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A Two-stages Microstrip Power Amplifier for WiMAX Applications

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Abstract

Amplification is one of the most basic and prevalent microwave analog circuit functions. Wherefore power amplifiers are the most important parts of electronic circuits. This is why the designing of power amplifiers is crucial in analog circuit designing. The intent of this work is to present an analysis and design of a microwave broadband power amplifier by using two stages topology. A two stages power amplifier using a distributed matching network for WiMAX applications is based on ATF-21170 (GaAs FET). The configuration aims to achieve high power gain amplifier with low return loss over a broad bandwidth. The proposed BPA is designed with a planar structure on an epoxy (FR4) substrate. The planar structure is also utilized for getting the good matching condition. The advanced design system (ADS) software is used for design, simulation, and optimization the proposed amplifier. The complete amplifier achieves an excellent power gain; is changed between 28.5 and 20 dB with an output power of 12.45dBm at 1dB compression point. For the input reflection coefficient (S11) is varied between -20 and -42 dB. While the output reflection coefficient (S22) is varied between -10 dB and -49 dB over the wide frequency band of 3.2-3.8 GHz.

***Keywords**: broadband power amplifier (BPA), microstrip technology, input matching, output matching, gallium arsenide field-effect transistor (GaAs FET), advanced design system (ADS)*

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1. Introduction

Recently, demands for short-range, high-speed wireless communication systems have been increased. As a result, the design of a broad bandwidth circuit becomes the very important topic. For those wireless communications systems, the design of broadband power amplifiers (BPAs) with reasonable performances is one of the major challenges.

Most of the power amplifiers have been designed utilizing CMOS processes due to of high-efficiency characteristic. However, the compound CMOS processes generally have high cost and poor performance in high frequency. As an alternative for the compound semiconductor processes, Gallium Arsenide Field-Effect Transistor (GaAs FET) could be considered for the power amplifier design. The GaAs FET process has been advanced, the channel length of the device gets shorter and shorter. Hence, their applications for high-frequency band become possible. In addition, GaAs FET technology has low cost and high performances. Therefore, GaAs FET PA design for next-generation communication systems, such as LTE and mobile world-wide interoperability for microwave access (WiMAX), even in the microwave band becomes a highly interesting topic for many circuit designers [1-4].

For wireless communication systems, the power amplifiers must have high performances; wide bandwidth, high power gain, high linearity, and high output power. However, Power amplifier design using GaAs FET process is still challenging, due to significant substrate loss and large parasitic components. generally, several circuit architectures are usually used to realizing broadband power amplifier (BPA) such as distributed structure, balanced structure, and broadband matching network, etc. [5-7]. The challenge of each architecture is to find an arrangement in such a way that achieves good performances in terms of gain, linearity, output

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power under stable conditions, and over a wide frequency range, and this is the base of the broadband design approach.

In this paper, two stages power amplifier (PA) using distributed matching network was designed to obtain good performances matching impedances and high gain. The PA design is proposed for WiMAX band. In the design process, Gallium Arsenide Field Effect Transistor (GaAs FET) is used as an active device at first and second stage to obtain high performances. The epoxy (FR4) is chosen as the substrate for planar structure matching network. In the design process, the advanced design system (ADS) software is used, and it can also give simulation result of amplifier final circuit such as power gain, isolation coefficient, and output power.

2. Theoretical Aspects and Design Procedure

In this section, we will introduce basic theory and design procedure of power amplifier configuration using the distributed matching network. The power amplifier is designed for the best possible performances. PA is commonly designed to obtain maximum power gain with minimum power reflection in order to minimum VSWR. Impedance matching networks are needed to reduce the unwanted reflection of signal and to improve the efficiency of the transmission from source to load [8-9]. Distributed matching is applied to satisfy it.

