SiTime Studio User Manual

Learn how to use SiTime Studio desktop software (free) to analyze phase-noise data for a variety of applications.
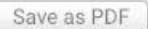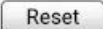
Table of Contents

1   Introduction

This document discusses a free phase-noise calculator available on the SiTime website [1]. Access requires users to download and install SiTime Studio on their desktop PC running Windows or Mac operating systems. The calculator enables users to enter data into the application in one of three ways: (1) manual entry, (2) cut-and-pasting comma-separated value (CSV) data, or (3) selecting a file with data in csv format. Optional jitter filters may be applied to the phase noise data for analysis. These filters can be defined manually or selected from a list of predefined filters. Typically, these filters are derived from product, application and/or industry-standard requirements.

The application is designed to be intuitive for users to learn-as-you-go. Nevertheless, this document provides more detailed information for interested users. It is organized according to the 3 tabs that make up the calculator, which should be completed sequentially.

1. In the "Enter Phase-noise Data" tab, enter at least two phase-noise data points (in dBc/Hz) at corresponding offset frequencies (in Hz). One may optionally enter spurious noise (in dBc) and their related offset frequencies (in Hz).

2. Click the "Enter Jitter Filter" tab and either accept the default jitter filter, or manually enter or select a custom filter.

3. Click the "View PN Results" tab to view calculator results and optionally export them to a PDF file.

2   Phase-noise Data

The calculator opens in the Enter Phase-noise Data tab, as shown in Figure 2.1. The buttons and icons located in the upper-right corner of the application (Save as PDF Reset ⚙ i) are common to all tabs, and function as follows:

- **Save as PDF button.** This button is enabled when viewing the View PN Results tab. Click this button to receive an e-mail summarizing the calculator's results in a PDF file.

- **Reset button.** Click this button to reset all tabs to their default state.

- **User Preferences icon.** Click this icon to open the User Preferences panel, which allows users to change plot colors.

- **About icon.** Hover the mouse over this icon to display general information about the calculator. Click the icon to open a panel that lists the software revision, support email, Terms of Use, Privacy Policy, and other helpful links.
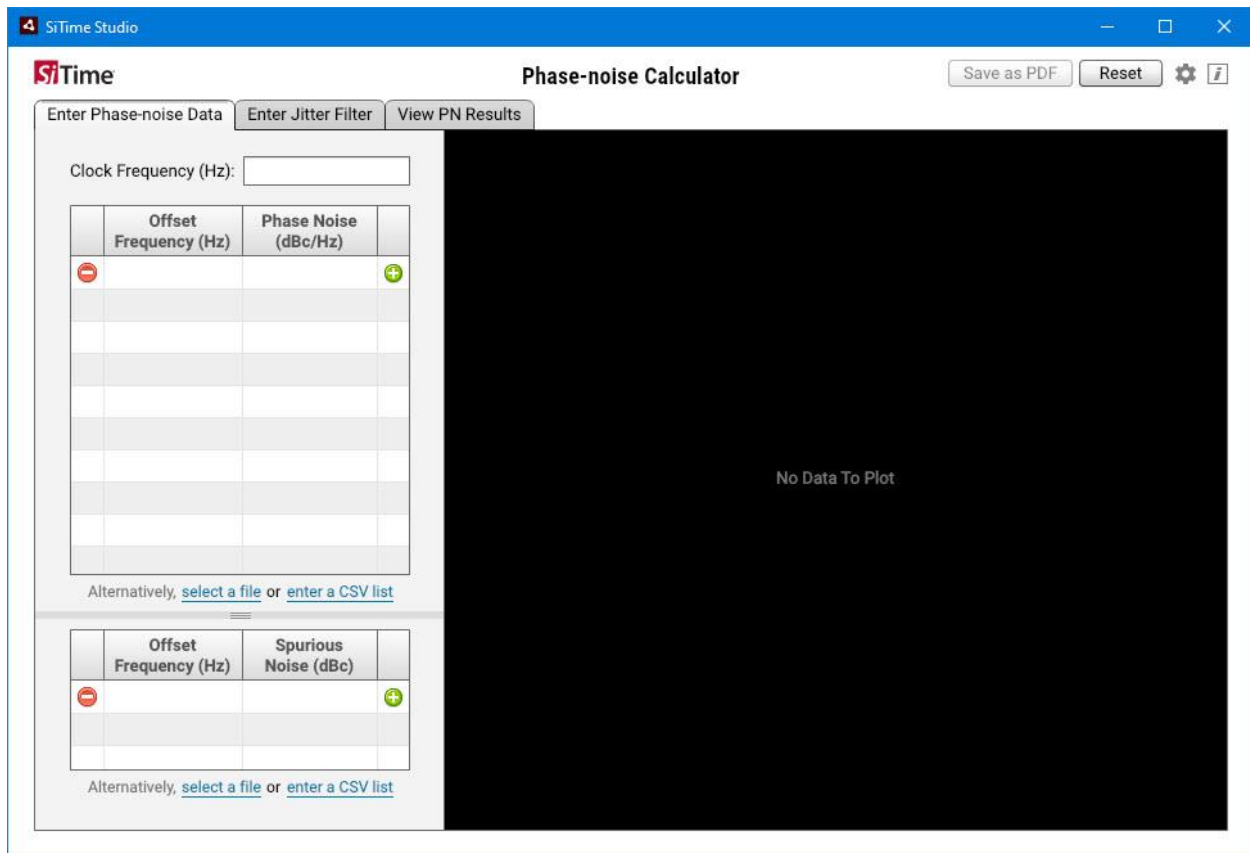
Figure 2.1 Use the "Enter Phase-noise Data" tab to input random phase noise and (optionally) spurious noise data.

The Enter Phase-noise Data tab must be completed before viewing the results tabs. The minimum requirement for completing the Enter Phase-noise Data tab is to enter a value in the Clock Frequency field from 10 kHz to 100 GHz, and at least two data points for phase noise (the spurious noise table is optional).

When entering numbers in the calculator, scientific notation is supported using the letter "e" or "E" to represent ten raised to some power. For example, entering "1e9" or "1E9" in the Clock Frequency field represents 1 GHz.

To enter data into a table cell, double-click a cell and enter a number. Only valid characters are accepted (e.g. if you keep pressing a keyboard key and it's not appearing in the field, that key is probably not a valid character). Press the Tab key to move to the next cell or press the Return (or Enter) key to complete editing the cell. Click the green "+" icon or the red "-" icon to add or delete a row in the table, respectively. The chart updates automatically.

Valid offset frequencies are from 1 Hz to 50 GHz. Neighboring offset frequencies cannot be closer than 0.001 Hz. Offset frequencies must increase monotonically with each subsequent row.

Valid phase noise values are from -300 to 20 dBc/Hz.

Valid spurious noise values are from -300 to 20 dBc.

To display more or less table rows, left-click-and-drag the gray horizontal divider bar located between the two tables vertically up or down, as shown in Figure 2.2.
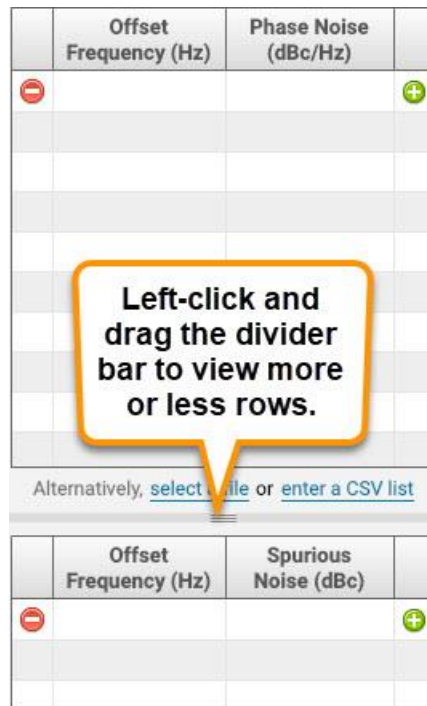
Figure 2.2 Drag the divider bar between tables to resize the tables.

