A 28-GHz Active Bidirectional Vector Modulator With Impedance-Invariant Variable Gain Amplifier

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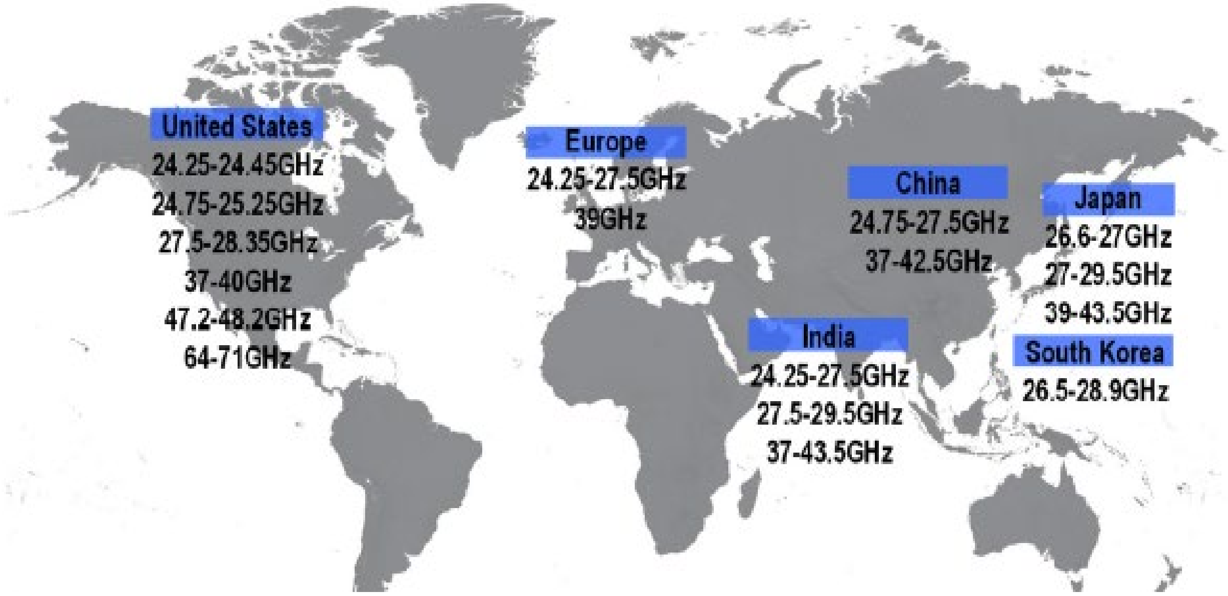
Introduction

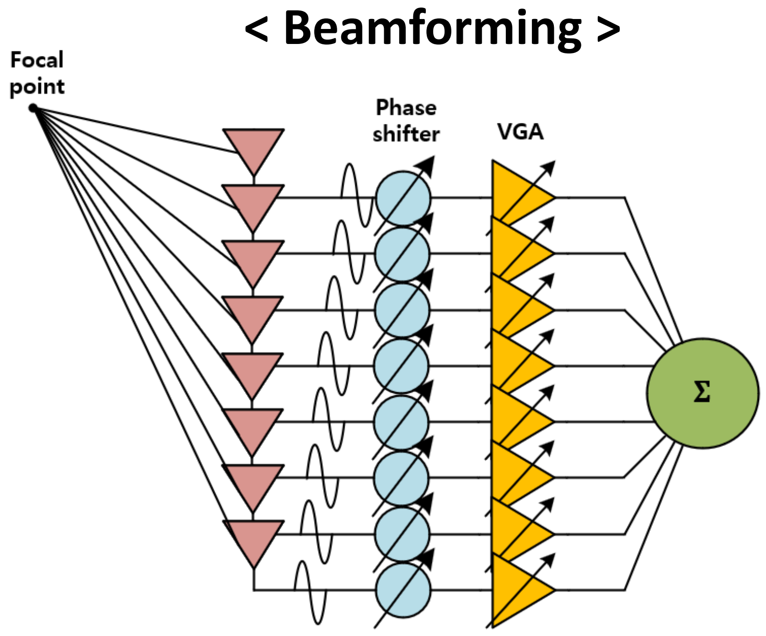
- **Increasing demand of mm-Wave 5G for high-speed communication**
  - **Gb/s communication, wireless backhaul, AR/VR, automotive radar, etc.**
  - **Broad/multiband 5G systems required for international/cross-network roaming**

