International Journal of Electrical and Computer Engineering (IJECE)
Vol. 8, No. 3, June 2018, pp. 1837~1843
ISSN: 2088-8708, DOI: 10.11591/ijece.v8i3.pp1837-1843

0.5GHz - 1.5GHz Bandwidth 10W GaN HEMT RF Power Amplifier Design

Shiva Ghandi Isma Ilamaran[1], Zubaida Yusoff[2], JahariahSampe[3]
[1,2]Faculty of Engineering, Multimedia University, Malaysia
[3]Institute of Microengineering and Nanoelectronics, University Kebangsaan Malaysia University, Malaysia

Article Info

Article history:

Received Dec 11, 2017
Revised Apr 18, 2018
Accepted Apr 25, 2018

Keyword:

GaN
RF power amplifier
Wideband

ABSTRACT

With the current development in wireless communication technology, the need for a wide bandwith in RF power amplifier (RF PA) is an essential. In this paper, the design and simulation of 10W GaN HEMT wideband RF PA will be presented. The Source-Pull and Load-Pull technique was used to design the input and output matching network of the RF PA. From the simulation, the RF PA achieved a flat gain between 15dB to 17dB from 0.5GHz to 1.5GHz. At 1.5GHz, the drain efficiency is simulated to achieve 36% at the output power of 40 dBm while the power added efficiency (PAE) was found to be 28.2%.

Corresponding Author:

Zubaida Yusoff,
Faculty of Engineering,
Multimedia University,
Jalan Multimedia, 63100 Cyberjaya, Selangor, Malaysia.
Email: zubaida@mmu.edu.my

1. INTRODUCTION

Communication requirement in radar systems and wireless technologies have allowed development in research to make an improvement in the design of wideband RF power amplifier (RF PA). In the near future, a wide bandwidth and a low power RF PA would be an important aspect of the communication technology to cater the need for microcell network topology. A wider bandwidth in an RF PA could improve the spectral efficiency of the communication and at the same time satisfy the real time communication requirements [4], [12]. Besides that, the efficiency of the RF PA should also be taken into consideration regardless of the wide bandwidth nature of the RF PA. A low efficiency RF PA would increase the cost to maintain a base station [6], [11]. In order to design an efficient and wideband RF PA, correct design approach considering the harmonic frequencies should be followed to achieve the wide bandwidth of the RF PA. Matching netwok of the RF PA should be designed carefully in order to achieve the desired bandwidth [2], [10]. Furthermore, the stability of a wideband PA is also very important because transistors can be potentially unstable during wideband operations [5]. Therefore, the stability simulation should be performed before proceeding to the design procedure of the RF PA. In this work, a wideband class AB PA is designed using Load-Pull and Source-Pull approach. A 10 W GaN HEMT CGH4001F device from Cree was selected because of its property as a high band gap semiconductor which allows it to operate at high power. Comparison between the performances of the designed RF PA in this paper with state-of-art results of high efficiency wideband RF PAs in the literature are summarized in Table 1.

Table 1. State-of-Art Wideband RF PAs

Reference	BW(GHz)	Gain(dB)	Drain Efficiency (%)
2012 [7]	1.45-2.45	10-12.6	81
2014 [8]	1.6-2.8	10-15	55
2015 [9]	0.5-0.9	18-20	75
This work	0.5-1.5	15-17	36

2. RESEARCH METHOD

2.1. Design approach

In this work, the Source-Pull and the Load-Pull technique were used to design the RF PA. In this technique various impedances were presented to the transistor to assess its performance. Optimum impedance was chosen for a compromised performance between power delivered and the PAE. Figure 1 shows the Load-Pull simulation result with optimum impedance point for a compromised PAE and power delivered for 1GHz and 1.5GHz.