The most important parameter in the design process of an amplifier is stability condition. Stability in an amplifier circuit can be determined by S-parameters. If either the input or output port, or both have negative resistance, oscillations are possible in a two-port network. In unilateral case $(|S_{12}|=0)$, this occurs when $|S_{11}|$ or $|S_{22}|$ are greater than unity [10-11]. There are two types of stability, namely conditional stability and unconditional stability. To get unconditional stable for a microwave amplifier, the transistor's inherent stability factor (K) must be greater than unity. It means the magnitude of $S_{11}, S_{22}, \Gamma_{in}$ and Γ_{out} must be smaller than unity , stability factor (K) is given by (1) [12].

$$k = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{12}S_{21}|} > 1 \qquad (1)$$

Figure 1, illustrates two stages configurations of BPA which has designed in this project. The maximum transducer power gain $G_{T\max}$ is gotten with optimum termination at intput and output port. Optimum termination occurs when a conjugate match is realized at the side $\Gamma_{S1}=\Gamma_{in1}^{*}, \Gamma_{out1}=\Gamma_{L1}^{*}, \Gamma_{S2}=\Gamma_{in2}^{*}$ and $\Gamma_{out2}=\Gamma_{L2}^{*}$. The maximum transducer power gain can be calculated from the following relation (2) [10] and [13].

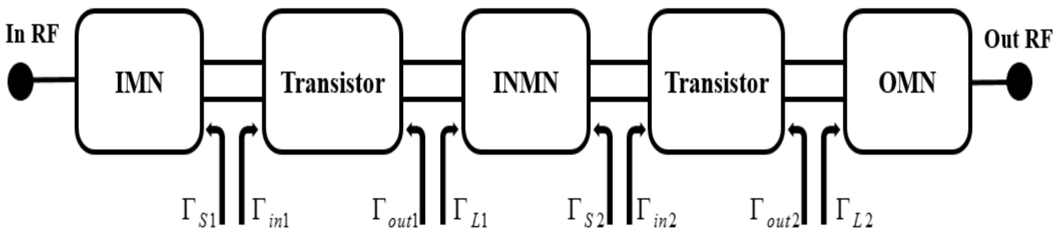


Figure 1. Block diagram of two stages power amplifier

$$G_{TMAX} = \left|\frac{S_{21}}{S_{12}}\right|\left|K-(K^2-1)^{1/2}\right| \qquad (2)$$

when $\Gamma_{S1}=\Gamma_{in1}^{*}$ the input power is equal to the maximum available input power [13]. Therefore, under these conditions the maximum transducer power gain and the operating power gain is equal, and the value of Γ_S and Γ_L that result in $G_{T\max}$ are identical to Γ_{SM} and Γ_{LM}, which is given by (3) and (4), respectively.

$$\Gamma_{SM} = C_S \left[\frac{B_S \pm \sqrt{B_S^2 - 4|C_S|^2}}{2|C_S|^2} \right] \quad (3)$$

$$\Gamma_{LM} = C_L \left[\frac{B_L \pm \sqrt{B_L^2 - 4|C_L|^2}}{2|C_L|^2} \right] \quad (4)$$

where

$$B_S = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \quad (5)$$

$$B_L = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \quad (6)$$

$$C_S = S_{11} - S_{22}^* \Delta \quad (7)$$

$$C_L = S_{22} - S_{11}^* \Delta \quad (8)$$

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| \quad (9)$$

There are many parameters that should consider in the design of power amplifiers, such as scattering parameters of the active device (ATF-21170), DC-biasing circuit and stability factor. Those parameters can affect circuit performance. Basically, the high gain with wide bandwidth can be gotten by cascade topology. Figure 2 present two stages PA circuit using microstrip lines technology. To obtain input and output matching network, it must compute distance and length of transmission lines where the conditions are $\Gamma_S = \Gamma_{in}^*$ and $\Gamma_{out} = \Gamma_L^*$. In this design, A "T" matching technique is used for input stage and a "PI" matching technique is used for output stage. The substrate material for transmission lines matching is used Epoxy (FR4) with dielectric substrate material (ε_r = 4.4), the thickness of the substrate (h = 1.6 mm) and width of all transmission lines (W= 3.3 mm) for characteristic impedance (50 Ω).

