Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Design of 2.45-GHz High-Efficiency Miniaturized Power Oscillator Using GaN HEMT

To cite this article: Qingyu Guo *et al* 2023 *J. Phys.: Conf. Ser.* **2527** 012064

Design of 2.45-GHz High-Efficiency Miniaturized Power Oscillator Using GaN HEMT

Qingyu Guo[1, *], Yifeng Lu[2], Chaowu Mao[2], Jianyang Zhou[1]

[1.] Department of Microelectronics and Integrated Circuit, Xiamen University, Xiamen 3661102, China.

[2.] NP Device, Xiamen San'an Integrated Circuit Co., Ltd., Xiamen 3661102, China.

[*]36120201150353@stu.xmu.edu.cn.

Abstract. This study presents a method for designing a highly efficient miniaturized power oscillator with gallium nitride high electron mobility transistor (GaN HEMT). A harmonic-tuning highly efficient power amplifier (PA) using GaN HEMT is designed firstly by finding optimal fundamental, 2nd and 3rd harmonic load impedances. After the performance of PA meets the requirements, the feedback circuit that is made of a hairpin resonator and a coupler is studied based on the power gain of PA and the required frequency. Both the size of the PA and the feedback circuit should be taken into account to minimize the oscillator at last. Finally, the PA and feedback circuit are combined into a power oscillator. Through this way, the highly efficient miniaturized power oscillator with a size of 2.7*4.9 cm^2 fabricated on substrate of FR4 outputs 37.7 dBm power and 72% efficiency at 2.4518 GHz under the bias condition of Vgs = -3.21V, Vds = 28V, Ids = 25mA.

1. Introduction

With the development of third generation semiconductors, the excellent performance of GaN HEMT in high power, high frequency and high efficiency makes GaN HEMT widely used in the design of high efficiency power amplifiers and power oscillators [1]. The high efficiency power oscillator as microwave source based on GaN HEMT has a promising application in microwave heating [2]. In terms of improving efficiency, the design of a harmonic-tuning load network has been adopted in some reported high efficiency oscillators [3], [5] and [6]. However, in addition to the output power and efficiency, the size of the power oscillator should also be taken into account. Therefore, this article presents a highly efficient miniaturized power oscillator with greater than 37 dBm output power at 2.45 GHz and over 70% efficiency. The following sections are written to describe the power oscillator design in detail.

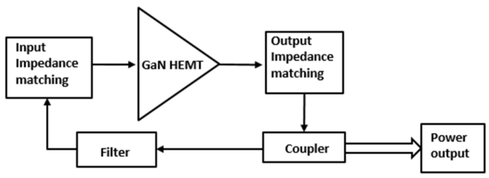

Figure 1. Diagram of the designed power oscillator.

2. Power Oscillator Design

As shown in figure 1, the proposed power oscillator consists of a power amplifier using GaN HEMT, coupler and filter. The GaN HEMT provides the active component and outputs RF power to achieve the designed performance. The coupler is then composed of two parallel microstrip lines, aiming to transport little RF power from the output terminal to the input terminal. And the coupling structure can isolate the output impedance matching network of the PA and feedback circuit, greatly reducing the design difficulties [7]. Finally, the assignment of selecting the required frequency - 2.45GHz - is done by a filter, composed of a hairpin resonator [8, 9].

2.1 Power Amplifier Design

Taking the target performance into account, a GaN HEMT with a gate width of 10*125 um made by Xiamen San'an IC Ltd is selected for this power amplifier design, with power density of more than 6 W/mm and maximum drain efficiency of over 80%. The bias condition of the power amplifier operating on Class AB is V_{ds} = 28 V, V_{gs} = -3.21 V, I_{ds} = 25 mA.

