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Author(s): Hussaini, Abubakar Sadiq, Gwandu, Bashir A. L., Abd-Alhameed, Raed A. and Rodriguez, Jonathan.

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Design of Power Efficient Power Amplifier for B3G Base Stations

Abubakar Sadiq Hussaini[#*], Bashir A. L. Gwandu[†], Raed Abd-Alhameed[#], Jonathan Rodriguez[*]

[#]School of Engineering, Design and Technology, University of Bradford, UK

[†]Nigerian Communications Commission (NCC), Abuja, Nigeria

[*]Instituto de Telecomunicações , Aveiro, Portugal

ash@av.it.pt, Gwandu@ncc.gov.ng, r.a.a.abd@brad.ac.uk, jonathan@av.it.pt

Abstract— **Fourth generation systems require the use of both amplitude and phase modulation to efficiently utilize the available spectrum and to obtain high data rates, hence imposing stringent requirements on the power amplifier in terms of efficiency and linearity and requires the power amplifier to operate linearly and efficiently. The B3G base station transceiver Doherty power amplifier was designed to operate over the frequency range of 3.47GHz to 3.53GHz mobile WiMAX band using Freescale's N-Channel Enhancement-Mode Lateral MOSFET Transistor, MRF7S38010HR3; The performances of the Doherty amplifier are compared with that of the conventional Class AB amplifier. The results of 43 dBm output power and 66% power added efficiency are achieved.**

Keywords-Class AB; 4G; Doherty RF power amplifier; OFDM; mobile WiMAX; 3.5GHz band, base station

I. INTRODUCTION

The Beyond 3G (B3G) wireless communications adopts OFDM modulation scheme. This scheme offers high data rate but on the other hand has a high crest factor. The beyond 3G base stations require the transceiver to operate linearly and efficiently. Linearity is needed in order to preserve the information, and transmit the signal without error, while efficiency of the base station transceiver is an important attribute that leads to decreased power consumption and active cooling of the base station. All these depend primarily on the performance of the RF power amplifier of the transceiver. As a result of this phenomenon, the power amplifier mostly operates at the back-off region and thus the resultant efficiency degrades dramatically. Power amplifier design has becomes more compound in terms of contending multi dimensional necessities of power output, linearity and efficiency performances. There is a trade-off between power per cost versus efficiency and linearity. To enhance the efficiency and keep the same periphery for high crest factor signal, Doherty techniques with 15mm offset line are employed.

The Doherty configuration was proposed in 1936 [1] to work with AM broadcasting transmitter, but at that time nobody adopted it. This was mainly because the signals of the AM transmitter were around 0dBm crest factor. However, the onset of 2G system has led to the widespread adoption of the Doherty techniques, where the signal crest factor is between 8 to 12dB. The concept of Doherty technique has been fully explained by the present authors in their previously reported work [2]. The Doherty amplifier consists of Class AB carrier and Class C peaking amplifiers connected by a quarter wave transmission line coupler. The resultant linear power amplifier achieved a higher efficiency at the outputs below peak output power (PEP) than conventional class B linear power amplifier [3], [4]. The technique essentially makes use of a Class C amplifier to adapt the load impedance at the Class AB amplifier for optimum efficiency over a wide range of output power. The quarter- wave transformers based on a transmission line structure are served as the power-coupling element between the two amplifier paths.

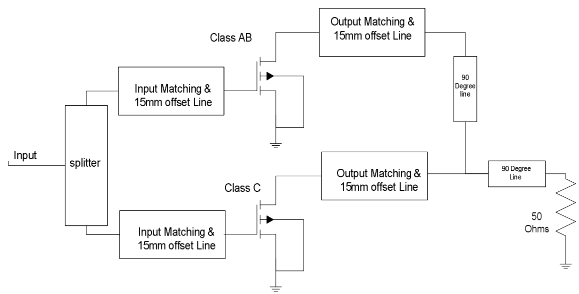

Figure 1. The proposed block diagram of Doherty RF power amplifier

In this paper, the efficiency and the output power of the Doherty RF power amplifier has been achieved by two identical 33dBm, 15dB gain, 30V devices for 3400 – 3600MHz configured as Class AB and Class C respectively, with the proposed additional of 15mm offset lines at the output matching to adopt to the Doherty configuration and prevents the power leakage at the output junction between the output impedance transformer and peaking Class C amplifier. The 15mm length of micro strip line was obtained by using "LineCalc" from ADS simulator with RT 5880 substrates' parameters Er = 2.2, H= 0.5mm, Zo = 50 Ohms, T= 35um, TanD= 0.017. The 50 Ohm 90 degree open short circuits were added to right angle of the RF blocking transmission lines. The proposed schematic diagram of this kind of amplifier is presented in Fig. 1.

