Application Note

MEASUREMENT OF RESIDUAL PHASE NOISE OF AMPLIFIERS AT 80 GHZ USING INTERFEROMETRIC MEASUREMENT TECHNIQUE

Products:

- R&S®FSWP
- R&S®FS-Z90
- R&S®FS-SNS110
- R&S®NRP90T

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Contents

1 Overview

The additive/residual phase noise of power amplifiers or multipliers adds noise in the signal path. For example for automotive RADAR sensors at 80 GHz designers of RADAR applications require the added phase noise in the TX path to be lower than <-130 dBc/Hz at 100 kHz offset or even lower to further increase the S/N for detection of small moving targets. The interferometric measurement approach in combination with a phase noise test system provides a way to characterize the additive/residual phase noise of amplifiers down to -150 dBc/Hz at 100 kHz offset even in the microwave range at 80 GHz.

Keywords—phase noise, additive noise, automotive RADAR, FMCW, multipliers, residual phase noise.

2 Introduction

Power amplifiers especially when driven close to the 1 dB compression point for higher efficiency add phase noise to the signal. For FMCW RADARS like used for automotive applications at 80 GHz this noise reduces the sensitivity of the RADAR sensor, because the phase noise of the amplifier is present only in the TX path and not suppressed during signal processing. With increasing resolution requirements and wider FMCW bandwidth range designers of automotive RADAR applications currently require the amplifier's added phase noise in the TX path to be lower than -130 dBc/Hz at 100 kHz offset.

There are different approaches to measure additive/residual phase noise. The easiest way is to use a high end signal source and to measure the phase noise with and without the amplifier to characterize the added phase noise of the amplifier. However, it is quite difficult to find sources at 80 GHz with a phase noise clearly below -120 dBc/Hz at 100 kHz offset.

Therefor mostly the standard additive/residual phase noise measurement setup is used, where the signal of a high end source is split into two paths and connected to the LO and RF input of a mixer or phase detector. A phase shifter is added to one path to put the two paths into quadrature, so that the mixer demodulates the phase fluctuations between LO and RF and the phase noise of the source is suppressed as it is coherent on both mixer ports.

Adding the DUT into one path with an attenuator to get the same power levels at the input of the phase detector then shows the additive/residual phase noise of the amplifier. However, a mixer with low additive phase noise at 80 GHz is needed as phase detector and a quite complex calibration step at 80 GHz to calibrate the detector slope of this setup for accurate measurements.

The interferometric measurement approach presented in this paper and suggested already in [1,2] provides an easy method to measure the additive/residual phase noise of amplifiers and multipliers with just a phase noise analyzer [3], a power meter and some waveguide components without the need of complex calibration steps.

3 Measurement Setup

3.1 Components and Instruments

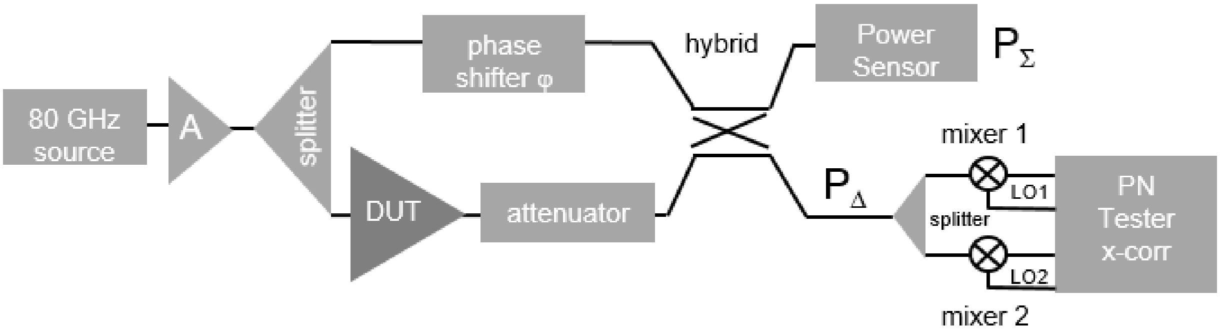


Fig. 1. Setup for the interferometric measurement technique with a phase noise analyzer with down converters and a power sensor instead of a phase detector setup.

