

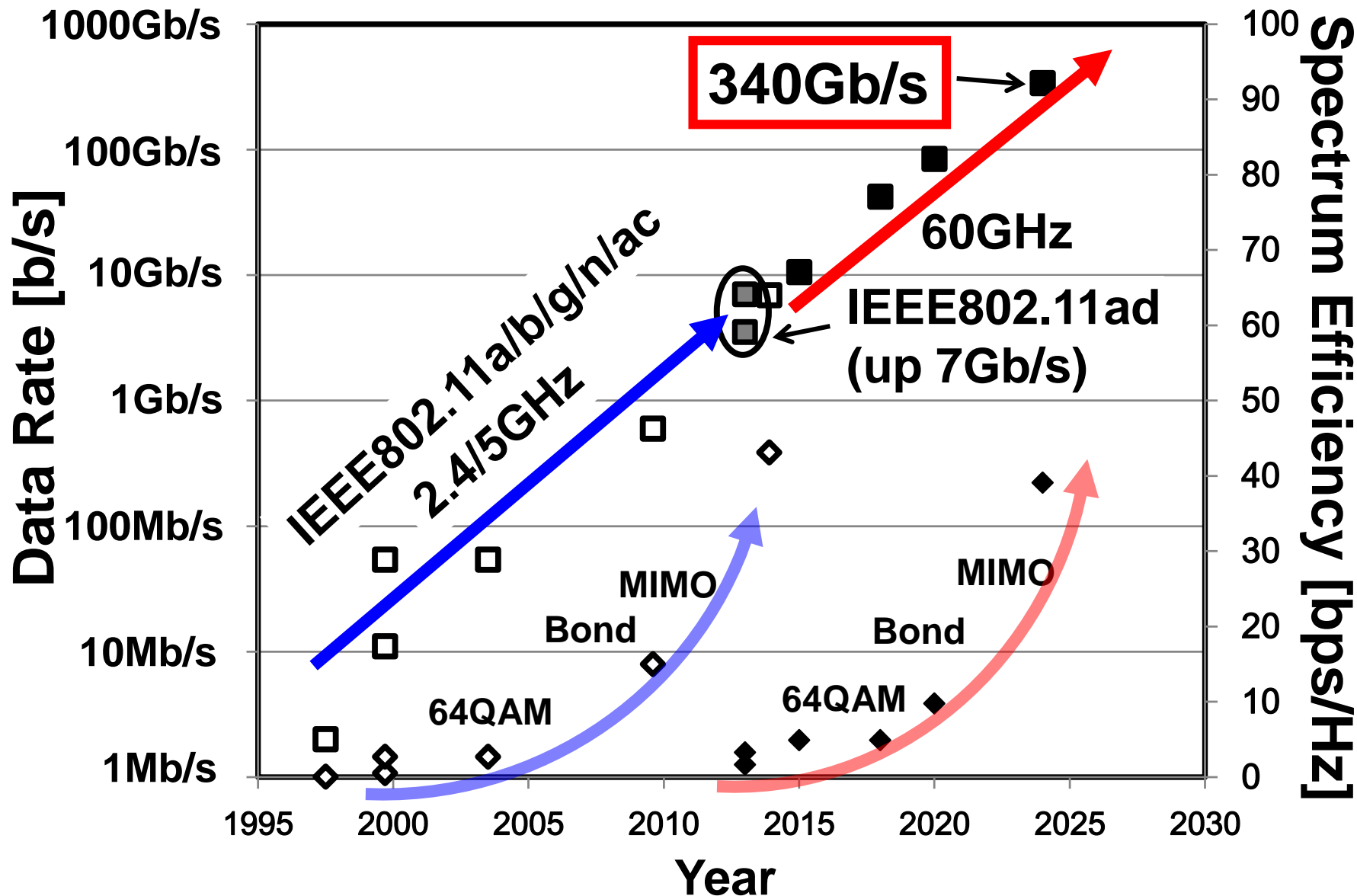
300Gb/s超を目指した 60GHz帯CMOS無線機

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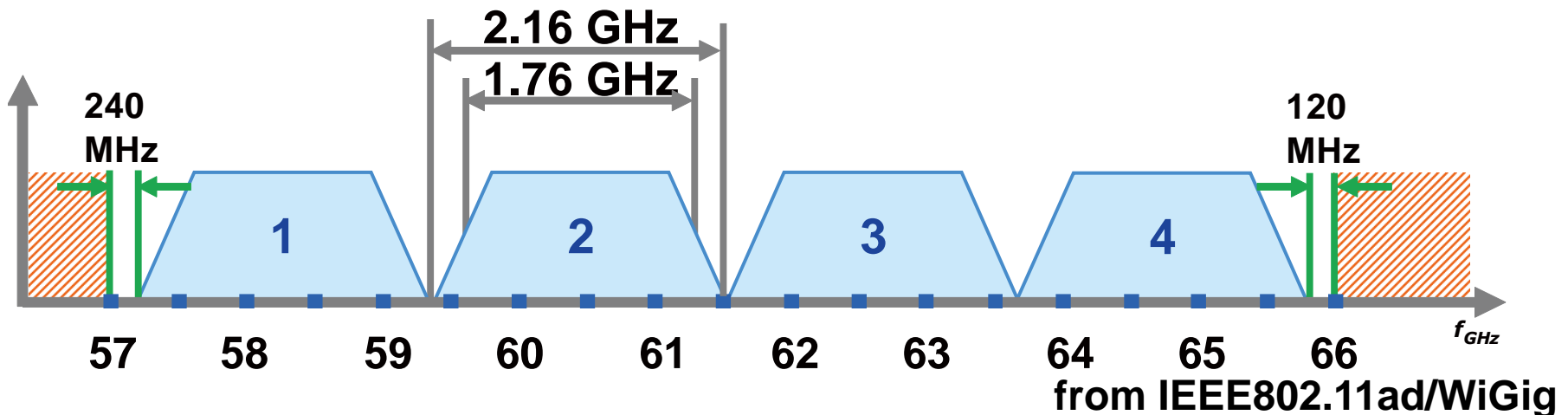


