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# One-dimensional reconfigurable three-stage Doherty power amplifier with load mismatch resilience

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**Key words:** Doherty power amplifier; Load mismatch; One-dimensional (1D) control; Reconfigurable; Three-stage

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# Motivation

Targeting the inadequacy of current analysis on the resilience of three-stage Doherty power amplifiers (DPAs) under load mismatch conditions and the complexity of traditional resilience enhancement solutions, a novel reconfigurable three-stage DPA architecture based on exceptionally simple circuits and a one-dimensional (1D) control method is proposed, which can significantly enhance the resilience to load mismatch.

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# Main idea

- A novel three-stage DPA architecture is proposed which provides a large high-efficiency range against load mismatch, through the utilization of a 1D control method.
- A simple 1D control circuit is introduced to enhance mismatch resilience by changing reactance conditions at a single control port in the proposed load modulation network (LMN).

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# Method

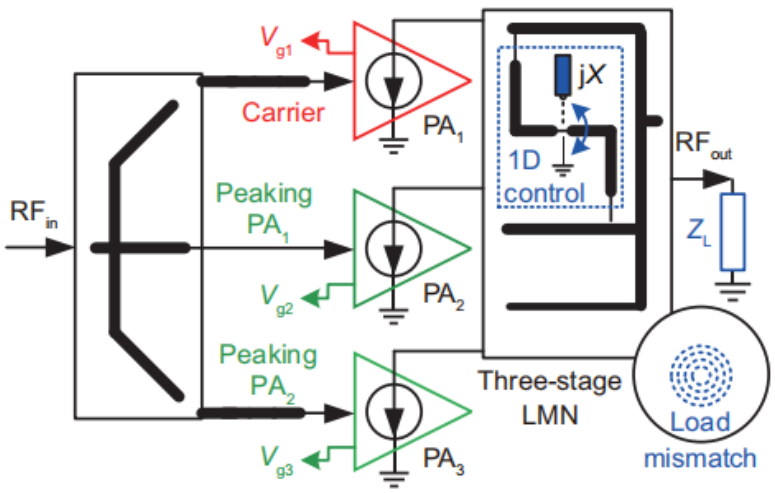



**Fig. 1 The proposed three-stage DPA architecture (RF: radio frequency)**

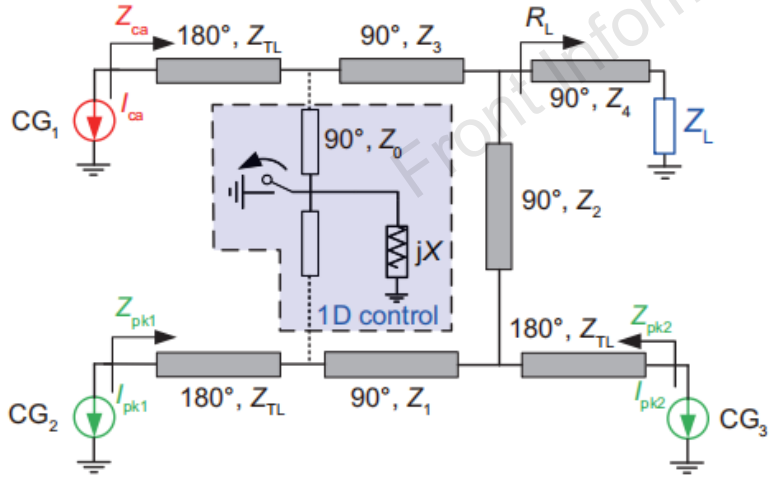



**Fig. 2 Theoretical block diagram of the proposed sub-network (TL: transmission line)**

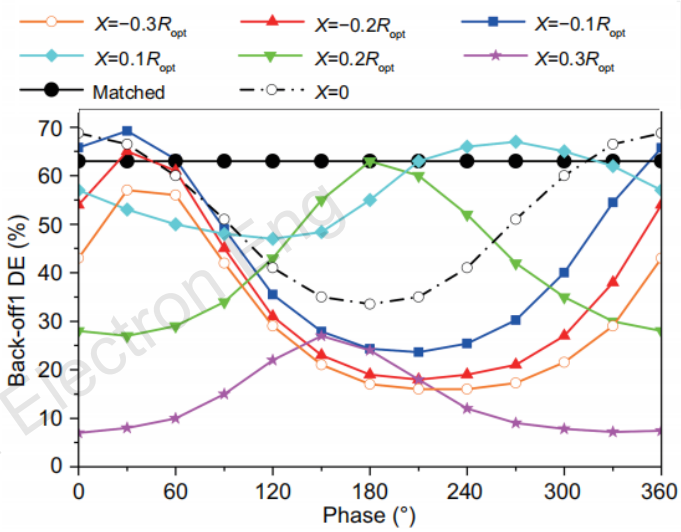



**Fig. 6 Theoretical DE at OBO1 versus phase with different $X$ values of 1D control**

$$\hat{\boldsymbol{Z}}_2 = R_{\text{opt}} \begin{bmatrix} 0 & \frac{-\mathrm{j}2}{1+\beta} & 0 & 0 \\ \frac{-\mathrm{j}2}{1+\beta} & 0 & \frac{+\mathrm{j}}{1+\beta} & \frac{-\mathrm{j}\frac{5}{2\sqrt{3}}}{1-\beta} \\ 0 & \frac{+\mathrm{j}}{1+\beta} & 0 & \frac{-\mathrm{j}\frac{5}{4\sqrt{3}}}{\beta} \\ 0 & \frac{-\mathrm{j}\frac{5}{2\sqrt{3}}}{1-\beta} & \frac{-\mathrm{j}\frac{5}{4\sqrt{3}}}{\beta} & 0 \end{bmatrix}, \tag{11}$$

where $\beta = \frac{2x}{z_0^2}$, and $z_0$ and $x$ are the normalized values of $Z_0$ and $X$ for $R_{\text{opt}}$, respectively.

