

Design of Wide-band Power Amplifier Based on Power Combiner Technique with Low Intermodulation Distortion

Mussa Mabrok, Zahriladha Zakaria, Nasrullah Saifullah

Center for Telecommunication Research and Innovation (CeTRI), Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Durian Tunggal, Melaka, Malaysia

Article Info

Article history:

Received Jun 7, 2018

Revised Sep 20, 2018

Accepted Sep 27, 2018

Keyword:

Inter-modulation distortion

Power amplifier

Wide-band

ABSTRACT

RF power amplifiers are one of challenging blocks in designing radio frequency transceivers, this is due to non-linearity behavior of power amplifiers that leads to inter-modulation distortion. This paper presents the design of wide-band power amplifier which combined with parallel coupled line band pass filter at the input and output of power amplifier to allow the only required frequency band to pass through the power amplifier. Class-A topology and ATF-511P8 transistor are used in this design. Advanced Design System software used as a simulation tool to simulate the designed wide-band power amplifier. The simulation results showed an input return loss (S11) which less than -10dB, and gain (S21) is higher than 10 dB over the entire frequency band and considers as flat as well. The designed amplifier is stable over the bandwidth ($K > 1$). Inter-modulation distortion is -56.919dBc which is less than -50dBc with 10dBm input power. The designed amplifier can be used for the microwave applications which include weather radar, satellite communication, wireless networking, mobile, and TV.

Copyright © 2018 Institute of Advanced Engineering and Science.
All rights reserved.

Corresponding Author:

Zahriladha Zakaria,

Center for Telecommunication Research and Innovation (CeTRI),

Faculty of Electronics and Computer Engineering,

Universiti Teknikal Malaysia Melaka (UTeM),

Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

Email: zahriladha@utem.edu.my

1. INTRODUCTION

Power amplifiers are main blocks for constructing wireless communication systems. Also, radio frequency power amplifiers are one of challenging blocks in designing RF transceivers, this is due to non-linear behavior of power Amplifiers that leads to inter-modulation distortion. The rapid growth of mobile telecommunication services has increased demand for low- cost, high-efficiency, and compact equipment. Generally, power amplifier (PA) is one of the most important subsystems for radio frequency (RF) transmitters. In addition, it is also a component which requires a lot of electrical power [1]. From the transmitter point of view, PA is the most critical component since its performance strongly influence the overall system features in terms of bandwidth, output power, efficiency, and operating temperature. This makes wide-band PAs that cover many frequency bands while maintaining high efficiency an important research topic. Nowadays, Wireless network is a network system which used by all people around the world in many fields of the life and becomes one of the important demands. Wide-band power amplifier design becomes more important because; wider bandwidths are required to cover many microwave applications such as radar communications, WiMAX, satellite communications, military communication, and other related applications. Designing of wide-band power amplifier will cause a problem in generating more inter-modulation distortion products that make power amplifiers have losses. And therefore, will influence on the efficiency of power amplifier. In other words, the higher the input signal power, the higher the output signal

power produced and the more the inter-modulation distortion (IMD) product generated due to more frequency interferes with each other in the large frequency range. Reduce the input power will make the power amplifier to lose its identity as a device to make the signal stronger to propagate in the medium [2].

RF power Amplifier circuits consist of several components: Transistor, DC biasing circuit to let the transistor work in its active region, input and output matching networks to allow maximum power to transfer from input to output. Figure 1 shows the components of RF power amplifiers.

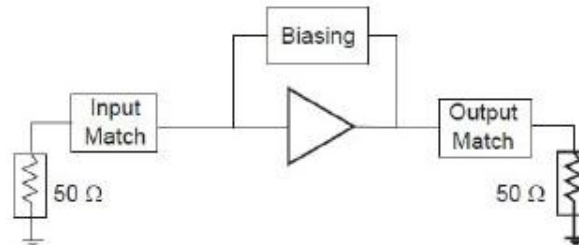


Figure 1. Components of RF power amplifiers [2]

