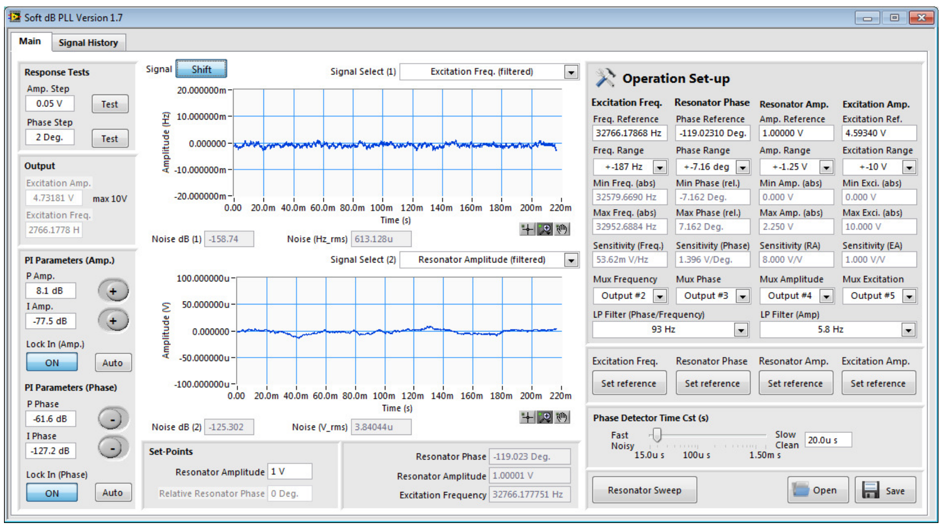
SPM PLL

User's Manual

Version 1.8



by

Soft dB

In association with

Convergence Instruments

January 2012

1040, avenue Belvédère, suite 215
Québec (Québec) G1S 3G3 Canada
Tél.: (418) 686-0993 Fax: (418) 686-2043

1 SPECIFICATIONS 4

1.1 Power Supply 4

1.2 USB 4

1.3 Analog Inputs 4

1.4 Analog Outputs 5

1.5 PLL Performance 6

2 THEORY OF OPERATION 7

3 SOFTWARE AND HARDWARE INSTALLATION 8

4 PLL USER INTERFACE 9

4.1 Phase Detector Time Cte (s) 9

4.2 Resonator Sweep 9

4.3 Operation Set-up Controls 11

4.4 Excitation Parameters 11

4.5 Set-Points 12

4.6 PI Controls and Switches 12

4.7 Loop-Response-Test Controls 13

4.8 Phase, Output Amplitude and Excitation Frequency Indicators 14

4.9 Time Signal Graph and Signal Selection 15

4.10 Signal History 16

4.11 Save and Recall Configuration Files 18

1 Specifications

The GXSM software for the SPM controller (model Mk3) includes a PLL module. However, the SPM controller (model Mk3) can be used as a stand alone PLL when using the PC software described in this document. The next figures present the front and the back of the SPM controller (model Mk3):

1.1 Power Supply

The PLL works with an external 5V (+-5%) power pack.

1.2 USB

The PLL is controlled by a Windows PC through a USB connection. The high-speed USB 2.0 PC link provides a throughput in excess of 35 Mb/s in the read and write directions.

1.3 Analog Inputs

Number of Inputs:	1
Resolution:	16 bits
Raw Noise Figure:	300 µV RMS
Sampling Rate:	150 kHz
Analog Input Bandwidth:	0 to 10 MHz (includes DC)
Input Type:	Single Ended
Input Leakage:	+-1 µA max
Anti-Aliasing Filter:	None
Dynamic Range:	+-10V
Group-Delay:	2 samples

1.4 Analog Outputs

Number of Outputs:	5
Resolution:	16 bits
Noise:	
• 20MHz bandwidth:	Up to 55 mV pk-pk on $FFFF_H$- 0000_H alternating code sequence.
• 20 kHz bandwidth:	<25 µV RMS
Offset Drift with Temperature:	+-2 ppm FSR / degC
Gain Drift with Temperature:	+-2 ppm FSR / degC
Offset Drift with Time:	+-13 ppm FSR / 500 hours
Sampling Rate:	150 kHz
Analog Output Bandwidth:	0 to 80 kHz (includes DC)
Output Type:	Single Ended
Dynamic Range:	+-10 V
Source/Sink ability:	4mA
Anti-Aliasing Filter:	None
Group-Delay:	
• Output #1 and #2:	2.5 samples
• Output #3 and #4:	2.75 samples
• Output #5	3 samples

