PLL Analysis Tool

Quick Reference Guide For the SIA-3000

Applications of PLL Analysis Tool

- Find the transfer function of a 2nd-order PLL
- View the Bode plot of a PLL.
- Identify poles and zero of a 2nd-order PLL.
- Determine PLL characteristics such as lock in damping factor, natural frequency, lock range, lock-in time, pull-in time, pull-out range, etc.

Introduction

The focus of this guide is to familiarize the user with the Advanced PLL tool allowing quick and easy measurements and interpretation of results. Refer to the SIA-3000 User's Manual and the VISI help files for more information.

Theory of Operation

The PLL measurement tool is based on a white paper authored by *Wavecrest* Corporation [i]. The fundamental measurement of this tool is the 1-sigma (σ) vs. UI plot similar to the High Frequency Modulation tool [ii]. The relationship between the jitter variance (σ^2) and the jitter power spectral density (PSD) is well-established [iii]. The jitter PSD of the PLL output clock is related to the PLL reference clock noise via the transfer function. Therefore, with reasonable assumptions about the input noise of the PLL reference clock, we can infer the transfer function of the PLL.

At the current time, we assume that the input noise spectrum is white and the PLL is of 2nd order. The 2nd-order PLL transfer function in Laplace space is given by

Eq. 1

$$H(s) = \frac{2\zeta\omega_n s + \omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}.$$

where $s = i\omega$ is the complex frequency, ω_n is the natural frequency, and ζ is the damping factor. The parameters ω_n, ζ, and the input noise level is found from a least-squares fit of the variance. Once $H(s)$ is determined, PLL characteristics such as natural frequency, damping factor, damping frequency, pull-in range, pull-in time, pull-out range, pull-out time, lock range, lock time, lock frequency, Bode plots, root locus, poles, zeros, and stability are readily obtained.

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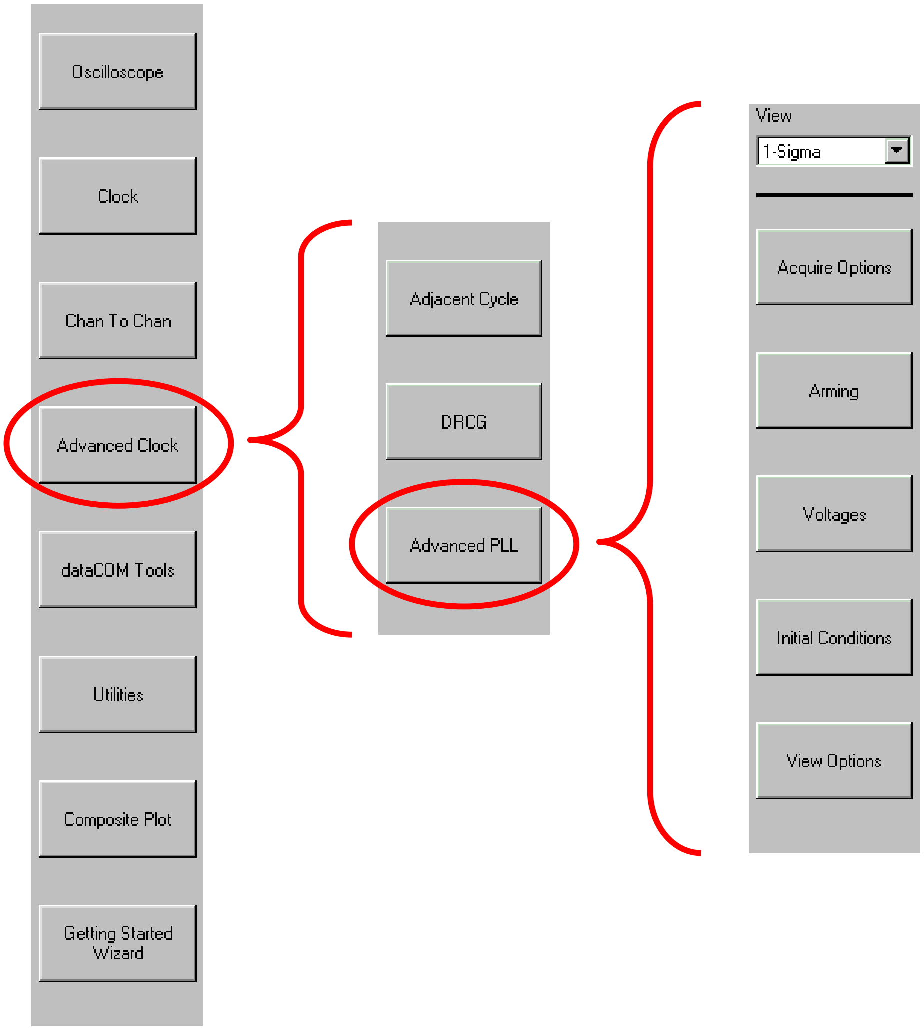
Advanced PLL Tool Main Menu

