A High Power GaN-HEMT Power Amplifier at 2.4GHz

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Abstract This paper presents the design, implementation and measurement of a high efficient GaN-HEMT power amplifier working at 2.4GHz. The maximum gain and harmonic load-pull design approaches are used to design to achieve over 70 MHz bandwidth along with high output power. For a continuous wave output power of 35.4dBm , the measured results show that the PA exhibit a gain of 17.5dB, the power added efficiency of 51%, and input reflection coefficient S11 below -9dB over operation bandwidth. The designed power amplifier is stable with both small and large input signals.

Keyword: Power amplifier, gallium nitride (GaN, high electron mobility transistor (HEMT).

1. INTRODUCTION

Fast developments of wireless communications provide a lot of benefits for human life [1]. Power amplifiers (PAs) play important roles in wireless systems. PAs with medium output power (5 – 10W) using for various special purposes are highly demanded, such as for rescue or remote surveillance systems. However in Viet Nam the researches on the design and fabrication of microwave amplifiers are limited. The lack of available qualified components, good design techniques and measuring equipment's are among difficulties in this field in Viet Nam.

This paper presents the design, fabrication and measurement of a single-band PA working at 2.4 GHz used for wireless Video transmission system. The maximum gain and harmonic load-pull techniques are used to have high gain and high output power for the designed PA. The designed PA exhibit a gain of 17.5 dB and power added efficiency (PAE) of 51%. This paper is organized as follows. In Sec. II, a description of the design approach and the implementation of the single band PA is presented. The experimental results are presented in Sec. III, while conclusions are given in Sec. IV.

2. 2.4-GHZ PA DESIGN AND IMPLEMENTATION

In the design, the GaN-HEMT packaged device, TriQuint T2G6000528-Q3 was used. The device operates from DC to 6 GHz, output power at 3dB compression gain P3dB = 9.2W with gain of 15.5 dB at testing conditions of TA = 250C, VDS = 28V and ID = 50mA. This device is good for both wideband and narrowband amplifiers design. The first step in the PA design process is to find VGS value that matches with VDS = 28V to get ID = 50mA (manufacturer recommendation) at small-signal condition. The simulation results show that VGS = -2.634V which is well agreed with measurement result from manufacturer.

Stability simulation is strictly considered on entire operating frequency band of T2G6000528-Q3 device. The stability coefficient μ of device is simulated. Due to the lack of accuracy in fabricating process (approximately 0.2mm), so unconditional stability on the entire operating frequency band of device is required in this PA design. A parallel RC circuit and paralleling R of 250Ω at the Gate terminal are used to improve the stability of device. The simulated stability factors of the transistor before and after adjusting are shown in Fig. 1. Value of μ > 1 demonstrates the unconditional stability of device.

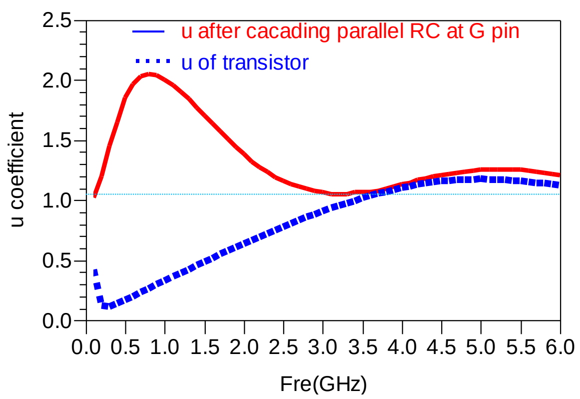

Figure 1. μ coefficient of device and μ coefficient after cascading parallel RC circuit at G pin.

The next step of the design process is to perform load-pull simulations for transistor T2G6000528-Q3 at 2.45GHz in order to find fundamental load impedance that maximizes the output power of the device. The results of load-pull simulations are shown in Fig. 2. Output power and PAE contour curves are drawn on the Smith chart. In this design we chose the output impedance of 22.6 – j14.4Ω (marker 2) for achieving an output power of 39.17 dBm which is 1dB lower than the maximum available output power of the device while achieving 70.9% PAE. The output matching network is designed to match 50□ load with fundamental load impedance of ZL = 22.6 – j14.4Ω that corresponding with output reflection coefficient $\Gamma L = 0.418\angle -141.056$.