Fig 1 shows the setup of the measurement as shown in [3]. A generator in combination with a multiplier is used as signal source (R&S SMA100B + R&S SMZ90). The signal is split into two paths. In one path a phase shifter is located to establish the 180° phase shift between the two paths. In the other path the DUT is located in combination with an adjustable attenuator. For measurement of the system noise floor the DUT is bypassed. The two paths are fed into a hybrid coupler, which delivers the sum of the power P_Σ of the two paths at one output, which can be measured with a power sensor (R&S NRP90T) and the difference P_Δ of the power at the other output, which is connected to a phase noise analyzer. To measure the phase noise at 80 GHz a phase noise analyzer is needed, which supports external down converters, because there is no single box solution available up to 80 GHz. The downconverter in combination with a spectrum analyzer can be used as well to measure the power at this output P_Δ. For phase noise measurement a phase noise analyzer is used, which supports two external downconverters to apply cross correlation [4,5], which is needed due to the high noise floor according to the conversion loss of the down converters. The phase noise analyzer provides different local oscillators as well for the two mixers (LO1, LO2) to get rid of the inherent phase noise of the internal sources by cross correlation (x-corr). In our setup we used the phase noise analyzer R&S FSWP, which can be used as phase noise and spectrum analyzer in combination with one or two harmonic mixers (R&S FS-Z90) to measure the single sideband phase noise L(f) and power P_Δ. P_Δ should not drop below -45 dBm, which is the minimum level for the phase noise analyzer to work properly. If the sensitivity is not good enough or higher power is needed to drive the power amplifier DUT an additional amplifier A can be added to get a higher power and P_Σ. With the use of harmonic mixers a phase noise analyzer based on real demodulation is needed, because a phase detector approach might not work with a lot of unwanted mixing products present (see Fig 2). For the latter a down converter with preselection would be needed.

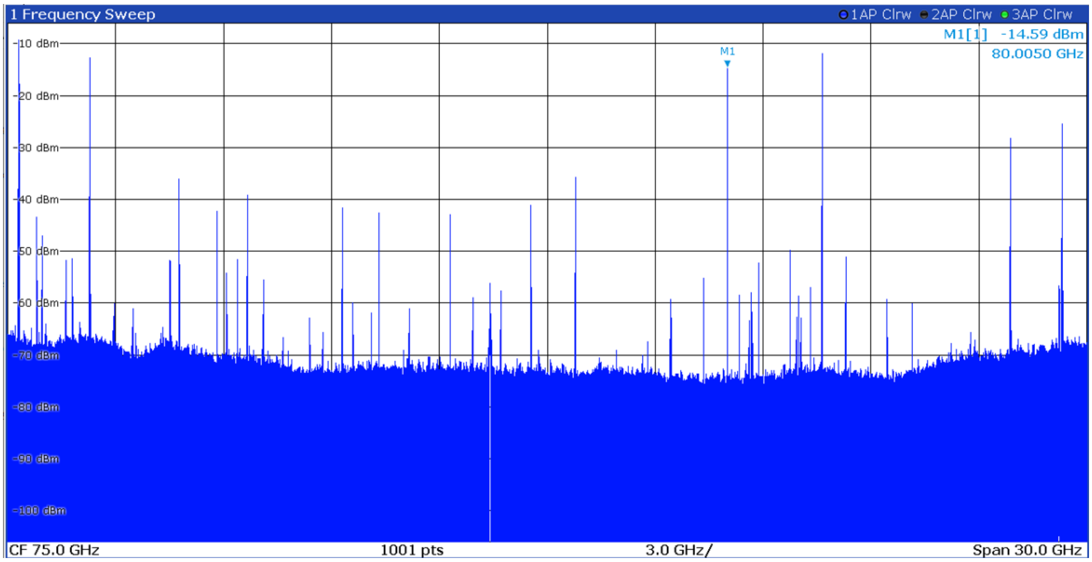


Fig. 2. Spectrum of a harmonic mixer from 60 GHz to 90 GHz showing unwanted mixing products.

