Tu3D-3

PA Output Power and Efficiency Enhancement Across the 2:1 VSWR Circle using Static Active Load Adjustment

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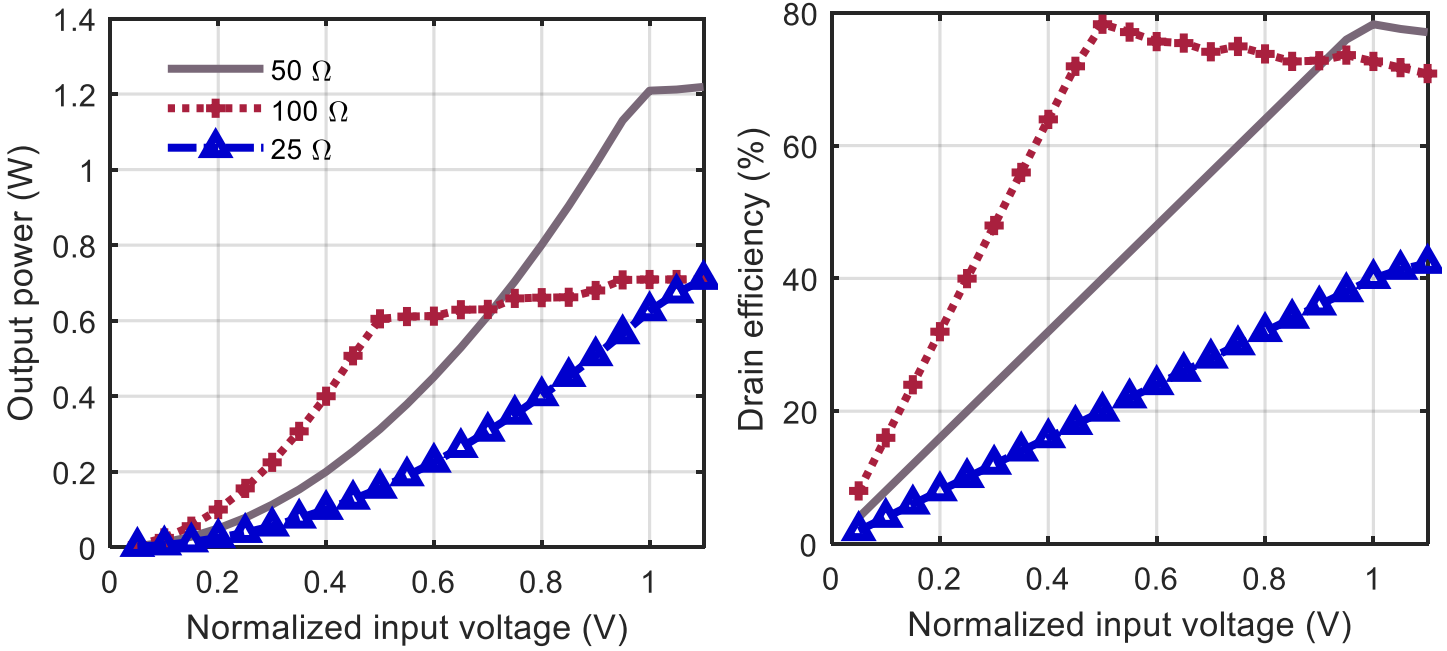
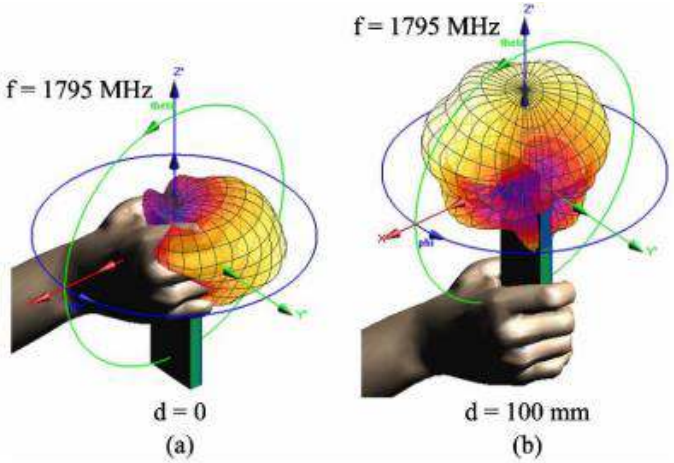
Outline

- Motivation
- Prior Art
- Proposed Concept
- Theoretical Analysis
- Simulation Results
- Measurement Results
- Conclusion

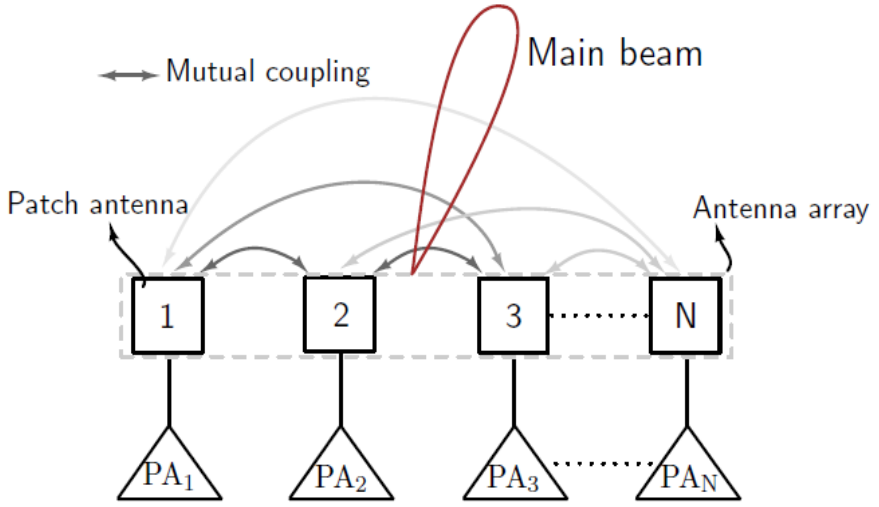
Motivation

Power amplifier output power, efficiency, and linearity are load dependent.