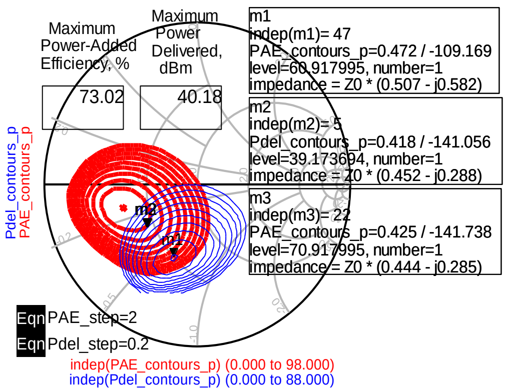

Figure 2. Load-pull simulation results (marker 2 and marker 3 is nearly at a point).

Input refection coefficient Γin is determined using formula from [2] as follow:

$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \qquad (1)$$

From which, the input impedance of 7.13 + j28.74Ω is obtained. The conjugate matching at the input power is implemented to get the maximum power gain.

Table 1. Simulated S11 when output is matched.

freq	S(1,1)
2.420 GHz	0.798 / 123.314
2.430 GHz	0.801 / 122.041
2.440 GHz	0.804 / 120.750
2.450 GHz	0.807 / 119.443
2.460 GHz	0.809 / 118.123
2.470 GHz	0.811 / 116.791
2.480 GHz	0.813 / 115.452

To reduce the deviation between simulation and fabrication due to welds that uncovered in simulation, EM simulation is used along with circuit simulator.

Output matching network shown in Fig. 3 is designed using the single-stub topology with micro-trip lines. Input matching network is designed using double-stub matching topology as shown in Fig. 4. A 0.9-pF capacitor is used with micro-trip lines to reduce the size of input matching network and function as DC block component.

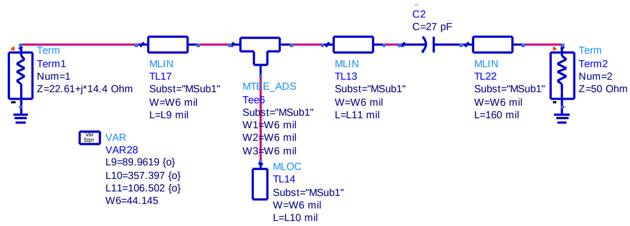

Figure 3. Output matching network.

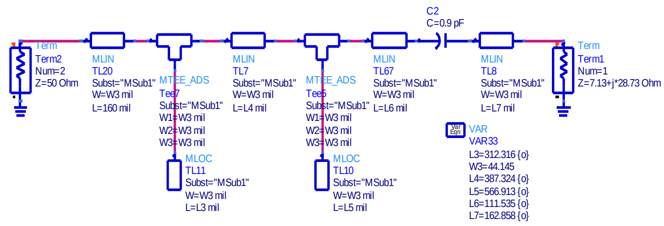

Figure 4. Input matching network.

The whole designed PA is then simulated using EM-simulator. This is a very important step before fabrication to estimate the performance of the fabricated PA. The layout of the PA is done using ADS Momentum for EM simulation. Based on EM-simulation results, the PA is further optimized.

The single-band PA is implemented on Isola IS680-345 substrate with εr = 3.45 and thickness of 0.508mm. Fig. 5 shows the picture of design PA using packaged GaN-HEMT device. The total size of the PA is 6x7 cm2.

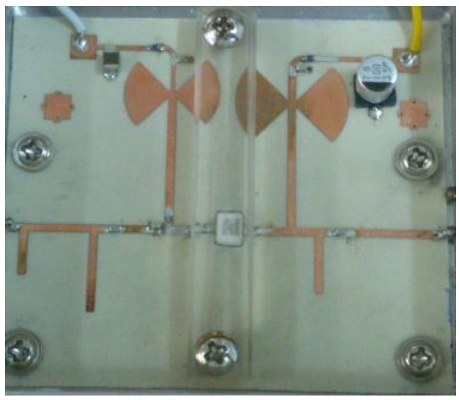

Figure 5. Photo of the implemented single-band PA at 2.4GHz, size 6x7 cm^2.

