Proving the Usefulness of a 3-port Nonlinear Vectorial Network Analyser through Mixer Measurements

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Abstract - **A 3-port Nonlinear Vectorial Network Analyser (NVNA) is presented. This new measurement instrument allows designers for the first time to measure the full nonlinear 3-port behaviour for any arbitrary mixer. The usefulness of the 3-port NVNA is proven on amplitude and phase calibrated 3-port measurements of a microwave mixer.**

I. Introduction

One of the major drawbacks of today's Nonlinear Vectorial Network Analysers [1] is their limitation to two-port measurements due to the four channel downconvertor. As a result, mixers can not be fully characterised by the NVNA since two signal waves can never be measured with the full 50 GHz bandwidth. Two additional IF channels could be added, but the bandwidth of this 'third port' is still limited from DC to 8 MHz [2]. Hence, only mixers with a baseband IF can be measured.

A three-port or six-channel DC would clearly solve this problem and allow to measure the full 3-port behaviour in magnitude as well as in phase for an arbitrary mixer.

In the following paragraph, the hardware setup and the calibration procedure for the 3-port NVNA is highlighted. Last but not least, microwave mixer measurements are demonstrated in detail.

II. 3-port NVNA

A. The Hardware Setup

A 3-port Nonlinear Vectorial Network Analyser is developed starting from the 2-port NVNA [1]. The 2-port NVNA is an absolute wavemeter that captures the whole wave spectrum in one single take. The instrument is not only able to measure the absolute magnitude of the waves but also the absolute phase relations between the harmonics. In other words, the NVNA can be seen as an absolute Fast Fourier Transform (FFT) analyser for microwaves.

However, to obtain fully calibrated nonlinear measurements of mixers, a 3-port NVNA is needed.

Figure 1 represents a simplified block schematic of a 3-port NVNA to perform connectorised continuous wave (CW) measurements.

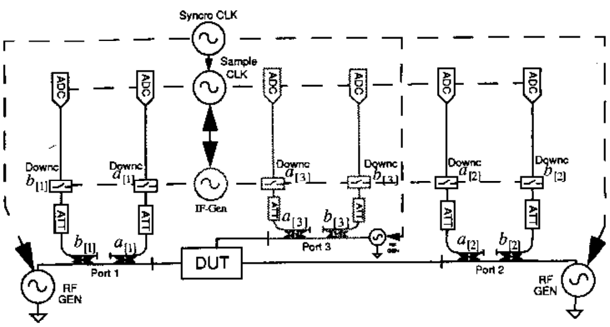

Fig. 1. Simplified block schematic of a 3-port NVNA

The DUT can be excited at one, two or three ports ~~by an RF~~ generator. The incident and reflected waves at all three ports of the DUT are measured through couplers, which have a bandwidth from about 500 MHz to 50 GHz. The high frequency content of the signals does not allow to digitize these signals immediately. Therefore, the measured RF spectrum is downconverted to an IF spectrum using harmonic mixing and is explained in detail below. This part of the setup is referred to as the downconvertor of the NVNA and is in fact the key component of the instrument: six fully synchronised RF data acquisition channels are available. After downconversion, the measured data can be amplified and digitized by six synchronised analog-to-digital convertor (ADC) cards of type HPE1437 [3]. The six ADC cards, the downconvertor and the RF generator are clocked by a common 10 MHz reference clock in order to obtain a fully synchronised phase coherent measurement instrument.

B. Harmonic Sampling

Before digitizing the measured RF signals, they must be downconverted to a much lower frequency content. Thereto, all signals are folded down into an IF spectrum. This is done by the downconvertor which is based on the same principle as sampling oscilloscopes: the harmonic mixing principle. In simple words, this means that the RF

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signals are sampled by a sampling frequency which introduces alias on purpose! In other words, the sampling is done by neglecting the Shannon-Nyquist theorem.

Designing a three-port NVNA requires two extra signals to be downconverted as can be seen in Figure 1. Therefore, the sample pulse that steers the downconvertor sampling heads needs to be split into six instead of four synchronised signals. Thereto, a new symmetrical splitting setup was designed which is capable of delivering sufficient power to drive the six sampling heads.

Tests reveal that this hardware adaptation does not significantly increase the instrument's phase noise.

C. Calibration Procedure

The calibration of a 3-port NVNA consists of three steps: a classical S-parameter calibration, a power calibration and a phase calibration.

The calibration procedure starts with the regular relative calibration. Since the crosstalk between the three ports is neglected, only 12 error correction terms need to be determined. Instead of using a classical analytical S-parameter calibration, a stochastic calibration is used which solves the error equations using a weighted nonlinear least squares estimator [5]. This technique was already available for a 2-port NVNA, but is now extended and adapted for the 3-port NVNA. After the S-parameter calibration, the 3-port NVNA can be easily used as a classical vectorial network analyser to obtain S-parameter measurements.