Hand effect on the radiation pattern*



Mutual coupling in phased array antenna

*Chih-Ming Su, et al., "User's hand effects on EMC internal GSM/DCS mobile phone antenna," IEEE AP-S Int. Symp. Dig., Albuquerque, NM, USA, 2006

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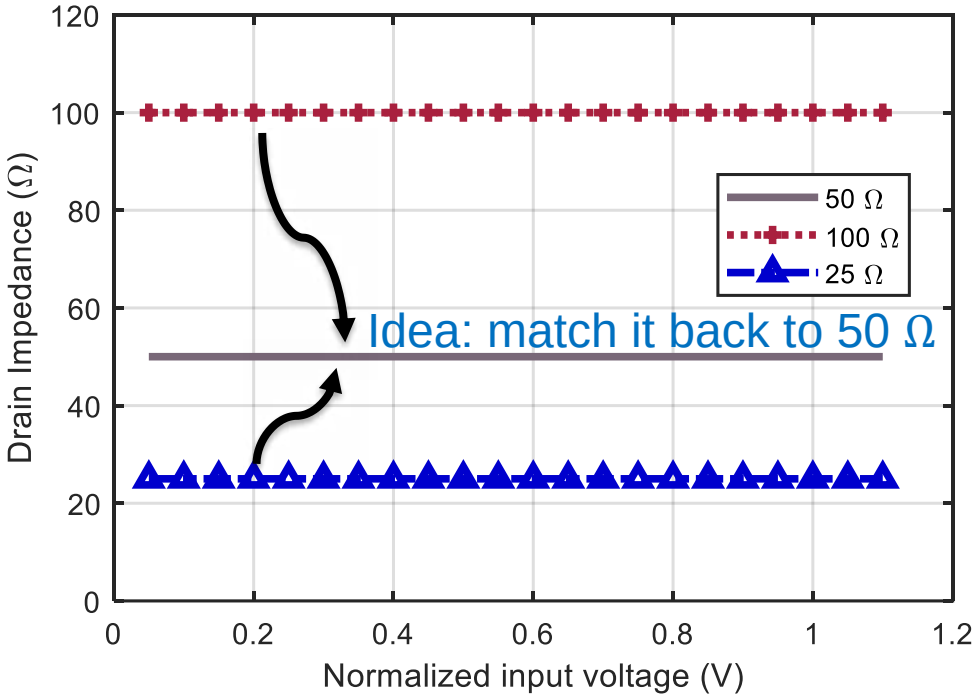

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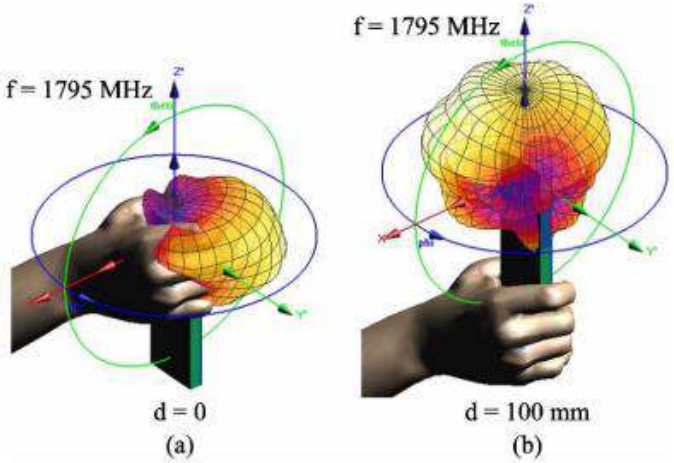

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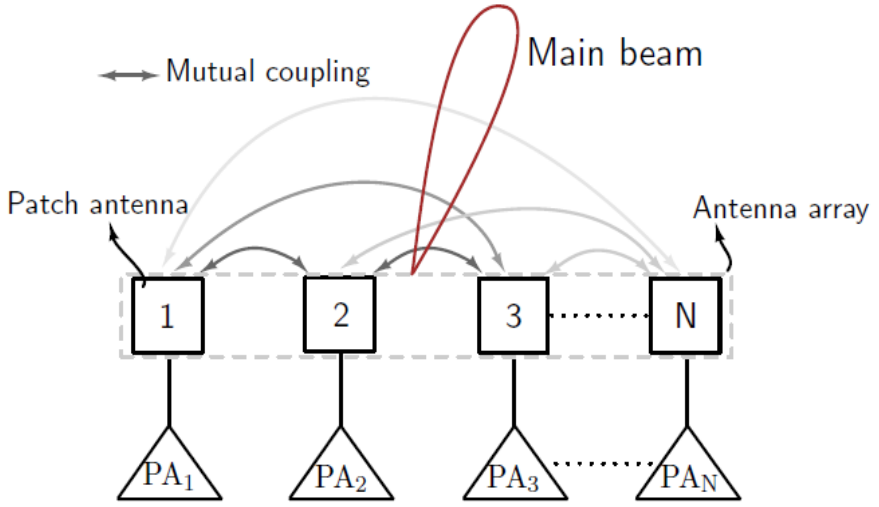


