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Design of a wideband symmetric large back-off range Doherty power amplifier based on impedance and phase hybrid optimization

Key words: Back-off power range; Doherty power amplifier; Fragment-type structure; Impedance–phase hybrid function

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Motivation

1. Conventional symmetrical Doherty power amplifiers (DPAs) achieve efficiency enhancement only at a 6-dB back-off power (BOP), which is insufficient to meet the increasing demands of modern communication systems.

2. The DPA based on integrated enhancing reactance (IER) does not consider the effect of phase dispersion in the output matching network (OMN) on the IER across a wide frequency band, resulting in significant efficiency variations between high and low frequencies at the BOP and limiting its ability to achieve a wider band.

3. Conventional power amplifier designs commonly use regular microstrip circuit structures, which limits the feasibility of circuit optimization.

Main idea

1. An impedance–phase hybrid objective function was employed to reduce efficiency inconsistencies caused by phase dispersion across the wideband range.

2. To enhance design flexibility, a fragment-type matching circuit is employed in the OMN design.

3. Compared to conventional regular structure designs, the optimized fragment-type structure DPA achieves an expanded relative operating bandwidth while maintaining high BOP efficiency.

Method

1. By calculating the desired reactance for an extended back-off power range and integrating it with the two-impedance matching method, the *S*-parameters of the OMN are obtained. Additionally, impedance and phase constraints of the OMN are introduced to narrow the distribution range of the IER.

$$F_{Z\_\theta}(Z_{\mathrm{L}},\theta)=\max\left(\left|R_{\mathrm{L}}-R_{\mathrm{opt}}\right|+\left|X_{\mathrm{L}}-X_{\mathrm{opt}}\right|,\left|\theta-\theta_{\mathrm{opt}}\right|\right) \qquad (1)$$

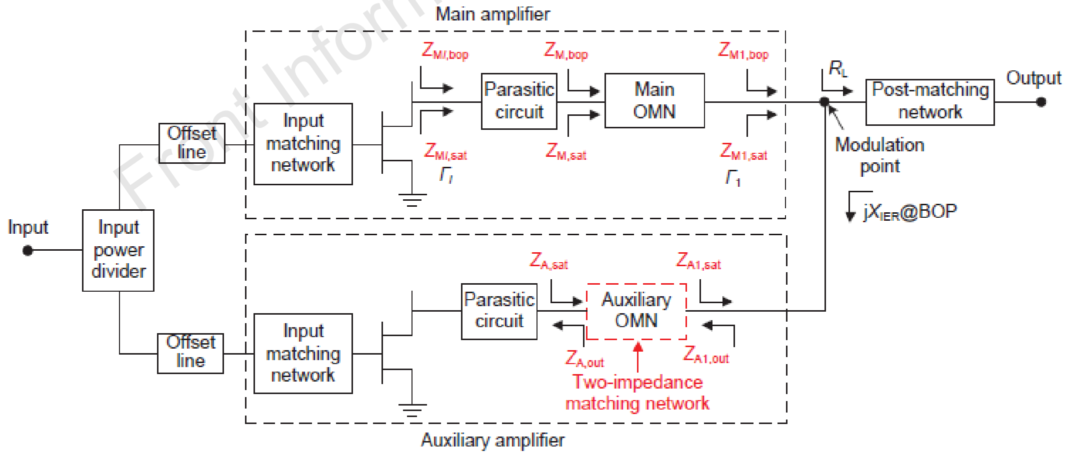

Fig. 1 Schematic of the proposed DPA (DPA: Doherty power amplifier; OMN: output matching network; BOP: back-off power)

Method (Cont’d)

2. For high frequencies, the optimal load impedance at 2.5 GHz under saturation is determined to be (14+j1) Ω through load-pull simulation. Based on Eq. (2), when R_L is 28 Ω, jX_{IER} is calculated as −j30 Ω. Using the two-impedance matching method, the corresponding phase of OMN_A at 2.5 GHz is determined to be −215°. Therefore, the optimization objective function for OMN_A at the high frequency is given as in Eq. (3).

$$\mathrm{j}X_{\mathrm{IER}} = \frac{-2R_{\mathrm{L}}\left(1+\Gamma_1\right)}{1+3\Gamma_1} \tag{2}$$

$$F_{Z\_\theta\_2.5\mathrm{GHz}}(Z_{\mathrm{L}},\theta) = \max\left(\left|R_{\mathrm{L}}-14\right|+\left|X_{\mathrm{L}}-1\right|,\left|\theta+215\right|\right) \tag{3}$$

Method (Cont'd)

3. For the center and low frequencies, an impedance constraint circle is employed as the impedance target, and a phase balancing strategy is applied to minimize the phase difference.

