An Improved Broadband Conversion Scheme for the Large-Signal Network Analyzer

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Abstract—The key component of a large-signal network analyzer (LSNA) is the downconverter, which allows the transformation of the measured RF spectrum into an IF spectrum by using the harmonic sampling principle. However, a drawback of the harmonic sampling principle is that, for broadband signals, a “descrambling” of the measured IF spectral components is necessary after downconversion. In this paper, the classical two-port LSNA is adapted to allow direct conversion of broadband signals. The necessary hardware adaptations are explained, and the improved broadband conversion is shown on some significant measurement examples.

Index Terms—Large-signal analysis, microwave measurements, nonlinear measurement system.

I. INTRODUCTION

In 1989, one of the early foundations of today’s large-signal network analyzer (LSNA) [1]–[4] was made by Lott [5]. A new method for simultaneously measuring the magnitude and phase of the harmonics generated by a microwave two port was designed. The output harmonics of a nonlinear device under test (DUT) were measured in the frequency domain with a setup including a vectorial network analyzer. For the first time, power and phase calibrations were performed. The power calibration was obtained by a power meter. For phase calibration at the harmonic frequencies, a “golden diode” or millimeter-wave Schottky diode was used as a reference device.

The first prototype of the LSNA was developed in 1993 through the cooperation of the HP-NMDG group and the Department of Fundamental Electricity and Instrumentation (ELEC) of Vrije Universiteit Brussel (VUB). The purpose of this was to build an absolute wavemeter that allows the capture of the whole wave spectrum in a single take. It was the first instrument that was able to measure the absolute magnitude of the waves as well as the absolute phase relations between the measured harmonics. In other words, the LSNA can be seen as an absolute fast Fourier transform (FFT) analyzer for microwaves.

However, due to the way the currently available LSNA is designed, it is a very hard task to measure the absolute time-domain waveforms of signals with a bandwidth in excess of 10 MHz. The harmonic sampling principle [6] that is used in the LSNA is not the bottleneck, as it is capable of compressing any signal with a reasonable number of commensurate harmonics (a few hundreds) into the IF bandwidth. After downconversion, the measured data are digitized by analog-to-digital converter (ADC) cards with a sample rate of 20 MHz. The major drawback of the current setup is that, for broadband RF signals, the spectral lines are compressed in a scrambled way into the IF spectrum. Descrambling can be a very hard task as the number of measured frequency lines increases and has a negative influence on the calibration accuracy.

Fortunately, the available current downconverter hardware can be enhanced with minor hardware adaptations to allow the harmonic sampling convertor be used to downconvert broadband RF signals without the need to descramble the IF spectrum. The proposed improved downconversion method is based on the principle of using only one sampling point per period.

Section II gives a short overview of the layout of the LSNA and the basic principles of harmonic sampling. After explaining the improved downconversion scheme in Section III, a measurement example of a broadband (> 500 MHz) RF signal is given in Section IV.

II. LSNA

The LSNA is an absolute wavemeter that allows to capture the whole wave spectrum in one single take. The instrument is able to measure the absolute magnitude of the waves as well as the absolute phase relations between the harmonics. In other words, the LSNA is the equivalent of an absolute FFT analyzer for microwaves.

Fig. 1 shows a simplified block schematic of a two-port LSNA setup as is used to perform continuous-wave (CW) measurements.

The incident and reflected multicarrier traveling waves at both ports of the DUT are measured through couplers. The high-frequency content of the signals does not allow direct digitalization of these signals. To obtain a low-frequency replica of the RF signal, the measured RF signal is downconverted to an IF spectrum using harmonic sampling. This time stretching part of the setup is referred to as the downconverter of the LSNA and is, in fact, the key component of the instrument.

The downconverter is based on two modified microwave transmission analyser (MTA) boards: Four phase-coherent RF data acquisition channels are available. After downconversion, the
time-stretched data are digitized by four phase-coherent ADCs. The ADC cards sample the data at a rate of 20 MHz and have a usable bandwidth of 8 MHz. The four phase-coherent ADCs, the downconverter and the RF generator are all clocked by a common 10-MHz reference clock to obtain a fully synchronized phase-coherent measurement instrument.

A. Harmonic Sampling Revisited

1) Harmonic Carriers: Time stretching the RF signals results in the compression of all the spectral lines in a much lower frequency band, since the signals are sampled at a sampling rate that is much lower (500 times) than the actual frequency content of the signals. This is roughly the same principle used for sampling oscilloscopes: the harmonic sampling principle [7], [8].

The stretching of time signals is obtained by smart selection of the sampling frequency $f_s$. As shown in Fig. 2, a distortion-free low-frequency replica of the signal is, hence, obtained by an ideal sampler.

In the frequency domain, the harmonic sampling principle is easily understood by taking a closer look at Fig. 3.

Consider that the measured spectrum contains a fundamental RF frequency $f_{RF}$ and its second harmonic $2f_{RF}$. Mixing this spectrum with an appropriate sampling frequency $f_s$, which does not obey Nyquist’s theorem [9], results in aliasing. The RF frequency and its harmonic are, respectively, downconverted to a much lower frequency $f_{IF} = f_{RF} - kf_s$ and $2f_{IF} = 2f_{RF} - 2kf_s$ with $k \in \mathbb{N}$. Note that for the LSNA, the sampling frequency $f_s$ is typically chosen between 19 and 20 MHz.

