A Symmetrical Optimized Doherty Power Amplifier for LTE Band41

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Abstract
A symmetric Power Amplifier with an optimized impedance quarter wave transmission line is presented using a thermally enhanced high Power LDMOS FET i.e. a 140W Infineon PTFC261402 device. This implementation is realized in the operating frequency of LTE Band41 (2.496GHz-2.69GHz) applicable for LTE base stations. This design achieves a high efficiency that persists for an output power back off region of 6dB. The efficiencies of both class AB and Doherty are compared with respect to their output powers. Doherty attains efficiency of 59.6% at P1dB of 50dBm and fulfils the requirement of obtaining higher efficiency at the back off levels necessary for the modern communication involving high PAPR signals. The gain flatness is for 200MHz bandwidth giving a maximum gain of 16dB.

Keywords
Doherty Power Amplifier, LDMOS, LTE Band41

I. Introduction

There has been a tremendous progress in the currently growing field of wireless communication towards the bandwidth extension and the number of carriers required for high data rate applications. Modern system of wireless communications such as CDMA-2000, WCDMA, and OFDM etc. differ widely and expeditiously bearing high peak to average power ratio (PAPR) signals. The power amplifiers in base station for such systems require high linearity for the amplification of the high PAPR signal without distortion. These linearity requirements are met often by employing power amplifiers that are usually biased at class A or class AB and are operated at a substantial measure of back-off from the maximum output power.

The modern wireless communication system for the power amplifiers in BTS demands for another necessity which is efficiency. For the communication system to have a reduced cost and size the cooling system should be uncomplicated and small which requires a power amplifier possessing high efficiency [1]. Since back off operation makes the base station to have low efficiency, it becomes important to look for efficiency enhancement techniques. In order to deliver both efficiency and linearity, Doherty power amplifier is competent and proficient in meeting the rigid requirements for the capable base station power amplifiers [2].

This paper presents a symmetrical Doherty power amplifier for the application of LTE base stations operating in the frequency of LTE band41 (2.496 GHz - 2.69 GHz) implementing different LDMOS devices and an even power divider with an aim of obtaining 51dBm output power. The amplifier design is simulated and optimized in ADS. Section II will describe the symmetrical DPA operation while the design and simulation results of the DPA will be elucidated in section III. The conclusions are briefed up in section IV.

II. Operation of DPA

The Doherty power amplifier was proposed by W.H.Doherty in 1936 [3]. The operation of DPA can be classified into 3 stages namely low, medium and high power levels. Figure.1 shows the block diagram of a symmetrical DPA [4]. The idea used for Doherty is to combine class C and class AB amplifier in parallel so that, due to high peak capability operation of class C, it can deal with the signals when the class AB goes into compression. The design includes hybrid coupler for even power division with identical devices combined through λ/4 transmission lines.

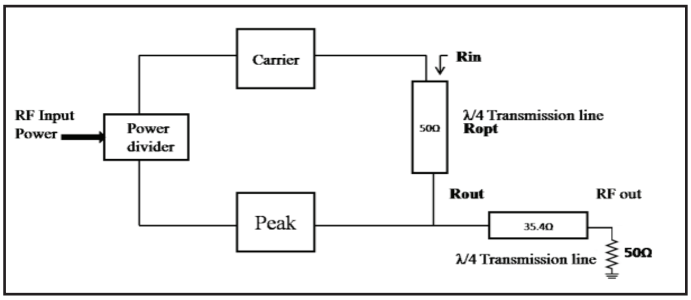


Fig. 1: Block Diagram of Symmetrical DPA

1 Stage: When low input signals are given, the peak amplifier (class C) is in switch off state. It is only the carrier amplifier (class AB) that operates acquiring the total input signal. As shown in Fig. 2, peaking amplifier experiences infinite impedance when it does not operate and in turn makes the impedance at the carrier amplifier twice the optimum resistance.