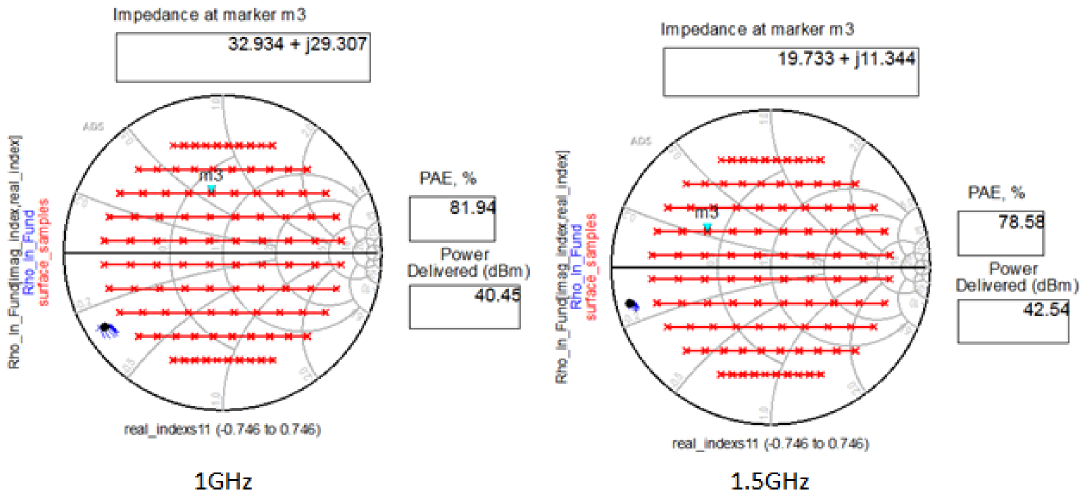
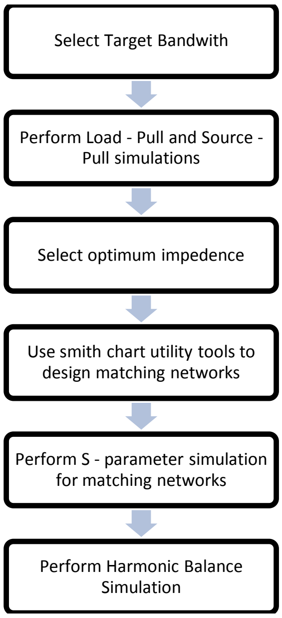


Figure 1. Optimum point at 1 GHz and 1.5 GHz

2.2. Design methodology

The target bandwidth of the designed RF PA is set to be from 0.5GHz - 1.5GHz. The Load-Pull and Source-Pull approach is used to design the input and output matching networks. In a wideband RF PA design, the second harmonic frequency influence should be taken into consideration especially in the multi octave PA design in which the harmonic frequencies are in band. Extra design effort is needed to either follow waveform engineering approach or Load-Pull approach [1]. In this paper, the Load-Pull approach is presented. Load-Pull simulations for different frequencies within the bandwidth are carried out to obtain optimum load impedence trajectories at the output of the active device [1]. Therefore, the first step to design the RF PA is to find the optimum source and load impedence that will maximize the performance of the PA in terms of the PAE and the output power delivered as mention in the previous section [3]. Since the harmonic frequencies of 0.5GHz fall in the targeted bandwidth, therefore 1.0GHz and 1.5GHz, which are the second and third harmonic frequencies, are chosen to be the optimum fundamental frequencies for the following Load-Pull simulations to find the optimum source and load impedances. By designing matching network from the harmonic frequencies, the harmonics effect from 0.5GHz can be compensated along the targeted bandwidth. Optimum Load and Source impedances are found from the simulation results. The values of the impedance are conjugated and the Smith chart utility tool in ADS is used to design the matching network. Transmission line is used as a matching network in this work. The transmission line of the matching network at 1GHz is cascaded with the transmission line of 1.5GHz matching network. The input matching network and output matching network of each frequency is simulated using the S-Parameter simulation tool in ADS to ensure the S11 and S22 is matched [2]. In order to study the performance of the RF PA, the harmonic balance simulation tool is used by sweeping the input power to determine the gain, drain efficiency and PAE. Flowchart 1 shows the design process ofthe matching networks.



