5G Enhanced Mobile Broadband Radio interface on mmWave – Hardware Architecture and role of Silicon Technologies

Dr. Anirban Bandyopadhyay, Director, RF Business Development, GLOBALFOUNDRIES, Inc., New York

Outline

1. Introduction to 5G
2. mmWave 5G Radio Access Technology Overview
3. mmWave 5G Radio Interface Architecture
4. Differentiated Silicon Technologies for mmWave 5G
5. Summary & references

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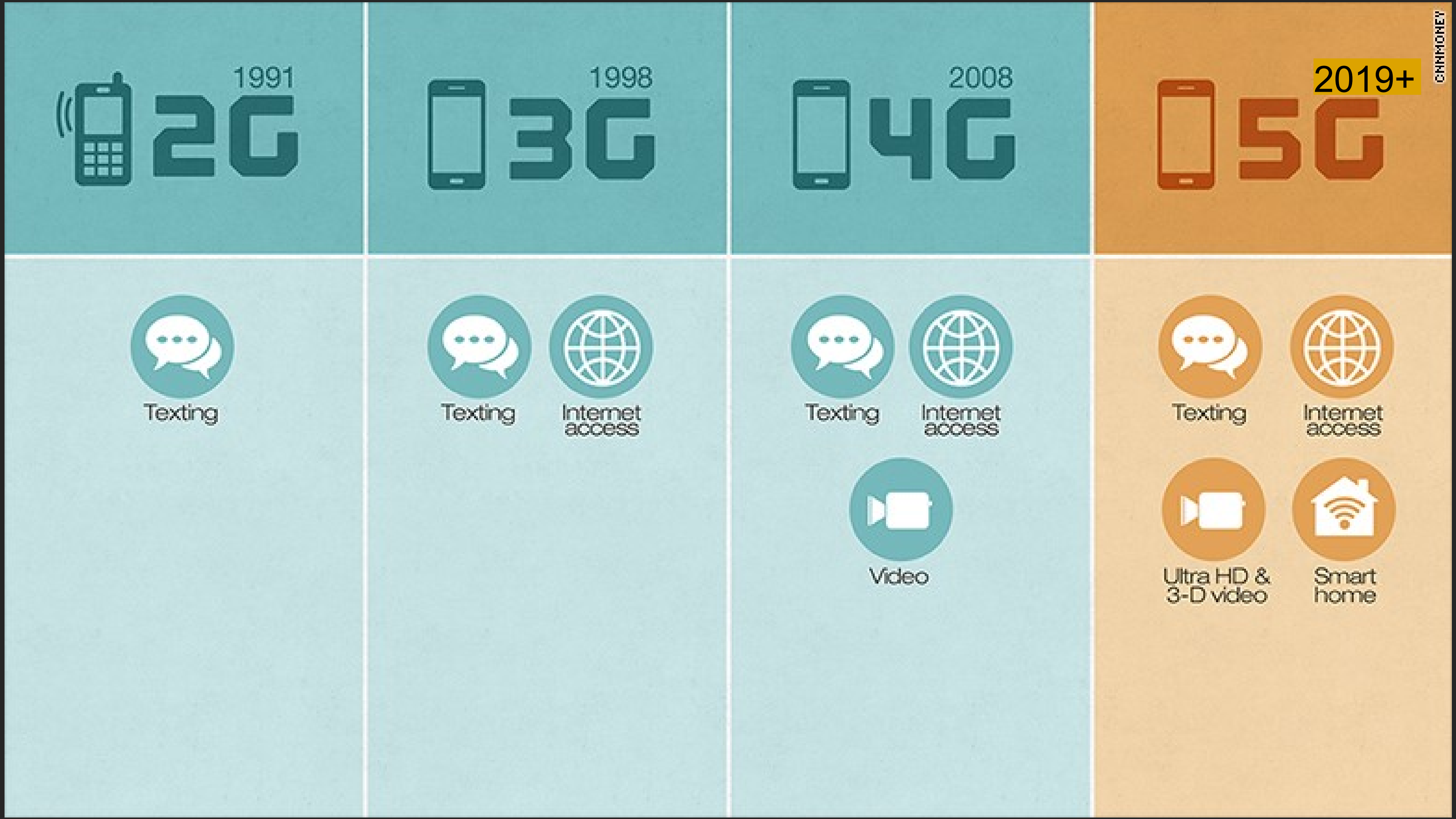
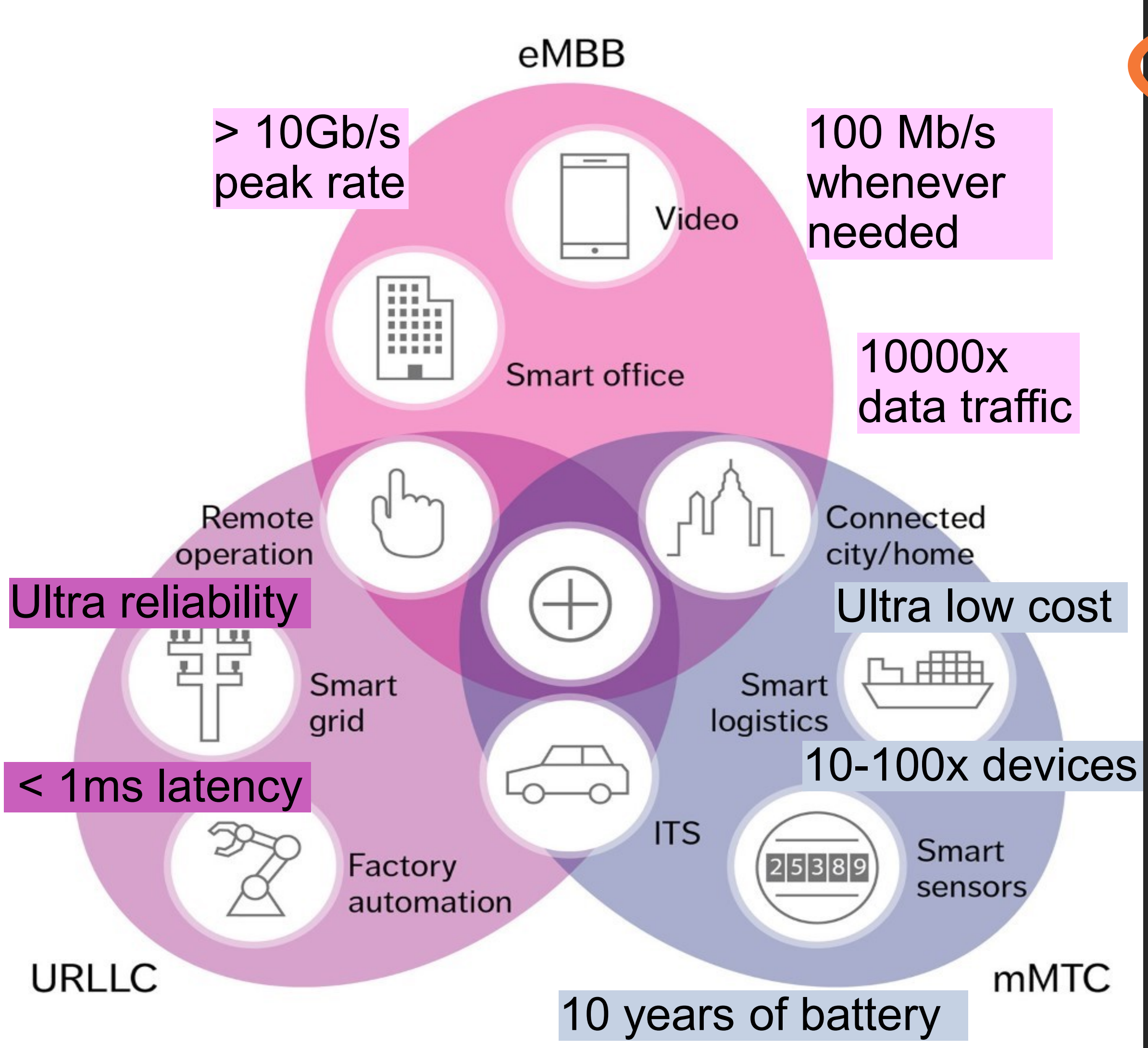
What is 5G ?



5G is the next Generation cellular standard to support ***faster data rate****,* ***lower latency*** *&* ***more number of connected devices***

5G Usage Scenario



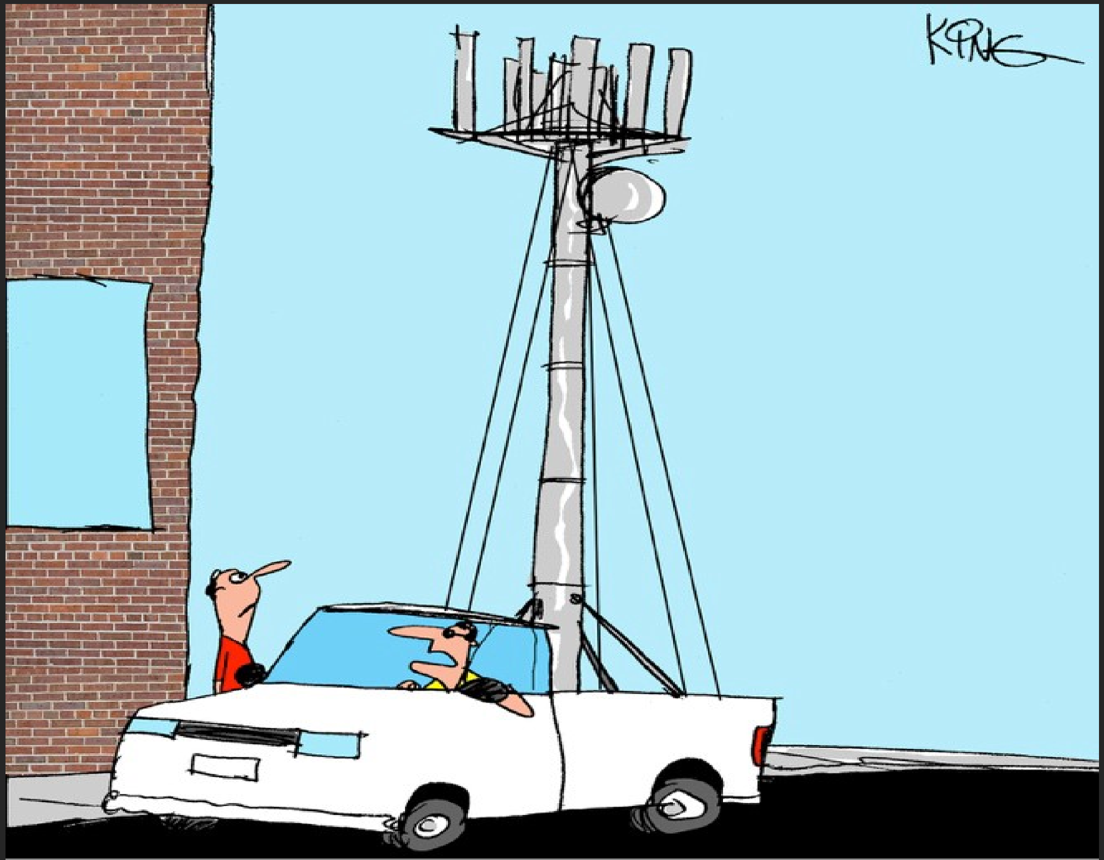
eMBB : enhanced Mobile BroadBand

uRLLC : Ultra Reliable Low Latency Communication

mMTC : massive Machine Type Communication

5G is a superset in terms of usage scenarios, not backward compatible with 4G

Do we really need 5G ?



"I got so fed up with dropped calls and no service, I bought my own cell tower and take it where ever I go."

Source: IWPC presentation, 2017

Key Problems faced by current 4G connections

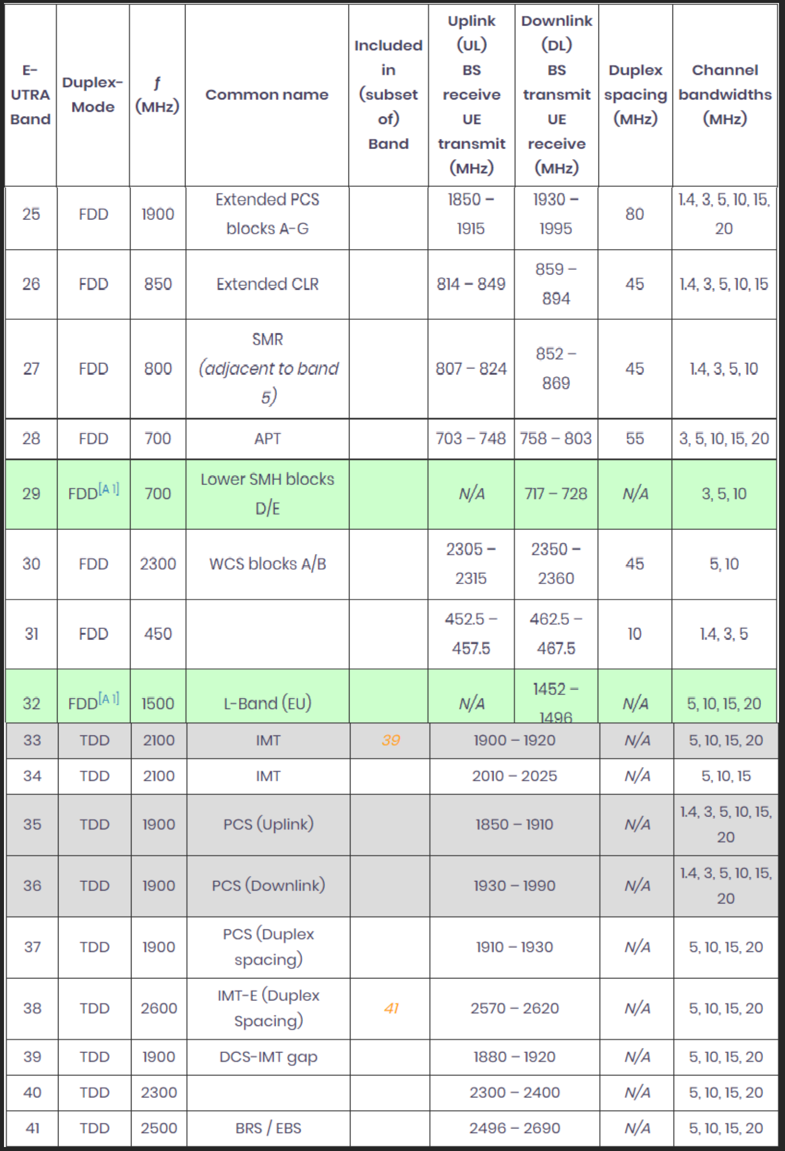
- Cell edge coverage
- Peak & average data rate / throughput

Concept of always being connected remains a myth

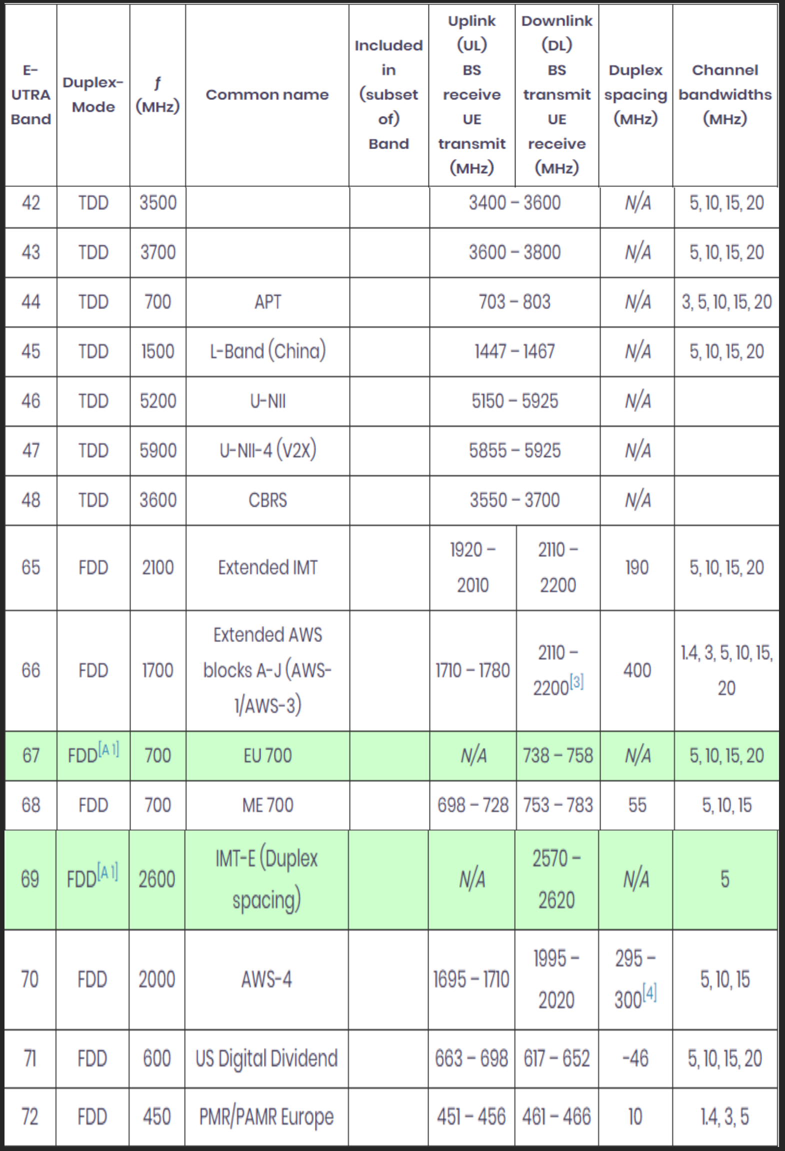
Data traffic density and higher data rate demand will always be on the rise