60GHz帯無線通信における将来性

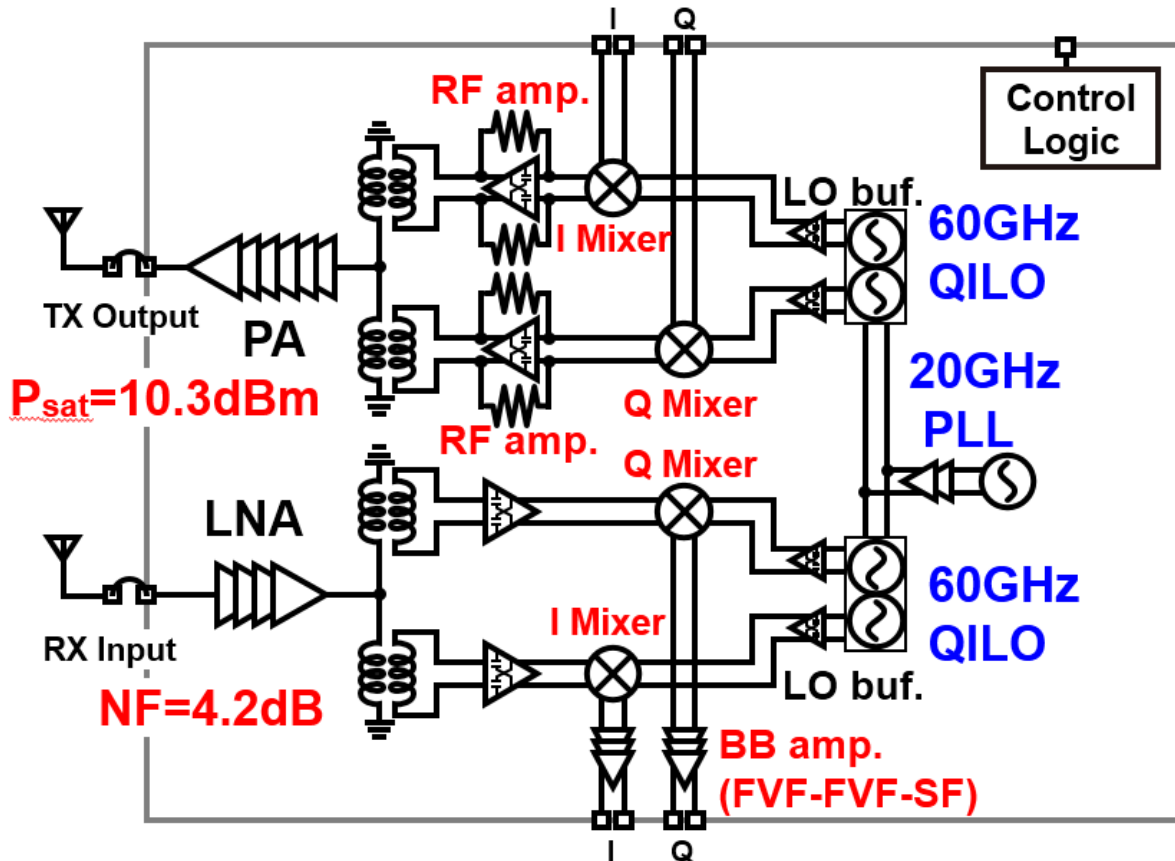


60GHz帯における帯域

- QPSK → 3.52Gbps/ch
- 16QAM → 7.04Gbps/ch
- **64QAM → 10.56Gbps/ch (not reported yet)**
- 16QAM
 - 2-ch bonding → 14.08Gbps
 - 3-ch bonding → 21.12Gbps (not reported yet)
 - 4-ch bonding → 28.16Gbps (not reported yet)**



