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Broadband and asymmetrical Doherty based on circuit parameter solution space

Key words: Doherty power amplifier; Output matching network; Parameter solution space

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Motivation

With the rapid development of the fifth-generation (5G) wireless network technology, the design of Doherty power amplifier (DPA) has become one of the key technologies in the field of wireless communications. However, traditional methods for designing DPAs are often theoretically complex and difficult to implement, limiting their widespread application. Therefore, a simple and universally applicable design method for DPAs is needed to meet the growing market demand.

Main idea

This paper proposes a novel design method for DPAs by traversing the parameters of the DPA's output matching network to find a parameter solution space that achieves high efficiency. Based on this parameter solution space, the output matching network of carrier power amplifier (PA) (OMN_c), the output matching network of peaking PA (OMN_p), and post-matching network (PMN) of the DPA are designed separately, and combined together to achieve Doherty's functionality. This method is suitable for different types of DPA designs, demonstrating strong universality, with a clear and concise design process that is easy to understand and master.

Basic principle

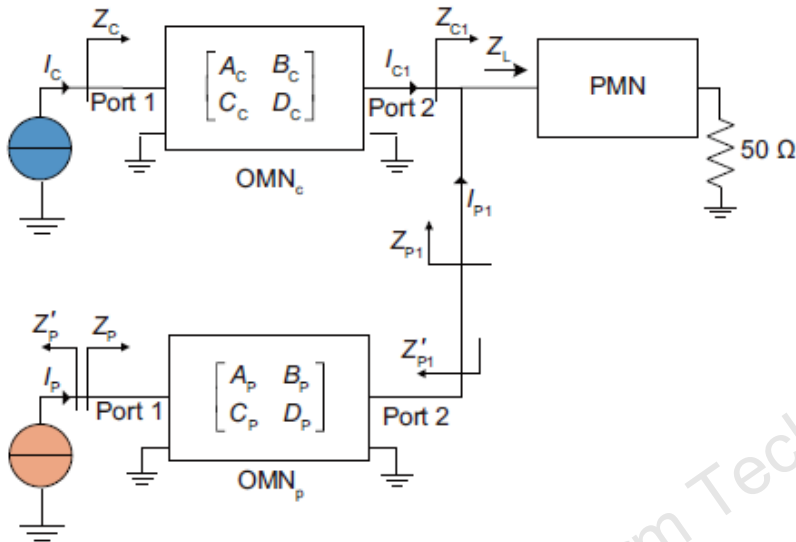
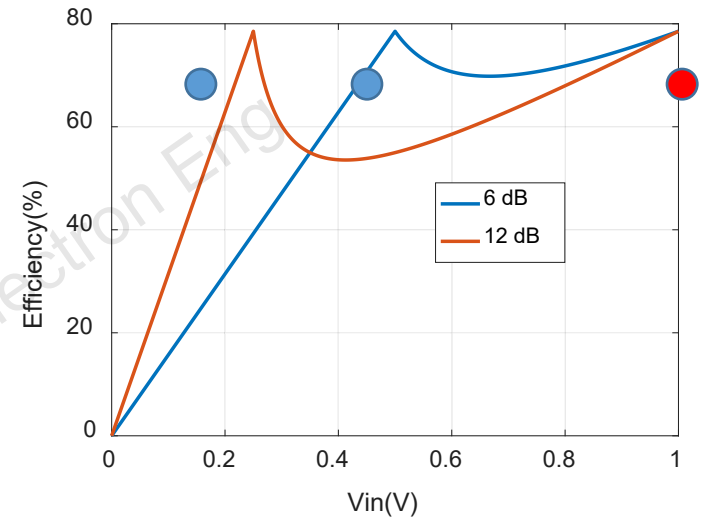


Fig. 1 Topology of the simplified traditional Doherty power amplifier

DPA's principle is to increase the impedance of the carrier amplifier at the current source plane at the power back-off (OBO) level, causing the carrier PA voltage to saturate early, thus increasing the efficiency.



