



**DESIGN OF A HIGH EFFICIENCY POWER AMPLIFIER FOR WIRELESS
AND RADAR APPLICATIONS**

**Peyman MAHOUTI*, Mehmet Ali BELEN, Hakan Paşa PARTAL, Salih
DEMİREL, Filiz GÜNEŞ**

Yıldız Teknik Üniversitesi, Elektronik ve Haberleşme Mühendisliği Bölümü, Yıldız-İSTANBUL

Received/Geliş: 14.10.2014 Revised/Düzelme: 21.12.2014 Accepted/Kabul: 04.02.2015

ABSTRACT

This article reports a 46% efficient Class-A power amplifier (PA) designed for wireless transceiver communication systems. The compensation elements with a series capacitor and a shunt inductor are used to compensate for the internal parasitic components of the packaged transistor. The peak PA efficiency of 46% with a power gain of 18 dBm is achieved at an input power of 0dBm for a continuous wave designed for 1850-1950 MHz. To improve output power and efficiency by suppressing harmonic powers, an output matching circuit using the transmission lines is used. The power amplifier exhibits a 0Bm, 18-dB power gain while using a low quiescent current of 56 mA. The simulation results of the designed PA are found to be useful for many commercial wireless and radar applications, since it is compact in size, low loss, and cost with good performance. The PA can be scaled to the commercial frequencies up to 2.5GHz, offering advantages for most ISM and cellular band applications. This work demonstrates the feasibility of using class-A PAs for short-range, low-power applications.

Keywords: Power amplifiers, high efficiency power amplifiers, wireless transceivers.

**KABLOSUZ HABERLEŞME VE RADAR UYGULAMALARI İÇİN YÜKSEK VERİMLİ GÜÇ
KUVVETLENDİRİCİSİ TASARIMI**

ÖZET

Bu çalışmada kablosuz haberleşme sistemlerine uygun %46 verimliliği sahip bir A sınıfı güç kuvvetlendiricisi incelenmiştir. 1850-1950MHz frekans bandında 0 dBm giriş gücüne karşılık 18dBm kazançla en yüksek PAE değeri %46 elde edilmiştir. Mikroşerit iletim hatları kullanılarak devrenin verimliliğinin artırılması hedeflenmiştir. Benzetimi yapılan güç yükseltici 56mA'lık düşük akım çekmektedir. Tasarlanan PA'nin simülasyon sonuçlarının yanı sıra boyutu, düşük ekleme kaybı ve yüksek performansı ile birçok ticari kablosuz ve RADAR uygulamaları için uygun olduğu gözlemlenmiştir. Tasarlanan kuvvetlendiricinin çalışma frekansı 2.5 GHz'e kadar genişleyebildiği için birçok ISM bant uygulamalarına uygundur. Bu çalışma kısa menzilli düşük güç uygulamaları için A sınıfı PA'nın fizibilite çalışmasını sunmaktadır.

Anahtar Sözcükler: Güç kuvvetlendiricisi, yüksek verimli güç kuvvetlendirici, kablosuz alıcı verici.

* Corresponding Author/Sorumlu Yazar: e-mail/e-ileti: pmahouti@gmail.com, tel: (507) 930 00 74

1. INTRODUCTION

Radio frequency (RF)/microwave PA is the most expensive component in radio transmitters of modern communications and radar systems. A high power amplifier efficiency (PAE) is one of the key requirements in RF/microwave PA designs, as it will lead to low power consumption, reduced cooling requirements, small battery size and low cost in RF front ends. To achieve a high PAE, it is necessary to drive the active device heavily into compression, leading to highly non-linear behaviour [1, 2]. Class-A power amplifier is widely used in communication systems with variable envelop modulation scheme, despite its relatively low efficiency. One of the most challenging tasks in Class-A PA design is to determine the optimal load resistance R_{opt} , which ensures that maximum output power can be achieved, this work can be done by using an off-chip commercial load-pull system [3-6].

Wireless communications have been continuously evolving to meet the user's diverse needs. In this regard, several wireless standards are either currently deployed or will be introduced in the near future. Service providers have to cope with multiple protocols as the different standards will need to coexist. To deal with multiple standards, several solutions can be considered such as multiple radios, multiband radios, and broadband ones. Using multiple radios to cover the multiple standards is a costly, large, and none optimal solution. However, multiband and broadband structures make use of one radio that meets the needs of multiple standards. In other words, multiband systems work for multiple, discrete, and narrowband frequency intervals (usually far from each other), whereas broadband structures aim for a single but broader frequency range trying to target at least two wireless standards. The main challenge of the design of multiband/ broadband power amplifier (PA) is to maintain as good RF performance compared with narrowband PA.

