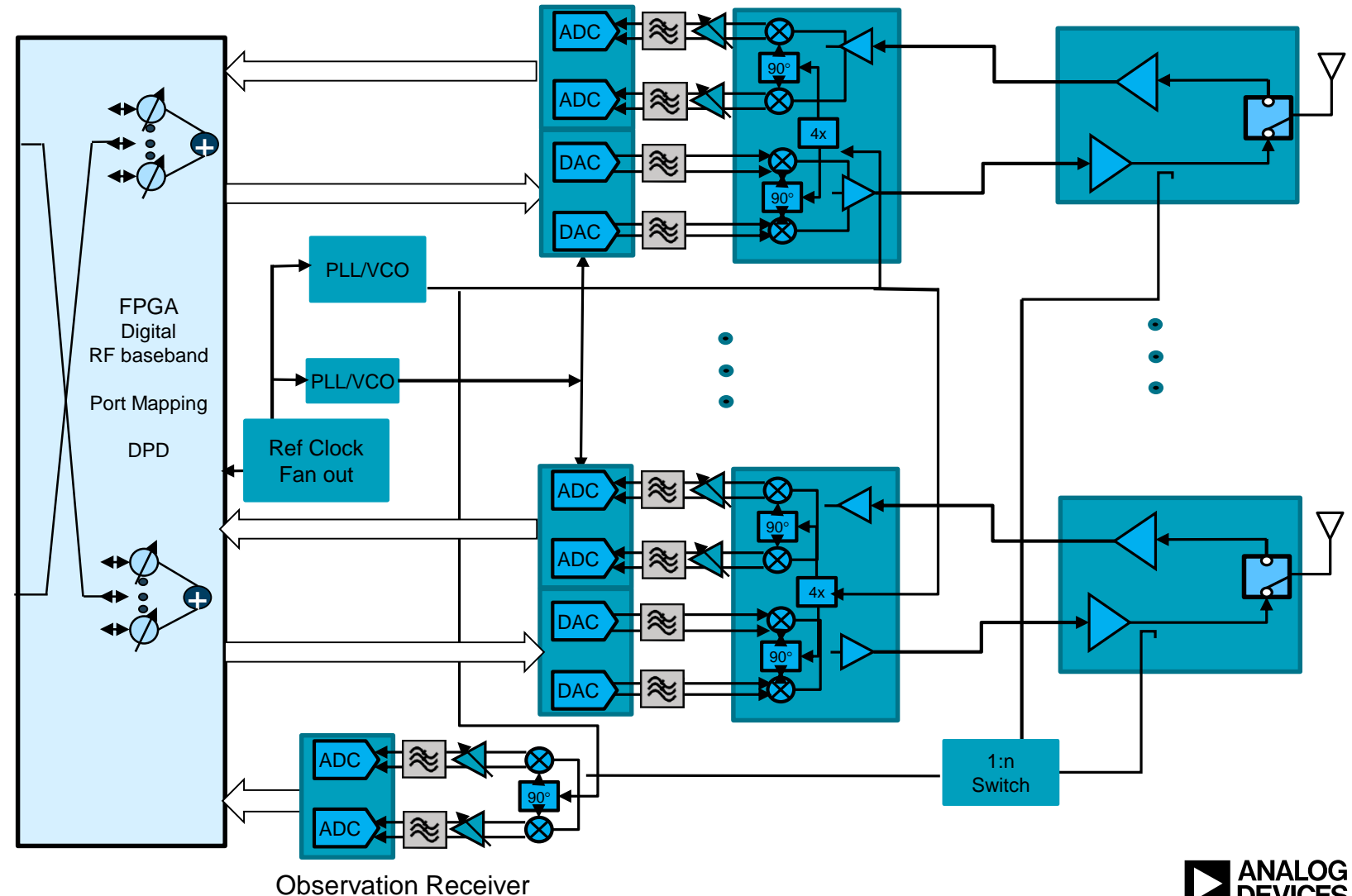
Hybrid Beamformer

- Combines digital and analog beamforming to enable spatial multiplexing
- If $m=8$ and $n = 128$ then total array size is 1024
- While scalable - the power consumption adds up very quickly