The main menu of the Advanced PLL tool is found in the VISI menu path shown below



View: Provides the user with several different ways (**1-Sigma, PLL Transfer, Bode Plot, Poles & Zero, Summary**) to visualize the acquired data.

Acquire Options: Opens the Acquire Options menu.

Arming: Opens the Arming menu.

Voltages: Opens the Voltages menu.

Initial Conditions: Opens the Initial Conditions menu.

View Options: Opens the View Options menu.

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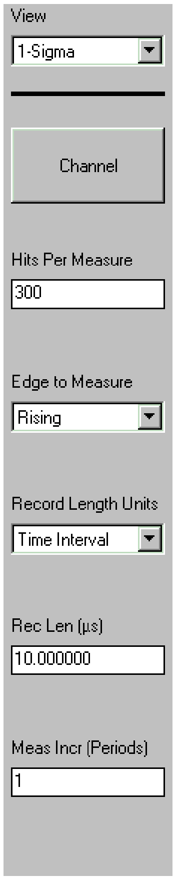
Acquire Options Menu



Channel
Opens the channel selection menu. Use the keypad or mouse to select a measurement channel

Hits Per Measure
Determines the number of time measurements that will be made for each edge or point on the plot.

Edge to Measure
Select **Rising** or **Falling** edge to measure.

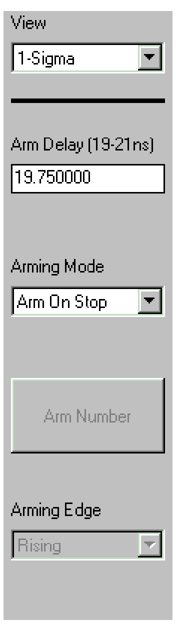
Record Length Units
Sets the unit of measurement for the data record length. Options are: **Time Interval, Periods,** and **Bandwidth.**

Record Length
Options depend on the selection of **Record Length Units.**

- **Rec Len (µs)** for **Time Interval**. Number of cycles to measure determined by the time entered.
- **Rec Len (Periods)** for **Periods**. Number of cycles to measure determined by the number of periods.
- **HPF –3dB Freq (kHz)** for **Bandwidth**. Number of cycles to measure determined by the half power point of the 20dB/decade low frequency roll off.

Meas Incr (Periods)
Choose the increment step size of the number of cycles to measure.

Arming Menu



Arm Delay (19-21ns)
Sets the minimum delay time from an arm event to the first measurement edge.

Arming Mode
Arming is required to make every measurement.

- **Arm on Stop** uses a falling edge from the measurement channel to arm the instrument.
- **Arm on Start** uses a rising edge from the measurement channel to arm the instrument.
- **External Arm** uses a signal from a channel different than the measurement channel to arm the instrument.

Arm Number
Opens the channel selection menu for choosing a channel to be used for arming when **External Arm** is selected.

Arming Edge
Selects **Rising** or **Falling** edge to arm the measurement when External Arm is selected.