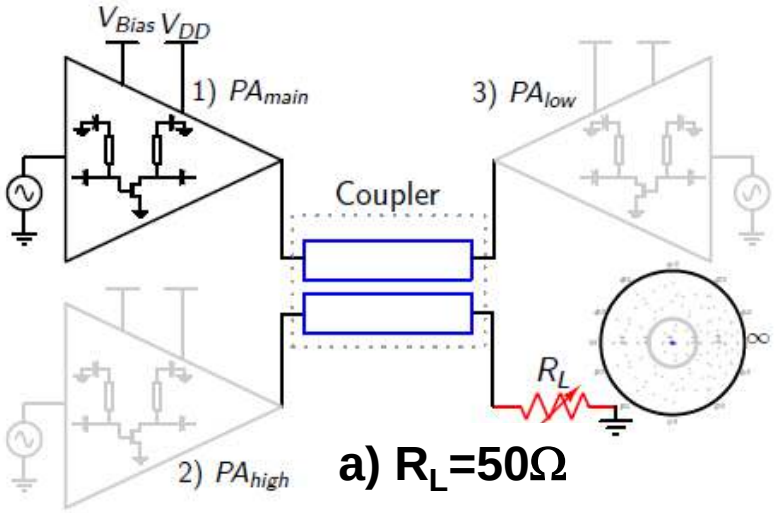
Mutual coupling in phased array antenna

Prior Art

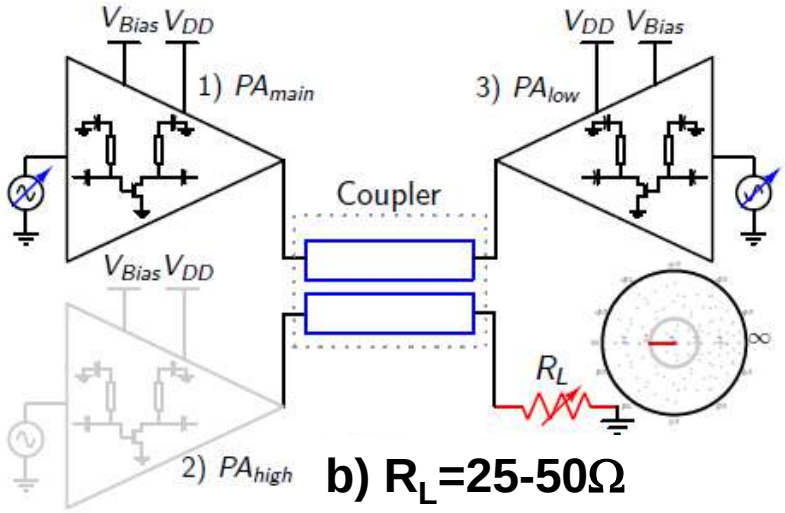
1. Isolator
   - A. Handle large VSWR with plug & play
   - B. Output power is still load dependent i.e., $P_{out} = (1 - |\Gamma|^2)P_{in}$
   - C. Difficult to integrate
2. Tunable matching network
   - A. Theoretically best solution (with ideal loss-less components)
   - B. High-Q conditions causing high insertion loss and bandwidth restrictions
   - C. Low-RF power handling capability
3. Supply adaptation with TMN
   - A. Relaxes high-Q requirement on TMN
     - a) TMN for complex load Supply adaptation with input drive for ohmic load
   - B. Needs DC-DC converters
   - C. RF-power handling gets limited due to TMN

Proposed Concept

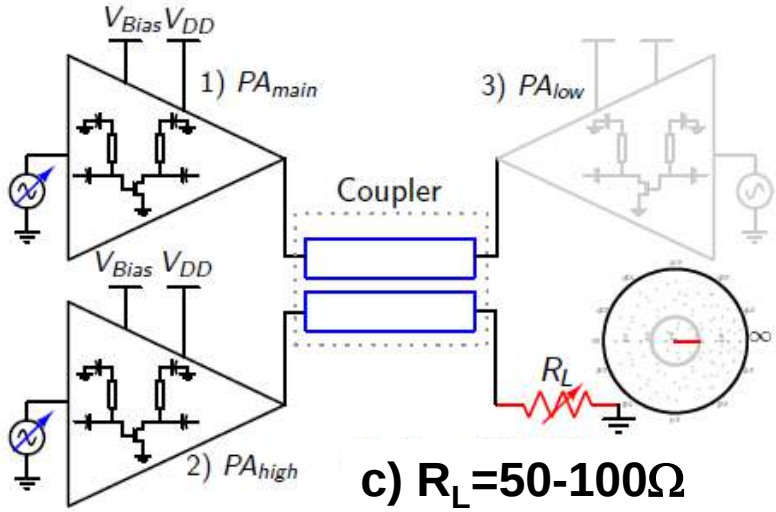
1. Core idea: match PA loading impedance using only active devices.
2. Enforce in-phase power combining at the load to maximize efficiency.



