Measurement Setup for Phase Noise Test at Frequencies above 50 GHz
Application Note

Products:

- R&S®FSWP

With recent enhancements in semiconductor technology the microwave frequency range beyond 50 GHz becomes more and more attractive especially for wideband communication applications like 802.11ad, microwave links or automotive RADAR. Low phase noise is essential for these applications to work properly. Accurate measurement of phase noise is needed to improve the performance. However, test setups at these frequencies become difficult, especially when cross correlation of two receive paths is needed to suppress additional phase noise added by the local oscillators or mixer stages. Two external harmonic mixers in combination with a commercially available phase noise tester are used for phase noise analysis. Signal sources with frequencies up to 500 GHz can theoretically be measured with this setup.

Note:

Please find the most up-to-date document on our homepage http://www.rohde-schwarz.com/appnote/1EF101.

ROHDE&SCHWARZ

Application Note
Dr. W. Wendler, M. Schmähling
2.2018 – 1EF101_1E

Measurement Setup for Phase Noise Test at Frequencies above 50 GHz

Dr. Wolfgang Wendler and Martin Schmaehling
Rohde & Schwarz GmbH & Co. KG
Munich, Germany
Wolfgang.wendler@rohde-schwarz.com, martin.schmaehling@rohde-schwarz.com

Abstract— **With recent enhancements in semiconductor technology the microwave frequency range beyond 50 GHz becomes more and more attractive especially for wideband communication applications like 802.11ad, microwave links or automotive RADAR. Low phase noise is essential for these applications to work properly. Accurate measurement of phase noise is needed to improve the performance. However, test setups at these frequencies become difficult, especially when cross correlation of two receive paths is needed to suppress additional phase noise added by the local oscillators or mixer stages. Two external harmonic mixers in combination with a commercially available phase noise tester are used for phase noise analysis. Signal sources with frequencies up to 500 GHz can theoretically be measured with this setup.**

Keywords— Phase noise, harmonic mixer, millimeter wave, Pulsed phase noise, I/Q mixer, Cross Correlation

I. INTRODUCTION

Traditionally phase noise (PN) is measured by dedicated phase noise testers or spectrum analyzers. With spectrum analyzers this measurement is a simple task. The signal source under test has to be connected with the analyzer and then the analyzer measures the noise power in the sideband. Most analyzers are equipped with an internal measurement application, which normalizes the noise power to a bandwidth of 1 Hz and put it into relation to the carrier power. Spectrum analyzers are available up to a frequency of 50 GHz, some high end units cover the range up to 85 GHz. For higher frequencies external harmonic mixers can be used. However, there are some restrictions using spectrum analyzers. AM noise and phase noise are not separated and drifting sources are difficult to measure close to carrier. Some modern instruments overcome this drawback with IQ based phase noise measurement close to carrier, which enables to track the carrier and to suppress AM noise. However, the biggest problem with spectrum analyzers is, that the sensitivity is always limited by the phase noise of the local oscillator (LO) of the instrument. When using external harmonic mixers the phase noise sensitivity has to be scaled according to the number of harmonic N, which is used, according to the following formula:

$$PN_{Sensitivity} = PN_{LO} + 20\log(N_{Harmonic}) \qquad (1)$$

Not to be limited by phase noise of internal local oscillators for high end phase noise test dedicated phase noise testers are used, where the analyzers recover the phase difference between a local reference oscillator and the device under test (DUT) with an analog phase-locked loop (PLL). In this setup the reference source mainly defines the sensitivity for phase noise test and an appropriate source can be selected according to the sensitivity which is needed. If no good source is available, the DUT can be used as DUT and another DUT of the same quality as reference. A correction of 3 dB will give the right results. With two different receive paths cross correlation can be applied to suppress the phase noise of the references and phase detectors. However, setting up the loop bandwidth and the phase detector correctly requires deep knowledge of the oscillator to be measured or an extensive premeasurement of the DUT's frequency drifting characteristics. The frequency response of the analog PLL must be known or calibrated to correct the final measurement result. This becomes even more complex, when applying cross correlation to suppress the inherent noise of the reference sources or phase detectors. Furthermore an analog PLL achieves only a rather poor rejection of amplitude noise to the phase output.