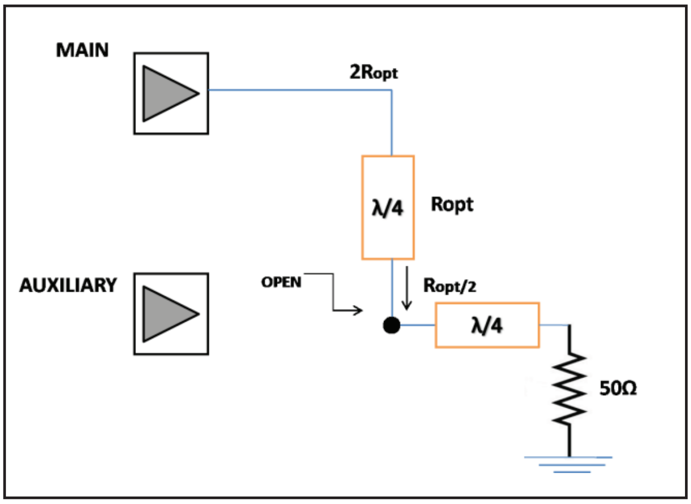


Fig. 2: Stage 1- Operation of Doherty Power Amplifier

The impedance at carrier amplifier becomes twice because saturation is to be achieved at half the maximum power. Hence, the carrier undergoes pre mature saturation (i.e. at half of the maximum current). But voltage would be at its maximum value and thus, it provides efficiency even though the input power hasn't reached its maximum [5].

2 Stage: With the medium level input signals, the point where the carrier saturates, the peak begins to operate with a suitable bias. The impedance at the output of the peak increases due to the increase in its current due to the active load pull technique [6] as depicted in fig. 3.

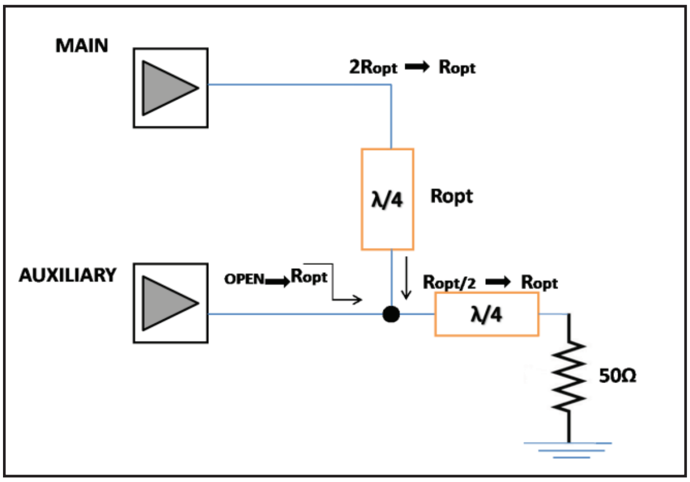


Fig. 3: Stage 2 Operation of DPA

The characteristic impedance of the quarter wave line is given by equation 1):

$$R_{opt} = \sqrt{R_{in.}R_{out}} \qquad (1)$$

Hence, R_{in} decreases as Rout increases. This causes the carrier output to remain constant without going into saturation and higher current from carrier results in increase in the output power.

3 Stage: With the gradual increase in input power, the load value at peak amplifier output keeps increasing till it saturates. But when both peak and carrier reach their maximum power, they have an optimum resistance R_{opt} equal to the characteristic impedance of the quarter wave transmission line as shown in fig. 4. It is at this particular point where the output power is the largest.

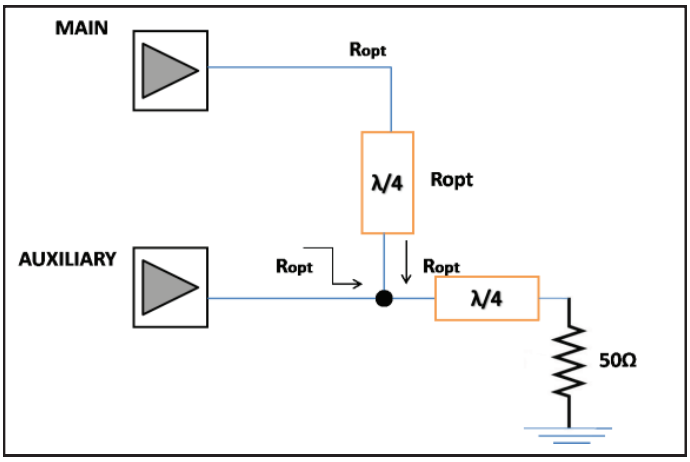


Fig. 4: Stage 3 Operation of DPA

Thus, maximum efficiency is maintained by the peaking amplifier by modulating the load for the signal peaks to prevent the carrier amplifier from getting into saturation.