Block Diagram



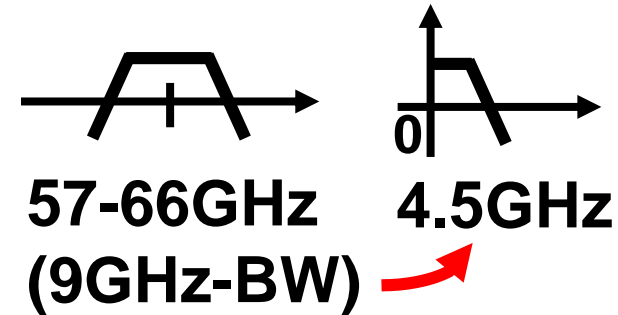
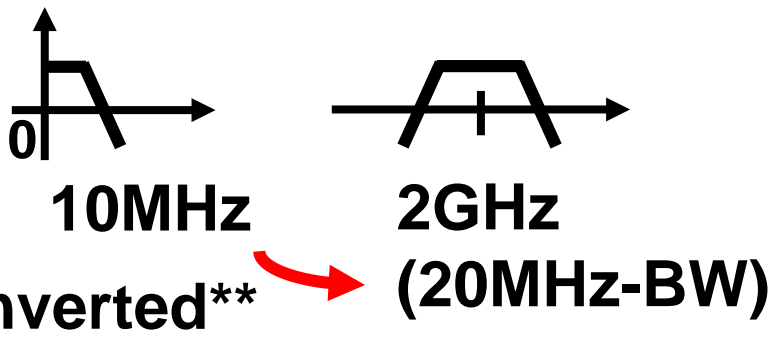
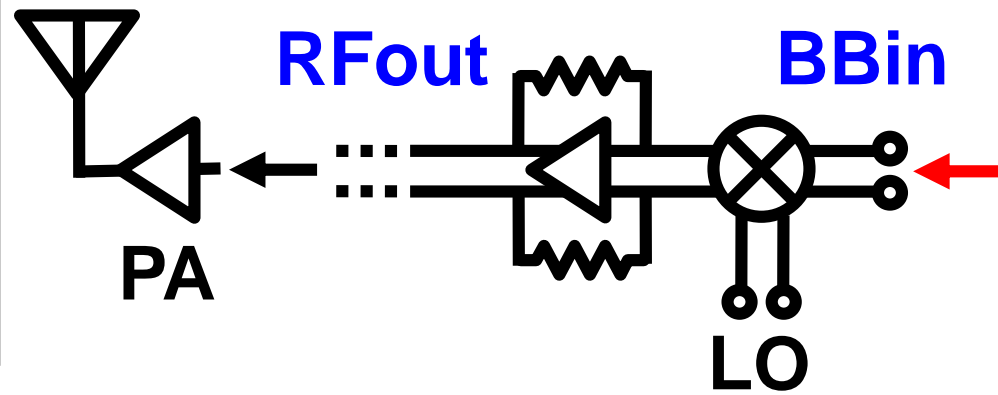
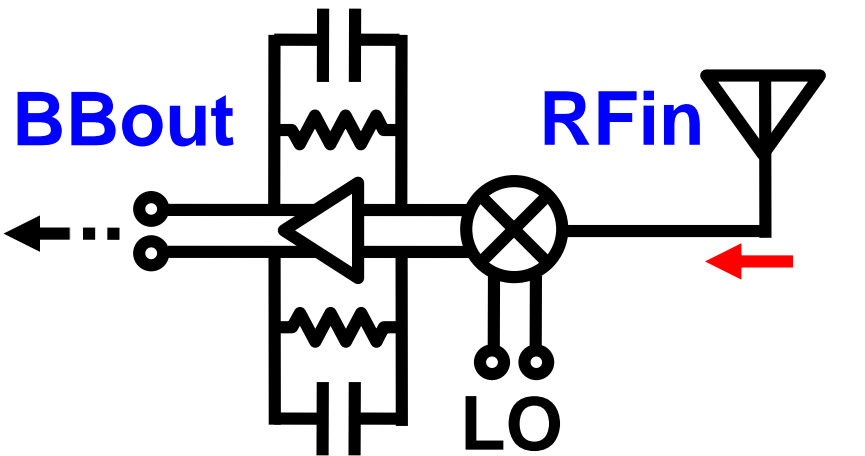
- Direct-conversion
- TX
 - Mixer-first topology
- RX
 - FVF BB amp.
 - Current-bleeding mixer
- LO
 - Injection-lock
 - 60GHz QILO* +20GHz PLL

