

# Iterative Direct DPD

## White Paper

### Products:

- R&S®FSW-K18D
- R&S®FPS-K18D

Digital pre-distortion (DPD) is a common method to linearize the output signal of a power amplifier (PA), which is being operated in its non-linear operating range.

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 models, which are specific to the signal transmitted.

Even though these complex models are required for transmitter development, they are not needed during PA verification and development.

This article describes an approach to generate a pre-distorted signal based on a hard-clipper. The resulting waveform pushes the output of the DUT as close to the hard-clipper as possible.

Due to the waveform approach, the algorithm compensates all memory effects.

### Note:

Please find the most up-to-date document on our homepage <http://www.rohde-schwarz.com/appnote/1EF99>.

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# 1 Introduction

Amplifiers and specifically power amplifiers operate most efficiently at or close to their maximum output power.

Efficiency is a key design parameter for power amplifiers, for several reasons. In mobile devices, battery lifetime depends significantly on efficiency. In stationary devices, operating cost depends not only on the power consumption for the device itself, but cooling can make up for more than 50% of the power bill.

Consequently, most amplifiers operate in the so-called non-linear range, i.e. somewhere in compression. As the non-linear range significantly distorts the signal (increased EVM: error vector magnitude) and the related out-of-band emissions (increased ACLR: adjacent channel leakage ratio), signal processing algorithms aim to minimize these distortions.

A DPD (digital pre-distortion) algorithm ideally distorts the signal in exactly the opposite way as the DUT does (see Figure 1). In an ideal world, the DUT distorts the pre-distorted signal so that the output signal is linear. DPD requires significant computational power, which is either limited by power or cost restrictions.

Therefore, many people have specialized in generating the most effective DPD algorithm for one specific device.

A key question during amplifier design is the maximum performance of a device assuming perfect DPD. Rohde & Schwarz provides a new DPD approach that allows the measurement of a device's performance, by pre-distorting a given waveform, instead of developing a DPD algorithm. This approach allows comparative measurements across devices and saves amplifier designers from having to sort out the influences of different DPD algorithms. This new approach for DPD is available on the signal- and spectrum analyzers R&S®FSW and R&S®FPS as an add-on (R&S®FSW-K18D, or R&S®FPS-K18D) to the amplifier measurement option K18.

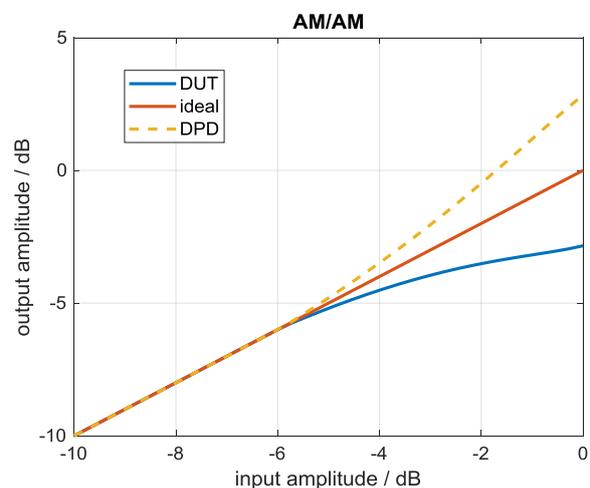


Figure 1 AM/AM curve of DUT, and pre-distorted signal compared against the ideal (linear) curve

## 2 Pre-Distortion of a Known Signal

### 2.1 Direct DPD

A DPD algorithm will take any input signal and pre-distort it, i.e. an FPGA or ASIC applies the algorithm in real-time to a signal. However, algorithms are limited by their complexity. Complexity limitations also apply for non-memory models, but are the dominant factor when it comes to memory models.



Figure 2 Measurement Setup

All examples below focus on amplitude distortion for simplicity, but the below text is valid also for complex signals, i.e. for phase and amplitude.

