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Design Of A Doherty Power Amplifier For GSM Systems

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Abstract

This paper presents the design and analysis of Doherty power amplifier. The Doherty amplifier is used in a base station for mobile system because of its high efficiency. The class AB power amplifier used in the configuration of the main and auxiliary amplifier. The result obtained shows that the Doherty power amplifier can be used on a wide band spectrum, the amplifier works at 900MHz and has very good power added efficiency (PAE) and gain. The amplifier can also work at 1800MHz at input power greater than 20dBm.

Keyword: Power Amplifier, Doherty Amplifier, Classes Amplifier

تصميم مكبر القدرة نوع (Doherty) للأنظمة الخلوية

الخلاصة

تم في هذا البحث تصميم وتحليل مكبر القدرة نوع (Doherty). يستخدم مكبر نوع (Doherty) في المحطة الأساسية في أنظمة الاتصالات الخلوية بسبب كفاءته العالية. استخدم في بناء المكبر مكبر القدرة نوع (AB) لكل من المكبر الرئيسي والمكبر الفرعي. تبين من خلال النتائج أن المكبر يعمل على طيف واسع من الترددات ويمكن استخدامه للنظام الخلوي 900MHz بشكل جيد من حيث كفاءة القدرة المضافة والكسب، وكما يمكن استخدام المكبر للنظام 1800MHz ولكن بشرط أن يكون مقدار القدرة الداخلة اكبر من 20dBm.

الكلمات الدالة: مكبر القدرة، مكبر دهورتي، أنوع المكبرات.

Introduction

Mobile communication has become quite common in today’s world with the increasing needs of effectively utilized bandwidth, and efficient and compact device technologies. The growth of wireless technologies is extremely fast. The information can be easily communicated by mobile communication system such as GSM and third generation Wide-Band Code Multiple Access (W-CDMA).High speed and high data rate are always required to provide better communication qualities and services in these wireless systems. High efficiency and good linearity are among the important characteristics of a base station power amplifier used in plurality of the communication applications. The characteristics have always been contradictory to demand for creative power amplifier design techniques. Maintaining the high efficiency reached, which over a wide range of the power amplifier operation is an added requirement in these applications making power amplifier design a challenging task. Power amplifiers (PAs) are typically blocks of radio frequency(RF) front end circuits, which take more care to get efficient RF PA for saving the power consumption.

However, PAs are most efficient when operating at compressed region as a nonlinear amplifier [1].

Classes of PA Operation

GaAsFET power amplifiers used in transceiver circuits exhibit varying degrees of nonlinearity, depending on its class of operation. The output current's harmonic content varies with the DC bias at the gate of the GaAsFET device, while maintaining a constant RF input signal. In certain applications, it may be desirable to have the transistor conducting for only a certain portion of the input signal. The portion of the input RF signal for which there is an output current determines the class of operation of a power amplifier. discusses four classes of power amplifier operation, which are predominantly used in Doherty power amplifiers. Figure(1) shows the typical classes based on the transistor transfer characteristics [2,3].

The Doherty Amplifier

The simplest configuration of a Doherty circuit consists of two amplifiers, namely the "main" and the "auxiliary" as shown in figure (2).The amplifiers are connected in parallel with their outputs joined by a quarter-wave transmission line, which performs impedance transformation. The auxiliary amplifier delivers current as the main amplifier saturates, thereby reducing the impedance seen at the output of the main amplifier. Thus, the main amplifier delivers more current to the load while it is saturated because of the "load-pulling" effect. Since the main amplifier remains closer to saturation for a range of 6 dB backed off from the maximum input power, the total efficiency of the system remains high over that range. The following sections explain in detail the load pull technique, the role of quarter wave transmission line and the working principles of the Doherty power amplifier [3,4,5,6].

Active Load Pull Technique

The active load pull technique is based on the principle that applying current from a second phase coherent source can vary the resistance or reactance of a RF load. This defies the usual understanding that RF loads are physically passive entities. The following analysis explains the concept as presented by Cripps in [3]. According to circuit theory, generator 1 sees a load resistance of R when generator 2 is set to supply zero current as shown in figure(3). If generator 2 starts to supply current as well as generator 1, the voltage appearing across the load resistor can be given as

$$V_L = R[I_1 + I_2] \quad \text{.......................................(1)}$$

With the addition of supply current to the load resistance from second generator, the resistance seen by generator 1 now becomes

$$R_1 = R\left[\frac{I_1 + I_2}{I_1}\right] \quad \text{.......................................(2)}$$

