DER EINFLUSS DES PHASENRAUSCHENS BEI RF-ANWENDUNGEN UND MODERNE TECHNIKEN ZUR MESSUNG

Dr. Wolfgang Wendler

ROHDE & SCHWARZ

Make ideas real

AGENDA

- **Introduction**
  - **Phase Noise – a crucial parameter for many applications**
- Phase Noise Measurement techiques
  - Spectrum anylzer
  - PD or PLL method
  - Direct demodulation with FSWP
- Architecture of the instrument
- Cross correlation technique
- Additive/residual phase noise measurement

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WHAT IS PHASE NOISE?

- **Ideal Signal (noiseless)**

  V(t) = A sin(2πνt)

  where

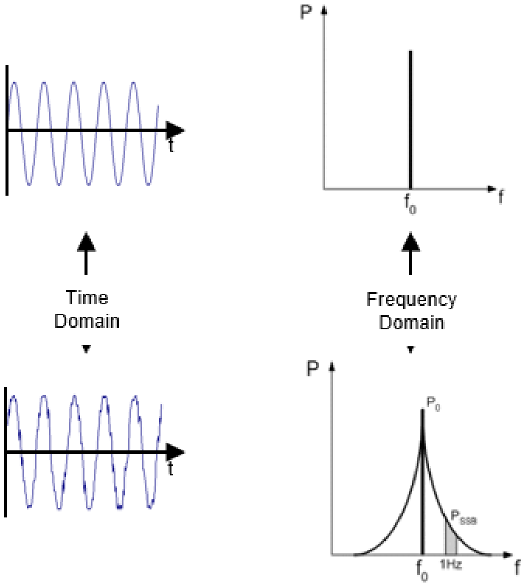
A	=	nominal amplitude
ν	=	nominal frequency

- **Real Signal**

  V(t) = [A + E(t)] sin(2πνt + ϕ(t))

  where

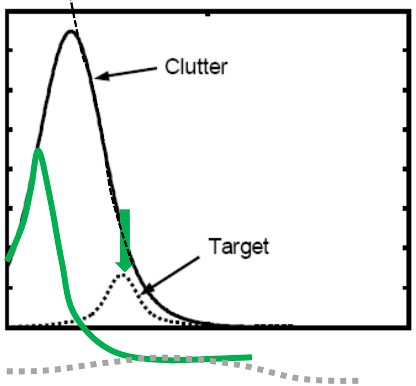
E(t)	=	amplitude fluctuations
ϕ(t)	=	phase fluctuations

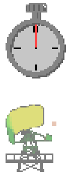


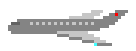
$$L(f_m) = 10\log\left(\frac{Single\_Sideband\_Power\_related\_to\_1Hz\_P_{SSB}}{Carrier\_Frequency\_Power\_P_0}\right) \quad [dBc(1Hz)]$$

PHASE NOISE - IMPORTANT FOR RADAR

Radar Applications – Moving Target Indication



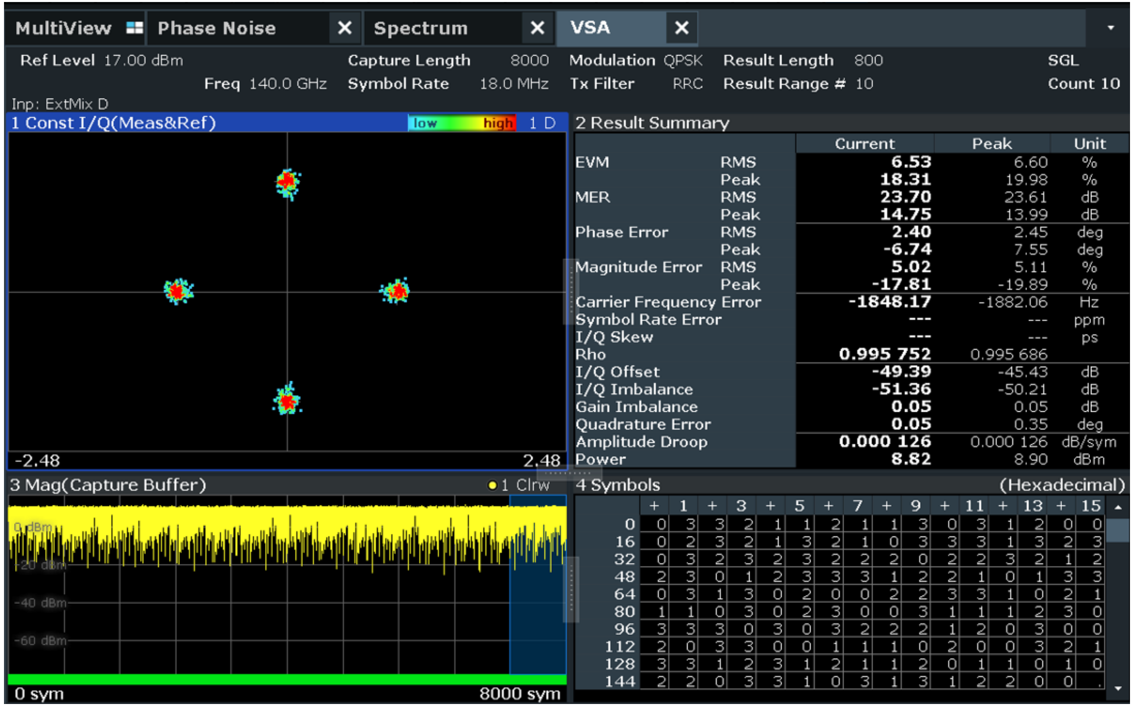




High phase noise in radar LO spreads clutter signal and masks desired low-level target response