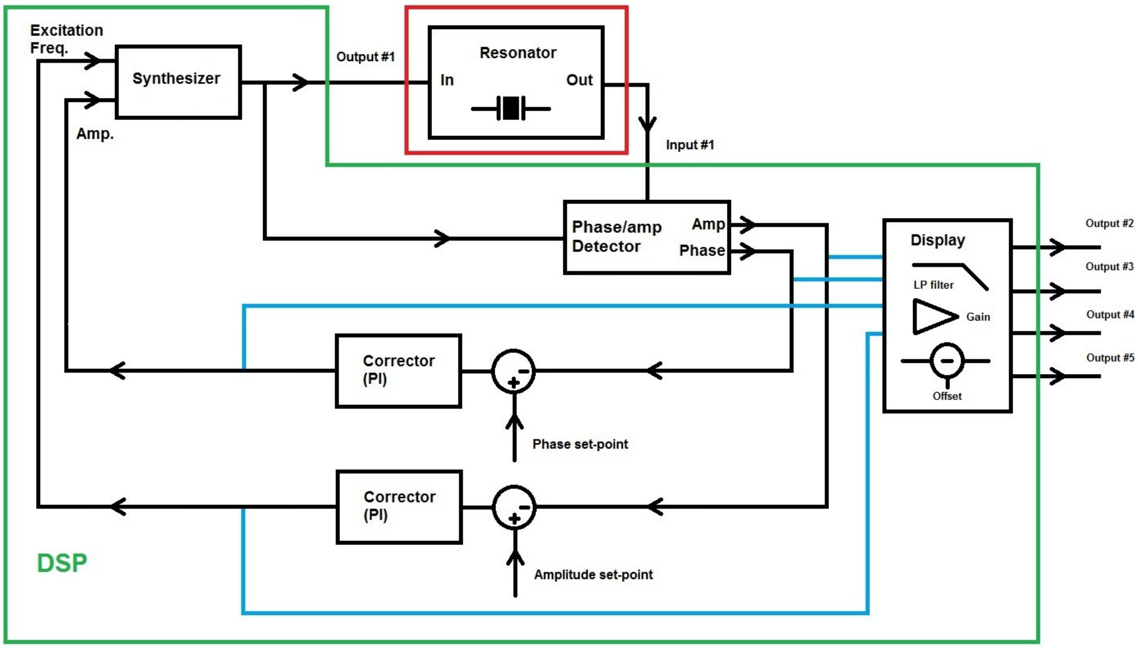
1.5 PLL Performance

<table>
<tr><th colspan="4">PLL Module Specifications</th></tr>
<tr><td>Input Range</td><td colspan="3">+-10V</td></tr>
<tr><td>Output Range</td><td colspan="3">+-10V (external 1/100 and 1/1000 attenuators provided)</td></tr>
<tr><td>Frequency Range</td><td colspan="3">3.2 kHz to 75 kHz</td></tr>
<tr><td>Resonator Test Board</td><td colspan="3">An active resonator board is included with the SPM controller for easy testing and setup of the PLL module</td></tr>
<tr><td>PLL Output Signal Ranges (Stand-Alone Operation)</td><td colspan="3">Excitation Frequency: +-2.85 mHz to +-23.9 kHz
Excitation Amplitude: +-1.19 µV to +-10 V
Resonator Phase: +-6.83 µDeg to +-57.3 Deg
Resonator Amplitude: +-1.19 µV to +-10 V</td></tr>
<tr><td rowspan="7">PLL Signal Noise Levels*</td><td></td><td>Phase Controller Bandwidth: 1kHz</td><td>Phase Controller Bandwidth: 5Hz</td></tr>
<tr><td>Excitation Frequency</td><td>60mHz RMS</td><td>20µHz RMS</td></tr>
<tr><td>Resonator Phase</td><td>4mDeg RMS</td><td>200µDeg RMS</td></tr>
<tr><td></td><td>Amplitude Controller Bandwidth: 7.5Hz</td><td>Amplitude Controller Bandwidth: 1.5Hz</td></tr>
<tr><td>Excitation Amplitude</td><td>400µV RMS</td><td>50µV RMS</td></tr>
<tr><td>Resonator Amplitude</td><td>5µV RMS</td><td>2µV RMS</td></tr>
<tr></tr>
<tr><td>Phase/Amplitude (PAC) Detector Bandwidth</td><td colspan="3">100Hz to 10kHz. The bandwidth is automatically adjusted when the loop auto-set function is used</td></tr>
<tr><td>Software Features</td><td colspan="3">1) Resonator frequency sweep for automatic measurement of resonator frequency characteristics
2) Loop-gain auto-set for amplitude and phase controllers. Gains are set according to desired closed-loop bandwidth
3) In-circuit closed-loop step response measurement function validates the setup of both controllers
4) Adjustable low-pass filter on PLL signals: Excitation amplitude/frequency and Resonator phase/amplitude. These filters can be adjusted from 1.5 Hz to 16 kHz or bypassed
5) Real time monitoring of all PLL signals.
6) Long term monitoring of PLL signals to assess the low frequency stability and noise</td></tr>
<tr><td>Temperature Coefficient</td><td colspan="3">TCXO Stability: 140 ppb over a temperature range from -20 °C to 70°C
TCXO Precision: 2 ppm</td></tr>
</table>

* *Note: Noise levels are measured using the resonator board included with the SPM controller (gain –13 dB at the resonance) and the auto-set of loop gains for both controllers. The new PLL technique ensures that the noise levels are independent of measurement ranges.*

2 Theory of Operation

The diagram of PLL running on the Signal Ranger Mk3 DSP board is illustrated in the following figure:



PLL schematic

The synthesizer sends a sine wave on output #1. Input #1 measures the output of the resonator. The phase detector measures the amplitude and the phase of the resonator output signal, with respect to its excitation. The phase detector algorithm measures the phase of the resonator alone, automatically correcting for the phase of board's digital and analog chains. So, no special calibration is necessary before using the PLL. When working with a second-order resonator, specifying a phase of -90 degrees will lock the PLL at precisely the resonance frequency.

