# Measuring the Dynamic Characteristic of High-Frequency Amplifiers with Real Signals

**Martin Weiß**

Rohde & Schwarz GmbH & Co. KG, Test and Measurement Division
Muehldorfstraße 15
81671 Muenchen
Phone: +49 89 4129 11694
Fax: +49 89 4129 12131
E-Mail: Martin.Weiss@RSD.ROHDE-SCHWARZ.COM

## Abstract

A new method for measuring non-linear parameters of RF-amplifiers with real signals was developed and tested. The aspired decrease in ACP could be reached with varios amplifiers by predistoring the input signals of the amplifiers, and the characteristic curves could be measured.

## 1. Introduction

The increasing scarcity of the resource frequency is forcing manufacturers of mobile radio equipment to use better and thus inevitably more expensive high-frequency amplifiers to meet the requirements for adjacent-channel power (ACP), modulation quality etc. More and more efforts are thus required to improve the amplifiers in a simple way without additional costs involved.

As far as broadband signals are concerned, these tried and tested methods unfortunatly involve a number of partly unsolved problems such as:

- Feed-forward control becomes more and more expensive with increasing bandwidth
- Feed-back control involves higher noise with increasing bandwidth
- Measurement with a network analyzer does not show the characteristic expected when driving with broadband input signals. This is due to different characteristics of the amplifier, e.g. memory effects, temperature drift etc.

Therefore, a new method has been developed to better characterize the amplifier.

## 2. New Method

### 2.1. Introduction

With the new method presented in the following it is possible to determine the AM/AM and AM/PM characteristic by driving the amplifier with a real signal (e.g. W-CDMA, IS-95,...) or a signal similar to the signal characteristic (e.g. band-limited noise).

### 2.2. Measurement setup

**Fig. 1** shows a block diagram of the measurement setup.
The measurement signal is generated by the measurement software which runs on a external computer, loaded in an arbitarary waveform generator, converted into the RF and applied to the amplifier (DUT = device under test). The amplifier output signal is down-converted again into the baseband and sampled.

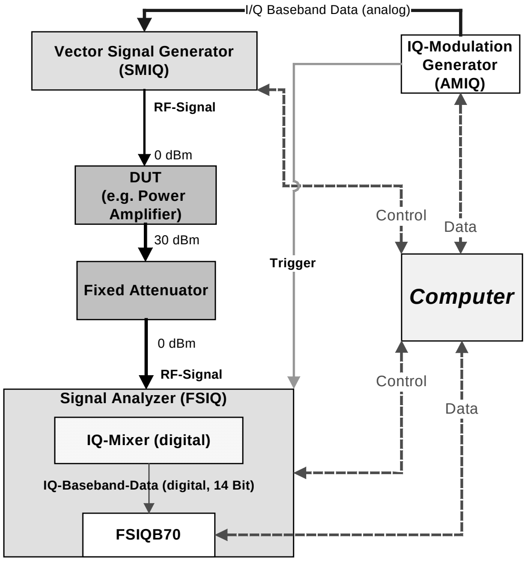


**Fig. 1:** Test setup

Thus, two data sets with complex digital IQ data - the data which are generated by the measurement software and the measured IQ data at the output of the DUT - are available which

- generally show different levels
- have a time offset to each other
- are AM/AM and AM/PM distored

## 2.3. Signal processing

The level difference is eliminated by a previous reference measurement. This can be done by replacing the DUT by a direct connector and making a reference measurement or by decreasing the level to a point where the DUT is in linear operation and making a measurement at this point of operation.
To eliminate the time offset (between the reference measurement and the measurement at the amplifier output) both signals are subject to FFT, the phases are deducted from each other in the frequency domain and a regression calculation is carried out over the linear phase obtained by the time offset of the two measurements:

If 2 measurements $x_1(t)$ and $x_2(t)$ only show a different timing, that means

$$x_2(t) = x_1(t-\tau)$$

then the timing difference can be derived by

$$\begin{aligned}
x_1(t) &\xrightarrow{\text{FFT}} X_1(f)\\
x_2(t)=x_1(t-\tau) &\xrightarrow{\text{FFT}} X_2(f)=X_1(f)\cdot e^{-j\cdot 2\cdot\pi\cdot f\cdot\tau}\\
\operatorname{corr}(x_1(t),x_2(t)) &\xrightarrow{\text{FFT}} X_1(f)\cdot X_2^*(f)=\left|X_1(f)\right|^2\cdot e^{j\cdot 2\cdot\pi\cdot f\cdot\tau}
\end{aligned}$$

$$\Rightarrow \arg\left(\text{FFT}\left(\operatorname{corr}\left(x_1(t),x_2(t)\right)\right)\right)=2\cdot\pi\cdot f\cdot\tau$$

