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Optimized Dual-Band Reconfigurable Power Amplifier for 5G

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Article Info	ABSTRACT
	This article presents the design of a dual-band power amplifier capable of operating in three different classes: A, AB, and B. Simulation results reveal that a single power amplifier can efficiently operate at two specific frequencies of the 5G core band, namely 3.5 GHz and 3.8 GHz. The amplifier demonstrates exceptional stability and matching across both frequency bands. It achieves a maximum gain of 17.7 dB, a maximum output power of 41.2 dBm, and a maximum power-added efficiency (PAE) of 70%. These performance characteristics are achieved through an innovative design that allows for frequency band reconfiguration via a PIN diode switch, as well as the selection of the operating mode among classes A, AB, and B. This flexibility makes the amplifier ideal for applications in 5G communication systems, offering an optimal balance between linearity, energy efficiency, and overall performance.

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1. INTRODUCTION

In the field of power electronics, the design of power amplifiers is of crucial importance for numerous applications, ranging from wireless communication systems 5G [1, 2]. to high-fidelity audio devices. A dual-band power amplifier, capable of operating on two distinct frequency bands, offers a versatile and efficient solution to meet the diverse needs of these applications. This article aims to thoroughly explore the design of such an amplifier, with a particular focus on its operation in three distinct classes: A, AB, and B [3, 4].

Class A, while known for its exceptional linearity and signal quality, suffers from relatively low energy efficiency, limiting its use to specific applications where signal fidelity is paramount. On the other hand, Classes AB and B offer interesting compromises between linearity and energy efficiency. Class AB, for example, is often used in contexts where better energy efficiency is desired without significantly sacrificing signal quality. Class B, meanwhile, is ideal for applications requiring maximum energy efficiency, although this may come at the expense of linearity and harmonic distortion [5].

The challenge in designing a dual-band power amplifier lies in optimizing performance across both frequency bands while allowing flexible operation in the three mentioned classes. This requires a deep understanding of the basic principles of each operating class, as well as mastery of advanced design techniques to minimize the inherent trade-offs in each approach. Critical aspects include heat management, circuit stability, linearity, and energy efficiency[6, 7].

This article addresses various aspects of designing a dual-band power amplifier in three classes. We will begin with a review of the fundamental principles of power amplifiers, followed by a discussion of the specific challenges of dual-band design. Next, we will explore the design techniques employed for each operating class, highlighting the trade-offs and solutions adopted to optimize performance. Finally, we will present experimental results and performance analyses to illustrate the advantages and disadvantages of the proposed approach.

The design of a dual-band power amplifier capable of operating in Classes A, AB, and B represents a significant advancement in the field of power electronics. Such flexibility allows designers to meet the specific requirements of various applications while maximizing energy efficiency and signal quality. This article offers a comprehensive guide for engineers and researchers interested in this innovative and versatile approach.

This article presents a GaN HEMT power amplifier at 3.5 GHz as a single hardware unit whose operating mode can be selected between class A for superior linearity and class B for maximum efficiency. With additional adjustments to the PA circuit, the frequency band can also be reconfigured using a PIN diode switch. A single power amplifier circuit capable of covering the 3.5 GHz and 3.8 GHz frequencies is presented, and its operating mode can be selected among classes A, AB, and B, as demonstrated by the simulation results

2. RESEARCH METHOD
2.1. Input and output matching
The key concept in designing a microwave power amplifier is to match the input/output circuits of the transistor to the resonant frequency to improve the transmission efficiency from the source to the load and to avoid any spurious signal reflection[8].

The fundamental operation and design criteria of a microwave amplifier[9] are illustrated in Figure 1.
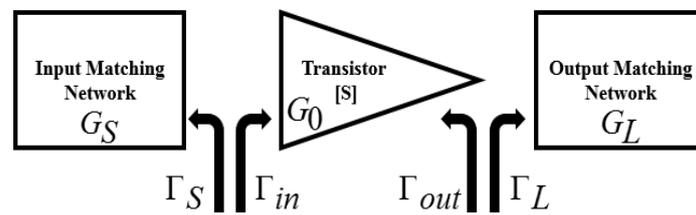

Figure 1. Network architecture

The reflection coefficient of the source.

$$\gamma_S = \frac{z_S - z_0}{z_S + z_0} \tag{1}$$

Z_S: source impedance
Z_0: characteristic impedance of the line
If $\Gamma s = 0$, the source is perfectly matched (no reflection).