4G Frequency Bands

E-UTRA Band	Duplex-Mode	ƒ (MHz)	Common name	Included in (subset of) Band	Uplink (UL) BS receive UE transmit (MHz)	Downlink (DL) BS transmit UE receive (MHz)	Duplex spacing (MHz)	Channel bandwidths (MHz)
1	FDD	2100	IMT	*65*	1920 – 1980	2110 – 2170	190	5, 10, 15, 20
2	FDD	1900	PCS blocks A-F	*25*	1850 – 1910	1930 – 1990	80	1.4, 3, 5, 10, 15, 20
3	FDD	1800	DCS		1710 – 1785	1805 – 1880	95	1.4, 3, 5, 10, 15, 20
4	FDD	1700	AWS blocks A-F (AWS-1)	*66*	1710 – 1755	2110 – 2155	400	1.4, 3, 5, 10, 15, 20
5	FDD	850	CLR	*26*	824 – 849	869 – 894	45	1.4, 3, 5, 10
7	FDD	2600	IMT-E		2500 – 2570	2620 – 2690	120	5, 10, 15, 20
8	FDD	900	E-GSM		880 – 915	925 – 960	45	1.4, 3, 5, 10
10	FDD	1700	Extended AWS blocks A-I	*66*	1710 – 1770	2110 – 2170	400	5, 10, 15, 20
11	FDD	1500	Lower PDC		1427.9 – 1447.9	1475.9 – 1495.9	48	5, 10
12	FDD	700	Lower SMH blocks A/B/C		699 – 716	729 – 746	30	1.4, 3, 5, 10
13	FDD	700	Upper SMH block C		777 – 787	746 – 756	-31	5, 10
14	FDD	700	Upper SMH block D		788 – 798	758 – 768	-30	5, 10
17	FDD	700	Lower SMH blocks B/C	*12*	704 – 716	734 – 746	30	5, 10
18	FDD	850	Japan lower 800	*26*	815 – 830	860 – 875	45	5, 10, 15
19	FDD	850	Japan upper 800	*26*	830 – 845	875 – 890	45	5, 10, 15
20	FDD	800	EU Digital Dividend		832 – 862	791 – 821	-41	5, 10, 15, 20
21	FDD	1500	Upper PDC		1447.9 – 1462.9	1495.9 – 1510.9	48	5, 10, 15
22	FDD	3500			3410 – 3490	3510 – 3590	100	5, 10, 15, 20
24	FDD	1600	L-Band (US)		1626.5 – 1660.5	1525 – 1559	-101.5	5, 10



E-UTRA Band	Duplex-Mode	ƒ (MHz)	Common name	Included in (subset of) Band	Uplink (UL) BS receive UE transmit (MHz)	Downlink (DL) BS transmit UE receive (MHz)	Duplex spacing (MHz)	Channel bandwidths (MHz)
25	FDD	1900	Extended PCS blocks A-G		1850 – 1915	1930 – 1995	80	1.4, 3, 5, 10, 15, 20
26	FDD	850	Extended CLR		814 – 849	859 – 894	45	1.4, 3, 5, 10, 15
27	FDD	800	SMR *(adjacent to band 5)*		807 – 824	852 – 869	45	1.4, 3, 5, 10
28	FDD	700	APT		703 – 748	758 – 803	55	3, 5, 10, 15, 20
29	FDD[A 1]	700	Lower SMH blocks D/E		*N/A*	717 – 728	*N/A*	3, 5, 10
30	FDD	2300	WCS blocks A/B		2305 – 2315	2350 – 2360	45	5, 10
31	FDD	450			452.5 – 457.5	462.5 – 467.5	10	1.4, 3, 5
32	FDD[A 1]	1500	L-Band (EU)		*N/A*	1452 – 1496	*N/A*	5, 10, 15, 20
33	TDD	2100	IMT	*39*	1900 – 1920		*N/A*	5, 10, 15, 20
34	TDD	2100	IMT		2010 – 2025		*N/A*	5, 10, 15
35	TDD	1900	PCS (Uplink)		1850 – 1910		*N/A*	1.4, 3, 5, 10, 15, 20
36	TDD	1900	PCS (Downlink)		1930 – 1990		*N/A*	1.4, 3, 5, 10, 15, 20
37	TDD	1900	PCS (Duplex spacing)		1910 – 1930		*N/A*	5, 10, 15, 20
38	TDD	2600	IMT-E (Duplex Spacing)	*41*	2570 – 2620		*N/A*	5, 10, 15, 20
39	TDD	1900	DCS-IMT gap		1880 – 1920		*N/A*	5, 10, 15, 20
40	TDD	2300			2300 – 2400		*N/A*	5, 10, 15, 20
41	TDD	2500	BRS / EBS		2496 – 2690		*N/A*	5, 10, 15, 20



E-UTRA Band	Duplex-Mode	ƒ (MHz)	Common name	Included in (subset of) Band	Uplink (UL) BS receive UE transmit (MHz)	Downlink (DL) BS transmit UE receive (MHz)	Duplex spacing (MHz)	Channel bandwidths (MHz)
42	TDD	3500			3400 – 3600		*N/A*	5, 10, 15, 20
43	TDD	3700			3600 – 3800		*N/A*	5, 10, 15, 20
44	TDD	700	APT		703 – 803		*N/A*	3, 5, 10, 15, 20
45	TDD	1500	L-Band (China)		1447 – 1467		*N/A*	5, 10, 15, 20
46	TDD	5200	U-NII		5150 – 5925		*N/A*	
47	TDD	5900	U-NII-4 (V2X)		5855 – 5925		*N/A*	
48	TDD	3600	CBRS		3550 – 3700		*N/A*	
65	FDD	2100	Extended IMT		1920 – 2010	2110 – 2200	190	5, 10, 15, 20
66	FDD	1700	Extended AWS blocks A-J (AWS-1/AWS-3)		1710 – 1780	2110 – 2200[3]	400	1.4, 3, 5, 10, 15, 20
67	FDD[A 1]	700	EU 700		*N/A*	738 – 758	*N/A*	5, 10, 15, 20
68	FDD	700	ME 700		698 – 728	753 – 783	55	5, 10, 15
69	FDD[A 1]	2600	IMT-E (Duplex spacing)		*N/A*	2570 – 2620	*N/A*	5
70	FDD	2000	AWS-4		1695 – 1710	1995 – 2020	295 – 300[4]	5, 10, 15
71	FDD	600	US Digital Dividend		663 – 698	617 – 652	-46	5, 10, 15, 20
72	FDD	450	PMR/PAMR Europe		451 – 456	461 – 466	10	1.4, 3, 5

Bands are very fragmented with passband 20-200 MHz allocated among many carriers

Max Channel Bandwidth 20MHz

Network Capacity Improvement

Larger Channel Bandwidth X **Higher Spectral Efficiency** = **Higher Capacity/ Higher Peak Speeds**

How good 4G can be ?

Max. 20MHz Channel BW

Carrier Aggregation (2X – 5X)

Downlink 100MHz (5 x 20MHz)
Uplink 40MHz (2 x 20MHz)

Higher Modulation level (16 QAM → 256QAM)

Multiple Input Multiple Output (MIMO) Antenna

Downlink up to 256 QAM, 4X 4 MIMO
Uplink up to 64 QAM, 2x2 MIMO

Downlink Theoretical max data rate ~2 Gb/s (using 5X CA, 256 QAM & 4x4 MIMO

Further enhancement in capacity/ peak data rate needs larger channel BW and/or higher Spectral Efficiency

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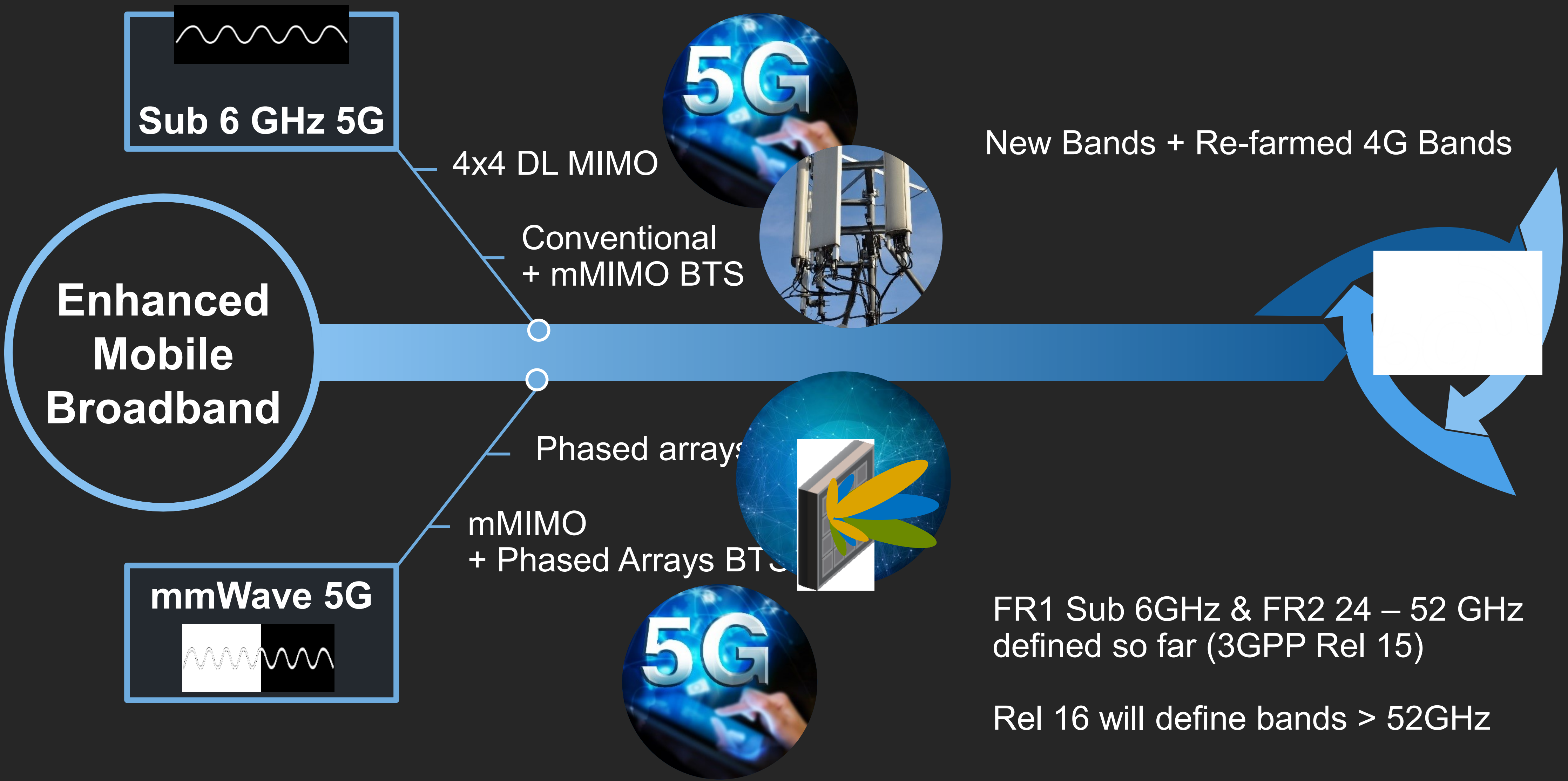
5G will have both sub 6GHz & mmWave Bands



Sub 6 GHz 5G

4x4 DL MIMO

Conventional
+ mMIMO BTS

Enhanced Mobile Broadband

Phased arrays

mMIMO
+ Phased Arrays BTS

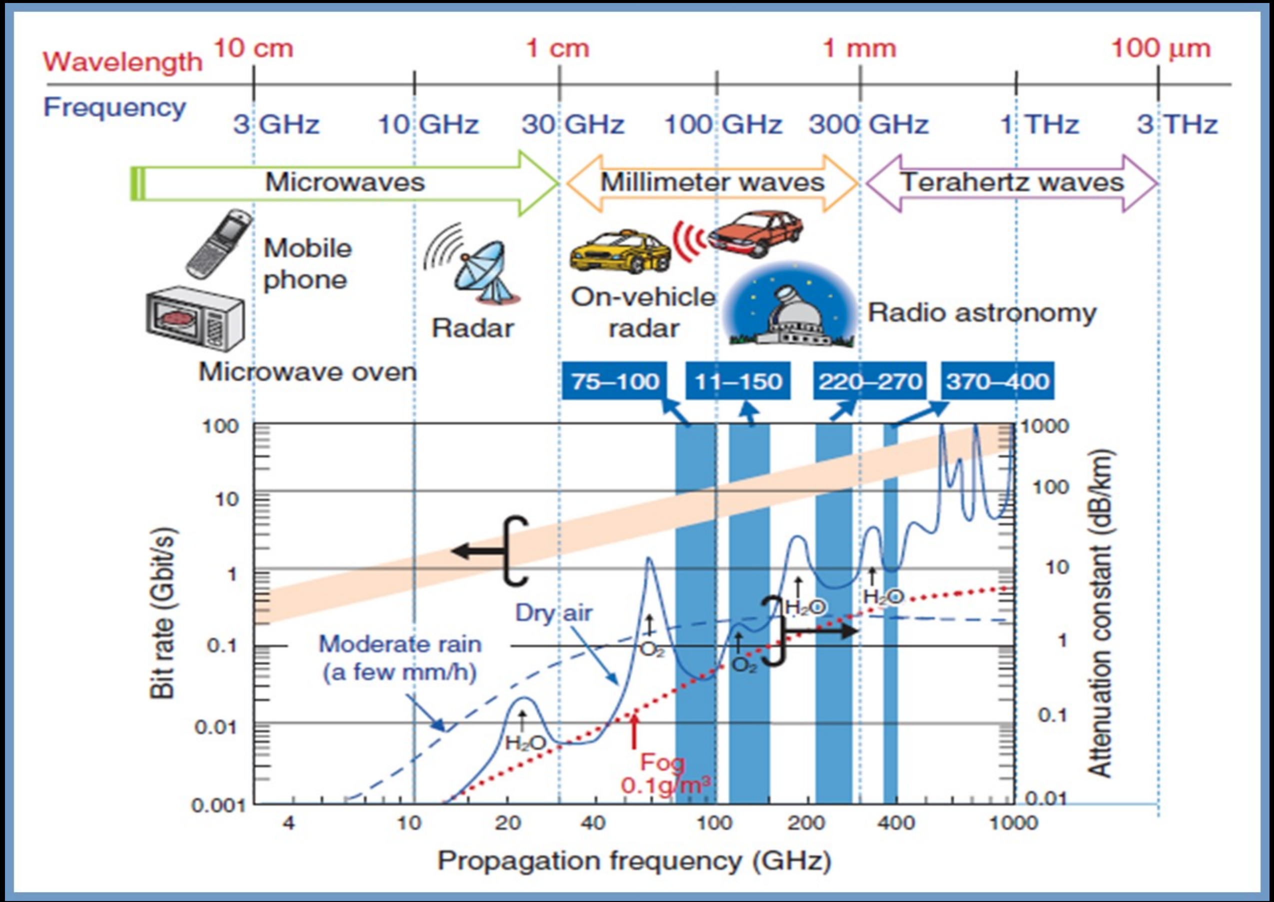
mmWave 5G

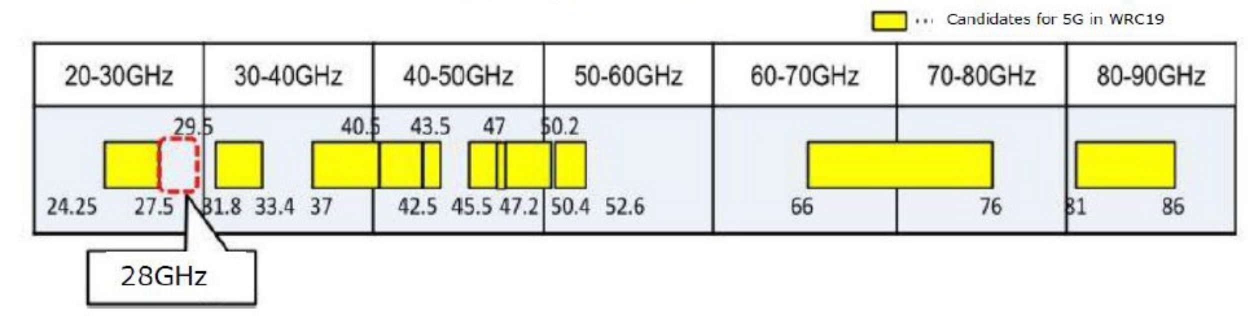
New Bands + Re-farmed 4G Bands

FR1 Sub 6GHz & FR2 24 – 52 GHz defined so far (3GPP Rel 15)

Rel 16 will define bands > 52GHz

Why mmWave?