The efficiency curve of the DPA

- OBO state: Peak PA is just turned on, and carrier PA is not saturated.
- Saturation state: Peak PA is just turned on, and carrier PA is not saturated. The OBO level is changed by changing the current ratio of the two PAs.

Parameter solution space acquisition

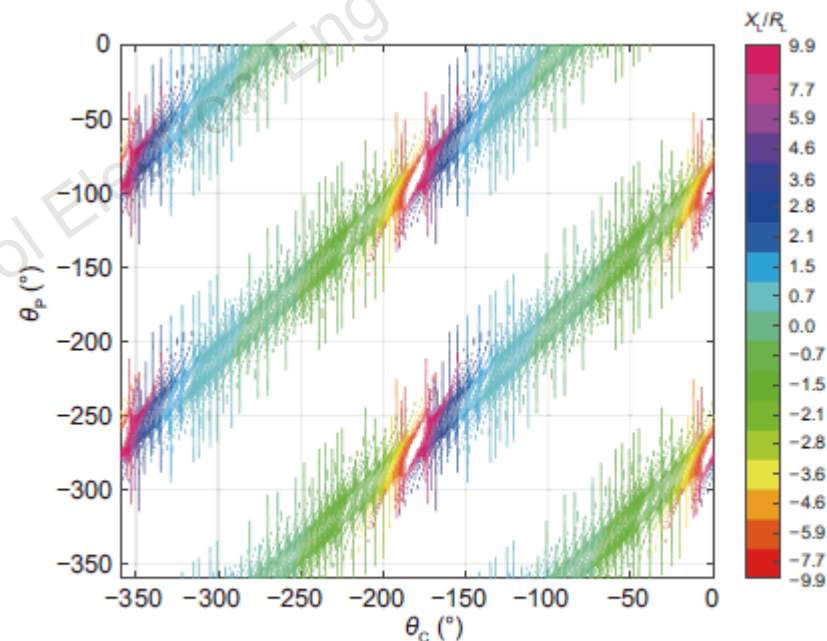
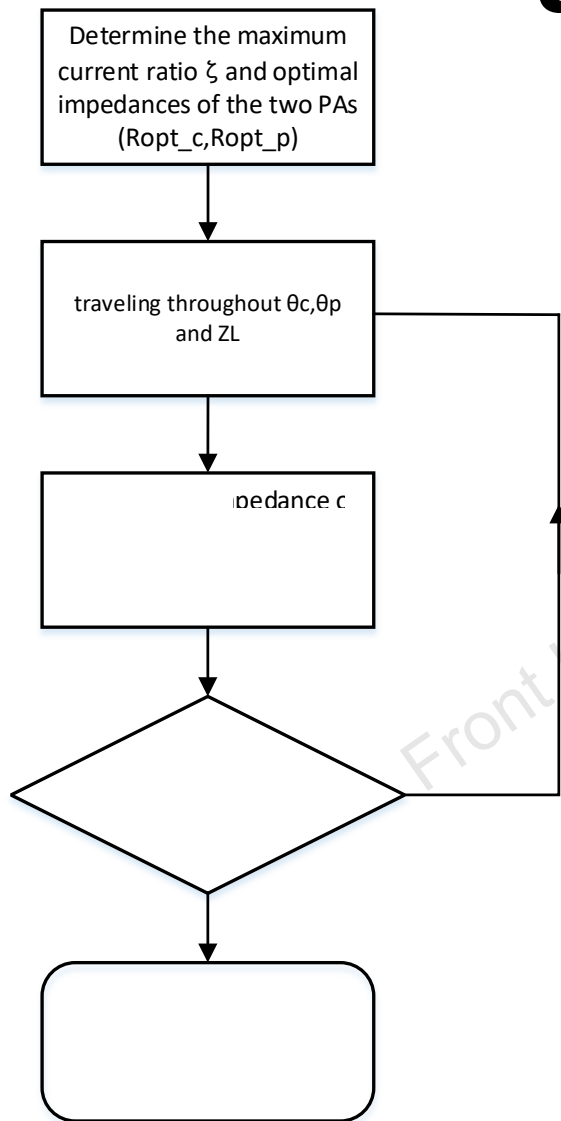


Fig. 4 The parameter solution space $[\theta_C, \theta_P, Z_L]$

Parameter solution space acquisition

At the OBO state, the fundamental impedance of Z_C is in the continuous class-J mode. Therefore, the designed DPA can achieve high efficiency at both saturation and OBO states.