The design in this paper involves R_{opt} (TL1) optimization to 65.2Ω from 50Ω for the better performance of the main amplifier. According to the DPA principle, the impedance at the output of the main amplifier is transformed to 130.4Ω ($2R_{opt}$) and modulated to 65.2Ω. The characteristic impedance of TL2 is optimized to 40.37Ω that transforms the R_{opt} to 50Ω. The Doherty schematic is shown in fig. 5.

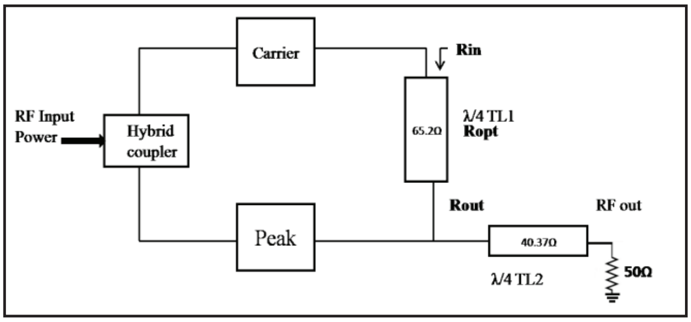


Fig. 5: DPA Schematic With Optimized Impedances

III. Symmetric Doherty Amplifier Design

The frequency band chosen for the operation of the DPA is the LTE band41 having the frequency range of 2.496GHz-2.69GHz involving its application in LTE base stations. Thermally enhanced high power LDMOS FET 140W PTFC261402 from Infineon has been used for main and peak amplifiers. The carrier amplifier is biased in class AB with V_{DS}=28V, V_{GS}=2.76V & I_{DS}=900mA. The peak amplifier is biased in class C with V_{GS}=1.025V, and V_{DS}=28V. With all these set, the even input power splitting is performed by a hybrid coupler.

The schematic of the DPA in ADS is shown in fig. 6. Both the carrier and the peak amplifiers are connected to their respective matching networks after load pull modulation by matching the device to the optimum impedance. The classical 50Ω λ/4 transmission line is replaced with optimized 65.2Ω line and the TL2 line is optimized from 35.4Ω to 40.37Ω as in the design.