In [3], C-band microwave power amplifier design proposed by A.S.Alqadami and M. F. Jamlos for wireless applications, the design can achieve up to 2.14dB gain and covers from 5.6GHz to 6GHz frequency band. However, the achieved bandwidth only 0.4 GHz which cannot be considered as a wide-band. High power, and wide-band power amplifier using gallium nitride-high electron mobility (GaN-HEMT) technology was proposed in [4], this work achieved around 10W output power with approximately 15dB gain, and maximum power added efficiency (PAE) of 61%. However, this work suffers from a limited bandwidth which is 1.1GHz, and which does not meet the specifications of wide-band power amplifier. In [5], Cascaded class A power amplifier operated at 2.4 GHz has been designed. The designed device can achieve 0.5 watts or 27 dBm output power. However, this work suffers from the limitation on important results. Where has not shown important PA parameters such as, efficiency. This paper [6] presents the design of low voltage class AB PA for Wireless Sensor Network. Recently, many researchers designed and developed power amplifiers, but most of the designed power amplifiers suffered from limited bandwidth and high intermodulation distortion [7]-[11]. This work presents a wide-band power amplifier design using power combining technique for S-band. Single-section quarter wave transformer matching network is designed to provide maximum power delivered to the load. The design meets the requirement of the wide-band frequency band which covers from 2 GHz to 4 GHz. The Simulation results of the designed wide-band power amplifier are presented.

2. DESIGN METHODOLOGY

To achieve wideband Power Amplifier (WPA), narrow band power amplifiers can be designed separately and then recombine using power combiner. The concept of power combining technique can be described as follows: two or more amplifiers arranged in parallel where their inputs connected to the output of power divider, and their output recombined by using power combiner [12].

Wide-band power amplifier design:

a. Transistor selection

The first step in designing PA is selecting an appropriate transistor, the transistor that has been selected in this work is ATF-511P8 provided by Avago technologies. The device is ideal as a high linearity, low-noise, medium power amplifier. Its operating frequency range is from 50MHz to 6GHz. This transistor is manufactured under Gallium Arsenide Enhancement Mode pHEMT process.

b. Biasing network

The Biasing network uses to supply the transistor with optimum DC voltage, to give optimum performance of WPA. For ATF-511P8 transistor used, the transistor should be biased at the point where $V_{DS} = 4.5V$ and $I_{DS} = 200mA$ (0.2A) as shown in Figure 2.

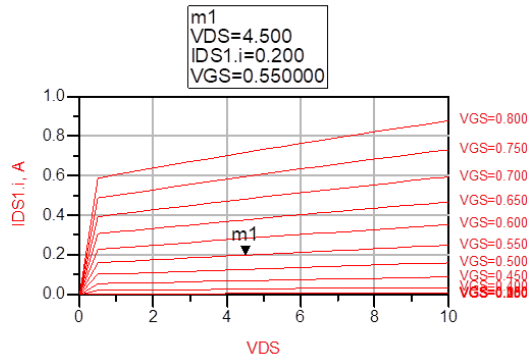


Figure 2. Biasing point of ATF-511P8

c. Impedance Matching network

The matching network uses to provide maximum power delivered to the load. Matching network is usually placed between the transistor and the source (input matching), and between the transistor and the load (output matching). Single section quarter wave transformer technique used as a matching network, because it considers as a useful and practical circuit for impedance matching. Furthermore, its simple transmission line circuit [13]. Single section quarter wave transformer matching network is shown in Figure 3.

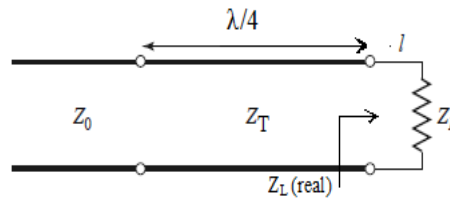


Figure 3. Single section quarter wave transformer matching network [13]

d. Integration of Power Amplifier (PA) and Filter

The purpose of using band-pass filters (BPFs) at the input and output of amplifiers is to allow only the required bands to pass through the amplifier and will lead to attenuate unwanted frequency components generated in a wide band of the amplifier. BPF used in this work is parallel coupled line band pass filter. Figure 4 shows a schematic diagram of the BPF design in Advanced Design System (ADS).