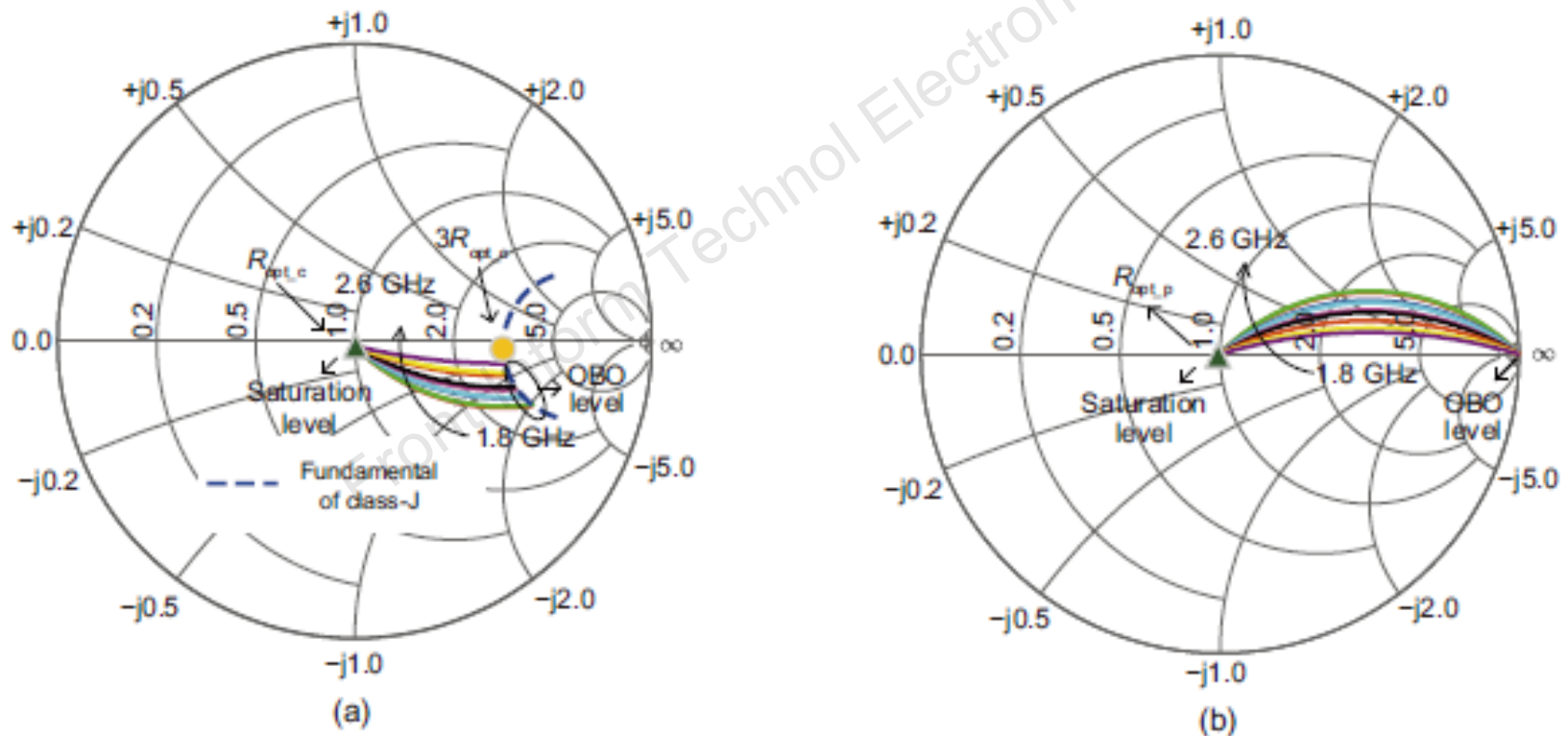


Fig. 3 Theoretical trajectories of Z_C (a) and Z_P (b) from the output OBO to the saturation level across the working frequency band.