Current and next-generation wireless communication systems, such as wide-band code division multiple access (WCDMA), worldwide interoperability for microwave access (WiMAX) and so on, are progressed toward the wide band-width and large number of carriers to transmit high-data-rate signals for multimedia communications. To sustain these communications, the power amplifiers (PAs) should amplify the modulated signals without distortion. However, the PAs cannot linearly amplify the signals due to severe memory effects for the wideband signals. Thus, the memory-effect suppression is an important issue for the applications. Moreover, a highly efficient PA is required to reduce size and cost of the overall system [3].

2. POWER AMPLIFIER DESIGN

RF power amplifiers come in many common flavors, such as Class A, B, C, D, E, and F. Class A is the only amplifier type that is considered fully linear, and has the highest gain of any other class of large signal amplifier. Both the linearity and gain are due to the Class A amplifier's ability to fully amplify both the positive and negative alternations of an input signal. Class A can also effectively operate at higher frequencies than any other class (very near the f_{MAX} of the transistor itself) due to its lower level of output harmonics. Its overwhelmingly negative attribute is its very low efficiency, which can be critical in large-signal applications. Thus, Class A amplifiers are normally only used as PAs when the wireless system's modulation scheme will demand a very linear level of amplification, or if only low RF output powers are required. Nonetheless, in order to accommodate modern linear digital modulation schemes, many of the PAs designed today are Class A.

An amplifier will exhibit low order harmonics, and their peak distortion is less than twice the average distortion. In power amplifier design, it is more concern with the maximum output power than the gain of the amplifier. Traditional PA designs for low-power applications use linear class amplifiers, such as class-A to avoid output filters that degrade the efficiency. Class A Amplifier configuration is the ideal operating mode, because there can be no crossover

or switch-off distortion to the output waveform even during the negative half of the cycle. Class A amplifiers have very low distortion (lowest distortion occurs when the volume is low). The distortion is low because the transistors in the amp are biased such that they are half "on" when the amp is idling (this is the point at which the semiconductor devices are most linear in behaviour).

Class A circuit topology is one in which the total current the amplifier is capable of delivering, is kept flowing in the circuit regardless of demand. In a conventional or Class AB amplifier circuit this current flow varies when demand varies. Furthermore, as current varies, the voltage on the rails (as seen by the output stage) varies too. In a Class A circuit, current draw should be constant therefore there is an absence of the power supply modulation common in Class AB design amplifiers. Pinpoint images, tonal clarification, intertransient silence, more readily defined dynamic shadings, inner detail and authority are all inherent advantages of good Class A design. The class-A amplifier has the highest linearity over the other classes. It operates in a linear portion of its characteristic; it is equivalent to a current source. An HBT Class-A power amplifier, along with its ideal circuit model and waveforms are shown in Fig. 1a, where V_{AC} and I_{AC} are amplitudes of the collector voltage and current, respectively [7].

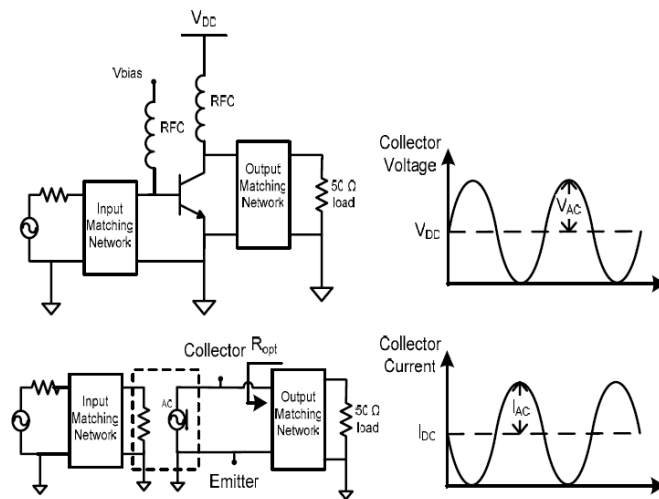


Figure 1a. Class-A PA with its ideal circuit model and waveforms. [7]

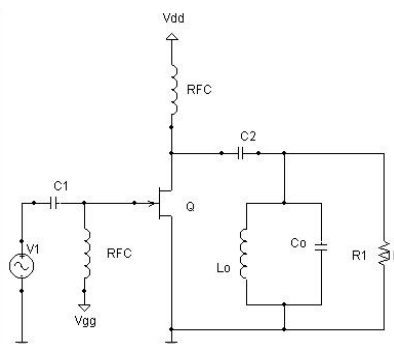


Figure 1b. Single-ended Power Amplifier

To achieve high linearity and gain, the amplifier’s base and drain dc voltage should be chosen properly so that the amplifier operates in the linear region. The device, since it is on (conducting) at all times, is constantly carrying current, which represents a continuous loss of power in the device.

