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Linearization of Active Transmitter Arrays in Presence of Antenna Crosstalk for 5G Systems

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***Abstract*—By increasing the number of antennas and power amplifiers connected to each in 5G system, the linearization methods like digital pre-distortion (DPD) of each power amplifier is inefficient due to antenna imperfections such as crosstalk. As a result of limited area the distance between antennas in array can vary which leads to unwanted coupling between antennas. A solution to this problem could be treating the amplifiers and antennas as one system and linearizing the main beam signal at the receiver rather than on each single power amplifier. In the work described in this paper, the whole system including amplifiers, antennas and the receiver is treated as a 2-ports system and the impacts of the above mentioned constraints are investigated.**

***Index Terms*—Power Amplifier (PA), Digital pre-distortion (DPD), Multiple Input Multiple Output (MIMO), Digital to Analog Converter (DAC), Local Oscillator (LO).**

I. Introduction

DUE to growing demand for higher data rate, which needs extended bandwidth, new mm-Wave frequency bands are introduced as enabling technology in 5G mobile system. Together with the requirements of massive MIMO, highly integrated beam-steerable active arrays consisting of a high number of PAs and antennas are considered as an efficient solution [1]. The active array topology where the PAs are placed after the phase shifters, and just before the antennas, gives several benefits such as reducing the power handling of phase shifters, reducing the output power requirements for each element and allowing small integrated devices to be used while connected to the antenna. On the other hand active arrays place many challenges for the traditional linearization methods used for PA efficiency:

- Antenna crosstalk
- Coupling vs distance between antennas
- Varying power levels at antenna branches due to side-lobe control requirements

In this paper, the linearization of power amplifiers in the presence of cross talk is investigated. The task includes the characterization of the crosstalk and its impact on the system linearity and DPD of PAs under effect of antenna crosstalk. The applied DPD technique captures the combined non-linearity of the whole array including the PAs and antenna elements. Specifically the particular focus is to reduce the system complexity, while maintaining the linearization performance. The investigations in this paper are done by combining measurements together with analyses in Matlab.

The paper is organized as follows: Section I is the introduction. Section II discusses system theory and background. Measurement set-up of proposed system DPD and results have been provided in section III. Finally, the conclusions of this work are presented in section IV.

II. System Theory and Background

A. Antenna crosstalk in arrays

A common beam-forming structure, the so-called "hybrid beam forming", is shown in Fig. 1. Each sub-array includes a DAC and a modulator. The number of antennas in each sub-array is higher than the number of modulators in order to minimize the power consumption since the DAC, the modulator and the preceding digital part are the most power consuming elements [2]. Crosstalk as coupling from one branch to another of transmitter in an active antenna array can be categorized in two types: before PA and after PA.

1) Crosstalk before PA: This is mainly due to RF leakage through the common LO and coupling between different transmit paths because of the electromagnetic coupling [3].

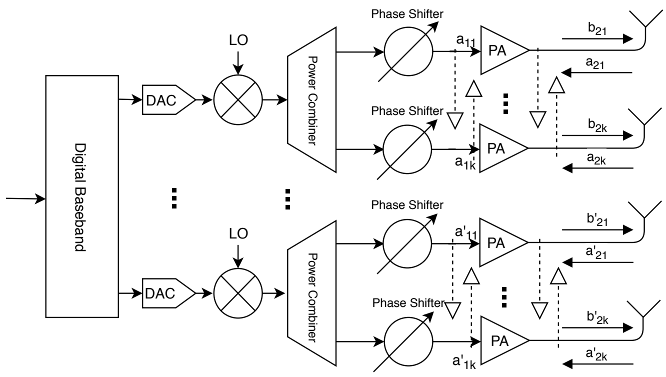

Fig. 1. Model of crosstalk in Hybrid beam-forming

2) Crosstalk after PA: When no isolators are present at the PAs' outputs, there is mutual coupling between them via the antennas [4]. A sketch of this is shown in Fig. 1 where a_{1k} is the incoming signal to the amplifier, b_{2k} is the output from

