10W Class, Wideband GaN Power Amplifier Module for 5G Base – Stations

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1. Introduction

In recent years, implementation of 5th generation mobile communication system (5G) has spread to meet the demand for high speed, large capacity communications. If a single amplifier module is able to support a variety of frequencies, then this contributes to low cost and joint use of the radio units of 5G base stations. In this article, we discuss the 10W class, wideband GaN power amplifier module for 5G base stations which covers almost all the bandwidths of 5G frequencies in the 3 - 4 GHz band.

2. Background

In recent years, implementation of 5G has spread to meet the demand for high speed, large capacity communications. The 5G frequencies allocated in the 3 - 4 GHz band are distributed across a frequency range of the order of 700 MHz depending on the country or region. When using a conventional amplifier module, the operating bandwidth is at most of the order of 400 MHz, so it was difficult to cover all the 5G frequencies in the 3 - 4 GHz band with a single amplifier. If a single amplifier module is able to support a variety of frequencies, then this contributes to low cost and joint use of the radio units of 5G base stations. The Doherty power amplifier, which has been used until now for the amplifier module's final stage, has a narrow band, so extending it to wideband use was difficult. In addition, the design method[1] which configures the load modulation circuit in the Doherty power amplifier using the Tee-Type network in the Doherty power amplifier's main amplifier, proposed as a method to realize compact, highly efficient wideband from before, and using the transistor's parasitic capacitance without placing a circuit in the auxiliary amplifier, was difficult to employ in this module's configuration because a circuit has to be placed in the auxiliary amplifier.

In this article, we will discuss a new design method which realizes wider band operations even when a circuit is placed in the auxiliary amplifier, while making use of the advantages of the conventional design method, by designing the main amplifier and auxiliary amplifier circuit in an integrated manner. Using this design method, we created and evaluated a prototype 10W class, GaN power amplifier module with the result that, in the 700 MHz band from 3.4 - 4.1 GHz, the Adjacent Channel Leakage Ratio (ACLR) after digital pre-distortion was -46 dBc with a 20 MHz modulation bandwidth signal, while a Power Added Efficiency (PAE) of 42.0 - 44.6% and a gain of 28.6 - 31.0 dB were achieved.

3. Doherty Power Amplifier's New Circuit Design Method

The circuit diagram of the Doherty power amplifier designed is shown in Fig. 1. The main amplifier and the auxiliary amplifier are represented ideally with the current source and the shunt parasitic capacitance ($C_{ds,m}$, $C_{ds,a}$). We place the Tee-Type network composed of the transmission line between the main amplifier and the combining point, and set their electrical lengths and characteristic impedances to θ_1, θ_2, θ_3, Z_1, Z_2, Z_3 respectively. We place the Tee-Type network composed of the lumped component between the auxiliary amplifier and the combining point, and it is composed of the series inductor L_{a1}, the shunt inductor L_{a2}, and the series capacitor C_{a1} respectively. The series inductor L_{a1} is assumed to be a wire to the transistor. When there is a multi-chip configuration like a module, because it is necessary to connect the external circuit to the transistor with a wire, a circuit must be placed in-between the auxiliary amplifier and the combining point.

Next, we will discuss the circuit's operation principle. The circuit design method proposed in this article differs from conventional circuit design methods in that it transforms the impedance at the combining point. Specifically, as shown in Fig. 1, the impedance viewed at the output from the combining point is transformed into $\gamma \cdot (R_{opt,m} // R_{opt,a})$ and $\gamma = 1$ for conventional circuit designs, but in this circuit design method, it is possible to set $\gamma > 1$ because the circuit is inserted into the auxiliary amplifier side. Here, the γ represents the impedance transformation ratio, and $R_{opt,m}$, $R_{opt,a}$ represent the main amplifier's and the auxiliary amplifier's optimal impedances respectively. To operate as a Doherty power amplifier, both the main amplifier and the auxiliary amplifier are required to match the optimal impedances ($R_{opt,m}$, $R_{opt,a}$) respectively at saturation. In the case of this circuit, as shown in Fig. 1(b), it is easy to understand the operation if the circuit is replaced by an equivalent circuit that adds the virtual shunt capacitor (C_{vir}) and the virtual shunt inductor (L_{vir}) which cancel each other

