

e4ds 웨비나

## 5G 무선 통신칩과 AI 솔루션

소속 (주) 스카이칩스/성균관대학교

발표자 이강윤 대표이사/교수

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홈페이지 <http://www.skaichips.co.kr>

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- III Neuromorphic 개요
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- V 결론

# 1 연사 소개



이강윤 대표

- ▶ **연구 분야** RF/Analog/Mixed 집적회로, 무선충전/Power IC, AI 분야
- ▶ **연구 시설** 국내 최고 수준의 IC 연구시설 보유
- ▶ **연구 인력** 14명의 석박사급 연구원 + 66명의 IC Lab 연구원

## 약력

- 2019 – 현재 : (주)SKAIChips 대표
- 2012 – 현재 : 성균관대학교 교수
- 2005 – 2012 : 건국대학교 부교수
- 1998 – 2005 : (주)GCT 반도체 창립 멤버  
및 Design Manager

• B.S., M.S., Ph.D. all in School of Electrical Engineering,  
**Seoul National University**

## 대외활동이력

- 반도체공학회 총무이사
- 대한전자공학회 상임이사
- 대한전자공학회 사업화위원장
- JSTS Journal Associate Editor
- 대한전자파학회 이사
- 대한전자공학회지 SD편 편집위원
- 한국 반도체 학술대회 RF 분과위원장
- Senior Member of IEEE
- WPTC 2014-2016 TPC Member
- ISOCC 2015-2016, 2019 TPC Member
- ITC-CSCC 2013 Exhibition Chair
- APMC 2013 TPC Member
- ISCAS 2012 Exhibition Chair

## 수상이력

### 2019년

- ISOCC Anritsu-Korea Award 수상
- ISOCC Best Poster Award
- 하계종합학술대회 현대자동차그룹 논문상 수상

### 2018년

- 제 19회 반도체설계 대전 대통령상 수상
- 제 1회 반도체 산학연 교류 워크샵 우수연구상 수상
- ISOCC Zaram Technology Award
- ICEIC 2016 Best Paper Award 수상

### 2017년

- 삼성전자 휴먼테크논문대상 장려상 수상
- RF/아날로그 워크샵 IEEE MTT-S Best Paper 수상
- ISOCC Best Paper 수상

### 2016년

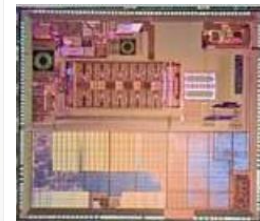
- 미래부 주관 국가연구개발 우수성과 100선 선정
- 추계학술대회 공로상 수상
- RF/아날로그 워크샵 최우수 연구실상 수상
- 반도체학술대회 동부하이텍상 수상
- 하계종합학술대회 LG논문상 수상
- ICEIC 2016 Best Paper Award 수상

### 2015년

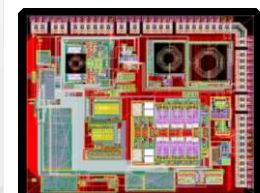
- 제 8회 반도체의 날 산업통상자원부 장관 표창
- 대한민국 반도체 설계대전 특별상 수상
- ITC-CSCC 2015 Best Paper Award 수상

## 대표 기술 상용화 사례

- ABOV 반도체 : BLE RF Transceiver
- 삼성전자 : mmWave 5G RF Transceiver
- ETRI & A2U 정보통신 : IoT 용 WiSUN RF Transceiver
- 삼성전자 : Galaxy S4 용 PLL
- LG전자 : DTV Tuner Receiver IC (기술자문)
- GCT반도체 : 4G LTE Transceiver IC
- 삼성전기 : DVB2용 Transceiver
- GCT반도체 : PHS Transceiver IC
- GCT반도체 : WCDMA Transceiver IC
- GCT반도체 : PHS Transceiver

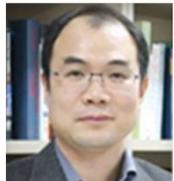


ABOV 반도체 BLE RF Transceiver



삼성 Galaxy S4용 PLL 알고리즘

# 2 (주)스카이칩스 소개



이강윤 대표

- ▶ 연구 분야 RF/Analog/Mixed 집적회로, 무선충전/Power IC, AI 분야
- ▶ 연구 시설 국내 최고 수준의 IC 연구시설 보유
- ▶ 연구 인력 14명의 석박사급 연구원 + 66명의 IC Lab 연구원

## 1. Power IC

- 전력 관리 회로 (LDO, DC-DC)
- AI 기반 DVFS 연구 진행

## 2. RF IC

- 무선 통신용 IC (RF Transceiver, PLL, DLL, PA)
- AI 기반 Adaptive Matching 연구 진행



## 3. Analog-Digital Mixed Signal

- ADC, DAC, Analog-Front End 등



스카이 칩스 (SKAIChips)



## 4. Artificial intelligence IC

- CNN, Perceptron, Neuromorphic 등



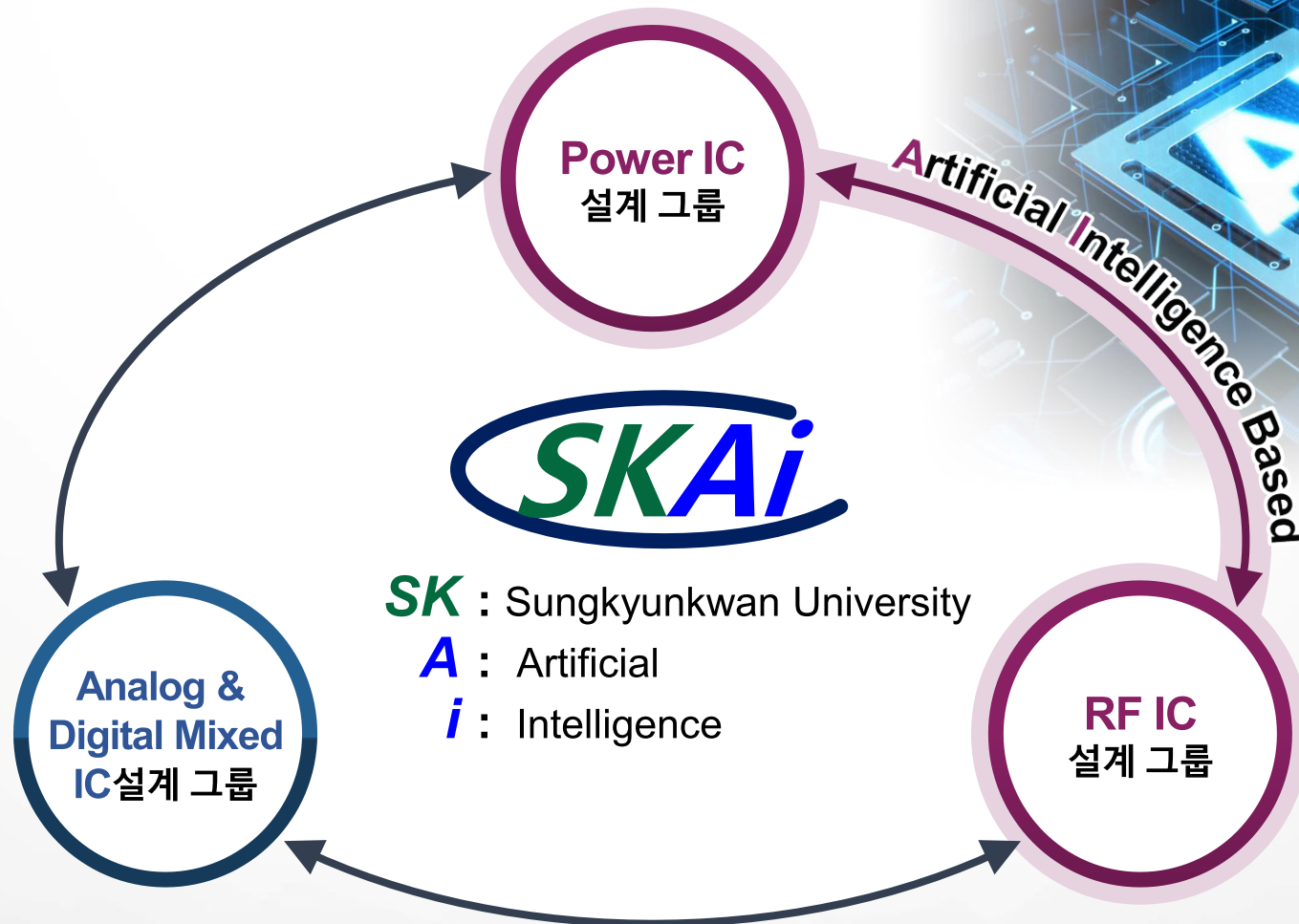
집적회로 설계 연구실 (SKKU IC Lab.)

Research Achievements (IC Lab)				
논문 (최근 5년)	SCI 상위 10%	7 편	SCI	99
	학회	293 편	국제	68
특허 (최근 5년)	등록	31 건	국제	6
			국내	25
	출원	21 건	국제	6
			국내	15
정부과제 (최근 5년)	진행 중			4
	완료			36
산업체과제 (최근 5년)	진행 중			7
	완료			35
기술이전 (최근 5년)	총 16건, 총 41,000 만원			

## SKAI Chips + IC Lab. Members

Total	Advisor	Research Professors	Ph.D	M.S.	B.S.
80	1	3	16	45	15

## 2 (주) 스카이칩스 소개



Intelligent IP

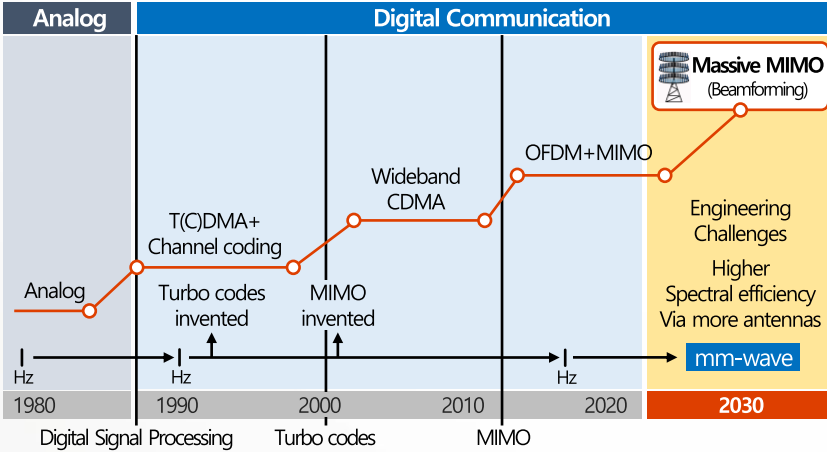


IC Business

# 5G 무선 통신 시스템 개요

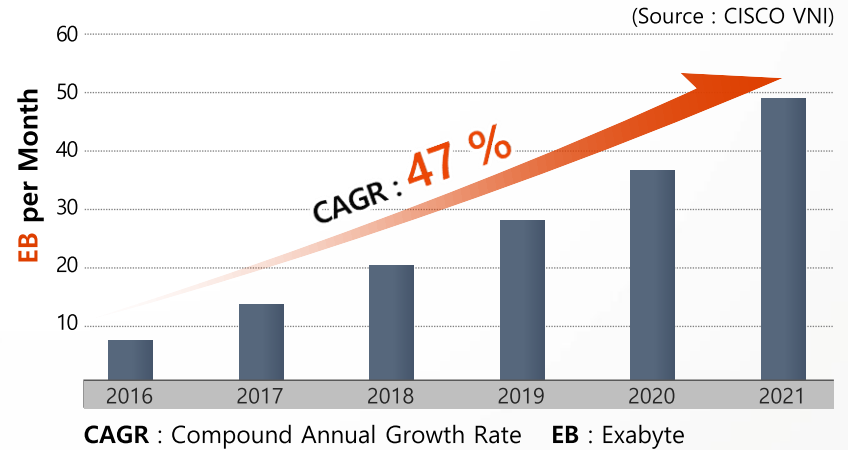
# 1 5G 통신 기술

## 통신 기술의 변화

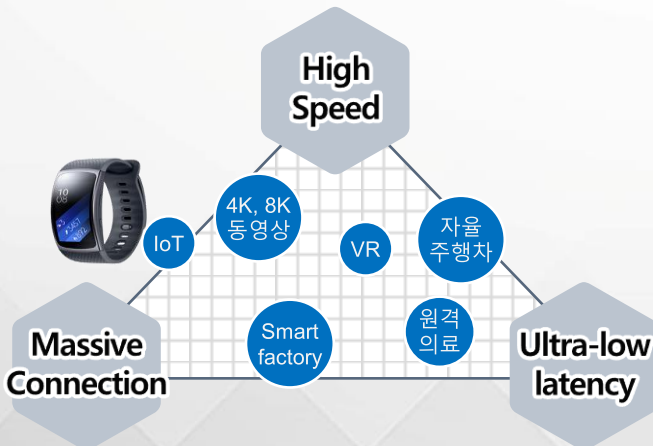


## Global Traffic 전망

Traffic 증가로 인하여 최대 속도가 20Gbps에 달하는 5세대 이동통신 기술이 필수적



## 5세대 이동통신 기술 : High Data Rate / Massive IoT / Low Latency · High Reliability

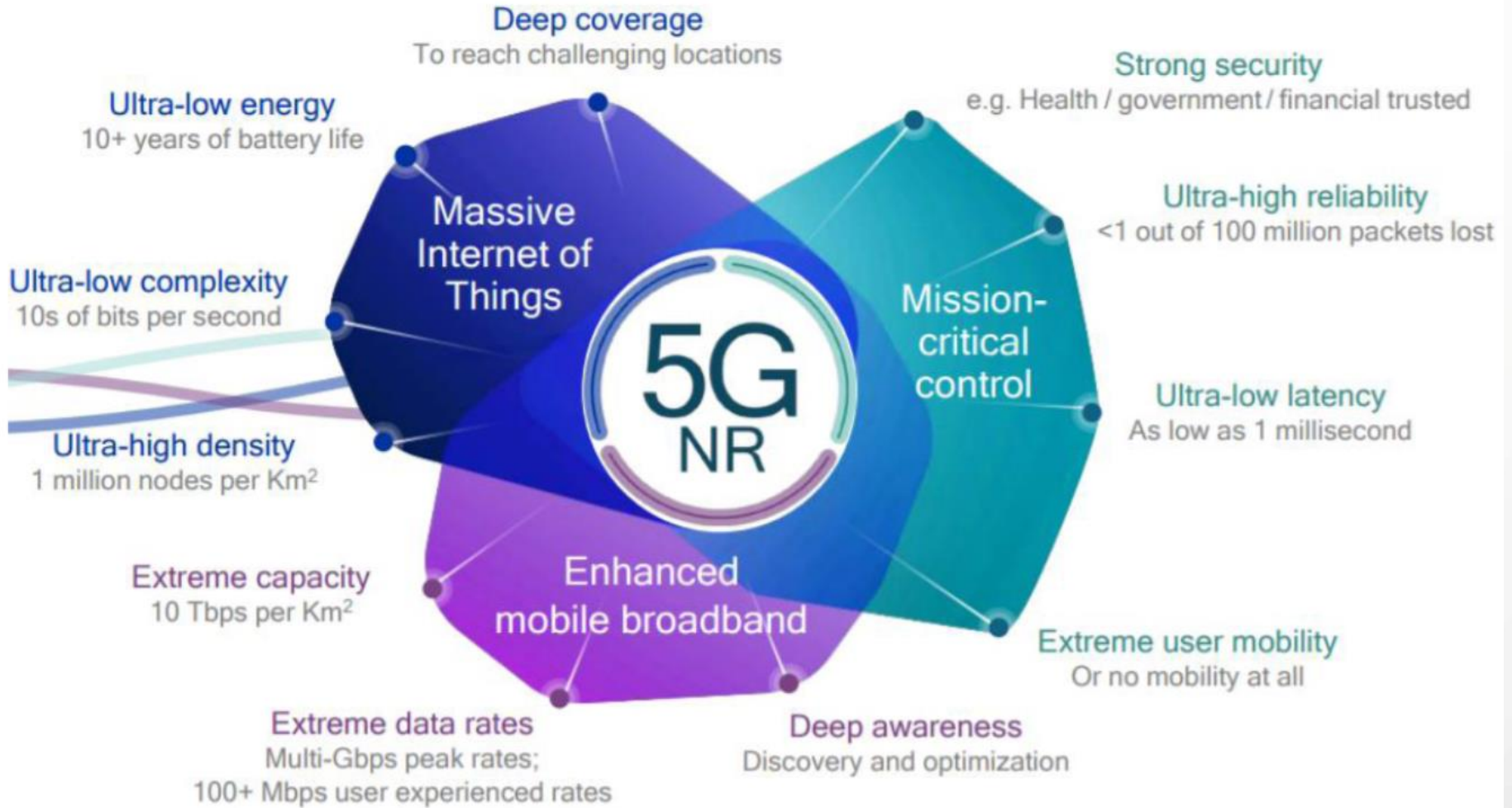


기가비트급의 높은 전송속도

매우 낮은 지연 시간과 접속의 안정성

대규모 단말 접속과 네트워크 효율성

2020년 세계 5G 산업규모 약 7,914억 달러



Source: Qualcomm, Challenges and Design Aspects for 5G Wireless Networks

# 1 Introduction: 5G Needs & Applications (1)

- It is expected that
  - Massive growth in data traffic volume ( $\times 1000$  [1])
  - Massive growth in connected devices (25 Billion devices [2])
- Key drivers for the development of 5G are expected to be
  - Low latency ( $< 1\text{ms}$ )
  - High throughput ( $> 1\text{Gb/s}$ )

[1] T. S. Rappaport *et al.*, "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!," in *IEEE Open Access*, 2013.

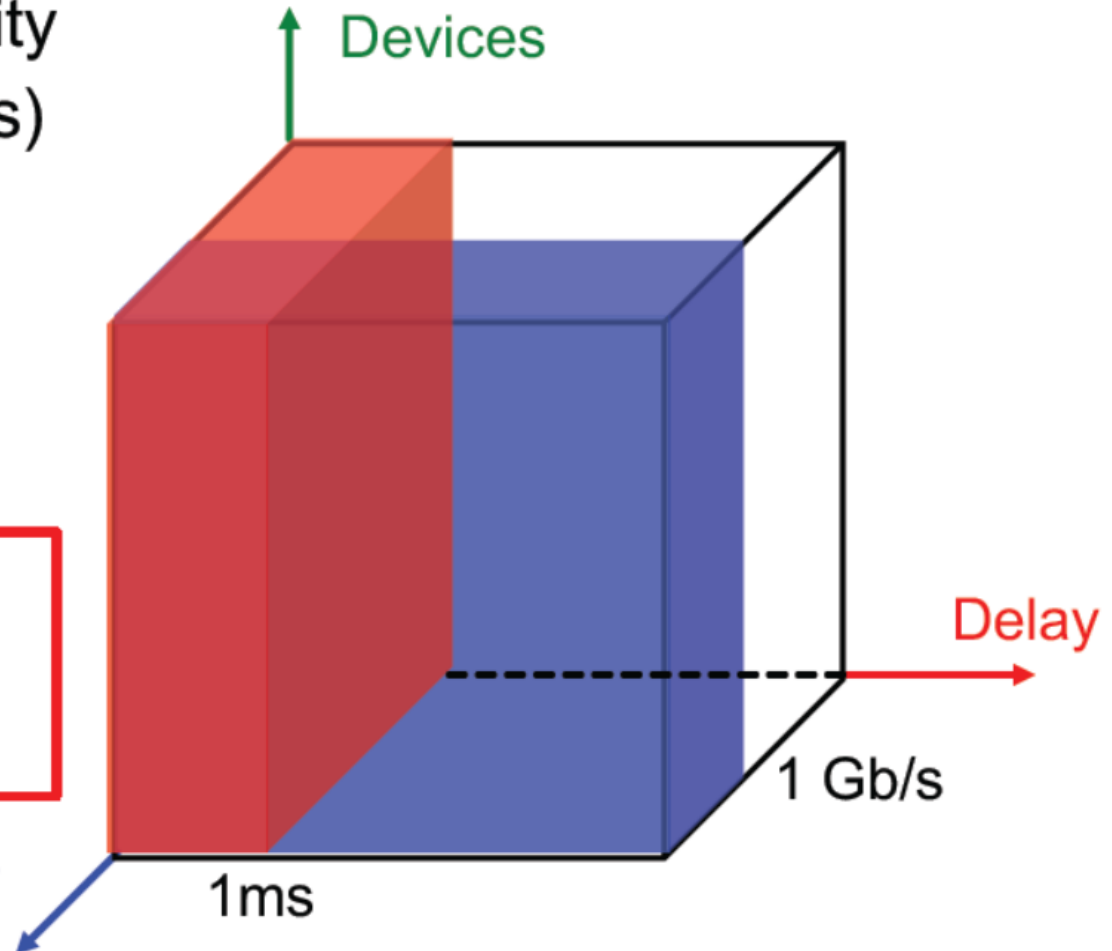
[2] C. Koverman, "Next-Generation Connected Support in the Age of IoT: It's time to get proactive about customer support.," in *IEEE Consumer Electronics Magazine*, Jan 2016.

- 3D (Data-rate, Delay, Devices)

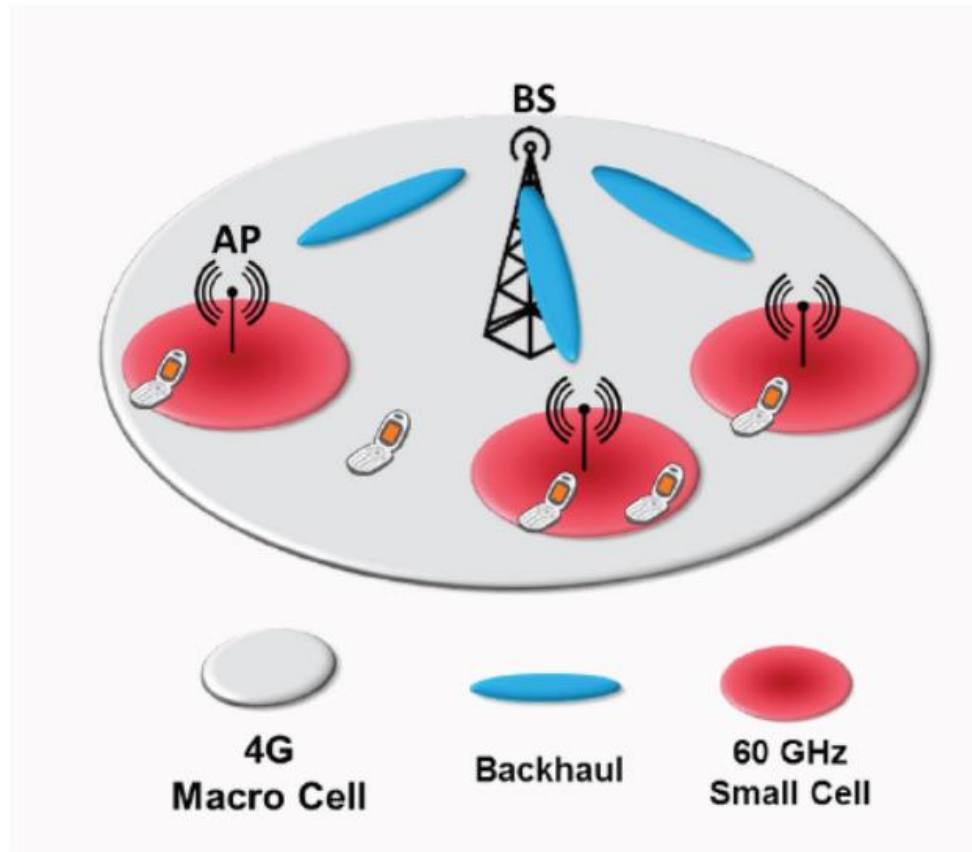
- Data Capacity  
(data highways)
- Responsive  
Objects  
("real time")

