D-3-02 (Invited) Extended Abstracts of the 2020 International Conference on Solid State Devices and Materials, VIRTUAL conference, 2020, pp205-206

Breaching the 70 % Efficiency Plateau: a Mixed-Signal Approach to RF-PA Design

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Abstract

With the advent of 5G and external pressure to reduce green-house-emissions, wireless transceivers with low power consumption are strongly desired for future cellular systems. According to recently published papers, the average power efficiency has plateaued around 60 % when operating at a typical 10 dB output power back-off level. To overcome this apparent barrier, a mixed-signal approach to enhance the power efficiency at large output power back-off levels has been shown to be a promising technique. Combined with the newly proposed Doherty-outphasing power amplifier, an average power efficiency of over 70% at a 10 dB output power back-off level was measured.

1. Introduction

5G ultra-high capacity and ultra-low latency systems are beginning to be brought online and discussions on beyond-5G or 6G are also starting to take place. It is expected that higher order modulation, e.g. 1024-QAM, will become a requirement to meet the increasing capacity demand. This in turn requires a more stringent error-vector-magnitude (EVM) specification that ultimately means that current signal processing techniques, such as clipping the peaks of a modulated waveform, are no longer viable. As such the power amplifier (PA) located within the base stations of cellular networks have to operate at even larger back-off levels from saturation in order to meet the more stringent EVM specification.

A PA is the most power-consuming component in a remote radio head (RRH). At maximum output power, as shown as 0 dB normalized output power in Fig.1, maximum power efficiency is attained. In the case of a class-B PA, the theoretical maximum power efficiency is 78.5 %. However, modern signals do not continuously operate at this output power level. On average they typically operate at 10 dB backed-off from the maximum output power level. In the case of the class-B PA, the power efficiency collapses from 78.5 % to around 25 %. If the average operational point were to shift further away from the maximum output power level, the power efficiency would decrease to below 25 %. As a result, there is a trade-off between power efficiency and higher capacity in radio frequency (RF) PA design.

According to the results presented in [1] and [2], with the aid of efficiency enhancing techniques, an average power efficiency of 60% was measured when operating at a 10 dB output power back-off level.

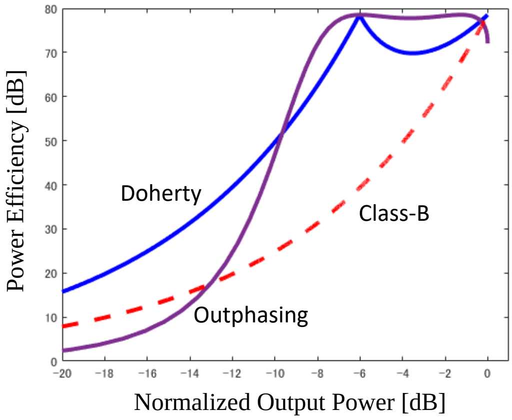

Fig. 1 : The theoretical power efficiency of various PA architectures including a conventional class-B amplifier.

2. Efficiency Enhancing Techniques

To overcome the degradation in power efficiency suffered by the class-B PA as the operating point shifts away from output power saturation, efficiency enhancing techniques have been developed. Two famous efficiency enhancement techniques from the 1930's have continuously been at the forefront of efficient RF-PA design. They are the Doherty amplifier [1] and the outphasing amplifier [2]. In their simplest form, both architectures employ 2 PAs operating together to enhance their total power efficiency. Although it should be noted that the Doherty amplifier can be implemented with 2 or more PAs. In the case of the Doherty amplifier, by manipulating Ohm's Law and exploiting the output voltage levels associated with output power saturation, two distinct power efficiency peaks can be generated as shown by the Doherty efficiency profile in Fig. 1. There is a notable dip in efficiency between these two peaks and a gentle roll-off at large output power back-off levels. Outphasing amplifiers operate on a different principle. Notably in and out-of-phase vector manipulation. By varying the phase relationship between two PAs operating at output power saturation, and hence maximum power efficiency, any resulting output signal magnitude can be realized. With the aid of a suitable output combiner, an efficiency profile with a near flat power efficiency response between saturation and 8 dB output power back-off can be realistically attained as shown in Fig.1. This is typically better than the Doherty amplifier power efficiency profile. However, at output power levels larger than 8 dB, the power efficiency degrades rapidly. For both the classical

Doherty and outphasing amplifier, at a 10 dB output power back-off level, the power efficiency decreases to around 50 %. It should be noted that these efficiency profiles are theoretical and in a practical environment achieving 78.5 % power efficiency at even small output power back-off levels is a challenging endeavor. With a highly optimized architecture, an average power efficiency of 60 % for signals operating at a 10 dB output power back-off level have been successfully recorded in the literature [1][2]. However, due to the non-linear nature of PAs, pushing beyond 60 % power efficiency is a daunting task. One promising technique to push beyond this power efficiency limit is to incorporate a mixed-signal approach, where amplitude and phase are controlled independently for each input, into RF-PA design. However, this inherently requires a multiple input architecture.