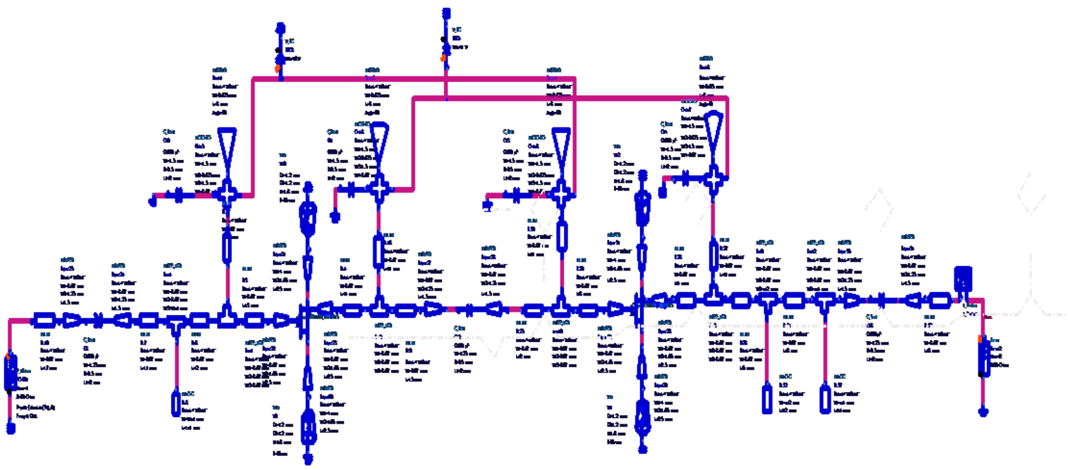


Figure 2. Schematic of the proposed two stage PA circuit using microstrip lines technology