The design of the output impedance matching network including fundamental, 2nd harmonic and 3rd harmonic impedances is critical to improving the efficiency of the PA [10]. And the optimal impedances meeting these requirements can be obtained by the load pull and harmonic load sweep provided by ADS simulation. Based on these optimal impedances, this paper proposes a miniaturized output impedance matching network, as shown in figure 2. First, the second harmonic impedance matching network is composed of microstrip lines TL1, TL2 and capacitor C2 – 12pF. The length of the TL2 microstrip line is 1/4 wavelength at 2.45 GHz and TL2 linking with capacitor C2 forms the short-circuit transmission line. This structure allows the 2nd harmonic component to be shortly circuited while barely affecting the power transmission of the fundamental and 3rd harmonic components. TL2 also connects to the drain bias voltage, eliminating the need to add additional bias line and reducing the size of the matching network. Finally, tuning the TL1 microstrip line allows the second harmonic component to achieve optimal impedance matching. Secondly, the third harmonic control circuit is composed of microstrip lines TL3 and TL6. The length of TL6 is 1/12 wavelength at 2.45 GHz, forming a short circuit at the 3rd harmonic and optimal control of the 3rd harmonic is achieved by tuning TL3. Finally, the fundamental load impedance matching to 50ohm is completed by tuning the TL5 microstrip line and capacitor C1. The capacitor C1 also acts as a DC-block to reduce the size of the matching network. The final results of the output impedance matching network are shown in figure 3. Similar impedance matching work is also done in the input terminal, including a 20ohm resistor that stabilizes the power amplifier in the bias microstrip line.

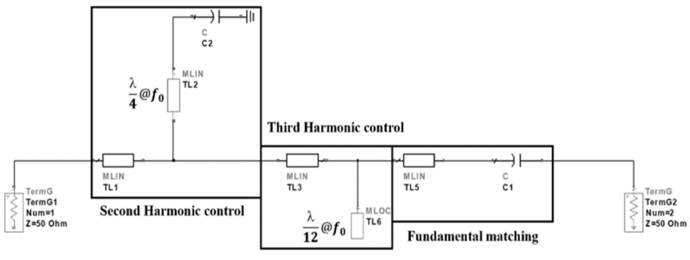

Figure 2. Output impedance matching network.

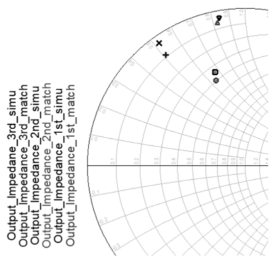

Figure 3. Simulated impedances versus matching impedances.

This paper selects FR4 board that Er = 4.7, H = 0.7mm, TanD = 0.02. Figure 4 shows the fabricated power amplifier and figure 5 shows the measured and simulated performance of the output power and drain efficiency under the test condition of Vgs = -3.21V, Vds = 28V, Ids = 25mA and continuous wave mode. The realized power amplifier outputs 37.7 dBm power at 2.45 GHz and 76% drain efficiency compared to the 37.25 dBm output power and 78.4% drain efficiency from the ADS simulation. Therefore, this power amplifier has reached the design requirements and can be used for the high efficiency power oscillator design.

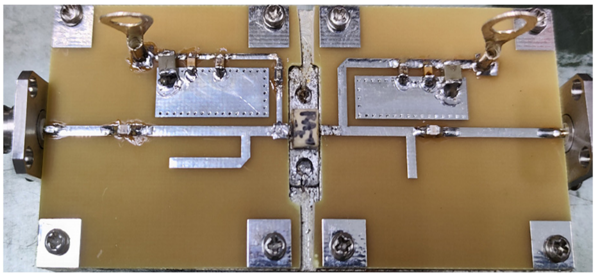

Figure 4. Photograph of implemented power amplifier.

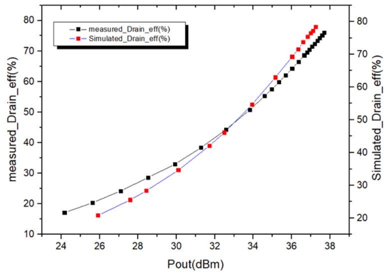

Figure 5. Measured and simulated performance of power amplifier at 2.45 GHz.

2.2. Feedback Circuit Design

As described above, the feedback circuit consists of a coupler and a filter. And the most important part of the feedback is the filter design, aiming to obtain the required frequency - 2.45GHz. Furthermore, this design uses a hairpin resonator for the purpose of reducing the size of the power oscillator. And the essential principle of the hairpin resonator is half wavelength transmission line resonance. In addition, the coupler is composed of two parallel microstrip lines. The details of feedback circuit are illustrated in figure 6. The primary performance of this feedback circuit is the coupling degree closely related to the gain of the PA, as shown in figures 7 and 8.