Likewise, the resistance seen by generator 2 can be represented as

$$R_2 = R\left[\frac{I_1 + I_2}{I_2}\right] \quad \text{.......................................(3)}$$

The above concept can be extended to ac circuits by using complex notation for representing the magnitude and the phase of the currents and voltages and the resistive and reactive components.
Thus, equation 3 can be represented as

$$Z_1 = R\left(1 + \frac{I_1}{I_2}\right) \quad \text{.......................................(4)}$$

Z_1 can be transformed to higher value if I_2 is made in phase with I_1 and to a

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smaller value if I_2 is made antiphase with I_1.The concept of load pull technique can be implemented with transistors if the generators are replaced by the output transconductances of the RF transistors. Thus, when two transistors are connected in parallel, one can modify the impedance seen by the other through proper biasing. This concept, extended to the combination of two unlike devices with different periphery and biasing, results in the Doherty configuration [6,7].

Quarter Wave Transformer

Doherty amplifier configuration needs an impedance inverter between the main amplifier and the load R for the proper implementation of load modulation and most of the designs use quarter wave transmission lines for the same. The impedance matrix of a quarter wave transmission line in Figure (4) can be represented as follows [2,3].

$$\begin{bmatrix} V_p \\ I_1 \end{bmatrix} = \begin{bmatrix} 0 & jZ \\ 1/jZ & 0 \end{bmatrix} \begin{bmatrix} V_m \\ I_m \end{bmatrix} \quad \text{.......................................(5)}$$

Expanding the matrix,

$$V_p = jZI_m \quad \text{..(6)}$$

From Figure (4), it is clear that V_p is same as the final output voltage, which depends on the main current. Thus, the linearity of the entire setup depends only on the main device characteristics. The peaking device simply maintains the level of the main voltage below the clipping level. This can be represented using the equations as follows.

$$I_1 = \frac{1}{jZ_o} V_m \quad \text{...(7)}$$

Where I_1 is related to I_p by

$$jI_p = \frac{V_p}{R} + I_1 \quad \text{......................................(8)}$$

Thus, the action of the peaking amplifier on the main amplifier can be consolidated using the equation

$$V_m = Z\left[\left(\frac{Z}{R}\right) I_m - I_p\right] \quad \text{........................(9)}$$

The role of the quarter wave transmission line can be appreciated more once the working principle of DPA is explained. It enables the decrease of the impedance seen by the main amplifier once the main voltage reaches saturation, thereby increasing the flow of the current and thus maintaining the efficiency[2,4,8].

Design of Doherty power amplifier

Load pull is a technique wherein the load impedance seen by the device under test (DUT) is varied and the performance of the DUT is simultaneously measured [4].Similarly in source pull the performance of the DUT for varying source impedances is measured. The measured results are very useful in determining the optimum load and source impedance which the device must see to give the best performance. Load pull, in particular, is commonly used to determine the load impedance required for maximizing efficiency. The input of a power amplifier is usually conjugate matched and the source pull is not always required. It should be noted that the calculated impedance values vary with bias. In this design load pull and source pull were performed to obtain maximum efficiency. The results obtained from these simulations show that the optimum value of load impedance is equal to (4.226-j1.04)ohm as shown in figure (5).

To approximate real value of impedance to 5ohm that caused the impedance of transmission line and output load equal to 5ohm for transmitted maximum power because the matching. Figure (6) shows the block diagram of Doherty amplifier using class AB power amplifier, the input matching network, input source impedance and the input transmission line $\lambda/4$ equal to 50ohm.The value of power supply Vlow is equal to -2.5V and Vhigh is 4.8V.

Simulation Results

Doherty amplifier is a combination of Class AB main stage and Class AB auxiliary stage. Two tone simulations were performed with a center frequency of 850MHz.

Figure(7) shows a power sweep with output power ,PAE, and gain as a function of input power. The characteristic behavior of the Doherty amplifier is apparent from the fact that the PAE reaches an initial peak and remains high until peak power is reached. This initial peak in PAE at (61.384%) occurs at an output power of(34.738 dBm).The P_{1dB} is at $P_{in,1dB}$ (22dBm) and $P_{out,1dB}$ (33.358dBm).

The gain is increasing with increasing input power to give maximum gain which is equal to (11.424dB) at input power (22.5dBm),and with output power equal to (34.738dBm). After this peak value, the gain starts decreasing with increasing input power.