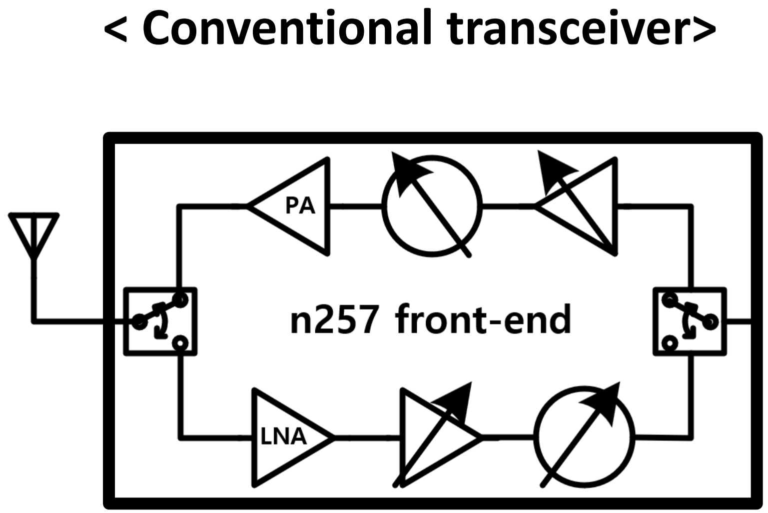


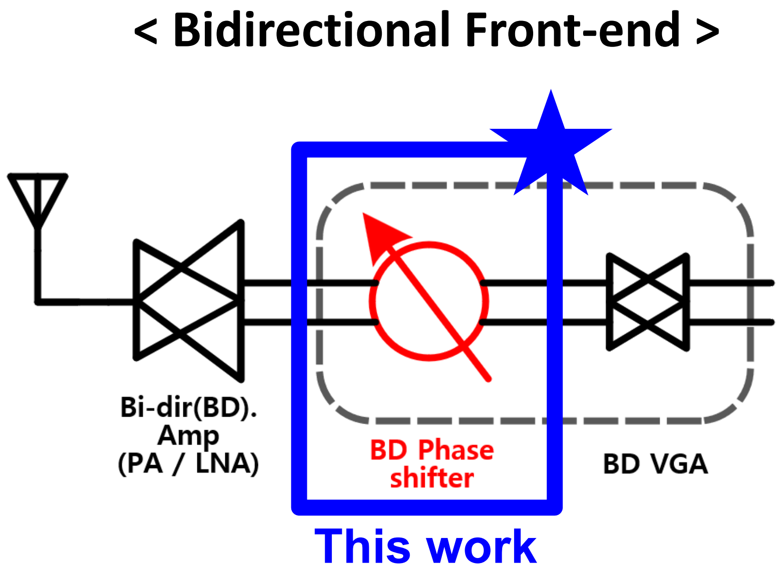
[Global update on 5G spectrum, Qualcomm, Nov.2019]

5G NR FR2	Frequency
n257	26.5 – 29.5 GHz
n258	24.25 – 27.5 GHz
n259	39.5 – 43.5 GHz
n260	37 – 40 GHz
n261	27.5 – 28.35 GHz
n262	47.2 – 48.2 GHz

5G RF front-end architecture

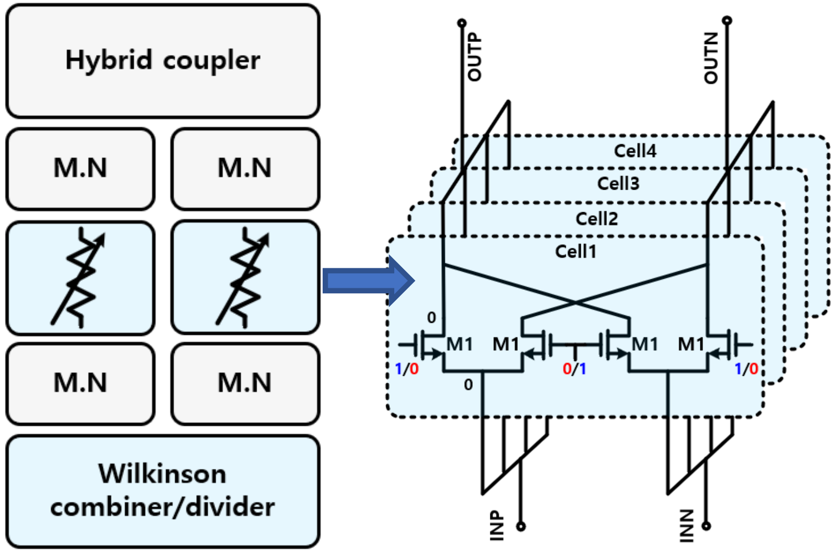
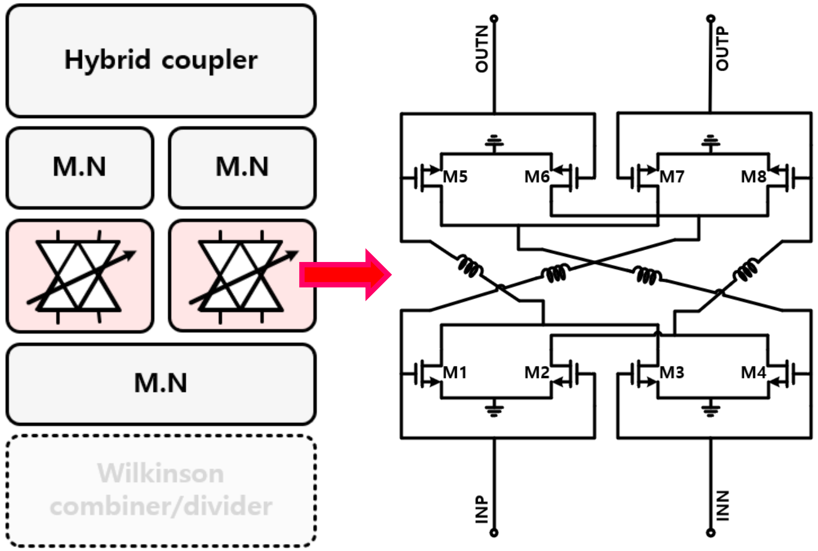