Typically, one would complete the Clock Frequency field before the spurious-noise table. Doing so ensures that when spurious-noise data is entered, a tool tip displays that converts spurious-noise data (entered in dBc) to units of seconds peak-peak, as shown in Figure 2.3. This process requires the Clock Frequency data to be valid, otherwise the tool tip displays a reminder to enter the Clock Frequency.
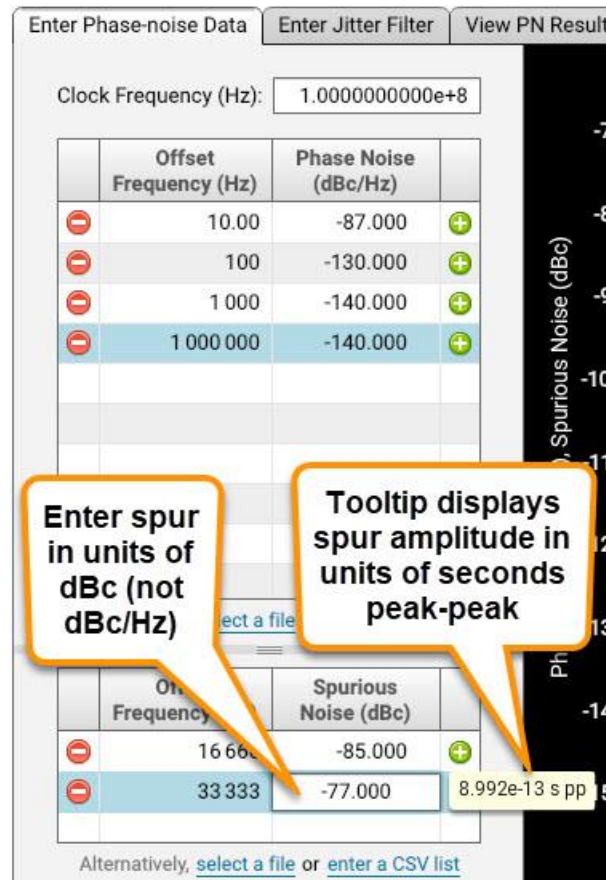
Figure 2.3 If the Clock Frequency is entered (e.g. 1e+8 is shown in the figure), then entering a spurious-noise value displays a tool tip that converts units of dBc to seconds peak-peak.

The following equation is used to convert units from dBc to seconds peak-peak:

$$\text{spur\_s\_pp} = 2 \times \text{SQRT}(2) \times \text{SQRT}[\ 2 \times 10^{\wedge}(\text{spur\_dBc}/10)\ ]\ /\ (2 \times \text{pi} \times \text{fc})$$

where spur_s_pp is the spurious noise in seconds peak-peak, spur_dBc is the spurious noise in dBc, and fc is the Clock Frequency in Hz.

Note that the spurious noise must be entered in units of dBc and not dBc/Hz. Typically, an instrument's software can be configured to output spurs in dBc directly by accounting for the resolution bandwidth of the instrument.
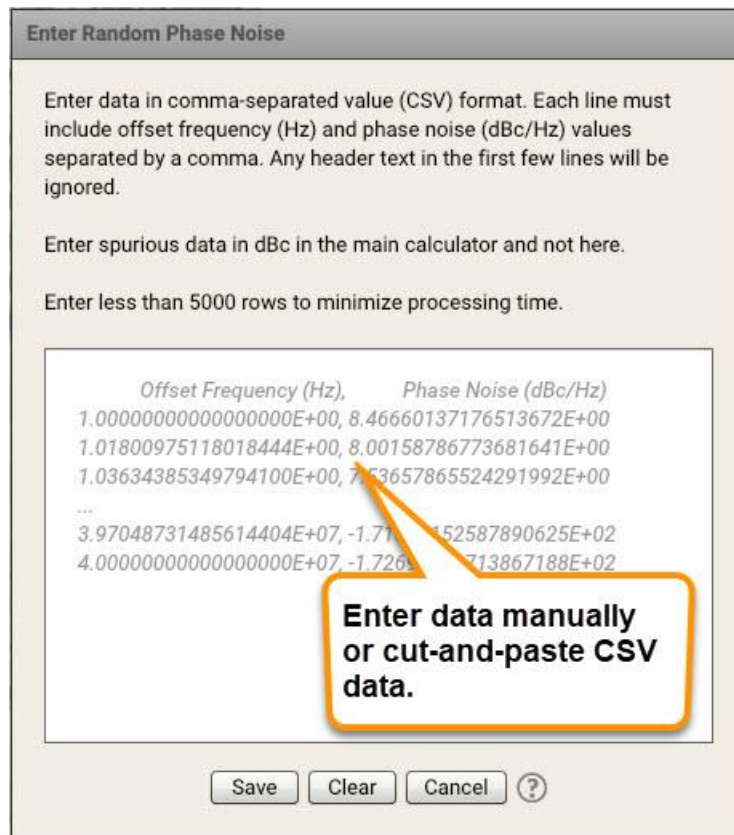
All spurious-noise data points must fall inside the offset-frequency range used by the phase-noise table. Also, the spurious-noise amplitude must extend above the phase-noise curve. Otherwise, the spurious-noise data is displayed in red italic font, as shown in Figure 2.4.

Figure 2.4 Spurious-noise data must fall inside the frequency range of the phase-noise data, and the amplitude of spurious noise must extend above the phase-noise data, otherwise the data points are shown in red italic fonts.

Instead of entering data directly in the phase-noise table, it may be more convenient to enter data as a CSV list. Click the "enter a CSV list" link located below the phase-noise table in the Enter Phase-noise Data tab. This opens the "Enter Random Phase Noise" popup window shown in Figure 2.5.

Figure 2.5 Optionally click the "enter a CSV list" link in the Enter Phase-noise Data tab to enter data manually or cut/paste it in from an external CSV text file.

Each line must contain an offset frequency in Hz, followed by a comma character, followed by phase noise in dBc/Hz. Any header lines appearing before the data are ignored. Empty lines are ignored. Spurious noise, if present, must be removed from this data, and entered (separately) into the spurious-noise table in the Enter Phase-noise Data tab.

Alternatively, click the "select a file" link in the Enter Phase-noise Data tab (below the phase noise table) to select a CSV file and import its data into the calculator.

Data may be entered separately into the spurious noise table using a similar procedure outlined above for the phase noise table.