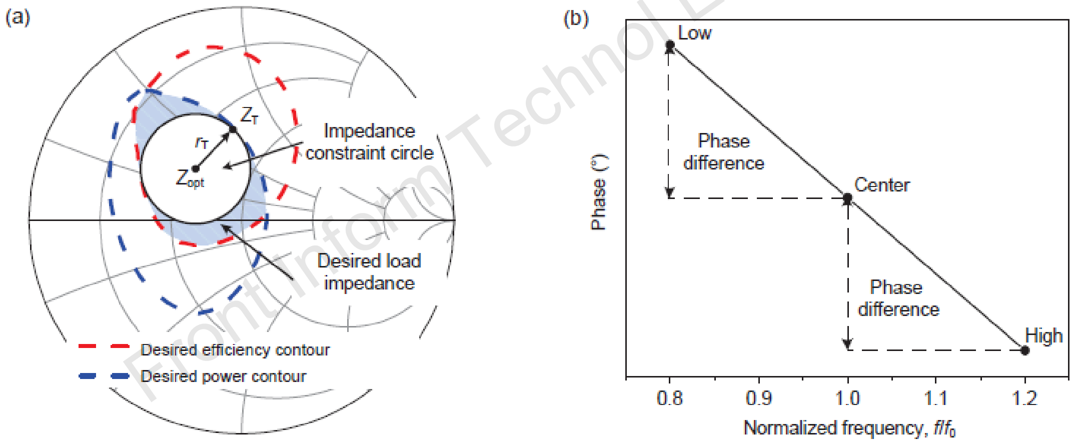

Fig. 2 Illustration of the objective functions for center- and low-frequency optimization: (a) impedance; (b) phase

$$F_{Z\_\theta\_2.1\mathrm{GHz}}(Z_{\mathrm{L}},\theta) = \max(F_{Z\_2.1\mathrm{GHz}}(Z_{\mathrm{L}}), F_{\theta\_2.1\mathrm{GHz}}(\theta)) \qquad F_{Z\_\theta\_1.7\mathrm{GHz}}(Z_{\mathrm{L}},\theta) = \max(F_{Z\_1.7\mathrm{GHz}}(Z_{\mathrm{L}}), F_{\theta\_1.7\mathrm{GHz}}(\theta)) \tag{4}$$

Method (Cont'd)

4. Based on the previously mentioned optimization strategy, a fragment-type structure is selected for the OMN_A design to reduce phase dispersion.

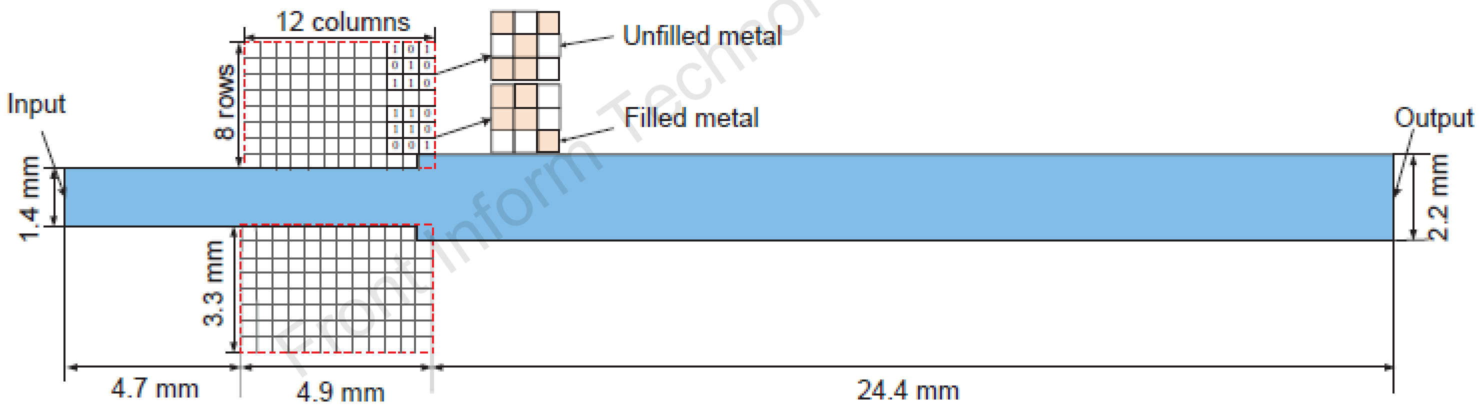

Fig. 3 Structure of the fragment-type auxiliary output matching network (OMN_A)

