Model Derivation from Direct DPD (Digital Pre-Distortion)

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***Abstract* — Digital pre-distortion (DPD) is a common method to linearize the output signal of a power amplifier (PA), which operates in its non-linear operating range. Direct DPD takes DPD a step further and provides a method to show the theoretical limit of DPD as well as a fair comparison between different PA models, even across semi-conductor technologies.**

For real-world applicability, a PA vendor must not only show the theoretical performance of his device under DPD conditions, but also provide specification for operation under real-world, i.e. modelling DPD.

***Keywords* — Power amplifiers, Predistortion, Modelling, Radiofrequency amplifiers.**

I. Introduction

Most PAs operate in their non-linear range for efficiency reasons. The drawback of higher efficiency is the non-linear operating range. In order to maintain signal quality, many transmitters employ DPD. Implementing real-time DPD in a transmitter is a challenging task and often ends in PA or DPD models, which are specific to the signal transmitted. Besides being signal specific, a DPD model is always tailored to its surrounding system, especially the PA it is designed to linearize.

Iterative DPD (see [1]) is a method to characterize an amplifier's performance assuming unlimited computational power for DPD. This approach is well suited to describe the theoretical limits of a PA under DPD conditions – however it does not describe the PA's performance under real world DPD conditions. Many PA developers use Direct DPD during the development process to get an indication about how well the current design can be linearized. Moreover, it is a great method to compare different designs or even different PA models.

This article discusses a software tool based approach to derive device specific DPD models combining the advantages of Direct DPD with the applicability of a model-based DPD.

II. Direct DPD

A. Principle of Operation

A test signal *A* is applied to the device under test (DUT). The device adds its transfer function (non-linearity, frequency response, etc.). A measuring device captures the output signal *M*. It generates a pre-distorted signal *P*, based on the comparison of *M* with *A* (see Fig. 1) .

So assuming a DUT with an AM/AM characteristic as in Fig. 2, the Direct DPD algorithm measures a difference of output amplitude (e.g. 18.2 dBm) to expected output amplitude (18.5 dBm) of .3 dB for 0 dBm input power. Therefore, it will correct all samples of the original signal (*A*) with 0 dBm input power to .3 dBm amplitude in the pre-distorted signal (*P*). The same approach also applies for the phase of each sample. For simplicity reasons, this article focuses on the amplitude only.

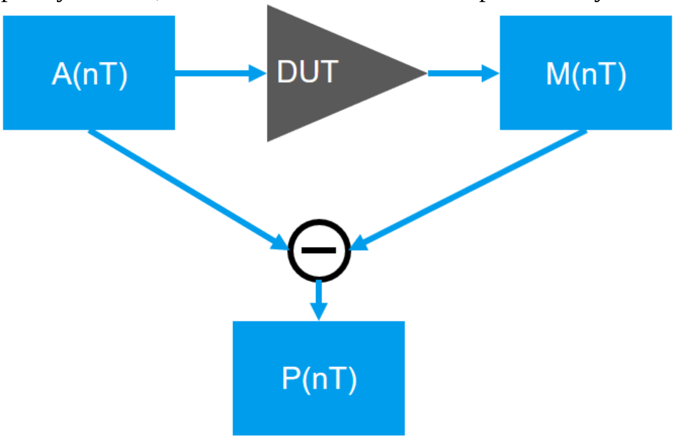

Fig. 1. Operating principle Direct DPD. Ideal signal A goes into DUT and is measured at the output (M). The difference is evaluated for each sample and defines the pre-distorted signal. Ideally, this algorithm is carried out iteratively.

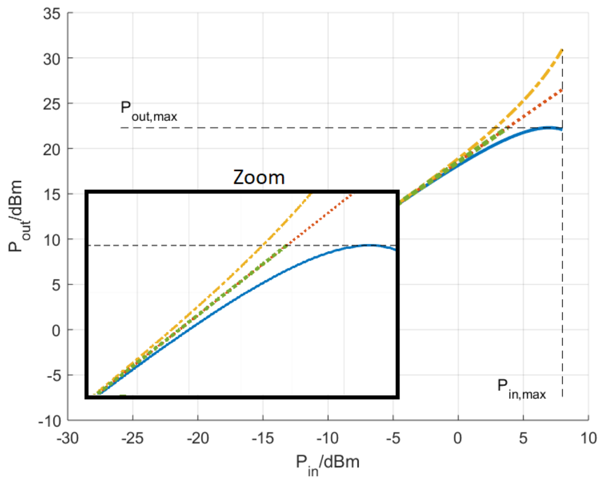

Fig. 2. Exemplary DUT characteristic (solid), constant gain (dotted), and pre-distorted (dash-dotted) input signal.