Figure 2.6 shows the Enter Phase-noise Data tab with example data.
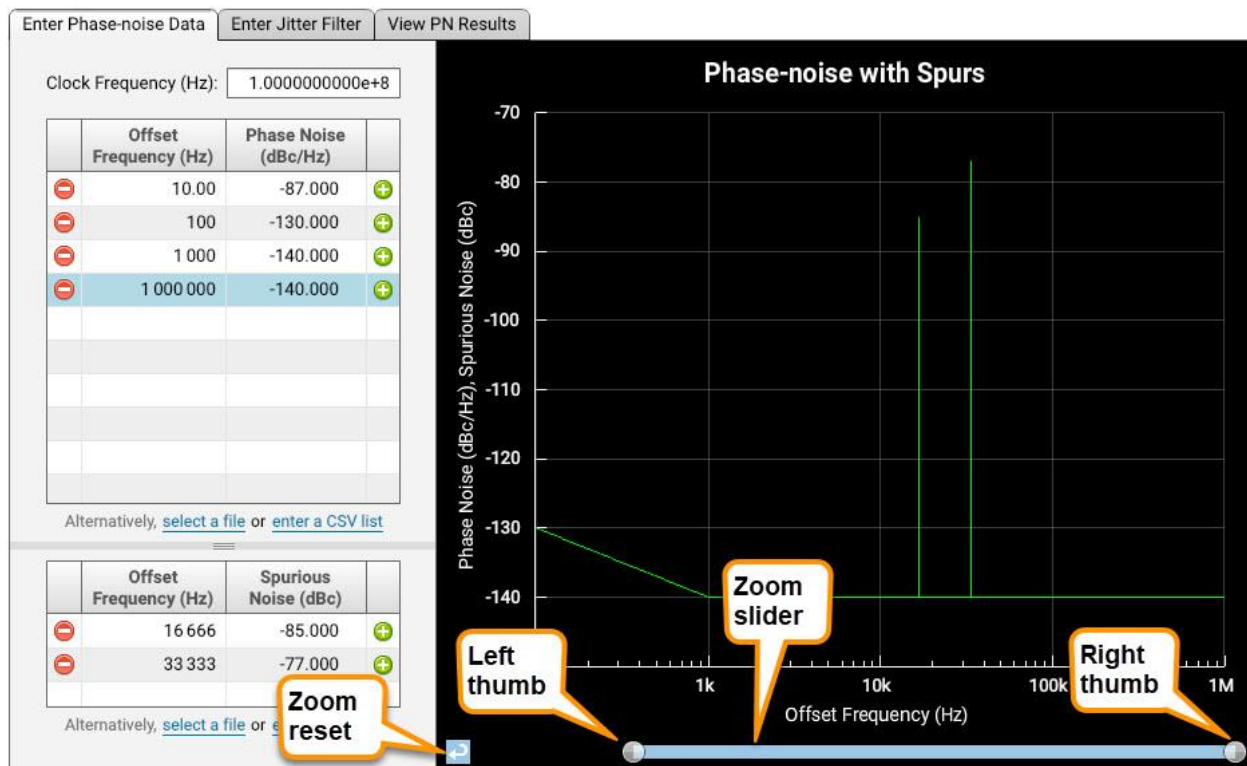
Figure 2.6 Example data showing chart with zoom controls.

There are two methods to zoom in the chart. The first method is to left-click-and-drag one of the zoom-slider thumbs left or right, as illustrated in Figure 2.6. Note that the zoom-slider's width is proportional to the x-axis width, and that the zoom-slider thumb auto-snaps to decade (frequency axis) intervals. For example, dragging the left thumb to the mid-point of the slider zooms-in on the right-half of the plot. The zoom-slider's bar may also be dragged left or right to pan the zoom window as desired. The y-axis auto-scales after each zoom.

The second zoom method is simply to left-click-and-drag to define a rectangular zoom window inside the chart, as shown in Figure 2.7.
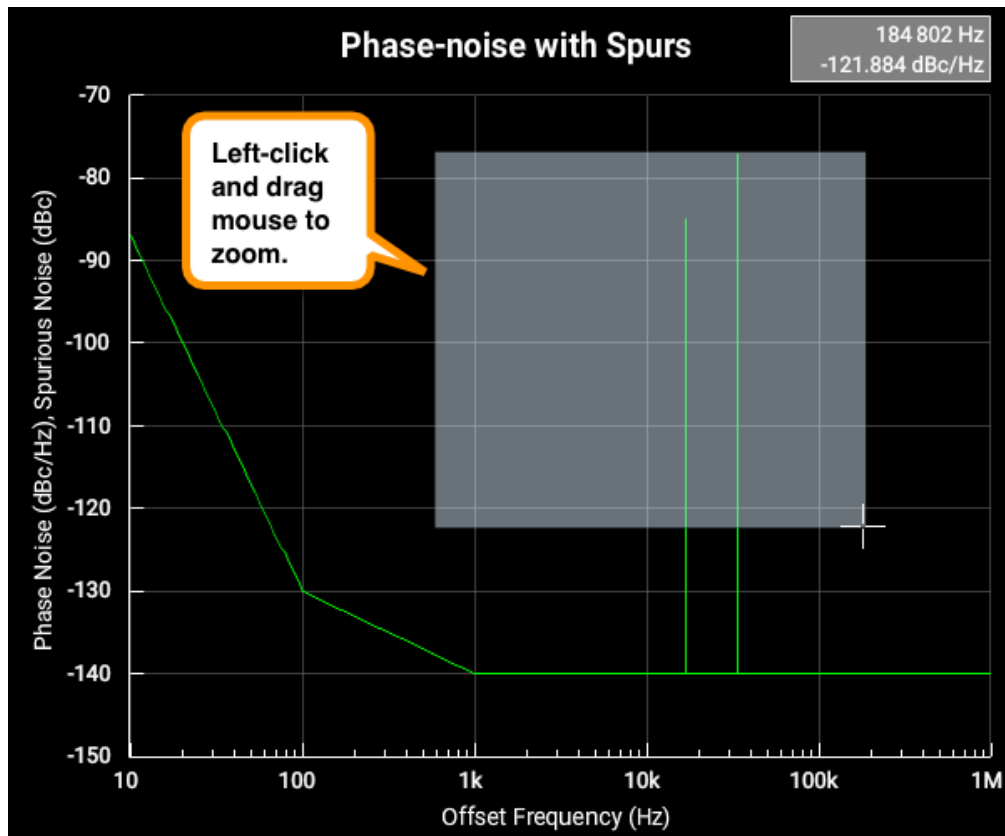
Figure 2.7 Left-click-and-drag to define a zoom window inside the chart.

Regardless of how the chart is zoomed, click the Zoom Reset icon shown in Figure 2.6 to reset the chart.

These zoom controls work the same for charts displayed in the other tabs.

3 Jitter Filter

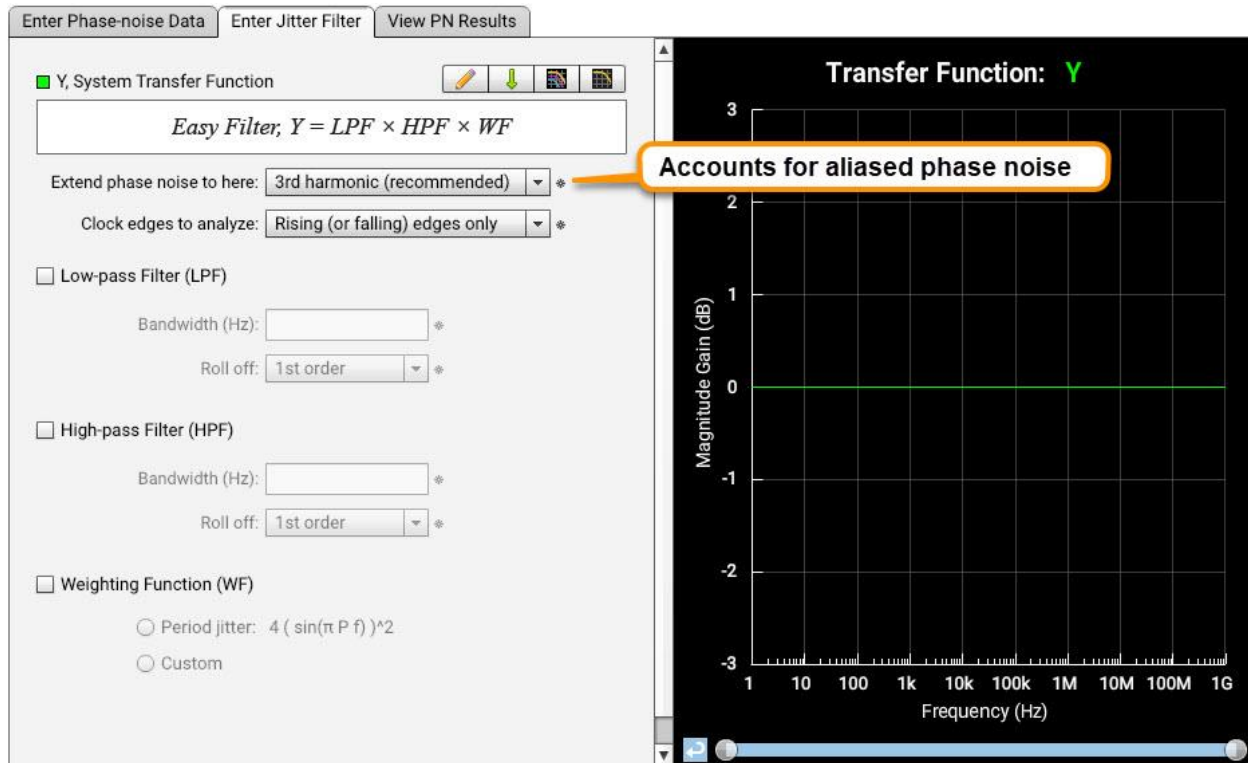After completing the Enter Phase-noise Data tab, select the Enter Jitter Filter tab. The default filter is shown in Figure 3.1.