Method (Cont'd)

5. A multi-objective evolutionary algorithm based on decomposition (MOEA/D) is used to generate the design parameters of the fragment-type structure for OMN_A.

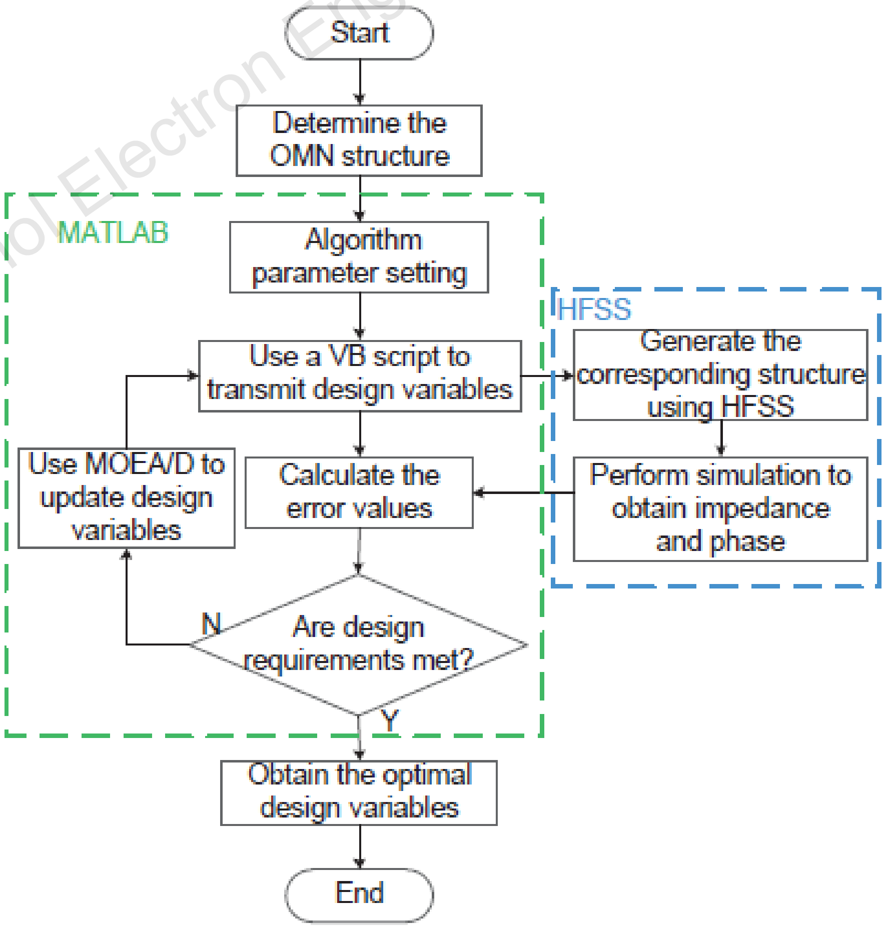

Fig. 4 Design flowchart of the proposed method (OMN: output matching network; MOEA/D: multi-objective evolutionary algorithm based on decomposition; HFSS: High Frequency Structure Simulator)