In memory models, the pre-distortion of a given amplitude  $A$ , not only depends on the value of  $A$  as in a non-memory model, but also on the previous values of  $A$ . So the pre-distorted value  $P$  at time  $nT$ ,  $P(nT)$ , depends not only on  $A(nT)$ , but also on  $A((n-1)T)$ ,  $A((n-2)T)$  and so on. The complexity will grow exponentially with the amount of memory taken into account.

Direct DPD, opposite to DPD algorithms, pre-distorts a given input signal on a sample-by-sample basis. The sample based approach, allows the modelling of any memory effect without increasing the complexity, since any  $P(nT)$  depends only on the measured sample  $M(nT)$ ,

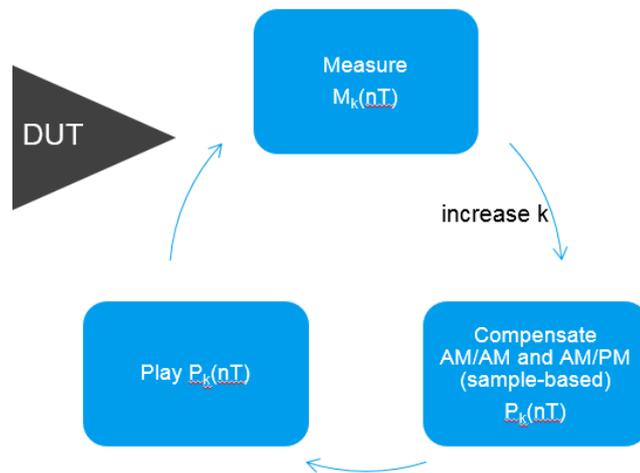


Figure 3 Iterative approach for sample-based pre-distortion

where the memory effect of the device is present in the measured samples  $M$ . The device under test (DUT) adds its memory effect for a given waveform  $A$ , so that the output signal  $M$  includes all memory effects.

In our approach to pre-distort each individual sample of  $A$ , so that the output signal  $M$  comes as close to the original signal  $A$  as possible, it is obvious that a single execution of this step is not sufficient, as soon as the DUT shows significant memory effect or significant non-linear behavior.

So in order to pre-distort all significant memory effects, our sample based approach works iteratively. Figure 3 shows the iterative approach. Initially,  $P_0$  corresponds to the original signal A. Our DSP (digital signal processor) calculates the first pre-distorted signal  $P_1$ , based on the initial measurement  $M_0$ . The three steps shown in Figure 3 repeat until the results converge, i.e. in terms of EVM or ACLR.

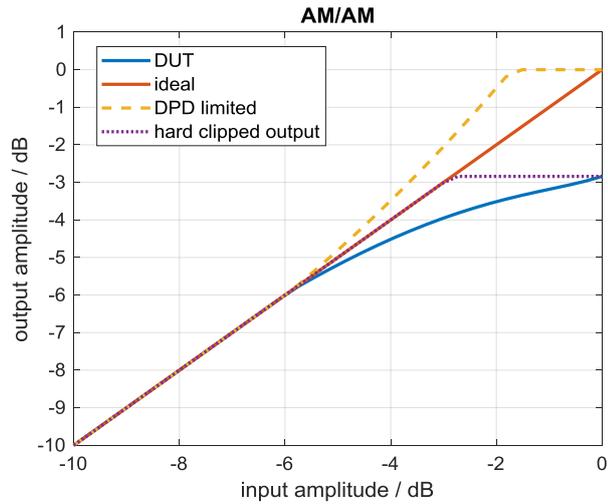


Figure 4 Overview plot: measured AM/AM, ideal output, pre-distorted input signal, and target output signal (hard clipped)

Since any real DUT has a maximum output power, this approach is likely to increase certain input samples to an infinite amplitude (see and extrapolate dashed line in Figure 1). Consequently, the R&S®FSW-K18D DSP limits the maximum input power of any pre-distorted signal in the iteration  $P_k$  to the maximum input power of the original signal A. This limitation not only protects the DUT from excessive input power, but also keeps the algorithm from generating infinite signal amplitudes (compare dashed line in Figure 4 to dashed line in Figure 1).