Figure 3.1 Use the Enter Jitter Filter tab to create a jitter filter that gets applied to the phase- and spurious-noise data. To increase accuracy, most filters have options to include aliasing and select edges for analysis.

Hover the mouse over the various options to read tooltips explaining their functionality.

Certain system transfer functions require one to select whether to including aliasing. In these cases, an option is available to extend the phase noise plot to account for aliasing and provide more accurate results [2],[6]. Aliasing is accounted for using the first drop-down list shown in Figure 3.1. Note that a direct phase noise analyzer instrument includes an anti-aliasing filter that is not present in most real applications such as reference clocks driving PLLs, data converters or SerDes chips. In such applications, the aliased phase noise data must be "added" back in during the analysis to emulate how the real application observes the actual device's phase noise spectrum. Extending the measured phase noise curve flat to higher frequencies results in adding more aliased phase noise. For simplicity, the last data point is automatically extended flat to create the phase-noise extension (therefore, if there is noise in the phase noise data at high offsets, please review the last data point and manually adjust it as needed to represent an average value for the noise floor). The third harmonic setting is recommended since it

has been found to provide the most accurate results [2] for applications that sample the clock signal (e.g. PLLs, ADCs, SerDes, etc.). For this reason, the "3rd Harmonic (recommended)" option is selected by default. For applications that don't include aliased jitter (or phase noise), aliasing can be ignored by selecting the First Nyquist Zone setting (the first option in the drop-down list). Contact SiTime if any questions.

The "Clock edges to analyze" drop-down list is only used to determine the Nyquist frequency, and therefore how much aliasing is included. Most SerDes reference-clock applications use either rising (or falling) edges only to avoid introducing duty-cycle distortion jitter into data signals, so this option is selected by default and is a safe option to use when no further information is available.

You could accept the default filter by clicking the View PN Results tab (and proceed to Chapter 4), but we strongly recommend you change the default filter to model your application as close as possible. This is because real systems observe phase noise over a limited bandwidth. Thus, the default filter, which is broadband, isn't realistic. You must know something about your application to create a realistic filter for it. Typically, these filters are defined by the application and/or silicon vendor datasheets. Contact your silicon vendor (e.g. SerDes, data converter, PLL, etc.) or SiTime for additional support.

There are two methods to enter a jitter filter. The first method is to click the predefined-filter icon (⬇) located in the System Transfer Function icon bar. In the Select A Predefined Jitter Filter popup window that appears, highlight a row for a predefined filter by left-clicking on it, then click the "Save" button. The predefined jitter filter parameters populate the Enter Jitter Filter tab. If needed, edit these values as desired.

The second method is to manually enter a jitter filter by clicking the Edit icon (✏) in the System Transfer Function icon bar. The System Transfer Function popup window opens as shown in Figure 3.2. Select a filter to view an example application.

The "Easy Filter" (i.e. *Y=LPF×HPF×WF*) is selected by default as shown in Figure 3.1. This filter is the easiest to configure. Simply enter the bandwith and select the roll off characteristic appropriate for your application. You may combine one or more filters for low-pass (LPF), high-pass (HPF) and weighting function (WF). Select the WF "Period jitter" option to convert the View PN Results tab data to period jitter, or select the "Custom" option to enter a custom filter by selecting a CSV file or manually entering CSV data. The LPF, HPF and WF filters are applied sequentially after accounting for aliased phase noise. When you are done configuring the Easy Filter, click the View PN Results tab and proceed to Chapter 4.

The Easy Filter is intended to satisfy most applications. In particular, the "Custom" WF filter allows circuit designers to export their exact filter characters (computed using EDA software) as a CSV file that can be imported as a WF filter to obtain the most accurate results.

Beyond the Easy Filter, additional filters are available in the s-domain using Laplace equations.
Figure 3.2 illustrates an embedded-clock selection having a system transfer function of *Y=H1× (1-H2)*,
where H1 and H2 are defined using Laplace equations. If the "Select" button is clicked, the popup
window closes and the required block transfer function sections display in the Enter Jitter Filter tab as
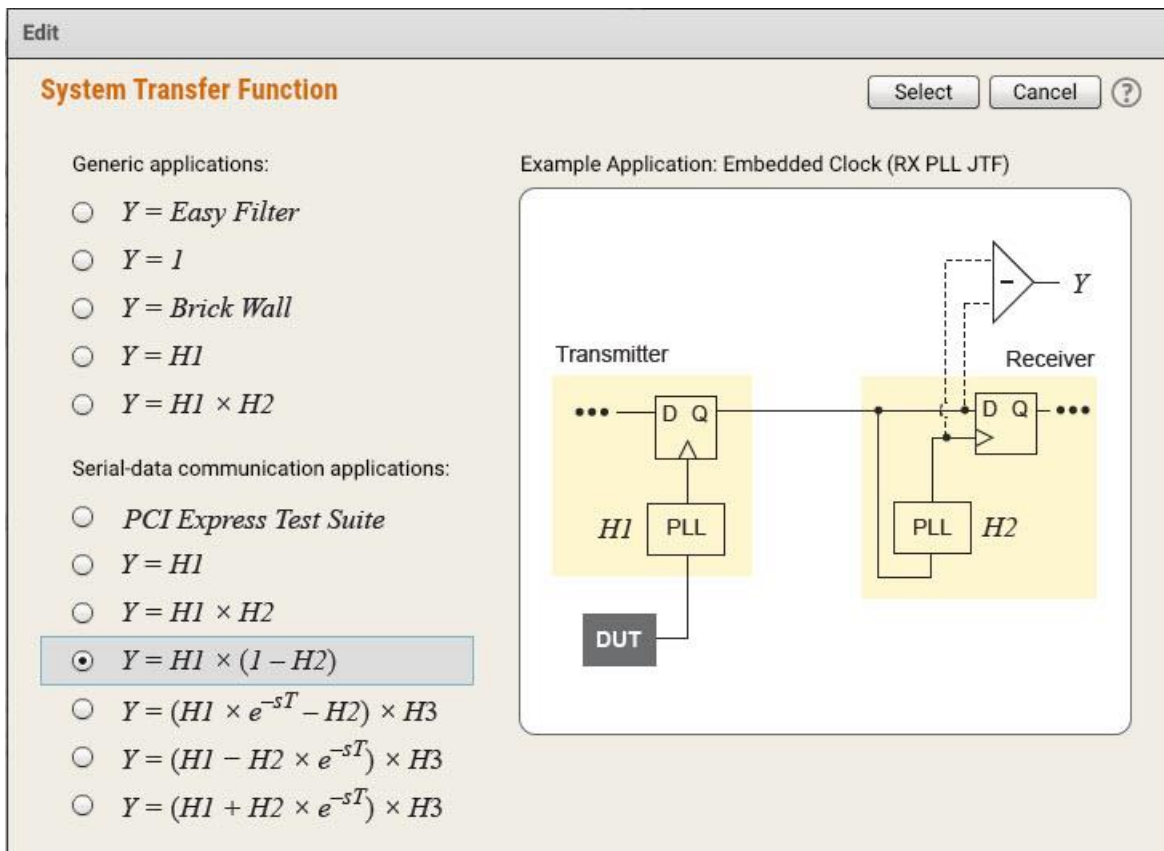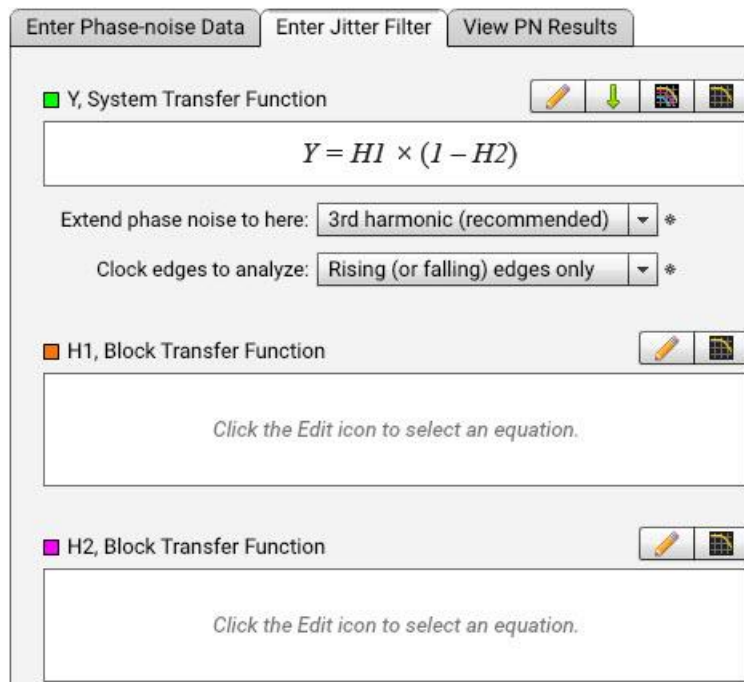shown in Figure 3.3.