Major results

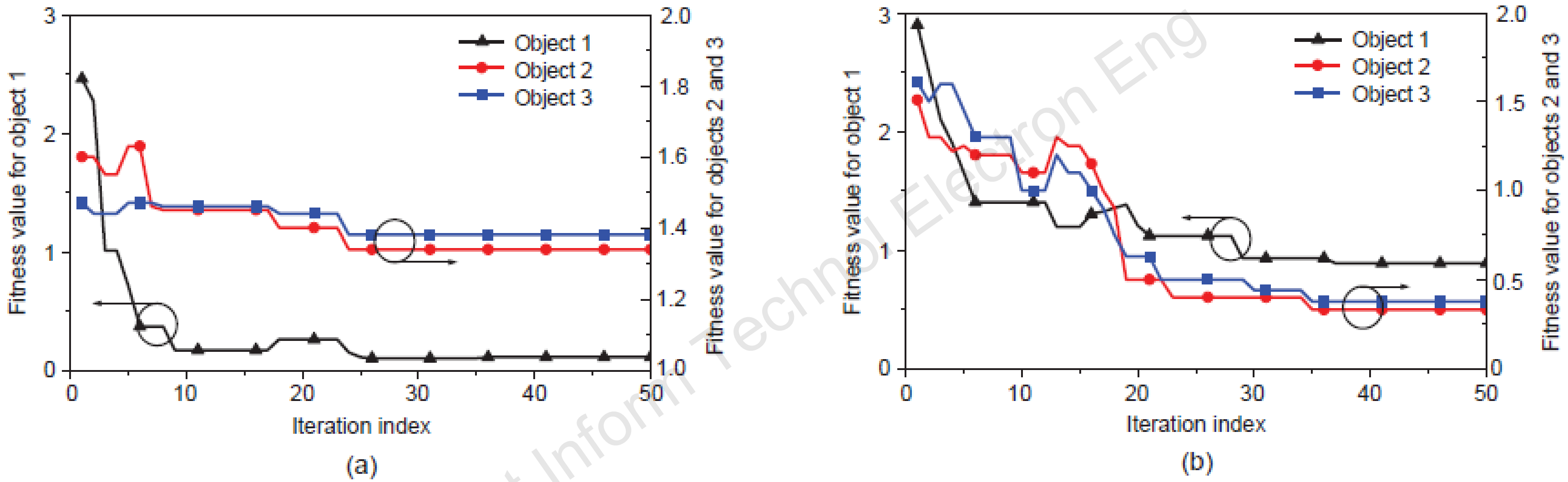

Fig. 5 Fitness value of the objective functions in the optimization process: (a) regular structure; (b) fragment-type structure

Major results (Cont'd)