The reflection coefficient of the load:

$$\gamma_L = \frac{z_L - z_0}{z_L + z_0} \tag{2}$$

Z_L: load impedance
When $\Gamma L = 0$, the load is perfectly matched.

The input reflection coefficient:

$$\gamma_{IN} = S_{11} + \frac{S_{12} S_{21} \gamma_L}{1 - S_{22} \gamma_L} \tag{3}$$

If $|\Gamma in| < 1$ and ideally close to 0, the input is well matched.

The output reflection coefficient:

$$\gamma_{OUT} = S_{22} + \frac{S_{12} S_{21} \gamma_S}{1 - S_{11} \gamma_S} \tag{4}$$

If $|\Gamma out| < 1$ and ideally close to 0, the output is well matched.

2.2. Stability

It's crucial to plot the stability circle on the Smith chart to determine the frequency range in which the PA is unstable and to avoid these oscillations . The Rollet conditions are given by[10]:

$$K = (1 - |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2)/2. \ |S_{12}S_{21}| \ > 1 \tag{5}$$

$$B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 > 0 \tag{6}$$

With

$$\Delta = |S_{11} \times S_{22} - S_{12}S_{21}| \tag{7}$$

3. Design of a dual-band reconfigurable power amplifier in Classes A, AB, and B

In our work, we designed a reconfigurable power amplifier based on the GaN HEMT CGH35030F from Cree Inc. Adjustable capacitors are used to tune the input and output matching networks[11, 12]. The optimal input and output impedance was determined using Agilent Technologies' Advanced Design System (ADS) parameter analysis tool. The optimization technique under ADS allowed us to achieve excellent matching for the different classes, A, AB, or B, at 50 Ohms [13].

3.1. Design of the reconfigurable power amplifier in class

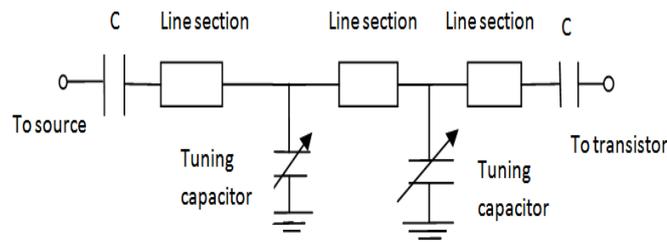The basic structure of the input matching network is presented in Figure 2

Figure 2. The input adaptation network

Table 1 indicates the bias voltages for each operating class:

Table 1. Polarization conditions

Class	V_{GS} (V)	V_{DS}(V)
A	-1.7	28
AB	-2.7	28
B	-3.2	28

3.2. Dessign of the power amplifier reconfigurable in operating frequencies

Figure 3 presents the overall architecture of the proposed dual-band power amplifier, featuring reconfigurability with respect to the operating class.
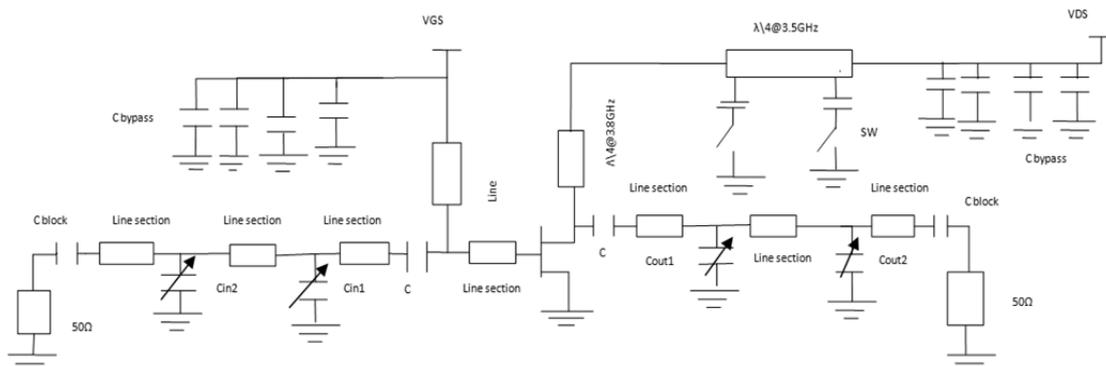

