

**Tu3C-5**

# **Beam Control Free 28GHz 5G Relay Transceiver and 24GHz Wireless Power Receiver Using On-Chip Butler Matrix**

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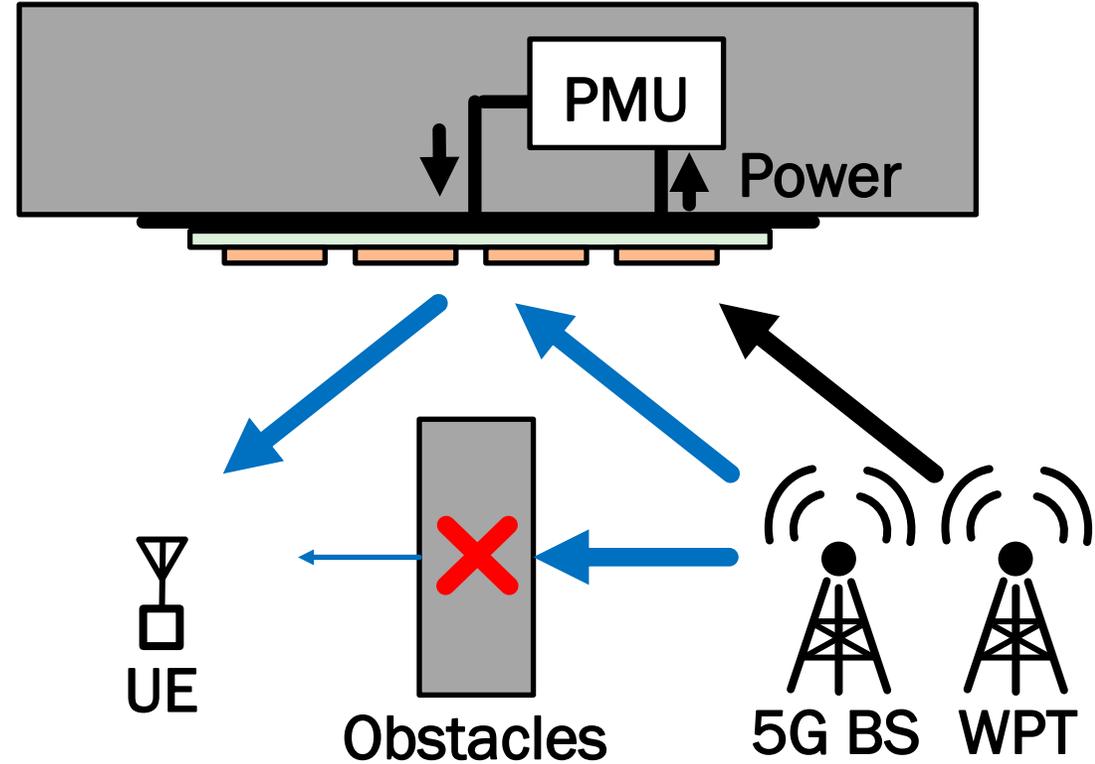
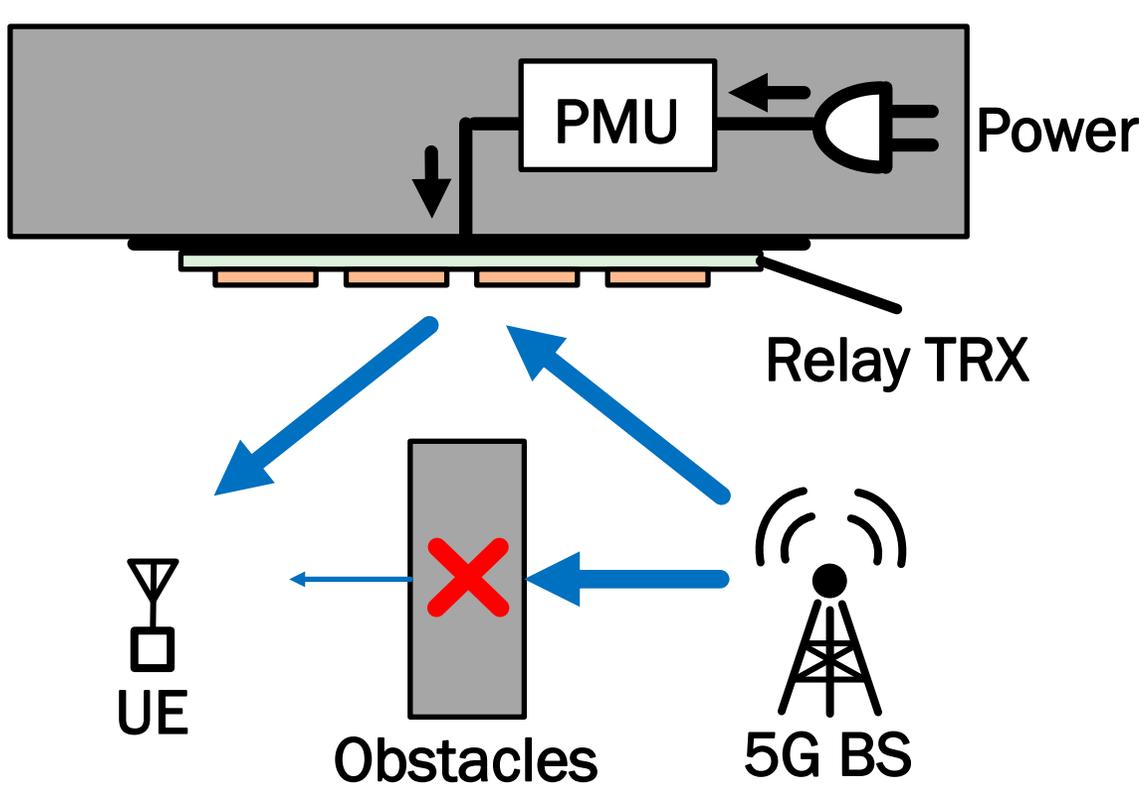
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- Background and Motivation
- Proposed Battery-less Relay TRX
- Implementation
- Measurement Results
- Conclusion

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# Battery-less Relay TRX



## ❑ Active Relay TRX

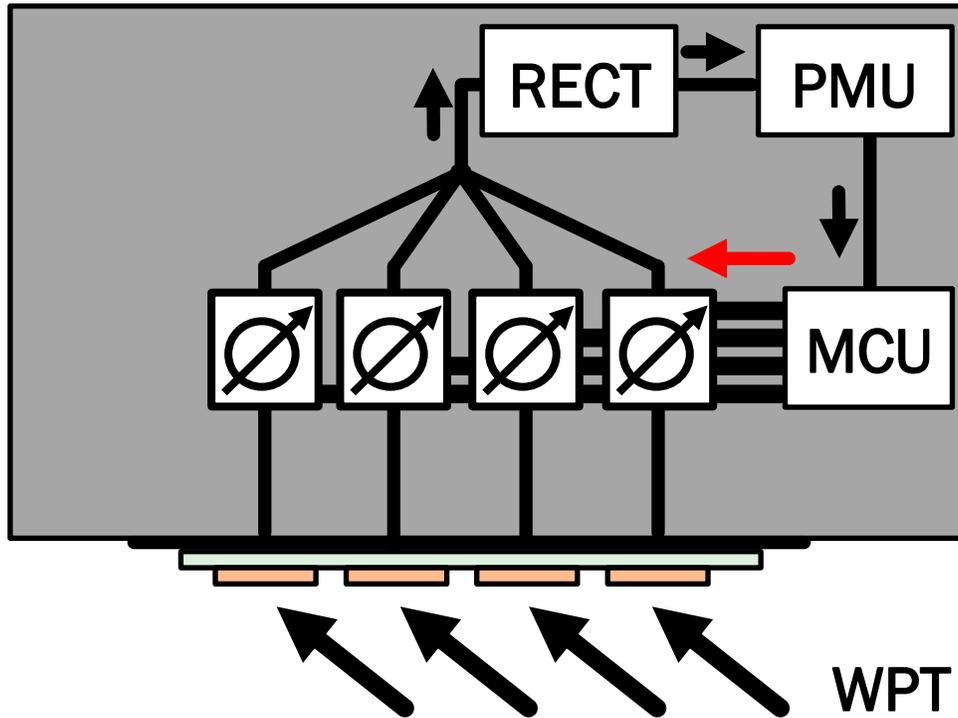
- ☺ Expansion of 5G communication area
- ☹ Needs power supply unit
- ☹ High cost for implementation

## ❑ Battery-less Relay TRX

- ☺ Expansion of 5G communication area
- ☺ No need power supply unit
- ☺ Low maintenance cost

[1] L. Wei, *et al.*, WC, 2014.