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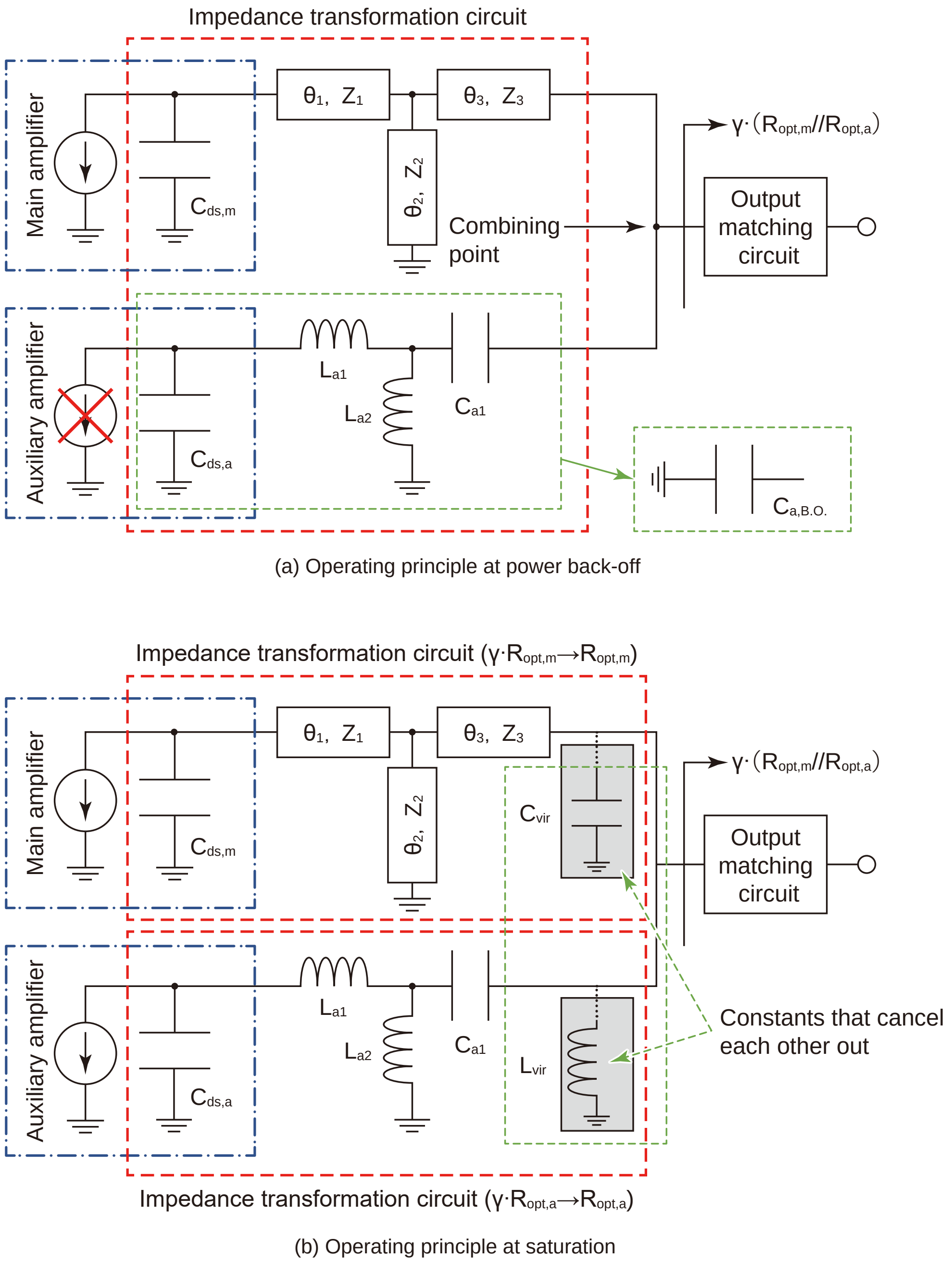

