Towards Over-the-Air Characterized Transmitter Array Nonlinearity

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Abstract

Millimeter-wave (mmW) phased arrays challenge the standard ways to measure and specify the nonlinearity of the radio frequency transmitter. Furthermore, the linearization of these multi-antenna transmitters is challenging due to the single digital input shared by multiple nonlinear elements. The figures of merit of linearity of mmW phased array transmitter must be measured in the radiated far-field and the array linearization must be designed for the signal observed over-the-air.

1 Introduction

Millimeter-wave (mmW) frequencies are utilized in fifth generation (5G) cellular systems [1]. First commercial products are already available and third generation partnership project / new radio (3GPP/NR) has defined specifications for the systems from waveforms down to the hardware figures of merit (FOMs) [1-2]. High path loss, radio frequency (RF) routing losses and small antenna elements require compact and highly integrated multi-chain RF design. High-order modulations and orthogonal frequency division multiplexing (OFDM) waveforms require linear power amplifiers (PAs) which are known to suffer from bad power efficiency. Hence, linearization techniques are required to enhance transmitter efficiency by enabling the usage of nonlinear PAs, enable low error vector magnitude (EVM), and reduce the adjacent channel power ratio (ACPR).

In mmW frequencies the multi-antenna transceivers are often implemented as phased arrays where multiple transceiver chains share a single digital input. In these systems the radiated nonlinearity is composed by multiple parallel elements which makes the nonlinearity direction dependent [3-4]. The spatial distribution of the distortion challenges the traditional single-chain linearization concepts such as digital predistortion (DPD) and makes it more challenging to specify the standard figures of merits such as EVM and ACPR. Hence, the concepts of array linearization and FOMs of linearity should be revised [3].

2 From Conducted to Over-the-air Characterized Nonlinearity

3GPP/NR specifies the major part of the sub-6 GHz (FR1) systems by conducted measurements [1]. For phased arrays this would require that the testing authority has access to measure each array output separately. However, in compact mmW phased array systems the PAs, analogue beamforming, mixers etc. are brought as close as possible to the antennas to avoid notable wiring losses and hence improve the efficiency. In these systems it is not practical to have test connectors for each PA output. Therefore, the systems operating above 6 GHz (FR2) are specified by over-the-air (OTA) measurements [1-2].

In system level measurements with modulated signals, the transmitter nonlinearity is characterized by EVM and ACPR. For arrays, EVM is characterized in the main beamforming angle. ACPR is characterized as total radiated power (TRP) which is integrated over the space. [1-2] In practice, TRP measurements may vary several dBs depending on the measurement method which is seen as relaxed test specifications [2]. Also, the maximum absolute adjacent channel power (ACP) is specified. The specifications for the OTA ACPR of FR2 systems are significantly relaxed compared with the FR1 systems. In practice, this means that we can use even more nonlinear PAs if DPD can be used to linearize them.

3 Impact of Array Linearization for OTA Nonlinearity

The distortion of each parallel PA branch has its own contribution to the radiated distortion. If the distortion characteristics are different, the distortion will form a beam that may be different from the linear part of the beam [3]. This principle is illustrated in Fig. 1. Without DPD, the difference between the beams of the distortion and linear signal is hard to notice because the distortion is often mainly caused by compression, i.e. the sign (phase) of the nonlinear components are same for all the branches. The aim of DPD applied for the array input is to linearize the response in the beamforming direction. The far-field linearity may be achieved even if the parallel branches have very different nonlinear characteristics [4]. In fact, DPD of such array can form a mixture of compressing and expanding PA that can be combined to form a linear response in the beamforming direction. However, the linear combination of the compressive-expansive PA outputs in different directions has a major impact on the beam shape of the distortion. This concept should be considered when specifying OTA ACPR requirements of phased array systems.

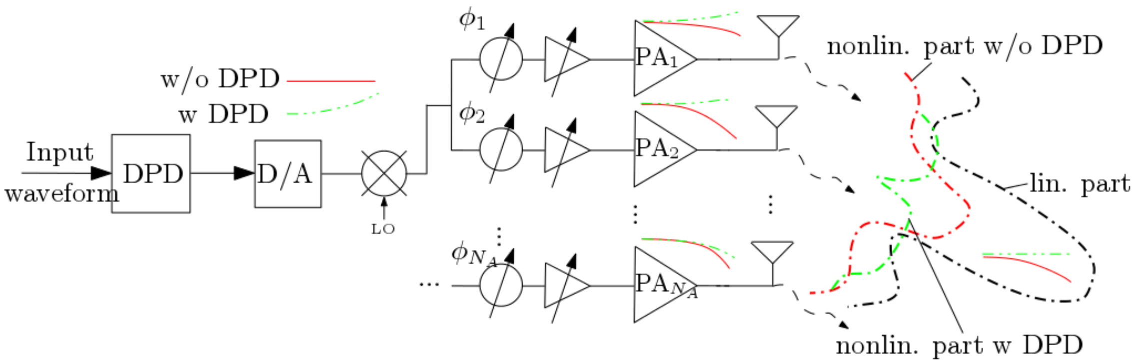

Fig. 1: Concept of radiated distortion with and without array linearization.

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