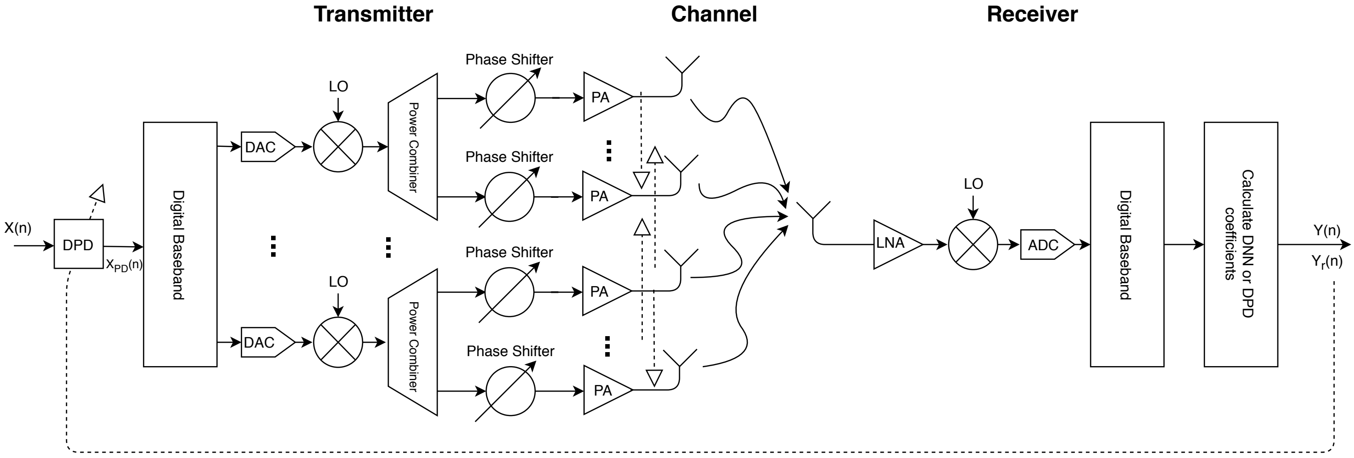

Fig. 2. Estimation of DPD coefficient at receiver side

the amplifier and a_{2k} is the reflected signal form the antenna array at the kth branch.

The relationship between a_{2k} and the output signal b_{2k} is determined by the characteristics of the antenna array's s-parameters. The system model of the multi-antenna transmitter could therefore be split into a crosstalk and mismatch model. This model could also be used together with the DPD that holds the model for the PA, to linearize it [5].

A major problem with this approach is that the s-parameters for the antennas must be known and that the method needs feedback from each amplifier which is a problem if several amplifiers are used.

B. On-line system linearization

A novel solution to the above mentioned concerns could be to treat amplifiers and antennas as a single system and then do the DPD estimation for the main beam at the receiver side as depicted in Fig. 2. In order to make this configuration to work, the transmitter has to send a pilot sequence which is known to own receiver. Then the receiver can obtain the coefficients for the DPD algorithm and feed those back to the transmitter. Calculation of the linearization coefficients can either be done as traditional memory polynomial or Deep Neural Network (DNN). On-line system linearization can also be used in satellite communication as post distortion analysis for power efficiency [6], [7] done in ground-station receiver. The benefit with the last approach is that it includes also the channel response.

III. Measurements

A. Measurement setup

Figure 3 shows the measurement setup in lab which is consisting of an array of 4 antennas with one PA connected to each and the receiver antenna spaced one meter from the transmitter. Power amplifier of type CREE CGH400006P [8] is used for the measurements.

The gate voltage for the amplifier is adjusted to Vg =2.798 V resulting in a quiescent drain current of Id = 100 mA.

