Phase Noise Measurements with Spectrum Analyzers of the FSE family

Application Note 1EPAN 16E

Subject to change

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Products:

FSEA 20/30, FSEB 20/30

ROHDE&SCHWARZ

Measured Quantities

In addition to frequency, power and long-term stability, short-term stability or its equivalent, phase noise, is an important characteristic of signal sources. For example, the phase noise of conversion oscillators of receivers obtained in the presence of a strong signal determines adjacent-channel sensitivity. In the case of transmitters, the phase noise of the oscillator together with the modulator characteristics is responsible for the power generated in adjacent channels. The phase noise of oscillators or synthesizers and the relevant measurements therefore play an important role in radio transmission systems.

Mathematically, the output signal of an ideal oscillator can be described as follows:

$u(t) = U_o \sin(2\pi f_o t)$

where:
U_o = amplitude of signal
f_o = frequency of signal
$2\pi f_o t$ = phase of signal

For real signals, both the amplitude and phase are subject to variations:

$u(t) = (U_o + \varepsilon(t)) \sin(2\pi f_o t + \Delta\varphi(t))$

where
$\varepsilon(t)$ = amplitude variation of signal
$\Delta\varphi(t)$ = phase variation or phase noise of signal

As to the term $\Delta\varphi(t)$, a differentiation must be made between two types of phase variation:

- deterministic phase variation due to AC hum or insufficient suppression of the reference frequency in synthesizers, the latter shown by discrete lines of interference, and
- random phase variation (= phase noise) caused by thermal, shot or flicker noise in the active elements of oscillators.

A measure of phase noise is SSB noise power density referred to 1 Hz bandwidth:

$$S_{\Delta f}(f) = \frac{\Delta f^2_{rms}}{1\,\mathrm{Hz}} \frac{\mathrm{rad}^2}{\mathrm{Hz}}$$

In practice, SSB phase noise L is commonly used to describe the phase noise characteristics of an oscillator. L is defined as the ratio of the noise power measured in a sideband over a bandwidth of 1 Hz at a frequency offset f_m from the carrier to the total signal power.

$$L(f_m) = \frac{P_{SSB}[1\,\mathrm{Hz}]}{P_{signal}}$$

If the modulation sidebands are very small due to noise, ie if phase deviation is much smaller than 1 rad, the SSB phase noise can be derived from the noise power density:

$$L(f) = \frac{1}{2} \cdot S_{\Delta f}(f).$$

The SSB phase noise is commonly specified as a logarithmic function:

$$L_c(f_m) / [\mathrm{dBc} / \mathrm{Hz}] = 10 \cdot \log(L(f_m))$$

Methods of Measurement

The simplest and fastest method of determining the phase noise of an oscillator is the direct measurement by means of a spectrum analyzer. For this measurement, the oscillator must fulfill the following conditions:

- The oscillator drift must be small relative to the spectrum-analyzer sweep time since otherwise the oscillator frequency varies during the sweep, leading to distorted results. The synthesizers commonly used in radiocommunications fulfill this condition since they are locked to a stable reference.
- The phase noise of the local oscillators of the spectrum analyzer must be low enough to ensure that the characteristics of the DUT and not those of the spectrum analyzer are determined. FSE meets this condition for a wide variety of applications.

Another, frequent method is measurement by means of a reference oscillator and a phase detector (FIG 1).

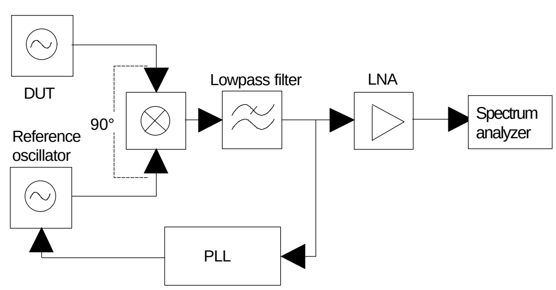

FIG 1 Test setup for phase noise measurements with a reference oscillator

The reference oscillator is synchronized to the DUT by means of a PLL of a very small bandwidth. The PLL sets the phases of the two oscillators to a difference of 90°. The phase noise of the DUT is eliminated within the loop bandwidth.