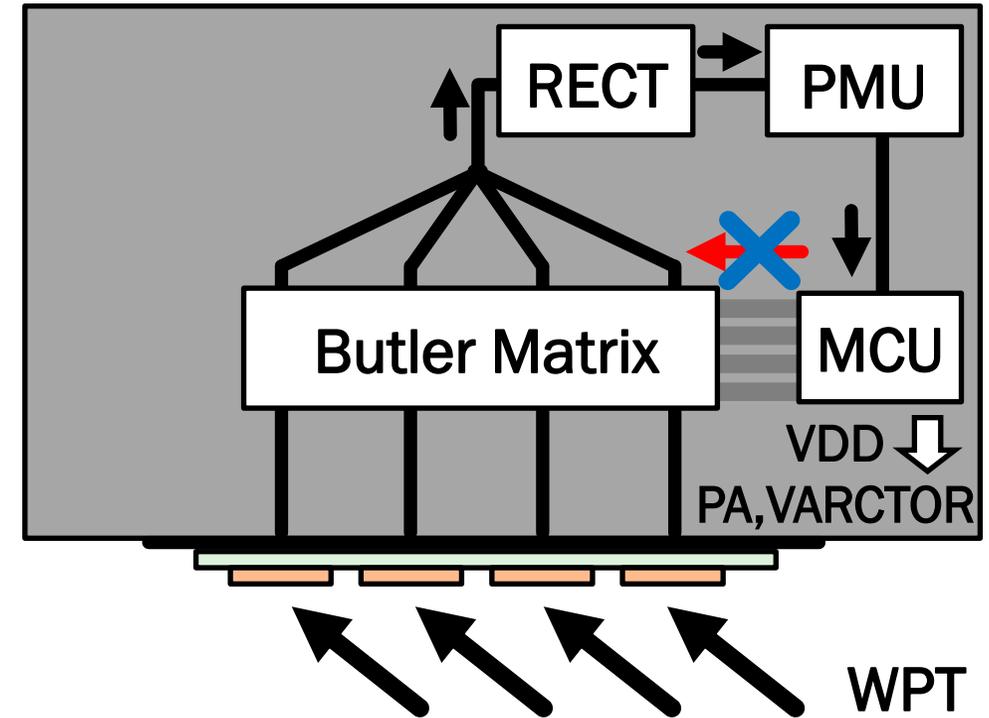
# Battery-less Relay TRX for Start-up



□ Pactive Phase Shifter with MCU control

- ☺ Increased Transmission distance
- ☹ Needs power supply for PS

[2] M. Ide, *et al.*, *JSSC*, 2022.



□ Proposed Battery-less Relay TRX without MCU control

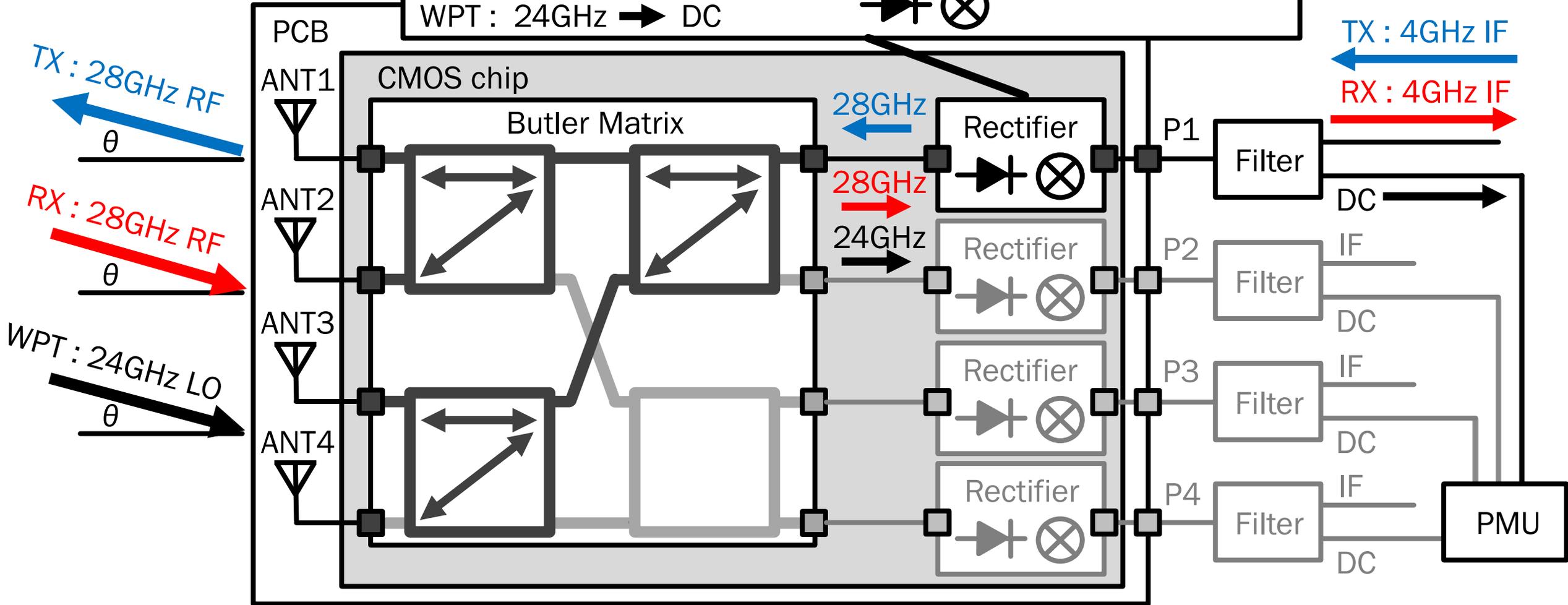
- ☺ Increased Transmission distance
- ☺ No need power supply for PS

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# Proposed Battery-less Relay TRX

$\theta = 15^\circ$  case

**RX : RF+LO  $\rightarrow$  IF** Rectification and frequency conversion  
**TX : RF  $\leftarrow$  LO+IF**  
**WPT : 24GHz  $\rightarrow$  DC**