Parameter solution space acquisition

Selecting parameters such that the phase parameter varies linearly with frequency

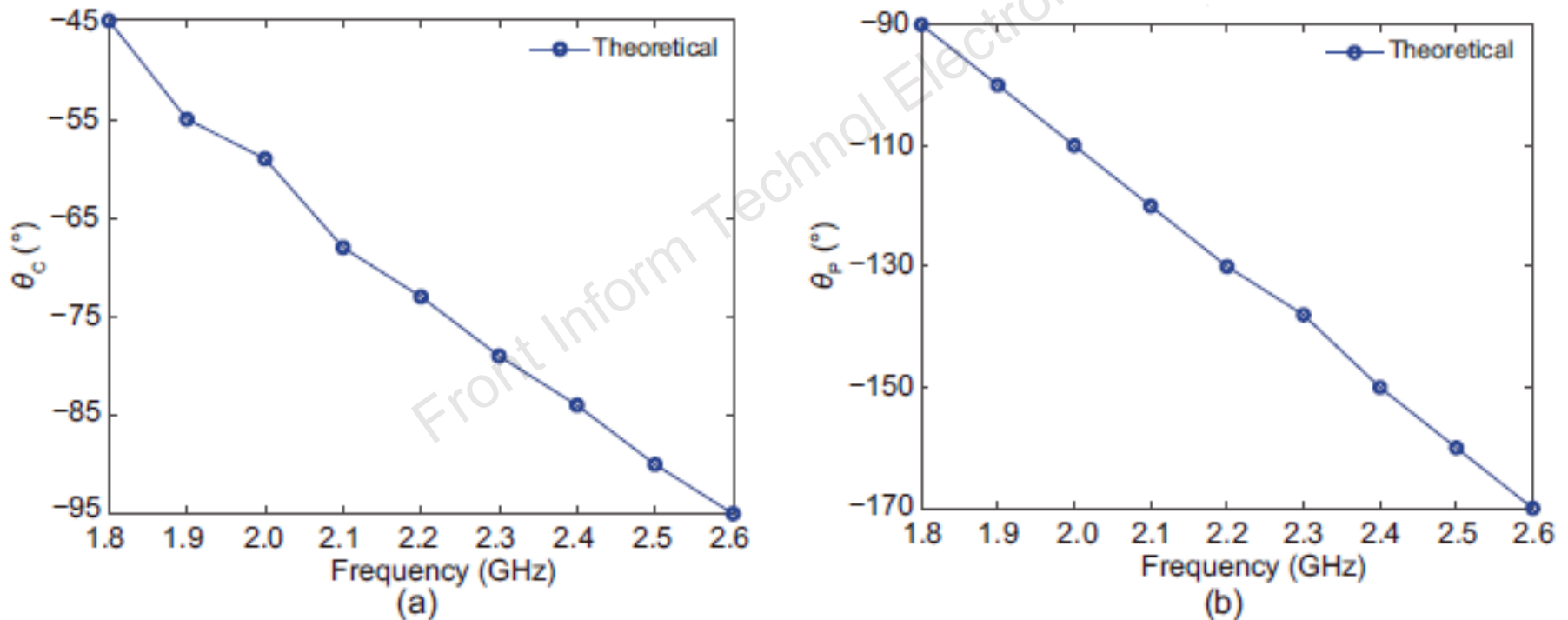


Fig. 5 Theoretical θ_c of OMN_c over the working frequency band (a) and theoretical θ_p of OMN_p over the working frequency band (b)