3. Mixed-Signal Approach and its Application

As the outphasing amplifier inherently has two independent inputs, applying the mixed-signal approach is a fairly straightforward endeavor. Rather than just controlling the phase relationship between the two inputs, the input amplitude level is also controlled. This is especially beneficial small output power levels where in a classical outphasing amplifier large input drive signals are used to generate a small output signal by using out-of-phase vector superposition. However, this approach has become fairly standard in outphasing design [2]. It has therefore become apparent that to attain a power efficiency greater than 60 %, multiple efficiency enhancing techniques will have to be merged together.

4. Doherty-Outphasing Power Amplifier

By carefully designing the output combiner of the Doherty amplifier such that two of them can be cascaded with the output combiner of the outphasing amplifier a Doherty-Outphasing power amplifier (DOPA) can be realized [3]. If designed optimally, the Doherty and outphasing efficiency enhancement principles are left intact. Identical to the classical outphasing amplifier, the DOPA has two independent inputs that allow for a mixed-signal approach where phase and input amplitude can be controlled independently. By applying a more sophisticated input drive signal, two operational modes can be realized. At small output power levels, the DOPA operates similar to a Doherty amplifier while at large output power levels the DOPA operates like an outphasing amplifier. In other words, the efficiency profile of the Doherty and outphasing amplifier are cascaded together such that at output power back-off levels larger than 10 dB substantial efficiency enhancement occurs. A photograph of the proposed DOPA showing a dual-input structure and its test set-up are shown in Fig. 2. The power efficiency (drain efficiency) and gain of the DOPA are shown in Fig. 3. At 10 dB output power back-off an average drain efficiency of around 71 % was measured with a corresponding gain of approximately 11.5 dB. At 12 dB output power back-off, a drain efficiency of 66 % was measured.

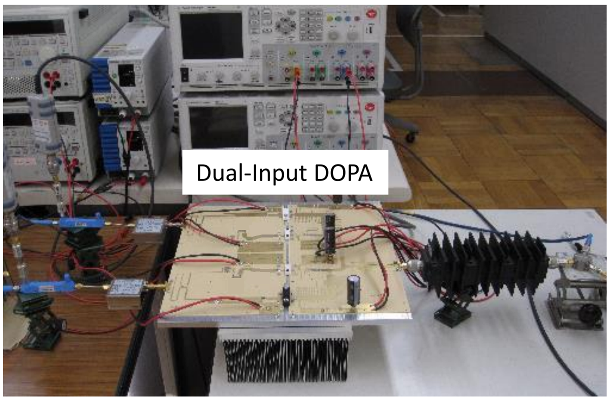

Fig. 2 : Photograph of the developed dual-input DOPA and measurement setup.

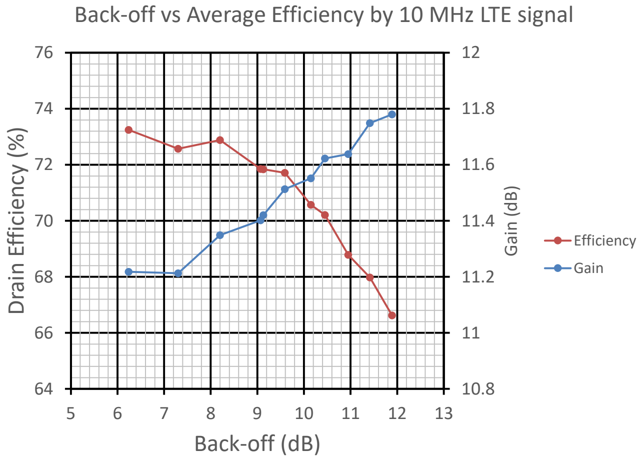

Fig. 3 : Performance summary of the drain efficiency and the gain for different output power back-off levels.

5. Conclusions

The feasibility of merging three efficiency enhancing techniques has been successfully realized with the proposed dual-input Doherty-Outphasing power amplifier with a mixed signal input drive. An output combiner that functions as a Doherty amplifier at small output power levels and as an outphasing amplifier at large output power levels is of paramount importance when trying to breach the 60 % power efficiency barrier such that the new power efficiency plateau is now situated at 70 %.

References

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