WE2C-5

Reconfigurable Hybrid Asymmetrical Load Modulated Balanced Amplifier with High Linearity, Wide Bandwidth, and Load Insensitivity

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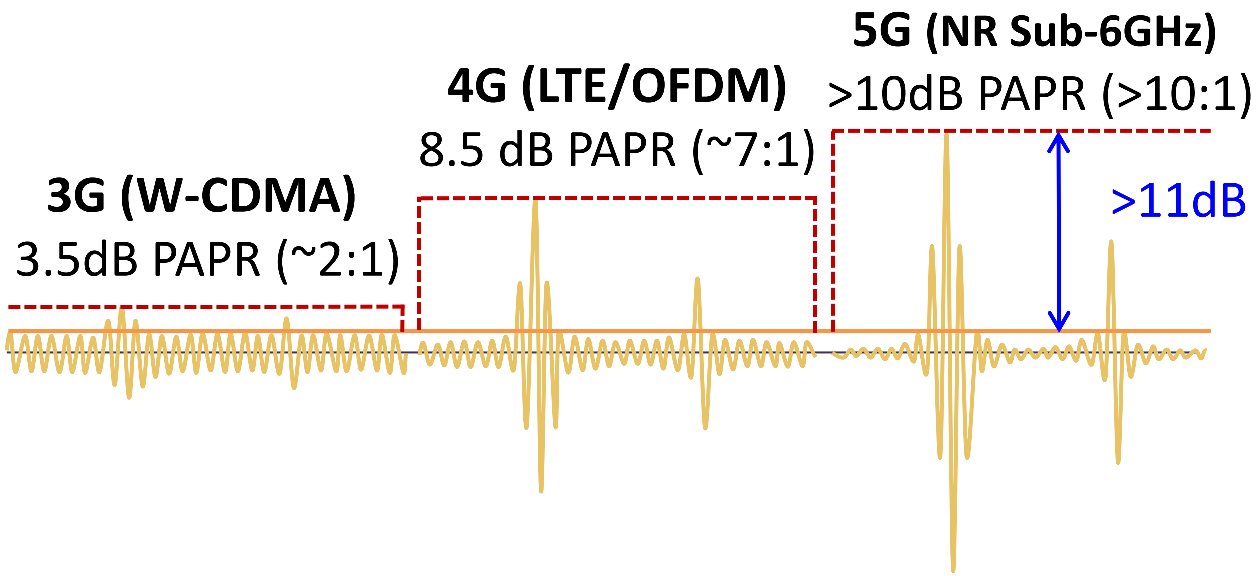
Outline

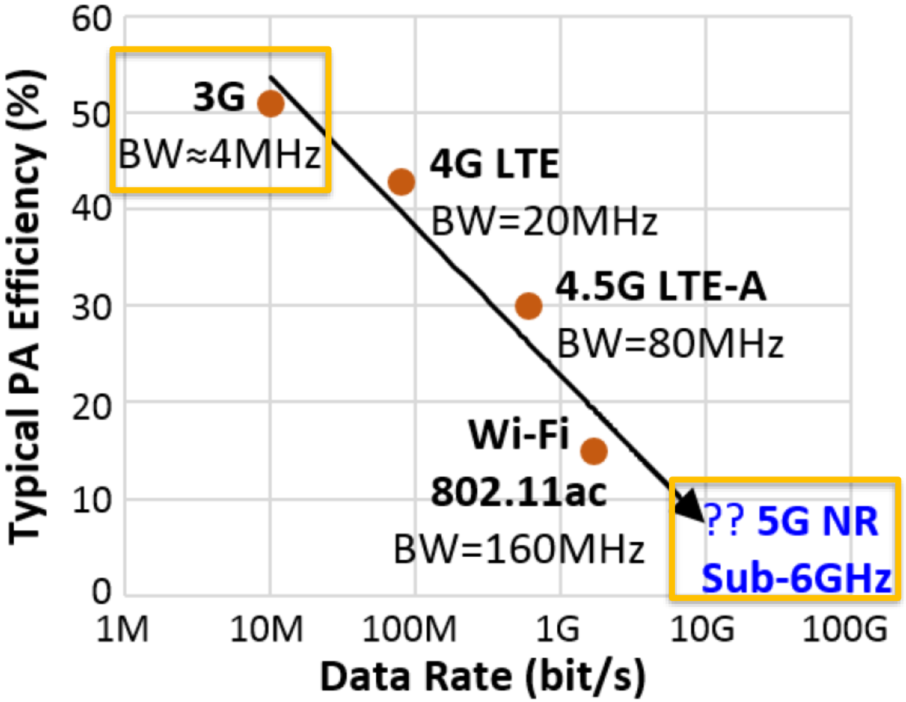
- ➢ Introduction
- ➢ Hybrid Asymmetrical LMBA Theory (H-AMLBA)
- ➢ Highly Linear H-ALMBA with Load Insensitivity
  - High-Linearity Design of H-ALMBA
  - Reconfiguration for Resilience against Load Mismatch
- ➢ Practical Design and Measurement Results
- ➢ Conclusion

Importance of PA Efficiency in Array-Based Systems

- Ever-Increasing Demands for Higher Data Rate
  - Higher modulation order → 1024QAM
  - Wider instantaneous BW → OFDM needed
  - More stringent linearity requirement for PA

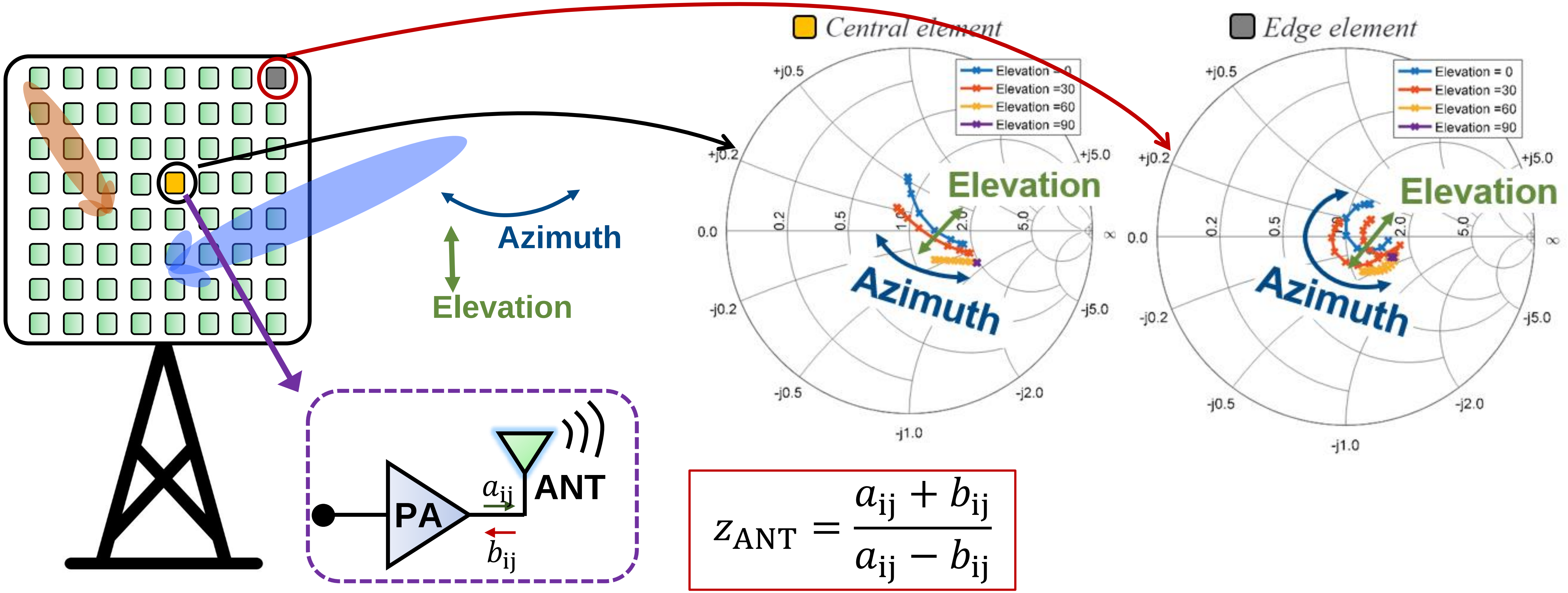
PAPR: 3G – 5G Evolution





New Challenge for PAs in Antenna Array

- ANT impedance mismatch due to mutual coupling
- Z_{ANT} depends on both scan angel and element location

