Spectral Filtering Setup for Uncorrelated Multi-tone Phase and Amplitude Measurement

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Abstract — This paper presents a setup for correlated and uncorrelated multi-tone phase and amplitude measurement. This method is based on a simple hardware implementation using only an ordinary scope as main device. The validity of the technique has been confirmed by a simulation setup using a two-tone uncorrelated input signal. The simulated values agree with the theoretical results stating the validity of the technique.

I. INTRODUCTION

The new trends in communication systems point out to a diversification of applications where low power, low consumption, compactness, friendly interface and low price are the main goals. These extreme conditions impose some challenges in the system conception and design. To cope with the increase of complexity, a collection of accurate and full characterizing measurements are needed, and become the subject of investigation of the scientific community.

In order to characterize the behavior of a system in the frequency domain, a detailed description of the amplitude and phase of every tone composing the input and output signals are needed. The characterization of phase response in microwave systems assumes a special importance in the design of mixer and amplifier linearizers especially when memory effects are noticeable. The measurement of phase has been a difficult issue to overcome especially when signals are quite complex i.e., multi-tone signals. To seek a way out some approaches have been presented, which are going to be discussed in the following.

The usual schemes available for multi-tone phase measurement are based on sampling oscilloscopes and nonlinear phase references. There is a fundamental difference among measurement setups concerning the degree of correlation between the tones composing the test signal.

The setups based on sampled waveforms [1-2], only deal with correlated tones due to the discrete nature of the sampling process.

When these signals are harmonically related they become periodic and are suitable to be represented digitally, allowing all the flexibility of the digital signal processing capabilities.

Performing an FFT on both the input and output sampled signals allows the error correction and the determination of the phase and amplitude of each tone.

The main difficulty of these methods is on the triggering process since the evaluation of the phase is time dependent.

Other suitable approach to measure phase is based on the generation of spectral reference by a well known nonlinear device. The signal to be characterized is added to the reference signal at the output stage and the phase value obtained by the extra phase shift needed to achieve a proper cancellation of each tone at the output [3-5].

In the next section we present an overview of the known setups for multi-tone uncorrelated phase measurement.

Then in section III a new setup that overcomes the issues of the standard setups is proposed and validated by simulation in section IV.

Finally some conclusions are drawn.

II. PHASE MEASUREMENT OF UNEOORELATED SIGNALS

To measure the phase of harmonically uncorrelated tones it is unworthy to use the FFT because it is not possible to get a finite set of points that contain simultaneously one period of all the components involved.

A way to overcome this limitation is to get a reference independently of the time. This is valid when only relative measurements are needed, for instance, the characterization of an amplifier where only the phase change relative to the input is needed [3-5].

In order to make this measurement two different approaches are normally made, the signal cancellation approach and the signal injection approach.

• Signal cancellation approach

The principle of this technique is to generate a signal with the same spectral content of the one to characterize. The input signal is composed by two tones but a more complex multi-tone signal could also be considered.

Fig. 1. Automatic uncorrelated phase measurement
Before starting the measurements, it is required to proceed to the calibration of the setup. The DUT is replaced by a bypass so that the signal flow to the output through a vector modulator.

The lower branch applies the reference signal directly to the output. Both branches are added and the result is displayed in a spectrum analyzer. The calibration process comprises the change of amplitude and phase of the signal coming from the upper branch so that the amplitude seen in the spectrum analyzer reaches a minimum value.

When the optimum point is reached, the information contained in the vector modulator is measured. The phase value obtained is used to calibrate future measurements.

Now, to determine the phase difference between the input and the output of a DUT it is only necessary to put it in the setup and to minimize the output of the desired tone in the spectrum analyzer. The actual phase value is the difference between the value measured in the vector modulator and the calibration value.

The cancellation could be done in the RF or IF band. The advantage of doing the canceling in the IF band is to prevent phase rotations and memory effects induced by the parasitic capacitances of the reference device since at low frequency they have no effect.

- **Signal injection approach**

  This setup allows the phase measurement of tones non-harmonically correlated in an automated way [5]. The operating principle of this proposal is to add to the input signal, a tone whose phase is to be measured. By adjusting the amplitude and phase of the tone to be measured it is possible to minimize the output displayed in the spectrum analyzer. The wanted phase value is the deviation imposed to the generator so that the output signal is minimized. The setup calibration is achieved when the sum of the two signals down converted to baseband is null, e.g., the signals at the input of the DUT are in phase.

  Despite these two techniques are able to measure phase of an uncorrelated signal, they rely on cancellation approaches, and thus increased complexity.

  Next section presents a simple and most robust approach to this type of measurements without any cancellation restriction.

  **III. SPECTRAL FILTERING APPROACH**

  This setup is intended to measure the relative phase and amplitude of uncorrelated spectral components present at the output of a DUT.

  \[
  \omega_1
  \]

  ![Diagram](image)

  Fig. 3 - Phase measurement setup for uncorrelated tones

  The test signal, composed by two uncorrelated tones could be represented by:

  \[
  x(t) = \cos(\omega_1 t) + \cos(\omega_2 t),
  \]

  With: \( \omega_1 \) being an irrational number.