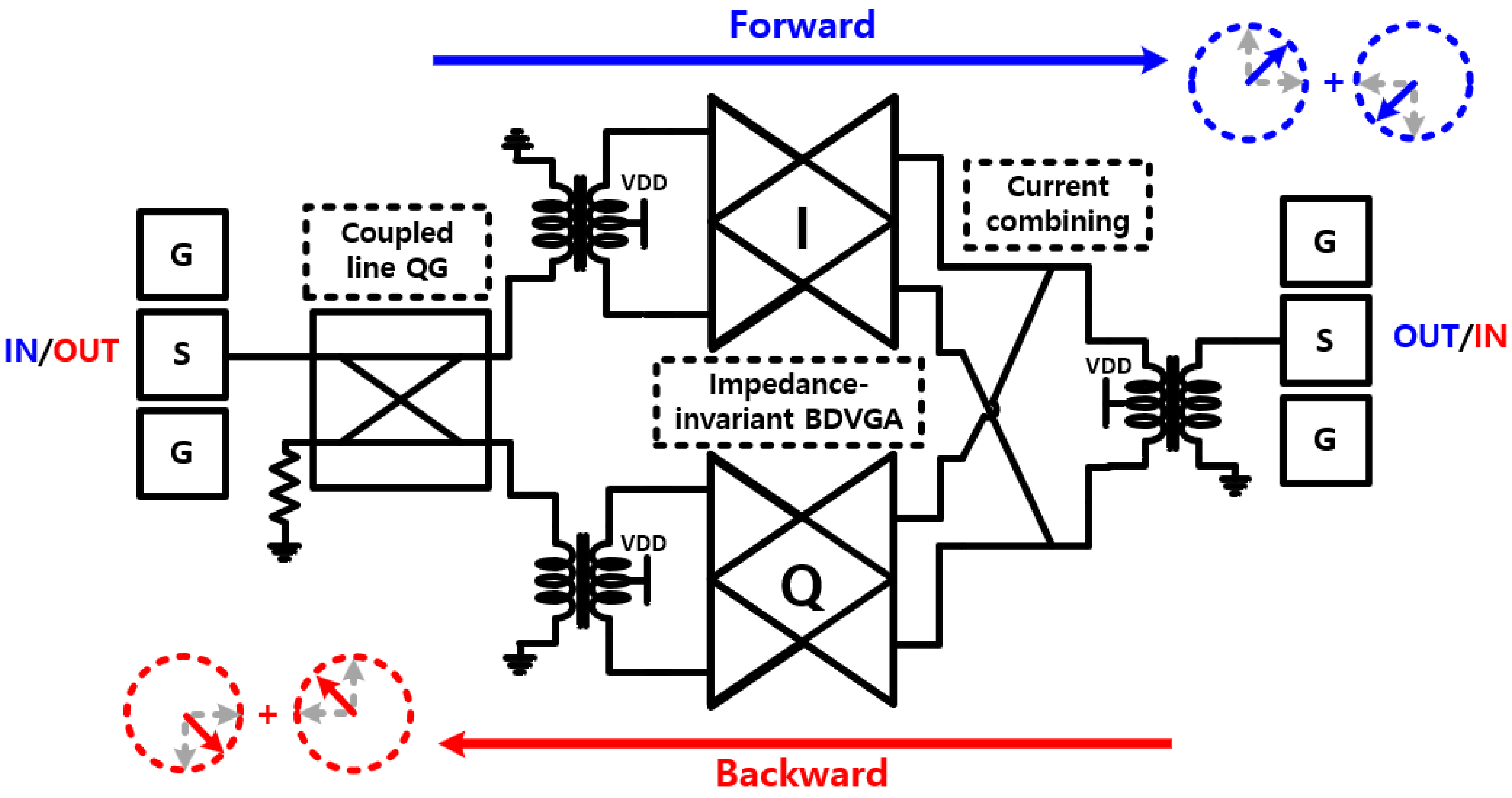


- Compact and high integration for limited form factor
- Design difficulties to get relatively high performance

