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Design and Validation of a Concurrent Dual-Band 1.84/2.65 GHz GaN Doherty Power Amplifier

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***Abstract*—This paper introduces a dual-band Doherty power amplifier (DB-DPA), using symmetrical GaN HEMT devices. The load modulation network incorporates a wideband Doherty combiner followed by a Chebyshev transformer as a post-matching network. The operating frequencies of the proposed DB-DPA are 1.84 and 2.65 GHz with a bandwidth of 70 MHz in each band. The DB-DPA showcases satisfactory performance with a peak output power of 47.4 dBm for 1.84 GHz and 47.1 dBm for 2.65 GHz. Furthermore, a drain efficiency of 50.4-64.5% and 44.4-64.4% is measured between 6-dB output back-off (OBO) level to peak power level, respectively, for 1.84 GHz and 2.65 GHz bands. Concurrent dual-band performance of the proposed DB-DPA is demonstrated using 20-MHz signals with a peak-to-average power ratio of 6 dB. For an average output power of 40 dBm, the DB-DPA yields 46.4% efficiency with an adjacent channel leakage ratio (ACLR) better than -51 dBc.**

***Index Terms*—Doherty, Power Amplifier (PA), GaN-HEMT, Dual-Band, Concurrent**

I. Introduction

In the today's evolving wireless communication landscape, achieving high data rates and low power consumption is of paramount importance. Power amplifiers (PAs), which are at the heart of these systems, play a pivotal role in the overall performance, including bandwidth, output power, and efficiency. To meet the stringent demands of modern communication standards, especially the need for high peak-to-average-power-ratio (PAPR) with multi-band operation, several efficiency enhancement techniques have been proposed, of which the Doherty PA (DPA) has emerged as a promising candidate [1], [2]. DPAs incorporate active load modulation to deliver high efficiency at OBO levels, while maintaining a relatively simple design.

The main challenge in DPAs, which limits the bandwidth, is the use of quarter-wave transformers ($\lambda/4$) for impedance inversion in the combiner network. To overcome this issue, various designs have been proposed in the literature. Most of these designs employ replacement of the narrow-band ($\lambda/4$) with wideband or dual-band structures like Π or T-networks [3], [4]. Meanwhile, some techniques focus on the synthesis of wideband combiners which provide decent matching conditions for both peak and back-off power levels [5], [6] and [2].

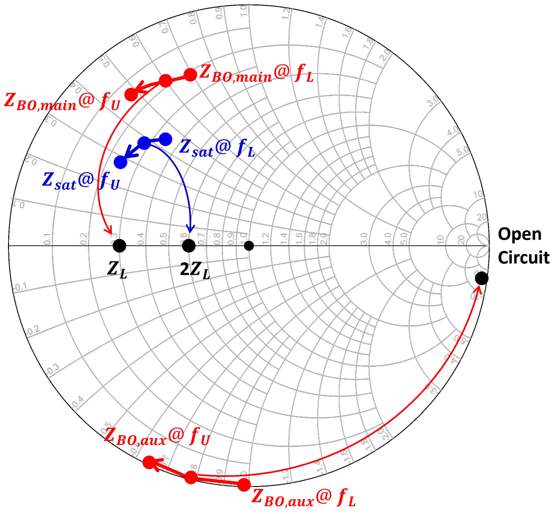


Figure 1: Impedance transformation of main and auxiliary amplifiers at saturation and back-off levels

In this paper, a DB-DPA is proposed with operational frequency bands of 1.81-1.87 GHz and 2.62-2.69 GHz. Firstly, a wideband Doherty combiner is designed and synthesized. The combiner network is then optimized in the desired bands to maximize the performance in terms of efficiency and output power.

II. Design of the Dual-Band Doherty PA

A. Combiner Network Design

In this design, two Wolfspeed CGHV27030S GaN HEMTs are used. The main amplifier is biased to operate in class-AB while the auxiliary amplifier is biased for class-C operation. To design the dual-band Doherty PA, the optimal load impedances to provide maximum power at saturation and maximum efficiency at 6 dB OBO are determined through load-pull analysis at the desired frequencies. Subsequently, output matching networks for main and auxiliary amplifiers are designed [5]. Assuming the OMN as a lossless two-port network, it can be represented in terms of its S-parameters matrix as [6]:

$$\mathbf{S} = \begin{bmatrix} -S_{22}^{*}e^{j2\theta_{21}} & \sqrt{1-|S_{22}|^2}e^{j\theta_{21}} \\ \sqrt{1-|S_{22}|^2}e^{j\theta_{21}} & S_{22} \end{bmatrix} \tag{1}$$