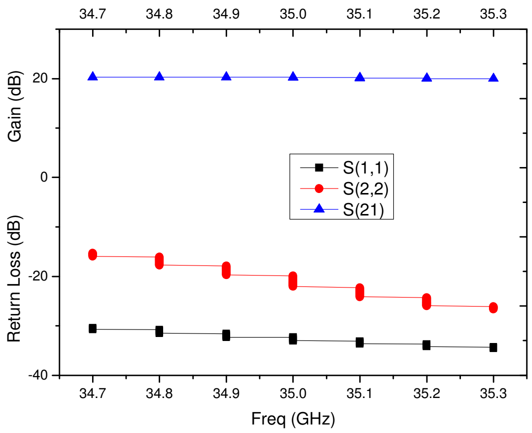

Figure 2. Linear simulation: Flat gain & return loss

II. CIRCUIT DESING

A 43dBm output power beyond 3G base station Doherty RF power amplifier have been designed using the Freescale N-Channel Enhancement-Mode Lateral MOSFET MRF7S38010HR3. The 50Ω quarter wavelength transmission line impedance inverter is used to provide a dynamic load adaptation. This also includes the optimized biases, and operation classes of carrier and peaking amplifier using a large signal harmonic balance simulation to offer improvements in efficiency. The design comprises several design steps for which the optimization is applied to each in order to obtain high performances of the entire Doherty RF power amplifier.

However, it is important to note that in the design of the Doherty RF power amplifier, the DC simulation should be carried out first in order to find the optimal bias point and bias network based on the class of operation and power requirements. In this paper the bias circuit was designed based on Class AB carrier and Class C peaking amplifiers. In Class AB, the transistor is biased just at the start of conduction, about 300mA while Class C is biased in the pinch off region and conducts as the input signal increases.

Having obtained the selected DC quiescent current to maximally cancel the signal distortions, the next step is to determine the design of Class AB amplifier and to obtain the performance regarding the output power and efficiency before incorporating into Doherty design. The output and input impedance was internally matched to 50 ohm impedance microstrip transmission lines, the 15mm offset lines is added to the input side before the input matching network and another 15mm offset line was added to the output side after the output matching network. The Class AB in this design will serve as a carrier amplifier in which the Doherty configuration and the quarter wavelength line will enable it to see high output impedance which leads to its saturation and keeps it maximum voltage at constant condition.

Figure 2 shows the linear results obtained from the matched Class AB power amplifier, the gain is flat in the range of 3.47 to 3.6GHz with excellent matching at the input and output return losses.

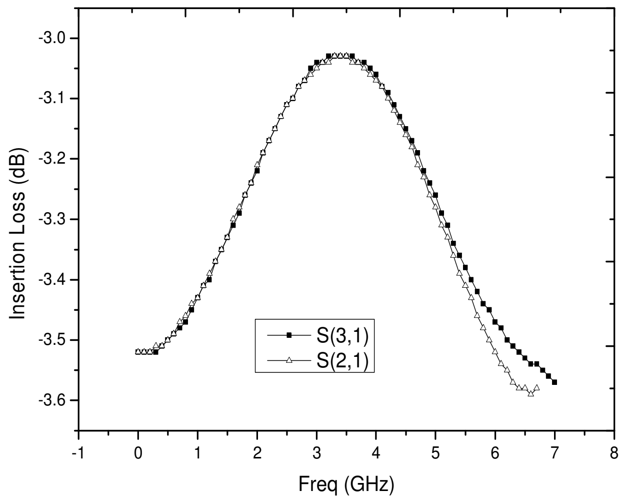

Figure 3. Insertion Loss

The non-linear simulation of Class AB was performed and the performance of the design in terms of output power and efficiency was observed. The 38dBm output power was achieved at 1dB compression point and 32% efficiency. The same was applied to Class C, but with different bias point.