The lower the phase noise the better is the resolution

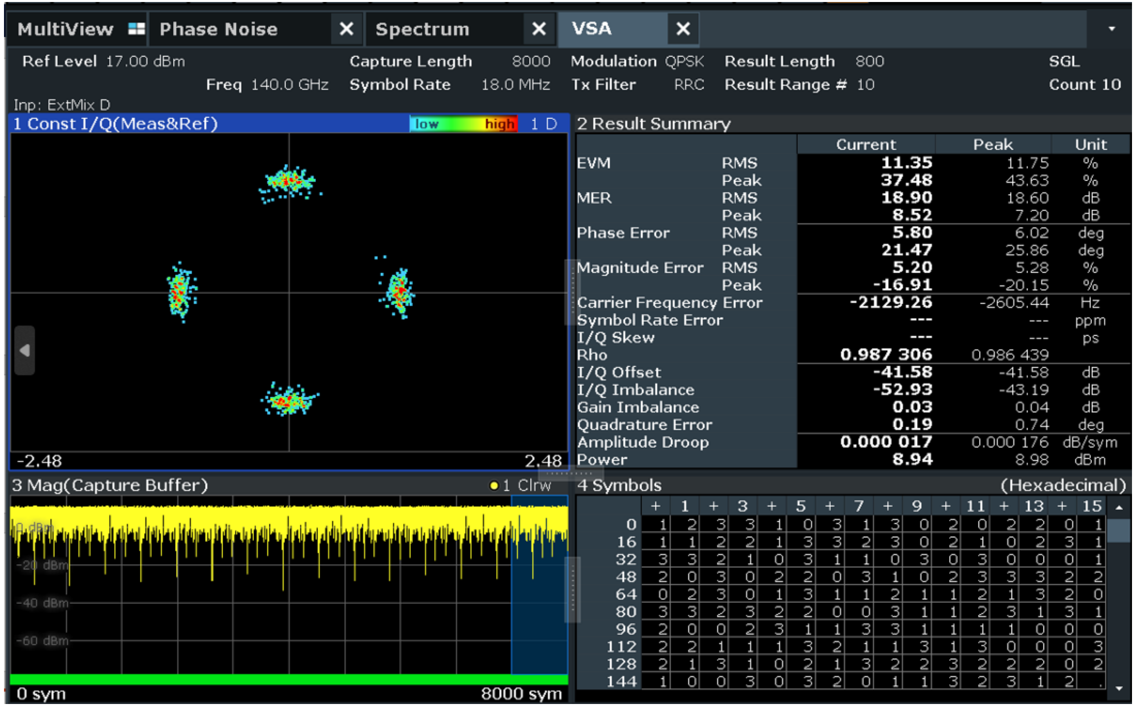
PHASE NOISE AND EVM PERFORMANCE



F_{RF}: 140 GHz

-95 dBc/Hz at 100 kHz Offset

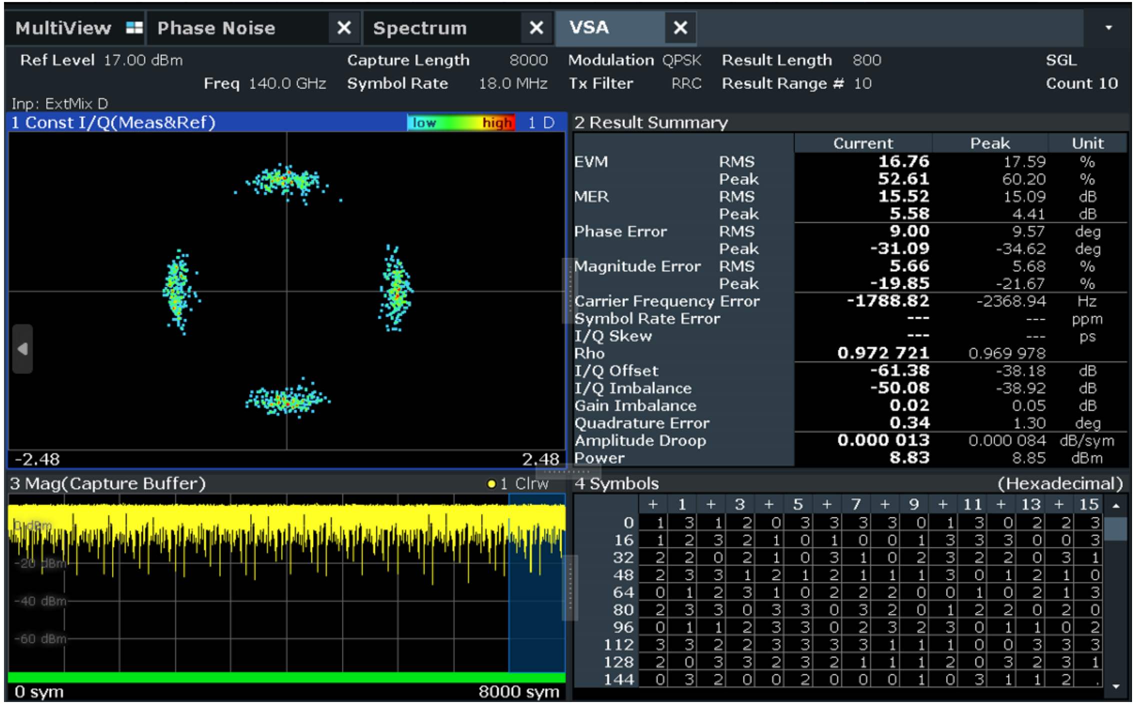
PHASE NOISE AND EVM PERFORMANCE



F_{RF}: 140 GHz

-90 dBc/Hz at 100 kHz Offset

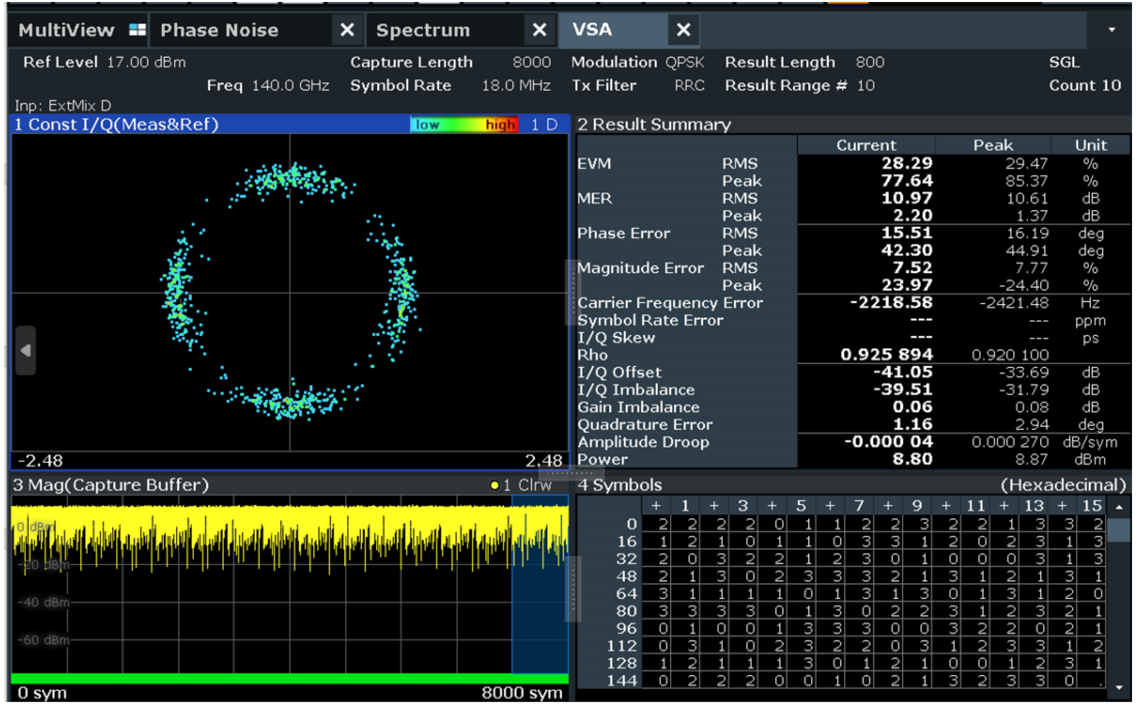
PHASE NOISE AND EVM PERFORMANCE



F_{RF}: 140 GHz

-85 dBc/Hz at 100 kHz Offset

PHASE NOISE AND EVM PERFORMANCE



F_{RF}: 140 GHz

-80 dBc/Hz at 100 kHz Offset

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RJ MEASUREMENT IN TIME AND FREQUENCY DOMAIN

Ideal Signal

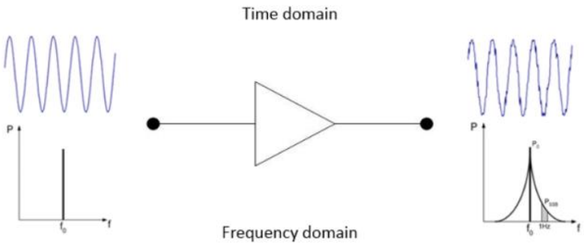
$V(t) = A_0 \sin \omega_0 t$

Where:
A_0 = nominal amplitude
ω_0 = nominal frequency

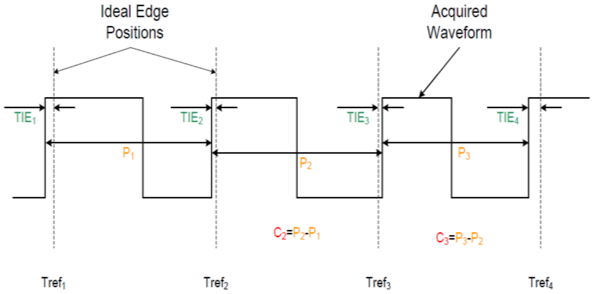
Real-world Signal

