COMPLETE 3-PORT MEASUREMENT OF MICROWAVE MIXERS USING A NON-LINEAR VECTORIAL NETWORK ANALYSER.

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ABSTRACT

The microwave vectorial network analyser for non-linear devices has been extended to allow full 3-port calibrated characterisation of microwave devices with 2-ports operating up to 50 GHz and 1 port up to 4 MHz. The new setup uses 6 synchronised digitizers to simultaneously measure the incident and reflected waves impinging the device, both in amplitude and phase. Measurements of the complex spectra of the conversion products of a mixer excited by a variable power LO at 4GHz and IF at 1MHz are proposed.

1. INTRODUCTION

Unlike a Vectorial Network Analyser (VNA) for linear systems, a Vectorial Network Analyser for non-linear device characterisation (VNLNA) is able to simultaneously measure the amplitude and phase of waves at different frequencies ([1], [2], [3]).

This is especially useful for the characterisation of frequency translators such as mixers. Simultaneous measurement of incident and reflected wave spectra at all the ports of the device allows to characterise the behaviour of any spectral product as a function of the incident waves and the frequency. The sensitivity of standard mixer parameters can hence be assessed as a function of the operating conditions of the device. Pulling of the device on the surrounding circuits can also be predicted.

In this paper, the 2-port prototype of the VNLNA is extended to 3-port measurements (6 channels). The setup has a bandwidth of 50GHz for 2-ports only, while the bandwidth of the third port is limited from DC to 4 MHz. The cause of this unusual configuration is that the harmonic mixer used to perform the frequency down conversion contains at most 4 measurement channels. The bandwidth of the latter 2 channels is then matched to the digital IF bandwidth to allow synchronous sampling of the 6 channel IF.

Measurements of an up convertor driven at 4 GHz with a modulation at 1.24 MHz are proposed. All the complex mixing products between DC and 40 GHz are measured for a power sweep of LO and IF.

2. MEASUREMENT SET-UP

fig. 1 shows the experimental setup used for the 3-port characterisation. The high LO and RF ports of the mixer under test (MUT) are connected the wide bandwidth port 1 respectively port 2 of the HP 85120A-K60 network analyser module, which is the heart of the measurement setup. This device contains 4 RF couplers for the signal separation and a 4 channel synchronised harmonic sampler. The harmonic sampling frequency F_s can be adjusted between 15 and 20 MHz, and can be externally synchronised on a 10MHz reference signal. The IF outputs of the harmonic sampler (a_1, b_1, a_2, b_2 in fig. 1) hence have a maximal bandwidth of 10MHz. The 4 output signals of the harmonic samplers are available at the 4 measurement ports of the device.

The LO power injected at port 1 of the MUT is drawn from an HP 83640 microwave synthesizer. To avoid excessive reflection, the MUT is loaded by a broad band 50 Ohm load. In the future, this load can be replaced by a tuner impedance to measure the load pull characteristic of the MUT.

The IF part of the analyser consists of a VXI card cage. The acquisition is performed by a group of 6 HPE1430 VXI waveform digitizer cards (sampling frequency 10 MHz, resolution 20 bits). These cards are configured such that both the sampling clock and the position of the acquisition window on all channels coincide. Hence, the 6 acquired data records contain a synchronous image of the 6 IF signals that starts at one single time origin. This very fact can be used to reconstruct the phase relationship between the different channels.

The first 4 channels of the digitizer are connected to the 4 outputs of the harmonic sampler. The 2 remaining channels are used to measure the waves at the modulation input of the MUT. To allow for low-frequency operation, a resistive coupler built up by two power splitters is used for the signal separation of incident and reflected wave. The outputs of the resistive coupler are then directly converted by the E1430 VXI cards. This imposes an upper limit of 4 MHz to the bandwidth of the modulation signal.

