The Effect of g_m-mismatch on the Performance of Doherty Power Amplifier

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Abstract

In this paper, the effect of g_m-mismatch on the performance of Doherty power amplifier is studied. For this purpose, the mismatch effect is mimicked by driving the main and peaking amplifiers, asymmetrically. Three mismatch scenarios corresponding to the cases where the peaking amplifier is overdriven, normal driven and underdriven are considered. Both simulation and experimental results clearly revealed that the amplifier's efficiency and linearity strongly depend on the drive levels of the main and peaking amplifiers. Increasing the drive level of the peaking amplifier improves the amplifier's linearity, but sacrifices its efficiency. This fact indicates that drive levels of peaking and main amplifiers, hence g_m-mismatches is a crucial factor that should be taken into consideration carefully in the design of Doherty power amplifiers. Experimental results of a 40 dBm Doherty amplifier operating at 2645 MHz showed that IMD3 of -24.83 dBc measured when peaking amplifier is overdriven is reduced to -21.16 dBc for the underdriven case. Nevertheless, the drain efficiency which is measured at 40.39 % when peaking amplifier is overdriven is improved to 43.8 % in the underdrive operation.

1. Introduction

In today's world, multimedia applications are part of everyday life. The trend topics of multimedia applications like 4K videos, high resolution live video demand, 3D videos and Virtual Reality (VR) applications need higher data rates ever. Despite the limited bandwidth, the needs for high data rates require the development of complex multiplexing techniques like Orthogonal Frequency-Division Multiplexing (OFDM). However, the complex techniques have very high Peak-to-Average Power Ratio (PAPR), posing a big challenge to the design of power amplifiers in view of efficiency and linearity.

To achieve higher efficiency levels, various techniques have been studied over the years [1-4]. The technique proposed by W. H. Doherty's over 80 years ago has been widely investigated to ensure high efficiency at back-off power (BOP) from saturation power. This technique still maintains its popularity in new generation communication technologies, like 5G mm-wave communication systems [5].

A basic Doherty Power Amplifier (DPA) is composed of two amplifiers, connected each other with quarter-wave impedance transformers. The main amplifier operates continuously, while the peaking amplifier only operates at higher power region starting from its BOP point.

Detailed theoretical results of DPA are first given in the literature by Raab [6]. Raab showed that the peak efficiency improvement can be achieved by controlling the impedance termination of the main amplifier depending on the drive levels of the amplifiers. This approach inspired us to investigate the influence of the drive levels of both amplifiers, thus g_m-mismatches, on the linearity and efficiency of the DPA.

The conventional 2-way DPA provides very good efficiency at 6-dB BOP values and suits well the modulated signals with at most 6-dB PAPR. However, advanced modulation schemes have much larger PAPR, thus new design approaches are required to improve DPA's efficiency at these complex modulation formats. In this paper, we propose the use of asymmetrical 2-way DPA architecture where drive levels and BOP are carefully controlled [7].

This paper is organized as follows. Main and peaking drain voltages of the ideal DPA is presented in Section 2. Simulation and test results revealing the effect of the g_m-mismatch are given in Section 3. In the conclusion, results and evaluations are given.

2. Transconductance Ratio of the Ideal DPA

As discussed in [8,9] where detailed analytical analysis of DPA is presented, transconductance ratio of the main and the peaking amplifiers can be given by:

$$\frac{g_{mp}}{g_{mm}} = -\frac{[B_m(C_pR_L+D_p)+A_mD_pR_L]}{[(A_mD_m-B_mC_m)R_L]} \qquad (1)$$

where, main amplifier's transconductance is g_{mm}, peaking amplifier's transconductance is g_{mp}, main branch's ABCD matrix is $T_m = \begin{bmatrix} A_m & B_m \\ C_m & D_m \end{bmatrix}$, peaking branch's ABCD matrix is $T_p = \begin{bmatrix} A_p & B_p \\ C_p & D_p \end{bmatrix}$ and R_L is the load.

In Fig. 1 the main and peaking drain voltages are shown for different drive levels which corresponds to different g_{mp} ratios.

