Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: A Japanese Activity on 300-GHz CMOS Transmitters
Date Submitted: 6 May 2017
Source: Iwao Hosako, contributors of the research are listed in “Contributors” slide
Company: NICT, Hiroshima University
Address 4-2-1, Nukuikita, Koganei, 184-8795, Tokyo, Japan
Voice: + 81 42 327 6824, FAX: +81 42 327 6669 , E-Mail: kasa@nict.go.jp

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Abstract: A 300GHz CMOS transmitters (TXs) in 40nm CMOS is presented. With the fmax being below 300GHz, it adopts a new PA-less QAM-capable architecture employing the “cubic mixer” and “square mixer”. The output powers of 300GHz CMOS TXs by cubic-mixer- and square-mixer-last architectures are −14.5 and −5.5 dBm, and the data rates of them demonstrate 17.5Gb/s/ch 16QAM transmission over 6 channels and 105Gb/s 32QAM transmission over a single channel, respectively.
Purpose: []

Introduction

- Purpose of this talk is to introduce a Japanese activity on 300-GHz silicon CMOS transmitters and their wireless demonstrations.
- The introduced work was performed by contributors listed in the next slide and financially supported by the Ministry of Internal Affairs and Communications of Japan.

List of Contributors

- Kyoya Takano (Hiroshima University)
- Kosuke Katayama (Hiroshima University)
- Ruibing Dong (Hiroshima University)
- Shuhei Amakawa (Hiroshima University)
- Takeshi Yoshida (Hiroshima University)
- Minoru Fujishima (Hiroshima University)
- Shinsuke Hara (NICT)
- Akifumi Kasamatsu (NICT)

Outline

- Background of 300GHz wireless communication
- 300GHz CMOS TXs
    - 300GHz CMOS TX by cubic-mixer-last architecture
      [1] K. Katayama et al., ISSCC2016
    - 300GHz CMOS TX by square-mixer-last architecture
      [2] K. Takano et al., ISSCC2017
- Performance comparison
- Wireless demonstration of the 300GHz CMOS TXs
- Conclusion

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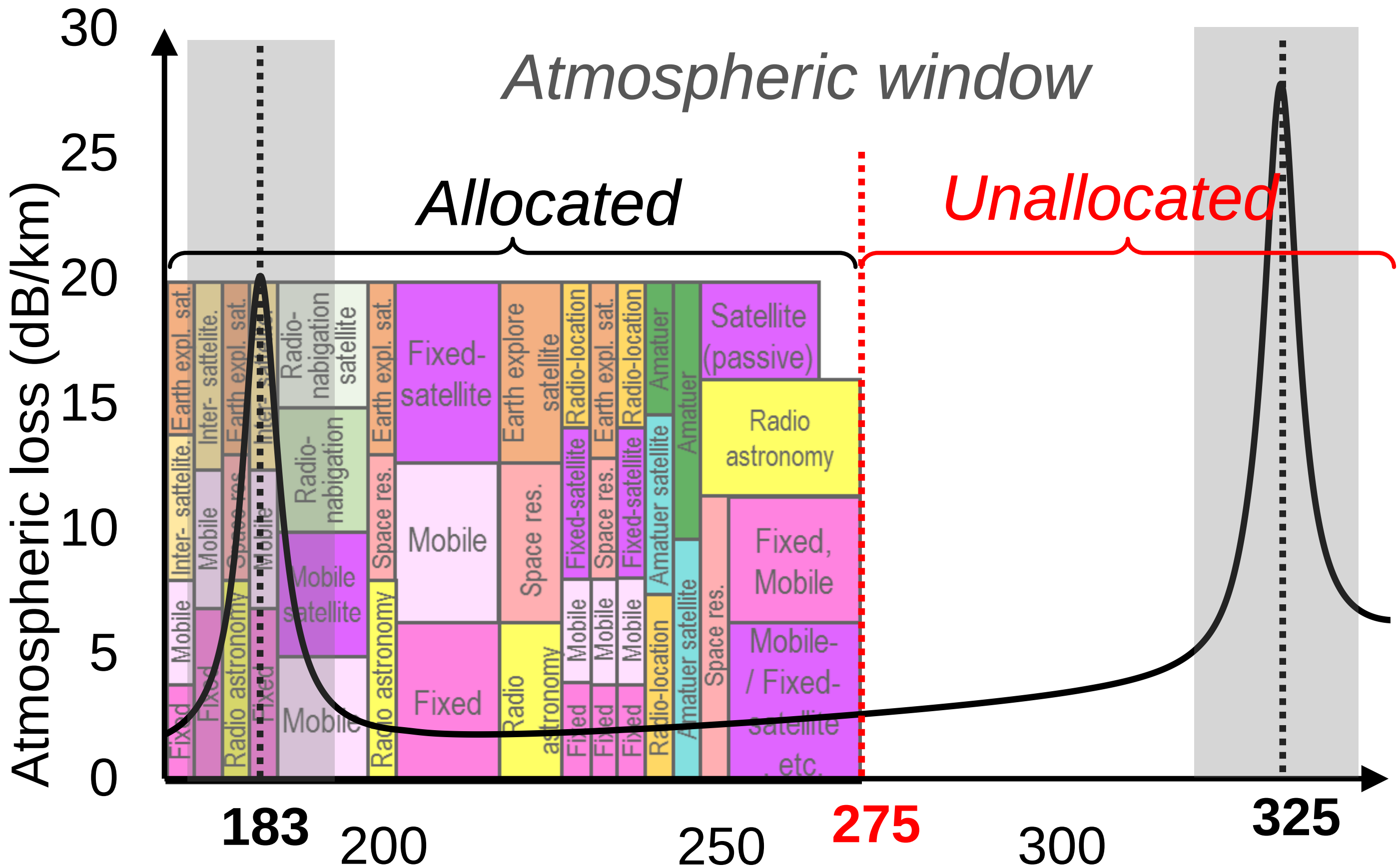
Atmospheric window and frequency allocation above 175 GHz