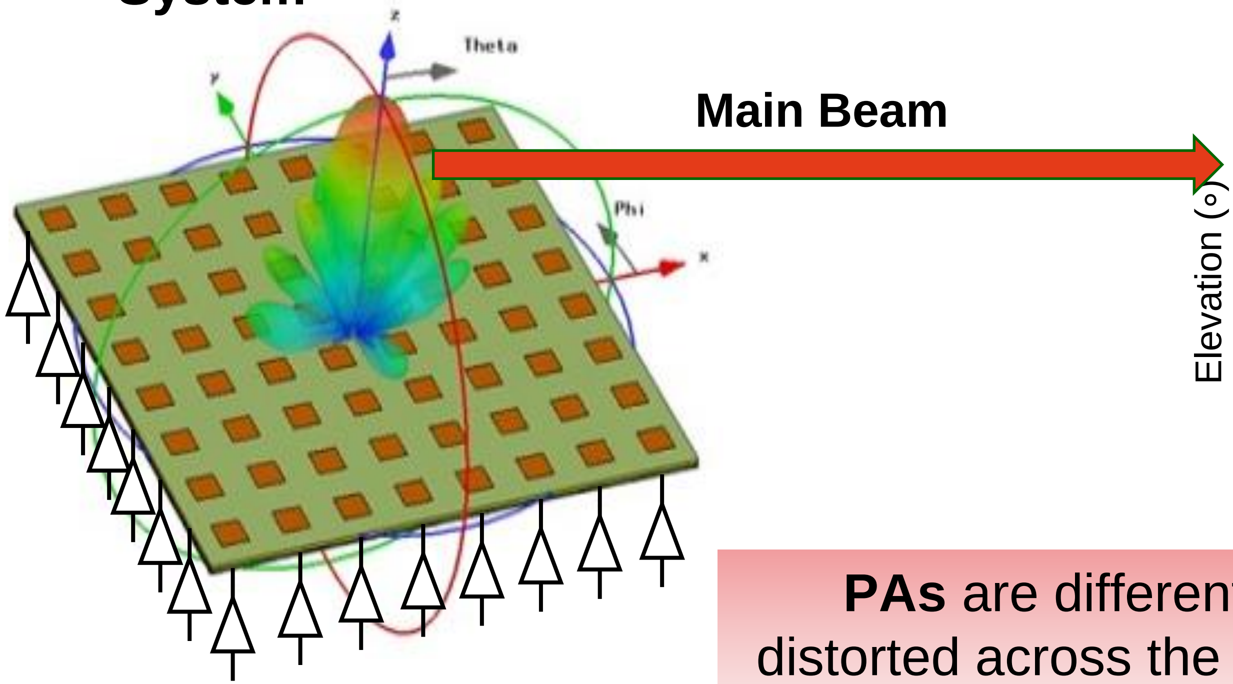


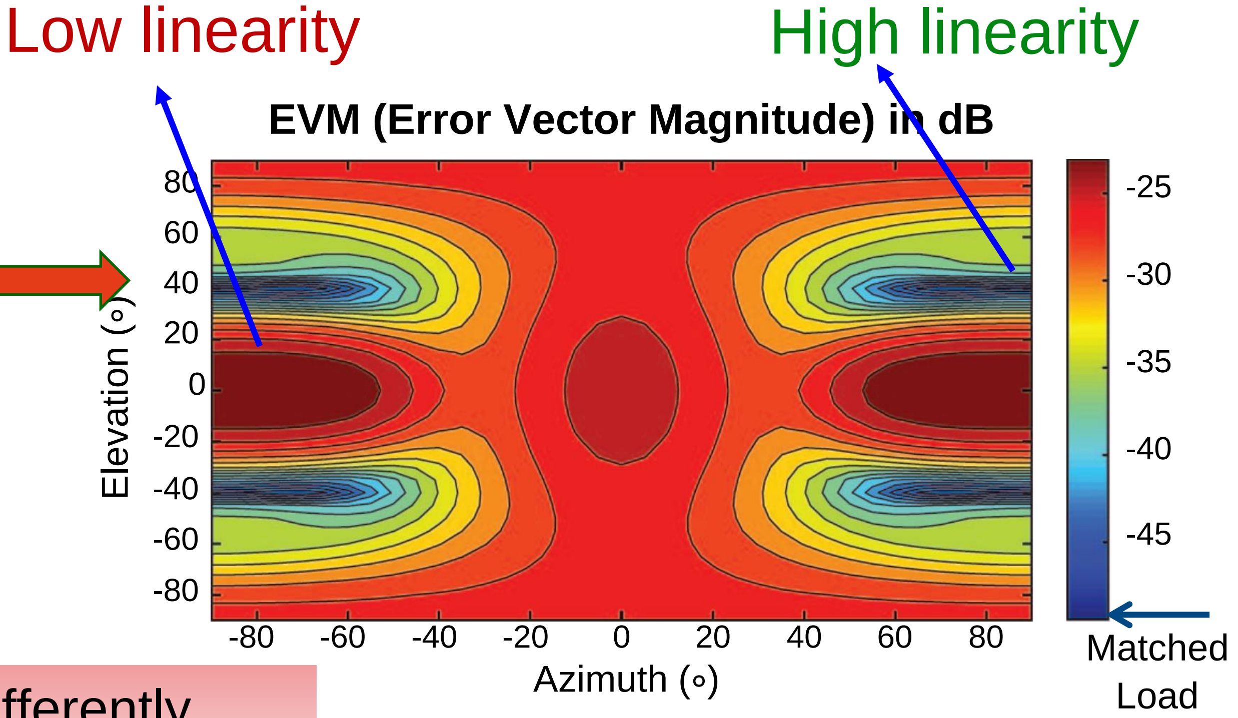
$$z_{ANT} = \frac{a_{ij} + b_{ij}}{a_{ij} - b_{ij}}$$

New Challenge for PAs in Antenna Array

- At system level: **Main-Beam Distortion**
- Spectrum eff. vastly degraded, invalidating the purpose of mMIMO

Massive MIMO System





PAs are differently distorted across the array!

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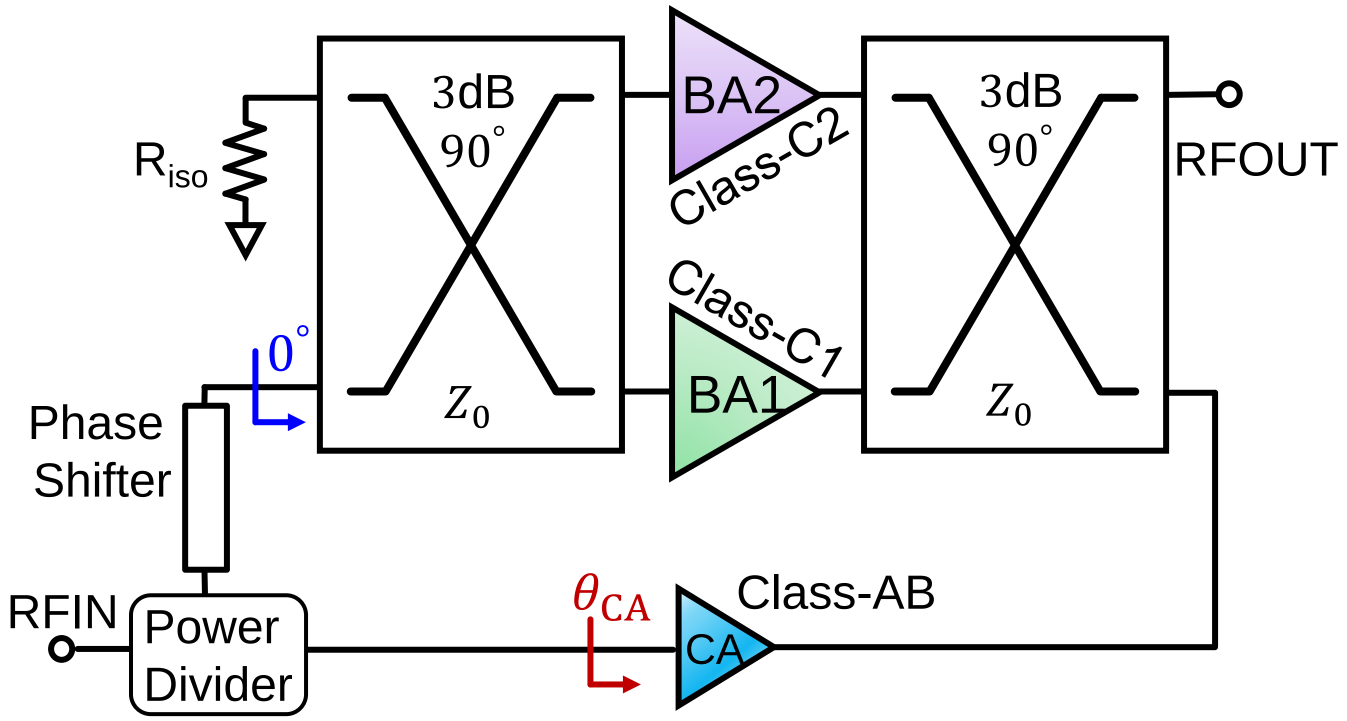
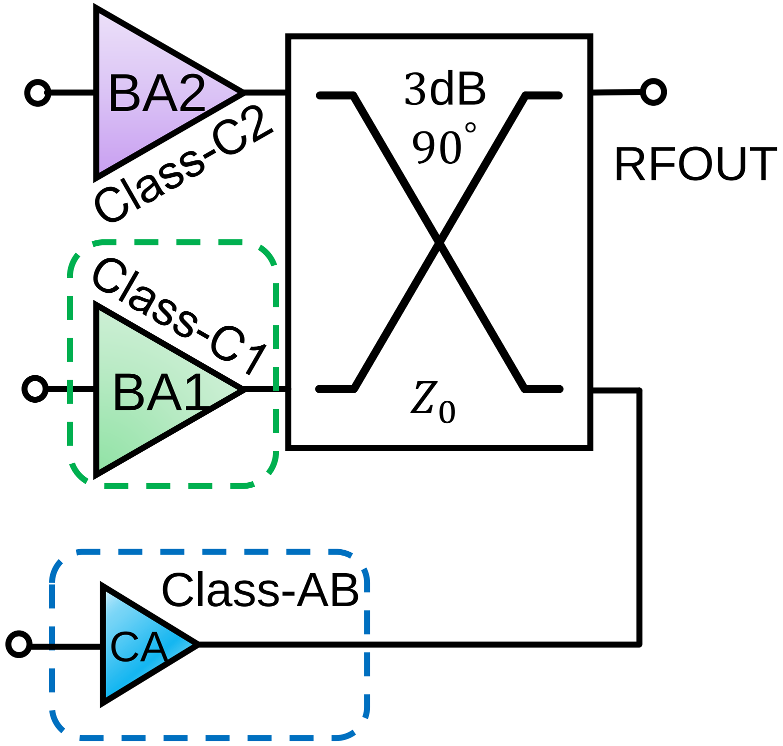
H-ALMBA Architecture

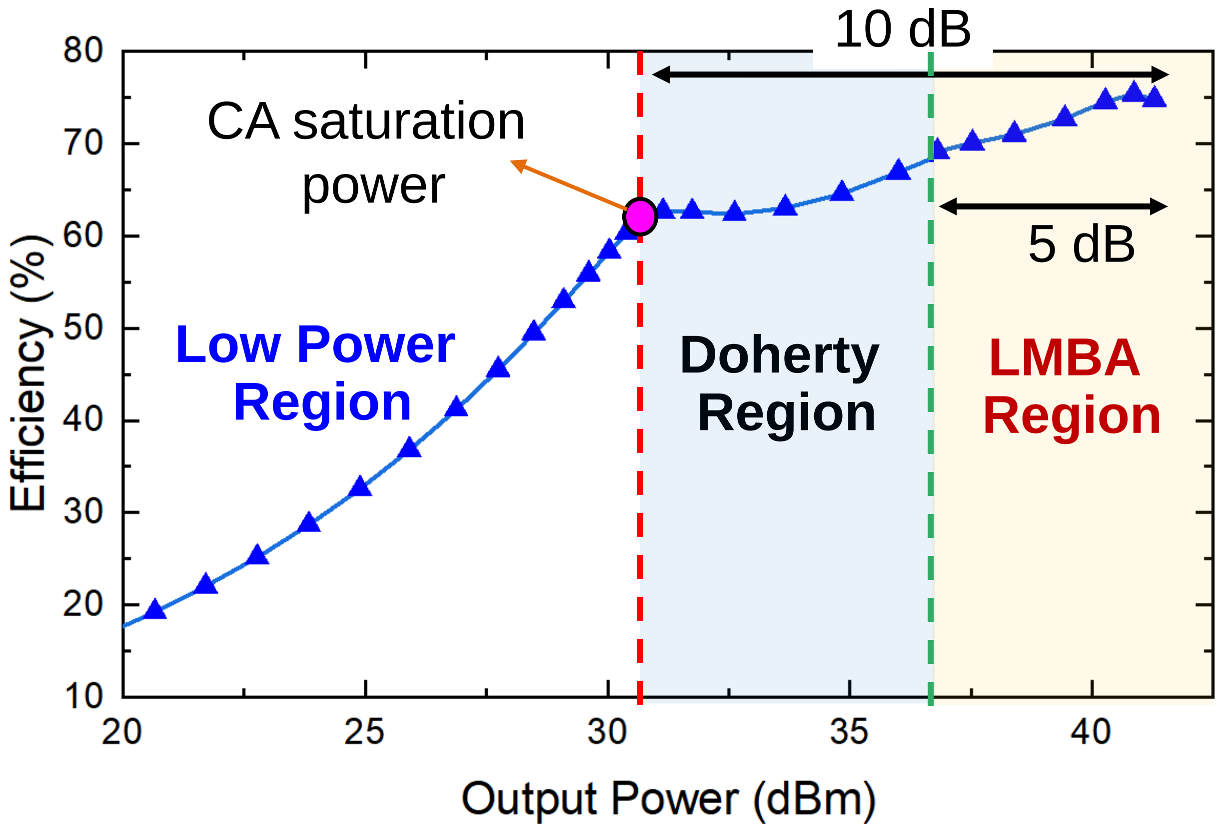
- 3-way-Doherty-like combination of BA1, BA2, and CA,
- Developed from the generic LMBA by sequentially turning on BA1 and BA2