B. Iterative Approach

Due to the non-linear characteristic of the DUT, the exemplary Direct DPD step above does not produce the expected result. The new input amplitude of .3 dBm produces an output amplitude of e.g. 18.4 dBm, which is still .1 dB below the expected output amplitude.

As the DUT operates in its non-linear range, Direct DPD achieves best results in iterative mode. In iterative mode, a new measurement follows each pre-distortion step as shown in Fig. 3.

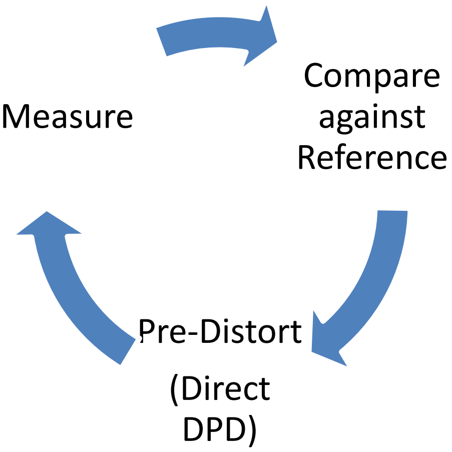

Fig. 3. Iterative approach. Direct DPD only accounts for the measured difference between input and output. Therefore, several iterations are recommended to account for the non-linear response of the DUT.

C. *Limitations of the Direct DPD*

In iterative mode, the output signal will converge to a state that is either limited by the system noise or the dynamic range of the measurement instruments. As shown in [1], I/Q averaging is a good approach to limit the influence of noise in this measurement. Dynamic range limitations, introduced e.g. by non-linear components of the measurement instruments (mixers, amplifiers) or quantization depths of ADCs or DACs will therefore be the final limiting factor for the iterative Direct DPD. As in every measurement setup, the instruments and their performance define the “measurement uncertainty”. Measurement uncertainty in the DPD case describes how well the DPD result pre-distorts the DUT but not the combination of measurement instruments plus DUT.

III. DPD Modelling

A. *Real-World DPD*

In any real-world system that applies DPD, the input signal is unknown since it consists of data that was unknown during system design. Therefore, Direct DPD is not applicable. The result from iterative Direct DPD however is well suited as the starting point for modelling. The modelling task is reduced to finding an algorithm that transforms the input signal *A* into the pre-distorted signal *P*, both known from the preceding iterative Direct DPD steps. Fig. 4 shows the application of an algorithmic DPD in a device, e.g. a handset.

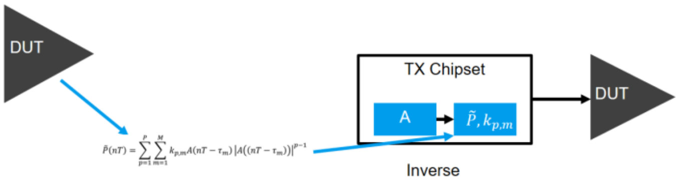

Fig. 4. A mathematical model is derived e.g. from a sample DUT. The model is the applied in e.g. the TX chipset of a handset before the signal is sent to the DUT (PA).

B. *Memory Polynomial Model*

A well-known approach for DPD models is the so called memory polynomial model.

$$\tilde{P}(nT) = \sum_{p=1}^{P} \sum_{m=1}^{M} k_{p,m} A(nT - \tau_m) \, |A(nT - \tau_m)|^{p-1} \quad (1)$$

Eq. 1 is a representation of a memory polynomial. It contains polynomial terms up to the order *P*, as well as memory terms to depth *M* for each polynomial order. The modelling task is to find the coefficients $k_{p,m}$. Since there are $k \cdot m$ coefficients, complexity rapidly grows if an extra polynomial order or memory depth is added.

C. *Applying other Mathematical Models*

The memory-polynomial model is a generic approach to DPD modelling. It is easy to derive, but it may not be the best choice, when efficiency is a design criterion. Even if power efficiency is not the main engineering design goal, financial efficiency is “the” design goal in any commercial design. Power dissipation of your DPD hardware and its cooling equipment can account for quite a significant amount of operational expenses (OPEX). So it may be a wise decision to spend extra R&D effort on optimizing the DPD model for your DUT to reduce the computational effort of the DPD.