- Vast unallocated frequency band lying above 275GHz

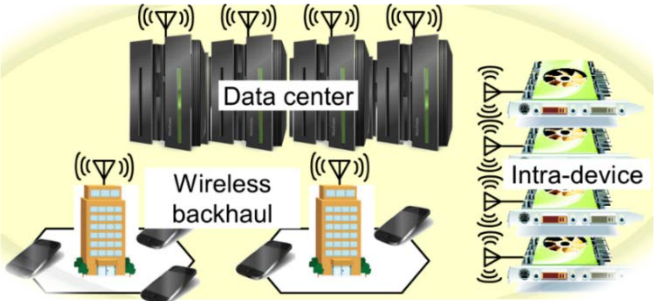


NICT Amaterasu: https://smiles-p6.nict.go.jp/thz/jp/decay.html,

https://www.ntia.doc.gov/page/2011/united-states-frequency-allocation-chart

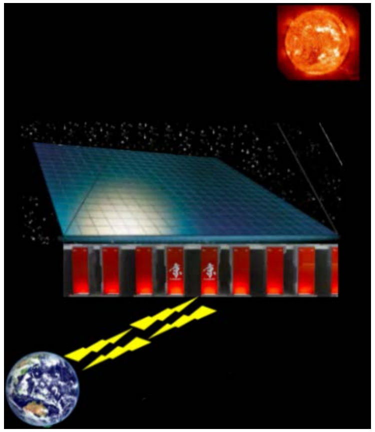
Possible applications of 300GHz wireless communication

- Enormous potential for THz wireless communication

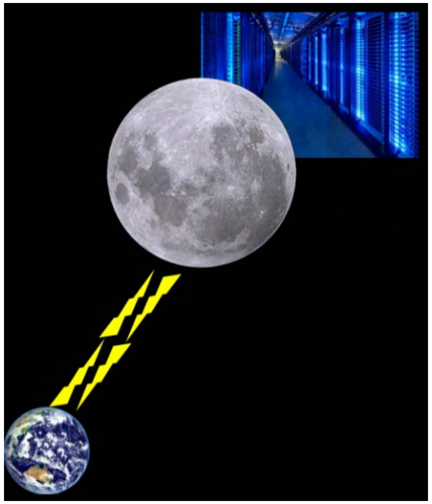


Ultrahigh-speed wireless communications

8K broadcasting



THz communication with
super computer in outer space



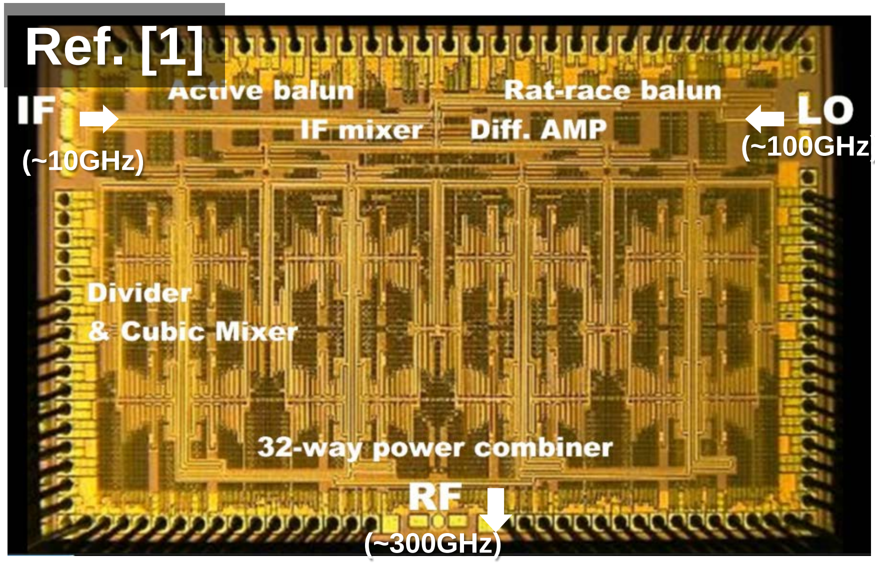
THz communication with
cold storage center on outer space

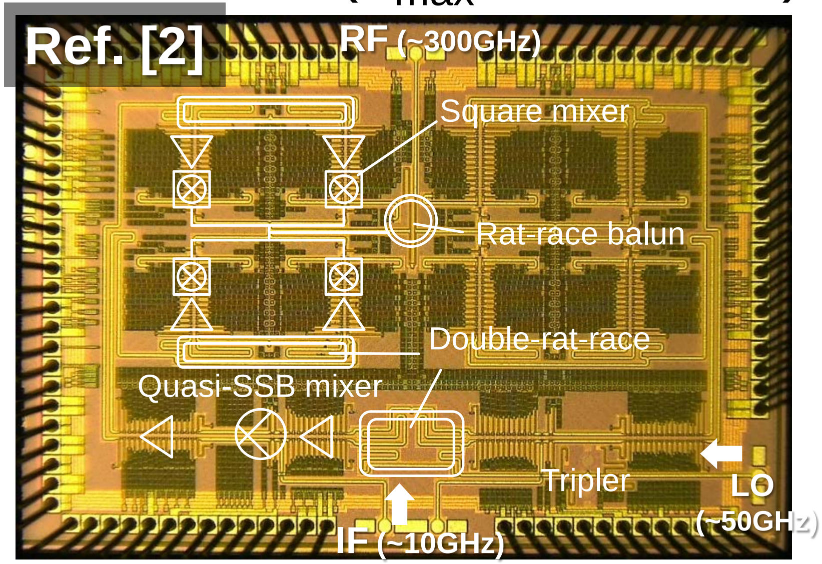
M. Fujishima, Keysight world 2016 Tokyo (14 June, 2016)

300GHz CMOS transmitters (TXs)