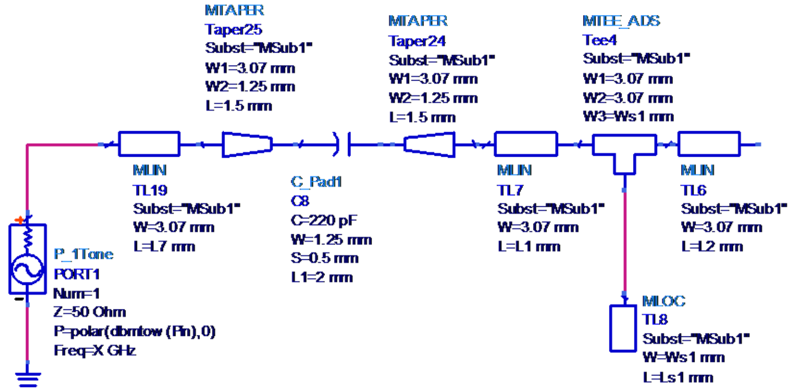


Figure 2(a). Input matching network circuit

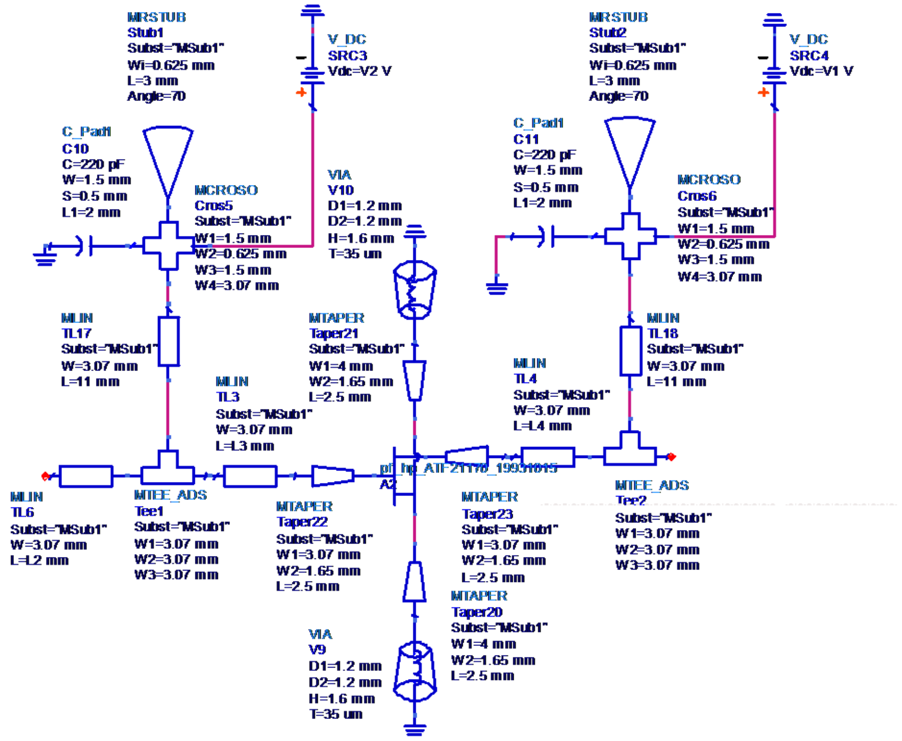


Figure 2(b). Biasing circuit

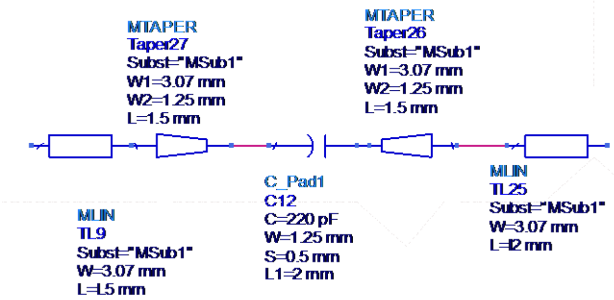


Figure 2(c). Inter-stage matching network circuit

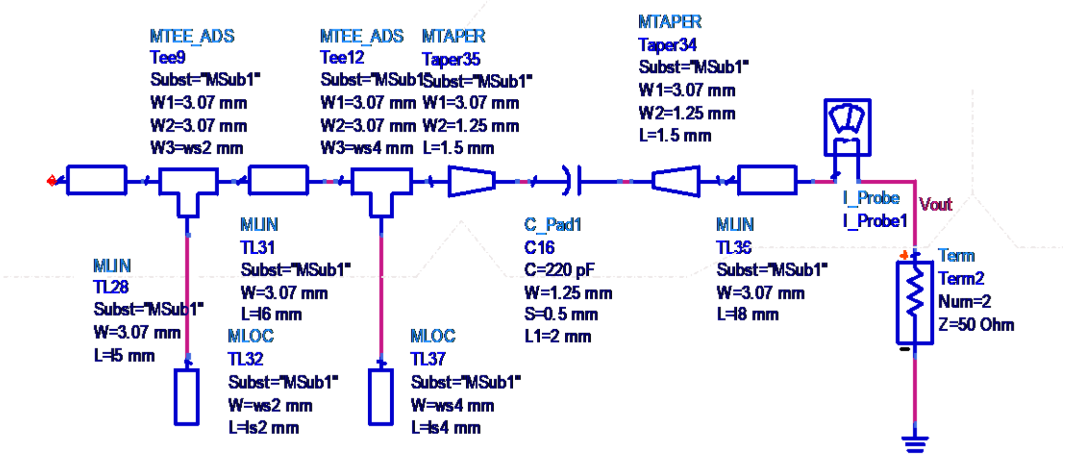
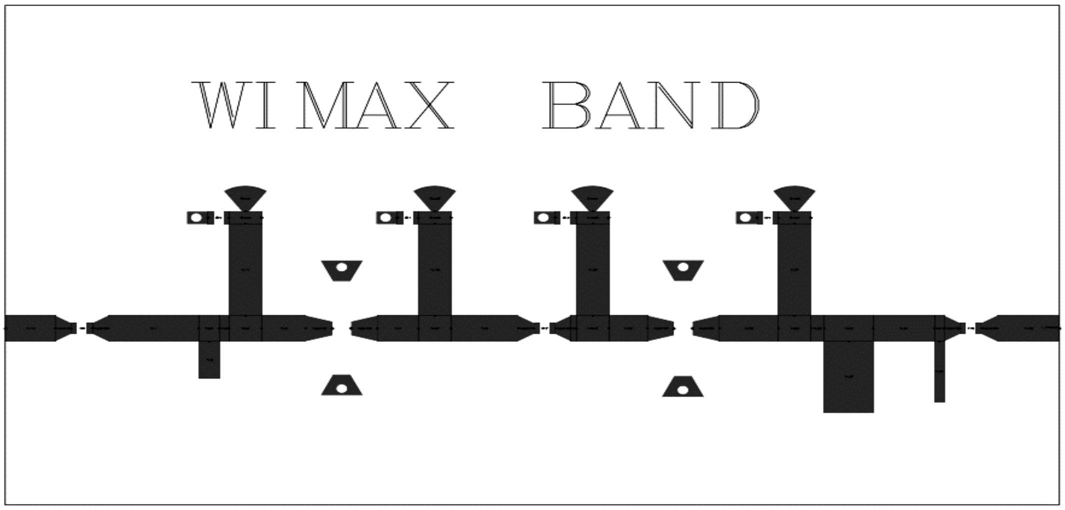