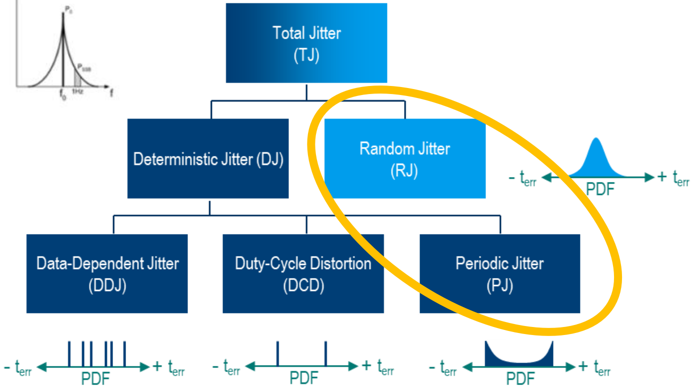
$V(t) = (A_0 + E(t)) \sin(\omega_0 t + \varphi(t))$

Where:
E(t) = random amplitude changes
Φ(t) = random phase changes



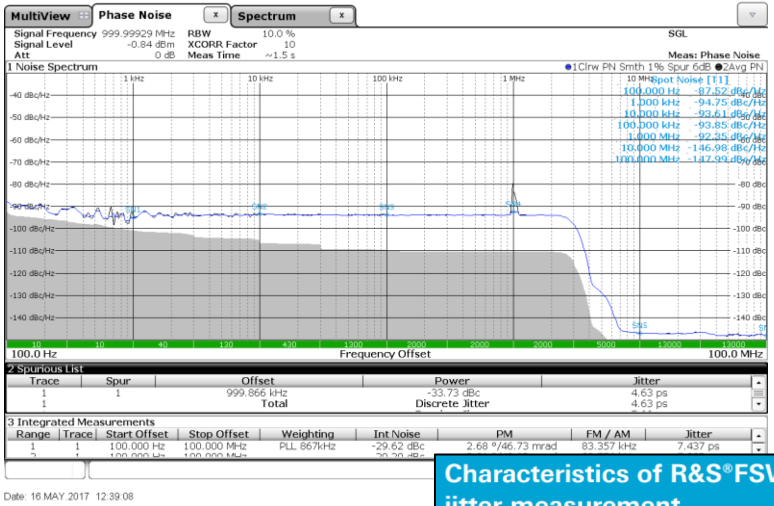
$$j_{TIE}(n) = (t_n - t_{REF_n})$$

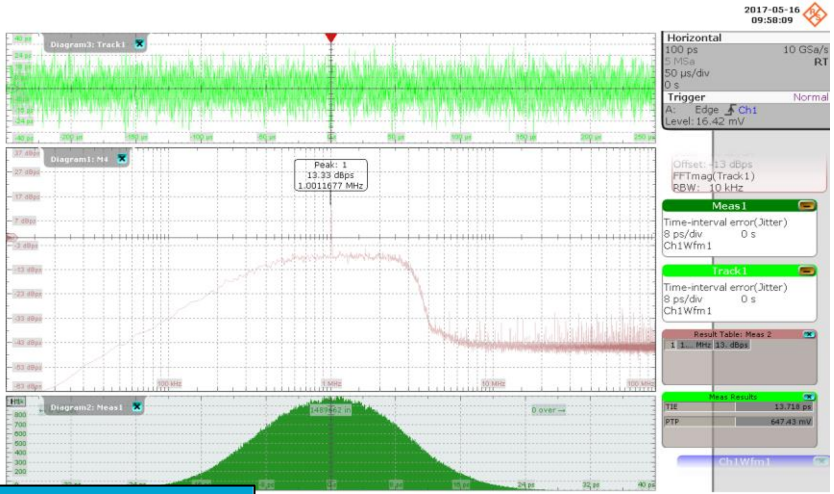




COMPARISON OF MEASUREMENTS

COMPARATIVE MEASUREMENT OF A SIGNAL FROM SIGNAL GENERATOR





Characteristics of R&S®FSWP and R&S®RTO for jitter measurement

	R&S®FSWP	R&S®RTO
Sensitivity	≤ 5 fs	600 fs (jitter noise floor)

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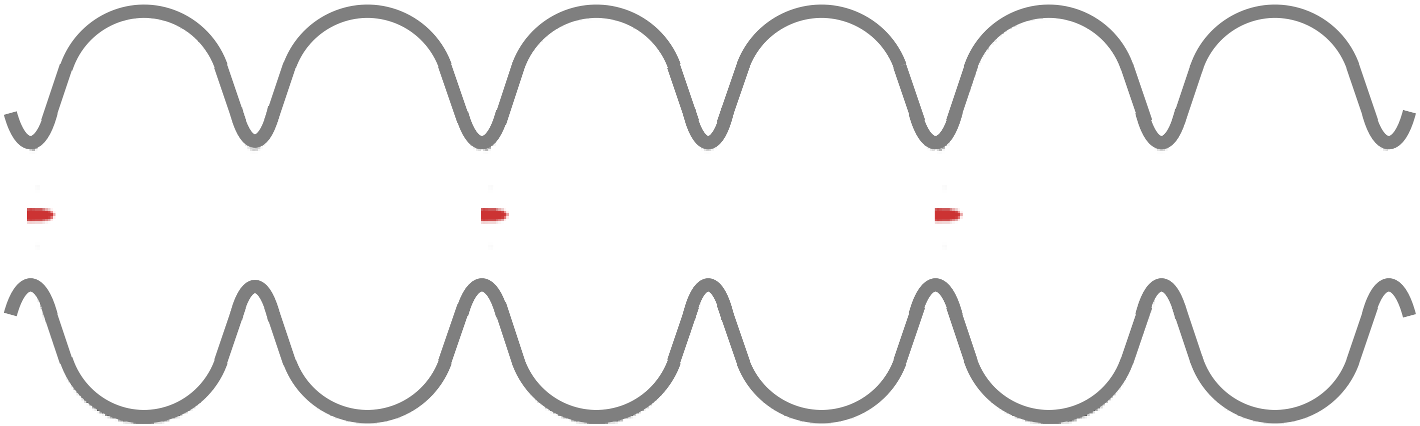
ACCELERATION OF ELECTRONS - VISUALIZATION WITH FIELD LINES

Watch the alternating field line direction.
The electrons can only be accelerated in a cavity if the field shows from the right to the left.
Synchronization is required.