  This signal is split in two branches. In the upper branch, the signal is applied to the DUT affected by a gain. The output spectral components of the DUT contains the input signal frequencies, which have a change in amplitude and phase due to the linear gain, and all the mixing products which derive from the nonlinear behavior of the device. This signal can thus be represented by:

  \[
  x(t) = G_n K_n (\cos(\omega_1 t) + \cos(\omega_2 t)) +
  \]

  with: \( G_n \) - Gain of the \( n \)th order products

  \( n \) - the order of the distortion of the DUT considered.

  \( K \) - the gain/attenuation of the attenuator in the upper arm.

  In the lower branch the input signal is applied to a nonlinear reference device with a known response. The output of the nonlinear reference remains unchangeable with time and amplitude of the signal applied to the DUT is represented by:
\( x(t) = G_1(\cos(\omega_1 t) + \cos(\omega_2 t)) + G_n(\text{n}^\text{o} \text{order distortion products}) \) 

(3)

with: \( n \) - the order of the distortion of the nonlinear reference considered.

The output of the DUT together with the output of the reference is down-converted by a couple of double balanced mixers to a proper IF. At the IF band the desired spectral component is selected by a filtering process.

The IF band could be chosen as low as needed, so that, the filter realization would be possible. The IF signals are mathematically represented by:

**Upper branch signal**

\[ x_i(t) = K_{m1} \left( G_i \cos(\omega_1 t) + \cos(\omega_n t) \right) + G'_n(\text{n}^\text{o} \text{order distortion products converted to IF}) \]

(4)

**Lower branch signal**

\[ x_i(t) = K_{m2} \left( G_i \cos(\omega_1 t) + \cos(\omega_n t) \right) + G'_n(\text{n}^\text{o} \text{order distortion products converted to IF}) \]

(5)

with: \( K_{m1} \) - the conversion gain of the mixer.

The tone to be characterized must be selected now from the whole present at each branch. After the filters we get:

**Upper branch signal**

\[ x_i(t) = G_{\text{dia}}K_{m1}(G_i \cos(\omega_1 t)) = \text{Gain} \cdot \cos(\omega_1 t) \]

(6)

**Lower branch signal**

\[ x_i(t) = G_{\text{dia}}K_{m2}(G_i \cos(\omega_1 t)) = \text{Constant} \cdot \cos(\omega_1 t) \]

(7)

with: \( G_{\text{dia}} \) - the gain of the filter stage.

The two signals at the output have the same frequency, and constant phase and amplitude differences. Measuring these quantities is an ordinary task for any measurement equipment, such as a vector signal analyzer [7].

The IF filter must have high stop band attenuation in order to guarantee a good dynamic range of the setup.

In order to account for the errors induced by the setup, in the measurement results, a proper calibration schema is needed. Firstly, to account the systematic errors of the setup, the DUT should be replaced by known standards and the response of the setup characterized. At this point, the setup is able to take relative phase and amplitude measurements. To perform absolute phase measurements a phase calibration of the nonlinear reference is needed. A suitable method to perform this characterization is the nose-to-nose technique [6]. An absolute amplitude calibration should also be performed in order that the calibration process be complete. In this case, the amplitude response can be compared with a power reference using a calibrated power meter. All these steps should comprise all the spectral components involved in the measurement.

This setup is able to characterize the nonlinear response of a DUT performing the amplitude and phase characterization of each spectral component of the output signal. This process is suitable to be automated since no cancellation adjustment is needed. Additionally there is no restriction in what concerns the correlation between the tones composing the test signal. The selection of the tone to characterize is done just by varying the local oscillator frequency.

IV. SIMULATION VALIDATION

To validate the setup, the system of Fig. 4 was simulated in ADS. The input signal is composed by two tones with central frequency of 2.4 GHz and 1 kHz separation. The considered DUT is an amplifier based on a dynamical model of 5th order and the reference signal is synthesized directly from the input signal through a nonlinear reference.

Both RF signals are down converted to a 10.7 MHz IF and filtered subsequently.
Fig. 5 presents a sweep over the input power. There, it could be verified an output fundamental power increasing at a rate of 1dB/dB and a IMD power increasing at a rate of 3dB/dB. After the compression point the rate of increasing for IMD is 5dB/dB.

Fig.6 presents the variation of the IMD phase with a sweep input power. In the low power input region the phase of the IMD is determined by the 3rd order distortion component imposing 180 degrees. When the influence of the 5th order becomes visible a phase change is noticed.

This result is in agreement with the usual behaviours of power amplifiers [8].

V. CONCLUSIONS

The proposed setup allows the characterization of a device with no correlation constrains in the input signal. Furthermore, it presents a simple topology and allows automated measurements. The selection of the tone to be characterized is only dependent on the local oscillator and the measurement is performed at very low frequency. This setup has no bandwidth limitations since all the signals are converted to IF where the measurement is done. The dynamic range of the setup is dictated by the stop band attenuation of the IF filters.

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