The sum noise power of the reference and the test oscillator obtained outside the loop bandwidth is present at the output of the phase detector. This output signal is amplified by means of an LNA (low-noise amplifier) and displayed on a spectrum analyzer starting at a frequency of 0 Hz.

This method offers the advantage of a very wide dynamic range, provided that the reference oscillator is of a very high spectral purity. Often, two identical oscillators are used for measurements on crystal oscillators, and the assumption made that the two oscillators have the same phase noise. In this case, 3 dB is subtracted from the result because the noise powers add up.

The disadvantages of the method are obvious:

- The method requires two oscillators at the same frequency that have to be synchronized to each other.
- An extra PLL and a low-noise amplifier are needed.
- Calibration is complex because the gain of all components is included in the result. Calibration is made by mistuning the two oscillators relative to each other and measuring the AC voltage obtained at the output of the LNA.

As this method is highly complex, direct phase noise measurement by means of a spectrum analyzer will be preferable. FSE with its excellent phase noise characteristics is an ideal choice for this task.

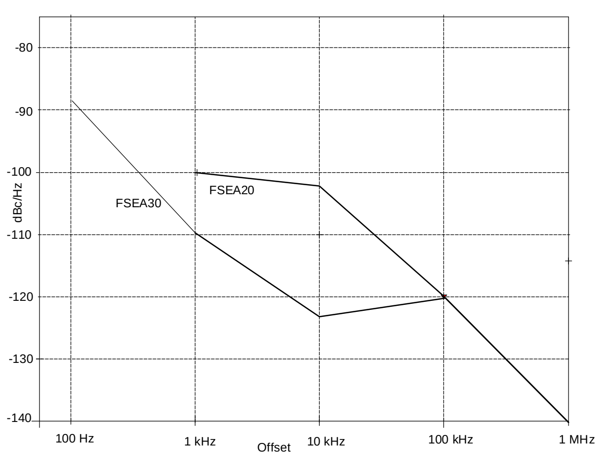

FIG 2 SSB phase noise of FSEA20 and FSEA30 at 500 MHz input frequency

FIG 2 shows the phase noise of FSEA20 and FSEA30 as a function of the offset from the carrier. As from 100 kHz from the carrier, phase noise is the same for the two FSEA models. FSEA30 incorporates an extra loop that substantially reduces its phase noise at carrier offsets below 100 kHz relative to that of FSEA20. FSEA20 can be retrofitted with an option to give the same phase noise values as FSEA30.

FSE has a marker function for direct phase noise measurements. With this function, the SSB phase noise is indicated directly in dBc/Hz. In calculating results, FSE automatically takes into account correction factors for the noise bandwidth of the IF filters, for the logarithmic amplifier and the weighting of the dectectors.

The following **example** describes a phase noise measurement on a synthesizer as commonly used for mobile-radio applications. In mobile radio, very stringent demands are made on the conversion oscillators of transmitters to ensure the stipulated suppression of adjacent-channel emissions. In our example, the phase noise of an oscillator at 1.91 GHz and 4 MHz offset from the carrier is to be measured. The level of the oscillator is assumed to be approx. 3 dBm.

Note*:*
In this example, Signal Generator SMHU from Rohde & Schwarz is used as a signal source. The results thus include the phase noise of FSEA plus the phase noise of SMHU since the SSB phase noise of these units is in the same order.

Step 1: Measure level of oscillator

- Bring FSE to its basic setting.
  [**PRESET**]
- Set center frequency of FSE to 1.91 GHz:
  [**CENTER**: 1.91 GHz]
- Set span to 10 MHz:
  [**SPAN**: 10 MHz]
- Set reference level to +10 dBm:
  [LEVEL **REF**: 10 dBm]
- Set RF attenuation to low noise indication:
  [LEVEL **REF**: ATTEN AUTO LOW NOISE]
- Switch marker on and set signal level to reference level:
  [MARKER **MKR->**: MKR->REF LEVEL].
  With key MKR->, FSE sets marker 1 to the maximum of the signal, with softkey MKR->REF LEVEL, it sets the reference level to the marker level.