Operation of H-ALMBA

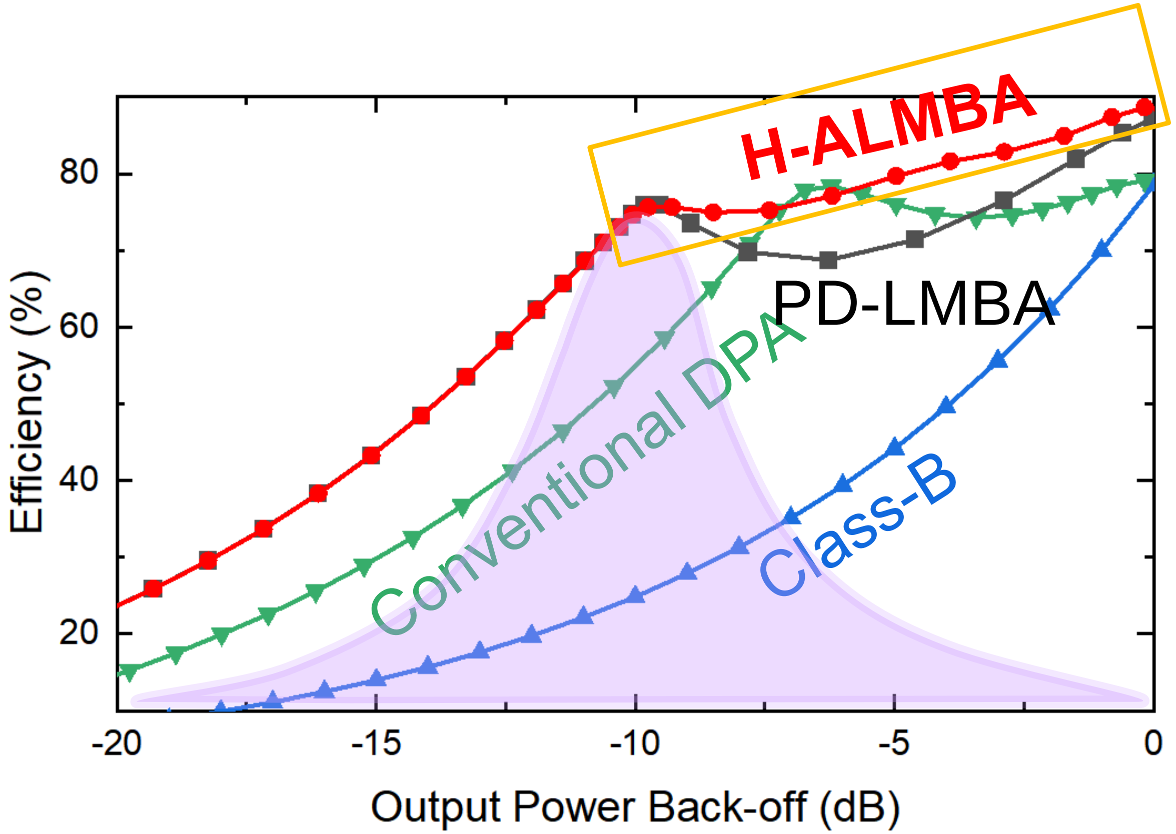
- Principle analysis operation divided into 3 regions
- LBO is determined by saturation power of CA and threshold of BA1.
- HBO is determined by the threshold of BA2.





Advantage of H-ALMBA

- Three-way load modulation based on 90° coupler, no efficiency drop
- ≥10 dB power back-off range achieved with proper amplitude control
- Nearly unlimited bandwidth inherited from PD-LMBA



- How to make the H-ALMBA has high linearity and keep high efficiency under mismatch with wide bandwidth?

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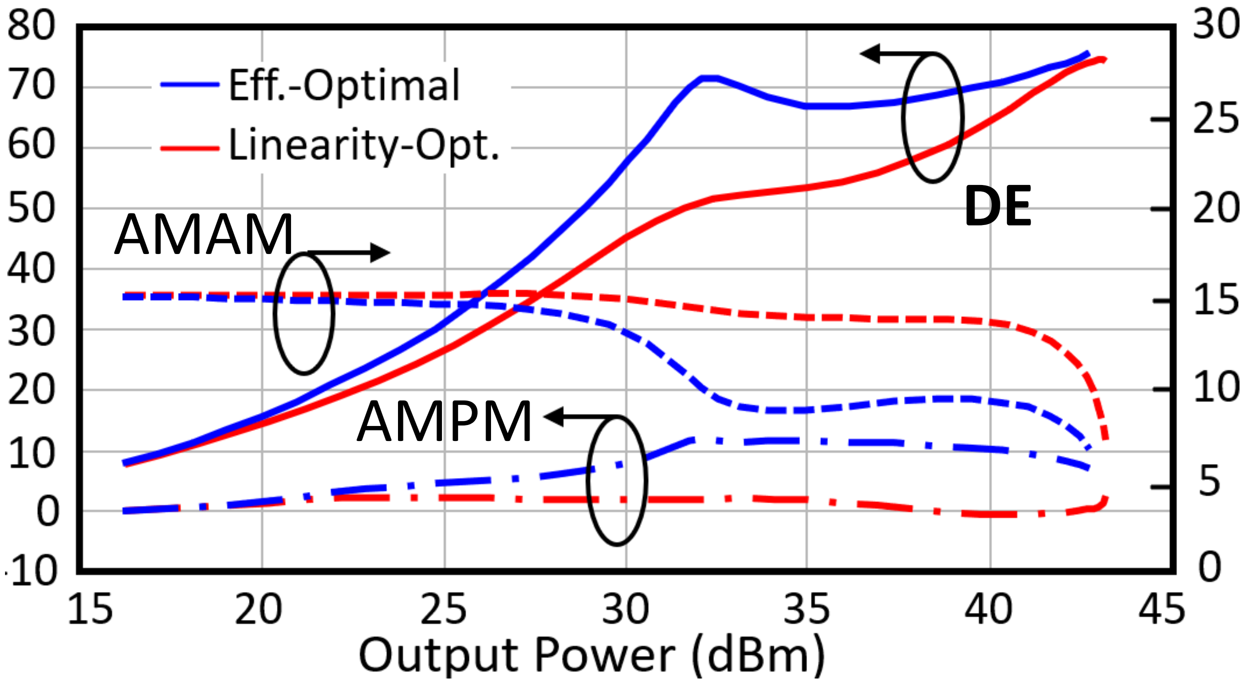
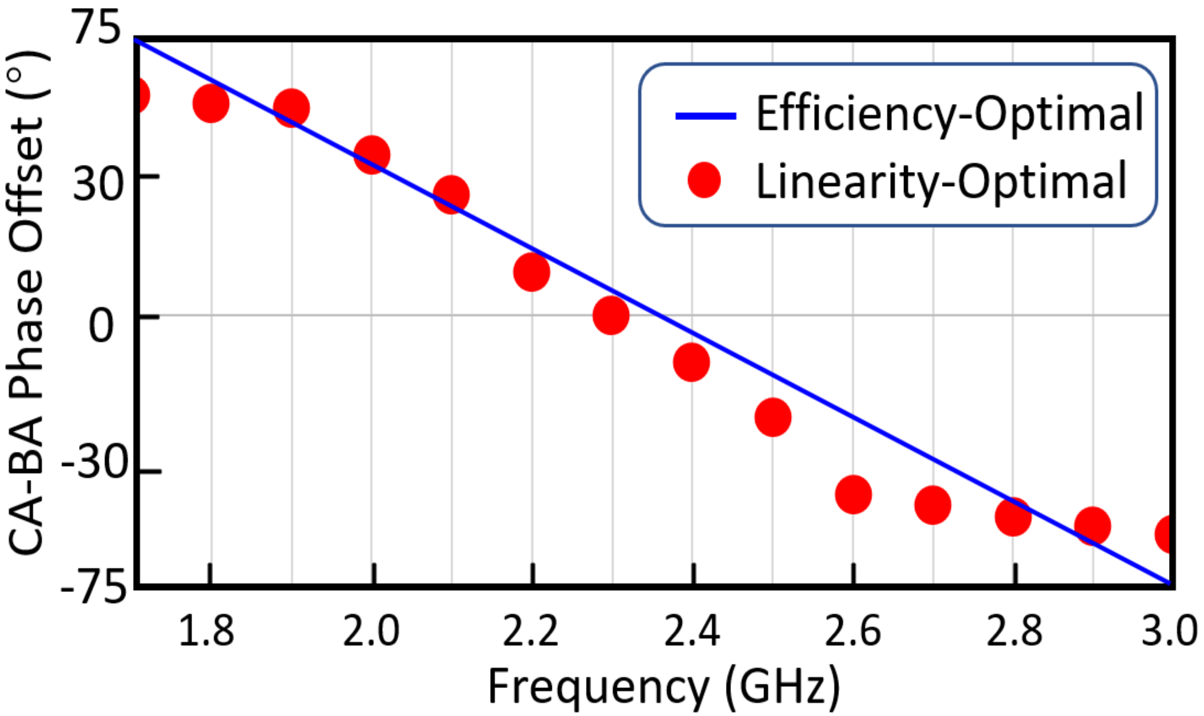
High-Linearity Design of H-ALMBA

