Analysis of Jitter with the R&S FSUP Signal Source Analyzer

Application Note

Products:

- R&S®FSUP8/26/50

This application note describes how to characterize RMS jitter with the R&S FSUP signal source analyzer. The instrument can distinguish random jitter and periodic jitter easily and measure all parameters of interest.

Application Note

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1 Introduction

With increasing data rates, jitter analysis of reference clock signals becomes more and more important. In the Gb/s range, even small jitter has significant influence on system performance. For example, the stability of reference clocks for components of high-speed serial links (see Fig. 1) has a strong influence on the bit error ratio. A detailed characterization of the jitter of the reference clock is necessary to improve the reliability with increasing data rates. In addition, for high-speed serial link designs, it is helpful to have a closer look at periodic jitter, generated by unwanted interference, and to get separate results for random jitter, mainly caused by noise from the components. Further improvement of system performance requires different solutions for the different types of jitter. This application note focuses on the jitter measurement of clock signals.

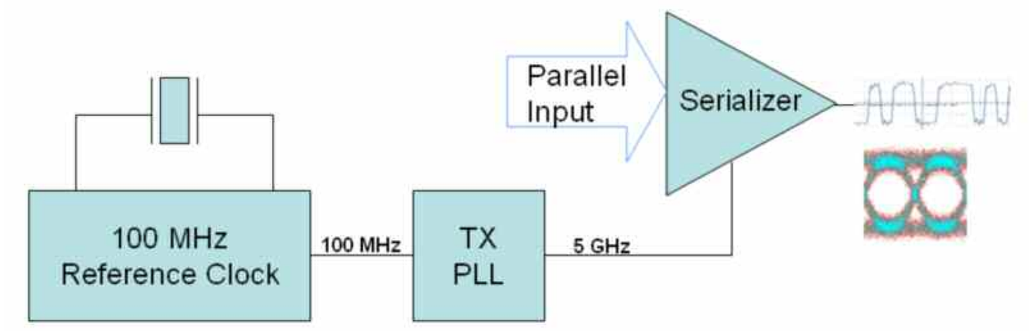


Fig. 1: Typical transmitter architecture for serial links with a reference clock, a TX clock and a serializer. The data stream at the output is analyzed with an oscilloscope. The clock signals can be easily characterized with phase noise testers.

1.1 Jitter Analysis in the Time Domain

The most common way of measuring jitter is to use a digital oscilloscope. The operator sets the trigger to the rising/falling edge of the clock signal and displays the next rising/falling edge of the clock on the screen. With modern oscilloscopes, he can use the persistence mode, which should be set to infinite, and then the **peak to peak** jitter can be seen on the screen. The results can directly be read out in seconds using two cursors (see Fig. 2). FFT algorithms can help to characterize jitter in the frequency domain as well. In addition, scopes offer histogram functions, which can help to characterize the jitter in more detail; e.g. random jitter shows Gaussian distribution, whereas any form of deterministic jitter has a different shape.
Analysis in the time domain is especially needed for modern high-speed designs, which get the clock directly from the data stream to reduce the negative effect of jitter. For detailed characterization of the recovered clock, data stream or data dependent jitter, signal oscilloscopes are inevitable.

However, due to inherent jitter of the clock of the oscilloscope and limited S/N performance of the A/D converters, the minimum resolution for jitter is in the range of several picoseconds (ps), which might be not good enough for the clocks of modern digital transmission systems.