3. MEASUREMENT RESULTS

The implemented PA has been characterized under small signal, large signal and modulated signal conditions.

The measured results show that the designed PA exhibits a good performance.

3.1. Small signal measurement

The scattering parameters of the realized PA is measured using Rohde & Schwarz ZVB8 Vector Network Analyzer. Transistor of the PA is biased with drain bias voltage of VDS = 28V, quiescent drain current of ID = 50mA, and gate bias voltage of VGS = −2.63V. The measured S parameters, presented in Fig. 6, with small input power of -20dBm show a good agreement with simulations and therefore, it demonstrates the correct behavior of the PA in the proximity of 2.41GHz. The input match S11 is -11.6dB at 2.41GHz, worse than -30.2dB of simulation at 2.46GHz. The small-signal gain S21 is around 18dB at 2.41GHz, lower than the simulation result of 20.6dB. Center frequency of realized PA is shifted 50MHz to the left, which is due to the effects of connectors and welds uncovered in simulation.

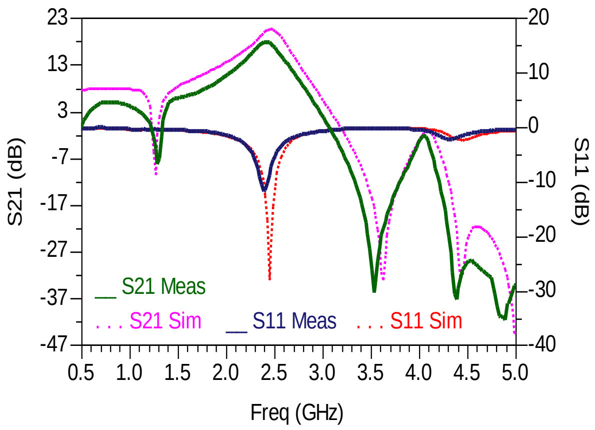

Figure 6. The measurement and simulation results of S parameter is compared.

The designed PA is stable from DC to 6 GHz. The calculation of μ coefficient based on the measured results is shown in Fig. 7.

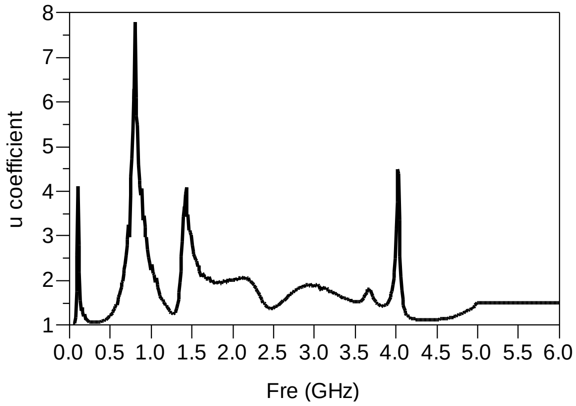

Figure 7. Measured μ coefficient.

3.2. Large signal measurement

Continuous wave microwave signal is generated by Rohde & Schwarz SMR30 Signal Generator for PA measurement. The output signal of PA is then measured by a Rohde & Schwarz FSP Spectrum Analyzer. The chosen DC bias is the same as in the S parameter measurement. Fig. 8 shows measured output power versus input power and Fig. 9 shows PAE versus input power at 2.41GHz. It can be seen that the behavior of output power of the PA is quite agreed with simulation results.