The amplitude and phase control loops keep the resonator phase and output amplitude at specific set-points.

The PLL can generate up to four analog signals on outputs #2, #3, #4 and #5. The possible selections for these signals are:

The resonator phase
The resonator amplitude
The excitation amplitude
The excitation frequency

For each signal, the gain (or the range) can be specified to obtain the desired output sensitivity. Also, an adjustable low pass filter is added to increase the resolution of the output signals if necessary. An offset (reference) can be added so the analog output signal is centered on a user-selectable value.

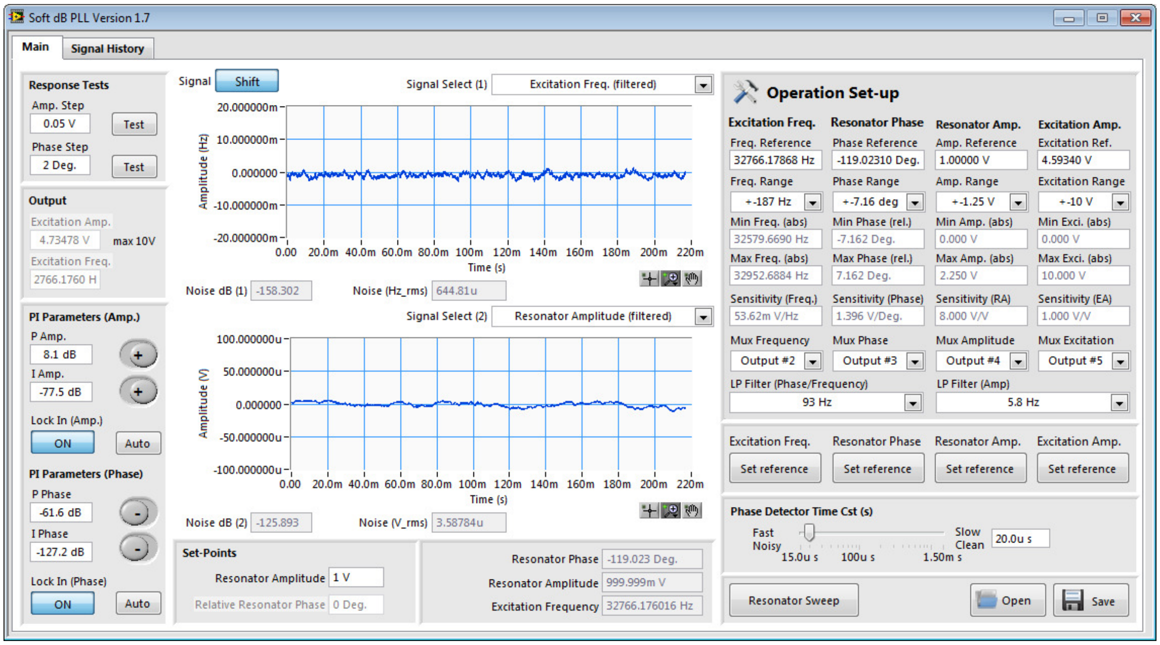
The PLL is controlled and adjusted using a graphical user-interface running on a Windows PC.

3 Software and Hardware Installation

Note: The software must be installed before connecting the PLL unit to a PC. The software installs the USB driver automatically. Windows XP, Windows Vista and Windows 7 are supported on a 32-bit or 64-bit PC.

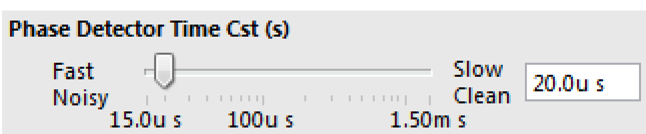
To install the software, launch the SoftdB_SPM_PLL_1_8.exe