3.2 Calculation

According to [3] the additive/residual phase noise of the DUT L(f)$_{DUT}$ can be expressed as:

$$L(f)_{DUT} = \frac{2L(f)}{g} \qquad (1)$$

where g is the suppression factor of the carrier:

$$g = \frac{1}{2}\frac{P_{\Sigma}}{P_{\Delta}} \qquad (2)$$

for LDUT(f) we get:

$$L_{DUT}(f) = \frac{4L(f)P_{\Delta}}{P_{\Sigma}} \qquad (3)$$

in logarithmic notation:

$$L_{DUT}(f) = L(f) + P_{\Delta} - P_{\Sigma} + 6dB \qquad (4)$$

For frequency converting devices like multipliers or multipliers in combination with an amplifier 2 DUTs are needed, one in every path and an additional attenuator. As both devices contribute the same amount of noise for this setup only 3 dB have to be added:

$$L_{DUT}(f) = L(f) + P_{\Delta} - P_{\Sigma} + 3\,dB \qquad (5)$$

4 Amplifier Results

4.1 System Noise Floor

The first measurement is done without the DUT to see the noise floor of the setup for residual/additive phase noise measurement. In this setup the optional amplifier A was added. The power sensor (see Fig. 3) shows a measured power of:

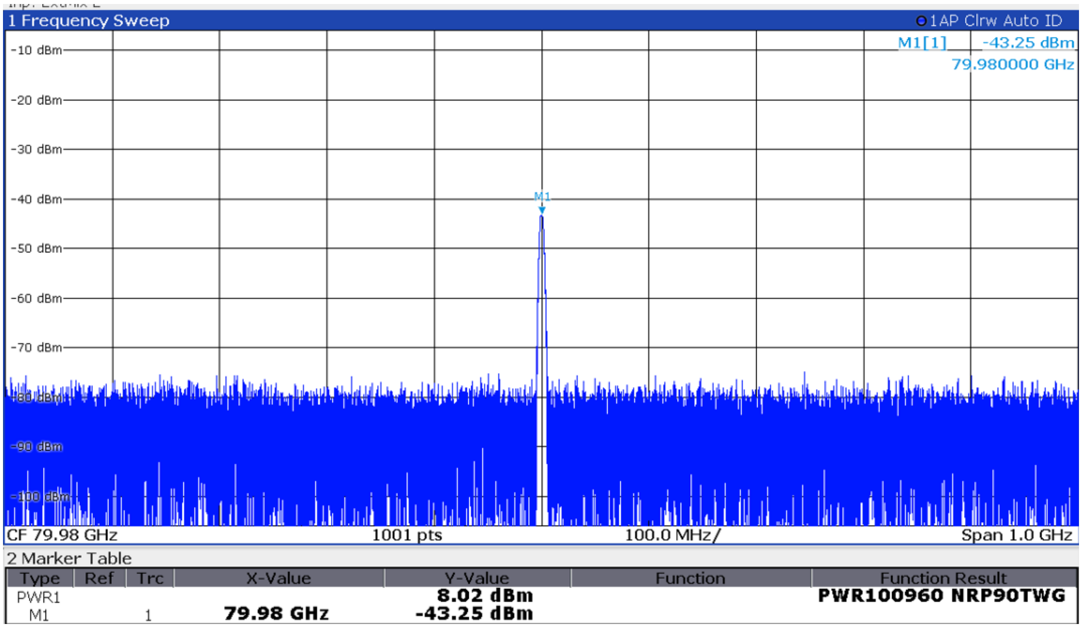
$$P_{\Sigma} = 8.0\ dBm \qquad (6)$$

The harmonic mixers, corrected by the conversion loss of the mixers and the 3 dB loss of the splitter show a power of:

$$P_{\Delta} = -43.3\ dBm + 3\ dB = -40.3\ dBm \qquad (7)$$

The absolute accuracy of the mixer is in the range of 2 dB to 3dB, but the mixer can easily be calibrated to a higher accuracy by using the power sensor for calibration in an appropriate power range for the power sensor and the harmonic mixers. This should be clearly below the 1 dB compression point of the mixer of around -6 dBm. The measured correction factor in the setup was +1.2 dB resulting in:

$$P_{\Delta} = -40.3\ dBm + 1.2\ dB = -39.1\ dBm \quad (8)$$



Type	Ref	Trc	X-Value	Y-Value	Function	Function Result
PWR1				**8.02 dBm**		**PWR100960 NRP90TWG**
M1		1	**79.98 GHz**	**-43.25 dBm**		

Fig. 3. Measurement of P$_{\Sigma}$ with a power sensor (see first line in the marker table) and P$_{\Delta}$ with a harmonic mixer (second line in the marker table)

For proper phase noise measurement at the P$_{\Delta}$ output the suppression of the carrier should not result in levels lower than -45 dBm to enable proper demodulation of the signal.

With these measurements we get a correction factor for the phase noise of the DUT, which can be entered as measurement offset in the phase noise analyzer.

$$L_{DUT}(f) = L(f) - 39.1\ dBm - 8.0\ dBm + 6\ dB \qquad (9)$$

$$L_{DUT}(f) = L(f) - 41.1\ dB \qquad (10)$$

With these correction factors the noise floor for additive/residual phase noise measurements at 80 GHz can be measured with and without cross correlation (see Fig.4). It can clearly be seen, that especially at offsets >10 kHz the cross correlation (orange trace) gives a huge improvement in sensitivity. In addition, the measurement shows, that additive phase noise down to -150 dBc/Hz should be possible with this setup at 100 kHz offset.

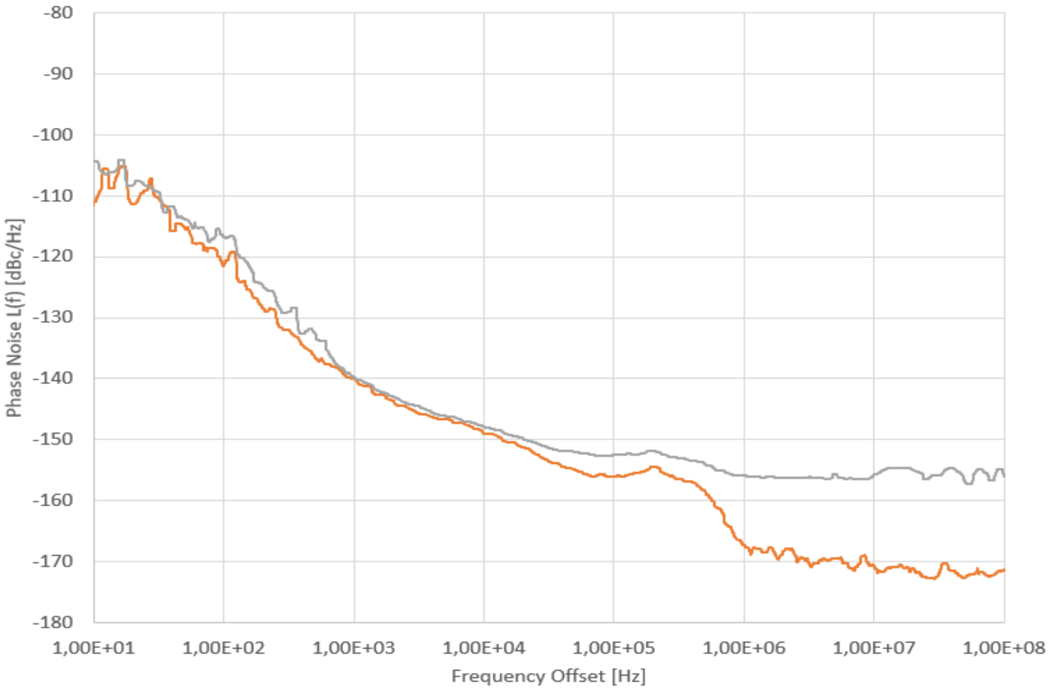


Fig. 4. System noise floor of the interferometric measurement techniques with (orange) and without (grey) x-corr at 80 GHz. Between 100 kHz and 1 MHz offset the PLL low pass of the source can be seen suppressed by 41 dB.