Parameter solution space acquisition

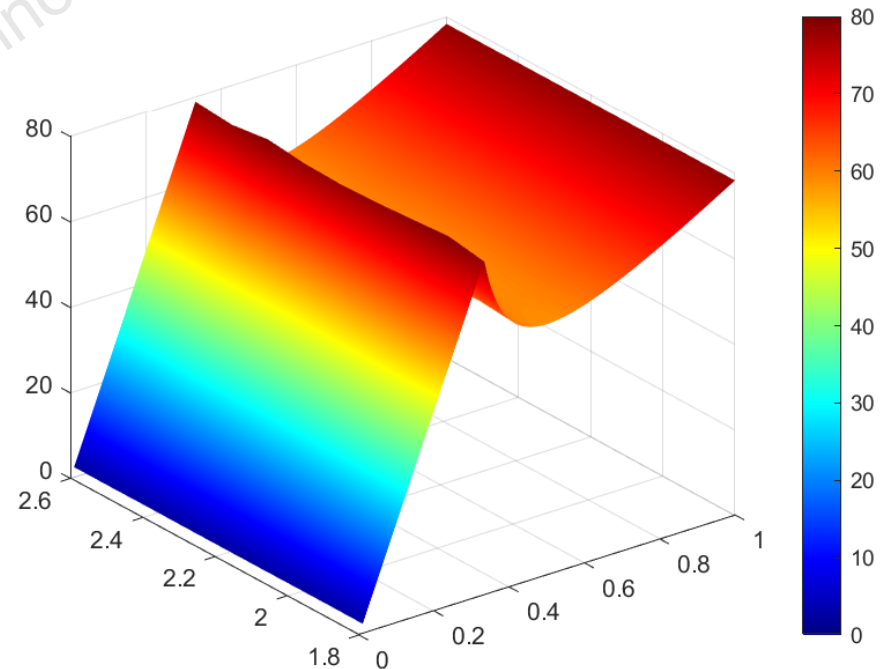
By simulating the ideal DPA based on the selected parameters in the ADS simulation software, it can be found that high efficiency can be achieved at both the saturation and OBO states.

Selecting the parameters of each frequency point within a frequency band in the solution space

Table 1 Theoretical parameters at frequencies over 1.8–2.6 GHz

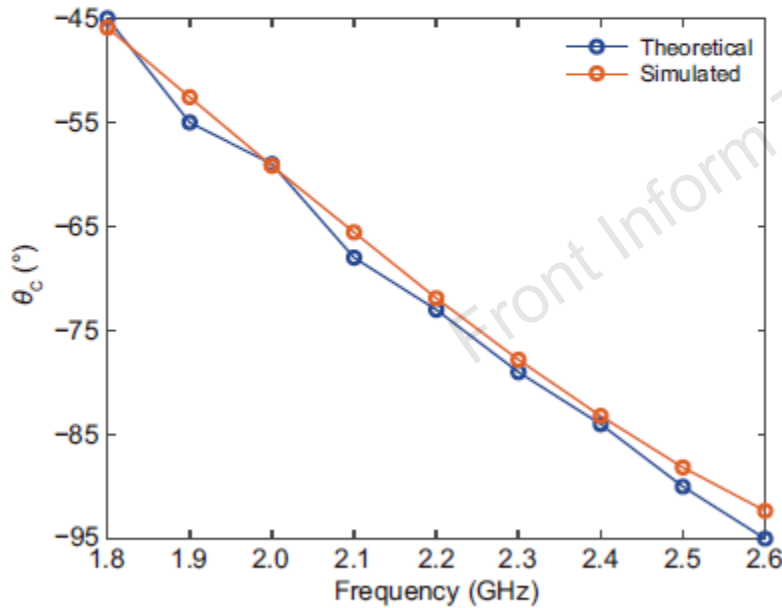
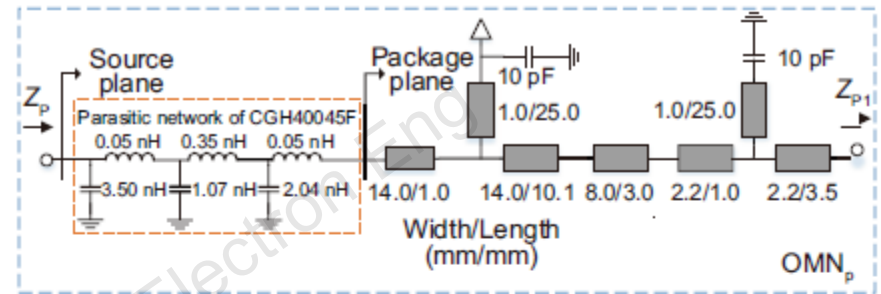
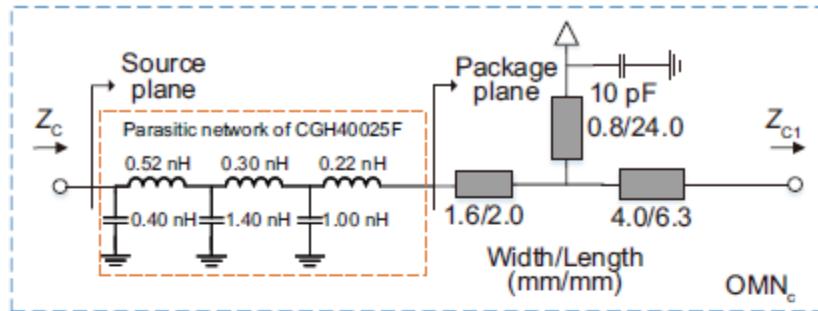
Frequency (GHz)	θ_C (°)	θ_P (°)	X_L/R_L
1.8	-45	-90	-1.00
1.9	-55	-100	-0.69
2.0	-59	-110	-0.60
2.1	-68	-120	-0.40
2.2	-73	-130	-0.31
2.3	-79	-138	-0.19
2.4	-84	-150	-0.10
2.5	-90	-160	0
2.6	-95	-170	0.10