Electrons do not occur one by one. The electrons are provided in groups = electron bunches

Source: http://tesla.desy.de/new_pages/4211_Cavity_design.html
Modifications by R&S, 5SIC

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PHASE NOISE MEASUREMENT WITH SPECTRUM ANALYZER FSW-K40 / FSV3-K40 / FPS-K40

- 2 modes:
  1.) „**Swept**“: „classical“, display spectrum trace right of carrier logarithmic
  2.) „**IQ FFT**“: run signal processing on captured IQ data

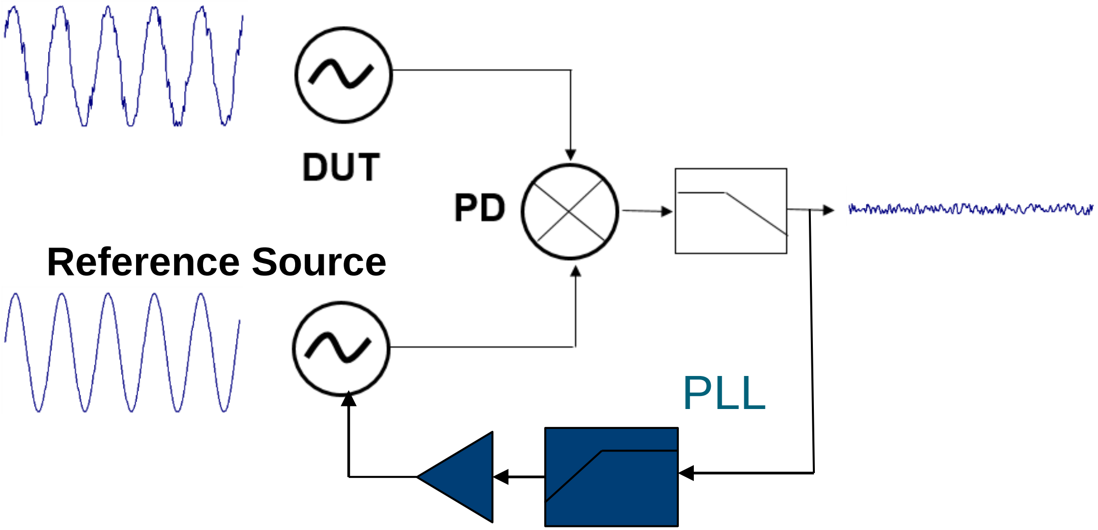
- „IQ FFT“ is more powerful, offering:
  - Higher measurement **speed**
  - Much better **frequency tracking** and correction function
  - **AM rejection** (measure ONLY phase noise, REMOVE AM noise)
  - More measurement **results** (e.g. level variation, frequency vs time)

  („IQ FFT“ uses the same signal processing DLL as used in the FSUP)

Performance limited by local oscillator LO

Performance

Phase Detector Method - *PLL Method*



R&S FSWP - PHASE NOISE AND VCO TESTER

- Signal- and spectrum analyzer and phase noise tester in one box
- Phase Noise Measurement fast with unrivalled sensitivity
  - typ. -172 dBc/Hz at 1 GHz and 10 kHz offset
- Real demodulation
  - AM noise and phase noise measurement in parallel
- Cross correlation for increased sensitivity
  - Correlation gain indicator
- Frequency range for phase noise measurement up to 50 GHz
  - Up to 325 GHz with external mixers
- Scalable RBW:
  - 0.1% to 30% to optimize performance/measurement time
  - Ultra small RBW 0.0003% for detection of very small spurs
- Measurement of pulsed phase noise by push of a button
- Internal source (up to 18 GHz) for residual/additive phase noise measurements
  - Without ext. phase shifter , just connect the DUT

- Ssignal and spectrum analyzer
  - 320 MHz analysis bandwidth

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DIFFERENCES: R&S FSW-K40 – R&S FSWP

Faster!

	Spectrum Analyzer **FPS & K40**	Spectrum Analyzer **FSW & K40**	Phase No Analyzer **FSWP**
Measure Phase Noise	✓	✓	✓
Pulsed Phase Noise	✗	✗	✓
Measure VCO‘s (phase noise)	✓	✓	✓
Dedicated VCO Measurements	✗	✗	✓
Cross Correlation (improve phase noise performance)	✗	✗	✓
Sensitivity (1 GHz, 10 kHz Offset)	**-110 dBc/Hz**	**- 135 dBc/Hz**	**- 172 dBc/Hz**
AM Noise Suppression	✓	✓	✓
AM Noise Measurement	✗	✗	✓
Additive Phase Noise	✗	✗	✓

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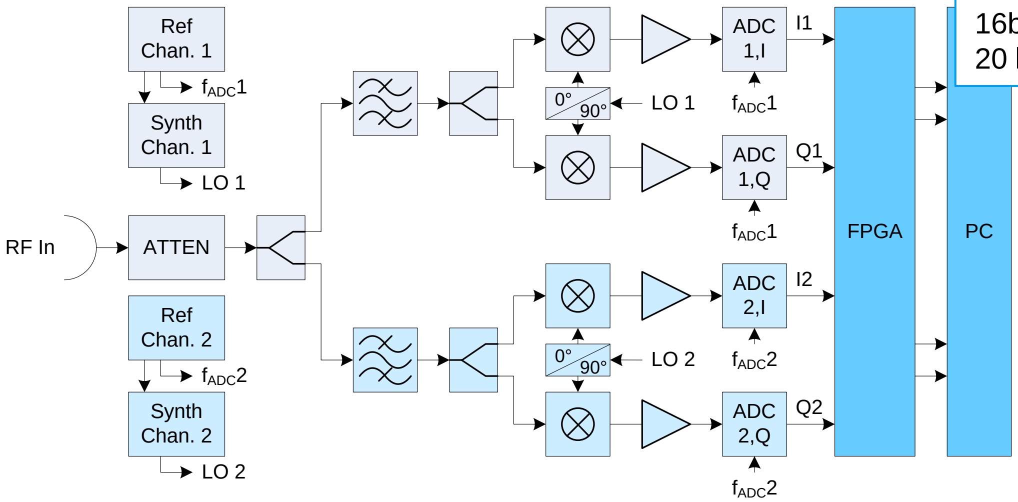
ANALOG SIGNAL PATH



100 Msamples/s,
16bit
$20 \log 2^{16} + 10^{*}\log 100\text{MHz} = 176$ dBc/Hz

- Two loosely coupled reference sources (PLL bandwidth < 0.1 Hz)
- Analog I/Q mixer with low- or zero-IF
  - IF depends on frequency offset to be measured
  - Optimized to avoid spurious emissions

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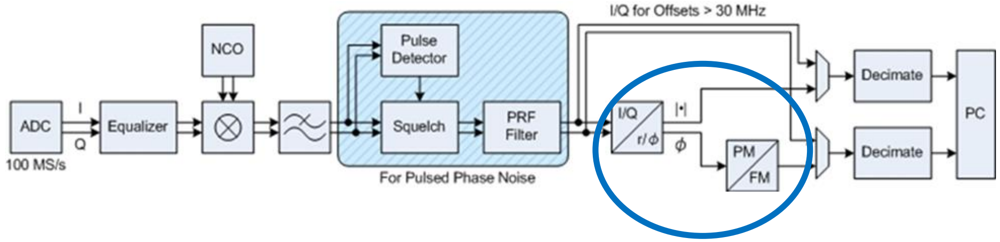
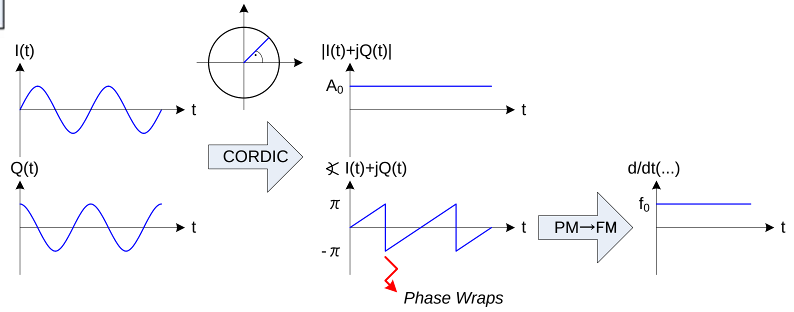
Digital Signal Path – FM Demodulator





- ► PM signal has phase wraps at ±π. No filtering or FFT possible.
- ► FM demodulator preferred to digital PLL due to its simplicity
- ► FM demodulator frequency response decreases with 20 dB per decade toward DC
  - – Analog FM demodulators are insensitive close to the carrier
  - – White noise, e.g. quantization noise, must be hold below the FM slope
  - – 48 bit signal dynamic do the job!