The target output amplitude is therefore not the ideal (linear) line, but a hard clipped version of the ideal line. Figure 4 shows a dotted line representing the target output AM/AM curve. Due to the maximum output power given by the DUT, a linear result is not possible. The direct DPD approach linearizes as long as possible and clips afterwards.

Today's communication signals have high PAPRs (peak-to-average-power-ratios) especially OFDM signals easily show a PAPR of 10 dB and more. Therefore, the RMS power of the input signal will be more than 10 dB below the maximum input power.

Using the graph in Figure 4 as a reference, the RMS power (and therefore the majority of samples) will remain on the linear range. In the above example, all input samples with a power of 3 dB below peak power or less will be linearized, whereas only samples in the upper 3 dB range of

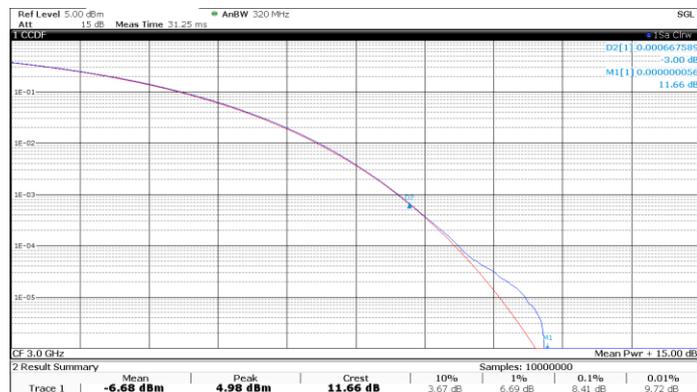


Figure 5 CCDF of a 113 MHz OFDM signal, showing a PAPR of 11.7 dB, delta marker 3 dB below peak shows .067 % probability for a signal level above the marker

power levels will be clipped.

Figure 5 shows a cumulative complementary distribution function (CCDF) of a wideband OFDM signal. In short, the graph shows that only one out of 1500 (.067 %) samples in the signal exceeds the 3 dB range of our exemplary device and will therefore be clipped instead of being linearized.

## **2.2 Influence of Noise**

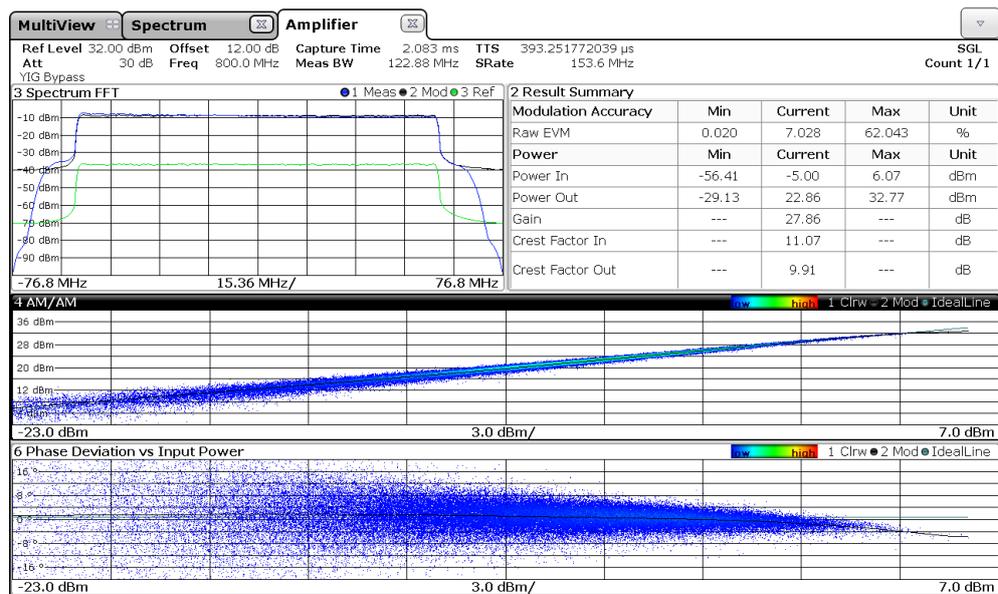
When comparing a measured signal to an ideal one, noise will make up for a significant portion of the difference. Every active part in the measurement setup adds extra noise, including the DUT as well as the measurement instruments. All noise contributions add up and reduce the signal-to-noise-ratio in the measured signal. So direct DPD requires a method to minimize the influence of noise or to separate noise and non-linearity influences.