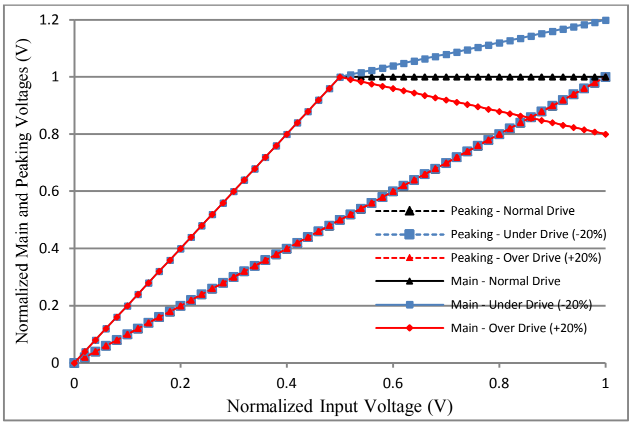

Fig. 1. The main and peaking drain voltages for different g_{mp} ratios

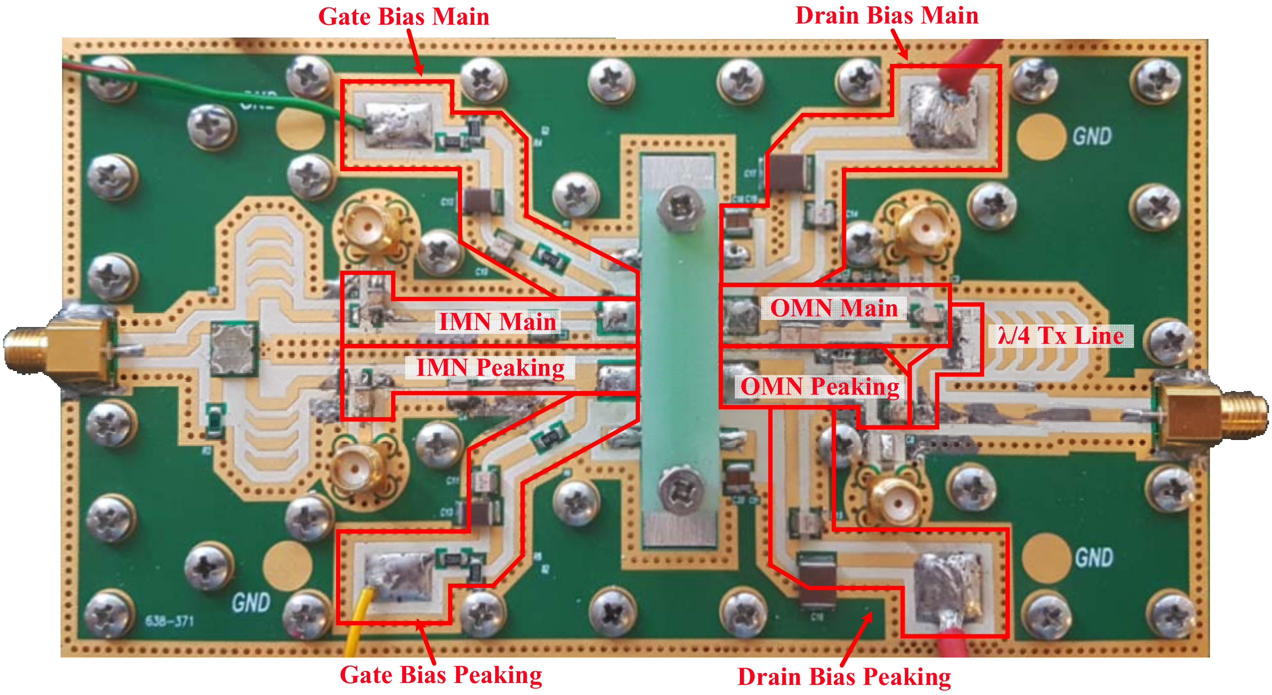

Fig. 2. Proposed Doherty power amplifier (IMN: Input Matching Network, OMN: Output Matching Network)

In practice, it is difficult to accurately set transconductances of the active devices to the desired values. Viable approaches to achieve this can be either to use additional power dividers at the inputs of main and peaking amplifiers or, alternatively, to drive the main and peaking amplifiers via two separate active drivers.

In order to analyze the effect of g_m-mismatch in DPA's efficiency and linearity, an asymmetrical DPA is designed with AWR Microwave Office for E-UTRA band 7 DL frequencies which correspond to 2620–2690 MHz. The amplifier shown in Fig. 2 is built using NXP's AFT26HW050S type RF power LDMOS transistors. Gate bias voltages are set to 5.78 V and 2.8 V, for the main and peaking amplifiers, respectively. Drain voltages are 28 V for both amplifiers. The quiescent drain current of the main amplifier is set to 100 mA. Offset lines are added at the outputs of both amplifiers and these connected each other via a quarter-wave impedance transformer network. The test of the manufactured DPA showed that the amplifier has a maximum of 64% drain efficiency and a maximum of 46 dBm (40 W) output power.

The proposed DPA can operate both in dual-drive and in single-drive mode. 5 dB directional coupler is used to divide the input power in single drive mode. Note that the power of the branch with the main amplifier is approximately 3.35 dB higher than that of the peaking amplifier's branch.