a) R_L=50Ω

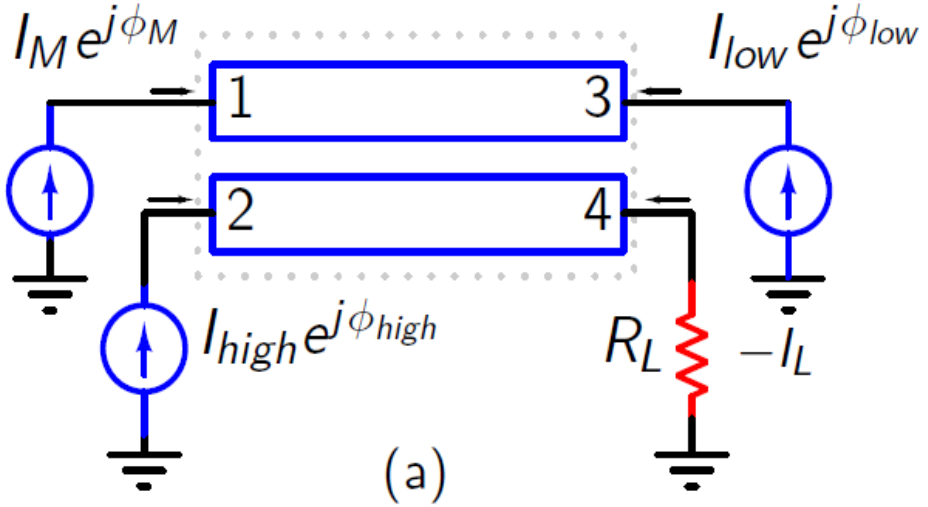


b) R_L=25-50Ω



c) R_L=50-100Ω

Theoretical Analysis



(a)

$$\begin{bmatrix} V_M \\ V_{high} \\ V_{low} \\ V_L \end{bmatrix} = \frac{Z_0}{\sqrt{1-C^2}} \begin{bmatrix} 0 & 0 & -j & -jC \\ 0 & 0 & -jC & -j \\ -j & -jC & 0 & 0 \\ -jC & -j & 0 & 0 \end{bmatrix} \begin{bmatrix} I_M e^{j\phi_M} \\ I_{high} e^{j\phi_{high}} \\ I_{low} e^{j\phi_{low}} \\ -I_L \end{bmatrix}$$

(b)

Proposed circuit topology: current sources with a coupler.

Z-matrix of the coupler used in the analysis.

Theoretical Analysis

- The loading impedance of the main stage (Z_M) can be adjusted
  - *A.* $\mathrm{PA_{high}}$ $(\mathrm{I_{high}})$ is used to increase $\mathrm{Z_M}$
  - *B.* $\mathrm{PA_{low}}$ $(\mathrm{I_{low}})$ is used to decrease $\mathrm{Z_M}$

$$Z_M = \frac{C^2}{1-C^2}\frac{Z_0^2}{R_L} + \frac{C}{1-C^2}\frac{Z_0^2}{R_L}\frac{I_{high}}{I_M} - \frac{Z_0}{\sqrt{1-C^2}}\frac{I_{low}}{I_M}$$

- The output power can also be adjusted

$$P_{out} = \frac{Z_0^2}{2R_L(1-C^2)}\left[CI_M + I_{high}\right]^2$$

Theoretical Analysis

- The power utilization factor (PUF) for ohmic loads.

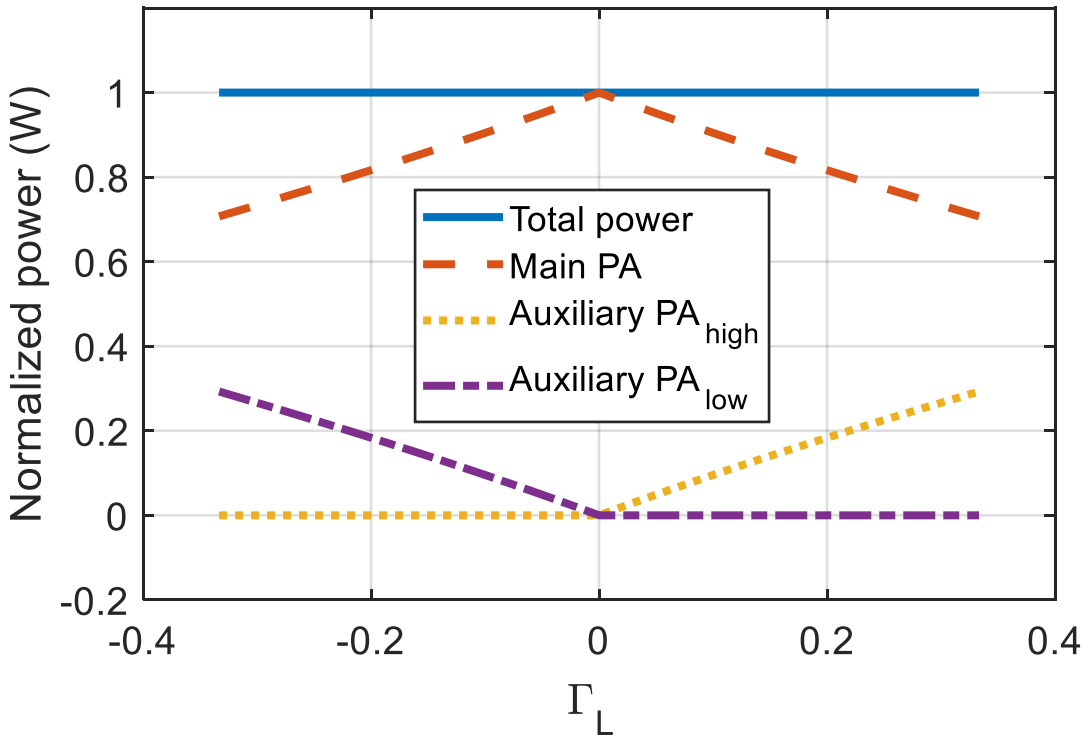
$$PUF = \frac{Power_M}{Power_M + Power_{Aux_1} + Power_{Aux_2}}$$