Since S-parameters do not fully describe a nonlinear system, the knowledge of the separate incident and reflected waves are required when measuring nonlinear devices. As a result it will no longer be sufficient to calibrate wave ratio's as done by a relative S-parameter calibration. Hence, the calibration for nonlinear devices must be extended by two additional calibration steps: a power and a phase calibration [1].

The power calibration is done using a power meter. The power flowing into the device-under-test, hence out of the excitation port of the NVNA, needs to be known absolutely. To do so, a power meter is connected to port 1 of the NVNA. The source is then exciting the DUT with a sine wave of constant power for every frequency. Measuring the source power by both the power meter and the NVNA allows to set an absolute power reference.

The phase calibration is based on a known reference element which is called a 'golden diode'. The phase relations between the frequency components of the 'golden diode' signal are assumed to be exactly known. Measuring the reference signal with the NVNA and comparing the measured phase relations with the known phase relations, allows to correct the measured signals of a DUT in phase at different frequencies.

However, the phase calibration technique only allows to calibrate the phases between the harmonic components of a fundamental frequency lying between 600 MHz and 1200 MHz. This obviously places some restrictions on the measurable signals of the three ports. To be able to do a phase calibration on the three ports, the measured frequency components must be commensurate frequencies with a common fundamental frequency lying between 600 MHz and 1200 MHz.

III. Microwave Mixer Measurements

A. Measurement setup

The Mixer-Under-Test (MUT) is a STDB-2006 double balanced mixer from St. Microwave corp. used as an upconvertor (see Figure 2).

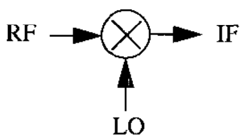

Fig. 2. Mixer-Under-Test

The RF input signal is generated by a HP83640A source and consists of a single tone carrier of 1500 MHz. The power of the RF signal is swept from -12 dBm to 10 dBm. The Local Oscillator (LO) signal is drawn from a HP83650B source which generates a single tone carrier frequency of 5250 MHz. The power of the LO signal is swept from 3 dBm to 15 dBm.

Note that care has been taken for both excitation signals to only contain commensurate frequencies with a fundamental frequency lying between 600 MHz and 1200 MHz, namely 750 MHz.

The incident and reflected waves at all three ports of the mixer are measured through couplers and downconverted to a much lower frequency by the harmonic samplers. Finally, the measured waves are digitized by six synchronised ADC cards. The whole measurement setup is synchronised by the common 10 MHz reference clock of the RF source (see Figure 1).

B. Experimental Results

Consider an ideal model for the mixer: $IF(t) = RF(t)*LO(t)$, where $RF(t)$, $LO(t)$ and $IF(t)$ represents respectively the RF-signal, the LO-signal and the IF-signal in the time-domain, the * symbol represents the convolution in time domain. In the frequency domain this result in an IF output signal which contains 2 frequency components: $IF(f_{LO}+f_{RF}) = LO(f_{LO})RF(f_{RF})$ and $IF(f_{LO}-f_{RF}) = LO(f_{LO})RF(-f_{RF})$.

Let's verify how good the behaviour of the MUT corresponds to this ideal model. Figure 3a represents the magnitude and phase of the ratio $IF(f_{LO}+f_{RF})/LO(f_{LO})RF(f_{RF})$ as a function of the LO power and RF power. If the behaviour of the MUT could be described by the ideal model, this plot would be a horizontal plane. However, the RF power level as well as the LO power level have a serious influence on the conversion efficiency of the mixer. Figure 3a clearly shows that the conversion efficiency depends on the LO power, even for slight variations: The same conclusions can be drawn for the IF difference component $IF(f_{LO}-f_{RF})/LO(f_{LO})RF(-f_{RF})$ in Figure 3b. At first sight both conversion components $IF(f_{LO}+f_{RF})$ and $IF(f_{LO}-f_{RF})$ have a similar behaviour. By plotting the complex difference between the two contributions, however, a slight asymmetry appears (see Figure 3c). Note that in fact this plot represent the 'slow mode' behaviour of the MUT.

To detect whether or not the IF output signal contains higher order harmonics an automatic harmonic selection can be used [6]. Figure 4 represents the response at $IF(f_{LO}+2f_{RF})$.

The ratio $IF(f_{LO}+2f_{RF})/(2RF(f_{RF})LO(f_{LO}))$ is plotted as a function of RF and LO power. From this figure, one can conclude that only at higher RF levels, the output harmonic $IF(f_{LO}+2f_{RF})$ will appear.

The LO-IF isolation is analysed next. How much of the LO signal can be found in the IF output signal?

To analyse this, the ratio $IF(f_{LO})/LO(f_{LO})$ as a function of RF and LO power is represented in Figure 5. If the mixer has a good LO-IF isolation, this ratio should be small. However, figure 8 shows that the contribution of the LO signal in the output IF signal can not be neglected. Furthermore, the RF power level has a serious influence on the LO-IF isolation!