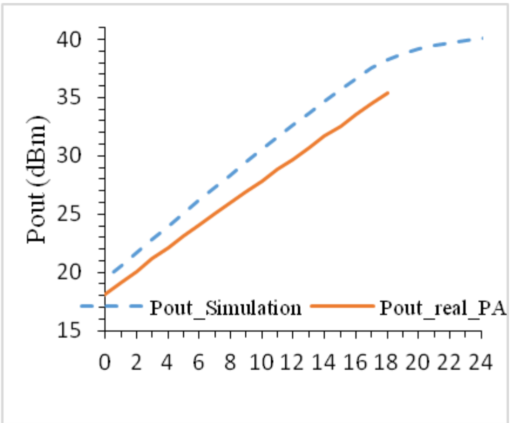

Figure 8. Measured output power is compared with simulated vs. input power at 2.41GHz.

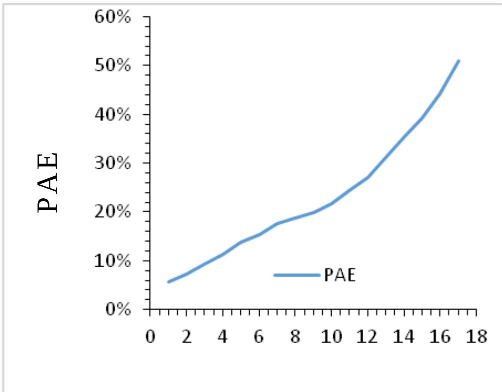

Figure 9. Measured PAE vs. input power at 2.41GHz.

3.3. Modulated signal test

The output signal from a wideband FM video transmitting module AWM651Tx is fed to PA and the output signal of the PA is observed on an spectrum analyzer. The output signal from module AWM651Tx is amplified by 17.7 dB with less distortion as shown in Fig. 10.

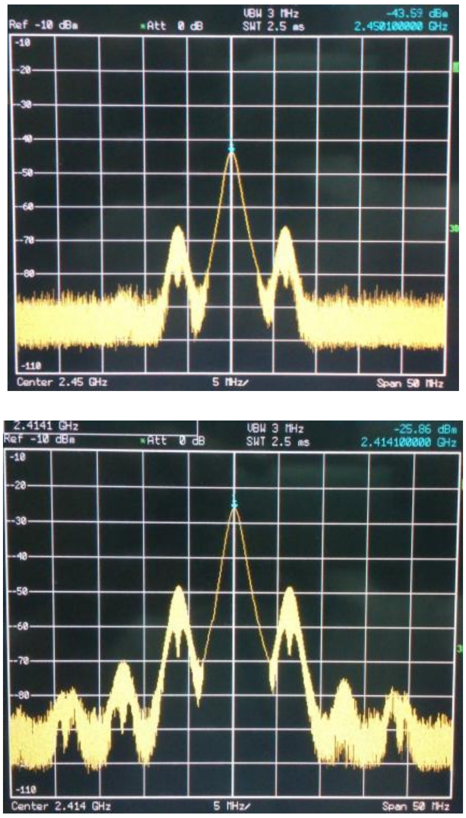

Figure 10. The output signal of video module AWM651Tx and boosted by the PA.

4. CONCLUSION

In this paper, the design of a single-band PA using a GaN-HEMT has been presented. The design approaches based on harmonic load-pull data and maximum gain method facilitates the realization of high performance single-band PA working at 2.4GHz. The measurement results show that the designed PA exhibits the power gain of 17.5dB, PAE of over 51% and P1dB over 35.4dBm. The designed PA may find many wireless applications in Viet Nam, specially for searching for rescue or remote surveillance. Although microwave amplifier circuit is developed so long in the world but mastering this technology still provides much benefit for communications engineering in Vietnam.

ACKNOWLEDGMENT

This research has been carried out at Ho Chi Minh City University Technology and in the Telecommunication Laboratory belong to Faculty of Electrical and Electronics Engineering. Model of T2G6000528-Q3 transistor is supported by Modelithics, laminate material IS680-345DK is supported by Isola Group, and special support from TriQuint for T2G6000528-Q3 device..

REFERENCES

[1] David M. Pozar, Microwave and RF Design of Wireless Systems, John Wiley &Sons, Inc., USA, 2001.

[2] David M. Pozar, Microwave Engineering, John Wiley &Sons, Inc., USA, 2012.