- ✓ QAM-capable 300GHz CMOS TX with 17.5Gb/s/ch [1]
- ✓ 300GHz CMOS TX over 100Gb/s [2]

in 40nm CMOS (f_{max}: ~280GHz)





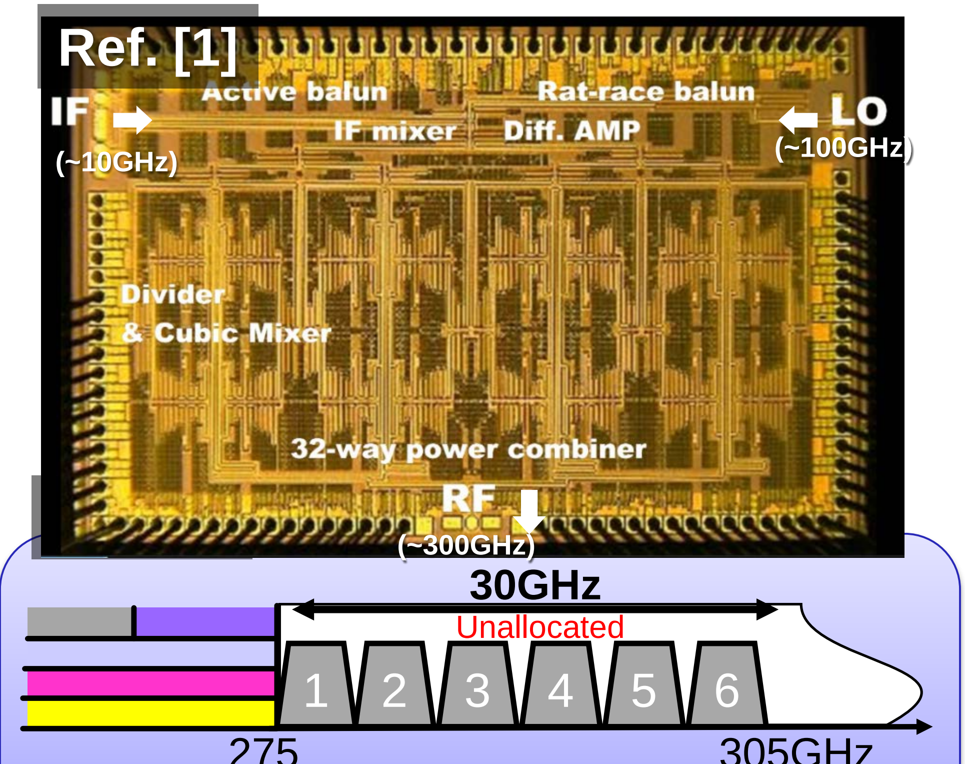
[1] K. Katayama, K. Takano, S. Amakawa, S. Hara, A. Kasamatsu, K. Mizuno, K. Takahashi, T. Yoshida, M. Fujishima, “A 300GHz 40nm CMOS Transmitter with 32-QAM 17.5Gb/s/ch Capability over 6 Channels,” *Int. Solid-State Circuits Conf. (**ISSCC2016**)*, pp. 342–343, Feb. 2016.

[2] K. Takano, S. Amakawa, K. Katayama, S. Hara, R. Dong, A. Kasamatsu, I. Hosako, K. Mizuno, K. Takahashi, T. Yoshida, M. Fujishima, “A 105Gb/s 300GHz CMOS Transmitter,” *Int. Solid-State Circuits Conf. (**ISSCC2017**)*, pp. 308–309, Feb. 2017.

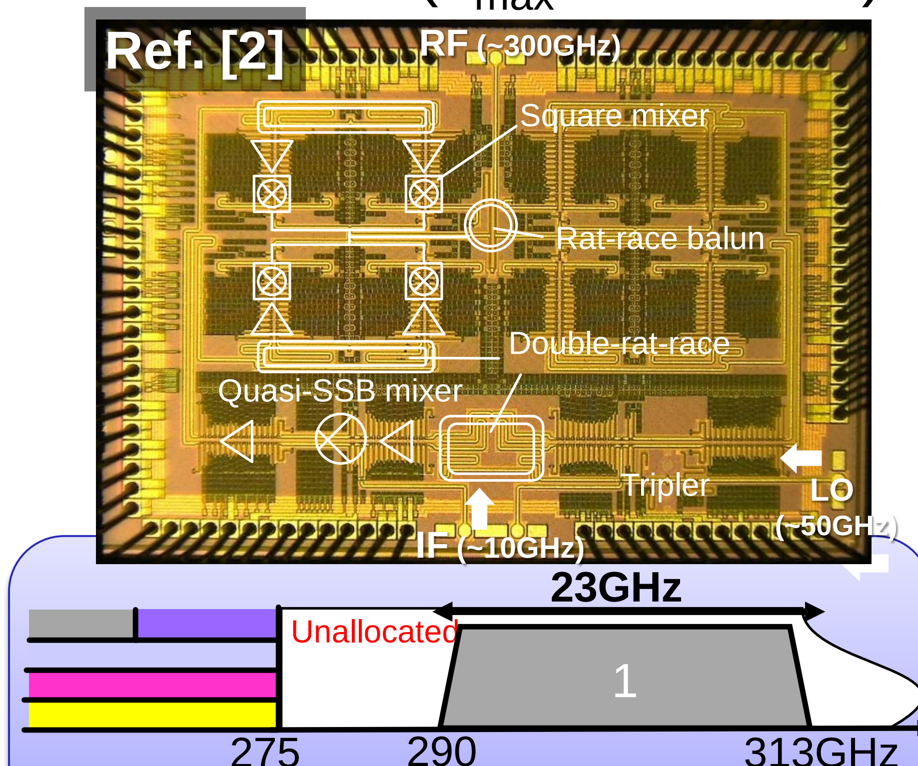
300GHz CMOS transmitters (TXs)