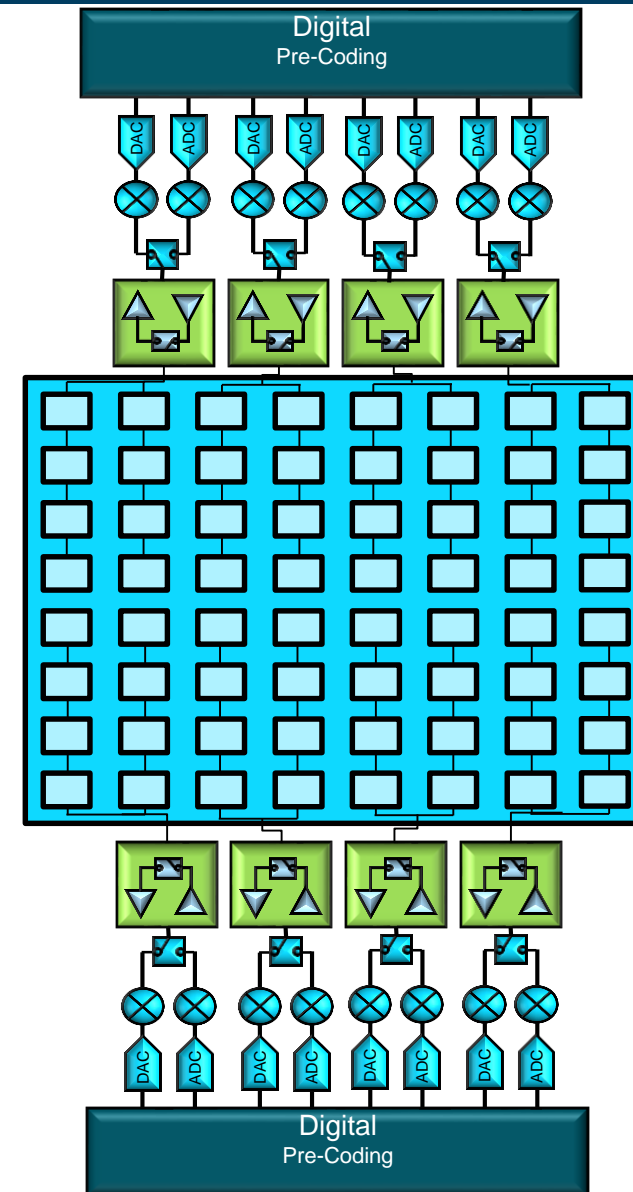
Digital Beamforming

- Phase shifting performed digitally
- First step toward massive MIMO at mmWave frequency
- Enables path to higher TX efficiency through use of DPD

