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Design and optimization of a high-efficiency current-biased reverse load modulated power amplifier with impedance and performance constraints

Key words: Current-biased reverse load-modulation; Broadband; High efficiency; Power amplifier; Optimization

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Motivation

- Conventional Doherty power amplifiers typically rely on a quarter-wavelength ($\lambda/4$) impedance transformer to realize load modulation. However, dispersion associated with this element limits their broadband capability, making it difficult to meet the growing demand for broadband, high-efficiency operation in modern communication systems. Reverse load-modulation can eliminate the need for the $\lambda/4$ structure and extend the operating bandwidth at power back-off.
- Although evolutionary computation has been widely applied to RF optimization due to its excellent global search ability, the current-biased reverse load-modulation power amplifier (CB-RLM PA) has a unique load-modulation mechanism, and how to apply this methodology effectively to the design of CB-RLM PAs remains to be explored.

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Main idea

- Impedance-constraint circles are used to construct impedance trajectory constraints under both saturated and power-back-off (PBO) operating conditions, ensuring that the load-modulation behavior is feasible and consistent over the wide band. Meanwhile, the in-band deviations of saturated efficiency, 6-dB PBO efficiency, and saturated output power are incorporated into the objective function.
- A decomposition-based multi-objective evolutionary algorithm is then employed to automatically optimize the parameters of the matching network, and a high-efficiency PA prototype is finally demonstrated over a 0.6–1.8-GHz bandwidth.

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Method

1. An impedance constraint circle is constructed on the Smith chart, centered at the target impedance Z_c with radius r_g. This circle defines the allowable deviation for the matching network output impedance. During optimization, the distance between the impedance obtained by the matching network Z_{MN} and the target impedance Z_{center} is defined as follows:

$$y_r = \left| \frac{Z_{MN} - Z_{center}}{Z_{MN} + \mathrm{conj}(Z_{center})} \right| \quad (1)$$

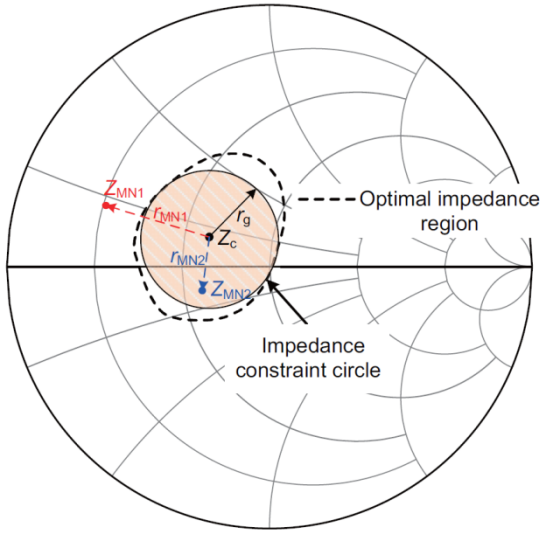


Fig. 1 Impedance constraint circle on the Smith chart

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Method (Cont'd)

The impedance error at different frequencies f is further defined as

$$E_{\mathrm{r}}(f) = \max(0, (y_{\mathrm{r},f} - r_{\mathrm{g},f})) \tag{2}$$

Thus, the impedance constraint function F_1 can be obtained:

$$F_1 = \sum_{f \in B} \max\left(E_{\mathrm{r,PBO}}(f), E_{\mathrm{r,SAT}}(f)\right) \tag{3}$$

2. To evaluate the performance of CB-RLM PA, we define in-band normalized performance error functions for efficiency and output power under the two critical and commonly used operating states in load-modulated PA design, namely saturation and PBO. The in-band errors are defined as follows, where the desired performance targets are $\mathrm{DE}_{\mathrm{PBO}}$, $\mathrm{DE}_{\mathrm{SAT}}$, and P_{SAT}, respectively:

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Method (Cont'd)

$$E_{\mathrm{DE,PBO}} = \max\left(0, \frac{\mathrm{DE}_{\mathrm{PBO}} - \min\limits_{f\in B}(y_{\mathrm{DE}_{\mathrm{PBO}}})}{\mathrm{DE}_{\mathrm{PBO}}}\right)$$

$$E_{\mathrm{DE,SAT}} = \max\left(0, \frac{\mathrm{DE}_{\mathrm{SAT}} - \min\limits_{f\in B}(y_{\mathrm{DE}_{\mathrm{SAT}}})}{\mathrm{DE}_{\mathrm{SAT}}}\right) \quad (4)$$

$$E_{P_{\mathrm{out}}} = \max\left(0, \frac{P_{\mathrm{SAT}} - \min\limits_{f\in B}(y_{P_{\mathrm{SAT}}})}{P_{\mathrm{SAT}}}\right)$$

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The above three performance metrics constitute the performance objective F_2:

$$F_2 = E_{\mathrm{DE,PBO}} + E_{\mathrm{DE,SAT}} + E_{P_{\mathrm{out}}} \quad (5)$$

Method (Cont'd)

3. Next, MOEA/D-ANGR from Ni et al. (2025a) was employed in conjunction with HB simulation for optimization.

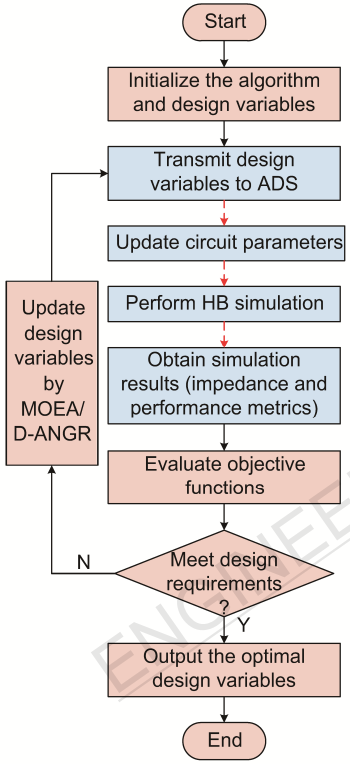


Fig. 2 Flowchart of the proposed method

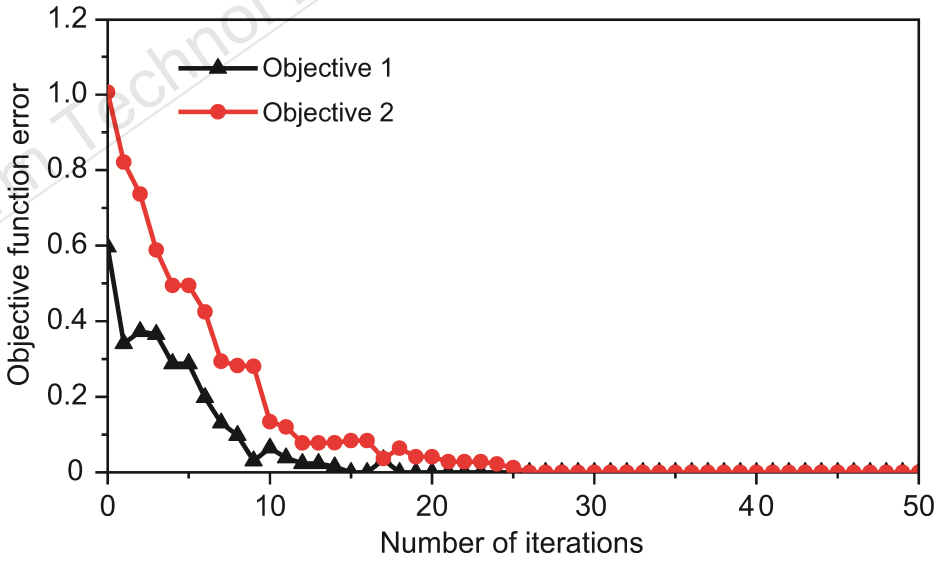


Fig. 3 Objective function error versus the number of iterations

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Major results

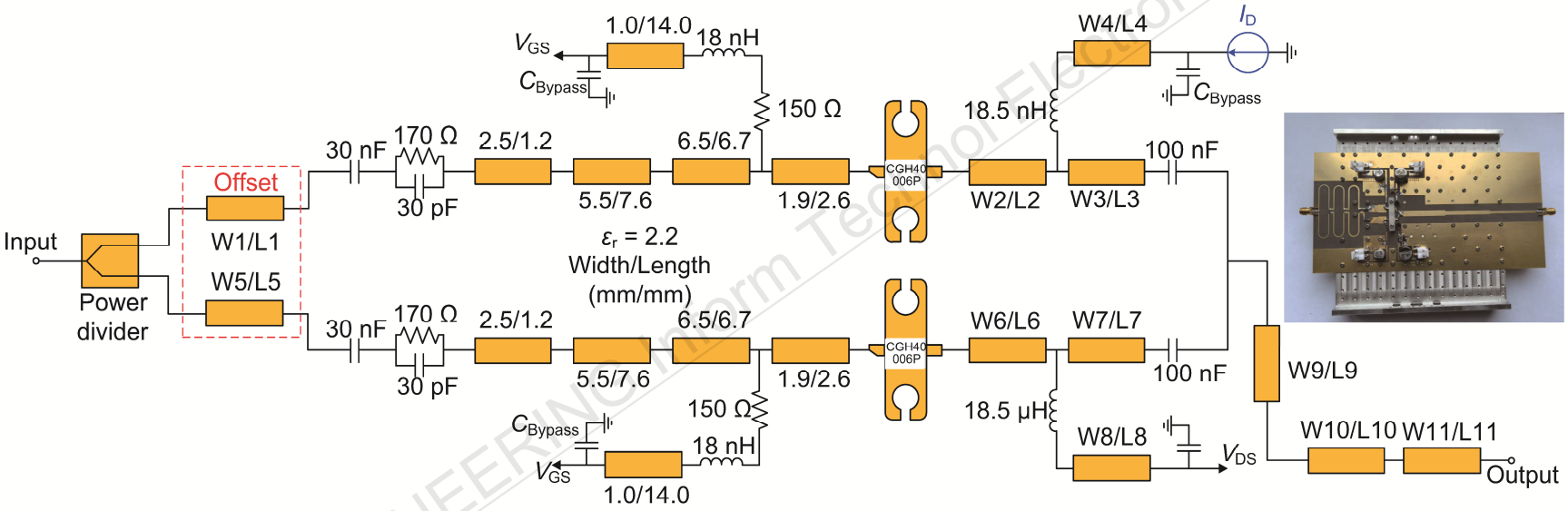


Fig. 4 Schematic of the current-biased reverse load-modulation power amplifier to be optimized

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Major results (Cont'd)

