Current State and Advanced Architectures of Doherty Power Amplifiers

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Abstract. Power amplifiers are critical components of wireless communication systems, providing the necessary power to transmit signals over long distances. Among various power amplifier solutions, the Dougherty power amplifier (DPA) remains a popular choice due to its high efficiency, speed, and power combination. However, conventional DPAs suffer from limited bandwidth and linearity, which have been major challenges in contemporary DPA design. This paper discusses the status, challenges, and potential solutions for improving the bandwidth and linearity of the DPAs. The limited bandwidth of conventional DPAs has been a challenge for their use in wireless data communication. Furthermore, concerning DPA linearity, this paper discusses the importance of linearity for modern wireless communication and potential DPA linearization techniques. The paper proposes several emerging DPA architectures, namely the Asymmetric Dougherty Power Amplifier, Multi-Stage Dougherty Power Amplifier, and Digital Dougherty Power Amplifier. The findings of this paper provide insights into the current status and future development of DPA technology, particularly in terms of bandwidth and linearity.

Keyword: Dougherty power amplifier, bandwidth, linearity, new DPA architectures.

1. Introduction

Power amplifiers and their components have gained tremendous momentum in the last decades. In the presence of many new amplifiers, the Dougherty power amplifier (DPA) remains a convenient, widely adopted pa solution due to its high efficiency at various output powers and its advantages in terms of high efficiency, high speed, and high-power combination. As current research continues, it can be found that for conventional DPA, bandwidth, and linearity are two key metrics. In the second part of this paper, we will discuss how to improve bandwidth and linearity. In the third part, we will discuss several emerging DPA architectures, describe their advantages and disadvantages, and make comparisons.

2. Status and challenges

2.1. Bandwidth of DPA

2.1.1 The current status of DPA bandwidth

Power amplifiers (PAs) have come into being with the development of wireless communication technology, especially in bandwidth or multi-band transmitting systems, and are in great demand. The intricacy involved in setting up the current communication system configuration has resulted in a rise in the peak-to-average power ratio (PAPR) of signals. When signals have high PAPR, it becomes difficult for effective PAs to handle them, especially when they are only operating in saturation mode. To tackle this challenge, experts have proposed the use of DPAs, which offer a wider effective output power back-off (OBO) range. Due to their exceptional average efficiency performance, DPAs have become increasingly popular in large-scale deployment, particularly in base stations [1].

Yet, at the time, DPAs had a limited bandwidth that was adequate for broadcast radio. There has been a demand for considerable growth in bandwidth due to the popularity of wireless data communication. Yet the quarter-wavelength transmission line architecture of the classical DPAs (a frequency-dependent component with structural restrictions) and the challenges in wideband open

impedance and phase alignment design [2] made it impossible for them to overcome the constrained intrinsic bandwidth, which significantly restricted their usefulness. As a result of the increasing focus, bandwidth expansion is a crucial element to take into account in contemporary DPA design.

2.1.2 DPA bandwidth expansion

Two power amplifiers—the primary amplifier and the auxiliary amplifier—typically make up the traditional DPA architecture. The load component of the amplifier is frequent ly referred to as the primary amplifier, while the modulation portion is frequently referred to as the auxiliary amplifier. These two amplifiers' output signals are merged into a single output network bef ore being sent to the load. Within this arrangement, a power divider links the inputs of the primary amplifier and auxiliary amplifiers, providing appropriate power distribution by routing signals to both amplifiers. Once the output signal of the auxiliary amplifier undergoes phase-shift and amplitude modulation, it combines with the main amplifier's output signal and proceeds to the load. However, it's worth noting that the efficiency at back-off may not be consistent across a broad frequency range, presenting a drawback. Fig. 1 shows the general composition of a traditional DPA.

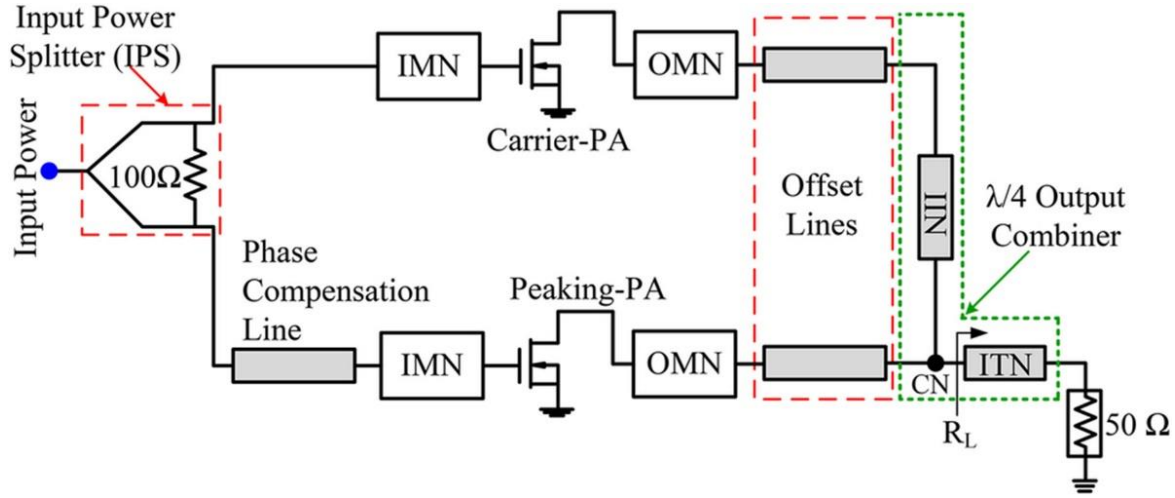


Fig. 1 Typical DPA schematic diagram [3].