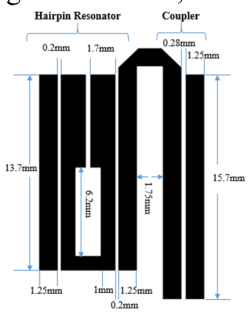

Figure 6. Proposed feedback circuit topology.

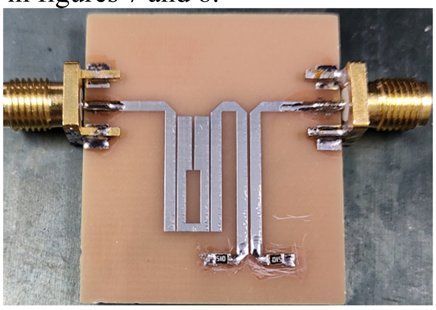

Figure 7. Photograph of fabricated feedback circuit.

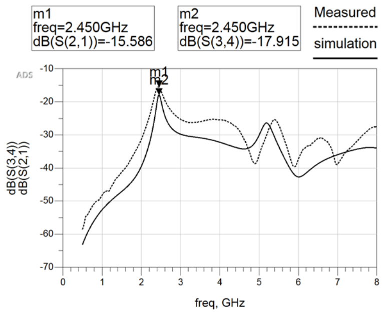

Figure 8. Measured and simulated coupling degree of feedback circuit.

3. Experimental results of Power Oscillator

With the PA and the feedback circuit well designed, it is convenient to combine them into a power oscillator. At this time, the offset line length between the input terminal of the PA and the feedback circuit must be well tuned to produce the proper oscillation at 2.45 GHz. Figure 9 shows the power oscillator fabricated on FR4 board that Er = 4.7, H = 0.7mm, TanD = 0.02, while Figures 10 and 11 show the measurement results of the power meter and spectrum analyzer, respectively.

Finally, under the bias condition of Vgs = -3.21V, Vds = 28V, Ids = 25mA, the designed power oscillator outputs 37.7 dBm power and 72% efficiency at 2.4518 GHz. In addition, the second harmonic component, which is the greatest harmonic, is 26.69 dB below the fundamental and the measured phase noise is -70 dBc/Hz under 1 MHz offset frequency. And the size of this designed power oscillator is 2.7*4.9cm^2. In table 1, the measurements of this designed power oscillator are compared with those reported highly efficient oscillators and validate the excellence of this designed power oscillator.

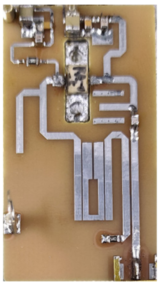

Figure 9. Photograph of implemented power oscillator.

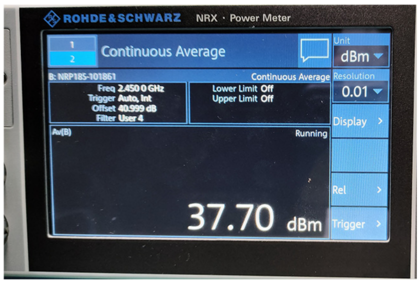

Figure 10. Measured output power of power oscillator.

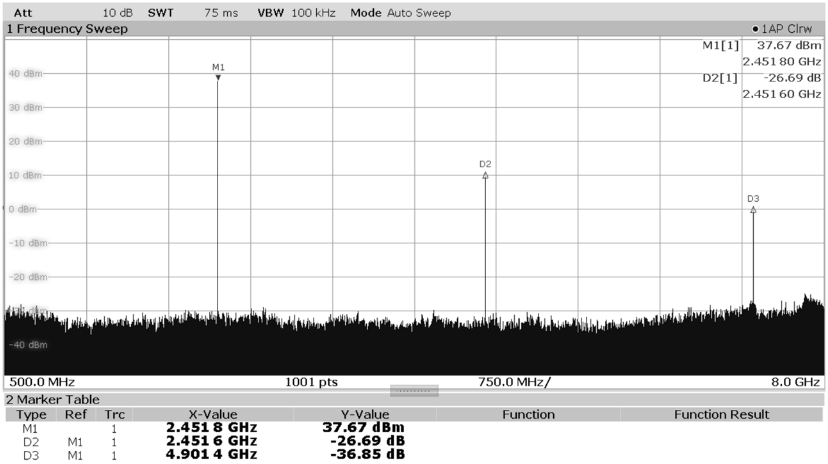

Figure 11. Measured output spectrum. The resolution bandwidth is 100 KHz.

