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

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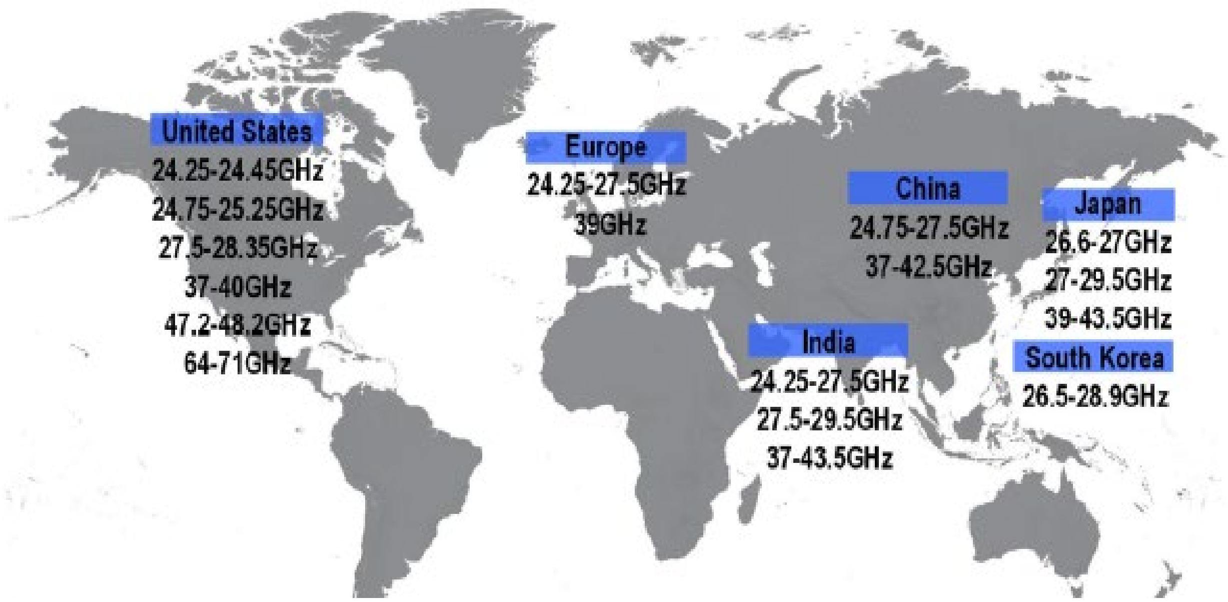
Contents

Introduction

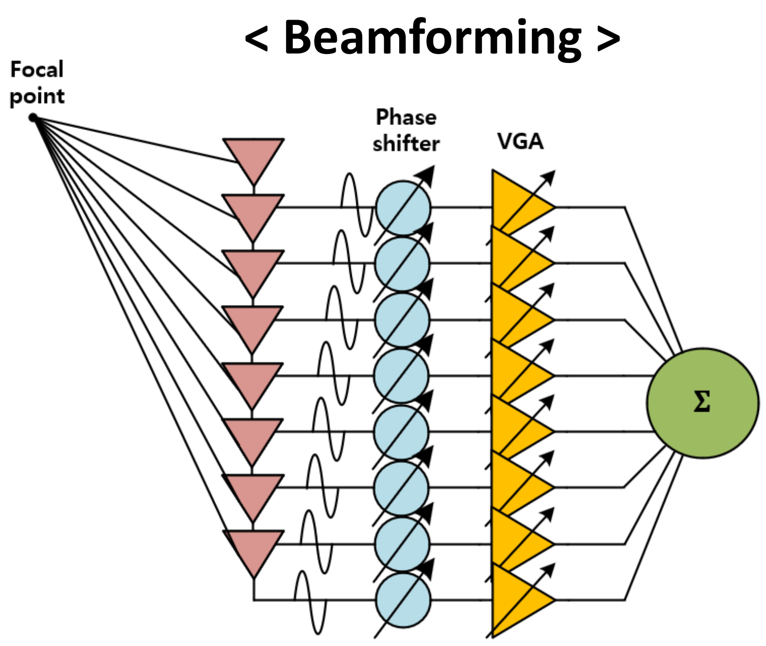
- **Increasing demand of mm-Wave 5G for high-speed communication**
  - **Gb/s communication, wireless backhaul, AR/VR, automotive radar, etc.**
  - **Broad/multiband 5G systems required for international/cross-network roaming**

