K18D MATLAB Modeling Toolkit
Application Note

Products:

- R&S®FSW-K18D
- R&S®FSV3-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.

The R&S K18D application family offers a very easy-to-use method to pre-distort amplifiers without modelling the DUT.
However, many engineers in PA design request a simple and easy-to-use tool that delivers a DPD model applicable to any real-world signal.

This application note with the accompanying software tool allows engineers without in-depth knowledge of DPD or remote programming to generate a DPD model and verify it against the DUT, based on the results of the K18D application.

Note:

Please find the most up-to-date document on our homepage http://www.rohde-schwarz.com/appnote/1EF105.

This document is complemented by software. The software may be updated even if the version of the document remains unchanged

Application Note
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1 Introduction

Today's amplifiers are highly optimized designs by means of efficiency. This applies not only to battery powered mobile devices, but also to higher power applications for example base stations or other transmitters, as the power consumption (for both operation and cooling) is the main contributor to operational expenses.

Along with the omnipresent efficiency requirement, carrier frequencies and bandwidths increase to satisfy the end user’s demand for more throughput. All these factors create a challenge the PA designer.

Consequently, the use of pre-distortion techniques is mandatory, even though these techniques require significant computational effort.

A key requirement for any PA vendor is to provide specification values of the amplifier under DPD conditions. Even though the PA might be sold without the accompanying DPD algorithm, it is definitely a huge competitive advantage if your amplifier comes together with an algorithm for DPD.

With the R&S K18 (Amplifier Measurements including memory-less polynomial DPD) and K18D (Direct DPD), Rohde & Schwarz provides measurement applications that simplify PA verification dramatically.

This application note takes DPD a step further and allows the user to derive a memory polynomial directly from the result of K18D, without any DPD or programming language. The memory polynomial (or any other DPD model) is the basis for real-time pre-distortion on a real-world signal.

Note: To get started immediately, directly continue with chapter 3.

2 Modelling DPD

2.1 Iterative Direct DPD

During the design phase of a power amplifier, it is important to quickly analyze the performance of the current design under DPD conditions or compare it to a different design. The K18D, Direct DPD application (see [1]) provides this analysis and comparison. Direct DPD quickly provides a highly linearized output signal, but does not derive a model. It compares the measured output of a DUT to the ideal reference signal on a sample-by-sample basis, and modifies each sample individually in amplitude and phase to derive the pre-distorted signal *P* (Fig. 2-1). Due to the non-linearity of the DUT, iterative usage of Direct DPD is highly recommended. Iterative Direct-DPD will converge after typically 5-10 iterations. Instrument noise and dynamic range will limit the performance, but techniques such as I/Q Averaging (see [1]) greatly reduce these effects.

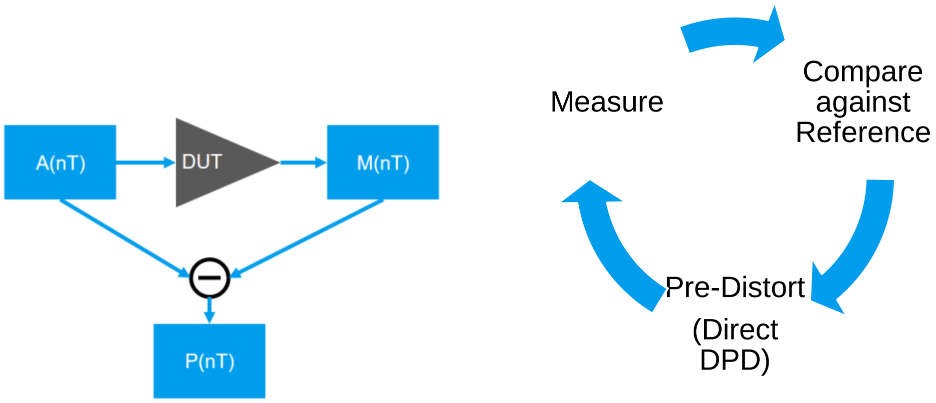

Fig. 2-1: (a, left) Direct DPD, where each sample of a reference signal *A* is compared against each sample of the output signal *M* of the DUT, and a pre-distorted signal *P* derived. Direct DPD delivers best results when operated iteratively in a loop (b, right).

2.2 Complexity of DPD Models

Any system integrator planning to use a PA under DPD conditions will require the PA vendor to specify its performance under modelling DPD, i.e. real-world DPD conditions (see Fig. 2-2).

Narrow bandwidth mobile devices often limit the DPD model complexity to memory-less polynomial models. These are easy to fit – the R&S FSW-K18 for example can directly deliver the polynomial coefficients. However, the larger the bandwidth, the higher the demand for memory modelling.