Table 1. Overview of the measurement sensitivity reachable with this setup at different frequency offsets using x-corr

Phase noise sensitivity				
100 Hz	1 kHz	10 kHz	100 kHz	1 MHz
-120dBc/Hz	-140 dBc/Hz	-148 dBc/Hz	-156 dBc/Hz	-168 dBc/Hz

4.2 Measurement of Power Amplifier

After the sensitivity measurement the DUT (power amplifier of FMI) is added and the attenuator and phase shifter are set accordingly. Fig. 5 shows the measurement of the amplifier. The blue line shows the result, the orange line the sensitivity like measured in Fig.4.

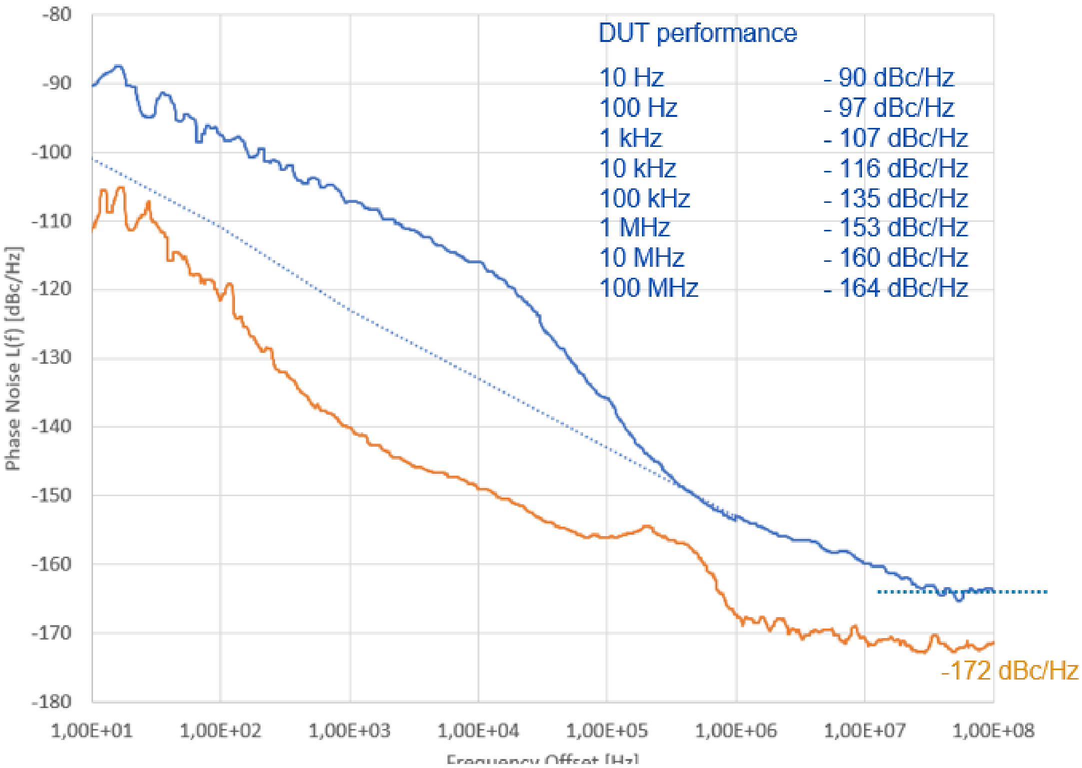


Fig. 5. Measurement of residual/additive phase noise of the DUT (blue) at 80 GHz. The orange line shows the sensitivity of the setup (see Fig. 4) and the dotted blue line the expected 1/f behavior and the horizontal slope for wideband noise.