4 PLL User Interface



PLL interface: Main Tab

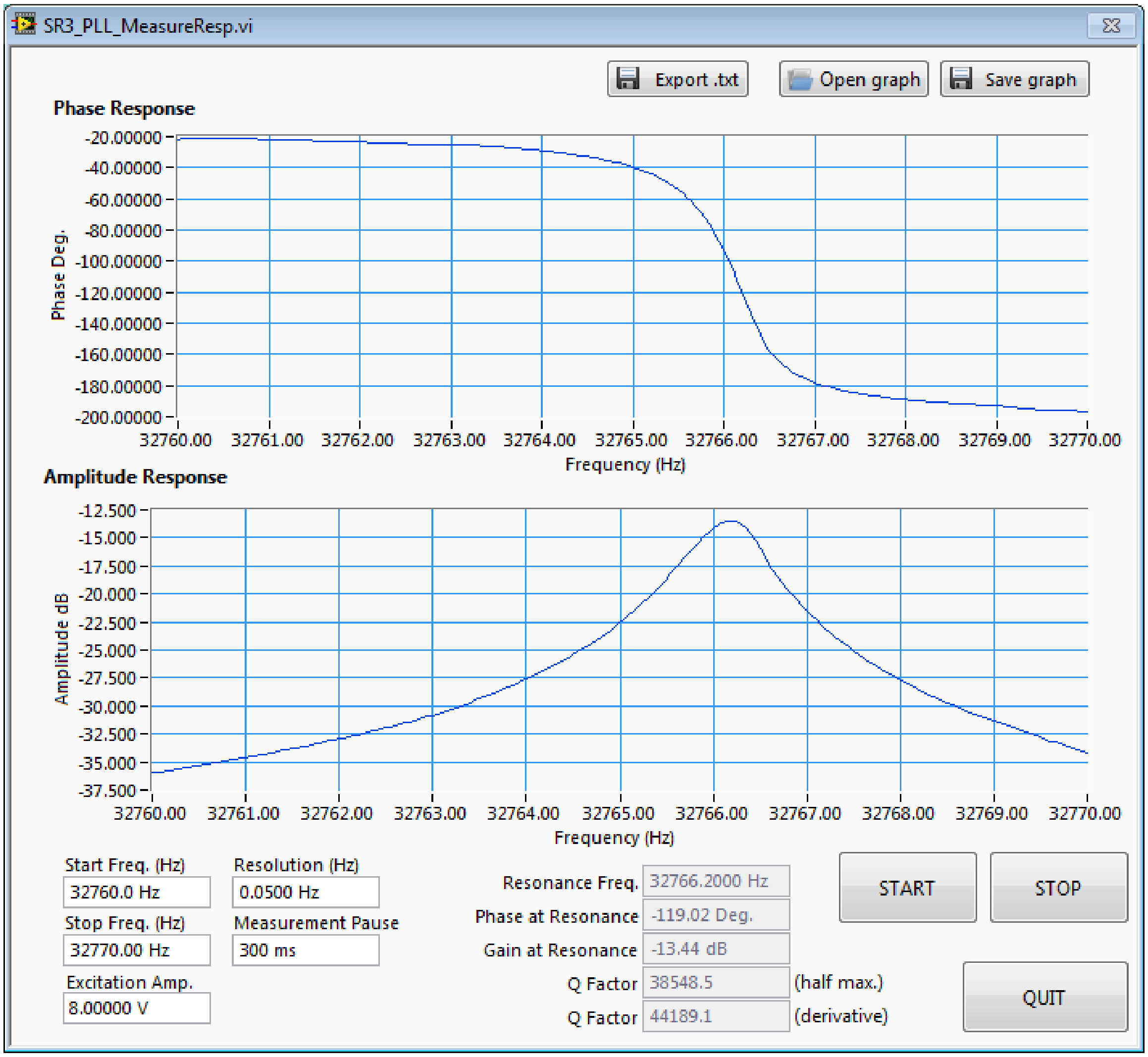
4.1 Phase Detector Time Cst (s)



This control adjusts the time constant of the phase detector. We suggest keeping time constant to 20us (fast set-up), which allows a bandwidth of about 8 kHz. Note that the auto-adjustment functions for the PI gains of both controllers (amplitude and phase) automatically set the time constant to 20us. This way, the bandwidth of the controller is only limited by the PI gains and the LP filter.

4.2 Resonator Sweep

The *Resonator Sweep* button performs a frequency scan of the resonator. A sweep over a limited frequency range is used to measure the frequency response. The following figure presents the measurement interface:



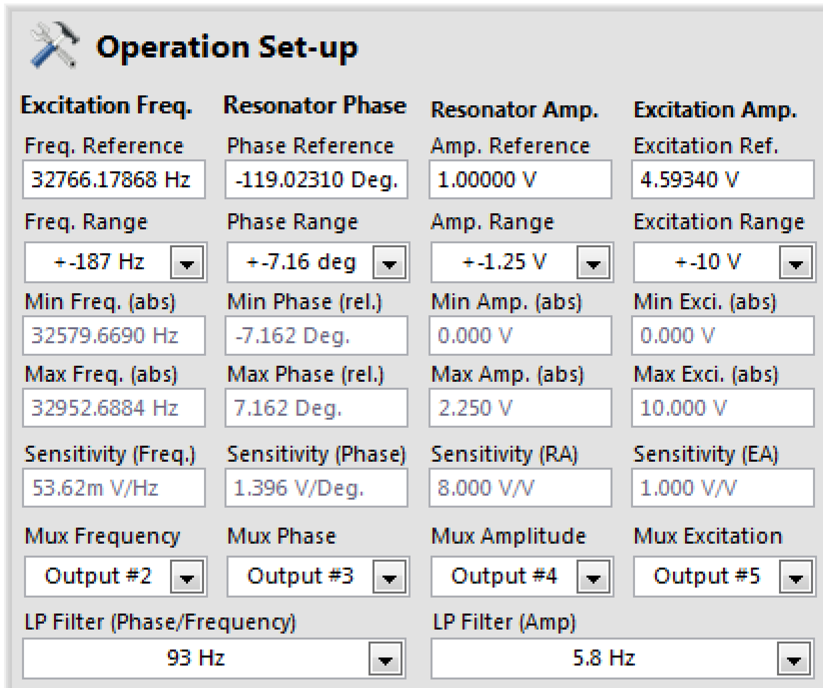
Resonator Sweep Interface

The resonator sweep interface automatically sets the time constant of the phase detector at 1ms to obtain a precise measurement of both the phase and amplitude. The original time constant for the phase detector is replaced after the sweep measurement.