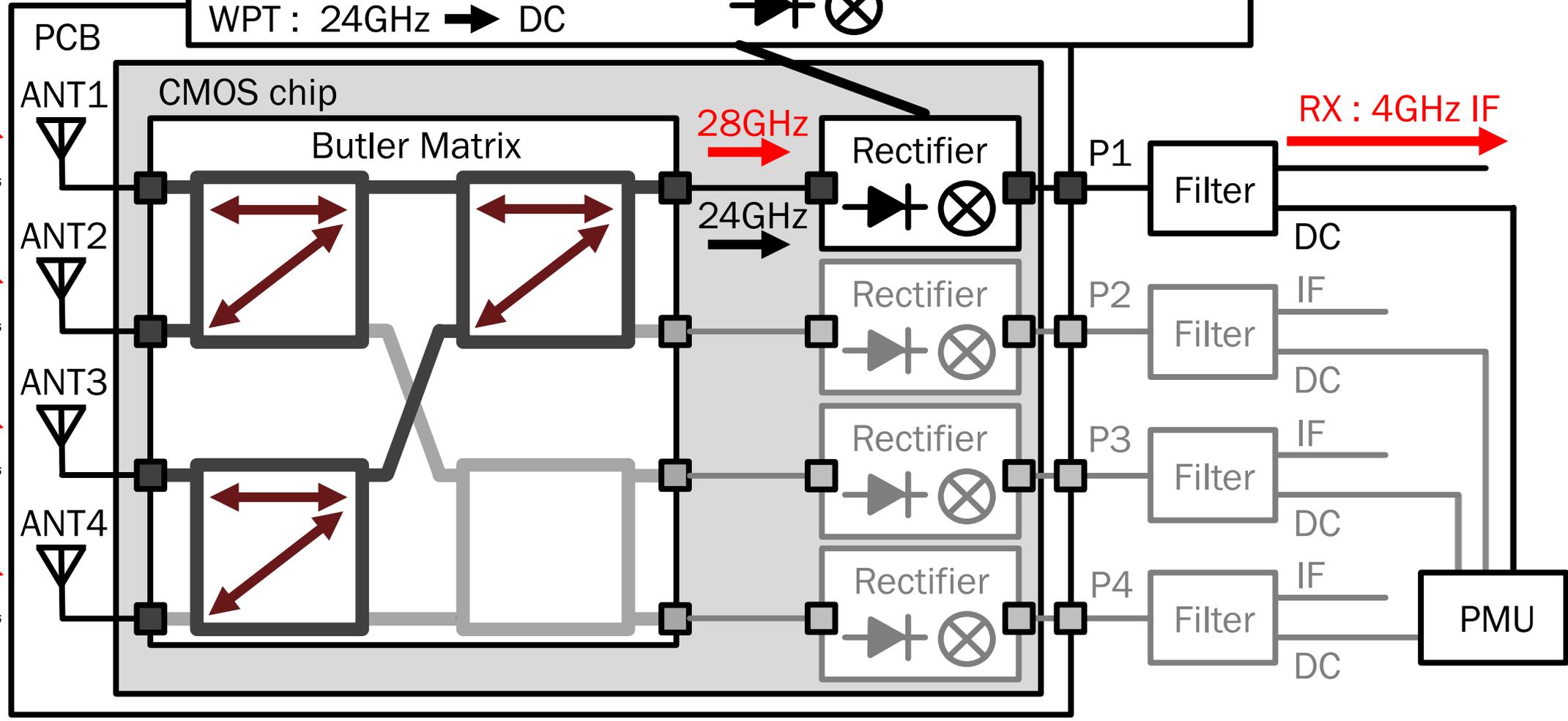


# RX Mode Operation

$\theta = 15^\circ$  case

RX: 28GHz RF  
WPT: 24GHz LO

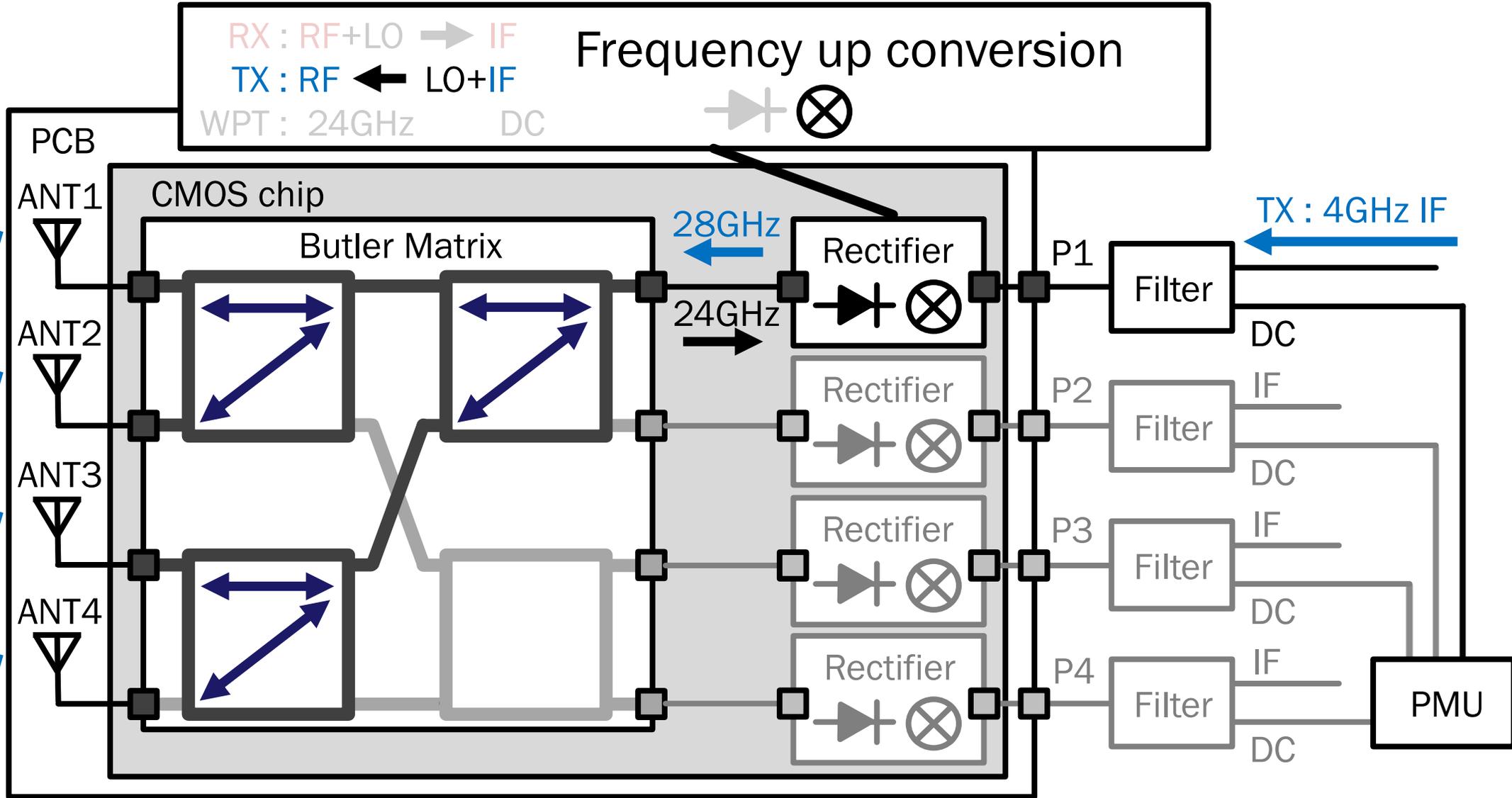
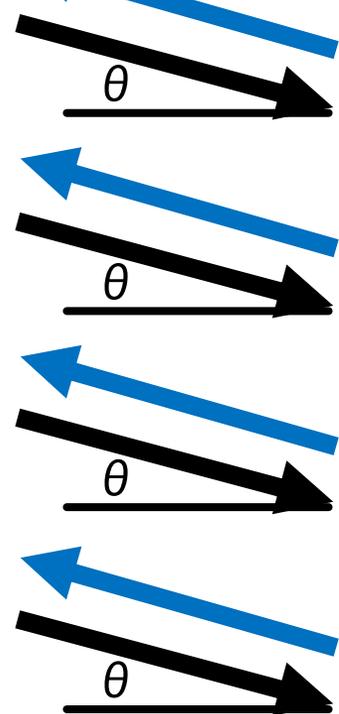
RX: RF+LO  $\rightarrow$  IF Frequency down conversion  
TX: RF  $\leftarrow$  LO+IF  
WPT: 24GHz  $\rightarrow$  DC



