Check Amplifier Dynamic Behavior With True Test Signals

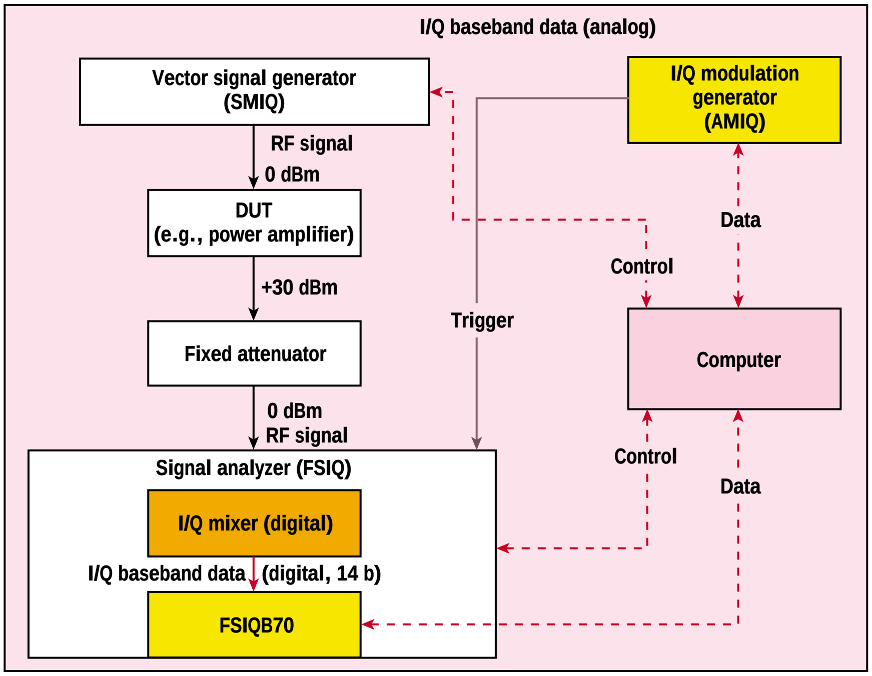
This new measurement technique uses Fast Fourier transform (FFT) techniques and predistortion to analyze amplifier characteristics.

Martin Weiss
Applications Engineer
Rohde & Schwarz GmbH & Co. KG,
Test and Measurement Div.,
Muehldorfstrasse 15, 81671 Munich,
Germany; (49) 89 4129 11694, FAX:
(49) 89 4129 12131, e-mail:
Martin.Weiss@rsd.rohde-schwarz.com, Internet:
http://www.rohde-schwarz.com.

AMPLIFIER quality is often evaluated with less-than-ideal test signals and measurement systems. Amplifiers for wireless communications systems, for example, are commonly tested with vector-network analyzers (VNAs) better suited for low-level linear-signal characterization. Due to a need to better understand the nonlinear behavior of large-signal RF amplifiers, a new method was developed for measuring amplifier nonlinear parameters. By predistorting the input signals to an amplifier under test, it was possible to decrease the level of adjacent-channel power (ACP) and thus more accurately evaluate amplifier amplitude-modulation/amplitude modulation (AM/AM) and amplitude-modulation/phase-modulation (AM/PM) performance.

In any wireless system, bandwidth is an expensive and limited resource. Service providers who have made large investments to license portions of available cellular and personal-communications-services (PCS) bands must recoup their investments by maximizing the number of subscribers served per cell and per channel. Because modern wireless communications systems are based on complex digital modulation schemes in order to increase the amount of information transmitted per bandwidth unit, increasing demands are placed on the transmit power amplifiers (PAs) to maintain a high degree of linearity even when boosting complex modulated signals. Excessive levels of ACP, for example, can disrupt the performance of nearby cells and prove costly to system operators in terms of lost coverage and subscribers. As a result, it is critical to accurately test the single-carrier and multicarrier PAs used in cellular and PCS systems.

But testing these amplifiers is not trivial. As far as broadband signals are concerned, these tried-and-tested methods unfortunately involve a number of partly unsolved problems



1. This block diagram shows the test setup used to demonstrate amplifier AM/AM and AM/PM characteristics by using accurate test signals.

such as:

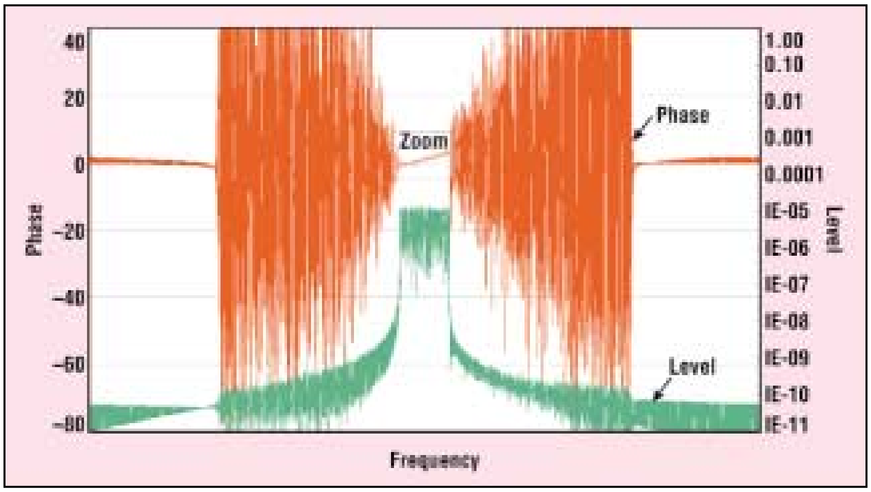
- Feedforward control becomes more expensive with increasing bandwidth.
- Feedback control involves higher noise with increasing bandwidth.
- Measurement with a network analyzer does not show the characteristic expected when driving with broadband input signals. This is due to different characteristics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