Figure 2(d). Output matching network circuit

This amplifier is also completed by DC biasing and DC blocking, component. The DC-biasing circuits consist of radial stub directly after a quarter-wavelength line (λ/4) add at the Drain and at the Gate, this biasing circuit will help to achieve proper isolation at desired RF frequency and to play the role of an RF choke [14]. The capacitors at input/output ports are utilized as DC blocking capacitors and capacitor (CI) is used for interstage impedance matching. Finally, the overall circuit is printed by using Momentum tool .The layout of the final proposed broadband power amplifier is illustrated in Figure 3.



.Figure 3. Layout of the proposed amplifier

3. Simulation Results and Discussion

The amplifier circuit in Figure 2 is designed and simulated using the advanced design system (ADS) software from Agilent Technology. This simulation is required to optimize BPA performance of circuit design. The simulation result at definite frequency range from 3.2 GHz to 3.8 GHz gives value of a return loss, output power, power gain and stability. This simulated result can be shown in Figures 4 to 7.

The Broadband PA is printed in microstrip technology using an Epoxy substrate (FR4) with a relative permittivity of 4.4, a thickness of 1.6mm, a metallization thickness t=0.035mm and a tangential loss of 0.025. The layout of the two stages BPA circuit is shown in Figure 3. The BPA occupies an area of 99x28mm² including all pads. This circuit has been adjusted by using optimization tools.The simulation results were carried out with a power supply applied on two stages of 4V for VDS and 0.5V for VGS. In Figures below shows the small-signal S-parameters of the BPA. It can be observed that the return loss is less than -10dB on the interested band; For the input reflection coefficient (S11) is varied between -20 and - 42dB. And the output reflection coefficient (S22) is varied between -10 and - 49dB at the desired frequency band. The small signal gain (S21) is changed between 28.5 and 20dB with an isolation coefficient (S12) less than -45dB over the wide frequency band of 3.2-3.8GHz. From Figure 6, it can be seen that K >1 over operating frequency band. Consequently, the conditions for unconditional stability of proposed broadband power amplifier are confirmed on the interested band. Figure 7 shows the simulation results of output power (Pout) according to the input power. The BPA exhibited a saturated-output power (PSAT) of 19dBm and an output 1dB compression point (P1dB) of 12.45dBm at a central frequency of 3.5 GHz.

Finally, we compared the proposed broadband power amplifier with other recently published articles on the state-of-the-art of broadband power amplifiers, the results are shown in Table 1. It can be remarked that the proposed amplifier has considerably a power gain and reflection coefficients over a wider bandwidth than other BPAs, which verifies the results show the excellent performance of our design approach compared to the reported works.