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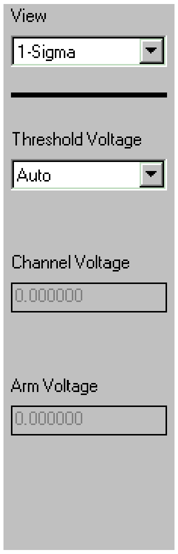
Voltages Menu



Threshold Voltage

- **Auto** sets measurement start and stop reference voltage based on the minimum and maximum levels of the measurement channel (found from **Pulsefind**). The threshold is automatically set to the 50% point. The voltages are shown in the **Channel Voltage** display after a successful **Pulsefind** is completed.
- **User Volts** allows the user to set the reference voltage.

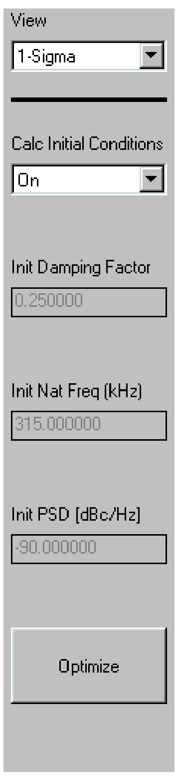
Channel Voltage

Either sets or displays the reference voltage for the measurement channel, depending on the setting of the **Threshold Voltage**.

Arm Voltage

Either sets or displays the arming voltage for the measurement channel, depending on the setting of the **Threshold Voltage**.

Initial Conditions Menu



Calc Initial Conditions

Chooses whether to automatically calculate the initial conditions or allow user entry.

Init Damping Factor

Either sets or displays the initial guess for fitting of the damping factor, depending on the setting of the **Init Damping Factor**.

Init Nat Freq (kHz)

Either sets or displays the initial guess for fitting of the natural frequency, depending on the setting of the **Init Damping Factor**.

Init PSD (dBc/Hz)

Either sets or displays the initial guess for fitting of the input noise level, depending on the setting of the **Init Damping Factor**.

Optimize

If **Calc Initial Conditions** is set to **On**, this will estimate initial conditions based on prominent features of the data and perform least squares fitting of data to 2^{nd}-order PLL transfer function

If **Calc Initial Conditions** is set to **Off**, this will perform least squares fitting of data to 2^{nd}-order PLL transfer function using user-entered initial conditions.

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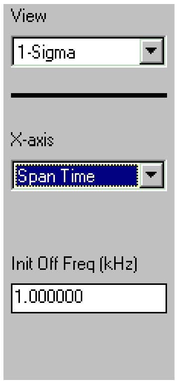
View Options Menu



X-axis
Selects the parameter plotted on the x-axis when **View** is set to **1-Sigma**:

- **Span Time** plots the time span of the measurement on the x-axis.
- **Span Periods** plots the number of periods spanned on the x-axis.

Init Off Freq (kHz) Offset Frequency
Sets the lowest frequency displayed when **View** is set to **PLL Transfer**.

Sample Measurement with the Advanced PLL Tool

Experimental Setup

As an example, we perform Advanced PLL measurements on a PLL clock output. The experimental set up is shown in Fig. 1. For this example, the PLL is has a reference clock of 10 MHz and an output clock of 1.2525 GHz.

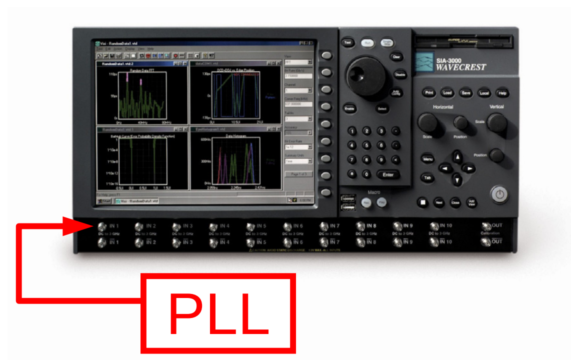


Fig. 1 SIA-3000 with signal source.