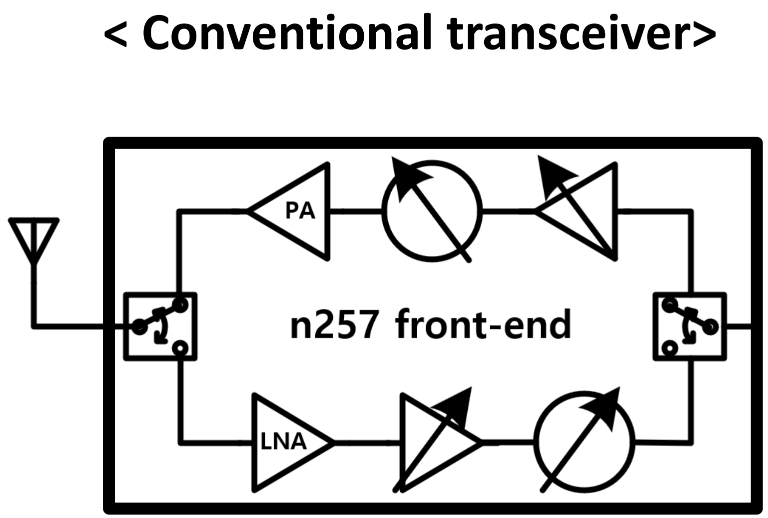


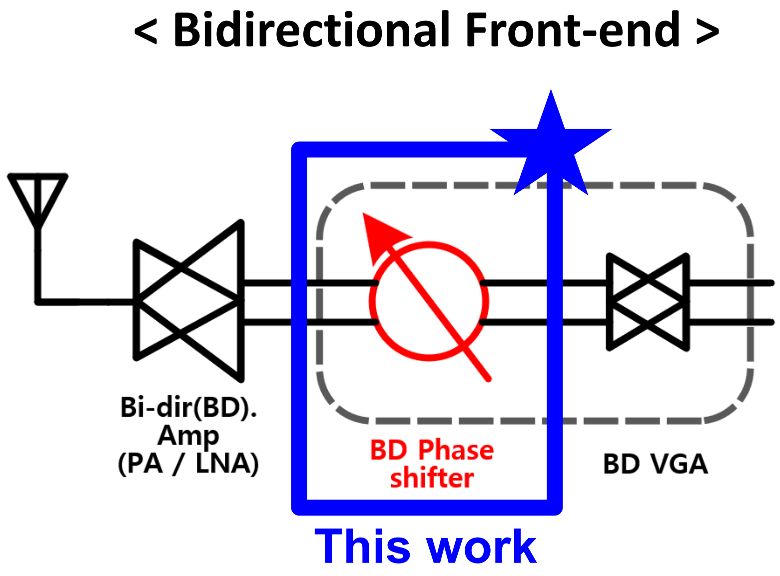
[Global update on 5G spectrum, Qualcomm, Nov.2019]

