Automatic Phase Noise Measurements with Modulation Analyzer FMA (or FMAB or FMB) and Option FMA-B8

Application Note 1EPAN15D

Subject to change

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Products:

FMA, FMAB, FMB

ROHDE&SCHWARZ

Measurement Problem: Determination of Phase Noise

The stability of oscillators is an important quality criterion in many transmission systems and methods. One must differentiate between:

- -- **long term stability** (t > 1 s)
- -- **short term stability**

The short term stability, which will be dealt with exclusively here, can be determined by a **spurious deviation measurement** in a defined bandwidth (see modulation analysis, PD 757.0793.11) and through a **phase noise measurement.**

The phase noise of an oscillator is understood to be random frequency changes that can be regarded as narrowband phase modulation of the carrier with noise. Phase noise is shown as a spectral broadening of the signal (bell-shaped distribution) that decreases with increasing offset from the carrier. In practice, phase noise is usually specified as single sideband phase noise, which describes the ratio of the power in a phase-modulated sideband (over a bandwidth of 1 Hz) to the total signal power.

With phase modulation (PSK, QAM, etc) being used to an increasing extent in modern transmission systems, phase noise has also become a parameter of interest.

Phase noise can be measured using three methods which differ, among other things, with regard to dynamic range and complexity. These are:

- -- measurement with a spectrum analyzer
- -- measurement with a phase detector
- -- measurement with an FM discriminator (modulation analyzer)

The three methods will be briefly described in the following.

Certainly the simplest possibility is the measurement with a spectrum analyzer. This measurement is however subject to severe limitations:

The maximum dynamic range is determined by the noise floor of the analyzer and generally does not exceed -120 dBc/Hz approximately 10 to 20 kHz away from the carrier. In addition to that, the spectrum analyzer cannot distinguish between amplitude and phase noise since the display is purely a representation of the power (see Application Note 110-02-0288, SSB Phase Noise Measurements with Spectrum Analyzer FSA). Finally, the measurement of free-running or drifting oscillators, such as YIG oscillators, close to the carrier frequency is especially difficult since such measurements require a narrow bandwidth and therefore a long sweep time, and the signal could disappear right after the sweep has passed.

Due to these limitations, the use of a spectrum analyzer is in general limited to relatively stable sources with high phase noise.

A further possibility is the measurement with a phase detector. In this case, a highly stable reference oscillator 90° out of phase is phase-locked to the signal. A mixer operates as the phase detector. This is the most common method, in which evaluation is usually carried out by means of an FFT analyzer.

The dynamic range of the measurement depends on the reference oscillator. With elaborate, spectrally pure, and correspondingly expensive synthesizers, values down to -170 dBc/Hz can be measured. The test setup is however difficult and complicated, so that this type of measurement is time consuming. In addition, there are numerous secondary conditions to be considered, for example, the matching of the phase-locked loop, especially with free-running sources.

This method is, therefore, generally avoided and its use is limited to cases in which a high measurement dynamic range is required.

A third and very simple measurement technique is the demodulation of the signal to be measured with an FM or PM demodulator in a modulation analyzer.

The dynamic range of the measurement is higher than when using a spectrum analyzer and depends on the quality of the FM demodulator and its internal synthesizer. An external reference oscillator is not needed. The test setup is very simple since no synchronization with the signal is required. In fact, a modulation analyzer like the FMA tunes itself automatically to the measurement frequency. Since the FM demodulator has a large bandwidth and the automatic tuning tracks the signal on its own, free-running, drifting sources can also be measured without difficulty.

A **modulation analyzer** is, therefore, ideal for measurements that require a **medium dynamic range** or that need to be carried out on **free-running sources** (eg YIG oscillators). Moreover, a modulation analyzer enables very fast **spurious deviation measurements**, which means that two parameters relating to short term stability can be determined with a single instrument. Table 3 in the Annex compares the three techniques described above.

Solution

Modulation Analyzers FMA (up to 1.36 GHz) and FMB (up to 5 GHz) are high-grade FM demodulators from Rohde & Schwarz with

- highly stable synthesizer,
- low-noise FM demodulator,
- automatic frequency tuning and fine-tuning,
- separation of AM from FM,

all of which make Analyzers FMA/FMB ideal for phase noise measurements. Table 1 shows the measurement limits of the analyzers.