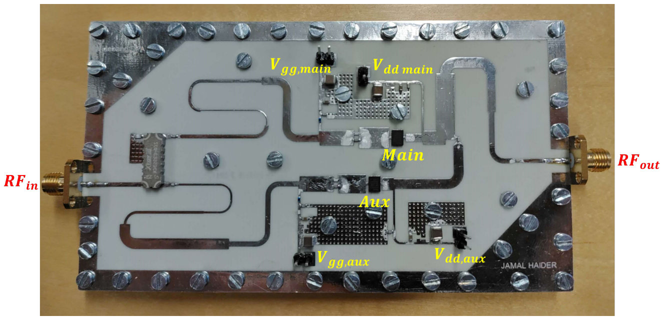


Figure 2: Fabricated DB-DPA

The optimal load impedances for three frequency points i.e., 1.84, 2.25 and 2.65 GHz are found to be 17 +j22, 14 + j19, 12 + j14 [Ω] at saturation, while at backoff level, the optimal impedances are 11 + j35, 9 + j30, 7 + j24 [Ω]. The optimal impedances are transformed to 30 Ω at saturation for both devices, as it gives a better response and a relatively simple network. Because of the DPA load modulation, at 6 dB OBO, the back-off impedances are transformed to 15 Ω for the main and quasi-open circuit for the auxiliary as illustrated in Figure 1. The S-parameters representation is transformed to ABCD-matrix form. The ABCD-matrix, along with the obtained and chosen impedances, is used to determine S_{22} and θ_{21} which provides the two-port representation of the network. By using the combiner synthesis approach in [2], the Doherty output combiner is further optimized for wideband operation. Finally, a four-section Chebyshev transformer is designed to transform the impedance at the common node to 50 Ω at the output [9].

B. Input Matching Network (IMN) Design

To obtain a wideband response, the IMN design is also crucial as it has to provide optimal source impedances to the active device. The IMN is designed using a stepped-impedance transformer in which high-impedance lines act as series inductors and low-impedance lines act as shunt capacitors [7]. A real-to-real low pass impedance transformer with a transformation ratio of 10:1 and fractional bandwidth of 60% is synthesized using lumped elements [8], [9]. The lumped elements network is transformed to distributed elements and optimized to provide a desired real-to-complex impedance transformation. At the input of the DB-DPA, an off-the-shelf 90° hybrid (Anaren, X3C22E3-03S) is used for power splitting. The phase shift introduced by the hybrid is compensated by the OMN in the auxiliary branch.

III. MEASUREMENT RESULTS

A photo of the fabricated DB-DPA is shown in Figure 2. The main amplifier is biased at a gate bias of -2.85 V and drain bias of 50 V, while the auxiliary amplifier is biased at -6 V and 50 V, respectively. The substrate used is Rogers Duroid R4003c with a dielectric constant of 3.55.