The modulation signal itself is generated by a VXI arbitrary waveform generator (type HP E1445/E1446). The sampling clock of this card is also synchronised to the 10 MHz reference signal to obtain a phase-coherent setup. During the test conducted later, this card will only generate a single sine wave. It is however self-evident that any modulation signal can be used as an excitation, as long as its bandwidth remains under 4 MHz.

After sampling, all applied frequency components fold back in the digital IF band (DC to 10 MHz). Since the E1430 digitizer cards have an analog bandwidth of only 4 MHz, only the lower half of the digital IF band is measured. Hence, care has to be taken during the experiment design to ensure that most of the required components fold at measurable frequencies.

3. THE CALIBRATION METHOD.

To obtain measurements with minimal systematic measurement errors, the instrument requires a calibration. The basic hypotheses for any network analyser calibration procedure is the linearity of the measurement instrument itself.

When linear time-invariant systems are to be characterised, it is sufficient to measure the ratio of input and output quantities to fully know the system, and hence it is also sufficient to calibrate ratio's of waves to calibrate S-parameter measurements.

For non-linear system characterisation however, the knowledge of the waves at the ports of the DUT is required. Hence the relative calibration, as used for S-parameter measurements is to be extended to yield calibrated waves.

The calibration of the 3-port setup starts with a regular relative calibration. If a full error-correction is to be performed, 36 error correcting terms are required. Neglecting the crosstalk between ports leaves 12 error terms to be determined.

Note that the measurement bandwidth of port 1 and 2 coincide (45 MHz to 50 GHz), but that the measurement bandwidth of port 3 (DC to 4 MHz) falls totally out of this band. Hence, a straight 3-port calibration is not applicable, because the mutually exclusive frequency ranges prohibit the use of a through connection between port 3 and the 2 other ports. A standard 2-port calibration (SOLT,TRL,LRM,..) is therefore performed on port 1 and 2. This yields 7 error correcting terms. Next, a 1-port calibration is performed on port 3. This yields an additional 3 terms.

The relative calibration yields only 10 of the 12 required error-correction terms. The two remaining terms are determined in 3 distinct experiments.

The coefficient connected to ports 1 and 2 can be determined by the procedure proposed in [5]. Amplitude and phase of the complex number are measured separately:

- a power meter calibration sets the absolute power level of the waves at the VNLNA ports 1 and 2
- a phase reference generator measures the phase relations between the waves a_1, b_1, a_2, b_2 on a harmonic frequency grid relative to one single time origin.

The 12th coefficient is measured using a nose-to-nose calibrated digital sampling scope [5]. This device is connected to port 3, while a sum of harmonically related sine waves with a known spectrum is generated by the E1445 AWG. By the absolute calibration (amplitude and phase) of the sampling oscilloscope, the signal at port 3, and hence also the 12th error-correction term, are absolutely known.

The RF phase reference generator generates a repeated known pulse synchronised by an RF source signal. Hence, the reference spectrum contains only spectral lines on an harmonically related frequency grid. Phase calibration is therefore performed directly on a commensurate frequency grid. The current version of the reference generator has a maximal bandwidth of 26 GHz. Hence, the measured waves are only calibrated up to this frequency, and this limits the usable bandwidth of the instrument.

A second problem arises from the fact that the frequency components at the mixer outputs do not always fall on the commensurate calibration grid. Theoretically speaking, the calibration should be repeated to obtain a calibration frequency grid that is rich enough to contain all the excited frequencies. Even if there is no theoretical limitation, practical computer resource problems prevented calibration on the full grid. To reduce the number of required calibration frequencies, it will be assumed that the error-correction obtained at the carrier frequency is also valid for the modulation components located around this carrier. This assumption is not restrictive at all, because of the low relative bandwidth of the modulation. A first rough experimental verification also indicates that this assumption only leads to very small deviations.

4. EXPERIMENTAL RESULTS

The mixer under test (MUT) here is a STDB-2006 double balanced mixer from St. Microwave corp. used as an up convertor. The mixer can be used with RF and LO signals in a band between 2-8 GHz. The allowed IF bandwidth is between DC and 2 GHz.