Advantages of active bidirectional vector modulator

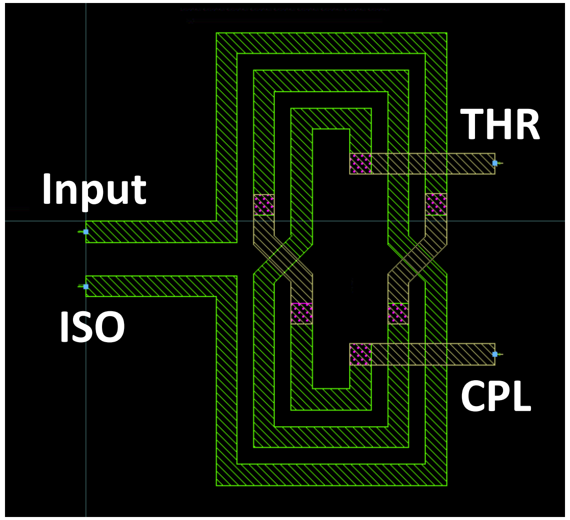
	Switched-type attenuator	Bidirectional VGA
Schematic	 [2021 TCAS-I]	 [Proposed Idea]
Pros	• Small impedance variation • Zero power consumption	• High reverse isolation • High gain
Cons	• Low reverse isolation • High insertion loss (< -15dB)	• Impedance variation • Power consumption

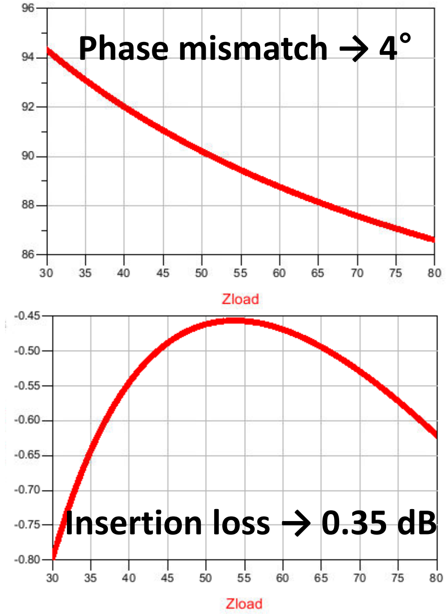
Proposed active bidirectional vector modulator



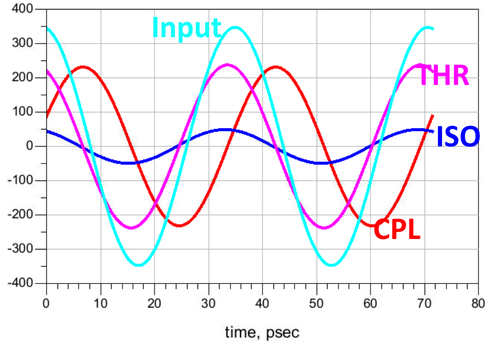
Coupled line IQ generator

- **Layout of coupled line IQ generator**
  (Z_{load} variation sensitivity)

