International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8, Issue-1, May 2019

Design of high linearity Efficiency GaN Power Amplifier with Second Harmonic Tuning Technique

S Raja Gopal, V S V Prabhakar

Abstract*: *In this paper a 3.8 GHz low voltage S-band power amplifier (PA) was designed. Second order harmonic technique is used at PA load to achieve high amount of output power and power added efficiency (PAE). GaN material is used for design purpose to satisfy tradeoff between PAE and output power. As GaN material provides high electron mobility property, high linearity operation is achieved. Major advantage of GaN material is its high thermal stability and exhibits fast switch mode operation when compared with other transistor designs. The proposed PA is designed based on MMIC technology. In addition to this PA output is connected to second order harmonic tuning circuit which in turn improves the output power and efficiency. At 1V of input supply proposed PA exhibits gain of 52dB and 62.5% PAE and output power of 54.22dB. The proposed PA is compared with conventional power amplifiers for better performance.

***Index Terms*: MMIC, PAE, S-Band, Power Amplifier.**

I. INTRODUCTION

The need for 5G communication has drawn high attention today due to drawbacks of low data rate and high latency of 4G communication. In this aspect current generation power amplifier (PA) designs are approaching towards high linear operation and thermal stability at larger output power. In general for very low frequency (VLF) to very high frequency (VHF) range Class C, Class D and Class E power amplifiers are implemented with switch mode operation. In Class C drain current is shaped as narrow pulse due to less harmonic reactance contents. Whereas Class E contains all negative harmonic reactance's and their magnitude is comparable to load resistance [1][2][3]. In this way the major disadvantage of these power amplifiers are their drain waveforms are non-sinusoidal and contains harmonics. Similarly Class B power amplifier also produces half sinusoidal waveforms with the presence of harmonics. Finally the major drawback of any PA is high amount of power dissipation at output due to harmonic contents presented in input signal. To overcome this disadvantage class F power amplifier are introduced with output filters consisting of multiple resonators. These filters controls the harmonics at output and provides high amount of collector current whenever low voltage is obtained. In this way a flatten collector voltage or collector current waveforms are obtained [4][5][6].

The major advantage of GaN material is having less space occupancy during board design, lower conductance losses and switching losses. Due to this reason GaN material is widely using in design of RF components. Another advantage of GaN material is providing high breakdown voltage which allows higher impedance for large drain voltage. Many S-band power amplifiers with GaN technology are proposed in [4]. In this paper class F PA is designed with GaN technology and an additional second harmonic tuning circuit is provided to obtain better impedance matching for high output power. Due to large band gap and high electron mobility property of GaN material provides many application in S-band. The basic advantage of class F power amplifier is improved efficiency due to presence of harmonic resonators at output stage which shapes the drain or load voltage. The harmonic resonators network will act as zero or infinite load impedance depending on harmonics generated by all frequencies [7][8][9]. This paper is organized as follows: Section II represents design flow of PA and the mathematical analysis of second order tuning circuit. Section III deals with the implementation of proposed power amplifier and its operation. Similarly section IV consists of proposed PA performance with respect to previous methods. A comparison of output power, PAE and gain are presented. Finally section V concludes the PA design and its future advancements.

II. DESIGN APPROACH OF POWER AMPLIFIER (PA):

The following flow chart Fig.1 represents the design approach of proposed power amplifier (PA).

In order to design class F power amplifier, initial requirements such as transistor material (GaN), device specifications and topology are considered. Based on class-F topology proposed power amplifier schematic is designed. An additional second harmonic tuning stage is added for better impedance matching at output. Designed schematic is tested and simulated for better performance. The values of capacitors and inductors for tuning circuit are chosen based on required resonance frequency. In this way schematic load circuit capacitor and inductor values are modified until better performance and required resonance frequency is obtained.

Revised Manuscript Received on 22 May 2019.

***** Correspondence Author
S.Raja Gopal*, B. Tech and M.Tech degree from JNTUH and JNTUK universities A. P. India
.**Dr.V.S.V. Prabhakar,** professor in the department of ECE at KL University, Guntur, A.P. India

The proposed schematic is placed for layout design for real time implementation.