	1	3	10	30	100	200	kHz
f_c = 200 MHz	- 105	-115	- 126	- 133	- 135	- 135	dBc/Hz
f_c = 1 GHz	- 100	- 110	- 125	- 128	- 130	- 130	dBc/Hz

Table 1: Measurement limits of FMA

Fig. 1 shows the basic test setup for phase measurements up to 5 GHz with FMB.

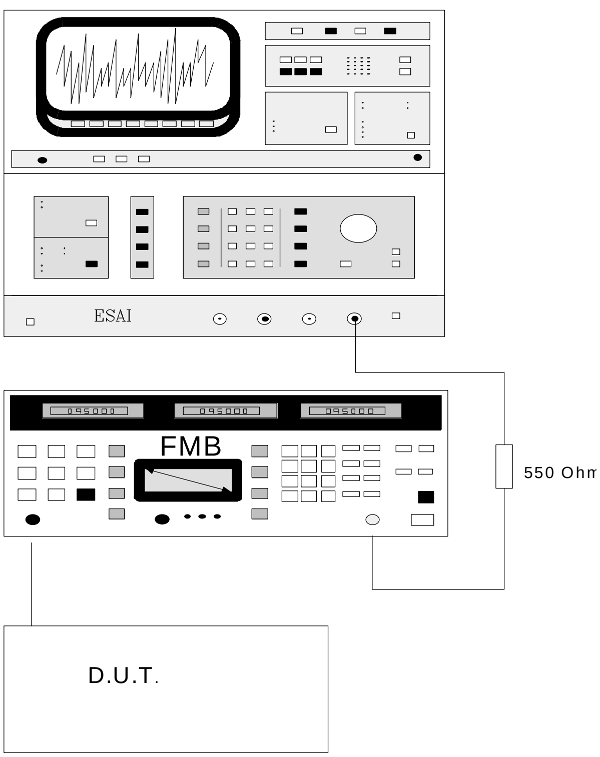

Fig. 1: Test setup with external spectrum analyzer

Measurement fundamentals and procedure

A signal carrying phase noise is basically a signal phase-modulated with noise. Since phase and frequency modulation are equivalent, phase modulation can also be measured by means of an FM demodulator. However, a frequency response governed by the following relationship has to be taken into account:

$$=$$

$$\text{or: } \Delta F = \Delta\Phi \,/\, f_m$$

With small phase deviations (modulation index η <0.1), only the first sidebands (upper and lower) appear in an FM spectrum. The levels of these sidebands can be calculated similarly to those obtained for AM modulation:

$$P_{SSB} = \Delta\Phi/2 \;*\; P_S$$

The level difference in dB of the sidebands can be found by:

$$P_{SSB}/P_S = -6 \text{ dB} + 20 \lg \Delta\Phi$$

Example: $\eta = \Delta\Phi = 0.1$ results in:

P_{SSB}/P_S = -6 dB + 20 lg 0.1 = -6 -20 dB = -26 dB

(see Fig. 2)

