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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.

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.

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:

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

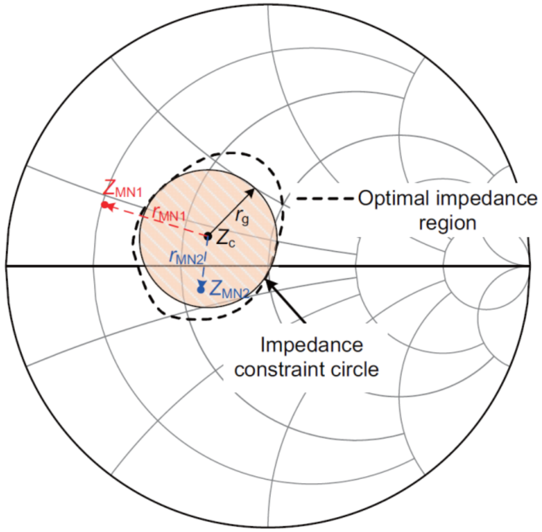


Fig. 1 Impedance constraint circle on the Smith chart

Method (Cont’d)

The impedance error at different frequencies *f* is further defined as

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

Thus, the impedance constraint function F_1 can be obtained:

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

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:

Method (Cont'd)

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

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

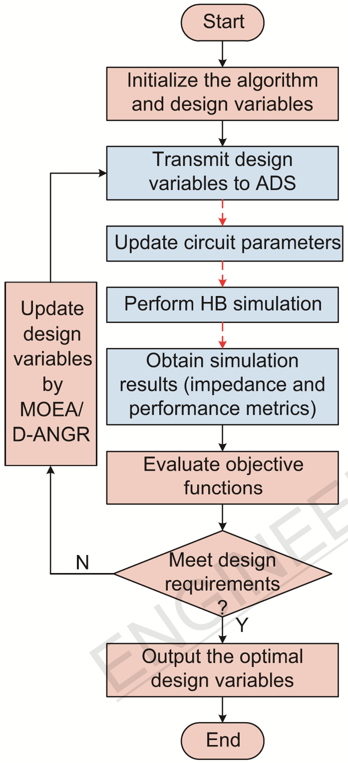
$$E_{P_{\mathrm{out}}} = \max\left(0, \frac{P_{\mathrm{SAT}} - \min\limits_{f \in B}(y_{P_{\mathrm{SAT}}})}{P_{\mathrm{SAT}}}\right)$$

The above three performance metrics constitute the performance objective F_2:

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

Method (Cont’d)

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



Start

Initialize the algorithm and design variables

Transmit design variables to ADS

Update circuit parameters

Perform HB simulation

Obtain simulation results (impedance and performance metrics)

Evaluate objective functions

Meet design requirements ?