Table 1. Performance of reported high efficiency power oscillator.

Reference	Frequency	Output power	Efficiency	Area
[3]	981 MHz	6.5 W	73%	\
[4]	410 MHz	67 W	69%	3.5*4.9cm^2
[5]	2.45 GHz	47.9 W	58%	\
[6]	2.44 GHz	4.9 W	75.9%	5*10cm^2
This work	2.4518 GHz	5.88 W	72%	2.7*4.9cm^2

4. Conclusion

In this article, a highly efficient miniaturized power oscillator is realized by designing the power amplifier and feedback circuit separately. In the design of the highly efficient PA, an output impedance matching network is studied according to the fundamental, 2nd and 3rd harmonic load impedances. Then, the feedback circuit composed of a hairpin resonator and parallel coupler is designed, whose coupling degree closely approximates the power gain of the implemented PA. Finally, the fabricated power oscillator with a size of 2.7*4.9 cm^2 outputs 37.7 dBm power at 2.4518 GHz and 72% efficiency. From the final results, it is known that the design of miniaturized harmonic-tuning impedance matching network and feedback circuit provided by this paper can increase the efficiency of the power oscillator while reducing its size. These results also show that GaN HEMTs manufactured by Xiamen San'an IC have great performance and can be attractive devices for high power and high efficiency power amplifier design. In the next research work, apart from maintaining the requirements of high efficiency and miniaturization of the power oscillator, the output power should be significantly increased to make it more suitable for microwave heating applications.

References

[1] Pengelly, Raymond S, et al. A review of GaN on SiC high electron-mobility power transistors and MMICs. *IEEE Transactions on Microwave Theory and Techniques* 60.6 (2012): **1764-1783**.
[2] Chandrasekaran, S., S. Ramanathan, and Tanmay Basak. Microwave food processing—A review. *Food research international* 52.1 (2013): **243-261**.
[3] W J Hwang, S W Shin, G W Choi, H J Kim, and J J Choi, High-efficiency power oscillator using harmonic-tuned matching network, *in IEEE MTT-S Int*. Dig., May 2009, pp. **1505–1508**.
[4] S Jeon, A Suárez, and D B Rutledge, Nonlinear design technique for high-power switching-mode oscillators, *IEEE Trans. Microw. Theory Tech*., vol. 54, no. 10, pp. **3630–3640**, Oct. 2006.
[5] S H Kim, H J Kim, S W Shin, J D Kim, B K Kim, and J J Choi, Combined power oscillator using GaN HEMT, *in IEEE MTT-S Int*. Dig., Jun. 2011, pp. **1–4**.
[6] Lee, S, Jeon, S, & Jeong, J. (2012). Harmonic-Tuned High Efficiency RF Oscillator Using GaN HEMTs. *IEEE Microwave and Wireless Components Letters,* 22(6), **318–320**.
[7] Pozar, David M. Microwave engineering. John wiley & sons, 2011.
[8] Sagawa, Morikazu, Kenichi Takahashi, and Mitsuo Makimoto. Miniaturized hairpin resonator filters and their application to receiver front-end MICs. *IEEE Transactions on Microwave Theory and Techniques* 37.12 (1989): **1991-1997**.
[9] Hsieh, Lung-Hwa, and Kai Chang. Compact lowpass filter using stepped impedance hairpin resonator. *Electronics Letters* 37.14 (2001): **1**.
[10] Woo, Young Yun, Youngoo Yang, and Bumman Kim. Analysis and experiments for high-efficiency class-F and inverse class-F power amplifiers. *IEEE Transactions on Microwave Theory and Techniques* 54.5 (2006): **1969-1974**.