Step 2: Set the phase noise marker

- Switch delta marker on:
  [MARKER: **DELTA**]
  The delta marker is moved to the main marker.
- Switch phase noise measurement in the delta marker menu on:

[PHASE NOISE]
The reference level is indicated by a horizontal line (FXD), the reference frequency by a vertical line (FXD).

- Set delta marker to the desired frequency offset, ie 4 MHz in this case.
[*4 MHz*: **ENTER**]
- FSE indicates the measured phase noise in dBc/Hz in the marker field.

Step 3: Activate signal averaging:

- Set video filter to noise weighting:
[**COUPLING**: COUPLING RATIO: RBW/VBW NOISE [10]]
For noise averaging, FSE sets the video bandwidth to 1/10 of the resolution bandwidth.

Note:
The reduction of the video bandwidth by the factor 10 increases the sweep time by a factor of up to 10 if the resolution bandwidth is small relative to the span. In the interest of maximum measurement speed, the video bandwidth can be selected equal to the resolution bandwidth; this will however be at the cost of a wider fluctuation of results.

- Activate trace averaging:
[**TRACE 1**: AVERAGE]
FSE performs a sliding average over 10 sweeps to obtain stable results. The sample detector is activated at the same time for correct noise weighting.

FIG 3 below is a hardcopy of the FSE screen showing the test signal at 1910 MHz (TRACE 1). The phase noise value indicated in the marker field is -141.12 dBc/Hz at an offset of 4 MHz. The second trace (TRACE 2) shows the thermal inherent noise of FSE measured without input signal. The diagram clearly shows the limitation of the dynamic range resulting from inherent noise.

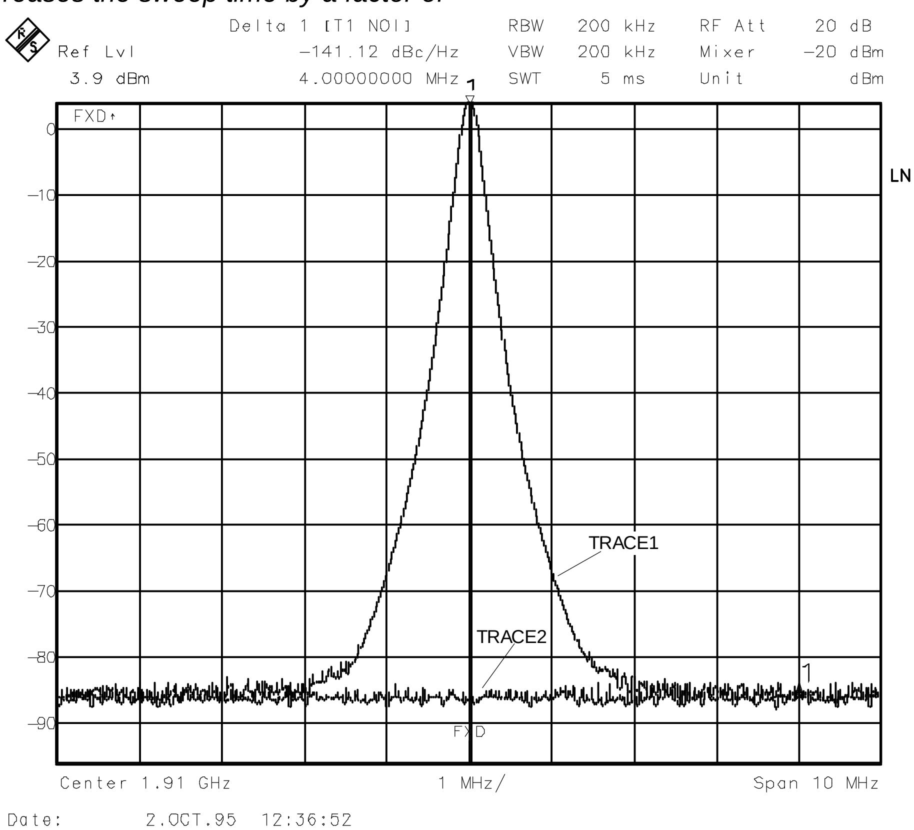

FIG 3 Phase noise measurements with FSEA30 with automatic setting of RF attenuation. The dynamic range is limited due to the inherent noise of FSE.