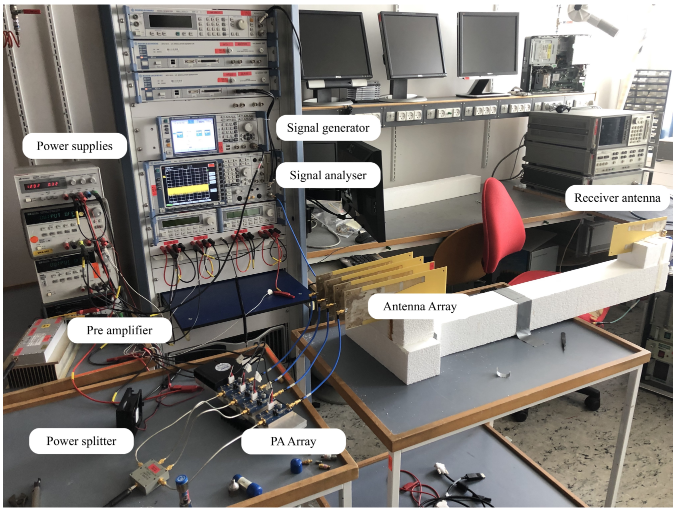

Fig. 3. Measurement setup.

Fig. 4 shows the gain response of the PA with 1 dB input compression point at 22 dBm and gain of about 8 dB. The signal generator generates an input signal that is a 10 MHz LTE signal with a center frequency at 3.5 GHz and peak to average power of 9.8 dB. A pre-amplifier at the output of the generator provides the necessary gain in order to get an average power of 22 dBm at each PA input.

B. Single PA linearization vs system level linearization

This section demonstrates how much mutual coupling and crosstalk between antennas influence the non-linear distortion, which can not be compensated accurately by conventional single PA linearization.

Measurement results are shown in Fig. 5. In the first set of measurements each PA is linearized using a standard DPD on a single PA without connection to antenna. Then these standard DPD's coefficients are applied to the system including antenna and the measurement is done at receiver antenna. The result is

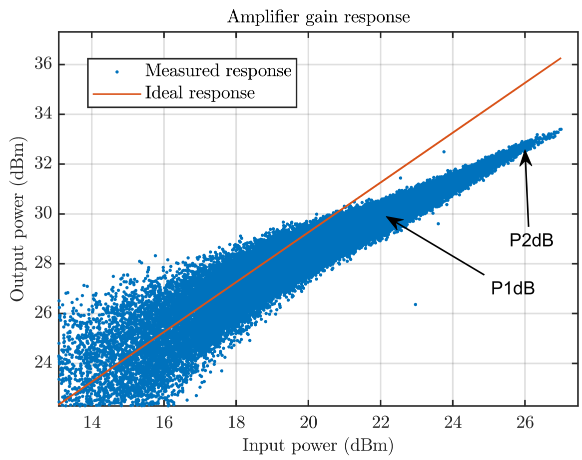

Fig. 4. Amplifier gain response.

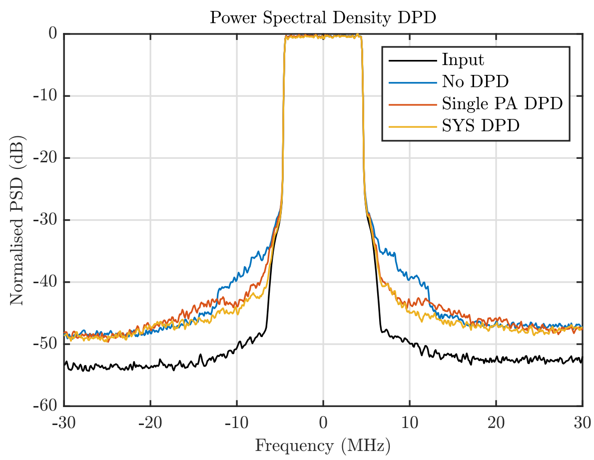

Fig. 5. PDS for single PA DPD vs system DPD.

called ”Single PA DPD”. In the second set of measurement the linearization is done based on the combined beam-form signals of all four power amplifiers at receiver antenna. The result is called ”SYS DPD”. As shown in Fig. 5, the normalized Power Spectral Density (PSD) of adjacent channel gets approximately 2 dB lower with the proposed model in Fig. 2 compare to ”single PA” model.