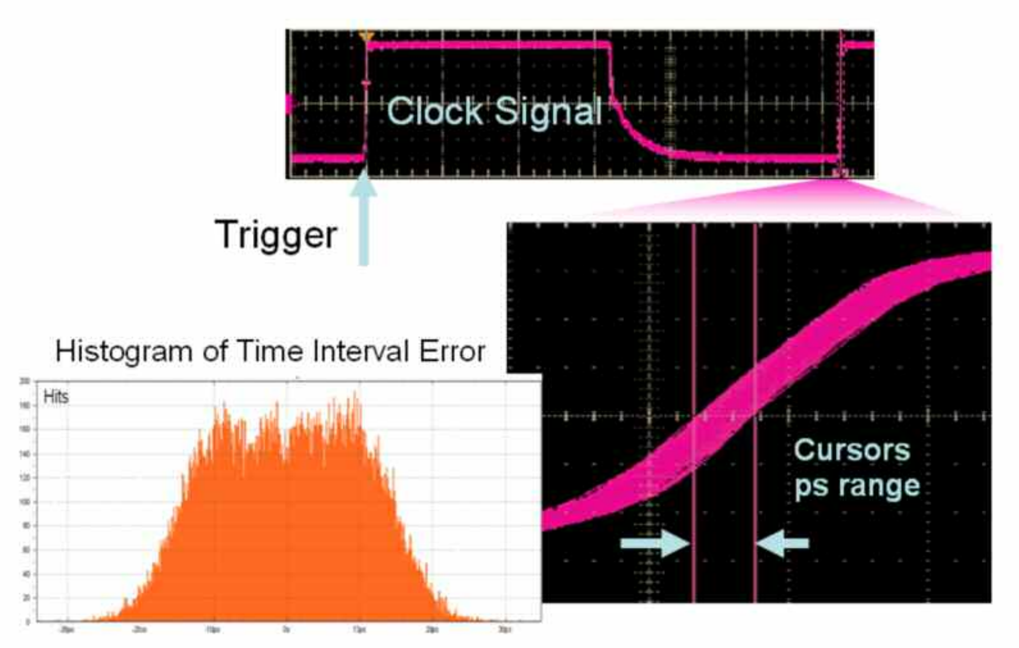


Fig. 2: Measurement of jitter in the time domain using a digital oscilloscope.

1.2 Jitter Analysis in the Frequency Domain

Jitter can be measured in the frequency domain as well. Timing jitter of the clock in the time domain generates phase noise in the frequency domain. Therefore, a professional phase noise test system can measure jitter more accurately than oscilloscopes, especially in the GHz range, due to very good internal oscillators and modern cross-correlation techniques in combination with higher resolution of A/D converters.

RMS jitter can be calculated from the phase noise measurement as follows:

1. Integration of the normalized phase noise P_{norm} over a selected frequency range gives the residual phase modulation Θ in degrees:

$$\Theta_{rms} = \sqrt{2\int_{f_1}^{f_2} P_{norm}(f)df}$$

2. Dividing by the input frequency gives the **RMS** jitter in seconds:

$$jitter_{rms} = \frac{\Theta_{rms}}{2\pi f_{osc}}$$

In the frequency domain, random jitter and periodic jitter can easily be separated. Periodic jitter forms a clear spur in the spectrum, whereas random jitter is represented by the noise floor. With modern phase noise test systems, RMS jitter in femtoseconds (fs) range can be measured, which is three orders of magnitude more sensitive than measurement with digital oscilloscopes.

2 Using the R&S FSUP Signal Source Analyzer for Jitter Analysis

The R&S FSUP signal source analyzer is a combination of a spectrum analyzer and a highly sophisticated phase noise tester providing cross-correlation capability up to 50 GHz input frequency, which improves the dynamic range by more than 20 dB (see application note 1EF68). Due to very low inherent phase noise and powerful spur detection algorithms, it is perfectly suited for jitter analysis.

For characterizing a reference clock, simply connect the clock (i.e. the DUT) to the R&S FSUP (RF IN), enter the Signal Source Analyzer mode (SSA) and start the measurement by pushing a button (NEW RUN). The instrument automatically measures the phase noise of the DUT using the PLL or phase detector method. This means that it measures all parameters needed for this application. such as the input frequency, power and drift of the DUT. Afterwards it automatically sets the internal reference to the same frequency and locks it to the DUT via phase locked loop. It sets the loop bandwidth automatically as well. Now two signals with the same frequency (reference and clock) are multiplied at the phase detector, This detector in principle is a mixer and suppresses the carrier when both frequencies are identical, and double the frequency is filtered by a low pass filter. Only the phase noise of the signal sources remains at the output. The instrument captures the noise, transforms it to the frequency domain and displays the result on the screen.
By default, trace 1 of the R&S FSUP is a smoothed line and trace 2 shows the raw data. For further analysis, it is convenient to blank out trace 2 and switch off smoothing of trace 1 (TRACE menu). Then the user gets the result displayed in Fig. 3. The column in the middle of the table at the top of the screen shows the **residual noise calculation** according to the formulas in chapter 1.2 for the whole measured offset range (e.g. 10 Hz to 30 MHz). In this plot, all spurs (periodic jitter) are suppressed (this is the default mode) and therefore only random jitter is calculated. The right column shows the output of the phase detector and the left column the input parameters of the DUT.

For a more detailed characterization of periodic jitter, the R&S FSUP offers different possibilities to display the spurs and calculate rms jitter. The user can define the parameters for spur detection and how the spurs are displayed in a special menu. To enter the menu, just press the SETTINGS hotkey and then the SPURS SETTINGS softkey. Here the user can select whether all spurs or some selected spurs are shown or suppressed. He can define a threshold for detection or highlight the spurs.