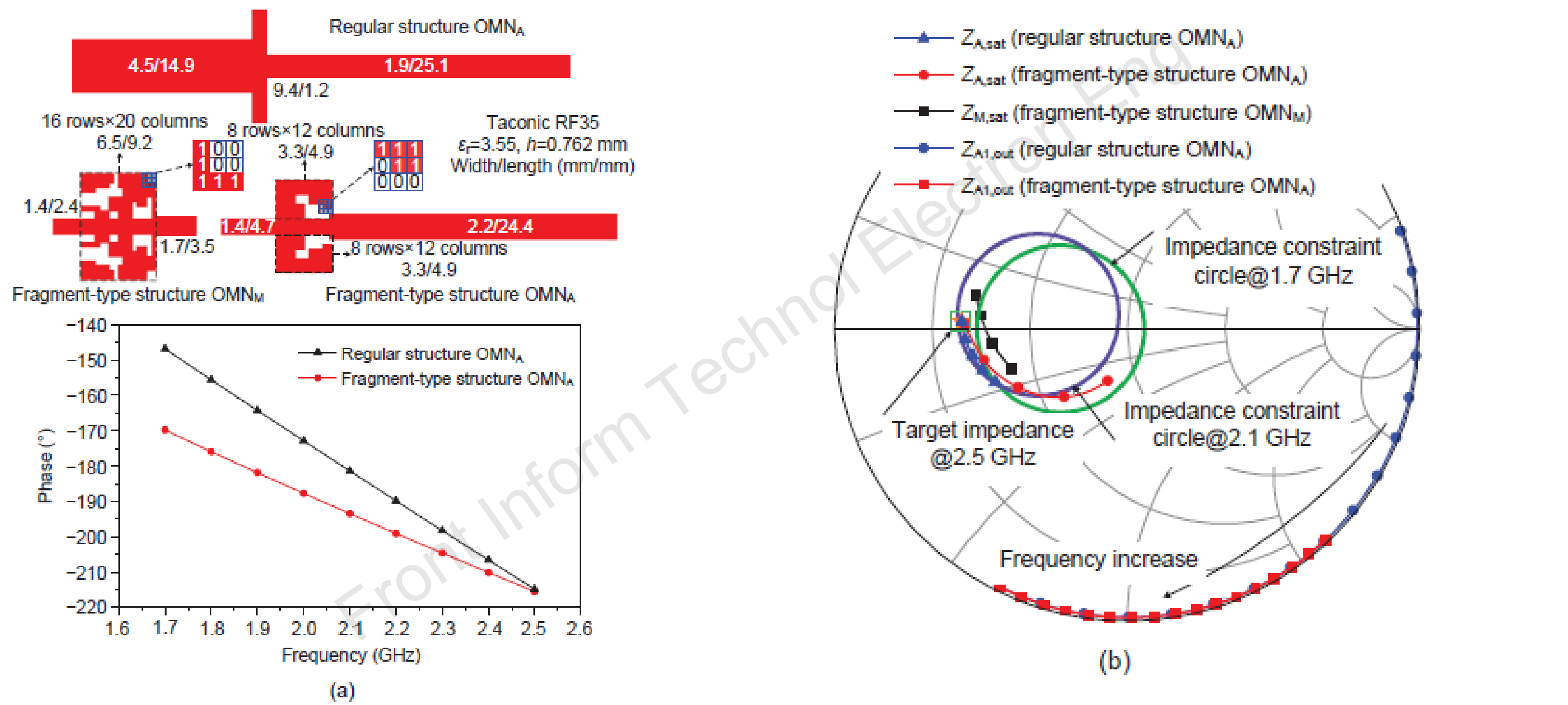

Fig. 6 The optimized output matching network (OMN) and simulation results in the 1.7–2.5 GHz frequency band: (a) phase; (b) impedance

Major results (Cont'd)

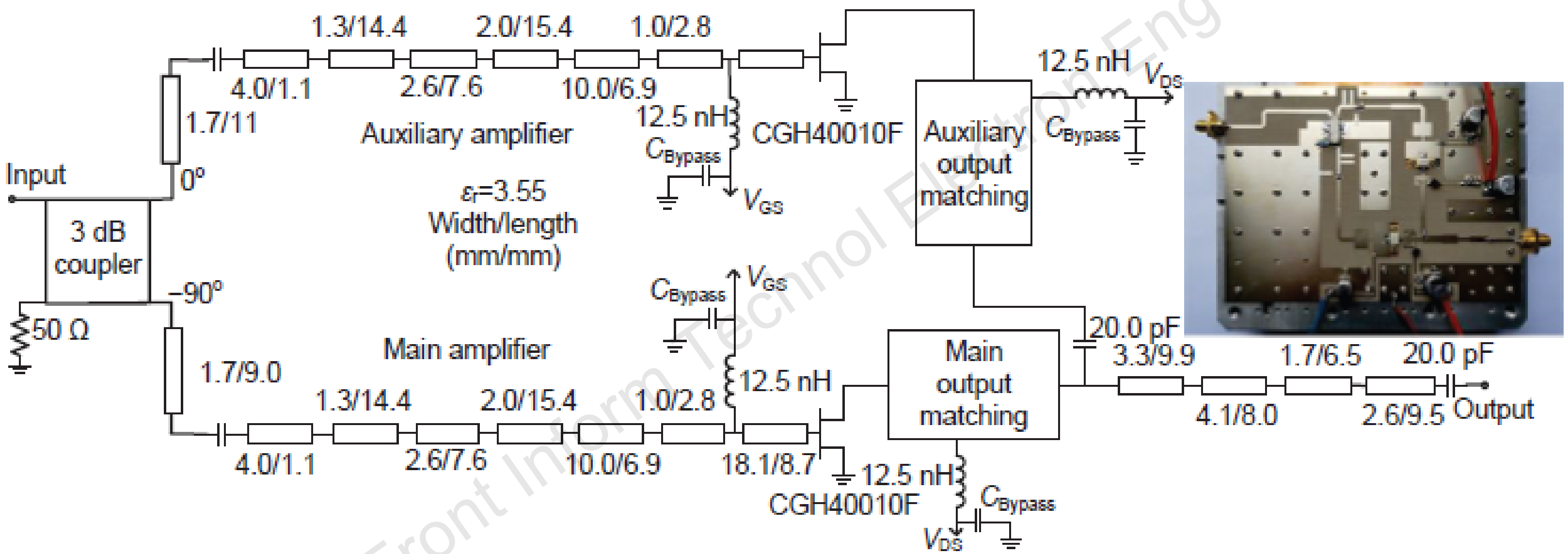

Fig. 7 Complete schematic of the proposed Doherty power amplifier (DPA) (Inset shows the fabricated DPA)