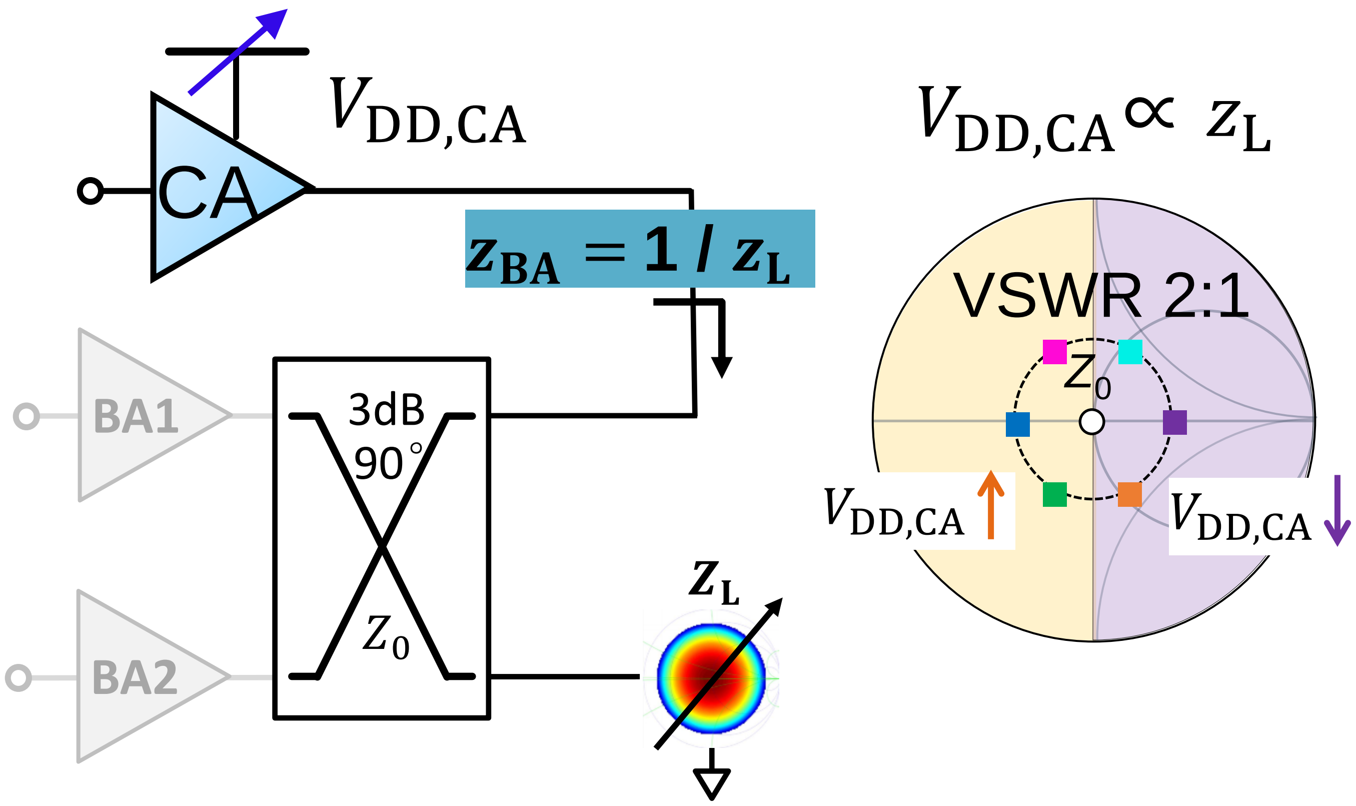
- AMAM Linearization: BA1 and BA2 can be turned on earlier to avoid compression.
- AMPM Linearization: Tunable phase offset between CA and BA.



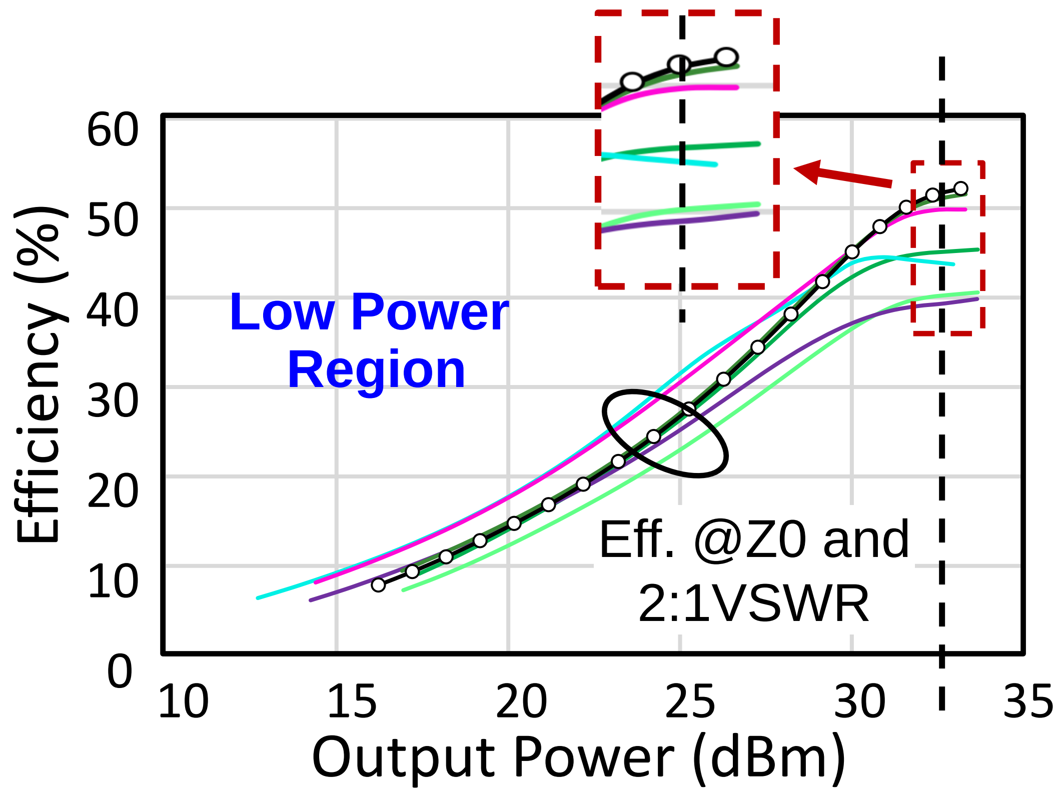


Reconfiguration for Mismatch Resilience In Low Power Region

- BAs turn off with CA solely operation
- Load-dependent $V_{\mathrm{DD,CA}}$



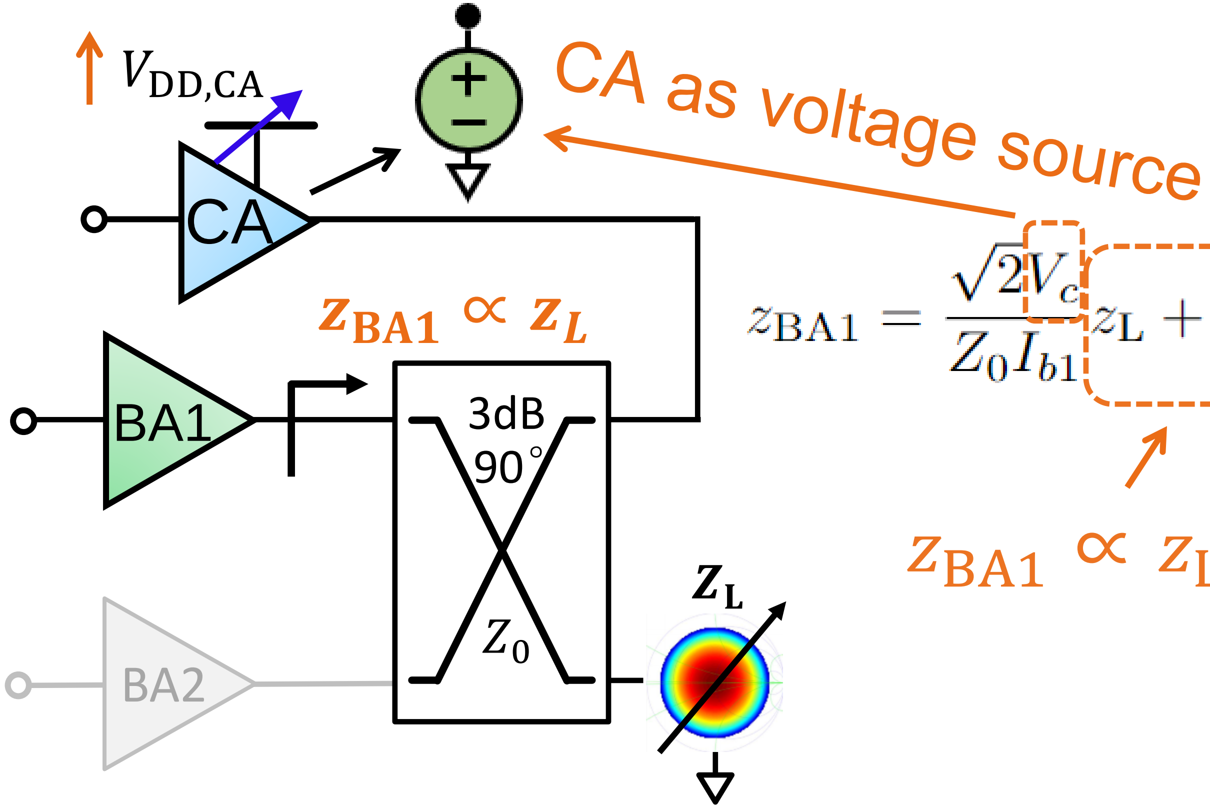
Constant CA saturation at target PBO(~10dB)