$$R_L = \frac{1}{3} R_{\text{opt}_c}$$

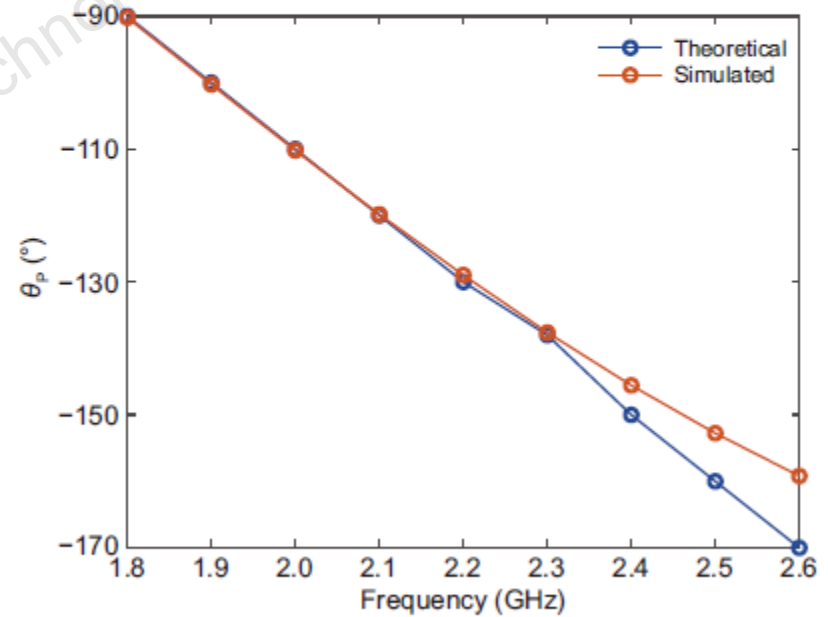


The ideal efficiency curve

Design



(a)



(b)

Fig. 6 Schematic (top) and phase parameter (bottom) of the output matching network: (a) OMN_c; (b) OMN_p.