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



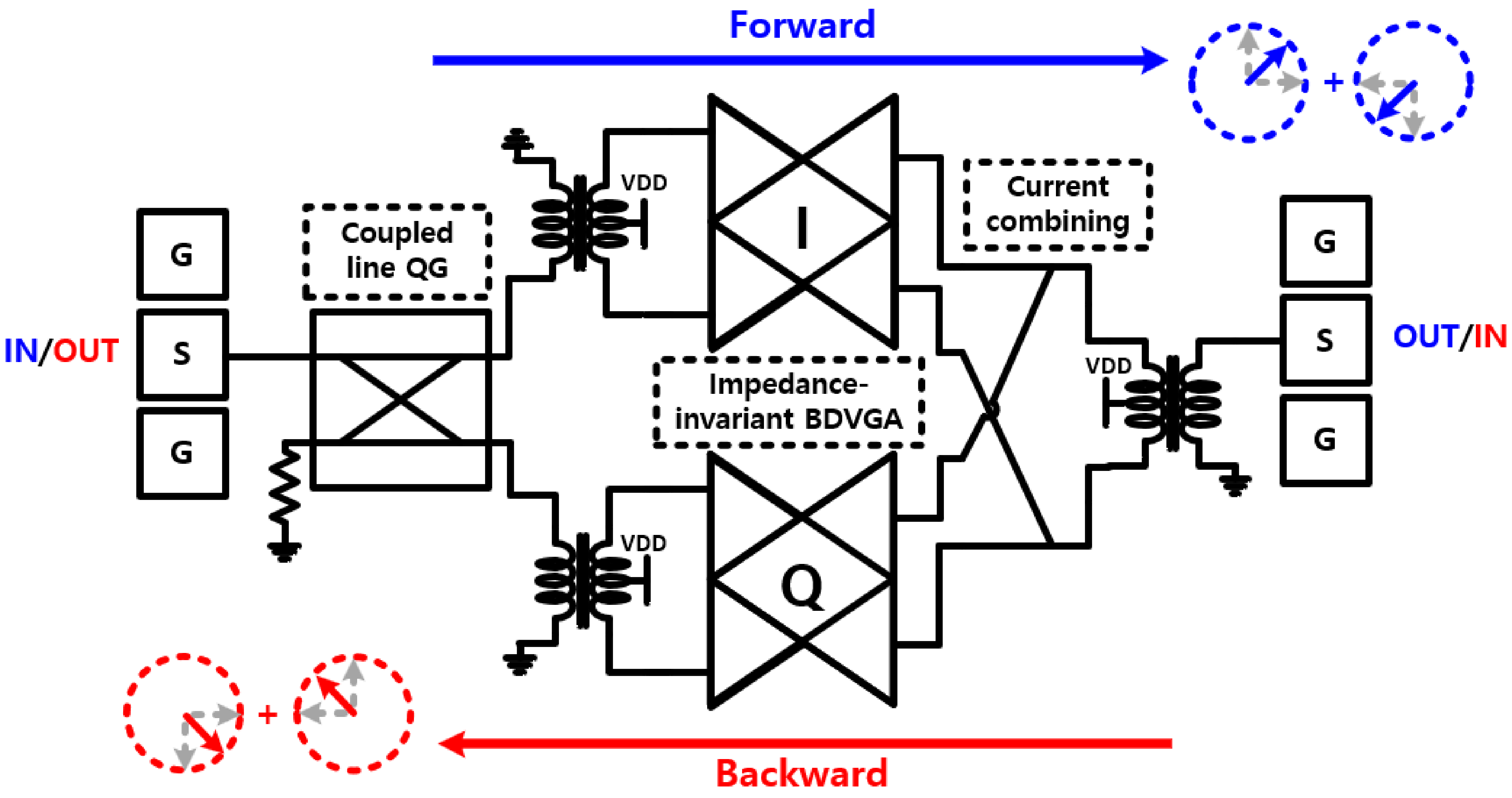




- Compact and high integration for limited form factor
- Design difficulties to get relatively high performance

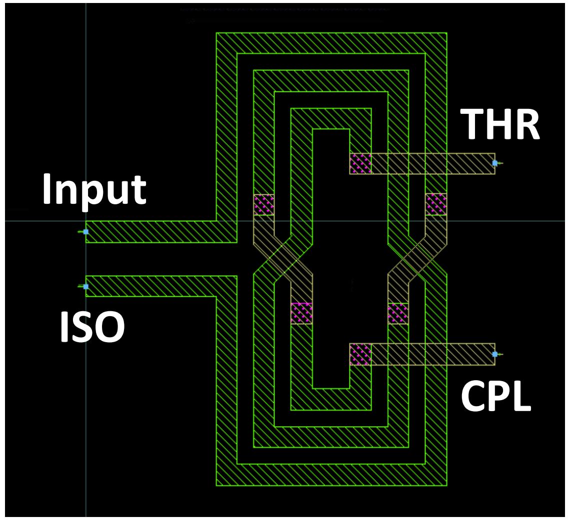
	Switched-type attenuator	Bidirectional VGA
Schematic		
Pros		

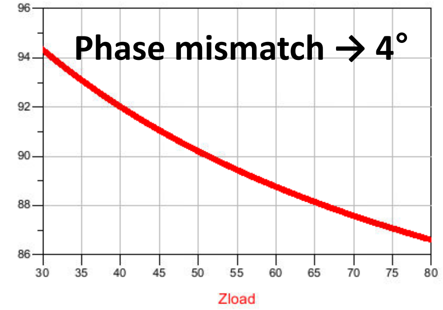
Proposed active bidirectional vector modulator