Mixer-First型送信機

Mixer-first receiver*, **

Mixer-first transmitter

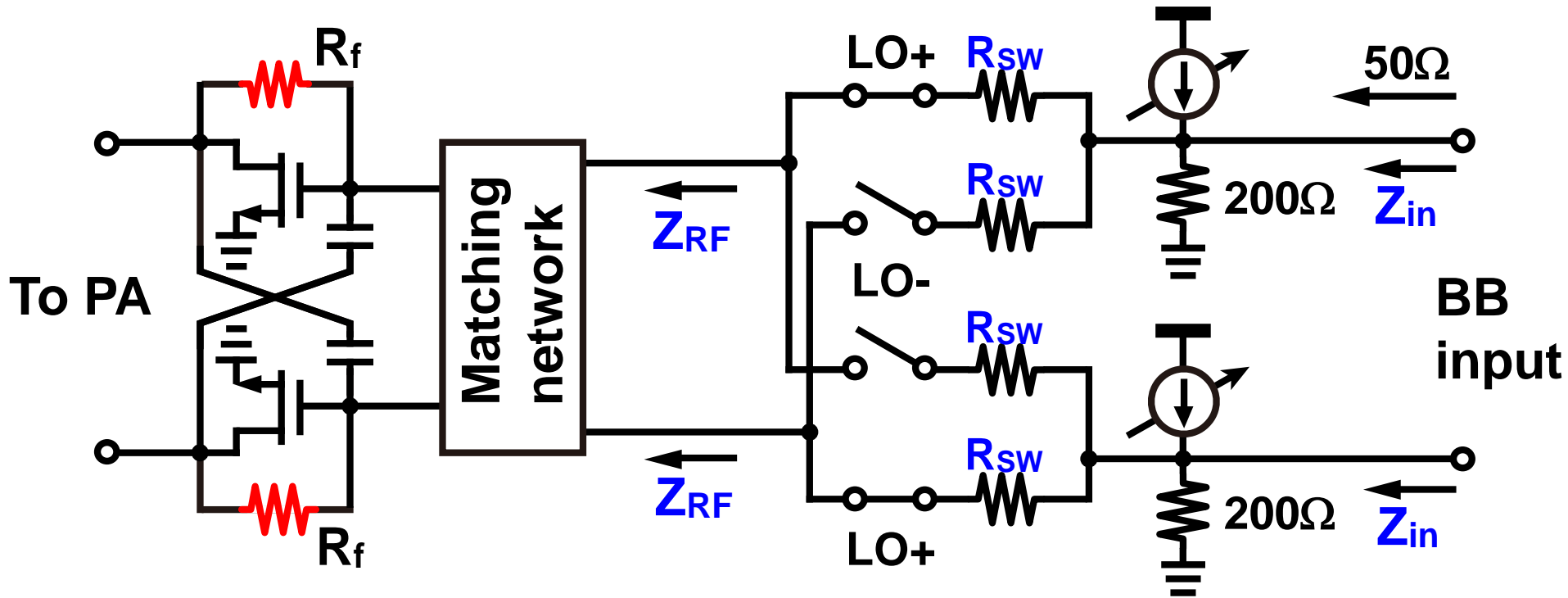
This work



down-converted
even for Z_{in}

*M. Soer, et al., ISSCC 2009 **C. Andrews, et al., ISSCC 2010

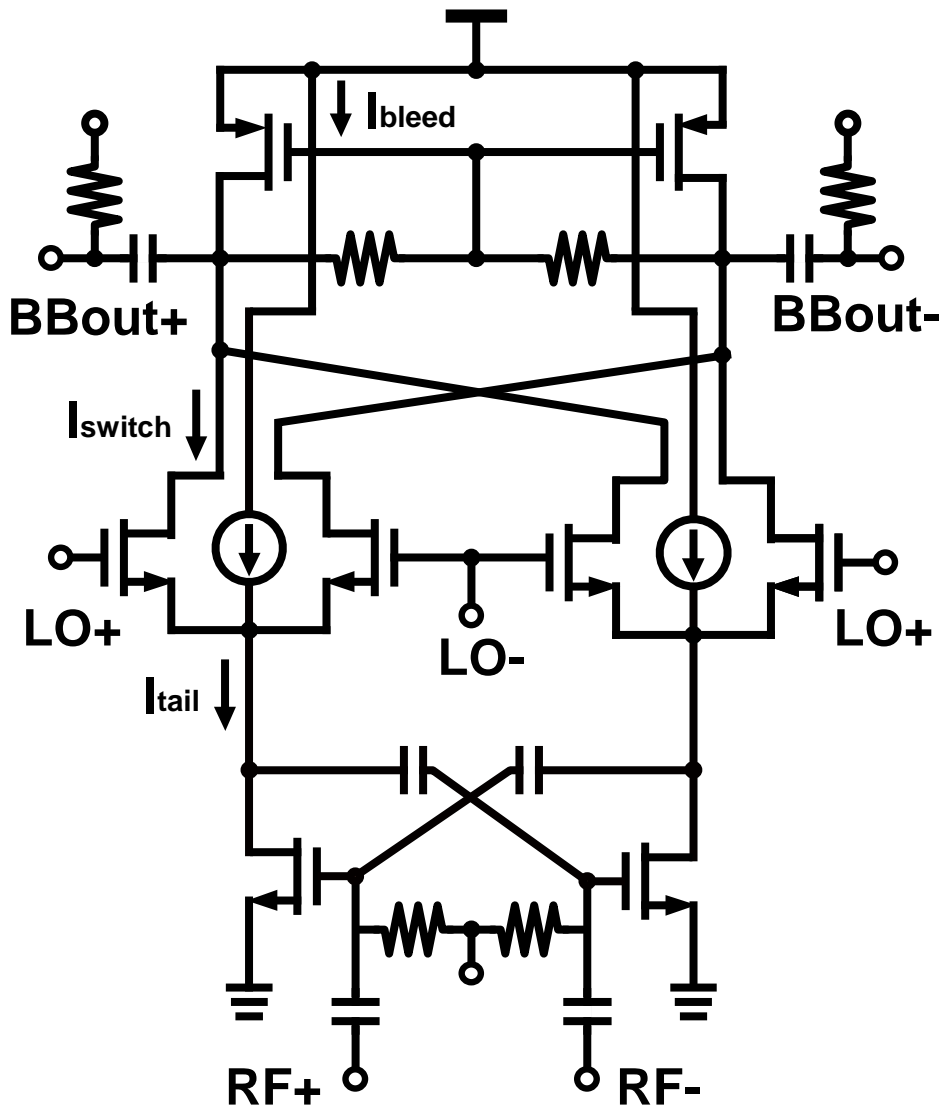
入力インピーダンスとリークの調整



$$Z_{in}(\omega_{BB}) = 200\Omega // \left[R_{sw} + \frac{4}{\pi^2} \{ Z_{RF}(\omega_{BB} + \omega_{LO}) + Z_{RF}(\omega_{BB} - \omega_{LO}) \} \right]$$

Wideband Z_{RF} is realized by R_f -feedback.

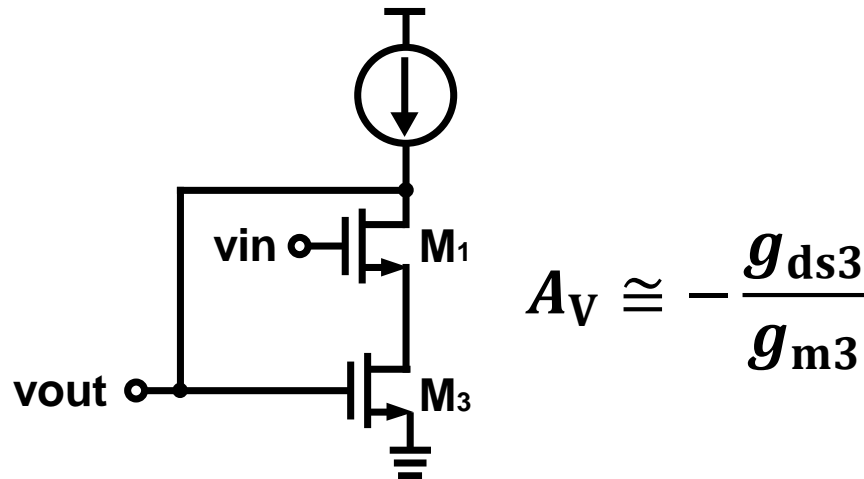
RX Mixer



- **Current-bleeding to reduce LO power**
- **CCC at RF input**
- **P_{dc} : 11mW**
- **CG: -7dB**
- **f_{low} : 0.27MHz**
- **f_{high} : >4GHz**

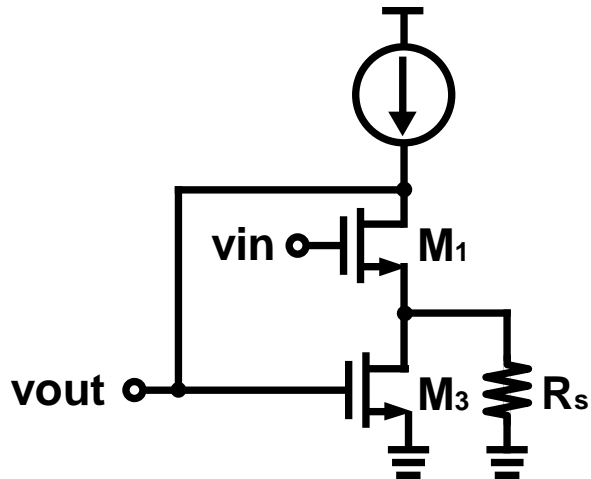
RX Baseband Amplifier

- Wide bandwidth (>5GHz)
 - High gain and high linearity
 - Low power consumption
- ⇒ Open-loop FVF-based amplifier



Flipped Voltage Follower* (FVF)

RX Baseband Amplifier (Cont.)