Figure (8) shows the output power against the DC supply current ,the current is increasing with increasing output power, until the output power reaches a value of 20dBm. After this value the output power tends to increase very sharply because the Doherty amplifier characteristics approximate to a non-linear region. The output spectrum harmonic with input power is shown in figure(9). It is clear that the 3rd harmonic is increasing with increasing of input power. The value of 3rd harmonic was reduced by amount of (-8dBm)at (22.5dBm) input power and starts increasing after that value. The overall difference between the 1st harmonic and the 3rd one is about 20dBm or more which gives the amplifier good output spectrum characteristics.

Figures(10,11,12) show the output power ,PAE and gain with input power at variable input frequency (800,900,1000 and1800)MHz .Its clear that the maximum output power, PAE and gain can be obtained at input frequency equal to 850MHz, and at input signal frequency equal to 1GHz. The amplifier still has good output power, PAE and gain. Increasing the frequency to 1.8GHz will reduce the gain of the amplifier to a very small value especially at small values of input power. But at higher value of input power, greater than 20dBm, the gain of the amplifier tends to increase and reaches a value of 6dB at input power equal to 24dBm. The Doherty amplifier can be used for GSM (900MHz) and (1800MHz) with input power greater than 20dBm.

Conclusions

The analysis and design of Doherty power amplifier were studied at different operating frequency. It is found that the amplifier can operate at GSM and CDMA base station at input power level more than 20dBm. The amplifier has good output spectrum and the 3rd harmonic spectrum is less than the main spectrum by amount of 20dBm.

References

1- S.M. Wood, R.S. Pengelly, “Design of a High Power Doherty Amplifier Using a New Large Signal LDMOS FET Model”, IEEE Reprinted from the Wireless and Microwave Technology Conference proceedings 2004.
2- V.Viswanathan,“Efficiency Enhancement Of Base Station Power

Amplifiers Using Doherty Technique”,Thesis, Msc,Virginia Polytechnic University, 2004.
3- S.C. Cripps, “RF Power Amplifiers for Wireless Communications,” Artech House,second Edition ,2002.
4- M. Iwamoto, A. Williams, P. Chen , A. G. Metzger, L. E. Larson, and P. M. Asbeck,“An Extended Doherty Amplifier With High Efficiency Over a Wide Power Range”،IEEE transaction on microwave theory and techniques, vol. 49,No. 12, December 2001.
5- N. Dubuc, C.Duvanaud and Ph. Bouysse,“Analysis of the Doherty technique and application to a 900MHz power amplifier”, IEEE Microwave and GuidedWave Letters, 1999, Vol. 9, Vo.3, pp. 114-116.
6- D. W. Ferwalt, “A Base Control Doherty Power Amplifier Design For Improved EfficiencyIn GSM Handsets”, thesis, Msc., Oregon State University 2004.
7- M. J. Pelk, Pengelly and L. C. N. de Vreede, “A High-Efficiency 100-W GaN Three-Way Doherty Amplifier for Base-Station Applications”,IEEE transaction on microwave theory and techniques 2008.
8- X. Chen,Y. Guo, “A High Linearity and Efficiency Doherty Power Amplifier for Retrodirective Communication”, Progress In Electromagnetics Research Symposium, Hangzhou, China, March 24-28, 2008.

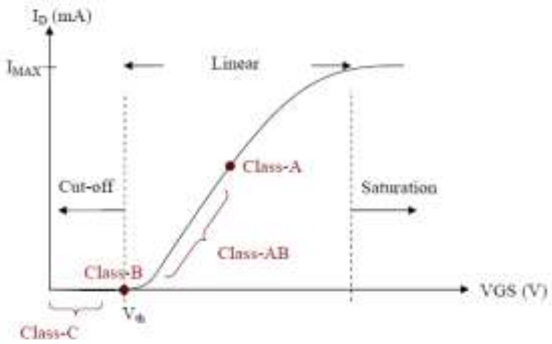

Figure (1): Classes of operation of Power amplifier based on transfer characteristics