C. Impact of coupling between antennas

For investigating the impact of correlation between antennas on DPD, a set of measurements with varying space between the four transmitter antennas, d = [0.1 0.2 0.3 0.4 0.5 0.6] times wavelength (λ), has been carried out. The same quiescent drain current (100 mA) has been applied to each amplifier. Measurements with and without DPD for each spacing has been carried out and for each set of measurements the Amplitude to Amplitude (AM/AM) distortion, normalized PSD and Adjacent Channel Power Ratio (ACPR) are measured. Fig. 6 shows that as a result of coupling between antenna the gain of array is reduced by 4 dB comparing 0.5λ distance between antennas with 0.1λ. Figures 7 and 8 showing an improvement of PSD and an ACPR of approximately 6 dB by doing the proposed system DPD.

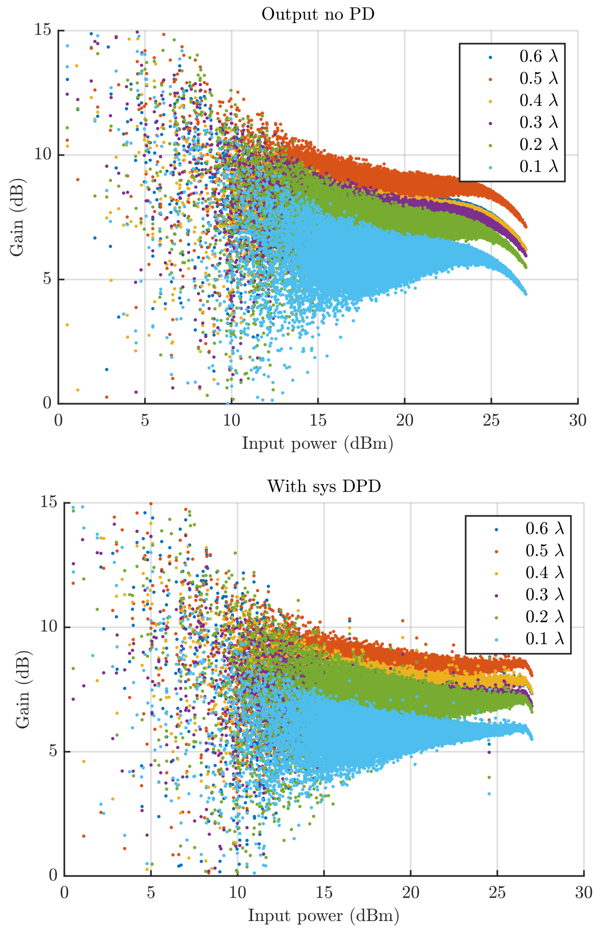

Fig. 6. AM/AM with same drain current but different spacing between antennas.

However, the ACPR difference when going from 0.1λ to 0.5λ is only app. 1 dB. An explanation could be that in the worst case spacing (0.1λ) the coupling between antennas is not so high. For investigating the coupling rate between antennas, the s-parameters for the array with 4 antenna has been measured. The strongest coupling is approximately -12dB as it is shown in Fig. 9. This means that in the actual setup the worst case coupling is still not significant and could not have major influence in linearization. Further investigation with stronger coupling between antennas needs to be carried out.

D. Impact of power variation of each branch on DPD

First set of measurements are conducted by keeping the quiescent current at all four amplifiers constant at 100 mA. This measurement is called ”Same Current”. A second set of measurements, called ”Same Volt”, are applied by keeping the quiescent gate voltage of amplifiers constant at -2.7 V which results in different drain current in PAs and consequently different output powers. For each set of measurements the