Design

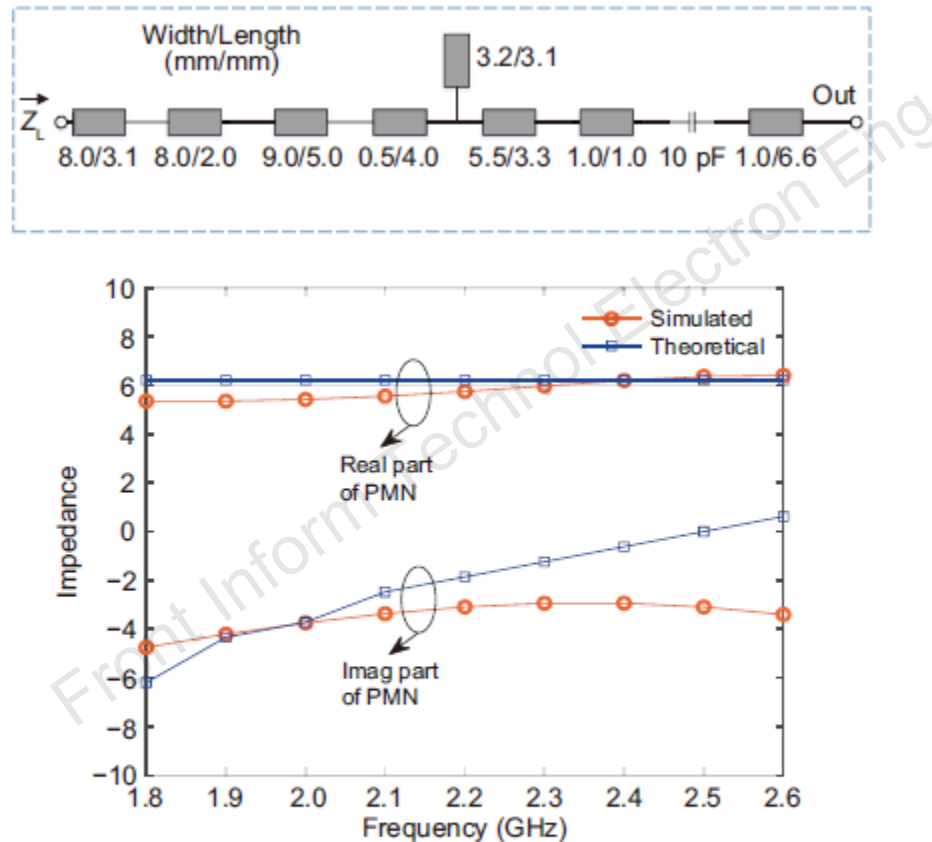


Fig. 7 Schematic of the post-matching network (top) and its input impedance across the working frequency band (bottom). References to color refer to the online version of this figure

Major results

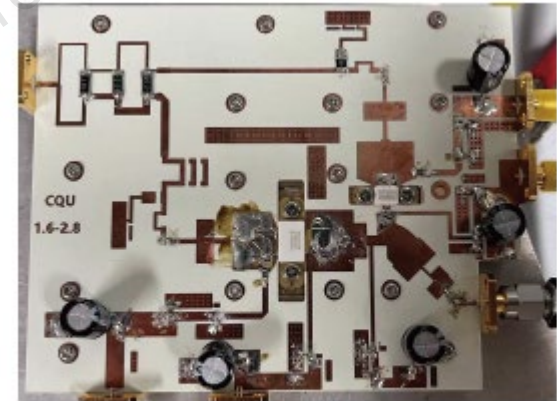
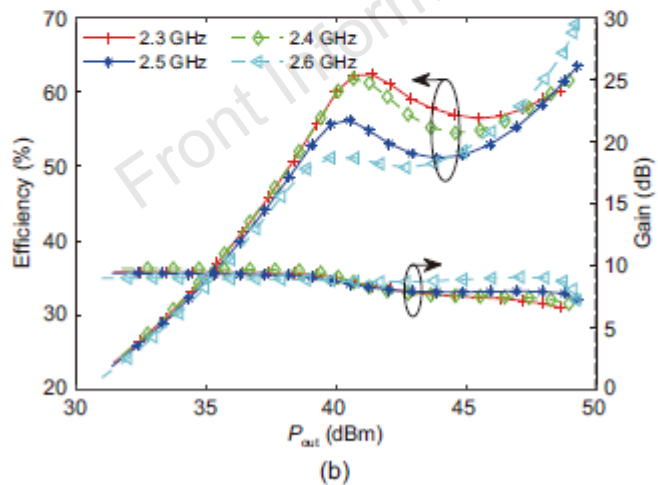
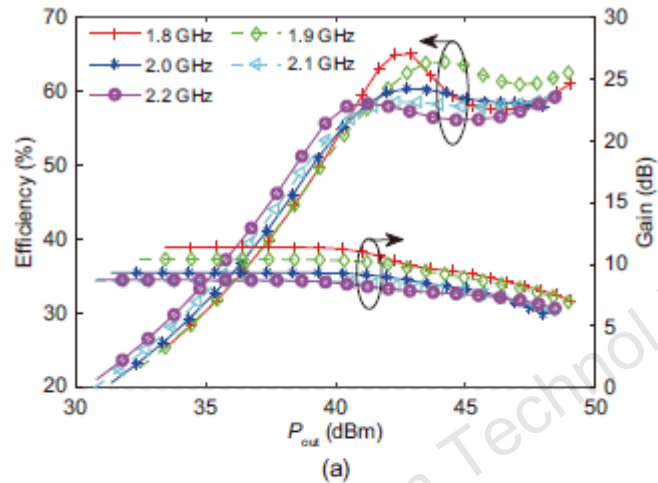