Figure 3. The concept of impedance matching conditions of the reconfigurable band and class power amplifier

The main methods to adjust the frequency band and operating class include [14]:
- To optimize the circuit operation:
- To ensure the matching of our power amplifier, it is sufficient to adjust the values of capacitors Cin1, Cin2, Cout1, and Cout2.
- Using a PIN diode switch at the drain level facilitates the transition between different frequency bands[15].
- To facilitate the transition from one operating class to another, it is possible to modify the VGS voltage[16].
- Adjusting the input and output impedances ($Z_S^* = Z_{IN}$ and $Z_{OUT}^* = Z_L$) to maximize the power amplification from the source to the load[17].

In Table II, the capacitors corresponding to each impedance matching state are listed, along with the class, the operational frequency range, the bias voltage, and the switching state of the PIN diode.

Table 2. Capacity values for each class and for each band

Class	Frequency in (GHz)	Cin1 (pF)	Cin2 (pF)	Cout1 (pF)	Cout2 (pF)	Vbias (V)	Diode PIN
A	3,5	4.02	2.32	0.5	2.6	-1.7	Off
AB	3,5	4.02	2.32	0.5	2.6	-2.7	Off
B	3,5	3.88	2.46	0.44	3.68	-3.2	Off
A	3,8	3.94	2	0.47	2.5	-1.7	On
AB	3,8	3.94	2	0.47	2.5	-2.7	On
B	3,8	2.96	2.14	0.43	2.8	-3.2	On

The data in Table 2 show a significant advantage of our power amplifier when transitioning from class A to class AB: only the adjustment of the bias voltage is required, while the matching capacitors at the input and output remain unchanged.

4. RESULTS AND DISCUSSION

Figure 4 represents the simulation results of the stability and matching, as well as the performance in terms of gain, PAE, and output power of the proposed reconfigurable power amplifier in both class and operating frequency
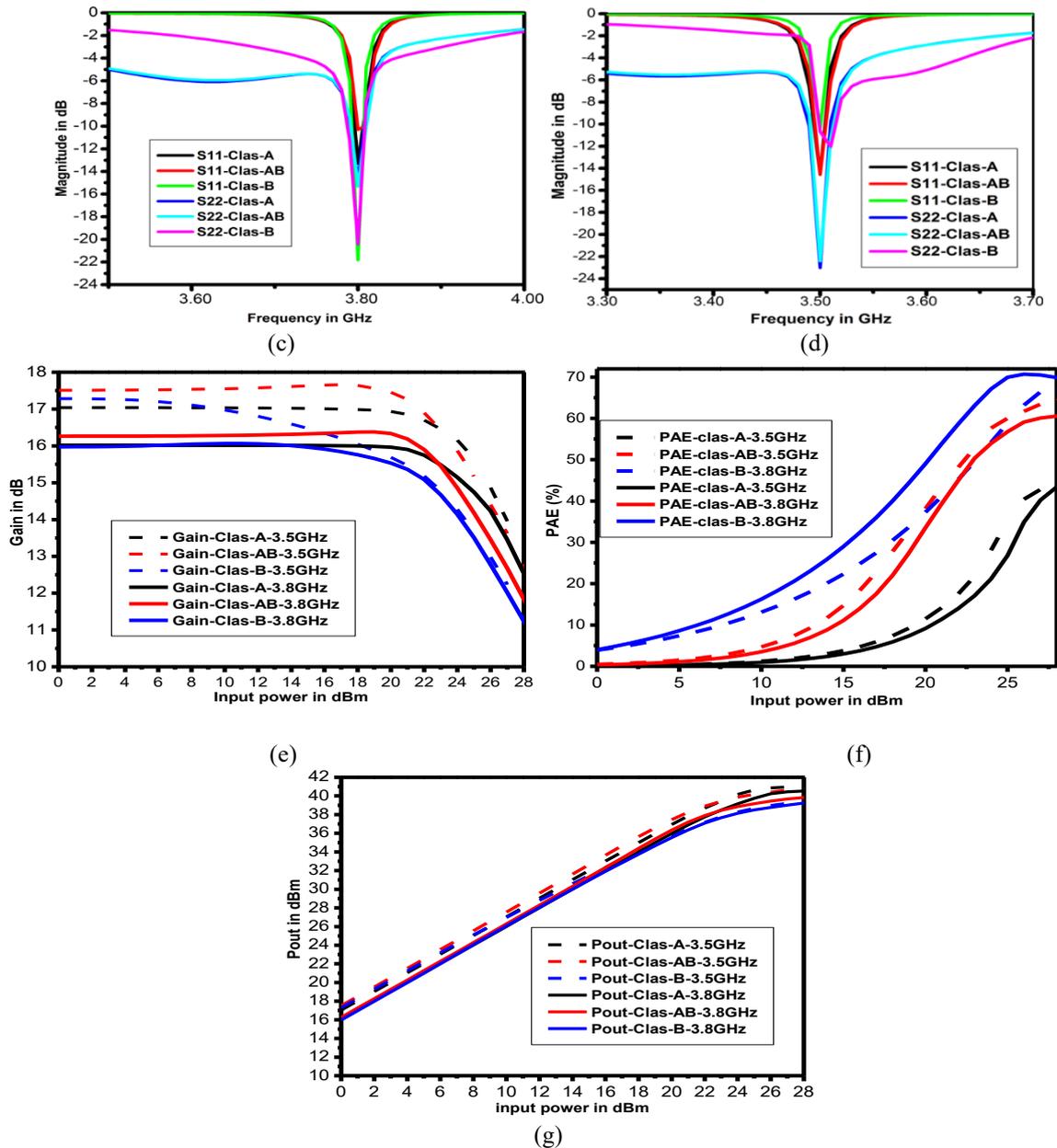