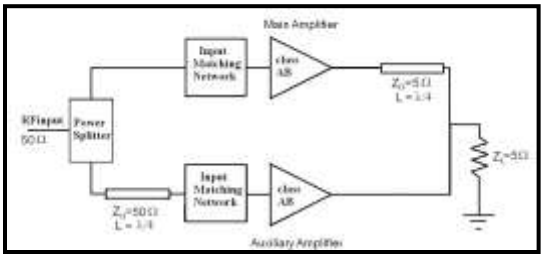

Figure (6): Block diagram of the Doherty amplifier

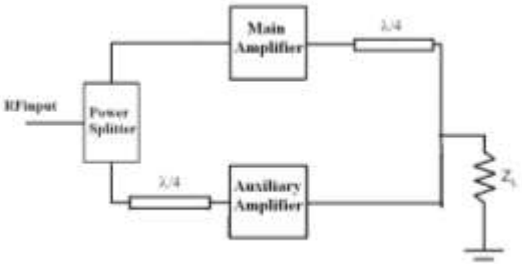

Figure (2): Block Diagram of Doherty power amplifier

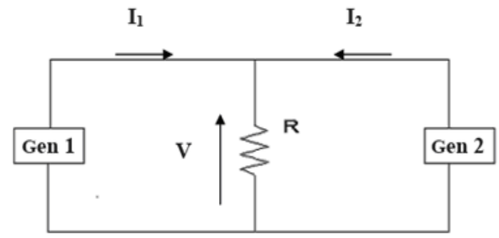

Figure (3): Active Load pull schematic

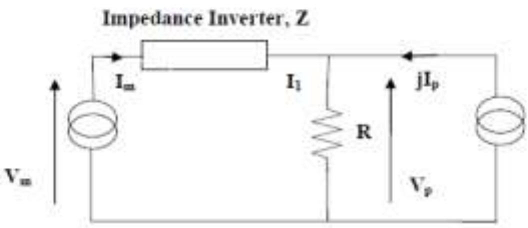

Figure (4):2-way Doherty power amplifier schematic

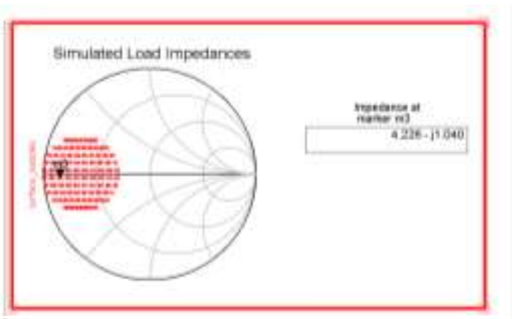

Figure (5): Load Pull Analysis to determine load impedance for maximum efficiency

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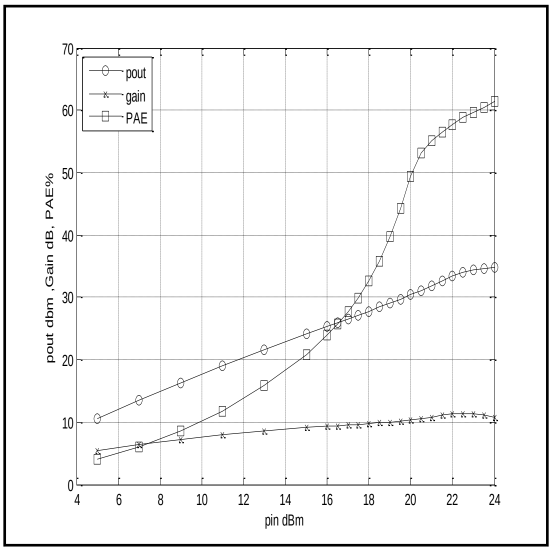

Figure (7): Output power, gain, and PAE as a function of input power.

