Analysis of the Doherty technique and application to a 900MHz power amplifier

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In this paper, we present the study, the realisation and the measurement of an amplifier at 900 MHz using the Doherty technique. This technique is based on the large signal performance analysis of the active devices under different drive levels. The improvements made by the application of this technique were checked by simulations and measurements on a prototype made with two MESFETs transistors. For a 6 dB backoff, obtaining significant values of Power Added Efficiency was possible thanks to the application of a methodology of design, specific to this technique.

INTRODUCTION

In recent years, there has been a strong demand to improve the efficiency of power amplifier for wireless communications. The techniques generally used are based on the description of particular loads at the harmonic frequency (1,2,3). Such techniques are efficient at high power level. More recently, with an aim of improving the spectral bandwidth of the signals, the systems used techniques of modulation characterised by the generation of a non-constant envelope. The amplification of a varying envelope signal leads to low global power efficiency.

The use of the Doherty technique allows to maintain the efficiency of the power amplifier across a wide range of variation of the input power. Although this technique appears to offer important improvements (4) of power capabilities, the number of implementations of this technique at this day is very limited (5).

High level of Power Added Efficiency (PAE) when operate under compression. So an extensive non linear analysis, requiring nonlinear device models, has been done to improve performances of the Doherty amplifiers.

The study shows that the control of the auxiliary amplifier is a key point of the design (6). A class B or C auxiliary amplifier can been used to turn on automatically the amplifier with increase of the input power. This solution is attractive because it doesn't require any control element. Simulation and measurement performances achieved, allow to establish the optimum operating parameters of the global amplifier.

The results presented in this paper allow to verify the properties of the Doherty technique, which is based on the use of an auxiliary amplifier to modify the operation's parameters of the main amplifier.

In first parts a theoretical and large signal analysis of the Doherty technique is proposed. Measurements of a Doherty amplifier are presented in the last part, they demonstrate that Power Added Efficiency can been maintained to a value greater than 50% for a 6 dB backoff of the output power.

THE DOHERTY TECHNIQUE

Power performances of an amplifier are mainly determined by the load impedance presented to the active device. The Doherty technique allows to modify the load impedance with the input drive level. Such a result is achieved using two amplifiers (main and auxiliary). The auxiliary amplifier operates as an active load for the main amplifier. As the input power increases, the auxiliary amplifier begins to conduct and modify the load presented to the main amplifier.

The values of the loads, presented to each device, are obtained by analysis of the conventional circuit shown figure1. For a $\lambda/4$ transmission line, with a characteristic impedance Zc, and for a phase of $\pi/2$ between the drain currents I_{ds1} and I_{ds2}, the impedance loads are given by :

$$Z_{d1}=Z_c^2/R-Z_c.(I_{ds2}/I_{ds1}) \qquad (1)$$

$$Z_{d2}=Z_c.(I_{ds1}/I_{ds2}) \qquad (2)$$

At high level, when I_{ds2} is equal to I_{ds1}, the loads can be expressed by $Z_{d1}= Z_c^2/R-Z_c$ and $Z_{d2}=Z_c$. For $Z_c=2R$, these loads are identical and equal to 2R. In this case, the two amplifiers work together to deliver a maximum of output power to the load. If, at low level, Ids2 is shut down, the load presented to the main amplifier becomes 4R. Such a modification of the load value can be used to maintain Power Added Efficiency at high values, even in the case of a decrease in the input drive level.

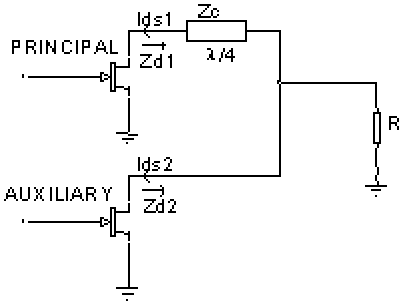

Figure 1 : Circuit for the analysis of the Doherty technique

LARGE SIGNAL ANALYSIS

The results of simulations obtained with an amplifier based on the Doherty technique (6) made it possible to check that this technique allows to maintain the Power Added Efficiency (PAE) for different levels of input power, even in the case of a 6 dB input level variation.

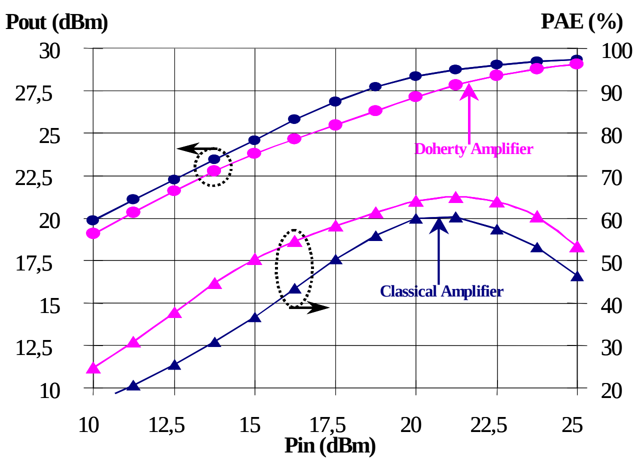

Figure 2 : Simulated Output Power and PAE versus Input Power

Figure 2 represents the variation of the output power and power added efficiency versus input of the nonlinear simulation. For the same gate bias voltage in class AB, the two amplifiers work together as a conventional amplifier constituted of two stages in parallel. In this case, the Power Added Efficiency is maximum for a high level of the input power and decreases rapidly for a power backoff. In a class AB gate bias of the main amplifier and a class B of the auxiliary amplifier, it is interesting to note that the PAE of the amplifier is maintained at strong values. This result allows to verify that the increase of the output power of the auxiliary amplifier modifies the load presented at the main amplifier. For the main amplifier, high PAE is achieved for a larger range of input and output power.