Due to the limitations of traditional measurement methods in characterizing cellular/PCS amplifiers, it was necessary to develop a new characterization technique that would rely on using test signals that were truer representations of the actual signals used in a communication system. With this new method, it is possible to determine an amplifier's AM/AM and AM/PM characteristics by using realistic test signals (such as band-limited noise) to emulate actual communications channels.

Figure 1 shows a block diagram of the measurement setup. The measurement signal is generated under the control of measurement software running on an external computer. The software code is loaded into an arbitrary waveform generator, converted to RF signals by means of a high-resolution digital-to-analog converter (DAC), and applied to the device under test (DUT). The amplifier or DUT's output signals are downconverted to baseband signals and then sampled.

With this measurement setup, two sets of complex in-phase/quadrature (I/Q) data are created—the data generated by the measurement software and the data measured at the output of the DUT. The two sets of data have a time offset and generally show different levels, due to the AM/AM and AM/PM distortion.

The differences in levels between the two sets of signal data can be eliminated by a reference measurement. This is done by replacing the DUT with a direct connection and making the measurement, or by decreasing the signal level to a point where the DUT operates in a linear region, then making the measure-



2. The FFT correlation, FFT[corr(x1, x2)], can be seen here for the phase and amplitude level of a sample amplifier.

ment at this point.

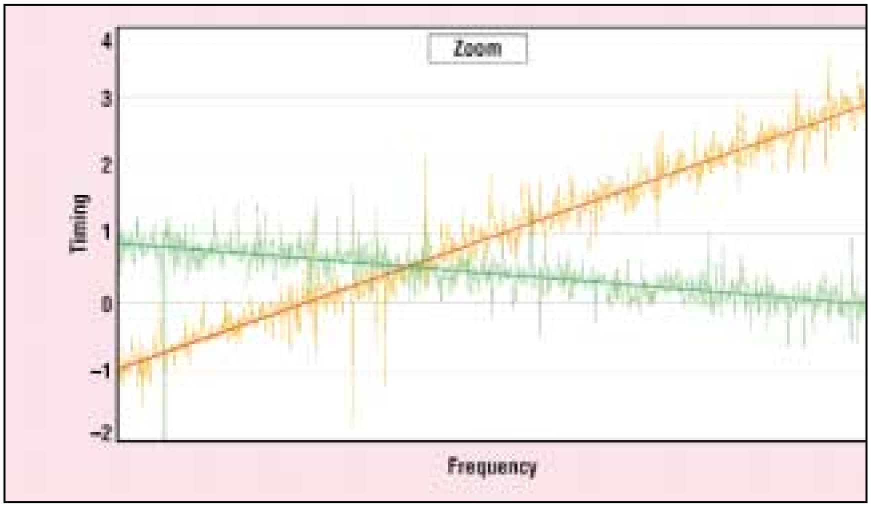
To eliminate the time offset (between the reference measurement and the measurement at the output of the amplifier DUT) both signals are processed by means of Fast Fourier transform (FFT). Phase differences are subtracted in the frequency domain and a regression calculation is carried out over the linear phase obtained by the time offset of the two measurements. If two measurements $x_1(t)$ and $x_2(t)$ show only differences in timing, so that:

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

then the timing difference can be derived by means of:

$$x_1(t) \xrightarrow{FFT} x_1(f);$$
$$x_2(t) = x_1(t-\tau) \xrightarrow{FFT} x_2(f)$$
$$= x_1(f) \times e^{j2\pi f\tau};$$
$$corr\left[x_1(t),\ x_2(t)\right]$$
$$\xrightarrow{FFT} X_1(f)X_2^*(f) =$$
$$\left|x_1(f)\right|^2 \times e^{j2\pi f\tau};$$
$$\Rightarrow arg\left(FFT\left\{corr\left[\begin{matrix}x_1(t),\\ x_2(t)\end{matrix}\right]\right\}\right) =$$
$$2\pi f\tau \qquad (1)$$

The FFT correlation,



3. This closeup plot shows the timing differences for positive and negative values of τ.

FFT[corr(x1, x2)], is shown in Fig. 2, while a close-up of the timing differences for positive and negative values of τ can be seen in Fig. 3. The use of FFT correlation is not affected by the nonlinear effects of the DUT since these effects are small compared with the effects of the timing offsets.