The amplifier measurement options R&S®FSW-K18 and R&S®FPS-K18 provide a mechanism called I/Q Averaging to minimize the influence of noise, before passing on the measured signal to the direct DPD processor.

I/Q Averaging averages the real and imaginary components of a complex baseband signal separately. It requires time and phase synchronous data acquisitions, as otherwise the averaging would cancel out noise as well as the signal itself. Time and phase synchronization between captures is inherent to the data, as every individual acquisition is synchronized to a known reference signal. Therefore, all data acquisitions are also mutually synchronous.

## 3 Measurement

This chapter shows examples for in-band performance improvements (EVM) as well as for out-of-band performance improvements (ACLR) using the DPD approach discussed above. Figure 6 shows the raw performance of the DUT. The screenshot shows a spectral plot of reference and measured signal, as well as a table containing numeric results for power and modulation accuracy. The bottom plots characterize the DUT in terms of non-linearity. Both plots, AM/AM as well as AM/PM show significant non-linearities above 0 dBm of input power. The AM/AM curve bends away from its constant grade, resulting from a decreasing gain. The AM/PM plot bends away from the flat "0" line. The "0" line indicates no dependency between amplitude and phase. In addition, both curves have a certain width, i.e. a single input amplitude corresponds to a number of different output amplitudes or phase differences. The curve width results from memory effects. In the frequency domain, memory effects show up as frequency response, i.e. amplitude and phase response vs. frequency. Frequency response translates to various output amplitudes even for a constant amplitude input signal. Output amplitude in this case depends on the instantaneous frequency of the input signal.



**Figure 6 AM/AM and AM/PM plots for a distorted wideband signal. Significant memory effect is present (width of lines)**

Figure 7 shows the result of the direct DPD. With the pre-distorted signal applied, the AM/AM curve is linear up to the clipping point, whereas the AM/PM curve is completely flat. Consequently, the EVM improved significantly compared to the original signal (7.2% vs. 1.8%).

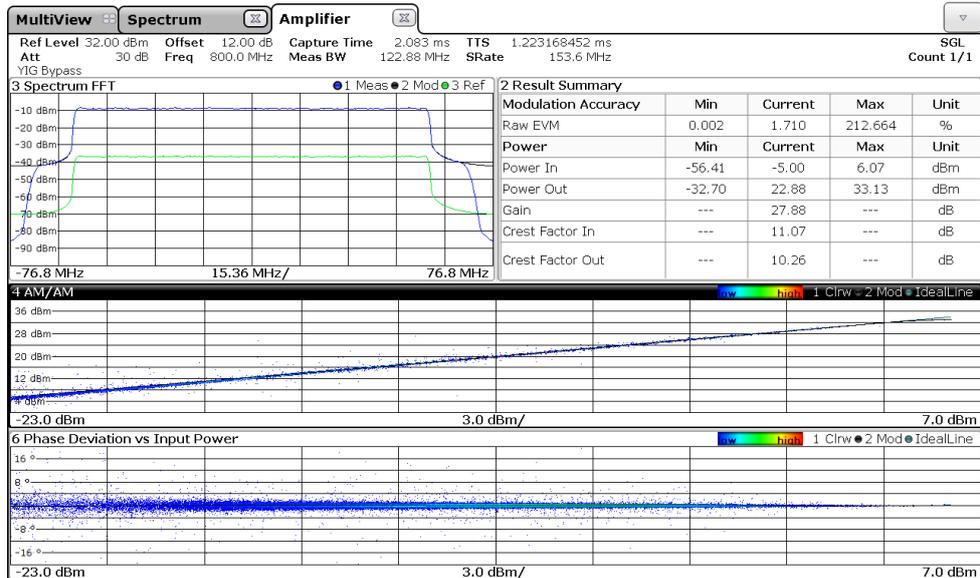


Figure 7 AM/AM and AM/PM curve of pre-distorted signal showing significant improvement

Figure 8 compares out-of-band emissions with and without pre-distortion. The ACLR measurement with pre-distortion (blue trace) shows 23 dB less power in the adjacent channels (ACLR improvement).