The maximum output power is

$$P_0 = \frac{1}{2} V_{om} I_{om} \approx \frac{1}{2} V_{DD} I_{dq} \tag{1}$$

And the efficiency is

$$\eta = \frac{P_0}{P_{dc}} \cdot 100 = \frac{1}{2} \cdot \frac{V_{om}}{V_{DD}} \cdot 100 \leq 50\% \tag{2}$$

The transducer power gain is the ratio of the power delivered to the load to the power available from the source. The transducer power gain is given by;

$$G_T = P_{delivered\ to\ load} / P_{available\ from\ the\ load} \tag{3}$$

The transducer power gain is computed from

$$G_T = \frac{1 - |\Gamma_s|^2}{|1 - \Gamma_{in} \Gamma_s|^2} S_{21} \frac{1 - |\Gamma_L|^2}{|1 - S_{21} \Gamma_L|^2} \tag{4}$$

where Γ_{in} , the reflection coefficient looking into the input, is given by;

$$\Gamma_{in} = S_{11} + \frac{S_{21} S_{12} \Gamma_L}{1 - S_{22} \Gamma_L} \tag{5}$$

This measurement is applicable to 2-port circuits only.

Transducer gain:

$$G_T = 10 \left[\log_{10} \left(\frac{|S_{21}| (1 - (|\Gamma_s|^2)) (1 - (|\Gamma_L|^2))}{(1 - (|S_{11} \Gamma_s|^2)) (1 - (|S_{22} \Gamma_L|^2)) - S_{12} S_{21} * \Gamma_s * \Gamma_L} \right) \right] \tag{6}$$

K is the stability factor for a two port, defined as:

$$K = \frac{1 - |S_{11}| - |S_{22}| - |\Delta|}{2 |S_{12} S_{21}|} \tag{7}$$

Where

$$\Delta = S_{11} S_{22} - S_{12} S_{21} \tag{8}$$

PAE computes the power-added efficiency of a circuit. The DC power is computed from the total DC power of all sources in the circuit. The RF power is computed using the specified measurement element. The power-added efficiency is defined as;

$$PAE = \left(\frac{|P_{out}| - |P_{in}|}{P_{DC}} \right) \times 100\% \tag{9}$$

3. SIMULATION RESULTS

There are various software packages in market for RF circuit design and simulation. In this study Advanced Wireless Revolution Microwave Office (AWR) simulation program used to provide more flexibility in the design process. In the selection of power amplifier study characteristics

(voltage, current, and temperature), reliability (the maximum leakage current, humidity limits, excessive load current), electrical properties (high voltage characteristics, insulation resistance, Return Loss, Insertion Loss, Noise Form (NF), etc.) and the mechanical properties (size, mounting problems) are the most important selection parameters. BFP 650 is selected as the core element of the PA design. Also BFP650 is a component which can be used for low phase noise oscillator designs [8].

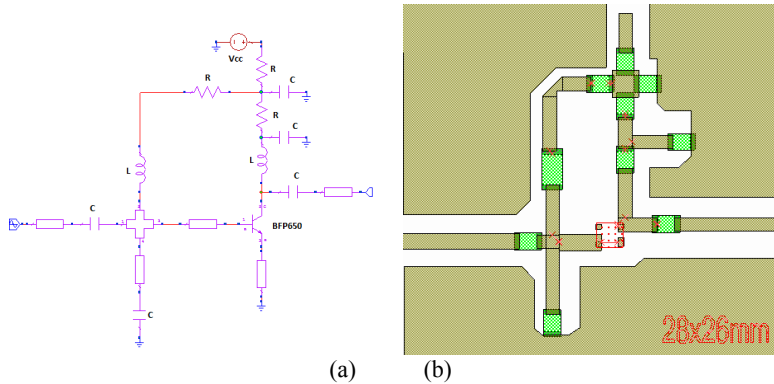


Figure 2 a, b. PA schematic without Matching Circuits (MC), PA Layout without Matching Circuits (MC)

The full circuit, including all the parasitic and matching/biasing/stabilizing networks, was initially simulated using AWR. The performance figs, based on this simulation, are presented in Figs. 3a-d, for class-A power amplifier. Design targets are an operating frequency of 1900MHz and output power $\geq +18$ dBm. To achieve such high output power level, an input & output Matching Circuit design is adopted as shown in Figs. 4a-b.