- ✓ QAM-capable 300GHz CMOS TX with 17.5Gb/s/ch [1]
- ✓ 300GHz CMOS TX over 100Gb/s [2]

in 40nm CMOS (f_{max}: ~280GHz)



32QAM 3.5Gbaud → 17.5Gb/s/ch (×6)



32QAM 21Gbaud → 105Gb/s

Outline

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- 300GHz CMOS TXs
  - 300GHz CMOS TX by cubic-mixer-last architecture
    [1] K. Katayama et al., ISSCC2016
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- Wireless demonstration of the 300GHz CMOS TXs
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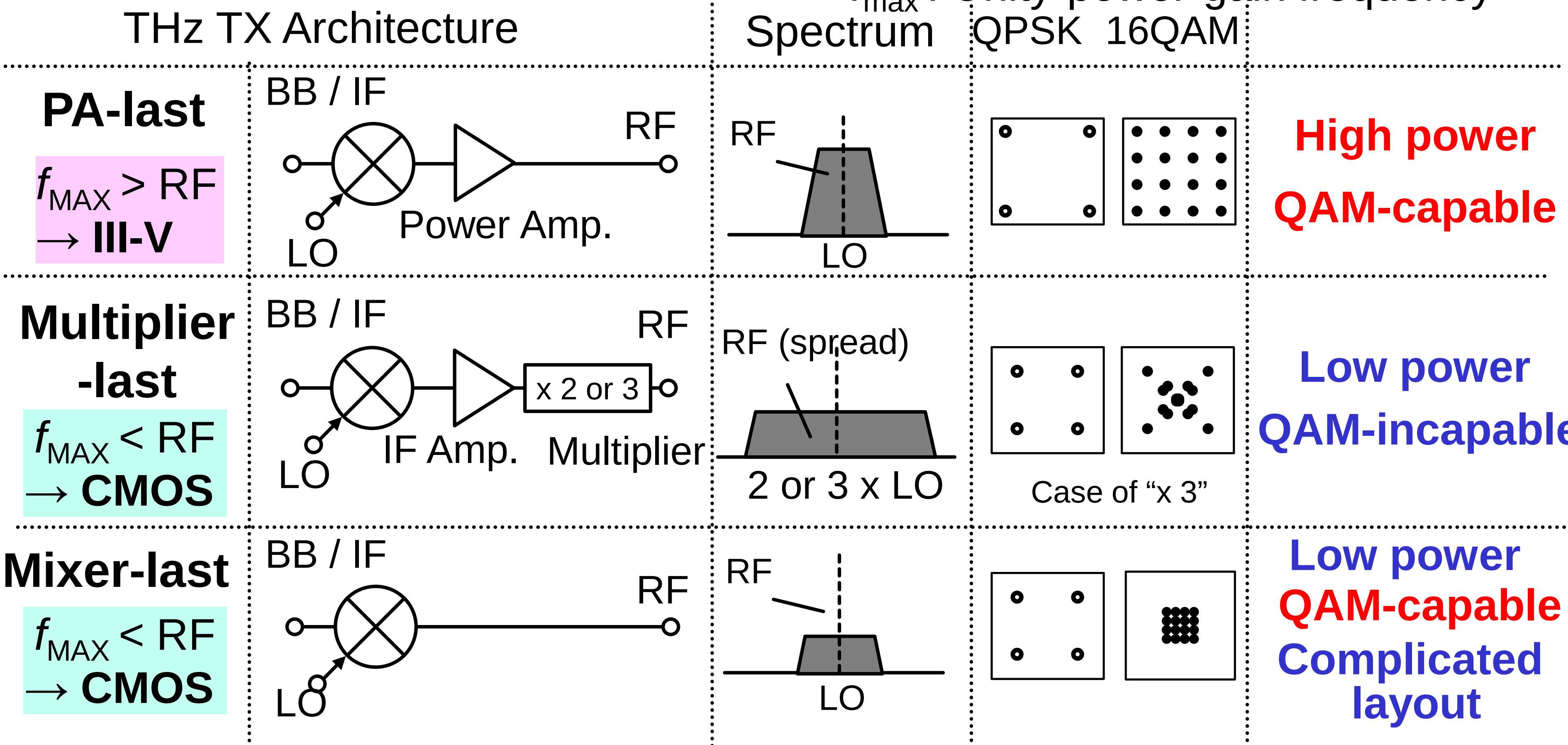
THz transmitters (TXs): State of the art

- TXs architecture depends on transistor f_{max}

f_{max} : Unity-power-gain frequency



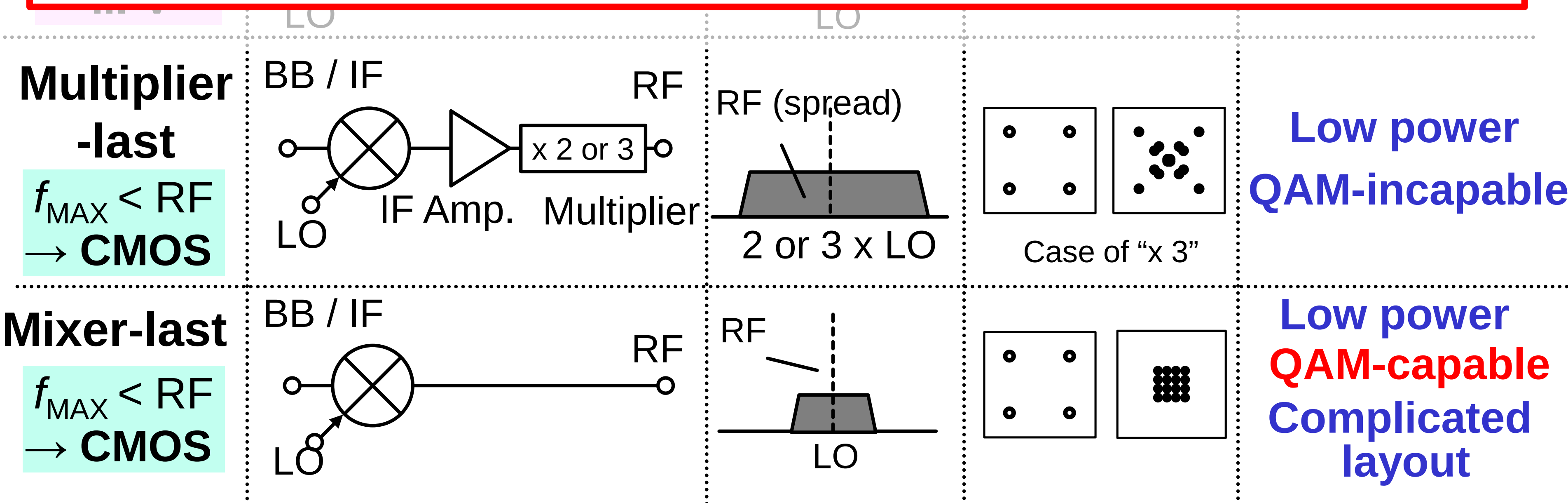
[1] K. Katayama, et al. *ISSCC2016*, pp. 342–343, Feb. 2016.