Layout for current design is carried out using MMIC technology. GaN material is used for design of power amplifier to meet fast switch mode operation. The designed power amplifier is simulated to set multiple non overlapping current and voltage waveforms. In the current design approach both output power and efficiency are accomplished by approximation of square wave (voltage) and sinusoidal wave (current) with odd and even harmonics respectively [1][2][3].

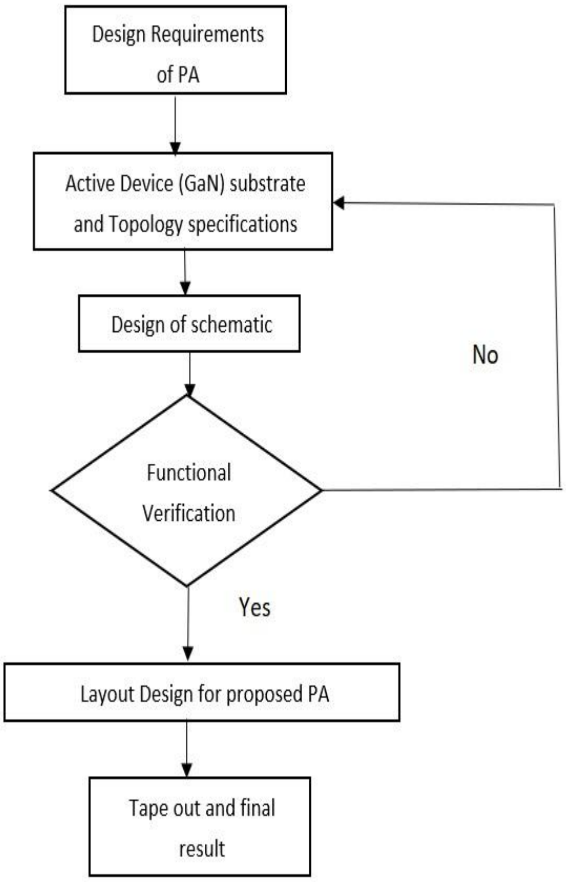

Figure1. Design flow of Power Amplifier

A. Second Harmonic tuning stage:

Second harmonic tuning circuit is mainly used to decrease the dc power dissipation at drain. This is obtained by connecting capacitor and inductor in series as shown in below Fig 2. An appropriate capacitor and inductor values are chosen to resonate circuit at '2f' (3.8GHz) at output node [6]-[8].

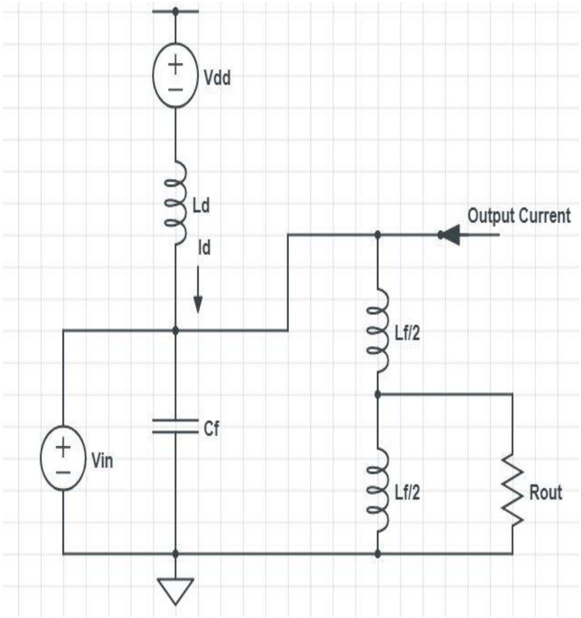

Figure 2. Second harmonic tuning stage

A series of mathematical analysis for second harmonic tuning circuit is given below based on zero voltage switching (ZVS) condition.