Before starting the measurement, the start and stop frequencies must be adjusted along with the frequency resolution and the excitation amplitude. The *Measurement Pause* control specifies the waiting period between a change in excitation frequency and the corresponding measurement. When the resonator Q factor is large, the stabilization time after the excitation change can be long. For instance, for a Q factor of 25k and a resolution of 0.05Hz, a stabilization time of 300ms is necessary. At the end of the measurement, the resonance frequency, the gain at the resonance, the phase at the resonance frequency and the Q factor are computed and presented by the interface. Two methods are used to compute the Q factor: 1) phase derivative at the maximum gain and 2) half maximum method. Use the *Quit* button to quit the measurement interface. The interface will ask for an update of the frequency reference and the phase reference. If the user clicks yes, the phase and the frequency references will be updated with the new phase at the resonance and the new resonance frequency.

Note: The Q factor and the gain at the resonance are important information for the auto-adjustment function of the amplitude controller.

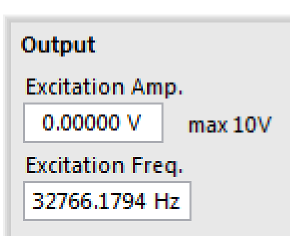
4.3 Operation Set-up Controls



PLL interface: Operation Set-up Controls

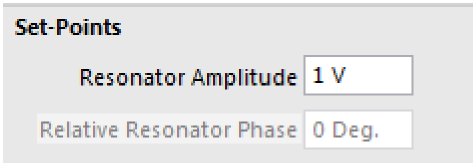
These controls allow the set-up of the reference values and the configuration of the analog output signals. Up to four analog signals can be generated by the PLL. For each signal, the reference, the range and the output number can be adjusted. A low pass filter is applied on the output signals and the frequency cut-off can be adjusted from a menu. There are two LP filters: one for the phase and excitation frequency signals and another one for the resonator and excitation amplitude signals. For each output signal, the reference can be automatically set to the current value with the button *Set reference*. The minimum and maximum values in unit are presented for each output. The minimum and the maximum depend on the selected range and the reference value. The sensitivity of the output is also displayed and can be modified by adjusting the range.

4.4 Excitation Parameters



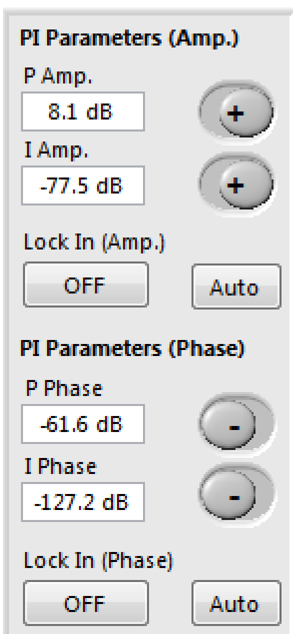
Output #1 of the PLL generates a high-purity sine wave. The frequency and the amplitude can be adjusted with these controls. If the phase controller is engaged, the frequency is not adjustable and the *Excitation Freq. (Hz)* control becomes an indicator. If the amplitude controller is engaged, the excitation amplitude is not adjustable and the *Excitation Amp. (V)* control becomes an indicator.

4.5 Set-Points



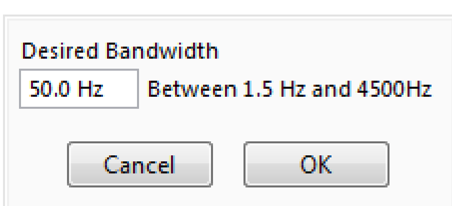
These controls adjust the set points for the phase and the resonator amplitude. Note that the phase set point is always the reference phase. So, the set-point adjustment for the phase is done through the phase reference control (see the Operation Set-up controls). This way, the phase controller always works centered around zero.

4.6 PI Controls and Switches



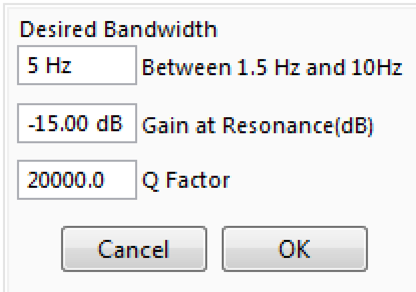
The sign and the gain of the Proportional and Integral factors can be adjusted with these controls for both controllers. The OFF/ON buttons engage or deactivate each controller.

The Auto buttons can be used to determine the PI gains and LP filter set-up for both controllers. For the phase controller, the following dialog box allows specifying the desired bandwidth:



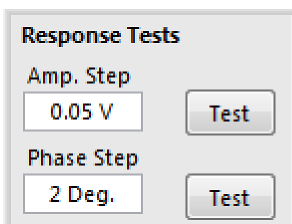
Select the desired bandwidth and click ok. Then, the interface will automatically set the LP filter (for the phase/frequency), the PI gains and the time constant of the phase/amplitude detector to reach the desired bandwidth.