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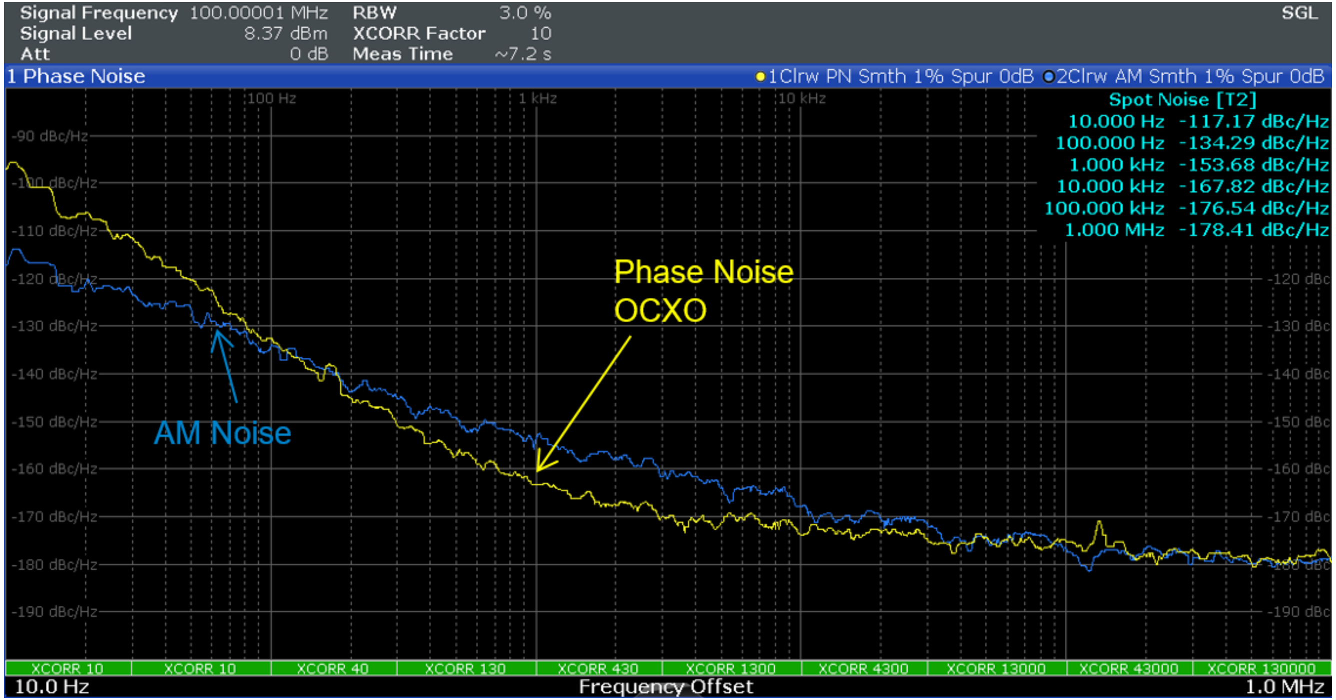
PARALLEL MEASUREMENT OF AMPLITUDE AND PHASE NOISE



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High end References for small Offsets

R&S FSWP-B61 vs Standard FSWP-B60

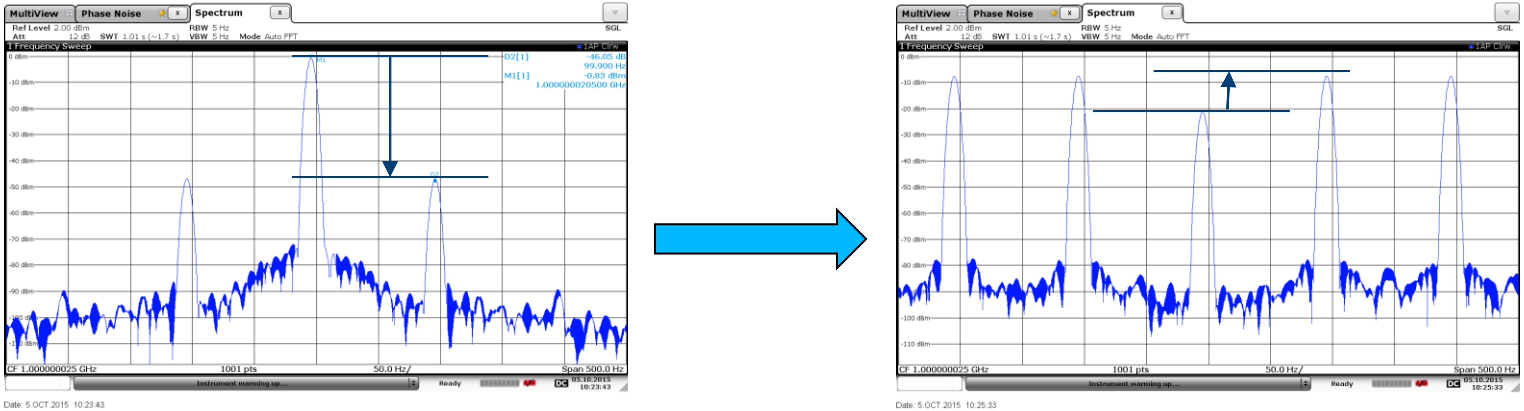
Start offset 1 Hz, correlation factor = 1

	Offset frequency from the carrier										
	0.01 Hz	0.1 Hz	1 Hz		10 Hz		100 Hz		1 kHz		
1 MHz	-60	-105	–118	–118	–136	–136	–148	–148	–166	–166	
10 MHz	-40	-86	–115	–106	–132	–130	–142	–140	–160	–158	
100 MHz	-20	-66	–95	–86	–117	–116	–140	–136	–166	–163	
1 GHz	0	-46	–75	–66	–97	–96	–120	–116	–150	–143	
3 GHz	+10	-36	–65	–56	–87	–86	–110	–106	–140	–133	
7 GHz	+17	-29	–58	–49	–80	–79	–103	–99	–133	–130	
10 GHz	+20	-26	–55	–46	–77	–76	–100	–96	–133	–128	
16 GHz	+24	-22	–51	–42	–73	–64	–96	–92	–129	–124	
26 GHz	+28	-18	–47	–38	–69	–60	–92	–88	–125	–120	
50 GHz	+34	-12	–41	–32	–63	–54	–86	–82	–119	–114	

FSWP-B61 - Specification

Positive Numbers for Phase Noise?

- 0.01 Hz causes **+20dB** to get dBc/Hz
- Real demodulation – what happens, if deviation of phase modulation is increased?
- Application note:
    - https://www.rohde-schwarz.com/applications/r-s-fswp-validity-of-positive-phase-noise-values-white-paper_230854-831492.html



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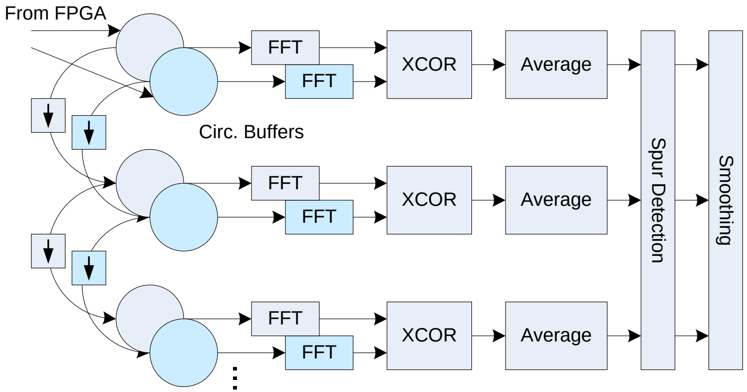
FFT and Cross-Correlation