**Bandwidth →  
mm-wave  
Transceivers**

Data-rate



- Big Data Capacity Wireless Communications and Networks



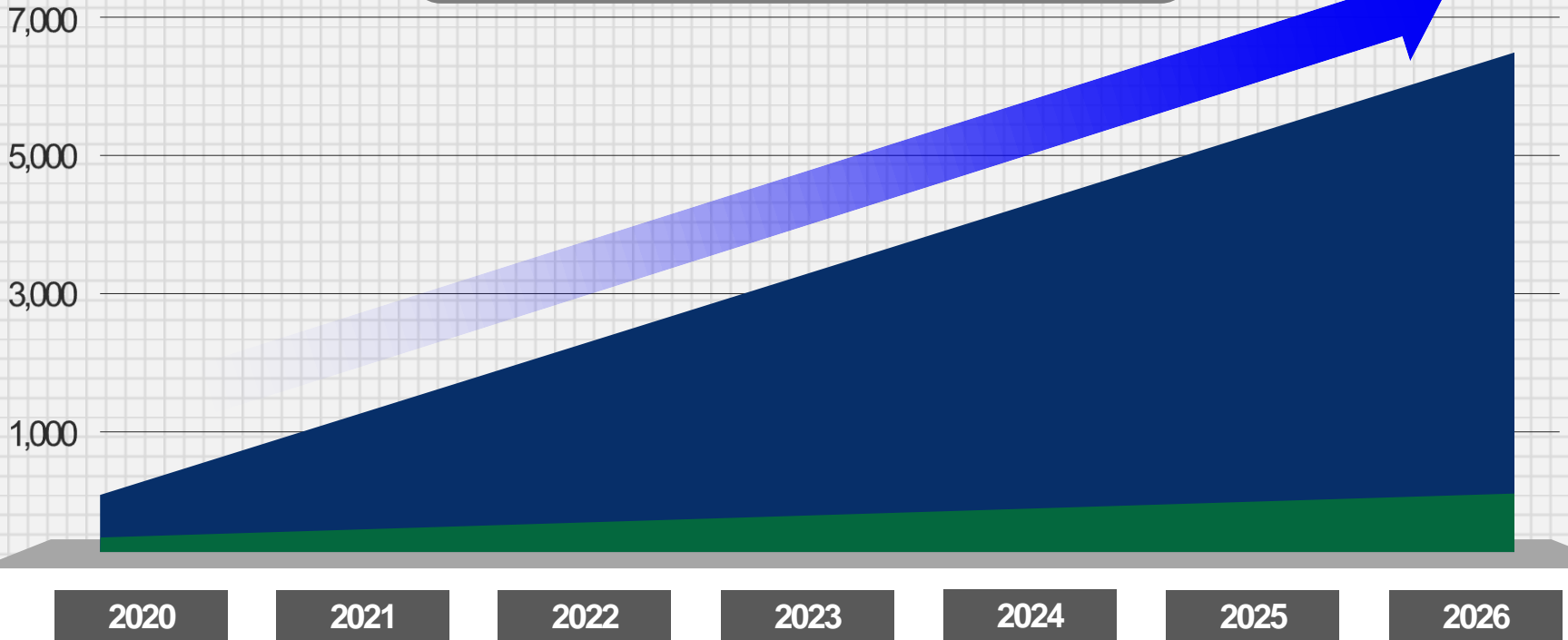
(Source: EU Project MyWaves)

## 국내·외 시장 규모 현황 및 전망

### 5G 국내·외 시장 규모 전망

■ 세계 시장 ■ 국내 시장

(단위: 억달러)



- 세계 5G 시장 규모 (2020년도 현재) : 약 43조 8474억 원
- 세계 시장 성장률 : 2024년 이후부터 매년 평균 22% 내외 (예측)
- 국내 5G 시장 규모 (2020년 올해) : 세계 시장 규모 대비 7.08%

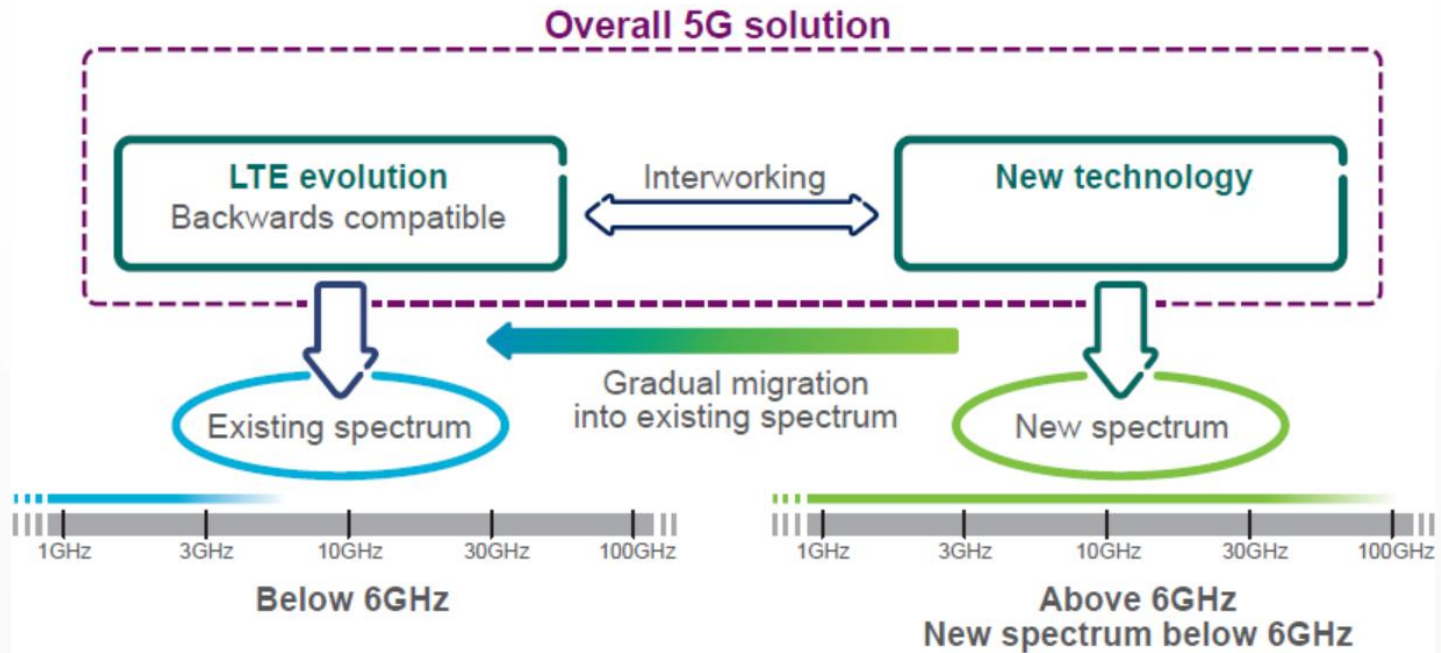


Figure 1: The overall 5G wireless-access solution consisting of LTE evolution and new technology.

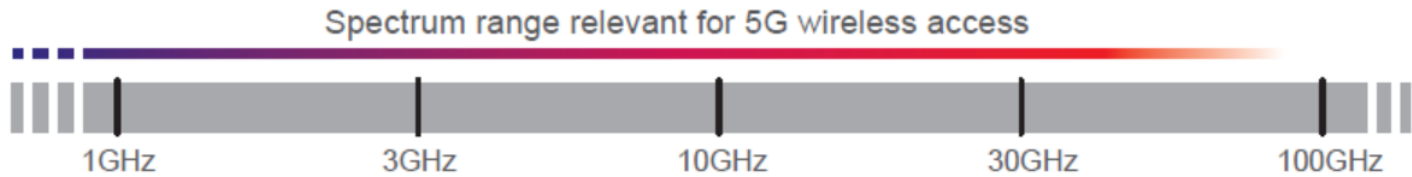
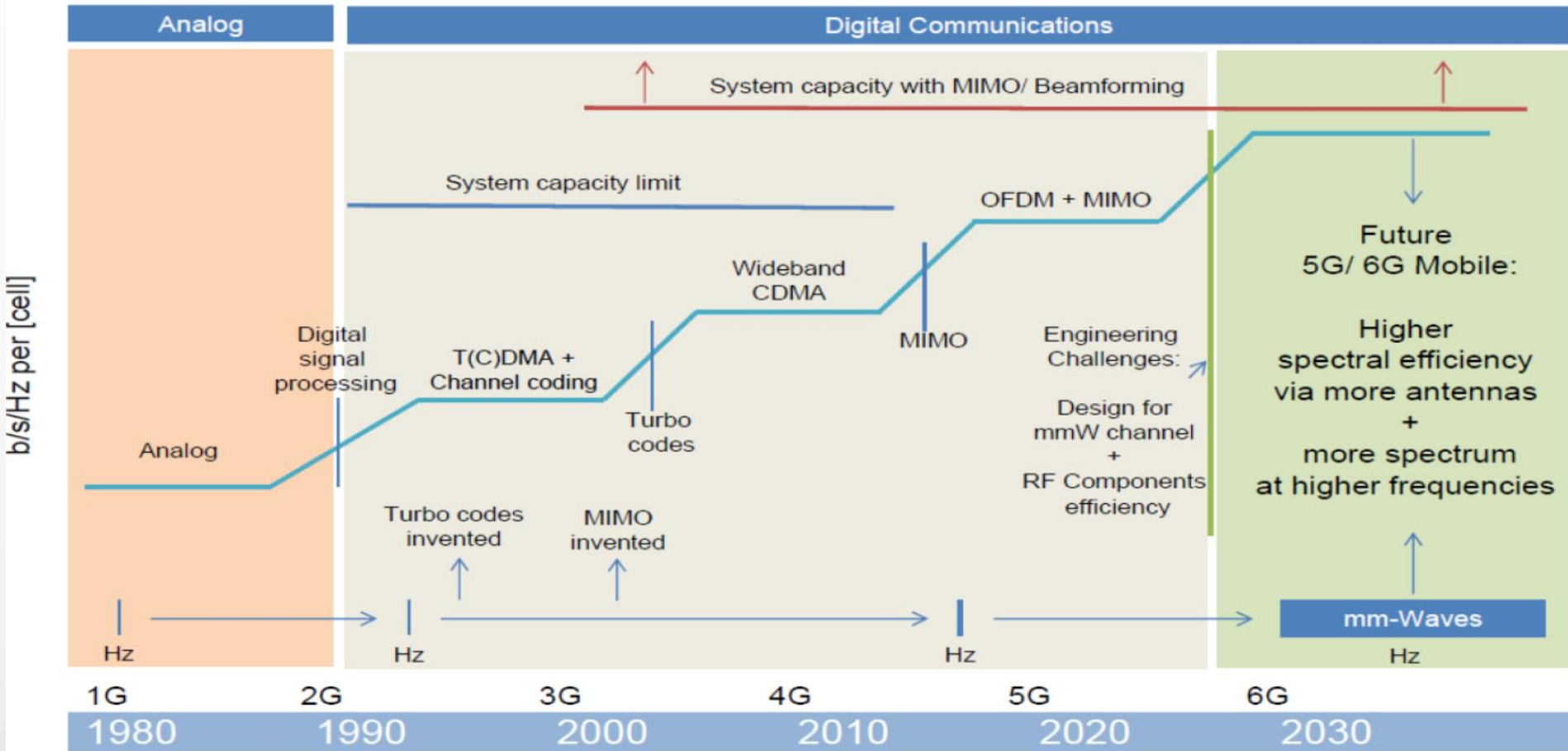


Figure 3: Spectrum relevant for 5G wireless access.



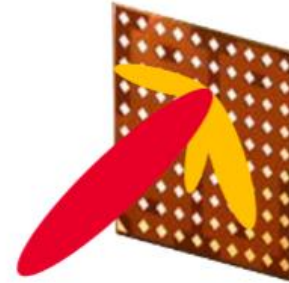
# Why Massive MIMO at mmWave Frequencies?

Massive MIMO resolves mmWave issues

Large available bandwidth at mmWave

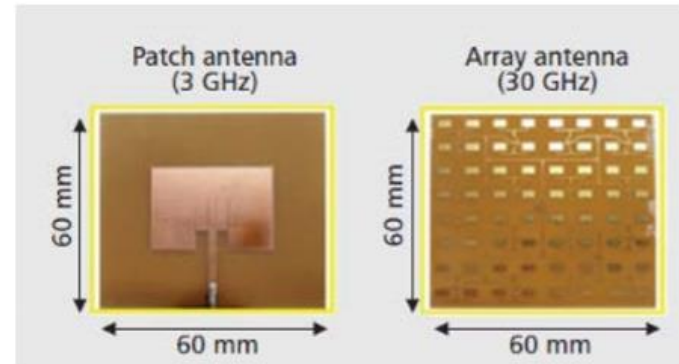
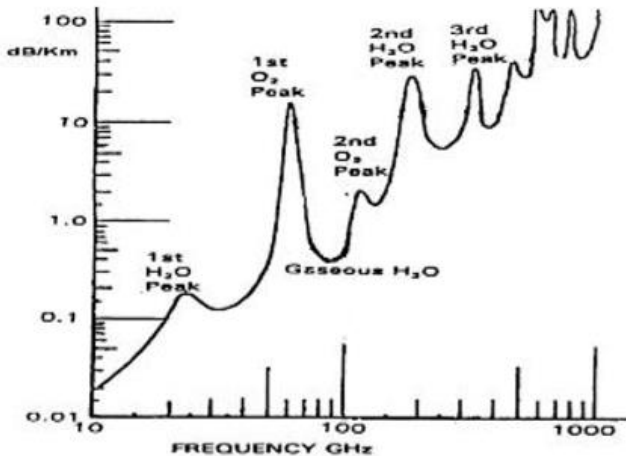
Frequency range	6-20 GHz	20-40 GHz	40-60 GHz	60-100 GHz
Specific bands identified	10 GHz band 10.125-10.225 GHz 10.475-10.575 GHz	32 GHz band 31.8-33.4 GHz	40 GHz band 40.5-43.5 GHz '45 GHz' band 45.5-48.9 GHz	66 GHz band 66-71 GHz
Potential bandwidth	2 x 100 MHz	1.6 GHz	5.8 GHz total	5 GHz

Source: Ofcom, Apr 2015



Path loss can be mitigated by high gain directional antennas

High path loss due to antenna aperture size and atmospheric absorption



mmWave geometry allows for very small, high gain antennas

## Potential mmWave Bands

- Samsung Experiments: 28 and 38 GHz (500 MHz)
- Japan: Tokyo Institute of Tech. 11 GHz, 400 MHz (some collaboration with NTT DoCoMo)
- METIS: Bands for investigation - see chart

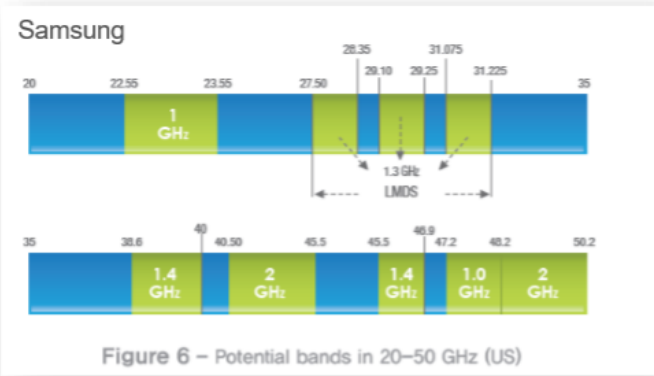


Figure 6 - Potential bands in 20-50 GHz (US)

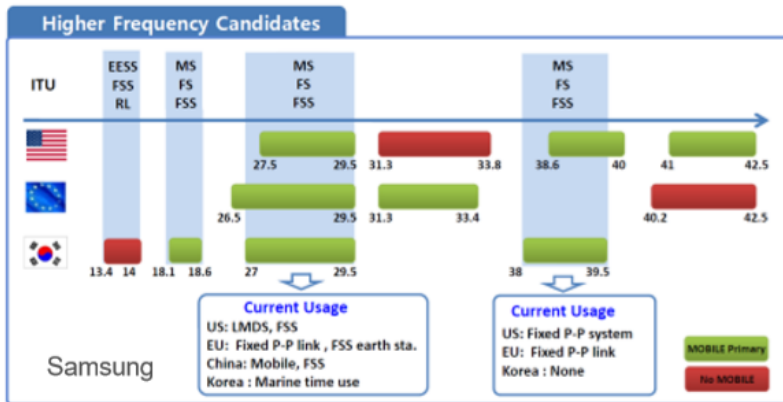
### METIS TIMELINE FOR SPECTRUM

<https://www.metis2020.com/documents/deliverables/>

- D1.2 Initial channel models based on measurements 30-10-2014
- D5.3 Description of the spectrum needs and usage principles 31-08-2014

### METIS

Band (GHz)	Size [GHz]	Priority
9.9 - 10.6	0.7	Medium / High
17.1 - 17.3	0.2	Low
17.7 - 19.7	2.0	Low
21.2 - 21.4	0.2	Low
27.5 - 29.5	2.0	Medium
31.0 - 31.3	0.3	Medium
31.8 - 33.4	1.6	High
36.0 - 37.0	1.0	Low



Band (GHz)	Size [GHz]	Priority
40.5 - 42.5	2	Medium
42.5 - 43.5	1	High
43.5 - 45.5	2	Low
45.5 - 47.0	1.5	High
47.2 - 50.2	3	High
50.4 - 52.6	2.2	Medium-Low
55.78 - 57.0	1.22	High
57 - 66	7	High
66 - 71	5	High
71 - 76	5	High
81 - 86	5	High

Summary of assessment results for the bands above 40.5 GHz

$$Power_{RX} = Power_{TX} + AntGain_{RX} + AntGain_{TX} - 20\log_{10}(4\pi R) - 20\log_{10}\left(\frac{f}{c}\right)$$

Distance
Frequency

In words. For a given distance, as the frequency increases, the received power will drop unless offset by an increase in some combination of transmit power, transmit antenna gain, and receive antenna gain.

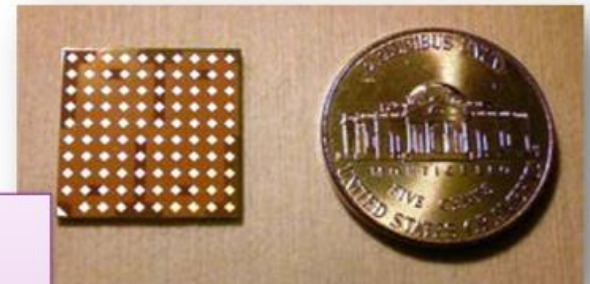
The decrease in power as a function of frequency is caused by the decrease in the antenna aperture.

### The Good News:

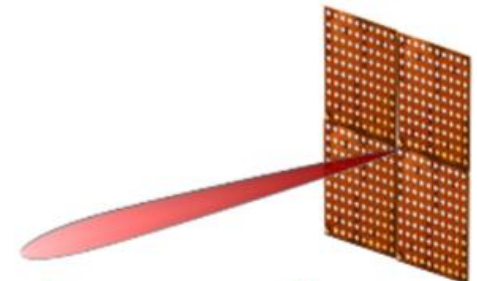
- Higher frequency antennas elements are **smaller**
- **Easier to assemble** into electronically steered **arrays**
- **Reduced interference**. Energy goes where it's needed
- Improve performance in **dense crowds** (5G goal)
- Higher frequencies **wider bandwidths**: faster (5G goal)

### Challenges:

- Increased **complexity** with more elements
- Multiple **antenna arrays** required for spherical coverage
- **Discovery and Tracking** (mobile devices)



IBM 94 GHz Array  
Can Tile for Larger Arrays  
IBM Press Release, June 2013



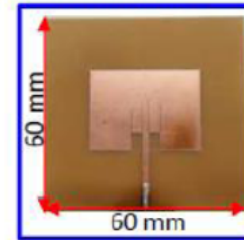
# 4 The mm-wave Challenge

- Free space losses and high data require 30dB more link budget compared to 5 GHz systems – **directive antenna**
- TX power that is dropping as we go higher in frequency and to more advanced Si process  $P_{\max} \propto V^2 / f$  – **antenna array**
- Need to cope with blocking and moving targets - **scanning capabilities**

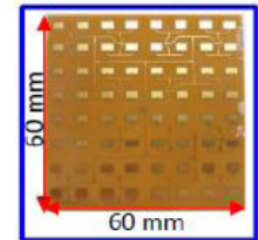
LOS Loss @ 10m, 60GHz: 88dB

	WiFi	60GHz	Diff
Tx power	~17dBm	10dBm	-7dBm
Freq	5-6 GHz	60GHz	-20dB
BW	~16MHz	1.7GHz	-20dB
Constellation	64 QAM	16 QAM	~+6dB
Distance	~30m	~10m (1/3)	-10dB
Antenna gain	0dBi	~15dBi Rx & Tx	+30dB

Patch Antenna @ 2.8GHz



Array Antenna @ 28GHz



$$G_{max} = \frac{4\pi A}{\lambda^2}$$

$$SNR = \frac{P_{TX} G_{TX} G_{RX}}{N_o} \left( \frac{\lambda}{4\pi d} \right)^2 = \frac{P_{TX} A_{TX} A_{RX}}{d^2 N_o \lambda^2}$$

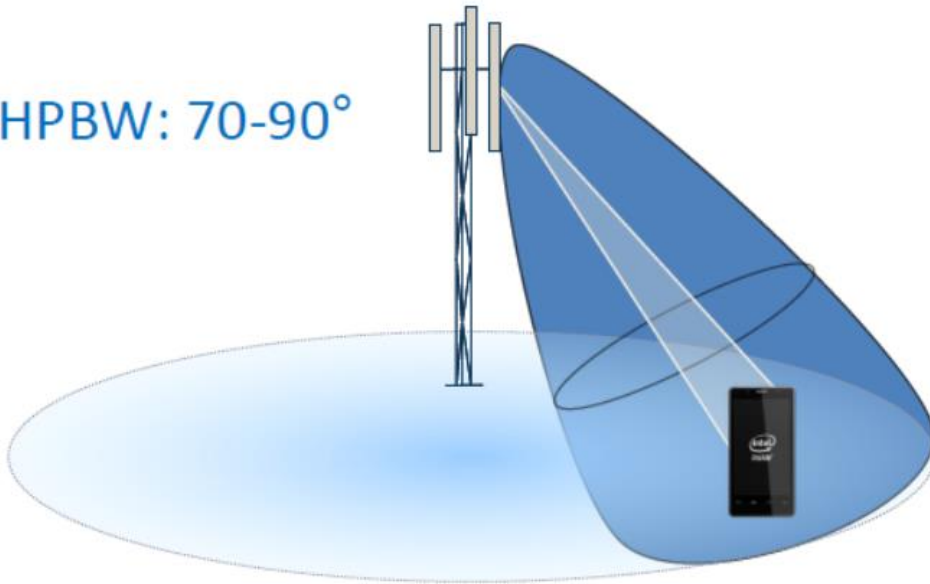
$$TX_{array\_gain} = 20 \cdot \log_{10}(N)$$

$$RX_{array\_gain} = 10 \cdot \log_{10}(N)$$

30dB gain TX+RX >30 elements

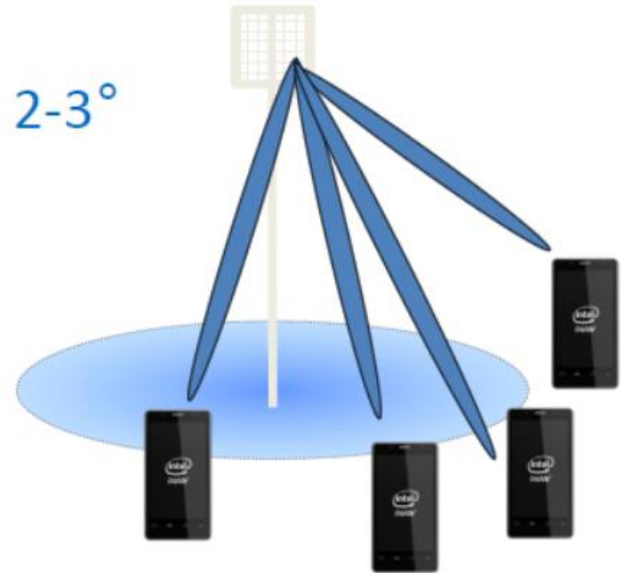
## Modern LTE Femto Cell vs. mmWave Small Cell

HPBW: 70-90°



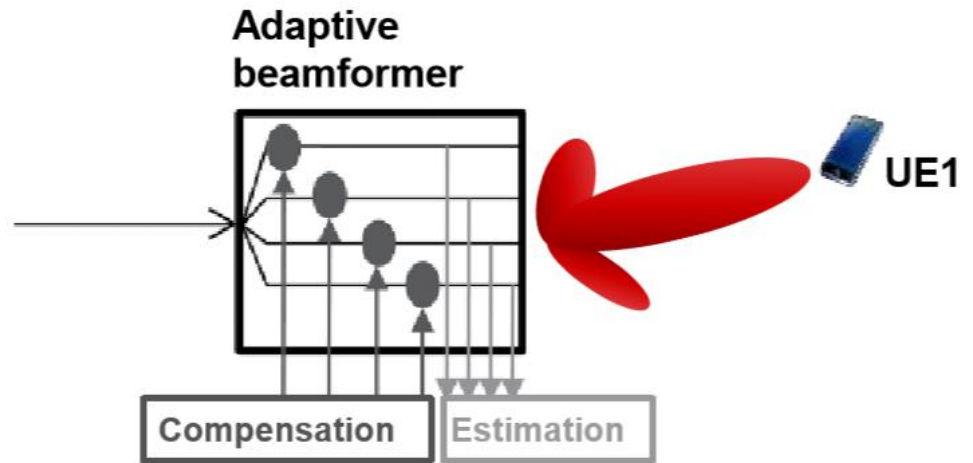
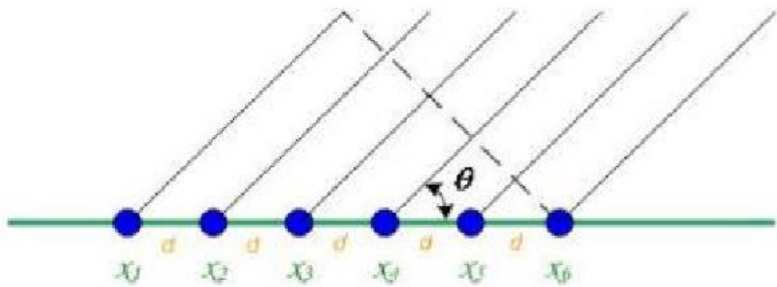
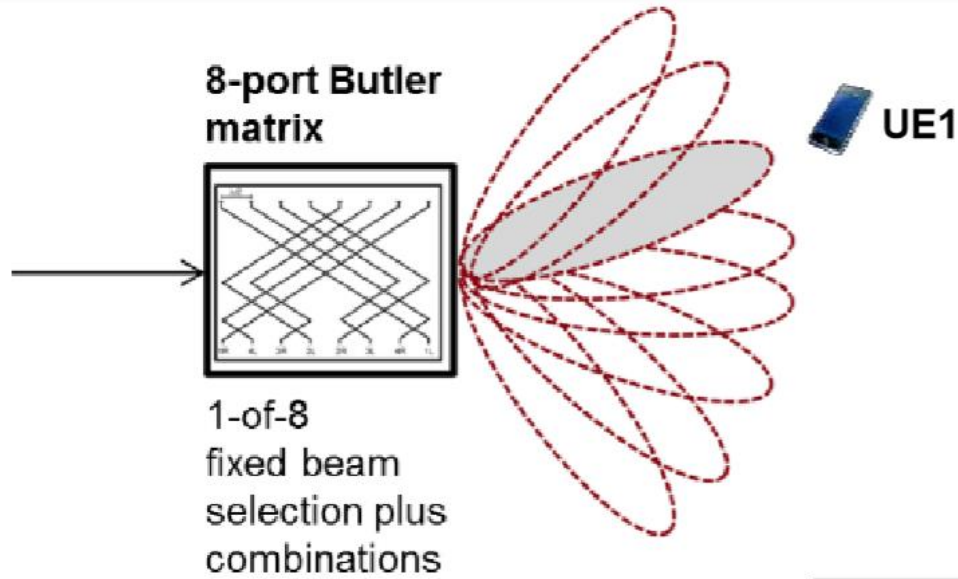
Average data-rate  
**50 Mbps/cell** MU