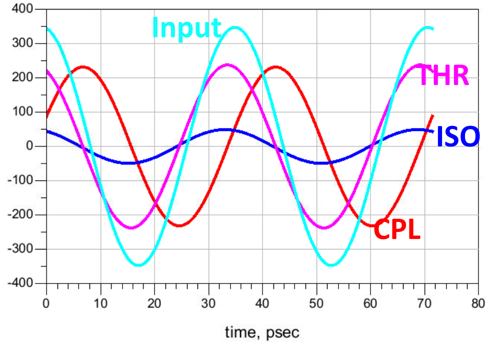
Coupled line IQ generator

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

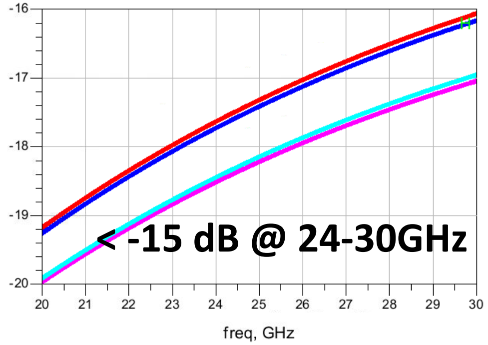




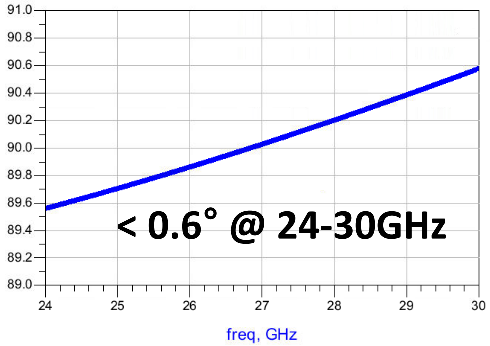
< Input / ISO / THR / CPL signal >



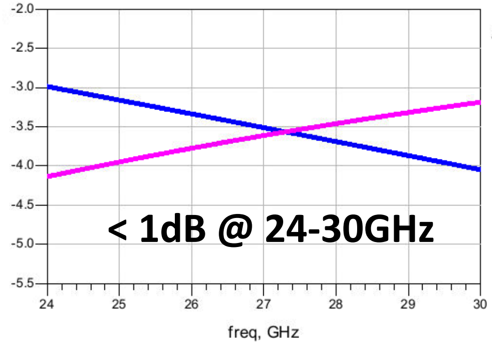
< Return loss >



< Phase mismatch >

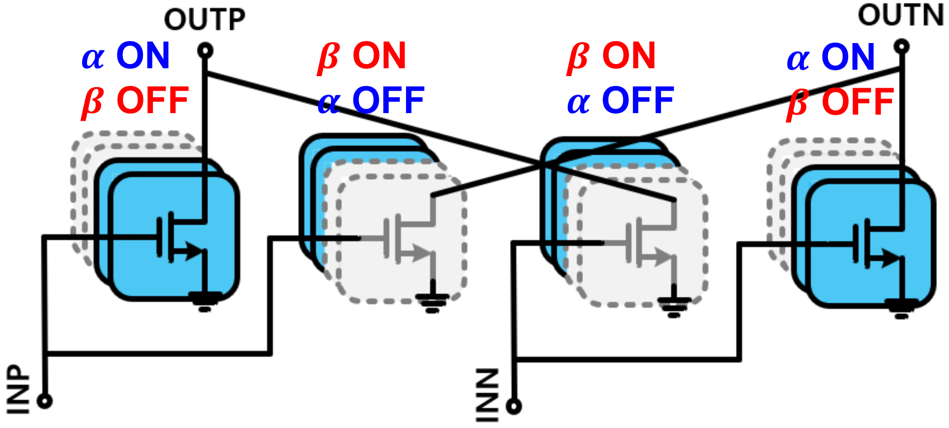


< Amp. mismatch >



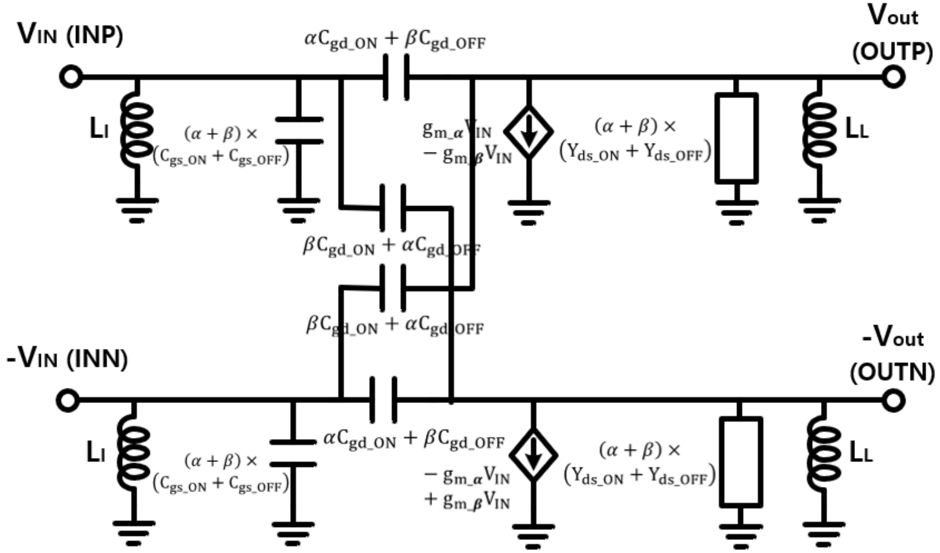
Impedance-invariant vector modulation

- **Unit array of CS structure**