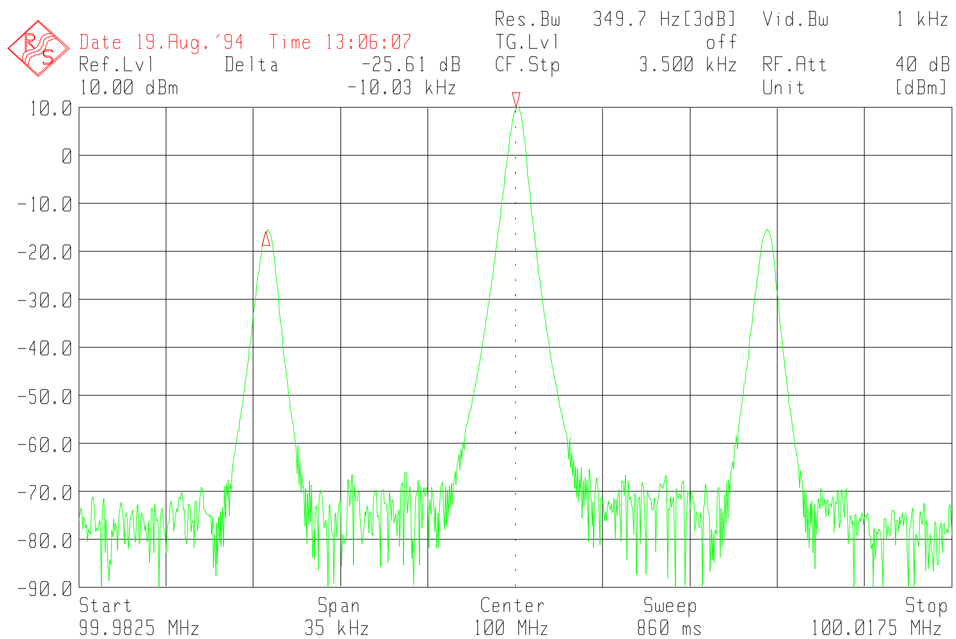

Fig. 2: The RF spectrum of the reference signal shows a sideband level of 26 dB

This is analogously valid for noise-induced modulation, the result being referenced to a 1-Hz bandwidth. The SSB phase noise level can be found from:

$$L\,(f) = P_{SSB}/P_S\,|_{1\ Hz} = -6\ dB + 20\ lg\ \Delta\Phi\,|_{1\ Hz}$$

By taking a signal of known deviation, and therefore of known sideband level, and measuring the noise of the signal of interest relative to the demodulated reference signal, the phase noise level can be determined by way of addition:

- difference between measured level and reference signal level and
- he known sideband level with reference to the carrier.

With this method it is not necessary to know the slope of the FM demodulator.

With the above measurement procedure, taking the level of one sideband with reference to the carrier as a reference, calibration to SSB phase noise is made at the same time.

Measurement with an external AF spectrum analyzer

A reference value is obtained using a signal of known deviation (and therefore a known sideband level), see Fig. 2. For this purpose, a frequency-modulated signal with a deviation of 1 kHz and a modulation frequency of 10 kHz is applied to FMA or FMB and a measurement made with the following settings:

Demodulation:	FM
Filters:	HP 10 Hz, LP 100 kHz
Detector:	RMS*$\sqrt{2}$

The deviation setting of the generator can then be corrected, if necessary.

Note: The complete measurement can be carried out with the FM demodulator, since the latter has approximately 15 dB more dynamic range than the phase detector. This results in correction factors whose values depend on the offset from the carrier.

The AF analyzer is to be connected to the FM output at the rear. (A 550-Ω resistance at the FM output is used to match the 50-Ω input impedance of the AF spectrum analyzer. If the input impedance is >600 Ω, the resistance can be omitted.) The level of the 10-kHz signal is to be measured, and is then used as a reference value. With the FSA family of analyzers, this is accomplished by the following operation:

Marker to Peak, followed by Marker Phase Noise

After this, the signal to be measured is applied and the level difference between the noise and the previously measured reference value is read (see Fig. 3).