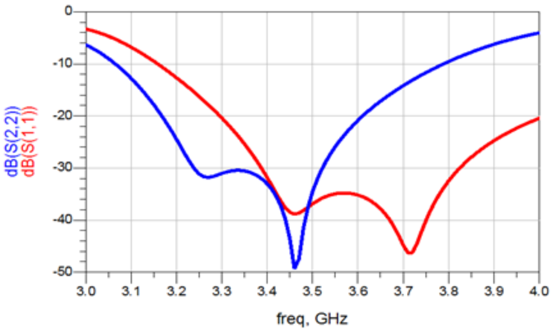


Figure 4. S11 & S22 versus frequency of the proposed amplifier

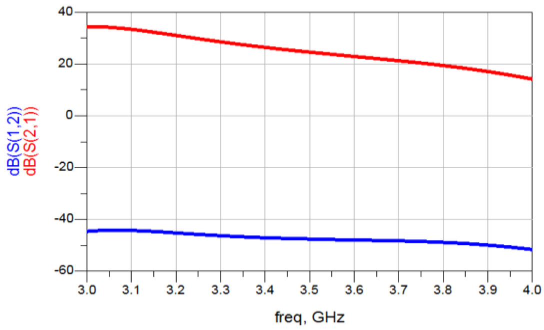


Figure 5. S12& S21 versus frequency of the proposed amplifier

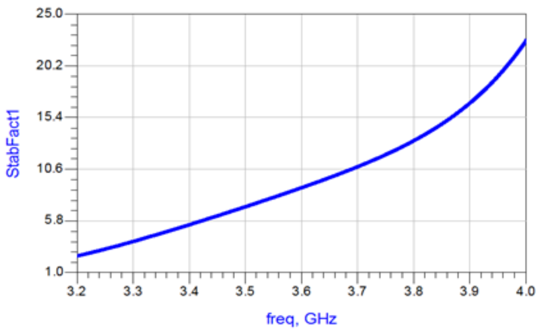


Figure 6. Stability Factor versus frequency characteristics

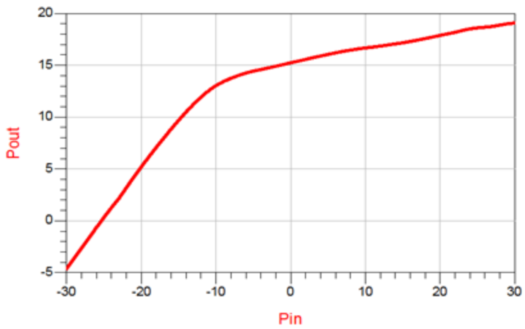


Figure 7. Input power versus output power for 3.5 GHz

Table 1. Comparision The Proposed Amplifier with Other Recently Amplifiers

Parameter	[15]	[16]	[17]	The Proposed BPA
Process	BJTs	GaN HEMT	CMOS	GaAs FET
Frequency (GHz)	1.75 to 2.15	1.9 to 2.5	1.65 to 2	3.2 to 3.8
Power Gain (dB)	11 ± 0.5	18.9	5.1 ± 5	28
Input Return Loss(dB)	-22	-17	-21	-30
Output Return Loss(dB)	-18	-	-8	-29

4. Conclusion

Two stages power amplifier (PA) in microstrip technology using “T” and “Pi” matching techniques which are modeled in ADS has been designed and simulated. A power amplifier based on GaAs FET is designed, simulated and tuned for the best possible performances. In order to get a better power gain of the designed PA, a second stage based on the same transistor is added in cascade. The design has been adjusted using optimization tools applied on matching networks such that the final design is improved in both gain and return loss. The complete designed (two stages PA) shows a peak power gain of 28dB, a low reflections, and high output power and unconditionally stable over a desired range of frequencies.