- Contiguous Spectrum availability

  - much more than sub 6GHz

➡ Higher Channel bandwidth (defined up to 400MHz, can be more) and hence data rate

- High frequency / small wavelength

  - Smaller antenna, makes large arrays possible

➡ Highly directive beam enables spatial multiplexing (spectral efficiency)

Less interference and more efficient use of Tx/ Rx power

- High link loss

  - Atmospheric, Rain, foliage, building material absorption

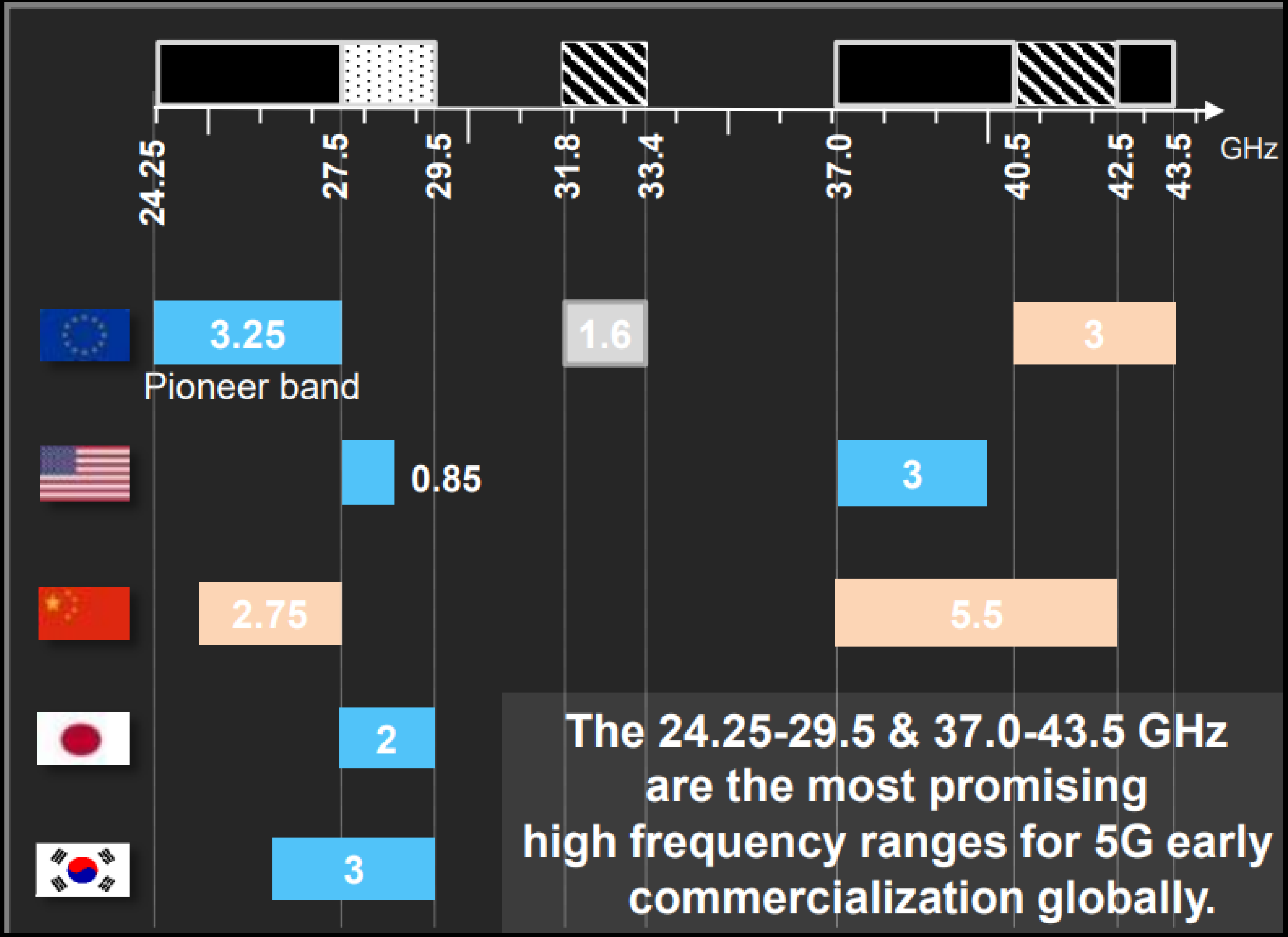
➡ Distance between Access point & User Equipment (UE) has to be small (< 100-200m)

5G mmWave Spectrum Candidates

Confirmed

Likely

TBD



The 24.25-29.5 & 37.0-43.5 GHz are the most promising high frequency ranges for 5G early commercialization globally.

Source: GSA , June, 2018

Beamforming & Steering by Phased Array Antenna System

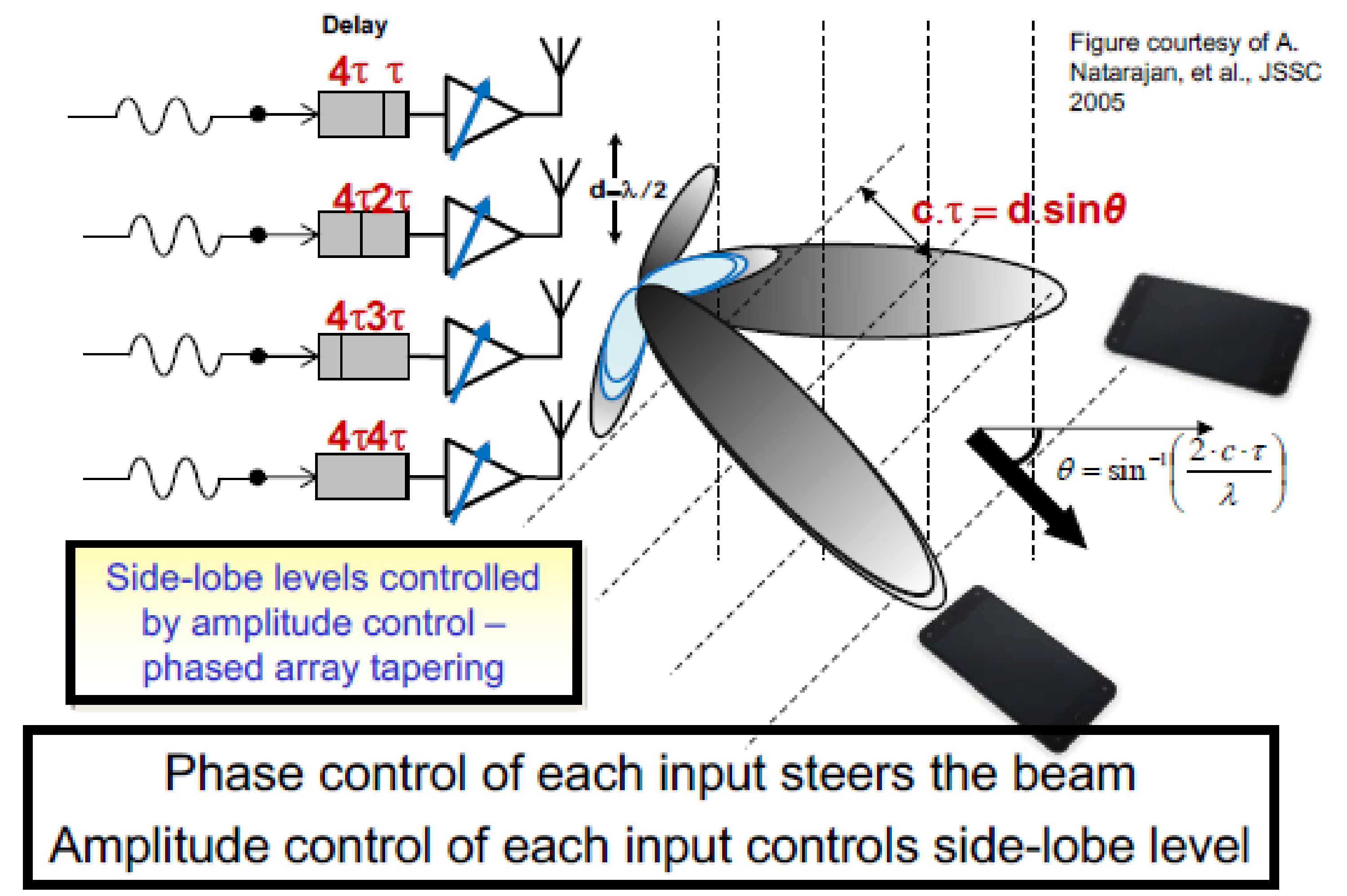


Figure courtesy of A. Natarajan, et al., JSSC 2005

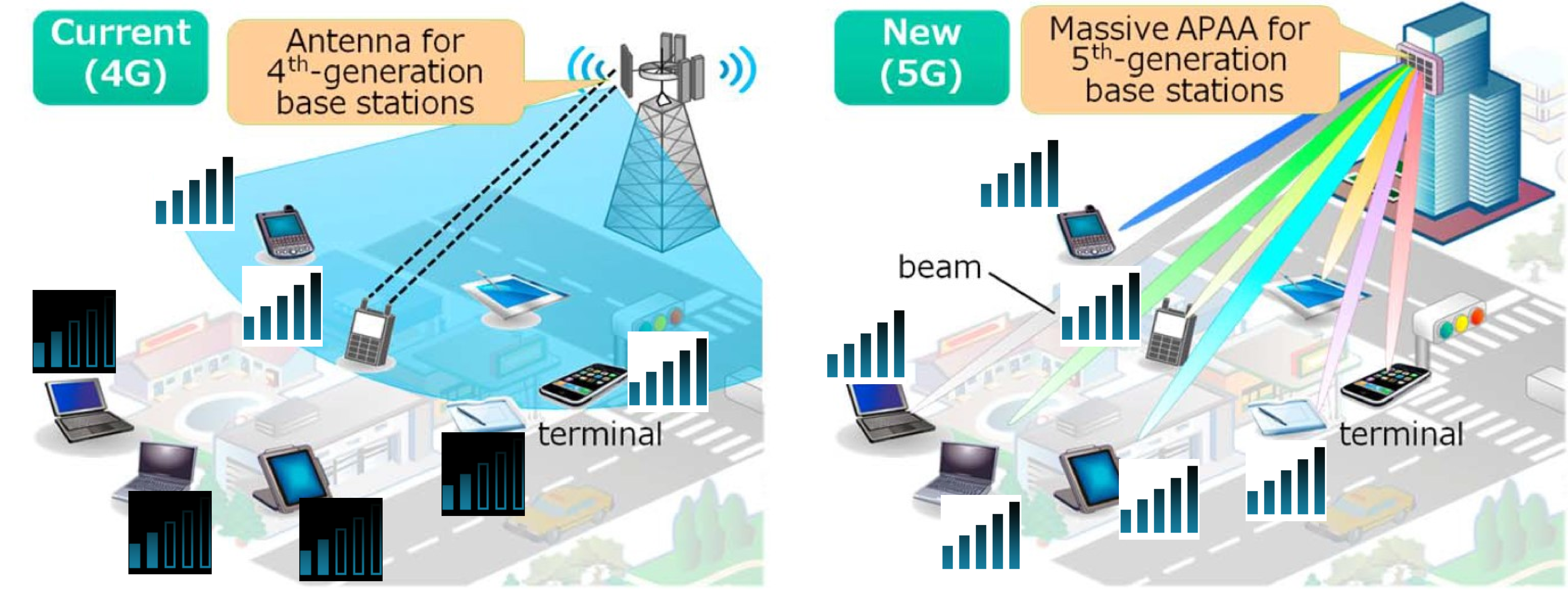
Side-lobe levels controlled by amplitude control – phased array tapering

Phase control of each input steers the beam

Amplitude control of each input controls side-lobe level

By locking each beam to an UE, a spatial multiplexing is achieved to increase Spectral efficiency and improve Signal-to-Interference Ratio

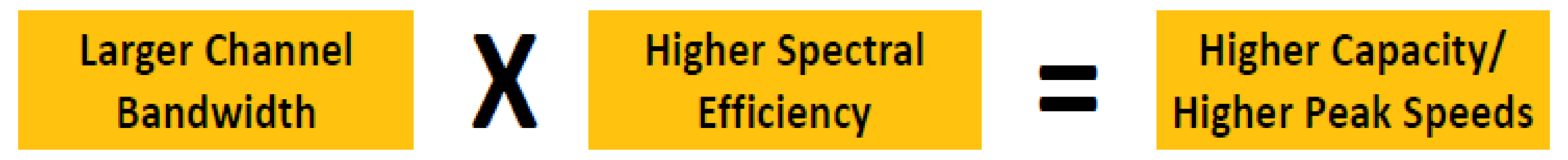
4G vs mmWave 5G Radio Access Network (RAN)



Source: Mitsubishi Electric

mmWave enables excellent spatial selectivity and hence high spectral efficiency & low interference

Capacity Improvement using mmWave 5G



Larger Channel Bandwidth X Higher Spectral Efficiency = Higher Capacity/ Higher Peak Speeds

Channel BW 50-400MHz

(4G max. 100MHz using 5X CA)

Spatial Multiplexing using Beamforming (8-16 Beams)

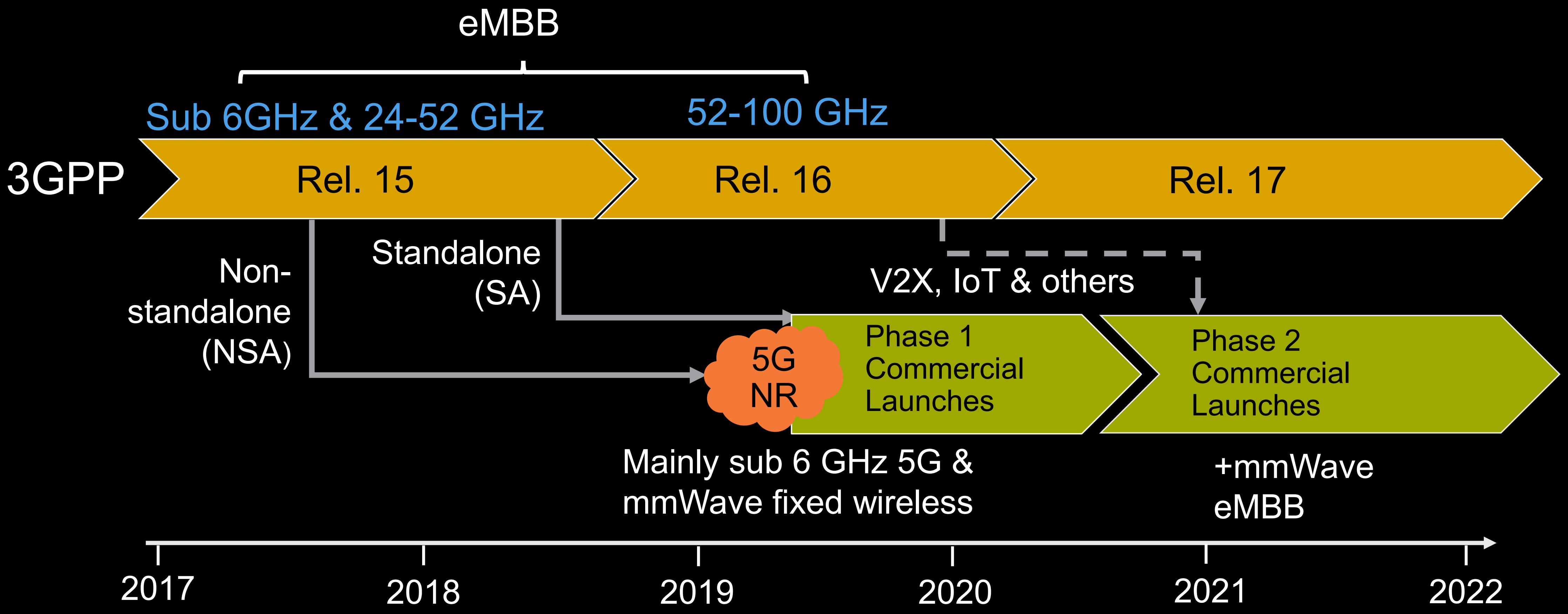
(4G 4x4 MIMO provides 4 data streams)

Might use lesser order Modulation to start with (64QAM instead of 4G 256QAM)

At least 5-10X of 4G

~10-20Gb/s

Timeline for 5G deployment



mmWave-based enhanced mobile broadband in UE will be widespread during phase 2 of 5G launch