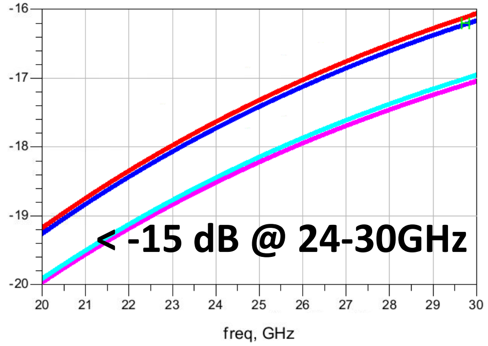




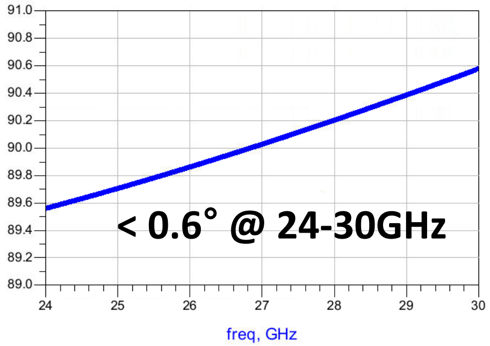
< Input / ISO / THR / CPL signal >



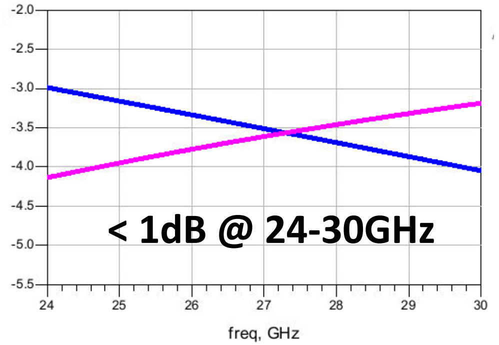
< Return loss >



< Phase mismatch >

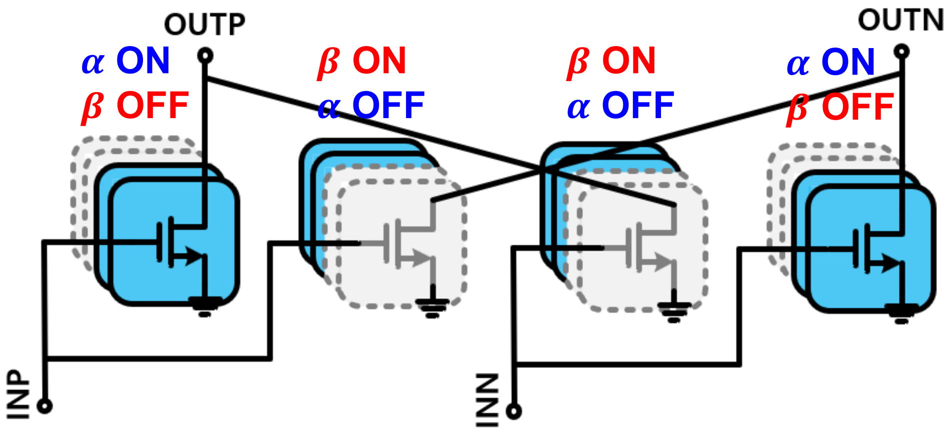


< Amp. mismatch >



Impedance-invariant vector modulation

- **Unit array of CS structure**

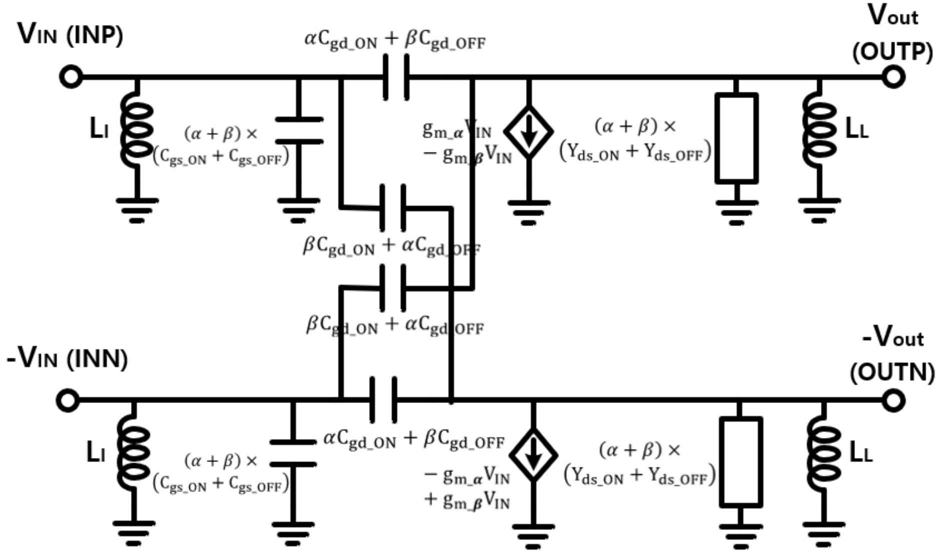


➢ **Total tr :** $2(\alpha+\beta)\times 2$

➢ **Gain determined by** $(\alpha-\beta)$

➢ $\alpha+\beta$ **is constant value, impedance is invariant in every gain state**

- **Small-signal model**



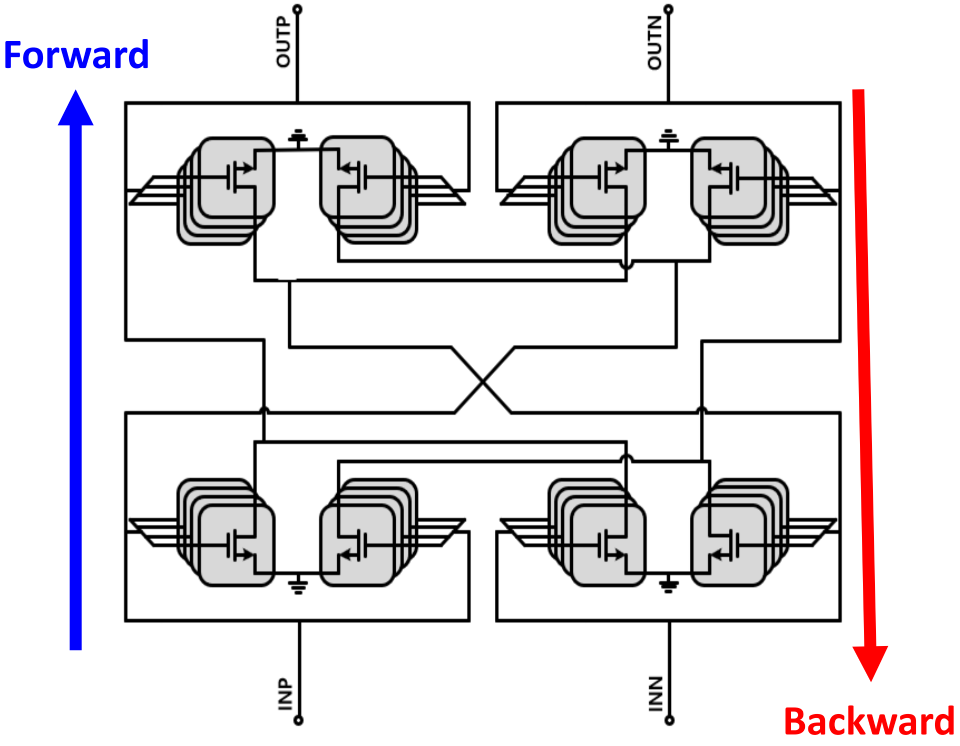
- $$A_V=\frac{-\left(g_{m\_\alpha}-g_{m_\beta}-s(\alpha-\beta)\left(C_{gd_{ON}}-C_{gd_{OFF}}\right)\right)}{s(\alpha+\beta)\left(C_{gd\_ON}+C_{gd\_OFF}+\frac{1}{s}Y_{ds\_ON}+\frac{1}{s}Y_{ds\_OFF}\right)+\frac{1}{sL_L}}\approx\frac{-(\alpha-\beta)g_{m0}}{Y_{out}}$$