Reconfiguration for Mismatch Resilience In Doherty Region **When $|z_L|<1$**

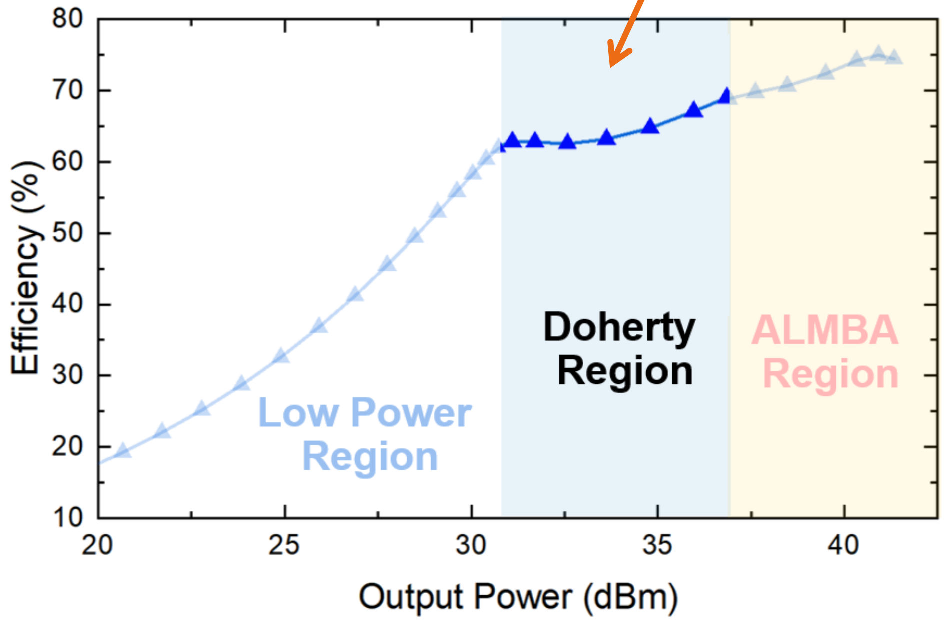
- BA1 turns on, BA2 remains off, and BA1 and CA cooperate like a DPA
- CA works as a voltage source (*VS*)

BA1 as primary peaking and BA2 turns off



$$z_{BA1} = \frac{\sqrt{2}V_c}{Z_0 I_{b1}} z_L + 2z_L - \frac{I_{b2}}{I_{b1}}$$

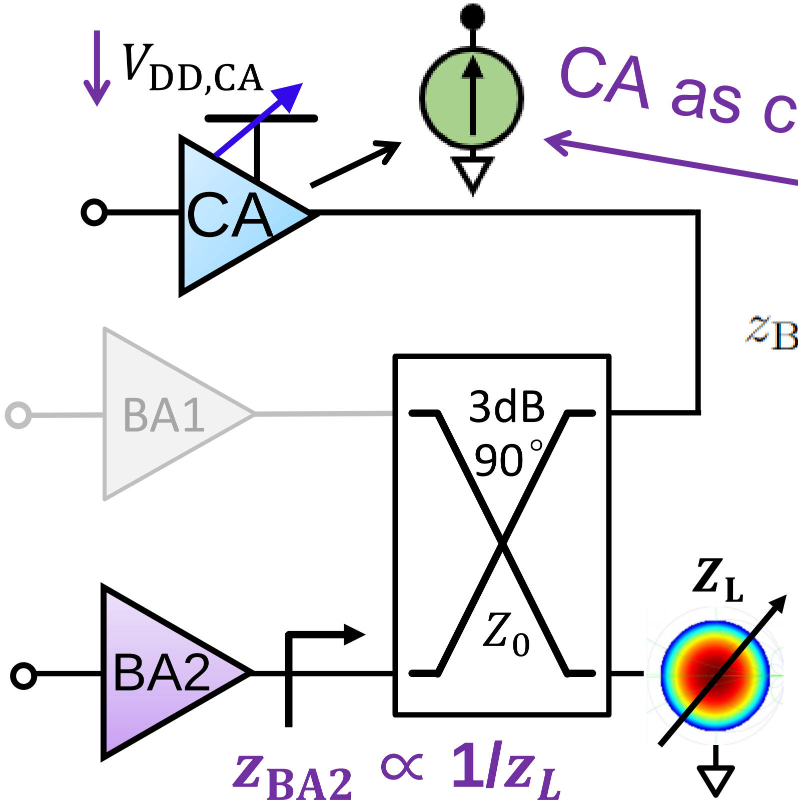
$z_{BA1} \propto z_L$



Reconfiguration for Mismatch Resilience In Doherty Region **When $|z_L|>1$**

- BA2 turns on, BA1 remains off, and BA2 and CA cooperate like a DPA
- CA works as a current source (*CS*)

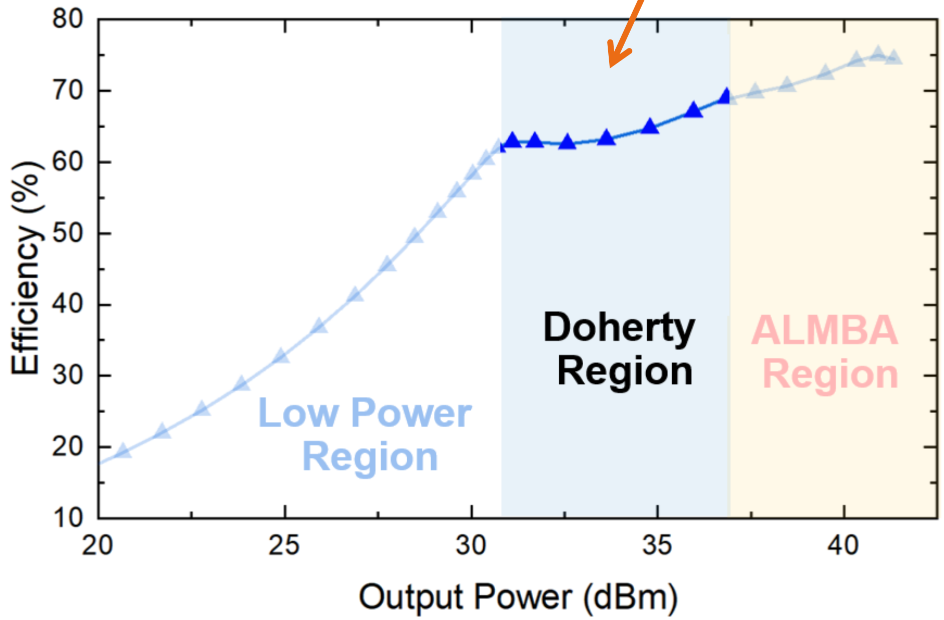
BA2 as primary peaking and BA1 turns off



CA as current source

$$z_{BA2} = \frac{\sqrt{2}I_c}{I_{b2}}\left(\frac{1}{z_L} + \frac{2}{z_L}\right) - \frac{I_{b1}}{I_{b2}}$$