It can be seen, that the setup can be used to measure the additive phase noise of the amplifier. The required sensitivity is good enough to measure -130 dBc/Hz at an offset of 100 kHz. For wider frequency offsets a horizontal slope can be seen at a level of around -170 dBc/Hz, which basically shows the wideband noise figure of the setup.

This amplifier does not show the perfect 1/f behaviour of the additive phase noise. It is very likely that the biasing of the amplifier causes some additional noise at offsets < 1 MHz.

4.3 Small Signal Approach

The wideband slope of the residual/additive phase noise measurement (blue line in Fig. 5) shows the noise figure of the amplifier and can be compared with a small signal noise figure measurement done with the Y factor method to a certain extend as long as the presence of the carrier does not change the operating points of the amplifier, which applies in our case.

The noise figure of the amplifier has been measured using a noise source and the Y factor method [6] with the setup shown in Fig. 6. A noise source (R&S FS-SNS110) is used to generate an ENR (enhanced noise ratio) at 80 GHz. To increase the sensitivity a low noise amplifier (RPG E-LNA 60-90) is used in front of the harmonic mixer (R&S FS-Z90) and a band pass filter to suppress the influence of unwanted harmonics. In this case the 6th harmonic is used for down conversion. For the spectrum measurements the spectrum analyzer of the phase noise and VCO tester R&S FSWP can be used.

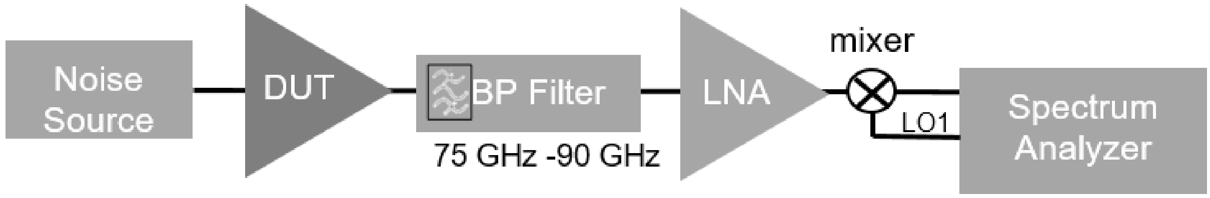
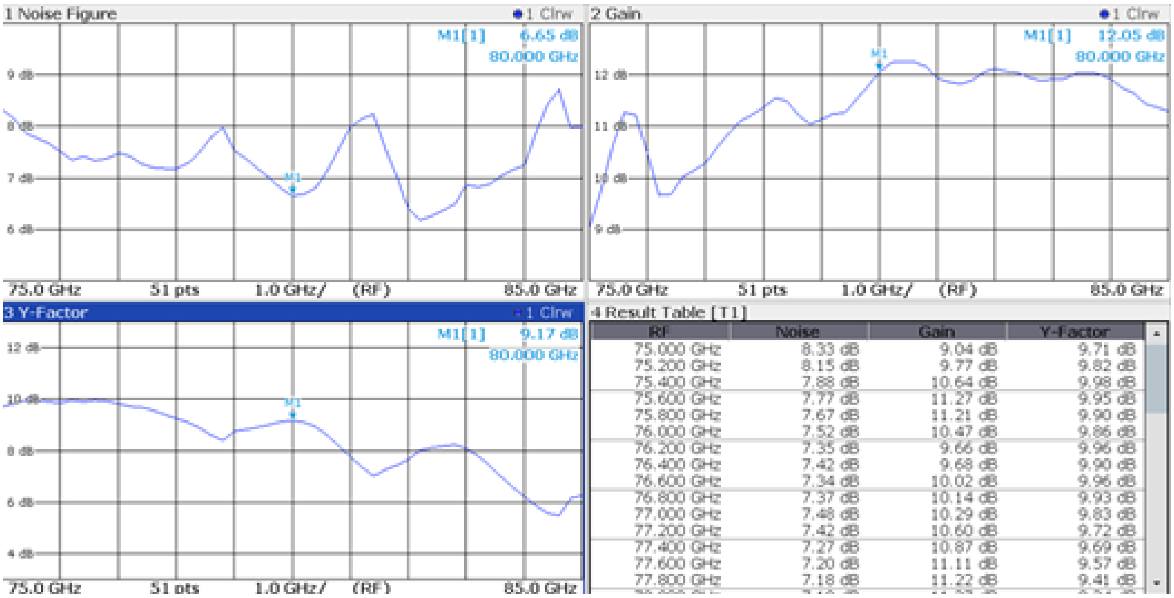