(a)   (b)
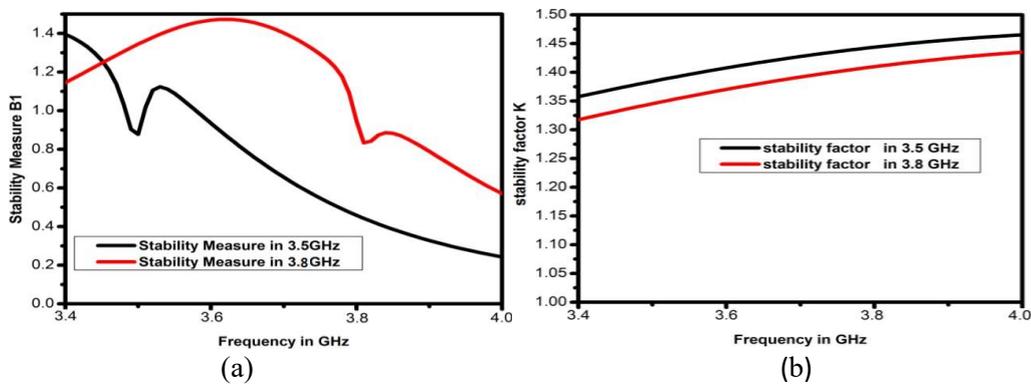
Fig 4. (a) Stability measure and (b) Stability factor, (c) |S11| and |S22| around the 3.5GHz and (d) |S11| and |S22| around 3.8GHz ,(e),Gain, (f) Efficiency of the added power,(g) Output power

The performance of the reconfigurable power amplifier operating in Classes A, AB, and B has been evaluated through key design parameters to assess its suitability for sub-6 GHz 5G applications.

The stability, illustrated in Fig. 4 (a) and (b), is confirmed by the stability factor K>1 and the stability coefficient B1>0 across the entire frequency band. According to standard criteria , these conditions ensure unconditional stability, meaning the circuit operates reliably without the risk of unwanted oscillations.

The reflection coefficients |S11| and |S22|, shown in Fig. 4 (c) and (d), remain below −10 dB at 3.5 GHz and 3.8 GHz. This indicates an excellent impedance match at both input and output, minimizing signal reflections and ensuring optimal power transfer to subsequent stages or the antenna.

The power gain, presented in Fig.4 (e), demonstrates comparable values across the classes. At 3.5 GHz, the amplifier achieves approximately 17 dB of gain, while at 3.8 GHz the gain is around 16 dB. This stability of gain across operating conditions highlights the effectiveness of the proposed matching and biasing design.