Fig. 11 Photograph of the fabricated Doherty power amplifier

Fig. 10 Simulated drain efficiencies and gains of the designed Doherty power amplifier over output power: (a) 1.8–2.2 GHz; (b) 2.3–2.6 GHz

Major results

Table 2 Performance comparison

Reference	Technique	Topology	Frequency (GHz)	FBW (%)	Power (dBm)	OBO (dB)	DE@OBO (%)	DE@SAT (%)	PAE@SAT (%)	ACPR (dBc)
Choi et al. (2021)	Smith chart	Asy.	1.68	–	43.5	9.5	54.7	56.4	53.6	–27.3 (1.68 GHz)
Li M et al. (2022)	Phase compensation	Asy.	1.55–2.2	35	45.2–47.3	11.1–13.2	42.2–52.1	47–62.7	33.1–51	–29.1 (2 GHz)
Zhou et al. (2022)	Phase compensation	Sym.	1.6–1.95	19.7	42.7–43.5	9–9.5	62.5–67.5	64.6–70.9	56.5–62.9	<–22
Li C et al. (2020)	Phase compensation	Sym.	1.9–2.4	23.3	44.2–49.7	8.5–9	44.2–49.7	65.2–71.8	52.8–56	–31.1 (2.4 GHz)
Xu et al. (2021)	Modified LMN	Asy.	1.4–2.5	56.4	44–45.9	9	44.6–54.6	61–75.5	53.2–66	–29.8 (1.6 GHz)
This work	Parameter solution space	Asy.	1.8–2.6	36.4	46.9–48.8	9.5	42.7–56.4	45.8–71.1	36.6–49.7	–33.6 (2.5 GHz)

ACPR: adjacent channel power ratio; Asy.: asymmetrical; DE: drain efficiency; FBW: fractional bandwidth; LMN: load modulation network; OBO: output power back-off; PAE: power-added efficiency; Power: saturation output power; Sym.: symmetrical; SAT: saturation state

Conclusions

In this paper, the parameter solution space that can achieve high efficiency at both OBO state and saturation state is proposed. To validate the rationality of the parameter solution space, an asymmetric DPA operating at 1.8–2.6 GHz has been designed. The DPA can achieve an efficiency of 42.7%–56.4% and 45.8%–71.1% at the 9.5-dB OBO level and saturation level, respectively. The saturation output power is 46.9–48.8 dBm with a saturated gain of 5.5–8.0 dB. This validates the rationality of this design method.



Cheng BI received the B.S. degree from the School of Electronic Engineering, Xi'an University of Posts & Telecommunications, Xi'an, China, in 2022. He is currently pursuing the M.S. degree at the School of Microelectronics and Communication Engineering, Chongqing University, Chongqing, China. His current research interests include the design of broadband power amplifier and the linearization of power amplifier.



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