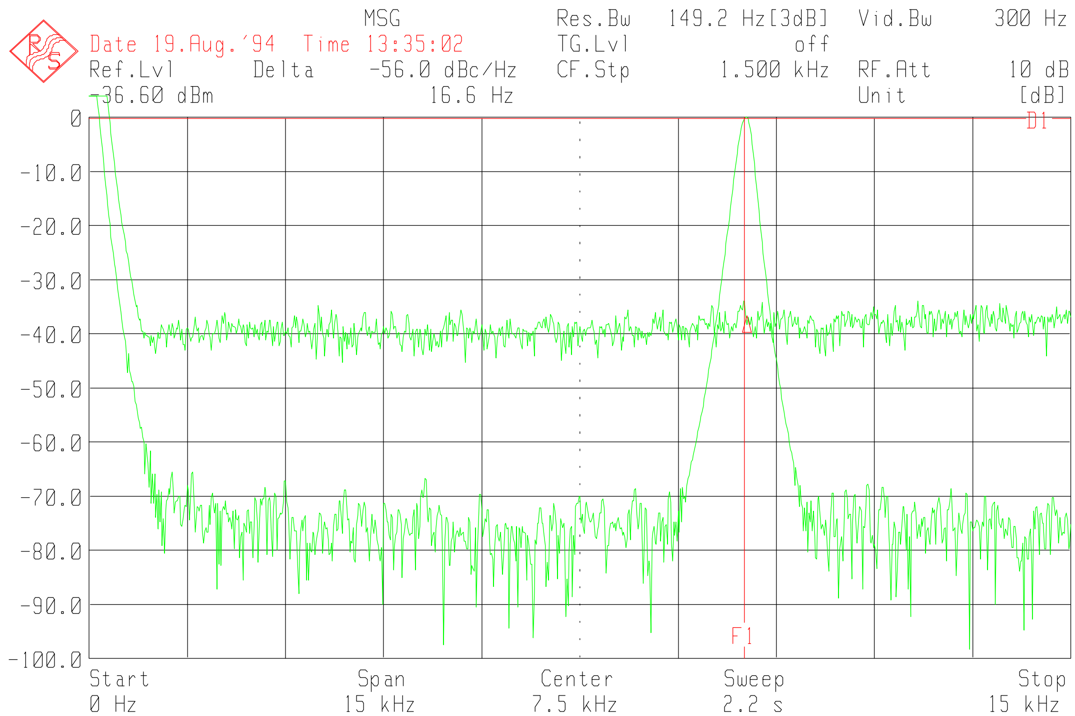

Fig. 3: The level of the demodulated reference signal is used as a reference (lines F1 and D1) in the phase noise measurement. The value of -56 dBc/Hz measured here must be corrected by 26 dB to allow for the carrier offset so that, as a final value, -82 dBc/Hz is obtained.

Correction factors

In establishing a reference value with a modulation frequency of 10 kHz and a deviation of 1 kHz (corresponding to $\eta = 0.1$), the measured value read in dBc/Hz should be increased by a correction value of 26 dB. For carrier offsets other than 10 kHz, an additional correction is needed:

$$k = 20 \lg f_m / f_{measured}$$

Table 2 below shows the total correction factor at various offsets from the carrier.

If the analyzer being used does not have a display in dBc/Hz, the correction value must be calculated by:

normalization to a 1-Hz bandwidth taking into account the noise bandwidth of the analyzer filter, or

consideration of the constant correction factors for the noise weighting of the logarithmic and peak detectors.

Offset from carrier	100 Hz	1 kHz	10 kHz	20 kHz	30 kHz	100 kHz	200 kHz
Total correction in dB	-34	6	26	32	35.5	46	52

Table 2: Correction values for a reference offset of $\Delta F = 1$ kHz ($f_m = 10$ kHz); to be added to the measured value in dBc/Hz

Simplified measurement using Option FMA-B8; selective audio analysis

With the FMA-B8 AF Analysis Option, the measurements described above can be carried out substantially more easily and faster. With the capability of this option to measure selective levels, the extra AF spectrum analyzer as well as the calibration of the test setup using an FM signal can be omitted since the slope of the FM demodulator is known. In addition, the phase noise function, displayed in dBc/Hz, contains all of the correction factors listed above, so that after inputting the carrier offset value (CarrOffs), the result simply needs to be read off.

All advantages, including the achievable measurement limits of FMA, remain.

Settings on FMA:

Demod righthand side menu, Phase noise	PM,
Input of desired offset frequency:	CarrOffs

Operation

The demodulated signal (noise signal) supplied by the FM demodulator is digitized in an A/D converter and analyzed in a DSP by an FFT. The rms noise level measured at the selected frequency offset (this relates to the AF frequency) is calculated using the correction values given above, and displayed.

AM noise

The AM noise as a function of the offset from the carrier can be measured in the same way, using the AM demodulator:

Demod righthand side menu AM noise	AM,
Input of desired offset frequency:	CarrOffs

In the test setup shown below, it is of great advantage that frequency tuning is performed automatically by FMA so that, after connecting the DUT, usually only a single operation has to be carried out, ie the carrier offset at which the measurement is to take place has to be entered. There is no need for manual fine tuning not even for drifting signals.