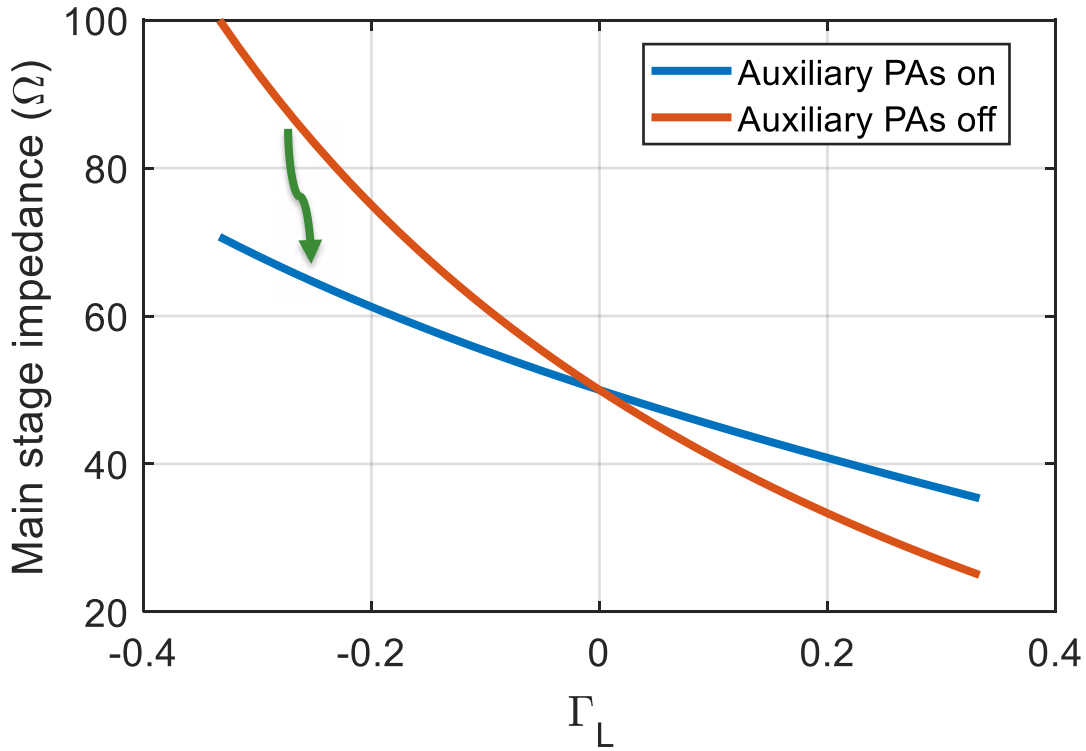
$$PUF = \frac{1}{\frac{Z_0}{R_{min}} - \sqrt{\frac{Z_0}{R_{min}}} + \sqrt{\frac{R_{max}}{Z_0}}}$$

- The $R_{min} = 25\ \Omega$ and $R_{max} = 100\ \Omega$ for the 2:1 VSWR.
- The PUF for ohmic 2:1 VSWR, $Z_0 = 50\ \Omega$ is 50 %.
- The auxiliary PAs are small!
- The PUF for 2:1 VSWR with supply adjustment is also 50 % (G. D. Singh, et al., TMTT 2021).