3dB quadrature splitters in the past were very expensive and difficult to design for wide bandwidths and at low frequencies are bulky in nature. The power input splitter is part of the Doherty configurations and if properly designed can contribute to the total efficiency of the system. Our investigation shows that the operation of this technique is strongly influenced by the coupling factor of the input splitter. In fact, in this research the splitters have been designed and tested in terms of operation frequency and bandwidth, and showed good results as seen in Figures 3, 4, and 5. It should be noted that this splitter, at the input of amplifier, divides the input signal equally, but 90 degree phase difference between the carrier and peaking amplifiers. The splitter, the Carrier Class AB, the peaking Class C, and impedance transformer at the output are combined to form the Doherty RF power amplifier.

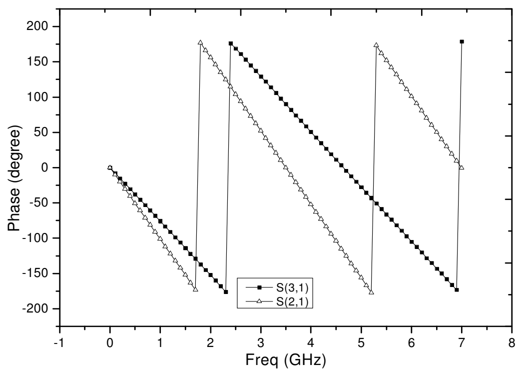

Figure 4. Phase Difference

III. IMPLEMENTATION & RESULTS

Figure 6, shows the prototype diagram of the proposed Doherty RF power amplifier with offset transmission lines at both output and input circuit which maximize the overall system's efficiency with the configuration of Class AB and Class C amplifiers. The Freescale N-Channel Enhancement-Mode Lateral MOSFET, MRF7S38010HR3 transistor with 33dBm output power was used for both Class AB and Class C amplifiers and produce a Doherty RF power amplifier with 43dBm output power and efficiency of 66%. The bias conditions used in this experiment are: class AB as carrier amplifier was set at Vgs = 3.0V (Ids =300 mA) and class C as the peaking amplifier was set at Vgs = 2.4V (Ids = 1 mA). Both amplifiers use the same drain voltage (30V).

The non-linear simulations of Doherty RF power amplifier was achieved through the Advance Design Systems (ADS) simulator. The following results are based on simulations and were initially characterized for AM-AM and AM-PM responses, as well as output power and efficiency. The performance comparisons between the Doherty amplifier and Class AB amplifier were performed. The output power of Class AB power amplifier standalone was 37.5dBm and with Doherty configuration, the output power was increased to 43dBm at 1dB compression point, while the efficiency increased to 66%. Figure 7 represent the variation of the input power in relation to output power of the Doherty amplifier. It clearly shows that 43dBm output power is achieved at linear region of the amplifier, and this was achieved due to the characteristic of gain compression and expression of the Doherty amplifier. The peaking amplifier Class C late gain expansion compensated the carrier Class AB amplifier gain compression. Figure 8 represent the AM-PM data and the graph shows the phase can vary approximately 40 to 47 degree at the 1dB compression point. Figure 9 represent the gain in relation to output power, the graph shows the power gain of Doherty amplifier degraded severely compared to Class AB amplifier due to the arrangement of lower biasing.

Figure 10 shows the power added efficiency versus output power. The Doherty RF power amplifier has higher efficiency over the range of wide output power levels compared to Class AB RF power amplifier.