HPBW: 2-3°



Average data-rate  
**50 Gbps** MU

# Beam Steering vs. Beam Forming Techniques



Adapts per antenna weightings and beam pattern to received signal and channel estimations

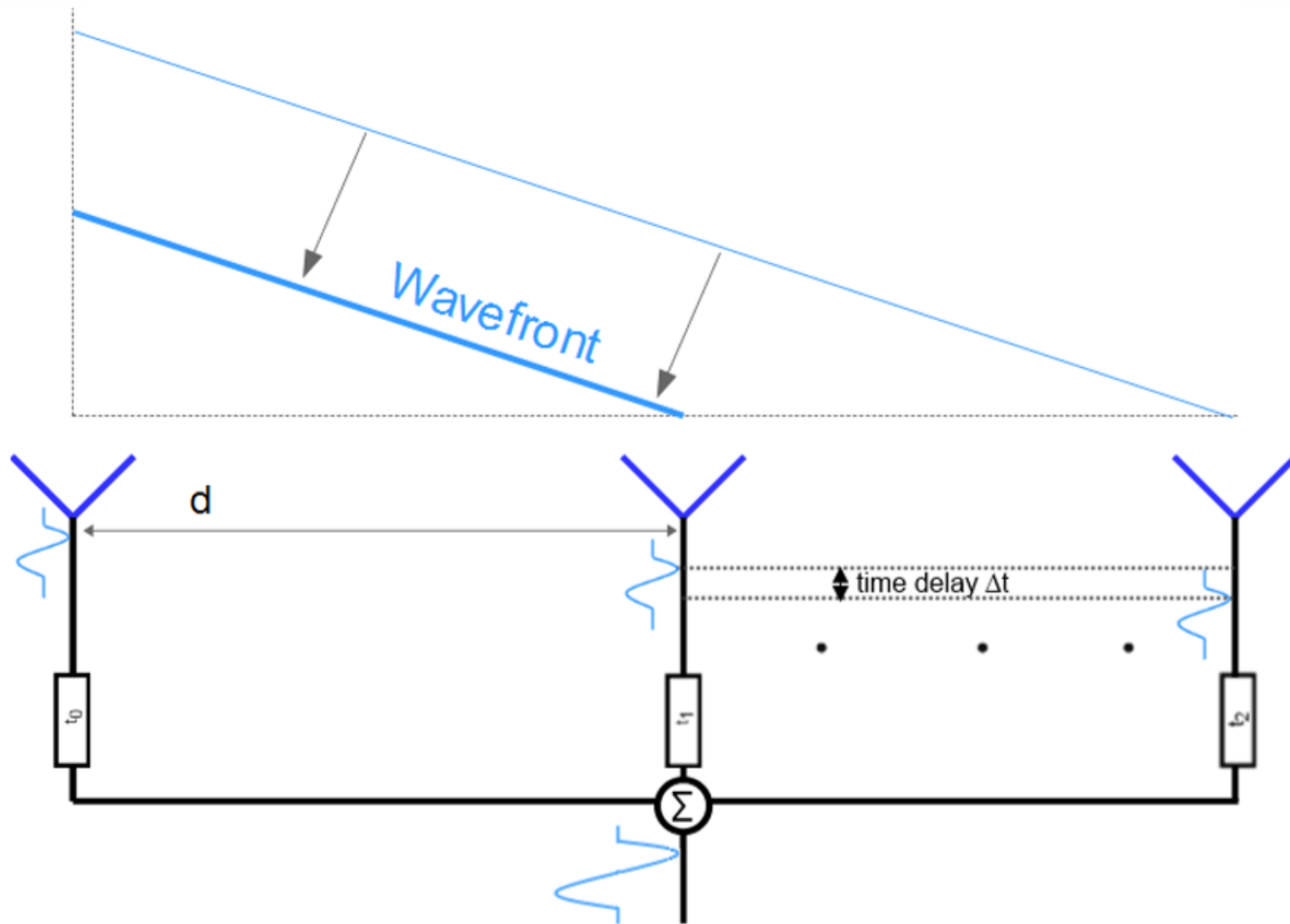
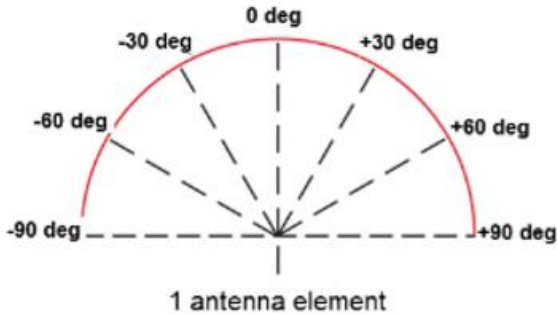


Figure 6: True Time Delay Beamsteering

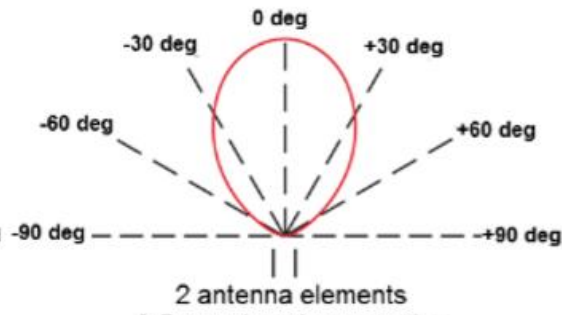
# Antenna Patterns vs. Number of Elements

Main lobe = omnidirectional



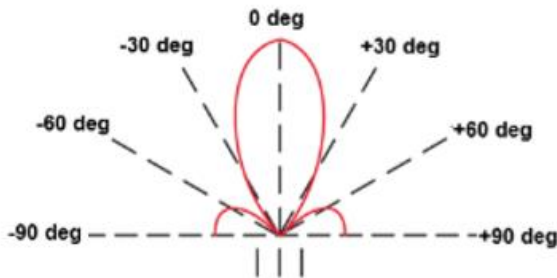
(a)

Main lobe = 0 deg azimuth  
# nulls = 1



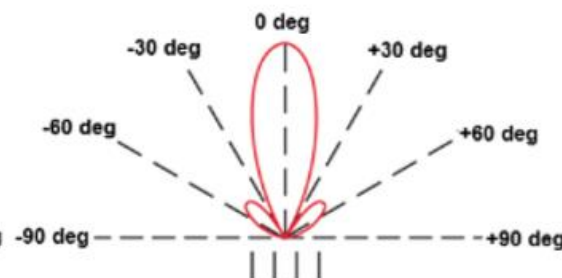
(b)

Main lobe = 0 deg azimuth  
# nulls = 2



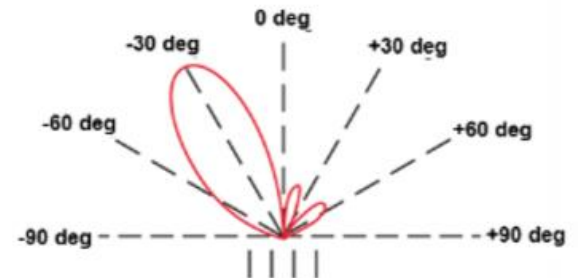
(c)

Main lobe = 0 deg azimuth  
# nulls = 3



(d)

Main lobe = -30 deg azimuth  
# nulls = 3



(e)

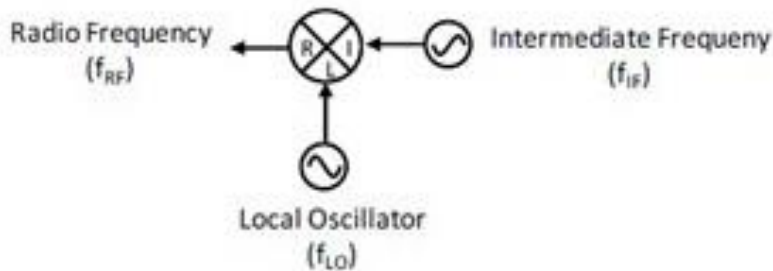
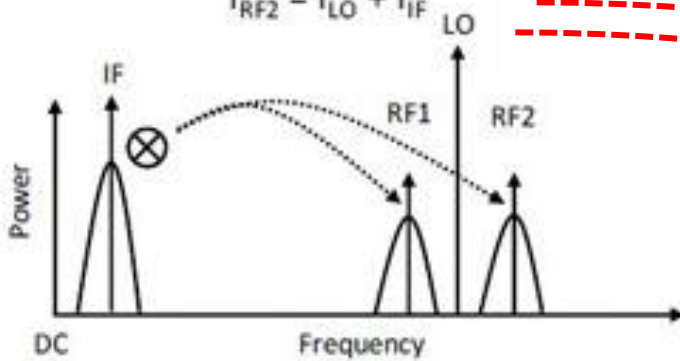
# 5G RF Transceiver 구조

## RF Transmitter

UPCONVERSION

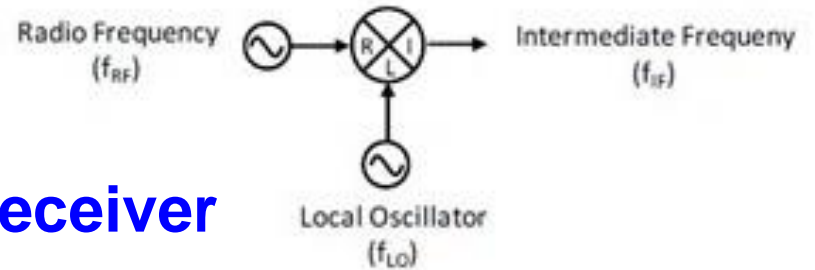
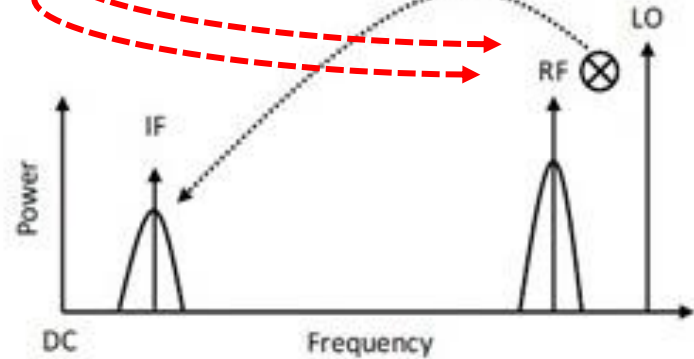
$$f_{RF1} = f_{LO} - f_{IF}$$

$$f_{RF2} = f_{LO} + f_{IF}$$



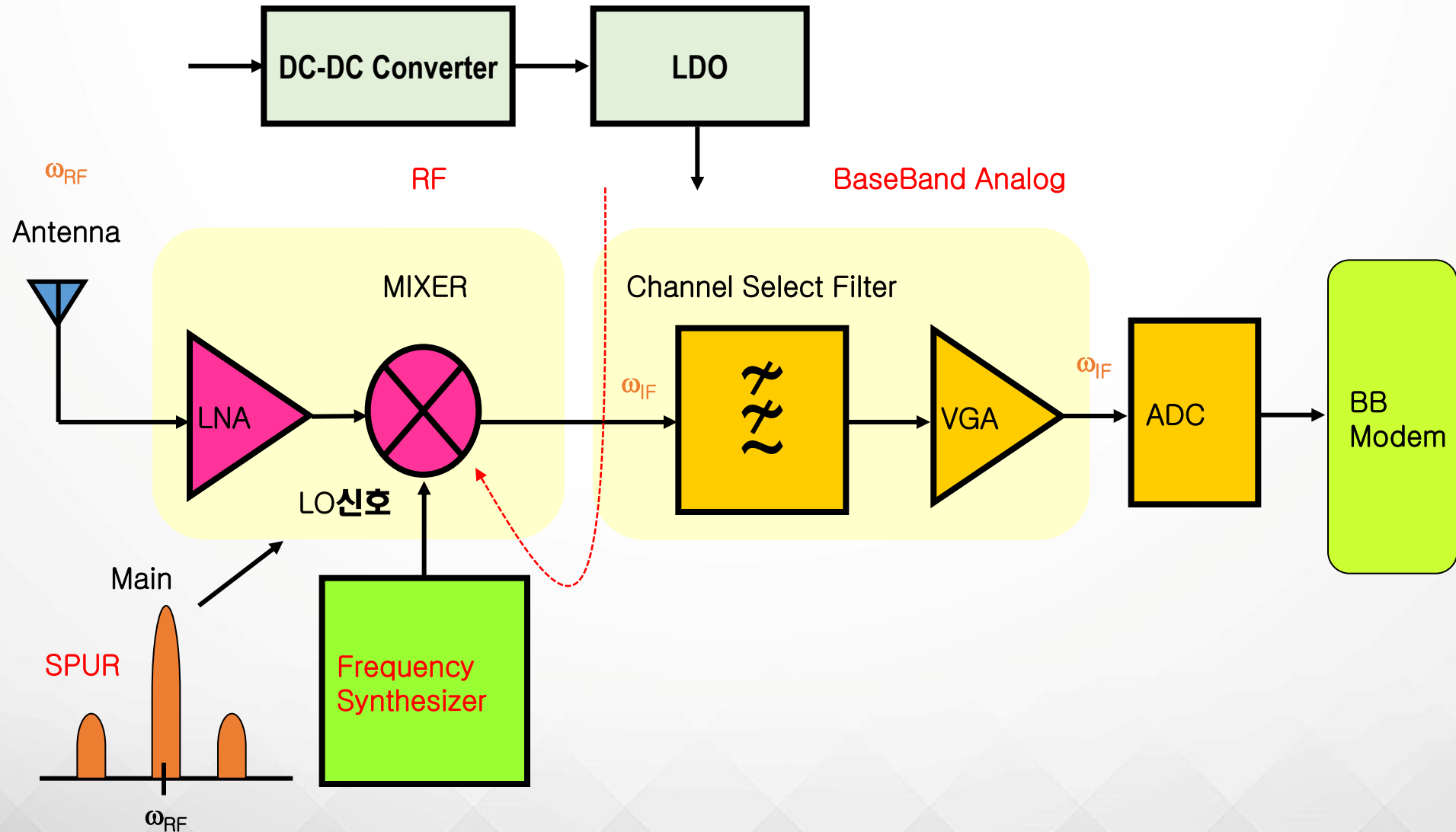
DOWNCONVERSION

$$f_{IF} = |f_{LO} - f_{RF}|$$

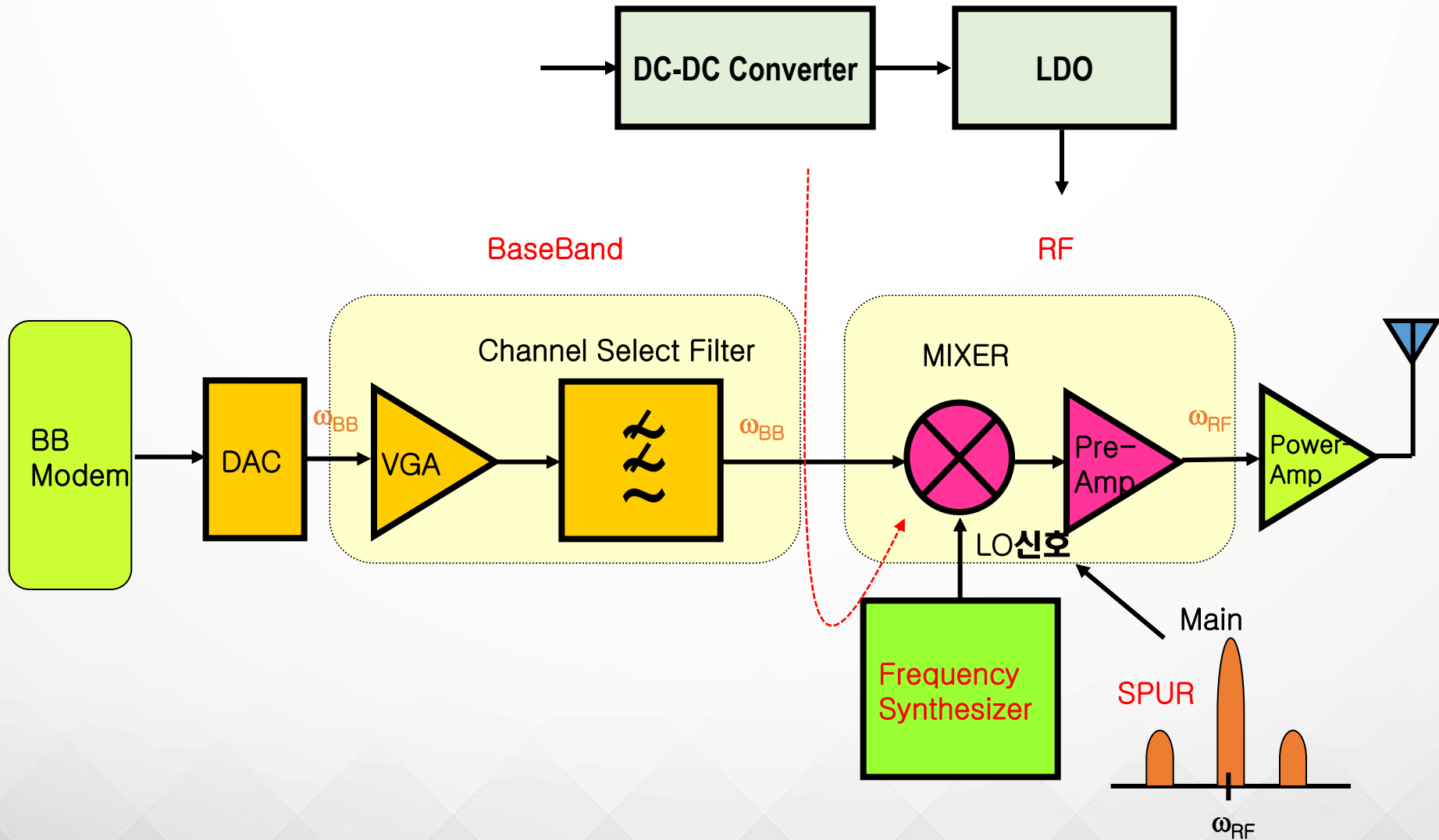


## RF Receiver

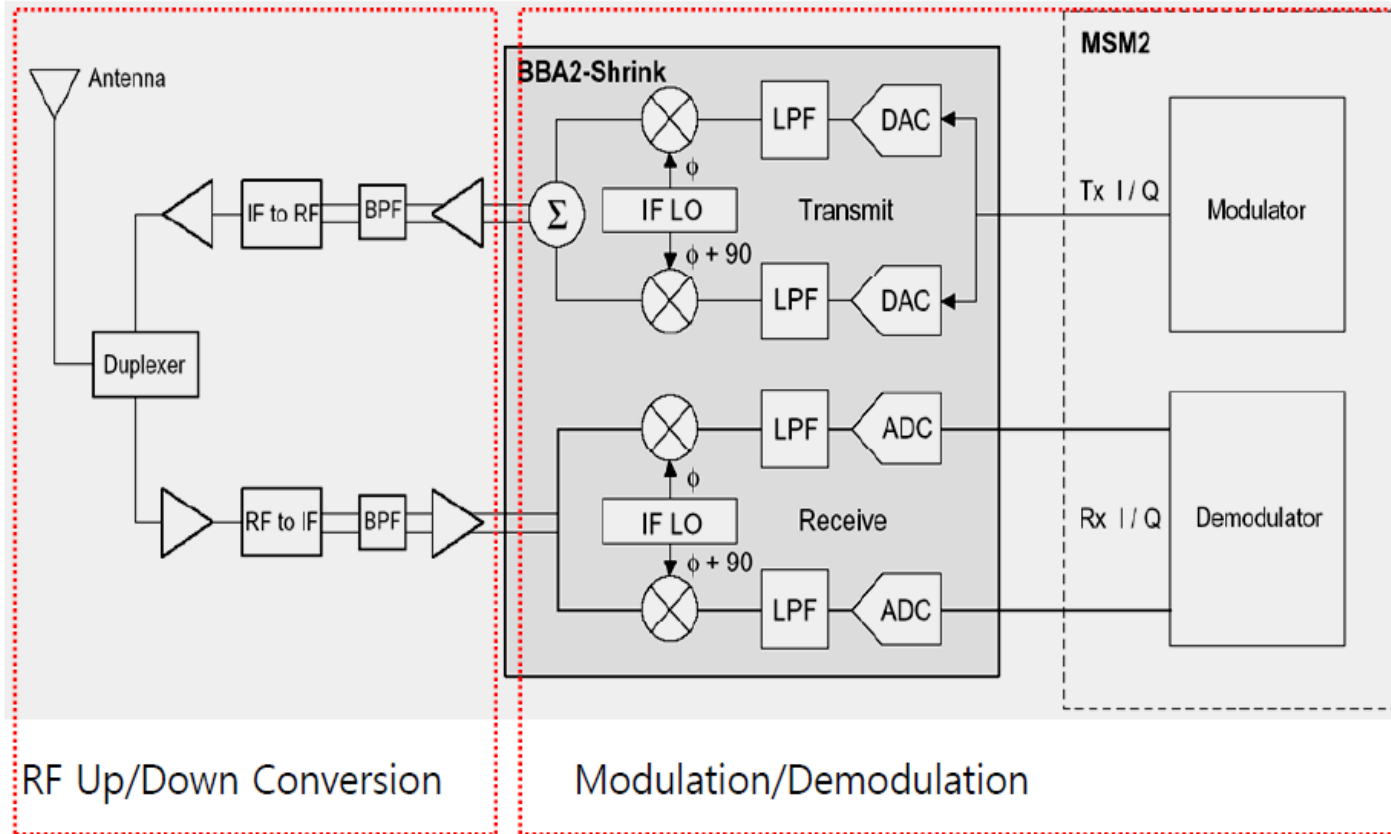
# 2 RF Receiver



## 2 RF Transmitter



# I/Q Modulation & Demodulation



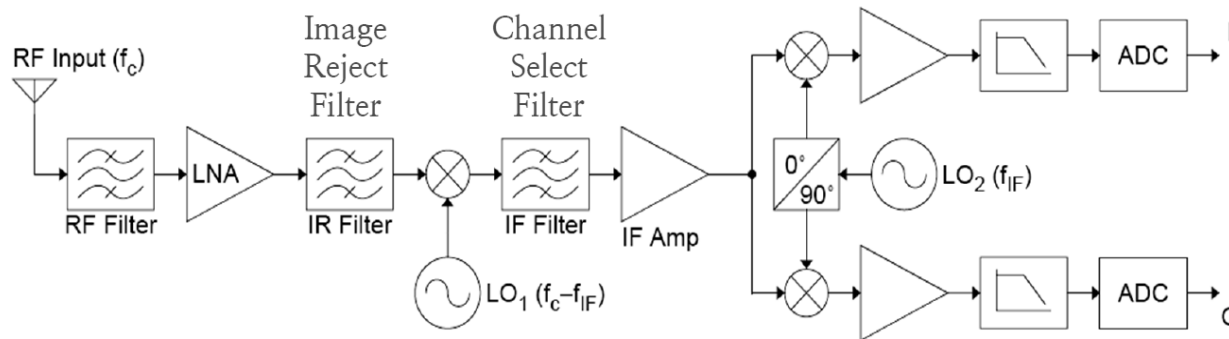
- Hetrodyne
- Direct Conversion
- Low IF
- Wideband IF

- ASK,OOK
- GMSK,MSK,FSK
- QPSK,OQPSK
- M-PSK,QAM

## ❖ Hetrodyne receiver

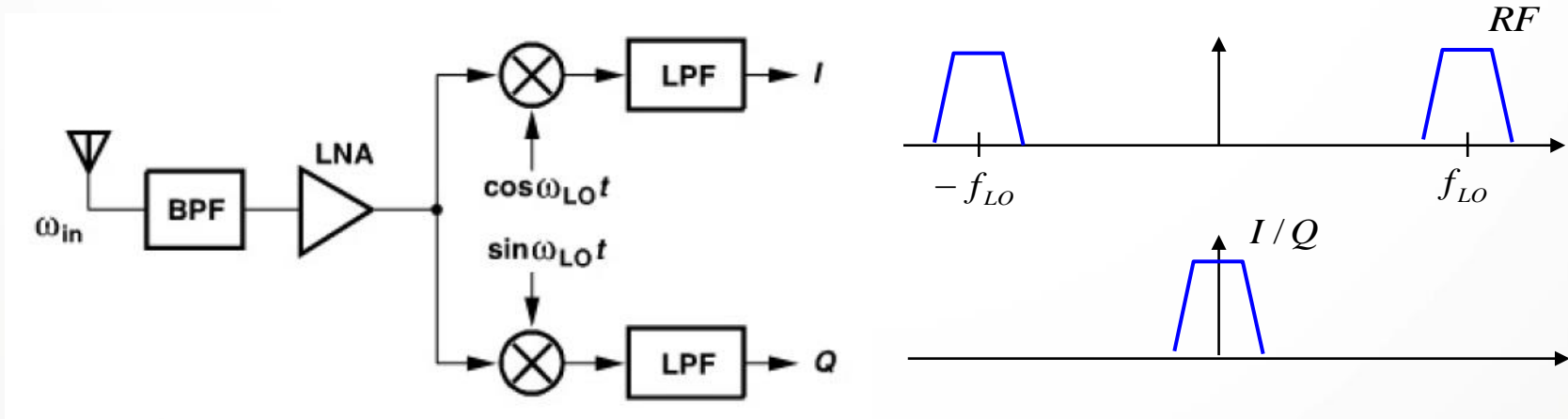
$f_{LO} > f_c$  : High side Injection

$f_{LO} < f_c$  : Low side Injection



- ▶ **Antenna → RF → IF → Demodulation**
- ▶ **Channel selection is done by a tunable LO and a fixed IF band-pass filter (BPF).**
  - Improved selectivity (sharper cutoff characteristic)
  - Easier band tuning
- ▶ **Required amount of gain can be allocated across two different frequency bands (RF and IF) → Can implement higher gain than tuned RF receivers.**
- ▶ **“Image” problem: Signals at the image band can degrade the receiver SNR.**
- ▶ **“Channel-selection filter” may be difficult to integrate in IC.**
- ▶ **May employ double-conversion for optimal performance.**

## ❖ Homodyne or Zero-IF



- ▶ LO frequency is equal to the RF center frequency.
- ▶ Channel-selection filter (BPF) is replaced by a low-pass filter (LPF) → More suitable for integration than heterodyne receivers.
- ▶ LO-to-RF leakage can cause problems.
  - Spurious radiation.
    - ▶ Remedy: Increase LNA isolation, use differential LO.
  - DC fluctuation (“self-mixing”)
    - ▶ Remedy: AC-coupling, offset-cancellation feedback loop.