$z_{BA2} \propto 1/z_L$

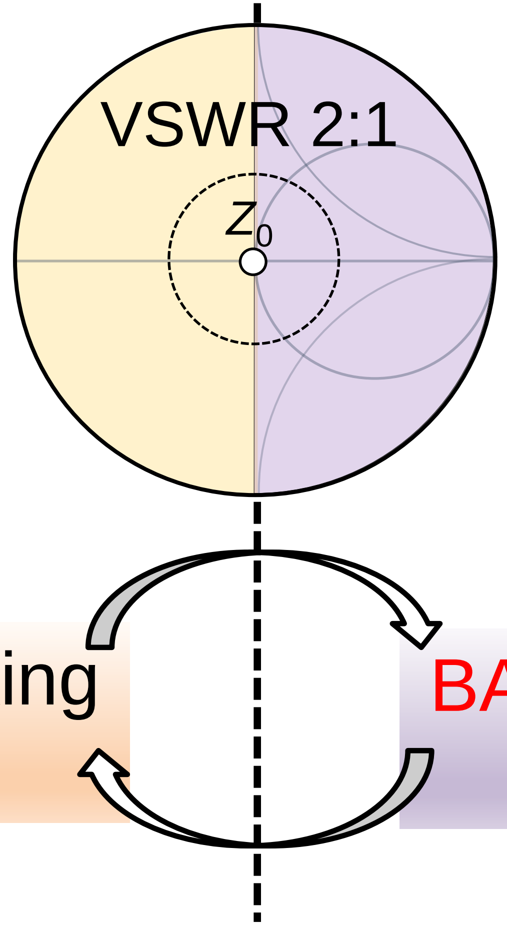


Reconfiguration for Mismatch Resilience In Doherty Region

- ❑ BA1 or BA2 turns on depends on load condition
- ❑ CA *CS*-*VS* duality

When $|z_L|<1$

CA as voltage source



When $|z_L|>1$

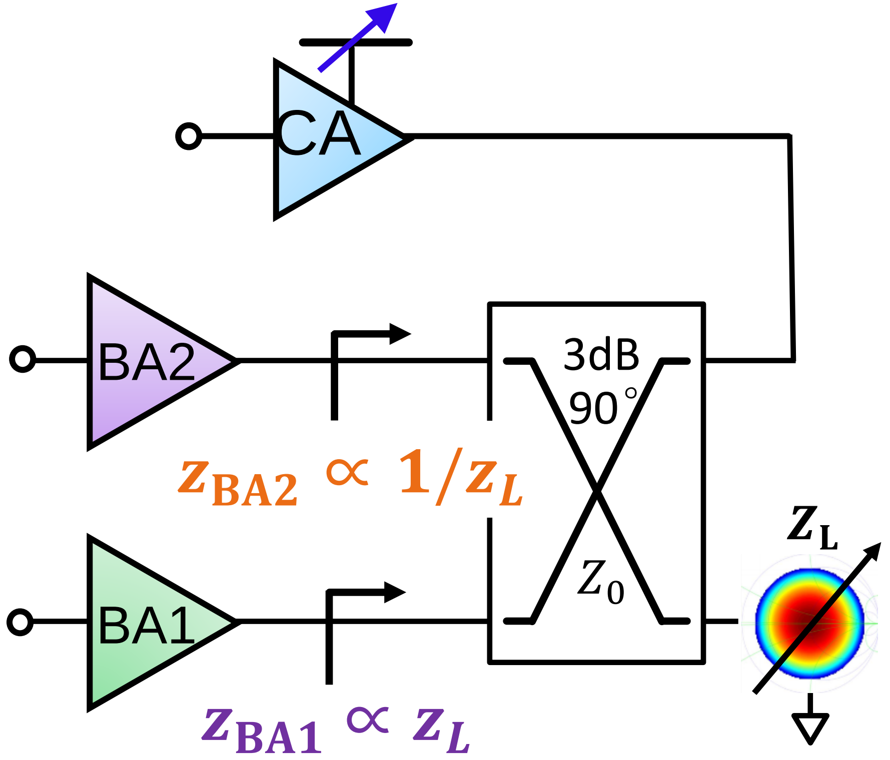
CA as voltage source

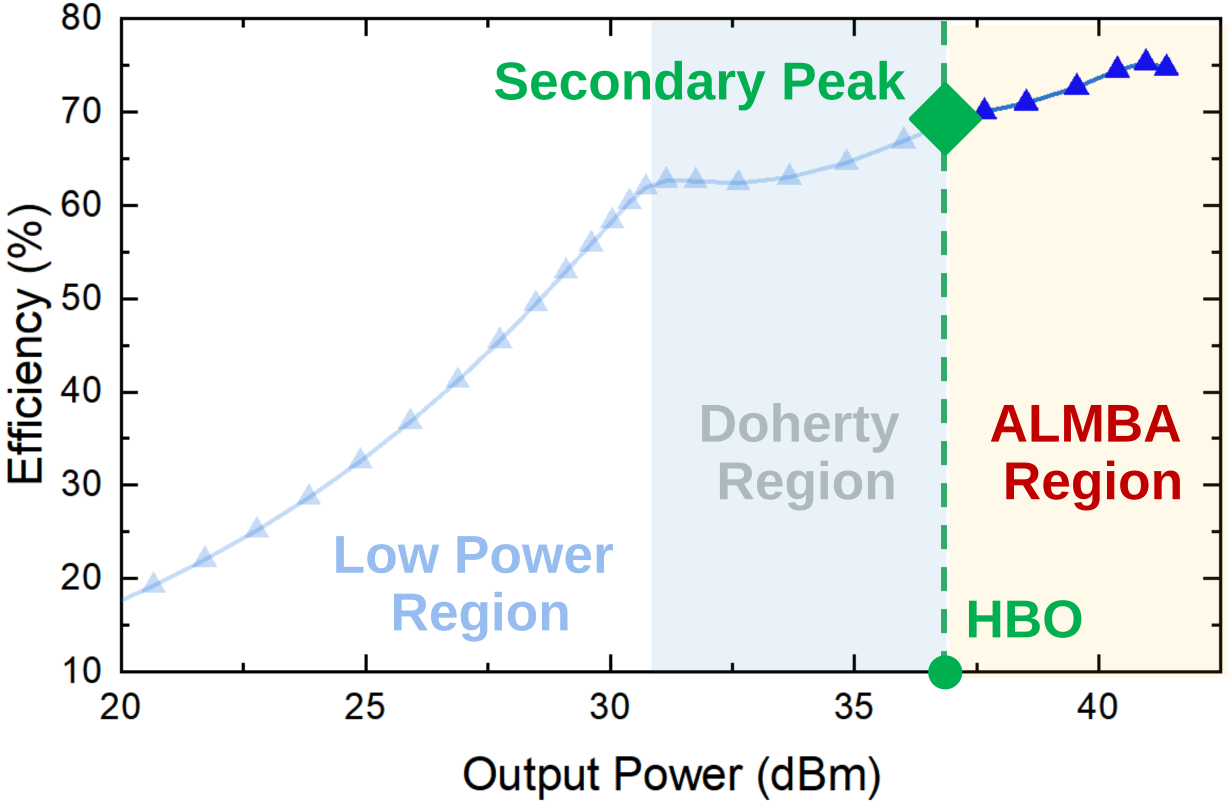
BA1 as primary peaking and BA2 turns off

BA2 as primary peaking and BA1 turns off

Reconfiguration for Mismatch Resilience In ALMBA Region

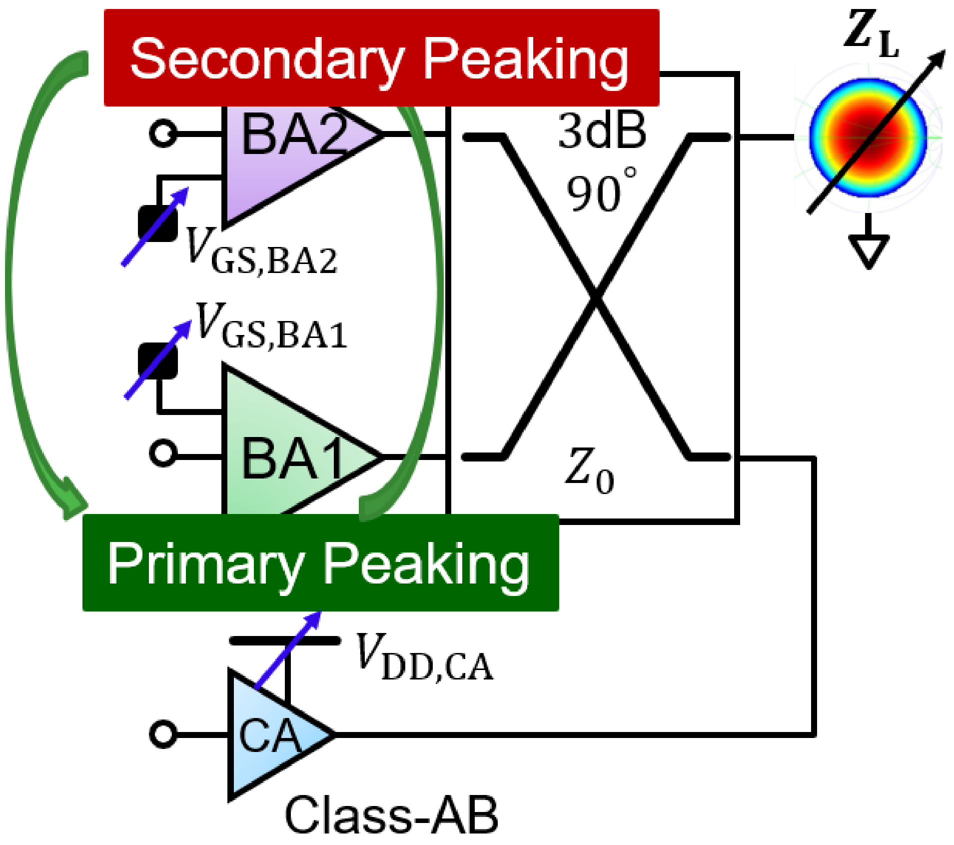
- BA1 and BA2 both turn on at secondary peaking, and saturate simultaneously with CA at maximum power.
- BA1 and BA2 remain balanced at AlMBA region and complement each other.

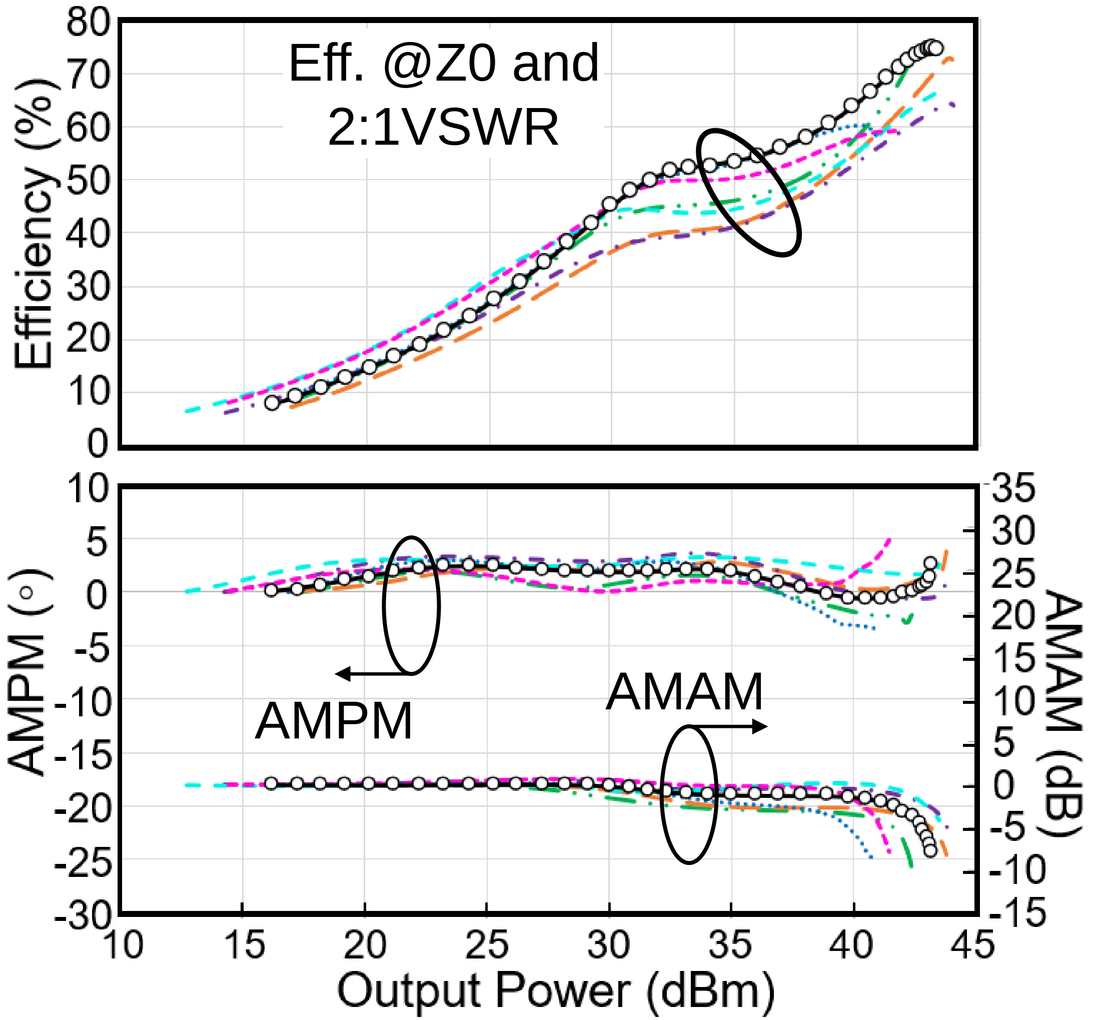




Overall Simulation Result

- Efficiency and linearity can both be maintained against 2 : 1 VSWR with the proposed Z_L-Optimal biasing