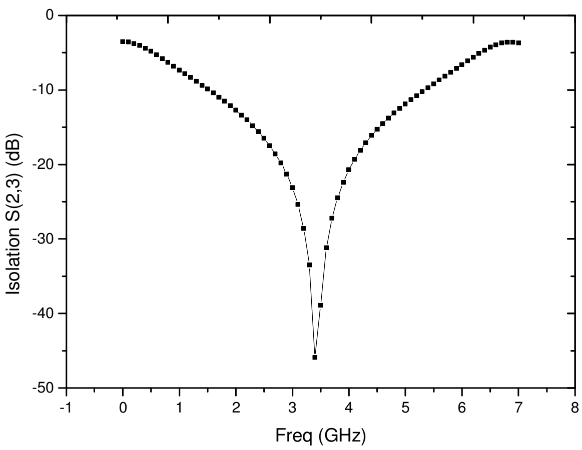

Figure 5. Isolation

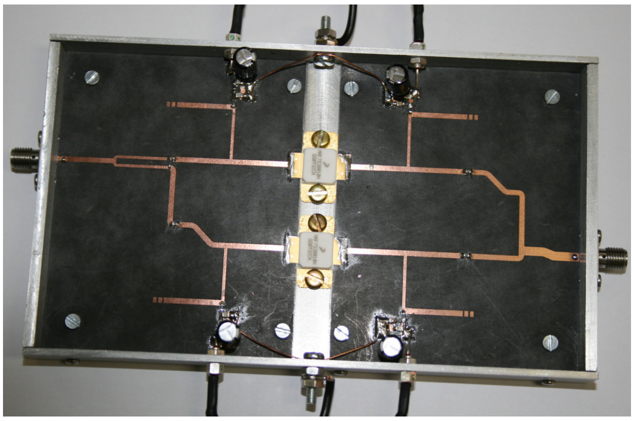

Figure 6. Implemented prototype of proposed power efficient power amplifier

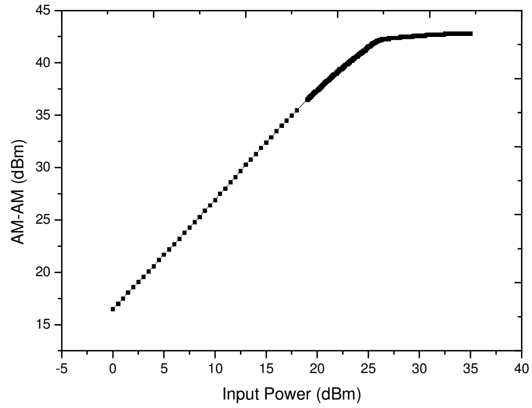

Figure 7. AM-AM characteristics of load modulation amplifier

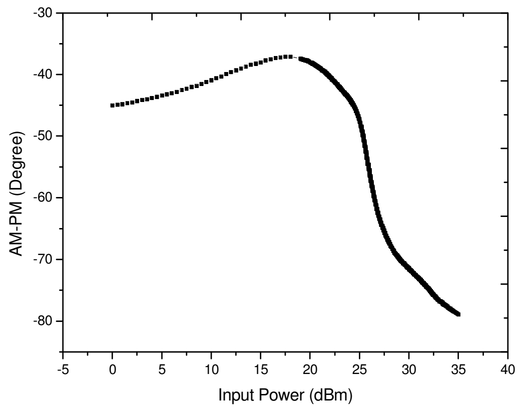

Figure 8. AM-PM characteristics of load modulation amplifier

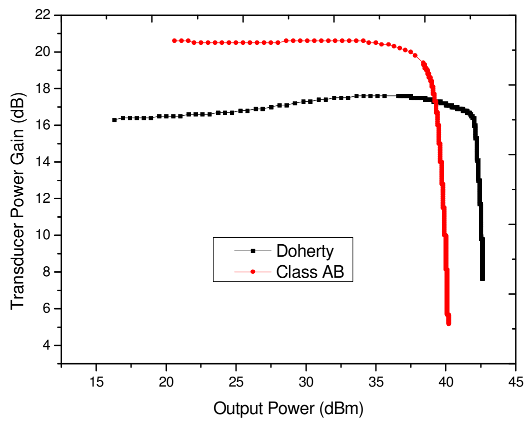

Figure 9. Gain characteristics

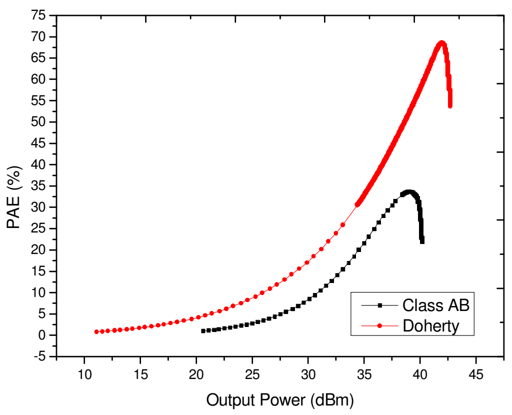

Figure 10. Power-Added Efficiency

IV. CONCLUSION

The Doherty RF power amplifier was designed using Freescale N-Channel Enhancement-Mode Lateral MOSFET transistor, the achieved results of the Doherty were compared with conventional Class AB amplifier, and it exhibited a power added efficiency of 66% for 43dBm output power. The Class AB, Class C, input signal splitter and output transformer were adjusted to optimize the design under Doherty operation. The Doherty RF power amplifier can make a good concession between the cost, linearity, efficiency, and output power. The proper phasing of 3dB quadrature splitter effectively contributed to the total efficiency of the system. In addition, the turn–on of the class C amplifier was dependent on the gate bias voltage and the input signal. The self-managing characteristic of the Doherty RF power amplifier has made its implementation more attractive.

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