# TX Mode Operation

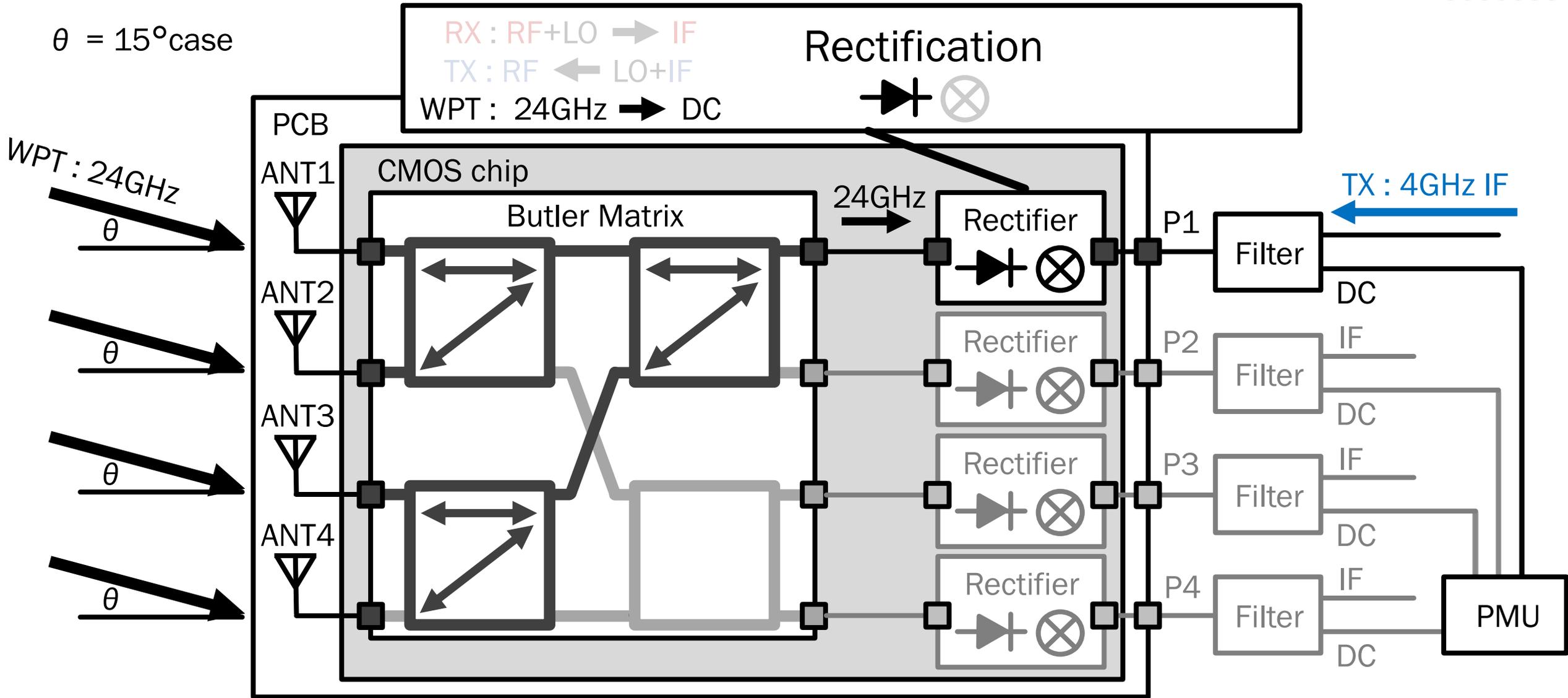
$\theta = 15^\circ$  case

TX: 28GHz RF  
WPT: 24GHz LO

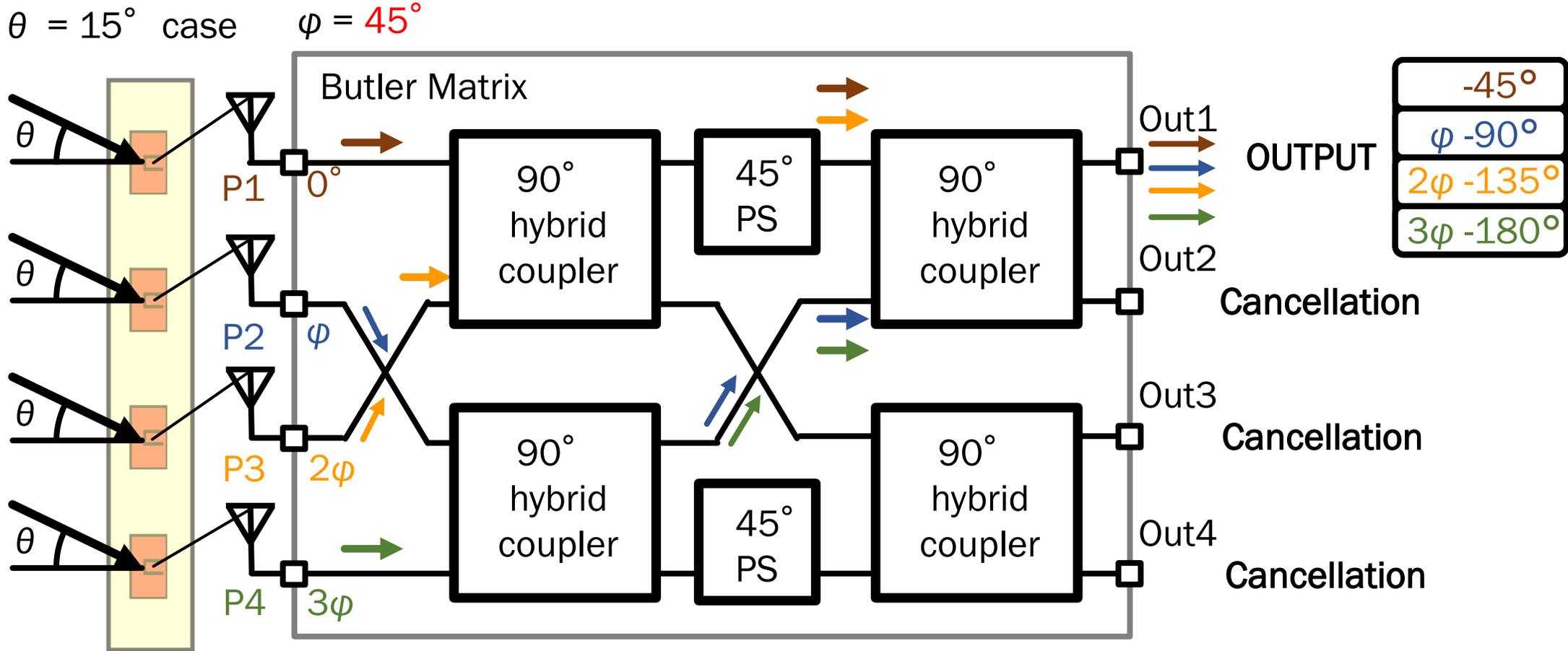


# WPT Mode Operation

$\theta = 15^\circ$  case



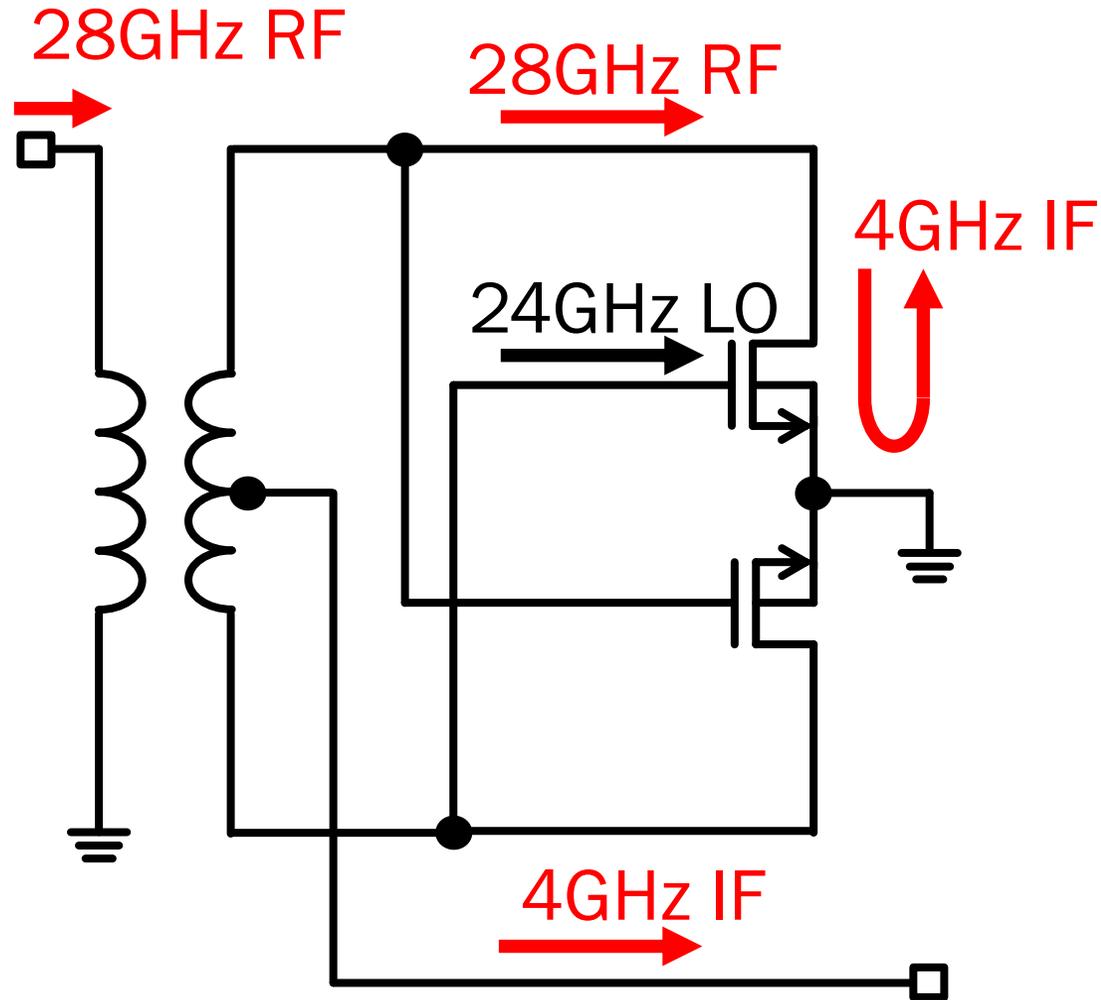
# Butler Matrix Operation



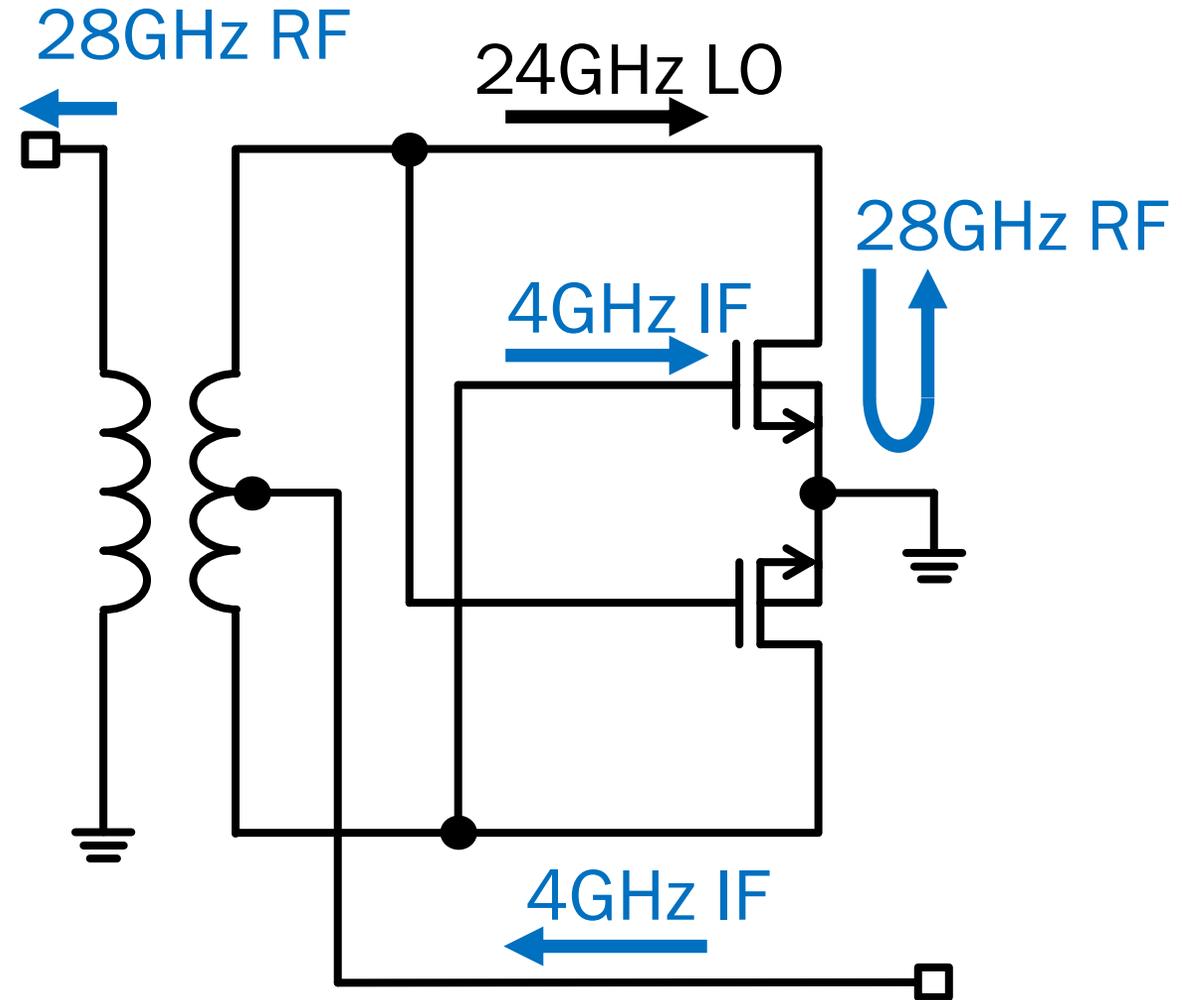
□ 24GHz WPT reception, 28GHz 5G Tx and Rx without beam control