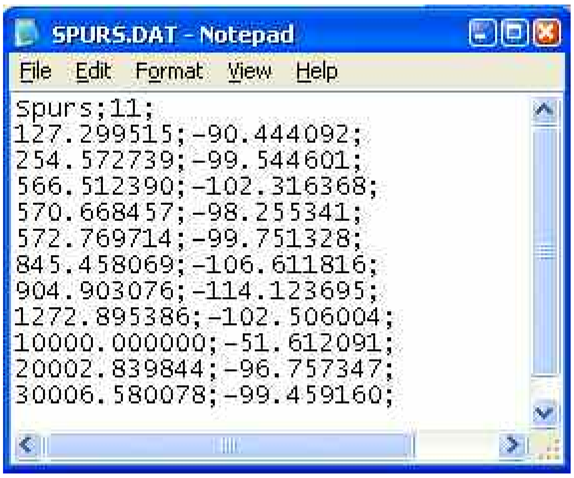
For example, Fig. 4 shows the same results as in Fig. 3 with all spurs displayed. Now the results for residual calculations have changed as well in the table at the top of the screen. Fig. 3 shows the results without spurs, i.e. just random jitter, and Fig. 4 shows the results including all spurs or periodic jitter.

Fig. 3: Phase noise measurement of a high-end DUT.

Fig. 4: Same measurement as in Fig. 3 with “SHOW ALL” selected in the spur setting menu.

Fig. 5 shows the measurement with “HIGHLIGHT SPURS” selected. The blue lines show the spurs in dBc corresponding to the y-scale at the right-hand side of the screen; in the yellow trace they are normalized to 1 Hz resolution bandwidth (dBc/Hz). If the user selects “LIST SPURS”, the right column in the table at the top of the screen lists all spurs. This list can be exported to an ASCII file for documentation (see Fig. 6).

Fig. 5: Same measurement as in Fig. 3 with “LIST SPURS” and “HIGHLIGHT SPURS” selected in the spur setting menu.