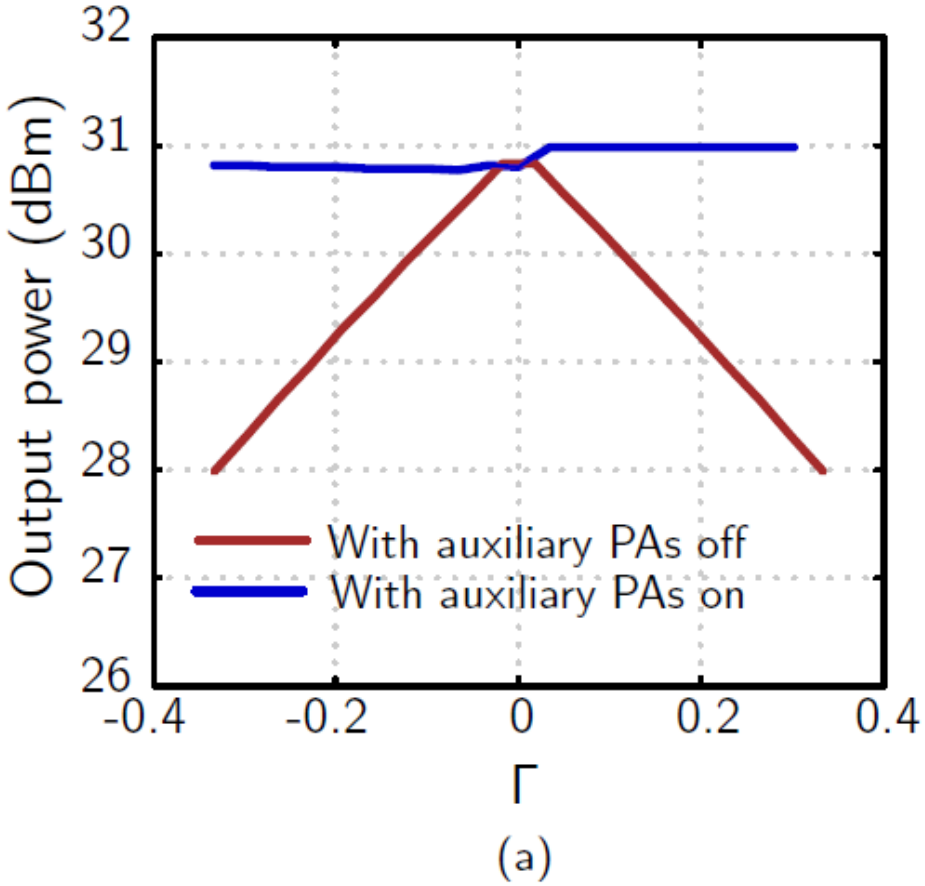
Theoretical Analysis

- The power extracted from the main and auxiliary PAs.
- Main stage static active load adjustment.