$$i_{RF}(\omega t) = I_{RF}\cos(\omega t + \theta) \quad (1)$$

$$i_2(\omega t) = I_2 cos(2\omega t) \quad (2)$$

By applying KCL at output node load current obtained as

$$i_{sw} = I_L + I_{RF} coc(\omega t + \theta) + I_2 coc(2\omega t) \quad (3)$$

I_L=Dc current.
θ=Initial phase angle.
Output power of second harmonic circuit is given as

$$I_2 V_{DD} = \frac{1}{2} I_{RF}^2 R_{Load} \quad (4)$$

$$P_L = \frac{P_{Out}}{V_{Peak} I_{rms}} \quad (5)$$

Voltage across output inductor mathematically represented as

$$V_L(\omega t) = \frac{1}{\omega C_s} \int_{\pi}^{\omega t} I_C(\omega t)\, d\omega t \quad (6)$$

$$\frac{I_L}{I_2} = \frac{2}{(2\pi + 3\omega t\theta)} \quad (7)$$

$$C_S = \frac{\pi cos^2(\theta)}{\omega R_{Load}} \quad (8)$$

C_S=Shunt Capacitance

Inverse Fourier transform of collector voltage is given as

$$V_C = \frac{1}{2\pi}\int_{\pi}^{\omega t} V_C(\omega t)e^{-2j\omega t}\,d\omega t \qquad (9)$$

Inverse Fourier transform of output current is given as

$$I_0 = \frac{1}{2\pi}\int_{\pi}^{\omega t} i(\omega t)e^{-2j\omega t}\,d\omega t \qquad (10)$$

Harmonic contents of output current represented as

$$i_0(\omega t) = I_{RF}\cos(\omega t + \theta) + I_2\cos(2\omega t) \qquad (11)$$

$$V_L(\omega t) = \frac{1}{\omega C_S}\int_{\pi}^{\omega t} I_C(\omega t)\ dt\ \frac{1}{\omega C_s}\{I_L(\omega t - \pi) - \frac{1}{2}I_2\sin(2\omega t) - I_R[\sin(\omega t + \theta) + \sin\theta]\} \qquad (12)$$

By solving equation (9) and (10) load impedance is given as

$$Z_L = \frac{V_L}{I_C} \qquad (13)$$

Z_L= Load Impedance.

III. PROPOSED POWER AMPLIFIER DESIGN (PA):

Figure 3 represents the schematic view of proposed PA (GaN). PA (GaN) is connected to second harmonic tuning circuit to obtain high power added efficiency (PAE).

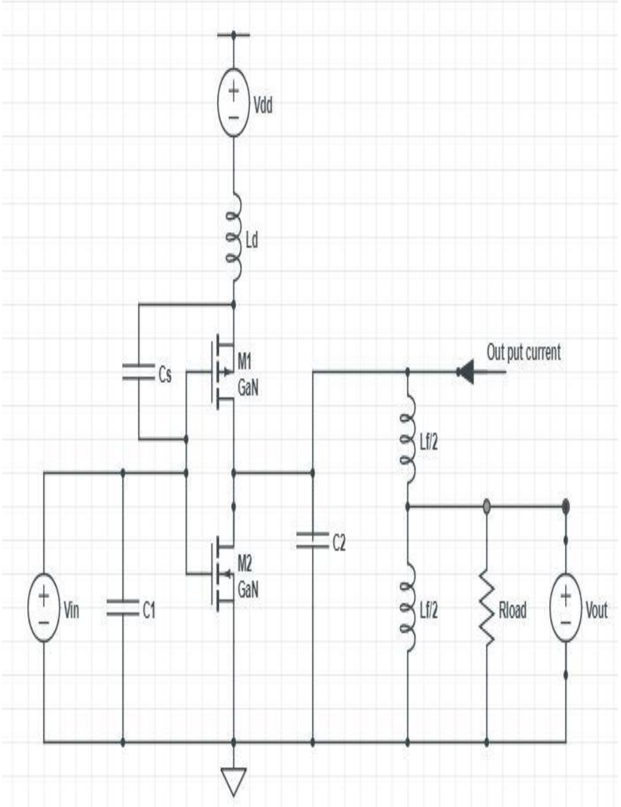

Figure 3. Class-F power amplifier with Second harmonic tuning stage.

Class F operation is obtained based on even and odd harmonics variation using second harmonic tuning circuit. A series of capacitor and inductor is placed at output section to compensate impedance matching for maximum power transfer. PA (GaN) is biased with half wave sine wave current which contains only even harmonics. At this condition odd harmonics are useful in flattening out put voltage. For proper wave shaping and linearity operation second harmonic tuning circuit is utilized [7] [8].