THz transmitters (TXs): State of the art

- **Technical challenges**

300GHz PA-less TX in CMOS operating beyond f_{max},

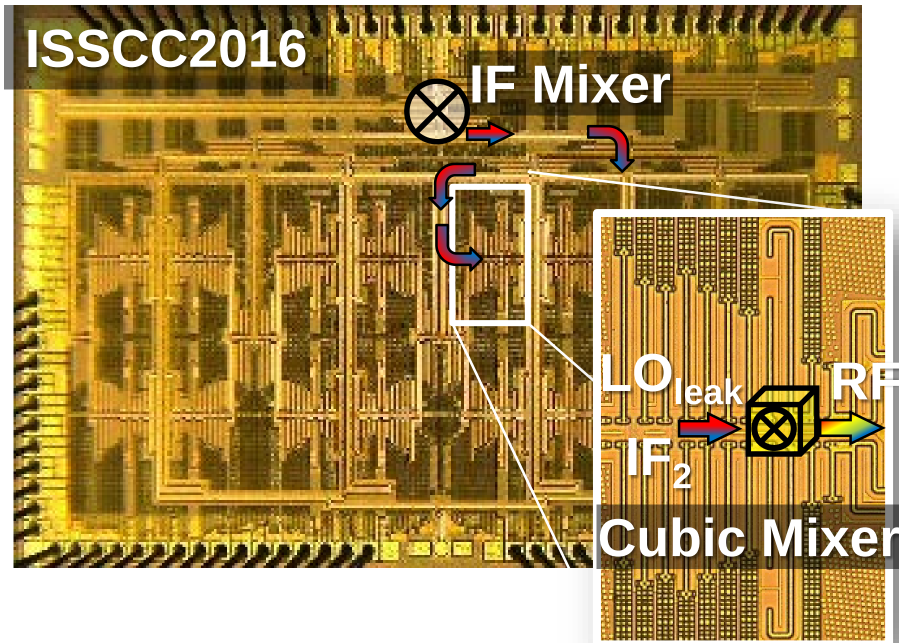
- ✓ QAM-capability for high data-rates
- ✓ Without undue layout complication

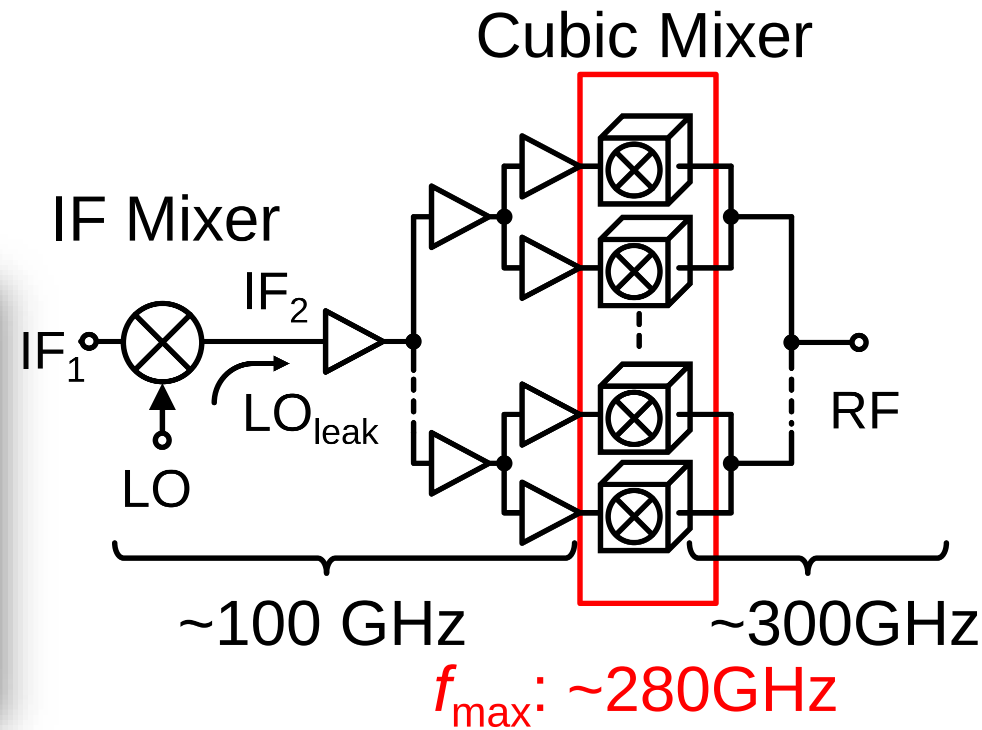


[1] K. Katayama, et al. *ISSCC2016*, pp. 342–343, Feb. 2016.