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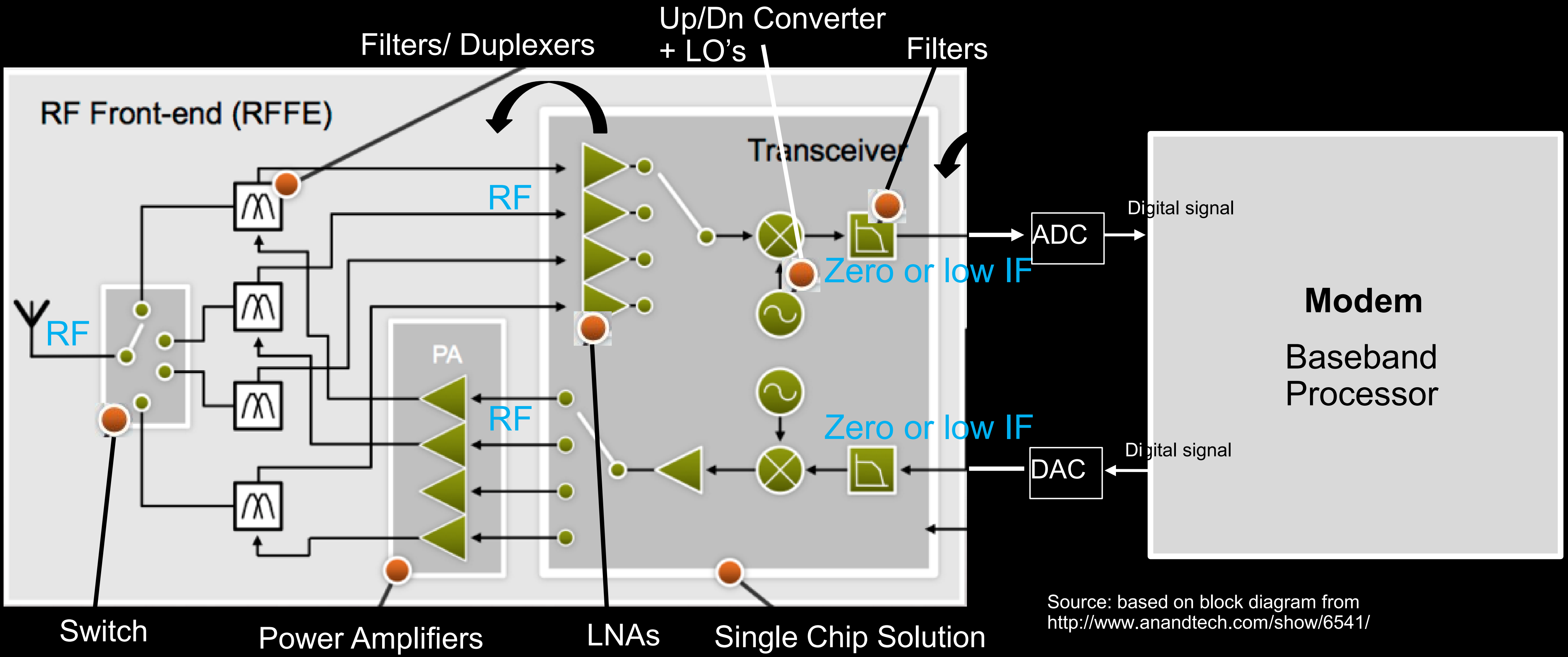
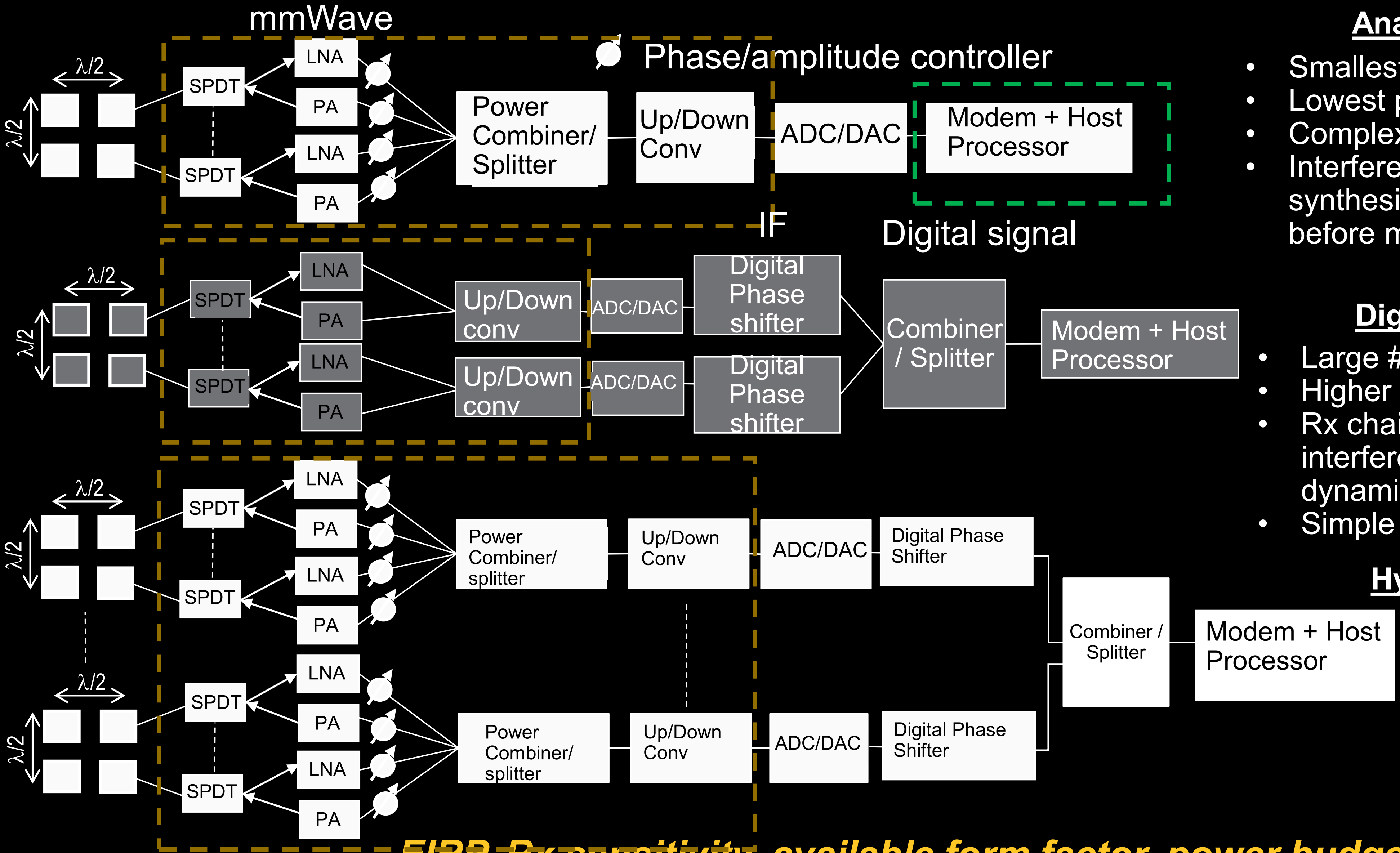
Current Cellular Radio Interface Architecture



Source: based on block diagram from http://www.anandtech.com/show/6541/

- Today’s most high tier LTE handsets have LNA’s in RFFE to increase Rx sensitivity
- Transceiver is a single-chip solution currently most system on 28nm, QTI has 14FF based transceiver for higher CAT (16+) 4G handsets
- CAT 16+ 4G (and sub 6GHz 5G) Handsets will need many LO generators to support 4x4 MIMO, high order CA

Different Beamforming Architectures



Analog Beamforming

- Smallest #components
- Lowest power dissipation
- Complexity in phase shifting
- Interference rejection (signal synthesized in power combiner before mixer)

Digital Beamforming

- Large # components
- Higher power dissipation
- Rx chains see spatial interference (requires high dynamic range)
- Simple to implement

Hybrid Beamforming

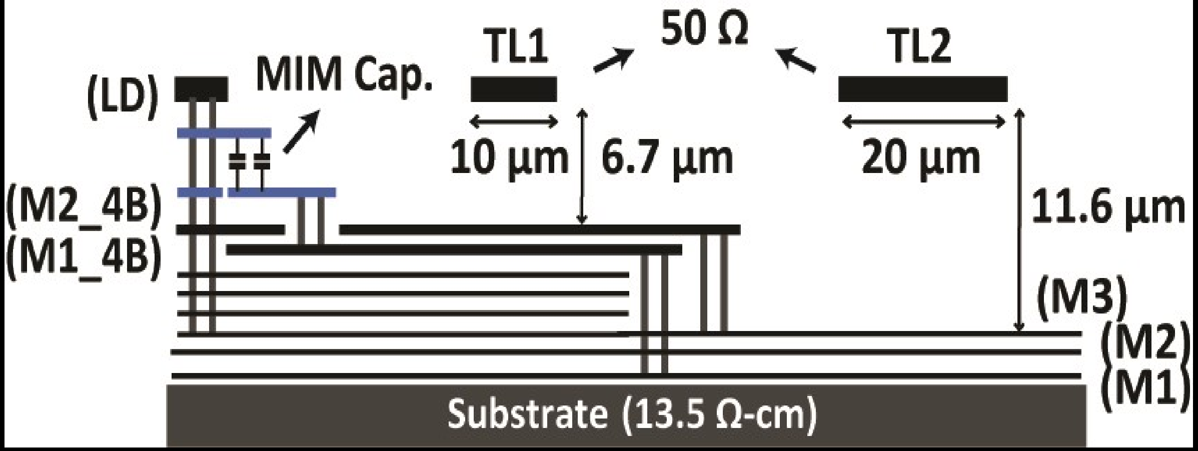
For large arrays where analog & digital beamforming are inefficient and complex

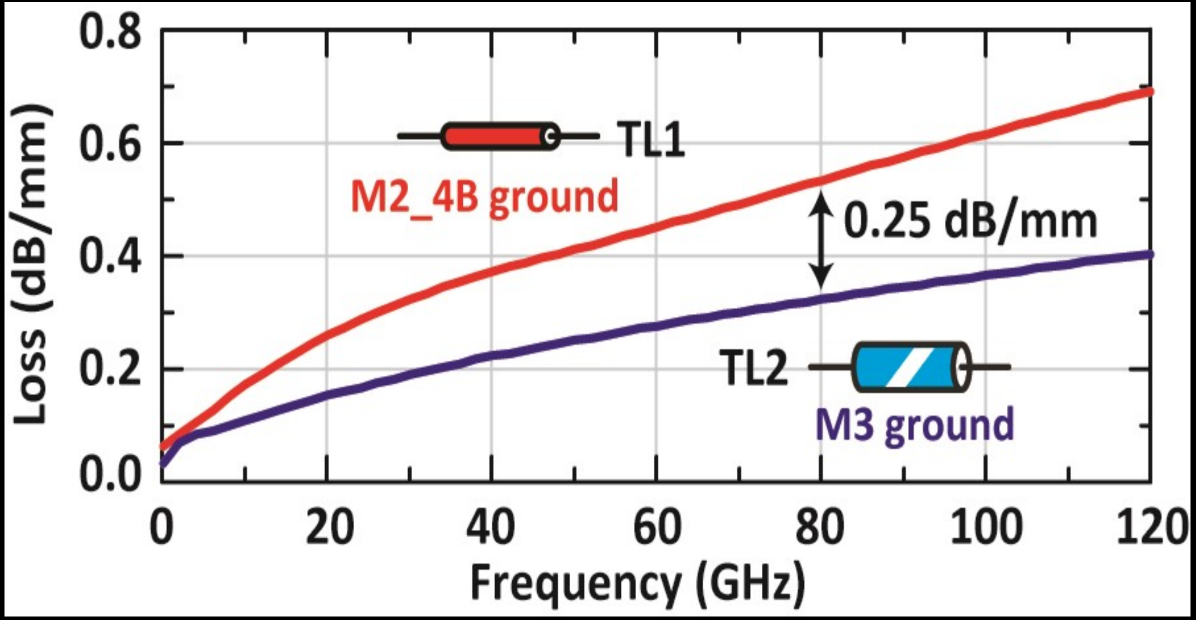
EIRP, Rx sensitivity, available form factor, power budget determine array size and beamforming architecture for a particular mmWave application

Transmission Lines Loss: Distance to Ground Plane

- Transmission line loss increases with frequency
  - Skin effect
  - Eddy current loss in substrate

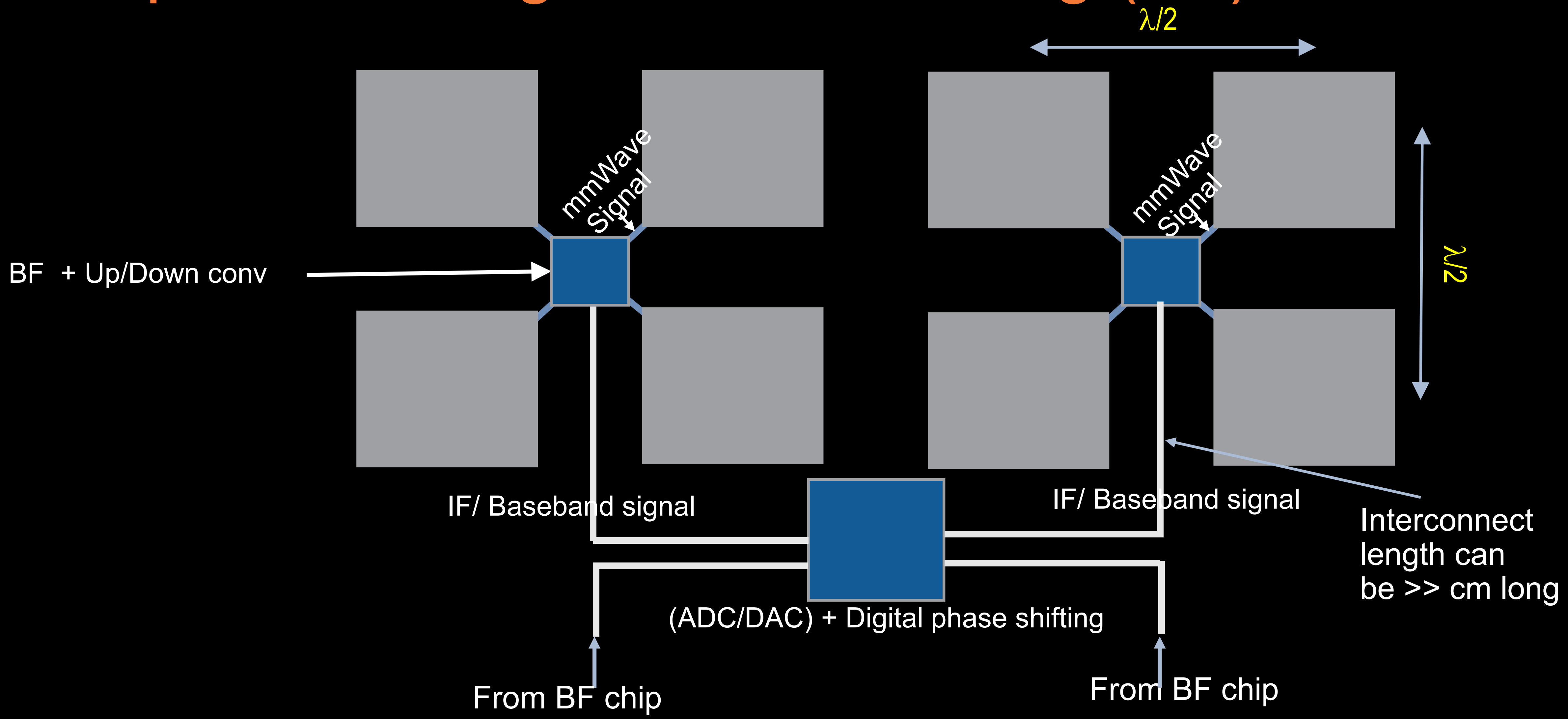
- Thick Top metals (more than skin depth)
- Ground plane in BEOL prevents fields from entering substrate
- Distance from Ground Plane helps
- Higher substrate resistivity up to a level (~200Ohm-cm) helps





Source: Prof. Gabriel Rebeiz, UCSD on 90nm SiGe

Chip Partitioning for Beamforming (BF)



- *For large 2D, linear array or where Transceiver is several cm away from FEM, the mmWave signal should be converted to IF / baseband in the nearest proximity of BF chip to avoid huge loss due to long interconnect*
- *In case of monolithic analog BF + Up/down converter, the on-chip interconnect loss is a key parameter*

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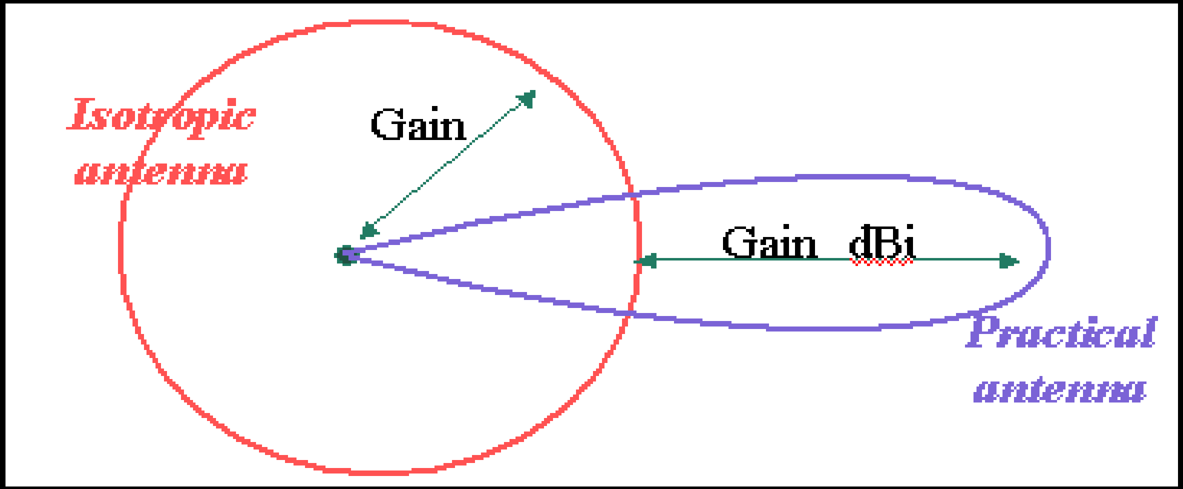
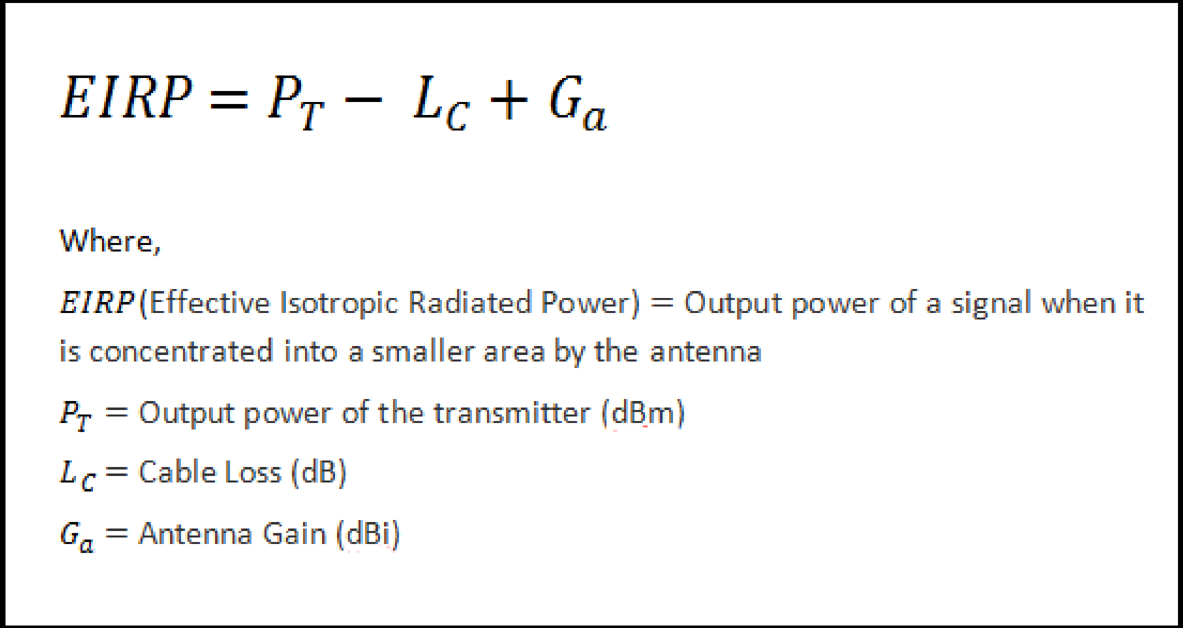
EIRP Definition

Equivalent Isotropic Radiated Power (EIRP) is the product of transmitter power and the antenna gain in a given direction relative to an isotropic antenna of a radio transmitter.