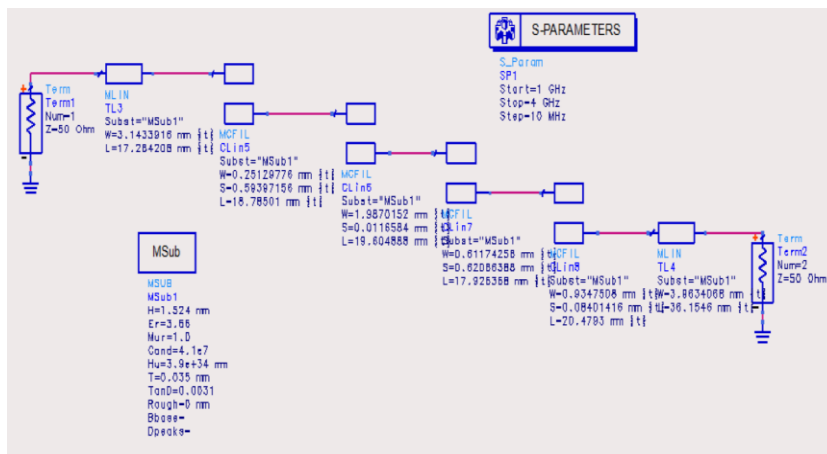


Figure 4. Schematic diagram of parallel coupled line BPF

3. RESULTS AND ANALYSIS

3.1. Parallel coupled line BPF

Due to dividing WPA into two narrow bands (2-3GHz & 3-4GHz), two BPFs have been designed for each band. Figure 5(a) and Figure 5(b) shows the simulation results of two BPFs. Where from Figure 5(a) we can observe that BPF has return loss (S_{11}) with around -30dB at the center frequency 2.5GHz, also it shows good insertion loss (S_{12}) around -1dB in the frequency range from 2 to 3GHz. The simulated results in Figure 5(b) show return loss (S_{11}) with around -30dB at the center frequency 3.5GHz, also it shows good insertion loss (S_{12}) around -1 dB in the frequency range from 3 to 4GHz.

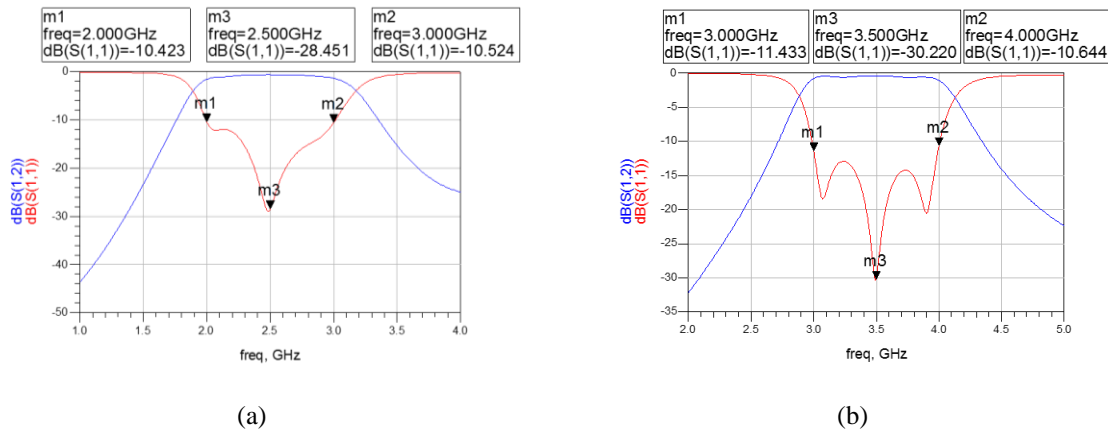


Figure 5. (a) Simulation results of BPF (2-3GHz), (b) Simulation results of BPF (3-4GHz)

3.2. Wide-band power amplifier (WPA) design

The design of WPA was constructed as in Figure 6 & Figure 7 using ADS. Where two parallel narrow band PAs (2 to 3GHz & 3 to 4GHz) integrate with parallel coupled line BPFs were firstly designed, and then recombined using Wilkinson power divider/combiner.