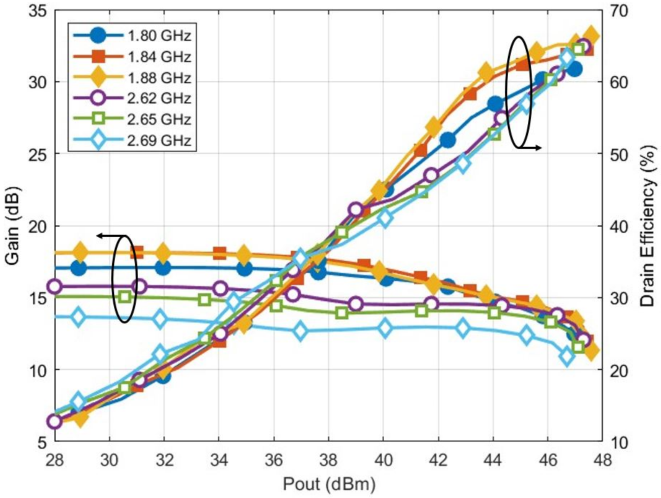


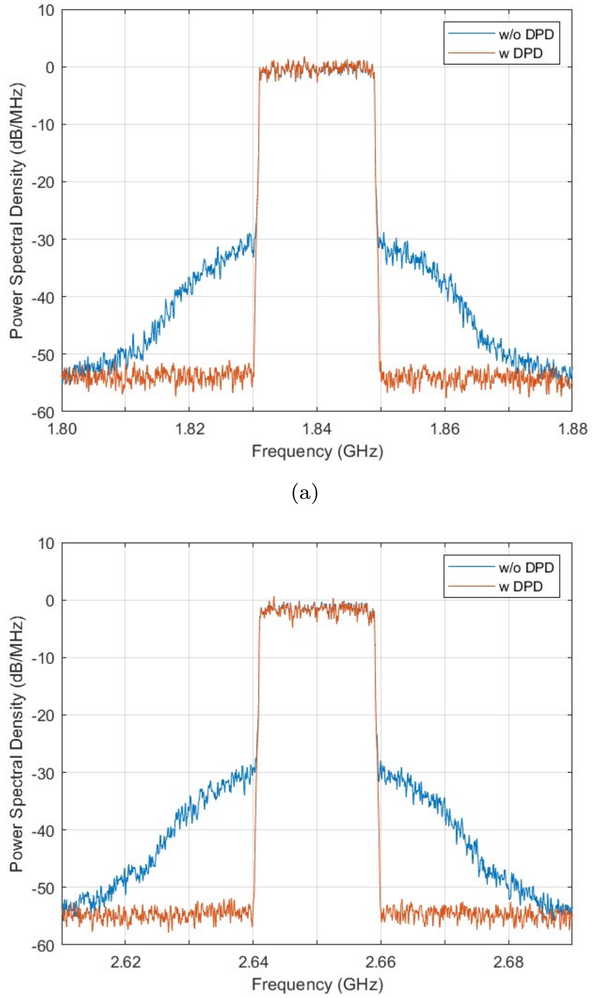
Figure 3: Measured drain efficiency and gain of the realized DB-DPA versus output power.

Table I: Modulated signal measurements for single-band and concurrent operation.

Freq (GHz)	Pout (dBm)	η (%)	ACLR (dBc) w/o DPD	ACLR (dBc) w DPD
1.81	40	48.8	-19.1	-48.6
1.84	40	50.4	-20.4	-48.8
1.87	40	50.6	-20.9	-47.9
2.63	40	41.1	-31.9	-52.9
2.65	40	44.4	-30.5	-53.4
2.68	40	40.3	-29.4	-52.7
1.84	40	46.4	-30.8	-27.2
2.65			-53.4	-51.1

Large-signal measurements of the DPA are performed using a pulsed CW excitation of 10% duty cycle with the main amplifier biased at a quiescent current of 27 mA. The measured drain efficiency (DE) and power gain for the concerned frequency bands are shown in Figure 3. A DE of 48.6-51.4% is achieved at 6 dB OBO level in the lower frequency band, while it ranges between 44.1-45% in the upper band. A peak output power of 47-47.5 dBm with a corresponding DE of 61.8-66.3% is achieved in the lower band. Similarly, for the upper band, 46.8-47.3 dBm output power is achieved with a DE of 63.4-64.9%. The power gain ranges between from 17.1-18.1 dB and 13.5-15.7 dB in the desired bands.

To demonstrate the practical performance of the DB-DPA with modern wireless communication signals, single-band and concurrent dual-band modulated measurements are performed. A 5G new radio (NR) signal of 20-MHz bandwidth having 6 dB peak-to-average power ratio (PAPR) is used. For the single band measurements, with an average output power of 40 dBm, the proposed DB-DPA achieves an average DE of 50.4% at 1.84 GHz. It exhibits an ACLR of -20.4 and -48.8 dBc with and without DPD, respectively. For 2.65 GHz, the average DE is 44.4% for the same average output power and an ACLR of -



(a)

(b)

Figure 4: Concurrent DB-DPA output signal spectrum before and after digital pre-distortion. (a) Lower frequency band (1.84 GHz). (b) Upper frequency band (2.65 GHz).

30.5 and -53.4 dBc with and without DPD. The results for single-band measurements are tabulated in Table I. For the concurrent measurements scenario, a DE of 46.4% and ACLR of -53.4 and -51.1 dBc is achieved, which is illustrated in Figure 4. Table II provides comparison of the proposed DPA with state-of-the-art dual-band and wideband DPAs in terms of DE and output power level. The proposed DB-DPA offers satisfactory performance in terms of back-off DE with a relatively higher gain than other compared designs.

Table II: Comparison with published DB-DPAs

Ref	Freq (GHz)	η (%) 6 dB	η (%) Peak	Peak Power (dBm)	Gain (dB)
[3]	1.8/2.4	64/49	71/62	43/43	12/10
[4]	1.9/3.5	40/30	59/49	42.8/41.8	8/11.5
[10]	1.9/2.6	45/51	65/61	44.5/44.2	15/17
[11]	2.15/3.4	52/51	68/55	47.3/47	9/10.5
This work	1.84/2.65	50.4/44.5	64.5/64.4	47.4/47.1	17.8/14.8

Conclusion

A GaN-HEMT based DB-DPA has been presented in this paper. The proposed DB-DPA incorporates wideband IMN and combiner networks and its performance was evaluated with a thorough measurement scheme. When driven concurrently with two 20 MHz signals of 6 dB PAPR, the presented DB-DPA demonstrates an average DE of 46.4% for an average output power of 40 dBm. The DB-DPA exhibits good linearity after linearization, throughout the 70 MHz bandwidth of each band making it suitable for modern communication systems.

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