It is the power that an isotropic (omnidirectional) antenna would have to transmit to match the directional reception

Normally the EIRP is given in dBi, or decibels over isotropic.





$$EIRP = P_T - L_C + G_a$$

Where,

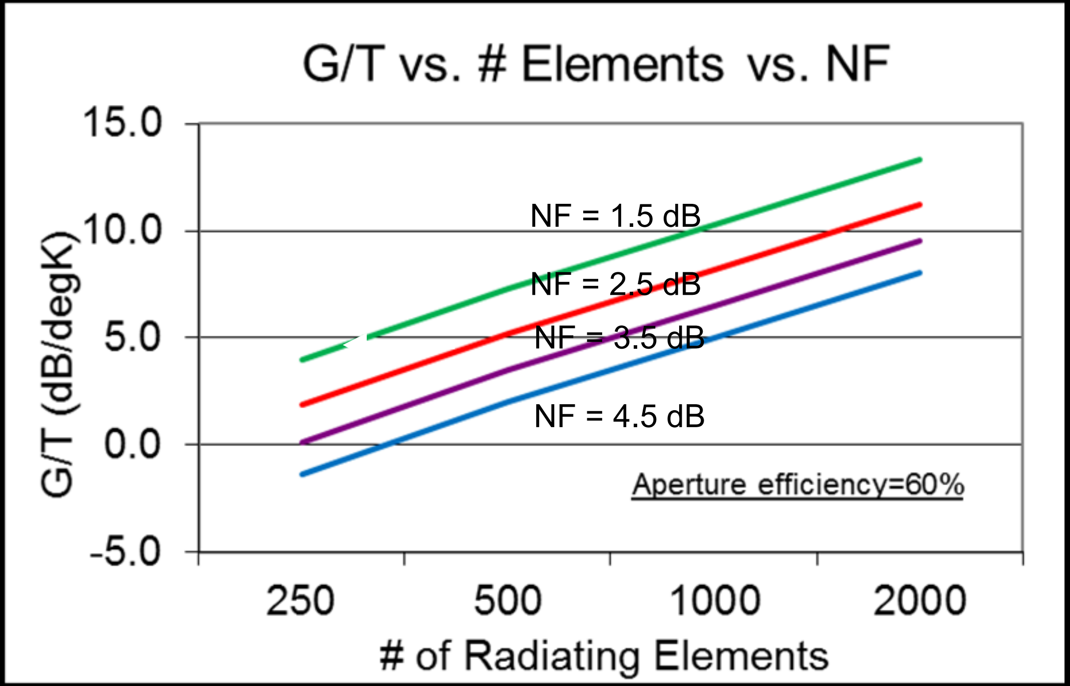
$EIRP$ (Effective Isotropic Radiated Power) = Output power of a signal when it is concentrated into a smaller area by the antenna

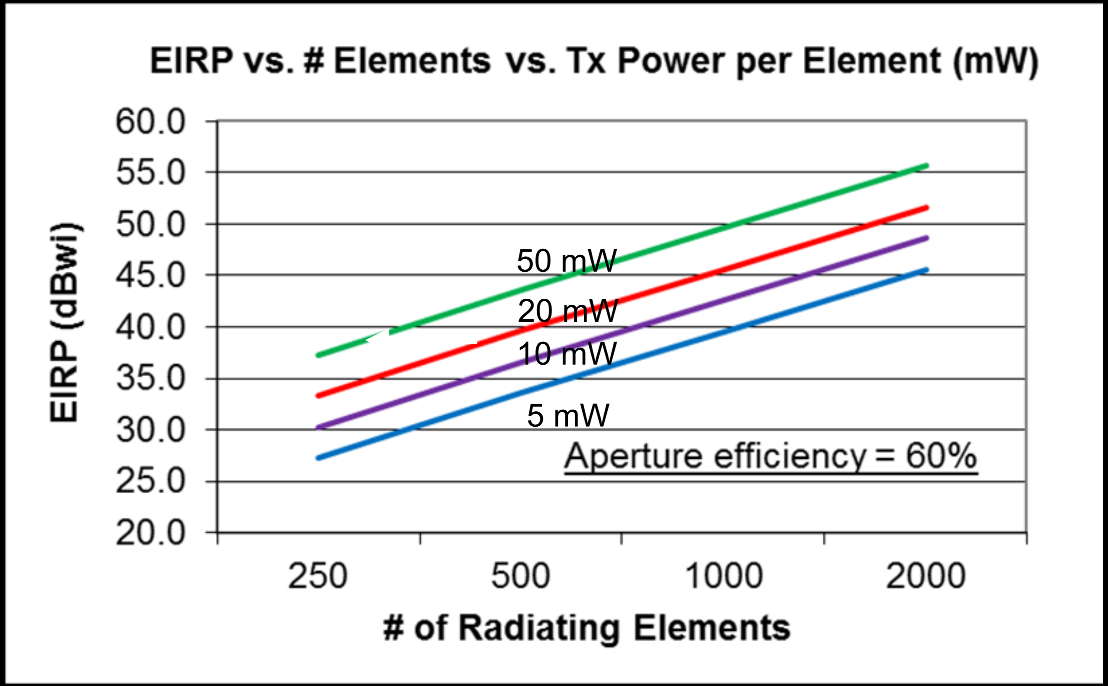
P_T = Output power of the transmitter (dBm)

L_C = Cable Loss (dB)

G_a = Antenna Gain (dBi)

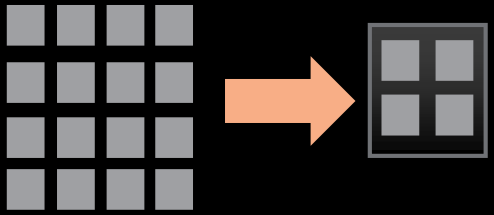
Impact of Semiconductor Technology on Array Size





Source: Anokiwave webinar

Technology with better Rx noise figure and higher per element Tx power output will need fewer array elements for a target Rx antenna G/T and Tx antenna EIRP, respectively

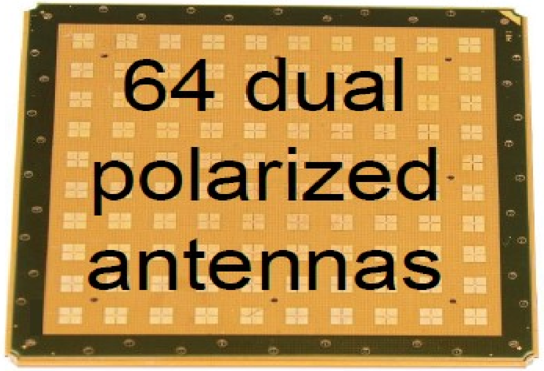


Technology with better FOM ⇨ smaller array ⇨ LOWER COST & AREA

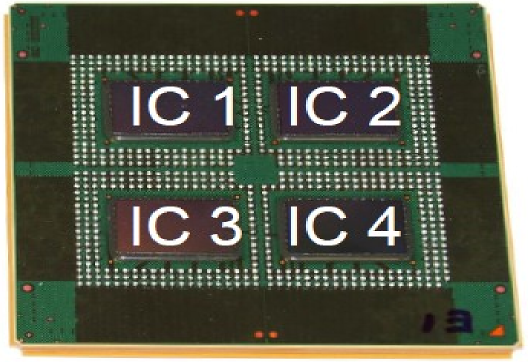
EIRP Example

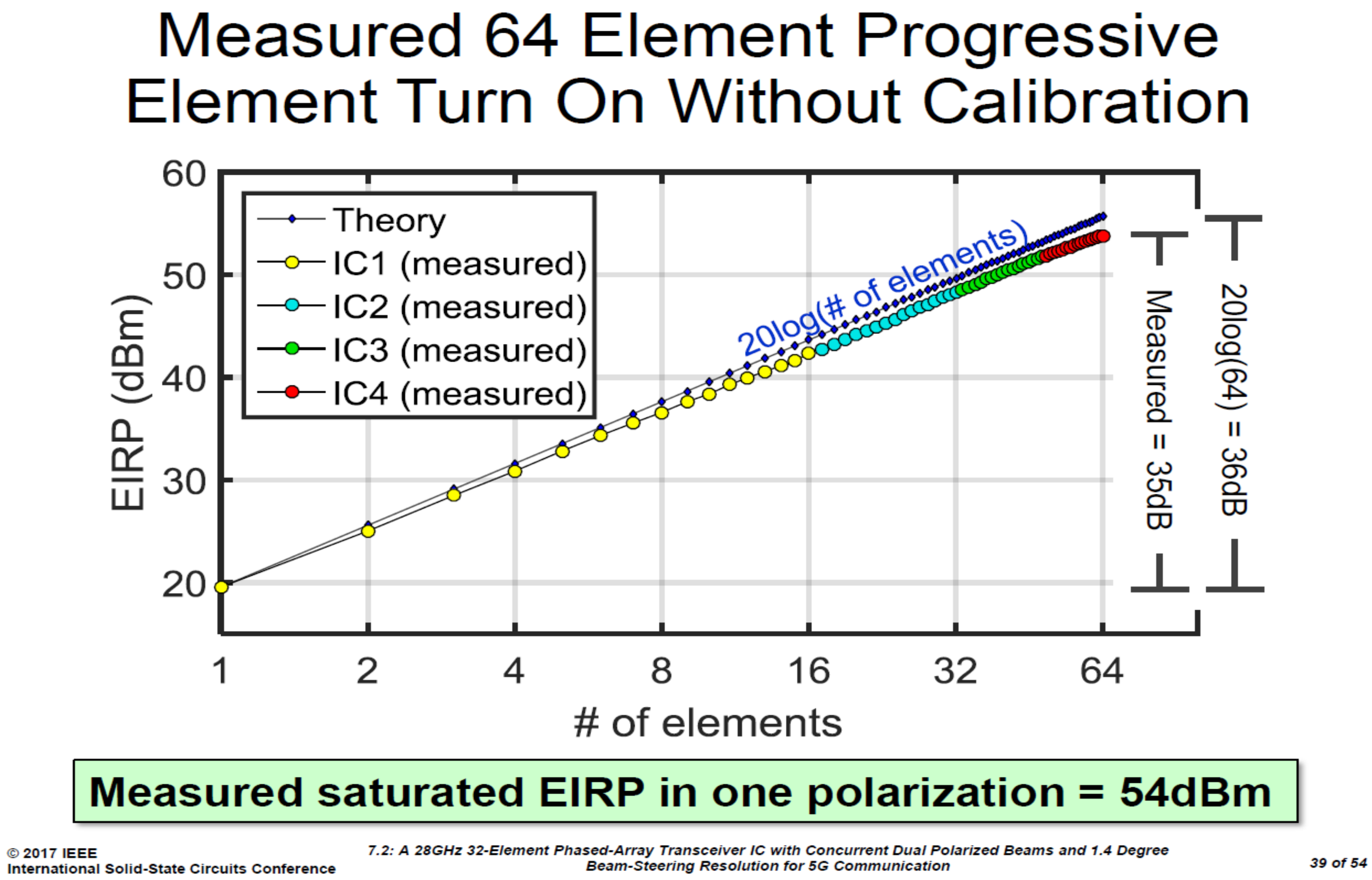
IBM/Ericsson 28GHz 64-Element Phased Array in 130nm SiGe (8HP)

Package top



Package bottom





Measured 64 Element Progressive Element Turn On Without Calibration

Measured saturated EIRP in one polarization = 54dBm

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7.2: A 28GHz 32-Element Phased-Array Transceiver IC with Concurrent Dual Polarized Beams and 1.4 Degree Beam-Steering Resolution for 5G Communication

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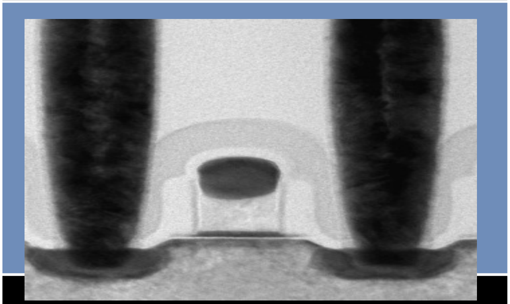
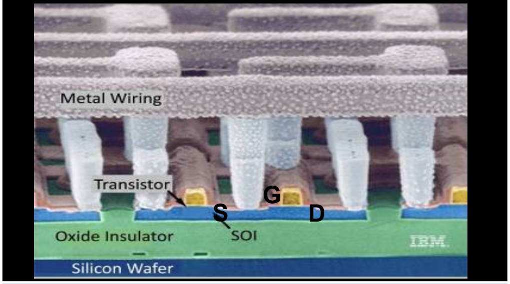
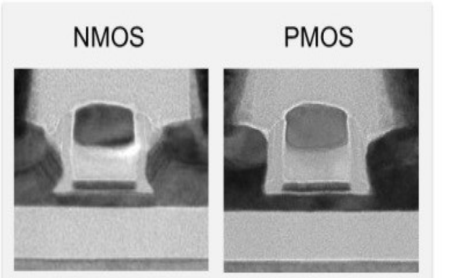
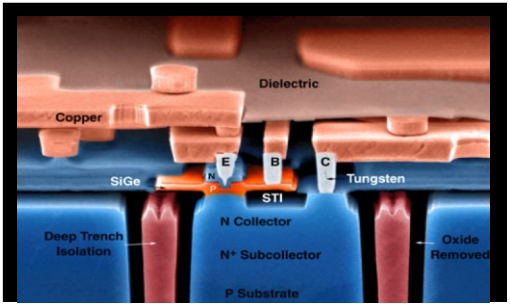
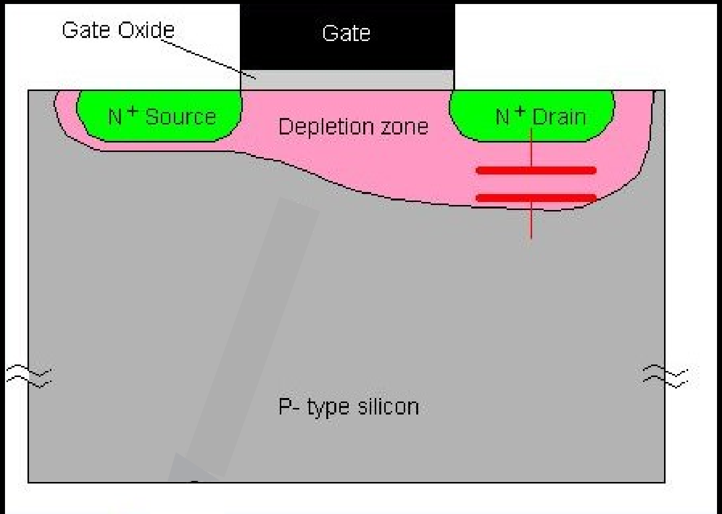
Silicon Technologies for mmWave 5G Radio Interface

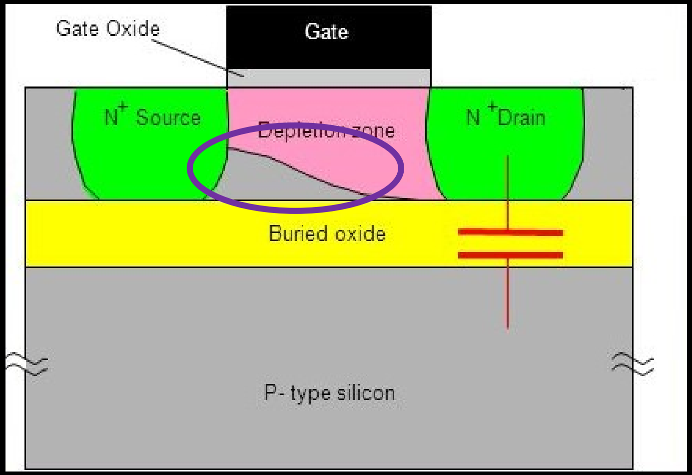
Technology	Key Features	Device Cross-Section
RF CMOS (65nm - 28nm)	• High-volume logic process technology base with multiple foundries • Comprehensive IP offerings for System-on-Chip (SOC) • Traction in mmWave markets: WiGig 802.11ad (60GHz), 77GHz auto radar	
PD-SOI (45nm)	**PD-SOI = Partially Depleted Silicon on Insulator** • **High-speed w/ lower junction capacitance, isolation & stacking** • 180nm RF SOI extensively used in cellular & Wi-Fi FEM • Early adoption in 5G & Sat Comm for 45nm PDSOI with highest Ft/Fmax & optimum BEOL stack	
FD-SOI (28nm - 22nm)	**FD-SOI = Fully Depleted Silicon-on-Insulator** • Delivers FinFET-like performance and power-efficiency at 28/22nm cost • **Transistor body-biasing for flexible trade-off between performance and power** • Enables applications across mobile, IoT and mmWave markets	 Electron micrograph of GF 22FDX transistors
SiGe (130nm - 90nm)	**SiGe = Silicon Germanium** • Based on higher performance & power tolerant HBT (vs FET) • **Technology optimized for micro and mmWave applications:** backhaul, E-band links, Sat Comm, automotive radar, A&D	