Therefore the latest innovation for dedicated phase noise testers relocates the phase detector into the digital domain, which is a much easier setup and promises an improved accuracy of the measurement, because the characteristics of the digital components are predefined and can be compensated exactly [1]. The alternative approach, realized in phase noise and VCO tester R&S FSWP, uses direct down-conversion of the DUT signal with a low phase noise local oscillator and an analog IQ mixer. The signal is then captured with AD converters with 16 bit resolution running with 100 MSamples/s. It achieves a signal to noise ratio (SNR) of about 84 dB relative to full scale. Then AM and FM demodulation is applied, which allows concurrent measurement of amplitude noise and phase noise up to an offset frequency of 30 MHz. The complex baseband I/Q signal is separated into its magnitude and its phase components using a CORDIC algorithm (**Co**ordinate **R**otation **D**igital **C**omputer, figure 1). The magnitude signal is directly used to calculate the amplitude noise spectrum whereas the phase signal has to be converted to a frequency signal before further processing steps.

In addition, a second independent receive path enables cross correlation to suppress uncorrelated noise on both paths and overcomes the drawback that the sensitivity is limited by the LO. Figure 2 shows the basic architecture of the instrument.

The R&S FSWP can be used up to 50 GHz with internal local oscillators. In [2] and [3] a more detailed description of the instrument and the signal processing chain can be found. For further frequency extension to millimeter waves an external harmonic mixer has to be used. To suppress phase noise of the higher harmonic of the local oscillator cross correlation, means two external harmonic mixers are needed.

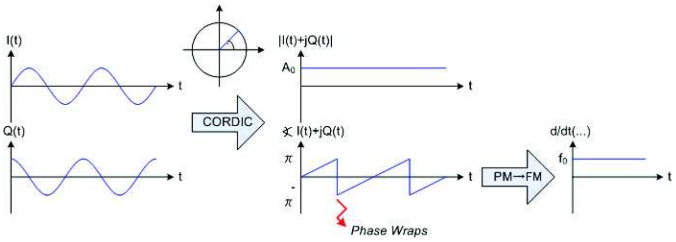

Fig. 1. AM and FM demodulation of an ideal CW source

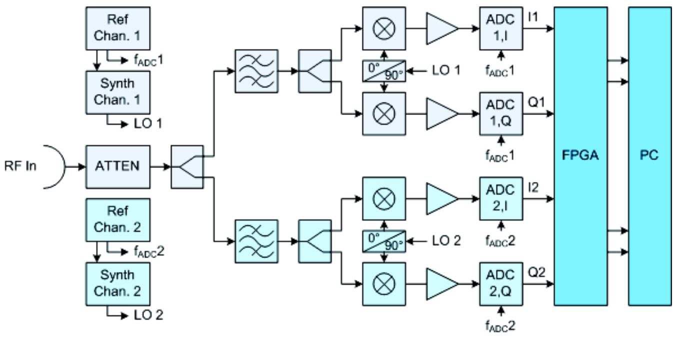

Fig. 2. Overall block diagram of the phase noise analyzer

II. HARMONIC MIXERS

The mixers multiply the spectrum analyzer's local oscillator output signal and use a suitable harmonic to down convert the millimeter-wave signal to be measured to the analyzer's intermediate frequency. However, the large number of harmonics created in the mixer and the input signal's harmonics produce a multitude of signals in the spectrum (see figure 3). The image frequency is not suppressed as well because there is no pre-selection. Normally these unwanted signals make it difficult to figure out, which one is the right one. Therefore, modern analyzers normally offer a reference sweep with shifted IF frequency to sort out real signals from lines created by images and other harmonics. In figure 3 the yellow line in the upper picture shows the measured spectrum with an external harmonic mixer, the blue line shows the result of the reference sweep. A simple operation of the two traces, displays only the lines, which are present in both sweeps and reveals the real signal (lower picture).