Flowchart 1. Matching network design process

3. RESULTS AND ANALYSIS

3.1. Matching network design

As mentioned earlier, the Load-Pull technique is used to design the output matching network. Load-Pull simulation is performed for 1GHz and 1.5GHz. An optimum load impedance of Z_{L_1GHz} = 32.934 + j29.307 for 1 GHz and $Z_{L\_1.5GHz}$ = 19.733 + j11.344 for 1.5GHz are achieved. Then, the value is conjugated to design matching network using the Smith chart utility tool. The matching networks for 1GHz and 1.5GHz are cascaded. The output impedance of the device, Z_{dev} is found to be 24 – j11 and the impedence of the output matching network, Z_{eff} at 1.5GHz is found to be 29.6 + j16.4. Both of these values are found to be close, therefore a matching network that gives a wideband cascaded performance can be obtained. Figure 2 shows the simulated device impedance and cascaded matching network impedance. S-parameter simulations of the matching networks are also performed to ensure the Load impedence and Source impedence is matched perfectly. Figure 3 shows the optimized output matching network for the RF PA.

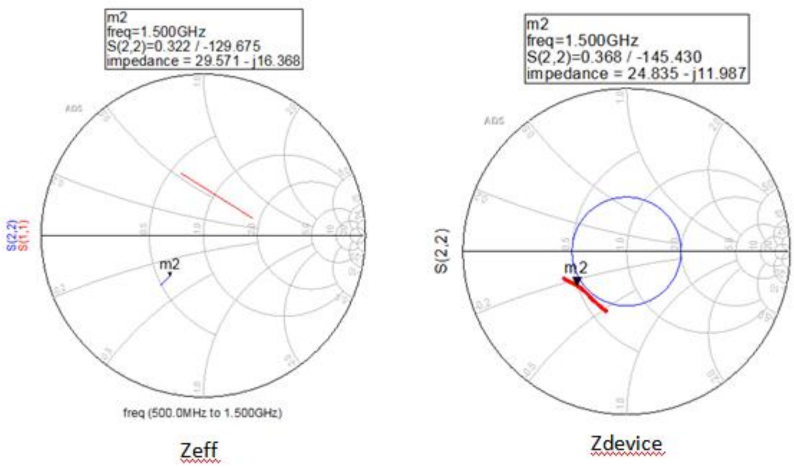


Figure 2. Device impedence Z_{dev} and the cascaded matching network impedence Z_{eff}

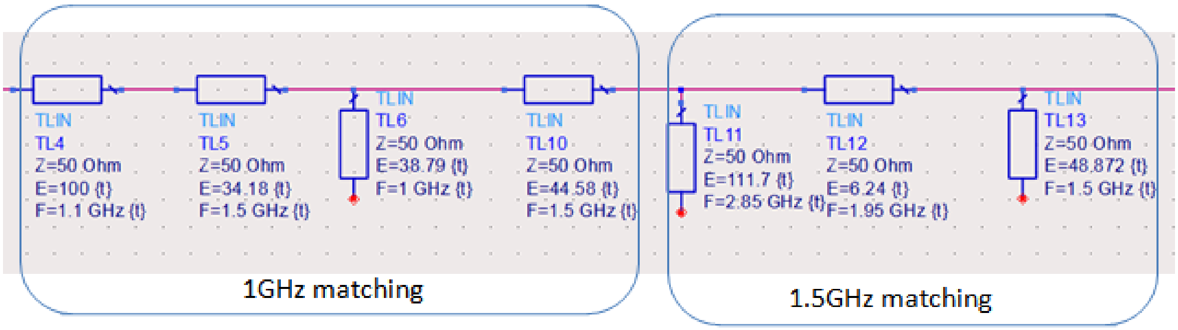


Figure 3. Output matching network after optimization

3.2. Stability analysis

Stability is an important aspect in microwave circuits. Microwave circuits can produce oscillation which will drastically increase the gain of an amplifier resulting in damaged transistor [4]. Therefore, stability simulation or K factor should be performed to ensure the stability of the amplifier. Since the amplifier can be described in S-parameter as two port network, it can be realized as the Equation (1).

$$K = \frac{1-|s11|^2 - |s22|^2 + |\Delta|^2 |}{2 \times |s12 \times s21|} \quad (1)$$