Design

- Cubic-mixer-last architecture (ISSCC2016)

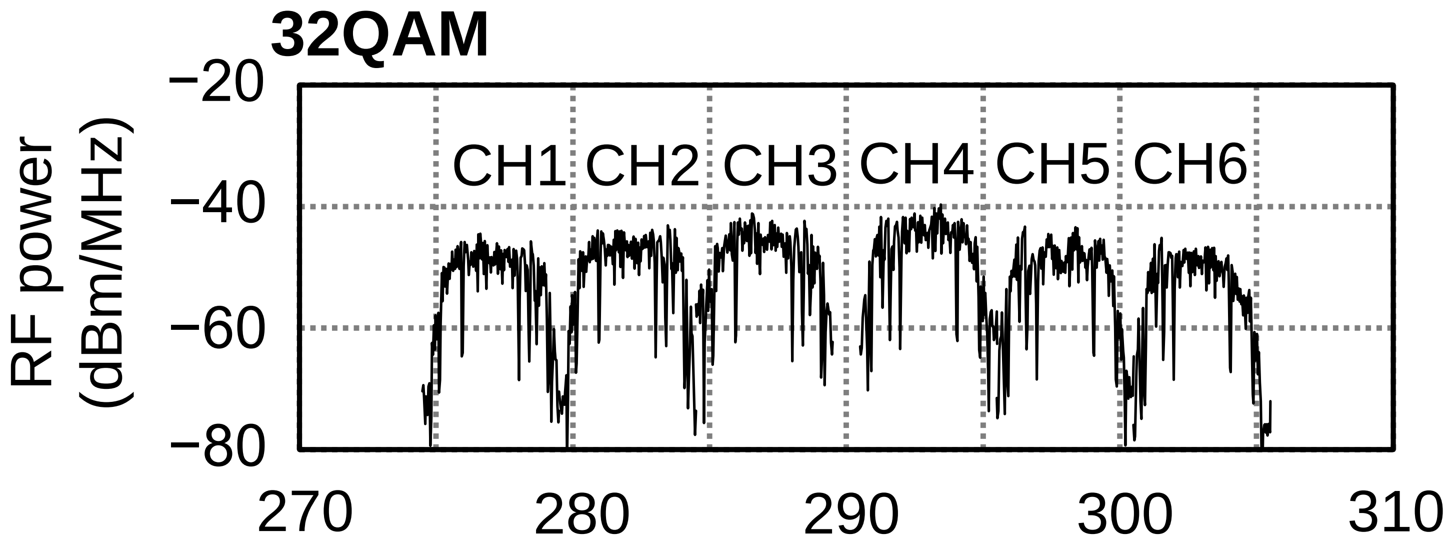


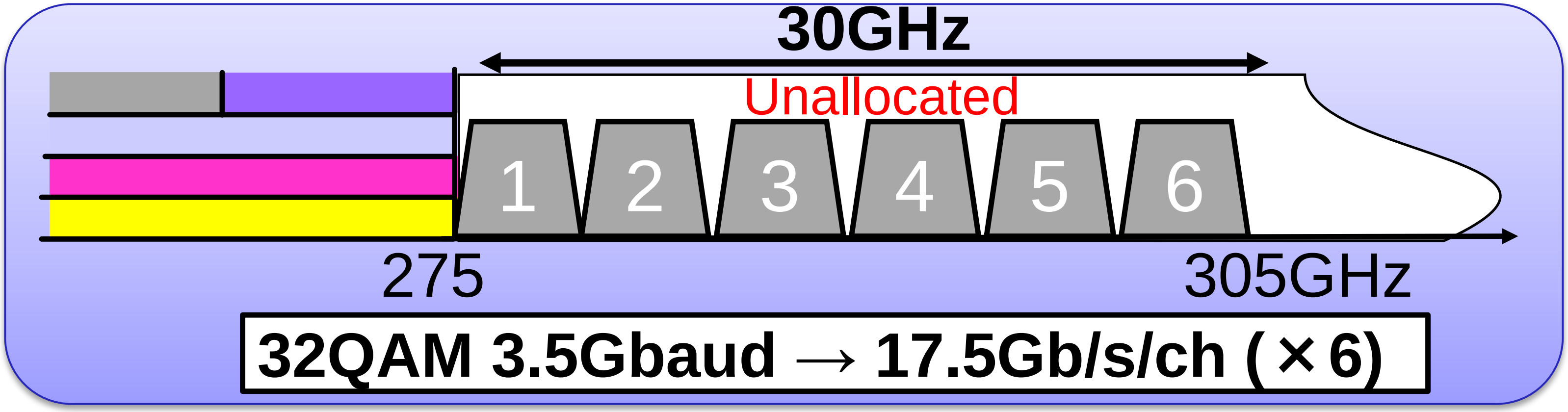


- Cubic mixer is essentially a ***tripler***
- It receives superposition of IF$_2$ (modulated) and LO (pure)

[1] K. Katayama, et al. *ISSCC2016*, pp. 342–343, Feb. 2016.

Power spectra and signal constellations





[1] K. Katayama, et al. *ISSCC2016*, pp. 342–343, Feb. 2016.

Power spectra and signal constellations

32QAM

Channel	CH1	CH2	CH3
Constellation (Equalized)			
EVM	8.9%rms	4.8%rms	7.0%rms
Data-rate	17.5Gb/s	17.5Gb/s	17.5Gb/s
Channel	CH4	CH5	CH6
Constellation (Equalized)			
EVM	7.1%rms	6.4%rms	5.9%rms
Data rate	17.5Gb/s	17.5Gb/s	17.5Gb/s

- Aggregate data-rate reaches 105Gb/s

[1] K. Katayama, et al. *ISSCC2016*, pp. 342–343, Feb. 2016.