Automatic test routine with P_RAUSCH.EXE application program

Operation, test setup

With the phase noise or AM noise function of FMA mentioned above, the application program measures the phase noise or AM noise as a function of the carrier offset and displays the results obtained for the test points in a diagram. FMA also measures, at the beginning of each test run, the carrier frequency and power and displays it in the diagram. The program runs under Windows and largely uses the automatic functions of FMA. This means, for example, that tuning to the reference frequency or setting of the level need not be made as this is performed automatically by FMA. On the other hand, the program will not change any manual settings made by the operator.

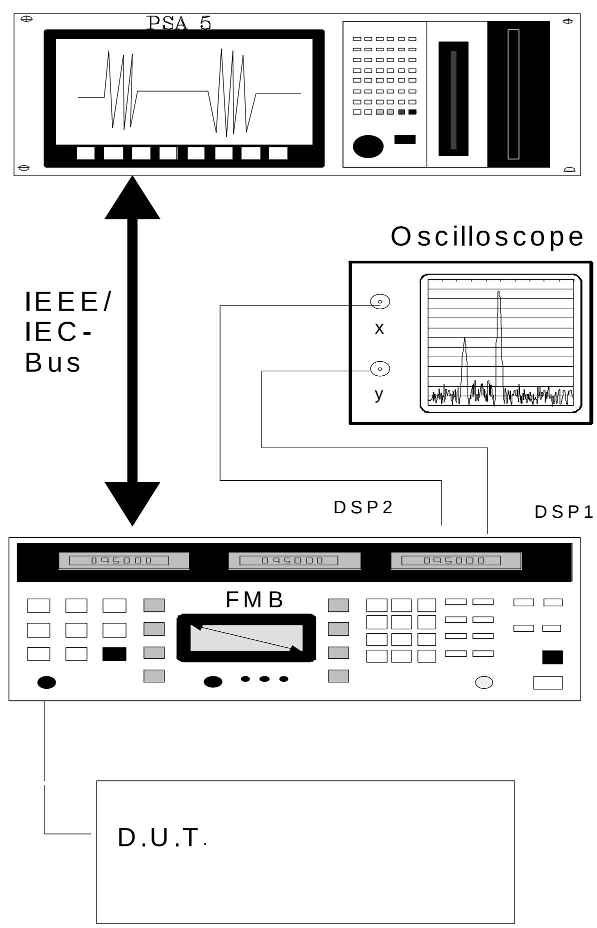

Fig.4. Test set-up for automatic test routine

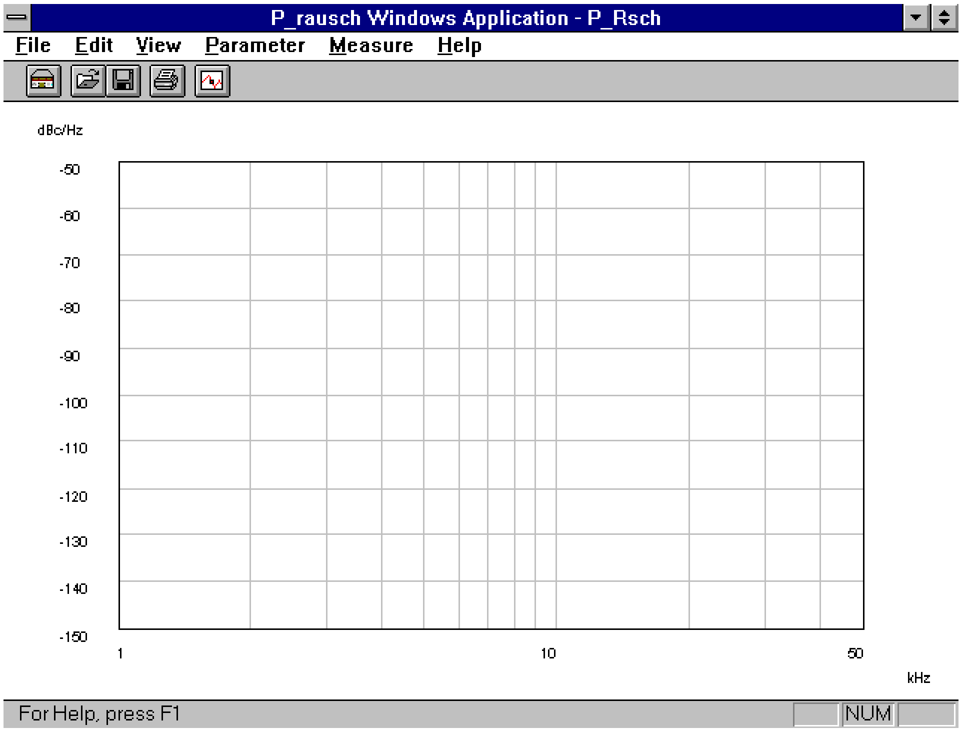

Fig. 5: Presentation of program after start with default settings

Operation

The program is started by clicking on the corresponding icon. The window shown in Fig. 5 will appear. The window should preferably be enlarged into a full-screen picture (see Windows operating manuals). The following program-specific menu items are available:

View	Tool Bar
	Status Bar
	Mark Curve
Parameter	Settings
	IEC/IEEE bus
	Marker
Measure	Measurement

The functions in detail:

VIEW

Tool Bar: for switching on/off a bar with icons. Upon clicking on these items, the functions *Measurement*, *Open*..., *Save*, *Print* and *Marker* will be performed.

Status Bar: for switching on/off a status bar displayed at the bottom of the screen. The bar shows the current measurement result and status messages.

Mark Curve:

With the *Mark Curve* function, the operator can select if the curve is to be displayed with or without the measurement points marked. Fig. 7, for example, shows a measurement curve without the measurement points marked.

PARAMETER

Settings: Activates a dialog box with parameters for measurement and display. The parameters are:

Offset start and stop frequency
Min. and max. phase noise
(setting is valid both for measurement and display)
Phase noise or AM noise
Number of test points

The frequency axis is always of a logarithmic scale.

Marker

Activates a dialog box that enables the marker to be shifted along a test trace and to repeat a measurement for any test point of interest. In this way, any outliers can easily be checked.

Measure

Starts a test run. The test run can be aborted by calling *Measure* again or by clicking on the measurement icon.

The remaining menu items are standard Windows items. Please refer to the Windows operating manuals for relevant information. The menu points are in English, the dialog boxes are in the language of the local Windows program.