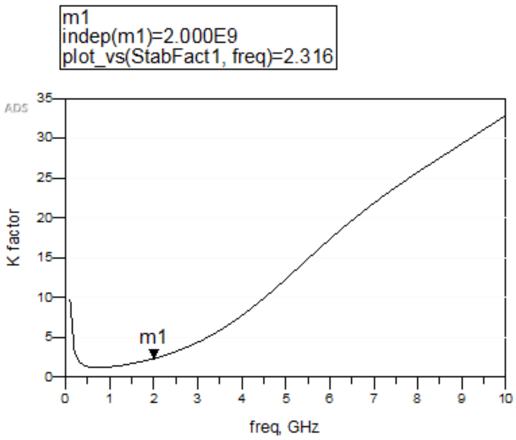


Figure 4. Graph of K factor against frequency

As can be observed from the Figure 4, the stability factor K is greater than 0 for frequency range of 0 to 10GHz. This proves that the amplifier is stable for the desired operating frequency. However, it is noticed that, the stability factor K is closed to zero at low frequencies. This effect can be stabilized by adding a resistor at the input port of the device.

3.3. RF PA design and performance

The RF PA is biased in deep class AB. DC sweep analysis is performed in the ADS software to obtain bias voltage. The harmonic balance simulation in ADS is used to optimize and simulate the performance of the RF PA. Figure 5 shows the schematic diagram of the wideband RF PA.

The drain bias voltage of the RF PA in Figure 5 is set as 28V and the gate bias voltage is -3V. For power sweep simulation purpose, the operating frequency of the RF PA is set to 1.5GHz following the LTE frequency band. The harmonic balance simulation results are presented in Figure 6, Figure 7, and Figure 8. It is observed that from Figure 6, the RF PA delivers linearly an output power of 40 dBm from an input power of 30dBm which satisfy the requirement of the design to have an output of 10W. The drain efficiency of the RF PA with respect to delivered output power of 40dBm is observed to be about 36% as shown in Figure 7.

This results from a careful design of the matching networks during the design process. In Figure 8, the RF PA is observed to have a compression point at input power of 30dBm when the power gain is 10dB. The RF PA also shows a good wideband characteristic as expected from 0.5GHz to 1.5GHz with gain ranging from 15dB to 17dB. Figure 9 shows the S21 simulation of the RF PA across targeted frequencies.