- Spectrum is divided into half decades (1 Hz to 3 Hz, 3 Hz to 10 Hz, …)
- Result is the magnitude of cross-correlation averages



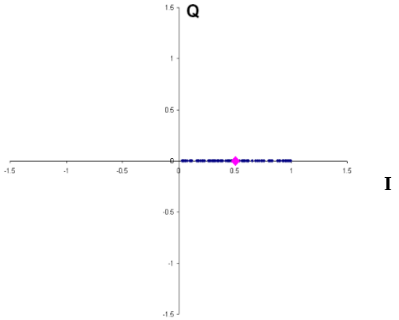
$$\hat{S}_{YX} = \frac{1}{N} \cdot \left| \sum_{i=0}^{N-1} Y_i \cdot \mathrm{conj}\left(X_i\right) \right|$$

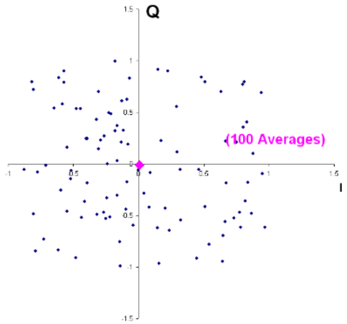
Improvement of sensitivity: 5 log (N)

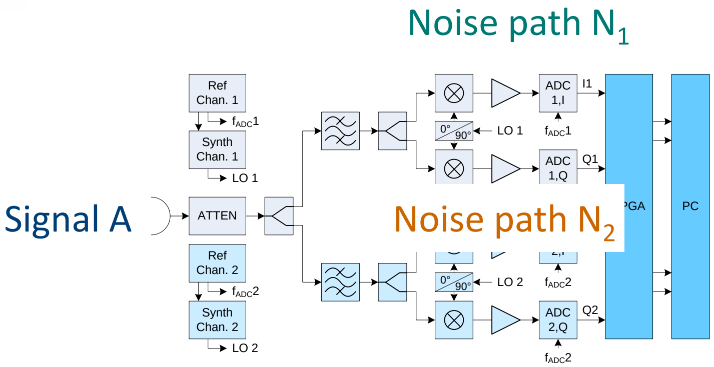
FFT and Cross-Correlation

$$L(f) \sim \left| \frac{1}{N} \sum_{i=1}^{N} (A_i + N_{1,i})(A_i + N_{2,i})^* \right|$$

$$L(f) \sim \left| \frac{1}{N} \sum_{i=1}^{N} A_i A_i^* + \underbrace{\frac{1}{N} \sum_{i=1}^{N} A_i N_{2,i}^*}_{\to 0} + \underbrace{\frac{1}{N} \sum_{i=1}^{N} A_i^* N_{1,i}}_{\to 0} + \underbrace{\frac{1}{N} \sum_{i=1}^{N} N_{1,i} N_{2,i}^*}_{\to 0} \right|$$



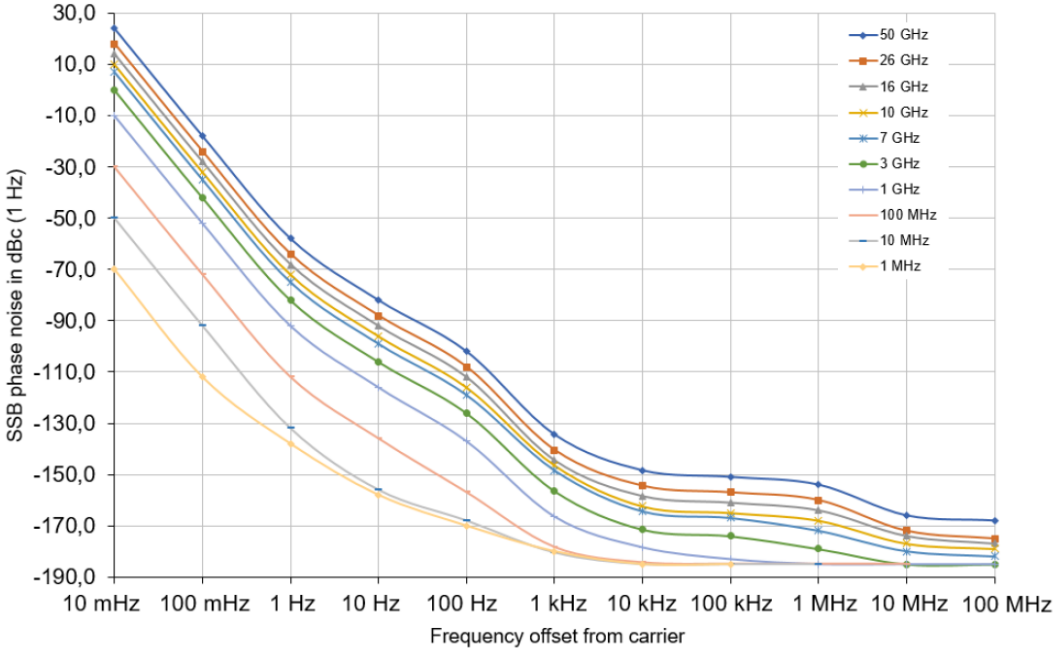




Sensitivity Improvement 5 log n

R&S FSWP PERFORMANCE

► Typical phase noise at different center frequencies with R&S®FSWP-B61 option (start offset = 10 mHz)