Figure 3 a, b. Simulation Result of PA without MC, Output power at 0 dBm without MC

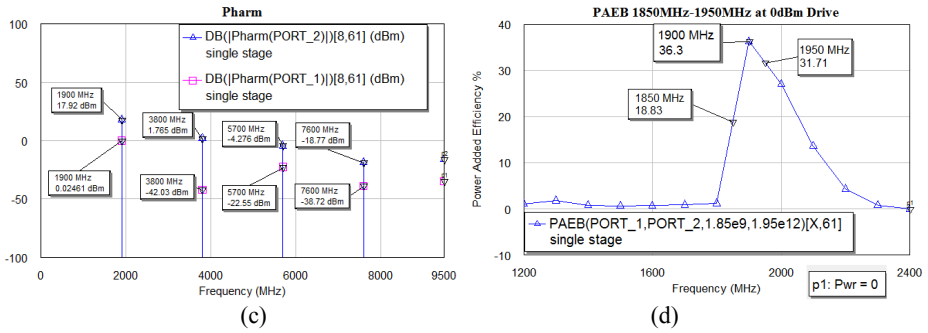


Figure 3 c, d. Harmonics of PA without MC, Efficiency of PA for 0 dBm input Power without MC

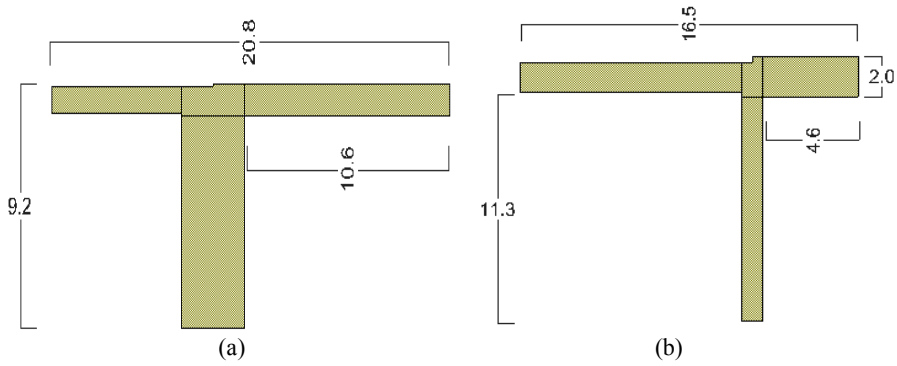


Figure 4 a, b. Input Matching Circuit, Output Matching Circuit

Figures 5(a-d) are simulated results for PA design with Matching Circuits. As it shown the performance of the PA has been improved.

