A 5–8 GHz wideband 100 W internally matched GaN power amplifier

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Abstract: A 5–8 GHz internally matched Gallium Nitride (GaN) power amplifier (PA) with 100 W output power was realized in this letter. The theory of load line match was used and extended. Power contour was depicted and revised by the output capacitance of GaN High Electron Mobility Transistor (HEMT). Impedance was matched into the −1 dB power contour in a wide frequency band due to the ladder transmission line matching network and broadband power combiner. With the package size of 14.5 × 14.8 mm, the proposed power amplifier has the maximum output power of 102 W with 45.8% associate power added efficiency (PAE) at the frequency of 6.5 GHz, and output power over 85 W and PAE over 42.8% at the frequency band of 5–8 GHz.

Keywords: GaN PA, internally matched, wideband, high power

Classification: Microwave and millimeter wave devices, circuits, and systems

References

1 Introduction

As an important component in the communication system, the power amplifier with high output power and large bandwidth is widely used in satellites and base stations. Due to the capabilities of high power density, high breakdown voltage and high electron mobility, GaN high-electron mobility transistors (HEMT) has promoted the development of power amplifiers. A series of high power GaN PAs were reported: a 5.2–5.8 GHz internally matched GaN PA with 164 W output power was reported in [1]. C. Berrached designed a 45 W internally matched PA in 2–4 GHz octave bandwidth in [2]. H. Shigematsu [3] realized a 4.8 GHz PA with 343 W output power and 9.8 GHz PA with 101 W output power. H. Maehara [4] realized a 5–6 GHz PA with the maximum output power of 224 W. However, the bandwidth of the high power internally matched PA should be further improved.

The output power of internally matched PA is limited by poor heat dissipation and the bandwidth is confined by small dimension of package. In this letter, the package made of diamond-copper composite material which has high heat conductivity is used to increase heat dissipation. At the same time, power contour theory, ladder transmission line matching network and broadband power combiner are used to increase the bandwidth. Finally, an internally matched PA with high power and large bandwidth is realized.

2 Design of proposed PA

The GaN HEMT with 14.4 mm gate width used in this letter was produced at Xidian University. The schematic cross-section is shown in Fig. 1.

![Schematic cross-section of GaN HEMT](image-url)
The AlGaN/AlN/GaN heterostructure layers were grown on SiC substrate. First, 100 nm AlN nucleation and 2 um GaN buffer were deposited to decrease dislocation. In addition, there was a 1 nm AlN interlay to increase the density of two-dimensional electron gas (2DEG) and followed by 20 nm Al_{0.3}Ga_{0.7}N barrier. Finally, SiN films were deposited to prevent current collapse effect [5]. The fabricated GaN HEMT exhibited a saturation current of 1.18 A/mm at $V_{GS} = 1$ V and the maximum transconductance 280 mS/mm was obtained at $V_{DS} = 10$ V.

The schematic of proposed internally matched GaN PA is shown in Fig. 2. The PA consists of power divider/combiner, which matches the system impedance 50 Ohm to relative smaller impedance in a wide band, and input/output match which completes impedance matching and block high frequency signal as well.

Power contour theory is used to find the best output impedance which can be divided into the following three steps. Firstly, based on the load line theory, load resistance $R_{opt}$ when PA obtains its maximum output power $P_{max}$ is determined by Eq. (1) where $V_{dc}$ is the drain bias voltage and $I_{max}$ is the maximum source-drain current. PA gets maximum voltage $V_{max}$ and maximum current $I_{max}$ at this time. Secondly, when PA gets output power of $P_{max}/p$ ($p$ is a number greater than 1), resistances $R_{low}$ and $R_{high}$ are determined by Eq. (2). At low resistance, current gets $I_{max}$ and voltage just reaches $V_{max}/p$, so output power is $P_{max}/p$. At high resistance, voltage gets $V_{max}$ and current just reaches $I_{max}/p$, so output power is $P_{max}/p$ as well. Finally, as reactance does not consume energy, the impedance $R_{low}$ at plane "A" and $G_{opt}$ at plane "B" [6] get the same output power of $P_{max}/p$ [6]. So the −1 dB power contour which is the intersection of $R_{low}$ resistance circle and $G_{low}$ conductance circle was depicted in Fig. 3 in solid line. However, the output capacitance which is about 0.5 pF per millimeter gate width [7] inside the HEMT has great influence on the matching network. As shown in Fig. 3, the PA needs a impedance of $R_{opt}$ at plane “A” according to the admittance calculation of parallel circuit, optimal admittance at plane “B” $G_{opt-B}$ will be calculate by Eq. (3) where $j$ is the imaginary unit, $f$ is the center frequency and $C_{ds}$ is the output capacitance of GaN HEMT. The optimal impedance at plane “B” $Z_{opt-B}$ is the reciprocal of $G_{opt-B}$.