Acquiring Data

The following steps describe the data acquisition process in VISI:

1. Open the Advanced PLL tool.
2. Connect the signal to a measurement channel (Fig. 1). Set the measurement channel in VISI by going to the **Acquire Option** menu and choosing **Channel**.
3. Confirm that a valid signal exists at the measurement channel by using **Pulsefind**
4. For this example, the **Rec Length (µs)** is 50 and the **Meas Incr (Periods)** is 10. All other parameters are left as default
5. Begin acquisition by pressing **Single/Stop** button on the front panel .
6. When acquisition is complete, the **Single/Stop** button will cease to illuminate.

Viewing Data in Time Domain (1-Sigma)

The initial default view is the time series shown in Fig. 2. The time domain data can be viewed by selecting **1-Sigma** under the **View** menu.

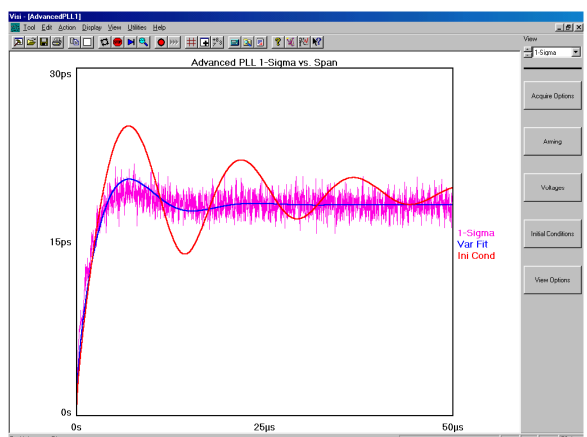


Fig. 2 1-Sigma vs. UI span plot.

The x-axis shows the span of the jitter accumulation. The y-axis shows the rms standard deviation of the accumulated jitter as a function of span. The magenta line is the acquired data. The red line is the behavior based on initial conditions. The blue line is the converged fit. If the converged fit does not agree with the data, the initial conditions may be manually modified to better match the data. This is performed under the Initial Conditions menu.

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Viewing the 2nd-order PLL Transfer Function

To view the 2nd-order PLL transfer function, select **PLL Transfer** under the **View** menu. The domain of the transfer function is frequency normalized to the natural frequency ω_n. The y-axis is magnitude in dB.

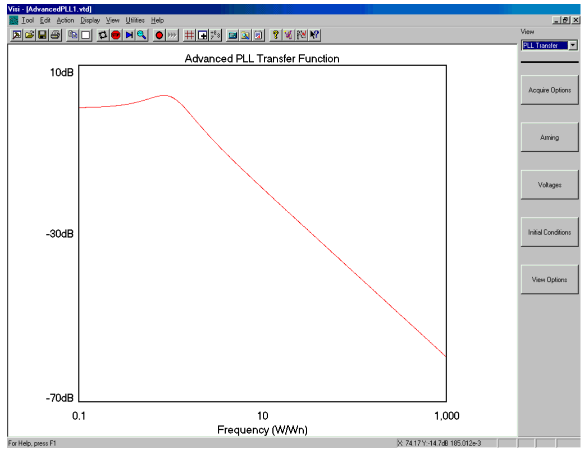

Fig. 3 2nd-order PLL transfer function.

Viewing the Bode Plot

To view the 2nd-order PLL Bode Plot, select **Bode Plot** under the **View** menu. The domain of the Bode plot is frequency normalized to the natural frequency ω_n. The upper plot is amplitude in dB and the lower plot is phase in degrees.

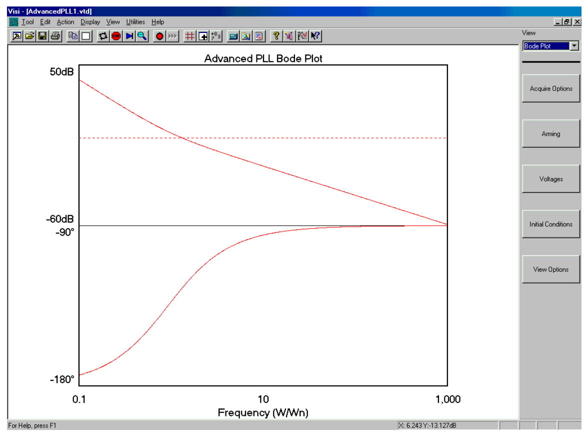

Figure 4. 2nd-order PLL Bode plot.