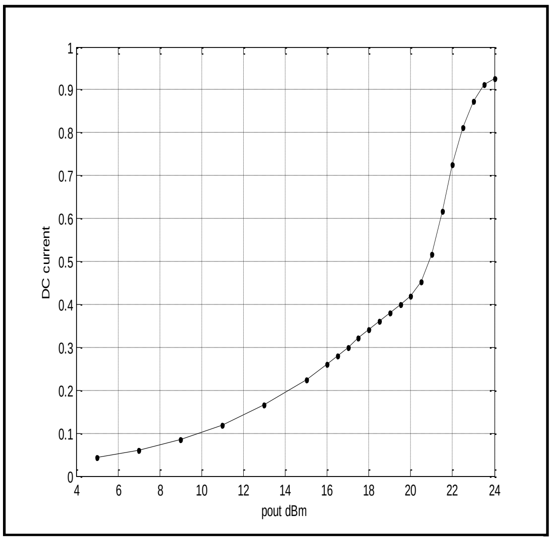

Figure (8): Power output with DC supply

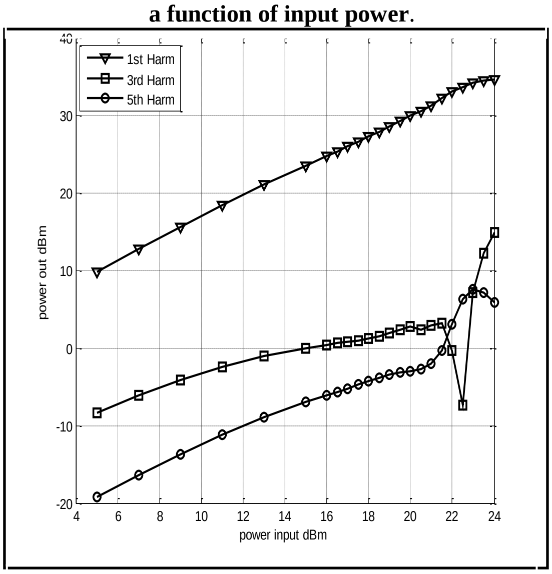

Figure (9): Power harmonic with input power

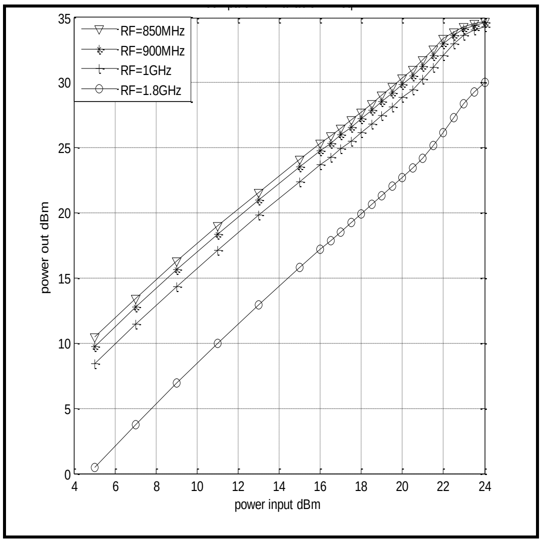

Figure (10): Output power as a function of input power for difference input signal frequency.

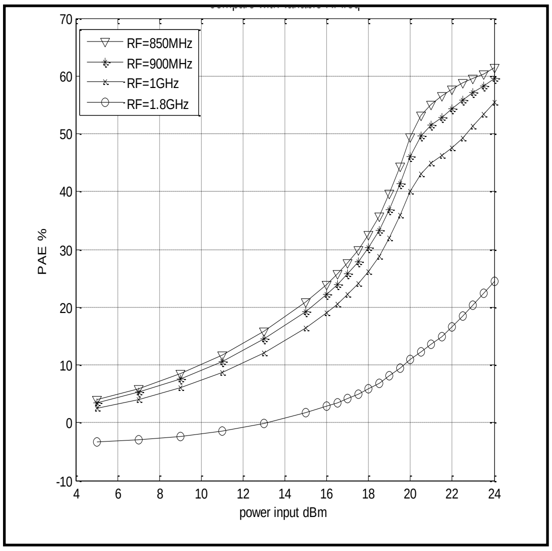

Figure (11): PAE as a function of input power for difference input signal frequency.

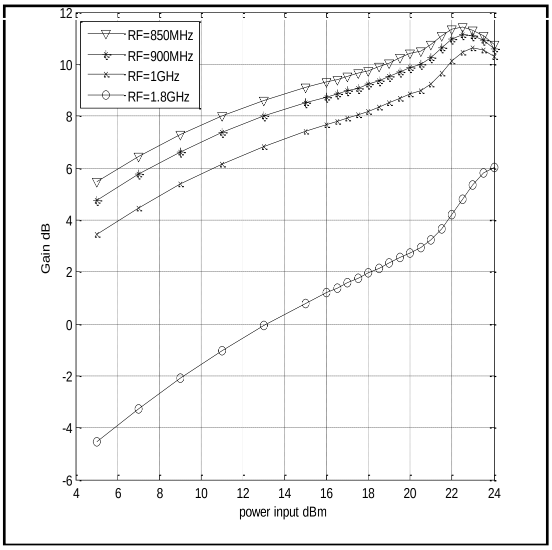

Figure (12) : The gain as a function of input power for difference input signal frequency.