Phase noise measurements are constrained by two effects:

- phase noise of the LOs and
- thermal inherent noise of the spectrum analyzer.

These effects cannot be displayed separately as they are indicated as amplitude noise because of the envelope detection method used by the spectrum analyzer. It is however possible to display the inherent noise of FSE alone, ie by disconnecting the test signal from the RF input. The phase noise without input signal should be clearly (ie 6 to 10 dB) below the phase noise with the input signal present.

To obtain a sufficiently great difference to the thermal inherent noise of the RF input, FSE can be overdriven by the test signal without any impairment of results. This is possible because of the high overload capacity of the signal path including the IF filters. The test signal level at the input mixer may be as high as 5 dBm without any overload resulting for the signal path including the IF filters. The overload occurring after the IF filters will not influence results if the reference level is measured without overloading FSE.

The mixer level results from the level of the input signal and the selected RF attenuation (RF ATT):

Mixer level = P_{in} - RF ATT, where:
P_{in} = power of input signal in dBm
RF ATT = set RF attenuation in dB

In our example, the test signal level is 3.9 dBm. What is the minimum RF attenuation required to avoid overloading of the signal path?

$(\text{RF ATT})_{min} = P_{in} - (\text{mixer level})_{max}$

$(\text{RF ATT})_{min} = 3.9\text{ dBm} - 5\text{ dBm} = -1.1\text{ dB}$

This means that with 0 dB RF attenuation FSE will not be overdriven. Setting 0 dB RF attenuation therefore appears appropriate to obtain the maximum dynamic range in phase noise measurements.

Calculating the minimum required RF attenuation as shown above is not necessary with FSE since all relevant stages of the signal path including the IF filters are fitted with overload indicators so that any overloading will be automatically signalled. It is thus possible to reduce the input attenuation until OVLD (overload) is indicated on the display.