Fig. 1 Circuit schematics of designed Doherty power amplifier

out at the combining point. These virtual components together form an impedance transformation circuit that provides the impedance transformation ratio γ for both the main amplifier and the auxiliary amplifier. While at power back-off, to function as a Doherty power amplifier, the combining circuit must function as a load modulation circuit for the main amplifier. As shown in Fig. 1(a), at power back-off, the auxiliary amplifier has halted operation, so the current source on the auxiliary amplifier side is open. At this time, the four elements of the auxiliary amplifier side circuit, $C_{ds,a}$, L_{a1}, L_{a2}, and C_{a1}, can be represented equivalently as a shunt capacitor ($C_{a,B.O.}$). This equivalent shunt capacitor ($C_{a,B.O.}$) and the main amplifier's Tee-Type network can form the load modulation circuit in the Doherty power amplifier with the main amplifier side parasitic capacitance ($C_{ds,m}$). In this way, it is possible to function as a Doherty power amplifier through this circuit, however, it is not east to find circuit constants to satisfy these operating conditions at saturation and at power back-off. Therefore, we established a circuit equation to satisfy the conditions shown in Fig. 1. In this case, when the values of Z_1, Z_2, Z_3, L_{a1}, γ, C_{vir} in the circuit are fixed, the other circuit parameters (θ_1, θ_2, θ_3, L_{a2}, C_{a1}) can be analytically determined uniquely. Therefore, as the parameters of the Z_1, Z_2, Z_3, and L_{a1} are determined by the module structure, at the circuit design stage when the module structure has been decided, it is not possible to choose them arbitrarily. Therefore, γ, C_{vir} can be arbitrarily chosen at the circuit design stage. However, not all combinations of γ, C_{vir} have solutions for which the circuit operates as a Doherty power amplifier, and indeed we have found out from circuit analysis that combinations that have solutions are limited. Furthermore, we have discovered that, among the combinations for which there are solutions, the solutions in which γ is made large are consistent with wideband. In Fig. 2, we show the results of simulating the frequency dependence of the Doherty power amplifier's load modulation using the current source model. In Fig. 2(a) and (b), the main amplifier side impedance (Γ_{main}, $\Gamma_{main(B.O.)}$) and the auxiliary amplifier side impedance (Γ_{aux}) are shown in a Smith Chart normalized to their respective optimal impedances. Regarding the main amplifier side impedance, the impedance loci of the respective frequencies are shown in a thin, solid line, and the frequency dependence of the impedance at power back-off are shown in a thick, solid line. In Fig. 2(c) and (d), the frequency dependence of the magnitude of the reflection coefficients corresponding to the respective optimal impedances are shown at saturation (thin, solid line) and at power back-off (thick, solid line) for the main amplifier, and only at saturation (dotted line) for the auxiliary amplifier. The parameters used in this simulation other than γ as follows.

$Z_1=Z_2=Z_3=R_{opt,m}$, $C_{vir}=0.9 \cdot C_{ds,m}$

From the diagram, we can see that wider band matching is obtained when γ = 1.8. In particular, we can see that a wideband characteristic is obtained for