Other well-known models for DPD are Volterra series, or the Wiener- and Hammerstein models. The final model decision will be a trade-off between computational effort and development cost.

IV. Toolkit For Modelling

A. *MATLAB based Modelling*

In an effort to make model based DPD available to RF engineers that typically do not focus on DPD details, Rohde & Schwarz provides a toolkit that directly derives the memory polynomial coefficients from a pre-distorted signal derived with Direct DPD.

The tool comes with a MATLAB function that supports DPD modelling based on the memory polynomial approach. This function (.m file) may be replaced with any custom tailored version of it, allowing you to run the same SW toolkit based on your device specific modelling algorithm.

Since the SW toolkit is based on a MATLAB function, it requires a MATLAB installation and license to be present on the PC.

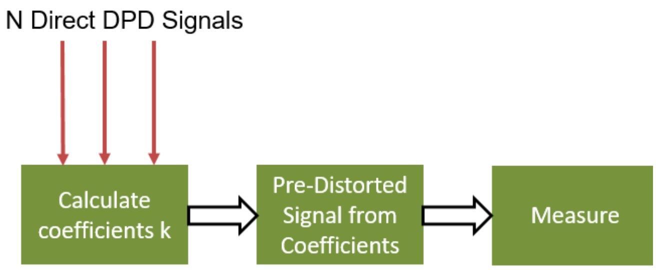

Fig. 5. Processing flow of the modelling toolkit.

B. *Resulting Pre-Distortion*

The software tool fully automates the entire process from the first measurement to model based DPD. It will run a user definable number N of iterations of the Direct DPD on any supported measurement instrument (e.g. the R&S FSW, with software options K18 & K18D and the R&S SMW200A). This results in the original signal A, plus N pre-distorted signals P. The tool will run the coefficient fitting using a MATLAB script, resulting in N sets of coefficients.

After coefficient fitting, there will be N Direct DPD files (P) plus an extra N modelled pre-distortion files ($\tilde{P}$). Finally, the tool will apply all $2N$ signals to your DUT and measure the resulting error vector magnitude (EVM) and adjacent channel leakage ratio (ACLR). Both are key indicators for the PA and DPD performance.

The results are summarized and allow you to pick the best fit for your application. As mentioned before, Direct DPD will converge, but due to the influence of noise and dynamic range, the last iteration step is not necessarily the best starting point for DPD modelling.

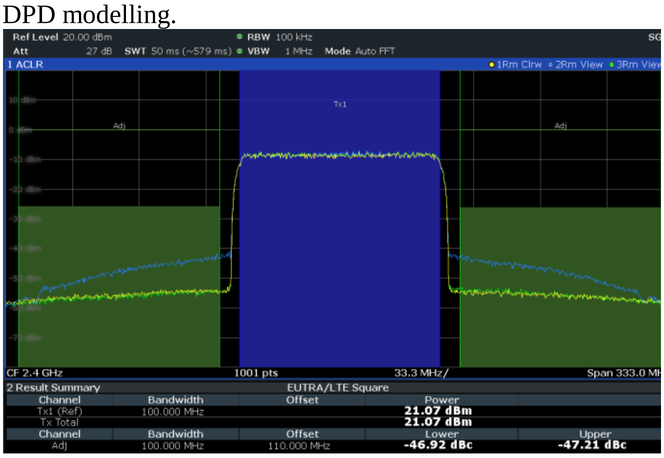

Fig. 5. Resulting ACLR. DUT output without DPD (blue), with Direct DPD (green) and memory polynomial DPD (yellow).

V. Summary

This paper presents an easy-to-use path from iterative Direct DPD to modelling DPD. It is possible to follow this path without any programming knowledge, but at the same time gives the user the freedom to customize the DPD algorithm.

The modelling approach uses the original ideal signal as well as the pre-distorted signal from a Direct DPD measurement. The transformation from the original to the pre-distorted signal corresponds to the DPD model. Finally the transformation function utilizes a MATLAB script, but is fully automated by the SW toolkit.

Even though a memory polynomial approach is the focus in this article, the method easily be extended to any device tailored DPD algorithm.

References

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[2] T. Williams, D. Tipton, F. Ramian, "Testing a 24-28GHz Power Amplifier using the 5G New Radio Test Standard, Challenges and Results", ARMMS RF & Microwave Society Conference – November 2018, available at https://www.rohde-schwarz.com/pl/applications/testing-a-24-28ghz-power-amplifier-using-the-5g-new-radio-test-standard-challenges-and-results-application-card_56279-596101.html.