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# Method

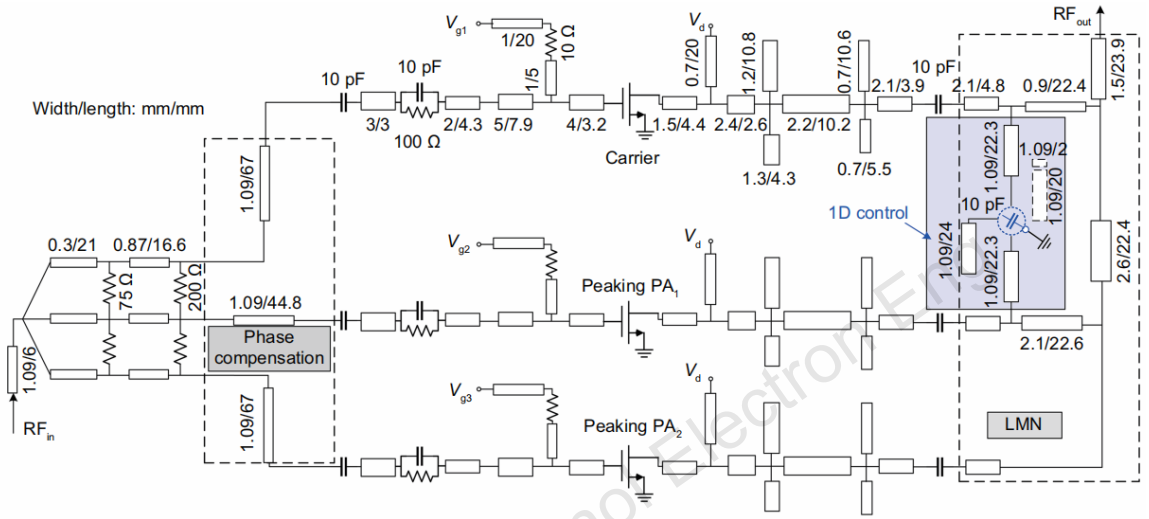



Fig. 10 Circuit details of the proposed three-stage DPA

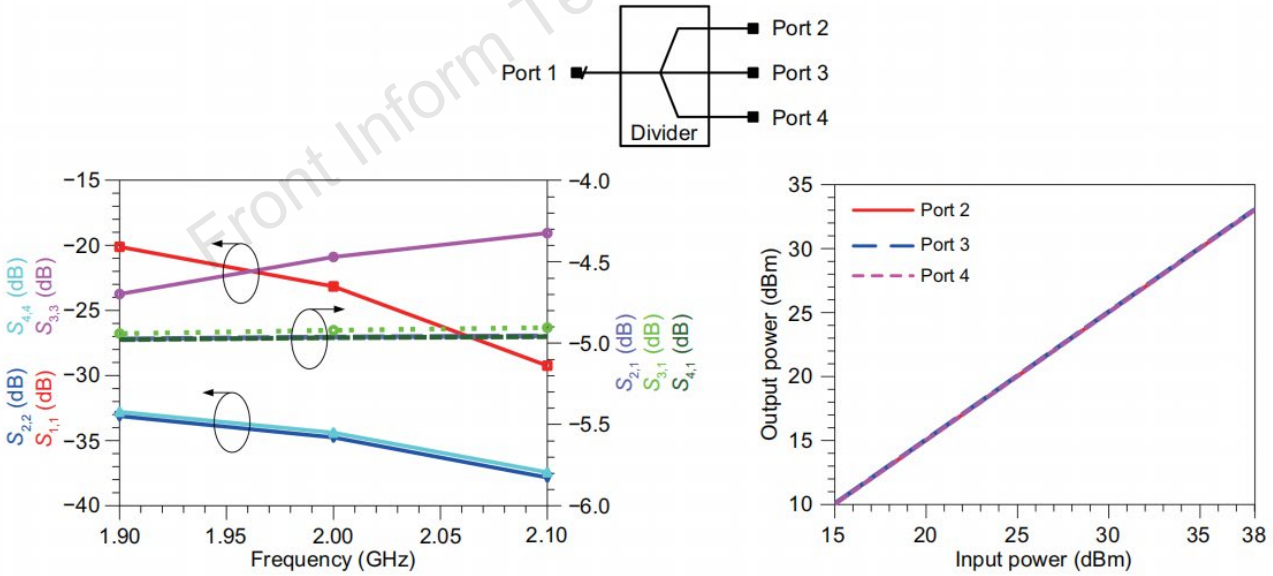



Fig. 11 Simulated *S*-parameters and output power versus input power of the three-way divider (References to color refer to the online version of this figure)