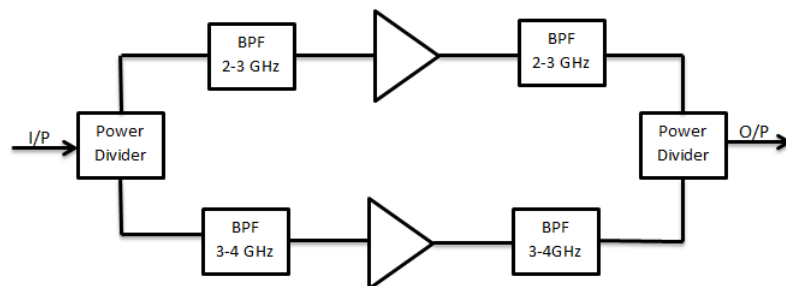


Figure 6. Block diagram of proposed Wide-band Power Amplifier (WPA)

The first parameter needed to be checked when we designing amplifier is stability. The amplifier must be stable over the range of the required frequency band. The Rollett factor K is used as a measure of stability and must be greater than one in order for an amplifier to be stable. The designed amplifier is stable, where k is greater than one over the whole bandwidth 2-4GHz as shown in Figure 8.

The simulated input return loss S_{11} was lower than -10dB within the entire frequency range 2-4GHz as shown in Figure 9(a), and which considers as a low input return loss. Ideally, with -10dB input return loss, the amplifier can give up to 90% of its output power. Furthermore, the simulated result of input return loss S_{11} meets the specification of WPA. From Figure 9(b), the designed amplifier can give 15dB \pm 2dB within 2GHz bandwidth (2-4GHz) and considers as flat gain as well. And also the gain is higher than 10dB, which meet the specifications of WPA.

At the center frequency 3GHz and input power of 24dBm, the proposed WPA can achieve Power Added Efficiency (PAE) around 33% as shown in figure 10(a), which is more than 30%. The achieved PAE considers good as class A Amplifier topology used in this design. Ideally, a class A amplifier can achieve around 50% PAE. Inter-modulation distortion (IMD3) is a parameter that determines the linearity of PA, and should be low as possible. As the IMD3 decreases, the distortion decreases and the PA become more linear. From figure 10(b), the simulation result of IMD3 shows that with 10dBm input power, the IMD3 was -56.919dBc which shows low inter-modulation distortion which is less than -50dBc, and satisfies the specification of designed wideband power amplifier as well.