The timing offset thus determined is corrected in the frequency domain so that level-normalized and phase-locked I/Q data are available by retransformation into the time domain. These data are then separated into amplitude and phase information, and entered as coordinates according to the definition of AM/AM and AM/PM compression. Then, a functional relationship, i.e., the numeric values for the amplifier's transfer characteristics, is obtained by regression. This calculation is performed with a few mathematical statements. For example, assuming xi as the reference signal (such as the signal amplitude that is fed to the input of the DUT) and yi as the measured signal (the DUT's output amplitude), the idea is to minimize the following statement:

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

$$= min$$

$$p(x) = \sum_{i=0}^{q} a_i \times x^i \qquad (2)$$

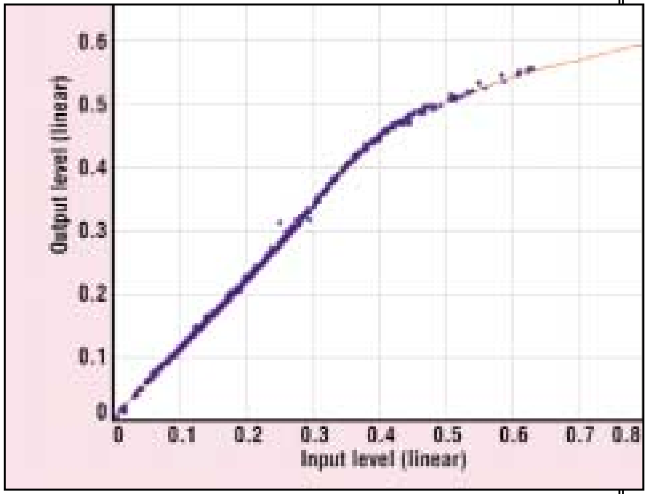
This can be done by solving the following expression:

$$\begin{pmatrix} \sum x_i^0 & \sum x_i^1 & \sum x_i^2 & \ldots & \sum x_i^q \\ \sum x_i^1 & \sum x_i^2 & \sum x_i^3 & \ldots & \sum x_i^{q+1} \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \ldots & \sum x_i^{q+2} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \sum x_i^q & \sum x_i^{q+1} & \sum x_i^{q+2} & \ldots & \sum x_i^{q+q} \end{pmatrix}$$

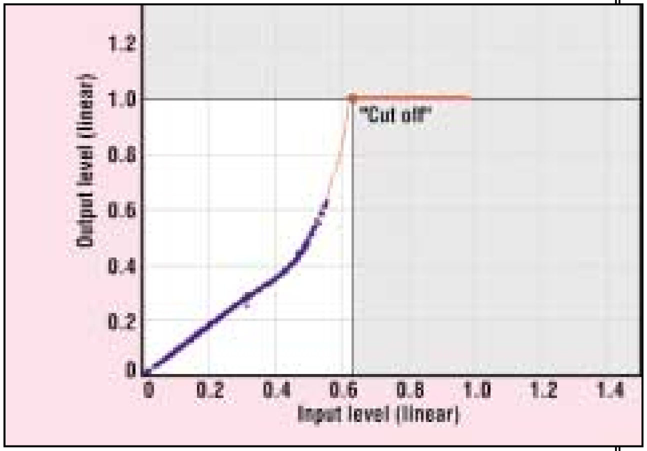
$$\times \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ \ldots \\ a_q \end{pmatrix}$$

$$= \begin{pmatrix} \sum y_i \times x_i^0 \\ \sum y_i \times x_i^1 \\ \sum y_i \times x_i^2 \\ \ldots \\ \sum y_i \times x_i^q \end{pmatrix} \quad (3)$$

The results of this calculation are the values of a_i; these are the coefficients of the polynomial which describe the DUT's characteristic transfer function. (It is also possible to use spline calculation or a combination of spline and polynomial regression for this purpose.) Figure 4 reveals the results of a timing-corrected measurement with a polynomial curve included for the amplifier's AM/AM characteristic curve.



4. This plot shows the results of an amplifier timing-corrected measurement for AM/AM characteristics.



5. The amplitude of the DUT used in the experiments is somewhat limited, although adequate for demonstrating the effectiveness of predistortion in RF measurements.

One way to prove that the initial data are really representative of the DUT's dynamic characteristics is to precorrect the I/Q data set generated by the measurement software using an inverse FFT characteristic. This can be used to perform an AM/AM and/or AM/PM characteristic measurement or to determine the improved ACP rejection in the frequency domain curve. However, due to the limited output power of the DUT, which cannot be improved by predistortion, it does not make sense to drive the DUT over its linearity cutoff point. Due to this, the amplitude of the DUT is somewhat limited in these measurements (Fig. 5).

By taking reference and measured I/Q data, estimating and eliminating the timing offset by FFT and inverse FFT operations, and calculating amplitude and phase through regression, the DUT's AM/AM and AM/PM characteristics can be measured. There are significant differences between the curves measured with a VNA and the curves measured with the new method. The new method provides reproducible results, compared to the results with the VNA, where careful calibrations must be performed and where much attention must be paid to the measurement setup (for example, to ensure that all coaxial connectors are properly torqued from measurement to measurement). When applied to other amplifiers, improvement in error-vector-magnitude (EVM) performance is possible. • •