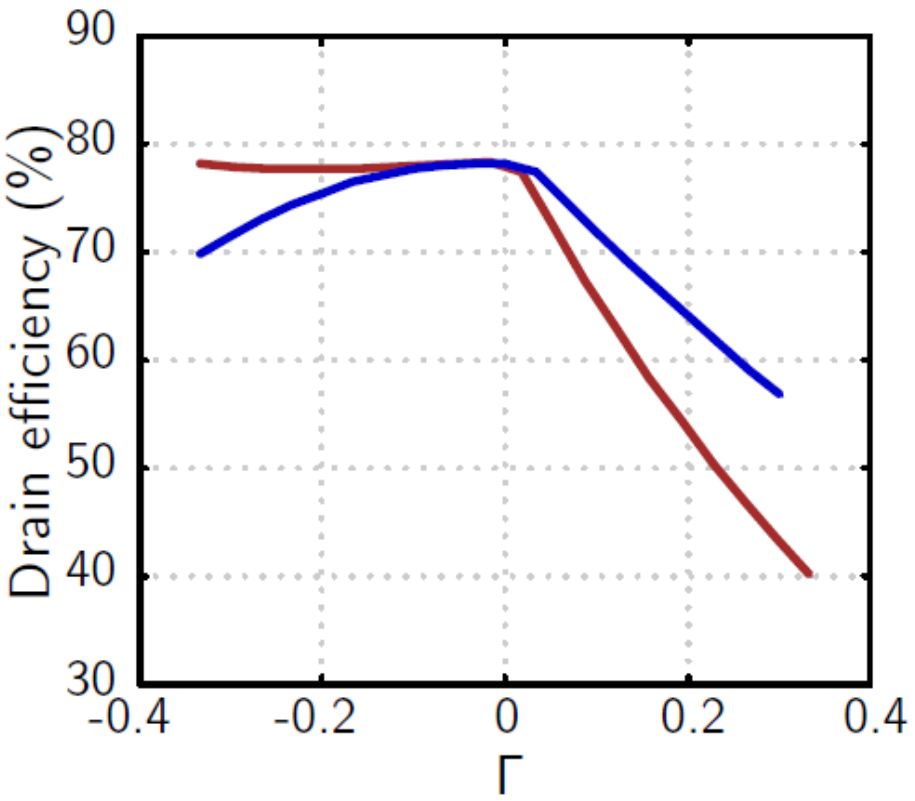




Simulation Results

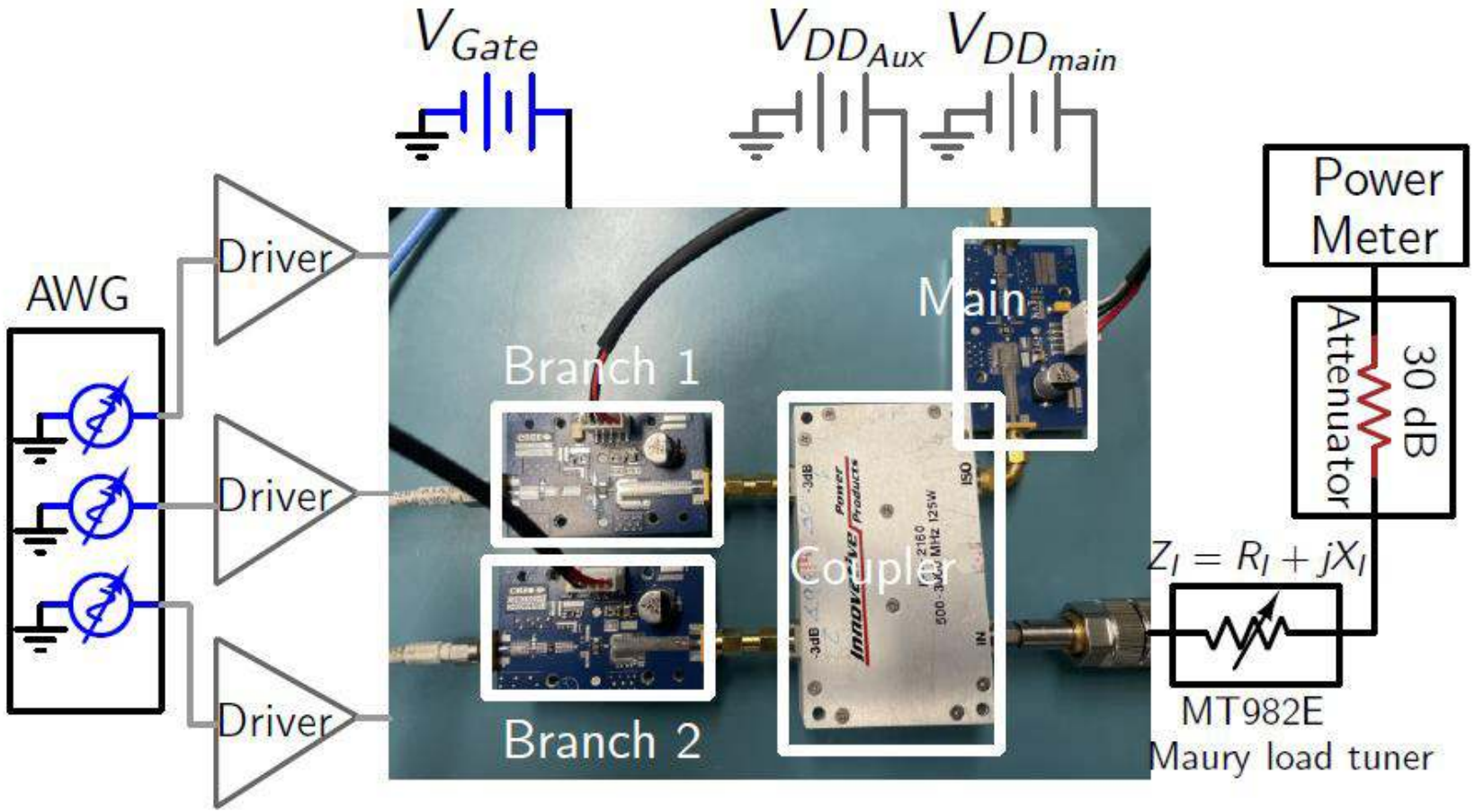


(a)



(b)

Measurement Setup



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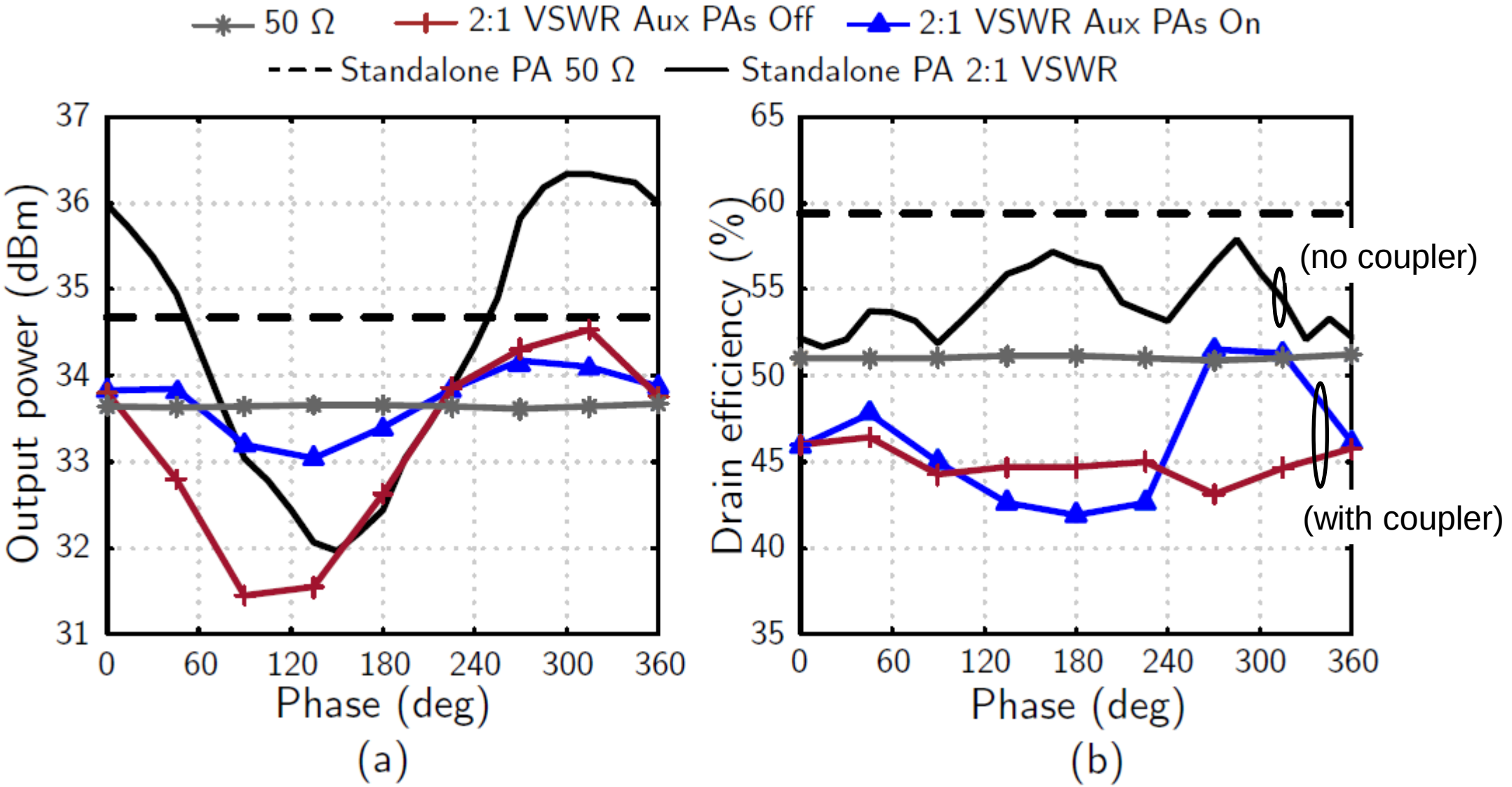