The measurements were taken at an LO frequency of 4.000680 GHz while the IF is a sine wave of

1.24 MHz. Combined with a sampling frequency of 20 MHz and an acquisition window length of 1000 samples, this leads to a maximal number of measurable harmonic components and a minimal number of overlapping contributions.

The LO power was swept between 0 and 12 dBm on a linear power grid containing 25 steps. At each LO settings, 91 IF power levels were measured. The IF powers range from -30 to +10 dBm on a linear power grid. All the mixing products up to the 9th harmonic of LO and IF have been measured. Each measurement has been repeated 5 times. Hence, the experimental measurement variance can easily be determined.

The side band $b_2(f_{LO} + f_{IF})$ is analysed first. Define $B_2(f_{LO} + f_{IF}) = b_2(f_{LO} + f_{IF})/(a_1(f_{LO})a_3(f_{IF}))$ to be the normalised spectral product. The magnitude of B_2 is shown as a function of the LO and IF power in fig. 2. Fig. 3 shows the inverted phase. Note that the conversion is indeed maximal at a drive power of about 7 dBm. This is in nice agreement with the +7dBm LO drive spec. At high drive levels, the available power of the source was insufficient to show much deviation from the "ideal" behaviour.

Fig. 4 show the amplitude of $B_2(3f_{LO} + f_{IF})$ mixing product($b_2(3f_{LO} + f_{IF})/(a_1^3(f_{LO})a_3(f_{IF}))$. This contribution is about 20 dB lower than $B_2(f_{LO} + f_{IF})$ and is much more power-dependent. Fig. 5 shows the phase, which is still relatively power-independent.

To get a grip on the noise behaviour of the instrument, small spectral products are shown. Fig. 6 gives the power of $b_2(f_{LO} + 2f_{IF})$, the second harmonic of the modulation around the carrier. Harmonic modulation distortion becomes detectable ($> -70\,dBm$) for IF levels above $0\,dBm$. In fig. 7 the 3th harmonic distortion $b_2(3f_{LO})$ of the LO shows a similar noise floor.

The next series of plots shows the spectra of the "modulated carriers" in the output wave b_2. Fig. 8 and fig. 9 show the modulation around f_{LO} for an LO drive of respectively 2 dBm and 9.5 dBm. The indices in the graph's legend indicate IF harmonics. Note the much higher dynamic in the carrier (0-full line) for the low drive level, and the much better linearity of the mixing products (1,-1) and the lower level of the higher modulation harmonics (-2,2,-3) for the nominal drive. Fig. 10 and fig. 11 show analogous plots around $3f_{LO}$. Note again that harmonics (1,-1) rise linearly for low IF levels and start to saturate around 0dBm IF.

Fig. 12 shows the spectral purity of the applied a_1 wave over the frequency band. Note that beside the DC component and the 4 GHz carrier, no spectral contributions exceed the noise floor.

In fig. 13, the reflected wave b_1 at the LO port is shown. This wave contains almost all the spectral components present in b_2 but they are attenuated about 20 dB.

5. CONCLUSION.

A measurement setup is proposed that allows to synchronously measure the 6 waves impinging a microwave mixer, both in amplitude and in phase.The two RF-ports of the setup allow for measurements between 50 MHz and 50 GHz. The bandwidth of the modulation port is restricted to 4 MHz. A calibration procedure for the full 3-port operation is proposed.

The measurement setup is then used to characterise a microwave mixer. The measured spectral contributions are shown both as a function of impinging power and frequency to prove that the setup is indeed capable of characterising 3-port devices.