Class-F amplifier is designed using GaN device. Since GaN material has high electron mobility and high thermal stability provides high linearity operation. Due to high thermal withstand of GaN material exhibits Q-point at saturation region with large bandwidth. The designed power amplifier is resonated at operating frequency of 3.8GHz for many applications in S-band [5][8][9].

IV. RESULTS AND DISCUSSIONS:

The designed PA is biased in class F condition with V_{DS}=3.2V and V_{GS}=-3.2V (I_{DS}=412mA). The load pull simulation of designed Class-F provides matching load impedance of Z_L=6.205+j3.2Ω. Similarly for source pull simulation gives source impedance of Z_S=2.01+j3.12Ω. The simulation test results gives out put power of 54.22dB, Gain of 52dB and 62.5% power added efficiency (PAE)[6]-[8]. A comparison of conventional class-F power amplifier and designed power amplifier is shown as below.

Power Amplifier	Class AB	Class C	Conventional Class F PA	Proposed Class F PA
Out Put Power	33.12dB	38.4dB	45.1dB	54.22 dB
Gain	31dB	35dB	43dB	52 dB
PAE	33.2%	36.4%	42.1%	62.5%
Efficiency	41.1%	49.2%	59.2%	64.3%

Table 1. Comparison and performance of different PA

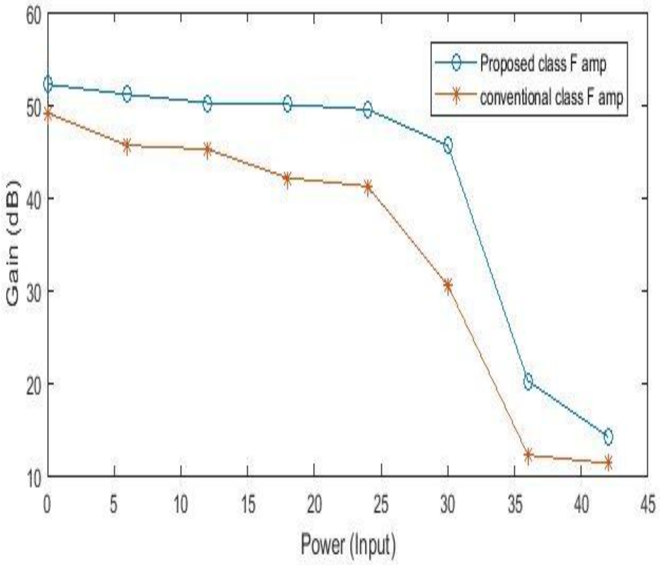

Figure 4. Input Power VS Gain (dB)