# Self-heterodyne Mixer Operation

□ Rx Mode – Down Conversion –



□ Tx Mode – Up Conversion –

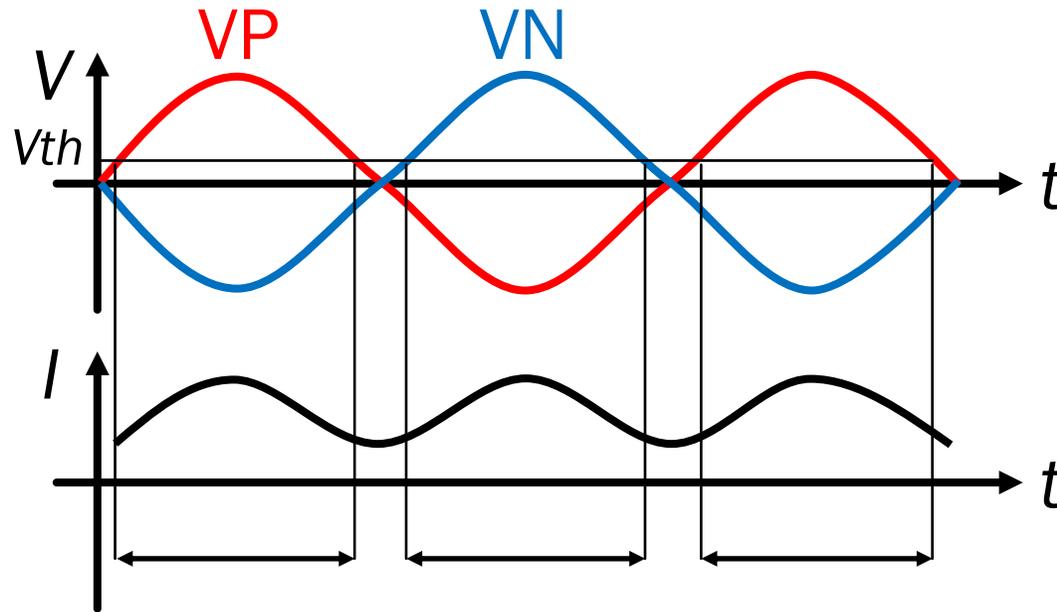


[3] S. Kato, *et al.*, *ESSCIRC*, 2022.

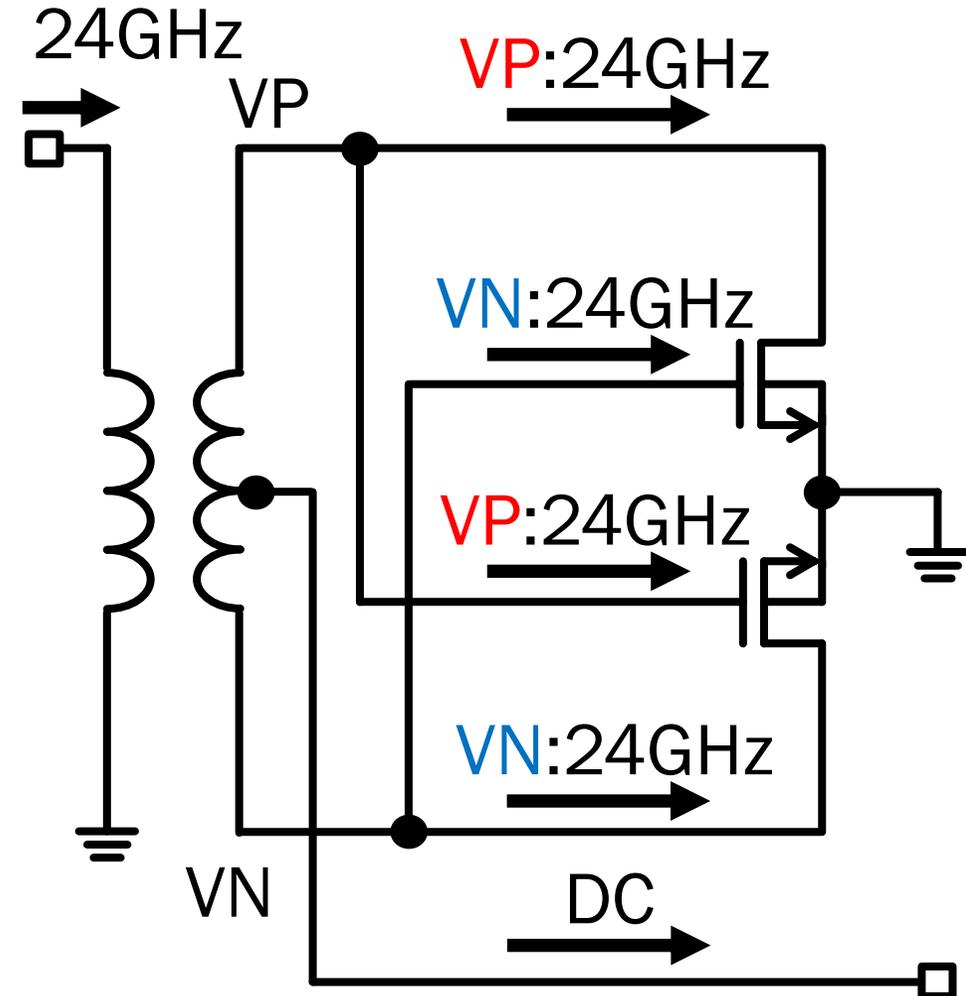
# Rectifier Operation

## □ WPT Mode

- Generate DC power from 24GHz WPT
- Full-wave rectification
- Performing simultaneously in both RX mode or TX mode