- $$Y_{out}\approx(\alpha+\beta)\left(sC_{gd\_on}+sC_{gd\_off}+Y_{ds\_on}+Y_{ds\_off}\right)+\frac{1}{sL_L}$$

- $$Y_{in}\approx(\alpha+\beta)\left(sC_{gs\_on}+sC_{gs\_off}+sC_{gd\_on}+sC_{gd\_off}\right)+\frac{1}{sL_I}$$

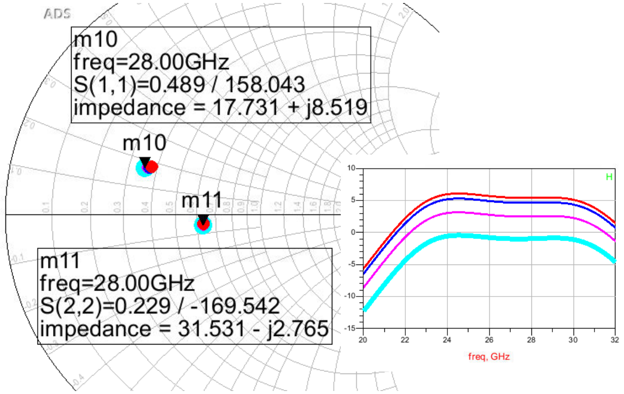
EM simulation results of BD VGA

- **Schematic of BDVGA**

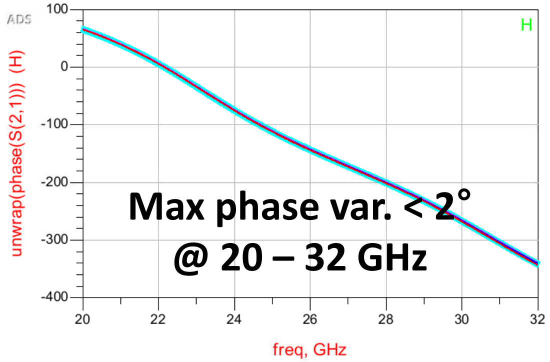


- ➢ **Core size : 160um x 280um**
- ➢ **Power consumption : 5.7mW**

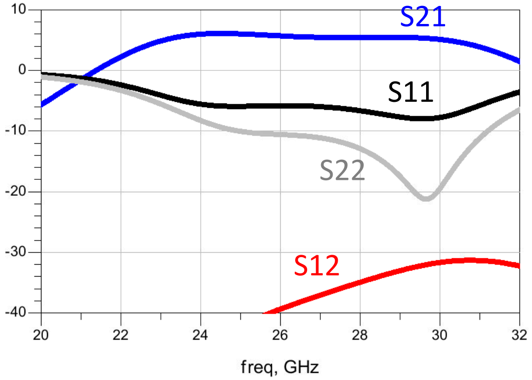
< S11, S22 variation>



< Phase variation >

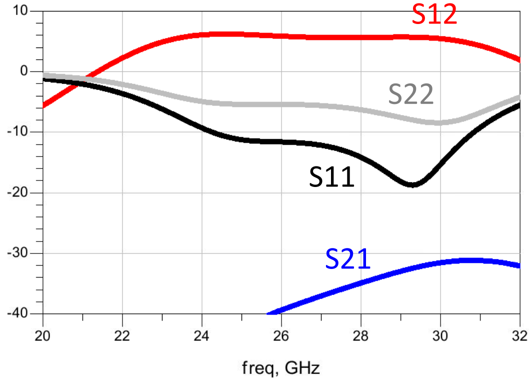


< Forward >



Max. gain : 6dB
3dB BW : 22-31GHz

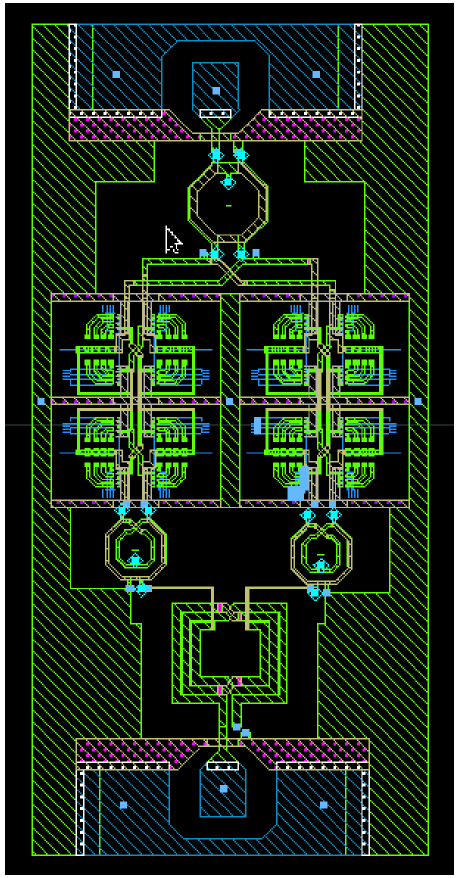
< Backward >



Max. gain : 6.1dB
3dB BW : 22-31GHz

Performance of active BDVM

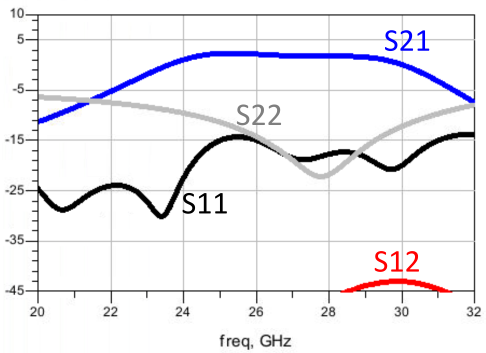
- **Layout of the active BDVM**



- ➢ **Core size : 750um x 400um**
- ➢ **Max Pdc : 11.4 mW**