Viewing the Poles and Zero Plot

To view the 2nd-order PLL poles and zero, select **Poles & Zero** under the **View** menu. The axes of the plot are complex frequencies normalized to the natural frequency ω_n.

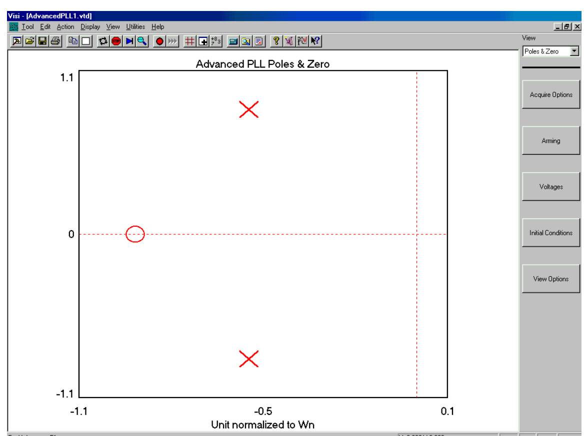

Fig. 5 2nd-order PLL poles and zero.

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Viewing the Data Summary

To view the 2nd-order PLL data summary, select **Summary** under the **View menu**. Information included in this view include:

- Statistics of the 1-Sigma measurements such as mean, minimum, maximum, and peak-to-peak.
- The value of the carrier frequency
- PLL characteristic parameters
- Goodness of fit (Chi-Squared)

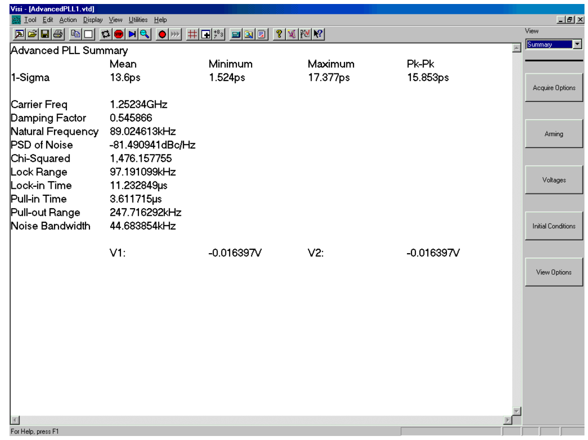

Figure 6. Data summary and PLL characteristics.

The PLL characteristics provided in the summary window are the following [iv]:

- Damping factor – ζ as defined in Eq. 1.
- Natural frequency – ω_n as defined in Eq. 1.
- PSD of noise – level of white input noise.
- Lock range – frequency range in which a PLL can lock within one beat note between the ω_{Ref} and ω_{Out}.
- Lock-in time – time scale for PLL to lock into from the lock range.
- Pull-in time – time scale for the PLL to lock from the pull-in range, which is the range within which the PLL will always lock.
- Pull-out range – the dynamic limit for stable operation of a PLL.
- Noise bandwidth – PLL output phase noise integrated over the bandwidth of the PLL.

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Understanding Results and Troubleshooting

It is important to also know when results are bad and cannot be fitted. There are conditions under which the PLL curve-fitting algorithm will not be able to fit the 1-sigma values. The following examples highlight some of these results along with good results that may have problems fitting for other reasons. **Also note that if problems show up on the output of the PLL it is often because the Reference Clock is bad. If you are able to analyze the output of the Reference clock, verify that it is good before assuming the PLL is bad.**

Figures 7a and 7b show typical PLL curves with some amount of Periodic jitter present. Periodic Jitter (PJ) is apparent by the "ripple" on the 1-sigma results. PJ will cause the algorithm to either not be able to fit or if it does fit, the results may be questionable. PJ can be analyzed and identified using the High Frequency Modulation tool.