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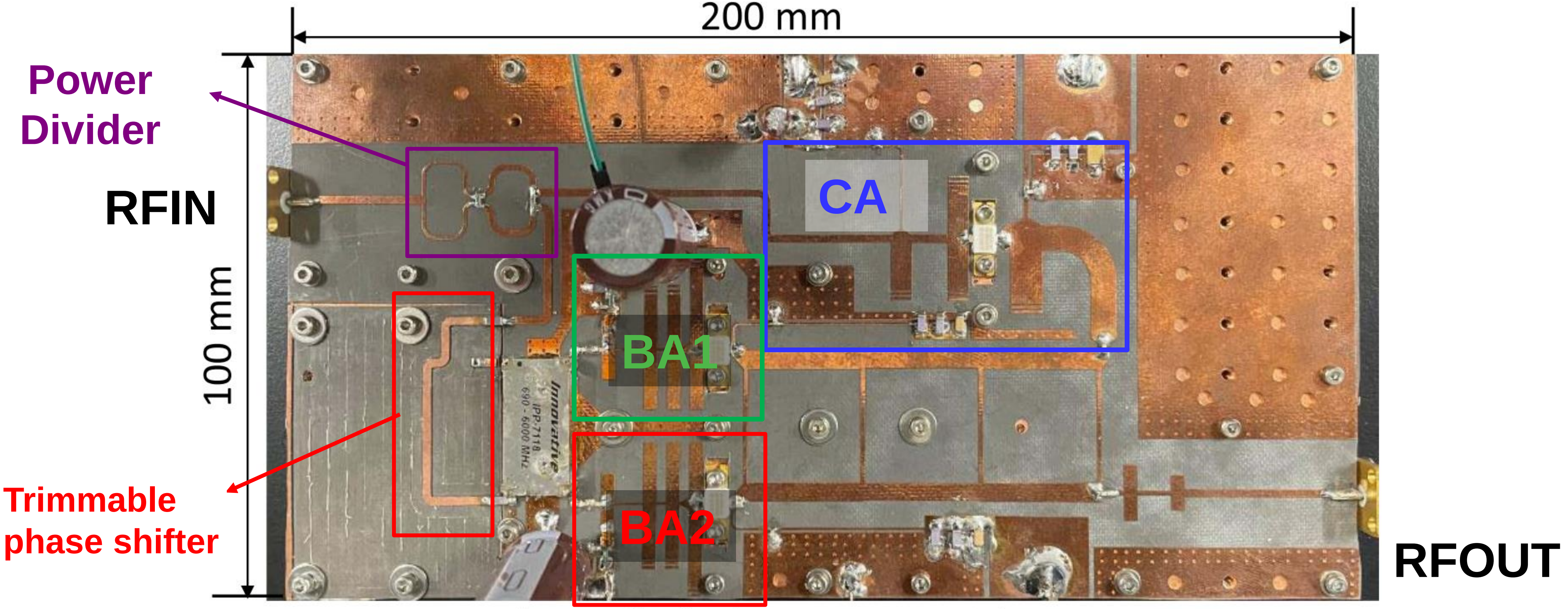
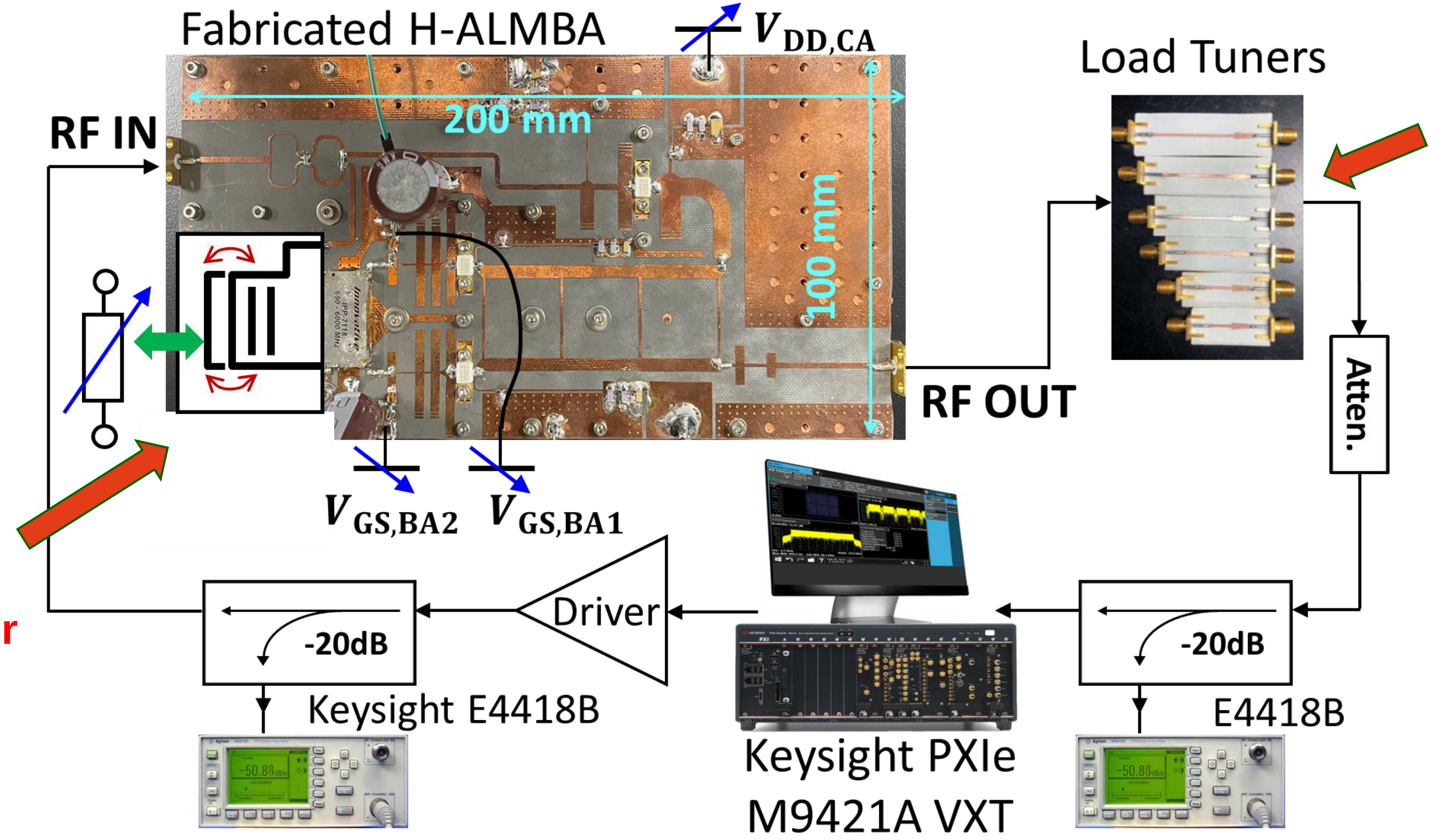
Hardware Demonstration