2) Modulated Signals: Downconverting an RF spectrum can be seen as folding a road map around every multiple of $f_s/2$. This can easily be seen in Fig. 4.
When downconverting narrowband-modulated RF signals (BW < \( f_s/2 \)), the spectral components will not get scrambled in the IF spectrum, since they all fall within \( k(f_s/2) \) and \((k + 1)f_s/2\) with \( k \in \mathbb{N} \).

When downconverting modulated RF signals with a total bandwidth larger than \( f_s/2 \), the spectral components will get scrambled, or in the worst case, they can even fall on top of each other [see Fig. 4(b)].

Fig. 4(b) clearly shows that for broadband-modulated signals, descrambling the IF spectrum is necessary if one wants to obtain the correct time-domain waveforms.

3) Practical Implementation: In practice, the RF signals are sampled by a sampling head that is driven by a local oscillator (Fig. 5), whose frequency is generated by the setup in Fig. 6.

A 10-MHz reference clock is fed to a fractional N-divider (FracN) synthesizer, which is able to synthesize any local oscillator frequency between 16 and 20 MHz with a frequency resolution of better than 1 Hz and an accuracy determined by the accuracy of the reference clock. Since this 10-MHz reference clock is also used to clock the RF generator of the LSNA, the whole setup is synchronized, and phase coherence between all signals is ensured. The step recovery diode (SRD) only has a limited impact on the receiver characteristics, i.e., more than one sample point (black and grey dots) per period.

The SRD “fire” only once per period of the measured modulated RF signal. Therefore, the switch is steered by a square waveform as the period of the modulated RF signal.

To sufficiently slow down the train of pulses coming from the SRD (see Fig. 6), to obtain \( T_s > T_{RF} \), with \( T_s \) as the sampling period and \( T_{RF} \) as the period of the modulated RF signal.

In the frequency domain, this means that the complete RF modulation falls within one \( f_s/2 \) window, as shown in Fig. 8.

The pulse train of the SRD can be slowed down by inserting a switch between FracN and SRD (see Fig. 9). Using a switch allows the selection of only one period out of \( N \) from the FracN signal. Therefore, the switch is steered by a square waveform with a duty cycle of < 50% so that it connects FracN to SRD only for a period of \( T_s \). This means that one is able to let the SRD “fire” only once per period of the measured modulated RF signal.

Reducing the duty cycle of the signal coming from the SRD only has a limited impact on the receiver characteristics,
Fig. 9. Adapted local oscillator setup.

\[ f_2, T = \frac{1}{f_s} \]

Fig. 10. (a) Time-domain and (b) frequency-domain representation of the applied RF signal.

since the receiver has an internal feedback loop to freeze the sampled value. This means that there is only a very limited drop in the samplers. The signal-to-noise ratio will, however, be diminished by an amount proportional to the duty cycle change.

IV. LSNA MEASUREMENT OF BROADBAND SIGNALS

The RF multisine signal is generated by a high-frequency arbitrary waveform generator from Tektronix (AWG710) and consists of a multisine with a total bandwidth of 500 MHz (see Fig. 10). The sampling frequency of the arbitrary waveform generator (AWG) is 4 GHz.

Fig. 10 shows the time- and frequency-domain representation of the applied RF signal. The RF spectrum contains nine groups of three spectral components, as can be seen from the zoom in Fig. 10(b).

In the first experiment, the signal is measured with the classical downconversion scheme. The sampling frequency \( f_s \) is set to 19.99 MHz. After downconversion, the spectrum is measured by a 20-MHz ADC that takes 80,000 acquisition points.

Fig. 11. Classical downconversion scheme. Measured spectrum of the downconverted signal.

In a second experiment, the same signal is measured by means of the improved downconversion scheme. In this case, only one period out of ten is passed from FracN to SRD (see Fig. 9). The switch is, therefore, steered by a 1.999-MHz square wave with a duty cycle of 10%. This results in an equivalent sampling frequency \( f'_s \) of 1.999 MHz. After downconversion, the spectrum is measured by a 2-MHz ADC that takes 80,000 acquisition points.

Fig. 12. Improved downconversion scheme. Measured spectrum of the downconverted signal.

Fig. 11 shows the uncalibrated downconverted spectrum of the multisine. This figure clearly shows that the original spectrum is scrambled after downconversion. There are still 27 spectral components present, but the nine groups of three spectral components are no longer visible. If one wants to obtain the correct time-domain waveform, descrambling is needed.

In a second experiment, the same signal is measured by means of the improved downconversion scheme. In this case, only one period out of ten is passed from FracN to SRD (see Fig. 9). The switch is, therefore, steered by a 1.999-MHz square wave with a duty cycle of 10%. This results in an equivalent sampling frequency \( f'_s \) of 1.999 MHz. After downconversion, the spectrum is measured by a 2-MHz ADC that takes 80,000 acquisition points.

Fig. 12 shows the uncalibrated spectrum of this downconverted multisine and clearly shows that the nine groups of three spectral components are present and measured without scrambling. It becomes straightforward to transform these data into the time domain without needing further calculations.

V. CONCLUSION

This paper has presented an improved broadband conversion scheme for the LSNA. By means of small hardware adaptations to the downconverter, the LSNA is able to measure the absolute time-domain waveforms of broadband RF signals (> 500 MHz).
without the need to descramble the IF spectrum. This results in a faster and easier measurement of ultrawideband RF signals. The power of this improved downconversion scheme is proven on broadband LSNA measurements.

REFERENCES


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