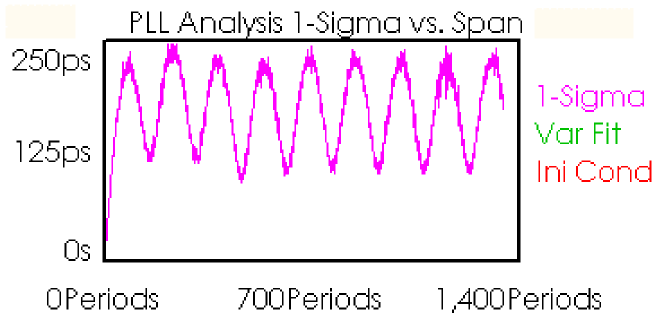

Figure 7a. Periodic Jitter (PJ) present

If you get these results, you may have some sort of interference present. Using the High Frequency Modulation tool, you can identify the magnitude and frequencies of these periodic components.

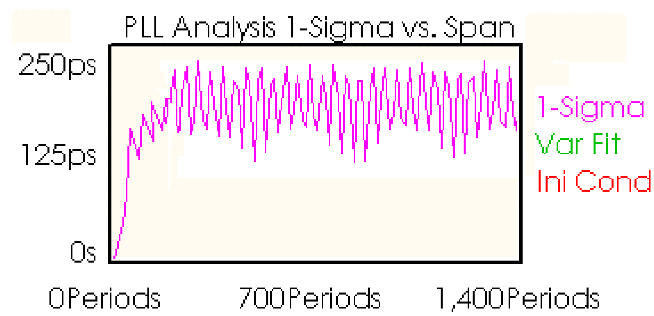

Figure 7b. PJ present

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Figure 8 shows the 1-sigma values constantly rising. This can be indicative of two things. Either the Span needs to be increased because we are only seeing a small portion of the rise and level off or the plot does not level off. If the span is increased and the plot does not level off, this could mean that the PLL reference clock has long term accumulation of jitter (or the PLL itself passes this accumulation of jitter). Note that certain signal generators exhibit this performance and if used as a reference clock may be the source of the problem. Check the output of the Ref Clock before changing any PLL designs! Typically, the Ref Clock should have a flat response on this plot.

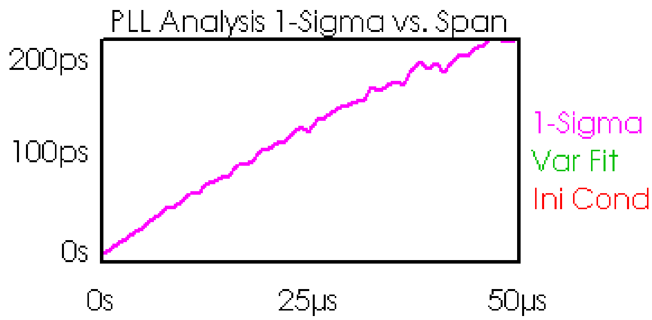

Figure 8. Constantly rising 1-sigma values

Figure 9 shows the typical response of an under-damped PLL. The highest damped line (red) is the Initial conditions line. "Initial conditions" is the function that the curve fitting algorithm uses as the starting values. The 1-sigma values ("noisy" flat line in purple) are the actual acquired values. The smooth line over-layed (green) on the 1-sigma values is the resulting variance curve fit. This is the result of the algorithm.