Bulk , PDSOI & FDSOI FET Devices

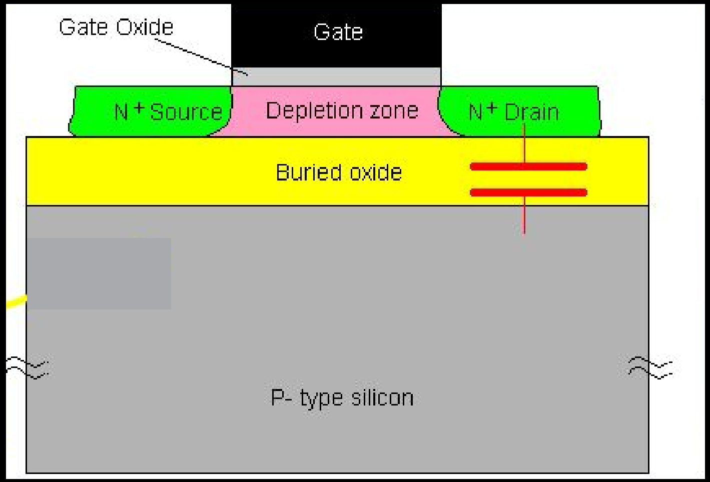
-2.0V to +2.0V
Body-Biasing



Bulk
NFET



Partially Depleted Silicon-On-Insulator (PDSOI) NFET



Fully Depleted Silicon-On-Insulator (FDSOI) NFET

- Depending on thickness above Buried Oxide, Silicon under the Gate can be partially or fully depleted of carriers
- Both PDSOI & FDSOI enable stacking of FET for high voltage(Power) tolerance

Essential Elements for a Silicon Technology for mmWave

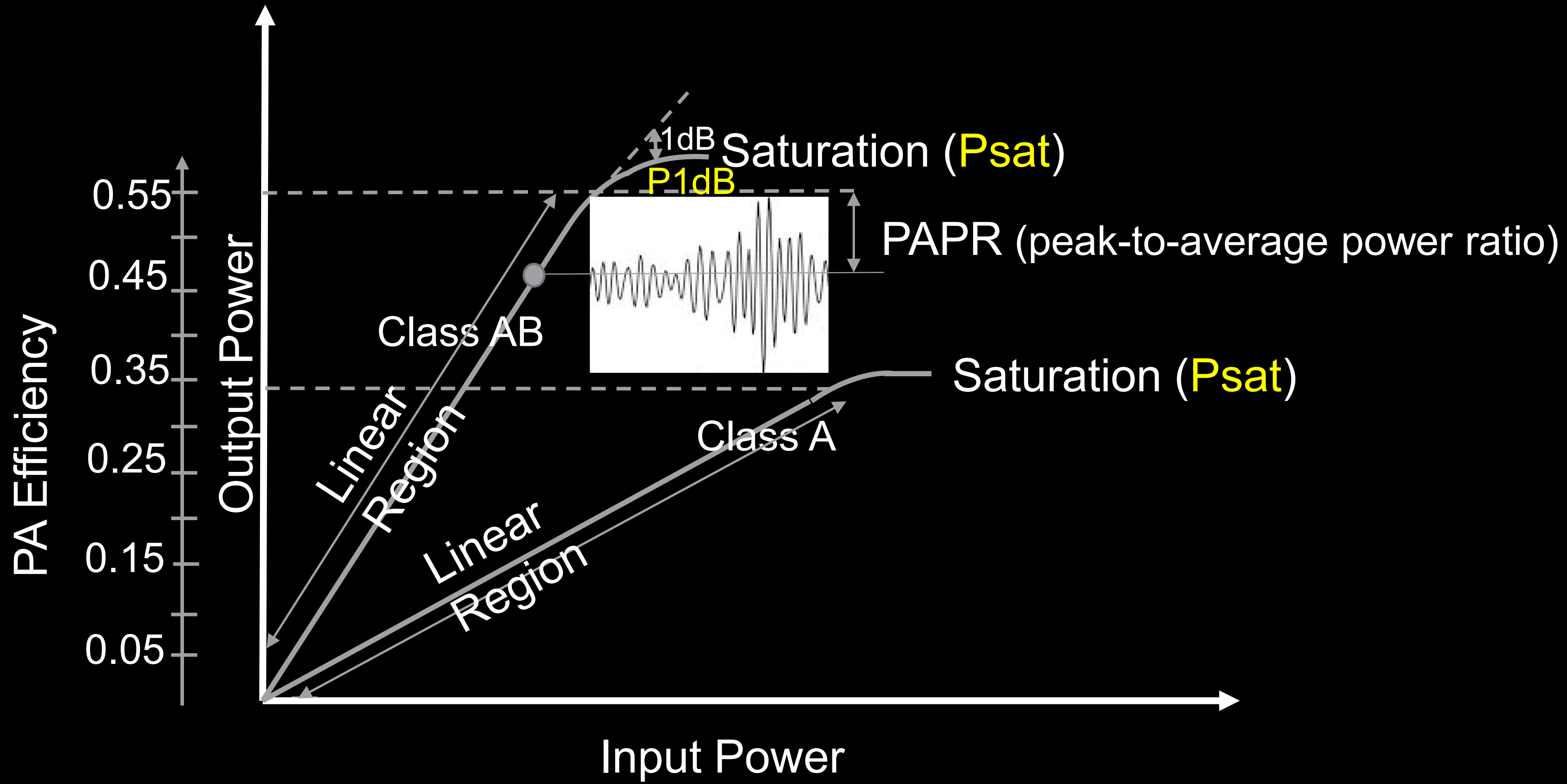
- High-performance technology
  - Higher performance enables design flexibility & techniques for a more robust design
  - f_T / f_{MAX} should be at a minimum 3x and preferably > 5x application frequency
  - RF FOMs (Self Gain, Gain efficiency, Ft/Fmax, Nfmin, 1/f noise) appropriate for target mmWave applications

- Low loss BEOL (metal and dielectric stack)
  - Thick top metal(s)
  - Distance to substrate
  - Substrate resistivity

- Well-modeled (including EM simulation) mmWave technology
  - mmWave model-to-hardware correlation is key to minimize design iterations

- Reliability and Ruggedness
  - Devices and components proven reliable and rugged over the voltage, temperature ranges

Power Amplifier – Psat, P1dB, Efficiency



- *PA Efficiency increases with Input power level*
- *PA linearity requirement and signal PAPR for the application determine the operating point back off from saturation*
- *PA Efficiency at operating point matters*

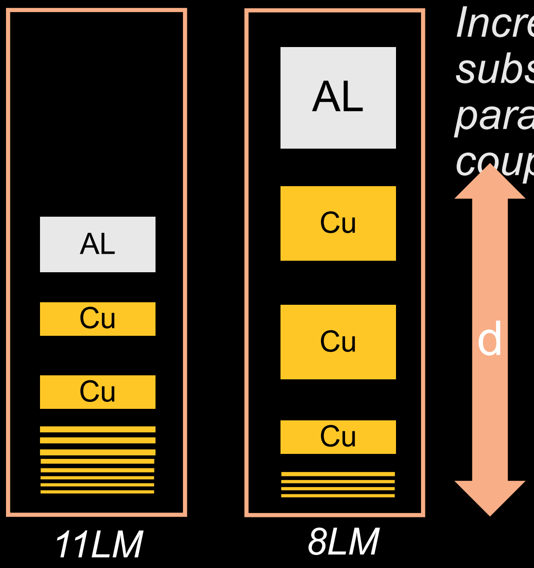
45RFSOI BEOL Is Optimized to Provide Benefits for Millimeter Wave Operation

1 Raised thick Cu levels:

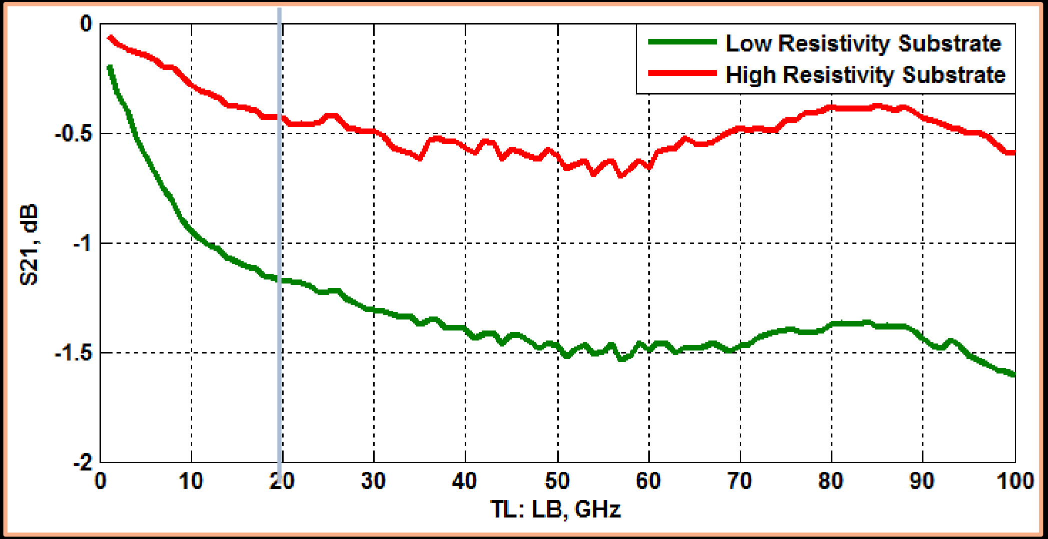
- High Q inductors and transformers
- Low loss transmission lines
- High Q MIMs; high density MIMs or APMOMs
- Dual thick Cu levels provide design flexibility

2 High resistivity trap rich substrate:

- Improves back-end-of-line (BEOL) losses due to parasitics (~0.8dB reduction in TL IL per mm @ 28 GHz)
- Reduces harmonics due to trap rich substrate for improved linearity

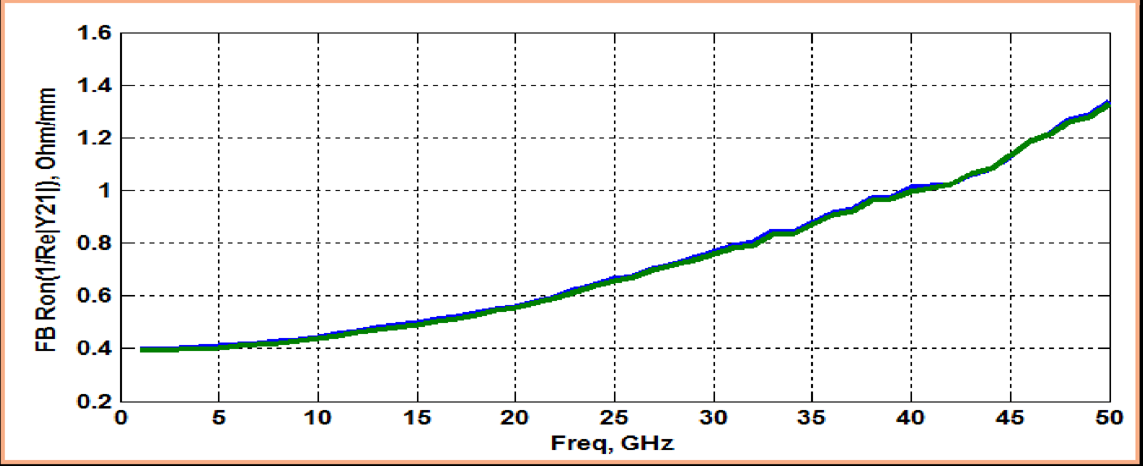


Increased 'd' to substrate reduces parasitics / coupling

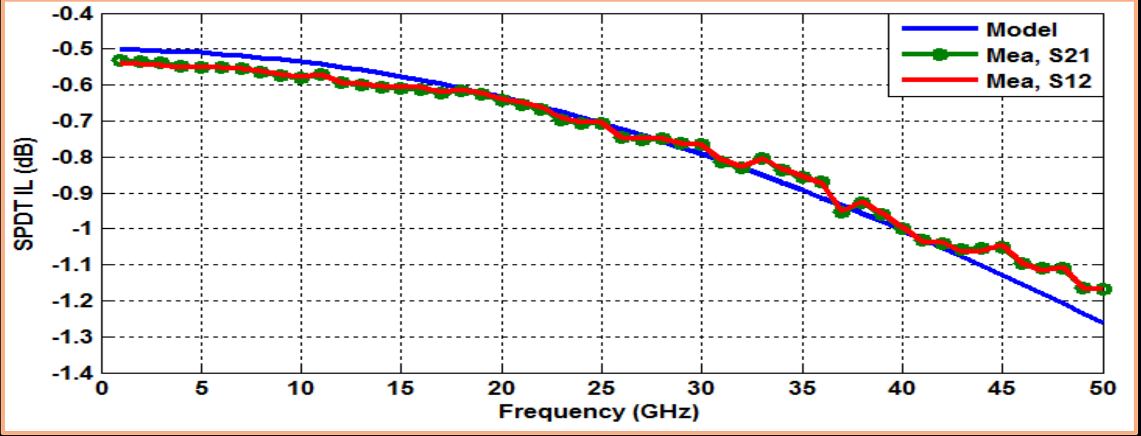


BEOL IL comparison with different substrates

45RFSOI : High Performance mmWave Switches



Measured Ron versus Frequency



Measured SPDT IL versus Frequency

- RonCoff ~90 fS
- 28 GHz SPDT 3 stack
  - IL 0.76 dB
  - Iso: 23 dB
  - Pmax: 23 dBm
  - One tone IIP3 49.5 dBm
- HR substrate provides improved parasitics over bulk

Number of stacks	IL @ 28/50 GHz (dB) W/Open	Iso @ 28/50 GHz (dB) W/Open	IP1dB (dBm) at 14 GHz	IIP3 (dBm) at 14 GHz
3	0.76/1.17	23.91/17.06	30	49.5
4	0.91/1.18	24.14/17.94	32	48.7
5	0.98/1.13	24.81/19.16	33	48.4

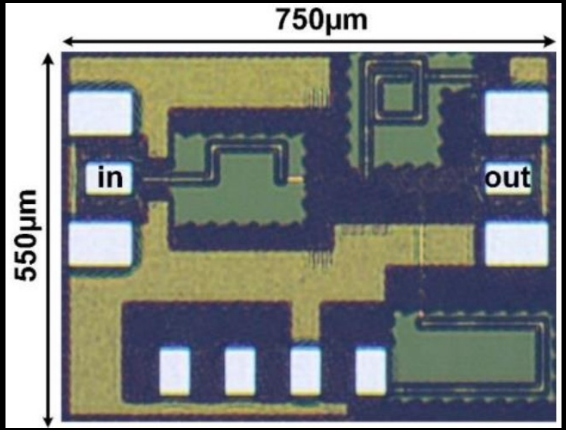
Source: Globalfoundries test results

45RFSOI differentiated silicon results: 23dBm Psat@42% PAEmax

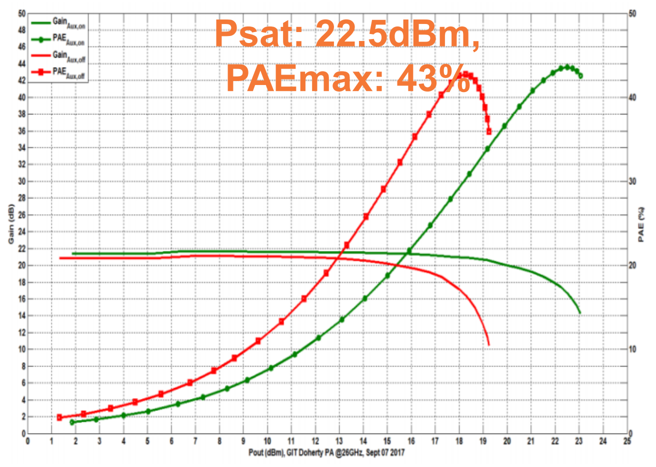
28 GHz LNA/PA/switch silicon results

PA	**PAE at Psat**	**Psat**	**Gain**
GF Single ended PA	41.5%	16.2 dBm	13 dB
Differential PA** (26 GHz)	42%	23 dBm	21 dB
Differential PA** (26 GHz)	37%	22.2 dBm	21 dB
LNA	**Gain**	**IIP3**	**NF**
GF Reference 45RFSOI designs	13 dB	4.3 dBm	1.3 dB
Switch	**Insertion Loss**	**Isolation**	**OIP3**
GF Reference 45RFSOI designs (RonCoff = 90 fs, 1 V)	0.65 dB	26 dB	46 dBm

** Georgia Tech



Silicon Verified Results


Psat: 22.5dBm, PAEmax: 43%

22FDX® Technology: Optimized for mmWave SoC

Low Power, High Density Logic Integration (Forward & Reverse Body Bias)