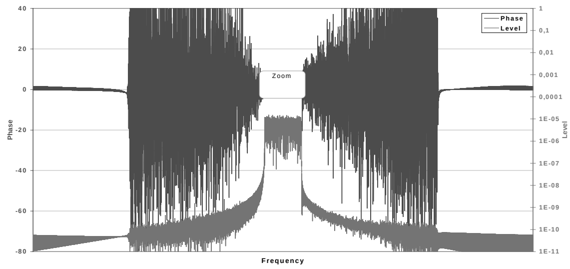


**Fig. 2:** FFT(corr($x_1$,$x_2$))

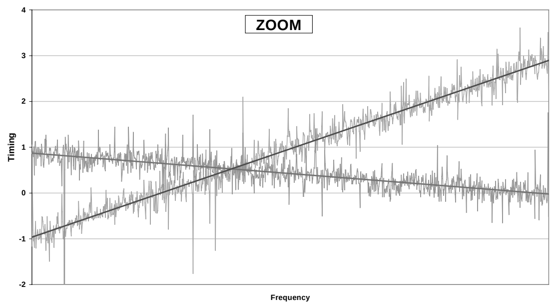


**Fig. 3:** Zoomed image (for pos. and neg. $\tau$)

This method does not depend on the nonlinear effects of the amplifier because these effects are too small compared with the effect of timing offset.
The timing offset thus determined is corrected in the frequency domain so that level-normalized and phase-locked IQ data are available by retransformation into the time domain.
This data is diveded into amplitude and phase, then entered as coordinates according to the definition of AM/AM and AM/PM compression, and a functional relationship, ie the numeric values for the amplifier characteristic, is obtained by regression.
At the current state of developement, this calculation is done by using the following statements:
With $x_i$ as reference signal (e.g. amplifier input amplitude) and $y_i$ as measured signal (e.g. amplifier output amplitude), we try to minimize the following statement:

$$S(a_0,a_1,\ldots,a_q) := \sum_{i=1}^{N}\left(y_i - p(x_i)\right)^2 \overset{!}{=} \min$$

$$p(x)=\sum_{i=0}^{q} a_i\cdot x^i$$

This is done by solving the following expression:

$$\begin{pmatrix}
\sum x_i^0 & \sum x_i^1 & \sum x_i^2 & \ldots & \sum x_i^q\\
\sum x_i^1 & \sum x_i^2 & \sum x_i^3 & \ldots & \sum x_i^{q+1}\\
\sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \ldots & \sum x_i^{q+2}\\
\ldots & \ldots & \ldots & \ldots & \ldots\\
\sum x_i^q & \sum x_i^{q+1} & \sum x_i^{q+2} & \ldots & \sum x_i^{q+q}
\end{pmatrix}\bullet\begin{pmatrix}a_0\\a_1\\a_2\\\ldots\\a_q\end{pmatrix}=\begin{pmatrix}\sum y_i\cdot x_i^0\\\sum y_i\cdot x_i^1\\\sum y_i\cdot x_i^2\\\ldots\\\sum y_i\cdot x_i^q\end{pmatrix}$$

The results of this calculation are the values of $a_i$ which are the coefficients of the polynomial which describe the characteristic curve of the DUT.
(Is is also possible to use spline calculation or a combination of spline and polynomial regression.)
**Fig. 4** shows the result of a timing corrected measurement with polynomial curve included for a AM/AM characteristic curve.

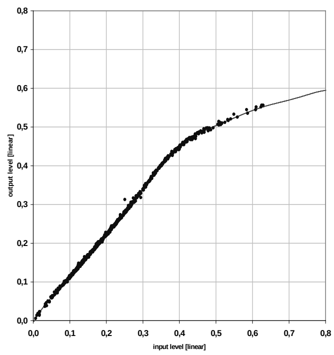


**Fig. 4:** measured AM/AM curve

## 2.4. Verification

To prove that the recorder characteristics are really the dynamic characteristics of the amplifier, the IQ data set which was generated by the measurement software is precorrected with an inverse characteristic to perform an AM/AM and/or AM/PM characteristic measurement or to determine the improved ACP rejection in the frequency domain.
**Fig. 5** shows the necessary AM/AM-predistortion curve. Due to the limited output power of the DUT which can not be improved by predistortion, driving the DUT over the "cut-off point" does not make sense. Thus, the input amplitude is limited as shown.

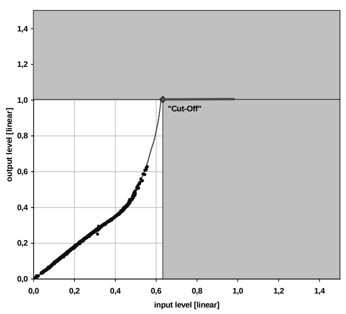


**Fig. 5:** predistortion curve (AM/AM)

## 2.5. Summary

By taking reference and measured IQ data, estimating and eliminating the timing offset by FFT and I-FFT, calculation amplitude and phase and regression, the AM/AM- and AM/PM characteristic curves can be measured.

# 3. Results

## 3.1. Measured curves

**Fig. 6 and 7** shows the measured AM/AM and AM/PM curves compared with the results of a measurement with a vector network analyzer.
There are significant differences between the curves measured with a vector network analyzer and the curves measured with the new method.
The results with the new method are much more reproduceable as with a vector network analyzer as well.