Memory modelling introduces a significantly higher computational complexity. Consequently, significant R&D effort is put into finding the best model for a given PA design and signal type. The meaning of “best” may vary, as it will always be a trade-off between linearity and complexity.

Popular models are the Volterra series, memory polynomial, generalized memory polynomial, or the Wiener and Hammerstein models.

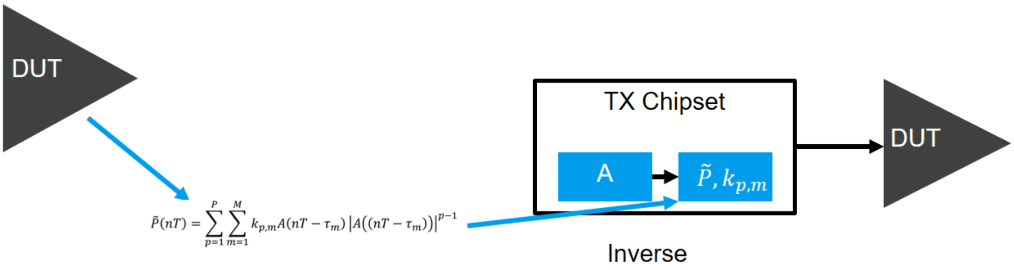

Fig. 2-2: Schematic of a DUT applying DPD to a signal in real-time.

2.3 From Direct DPD to Model DPD

The "K18D Modeling Toolkit" provided with this application note derives coefficients for a memory polynomial, based on the pre-distorted waveform resulting from K18D.

The toolkit uses MATLAB to find the coefficients. The toolkit comes with a set of MATLAB functions that follow the equation below.

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

It solves the equation by replacing the unknown model DPD signal $\tilde{P}$ by the known iterative Direct DPD result P (see chapter 2.1). Since *A* is the known reference signal, the resulting equations can be solved for $k_{p,m}$.

The equations will be solved not only for one pre-distorted signal *P*, but for all signals P_n resulting from *N* iterative Direct DPD steps, as show in Fig. 2-3. This allows the user to pick the best fit.

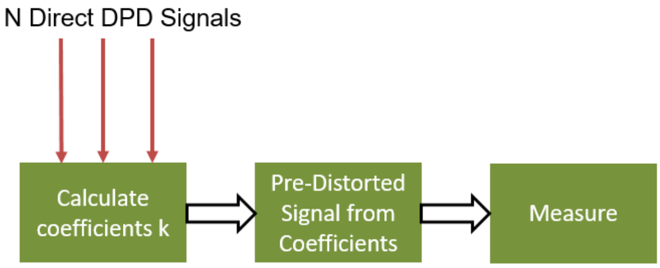

Fig. 2-3: Signal flow for the Modelling Toolkit. For each iteration step of Direct DPD, coefficients are calculated and a pre-distorted signal based on the model is created.

3 K18D Modeling Toolkit

This chapter describes the fast track from a measurement setup as in Fig. 3-1 to a model based DPD.

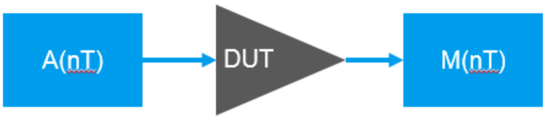

Fig. 3-1:Test setup when using the K18D Modeling Toolkit. A signal A (typically from a vector signal generator) is fed into the DUT. The DUT output signal is measured (typically with a vector signal analyzer).

The Modelling Toolkit SW has a header line, providing an icon for each required step towards the model DPD (see Fig. 3-2).

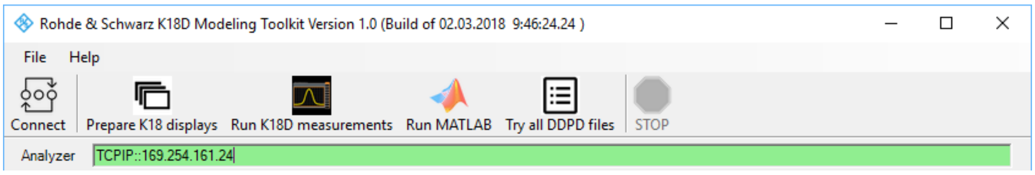

Fig. 3-2: Icons in the Modelling toolkit describing the six steps from the measurement setup to a model based DPD.

1. Configure the K18 on your measurement instrument so it successfully synchronizes on the reference signal. This is the only manual step. It allows maximum flexibility, since any input signal (OFDM, single carrier, pulsed, chirped, etc.) is accepted. (Note: since direct access to the signal is necessary, encrypted signals cannot be used, e.g. generated by a generator application).