- Multi mode 5G/4G
  - 2017 LTE 5 RX Carriers aggregated
    - > 44 bands
    - > more than 1000 DL (Down Link) CA combinations
    - > UL ( Uplink) CA concurrent with DL CA
  - 2G/3G also supported
- 5G adds further complexity
  - More bands both sub-6 and mm Wave.
  - Wider bandwidths
    - 100MHz component carrier, up to 8 component carriers
  - Higher carrier frequencies 24 to 71 GHz
  - Higher order modulation- 1024 QAM for sub 6GHz
  - Concurrent with 4G to enable > 5 Gbps data rates
  - Low latency control paths
    - AGC switching times
    - PLL settling
  - More antennas and additional PCB components adding PCB area.

## Phase Noise

Phase noise describes an oscillator's short term random frequency fluctuations. Noise sidebands are typically specified in terms of **dBc/Hz at a given offset frequency from the carrier frequency**

Typically, single sideband(SSB) is considered when specifying phase noise, thus giving single sideband performance

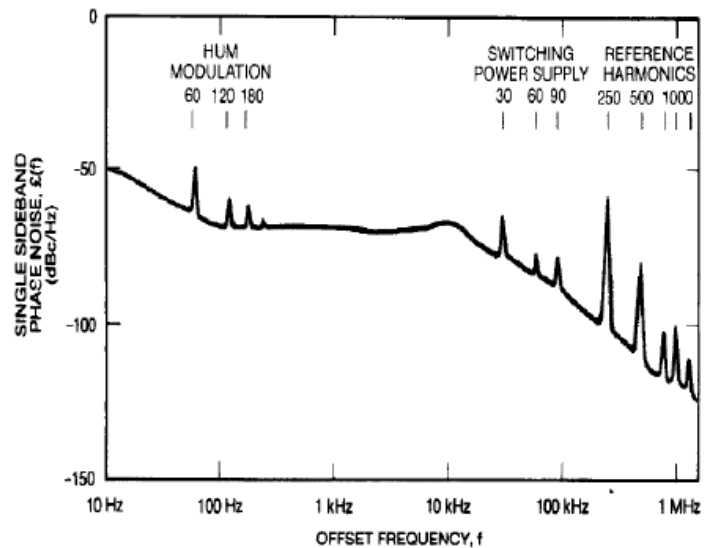
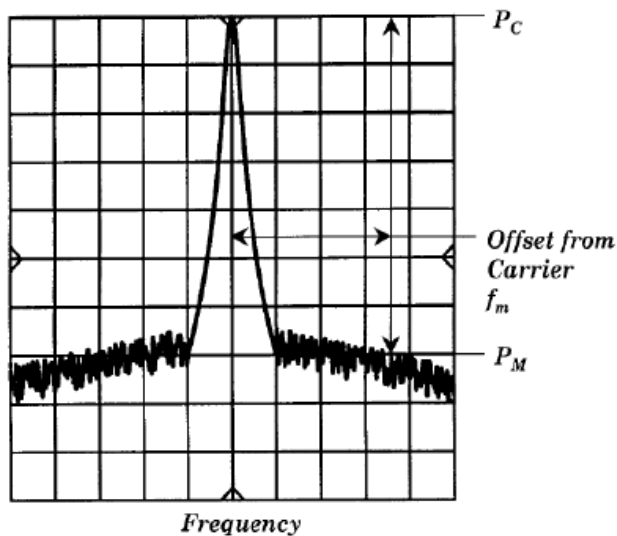
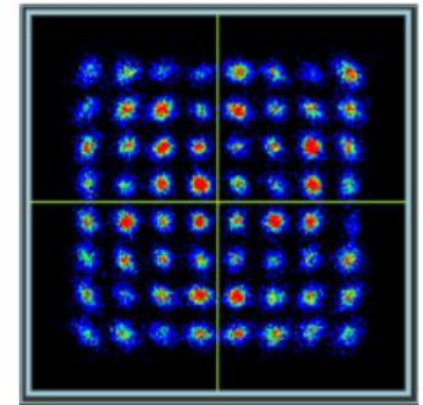
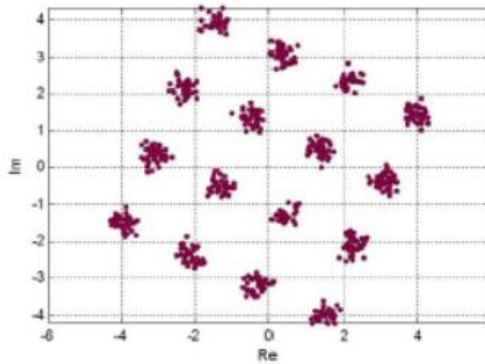
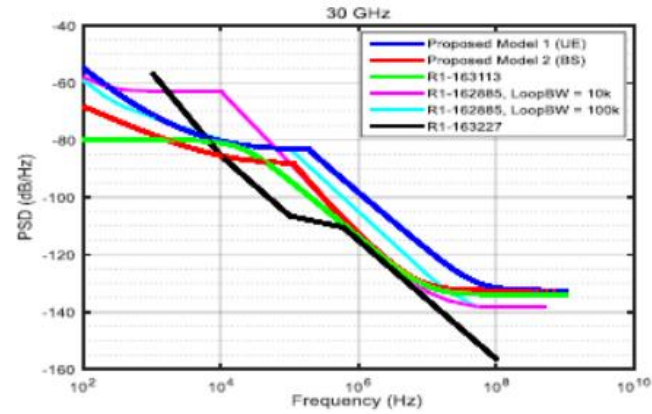
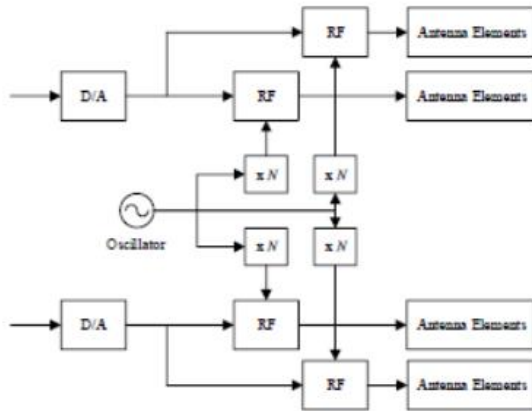


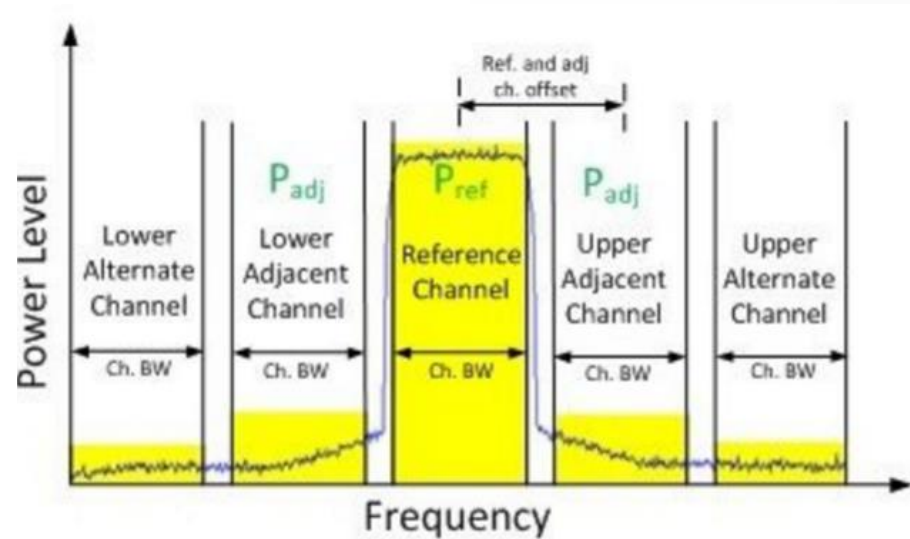
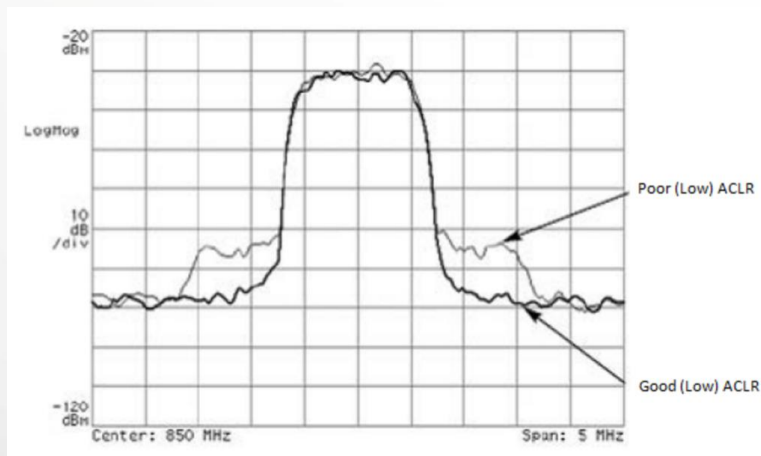
Figure 5. Local oscillator spurious signals.

- At carrier in higher frequency, phase noise becomes significant and could result in performance degradations



- Consider PN issue in spec. design

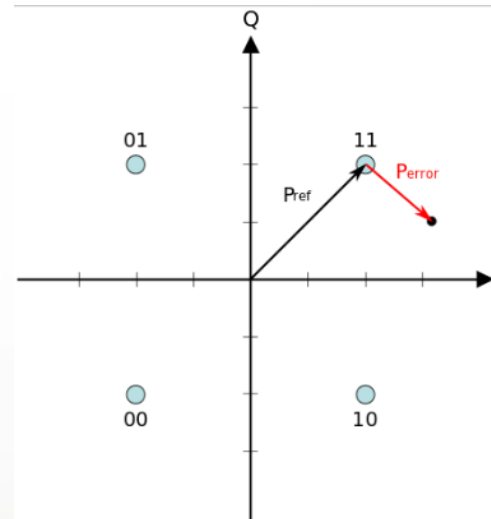
- ❖ Ratio of the RRC filtered mean power centered on the adjacent channel frequency to the RRC filtered mean power centered on the assigned channel frequency

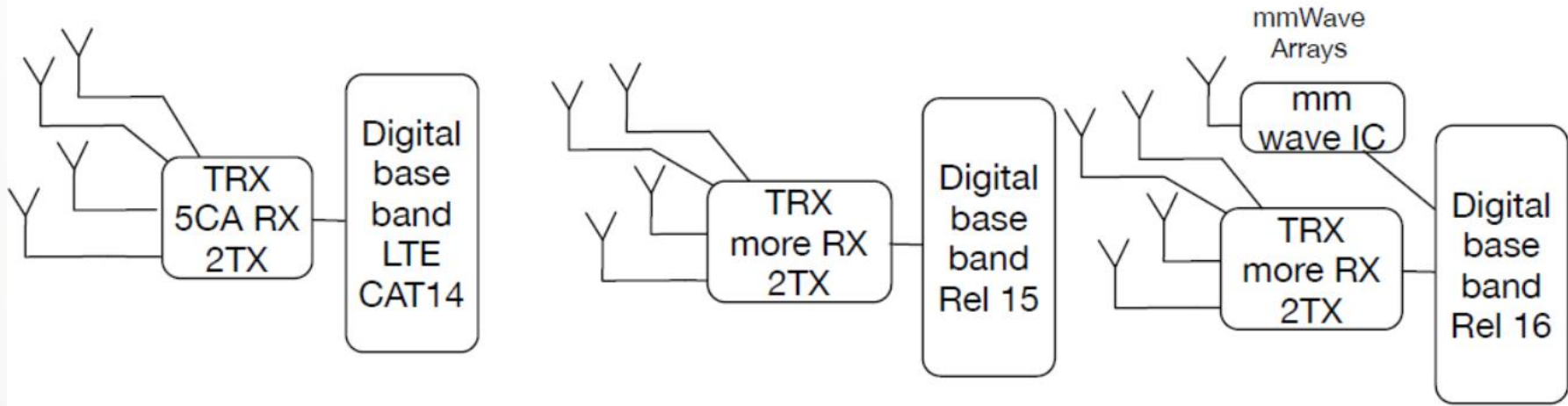


- ❖ **Error vector: a vector in the I-Q plane between the ideal constellation point and the point received by the receiver**

$$\text{EVM (dB)} = 10 \cdot \log \left( \frac{P_{\text{error}}}{P_{\text{reference}}} \right)$$

$$\text{EVM (\%)} = 100 \cdot \sqrt{\frac{P_{\text{error}}}{P_{\text{reference}}}}$$





2017

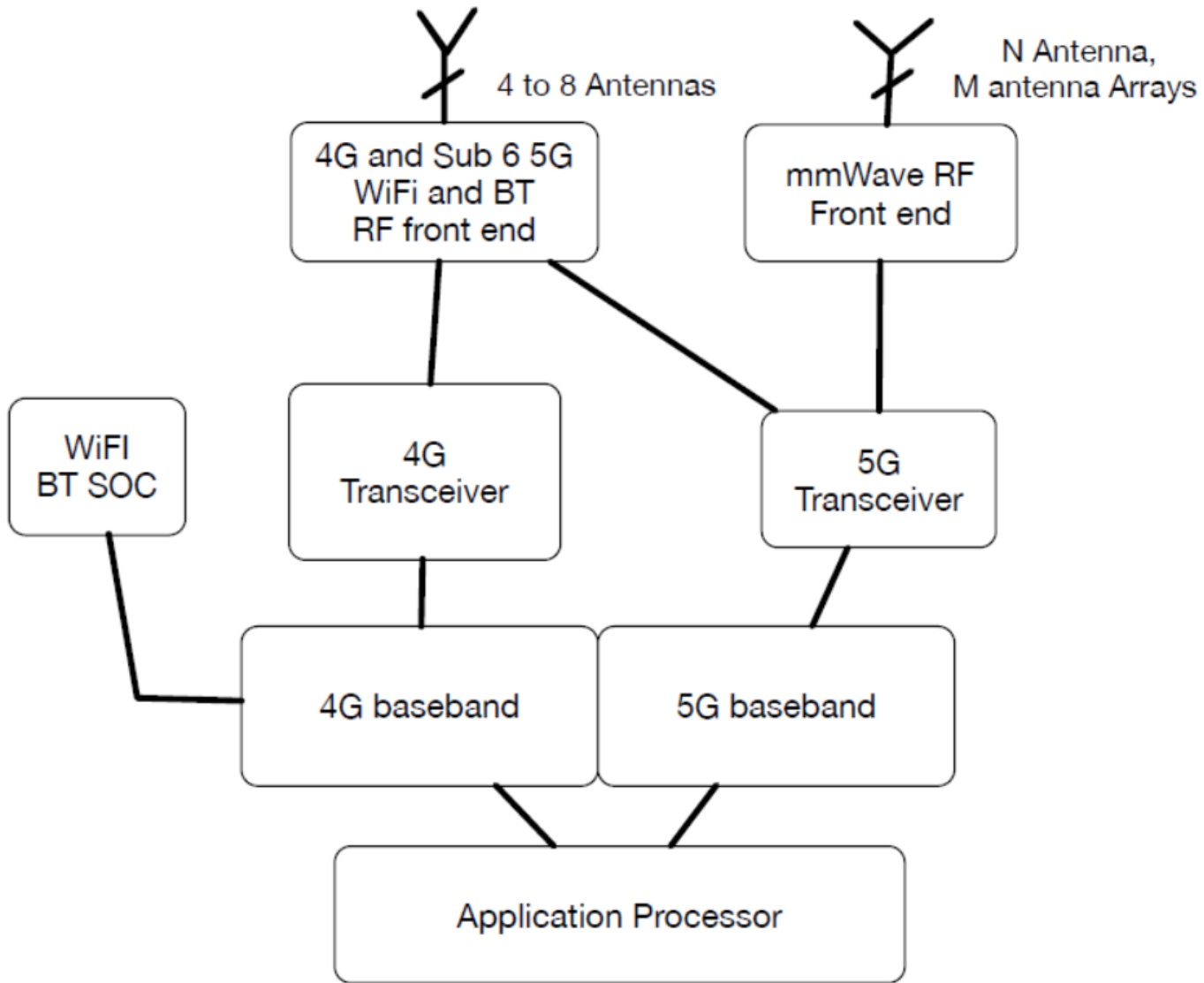
- 4x4 MIMO on 2 CA+
- 2x2 MIMO on 1 CA
- 1GBps data rates

2018

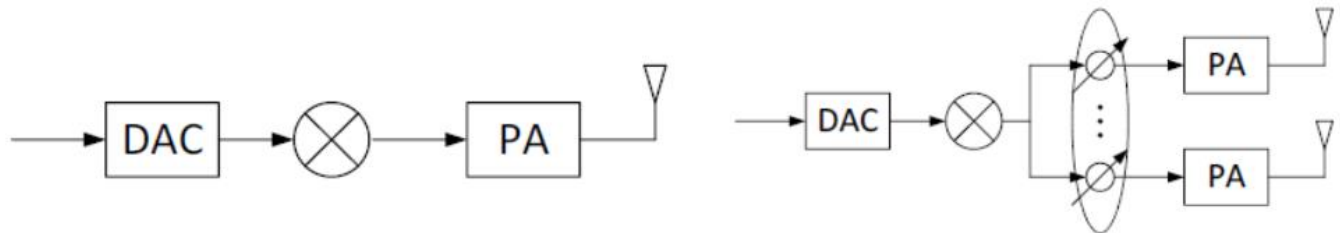
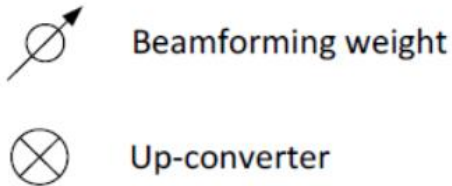
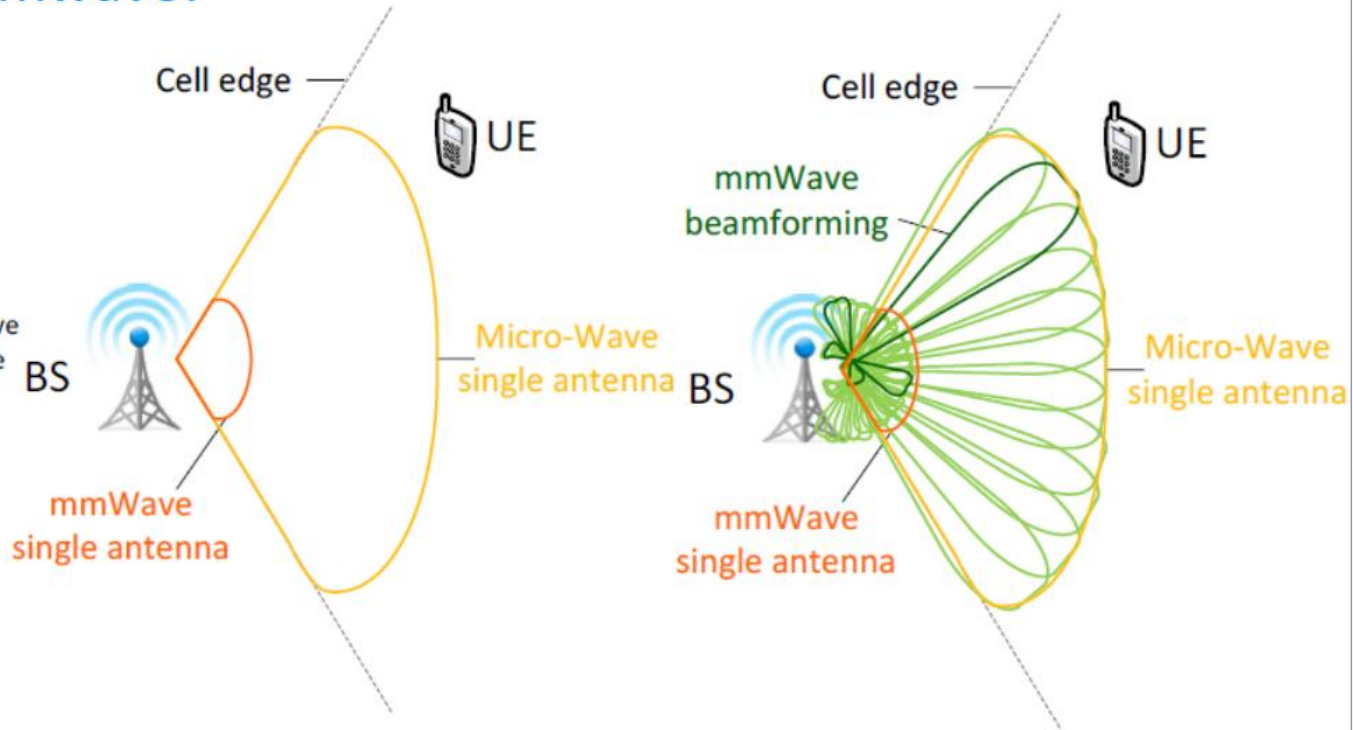
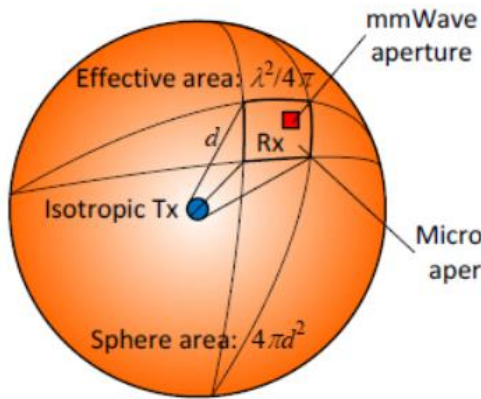
- 4x4 MIMO on more CA+
- 1.5GBps data rates
- 256 QAM
- 60MHz UL BW

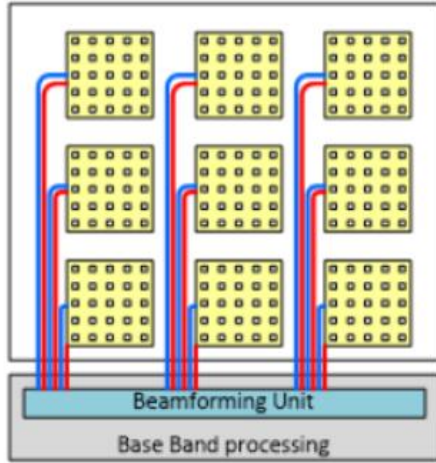
2019

- 4x4 MIMO on more CA+
- Sub 6 5G
- mm Wave 5G
- 100MHz component carrier
- 200MHz RF bw for sub 6
- 800MHz RF bw for mm Wave