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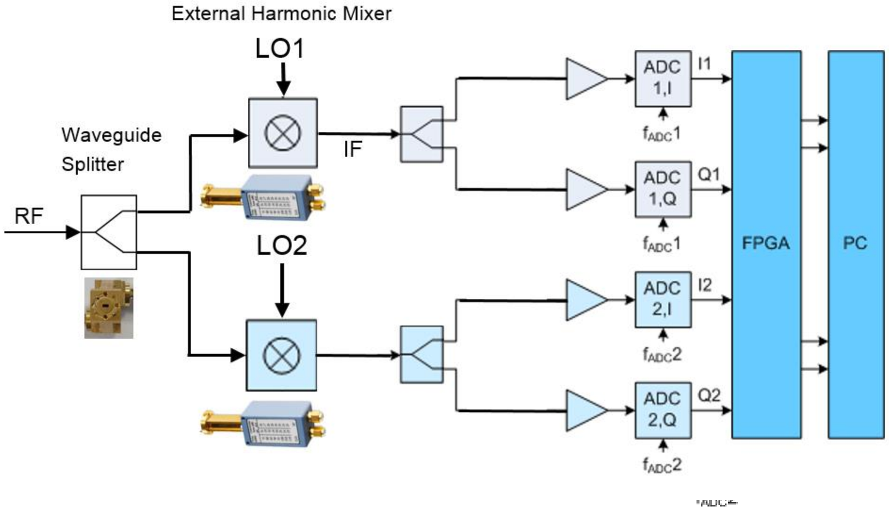
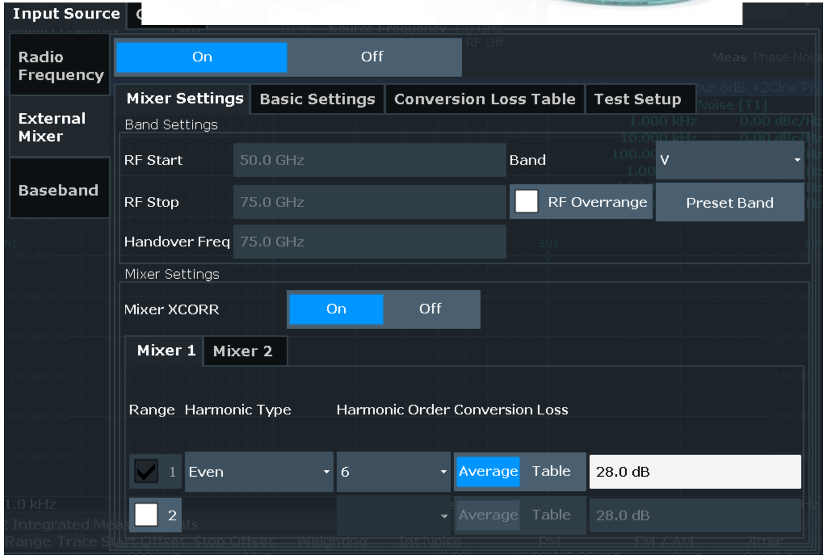
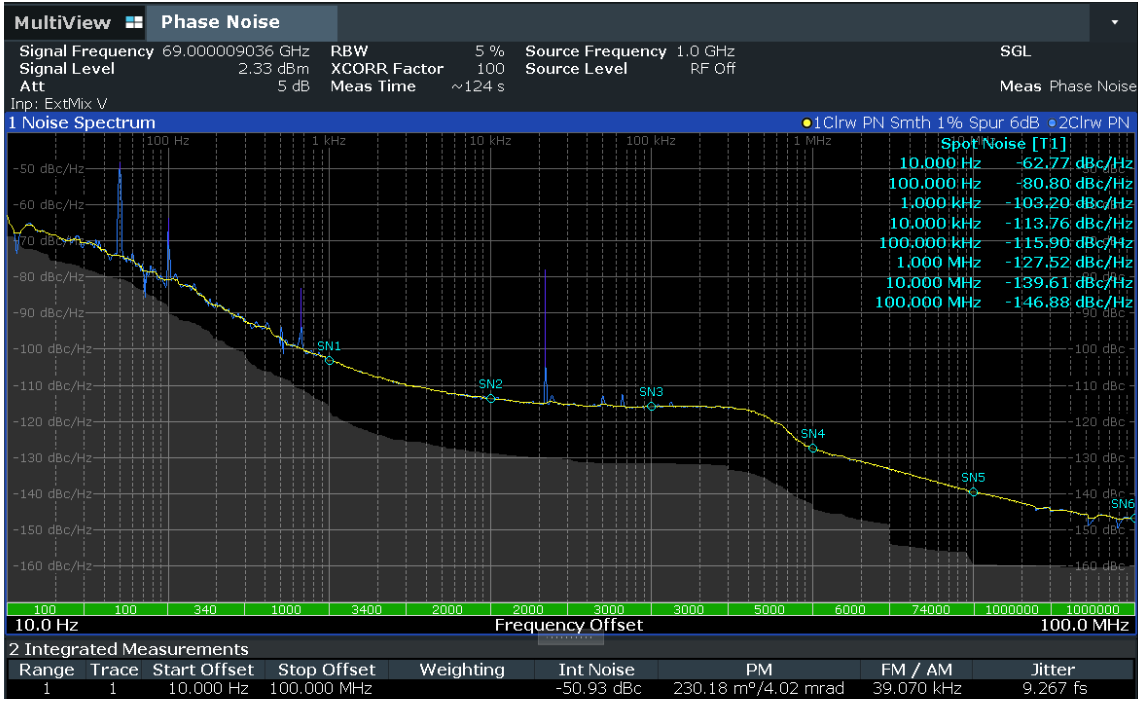
R&S FSWP +Harmonic Mixers





R&S FSWP +Harmonic Mixers

Measurement of the phase noise of an R&S SMA100B at 67 GHz



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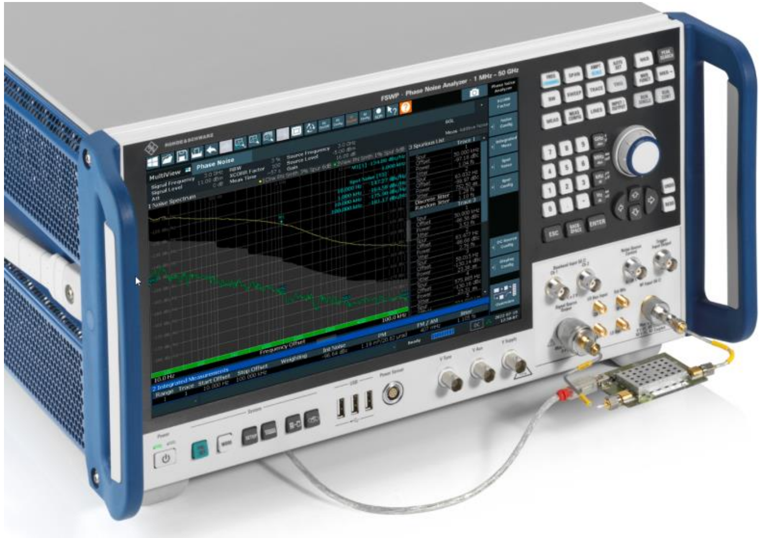
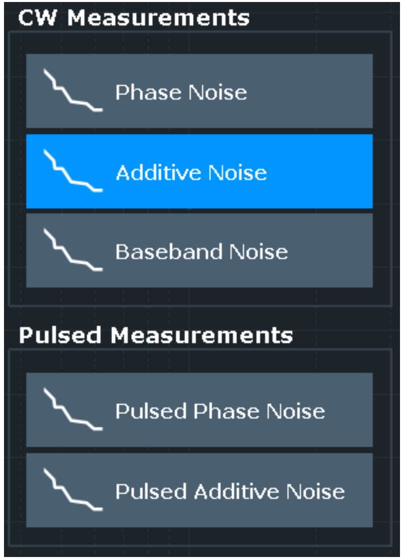
R&S FSWP – FSWP-B64
RESIDUAL/ADDITIVE PHASE NOISE MEASUREMENT





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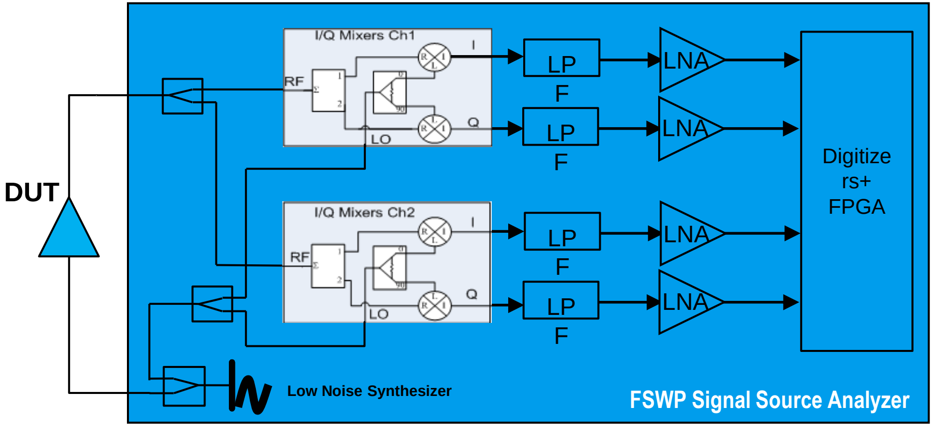
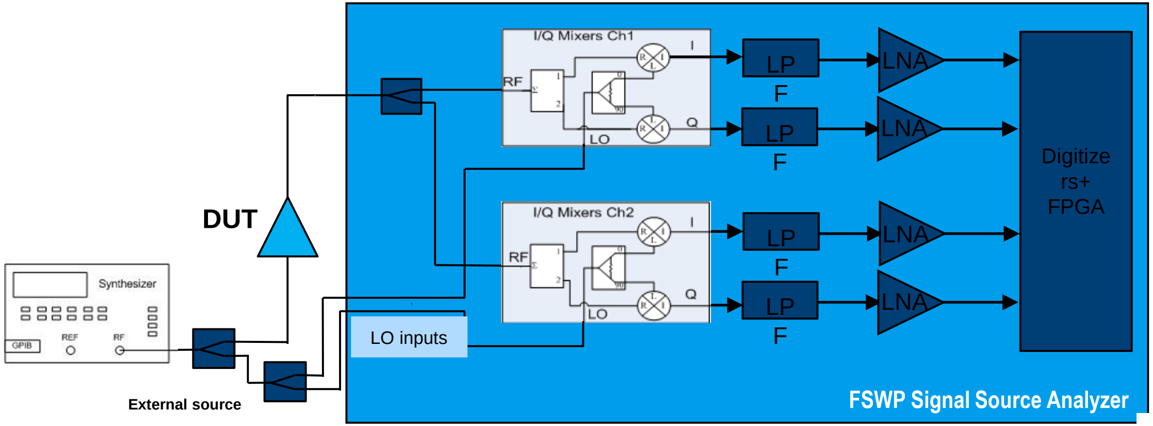
Additive Phase Noise – Digital Phase Demodulator