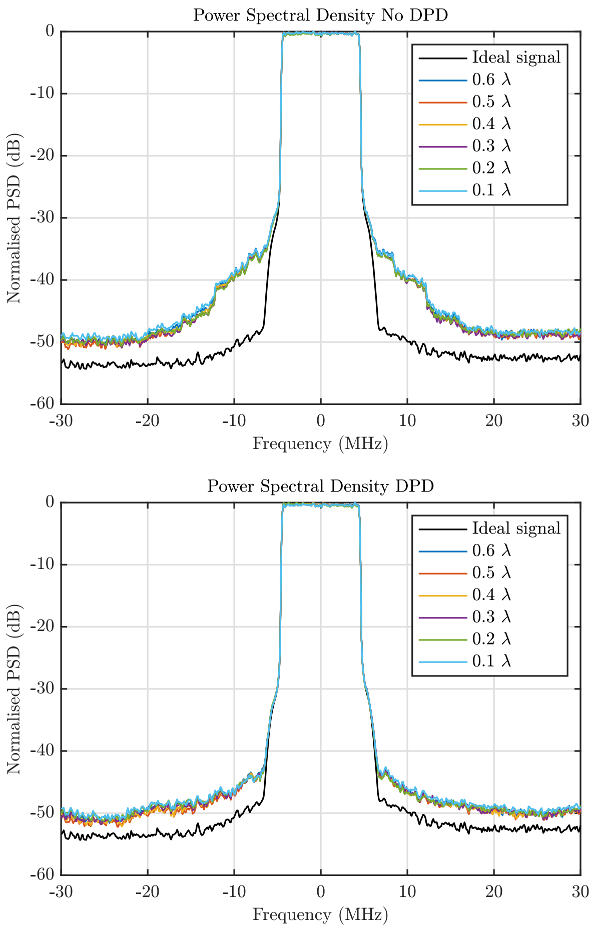

Fig. 7. PSD with same Drain current but different distance between antennas, using system DPD.

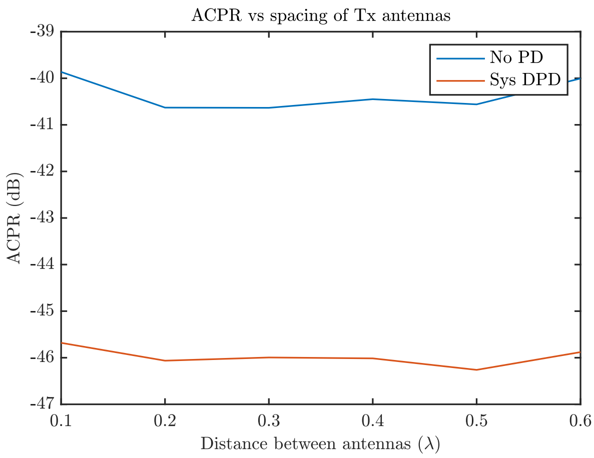

Fig. 8. ACPR with same drain current versus distance between antennas.

AM/AM and normalized PSD are measured. Measurement results are shown in Fig. 10 and Fig. 11.

The results show that if the amplifiers with antennas are treated as a whole, then the DPD algorithm is able to improve the normalized PSD of the adjacent channel on the received beam regardless of power variation on each branch.

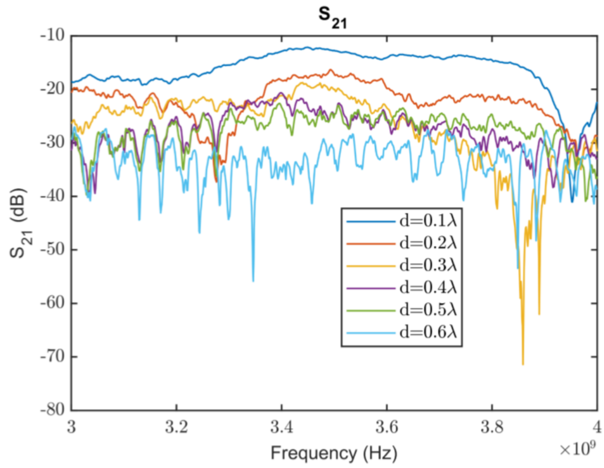

Fig. 9. Measured S21 with four antennas.