For the amplitude controller, the following dialog box allows specifying the desired bandwidth:

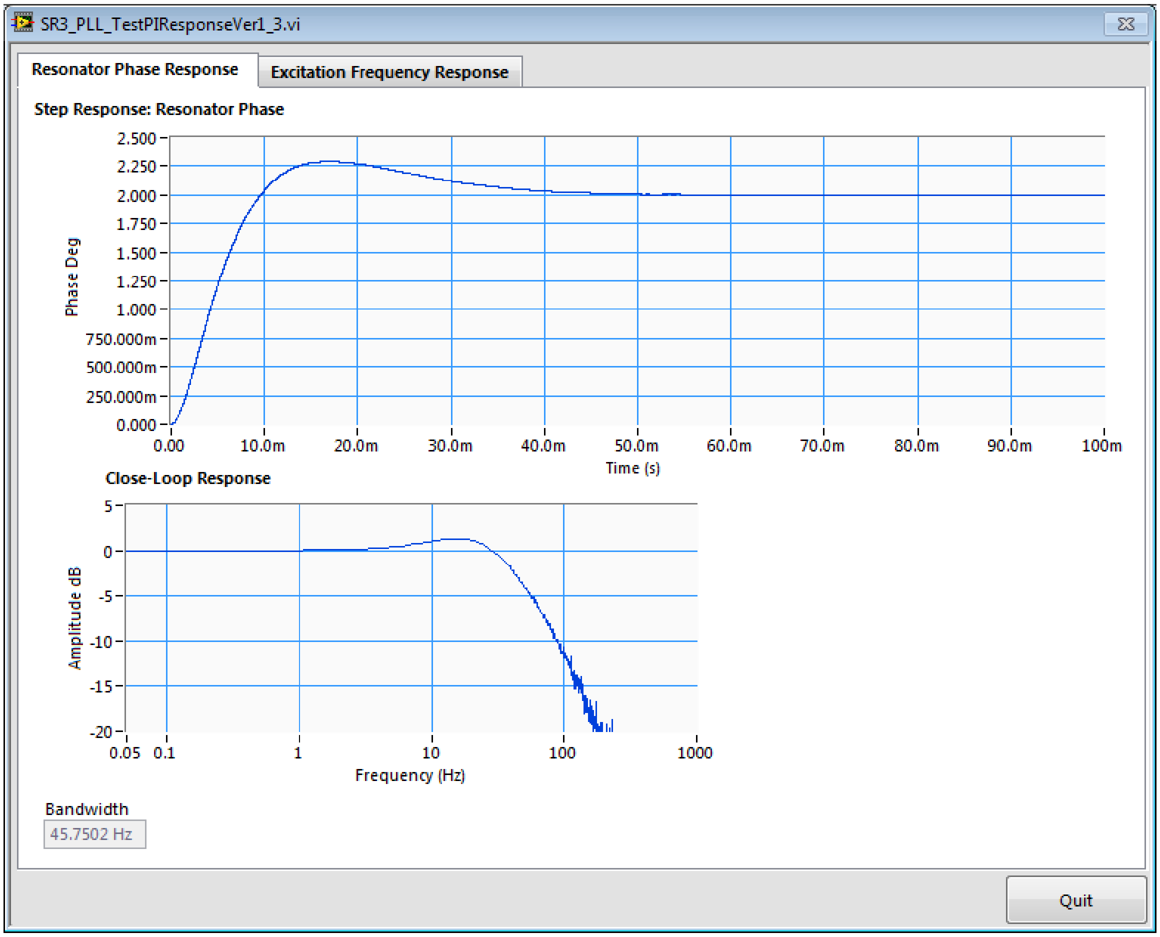


To be able to determine the proper PI gains, the auto-adjustment function must know the gain at the resonance and the Q factor of the resonator. These values can be measured with the Resonator Sweep function. The interface will automatically set the LP filter (for the amplitude signals), the PI gains and the time constant of the phase/amplitude detector to reach the desired bandwidth.

4.7 Loop-Response-Test Controls



Theses controls allow the testing of the loop response of both controllers. These controls can be used only if the corresponding controller is engaged. The test function measures the step response of the controller. An adjustable step is applied on the set-point and the resonator phase or output amplitude is recorded during the test. The *Amp. step* and *Phase step* are used to define the amplitude of the step. For instance, if the *Phase step* control is set to +3, the controller set-point will be stepped up by +3 deg for the test. The set-point step is returned to zero after the test. The *Test* button launches the following interface (phase controller case):

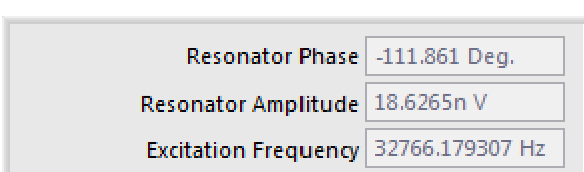


Phase controller test interface (Resonator Phase Tab)

In the first tab (Resonator Phase Tab), the top curve presents the step response and the bottom curve is the closed-loop frequency response of the derivative of the step response (i.e. the spectrum of the closed-loop impulse response). This curve allows the evaluation of the controller bandwidth.

The second tab presents the excitation frequency response. This is the output of the phase controller. If saturations appear on this curve it means that the output of the controller reaches the maximum or the minimum of the operation range. If required, the operation range can be increased to avoid this non-linear behaviour, or a smaller step excitation can be used to insure a linear behaviour.