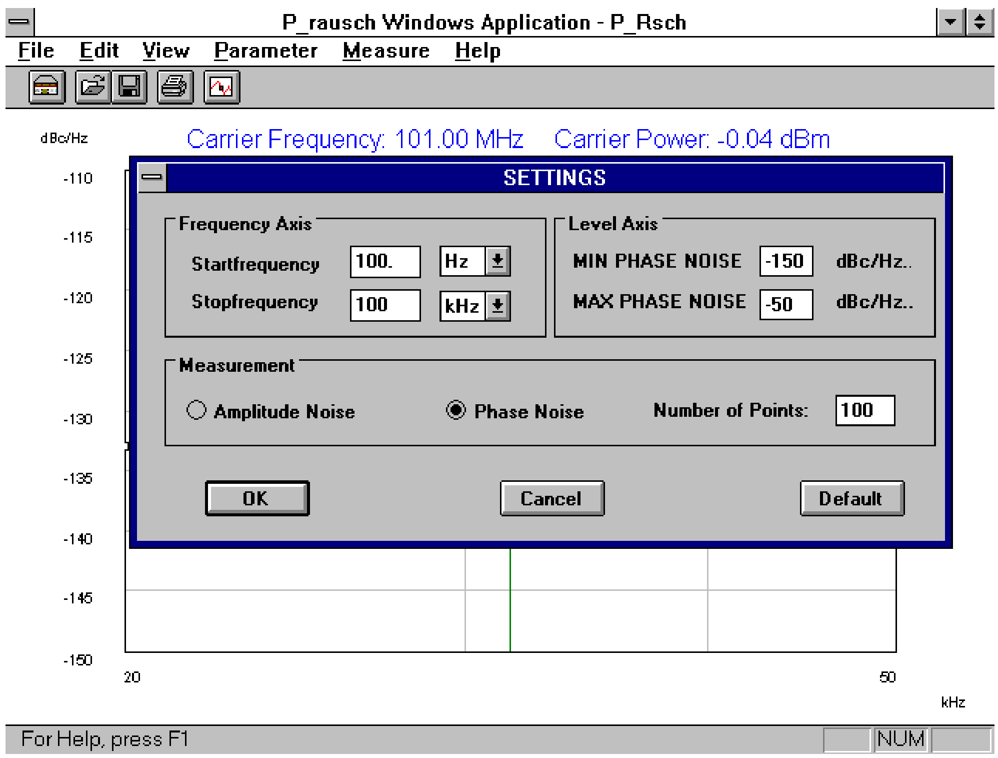

Fig. 6: *Settings* dialog box; the values given in the above example are the permissible min. and max. values

Measurement procedure

To perform a measurement, only a few steps have to be carried out.

1. Establish IEC/IEEE-bus connection with FMA.
2. Connect DUT to FMA.
3. Start program and check IEC/IEEE-bus address setting.
4. Enter measurement parameters under *Settings* menu item.
5. Start measurement by clicking on the measurement icon.

Fig. 7 shows an example of a measurement.

Detection of discrete spurious lines

Discrete spurious lines, such as hum, are not automatically detected by the program. They are, however, in most cases immediately discernible from the diagram (see Fig. 7). However, since these lines are likewise measured using the phase noise function and are thus normalized to 1 Hz, the level displayed for these lines is not correct. The correct level can easily be determined on FMA by means of the TUNED BP function in the lefthand filter menu.

The measured spectrum can additionally be displayed on an analog oscilloscope connected to DSP1 and DSP2 in XY mode. The start and the stop frequency of the displayed span can be read from the FMA display after activating the INFO, Spectrum menu item. In this way, discrete spurious signals, too, can easily be detected (also see Application Note 1E10-13-0893, FFT AF Analysis with FMA).