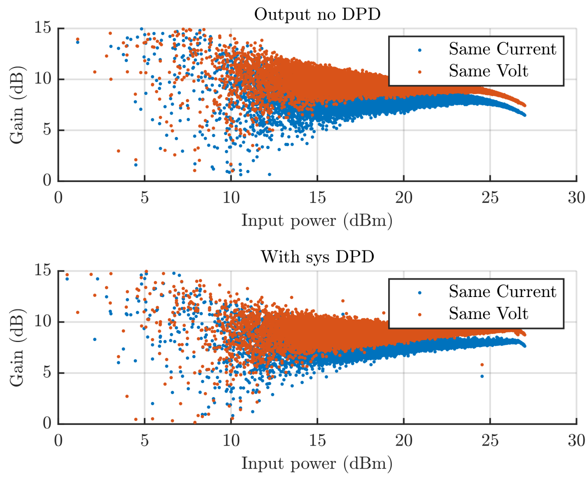

Fig. 10. AM/AM with same drain current vs same gate voltage.

IV. Conclusion

In this paper a DPD technique for linearizing of the antenna array in presence of crosstalk has been presented. By using the actual technique on system level it is possible to reduce the adjacent channel power by about 8dB without doing any intensive S-parameter measurements needed in existing work. Additionally it has been shown that with the system level DPD it is possible to improve the overall power spectral density although the array's chains have different power levels. So treating the amplifiers and antennas as one system and linearizing the main beam signal at the receiver rather than on each single power amplifier works and individual DPD is not needed. The complexity of pre-distortion used in this work is the time alignment. To determine the time alignment needed between input and output of PA, a simulation must be done. The time alignment is then made into a phase shift

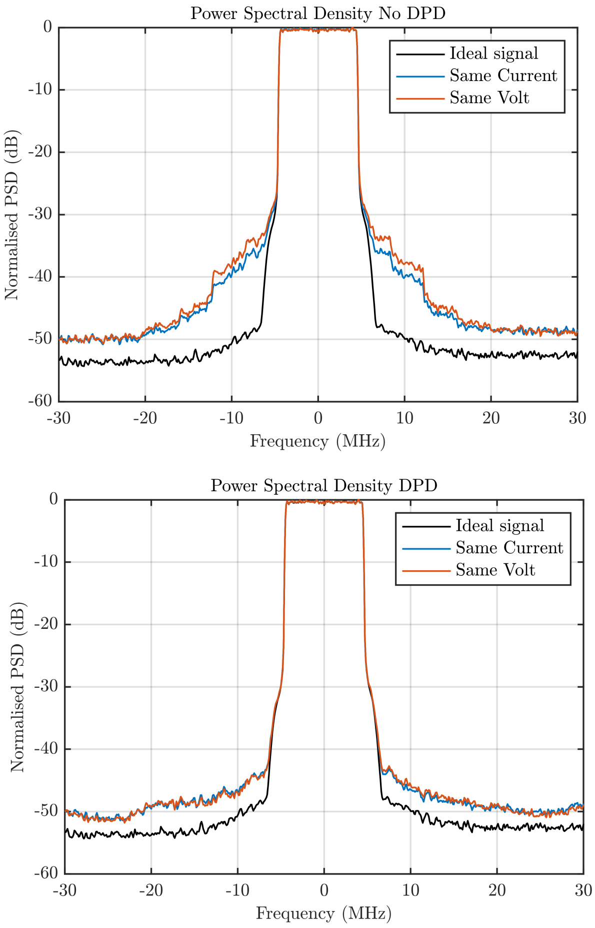

Fig. 11. Power Spectral Density with same drain current vs same gate voltage.

between the two input signals. The difference in the phase from input signal to output signal needs be calculated and used for the rest of the simulations. The presented system level linearization technique needs be proven in other scenarios such as multi path environment and varying distance between transmitter and receiver antennas. In order to use the presented system level DPD in practice, it is required a reverse link to pass the DPD coefficients, and synchronization of the training sequence. Main difficulty is that the receiver bandwidth must be large enough to cover the adjacent channels.

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