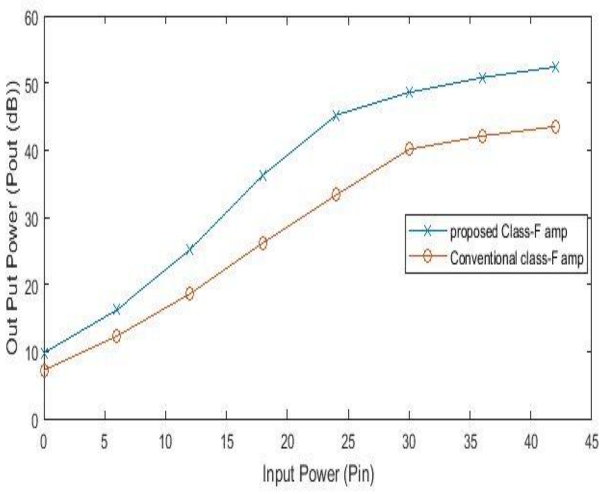

Figure 5. Input Power VS Output Power

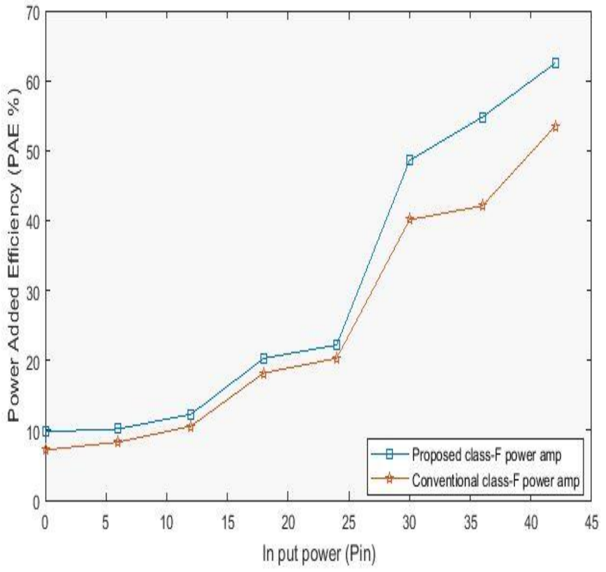

Figure 6. Input Power VS PAE

The simulated results shows that designed power amplifier has better performance when compared with conventional power amplifier.

V. CONCLUSION

In this paper design of class-F power amplifier with second harmonic tuning stage using GaN is presented. The designed PA exhibits gain of 52dB, 62.5% of PAE and output power of 54.22dB at 3.8GHz. The obtained results implies that proposed class-F power amplifier have high efficiency when compared with the conventional class-F power amplifier. In addition to this proposed class F power amplifier exhibits high linearity and gain in RF region. With this advantage proposed class-F power amplifier can be used in satellite and mobile communication systems.

ACKNOWLEDGMENT

The author wish to thank Research and Development department of K L University for financial support to carry out research work.

REFERENCES

1. Raab, F.H., 1997. Class-F power amplifiers with maximally flat waveforms. *IEEE Transactions on Microwave Theory and Techniques*, *45*(11), pp.2007-2012.
2. Mishra, U. K., Shen, L., Kazior, T. E., & Wu, Y. F. (2008). GaN-based RF power devices and amplifiers. *Proceedings of the IEEE*, *96*(2), 287-305.
3. Pengelly, R. S., Wood, S. M., Milligan, J. W., Sheppard, S. T., & Pribble, W. L. (2012). A review of GaN on SiC high electron-mobility power transistors and MMICs. *IEEE Transactions on Microwave Theory and Techniques*, *60*(6), 1764-1783.
4. Gao, S., Butterworth, P., Sambell, A., Sanabria, C., Xu, H., Heikman, S., ... & York, R. A. (2006, September). Microwave class-F and inverse class-F power amplifiers designs using GaN technology and GaAs pHEMT. In *2006 European Microwave Integrated Circuits Conference* (pp. 493-496). IEEE.
5. Shujian, G., Chen, P., & Ran, C. (2016, October). Design of a high-efficiency Doherty GaN power amplifier. In *2016 IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB)* (pp. 1-4). IEEE.
6. Kurniawan, T., & Yoshimasu, T. (2019). A 2.5-GHz 1-V High Efficiency CMOS Power Amplifier IC with a Dual-Switching Transistor and Third Harmonic Tuning Technique. *Electronics*, *8*(1), 69.
7. Nilsson, J., Billstrom, N., Rorsman, N., & Romanini, P. (2009, September). S-band discrete and MMIC GaN power amplifiers. In *2009 European Microwave Integrated Circuits Conference (EuMIC)* (pp. 495-498). IEEE.
8. Hayati, M. and Lotfi, A., 2013. Design of a highly PAE class-F power amplifier using front coupled tapered compact microstrip resonant cell. *AEU-International Journal of Electronics and Communications*, *67*(8), pp.681-685.
9. Góralczyk, M., & Gryglewski, D. (2016, May). S-band GaN PolHEMT power amplifier. In *2016 21st International Conference onMicrowave, Radar and Wireless Communications (MIKON)* (pp. 1-4). IEEE.

AUTHORS PROFILE

S.Raja Gopal received B.Tech and M.Tech degree from JNTUH and JNTUK universities in 2007 and 2012 respectively. Currently he is working towards Ph.D degree from KL University. His research interest include VLSI &IoT. He is a Life Time member of IETE and member of IEEE.

Dr.V.S.V.Prabhakar is a professor in the department of ECE at KL University, Guntur His research area includes VLSI and Cyber Security. He received MS degree from Sweden university and Ph.D. degree from JNTUK.He has published many papers extensively in the above areas. He is a Life Time member of IETE.