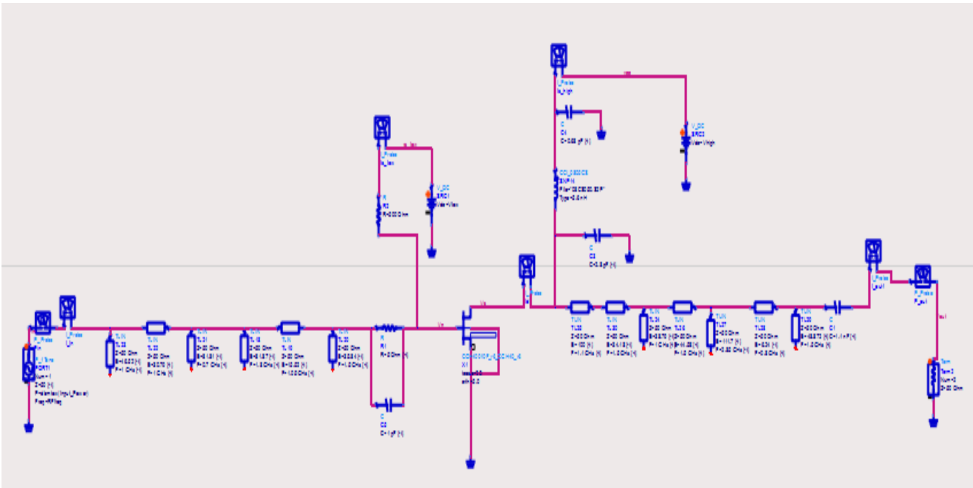


Figure 5. Schematic of the class AB RF PA

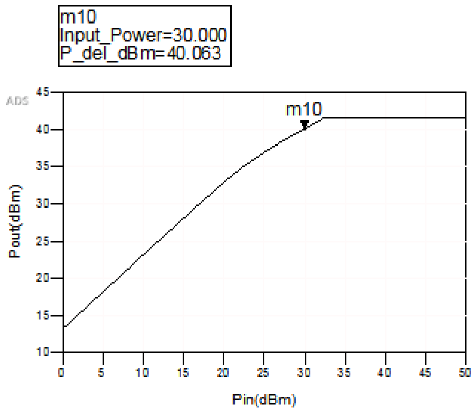


Figure 6. Graph of output power delivered against input power

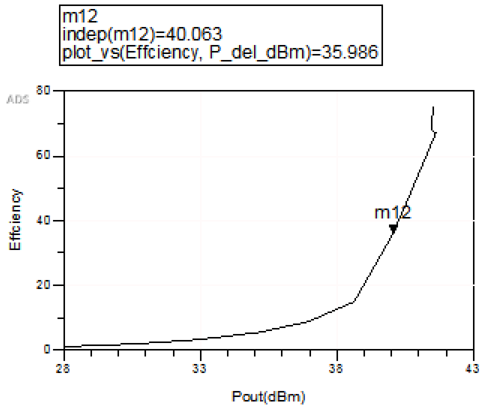


Figure 7. Graph of drain efficiency againts power delivered

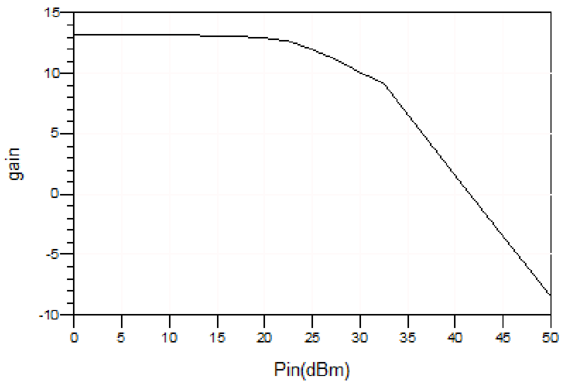


Figure 8. Gain versus input power

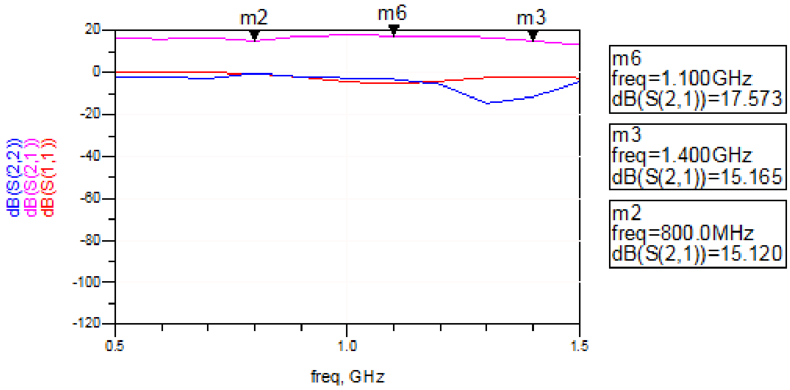


Figure 9. The RF PA gain across the frequency

4. CONCLUSION

In this paper, a wideband 0.5GHz to 1.5GHz Class AB RF PA design is designed. A method to compensate the harmonic frequencies in designing a wideband PA using the Load-Pull method is presented. The simulation results showed that the design is stable and have an overall good performance on the bandwidth, gain and efficiency. This paper has also presented a new way to compensate harmonics effect in a wideband PA by designing matching networks considering the in band harmonic frequencies by cascading it in the matching network in the order of lowest matching frequency to the highest. Although the efficiency achieved in this paper is moderate, for future works, this RF PA efficiency can be improved by improving the matching design technique and by incorporating the efficiency enhancement technique such as Doherty or Envelope Tracking. To validate the simulation results, the RF PA will be fabricated and tested.

REFERENCES

[1] Taghavi H, *et al.*, "Sequential load-pull technique for multioctave design of RF power amplifiers," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 63, no. 9, pp. 818-22, Sep 2016.

[2] Aniktar H, *et al.*, "A Class-AB 1.65 GHz-2GHz broadband CMOS medium power amplifier," *InNORCHIP Conference*, pp. 269-272, 2005.