3. Simulations and Test Results

The test bench built to analyze the g_m-mismatch effects is shown in Fig. 3. The input power is applied to the inputs of the amplifiers via a 3 dB directional coupler. Independently controllable attenuators are used to set the desired power level difference between the main and peaking branch. Additional voltage controlled attenuators are used, in order to increase the precision of the power level difference between the main and peaking branches.

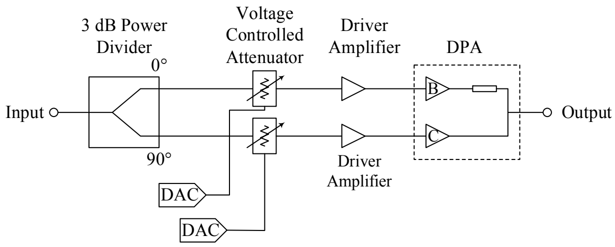

Fig. 3. Dual drive DPA test bench

During the tests, the peaking branch's power level is changed while the main branch's power level is kept constant. In order to mimic single-drive operation where the peaking amplifier is normally driven, the difference of the power levels between the main and the peaking branches is set to 3.35 dB. In order to evaluate the performance of the case where the peaking amplifier is overdriven, the power level difference is set to 0.9 dB. Finally, the power level difference is set to 5 dB in order to assess the amplifier performance when the peaking amplifier's operates in underdrive condition.

3.1. The Effect of g_m-mismatch on the Efficiency

Simulation results showing variation of DPA's output power and drain efficiency versus drive levels are given in Fig. 4. Test results given in Fig. 5 agree well simulation results. In Figs. 4 and 5, *x*-axis values correspond to the signal levels at the power dividers input in Fig. 3. Since there is an additional 3 dB directional coupler at the input of the main amplifier, input power of the main amplifier is always 3 dB below the values which appear on the *x*-axis. During the tests, the frequency of the input signal was 2655 MHz.

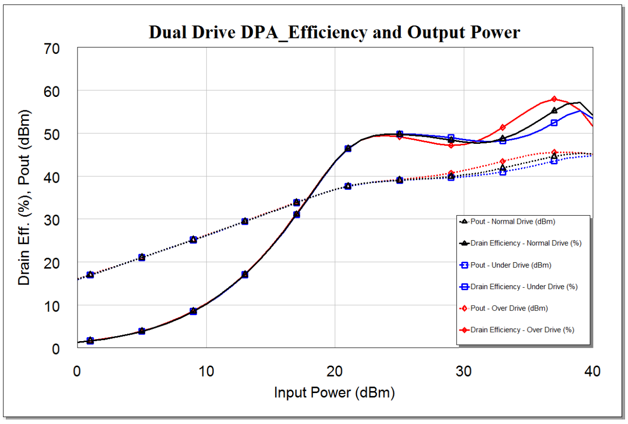

Fig. 4. Drain efficiency and output power simulation results

For both graphs, black, blue and red solid lines indicate the cases corresponding to normal drive, underdrive and overdrive drain efficiencies, respectively. Similarly, black, blue and red dashed lines are used to show normal, underdrive and overdrive output power variations.

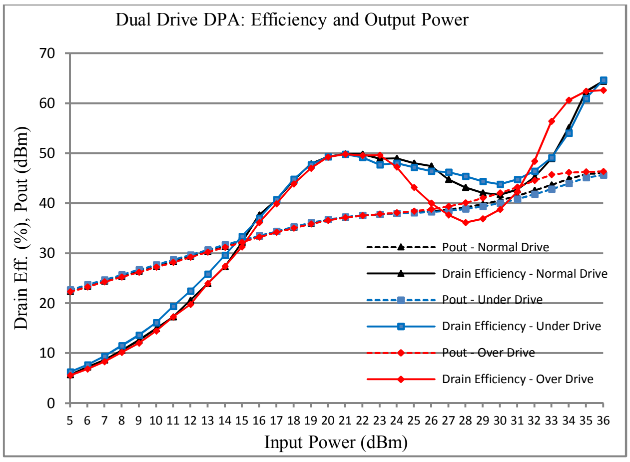

Fig. 5. Drain efficiency and output power test results

When the peaking amplifier is in the overdrive operation, the main amplifier goes under saturation level because of the load modulation. The main amplifier has reached saturation at relatively higher input powers compared to normal drive operation; as a consequence, after BOP efficiency of the DPA has decreased.

On the other hand, considering the underdrive operation, the main amplifier goes over saturation because of the insufficient load modulation. After BOP efficiency of the DPA has increased, though, the main amplifier has reached saturation at relatively lower input powers compared to normal drive operation.

The normal drive seems to be a compromise between the underdrive and the overdrive operations in terms of the efficiency. This operation provides benchmark points for the results.

The main differences between the measurements and simulation results are as follows: the correct phase differences between main and peaking branches can not be provided because the voltage controlled attenuators and driver amplifiers are not identical.