Thus, a low back-off Rcarrier impedance Doherty structure is needed. Thereby, a post-matching Doherty PA is suggested [4], in which the phase of the two devices has changed. Two FIIs at 90 degrees each make up the load modulation network, which also includes an offset line (90 degrees). To translate the resistances into real values and obtain the highest power transformation, a post-matching network could be applied just after LMN. This circuit configuration makes it possible to get a low R-carrier setback impedance. Because the carrier Fundamental Impedance Inverters' impedance transformation rate at the OBO is lower than the standard DPA's, the carrier FII has a wider bandwidth. Thus, it is possible to effectively widen the DPA's bandwidth.

In terms of bandwidth, the Dougherty amplifier offers a lot of possibilities. In [5], a new peak amplifier is suggested that makes use of a multi-resonant circuit as a FII. The circuit also makes up for the equivalent network found within the transistor. Furthermore, in order to precisely estimate the bandwidth, the power bandwidth was examined for the first time. In order to maximize the bandwidth, the ideal densities needed to provide the peak amplifier using the MRC approach were obtained from this.

2.2. Linearization of DPA

2.2.1 Why DPA needs linearization and its current status

Modern wireless communication has led to the development of improved modulation techniques, due to the ongoing increase of user capacity and spectrum efficiency (OFDM). The huge PAPR of the signal is one of the results of the development of sophisticated modulation algorithms inside OFDM [6]. The strong linearity of PAs is critical for modern wireless communications, and

modulation techniques necessitate broader bandwidths and greater PAPRs, which constrain PAs and impose requirements for efficient linear operation in the high-power fallback range.

2.2.2 A few potential DPA linearization techniques

To attain satisfactory linearity for modulated signals with PAPR, the transmitter has to operate with its mean output power disabled, at the cost of reduced effectiveness. The most widely used amplifier linearization technology for base stations today is digital pre-distortion (DPD), a strong and dependable linearization technique. Based on the inverse characteristic identification of power amplifiers (PAs), DPD is a useful method for linearizing PAs. It will linearize the PA, correct for these distortions, and offer linear amplification with high efficiency.

The DPA in [7] is designed using an active non-foster circuit architecture, which may produce a DPA with good linearity. Phase shifting by 90 degrees and impedance matching are both possible with this arrangement. The peak amplifier's AM-AM distortions are suppressed at the same time as AM-PM and it offers negative capacitance, which significantly improves the overall linearity by reducing peak amplifier distortion. A DITL algorithm for DPA is put out in [8], and it can provide DPA backoff with adjustable and decoupled AM-AM compensation. The linearity of DPA in wireless communication systems may be enhanced using this method, which offers a fresh thought.

In addition to increasing linearization for AM-AM distortion difficulties, GaN HEMT device technology has the property of solid linearity in addition to low cost. It is suggested in [9] to use the derivative superposition technique (DST) with a power-tracking GaN HEMT DPA. The results show that the DPA's linearity is optimized, and the carrier amplifier's drain bias is either higher or lower than that of the peak amplifier's drain bias ratio.

3. Advanced DPA Architecture

3.1. Asymmetric DPA (ADPA)

In a power amplifier system, using the same size carrier amplifier and peak amplifier in a DPA can result in a smaller maximum output power due to the smaller conduction angle of the peak amplifier. This leads to a decrease in the maximum output current, which affects the overall performance. Ideally, an asymmetric input power should be used for a DPA, as recommended by previous studies.

While the asymmetric Dougherty power amplifier (ADPA) is a new power amplifier design technique, it is a particular power amplifier structure with asymmetric power distribution compared to the symmetric power distribution of conventional amplifiers, which can improve the efficiency of power amplifiers without sacrificing linearity. The efficiency of ADPA is higher than that of traditional DPA. It can maintain better linearity and efficiency at high power output, while the linearity and efficiency of traditional DPA are usually sacrificed. Regarding applicable scenarios, ADPA is more suitable for systems with high power requirements and narrow bandwidth, such as mobile communication, satellite communication, etc.

3.2. Multi-stage DPA

The above-mentioned asymmetric Dougherty amplifier is more efficient in a specific setback case. One proposed solution to address the issue is a multi-stage DPA that can efficiently amplify power at several setback points. This approach allows for a wider dynamic range while maintaining high average efficiency due to the inclusion of extra power devices [10]. Studies have found that among different DPAs, the three-stage DPA stands out in terms of efficiency characteristics, as it possesses three established efficiency points at the output power level [11].