6. REFERENCES

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Fig 1: Experimental setup for mixer measurement

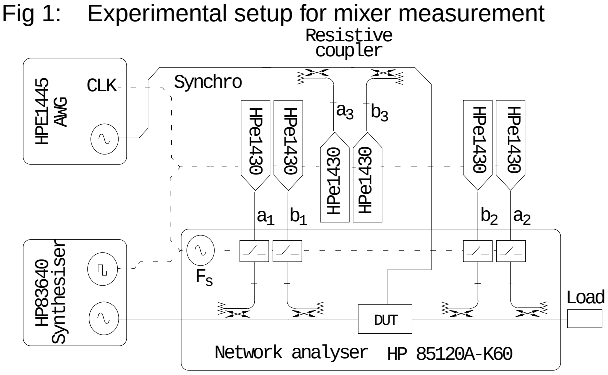

Fig 2: Magnitude $B_2(f_{LO} + f_{IF})$

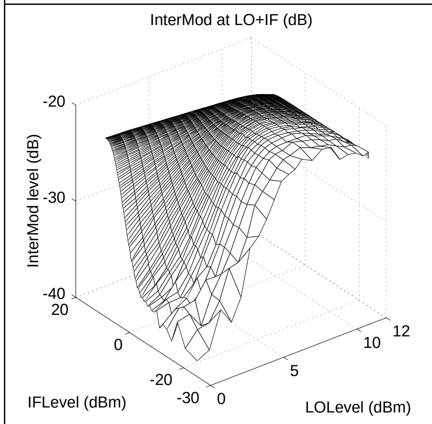

Fig 3: Phase $B_2(f_{LO} + f_{IF})$

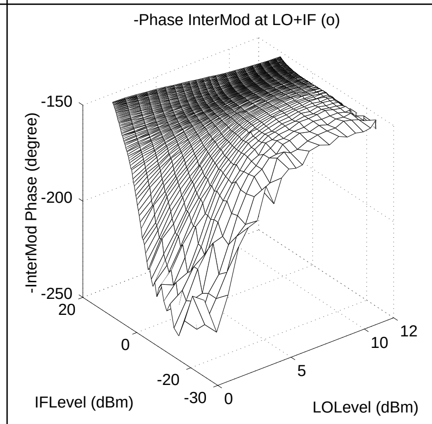

Fig 4: Magnitude $B_2(3f_{LO} + f_{IF})$

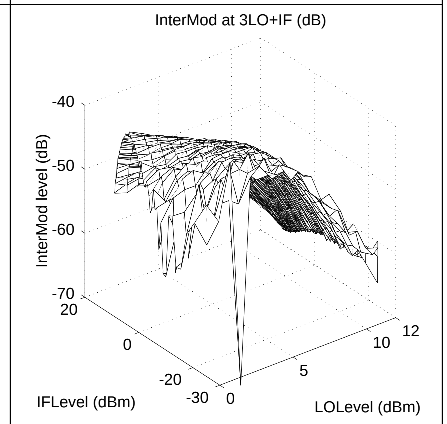

Fig 5: Phase $B_2(3f_{LO} + f_{IF})$

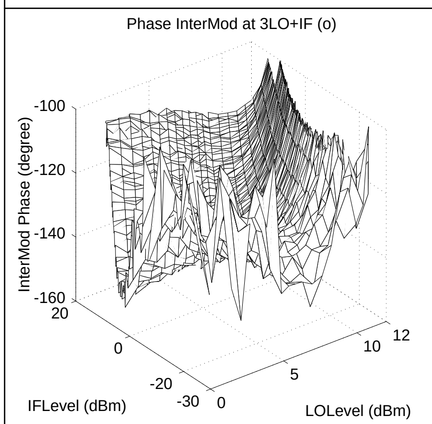

Fig 6: Magnitude $b_2(f_{LO} + 2f_{IF})$