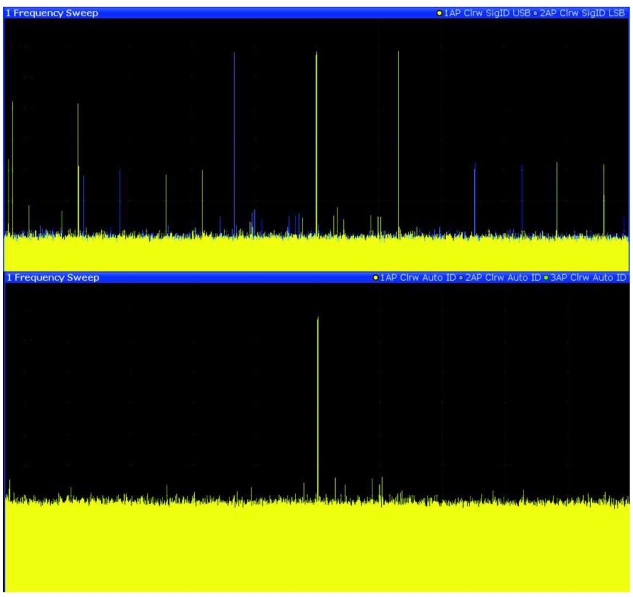

Fig. 3. Upper picture: normal sweep and reference sweep with external harmonic mixer; lower picture: suppression of unwanted signals

For phase noise measurements this operation is not needed and cannot be applied, because for IQ based analysis of phase noise like in R&S FSWP the analyzer captures the wideband signal in zero span, it is not a sweep based analysis. As long as all unwanted lines are outside the phase noise offset range of interest, these lines won't have an effect on the measurement results. However, this should be checked with a spectrum analyzer before the measurement. The R&S FSWP with its built in spectrum analyzer can easily be used for this task as well.

Table 1 shows the harmonic mixers, which are available at R&S with the number of used harmonic and typical conversion losses. The higher the number of the used harmonic, the more unwanted lines can be expected and higher conversion losses.

Mixer	Frequency range / GHz	Harmonics	Converison loss
R&S FS-Z60	40-60	4	23
R&S FS-Z75	50-75	6	20
R&S FS-Z90	60-90	6	23
R&S FS-Z110	75-110	8	20
RPG FS-Z140	90-140	10	28
RPG FS-Z170	110-170	12	30
RPG FS-Z220	140-220	16	32
RPG FS-Z325	220-325	22	40
RPG FS-Z500	325-500	36	58

Table 1: External harmonic mixers for R&S spectrum analyzers

III. PHASE NOISE TEST WITH MIXERS

The external harmonic mixers can extend the frequency range of the phase noise and VCO tester R&S FSWP beyond the range of 50 GHz. Figure 4 shows the block diagram when the R&S FSWP is used with external harmonic mixers. The

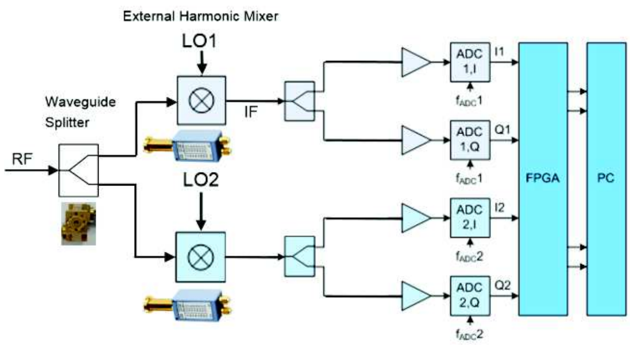

Fig.4: Block diagram of phase noise analyzer with external harmonic mixers and cross correlation.

signal of the DUT first passes a wave guide splitter. After the splitter the external harmonic mixers are connected. The two internal reference sources are used as local oscillators (LO1 and LO2). The signal is down converted to an IF frequency, which is in the range of several MHz. Down conversion to 0 Hz is done in the digital domain. No IQ mixers are needed in this mode leaving 2 AD converters unused. These additional 2 AD converters are connected for further correlation to reduce noise of AD converters and internal amplifiers.

Figure 5 shows the internal graphical menu to setup phase noise test with external harmonic mixers. Beside the selection of the frequency range users can decide whether to use cross correlation or not.