A key design element is the research of the ideal working parameters of the auxiliary transistor. At the input, a quarter wave line allows to obtain the optimum 90° phase between the two drain currents. To achieve the required variation of the drain load, the auxiliary drain current must be controlled by the input drive level. For a low input power, the auxiliary drain current must be turned off. When the main device starts to compress, the auxiliary current must increase to change the load impedance. At maximum input power the two currents must be equal to have the same load presented at each drain. A simple method to achieve the optimum auxiliary drain current, without the need for any circuit control, consists in operating the auxiliary device in class C. In such an operating class, for a low input voltage, the drain current is turned off. At high level the drain current is not as important as the one generated by the main device. The consequences are that the load value can't reach the theoretical maximum value and that the total output power is reduced. When the device is operating in deep class C, breakdown problems can be induced. The use of an auxiliary transistor operating in class B is investigated because in such a class the drain current component at the working frequency can reach the same maximum value than in class AB or A. For low values of the input power the drain current is small, in comparison with the current generated by the main device, because of the low transconductance of the drain current source near pinch-off.

DOHERTY AMPLIFIER DESIGN

The topology proposed for the amplifier is presented figure 3. The output circuit is composed of different matching circuits. A first matching circuit is introduced to transform the 50 ohms load to an intermediate real load of value R. The choose of the R value is a key point of the Doherty design. A second matching circuit is used to present the optimum load at the output of the device. For the main amplifier, a quarter wave line is introduce between the two marching circuits. A 900MHz Doherty amplifier has been implemented on epoxy FR4 using two Infineon Cly5 MESFETs.

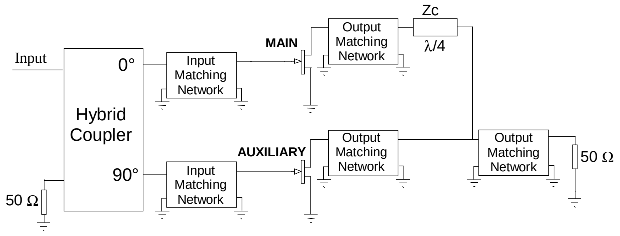

Figure 3 : The Implemented Doherty amplifier

MEASUREMENT RESULTS

Figures 4 & 5 show the output power and the power added efficiency measurements versus input power for a main amplifier biased in class AB and an auxiliary one used with several kinds of bias (class AB ,AB-, B and C).

For an auxiliary amplifier biased in class AB, the two amplifiers have the same bias point and the amplifier is operating as a conventionnal amplifier. In this case, a maximum of 29.5 dBm is reached for the output power and 53 % for the Power Added Efficiency. In the case of a 6 dB backoff PAE of 25 % is obtained.

By the adjustment of the gate bias voltage of the auxiliary amplifier to class B or C, the Power Added Efficiency is maintained at high values on a greater range of output power. In class B, for a high output power of 29 dBm, the power added efficiency is the same than the one achieved when the two amplifiers have the same gate bias voltage in class AB. In this case, for a 6dB backoff of the output power, the PAE is maintained over 50 % comprared to less than 25% for a conventional amplifier. For an auxiliary amplifier operating in class C, the variation of PAE is lower for an output backoff of the power. Such an operating class doesn't allow to reach a maximum output power as important than in the class B case.

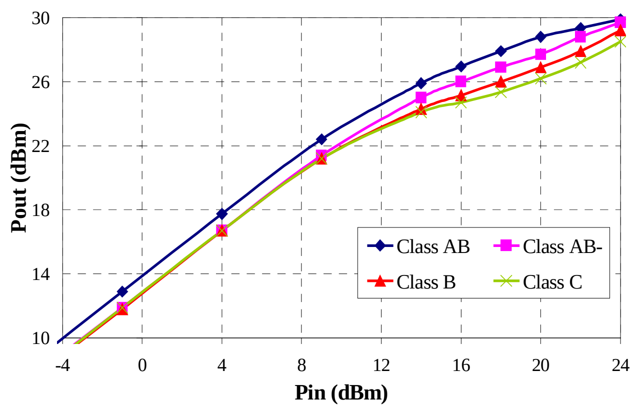

Figure 4 : Output Power measurement versus Input Power

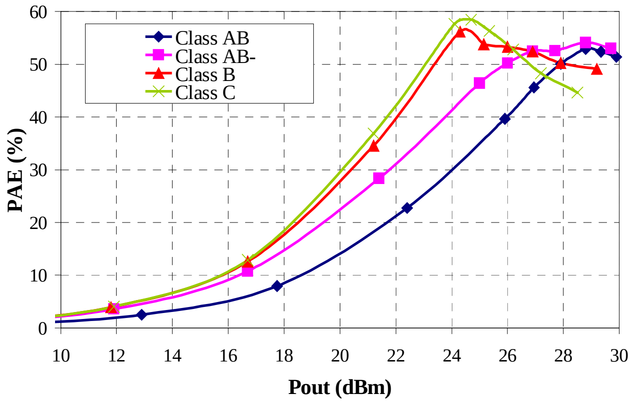

Figure 5 : Power Added Efficiency measurement versus Output Power

CONCLUSION

The Doherty technique allows to maintain the efficiency under different input drive levels. Measurement results obtained with a Doherty technique based amplifier made it possible to check that this technique allows to maintain the power added efficiency for different levels of input power. The research of the ideal working conditions of the auxiliary to obtain a high power added efficiency at different input drive levels has led to the use of a gate bias voltage in class B for the auxiliary amplifier. In this case, it was measured a power added efficiency of 50 % for an ouput power varying from 23 to 29 dBm.

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