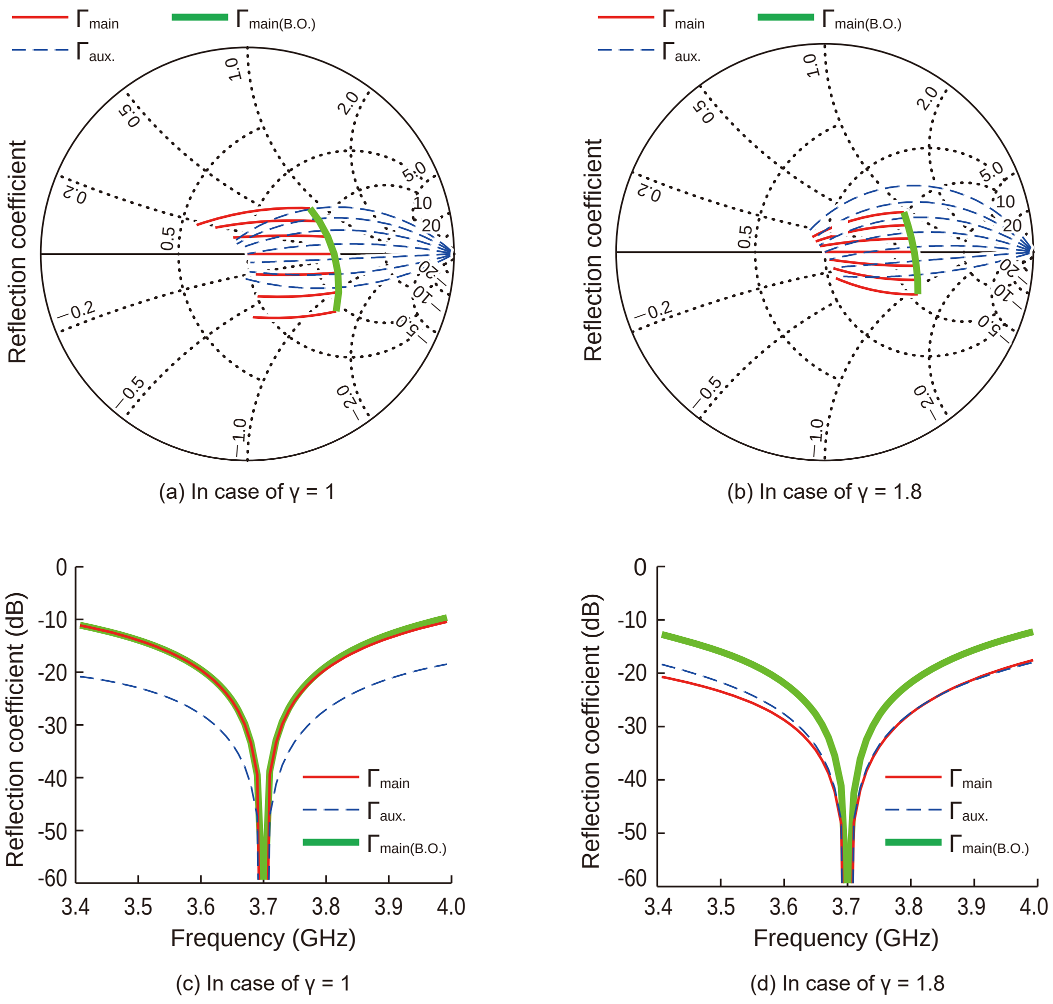

Fig. 2 Simulation result of frequency dependence of impedance modulation
in Doherty Power Amplifier using current source model

the main amplifier's impedance at saturation. Based on this we see that a wider band Doherty power amplifier operation is possible than conventionally (γ = 1.0) due to this circuit design method.

4. Results of Creation and Evaluation of a Prototype 10W Class, Wideband GaN Power Amplifier Module for 5G Base Stations

We conducted design and prototype creation of the 10W class, wideband GaN power amplifier module for 5G base stations that in the final stage had a Doherty power amplifier that used the circuit design method of Chapter 2. Figure 3 shows the module that was designed and prototyped. The module's effective area is 76 mm^2. Figure 4 shows the results of the evaluation when a 3.9 GHz pulse modulated signal was used. The graph's vertical axis indicates the final stage Doherty power amplifier's drain efficiency (DE (final)), the PAE including the driver stage's power consumption, and the Gain; and the horizontal axis indicates the output power (Pout). From the diagram we see that for the designed and prototyped module, at the peak output power of 47.9 dBm and 8 dB power back-off point, the drain efficiency is 53.8%, the PAE is 45.7%, and the Gain is 31.7 dB. Figure 5 shows the frequency dependence of the results of the evaluation using the modulation signal that has a 20 MHz modulation bandwidth and a 7.5 dB Peak to Average Power Ratio (PAPR). In the evaluation, the Digital Pre-Distortion (DPD) is applied and the post-DPD characteristics are represented. From the diagram we see that smooth characteristics are obtained across the 700 MHz from 3.4 - 4.1 GHz. In the 700 MHz band, the characteristics obtained are: average output power (Pave) of 40.3 - 40.8 dBm, PAE of 42.0 - 44.6%, Gain of 28.6 - 31.0 dB, post-DPD ACLR of less than -46 dBc. Figure 6 shows the results of the DPD evaluation using the 5G NR (New Radio) 100 MHz modulation signal. As shown in the diagram, we were able to apply DPD even for a wideband modulation signal, and we were able to obtain a characteristic of -51,7 dBc for the post-DPD ACLR. Table 1 shows the comparison between the amplifier with the design described in this article and other amplifiers for 3 - 4 GHz. We see that this designed and prototyped amplifier module shows the widest bandwidth characteristics in the 3 - 4 GHz band. From this conclusion, we were able to demonstrate the effectiveness of this design method.

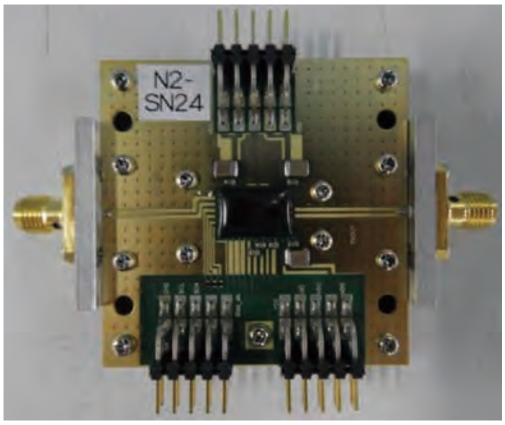

Fig. 3 Designed and fabricated 10W Class, **Wideband GaN Power Amplfier Module for** 5G Base-Stations