S-parameters

< Forward >



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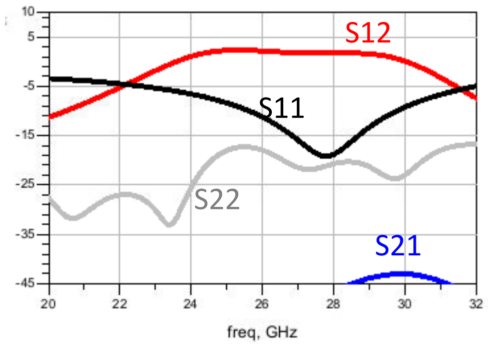
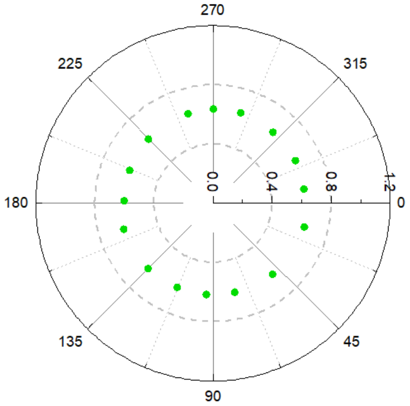


Phase constellation

< Forward >



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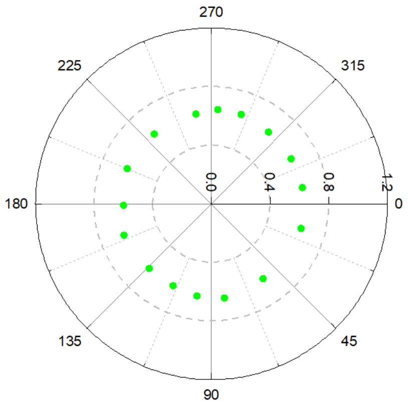


	Simulation results	
Technology	28nm CMOS	
Frequency (GHz)	28	
Max gain (dB)	*TX	*RX
	3.1	2.5
RMS phase error (deg.)	1.83	2.04
Power consumption (mW)	11.4	
Core size (mm^2)	0.3	

*Tx : Forward operation / Rx : Backward operation

Summary

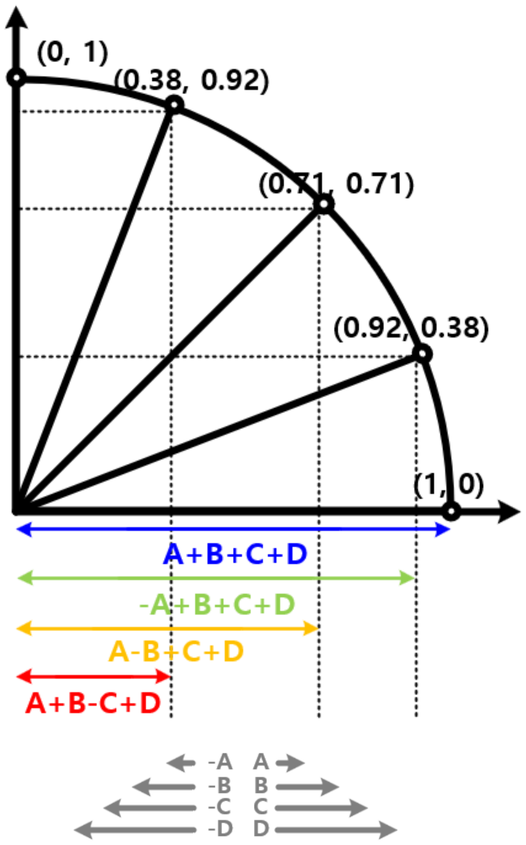
- Introduced 28 GHz active bidirectional vector modulator for bidirectional phased-array transceiver using 28nm bulk CMOS process

- Achieved bidirectional, low insertion loss performance
  - Coupled-line coupler (I/Q generator)
  - Impedance-invariant bidirectional VGA (Switchless bidirectional operation)