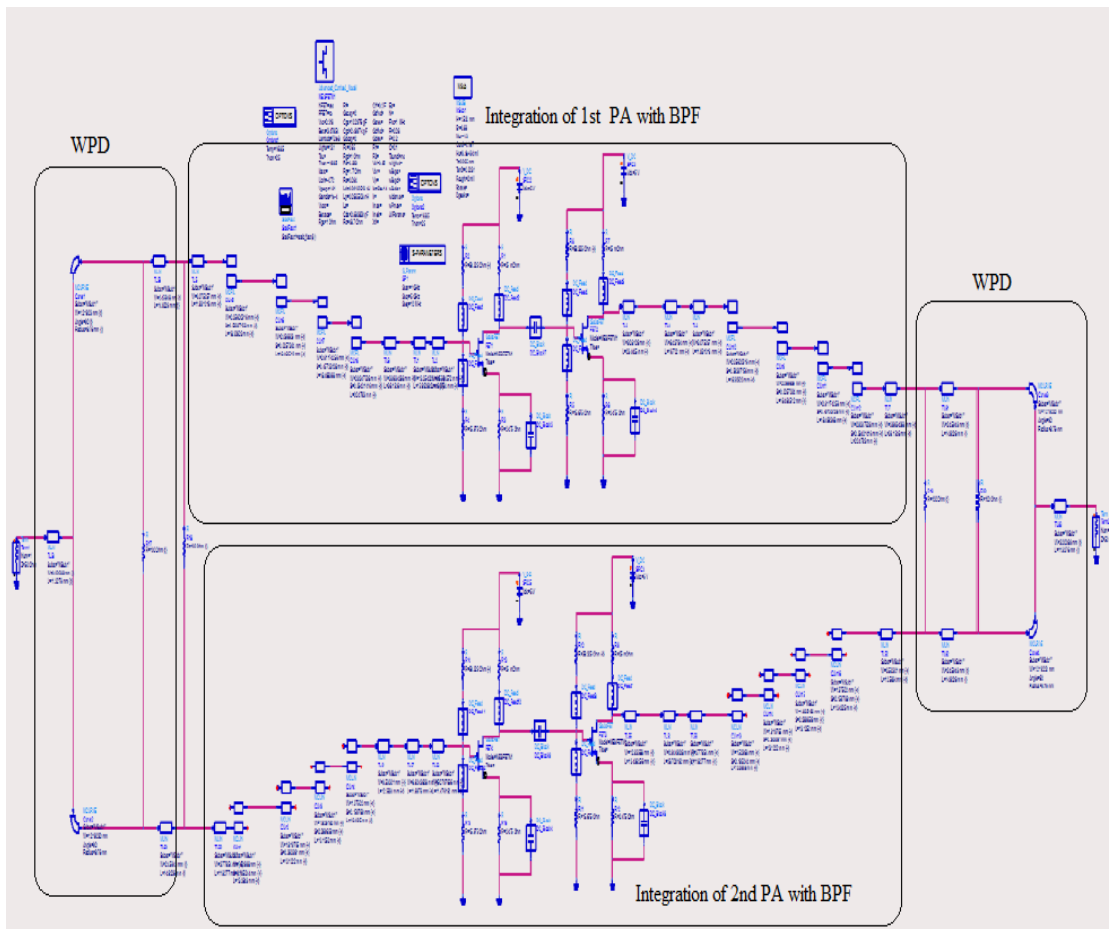


Figure 7. Schematic diagram of proposed Wide-band Power Amplifier (WPA)

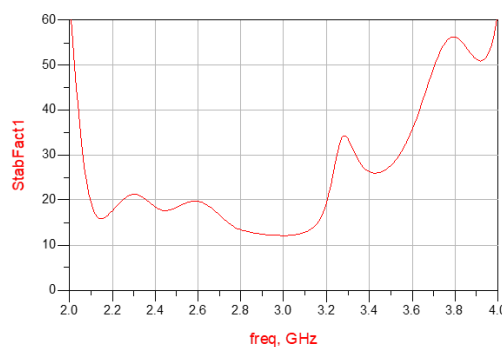


Figure 8. Stability of Wide-band Power Amplifier (WPA)

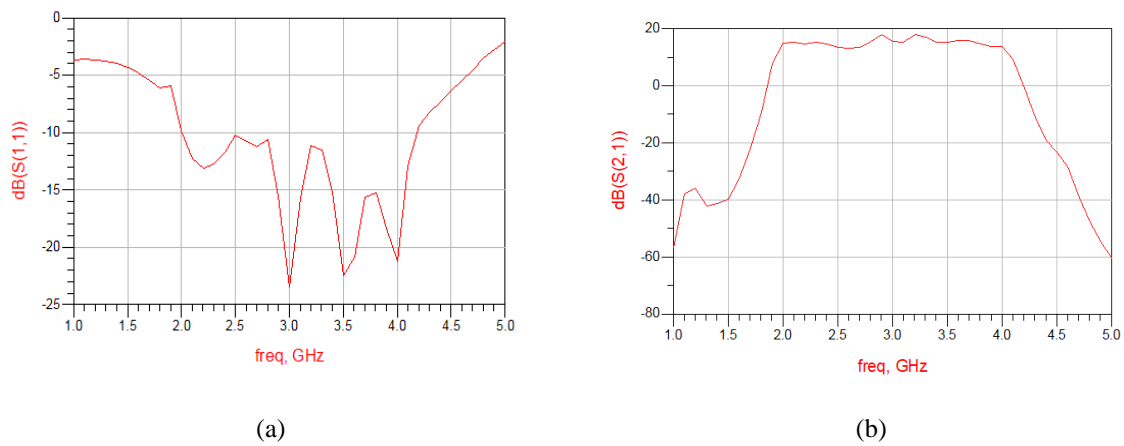


Figure 9. (a) Simulated return loss (S_{11}) of Wideband Power Amplifier (WPA) versus frequency (b) Simulated gain (S_{21}) of the WPA versus frequency.