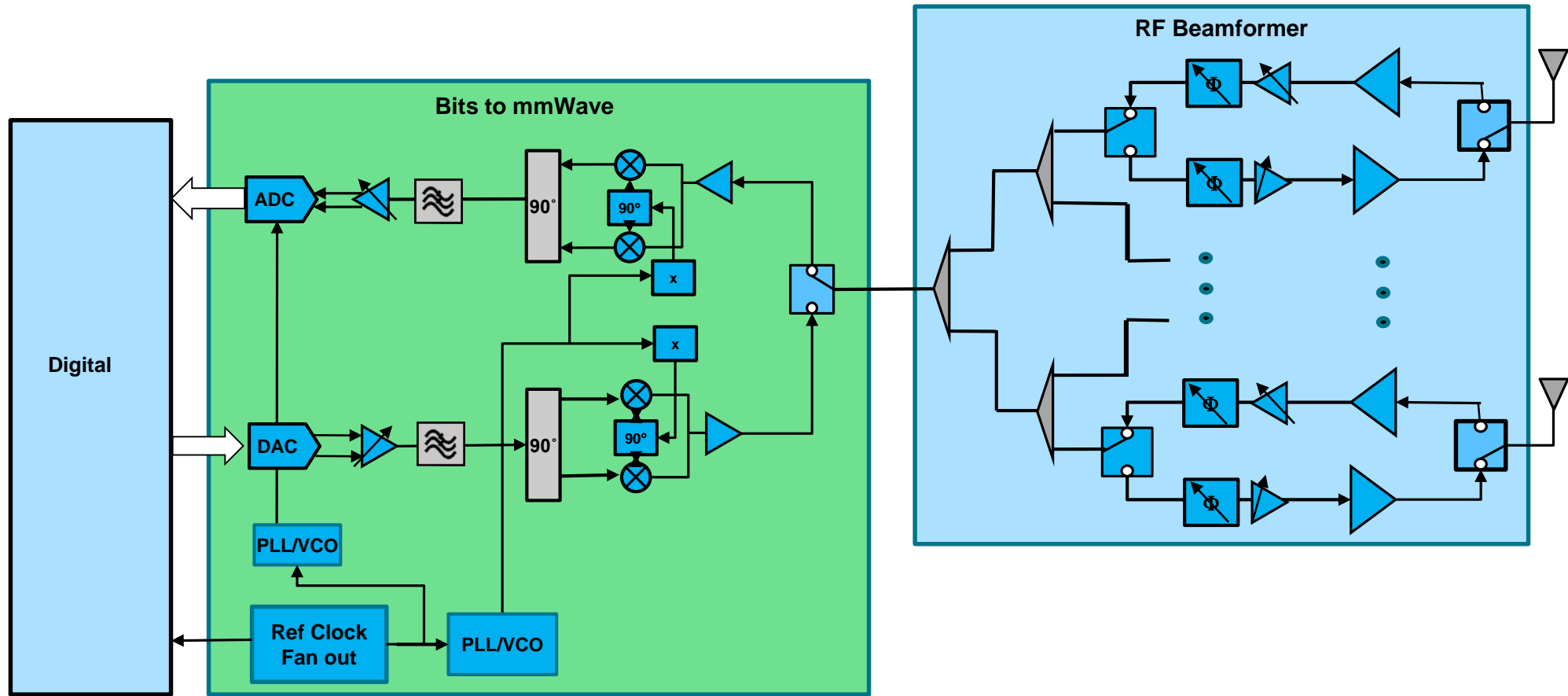


Digital Beamforming

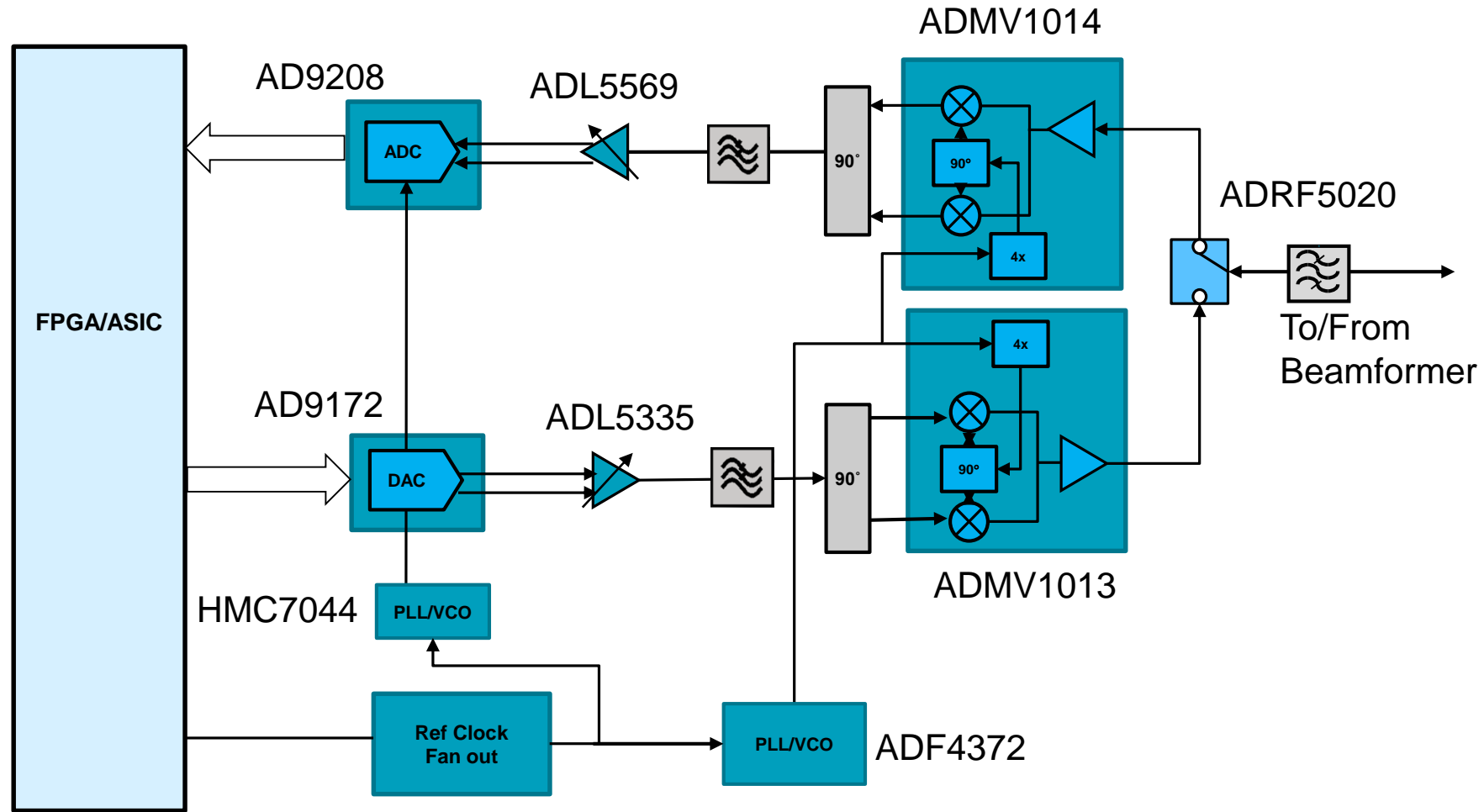
- Similar implementation to semi-integrated analog approach
- This is beamforming – not massive MIMO
- Simply moves phase shifter from RF to digital



Bits-to-mmWave Radio



Bits-to-mmWave Radio - Example



Reference: 5G Millimeter Wave Basestation,

<http://www.analog.com/en/education/education-library/videos/5804450511001.html>

Summary

- 5G mmWave use cases emerging
- Fixed in near term → nomadic → mobile in future
- Various approaches to beamforming
 - Analog Beamforming
 - Most efficient implementation with existing technology
 - Digital Beamforming in future
- Bit-to-mmWave Radio
 - Requires leading edge technology – available now!

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