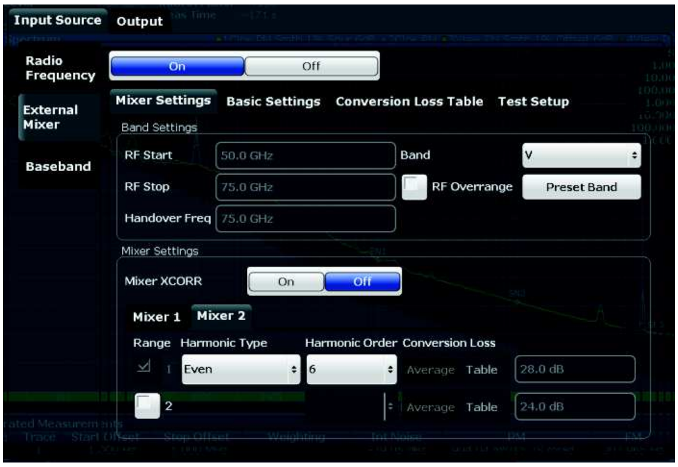

Fig.5: User interface for mixer setup

IV. CROSS CORRELATION

The cross correlation and the result trace calculation is done on a standard PC processor which is connected to the FPGA via PCIe. The frequency range is logarithmically divided into segments which cover about a half of a decade, e.g. from 1 Hz to 3 Hz, 3 Hz to 10 Hz and so on. The AM resp. FM signals from the FPGA are converted to the frequency domain via FFT. The cross correlation between the two independent signal paths is done by complex conjugate multiplication of the FFT results and averaging. The estimated power density spectrum for N correlations between the FFT of the first channel X and the FFT of the second channel Y can be expressed as

$$\hat{S}_{YX} = \frac{1}{N} \cdot \left| \sum_{i=0}^{N-1} Y_i \cdot \mathrm{conj}\left(X_i\right) \right| \qquad (2)$$

Cross correlation reduces the phase noise contribution of uncorrelated noise signals, i.e. the instrument noise arising behind the waveguide splitter, by

$$5\log(N) \qquad (3)$$

where N is the number of correlations. The instrument can stop the measurement automatically if no further improvement of the measurement result can be achieved.

V. PROVE OF CONCEPT

For prove of concept a signal source at 25.8 GHz is used with a doubler at the output to create a signal at 51.6 GHz. The signal can either be measured directly with the phase noise tester R&S FSWP26 or R&S FSWP50 without the doubler or at 51.2 GHz using external harmonic mixers R&s FS-Z75 (50 GHz to 75 GHz). The results with and without cross correlation at this frequency can be compared and a comparison with the base unit can be made assuming that the doubler adds just 6 dB to the phase noise performance and no additional phase noise according to formula:

$$PN_{51.2GHz} = PN_{25.8GHz} + 20\log(\frac{51.2GHz}{25.8GHz})$$

$$PN_{51.2GHz} = PN_{25.8GHz} + 6dB$$

Figure 6 shows the measurement at 25.8 GHz with an R&S FSWP26 at an offset range from 1 Hz to 1 MHz (green line)

Figure 6: Phase noise measurement at 25.8 GHz (green) with x-corr and at 51.2 GHz without x-corr (orange) and 51.2 GHz with x-corr (yellow)

directly measured with the FSWP26. Without much correlations the signal source can be measured. To set the number of averages at 10 Hz offset to 10 is more than enough and down to -118 dBc/Hz at an offset of 10 kHz at an input frequency of 25.8 GHz can be measured after a few seconds. Now the signal source ic connected to a doubler and the signal is measured at the input frequency of 51.6 GHz with one external harmonic mixer, where no cross correlation is applied to get rid of the phase noise of the internal LO (orange line). Activating cross correlation gives the yellow trace, which is clearly below the orange one. This shows that for this signal source at 51.6 GHz cross correlation is needed to really measure the performance of the source. Depending on offset range users get up to 10 dB improvemnets of their results.

To check, whether the measurement really gives the right numbers the results at 51.2 GHz and 25.8 GHz can directly be compared, if we add 6 dB to the signal without the doubler (Figure 7). The two traces overlap and this shows that the measurement at 51.2GHz with external harmonic mixers and cross correlation works and gives reliable results. The setup and measurement principle is the same for other mixers and therefore the measurement will work up to 500 GHz. However, it is really hard to find signal sources, where cross correlation is really needed at these frequency ranges.