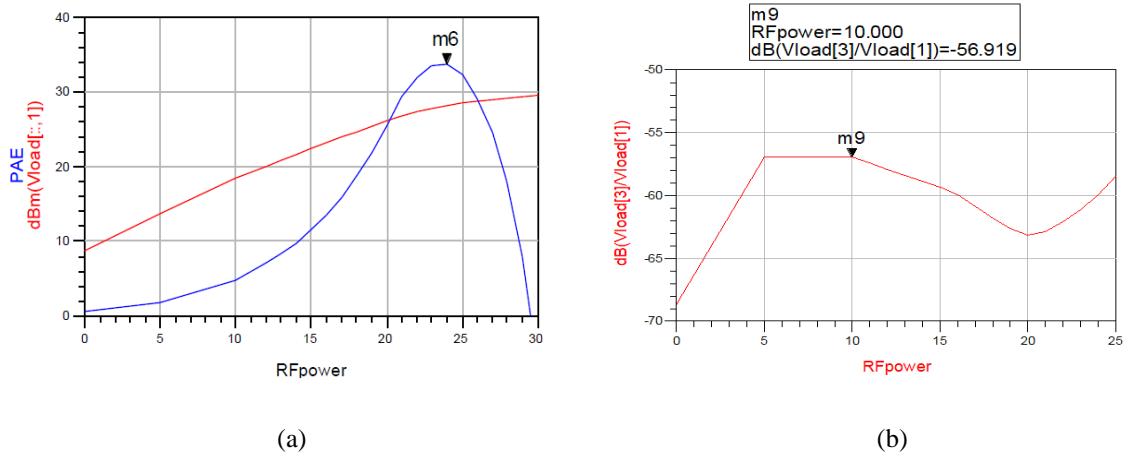


Figure 10. (a) Simulated Power Added Efficiency (PAE) of the WPA versus RF power at center frequency 3GHz (b) Simulated intermodulation distortion of the WPA at an input power of 10dBm.

Table 1 shows the comparison between the performance of the previous WPA design and this work. The proposed WPA design in this work achieved wider bandwidth (BW). Among Wideband Power Amplifiers (WPAs), the same wider BW is reported in [9] with power added efficiency (PAE) of 15.32%, which is 17.68% below that of the presented WPA. The implemented WPA achieves a good gain flatness, good linearity and wide bandwidth, when compared with the previous work.

Table 1. Comparison between the Performance of Proposed WPA and other recently Amplifiers

Reference	BW (GHz)	Pout (dBm)	Gain (dB)	PAE (%)
2014 [3]	5.7-6.0	–	12.39	–
2017 [4]	1.1	38.8	15	61
2013 [6]	2.4-2.4835	6.35	15.87	26.73
2013 [9]	3-5	–	13.3	15.32
2018 [11]	1.75-2.15	8	11	–
This work	2-4	27.896	15±2	33

3. CONCLUSION

In conclusion, wideband power amplifier with low distortion for S-band has been designed and simulated successfully using advanced design system (ADS). A power combining technique has been used to design the proposed WPA. The required wideband (2 to 4GHz) has been divided into two narrow bands, and then recombined using Wilkinson Power Divider (WPD). Class A amplifier topology and single section quarter wave transformer as matching network have been used in each of narrow band PAs. In order to avoid insertion loss caused by WPD which can affect the overall gain, two cascaded transistors have been implemented for each of narrow PAs. The simulation results of WPA show that input return loss (S11) less than -10dB, which considers as a good return loss. Gain S21 above 10dB, and was almost flat over the entire bandwidth. The proposed device was unconditionally stable ($K>1$), and inter-modulation distortion (IMD3) less than -50dBc. The designed amplifier can be used in satellite communications, wireless applications (WLAN, WiMAX), and other applications in microwave engineering. Other matching techniques such as multi-section quarter wave transformer can be used in order to minimize the return loss and increase the gain.

ACKNOWLEDGEMENTS

This work was supported by UTeM Zamalah Scheme. The authors would also like to thank Center for Research and Innovation Management (CRIM), Centre of Excellence, UTeM, UTeM's research grant JURNAL/2018/FKEKK/Q00001 and Universiti Teknikal Malaysia Melaka (UTeM) for their encouragement and help in sponsoring this study.