[3] Saad P, *et al.*, "Design of a highly efficient 2–4-GHz octave bandwidth GaN-HEMT power amplifier", *IEEE Transactions on Microwave Theory and Techniques*, vol. 58, no. 7, pp. 1677-1685. Jul 2010.

[4] Wang L and Chen D., "Design of broadband power amplifier based on ADS," *2016 IEEE International Conference In Ubiquitous Wireless Broadband (ICUWB)*, pp. 1-3, Oct 2016.

[5] Dettmann I, *et al.*, "Comparison of a single-ended class AB, a balance and a doherty power amplifier," *2005 Asia-Pacific Conference Proceedings In Microwave Conference Proceedings*, vol. 2, pp. 4-, Dec 2005.

[6] Carrubba V, *et al.*, "A novel highly efficient broadband continuous class-F RFPA delivering 74% average efficiency for an octave bandwidth," *2011 IEEE MTT-S International Microwave Symposium Digest (MTT)*, pp. 1-4, Jun 2011.

[7] Tuffy N, *et al.*, "A simplified broadband design methodology for linearized high-efficiency continuous class-F power amplifiers," *IEEE Transactions on Microwave Theory and Techniques*, vol. 60 , no. 6, pp. 1952-1963, Jun 2012.

[8] Chen J, *et al.*, "Design of broadband high-efficiency power amplifiers based on a series of continuous modes," *IEEE Microwave and Wireless Components Letters*, vol. 24, no. 9, pp. 631-633, Sep 2014.

[9] Sharma T, *et al.*, "A methodology for implementation of high-efficiency broadband power amplifiers with second-harmonic manipulation", *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 63, no. 1, pp. 54-58, Jan 2016.

[10] Muhammad Faheem Siddique, *et.al.*, "Design and Simulation of Cascaded Class-A Microwave Power Amplifier", *International Journal of Electrical and Computer Engineering (IJECE)*, vol.3, no. 5, pp. 635-639 ,Oct 2013.

[11] NSHU. Victor, *et.al.*, "Higher Efficiency Switching Mode Power Amplifier Design using the Third-Harmonic Peaking Turning Mode", *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 12, no. 10, pp. 7160-7166, Oct 2014.

[12] Siba Monther Yousif, *et.al.*, "Efficient Low-Complexity Digital Predistortion for Power Amplifier Linearization", *International Journal of Electrical and Computer Engineering (IJECE)*, vol.6, no. 3, pp. 1096-1105, Jun 2016.

BIOGRAPHIES OF AUTHORS

Shiva Ghandi Isma Ilamaran was an Electronics Engineering student majoring in Electronics from Multimedia University, Cyberjaya. As a requirement for his Bachelor's degree, he managed to design and fabricate a wideband RF PA for his Final Year Project (FYP) and finally he received his B.Eng. in Electronics Engineering in 2017. He is currently working as an Equipment Engineer in Texas Instruments Malaysia.

Zubaida Yusoff holds the position of a Senior Lecturer at the Faculty of Engineering, Multimedia University. She received her B.Sc. in Electrical and Computer Engineering (cum laude with distinction) and M.Sc. in Electrical Engineering from The Ohio State University, USA in 2000 and 2002 respectively. She worked with Telekom Malaysia International Network Operation in 2002 before she joined Multimedia University in 2004. She continued her studies at Cardiff University, Wales, UK in 2008 and received Ph.D degree in 2012. Dr Zubaida has presented technical papers at conference nationally and internationally. One of her conference papers has received "Honorable Mention" for the Student Paper Competition at the International Microwave Symposium, USA in 2011. She has authored/co-authored more than 25 journals and conference papers. Her teaching and research focuses in the area of Microelectronics, Analog/Mixed Signal RF Circuit Design and Microwave Power Amplifier System.

Jahariah Sampe is *Research Fellow / Senior Lecturer at* Institute of Microengineering and Nanoelectronics, UniversityKebangsaan Malaysia (UKM). Her field of research includes Very Large Scale Integration (VLSI) design, Wireless and Data Communication, Energy Harvesting etc. She has authored and co-authored numerous journals of repute and international conferences.