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References

[1] Ghannouchi FM, Ebrahimi MM, Helaoui M. *Inverse class F power amplifier for WiMAX applications with 74% efficiency at 2.45 GHz*. Communications Workshops, 2009 ICC Workshops 2009 IEEE International Conference on. 2009: 1–5.
[2] Rachakh A, El Abdellaoui L, Mandry R, Errkik A, Tajmouati A, Latrach M. *A New Design of a Microstrip Microwave Power Amplifier for PCS BAND*. Proceedings of the 2nd International Conference on Computing and Wireless Communication Systems. 2017: 3.
[3] Tabrizi MM, Masoumi N. *Wideband Doherty Power Amplifier for WiMAX Application*. 7th International Conference on Wireless Communications, Networking and Mobile Computing. 2011: 1–4.
[4] Lee K, Shin J, Lee J. *3.3 #x223C; 3.6GHz 28dBm power amplifier for WiMAX CPE applications*. 2011 IEEE Topical Conference on Power Amplifiers for Wireless and Radio Applications. 2011: 25–8.
[5] Rachakh A, El Abdellaoui L, Zbitou J, Errkik A, Tajmouati A, Latrach M. A Novel Configuration of a Microstrip Microwave Wideband Power Amplifier for Wireless Application. *TELKOMNIKA Telecommunication Comput Electron Control*. 2018; 16(1).
[6] Kalim D, Erguvan D, Negra R. *A 1.7 GHz-to-3.1 GHz fully integrated broadband class-E power amplifier in 90 nm CMOS*. Ph D Research in Microelectronics and Electronics (PRIME), 2010 Conference on. 2010: 1–4.
[7] Ribate M, Mandry R, Latrach M, Errkik A, El Abdellaoui L. *GaAs FET Broadband Power Amplifier for L and S Bands Applications*. Proceedings of the 2nd International Conference on Computing and Wireless Communication Systems. 2017: 42.
[8] Gonzalez G. Microwave Transistor Amplifiers Analysis and Design, 2nd. Prentice hall. 1997.
[9] Pozar DM. Microwave engineering. John Wiley & Sons. 2009.
[10] Cappelluti F, Traversa FL, Bonani F, Guerrieri SD, Ghione G. Floquet-Based Stability Analysis of Power Amplifiers Including Distributed Elements. *IEEE Microw Wirel Components Lett. IEEE*. 2014; 24(7): 493-5.
[11] Tan EL, Ning J, Ang K Sen. *Geometrical stability criteria for two-port networks in invariant immittance parameters representation*. Microwave Conference, 2008 APMC 2008 Asia-Pacific. 2008: 1–4.
[12] Vendelin GD, Pavio AM, Rohde UL. Microwave circuit design using linear and nonlinear techniques. John Wiley & Sons. 2005.
[13] Liao SY. Microwave circuit analysis and amplifier design. Prentice-Hall, Inc. 1987.
[14] Rachakh A, El Abdellaoui L, Errkik A, Tajmouati A, Latrach M. *A New Configuration of a Microstrip Power Amplifier Using Si-BJT in Class-A Mode for DCS Applications*. Proceedings of the 2nd International Conference on Computing and Wireless Communication Systems. 2017: 58.
[15] Rachakh A, El Abdellaoui L, Zbitou J, Errkik A, Tajmouati A, Latrach M. *A novel design of a microstrip microwave broadband power amplifier for DCS, PCS and UMTS bands*. Wireless Technologies, Embedded and Intelligent Systems (WITS), 2017 International Conference on. 2017: 1–5.
[16] Iqbal M, Piacibello A. *A 5W class-AB power amplifier based on a GaN HEMT for LTE communication band*. Microwave Symposium (MMS), 2016 16th Mediterranean. 2016: 1–4.
[17] Aniktar H, Sjoland H, Mikkelsen JH, Larsen T. *A Class-AB 1.65 GHz-2GHz broadband CMOS medium power amplifier*. NORCHIP Conference, 2005 23rd. 2005: 269–72.