2. Connect to the instrument measuring the output signal (e.g. R&S FSW or R&S FSVA3000). K18 must be open and running on the instrument. The instrument address is specified using the VISA resource string. To connect to an instrument with IP address "169.254.161.24" use the resource string "`TCPIP::169.254.161.24`" or "`TCPIP::169.254.161.24::HISLIP0`" for the faster HiSLIP connection. The resource string for a GPIB connected instrument with address 20 is "`GPIB0::20`".

3. Prepare K18 displays. This step ensures the necessary measurements in K18 are switched on, e.g. the ACLR measurement.

4. Run K18D measurements. Runs the iterative Direct DPD on the connected instruments resulting in N pre-distorted signals P_n, where N is the number of Direct DPD steps. Modelling Toolkit will save all pre-distorted signals into the data storage folder (default: ".\Data"), with filename "K18DD_iterated*n*.wv", where n is the iteration step.

5. Run MATLAB. Runs the coefficient finding using the specified MATLAB functions. This step results in N pre-distorted signals $\tilde{P}_n$ generated by a memory polynomial with coefficients $k_{m,p}^{n}$. Modelling toolkit will save all pre-distorted signals into the data storage folder, with filename "K18DD_calculated*n*.wv", where n is the iteration step.

6. Try all DPD. This step will verify all signals from Direct DPD as well as from the model DPD. It will show ACLR and EVM results for each (pre-distorted) signal.

7. Find the coefficients of the last step in “vfcCoeffs.bin” in the data storage folder or run “RunModelling.m” (also in data storage folder) and adjust the file names within the MATLAB function to any other signal from the previous steps.

```
13:38:22|Iteration| Raw |  Output   |Curve width|     SMx    |      ACP     |
13:38:22|    #    | EVM | RMS |Crest|AM/AM|AM/PM| RMS  | Peak |Left  |Right |
13:38:27| Original| 5.61|21.11| 4.69|0.097|2.120| -5.00| 1.405| -41.2| -41.6|
13:38:32|    MEAS1| 1.33|21.04| 4.91|0.018|0.282| -5.00| 1.409| -45.9| -46.3| (K18DD_iterated2.wv)
13:38:38|    MEAS2| 1.01|21.10| 4.93|0.016|0.187| -4.93| 1.413| -47.7| -47.7| (K18DD_iterated3.wv)
13:38:43|    MEAS3| 0.93|21.04| 5.03|0.016|0.186| -4.98| 1.413| -48.3| -48.1| (K18DD_iterated4.wv)
13:38:49|    MEAS4| 0.91|21.10| 4.99|0.016|0.180| -4.92| 1.417| -48.5| -48.3| (K18DD_iterated5.wv)
13:38:54|    MEAS5| 0.92|21.05| 5.03|0.016|0.183| -4.97| 1.420| -48.5| -48.4| (K18DD_iterated6.wv)
13:39:00|    MEAS6| 0.91|21.09| 4.97|0.016|0.181| -4.92| 1.418| -48.4| -48.3| (K18DD_iterated7.wv)
13:39:05|    MEAS7| 0.92|21.05| 5.01|0.016|0.188| -4.97| 1.414| -48.5| -48.4| (K18DD_iterated8.wv)
13:39:11|    MEAS8| 0.89|21.09| 4.96|0.016|0.168| -4.92| 1.414| -48.5| -48.4| (K18DD_iterated9.wv)
13:39:16|    MEAS9| 0.91|21.05| 4.99|0.016|0.183| -4.96| 1.418| -48.5| -48.4| (K18DD_iterated10.wv)

13:39:22|    CALC1| 1.50|21.03| 4.89|0.026|0.511| -5.00| 1.409| -47.2| -47.4| (K18DD_iterated2_calculated.wv)
13:39:27|    CALC2| 1.46|21.09| 4.89|0.026|0.512| -4.93| 1.413| -47.6| -47.8| (K18DD_iterated3_calculated.wv)
13:39:33|    CALC3| 1.47|21.03| 4.97|0.026|0.515| -4.98| 1.413| -47.5| -47.8| (K18DD_iterated4_calculated.wv)
13:39:38|    CALC4| 1.48|21.09| 4.92|0.026|0.515| -4.92| 1.417| -47.1| -47.4| (K18DD_iterated5_calculated.wv)
13:39:44|    CALC5| 1.50|21.04| 4.97|0.026|0.516| -4.97| 1.420| -47.0| -47.3| (K18DD_iterated6_calculated.wv)
13:39:49|    CALC6| 1.49|21.08| 4.92|0.026|0.513| -4.92| 1.418| -46.9| -47.1| (K18DD_iterated7_calculated.wv)
13:39:55|    CALC7| 1.50|21.03| 4.97|0.025|0.516| -4.97| 1.414| -46.9| -47.1| (K18DD_iterated8_calculated.wv)
13:40:00|    CALC8| 1.51|21.08| 4.92|0.026|0.518| -4.92| 1.414| -46.8| -47.1| (K18DD_iterated9_calculated.wv)
13:40:06|    CALC9| 1.51|21.04| 4.96|0.026|0.514| -4.96| 1.418| -46.9| -47.1| (K18DD_iterated10_calculated.wv)
```

Fig. 3-3: Table with results from Direct DPD (iterated) and modelling DPD (calculated).