REFERENCES

- [1] Z. Zakaria, *et al.*, "Development of Wideband Power Amplifier for RF/Microwave Front-end Subsystem", *Jurnal Teknologi*, vol. 68, no. 3, pp. 105-112, 2014.
- [2] M. F. M. Fadhli, *et al.*, "Intermodulation distortion of Integrated Power Amplifier and Filter using Single Stub Tuners for Green Communication", *2014 2nd International Conference on Electronic Design (ICED)*, pp. 378-382, 2014.
- [3] M. F. J. Abdulrahman shueai Mohsen Algadami, "Design and Development of C-band Microwave Amplifier for wireless Applications", *2014 IEEE 2nd International Symposium on Telecommunication Technologies*, pp. 404-407, 2014.
- [4] J. Tan, K. S. Yuk, and G. R. Branner, "Design of a High Power, Wideband Power Amplifier using AlGaIn / GaN HEMT", *2017 IEEE 18th Wireless and Microwave Technology Conference (WAMICON)*, 2017.
- [5] M. F. 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, 2013.
- [6] W. Chenjian, *et al.*, "0.18 μ m CMOS Low Voltage Power Amplifier for WSN Application", *TELKOMNIKA (Telecommunication, Computing Electronics and Control)*, vol. 11, no. 8, pp. 4470-4476, 2013.
- [7] F. You, *et al.*, "2-4GHz wideband power amplifier with ultra-flat gain and high PAE", *Electronics Letters*, vol. 49, no. 5, pp. 326-327, 2013.
- [8] N. Masoumi, "A Fully Integrated Linear CMOS Power Amplifier with High Output Power and Dynamic Range for WiMAX Application", *2013 8th International Conference on Design & Technology of Integrated Systems in Nanoscale Era (DTIS)*, pp. 30-34, 2013.
- [9] V. P. Bhale, *et al.*, "3-5 GHz CMOS Power Amplifier Design for Ultra - Wide-Band Application", *2014 International Conference on Electronics and Communication System*, pp. 3-5, 2014.
- [10] S. Mahersi, *et al.*, "Design of a Wide Band RF Amplifier using Scattering Parameters", *International Journal of Computer Applications*, vol. 66, no. 11, pp. 1-4, 2013.
- [11] A. Rachakh, *et al.*, "A Novel Configuration of a Microstrip Microwave Wideband Power Amplifier for Wireless Application", *TELKOMNIKA (Telecommunication, Computing Electronics and Control)*, vol. 16, no. 1, pp. 224-233, 2018.
- [12] S. C. Cripps, "RF Power Amplifiers for Wireless Communications", 2nd edition, Artech House Microwave Library, 2006.
- [13] D. M. Pozar, "Microwave Engineering", Fourth Edition. John Wiley, and Sons, Inc., 2012.

BIOGRAPHIES OF AUTHORS

Mussa Mabrok – was born in Libya, in 1991. He received the B.S degree in Electrical and Electronic Engineering (Telecommunication) from Sirte University, in 2014. And Master degree in Electronic Engineering from Universiti Teknikal Malaysia Melaka (UTeM), in 2017. His research interest includes microwave devices design such as filters, and amplifiers. He is currently working towards his doctorate degree in Electronic Engineering in Universiti Teknikal Malaysia Melaka (UTeM).



Prof Dr. Zahriladha Zakaria - was born in Malaysia in 1975. He received the B. Eng. and M. Eng. in Electrical and Electronic Engineering from the Universiti Teknologi Malaysia in 1998 and 2004 respectively. He obtained his Doctorate from The University of Leeds in 2010 in the field of Microwave Engineering. From 1998 to 2002, he was with STMicroelectronics, based in Malaysia where he worked as Product Engineer. He is currently a Professor and Coordinator of Centre for Telecommunication Research and Innovation (CeTRI) at the Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), where he teaches the electronic system, communication principles, microwave engineering, wireless communications and signal processing. His research interests include a variety of microwave devices development such as planar and non-planar microwave filters, resonators, amplifiers, and antennas. He also investigates data communication and radiowave propagation in wireless communication systems. He has published more than 100 scientific papers in journals, proceedings, and book-chapters. He holds 8 intellectual property rights and he has won several awards including gold medal during several research and innovation exhibitions at the national and international level, such as the UTeMEX 2012, 2013 & 2015, Malaysia Technology Expo (MTE 2012-2014 and 2016), ITEX 2016, International Trade Fair Ideas Inventions New Products (iENA 2012) in Nuremberg, Germany, Seoul International Invention Fair (SiiF 2013) in Seoul, Korea.



Nasrullah Saifullah - was born in Malaysia, in 1991. He received the B.S degree in Electronic Engineering (Wireless Communication) with honours from Universiti Teknikal Malaysia Melaka (UTeM), in 2014. He joined the Microwave Research Group, Centre for Telecommunication Research and Innovation (CeTRI), Universiti Teknikal Malaysia, in 2014 until present. His current research interests include a variety of microwave devices development such as amplifiers, filters and antennas. He is currently working towards his Master in Science of Electronic Engineering in Universiti Teknikal Malaysia Melaka (UTeM).