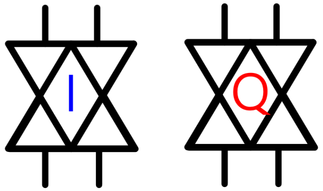
APPENDIX

Appendix A

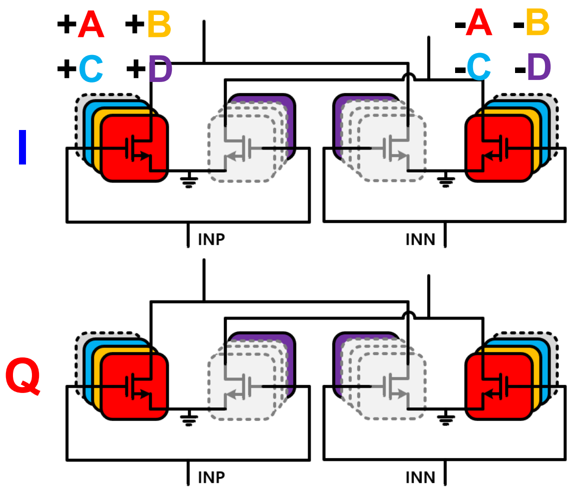
- **Conceptual diagram of phase control**



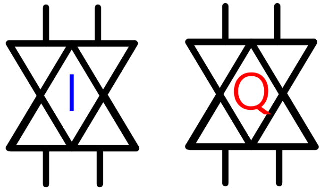
- **0° (0, 0)**



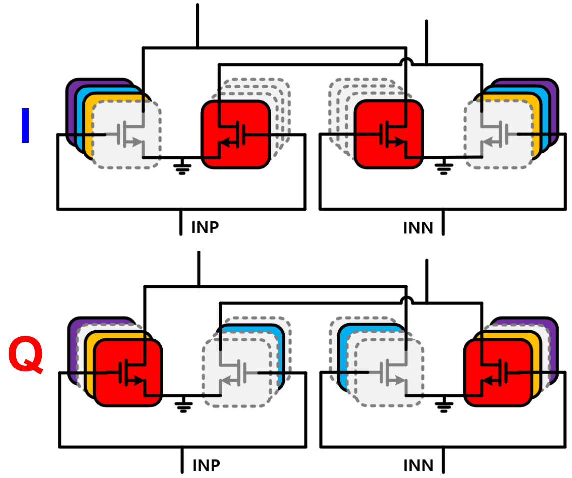
$A + B + C - D$ $A + B + C - D$



- **22.5° (0.92, 0.38)**



$-A + B + C + D$ $A + B - C + D$



References

[1] E. -T. Sung, C. So and S. Hong, "A 60-GHz Variable-Gain Phase Shifter With Particular-Sized Digital-RF Cells," in IEEE Transactions on Microwave Theory and Techniques, vol. 70, no. 2, pp. 1302-1313, Feb. 2022.

[2] T. -W. Li, J. S. Park and H. Wang, "A 2–24-GHz 360° Full-Span Differential Vector Modulator Phase Rotator With Transformer-Based Poly-Phase Quadrature Network," in IEEE Transactions on Very Large Scale Integration (VLSI) Systems, vol. 28, no. 12, pp. 2623-2635, Dec. 2020.

[3] W. Zhu et al., “A 21 to 30-GHz Merged Digital-Controlled High Resolution Phase Shifter-Programmable Gain Amplifier with Orthogonal Phase and Gain Control for 5-G Phase Array Application,” 2019 IEEE Radio Frequency Integrated Circuits Symposium (RFIC), 2019, pp. 67-70.

[4] A. Sethi, R. Akbar, M. Hietanen, T. Rahkonen and A. Pärssinen, "A 26GHz to 34GHz Active Phase Shifter with Tunable Polyphase Filter for 5G Wireless Systems," 2021 16th European Microwave Integrated Circuits Conference (EuMIC), 2022, pp. 301-304.

[5] S. Londhe and E. Socher, "28–38-GHz 6-bit Compact Passive Phase Shifter in 130-nm CMOS," in IEEE Microwave and Wireless Components Letters, vol. 31, no. 12, pp. 1311-1314, Dec. 2021.

[6] P. Gu, D. Zhao and X. You, "Analysis and Design of a CMOS Bidirectional Passive Vector-Modulated Phase Shifter," in IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 68, no. 4, pp. 1398-1408, April 2021.

[7] W. Y. Li, L. Wang, Y. J. Cheng and Y. Fan, "Design of Ku-Band Bi-Directional Wideband Active Phase Shifter Using Reconfigurable Network," 2021 International Conference on Microwave and Millimeter Wave Technology (ICMMT), 2021, pp. 1-3.

[8] G. H. Park, C. W. Byeon and C. S. Park, "A 60-GHz Low-Power Active Phase Shifter With Impedance-Invariant Vector Modulation in 65-nm CMOS," in IEEE Transactions on Microwave Theory and Techniques, vol. 68, no. 12, pp. 5395-5407, Dec. 2020.