Rectification Rectification Rectification



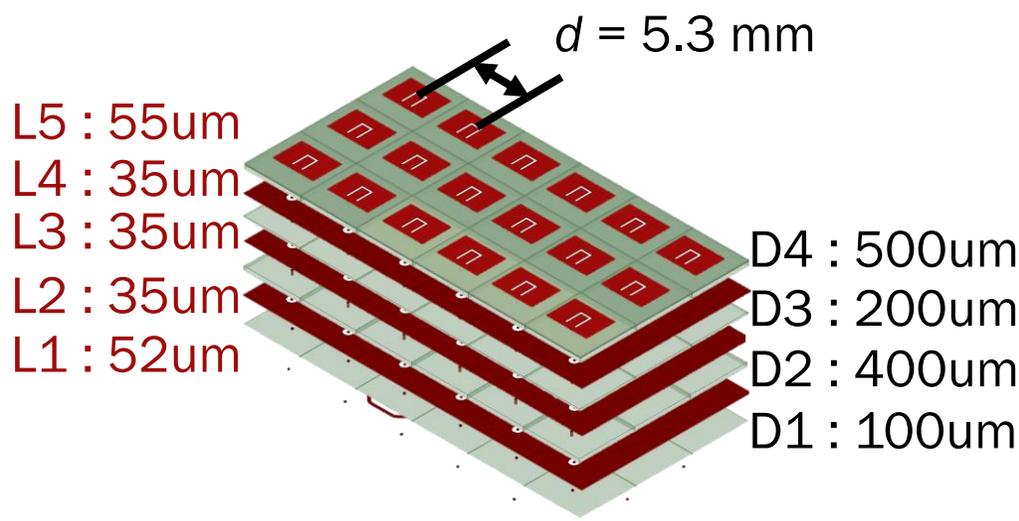
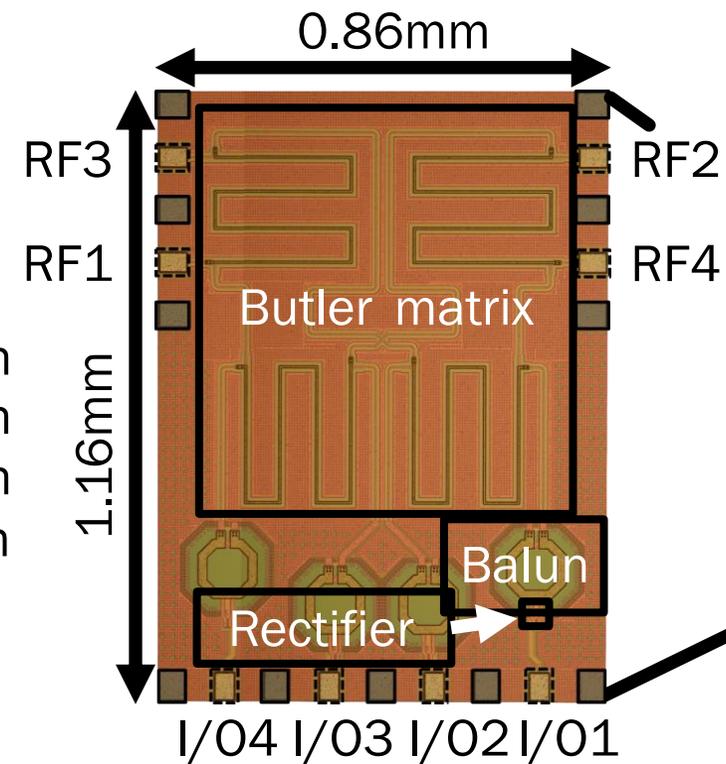
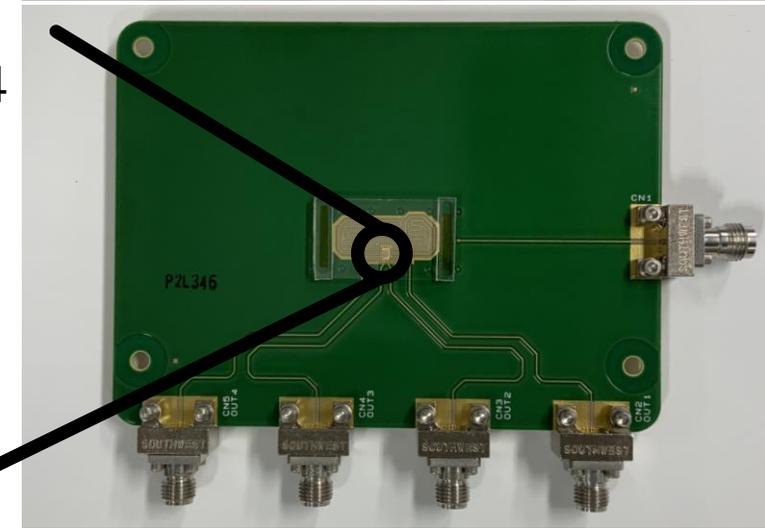
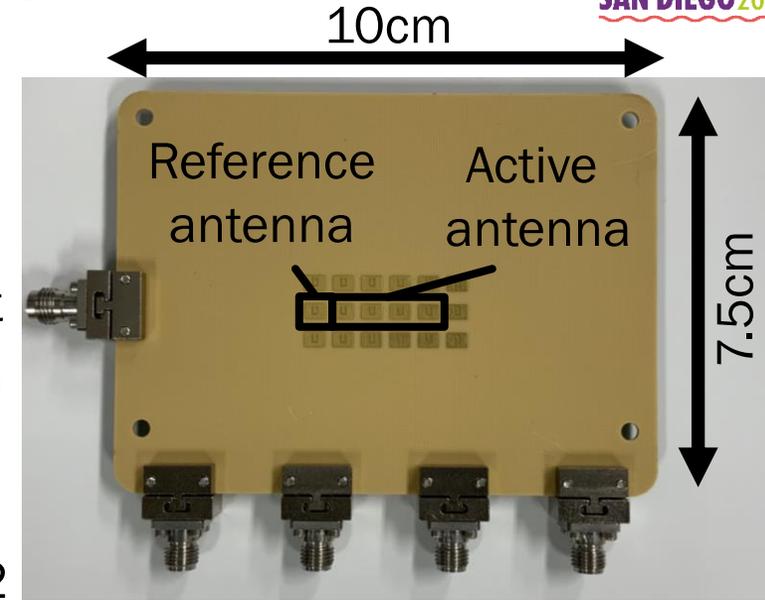
[3] S. Kato, *et al.*, *ESSCIRC*, 2022.

# Implementation

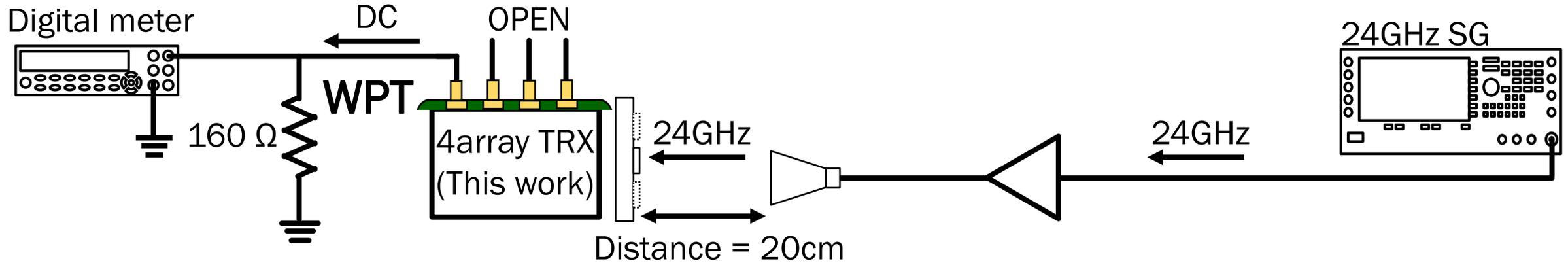
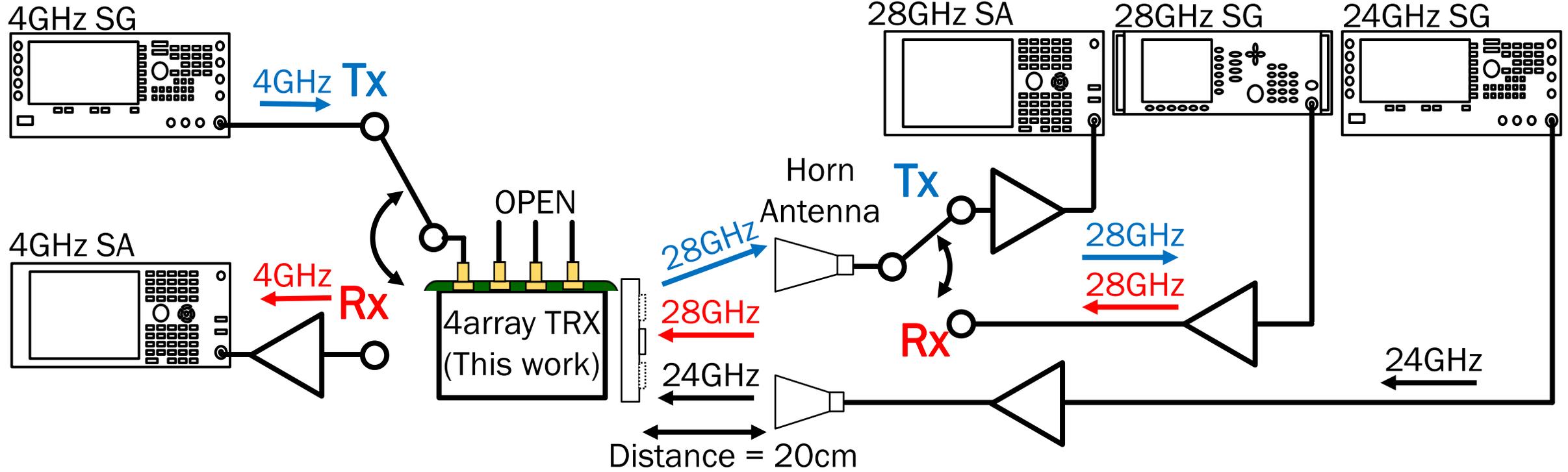
- 4-Element Phased Array
- Technology Process : Si CMOS 65nm
- Substrate : Megtron 6