The drain efficiency is measured as 40.39 % for overdrive, 41.99 % for normal drive and 43.8 % for underdrive at 2655 MHz and at 40 dBm output power.

3.2. The Effect of g_m-mismatch on the Linearity

Simulation results showing the variation of the IMD3 versus input power levels is shown in Fig. 6. Test results which agree well simulation results are given in Fig. 7. The power levels in *x*-axis specified at power dividers input in Fig. 3. The two tones signal which $(f_1+f_2)/2$ = 2655 MHz and frequency offset is 10 MHz used as input signal.

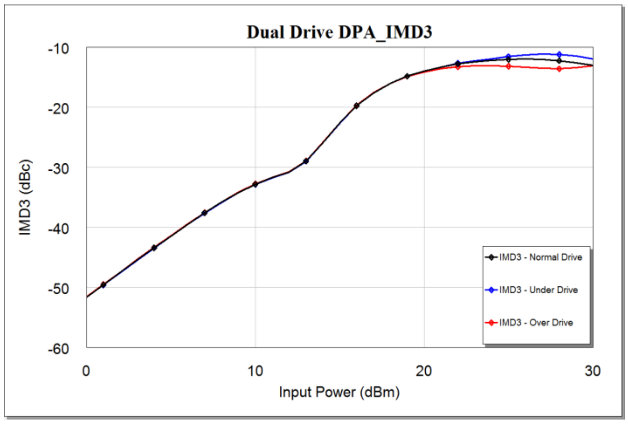

Fig. 6. IMD3 simulation results

For both graphs, black solid line is used for normal drive, blue solid line is used for underdrive and red solid line is used for overdrive IMD3 curves. IMD3 equals the difference between the output power level at f_1 frequency and the output power level at $2f_1$-f_2 frequency.

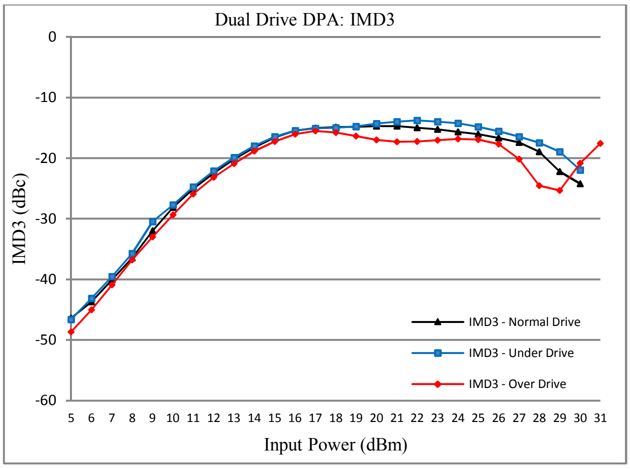

Fig. 7. IMD3 test results

According to the simulation results shown in Fig. 6, until the peaking amplifier turns on, all the three cases have approximately the same IMD3 levels. While input levels are increasing to the saturation level DPA's non-linearity increasing. As a result of the inevitable non-idealities of the attenuators and driver amplifiers used in the test bench, IMD3 levels measured before the amplifiers turn on differ slightly.

According to these results, considering the linearity after the peaking amplifier turns on, the overdrive operation provides the best performance. The underlying reason is that when the peaking amplifier operates in overdrive region, the main amplifier remains in under saturation level as a result of the load modulation. The fact that the main amplifier does not saturate substantially improves the linearity of the DPA. Nevertheless, with increasing input power levels, the main amplifier and peaking amplifier enter to the saturation region and IMD3 level reaches the same levels as the others operation.

However, in underdrive operation, because of the load modulation, the main amplifier remains in over saturation level. Therefore, the nonlinearity increases and IMD3 levels get worse than the others.

The normal drive is a compromise between the underdrive and the overdrive operations in terms of the efficiency and output power. This case can be considered as a benchmark point for amplifier performance.

The IMD3 measured -24.83 dBc for overdrive, -21.59 dBc for normal drive and -21.16 dBc for underdrive at 2645 MHz and 40 dBm output power.

4. Conclusion

Simulation and test results of a DPA which allow the detailed study of the effects of g_m-mismatches are provided. These effects mimicked by applying different signal levels to the main and peaking amplifiers. While the peaking amplifier's driving level increases, DPA saturates at higher power levels and it lowers their efficiency. But it makes DPA more linear.

The drain efficiency is measured as 40.39 % in overdrive, 41.99 % in normal drive and 43.8 % in underdrive operation regions while DPA has 40 dBm output powers at 2655 MHz. On the other hand, IMD3 is measured as -24.83 dBc in overdrive, -21.59 dBc in normal drive and -21.16 dBc in underdrive at 2645 MHz.

5. References

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