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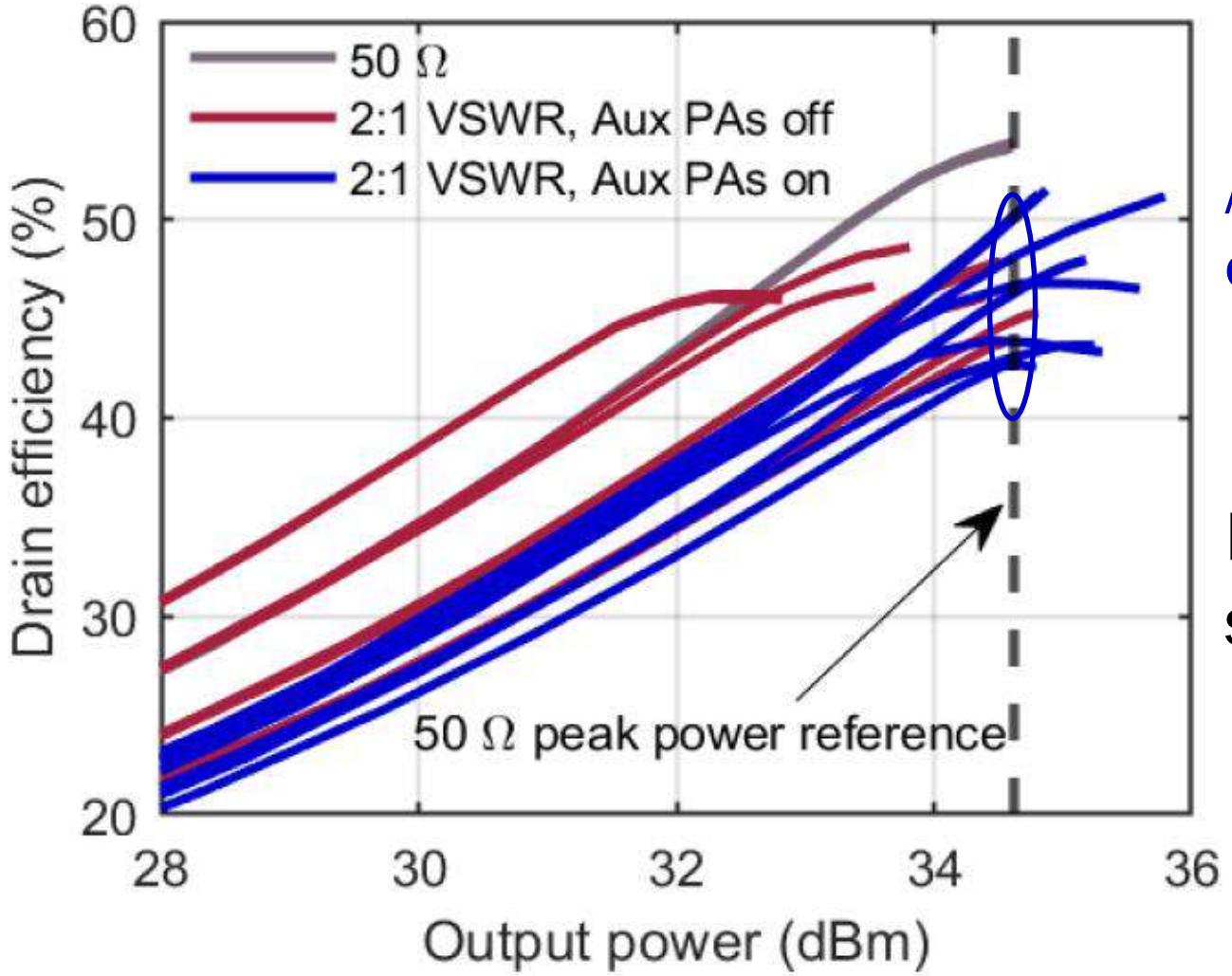

All blue curves reach the output power target!

Load changes in 45^o phase steps on the 2:1 VSWR circle

Conclusion

- Proposed an active load adjustment technique to recover the PA performance due to load mismatch
- Extracts maximum output power and efficiency from the main PA
- No supply voltage (VDD) adjustment is required. Only active devices.
- Demonstrated output power and efficiency enhancement on the 2:1 VSWR circle

Thank you very much for your attention!

Questions?

Comments?

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