Reference port

■ : GND PAD

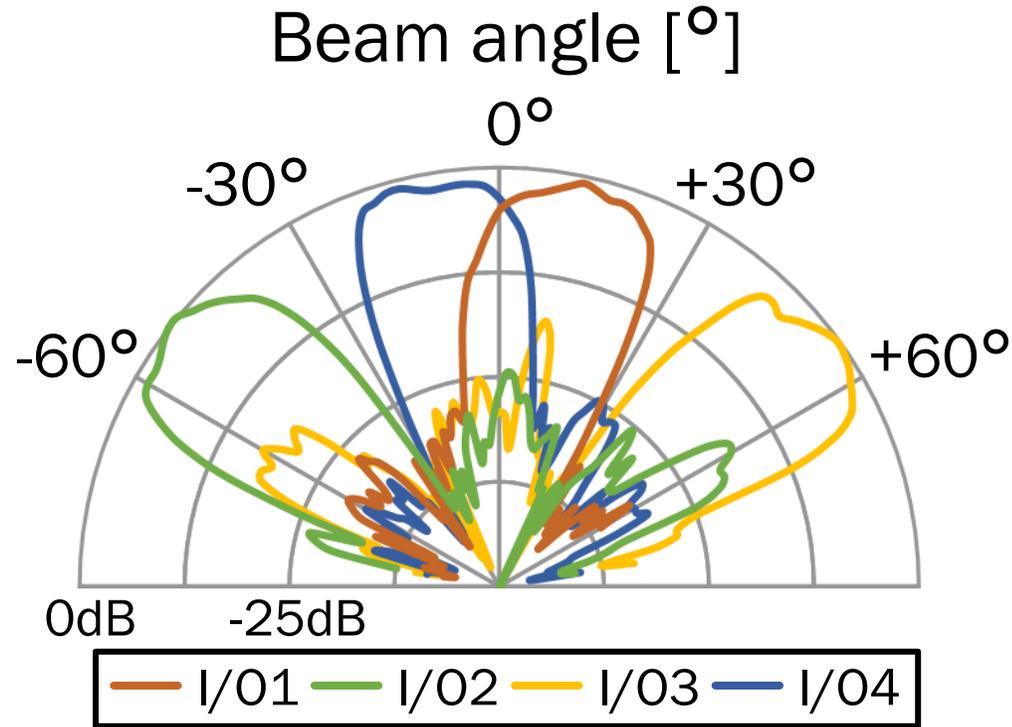


# Implementation : Measurement Setup



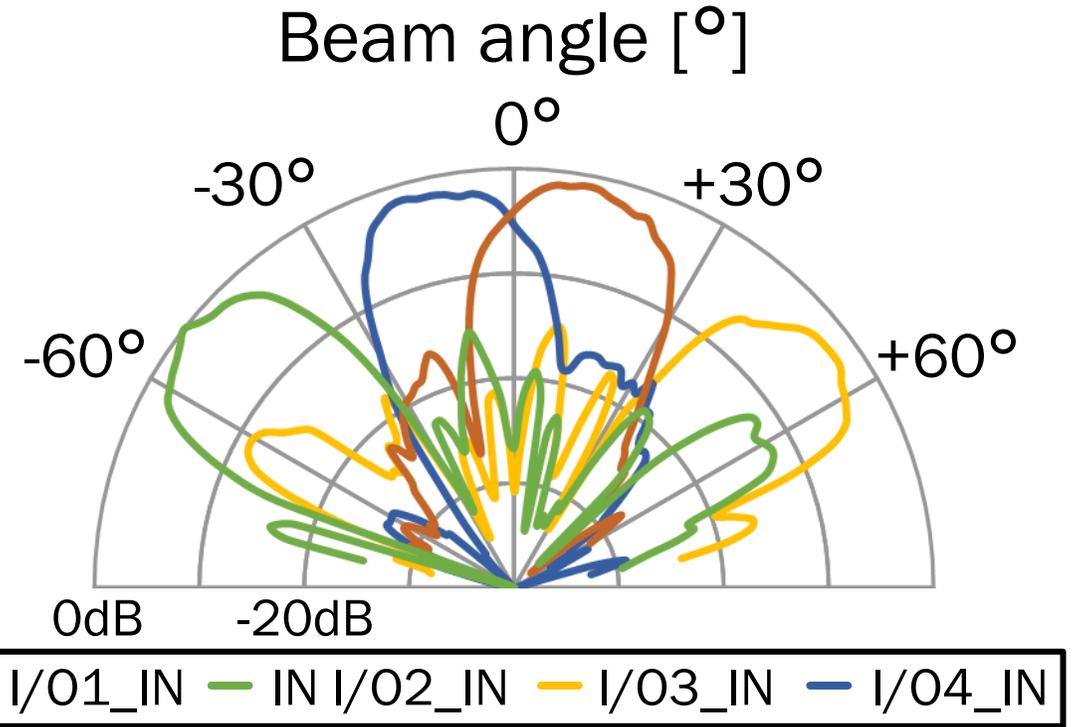
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RX Mode



Normalized Gain [dB]