N

Update design variables by MOEA/ D-ANGR

Y

Output the optimal design variables

End

Fig. 2 Flowchart of the proposed method

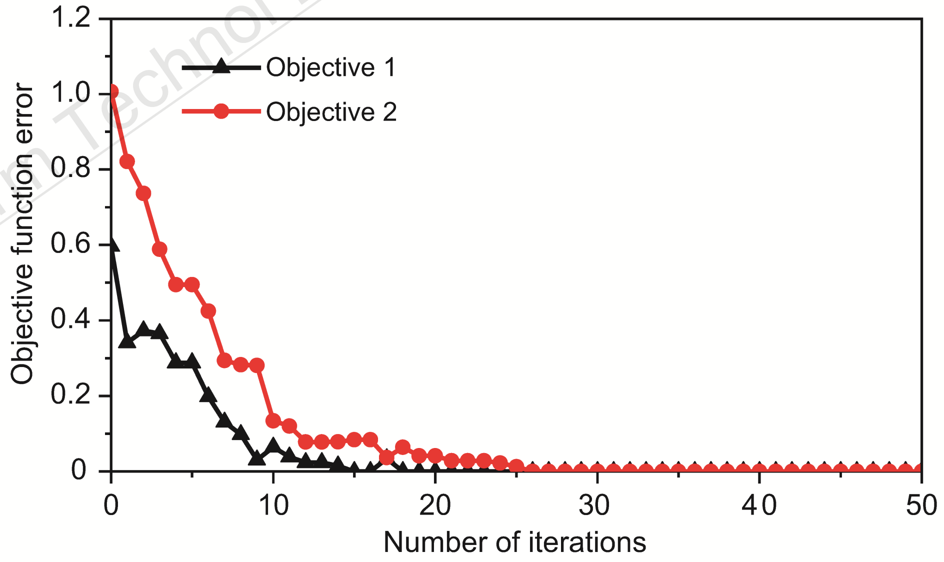


Fig. 3 Objective function error versus the number of iterations

Major results

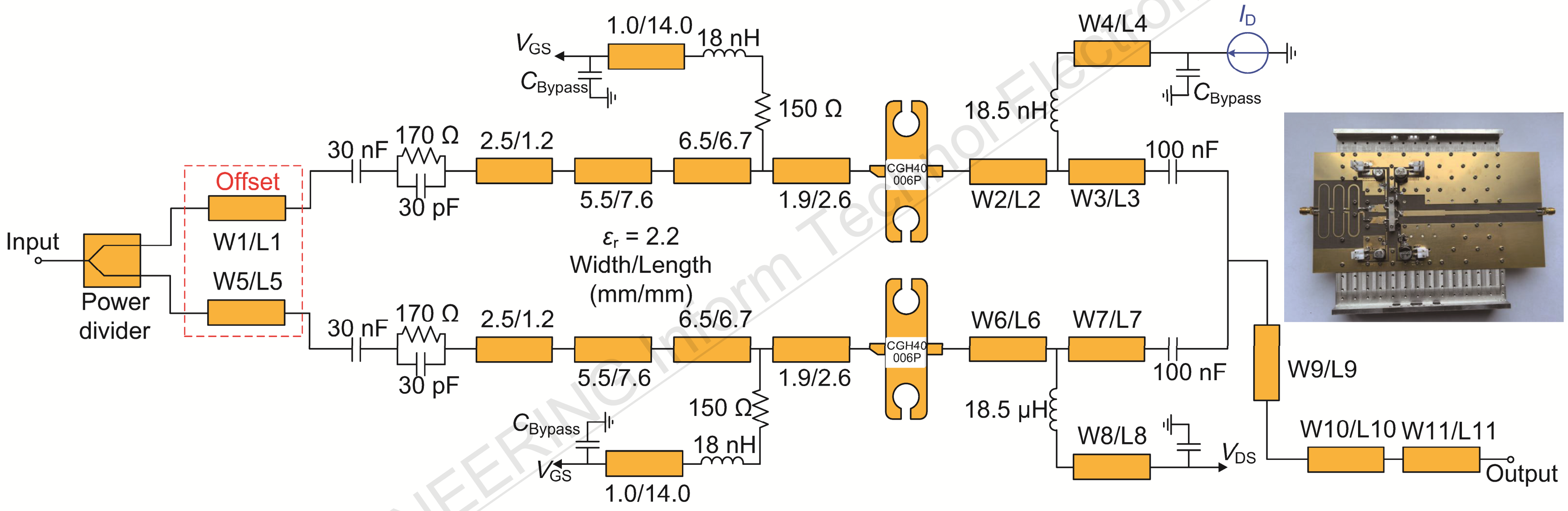


Fig. 4 Schematic of the current-biased reverse load-modulation power amplifier to be optimized

Major results (Cont’d)