➢ **Total tr :** $2(\boldsymbol{\alpha}+\boldsymbol{\beta})\times\mathbf{2}$

- **Small-signal model**



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

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

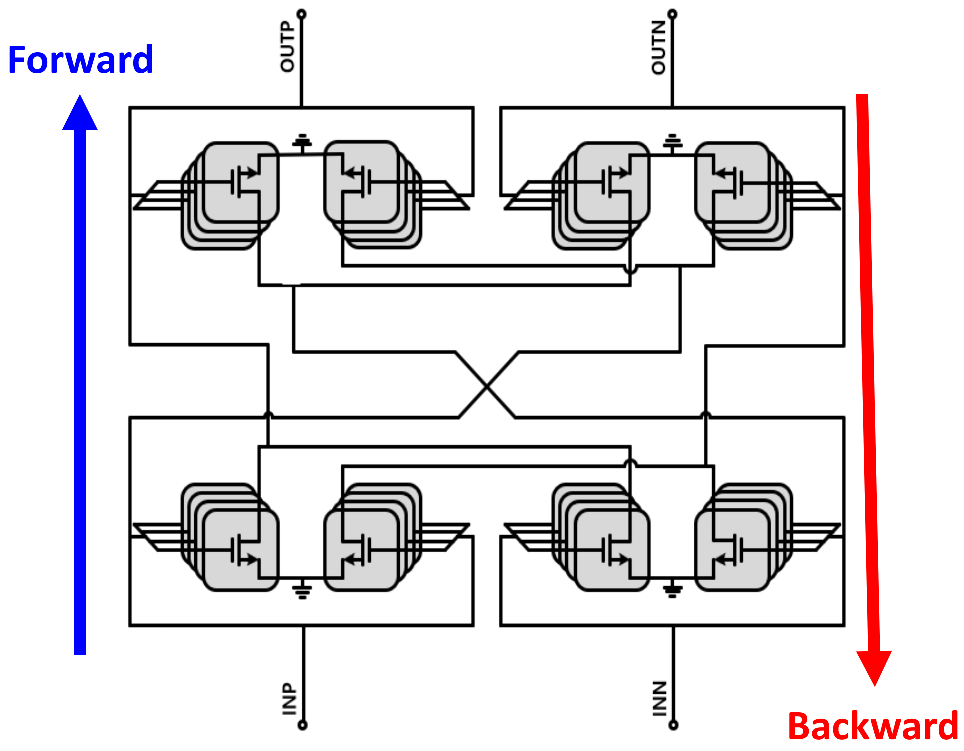
- $$A_v=\frac{-\left(g_{m\_\alpha}-g_{m_\beta}-s(\alpha-\beta)\left(C_{gd_{ON}}-C_{gd_{OFF}}\right)\right)}{s(\alpha+\beta)\left(C_{gd\_ON}+C_{gd\_OFF}+\frac{1}{s}Y_{ds\_ON}+\frac{1}{s}Y_{ds\_OFF}\right)+\frac{1}{sL_L}}\approx\frac{-(\alpha-\beta)g_{m0}}{Y_{out}}$$