Figure 3.2 Select a filter option in the System Transfer Function popup window.

Figure 3.3 Some system transfer functions require configuring one or more block transfer functions using Laplace equations.

You must now edit each of the block transfer functions to define the overall system transfer function.

To define a block transfer function, click its corresponding Edit icon (   ). Select an option in the Block Transfer Function popup window that appears, as shown in Figure 3.4.

Edit

Block Transfer Function

[Select] [Cancel] (?)

Low-pass functions:

$\circ \quad \dfrac{b_0}{s + a_0}$

$\circ \quad \dfrac{b_1 s + b_0}{s^2 + a_1 s + a_0}$

$\circ \quad \dfrac{b_2 s^2 + b_1 s + b_0}{s^3 + a_2 s^2 + a_1 s + a_0}$

$\circ \quad \dfrac{\omega_c}{s + \omega_c}$

$\circ \quad \dfrac{2s\zeta\omega_n + \omega_n^2}{s^2 + 2s\zeta\omega_n + \omega_n^2}$

$\circ \quad \dfrac{\omega_c(s + a_2\omega_c)(s + a_1\omega_c)}{s^3 + \omega_c(s + a_2\omega_c)(s + a_1\omega_c)}$

High-pass functions:

$\circ \quad \dfrac{a_1 s}{s + \omega_c \times e^{sT}}$

$\circ \quad \dfrac{b_2 s^2 + b_1 s + b_0}{s^2 + a_1 s + a_0}$

$\circ \quad \dfrac{b_3 s^3 + b_2 s^2 + b_1 s + b_0}{s^3 + a_2 s^2 + a_1 s + a_0}$

$\circ \quad \dfrac{s^2}{s^2 + 2s\zeta\omega_n + \omega_n^2}$

$\circ \quad \dfrac{s^3}{s^3 + \omega_c(s + a_2\omega_c)(s + a_1\omega_c)}$
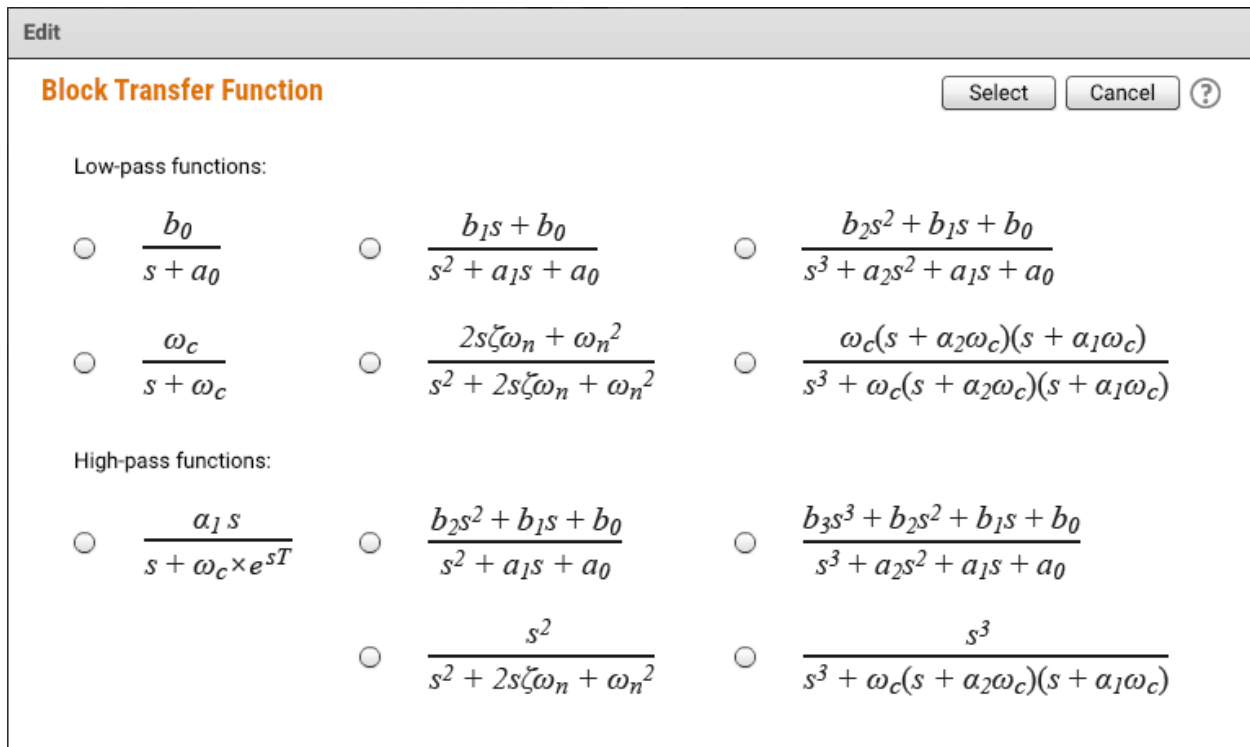
Figure 3.4 Select an equation in the Block Transfer Function popup window.

Filter options are available for 1st, 2nd and 3rd order low- and high-pass jitter transfer functions. Both jitter peaking and roll-off characteristics can be tailored to the application.

Once a function is selected, the required fields appear in the Enter Jitter Filter tab (see Figure 3.3). Enter values for all parameters required by the selected function. You can optionally click the Plot icon to graph the corresponding block transfer function.