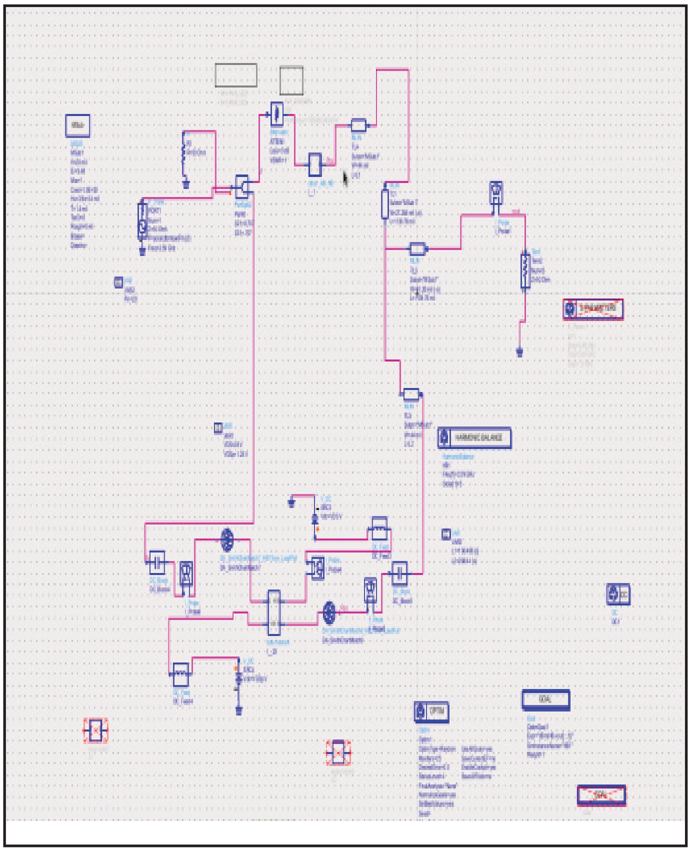
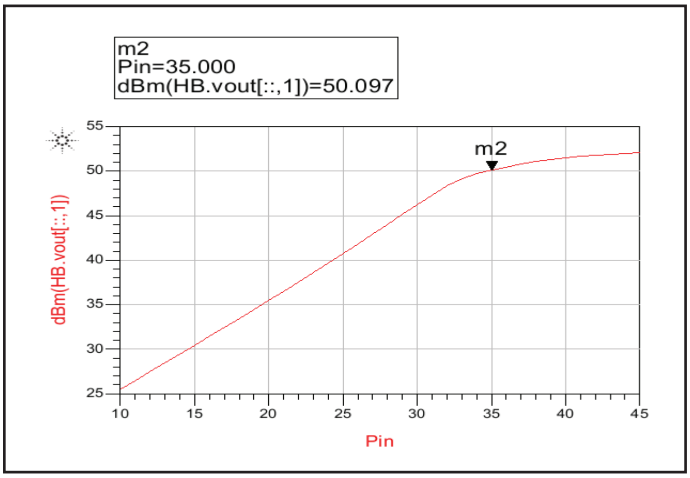
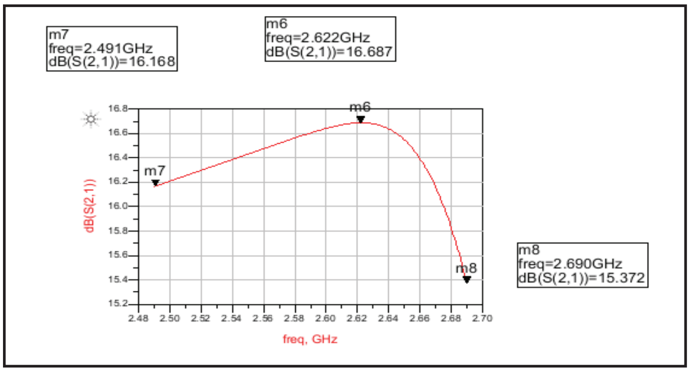


Fig. 6: ADS DPA Schematic

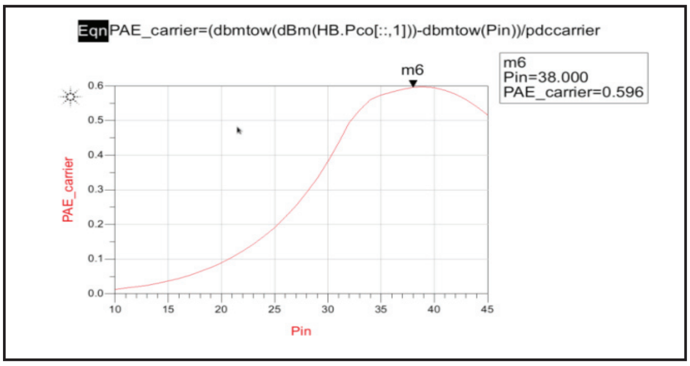
Fig. 7 shows the simulated graphs of the above schematic. The P1-dB obtained is 50.097dBm at centre frequency of 2.59GHz. The gain flatness is ±1dB with an efficiency of 59.6% at the maximum output power.