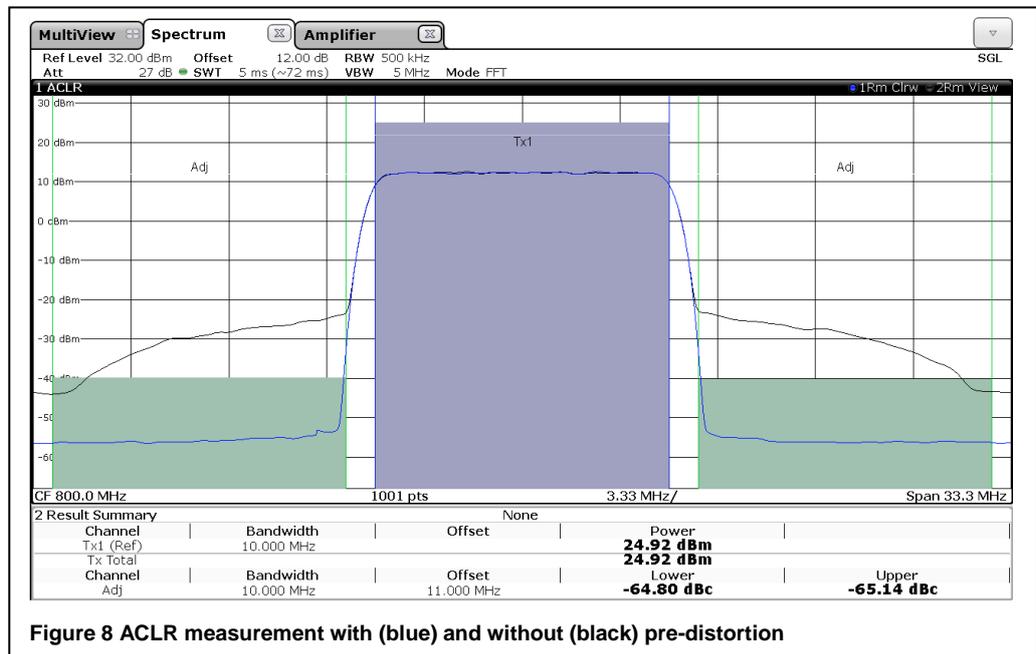


Figure 8 ACLR measurement with (blue) and without (black) pre-distortion

## 4 Summary

This paper presents direct DPD, a method to pre-distort a given signal, so that the output of the DUT matches the characteristics of a hard clipper.

The approach iteratively pre-distorts each individual sample of the input signal to improve EVM and ACLR of the output signal.

It is an ideal method to compare the performance of DUTs under DPD conditions, without the need to optimize a DPD algorithm for each DUT individually.

Direct DPD speeds up DPD algorithm development as well. A DPD algorithm developer may compare the output of his algorithm to the pre-distorted waveform from direct DPD and evaluate the performance of his algorithm based on this comparison.

## 5 Ordering Information

Designation	Type	Order No.
Amplifier Measurements Application	R&S®FSW-K18	1325.2170.02
Direct DPD Measurements	R&S®FSW-K18D	1331.6845.02
Amplifier Measurements Application	R&S®FPS-K18	1321.4662.02
Direct DPD Measurements	R&S®FPS-K18D	1321.4956.02

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## Sustainable product design

- Environmental compatibility and eco-footprint
- Energy efficiency and low emissions
- Longevity and optimized total cost of ownership



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