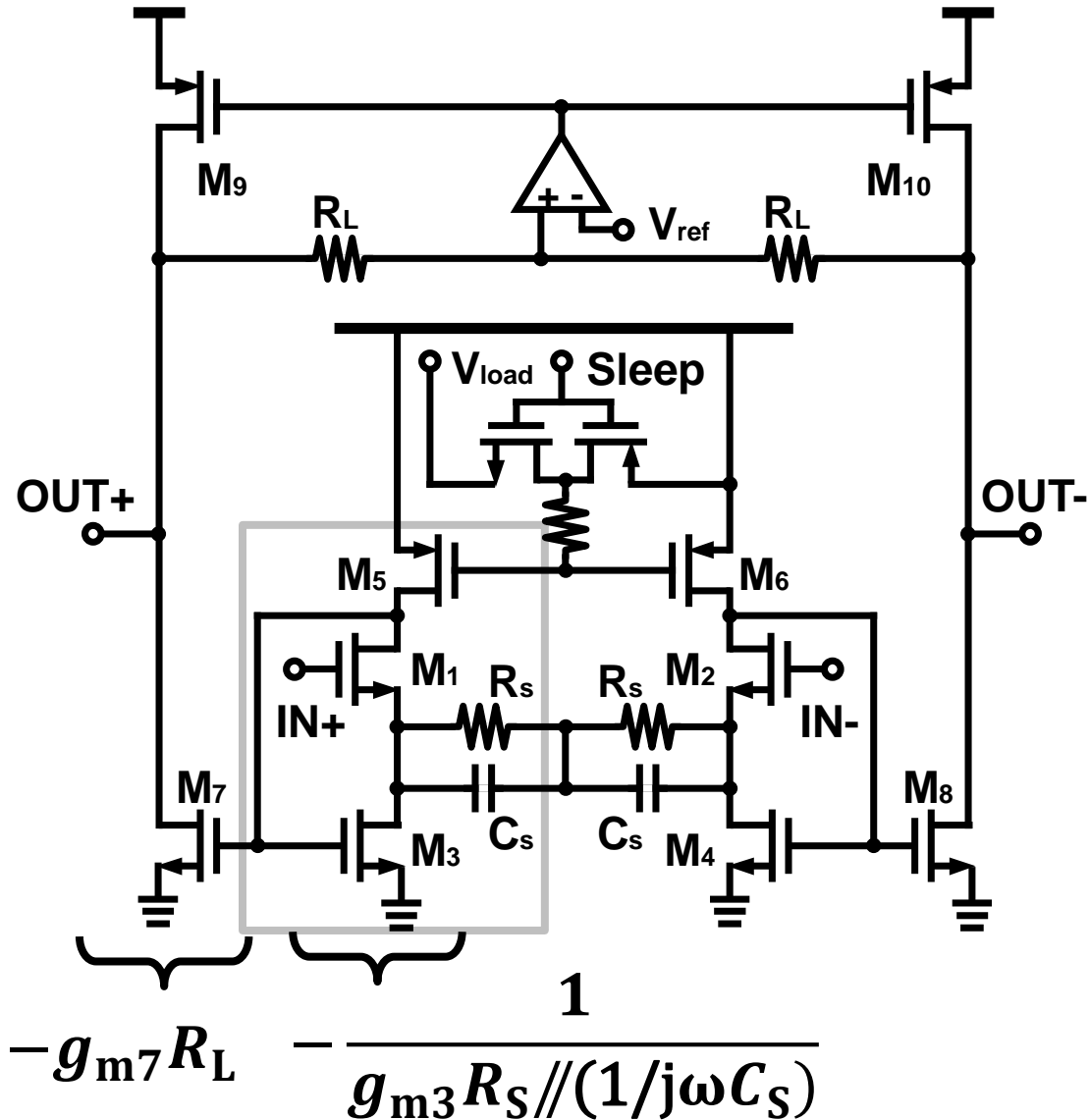


$$A_V \cong -\frac{1}{g_{m3}R_S}$$

modified FVF

$$A_V \cong \frac{g_{m7} R_L}{g_{m3} R_S}$$

by 6mW



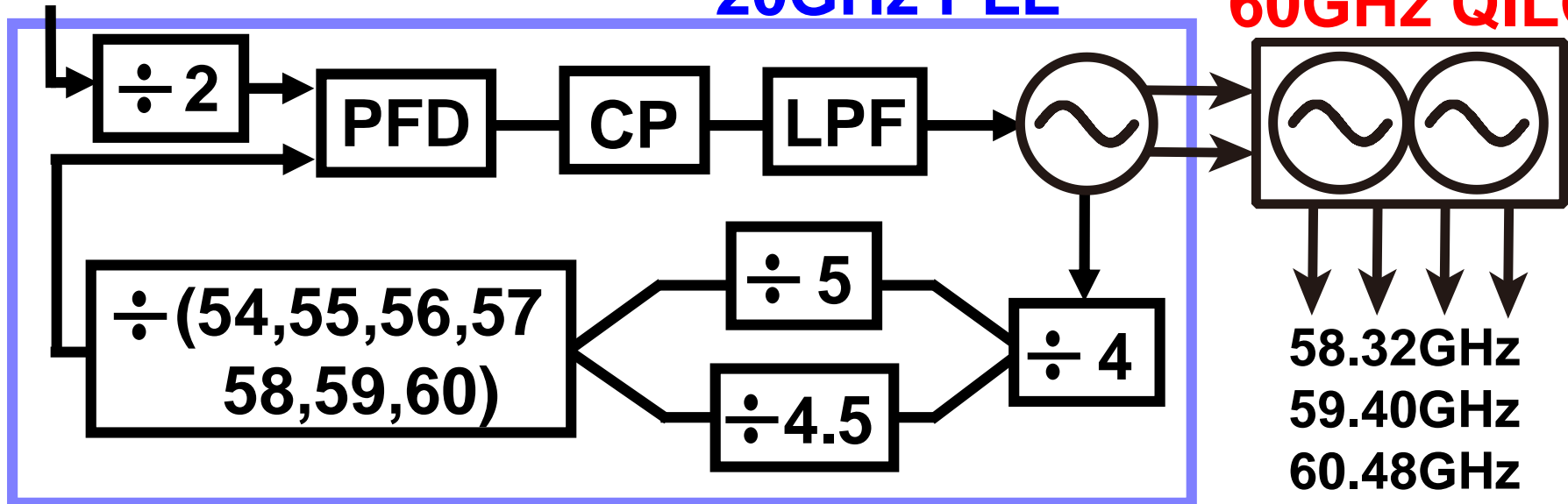
60GHz Quadrature LOの設計

*K. Okada, et al., ISSCC 2011