SPURS.DAT - Notepad

File Edit Format View Help

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Spurs;11;
127.299515;-90.444092;
254.572739;-99.544601;
566.512390;-102.316368;
570.668457;-98.255341;
572.769714;-99.751328;
845.458069;-106.611816;
904.903076;-114.123695;
1272.895386;-102.506004;
10000.000000;-51.612091;
20002.839844;-96.757347;
30006.580078;-99.459160;
```

Fig. 6: ASCII list of all detected spurs.

The residual calculation shows the random jitter with and without periodic jitter. The spurs or periodic jitter can be listed, saved, highlighted and suppressed. However, for most applications a more detailed evaluation of periodic jitter is needed or the residual calculation is needed for a special offset range only. To do this, the user can define evaluation lines in the GENERAL SETTINGS menu to restrict the integration range (see Fig. 7).

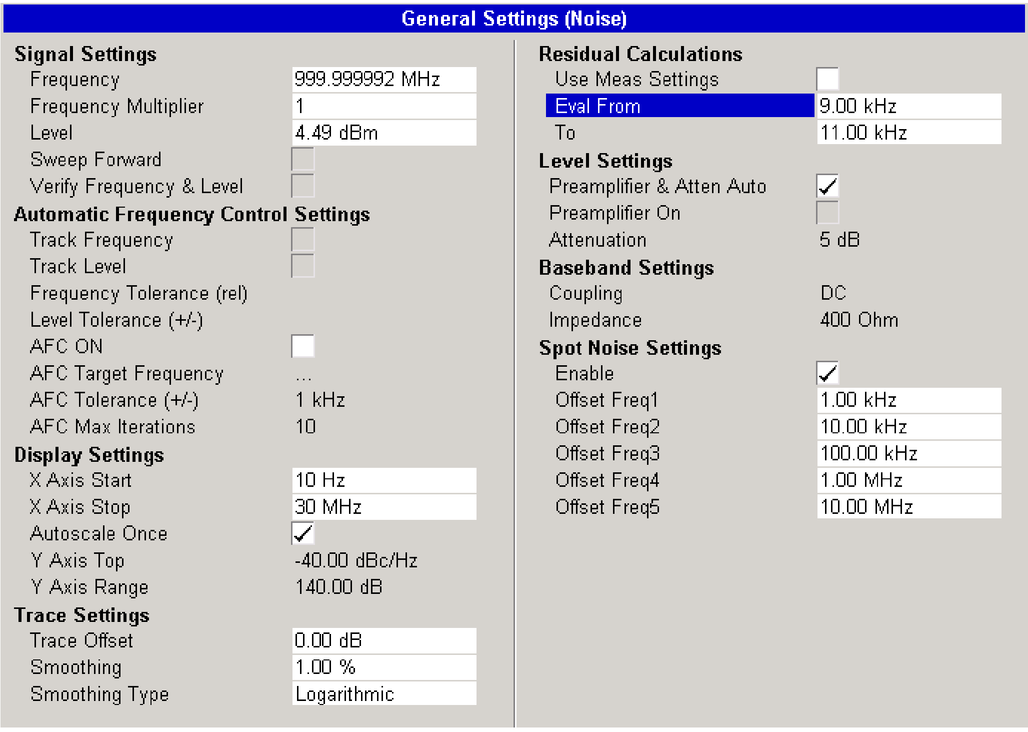

Fig. 7: The residual calculations can be done over the entire offset frequency range (“Use Meas Settings”) or only over a restricted frequency range (e.g. 9 kHz to 11 kHz).

Using the evaluation lines for residual calculations allows the user to look at just one specific spur, for example. Fig. 8 shows the evaluation restricted to 9 kHz to 11 kHz. The spur located at 10 kHz results in a residual FM of 37.35 Hz and an RMS jitter of 0.5938 ps. An FM modulation with a deviation of around 50 Hz ($37Hz \cdot \sqrt{2}$) and a frequency of 10 kHz could generate this spur or periodic jitter.

Fig. 8: Residual calculations for one spur only.

For most applications there are limits for the maximum jitter of reference clocks, which ensure proper operation and that the bit error ratio (BER) does not increase. Usually the user knows these limits and wants to test jitter for certification or manufacturing purposes using limit lines. If the clock is in line with specifications, the user is given a PASS; if it is not, he is given a FAIL.

As the formulas in chapter 1.2 show, jitter is calculated from the phase noise by integration over the frequency offset range of interest. If the user knows the phase noise or spur level from which the maximum allowable jitter can be calculated, he can define limits for spurs (periodic jitter) when the unit dBc is used or for phase noise (random jitter) when dBc/Hz is used. Fig. 9 shows how users can define the limit line. In Fig. 10 a typical measurement is shown with different limit lines for random jitter and periodic jitter. It can be seen that the random jitter of the measured device is in line with specifications, whereas the periodic jitter fails at 10 kHz offset frequency.

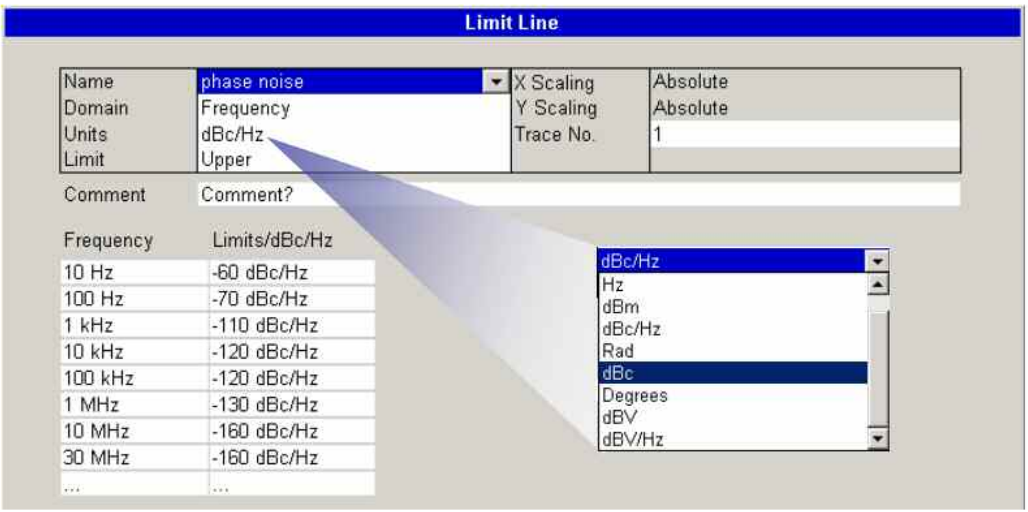

Fig. 9: Setup screen of limit lines. As unit for the line, dBc/Hz or dBc can be selected to act on periodic or random jitter.