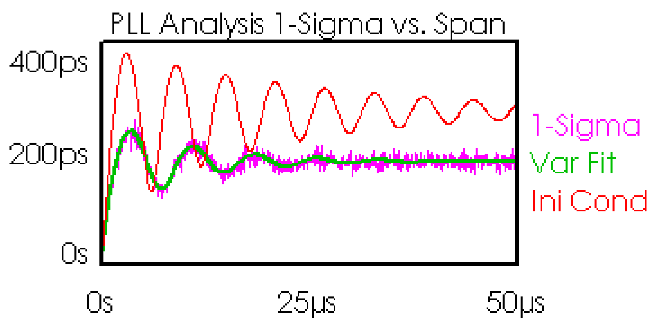

Figure 9. Shows the typical response from an under-damped PLL. The results are good because the Variance Fit line closely follows the trend of the 1-sigma values.

These results are good. The fit matches the 1-sigma values, and there is no PJ present. The "ringing" at the left of the 1-sigma values is due to the characteristics of the PLL and is not considered PJ because the values level off—or dampens to a level value.

Figure 10 shows an example of another PLL. Note that the Initial Conditions (red) line may be very different from the final result Variance Fit line.

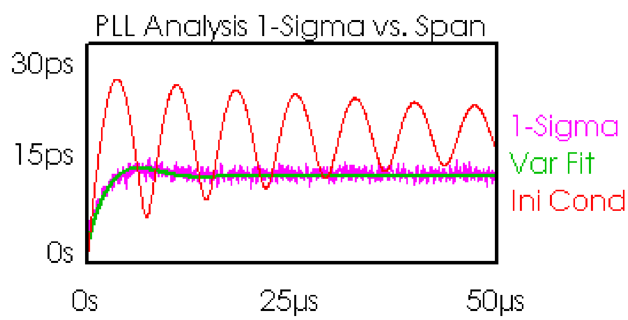

Figure 10. Shows the typical response of another PLL. The results are good because the Variance Fit line closely follows the trend of the 1-sigma values.

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Figure 11 shows a typical "best case PLL. There is a slight rise then level off. In this case, the Initial conditions just happened to be very close to the final result. Remember that it is not necessary for the Initial Conditions (red) to match the 1-sigma values, just that the Variance Fit (green) line matches. The Variance Fit line should model the 1-sigma values plot line.

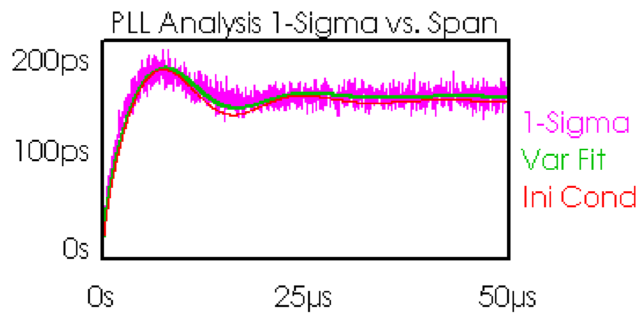

Figure 11. Shows a typical "best case" PLL. The results are good because the Variance Fit line closely follows the trend of the 1-sigma values.

Summary of the Advanced PLL Tool

The Advanced PLL tool allows users to study characteristics and parameters of a 2nd-order PLL. With a simple set of variance measurements, the tool can extract information such as damping factor, natural frequency, input noise level, lock range, lock-in time, pull-in time, pull-out range, and noise bandwidth. The tool also presents a transfer function and Bode plots up to the natural frequency, as well as a plot of the poles and zero for a 2nd-order PLL.

References

[i] Li, M., *A New Method for Simultaneously Measuring and Analyzing PLL Transfer Function and Noise Processes*, DesignCon Proceedings, 2002.

[ii] For more information, refer to "High Frequency Modulation", VISI 7 Quick Reference Guide, *WAVECREST* Corporation

[iii] Wilstrup, J., *A Method of Serial Data Jitter Analysis Using One-shot Time Interval Measurements*, ITC Proceedings, p.819, 1998.

[iv] Best, R., *Phase-Locked Loops*, 4th ed., McGraw-Hill, New York (1999).

FOR MORE INFORMATION CONTACT:

WAVECREST CORPORATION
7626 GOLDEN TRIANGLE DR.
EDEN PRAIRIE, MN 55344
WWW.WAVECREST.COM
1 (952) 646-0111

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