Major results (Cont'd)

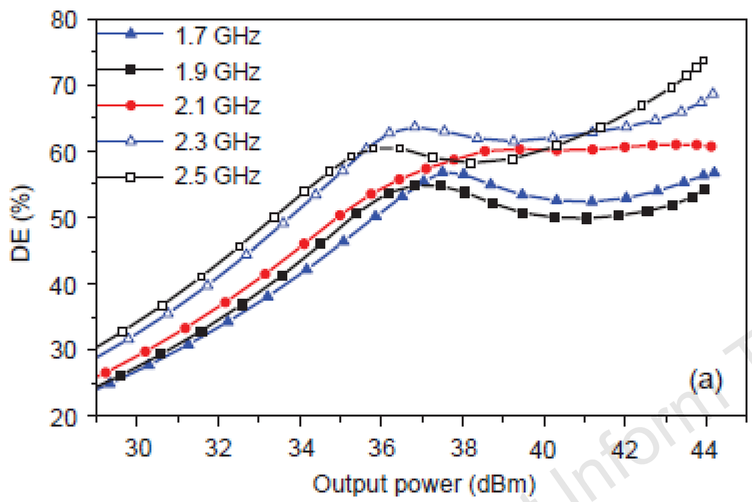

Fig. 8a Doherty power amplifier (DPA) simulation results

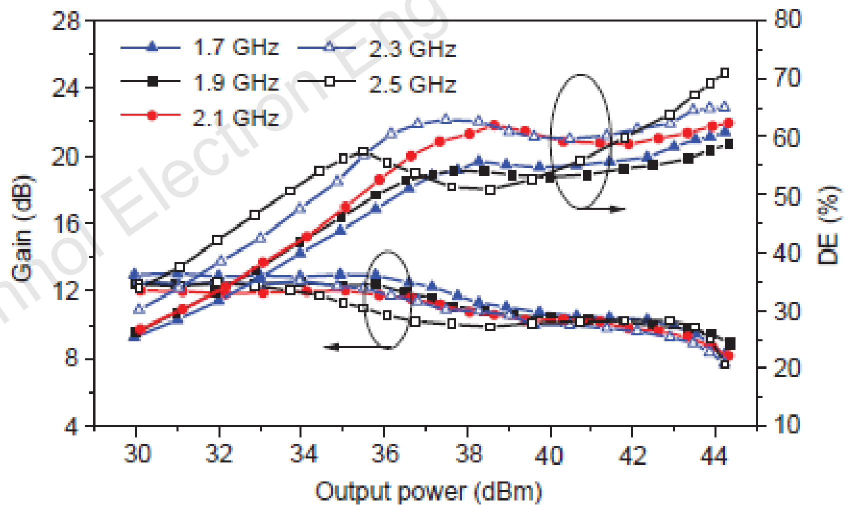

Fig. 9 Measurement results of the gain and drain efficiency (DE) for the proposed Doherty power amplifier (DPA)

Major results (Cont'd)