4.8 Phase, Output Amplitude and Excitation Frequency Indicators

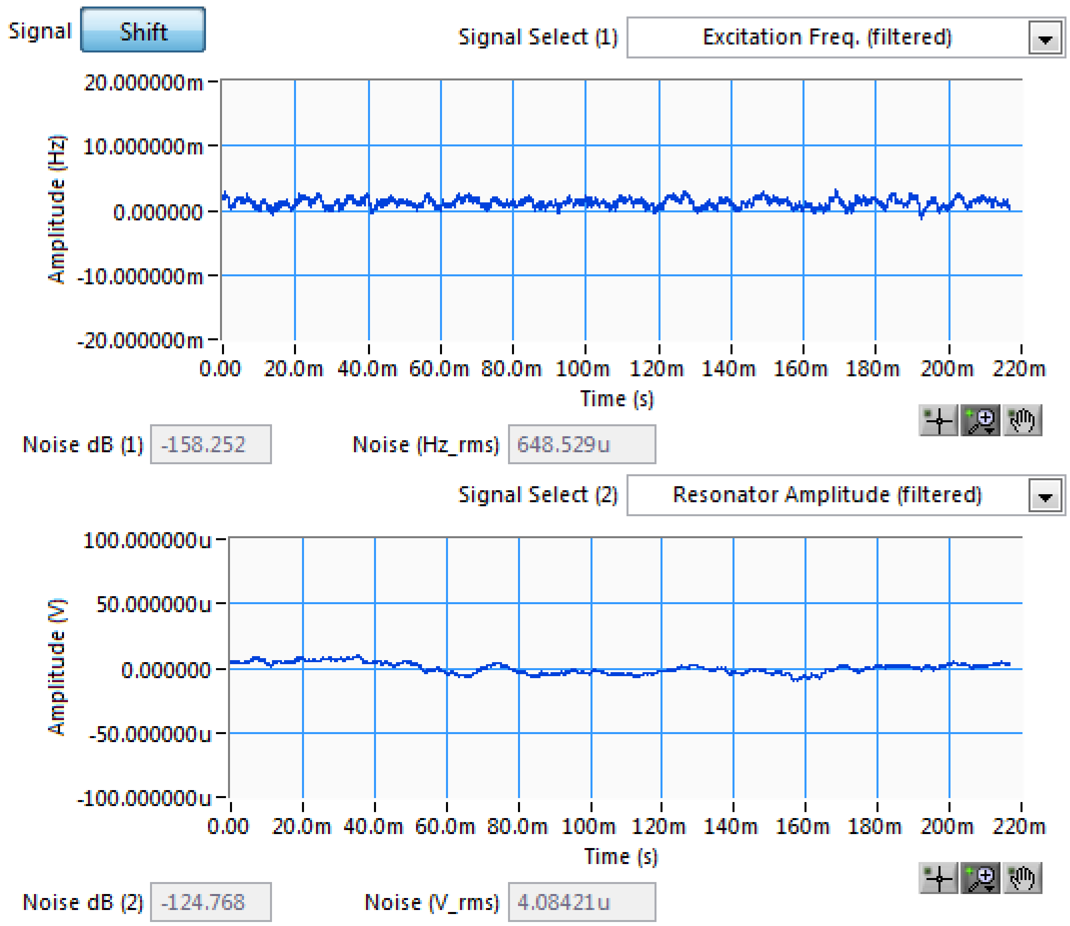


These indicators present:

The resonator phase
The resonator amplitude
The excitation frequency

A first order low pass filter is applied. The filter that can be adjusted with the *LP filter applied on Freq./Phase/Amp* control (see *Operation Set-up* controls).

4.9 Time Signal Graph and Signal Selection



These graphs present various signals of interest in real-time. The selection of the signals is done through the *Signal Select* menu. The following table presents the possible choices:

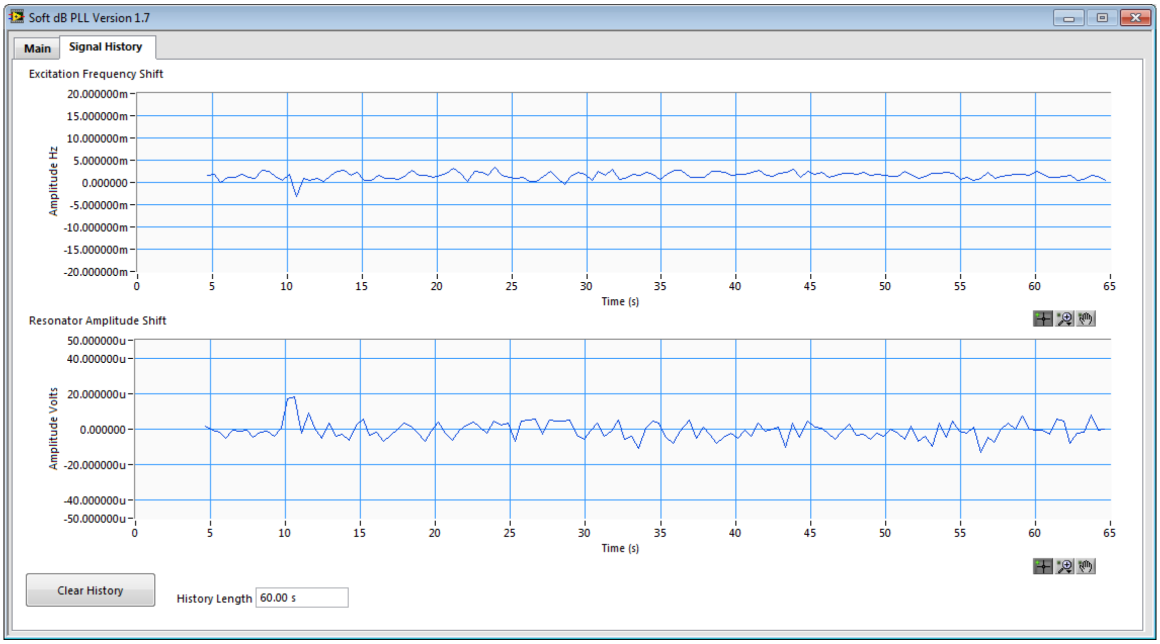
Resonator Output
Excitation
Resonator Phase (raw)
Excitation Freq. (raw)
Resonator Amp. (raw)
Excitation Amp. (raw)
Excitation Freq. (filtered)
Resonator Phase (filtered)
Resonator Amplitude (filtered)
Excitation Amplitude (filtered)
Output #2: Excitation Freq.
Output #3: Resonator Phase
Output #4: Resonator Amp.
Output #5: Excitation Amp.