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# Results

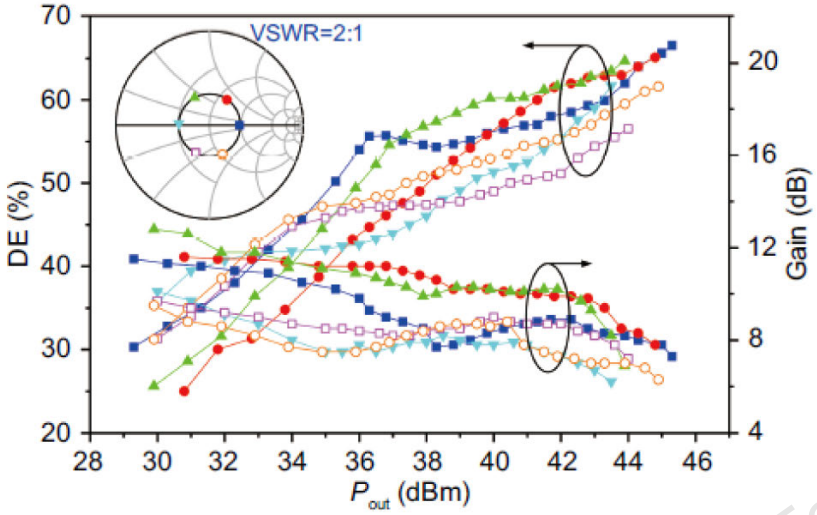



**Fig. 20 Measured DE and gain versus output power under different load mismatch conditions**

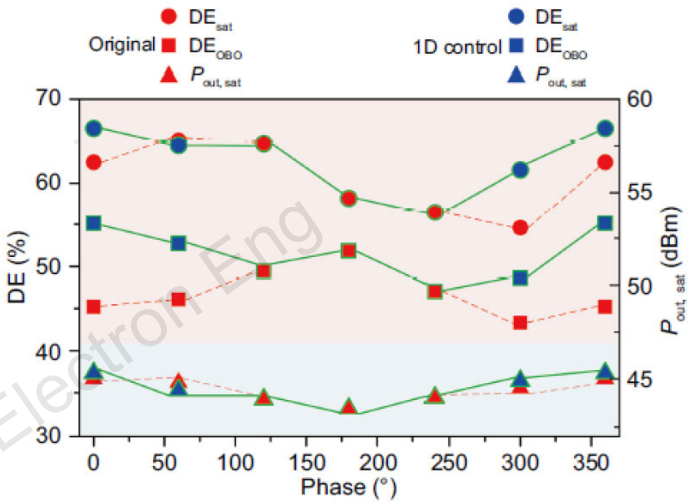



**Fig. 21 Measured DE and saturated output power versus phase under different load mismatch conditions when VSWR=2:1 (References to color refer to the online version of this figure)**

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**Table 1 Performance comparison of recently published PAs with load mismatch adaptability**

| Reference | Frequency (GHz) | Control variable | Load $Z_0$=50 (Ω) $P_{sat}$ (dBm) | $DE_{sat}$ (%) | OBO (dB) | DE* (%) | VSWR=2:1 $P_{sat}$ (dBm) | $DE_{sat}$ (%) | OBO (dB) | DE* (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| This work | 2 | 1D | 45.2 | 73.1 | 9.5 | 51.0 | 43.4–45.3 | 56.5–66.5 | 8 | 47.0–55.1 |
| Gonçalves et al. (2022) | 3.6 | 2D | 43.5 | 64 | 5 | 53 | 42.6–43.4 | 49–64 | 5 | 35–46 |
| Shi et al. (2023) | 2.4 | 3D | 43.4/43.7 | 69.1/70.8 | 6 | >60 | 41.5–43.3 | 52.8–60.7 | 6 | 50.1–62.5 |
| Guo et al. (2023) | 2.1 | 1D | 42** | 72** | 10 | 64** | 39.1–40.9 | 60.1–66.4 | 10 | 43.0–62.8 |
| Pang et al. (2024) | 2.0 | 3D | 46.4/46.7 | 70.3/72.2 | 9 | 62.8/60.7 | 44.8–46.3 | 50.2–65.8 | 9 | 47.8–56.7 |

* At 8 dB OBO; ** graphically estimated. $P_{sat}$: saturation output power; $DE_{sat}$: saturation drain efficiency

# Conclusions

In this paper, the load mismatch resilience of three-stage DPA is analyzed based on nonlinear current models. To further improve the mismatch resilience, a novel three-stage DPA with a very simple 1D circuit control method is then proposed. A DPA operating at 2 GHz is designed to verify the proposed method and architecture. The designed DPA has a 9.5 dB OBO DE of 51% for matched load and maintains DE of 47%–55.1% at 8 dB OBO against load mismatch when VSWR=2:1. The proposed three-stage DPA architecture with 1D control offers a brand-new solution to provide load mismatch insensitivity with a very simple circuit configuration.

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