The Power Added Efficiency (PAE), illustrated in Fig. 4 (f), highlights the benefits of class reconfiguration. At 3.5 GHz, Class B achieves 65.02 %, compared to 45.9 % for Class A. At 3.8 GHz, this trend becomes even more significant, with Class B reaching 70 % efficiency, while Class A records 46. %.

These results clearly demonstrate the trade-off between efficiency and linearity: Class A offers improved linearity at the expense of efficiency, whereas Class B maximizes energy savings, making it more suitable for power-sensitive applications.

In terms of output power (Pout), shown in Fig. 4 (g), Class A exhibits slightly higher performance than Class B. At 3.5 GHz, Class A delivers 41.16 dBm compared to 39 dBm for Class B, while at 3.8 GHz the values are 41 dBm and 40.6 dBm, respectively. These results confirm that Class A is more favorable when stable high output power and linearity are required, whereas Class B prioritizes efficiency.

Overall, the results demonstrate that the proposed reconfigurable amplifier successfully balances stability, impedance matching, gain, efficiency, and output power, depending on the selected operating class. The flexibility of switching between Class A, AB, and B modes allows the design to adapt to diverse 5G application scenarios:

- Class A → superior linearity and stable output power.
- Class AB → balanced trade-off between linearity and efficiency.
- Class B → maximum energy efficiency.

This versatility makes the architecture particularly attractive for modern 5G wireless systems, where the requirements for power, efficiency, and linearity vary depending on the operating conditions.

5.   COMPARISON WITH THE STATE OF THE ART

Table 4 compares the performance of our reconfigurable power amplifier with other 5G power amplifiers

Table 4. Comparison with the state of the art

reference	PA class	Fréquence (GHz)	PAE (%)	Pout (dBm)	Gain (dB)
[18]	AB	5.9	47.3	38.7	10
[19]	AB	5.9	48.5	33.9	10
[20]	Dual band class AB	7.7	34.7	37	10
		14.9	47	34.7	7
[21]	Dual band class AB	4.56	47	31	12
		8.16	48	32	12
[22]	Dual band hybrid AB	3.3-3.8	64	42.6	12
		5.8	55	41	10.5
[23]	Classe B	4.2–7.0	40–49	34.2–36. 4	10.6–12.4
		4.6–6.0	42–52	34.7–36.2	2.2–13.4
[24]	Class B	2.4	40.1	63	-
[25]	Dual band class A	2.1	43.2	41.2	18.4
		2.45	43	41.2	17.4
[25]	Dual band class AB	2.1	45.5	36.6	15.5
		2.45	45.2	37.1	17.2
[25]	Dual band class B	2.1	62.6	37.6	18.1
		2.45	63,8	37.7	15.3
This work	Dual band class A	3.5	45.9	41.16	17
		3.8	46.58	40.93	16.1
This work	Dual band class AB	3.5	64.82	39.5	17.7
		3.8	60.7	41	16.3
This work	Dual band class B	3.5	67.32	40.7	17.4
		3.8	70	40.6	16

When comparing our model with other dual-band amplifiers listed in Table 4, it is clear that our proposed structure outperforms the others in terms of PAE, while also providing high Pout and significant gain. This highlights GaN HEMT technology as ideal for designing high-performance power amplifiers for 5G applications.

6. CONCLUSION

In this study, we have developed a versatile power amplifier capable of operating across a wide range of classes and frequencies, from 3.5 GHz to 3.8 GHz. This flexibility is achieved through adjustment of the matching network capacitances and variation of bias voltage. By combining the inherent linearity of Class A with the notable efficiency of Class B, achieving up to 70% Power Added Efficiency (PAE), our amplifier emerges as a preferred solution for 5G applications.

Compared to other dual-band amplifiers listed in our study, our design offers superior performance in terms of PAE, high output power, and significant gain. This superiority highlights the advantage of GaN HEMT technology in crafting high-performance power amplifiers for 5G networks.

Furthermore, our design enables seamless transition between different operational modes, facilitating both power transmission and data communication within 5G networks. This adaptability and performance optimization tailored to specific 5G application needs underscore the relevance and effectiveness of our amplifier in environments where robustness, reliability, and high performance are crucial.

In conclusion, our work demonstrates that integrating the benefits of Class A and Class B in a GaN HEMT power amplifier provides an efficient and versatile solution to meet the increasing demands of 5G communication infrastructures, paving the way for advancements in power amplifier technology in the years ahead.

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