36/40MHz ref.

20GHz PLL

60GHz QILO*

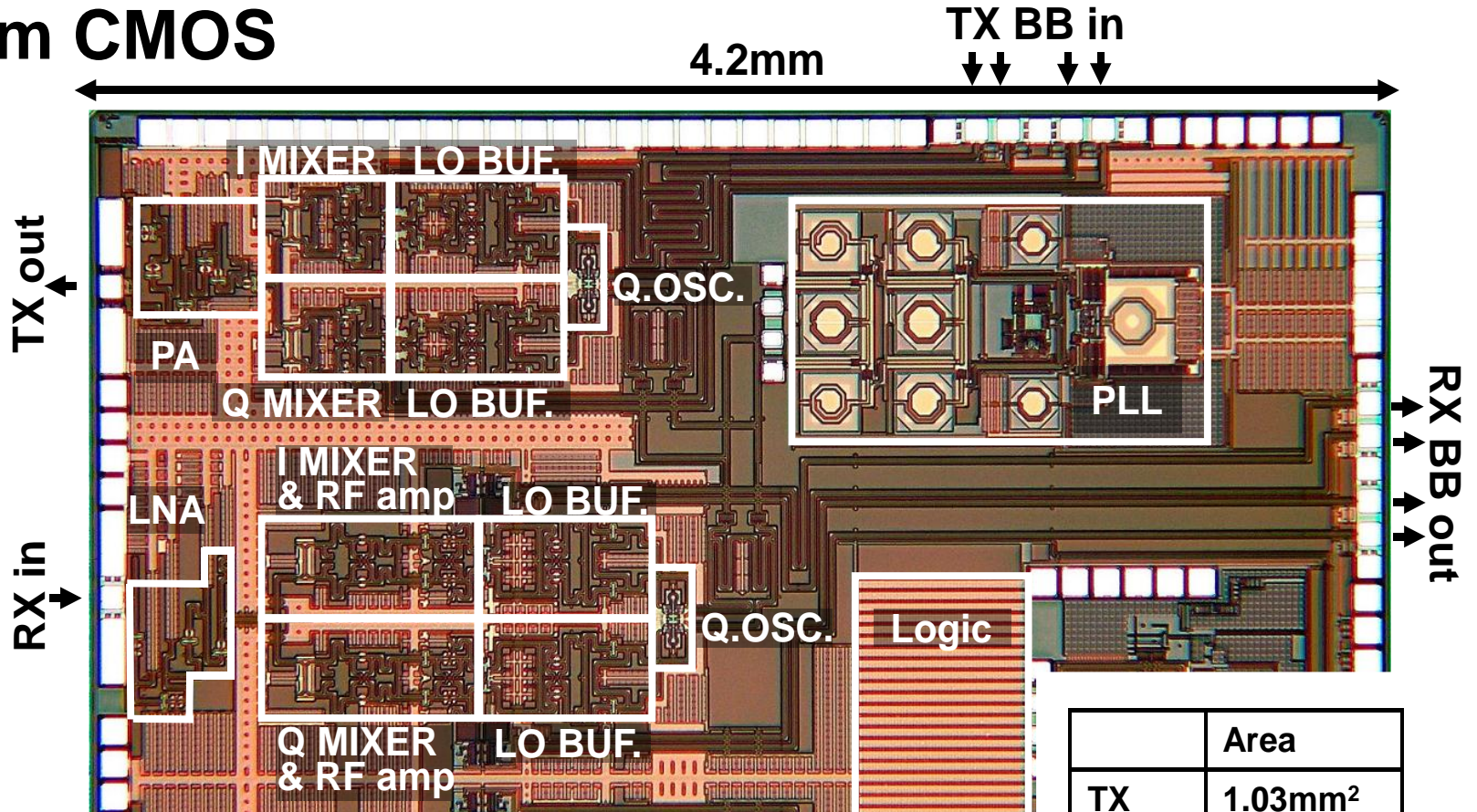


- 20GHz PLL: 64mW
- 60GHz QILO: 18mW(TX)&15mW(RX)
- QILO frequency range: 58-66GHz
- Phase noise improvement by **injection locking***
- **-96.5dBc/Hz @ 1MHz at 61.56GHz**