Signal	Description
Resonator Output	Resonator output time signal in V. This is the signal measured by the DSP board on input #1.
Excitation	Excitation time signal in V. This is the signal generated by the DSP board on output #1.
Resonator Phase (raw)	Resonator phase in degrees, as measured by the phase detector. The phase detector algorithm measures the phase of the resonator alone, automatically correcting for the phase of board's digital and analog chains. This is the raw signal and no low pass filter is applied.
Excitation Freq. (raw)	This value (in Hz) is fixed if the phase controller is OFF. If the phase controller is engaged, this signal is the output of the phase corrector. This is the raw signal and no low pass filter is used.
Resonator Output Amp. (raw)	Resonator output signal amplitude, as measured by the phase detector (in V). This is the raw signal and no low pass filter is applied.
Excitation Amp. (raw)	Excitation amplitude in V. This signal is constant at the specified value if the amplitude controller is OFF. If the amplitude controller is engaged, this signal is the output of the amplitude corrector. This is the raw signal and no low pass filter is applied.
Excitation Freq. (filtered)	Filtered excitation frequency (in Hz). This signal is constant at the specified value if the phase controller is OFF. If the phase controller is engaged, this signal is the filtered output of the loop controller. The display low pass filter is applied to lower the noise. For this signal the *Signal* control can be used to present the absolute value or the shift value. The reference value in the Operation Set-up tab is used to compute the shift value.
Resonator Phase (filtered)	Filtered resonator phase (in degrees), as measured by the phase detector. The phase detector algorithm measures the phase of the resonator alone, automatically correcting for the

	phase of board's digital and analog chains. For this signal the *Signal* control can be used to present the absolute value or the shift value. The reference value in the Operation Set-up tab is used to compute the shift value.
Resonator Amplitude (filtered)	Filtered resonator output amplitude (in V). The low pass filter is applied to lower the noise on this signal. For this signal the *Signal* control can be used to present the absolute value or the shift value. The reference value in the Operation Set-up tab is used to compute the shift value.
Excitation Amplitude (filtered)	Filtered excitation amplitude (in V). The low pass filter is applied to lower the noise on this signal. For this signal the *Signal* control can be used to present the absolute value or the shift value. The reference value in the Operation Set-up controls is used to compute the shift value.
Output #2, #3, #4 and #5	These selections represent the 16-bit signal generated by the DSP on outputs #2, #3, #4 and #5. The output signals are selected with the *Mux menu* of the *Operation Set-up* controls. The user can select between the excitation frequency, the resonator phase, the resonator amplitude and the excitation amplitude. An adjustable reference value is subtracted from these signals to present the shift value. The sensitivity of the output signal can be adjusted with a range control. Also, an adjustable low pass filter is used to lower the noise on all signals.

4.10 Signal History

The signal history for both the excitation frequency shift and the resonator shift are presented on the Signal History tab. The history length is adjustable and the user can clear the history graphs with the Clear History control. These graphs are useful to analyze the long-term stability of the PLL and to estimate the noise.



Amplitude controller test interface (Resonator Amplitude Tab)

4.11 Save and Recall Configuration Files

These buttons save and recall a configuration. All PLL parameters are saved in the configuration file. When a configuration is recalled, both controllers are automatically stopped.

GPIO Connectors

The GPIOs are located on two dB-25 connectors at the back of the instrument:

Left Connector

13	12	11	10	9	8	7	6	5	4	3	2	1
Gnd	Gnd	Gnd	QEP0_B	QEP0_A	GPIO_0(7)	GPIO_0(6)	GPIO_0(5)	GPIO_0(4)	GPIO_0(3)	GPIO_0(2)	GPIO_0(1)	GPIO_0(0)
	25	24	23	22	21	20	19	18	17	16	15	14
	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd

Right Connector

13	12	11	10	9	8	7	6	5	4	3	2	1
Gnd	Gnd	Gnd	QEP1_B	QEP1_A	GPIO_0(15)	GPIO_0(14)	GPIO_0(13)	GPIO_0(12)	GPIO_0(11)	GPIO_0(10)	GPIO_0(9)	GPIO_0(8)
	25	24	23	22	21	20	19	18	17	16	15	14
	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd	Gnd