$$R_{opt} = 2V_{dc}/I_{max} \tag{1}$$

$$R_{low} = R_{opt}/p, \quad R_{high} = R_{opt} \ast p \tag{2}$$

$$G_{opt-B} = G_{opt} - j2\pi fC_{ds}, \quad Z_{opt-B} = 1/G_{opt-B} \tag{3}$$
Fig. 4 shows the whole output matching network and corresponding result in SmithChart. The proposed power combiner has two improvements compared to traditional one: the diagonal corner is used to decrease loss, the two-section combiner and its graded variation contributes to wideband. The impedance is 50 Ohm at PA plane while it presents \( Z_m = 20 \) Ohm at power combiner plane. The ladder matching network consists of two transmission lines which have the corresponding widths of HMET and power combiner respectively. Gold bonding wire is used to connect each module and has the function of inductor. The ladder matching network transforms \( Z_m \) at combiner plane into \( Z_{opt} = 2.75 + j \times 5.82 \) Ohm at HEMT plane at center frequency of 6.5 GHz while the impedance falls into \(-1\) dB power contour throughout the band of 5–8 GHz. At last, optimal input impedance is found by measured S-parameter of GaN HEMT die while input matching network is realized by ladder transmission line and two-section power divider as well.

![Diagram](image)

Fig. 4. Output match network and corresponding result in SmithChart

3 Implementation and experiment results

Fig. 5 is the photograph of the packaged internally matched PAs with a cavity size of 14.5 \times 14.8 \text{ mm}. The package made of diamond-copper composite material which has high heat conductivity can increase heat dissipation. Measured small
signal S-parameter of the proposed PA is shown in Fig. 5 where DC bias condition is $V_{dc} = 40$ V and $I_{dc} = 300$ mA. $S11$ and $S22$ have 4 extremal points due to ladder matching network and two-section power divider/combiner. In the frequency band of 5–8 GHz, $S11$ and $S22$ are less than $-7$ dB and $S21$ is more than $15$ dB.

The pulse wave (PW) with a duty of 10% and 100 µs period power sweep measurement results are shown in Fig. 6, where DC bias condition is $V_{dc} = 40$ V and $I_{dc} = 300$ mA at center frequency 6.5 GHz. The peak power of the PA is 50.05 dBm (102 W) with 45.8% PAE and 13.05 dB associated gain with 3.54 dB gain compression. The circuit measured performance during the bandwidth with fixed available input power of 37 dBm is shown in Fig. 7. The proposed wideband PA has output power over 43.25 dBm (85 W) and PAE over 42.8% and the best performance of 102 W output power and 45.8% PAE at the frequency of 6.5 GHz.

The comparison of output power and bandwidth with other works is shown in Fig. 8. The proposed PA performs better in bandwidth in the area of hundred Watt PAs.
4 Conclusion

This letter proposes a 5–8 GHz wideband internally matched GaN PA. The power contour theory is used and it is revised by output capacitance of GaN HEMT. A ladder matching network and novel power divider/combiner are proposed to realize broadband high power amplifier. Compared with other works, a 100 W PA with state-of-art bandwidth is realized.

Fig. 7. Frequency response at 37 dBm input power of proposed wideband PA from 5 GHz to 8 GHz

Fig. 8. Comparison of output power and bandwidth with others