0.5-mm (20-mil) Thick Rogers Duroid-5880; ε_r: 2.2

Measurement Set Up

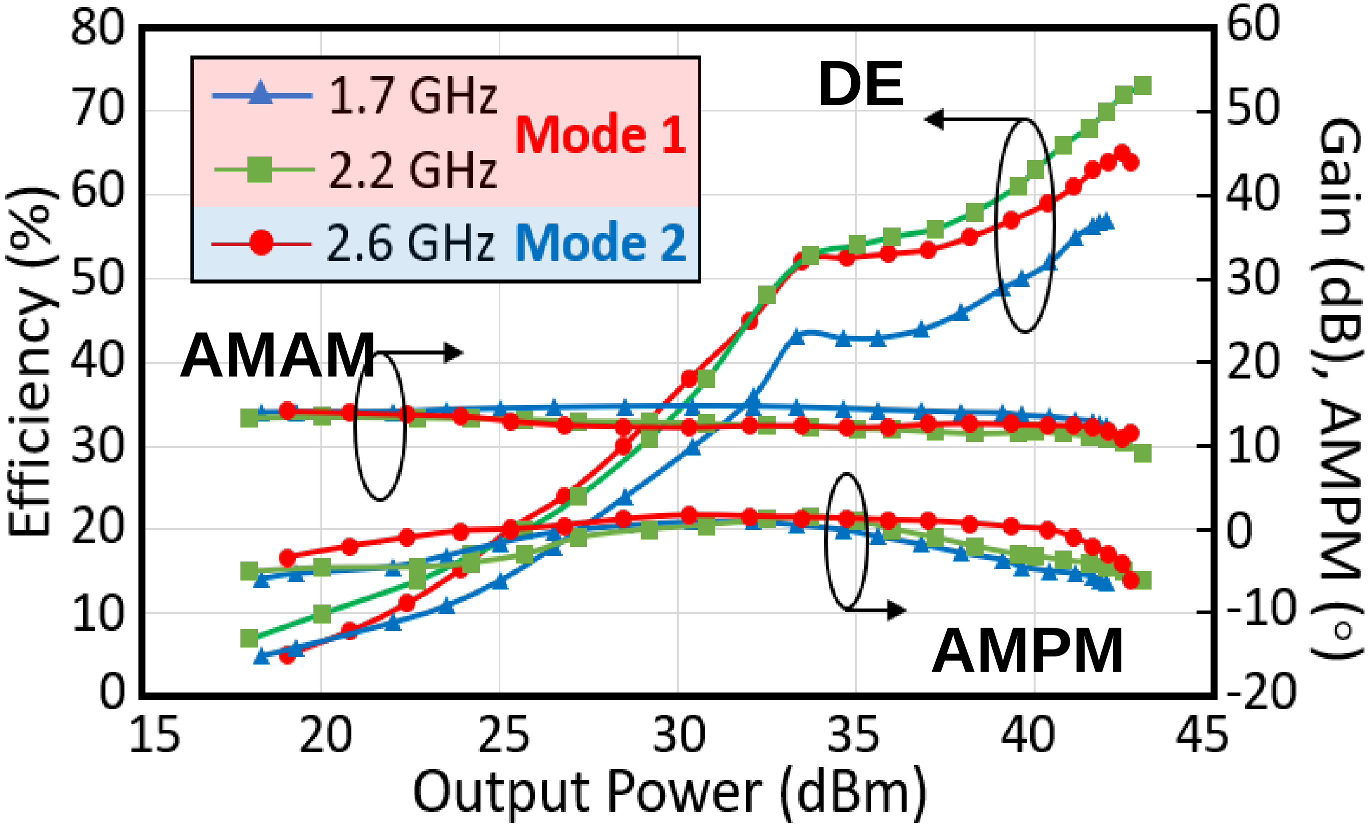


Load Tuners Covering 2:1 VSWR at 2.1GHz

Trimmable phase shifter for optimal AMPM

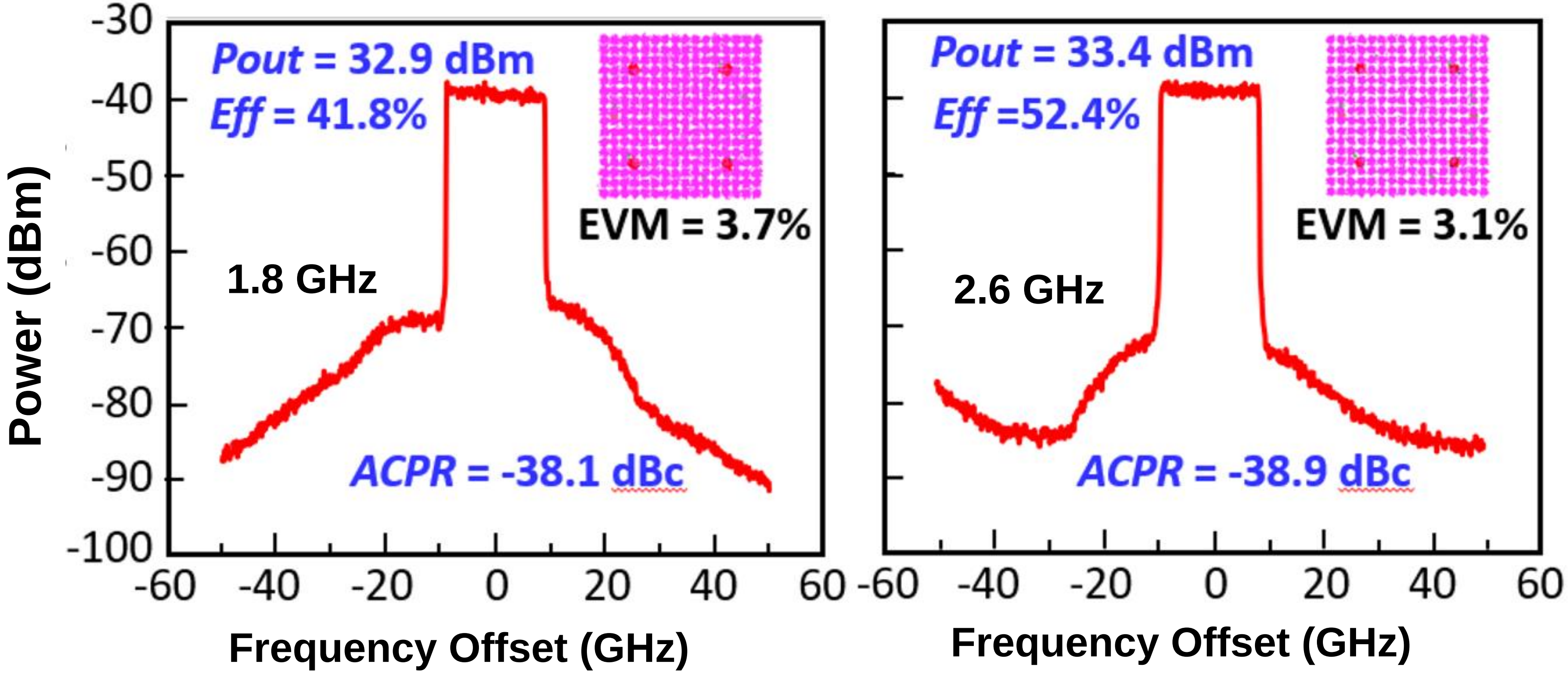
CW Measurement Results @ Z_0

- Max DE of 57%−73%, 10-dB OBO DE of 43.2%−52.8% and saturated out put power of 42−43 dBm at 1.7, 2.2 and 2.6 GHz
- AMAM< 4.5-dB and AMPM < 6.5°



Modulated Measurement Results @ Z_0

- Modulated measurement using 256 QAM LTE signal with 20-MHz bandwidth and 10.5-dB PAPR
- Average efficiency of 41.8%–52.4% and a best ACPR of -38.9 dBc and 3% of EVM

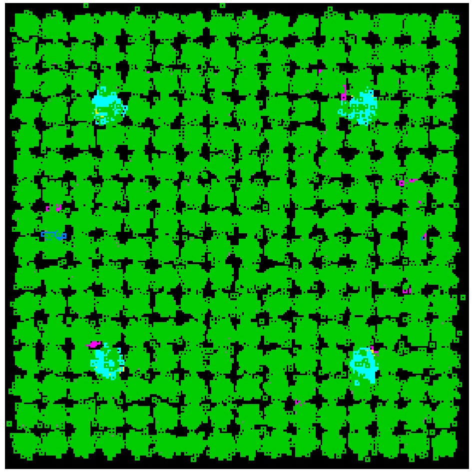


Modulated Measurement Results at 2.6 GHz

- Linearity of H-ALMBA is devastated with load mismatch
- EVM can be perfectly recovered through the proposed biasing reconfiguration

$Z_L = Z_0$

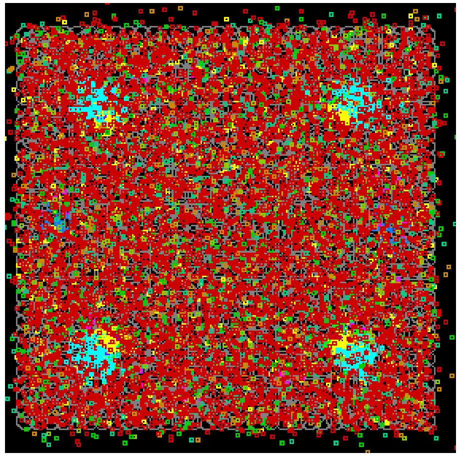
EVM =3.5%



Same Biasing as $Z_L = Z_0$ →

$Z_L = 0.5Z_0$

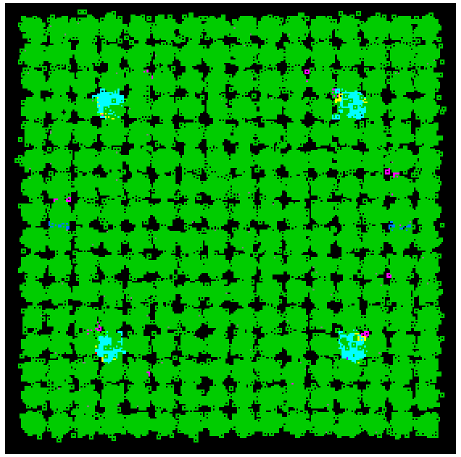
EVM = 49.2%



Z_L-Optimal Biasing →

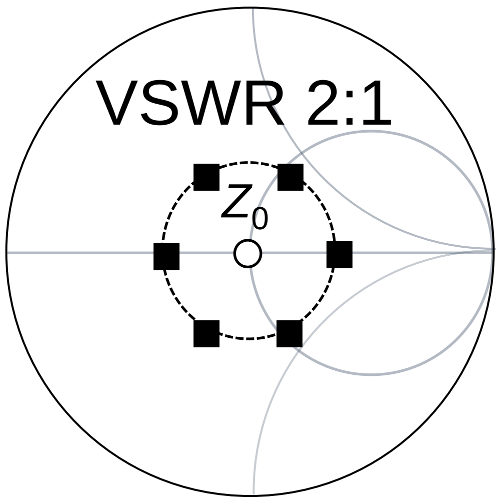
$Z_L = 0.5Z_0$

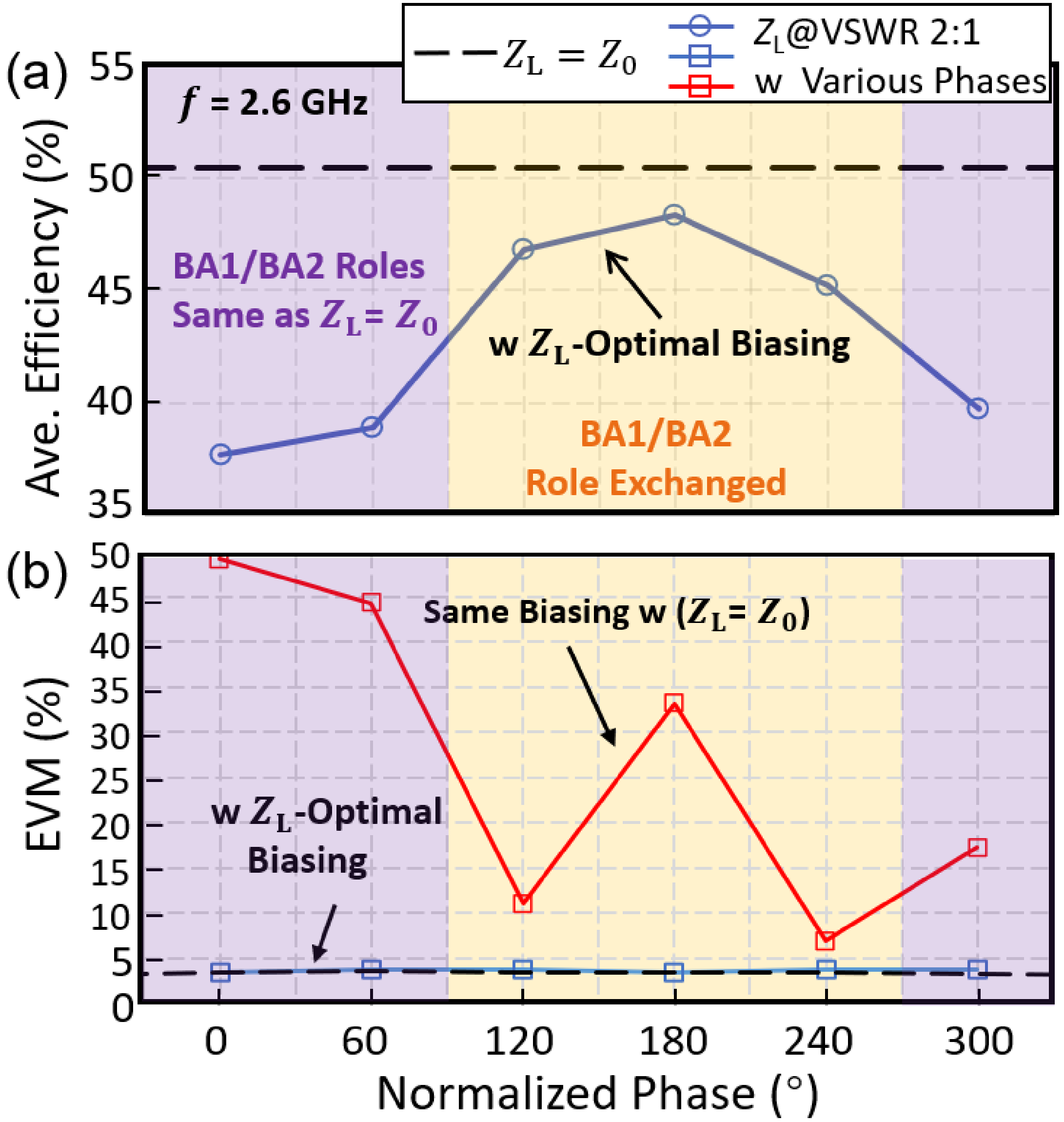
EVM = 3.7%



Modulated Measurement Results @ 2:1 VSWR at 2.6 GHz

- ❑ Six represented load on 2:1 VSWR circle are selected to evaluate the mismatch recovery





- ❑ A low EVM and high efficiency can both be experimentally maintained breconfiguration against VSWR

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Conclusion

- A wideband and linear three-way load modulation PA in H-ALMBA topology with mismatch resilience is achieved with reconfigured turning-on sequence of Bas
- Resolving the non-linearity caused by CA overdrive, thus improving the overall linearity and reliability
- Maximized efficiency across extended dynamic power range
- Excellent linearity and efficiency recovery with proposed reconfiguration to arbitrary load mismatch.

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National Science Foundation

Thank You !