Repeat this process for all required block transfer functions. An example completed filter in the Enter Jitter Filter tab is shown below.
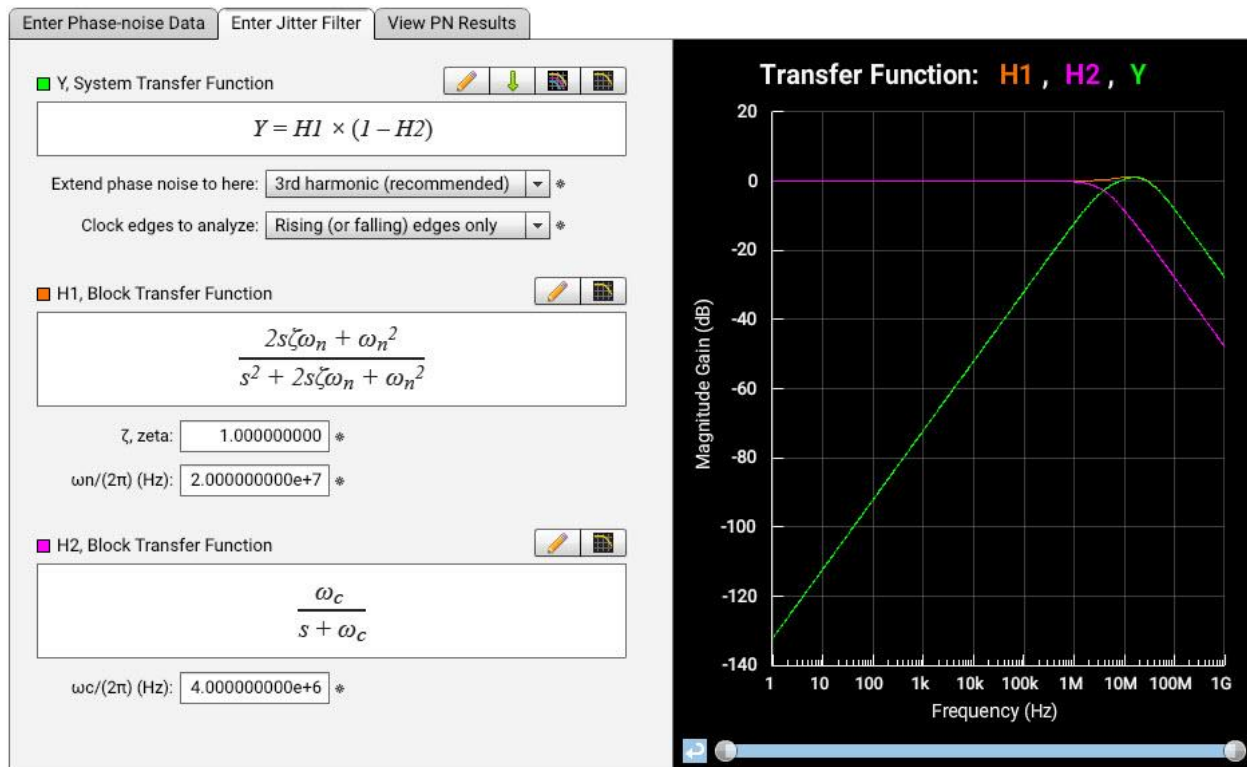
Figure 3.5 An example jitter filter.

When you're satisfied with the jitter filter entered in this tab, click the View PN Results tab to apply this filter to the data in the Enter Phase-noise Data tab.

4 View PN Results

4.1 General Analyses

The calculator computes results when the View PN Results tab is clicked. For reference, the Clock Frequency value is shown in the upper left corner of the tab, along with a Spur Count number that summarizes the total number of spurs entered in the Enter Phase-noise Data tab.

Figure 4.1 shows an example calculation, where computed results are shown on the left for unfiltered and filtered data. Click the checkbox for Unfiltered Results, Filtered Results, or Jitter Filter to toggle their respective plot traces on and off. The checkbox color matches the color of its corresponding plot trace.
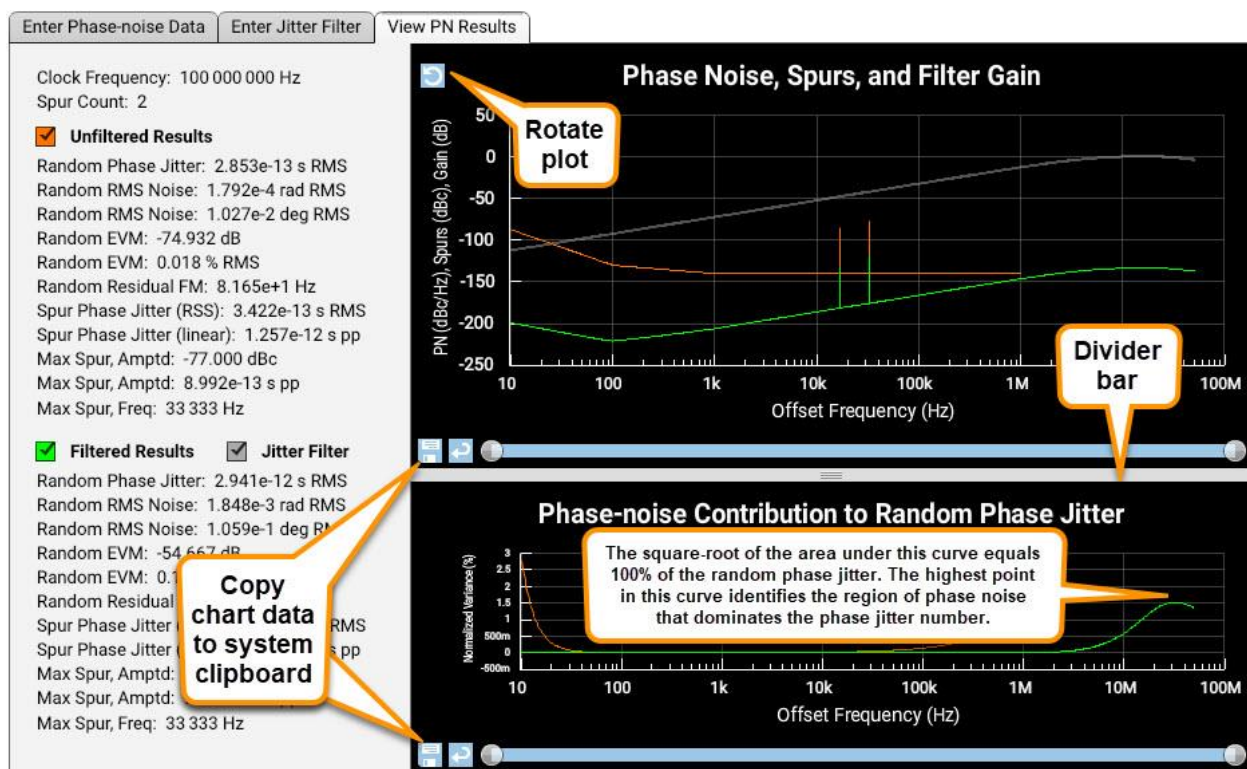

Figure 4.1 Example calculator results.

The Rotate Plot icon is located in the upper-left corner of the top plot. Click this icon once to maximize the top plot, click again to maximize the lower plot, and click a third time to return to the original plot arrangement.

Click-and-drag the horizontal divider bar located between the two plots to resize the plots.

The top plot contains traces for the jitter filter, the unfiltered phase- and spurious-noise data, and the filtered phase- and spurious-noise data. The phase-noise data in this plot has units of dBc/Hz, whereas the spurious-noise data has units of dBc.

Click the floppy-disk icon shown in Figure 4.1 to access the plotted data. This button opens a new window to copy the chart data to your system clipboard, which is useful to paste into other applications such as Microsoft Excel.

The bottom plot contains traces for unfiltered and filtered normalized variance versus offset frequency. A normalized-variance plot shows the contribution of phase-noise (spurious noise is ignored here) to the computed random phase jitter result in seconds RMS. A simple way of interpreting the variance curve, is that the square root of the area under the variance curve equals the random phase jitter value. Accordingly, the square root of the area under the *normalized* variance curve equals 100%.