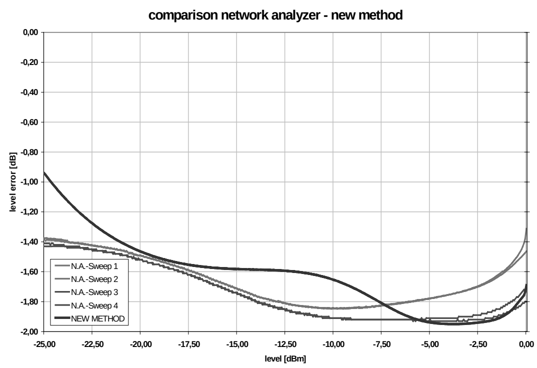


**Fig. 6:** AM/AM curves

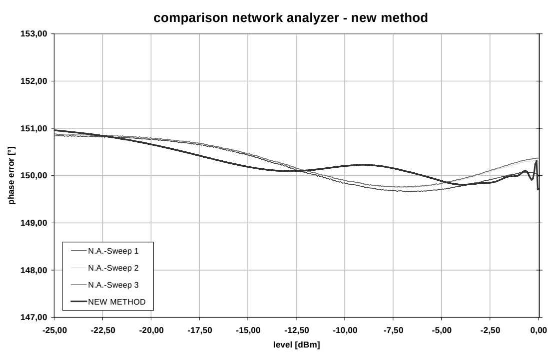


**Fig. 7:** AM/PM curves

## 3.2. Improvement in ACP

To test the derived methods, a pseudo-noise signal with 1 MHz bandwidth was measured, predistored and compared with the original signal at the output of the DUT. To see the results, the level was sweeped over a certain range, and the ACP in a 1 MHz wide channel, spaced 1.1 MHz from the main channel, was measured. **Fig. 8** shows the results:

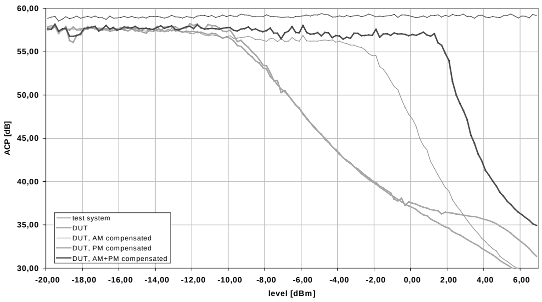


**Fig. 8:** Result of compensation

The first curve at the top of the diagramm shows the noise floor of the test system which generates about 59 dB constant ACP power rejection.
The curve of the DUT shows the same ACP power as the test system (1 dB increased due to additional noise of the amplifer), but at about -10 dBm input power, the ACP power rejection decreases constant up to 30 dB at +6 dBm input power due to nonlinear effects of the amplifier.
By compensating the nonlinear DUT via AM/AM predistortion, the inflexion point can be moved from -10 dBm to -3 dBm, for AM/AM and AM/PM event to +1 dBm. Using AM/PM compensation without AM/AM does not move the inflexion point because the AM/AM distortion is the dominant factor for this DUT.
**Fig. 9** shows the results of a AM/AM and AM/PM compensation at +2 dBm output power in frequency domain, applied to a 5 MHz noise signal.

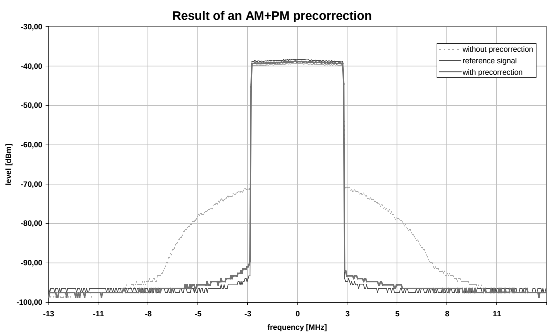


**Fig. 9:** Results of pre-distortion in frequency domain

## 3.3. Error vector magnitude

**Fig. 10** shows the improvement in error vector magnitude (EVM) with predistortion:

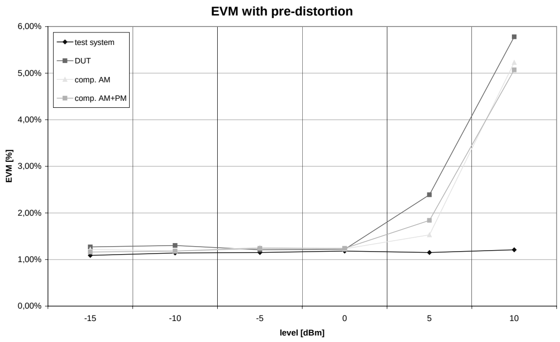


**Fig. 10:** improvement in EVM

If the DUT is not driven over the "cut-off point", the EVM could be reduced from 2,4 % to 1,5 %.
With other amplifiers, more improvement in EVM could be achieved.

# 4. Biography

**Martin J. Weiß** was born in Munich, Germany, in 1976. He received the Dipl. Ing. in electrical and communication engineering from the Technical University of Munich in 2000.
In 1998 he joined Rohde & Schwarz GmbH & Co. KG, Munich, Germany. He is engaged in support for the RF measurement equipment end developes new methods for amplifier measurement.
M. Weiss is member of the VDE and the ITG.