(a)



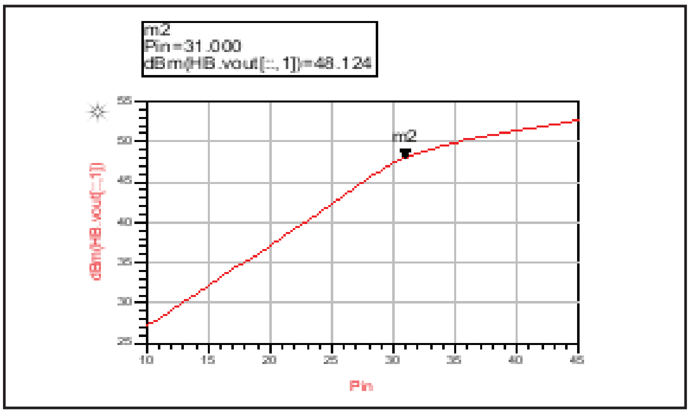
(b)



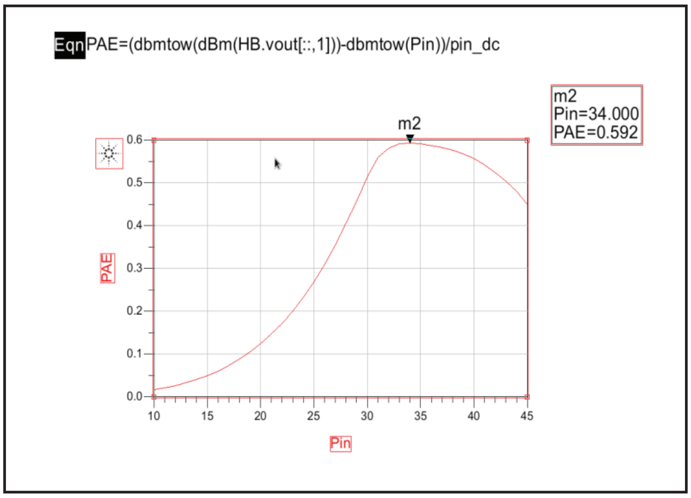
(c)

Fig. 7: Plots of (a) output power vs. input power, (b) gain flatness, and (c) efficiency of DPA

Similarly, in order to compare the efficiencies of DPA with class AB, the simulated Class AB efficiency shows 59.2% at the maximum output power of 48.12dBm as shown in Figure.8



(a)



(b)

Fig. 8: (a) Class AB P_{1dB} and b) efficiency

The above mentioned results are verified by implementing it on the fabricated device once the layout of the design is exported into the Gerber file. Fig.9 shows the photograph of the implemented Doherty power amplifier where the DPA is driven by the predriver (freescale MMG15241HT1) and the driver (freescale AFT27S010NT1) to achieve the required P_{1dB} of 50dBm.