Thus, offset-frequency regions having larger normalized-variance values contribute more to the random phase jitter number than offset-frequency regions having smaller normalized-variance values. For example, Figure 4.1 shows that low-offset frequencies in the unfiltered phase-noise plot contribute most to the unfiltered random phase jitter value of 2.853e-13 s RMS (because the unfiltered normalized-variance curve is largest at low offset frequencies). Similarly, the high-offset frequencies in the filtered phase-noise plot contribute most to the filtered random phase jitter value of 2.941e-12 s RMS (because the filtered normalized-variance curve is largest at high offset frequencies).

When aliasing is ignored, the phase-noise data (without spurs) is integrated across offset frequency using conventional techniques [3] to compute the following metrics (which quantify random noise) for both unfiltered and filtered data sets:

Random Phase Jitter (RMS seconds) = Random RMS Noise (radians) / (2 × π × fc)

Random RMS Noise (radians) = SQRT(2 × integ[10^(L(f) / 10)])

Random RMS Noise (degrees) = Random RMS Noise (radians) × 180 / π

Random EVM (dB) = 20 × LOG10(0.01 × Random EVM in % RMS)

Random EVM (% RMS) = 100 × SQRT(2 - 2 × exp(-0.5 × (Random RMS Noise radians)^2))

Random Residual FM (Hz) = SQRT(2 × integ(f^2 × 10^(L(f) / 10)))

where f is the offset frequency, L(f) is the set of phase-noise data (without spurs) as a function of f, integ is the integral over all offset frequencies, fc is the Clock Frequency in Hz, LOG10 is the base 10 logarithm, and exp(n) is the math constant e (e.g. 2.7183) raised to the power of n. Note that random error vector magnitude (EVM) is computed [4],[5] from phase noise without spurs, and assumes a very large energy-per-symbol to noise-density ratio (e.g. E_S/N_0) for QPSK modulated symbols.

When aliasing is included, the phase noise data point located at the highest offset frequency is extended flat to the specified location in the offset-frequency axis. For example, if the 3rd harmonic is selected, then a 100 MHz clock's phase noise data point at the highest offset frequency would be extended to 200 MHz offset frequency (i.e. 300 MHz in the signal spectrum). Then the phase noise located above the

first Nyquist zone (e.g. 50 MHz if analyzing rising edges only, or 100 MHz if all edges) is mirrored below the first Nyquist zone where it adds to the phase noise located there. Finally, this data is filtered using the conventional math described above for non-aliased data, then plotted in the chart.

For spurious-noise data, additional metrics (which quantify deterministic noise) are computed for both unfiltered and filtered data sets as follows.

Spur Phase Jitter (RSS) = computed by adding in root-sum-square (RSS) fashion each individual spurious-noise amplitude in seconds RMS. Note that spurious phase jitter in seconds RMS equals spurious phase jitter in seconds peak-peak divided by 2×SQRT(2).

Spur Phase Jitter (linear) = computed by linearly adding each individual spurious noise peak-peak amplitude in seconds peak-peak. See Chapter 2 to convert spurious noise from units of dBc to seconds peak-peak. Note that this calculation assumes all spurs are independent and uncorrelated to each other (which may not always be true; for example, if the spurs are harmonically related).

Max Spur, Amptd (dBc) = the amplitude of the largest-amplitude spur, in dBc.

Max Spur, Amptd (s pp) = the amplitude of the largest-amplitude spur, in seconds peak-peak.

Max Spur, Freq = the offset frequency of the largest-amplitude spur.

4.2   PCI Express Analysis

This analysis requires the Clock Frequency in the Enter Phase-noise Data tab to fall between 98.010389 MHz and 101.553772 MHz per the PCI Express Base Specification.

In the Enter Jitter Filter tab, click the pencil icon (🖉) in the system transfer function's icon bar. Click the PCI Express Test Suite option in the window that appears and click the "Select" button as shown in the following Figure 4.2.
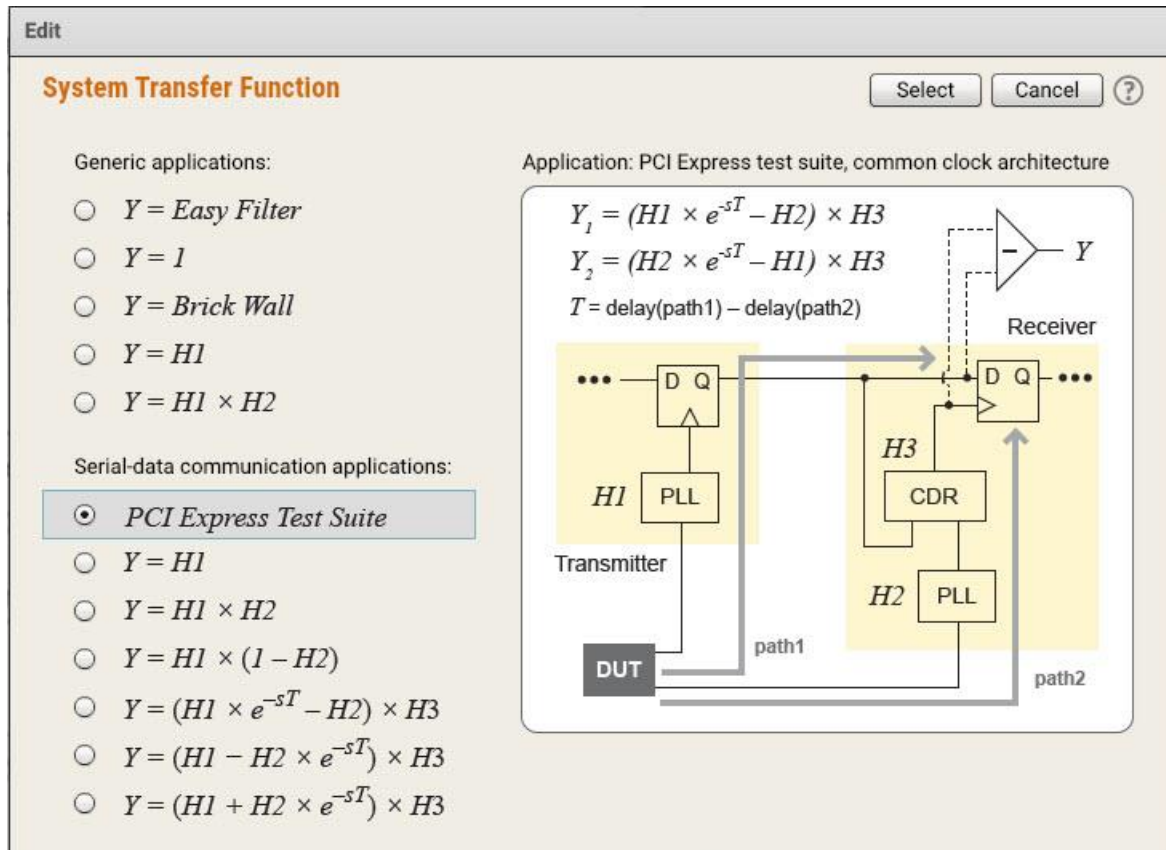
Figure 4.2 The PCIe test suite analysis is selected.

This analysis applies all required jitter filters for each of Gen 1 through Gen 6 according to the PCI Express Base Specification [7] for common clock architecture. Note that hundreds of jitter filters are applied here. The filter providing the worst-case phase jitter value for each generation is plotted in the View PN Results tab, along with plots of both unfiltered and filtered phase noise data.