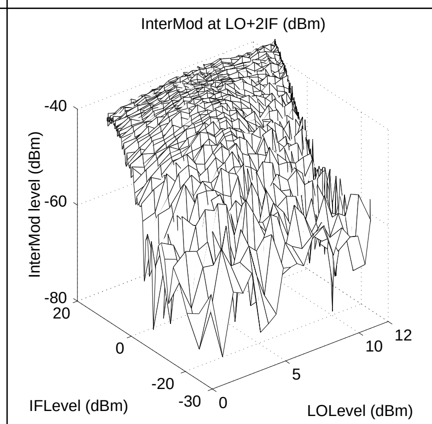

Fig 7: Magnitude $b_2(3f_{LO})$

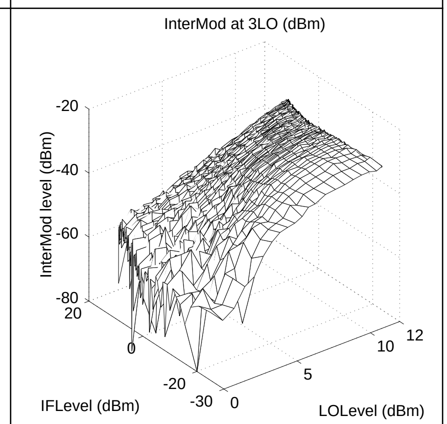

Fig 8: Mod. at f_{LO} $(P_{LO} = 2dBm)$

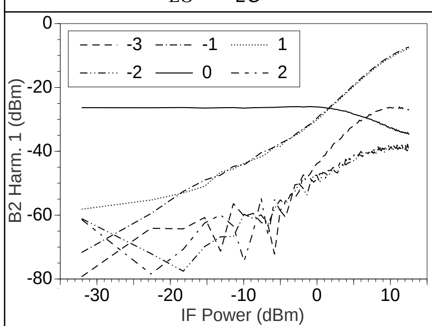

Fig 9: Mod. at f_{LO} $(P_{LO} = 9.5dBm)$

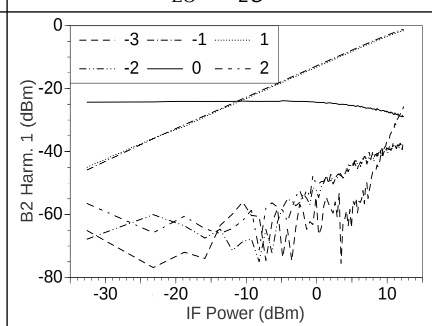

Fig 10: Mod. at $3f_{LO}$ $(P_{LO} = 2dBm)$

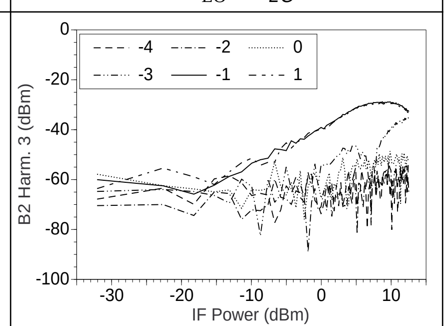

Fig 11: Mod. at $3f_{LO}$ $(P_{LO} = 9.5dBm)$

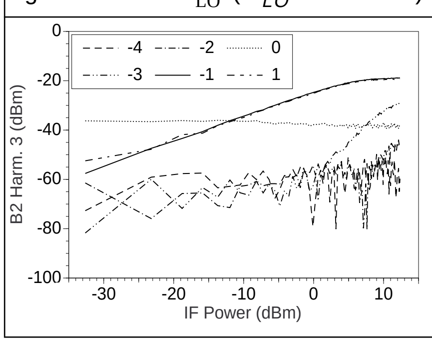

Fig 12: Spect. of a_1

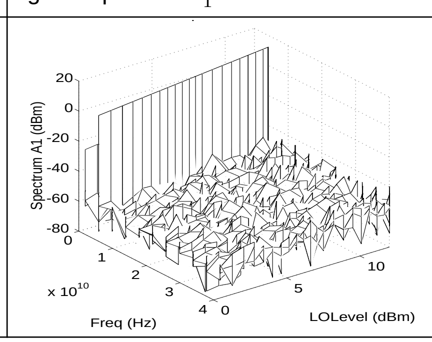

Fig 13: Spect. of b_1