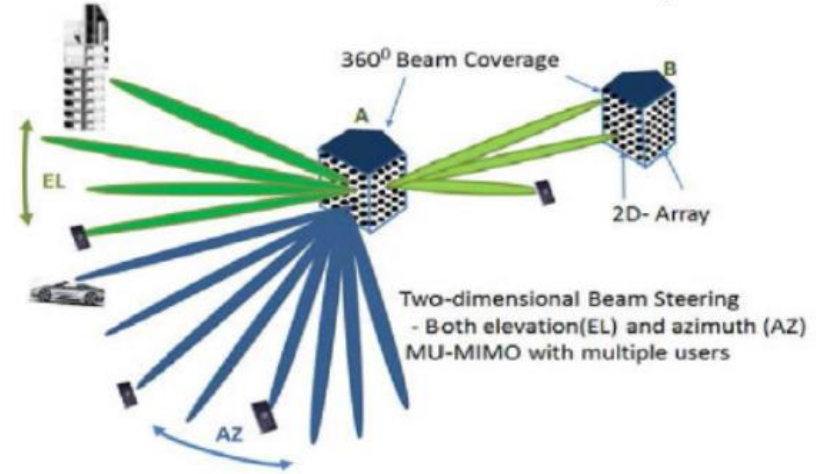


## ■ Microwave vs. mmwave:

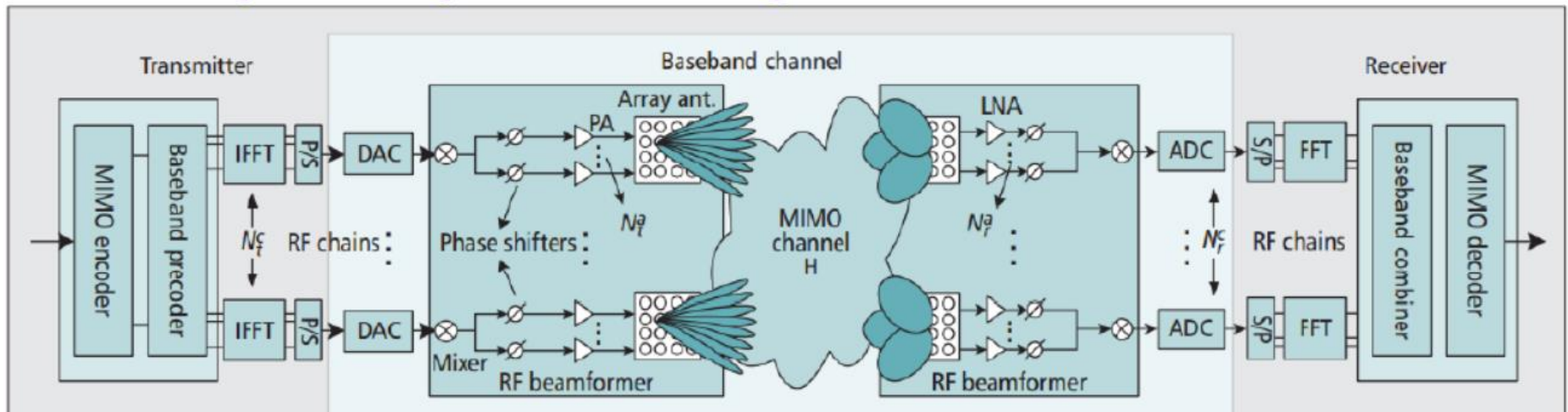




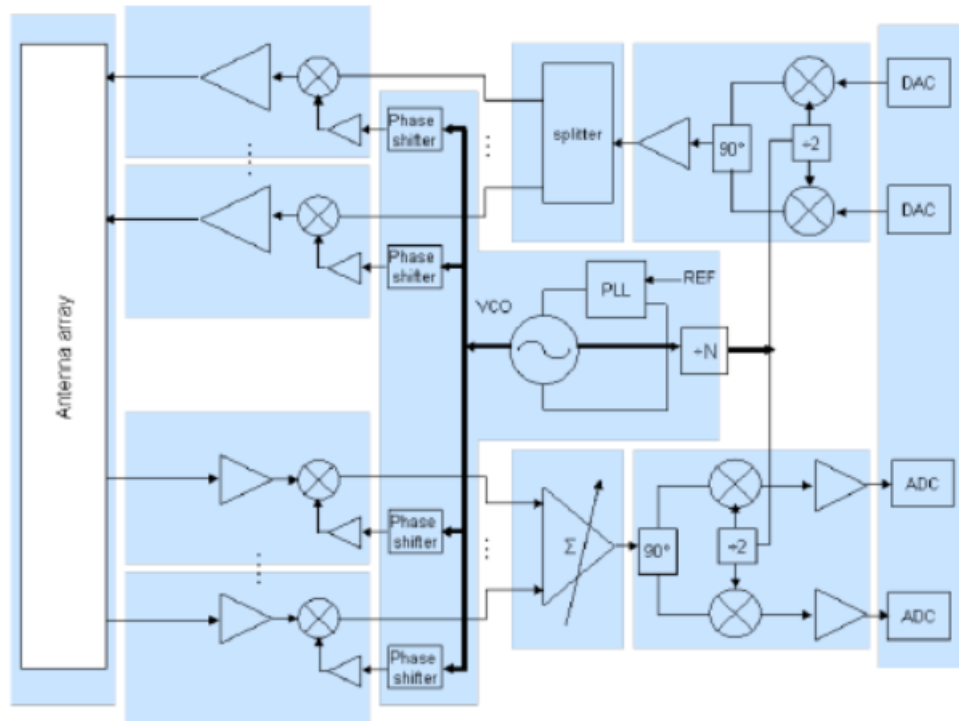
Massive MIMO with 2D array



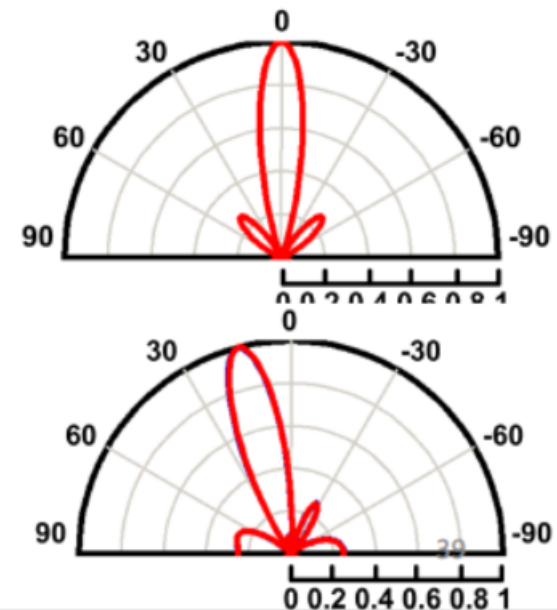
## Block diagram of a hybrid beamforming architecture



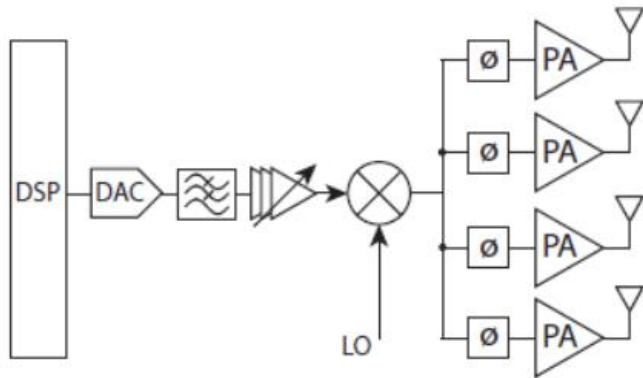
- Timed(Phased)-array Transceivers
  - Electronic beam steering
  - Compact antennas
  - Phase shifting (hardware  $\uparrow$ , power  $\uparrow$ )



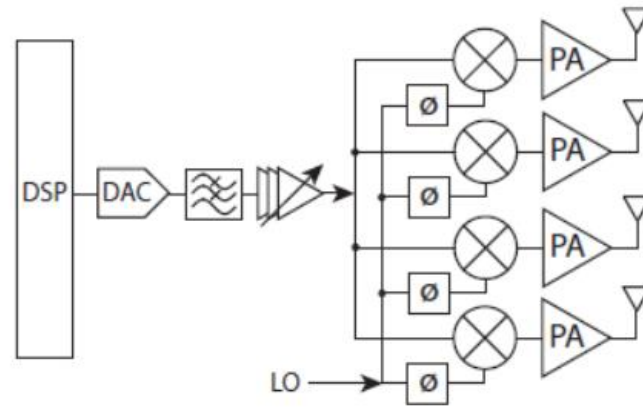
(Courtesy of Prof. S.P. Voinigescu, University of Toronto)



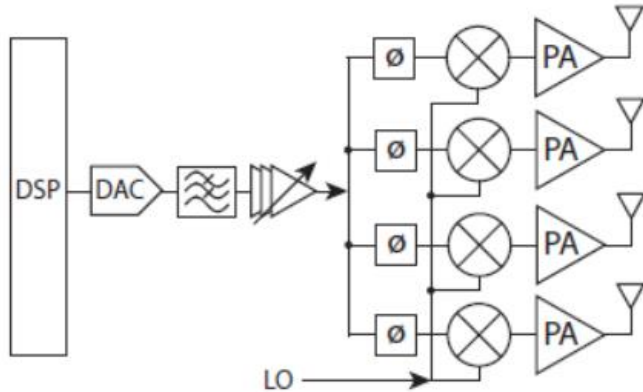
# TX Beam Forming Architectures



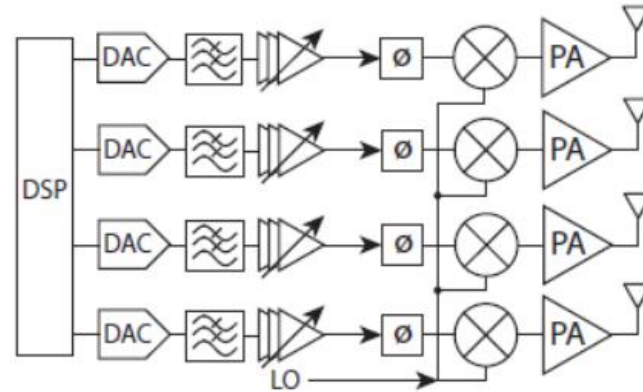
(a) RF Phase Shifting



(b) LO Phase Shifting



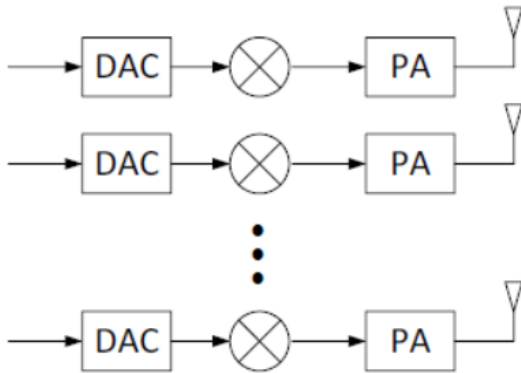
(c) Analog Baseband Phase Shifting



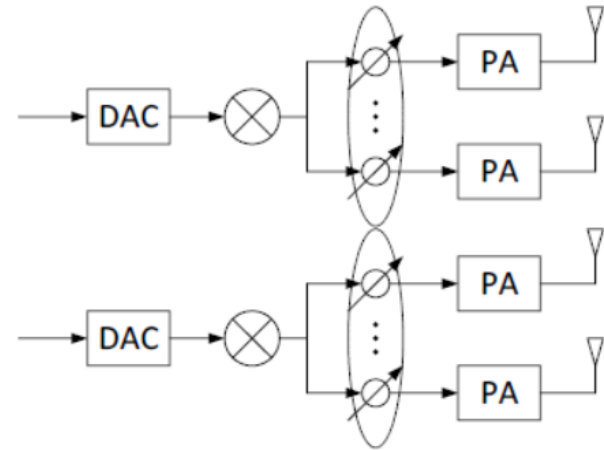
(d) Digital Baseband Phase Shifting

Figures from UC Berkeley PHD Thesis by Jiashu Chen "Advanced Architectures for efficient mmWave transmitters" Fall 2013.

## All digital vs. hybrid beamforming:



All digital beamforming



Hybrid beamforming

$12\text{bits} \times 2(I/Q) \times 250\text{MHz} \times 64 \text{ elements} = 384\text{Gbits/s}$



Beamforming weight

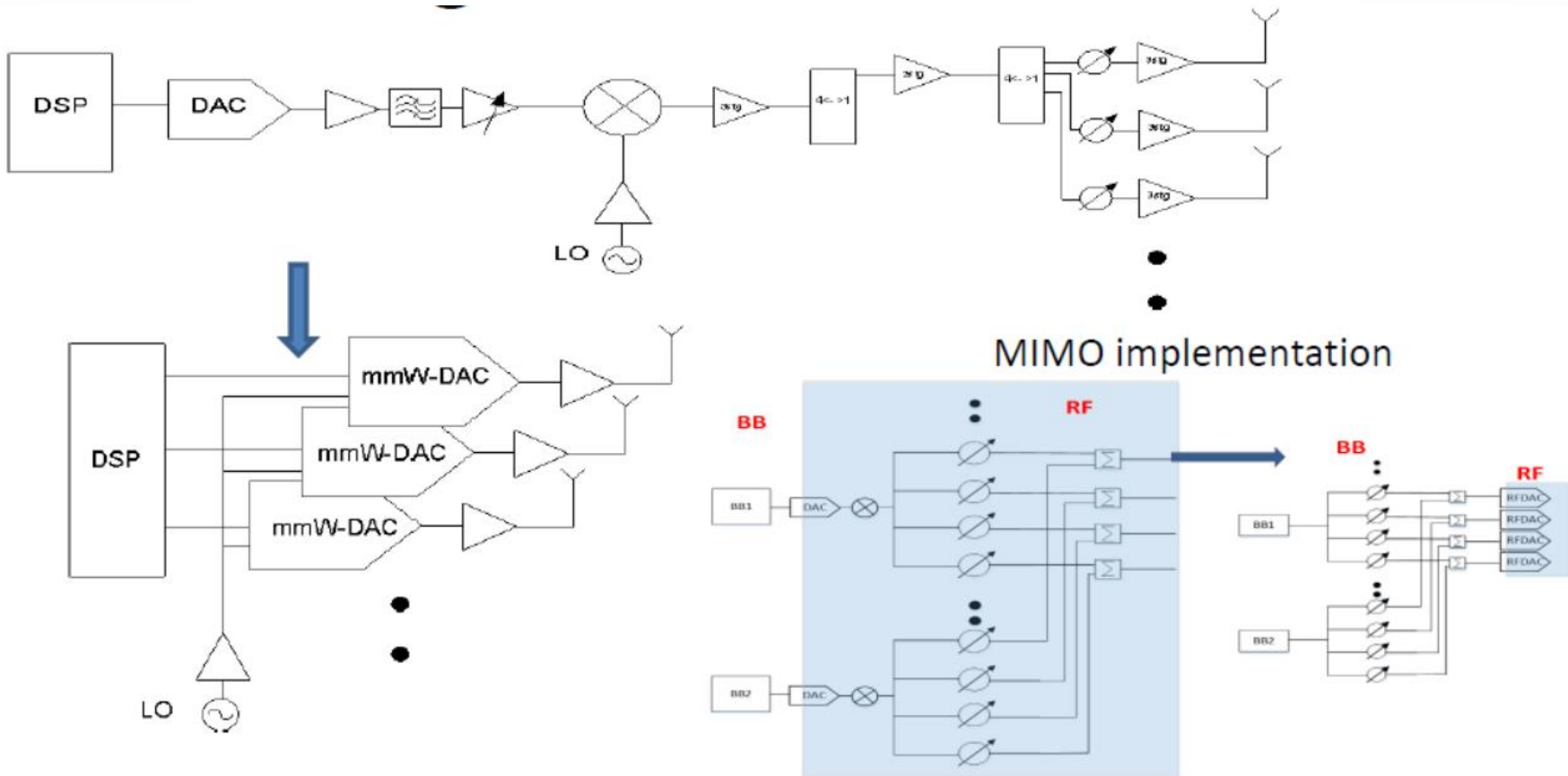


Up-converter

**Hybrid beamforming architectures may be a good choice by trading-off power consuming, cost and complexity.**

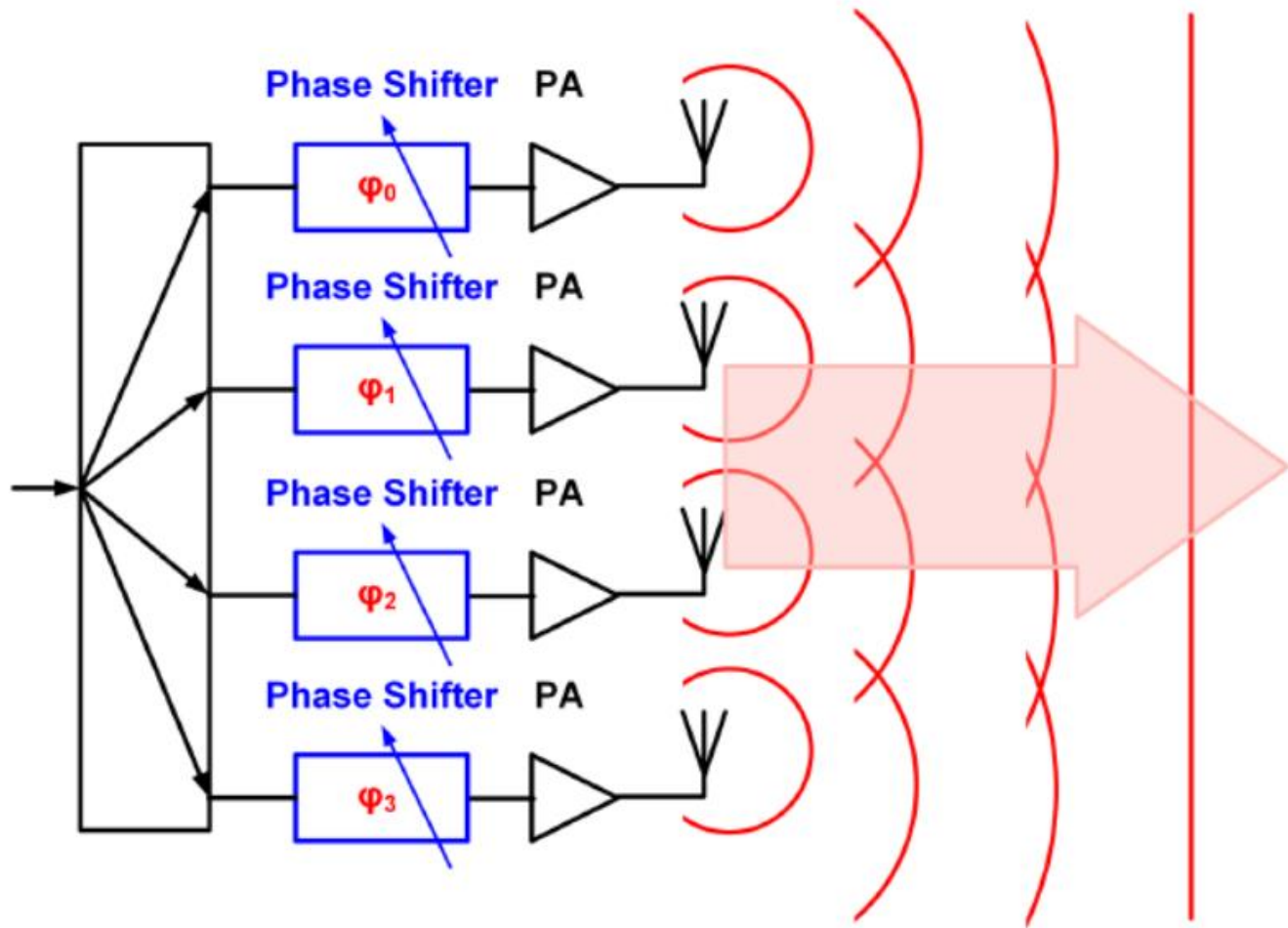
# 4

## Digital Beamformer

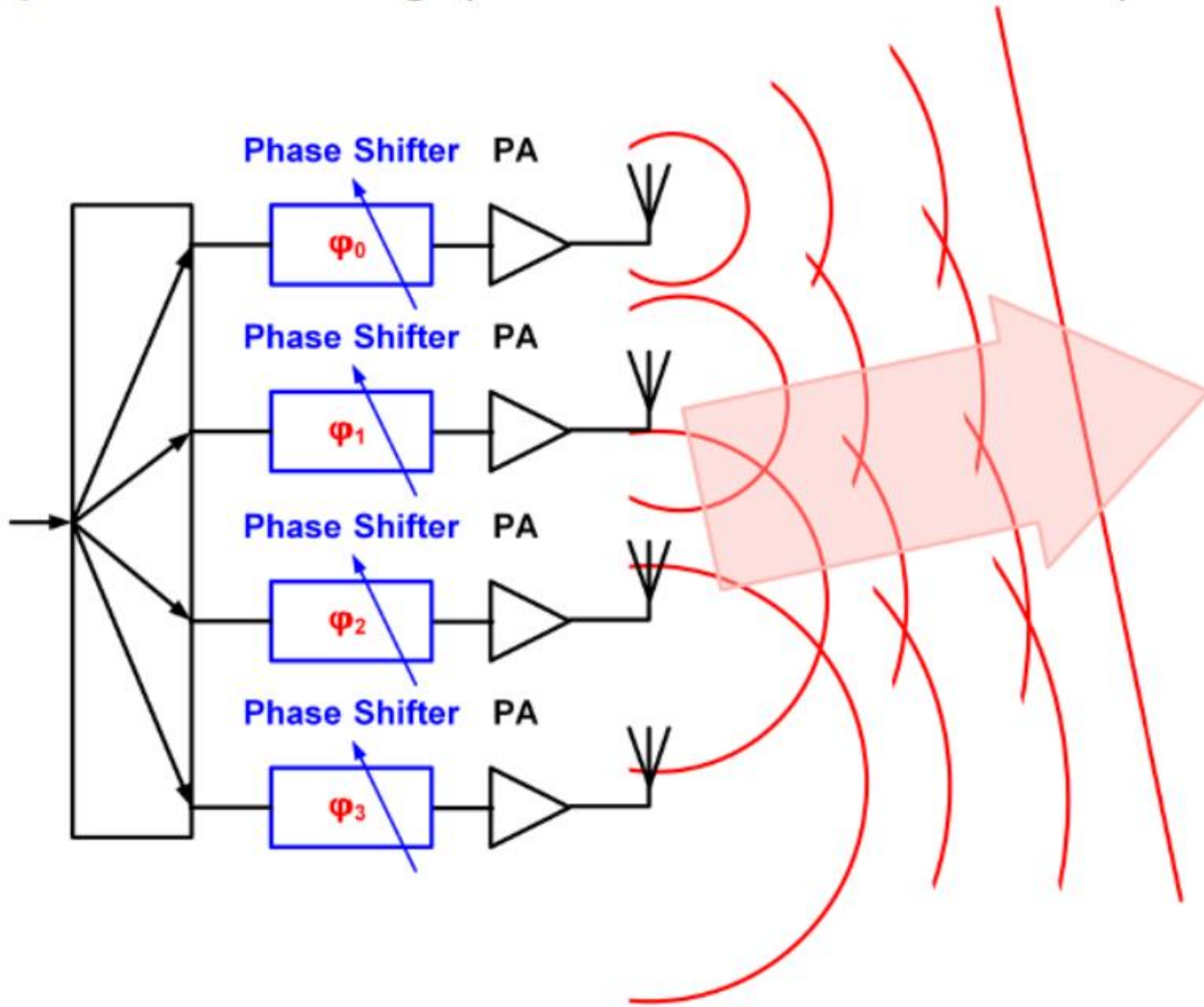


- Reduce die size, speed up design time, flexibility & power
- PS will have excellent resolution
- MIMO is done at BB before the RF chain