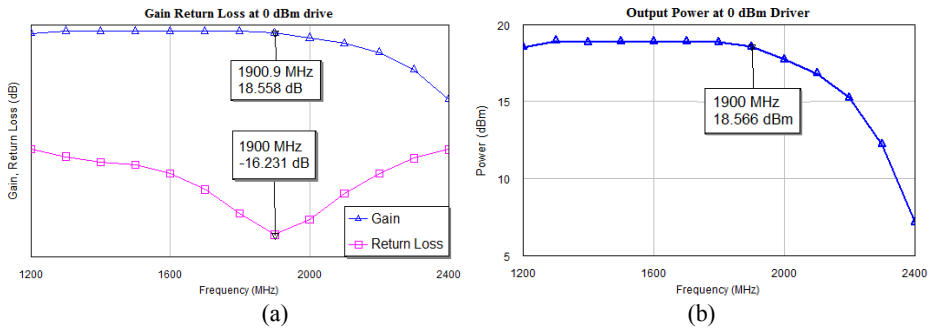


Figure 5 a, b. Simulation Result of PA with MC, Output power at 0 dBm with MC

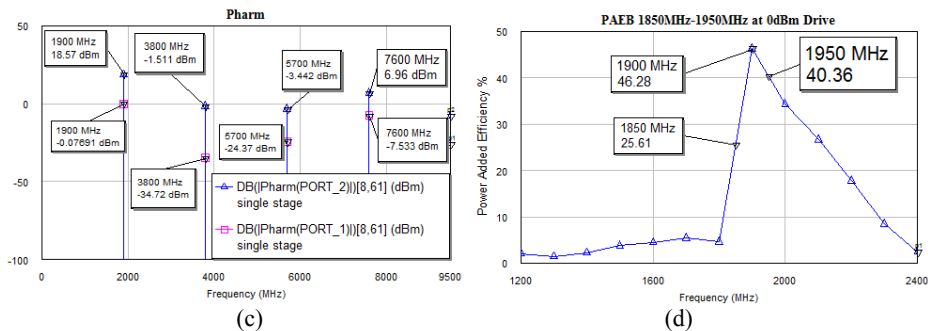


Figure 5c, d. Harmonics of PA with MC, Efficiency of PA for 0 dBm input Power with MC

The Pharm and PAE of the PA are shown in figure 5c,d. The maximum efficiency of this configuration is 46.28% with 0dBm input power. The PAE of the designed PA is 25-40% within the bandwidth of 1850-1950MHz. However it should be noted that at that point the amplifier has already reached well into saturation.

In table 1, Comparison of the Designed PA with and without matching circuits is shown. As it is shown in table 1 the gain and PAE values of the PA with matching circuit is increased with 10% and also the stability of the design is increased.

Table 1. Comparison of PA designs

	WITHOUT MATCHING	WITH MATCHING	A similar Class-A PA in literature [7]
Vcc	3.3V	3.3V	---
TR	BFP650	BFP650	0.35MICROMETRE SIGE BICMOS TECHNOLOGY
S11 dB	-22	-16	-19.3
S22 dB	-20	-19	-8.3
Frequency Range Mhz	1850-1950	1850-1950	2350-2550
Gain dB	17.91	18.55	18.87
PAE 0dBm input	%36	%46	18.5%
Current Consumption mA	55	55	---
Die size mm	26x28	55x40	---

4. CONCLUSIONS

This paper presents a detailed design and improvement procedures for a Class-A Power amplifier at 1900MHz for wireless transceiver applications. The size of the circuit is increased after matching, however, overall electrical parameters of the power amplifier is improved significantly. To improve output power and efficiency by suppressing harmonic powers and minimizing losses, an input and output matching circuit using the transmission lines was used. The power-added efficiency of 46.28% with a power gain of 18.55 dB was achieved at an input power of 0dBm at 1.9 GHz, which represents a very high efficiency for the class-A power amplifiers for the frequencies up to 2.5 GHz commercial wireless applications.

Acknowledgments / Teşekkür

This research has been granted by The Turkish Ministry of Science, Industry and Technology and VIKO Electrical & Electronics Industry Inc under the project number of 0230.STZ.2013-1.

REFERENCES / KAYNAKLAR

- [1] S. Gao, High-efficiency class-F RF/Microwave power amplifiers, IEEE Microwave Magazine, vol. 7, no. 1, Feb. 2006, pp. 40-48
- [2] S. Gao, P. Butterworth, S. Ooi, and A. Sambell, High efficiency class-F power amplifier design including input harmonic termination, IEEE Microwave and Wireless Components Letters, vol. 16, no. 2, Feb. 2006, pp. 81-83
- [3] A Highly Efficient Class-F Power Amplifier for Wideband Linear Power Amplifier Applications Jangheon Kim,¹ Junghwan Moon,¹ Sungchul Hong,² and Bumman Kim¹ microwave and optical technology letters / vol. 51, No. 10, October 2009.
- [4] "A SiGe BiCMOS Class A Power Amplifier Targeting 5.5GHz Application" Yan Qiong, Hua Lin, Chen Lei, Ruan Ying, Su Jie, Zhang Shulin, Zhang we., Liu Shengfu and Lai Zongsheng 978-1-4577-1610-2/11/\$26.00 ©2011 IEEE.
- [5] K. Nellis and P. Zampardi, A comparison of bipolar technologies for linear handset power amplifier applications, in Proc. BCTM, 2003. pp. 203-209.
- [6] S. Cripps, RF Power Amplifiers for Wireless Communications, Norwood, MA, Artech House, 1999.
- [7] A New Circuit Model for Designing Fully Integrated Class-A Power Amplifier, Xiaokang Guan, Haigang Feng, Albert Wang, Liwu Yang, PROC. 25th INTERNATIONAL CONFERENCE ON MICROELECTRONICS (MIEL 2006), BELGRADE, SERBIA AND MONTENEGRO, 14-17 MAY, 2006.
- [8] http://pdf.datasheetcatalog.com/datasheet/infineon/1-bfp650_preliminary.pdf