According to Fig. 2, it is possible to achieve higher efficiency levels using two and three-stage DPAs, compared to the conventional efficiency curve of a class B amplifier and an asymmetrical implementation. Research have shown that the three-stage DPA, which has three set efficiency points at the output backoff level, stands out among other DPAs in terms of efficiency features.

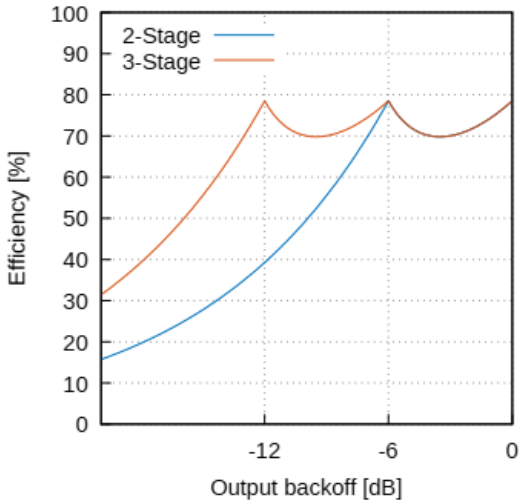


Fig. 2 Efficiency of multi-stage DPAs [12]

3.3. Digital DPA

Conventional DPA, which is used in practical applications, can face performance limitations due to the imperfect match between the carrier and peak amplifier. Controlling digital DPA can be a complex task due to the difficulty in precisely managing the turn-on point of the peak amplifier and the relative gain between the amplifiers. To overcome these difficulties and prevent plagiarism, a solution involves utilizing a two-RF data converter (DAC) architecture to implement the carrier and peak PAs. This architecture enables programmable and accurate gain control for both amplifiers, allowing for a precise definition of the peak PA turn-on point and the relative gain between the two PA paths. Therefore, digital DPA can achieve better setback efficiency than conventional DPA. Digital DPA also offers several other advantages. In terms of bandwidth, digital DPA can be adapted to different frequency ranges by adjusting digital signal processing parameters, and a wider bandwidth can be obtained. In terms of linearity, digital DPA can eliminate nonlinear distortion with digital pre-distortion techniques, thus achieving better linearity performance. Regarding practical use, digital DPA can be implemented with integrated circuits, completing a smaller size and participating in a more compact circuit design.

4. Conclusion

DPA is a highly efficient RF power amplifier with the advantages of high efficiency and high linearity, which enables it to be widely used in areas such as mobile communication and broadcasting systems. DPA has developed in the past few years regarding bandwidth expansion and linearity. Many new architectures have emerged, including PMN and MRC for bandwidth expansion and DPD and DST for linearity improvement. There are also three advanced architectures such as asymmetric DPA, multi-stage DPA, and digital DPA, which have higher performance and a more comprehensive application range.

References

[1] Jia P, You F, He S. A 1.8–3.4-GHz bandwidth-improved reconfigurable mode Doherty power amplifier utilizing switches. IEEE microwave and wireless components letters, 2019, 30(1): 102-105.

[2] Saurabh P, Asuti P, Deepika P. A Review of Efficiency Improvement Techniques in Modern Communication Systems.

[3] Naah G, He S, Shi W, et al. Harmonic-tuned continuum mode active load modulation output combiner for the design of broadband asymmetric Doherty power amplifiers. IET Microwaves, Antennas & Propagation, 2019, 13(8): 1226-1234.

[4] Zhou X Y, Chan W S, Chen S, et al. Broadband highly efficient Doherty power amplifiers. IEEE Circuits and Systems Magazine, 2020, 20(4): 47-64.

[5] Kang H, Lee H, Lee W, et al. Octave bandwidth Doherty power amplifier using multiple resonance circuit for the peaking amplifier. IEEE Transactions on Circuits and Systems I: Regular Papers, 2018, 66(2): 583-593.

[6] Kim B, Kim I, Moon J. Advanced doherty architecture. IEEE Microwave Magazine, 2010, 11(5): 72-86.

[7] Zhao S, Yang L, Ren Y, et al. Linearity improved Doherty power amplifier using non-foster circuits. IEEE Access, 2019, 7: 40109-40113.

[8] Hao P, He S, You F, et al. Configurable independently tunable linearizer for Doherty power amplifiers. IEEE Microwave and Wireless Components Letters, 2020, 30(11): 1077-1080.

[9] Lee Y S, Lee M W, Jeong Y H. Linearity-optimized power tracking GaN HEMT Doherty amplifier using derivative superposition technique for repeater systems//2008 IEEE MTT-S International Microwave Symposium Digest. IEEE, 2008: 427-430.

[10] Barthwal A, Rawat K, Koul S. Bandwidth enhancement of three-stage Doherty power amplifier using symmetric devices. IEEE Transactions on Microwave Theory and Techniques, 2015, 63(8): 2399-2410.

[11] Kim I, Moon J, Jee S, et al. Optimized design of a highly efficient three-stage Doherty PA using gate adaptation. IEEE Transactions on Microwave Theory and Techniques, 2010, 58(10): 2562-2574.

[12] Musacchio Adorisio G. Analysis and Design of Multi-Stage Doherty Power Amplifiers for Wireless Communications. Politecnico di Torino, 2021.