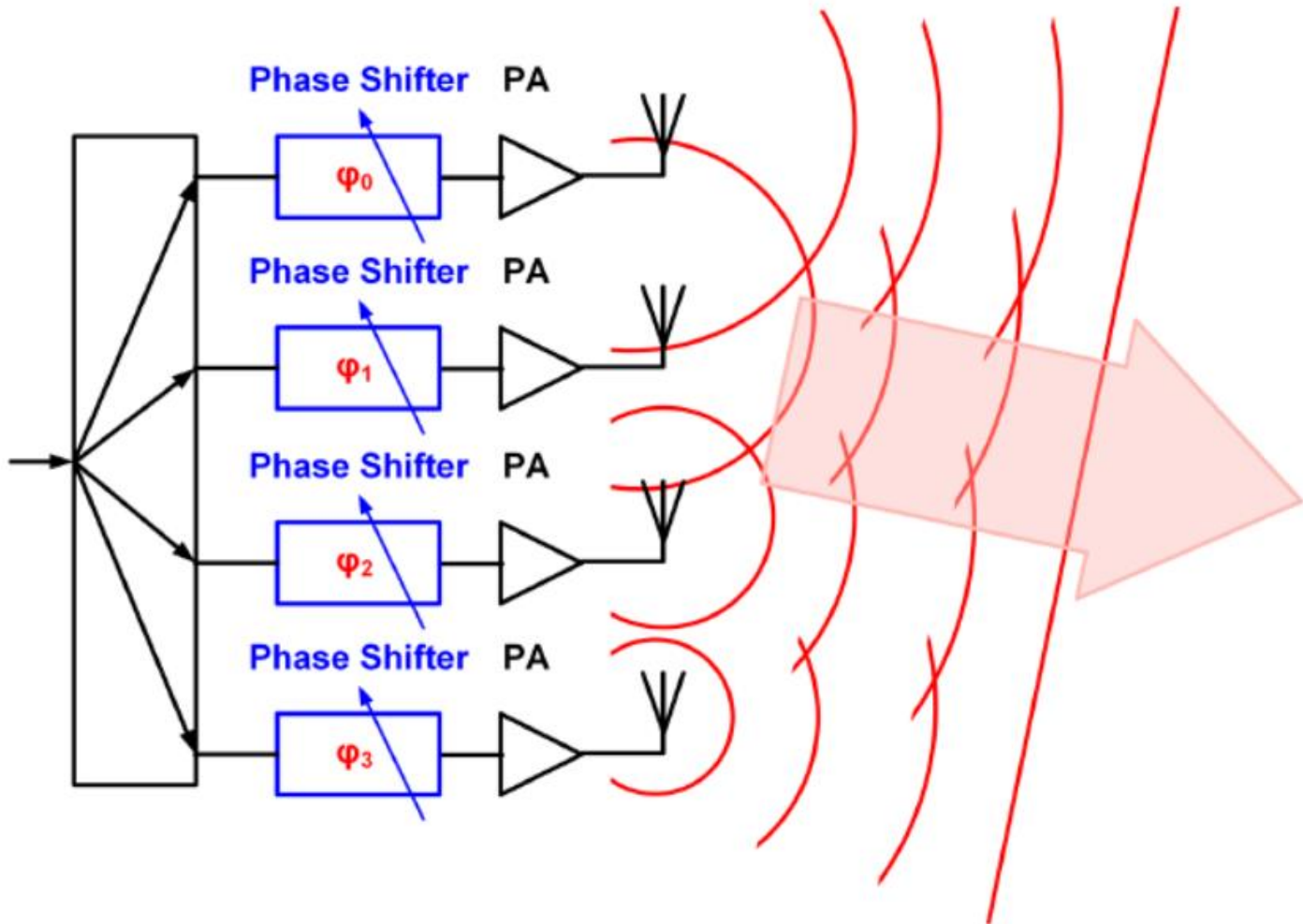
- RF phase shifting (4-element transmitter)



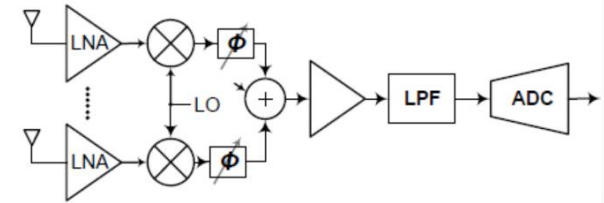
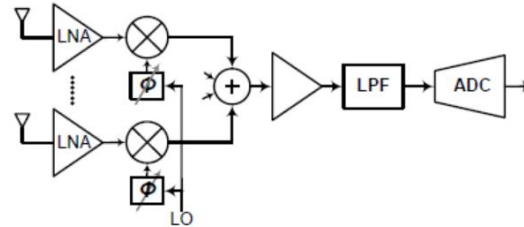
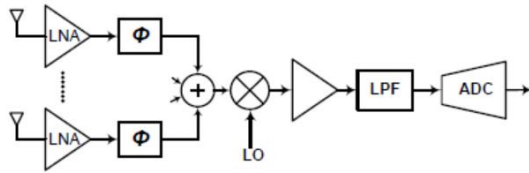
- RF phase shifting (4-element transmitter)



- RF phase shifting (4-element transmitter)

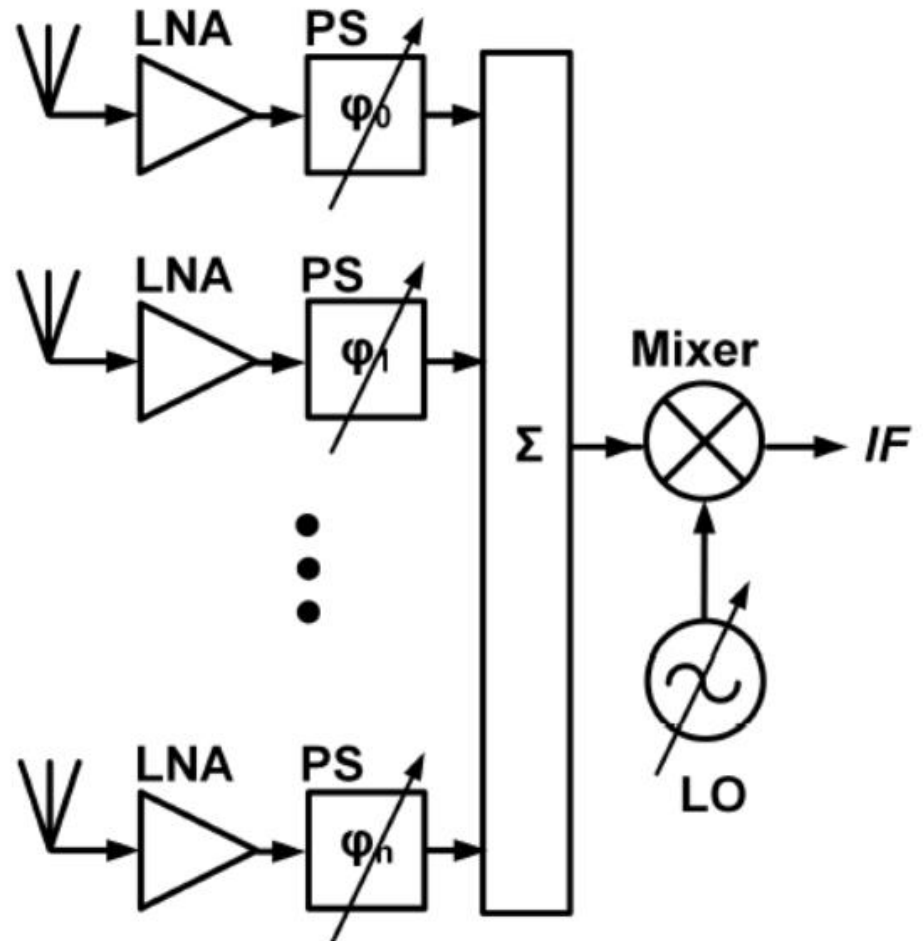


# 5 Wideband mm-wave Beamforming Receiver Architectures

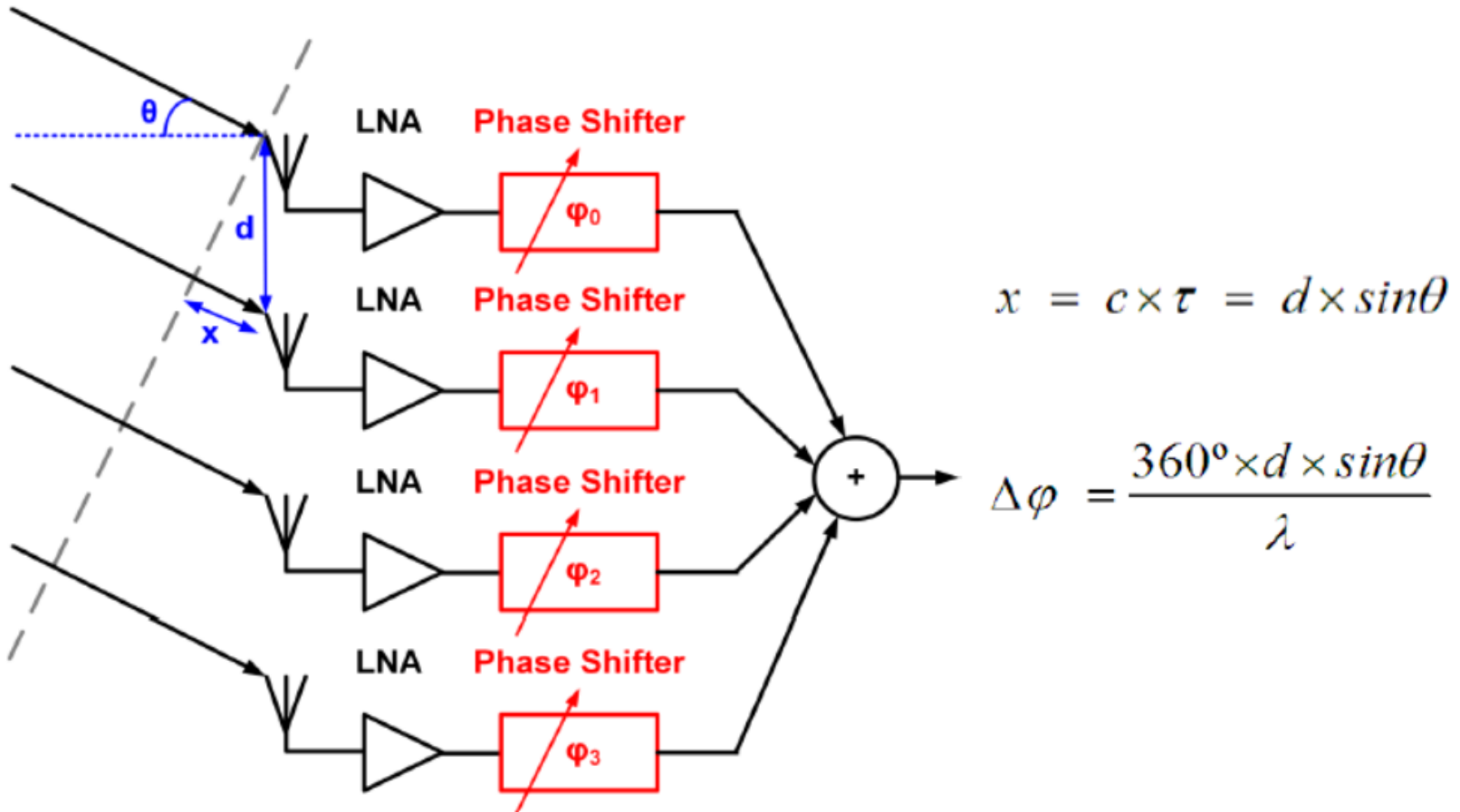


	RF Shifting & Combining	LO Shifting & BB Combining	BB Shifting & Combining
<b>LNA</b>	❌ Cover full RF BW	❌ Cover full RF BW	❌ Cover full RF BW
<b>Phase-shifter</b>	❌ Cover full RF BW ❌ Signal path loss	❌ Cover full RF BW ❌ LO attenuation	✅ Cover Channel BW ✅ Gain
<b>Amplitude Weight</b>	Loss Compensating VGA	VGA @ RF or IF	VGA @ BB
<b>LO Distribution</b>	Low Complexity Equiv. to single-antenna RX	High complexity	Intermediate complexity
<b>LO Generation</b>	Cover full RF BW → PN vs TR trade-offs, poor cap. Q @ mm-wave		

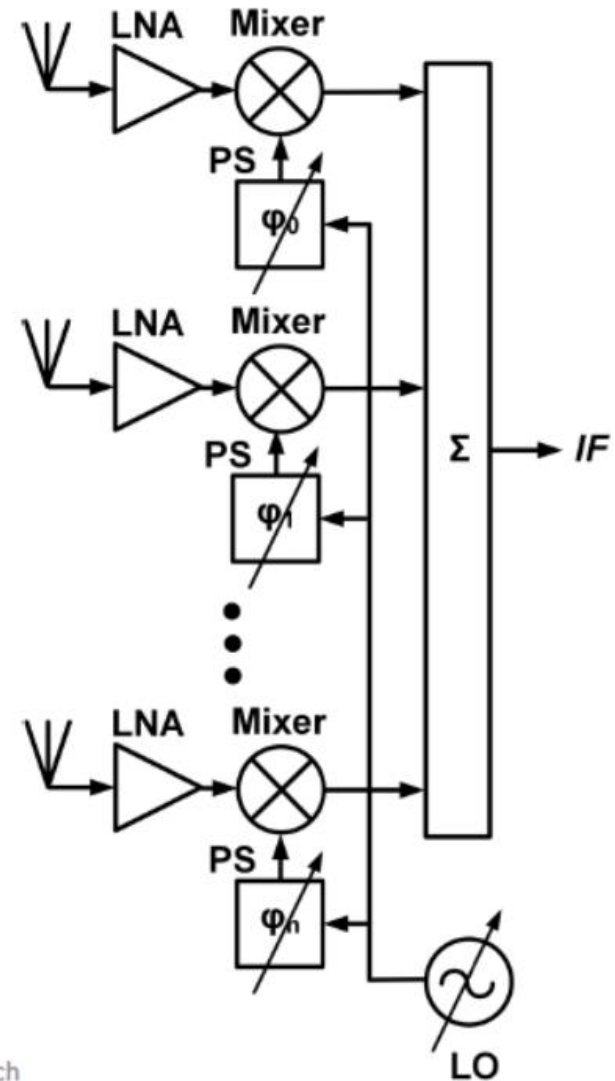
- Phased-Array Architectures
  - RF phase shifting



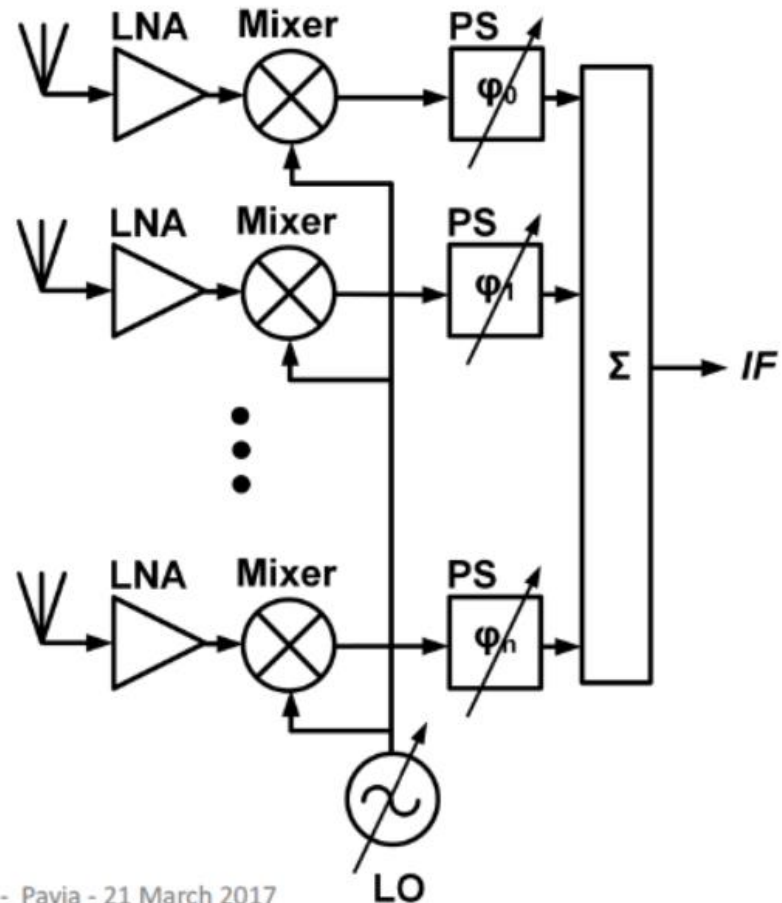
- RF phase shifting (4-element receiver)



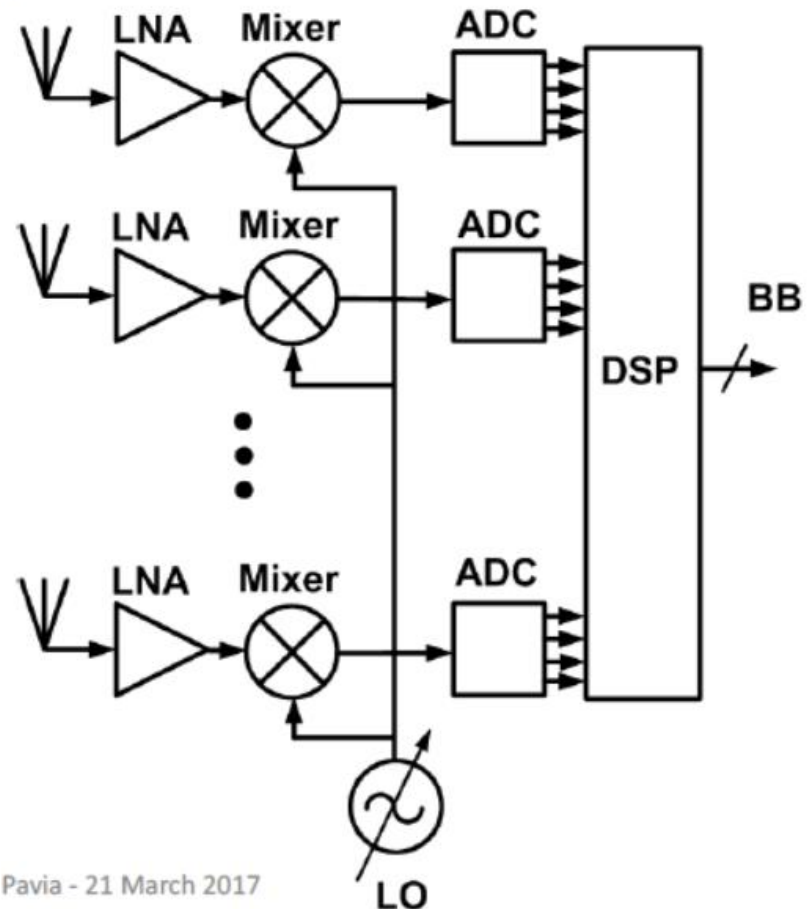
- Phased-Array Architectures
  - LO phase shifting



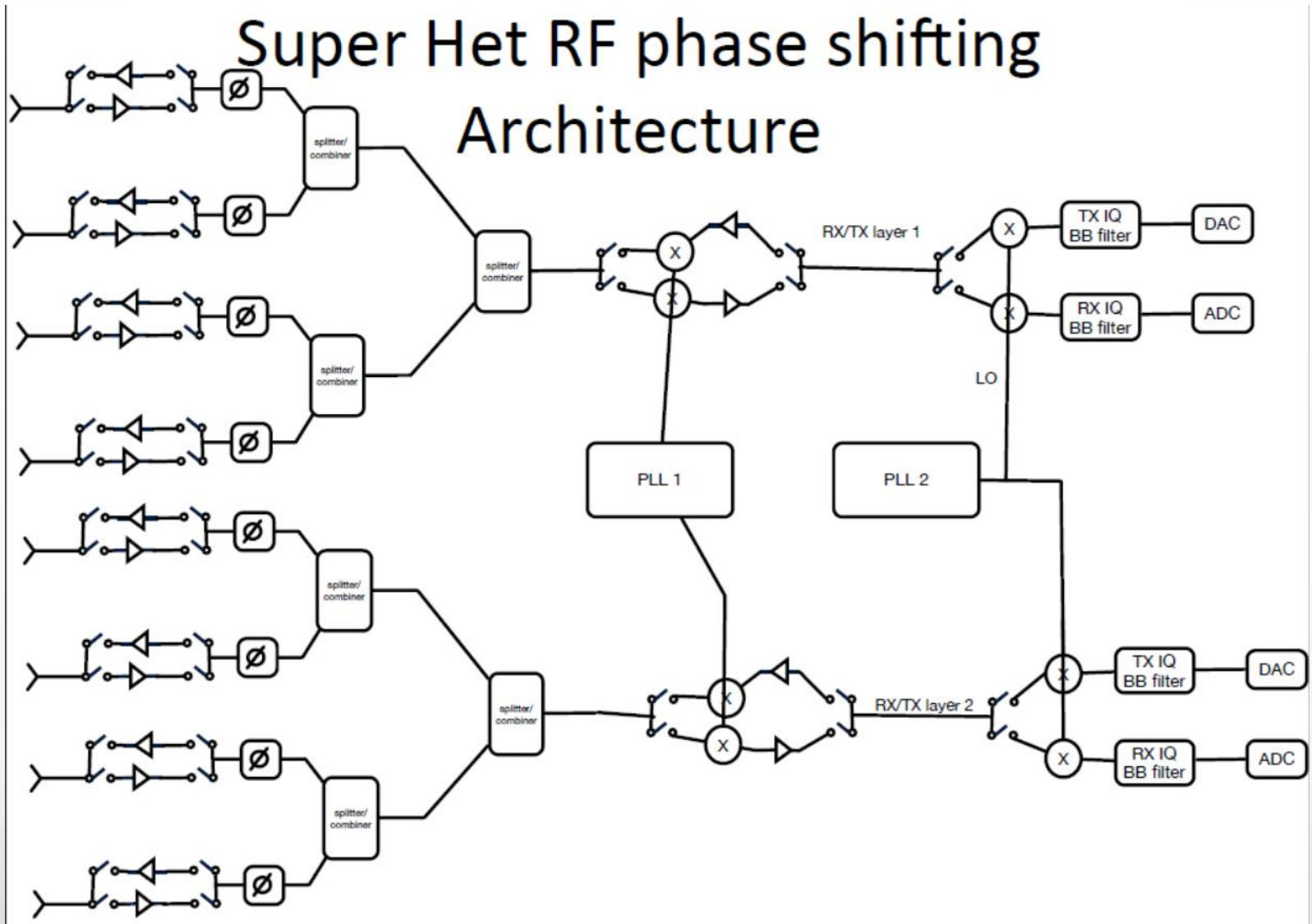
- Phased-Array Architectures
  - IF phase shifting



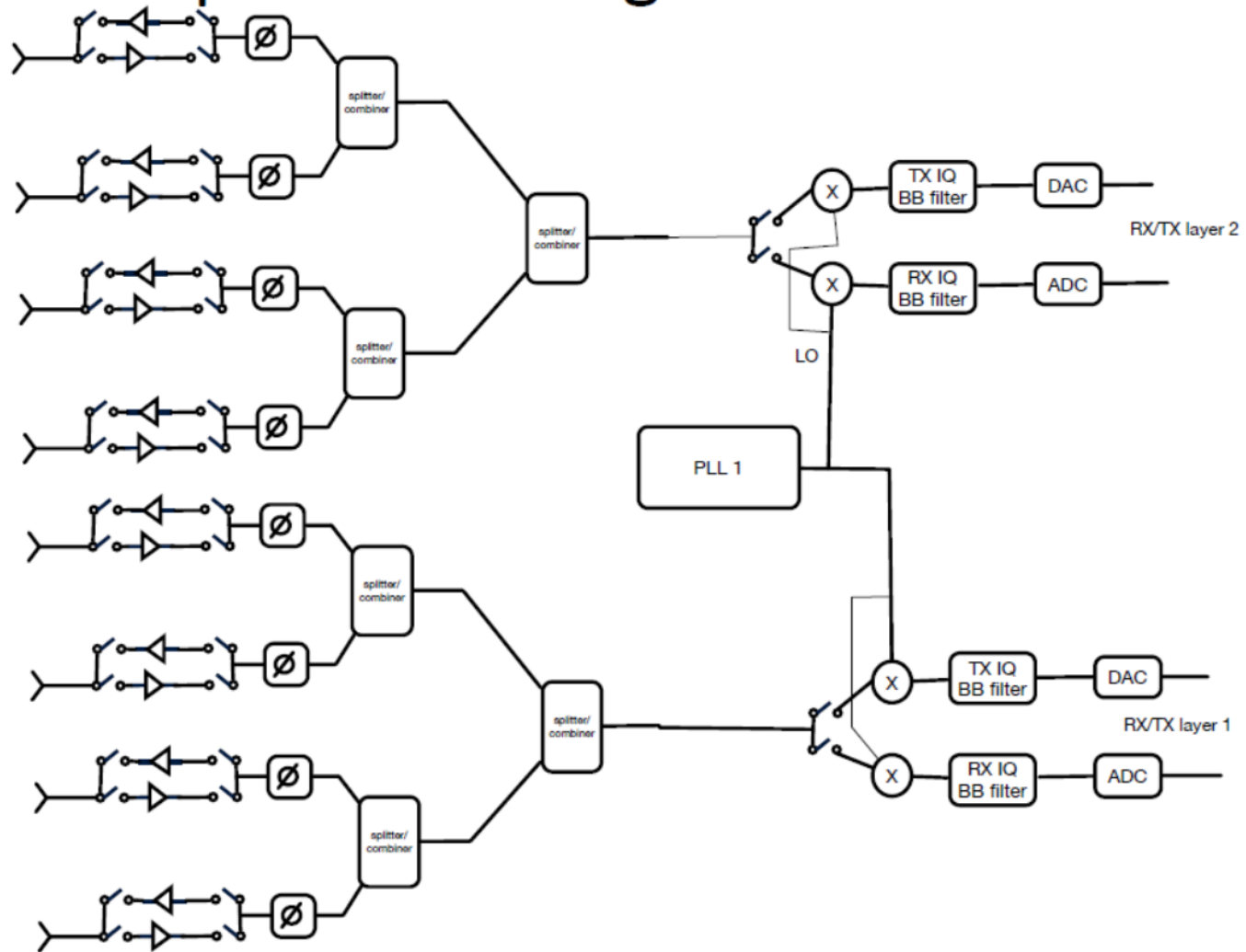
- Phased-Array Architectures
  - Digital (BB) phase shifting



- ZIF architecture would require large number of mixers if phase shifting architecture is used.
  - Larger power dissipation due to many LO chains running at RF frequency for large number of array elements.
- Super Het has less of a power penalty with phase shifting architecture.
  - Low side injection.
- Architecture choice also has PCB board level routing constraints.
  - SuperHet requires only IF lines vs Analog IQ.