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

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

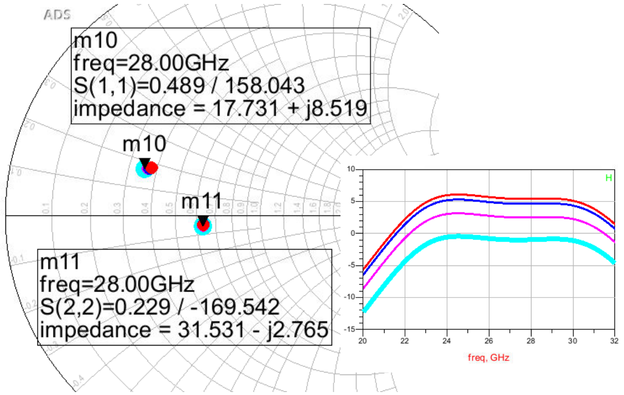
EM simulation results of BD VGA

- Schematic of BDVGA

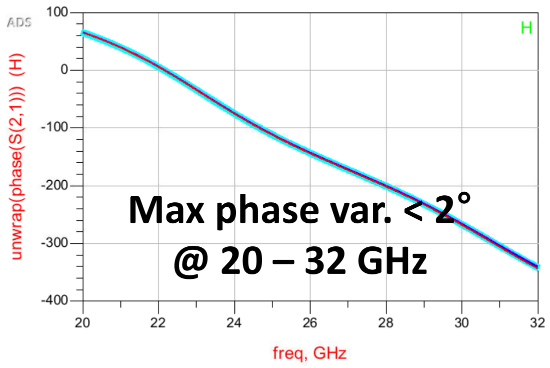


- Core size : 160um x 280um
- Power consumption : 5.7mW

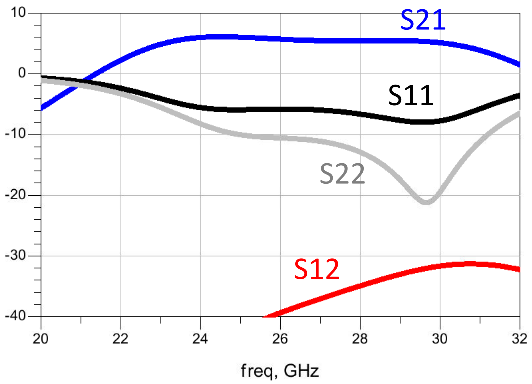
< S11, S22 variation>



< Phase variation >

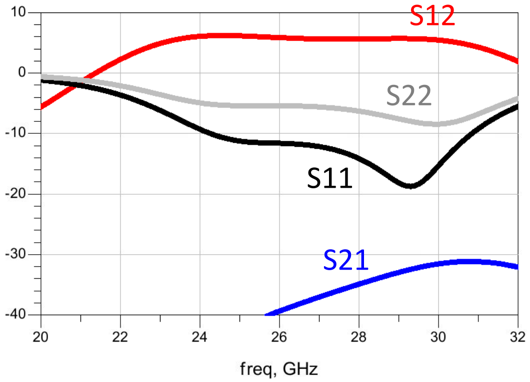


< Forward >



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

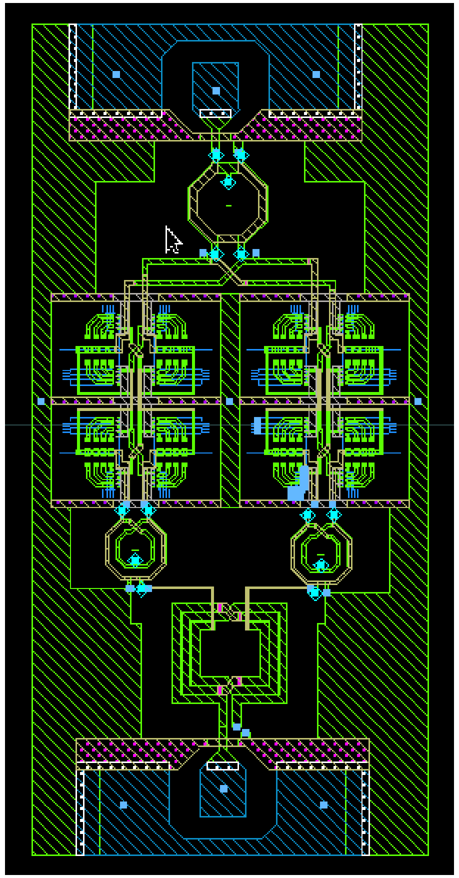
< Backward >



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

Performance of active BDVM