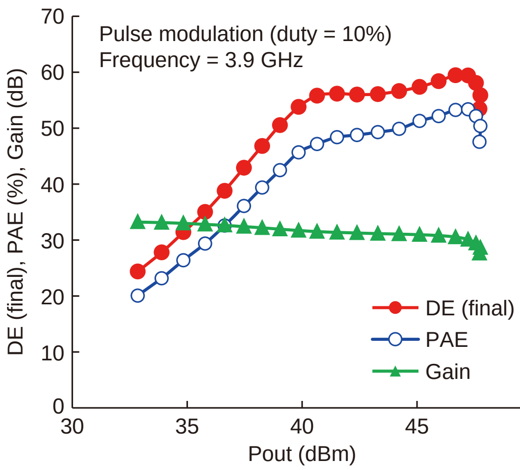

Fig. 4 Measurement result of fabricated power amplifier module using pulse modulated signal at 3.9 GHz

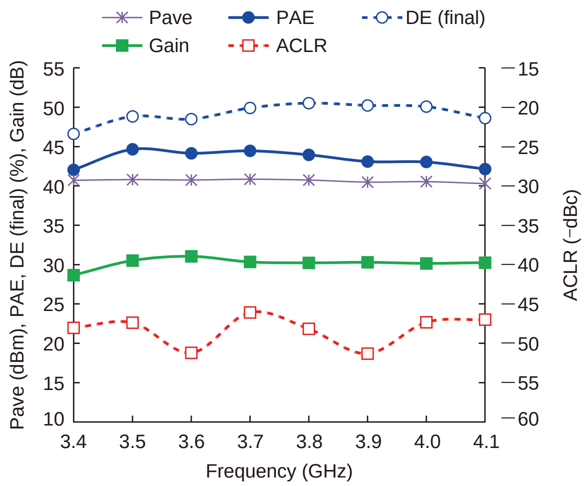

Fig. 5 Measured frequency characteristic using 20 MHz modulation signal with 7.5 dB PAPR

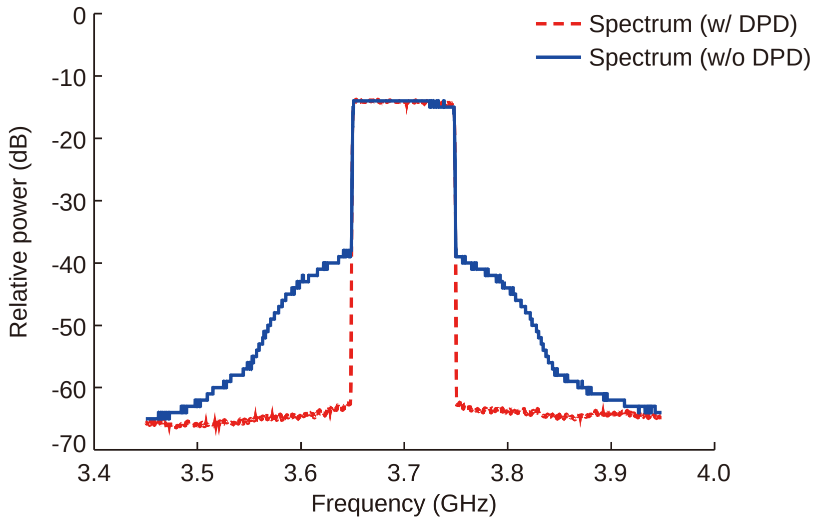

Fig. 6 Measured spectrum of the output signal using 5G NR 100MHz modulation signal before and after DPD

Table 1 Comparison of the designed power amplifier module with other amplifier operating in 3-4 GHz band

Amplifier	Frequency (GHz)	Drain efficiency (%)	PAE (%)	Modulation bandwidth (MHz)	PAPR (dB)
References (2)	3.3-3.6		40	20	7.2
References (3)	3.4-3.8	50.4-54.8	42.9-47.8	20	8
References (4)	3.0-3.6	45.9-50.2		20	7.5
Developed this time	3.4-4.1	46.6-50.5	42.0-44.6	20	7.5

5. Conclusion

We have described a new design method which, because it covers almost all the 5G frequencies in the 3 - 4 GHz band, realizes a wider band operation while making use of the advantages of the conventional design method. As a result of using this design method to prototype and evaluate a 10W class GaN amplifier module, in the 700 MHz band from 3.4 - 4.1 GHz, an ACLR after digital pre-distortion of -46 dBc was satisfied with a 20 MHz modulation bandwidth signal, and a PAE of 42.0 - 44.6% and a gain of 28.6 - 31.0 dB were achieved. In addition, from the fact that the widest bandwidth characteristics were obtained compared to other amplifiers, we were able to demonstrate the effectiveness of this design method.

References

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