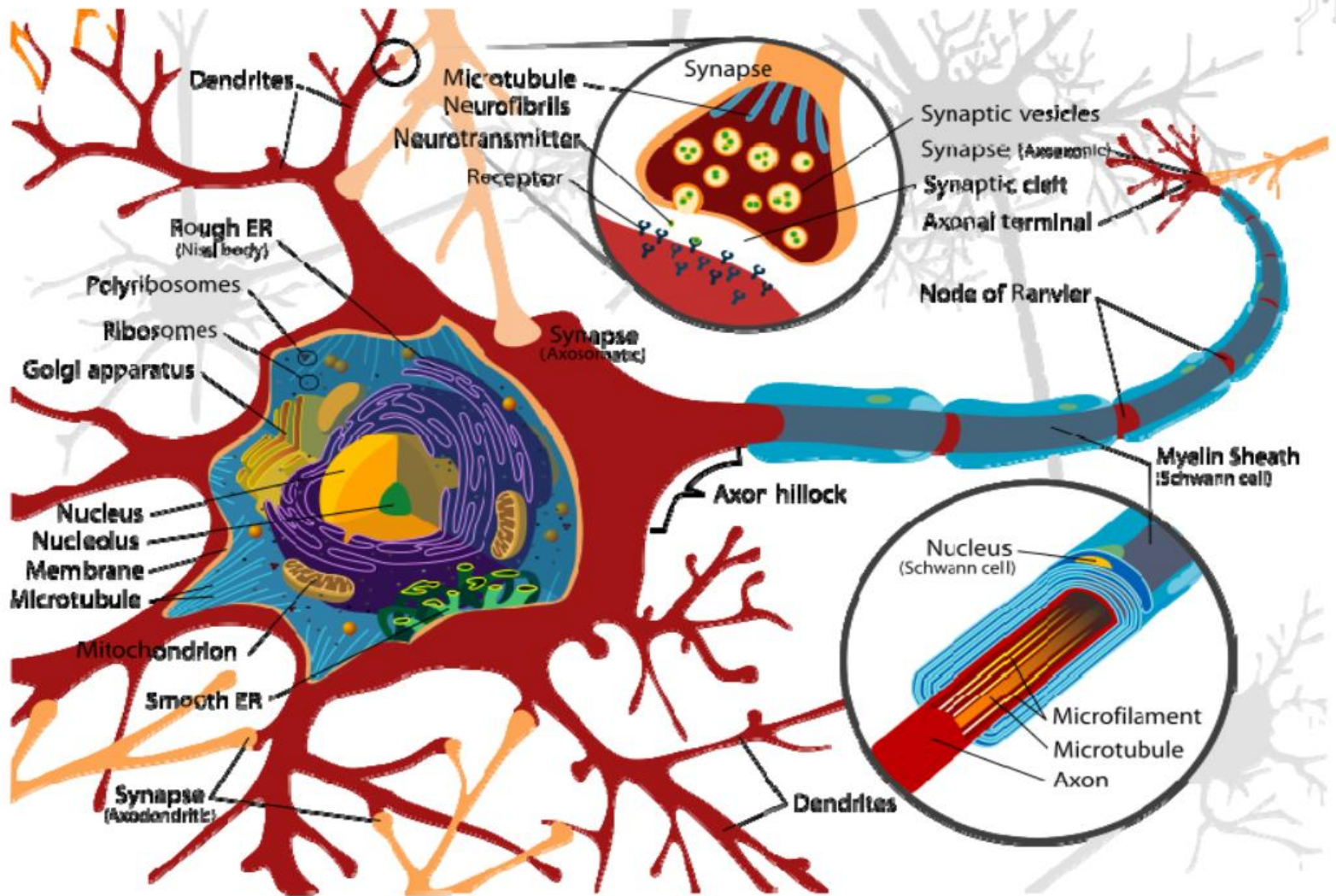


## RF phase shifting ZIF architecture



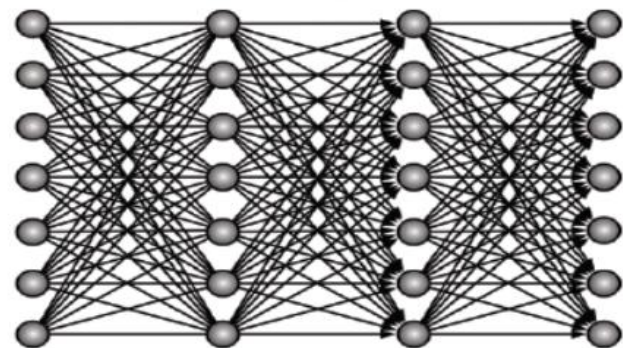
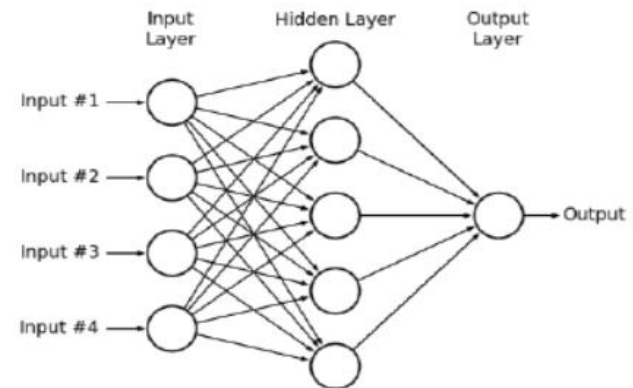
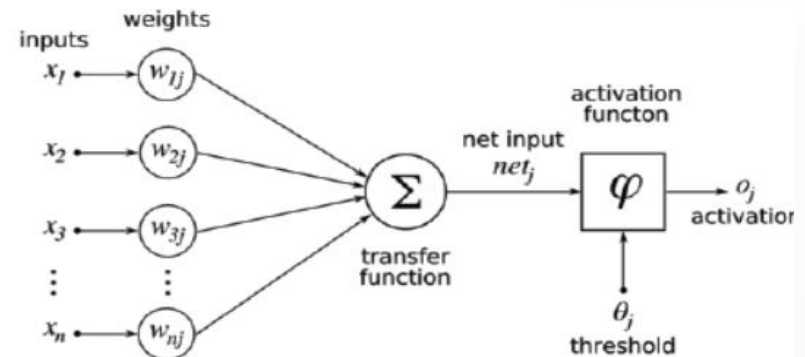
# Neuromorphic 개요

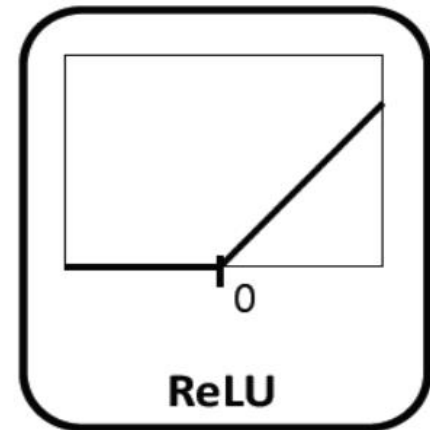
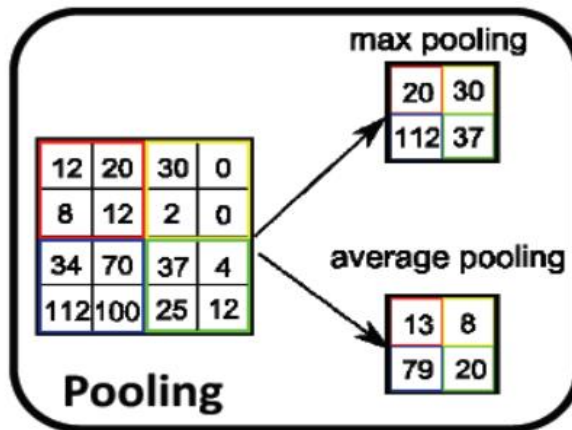
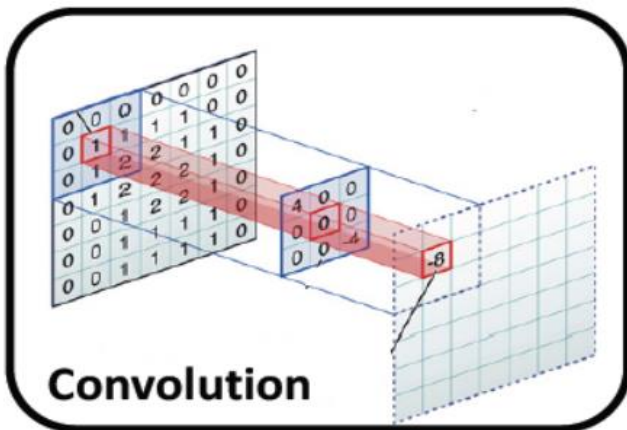
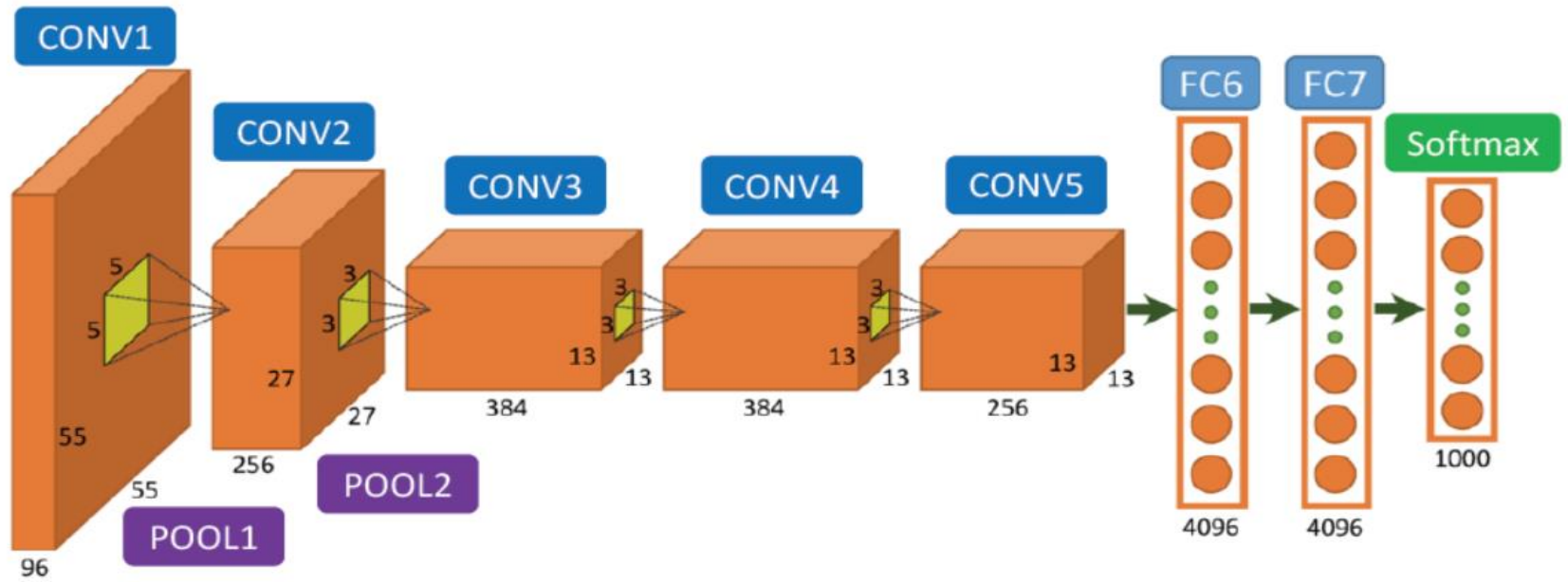
# A Neuron



\* Picture : Neuron,  
<https://en.wikipedia.org/wiki/Neuron>

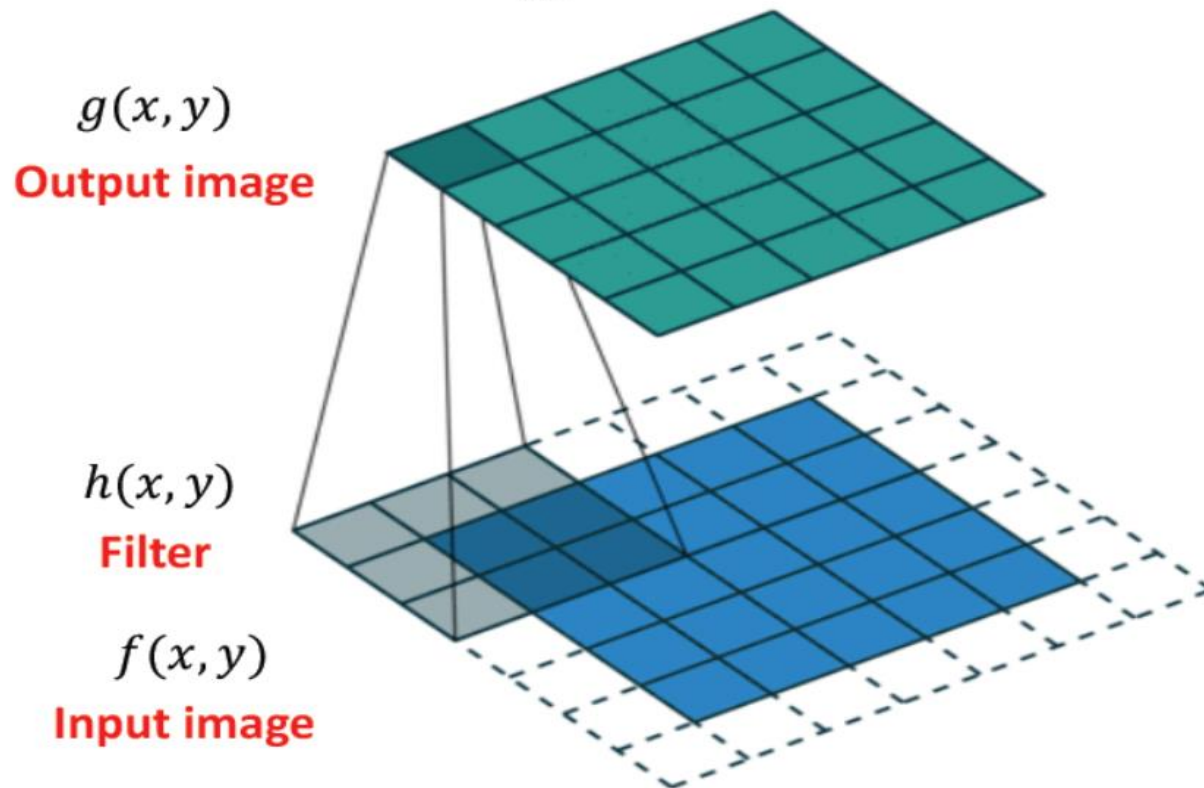
- First generation (since 1958):
  - Perceptrons
- Second generation (since 1986):
  - Multilayer perceptrons
- Third generation (since 2006):
  - Deep learning



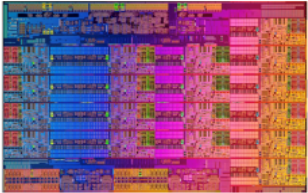
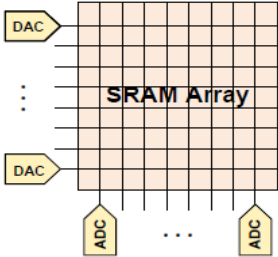
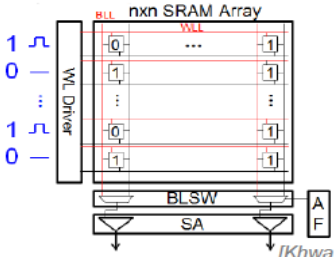


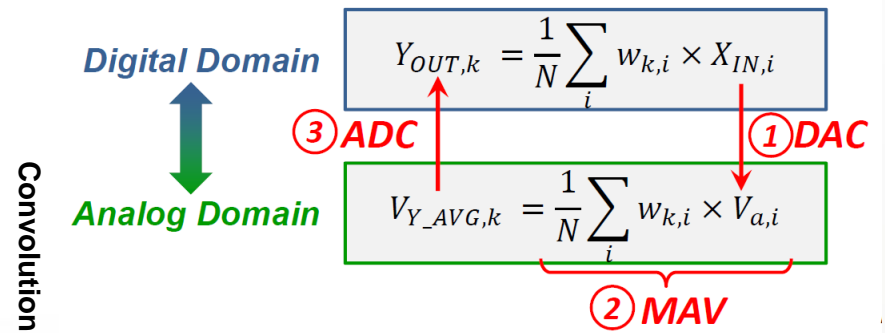
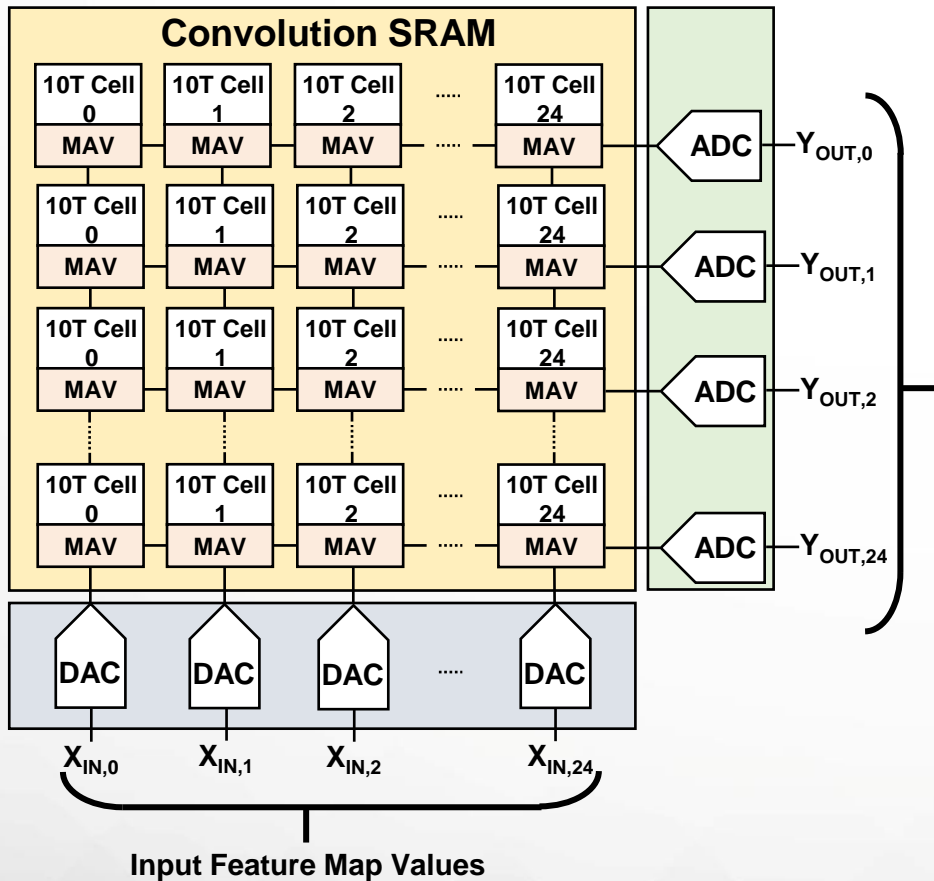
- Linear Filtering

$$g = f * h = \sum_{u,v} f(x+u, y+v)h(u,v)$$



[http://deeplearning.net/software/theano\\_versions/dev/tutorial/conv\\_arithmetic.html](http://deeplearning.net/software/theano_versions/dev/tutorial/conv_arithmetic.html)

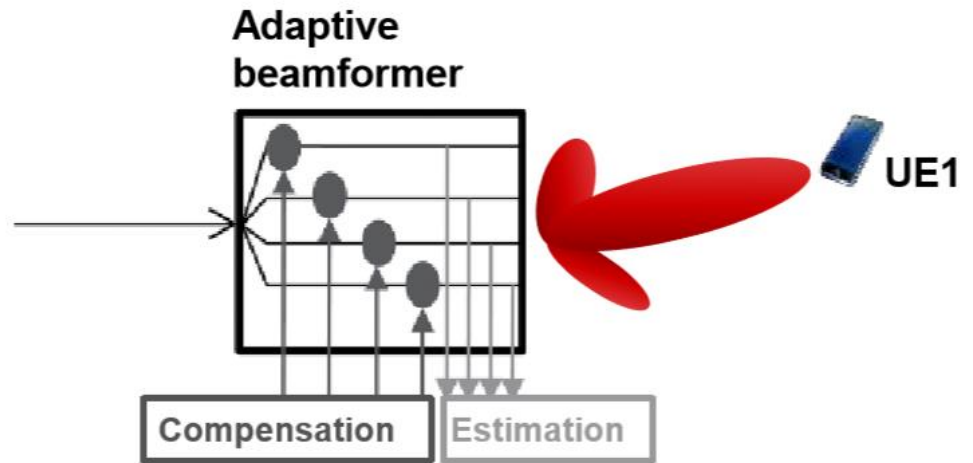
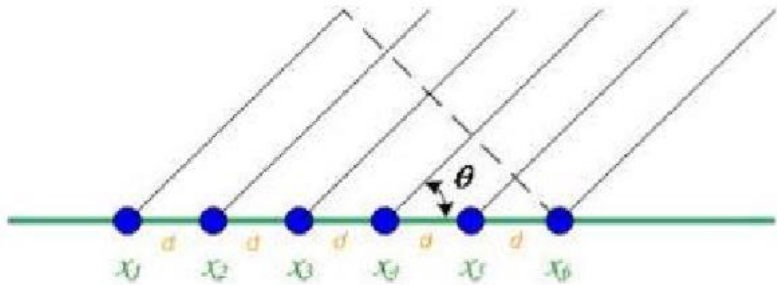
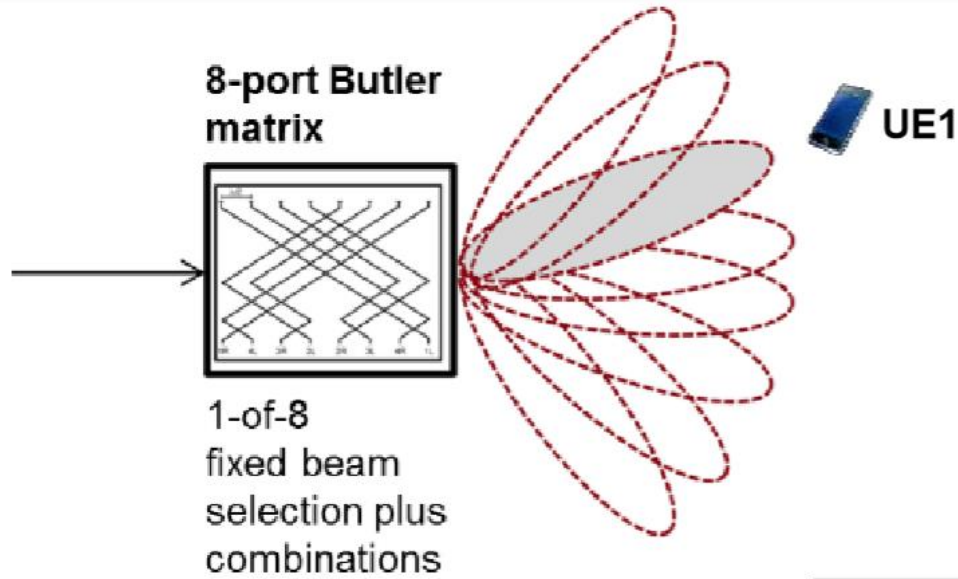
	Traditional Computing	Analog In-Memory Computing	Digital In-Memory Computing
<b>Pro</b>	<ul style="list-style-type: none"> <li>General Purpose</li> <li>Accurate</li> <li>Robust</li> </ul>	<ul style="list-style-type: none"> <li>High Energy Efficiency</li> <li>High performance</li> </ul>	<ul style="list-style-type: none"> <li>Moderate Energy Efficiency</li> <li>High performance</li> <li>Robust</li> </ul>
<b>Con</b>	<ul style="list-style-type: none"> <li>Poor Energy Efficiency</li> <li>Performance limited by memory bandwidth</li> </ul>	<ul style="list-style-type: none"> <li>Low precision</li> <li>Susceptible to noise and PVT variation</li> <li>ASIC</li> </ul>	<ul style="list-style-type: none"> <li>Limited functionality (eg. Only logic)</li> <li>Low precision (eg. Binary NN)</li> <li>ASIC</li> </ul>
<b>Example</b>	<ul style="list-style-type: none"> <li>CPU</li> <li>GPU</li> </ul> 	 <p>Diagram showing an SRAM Array with DACs (Digital-to-Analog Converters) connected to the word lines and ADCs (Analog-to-Digital Converters) connected to the bit lines.</p>	 <p>Diagram of an <math>n \times n</math> SRAM Array. It shows a WL Driver (Word Line Driver) connected to the word lines (WLL) and a Bit-Switch (BSW) connected to the bit lines (BLL). The array is connected to a Sense Amplifier (SA) and a Register (A, F). The array is labeled as [Khwa, ISSCC18].</p>



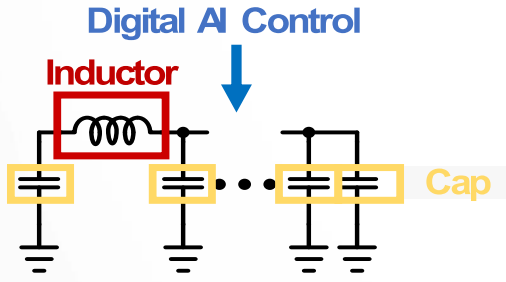
- Digital Conv Input ( $X_{IN}$ ) to Analog Voltage ( $V_a$ ) Conversion
- Row-Wise 1-bit Weight ( $w$ ) **Multiply and Average (MAV)**
- Analog Average Voltage ( $V_{Y\_AVG}$ ) to Digital Convolution Output ( $Y_{OUT}$ ) Conversion