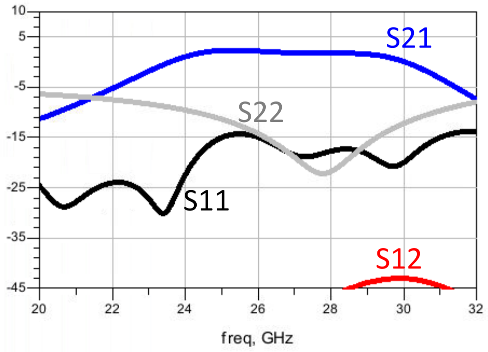
▪ Layout of the active BDVM



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

S-parameters

< Forward >



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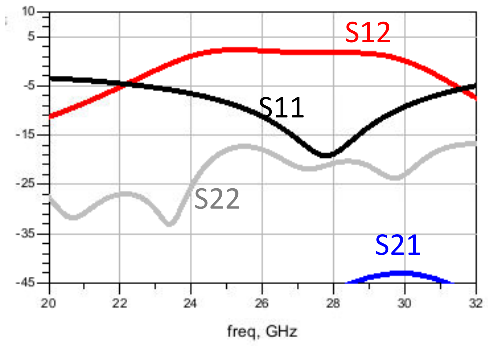

Phase constellation

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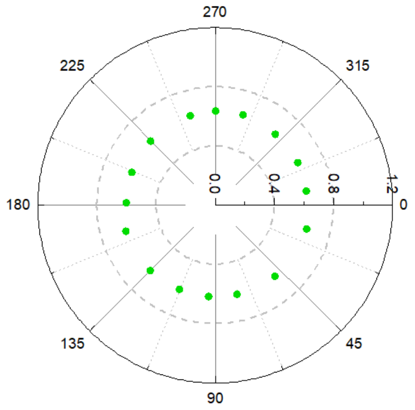

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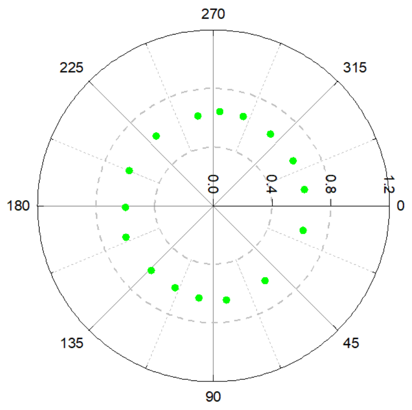


	Simulation results	
Technology	28nm CMOS	
Frequency (GHz)	28	
Max gain (dB)	*TX	*RX
	3.1	2.5
RMS phase error (deg.)	1.83	2.04
Power consumption (mW)	11.4	
Core size (mm^2)	0.3	