- Internal hardware automatically reconfigures when “Additive” is selected
- No phase detector needed for quadrature – no phase shifter
- Greatly simplifies measurement setup and calibration
- Internal Low Noise Synthesizer as DUT stimulus



Additive Phase Noise – Digital Phase Demodulator

- No phase detector needed for quadrature – no phase shifter
- Greatly simplifies measurement setup and calibration
- External Low Noise Synthesizer as DUT stimulus can be selected
  - High end source can be used
  - Support of freq. converting DUTs is possible



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Application Note

Additive/residual phase noise measurement

1EF100: 2-Port Residual Noise Measurements

As phase noise becomes an increasingly important system-level specification for electronic test equipment, communications systems, and radar systems. It is not only important to quantify the noise produced by oscillators, but also the noise added by each component in the signal processing chain. This application note reviews the fundamentals of residual or additive noise and addresses measurement techniques for determining the amplitude (AM) and phase noise added by two-port devices such as: amplifiers, mixers, block frequency converters, multipliers, dividers, and frequency synthesizers. Additionally, the Rohde & Schwarz FSWP phase noise analyzer will be introduced and a discussion of residual noise measurement techniques for the above-mentioned devices will be provided.

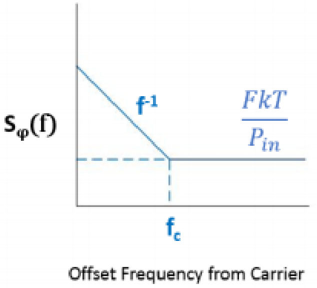
Name	Type	Language	Version	Date	Size
▸ 1EF100_1e_2-Port_Residual_Noise_Meas.pdf	Application Note	English	1e	09.10.2017	2 MB

https://www.rohde-schwarz.com/applications/2-port-residual-noise-measurements-application-note_56280-487744.html

Interesting – Noise Figure Measurement

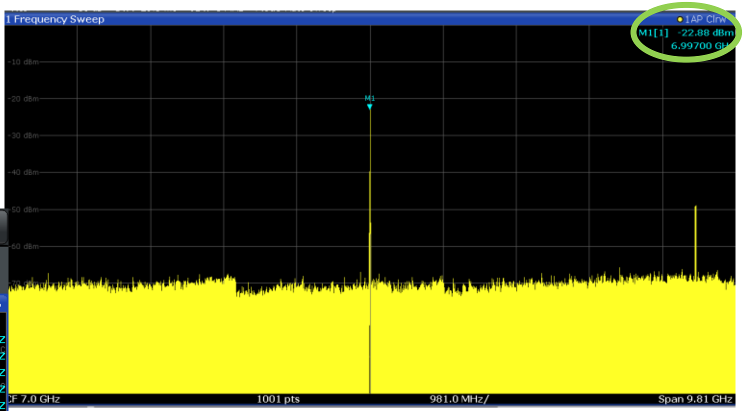
$$\mathcal{L}(f) = N_{TH} + FN - P_{in}$$

Where N_{TH} = -177 dBm/Hz.



Application Note

Additive/residual phase noise measurement



$$\mathcal{L}(f) = N_{TH} + FN - P_{in}$$

-147.9 dBc/Hz=-177 dBm/Hz+FN-(-22.9 dBm)

FN=6.2 dB

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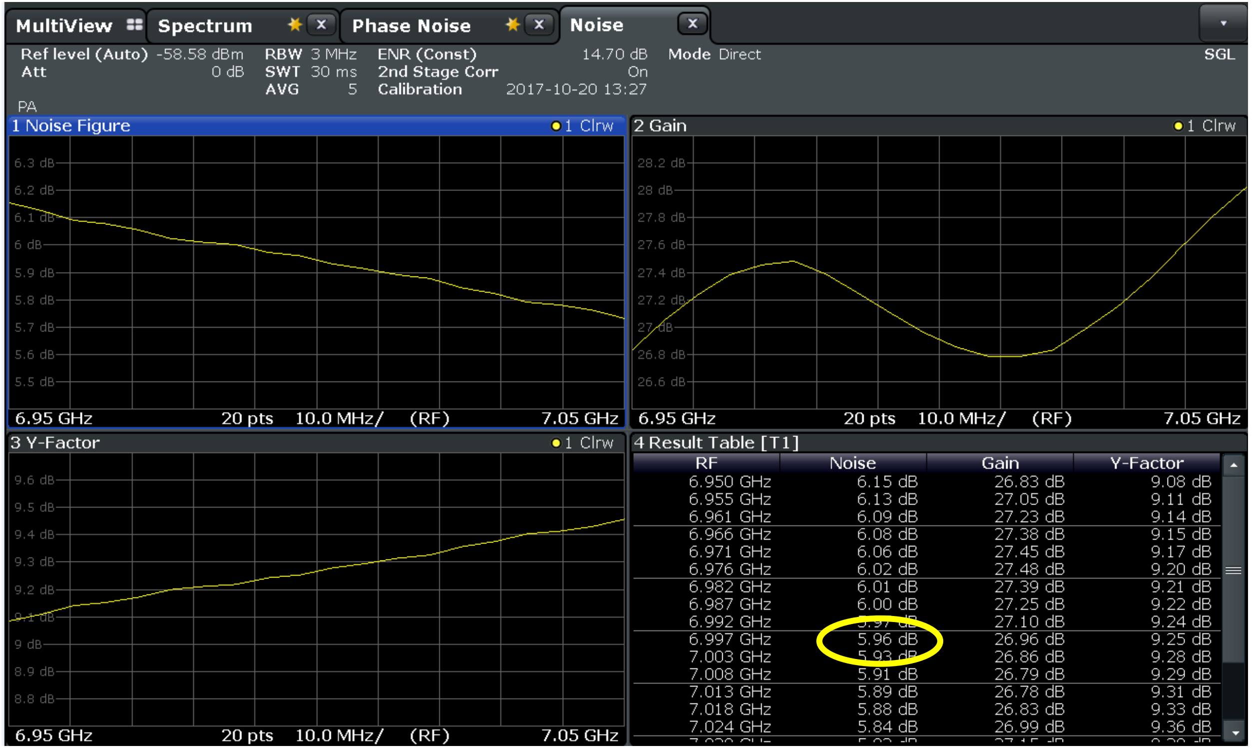
New Application Note

Additive/residual phase noise measurement



QUESTIONS

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