4 Fine Tuning Measurement and Modelling

The Modelling toolkit delivers results in just six steps. However, it can be configured in a number of ways. This chapter discusses the SW prerequisites and configuration parameters.

4.1 Pre-requirements and installation

The software requires

- A R&S instrument running the K18D connected via LAN, USB or GPIB bus to the PC the software is running on
- A VISA installation on the PC the software is running on
- A MATLAB installation (and valid MATLAB licence) on the PC the software is running on
- A 64-bit Windows operating system

The software does not require an installation – the executable may be placed in any folder.

4.2 Results

The modelling toolkit will save all resulting files into the "\Date" subfolder. The following files will remain in the folder after running the modelling toolkit.

K18DD_iterated1.wv	Files generated from the K18D during iteration.
K18DD_iterated1.mat	MATLAB vectors containing the WV file data.
K18DD_iterated1_calculated.wv	Files calculated from the toolkit script file.
K18DD_iterated1.wv.png	FSx screenshots – K18D file
K18DD_iterated1_calculated.wv.png	FSx screenshots – MATLAB file

4.3 Configuration Parameters

The modelling toolkit provides a number parameters that significantly influence the behavior of the measurement and modelling.

1. MATLAB Environment	
a) Data storage folder	Within this folder WV, MAT and other data files are stored during processing, by default this is "Data".
b) DSP files folder	This folder contains all M files that are used during MATLAB signal processing (memory modeling, …). The default is "DSP".
c) M file to run	Modelling Toolkit uses this MATLAB script to generate a pre-distorted signal from the previously generated DPD model. You may adapt or replace this script. File must be located in the DSP files folder.
d.1) REF vector name	Name of the MATLAB variables used (REF and D-DPD are used to generate the calculated vector; the used memory polynomial parameters are stored in the parameter file).
d.2) D-DPD vector name	
d.3) Calculated vector name	
d.4) Parameter file name	
e) M function to call	This M function must be stored in the DSP files folder and is called from "M file to run" to do the modeling work.
f) Plot results?	If selected, MATLAB plots with detailed results will be shown.
g) Show MATLAB output?	If selected, detailed MATLAB outputs are displayed (the console output of MATLAB during processing).
2. Measurement setup	
a) Root file name	Files generated from the modeling toolkit start with this name.
b) IQ averaging count	Number of I/Q averages to remove noise influence on the measurement - enter 0 to disable I/Q averaging.
c) Direct-DPD iterations	Number of Direct-DPD iterations - the distortion compensation should become better with each step and settles somewhere.
d) Power / linearity tradeoff	Select a value between 0% (max linearity) and 100% (max output power) as Direct DPD optimization criteria.
e) Generator RMS level	RMS signal level of the input signal to the DUT
f) Store screenshots	Store hardcopies of the measuring instrument (e.g. R&S FSW) during the measurement.

3. Memory polynomial model	
a) Memory depth	Memory depth ("filter taps") of the memory polynomial model.
b) Polynomial order	Polynomial order ("non-linearity") of the memory polynomial model.
c) Training vector length	Use the specified (limited) number of samples for model calculation in order to speed processing on long signals. Use 0 to indicate to use the complete signal.

4.4 MATLAB interoperation and signal processing

The Modeling Toolkit will automatically detect a MATLAB installation, automate it via the COM interface and start all processing steps. There is no need to start MATLAB manually.

The modeling toolkit auto-generates a script file called “RunModeling” (you can set the name in the modeling toolkit GUI as well as the other parameters used).

The script file will load both reference and DDPD file, normalize it to an amplitude of 1 (which makes signal processing easier to understand), call the modeling function “DPDModelSynthesis”, save the generated output files and the memory polynomial coefficients.

- By default, there are three MATLAB files installed with the modeling toolkit:
  - “DPDModelSynthesis” – the root function that is called.
  - “MemModeling” – this function calculated the model of the pre-distorter
  - “MemApply” – this function applies the model to a given input signal

5 Literature

[1] **Dr. Ramian Florian** 1EF99: Iterative Direct DPD [Online]. - Rohde & Schwarz, 9 13, 2019. - 1e. - https://www.rohde-schwarz.com/applications/iterative-direct-dpd-white-paper_230854-478144.html.

6 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®FSV3-K18	1346.3347.02
Direct DPD Measurements	R&S®FSV3-K18D	1346.3353.02
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

Certified Quality Management
ISO 9001

Certified Environmental Management
ISO 14001

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