*Tx : Forward operation / Rx : Backward operation

Summary

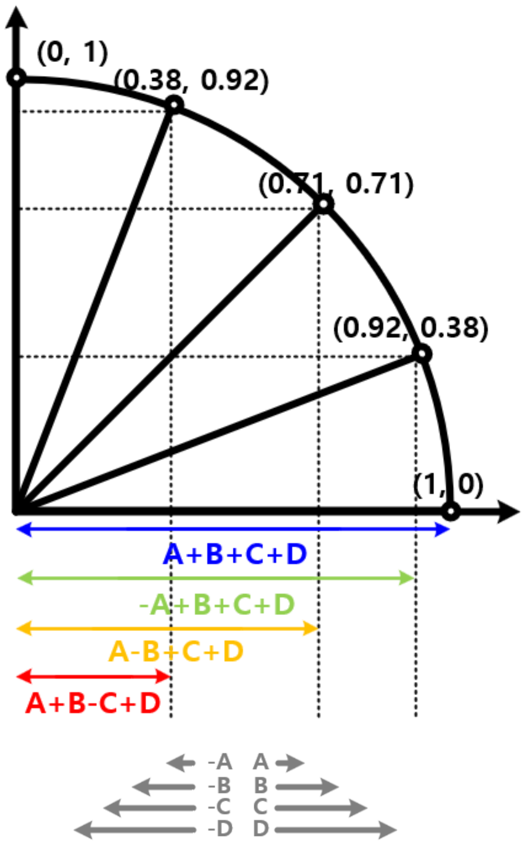
- Introduced 28 GHz active bidirectional vector modulator for bidirectional phased-array transceiver using 28nm bulk CMOS process

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

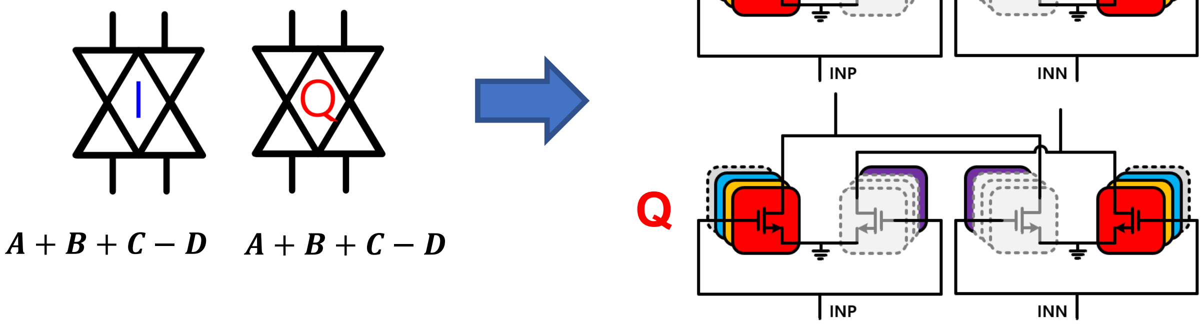
APPENDIX

Appendix A

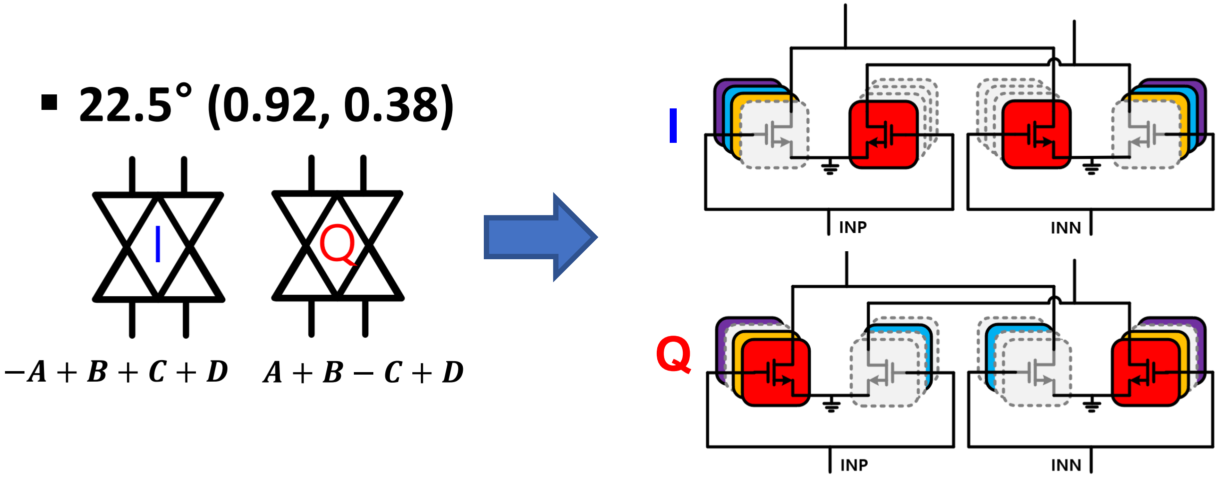
- **Conceptual diagram of phase control**



- **0° (0, 0)**



- **22.5° (0.92, 0.38)**



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