58.32GHz
59.40GHz
60.48GHz
61.56GHz
62.64GHz
63.72GHz
64.80GHz

チップ写真

65nm CMOS



TX: 186mW
RX: 155mW
PLL: 64mW

	Area
TX	1.03mm ²
RX	1.25mm ²
PLL	0.90mm ²
Logic	0.67mm ²

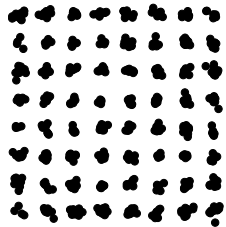
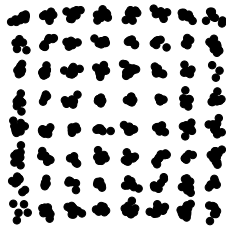
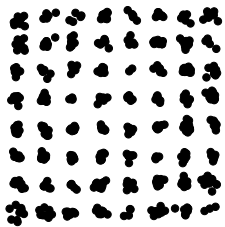
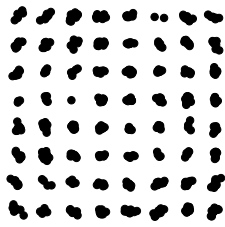
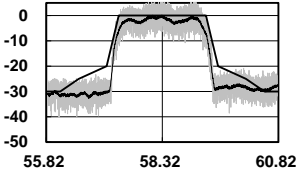
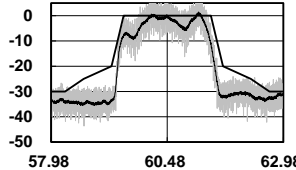
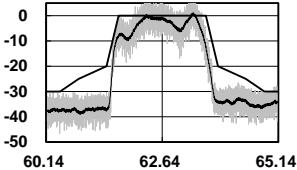
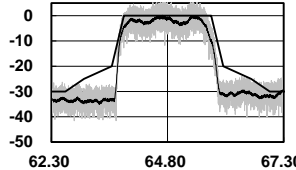
測定環境



- **25-GS/s AWG**
- **100-GS/s oscilloscope (33GHz BW)**
- **14-dBi horn antennas**

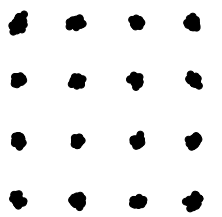
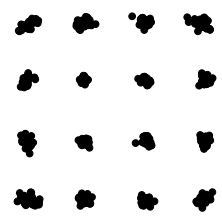
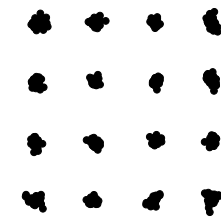
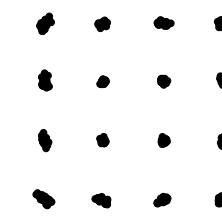
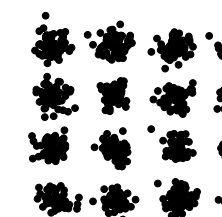
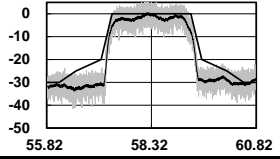
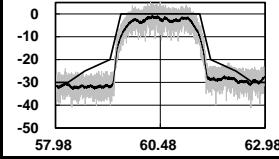
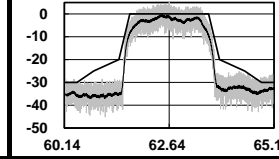
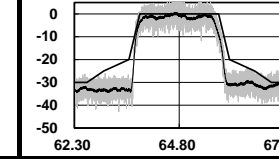
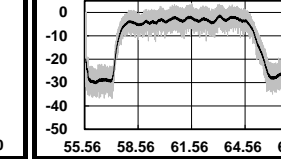
10.56Gb/s 64QAM

64QAM with 10.56Gb/s is achieved for the full 4 channels.

Channel/ Carrier freq.	ch.1 58.32GHz	ch.2 60.48GHz	ch.3 62.64GHz	ch.4 64.80GHz
Modulation	64QAM			
Data rate	10.56Gb/s	10.56Gb/s	10.56Gb/s	10.56Gb/s
Constellation				
Spectrum				
TX EVM	-27.1dB	-27.5dB	-28.0dB	-28.8dB
TX-to-RX EVM	-24.6dB	-23.9dB	-24.4dB	-26.3dB
Distance	0.08m	0.08m	0.13m	0.06m

7.04Gb/s 16QAM (max 28.16Gb/s)

28.16Gb/s is achieved by using 4-bonded channel.

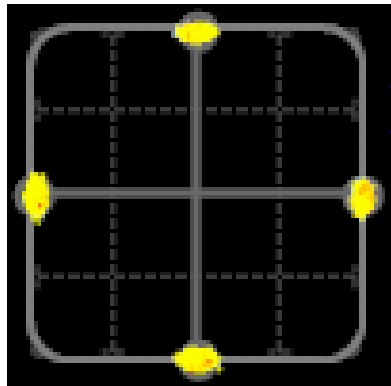
Channel/ Carrier freq.	ch.1 58.32GHz	ch.2 60.48GHz	ch.3 62.64GHz	ch.4 64.80GHz	ch.1-ch.4 Channel bond
Modulation	16QAM				
Data rate	7.04Gb/s	7.04Gb/s	7.04Gb/s	7.04Gb/s	28.16Gb/s
Constellation					
Spectrum					
TX EVM	-27.8dB	-27.6dB	-28.4dB	-28.8dB	-20.0dB
TX-to-RX EVM	-24.6dB	-24.1dB	-24.6dB	-27.0dB	-17.2dB
Distance	0.7m	0.6m	0.8m	0.4m	0.07m

60GHz TRXの性能比較

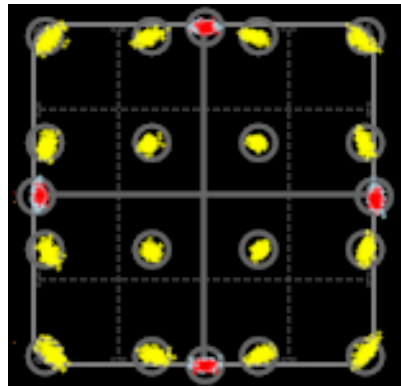
	Data rate / Modulation	TX-to-RX EVM	Power consumption
SiBeam [3]	7.14Gb/s(16QAM)	-19dB	TX: 1,820mW RX: 1,250mW
Tokyo Tech [4, 5]	16Gb/s(16QAM) 20Gb/s(16QAM)[5]	-21dB	TX: 319mW RX: 223mW
IMEC [6]	7Gb/s(16QAM)	-18dB	TX: 167mW RX: 112mW
Panasonic [9]	2.5Gb/s(QPSK)	-22dB	TX: 347mW RX: 274mW
This work	10.56Gb/s(64QAM) 28.16Gb/s(16QAM)	-26dB	TX: 251mW RX: 220mW