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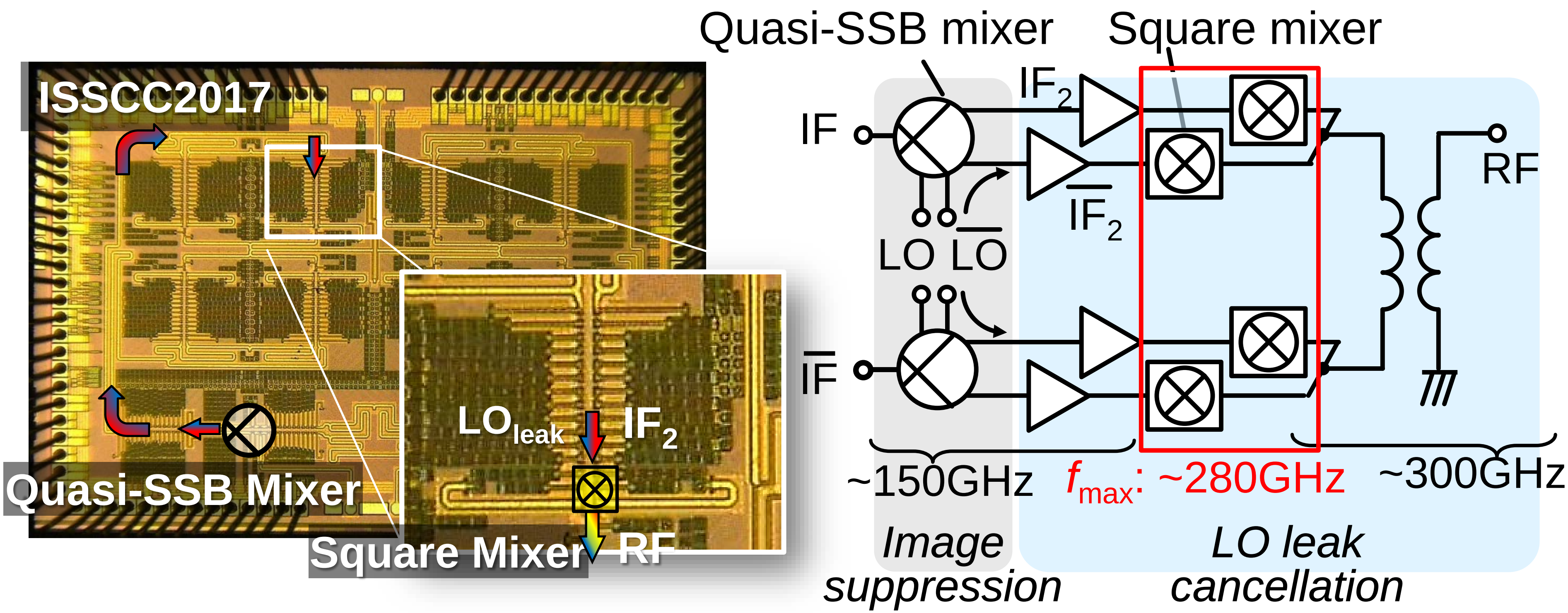
Design

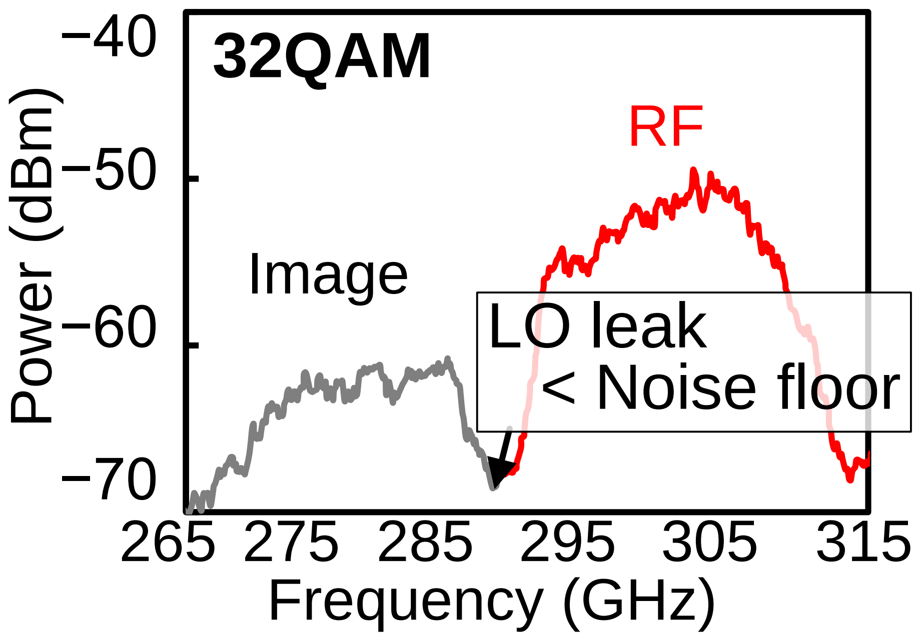
- Square mixer + quasi-SSB mixer (ISSCC2017)