# AI 기반 Beamforming

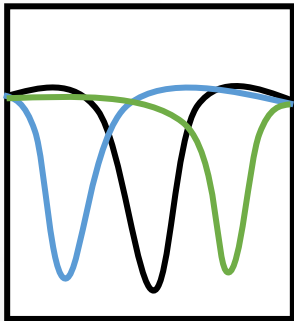
# Beam Steering vs. Beam Forming Techniques



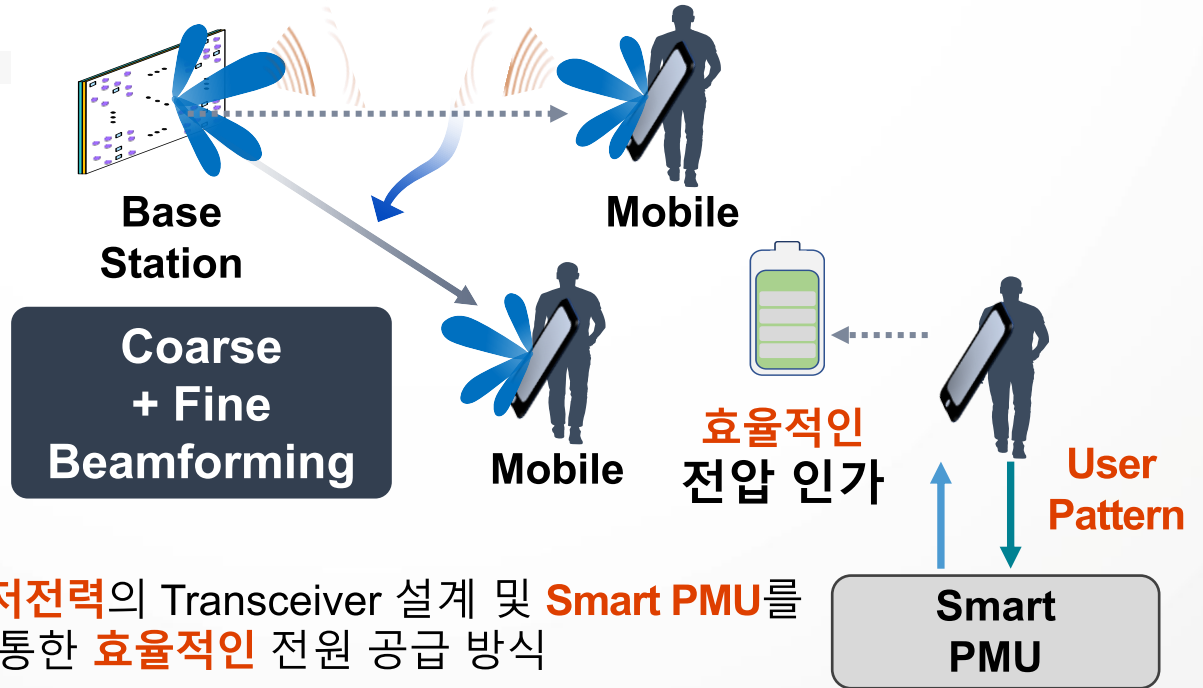
Adapts per antenna weightings and beam pattern to received signal and channel estimations



AI Controller 사용  
다양한 Matching 가능  
Wide Matching 확보



Neuromorphic AI 기반 3차원 Beam 형성 추정으로 User Equipment의 Low Latency, Adaptive Tracking 가능



저전력의 Transceiver 설계 및 Smart PMU를 통한 효율적인 전원 공급 방식

- AI 기반 Flexibility Matching, Beamforming 구현
- User Pattern Tracking 방식의 Smart PMU 구현

## AI 알고리즘 및 메모리 관련 연구

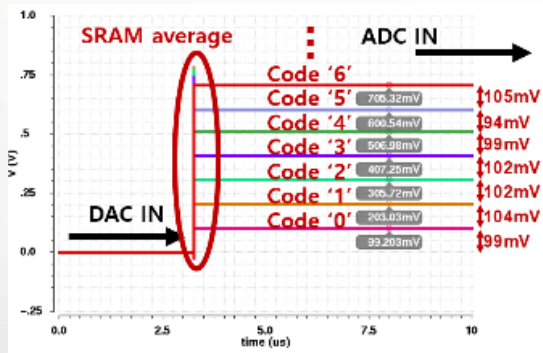
### 연구 내용

- AI 인공지능 구조 및 알고리즘 연구
- AI 알고리즘과 Convolutional SRAM Modelling 의 Co-Simulation 통한 동작 검증

### 5G 통신 시스템으로의 적용

AI Neuromorphic CNN Algorithm을 통한 Workload 변화 분석/ 학습으로 Data 처리속도 향상 효율적인 소비 전력 및 학습에 적용된 연구 개발 완료

### SRAM Weight 값에 따른 Charging Data

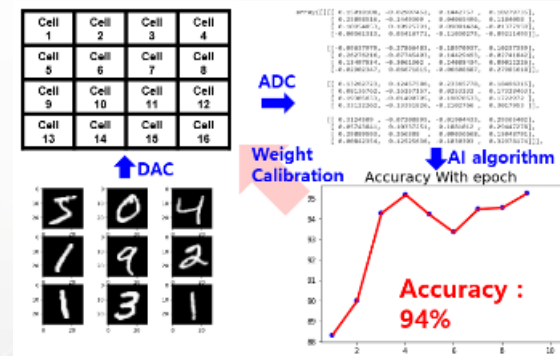


< SRAM Data Charging 검증 >

### 실적

Imran Ali, **Kang-Yoon Lee**, "An Ultra Low Power, Configurable Intelligent Biasing Calibration for Medical Sensor Applications in 130 nm CMOS Technology," **IEEE BigComp2020**, Feb. 2020

### Matrix Type의 Input을 Analog Filter 기반의 CNN으로 지도학습하여 정확성 향상



< Convolutional SRAM Modelling 및 Algorithm 구현 >

## AI Neuromorphic 구조 연구

### 연구 내용

- AI Neuromorphic Architecture 연구
- 저전력 Convolutional SRAM Modelling 및 Simulation 통한 전력 효율 검증
- Sensor Data의 Parallel Computing을 통한 속도 향상

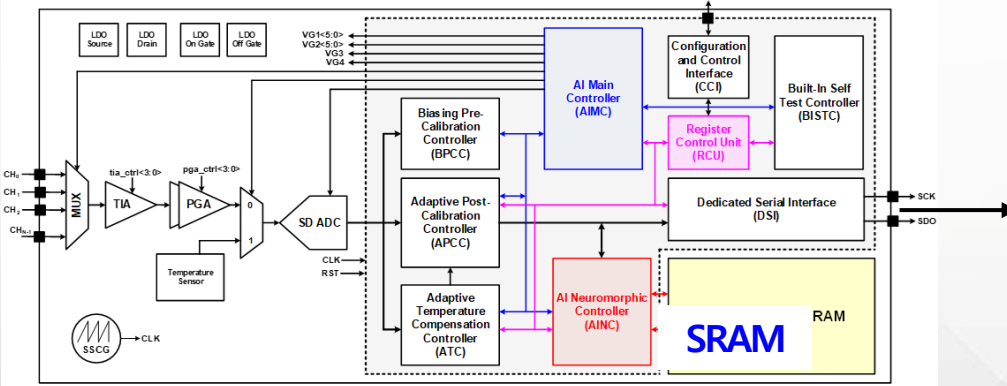
### 5G 통신 시스템으로의 적용

AI Algorithm 기반 실시간 Monitoring 기술 연구  
저전력 Convolution SRAM Circuit 구현 완료

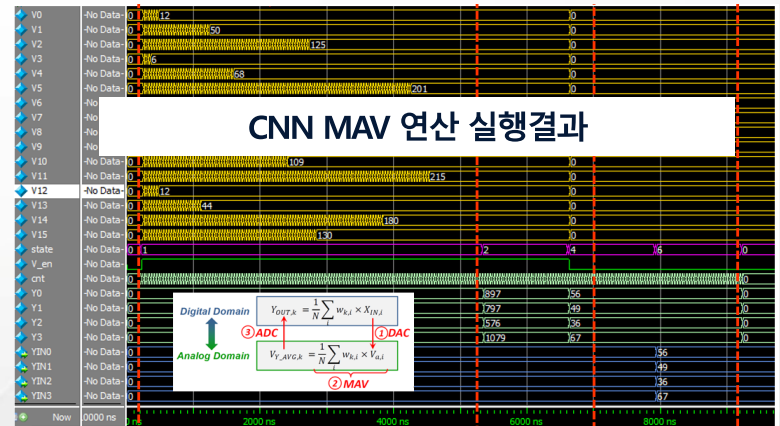
### 실적

Huo Yingge, **Kang-Yoon Lee**, "Deep Neural Networks on Chip," **IEEE BigComp2020**, Feb. 2020

하드웨어 영역에서 DNN(Deep Neural Networks)의 효율적인 처리를 통해 정확성을 향상 시키며 에너지 효율을 달성



< AI Smart Bio Sensing System 블록도 >



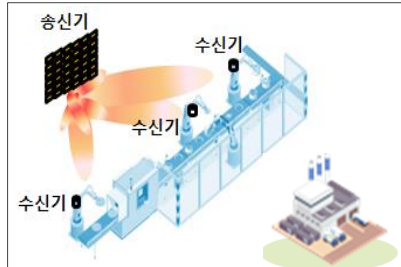
< SRAM 연산 Simulation >

# 요약 및 결론

# 1 5G 활용 방안 및 기대효과



5G App



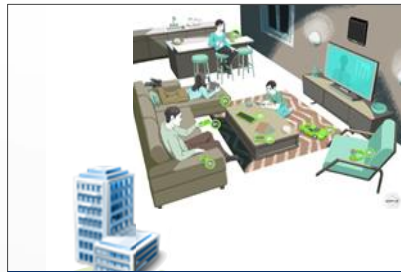
Smart Factory App



AI Algorithm for health care



초저전력 IoT App



Smart Home App



New AI Algorithm

- ❖ 5G 통신에서는 송신기와 수신기 사이의 거리 및 위치가 변화하며 수신기에 도달하는 신호 및 전력 크기를 키우기 위해서 MIMO 기반의 Beamforming 기술이 널리 사용되고 있음
  - 5G 통신에서 송신부와 수신부 사이의 위치와 거리에 따른 자유도를 확보하기 위해서 사용됨
- ❖ 5G 통신에서 송신부와 수신부 사이의 Beamforming 에 활용 목적으로 SARAM 또는 DRAM 을 활용해서 덧셈, 곱셈 연산을 수행하여 Neural Network 을 구현하는 Processor in Memory (PIM) 기술을 적용 가능함
  - 인공지능 PIM 기술은 뇌의 시냅스와 뉴런의 기능을 모방한 하드웨어로 소자, 회로, 아키텍처 및 알고리즘이 하나로 합쳐진 형태임
  - SRAM 또는 DRAM 을 활용해서 덧셈, 곱셈 연산을 수행하여 Neural Network 을 구현하는 Processor in Memory (PIM) 반도체 기반의 저전력 뉴로모픽 프로세서에 대한 개발이 필수적임



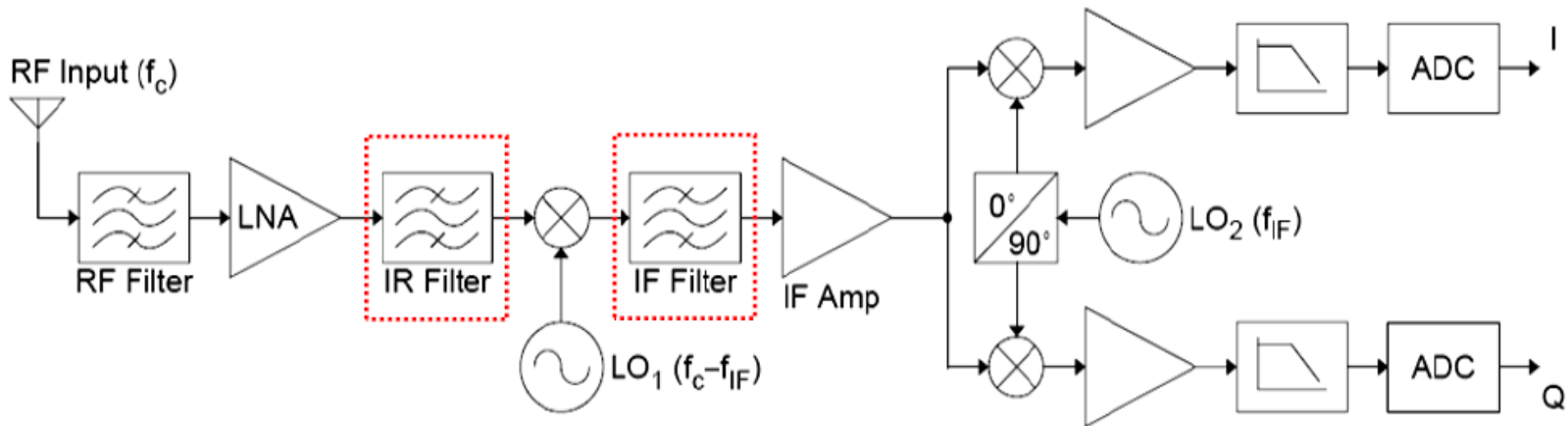
경청해 주셔서 감사합니다 !!!



# Appendix

## 2 Heterodyne Receiver

The signal band is translated to much lower frequencies so as to relax the Q required of the channel-select filter



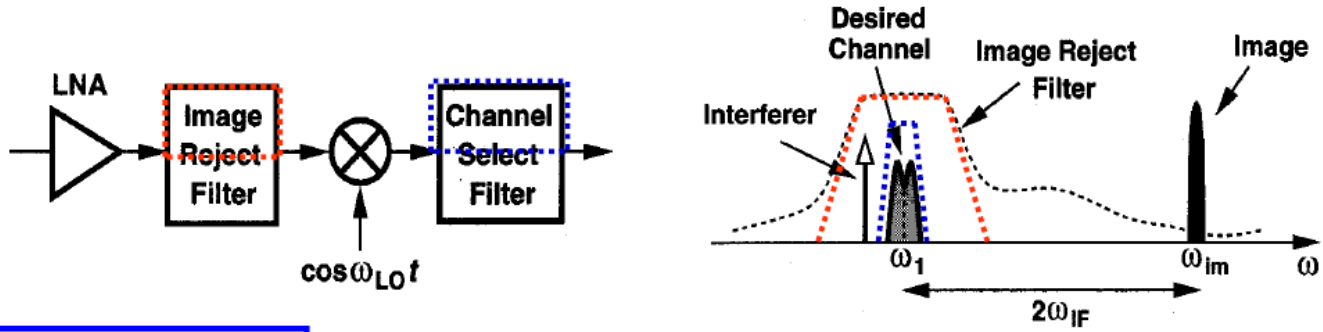
Down-conversion Mixing

Local Oscillator :

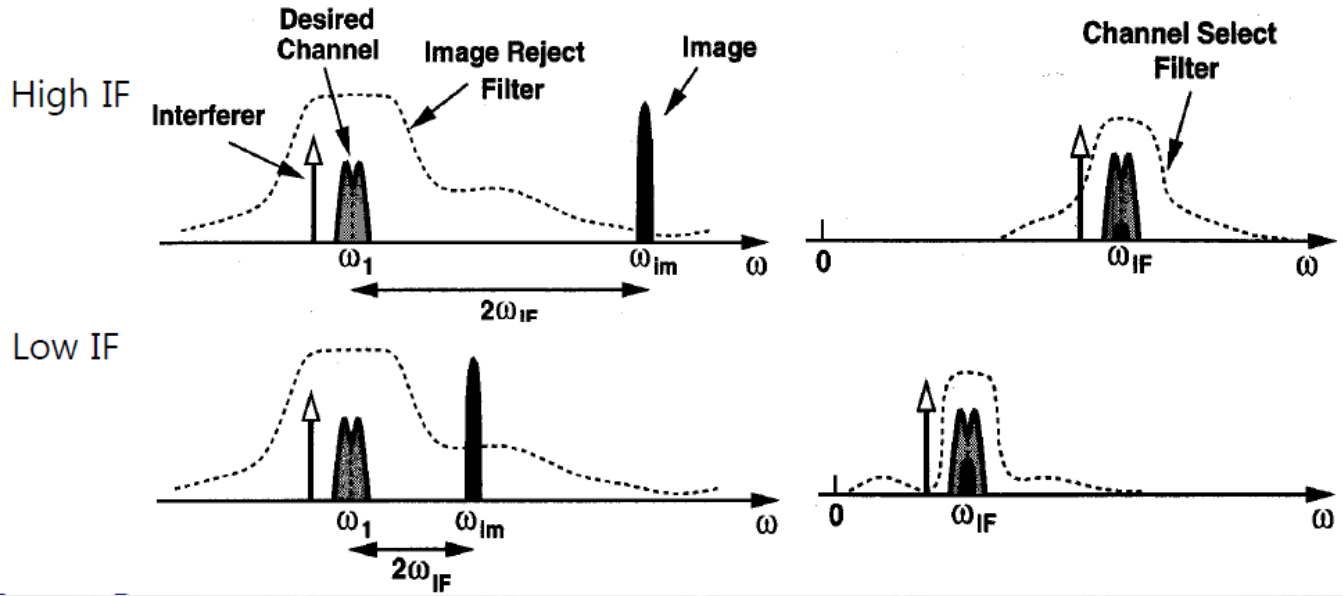
High side Injection  $W_{LO} > W_{RF}$

Low side Injection  $W_{LO} < W_{RF}$

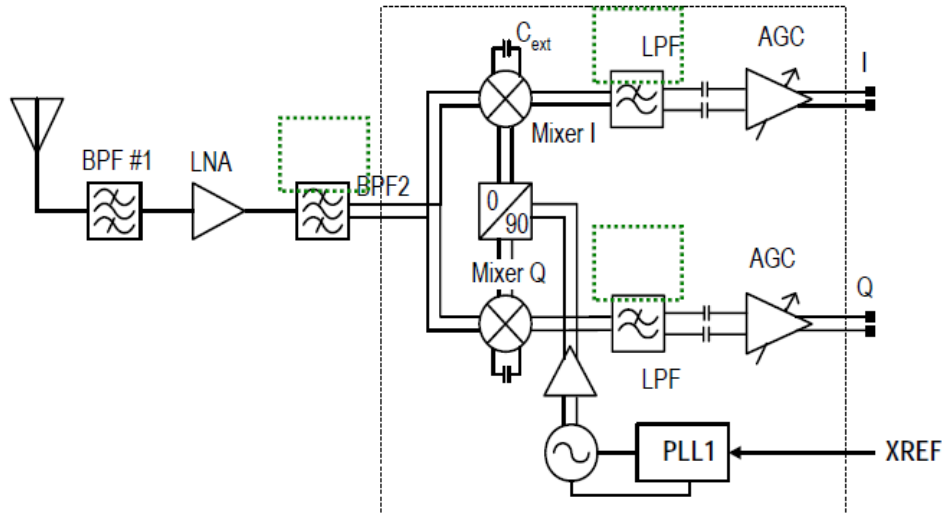
# Rejection of Image



High IF and Low IF



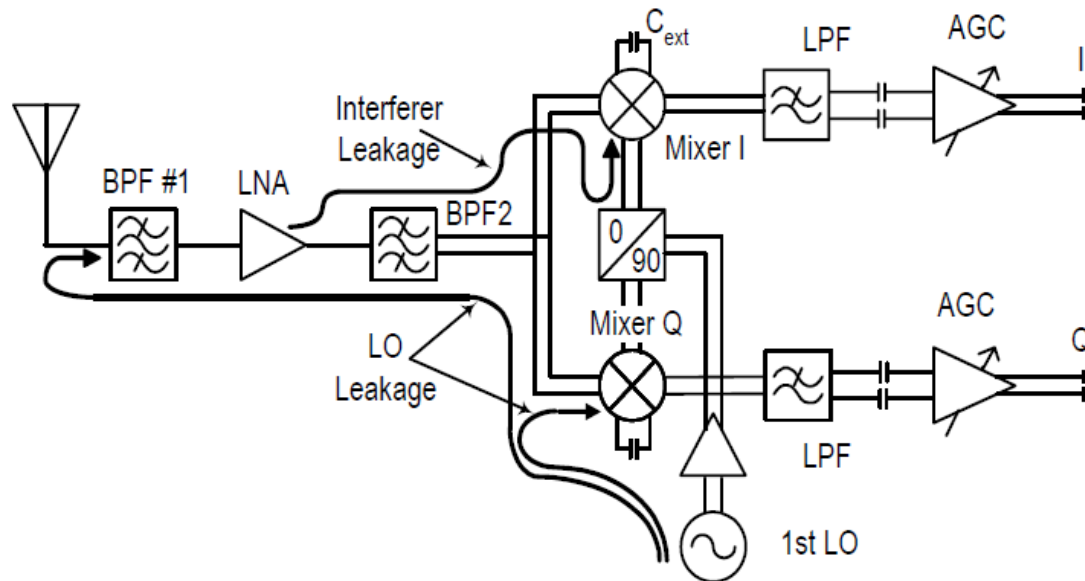
: Zero-IF or direct conversion



### **Advantages:**

- The problems of image frequency and "half-IF" spurious response are eliminated since  $F_{IF} = 0$ .
- RF BPF after LNA is optional; it is only needed for additional rejection of out-of-band interferers and TX power leakage.
- The bulky off-chip IF SAW filter is eliminated. All channel selectivity is done at baseband with low-pass filters and baseband amplifiers.
- One VCO and one PLL are needed for the whole receiver.

: Zero-IF or direct conversion



### Design Issues :

- Channel Selection
- Second-Order Inter-Modulation (IM2)
- LO Leakage
- DC Offsets
- I/Q Mismatch

# 1 5G 활용 방안 및 기대효과



핸드폰, 노트북, 태블릿 등 모든 모바일 기기에 적용

모바일 기기 산업

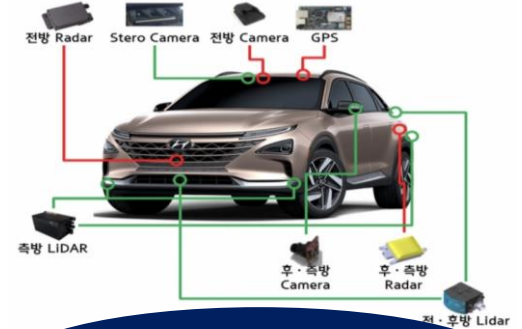
- User 거리 패턴 분석을 기반으로 하는 5G 모바일기기용 개발으로 고품질 신호 전달이 가능함
- AR, 초 고화질 영상과 같은 데이터 기반 콘텐츠를 빠르게 전송하여 이용 활성화함



초 연결 Massive IoT 스마트 홈 산업에 적용

생활 가전 산업

- TV, 공기청정기, 조명, 에어컨, CCTV 등 거의 모든 가전제품을 연동하는 Massive IoT에 적용 가능함
- 제조업에서의 비용절감과 생산성·효율성에서 혁신적인 제품 개발



초저지연·접속의 안정성이 중요한 자율주행 서비스에 적용

자율주행 자동차 산업

- 즉각적 응답이 필요한 자율주행 자동차 산업에 이용되어 센서를 통한 정보 처리에 지연 없는 실시간 서비스 구현 가능함

# 1 5G 활용 방안 및 기대효과

피트니스 밴드 위카+디 오리지널  
 피트니스 밴드 위카+디 커피  
 모바일 헬스케어  
 게임 바이크 스마트 X 바이크  
 스마트캡 워터클립  
 헬스케어

**다양한 의료기기 및 원격 의료시스템에 적용**

**헬스 케어 · 의료기기 산업**

- ▣ AI를 통한 빅데이터를 예측 분석하여 의사들이 환자의 건강 패턴을 빠르게 감지하고 진단의 정확성 향상
- ▣ 온도계, 청진기, 심장박동측정기, 혈당측정기 등 각종 헬스케어 의료기기 산업에 적용 가능

U+ 5G LGU+

- ▶ 제품 생산성 향상 검증 시스템  
제조 공정의 사선 시뮬레이션
- ▶ 스마트팩토리 / 친환경 공장  
태양에너지 / ESS 운영, FEMS, 안전사고 감지
- ▶ IoT 기반 네트워크  
공장 내의 모든 요소들의 유기적 연결
- ▶ 부품 적기 공급  
법정사 정보 동기화, 실시간 부품 추적
- ▶ 지능형 자동차 관리
- ▶ 자원의 활용 / 스마트 창고  
창고 작동률 / 실시간 제품 위치 추적
- ▶ 원격 운영, 예측 제어  
실시간 모니터링 및 운영 최적화, 예비 진단 및 품질 사전 예측

**초저지연성과 안전성으로 스마트 팩토리 산업에 적용**

**스마트 팩토리 산업**

- ▣ 설비유형에 맞게 네트워크 성능 조정하여 공장 형태와 상황 맞춤형 솔루션 제공 가능
- ▣ 실시간 모니터링 시스템, 5G다기능, 소형 자율주행 로봇, 머신 등 스마트 팩토리 사업에 적용 가능

**5G, IoT, AI 기술을 적용하여 재난 상황 예측 시스템 및 드론 활용**

**재난 안전 산업**

- ▣ 산불, 해상사고, 원전 사고 등과 같은 재난 현장 드론을 투입하는 등 재난 안전 산업에 적용 가능