High F_{max}

1.2X > 28 nm

High mmWave self gain

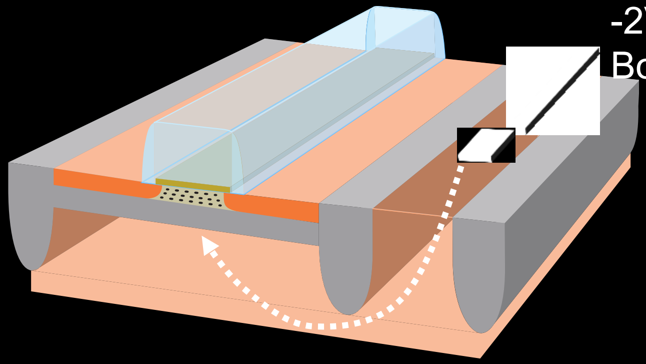
2.5x > 28 nm

Low mmWave noise

NFmin < 28nm

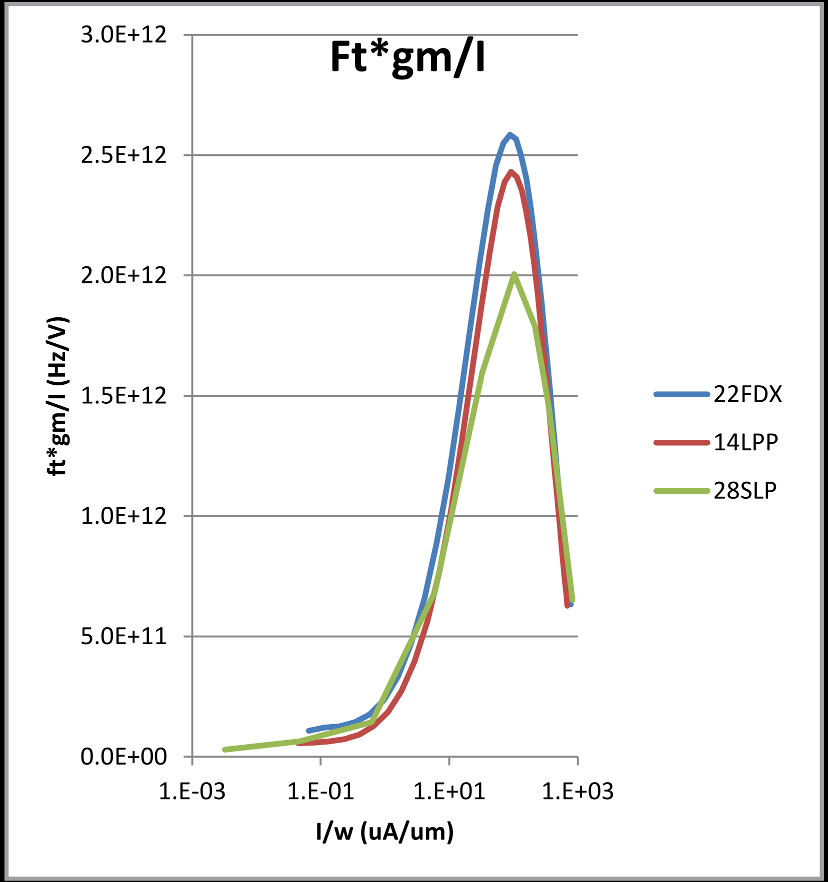
“mmWave FET stacking“ enables single chip mmWave integration

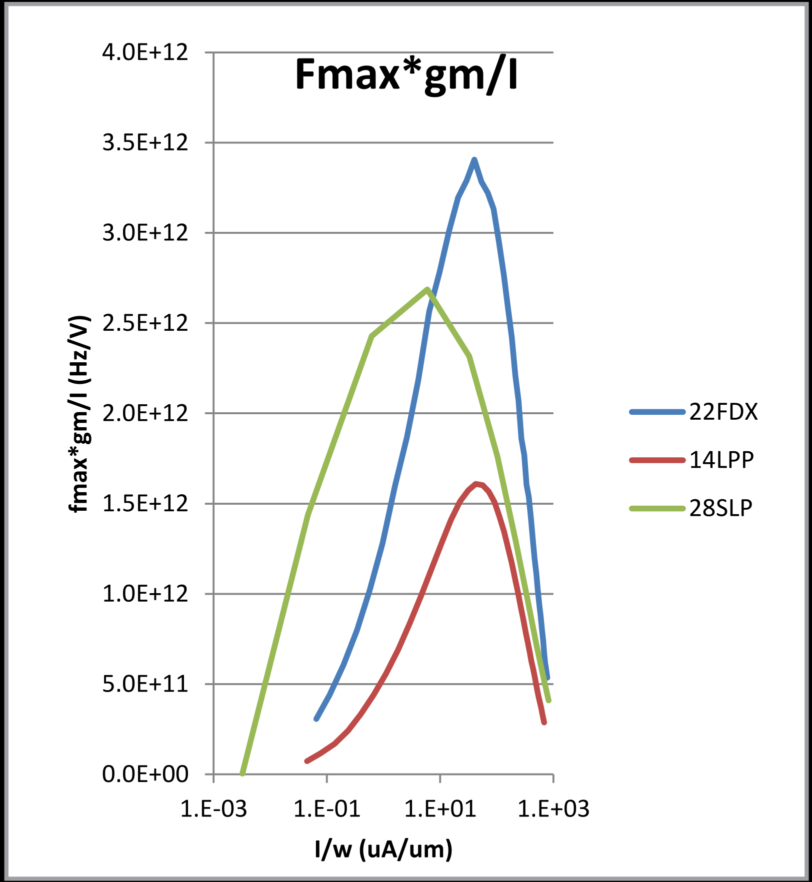
Single stage PA P_{out} >> 28 nm or much smaller die area for same EIRP



-2V to +2V Body-Biasing

22FDX Enables Lowest Power Consumption for mmWave Applications





For mmWave LNA, mixer circuits, 22FDX has 30% higher performance and 16% lower current than 28nm

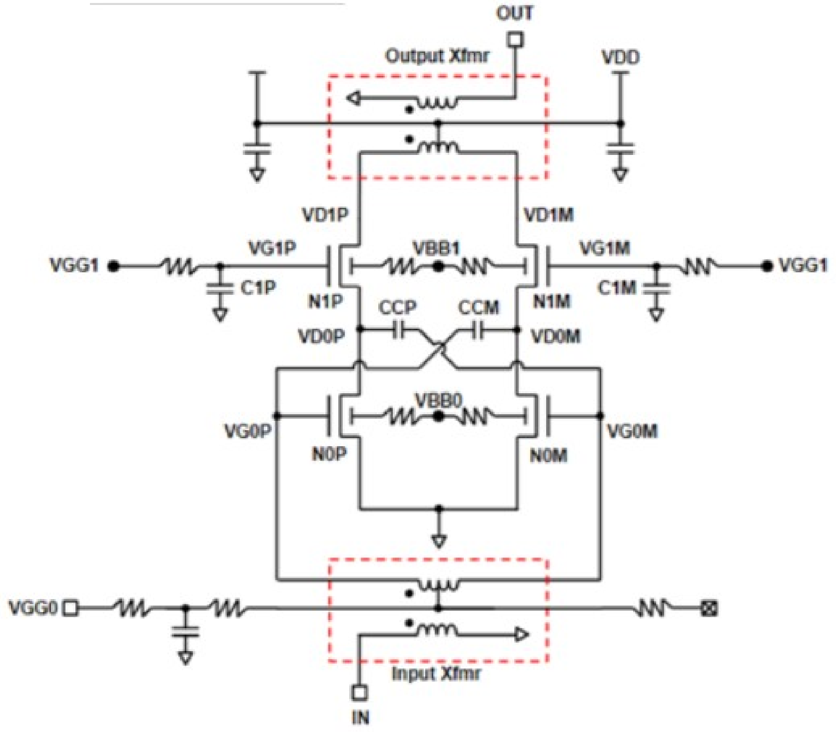
For mmWave PA circuits, 22FDX far outperforms any other CMOS node

Source: Globalfoundries test results

22FDX® based 5G 28 GHz differential PA

High efficiency, high gain amplification

MPW2217 PA (2-Stack) Schematic



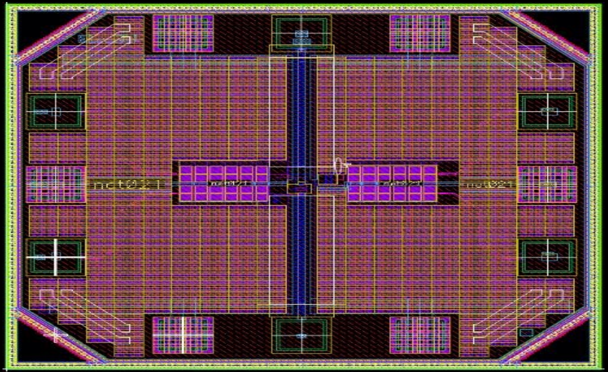
- All designs metal stack # 11
- Ruggedness stress tested at VSWR 5:1; Tests ongoing

Parameters	Measured	Measured
Stacking	3-Stack PA	2-Stack PA
S21 peak freq (GHz)	27.8	29
IDDQ (mA)	15.9	15.8
Gain (dB)	12.4	12.7
P1dB (dBm)	17.4	15.8
Psat/P3dB (dBm)	18.2	16.4
PAE_Psat-6dB (%)	18.3	20.8
PAE_peak (%)	30.2	41.0
S11	-10.6	-9.9
S22	-2.1	-1.2
Ruggedness Passed	18 dBm	15 dBm

Source: Globalfoundries test results

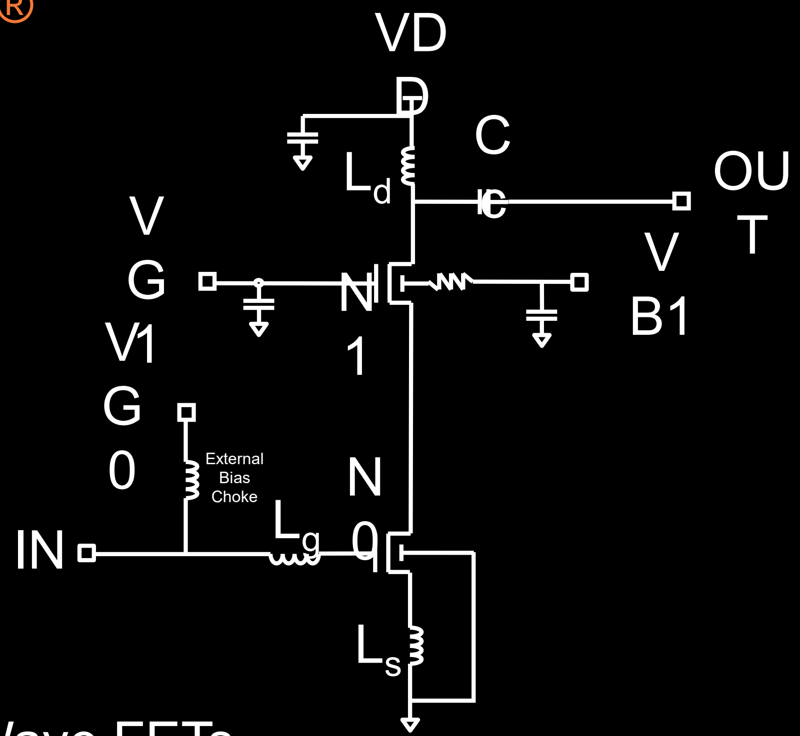
PA is the fulcrum around which 5G architecture revolves and 22FDX enables BIC PA performance for Integrated RF SOC

Measured switch & LNA performance on 22FDX®



Freq.	28 GHz	40 GHz
S21 (dB)	-0.95	-1.25
S11 (dB)	-13	-11
S21 (dB) OFF	-25.3	-21.5
IIP3 (dBm)	45	44

3-stacked switch architecture with power handling up to 23 dBm @ 4:1 VSWR



22FDX® mmWave FETs

- <10 mW power consumption
- NF 2.6 dB @ 28 GHz in 1st generation
- NF <2 dB @ 28 GHz in 2nd gen

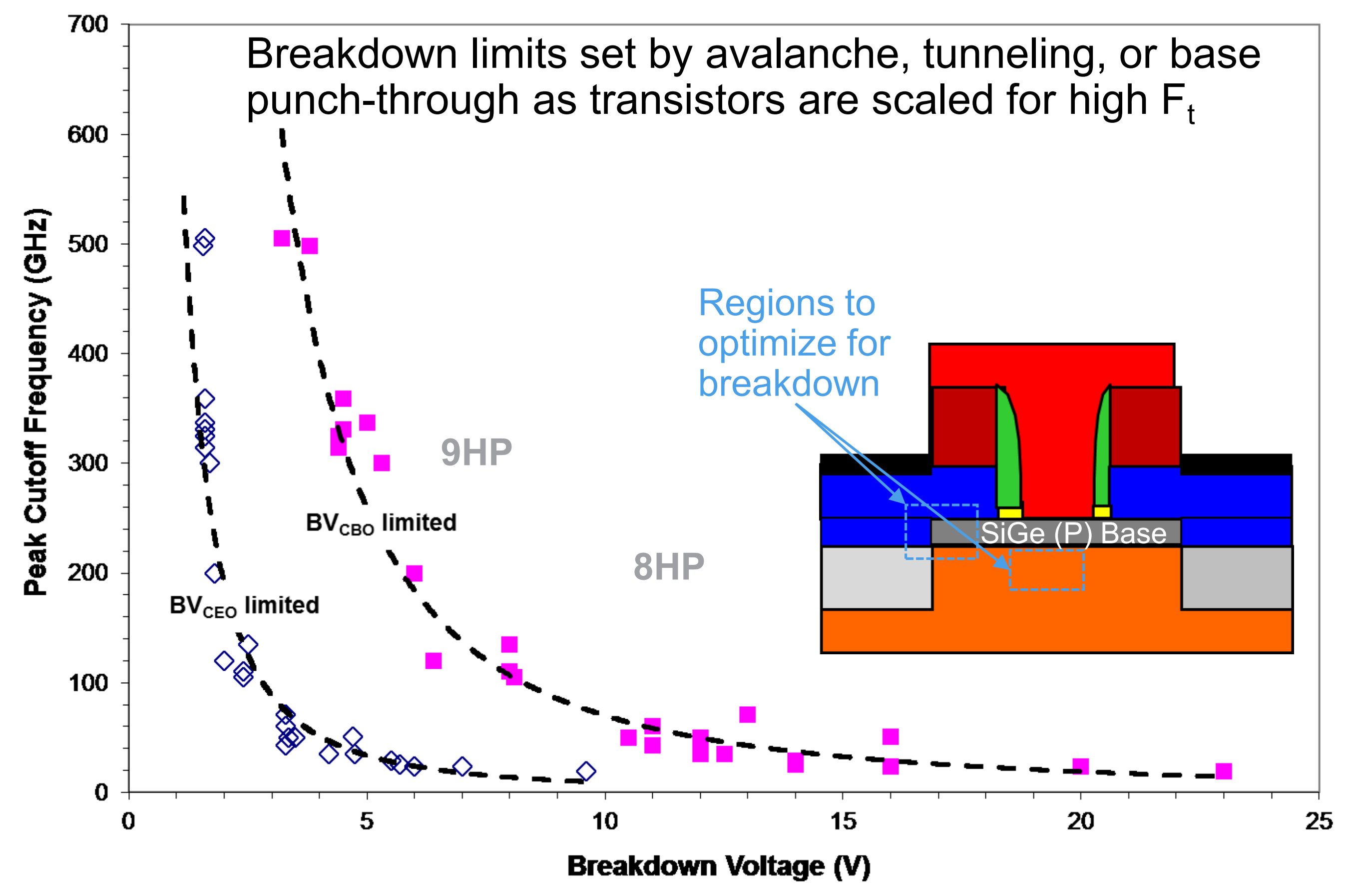
Source: Globalfoundries test results

5G mmWave switches based on mmWave layouts with increased gate pitch are targeted to have ~ 0.6-0.7 dB insertion loss at 28 GHz and better power handling due to low capacitances

“Beats Best GaAs pHEMT LNAs”
Prof. Gabriel Rebeiz, UCSD

SiGe HBT Breakdown (BV_{cbo}) Saturating at 4 V for F_t >500 GHz

- GF continues to push scaling of SiGe HBTs
- Optimizing vertical (intrinsic) & lateral (extrinsic) profiles allows one to gain F_t – BV margin