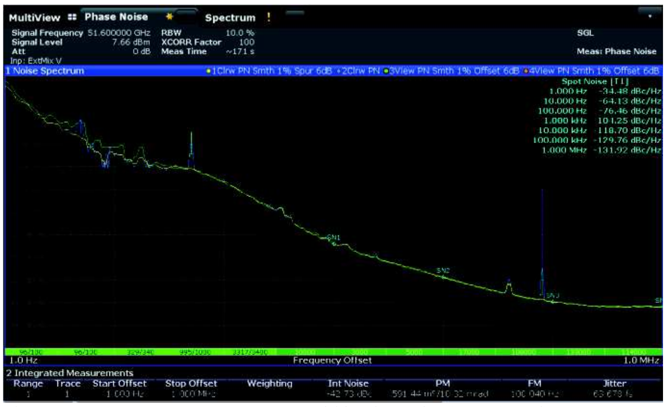

Figure 7: Measurement at 25.8 GHz shiftet by 6 dB (green) and measurement at 51.2 GHz (yellow)

In addition, the grey area in figure 7 shows the cross correlation gain. It shows the noise floor which can theoretically reached with the used number of correlations. If this area is clearly below the measured trace, the device under test is measured, if not the number of correlations has to be increased.

VI. Summary

The R&S FSWP is the most modern phase noise tester on the market with unrevalled sensitivity. It combines high end internal local sources with latest technology for AD converters in combination with cross correlation. Based on the digital architecture AM noise and phase noise can be measured in parallel and even pulsed signals can easily be measured.

The instrument offers a maximum frequency range for phase noise test up to an input frequency of 50 GHz. For further extension of the frequency range external harmonic mixers can be used and cross correlation can be applied. This works theoretically up to the maximum frequency range of 500 GHz. Prove of concept has been done at 51.6 GHz. The measurement results exactly fit the expected numbers.

References

[1] Grove, J. et al., "Direct-digital phase-noise measurement", Proc. of Frequency Control Sym-posium and Exposition, 2004, pp.287-291, 23-27 Aug. 2004.

[2] Gregor Feldhaus, Alexander Roth, " A 1 MHz to 50 GHz Direct Down-Conversion Phase Noise Analyzer with Cross-Correlation," European Frequency and Time Forum (EFTF), 2016, IEEE DOI: 10.1109/EFTF.2016.7477759

[3] Rohde & Schwarz, "Measuring phase noise from high-end signal sources for radar systems", NEWS Magazine 214/16.

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, radiomonitoring and radiolocation. Founded more than 80 years ago, this independent company has an extensive sales and service network and is present in more than 70 countries.

The electronics group is among the world market leaders in its established business fields. The company is headquartered in Munich, Germany. It also has regional headquarters in Singapore and Columbia, Maryland, USA, to manage its operations in these regions.

Regional contact

Europe, Africa, Middle East
+49 89 4129 12345
customersupport@rohde-schwarz.com

North America
1 888 TEST RSA (1 888 837 87 72)
customer.support@rsa.rohde-schwarz.com

Latin America
+1 410 910 79 88
customersupport.la@rohde-schwarz.com

Asia Pacific
+65 65 13 04 88
customersupport.asia@rohde-schwarz.com

China
+86 800 810 82 28 |+86 400 650 58 96
customersupport.china@rohde-schwarz.com

Sustainable product design

- Environmental compatibility and eco-footprint
- Energy efficiency and low emissions
- Longevity and optimized total cost of ownership

Certified Quality Management
ISO 9001

Certified Environmental Management
ISO 14001

This and the supplied programs may only be used subject to the conditions of use set forth in the download area of the Rohde & Schwarz website.

Version 1EF101_1E | R&S® Measurement Setup for Phase Noise Test at Frequencies above 50 GHz

PAD-T-M: 3573.7380.02/03.00/EN

Rohde & Schwarz GmbH & Co. KG
Mühldorfstraße 15 | 81671 Munich, Germany
Phone + 49 89 4129 - 0 | Fax + 49 89 4129 – 13777

www.rohde-schwarz.com