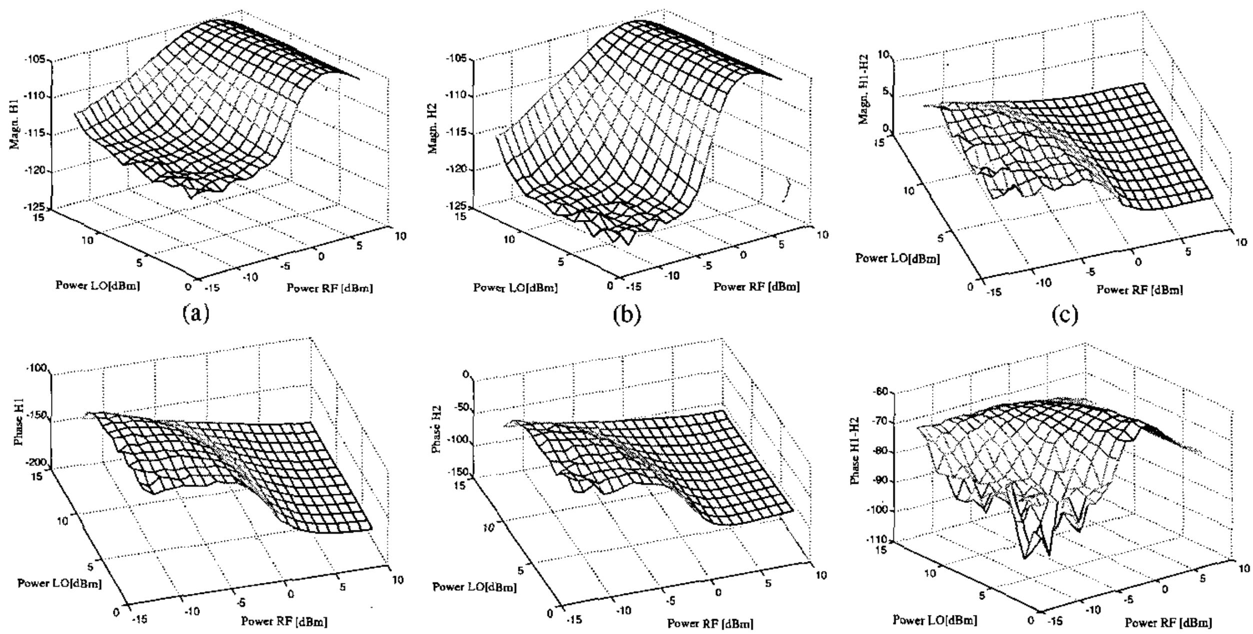

Fig. 3. Magnitude and phase of $H_1 = IF(f_{LO}+f_{RF})/LO(f_{LO})RF(f_{RF})$ (a), $H_2 = IF(f_{LO}-f_{RF})/LO(f_{LO})RF(-f_{RF})$ (b) and the difference (c) between (a) and (b)

Conclusion

In this paper a fully calibrated 3-port Vectorial Network Analyser for nonlinear systems was presented. Due to this measurement instrument it becomes possible to fully characterise the nonlinear RF-characteristics of 3-port devices, such as mixers, both in amplitude and in phase. The measured data allows to verify properties of the mixers, such as port isolations, slow modes, etc.

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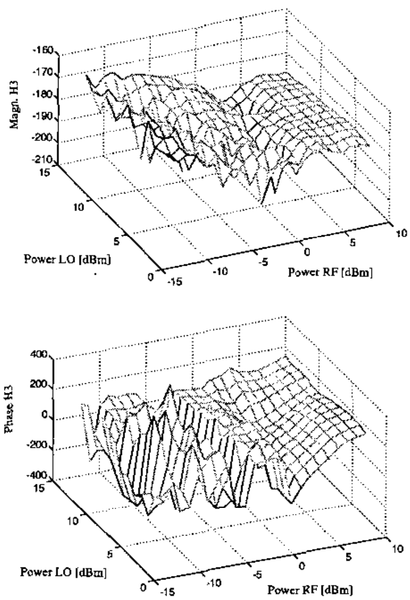

Fig. 4. Magnitude and phase of $H_3 = IF(f_{LO} + 2f_{RF})/(2RF(f_{RF})LO(f_{LO}))$

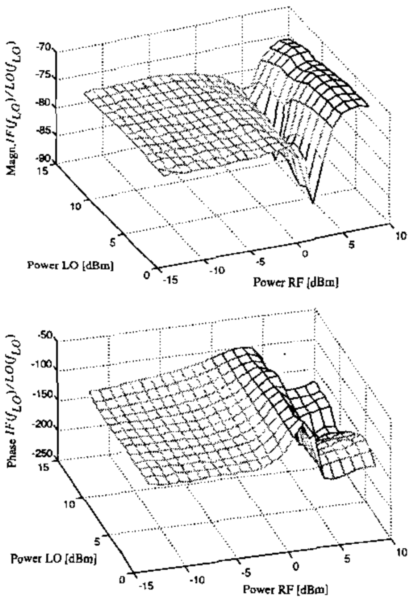

Fig. 5. Magnitude and phase of $IF(f_{LO})/LO(f_{LO})$

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