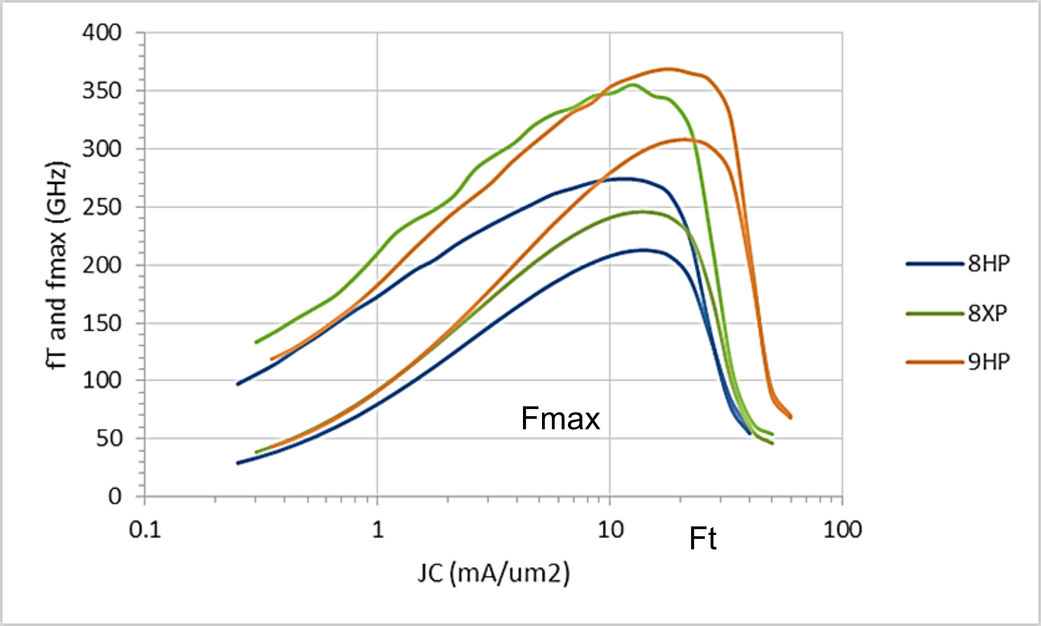


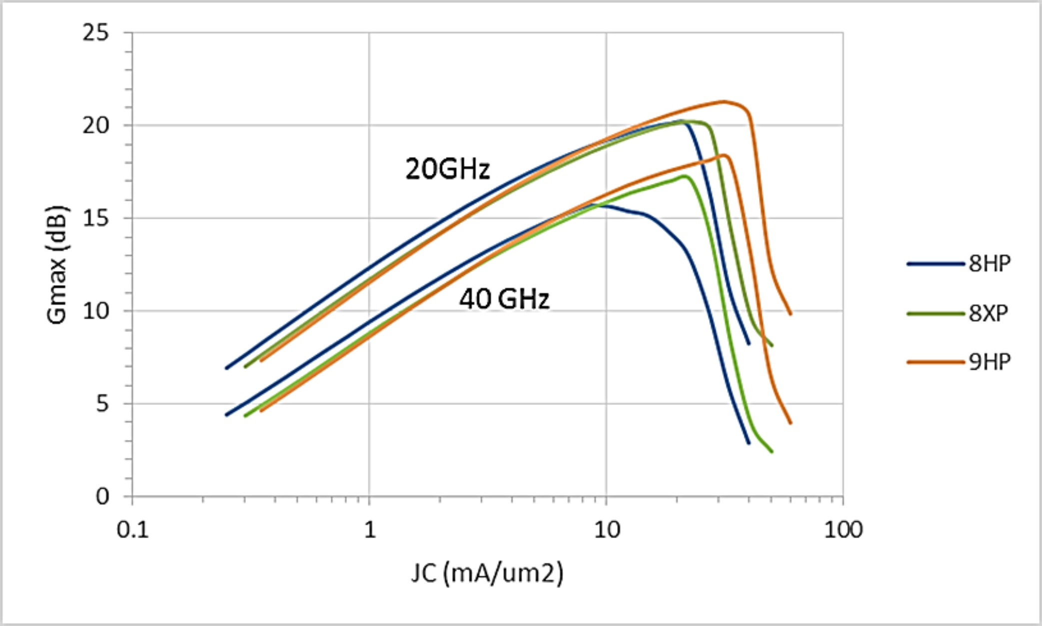
Avoids the need for multi-stacking approach used for FETs ⇨ improves PAE for PA

Source: GLOBALFOUNDRIES

130nm & 90nm SiGe Technologies - HBT's offer High F_t/F_{max} at low power

- SiGe (8XP) offers **F_{max} of 350 GHz**; SiGe (9HP) offers **F_{max} of 370 GHz**
- CMOS logic supporting thin and thick oxide for 1.2 V / 1.5 V, 1.8 V / 2.5 V / 3.3 V
- Thick top level metals for improved transmission line loss

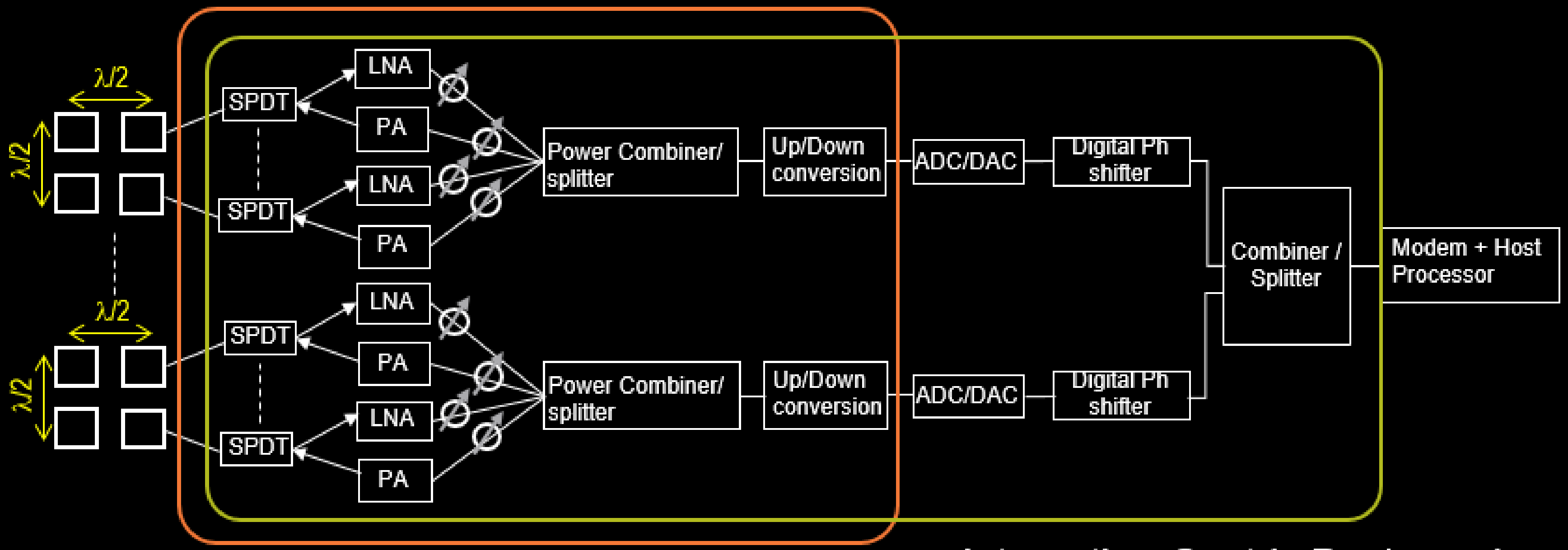




Source: GLOBALFOUNDRIES

➢ *High Fmax and breakdown voltage of SiGe makes it an ideal technology for high Psat, Gain, PAE, & linearity of PA with high reliability.*

Paving the way to 5G/mmWave: 45RFSOI & 22FDX®



FEM-Centric Designs: highest performance with architecture flexibility

Integration-Centric Designs : low system cost and low SOC power consumption

45RFSOI*

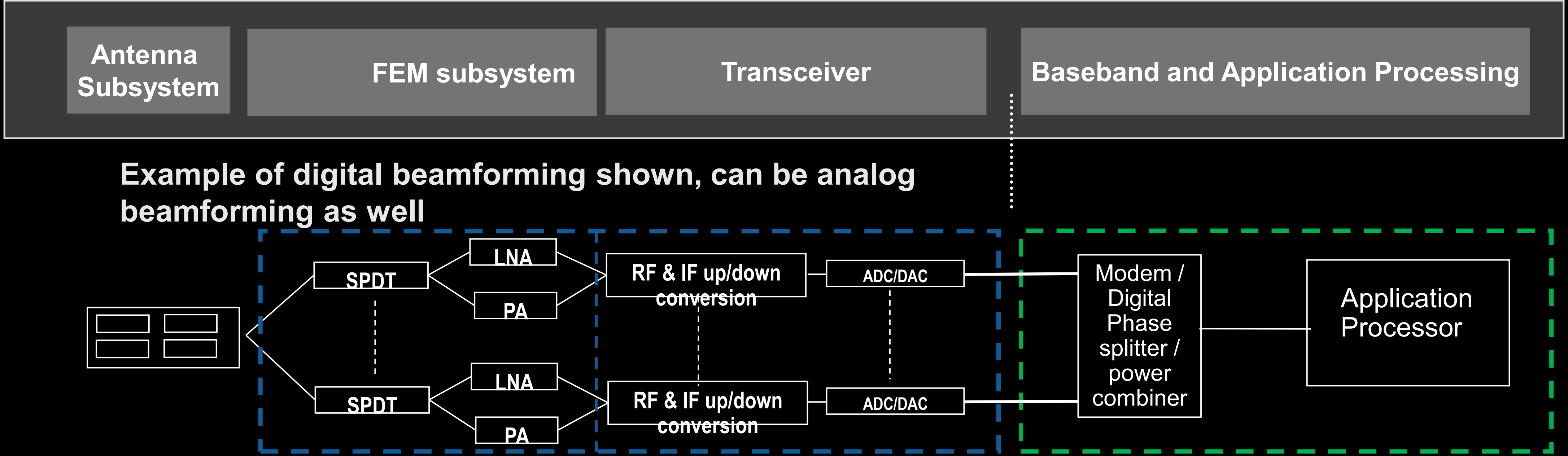
- High Ft / Fmax
- Hi-Res substrate for high power handling (>20 dBm) and low loss
- Low-loss BEOL
- Low density, medium leakage logic

SiGe8HP/8XP PA for Psat > 23dBm

22FDX

- High Ft / Fmax and high GM/I
- Power handling (< 20 dBm)
- Low-loss BEOL
- Low power and high density logic

Generic architecture : mmWave 5G radio interface for UE– chip partitioning options



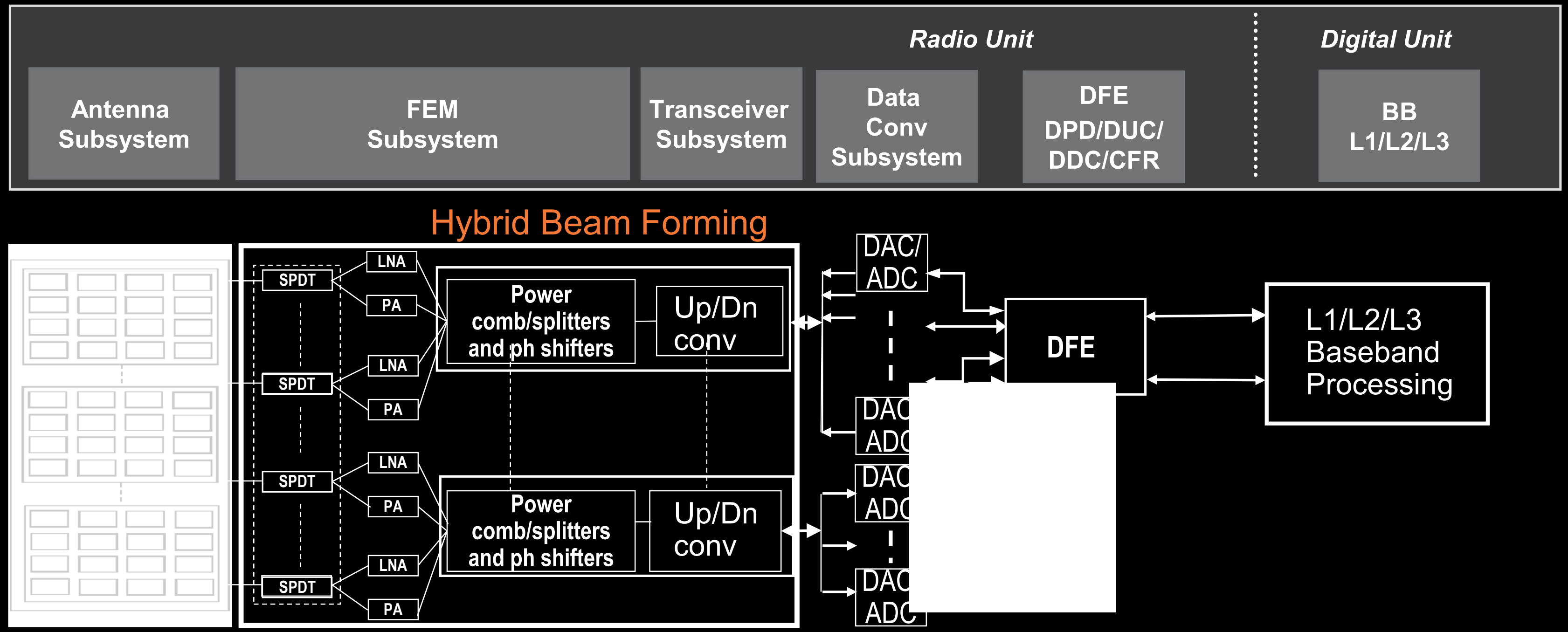
Example of digital beamforming shown, can be analog beamforming as well

Possible chip partitioning options

45RFSOI up to IF	14/12/10 nm FinFET	14/10/7 nm FinFET
45RFSOI up to IF	28/22 nm bulk	14/10/7 nm FinFET
22FDX®		14/10/7 nm FinFET
28/22 nm bulk CMOS w/ SiGe/III-V PA & RF SOI switch if needed		14/10/7 nm FinFET

Chip partitioning & technology adoption will depend on Tx power, power efficiency, cost and available form factor

Chip partitioning option: radio interface for mmWave 5G infrastructure



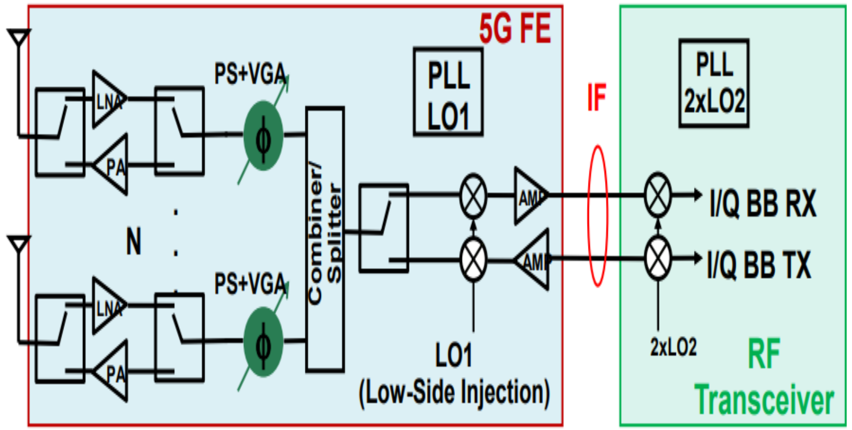
Possible chip partitioning options

SiGe or 45RFSOI	14/10/7 nm FinFET	14/10/7 nm FinFET
22FDX®		14/10/7 nm FinFET
planar bulk CMOS w/ SiGe/III-V PA & RF SOI switch, if needed	14/10/7 nm FinFET	14/10/7 nm FinFET

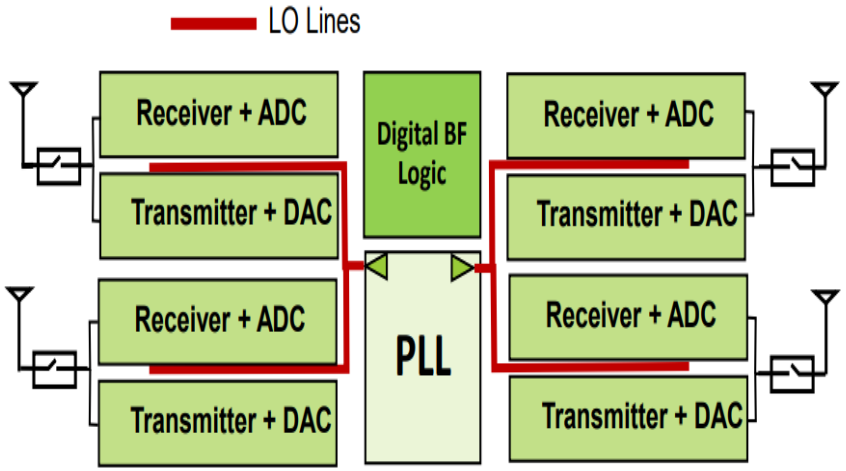
Technology solution will be determined by TX power, #arrays (system cost) & system power dissipation

Comparison of 22FDX® and 28 nm for beamforming

Analysis for 16QAM UL/DL, 100MHz RF BW



Analog Beamforming (ABF)



Digital Beamforming (DBF)

Source: Globalfoundries presentation at IMS 2018 workshop

All 22 nm FD-SOI power consumption results based on measured results of silicon blocks

Technology	**28 nm HKM**	**22 nm FD-SOI**			
Architecture	ABF, High IF, N=8	ABF, High IF, N=8	DBF, DC, N=8	ABF, High IF, N=4	DBF, DC, N=4
PA Pout (dBm)	7	7	7	13	13
Pdc (mW) (Tx/RX 0.3/0.7)	506	415	360	315	289

~20% reduction in power dissipation w.r.t. 28 nm bulk for analog high IF beamforming,

The power advantage of 22FDX is even better for digital beamforming

Outline

1. Introduction to 5G
2. mmWave 5G Radio Access Technology Overview
3. mmWave 5G Radio Interface Architecture
4. Differentiated Silicon Technologies for mmWave 5G
5. Summary & references

Summary

- We have covered the enhanced Mobile Broadband (eMBB) usage scenario of 5G
- The use of mmWave carrier frequency will enable large channel bandwidth and high spectral efficiency
- The phased array technique to be used for mmWave 5G will enable Silicon technologies to play key roles in mmWave 5G systems
- We highlighted partially depleted (PD) and fully depleted (FD) SOI technologies along with SiGe BiCMOS technologies as differentiated Silicon technology choices for mmWave 5G radio interface.

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Please feel free to contact me at anirban_bandyo@ieee.org with any questions or follow up