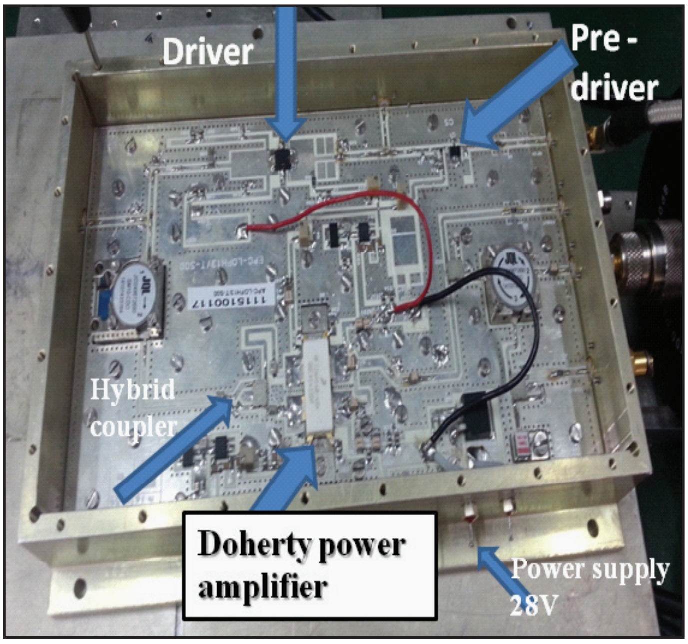


Fig. 9: Fabricated Doherty Power Amplifier

The substrate used is Rogers 4350 with $\varepsilon_r = 3.48$. The power supply of 28V is applied to the pin as shown in Figure.9 and 5V of supply is tuned and set for the pre driver through the voltage regulator which gives a constant voltage of 6.2V. The voltage regulator has another track towards the driver by which the V_{GS}=1.85V is set to give the required current of 90mA for the driver. There is a hybrid coupler which is dividing equal input power to each of the peak and the carrier of the Doherty amplifier. The total current at the Doherty would be 680mA. Agilent E4438C Signal Generator and Rohde & Schwarz Signal Analyzer were used to test the amplifier. Table 1 gives the reading of output power values at different input Power and is analyzed with the class AB results to relate their efficiency at an output power back off of 6dB.

Table 1: Implemented Doherty and Class AB Readings

CLASS AB		DOHERTY	
P_{out} (dBm)	η(%)	P_{out}(dBm)	η(%)
33.6	2.9	33.3	9.3
34.6	4	34	11.3
35.6	5.3	35	14.2
36.7	6.8	36	16.9
37.8	8.5	37	21.2
38.8	10.5	38	24.95
39.5	12.8	39	30.2
40.5	15.4	40	35
42	20.7	41	40.35
43.2	25.8	42	44.7
44.3	31	43	48.6
45	35.4	44	52.6
45.8	39.4	45	56.2
46.5	44.2	46	57.3
47.3	50	47	57.7
48.2	54.6	48	58.7
49.3	57.3	49.5	59.2
50	59.13	50	59.59

The above table provides the comparison between Doherty and Class AB efficiencies based on which Pout vs. efficiency is plotted. Fig. 10 shows the efficiency comparison between Doherty and Class AB with respect to the output power. Red line depicts Class AB and blue line shows Doherty efficiency for a back off range of 6dB. It can be observed from the graph that Doherty maintains good efficiency at the back off region as well unlike class AB which achieves it only at its maximum power. The simulated and the measured values are hence verified. As it can be seen from the curves, 52.6%-59.59% of efficiency at 44dBm – 50dBm is measured at the centre frequency 2.59GHz of the LTE band41.

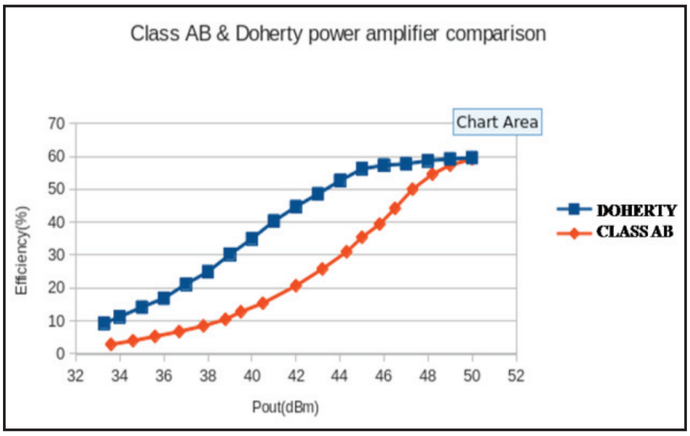


Fig.10: Comparison plot of Doherty & class AB Efficiency

Hence, Doherty increases the amplifier efficiency by around 22% in the back off region when compared to Class AB which in turn is apt for LTE high PAPR signals, and thus mitigates cost issues.

IV. Conclusion

A 140W LDMOS PTFC261402 symmetrical Doherty Power amplifier is implemented for the LTE band41. Class AB and Doherty were collated and differentiated. For a 6dB back off, efficiency in the range of 52.6% - 59.9 % was obtained which becomes very much suitable for high PAPR signals like LTE that need to be operated at back off levels to achieve good efficiency. The output power is 50dBm with maximum efficiency performance of 59.6% providing a flatness of over the complete band ranging from 2.496GHz - 2.69GHz. To the best of the author's knowledge, the designed Doherty configuration represents the first to be implemented using high power LDMOS (PTFC261402) in LTE band41.

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