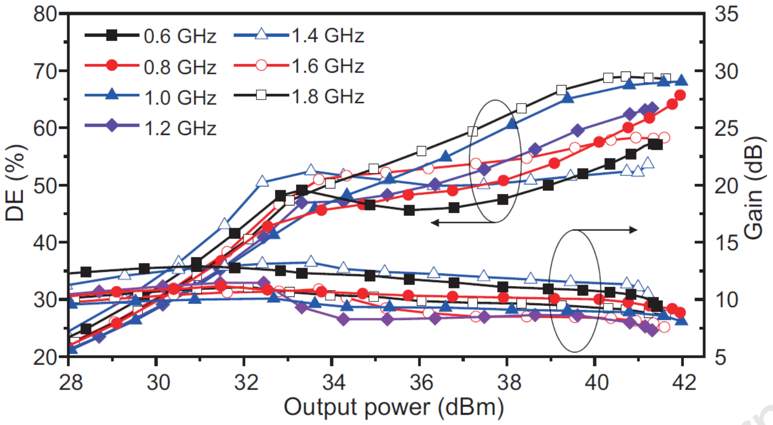


Fig. 5 Simulated efficiency and gain versus output power at various frequencies

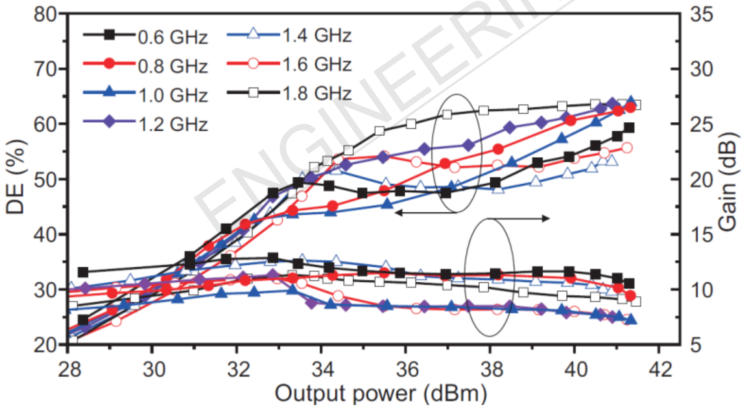


Fig. 6 Measured efficiency and gain versus output power

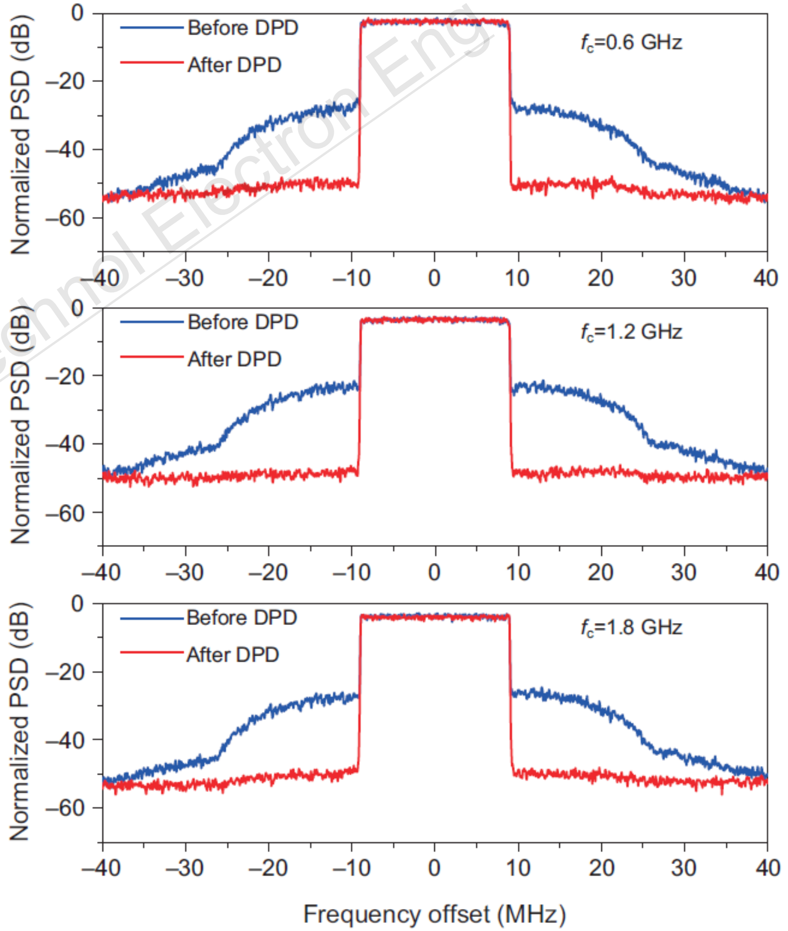


Fig. 7 Measured spectra with and without DPD at three frequencies

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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