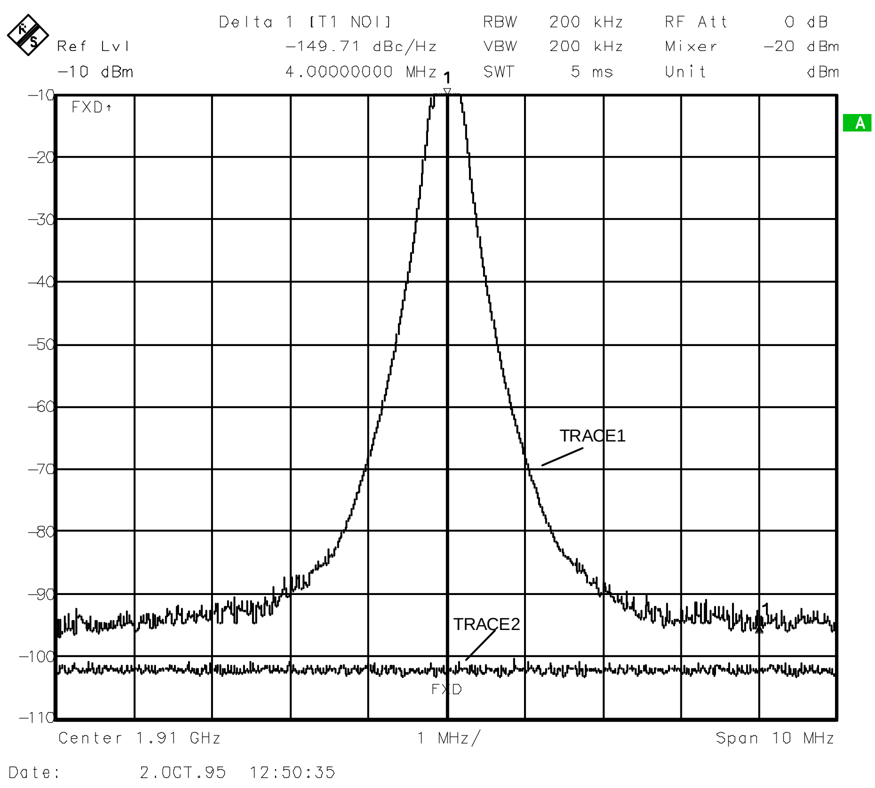

FIG 4 Phase noise measurement with FSEA30. The high overload capacity of the RF input gives a sufficiently wide dynamic range.

Step 4: Optimize the level setting

- Set RF attenuation to 0 dB:
  [**INPUT**: RF ATTEN MANUAL: 0 dB].
  The reference level will automatically be set to -10 dBm. Phase noise is still indicated correctly by the phase noise marker as the RF path is not overloaded at the position of the noise marker and the reference value for

phase noise measurement is not changed by changing the reference level. The measurement will be correct since the reference value remains fixed, ie REFERENCE FIXED is activated automatically when the phase noise function is switched on.

FIG 4 shows a phase noise measurement with 0 dB input attenuation. The spacing relative to the thermal noise of FSE is approx. 8 dB. The SSB phase noise of the synthesizer is approx. 149.7 dBc/Hz.

Effect of Inherent Noise on Result

The phase noise of the conversion oscillators of FSE and the thermal inherent noise will have an effect on results unless there is a spacing of min. 10 dB between the phase noise of the DUT and the inherent noise of the instrument. Please note that it is not the phase noise of the DUT alone that is indicated but the added powers of the phase noise of the local oscillators, the thermal noise and the DUT phase noise. For example, the phase noise will be indicated 3 dB too high if the phase noise of the local oscillators and the DUT is of the same value.

With the correction curve below, the actual phase noise of a signal source can be determined from the indicated phase noise and the inherent noise of FSE.

In the above diagram, the noise increase relative to the inherent noise is shown along the abscissa. This increase is equivalent to the reduction of the phase noise relative to the inherent noise of FSE. The ordinate shows the correction value to be added to the measured phase noise to obtain the actual phase noise.

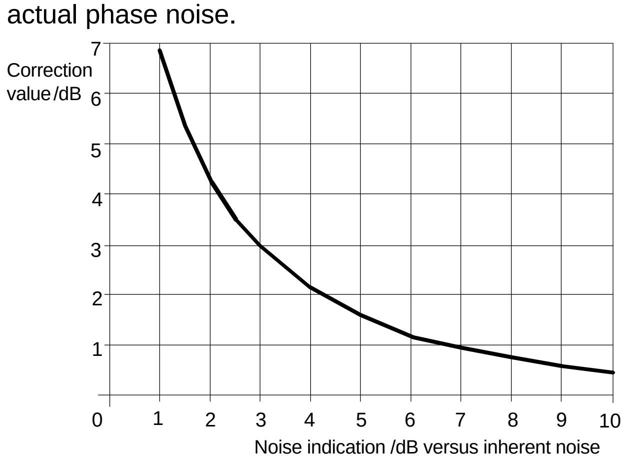

FIG 5 Curve for correcting SSB noise as a function of inherent noise

Examples:

1. In FIG 4, the spacing between the measured phase noise of the oscillator and the thermal noise of FSE is approx. 8 dB. The corresponding correction value from FIG 5 is 0.8 dB. The corrected SSB noise is thus 149.7 + 0.8 dB = 150.3 dB.
2. The inherent noise of FSE is 140 dBc/Hz at 1 MHz from the carrier. The value measured for a synthesizer is assumed to be 138 dBc/Hz. Taking the correction value of 4.3 dB from FIG 5, an actual phase noise of 142.3 dBc/Hz is obtained.

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