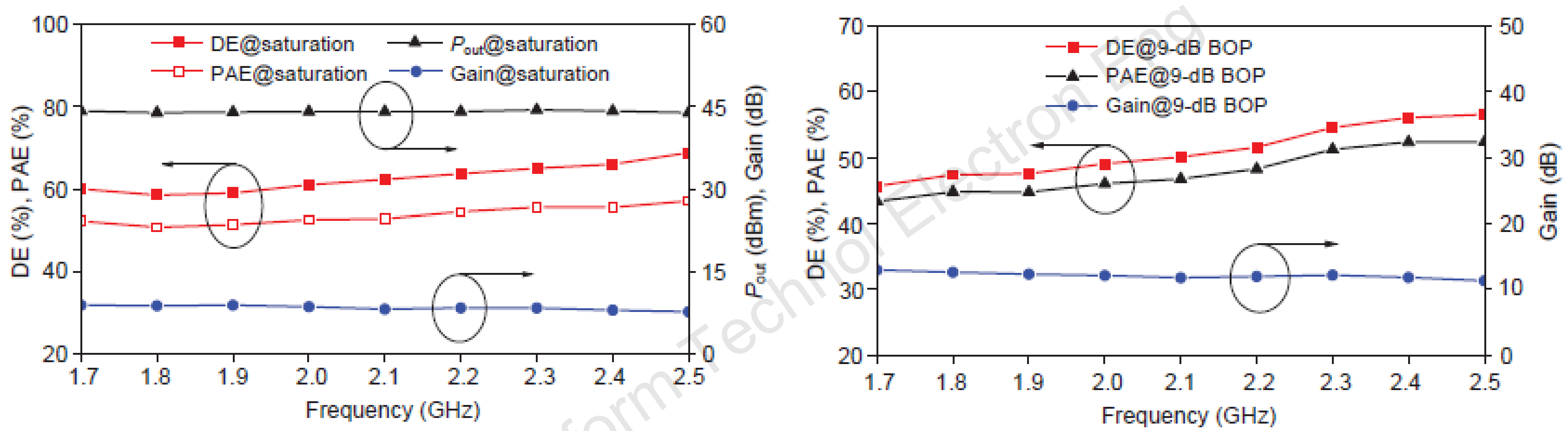

Fig. 10 Measurement results vs. frequency (DE: drain efficiency; PAE: power added efficiency)

Major results (Cont'd)

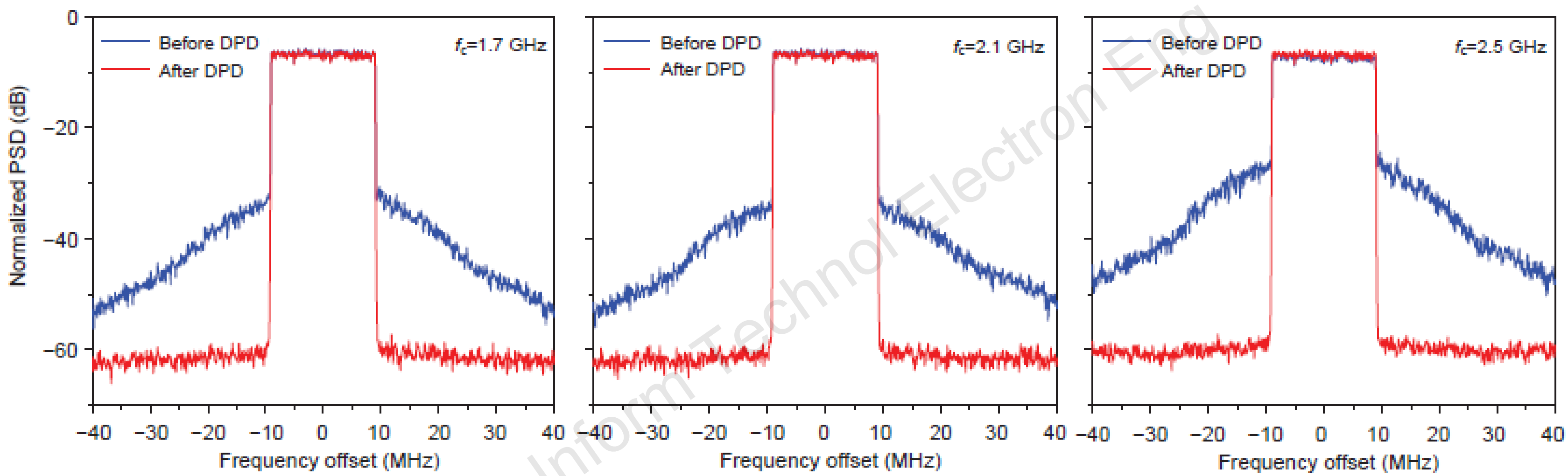

Fig. 11 Measured spectra before and after linearization for 20-MHz LTE modulation signal (LTE: long-term evolution; DPD: digital pre-distortion; PSD: power spectral density)

Conclusions

1. A fragment-type structure OMN optimization method using an impedance–phase hybrid objective function has been proposed.

2. To validate the effectiveness of the method, a 1.7–2.5 GHz DPA was fabricated and measured.

3. The fabricated DPA achieved a saturated output power exceeding 44 dBm within the operating bandwidth, with a DE ranging from 58.5% to 68% at saturation and from 45% to 55% at a 9-dB BOP.

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