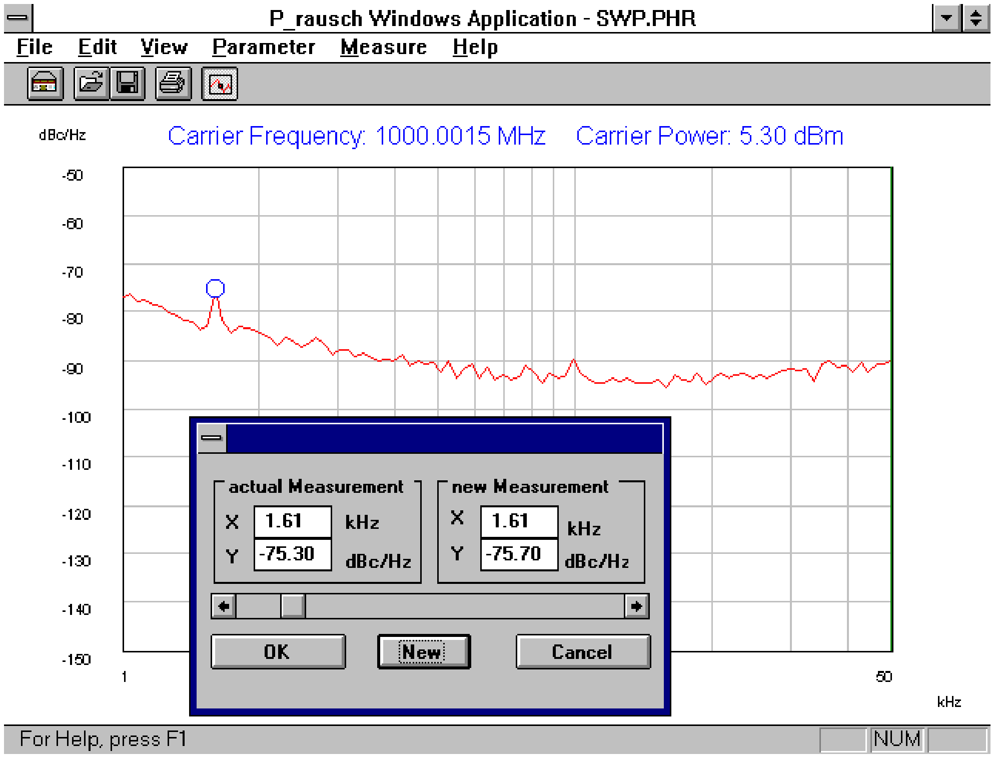

Fig. 7: Result of a repeated measurement using the *Marker* function

Storage and documentation of results

Measurement results and associated settings are stored under the *File, Save As...* menu items. The data are stored in ASCII format and can thus easily be used in spreadsheet programs such as EXCEL. Moreover, a comparison of curves can be carried out in such programs. The structure of a data file is given in the Annex. The settings of a measurement are stored along with the data and can be recalled for new measurements.

To print a data file, the *File, Print* menu items are to be selected or the corresponding symbol of the tool bar is to be clicked.

Installation

For installing the phase noise measurement program, the IEC/IEEE-bus card must be installed correctly. When using a National Instruments card, make sure that in file GPIB.INI the "Enable Auto Serial Poll" parameter is set to *"no"*.

For installation, P_RAUSCH.EXE and APL.INI are to be copied into a preferably separate directory. APL.INI contains the current IEC/IEEE-bus address of FMA/FMB and, if it does not exist, will be created when P_RAUSCH.EXE is called. P_RAUSCH.EXE is then to be installed as a new program under Windows under the *New file* item of the program manager.

Offset from carrier	Spectrum analyzer method (values apply to FSA)	Modulation Analyzer FMA	Phase noise technique, limits set by reference generator, here typical values for Signal Generator SMHU
10 Hz 100 Hz 1 KHz 10 kHz 100 kHz 1 MHz	 -100 dBc/Hz -110 dBc/Hz -115 dBc/Hz -120 dBc/Hz -135 dBc/Hz	- -70 dBc/Hz -105 dBc/Hz -126 dBc/Hz -135 dBc/Hz -	- 100 dBc/Hz -125 dBc/Hz -137 dBc/Hz -145 dBc/Hz -150 dBc/Hz -150 dBc/Hz
Application	Stable sources with high phase noise	Unstabilized sources, insensitive to AM noise; at an offset of approx. 20 kHz from the carrier, the dynamic range is wider than with a spectrum analyzer	Most universal method with the widest dynamic range
Notes	No separation of AM and PM noise, but fast and simple	Maximum offset from carrier is determined by AF bandwidth of demodulator	Complex operation

Table 1: Limits of various phase noise measurement techniques. This table does not include the S/N ratio of approx. -6 to 10 dB needed for accurate phase noise measurements.

Number of line	Contents of data file	Meaning
1	No comment	Comment line
2	1.000000	File version number
3	1	Test mode: 1: Phase noise
4	100	Start frequency in Hz
5	50000	Stop frequency in Hz
6	100	Number of measurement points
7	100	Number of measurement points
8	-50	Upper graticule line of graphics in dBc/Hz
9	-150	Lower graticule line of graphics in dBc/Hz
10	100,-18.100000	Frequency in Hz, level in dBc/Hz; measurement value 1
11	106,-33.799999	Frequency in Hz, level in dBc/Hz; measurement value 2
12	113,-38.000000	Frequency in Hz, level in dBc/Hz; measurement value 3
	120,-36.099998	Frequency in Hz, level in dBc/Hz; measurement value 3
	128,-37.000000	
	136,-38.500000	
	145,-36.299999	
	155,-39.299999	
n+9	165,-39.500000	Measurement value n

Table 2: Structure of a data file

Availability of the applicationn program
The program mentioned in this application note is available at the nearest Rohde & Schwarz representative.

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Rohde & Schwarz
25 April 1995