The following figure illustrates an example analysis, showing worst-case jitter values for Gen 1 to Gen 6 among all applied filters. The plot shows the specific Gen 6 filter that led to the worst-case jitter result of 10 fs rms.
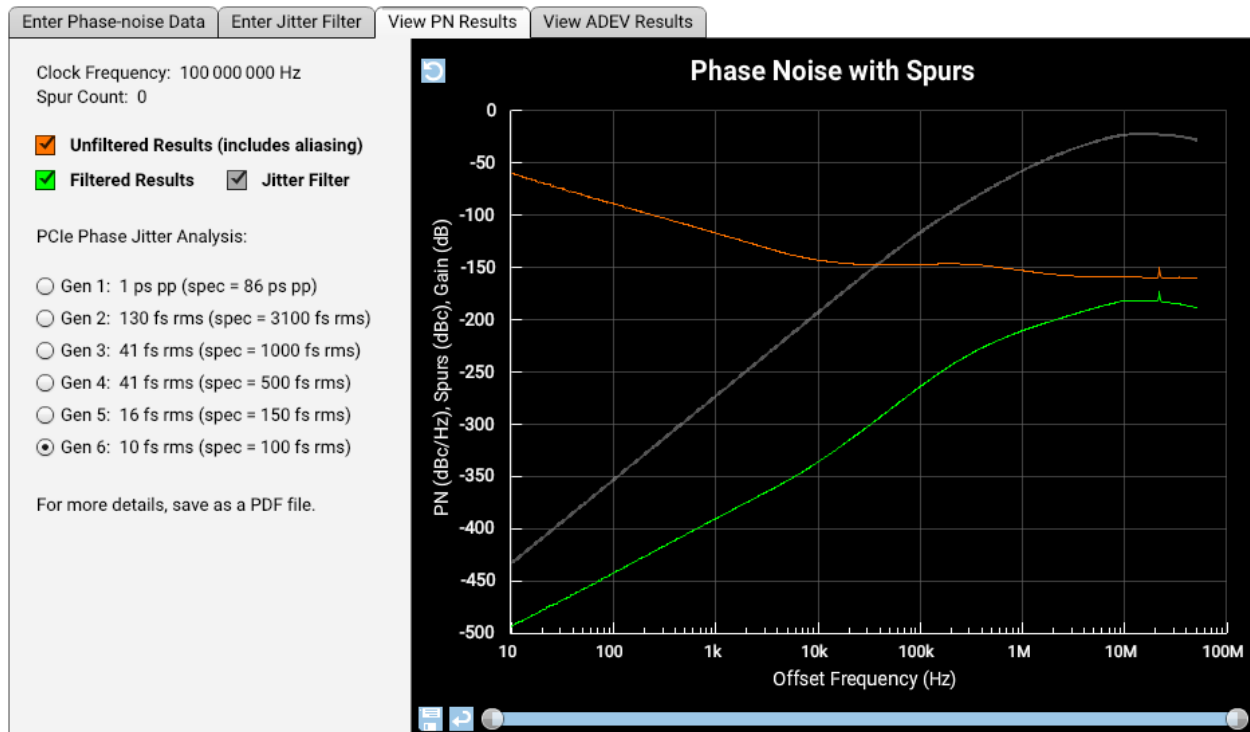
Figure 4.3 Example PCIe calculator results.
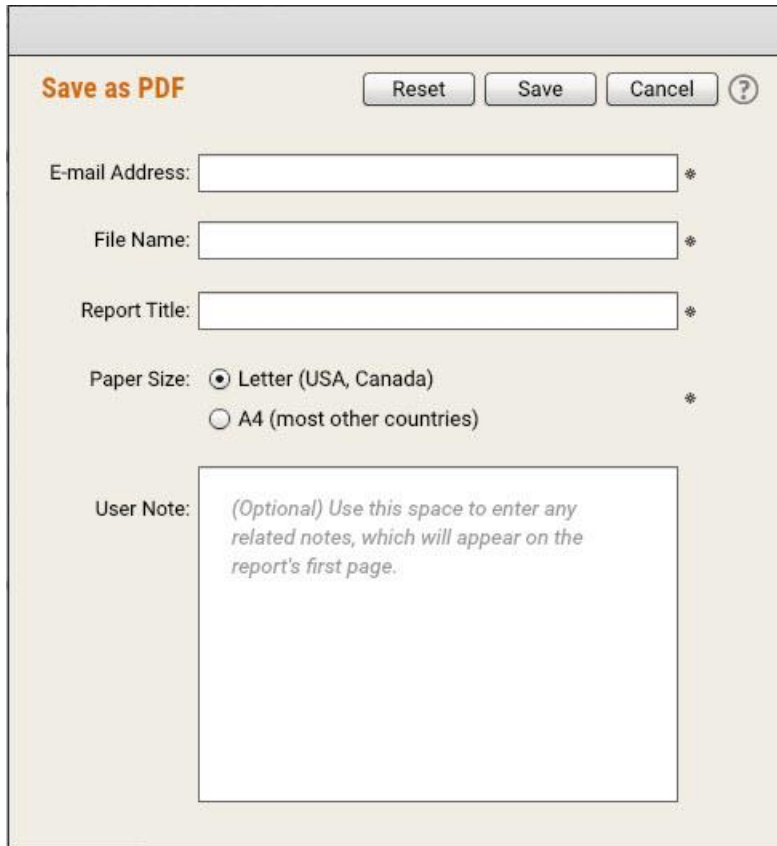
For view more detailed results, save the report as a PDF file. The PDF report describes the various jitter filters that get applied, and the resulting phase jitter for each.

The following notes are useful for analyzing PCIe using SiTime Studio:

- The absolute clock period must be between 9.847 ns and 10.203 ns per PCIe [1].
- PCIe [1] requires a direct phase noise analyzer to be used for measuring phase noise data. Spectrum analyzers are not allowed since they cannot distinguish between amplitude and phase noise.
- The entered phase noise data is extended flat up to the 3rd harmonic as required by PCIe [1]. SiTime Studio simply uses the last data point to extend the phase noise curve. As a result, for noisy data sets, you may benefit by manually adjusting the last data point to represent the average noise floor.
- For spread-spectrum clocks used in Gen-4 and above, remove all spread-spectrum spurs below 2 MHz offset frequency before analysis.

5 Save as PDF

Clicking the "Save as PDF" button opens the popup window shown in Figure 5.1. The resulting PDF is auto-generated on a server and e-mailed to you immediately.

Figure 5.1 Clicking the "Save as PDF" button opens this popup window.

Enter an E-mail Address, File Name, and descriptive Report Title in the fields provided. If needed, select a paper size. One can optionally add a note in the User Note section, which will appear in the first page of the report. Use this User Note space to enter part numbers, measurement details, or other critical parameters you don't want to forget or you want to communicate to other recipients. When complete, click the "Save" button to submit the form. An e-mail is auto-generated and sent to your inbox with the PDF file included as an attachment.

6 References

[1] SiTime Studio is available at https://www.sitime.com/sitime-studio.

[2] "How to evaluate reference-clock phase noise in high-speed serial links," G. Giust, Signal Integrity Journal (May 3, 2019). https://www.signalintegrityjournal.com/articles/1216-methodology-for-analyzing-reference-clock-phase-noise-in-high-speed-serial-links

[3] ISO/IEC Technical Report 14165-117, Edition 1.0, Information Technology – Fibre Channel – Part 117: Methodologies for jitter and signal quality (MJSQ), 2007, Annex E.2, pp. 220-221.

[4] A. Georgiadis, "Gain, phase imbalance, and phase noise effects on error vector magnitude." IEEE Transactions on Vehicular Technology, pp. 443–449, 2004. See equation 40.

[5] http://www.dsplog.com/2012/07/09/evm-phase-noise/

[6] Patents US 10,802,074 B2, US 11,231,459 B2, US 11,592,480 B2, "Method and apparatus for analyzing phase noise in a signal from an electronic device", G. K. Giust, JitterLabs LLC.

[7] PCI Express Base Specification Rev. 6.0.1, Version 1.0 (Oct 14, 2022), www.pci-sig.com.

7 Revision History

Table 7.1 Revision History

Version	Date	Changes
0.1	3 May 2023	Import from JitterLabs, numerous updates, beta release
0.2	19 June 2023	Added PCIe analysis
1.0	5 December 2023	Added Easy Filter system transfer function, file import, user preferences, predefined filters. Removed Allan deviation tab. Various style improvements and bug fixes.