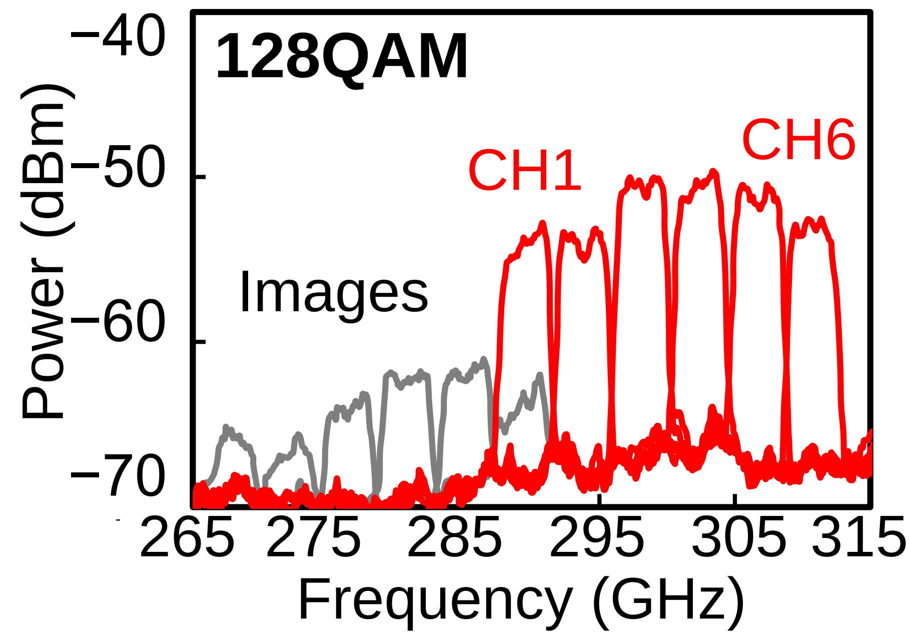


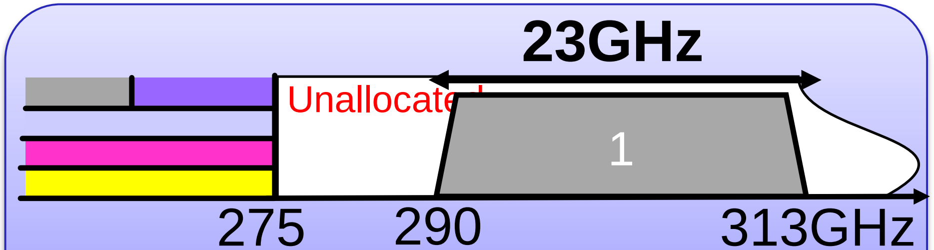
- Square mixer is essentially a ***doubler***
- Quasi-SSB mixer includes filters for image suppression

[2] K. Takano, et al. *ISSCC2017*, pp. 308–309, Feb. 2017.

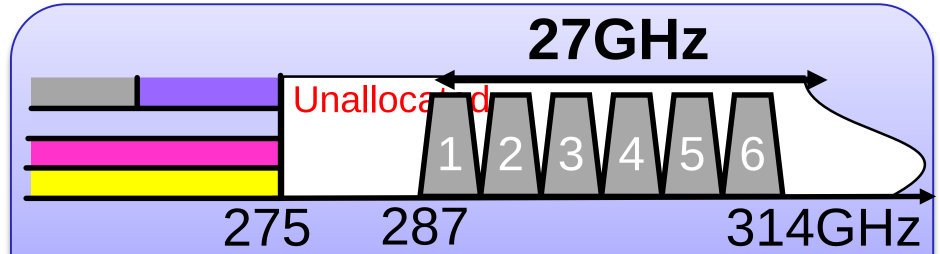
Power spectra and signal constellations







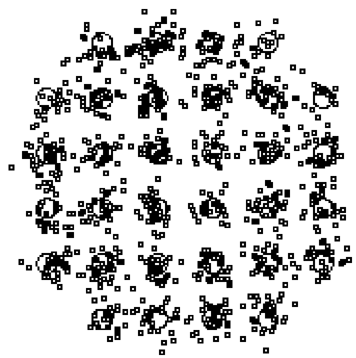
32QAM 21Gbaud → 105Gb/s

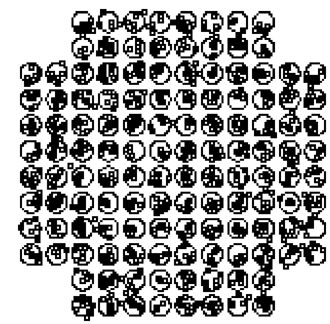


128QAM 3.52Gbaud → 24.6Gb/s/ch(×6)

[2] K. Takano, et al. *ISSCC2017*, pp. 308–309, Feb. 2017.

Power spectra and signal constellations

Modulation	32QAM
Constellation (Equalized)	
EVM	8.9%
Data rate	105Gb/s

Modulation	128QAM
Constellation (Equalized)	
EVM	3.3 ~ 4.1%
Data rate	24.64Gb/s x6

[2] K. Takano, et al. *ISSCC2017*, pp. 308–309, Feb. 2017.

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Performance comparison

	[1]	[2]		[3]	[4]	[5]	[6]
Technology	40nm CMOS	40nm CMOS		250nm InP	35nm GaAs	35nm GaAs	0.13μm SiGe
Freq. (GHz)	275-305	302	289−311	300	240	300	240
Modulation	32QAM	32QAM	128QAM	QPSK	8PSK	QPSK	64QAM
Pout (dBm)	−14.5	−5.5		−	−3.5	−4	7
Pdc (W)	1.4	1.4		−	−	−	0.54
Data rate (Gb/s)	17.5 x 6	105	24.64 x 6	50	96	64	1.02

[1] K. Katayama et al., ISSCC2016.
[2] K. Takano et al., ISSCC2017.
[3] Song et al., TMTT, 2014.
[4] Boes et al., IRMMW-THz, 2014.
[5] Kallfass et al., IEICE Trans., 2015.
[6] Sarmah et al., TMTT, 2016..

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Wireless demonstration

300GHz CMOS TX
by cubic-mixer-last-architecture

Ref. [1]

300GHz CMOS TX
by square-mixer-last-architecture

Ref. [2]

Video Contents

[1] K. Katayama, et al. *ISSCC2016*, pp. 342–343, Feb. 2016.
[2] K. Takano, et al. *ISSCC2017*, pp. 308–309, Feb. 2017.

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Conclusion

- A Japanese activity on 300-GHz silicon CMOS transmitters and their wireless demonstrations were introduced.
- QAM-capable 300GHz TXs in 40-nm CMOS operating beyond f_{max} were reported.
  - cubic-mixer-last architecture

    [1] K. Katayama et al., ISSCC2016.
  - square-mixer-last architecture

    [2] K. Takano et al., ISSCC2017.
- For realizing 300GHz wireless communication, Si CMOS is one of possible technology.