Fig. 6. Setup for noise figure and gain measurement using the Y factor method.

Fig. 7. shows the result, which we got with this setup. At 80 GHz the measurement shows a gain of 12 dB and a noise figure of roughly 6.7 dB. This is the wideband noise added by the amplifier, which can be seen as the slope in Fig.5 at wider offsets:

$$L_{DUT}(f) = -172\frac{dBc}{Hz} + 6.7\ dB = -165.3\ dBc/Hz \qquad (11)$$

which fits quite well to the measurement shown in Fig. 5.



RF	Noise	Gain	Y-Factor
75.000 GHz	8.33 dB	9.04 dB	9.71 dB
75.200 GHz	8.15 dB	9.77 dB	9.82 dB
75.400 GHz	7.88 dB	10.64 dB	9.98 dB
75.600 GHz	7.77 dB	11.27 dB	9.95 dB
75.800 GHz	7.67 dB	11.21 dB	9.90 dB
76.000 GHz	7.52 dB	10.47 dB	9.86 dB
76.200 GHz	7.35 dB	9.66 dB	9.96 dB
76.400 GHz	7.42 dB	9.68 dB	9.90 dB
76.600 GHz	7.34 dB	10.02 dB	9.96 dB
76.800 GHz	7.37 dB	10.14 dB	9.93 dB
77.000 GHz	7.48 dB	10.29 dB	9.83 dB
77.200 GHz	7.42 dB	10.60 dB	9.72 dB
77.400 GHz	7.27 dB	10.87 dB	9.69 dB
77.600 GHz	7.20 dB	11.11 dB	9.57 dB
77.800 GHz	7.18 dB	11.22 dB	9.41 dB

Fig. 7. Measurement of noise figure and gain using the Y factor method in the range from 75 GHz to 85 GHz.

5 Conclusion

There are different approaches to measure the additive phase noise of active components. Normally very high sensitivity of the measurement setup is needed to get reliable numbers for these small noise contributions. In general techniques are used to suppress the inherent noise of the instrumentation like using a mixer in quadrature with the same signal source on the LO and RF input shifted by 90°. These setups are quite complex and become even more complex at microwave frequencies in the range of 80 GHz, especially when it comes to the calibration of the setup. In this paper we have shown, that a phase noise tester supporting external harmonic mixers to cover the frequency range to 80 GHz enables an easy method with external circuitry to measure the additive phase noise of components without the need of complex calibration steps. However, it is still a complex way of measuring the additive phase noise and not suitable for production, even if the phase shifter and attenuator are set automatically. Nevertheless, it offers an easy method for verification of simulation results and a powerful tool for R&D applications.

6 Literature

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7 Ordering information

Designation	Type	Order No.
Phase noise analyzer 1 MHz to 26.5 MHz	R&S®FSWP26	1322.8003.27
Phase noise analyzer 1 MHz to 50 GHz	R&S®FSWP50	1322.8003.51
Support for harminic mixers for FSWP	R&S®FSWP-B21	1325.3848.02
Harmonic mixers 60 - 90 GHz	R&S®FS-Z90	3638.2270.02
Smart noise source 75 GHz to 110 GHz	R&S®FS-SNS110	1338.8008.11
Thermal power sensor	R&S®NRP90T	1424

PAD-T-M: 3572.7186.00/02.00/EN

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