Fig. 10: Test result of limit lines: The random jitter passes the test, whereas periodic jitter is above the limit.

It is important to know the phase noise of the oscillators or the references for design of high speed serial links with low jitter. However, in real systems a PLL is used to get a stable clock and for overall system performance the frequency response of the PLL has to be taken into account. With the R&S FSUP a filter function can be used for jitter calculation to simulate the frequency response of the PLL. Figure 11 shows the transducer table to define the response function. Figure 12 shows the different results we get for residual RMS jitter with and without transducer factor. In our example it changes from 0.0475ps to 0.0151ps.

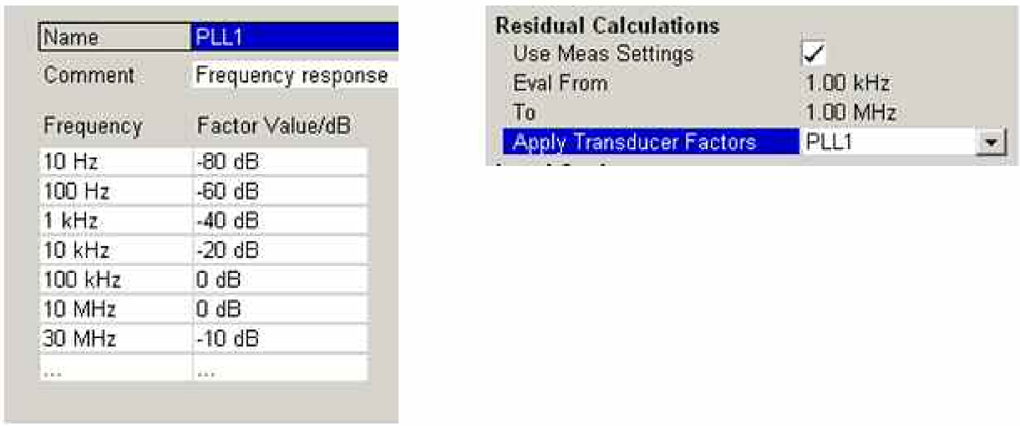

Figure 11: Definition of transducer factor for residual noise calculation. The transducer factor can then be loaded in the General Settings menu.

Figure 12: The RMS jitter calculated over the whole frequency offset range gives 0.0475ps. When the transducer factor (figure 11) is applied, which is illustrated in the picture as blue line, the result changes to 0.0151ps.

3 Summary

The R&S FSUP signal source analyzer is a spectrum analyzer and phase noise tester with a very high dynamic range even at 50 GHz, due to cross-correlation capability. Design engineers and manufacturers of clock oscillators can use this instrument not only to examine the spectrum and the higher harmonics; they also get a powerful and versatile tool for analyzing random and periodic jitter.

4 Ordering Information

Designation	Type	Ordering number
Analyzers		
Signal Source Analyzer 20 Hz to 8 GHz	R&S®FSUP8	1166.3505K09
Signal Source Analyzer 20 Hz to 26 GHz	R&S®FSUP26	1166.3505K27
Signal Source Analyzer 20 Hz to 50 GHz	R&S®FSUP50	1166.3505K51
Hardware options		
Low-Aging OCXO	R&S®FSU-B4	1144.9000.02
External Generator Control	R&S®FSP-B10	1129.7246.03
Removable Hard Disk	R&S®FSUP-B18	1303.0400.05
Second Hard Disk for R&S FSU-B18	R&S®FSUP-B19	1303.0600.05
LO/IF Ports for External Mixers	R&S®FSUP-B21	1157.1090.04
20 dB Preamplifier, 3.6 GHz to 26.5 GHz	R&S®FSU-B23	1157.0907.02
Electronic Attenuator, 0 dB to 30 dB, and 20 dB Preamplifier (3.6 GHz)	R&S®FSU-B25	1144.9298.02
Trigger Port	R&S®FSP-B28	1162.9915.02
Low Phase Noise	R&S®FSUP-B60	1169.5544.03
Correlation Extension	R&S®FSUP-B61	1305.2500.26
Correlation Extension (if R&S®FSU-B23 preamplifier to 26.5 GHz is added)	R&S®FSUP-B61	1305.2500.23
Correlation Extension to 50 GHz	R&S®FSUP-B61	1305.2500.50
AM Noise Detector	R&S® FSUP-Z1	1305.2700.02
R&S®FSUP8 DKD-calibration	R&S®FSUP8-DKD	1161.2723.02
R&S®FSUP26 DKD calibration	R&S®FSUP26-DKD	1161.2730.02
R&S®FSUP50 DKD-calibration	R&S®FSUP50-DKD	1161.2746.02

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