TX Mode

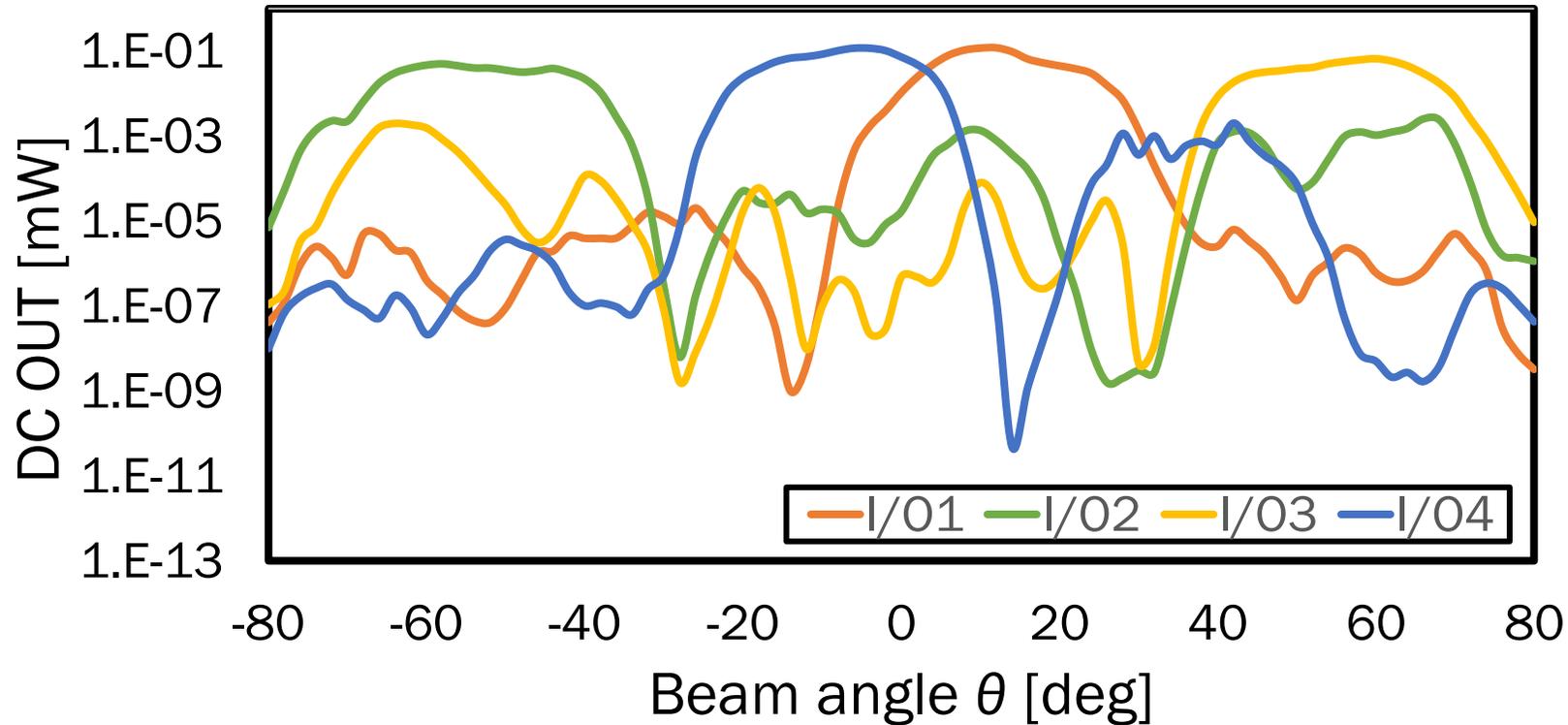


Normalized Gain [dB]

□ The beampattern has beam steering at  $\pm 45^\circ$ ,  $\pm 15^\circ$  for both RX and TX

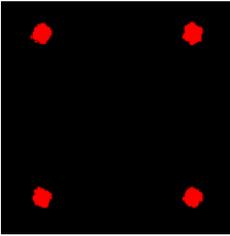
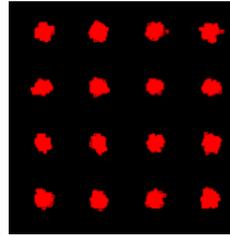
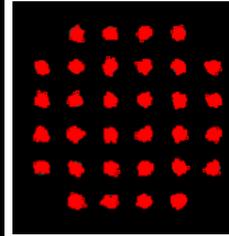
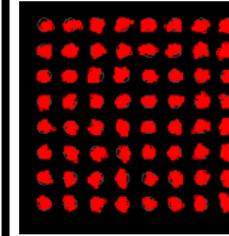
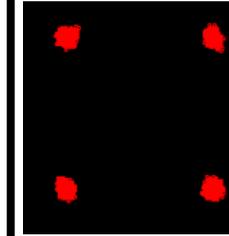
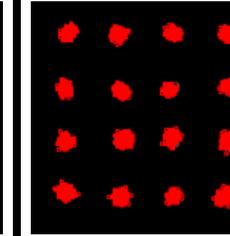
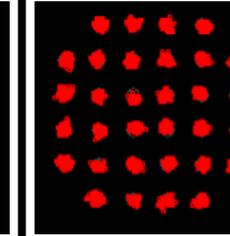
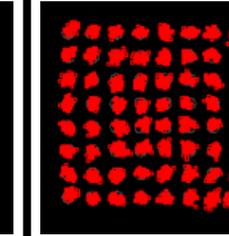
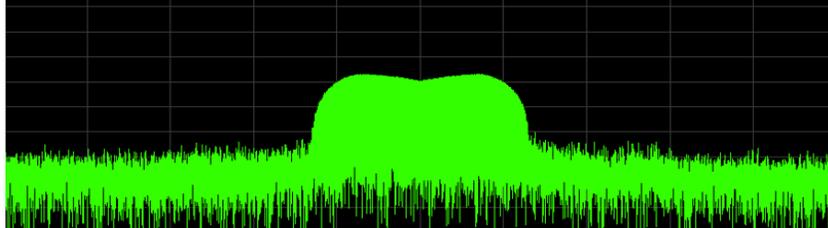
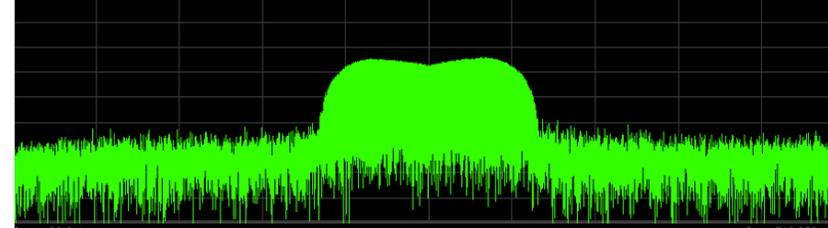
## WPT Mode

\* Input power : 0dBm



- Generate power in the directions of  $\pm 45^\circ$ ,  $\pm 15^\circ$  with a maximum power of 0.12 mW

# OTA Measurement : EVM

	RX Mode				TX Mode			
Modulation	QPSK	16QAM	32QAM	64QAM	QPSK	16QAM	32QAM	64QAM
Constellation								
Bandwidth								
	100MHz				100MHz			
EVM	-30.5 dB	-30.6 dB	-31.8 dB	-31.8 dB	-26.4 dB	-26.1 dB	-27.4 dB	-27.0 dB

# Comparison Table

	This work	JSSC2021[2]	VLSI2022[4]	MTT2016[5]	TMTT 2019 [6]
Frequency	24, 28 GHz	24, 28 GHz	27 - 29GHz	24 GHz	35GHz
Array number	4 × 1	2 × 4	8 × 8	1 × 1	1 × 1
Input Power $P_{in}$	0 dBm	0 dBm	6 dBm	0 dBm	0 dBm
Power Generation	0.12 mW	0.15 mW	0.64 mW	0.080 mW	0.10 mW
PCE@max.	12.2 %	15 %	16 %	8.0 %	10 %
RX Conv. Gain	<b>-12.0 dB</b>	-17.0 dB	-24.0 dB	N/A	N/A
TX Conv. Gain	<b>-21.9 dB</b>	-27.0 dB	-29.7 dB	N/A	N/A
Beam control	<b>Not required</b>	Required	Required	N/A	N/A

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# Conclusion

- ❑ The proposed battery-less relay TRX has beamforming without beam control
- ❑ It can generate DC power from WPT as well as up/down conversion of frequency.
- ❑ The proposed TRX can contribute significantly to the expansion of 5G coverage

# Acknowledgment

This work is partially supported by the MIC/SCOPE (#192203002, #192103003), JSPS (JP20H00236), MIC (JPJ000254), NICT(00601), STAR, and VDEC in collaboration with Cadence Design Systems, Inc., Mentor Graphics, Inc., and Keysight Technologies Japan, Ltd.

- [1] L. Wei, et al., "Key Elements to Enable Millimeter Wave Communications for 5G Wireless Systems," *IEEE Wireless Communications*, Vol. 21, No. 6, pp. 136-143, Dec. 2014.
- [2] M. Ide, A. Shirane, K. Yanagisawa, D. You, J. Pang and K. Okada, "A 28-GHz Phased-Array Relay Transceiver for 5G Network Using Vector Summing Backscatter with 24-GHz Wireless Power and LO Transfer," *IEEE Journal of Solid-State Circuits*, Vol. 57, No. 4, Apr.
- [3] S. Kato, K. Yuasa, M. Ide, A. Shirane, K. Okada, "A CMOS Full-Wave Switching Rectifier with Frequency Up-Down Conversion for 5G NR Wirelessly-Powered Relay Transceivers," *IEEE European Solid State Circuits Conference*, Sep. 2022.
- [4] M. Ide, A. Shirane, K. Yanagisawa, D. You, J. Pang and K. Okada, "A 28-GHz Fully-Passive Retro-Reflective Phased Array Backscattering Transceiver for 5G Network with 24-GHz Beam-Steered Wireless Power Transfer," *IEEE Symposium on VLSI Circuits*, 2022, pp. 1-2.
- [5] A. Collado and A. Georgiadis, "24 GHz substrate integrated waveguide (SIW) rectenna for energy harvesting and wireless power transmission," *IEEE MTT-S Int. Microw. Symp. Dig.*, Seattle, WA, Jun. 2013.
- [6] P. Burasa, et al., "High-Data-Rate Single-Chip Battery-Free Active Millimeter-Wave Identification Tag in 65-nm CMOS Technology," *IEEE Trans. Microwave Theory and Techniques (TMTT)*, vol. 64, no. 7, pp. 2294-2303, July 2016.