IEEE802.11ad/WiGigの測定

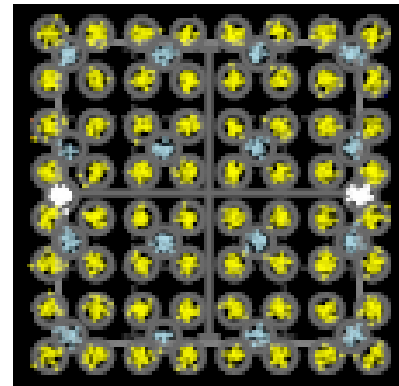
MCS	Modulation		Data rate [Mb/s]	TX EVM [dB]	
				Spec.	Meas.
9	QPSK	SC	2502.5	-15	-27.1
12	16QAM	SC	4620	-21	-27.0
24	64QAM	OFDM	6756.75	-26	-26.5



MCS9



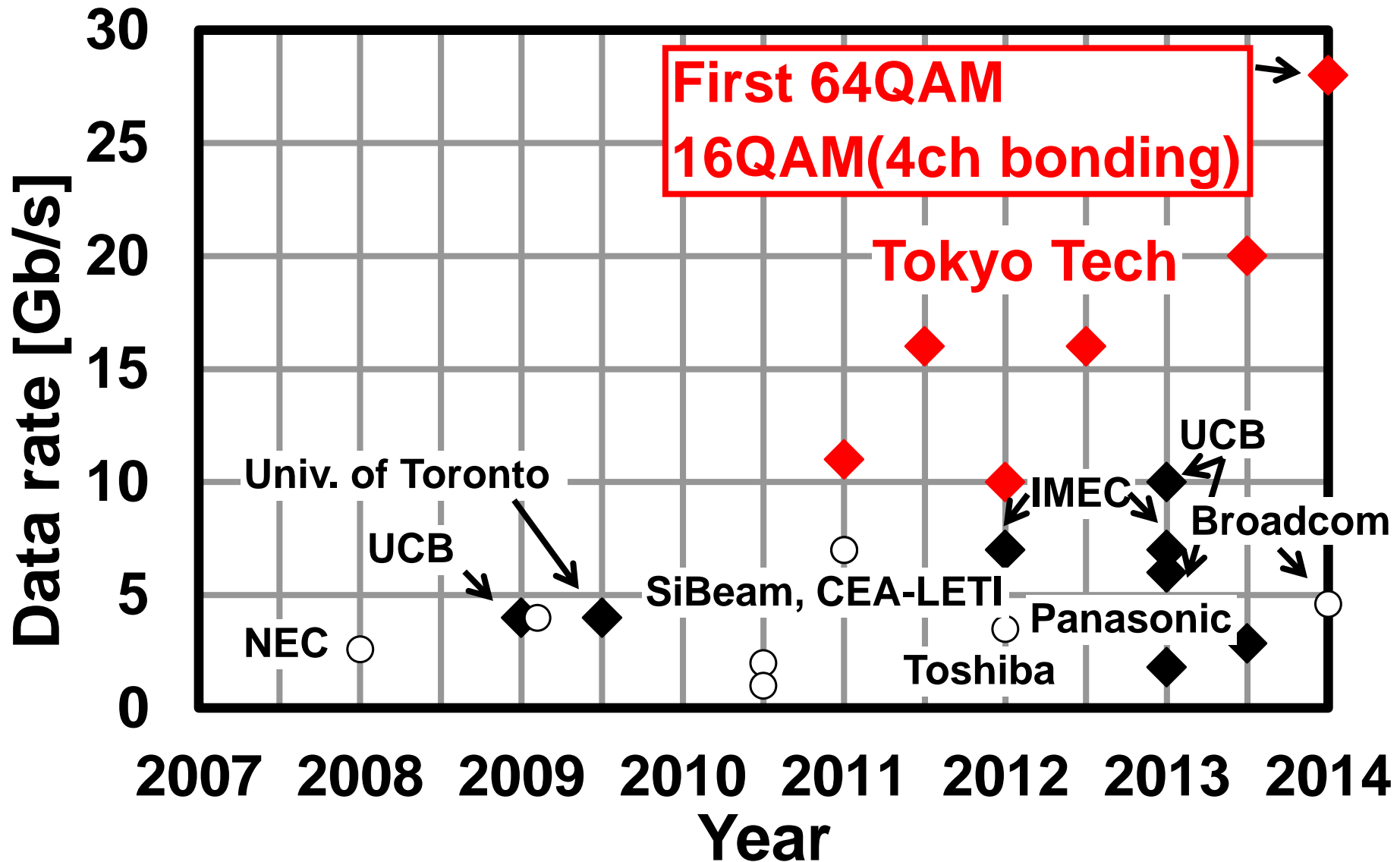
MCS12



MCS24

Measured by
Agilent AWG
+ Osc. + VSA
+ 81199A
in ch.3

60GHz CMOS Transceiver



結論

- 65nm CMOSプロセスを用いたダイレクトコンバージョン型無線通信機を開発
- 世界初: **64QAM**通信の実現 (10.56Gbps/ch)
 - **IEEE802.11ad/WiGig**準拠: MCS1-MCS24 (64QAM/OFDM)
- 世界初: **4チャンネルボンディング**通信の実現 (**28.16Gbps** by 16QAM)
 - 以下の技術によって達成:
 - Mixer-first型送信機
 - Open-loop FVF-based baseband amplifier
 - Quadrature injection-locked oscillator