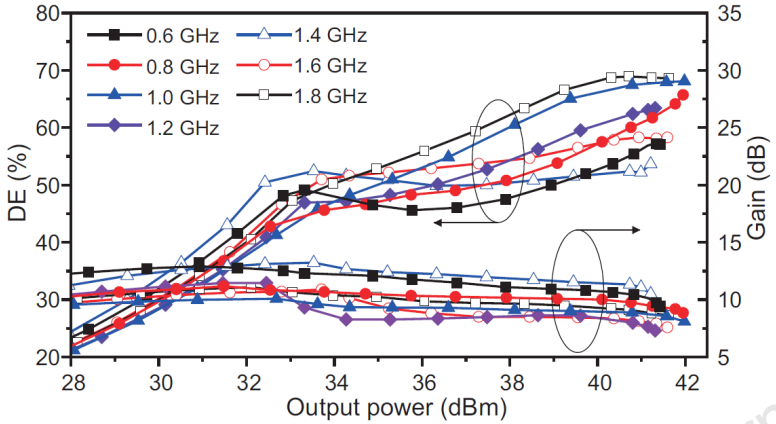


Fig. 5 Simulated efficiency and gain versus output power at various frequencies

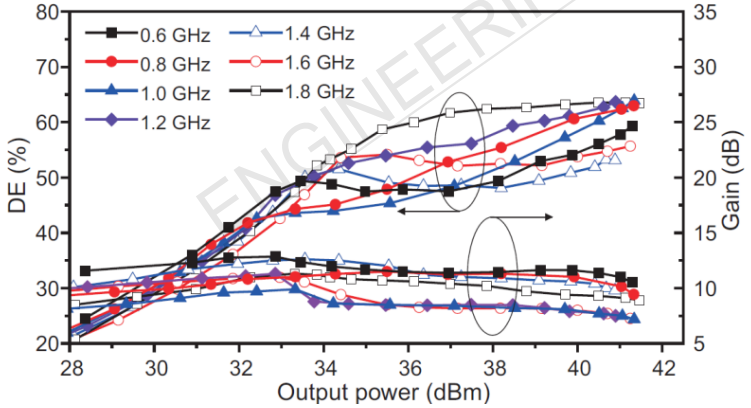


Fig. 6 Measured efficiency and gain versus output power

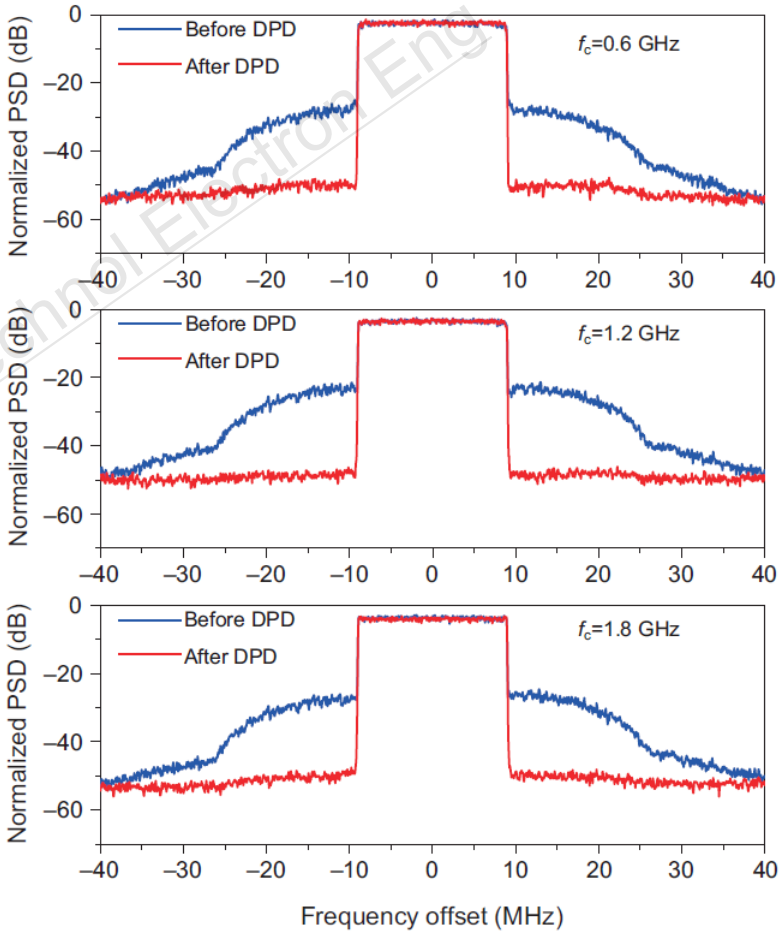


Fig. 7 Measured spectra with and without DPD at three frequencies

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Conclusions

- An optimization framework is proposed for wideband CB-RLM power amplifier design, where multi-state impedance-trajectory constraints and in-band performance deviations are jointly formulated as the objective function.
- To validate the proposed method, a 0.6–1.8-GHz CB-RLM PA prototype is designed, fabricated, and measured.
- The fabricated PA provides a saturated output power of 40.9–41.5 dBm across the operating band, achieving a DE of 53.2%–63.9% at saturation, 45.4%–58.7% at 6-dB PBO, and 43.6%–53.2% at 8-dB PBO, demonstrating wideband high-efficiency performance.

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