AFM / SPM Components
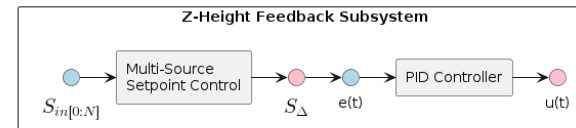
Nick Sullivan

October 4, 2023

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Laser

PSPD

R_z

Cantilever

Piezo

S_z

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Signal Generator

Lock-In Amplifier

$S_{sin}[\sim]$ $S_{cos}[\sim]$ $v_{sig}[-]$ $\varphi[-]$

Scanning Subsystem

Scan Pattern
Controller

$\langle R_x, R_y \rangle$

$\langle S_x, S_y \rangle$

Sample

Piezo

$\langle S_x, S_y \rangle$

LVDT

$\langle R_x, R_y \rangle$

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Multi-Source
Setpoint Control

PID Controller

$S_{in[0:N]}$ S_Δ e(t)   u(t)

2 Components

2.1 Main Hardware

2.1.1 Cantilever Subsystem

Diagram
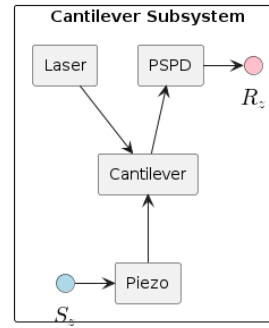
Parameters

Grouping	Parameter	Description	Units
Cantilever	`cantilever_invols`	Inverse Optical Lever Sensitivity	m/V
	`cantilever_k`	Spring Constant	
	`cantilever_f0`	Resonant Frequency	Hz
	`cantilever_q`	Q-Factor	
Tip-Surface	`tip_bias_voltage`	Tip-Surface Bias Voltage	V
	`tip_bias_amp_gain`	Bias Amplifier Gain	V
	`tip_bias_amp_offset`	Bias Amplifier Offset	V

2.1.2   Scanning Subsystem

Diagram
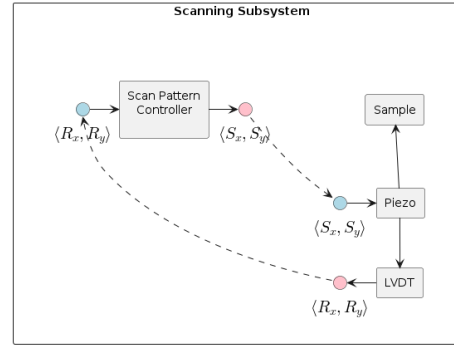
Parameters

Grouping	Parameter	Description	Units
Piezo	`piezo_sensitivity_{3d}`	Piezo Sensitivity	Ang/V
	`piezo_amp_gain_{3d}`	Piezo Amplifier Gain	V/V
	`piezo_amp_offset_{3d}`	Piezo Amplifier Offset/Bias	V
LVDT	`lvdt_sensitivity_{3d}`	LVDT Sensitivity	V/Ang
	`lvdt_offset_{3d}`	LVDT Offset/Bias	V
Scan Params	`scan_dim_{2d}`	Maximum Scan Dimensions	m
	`scan_roi_dims_{2d}`	Current Scan Dimensions	m
	`scan_roi_pos_{2d}`	Current Scan Offset (x,y)	m
	`scan_origin_pos_{2d}`	Coordinate System Origin	m
	`scan_roi_angle`	ROI Angle (if applicable)	°
	`scan_direction`	Scan Direction	N/A
	`scanning_speed`	Scanning Speed	m/s
	`moving_speed`	Moving Speed (not scanning)	m/s

2.2 Dynamic Mode Components

2.2.1 Signal Generator

Diagram
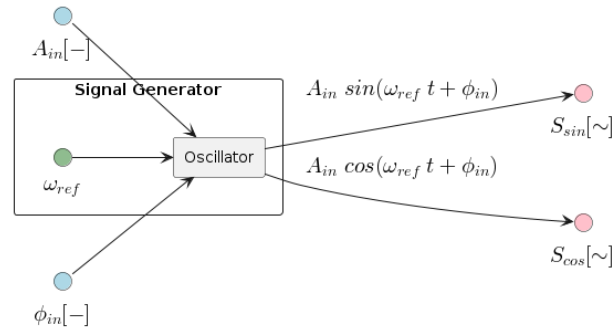
Parameters

Grouping	Parameter	Description	Units
Signal Generator	`oscillator_f_ref`	Oscillator reference frequency	Hz

2.2.2 Lock-In Amplifier

Diagram
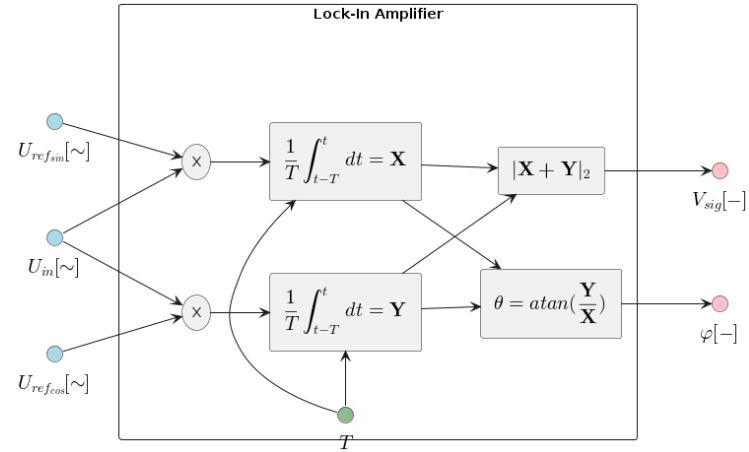
Parameters

Grouping	Parameter	Description	Units
Lock-In	`lockin_averaging_period`	Averaging Period	cycles

2.3 Feedback Subsystem

2.3.1 Multi-Source Setpoint Control

Diagram
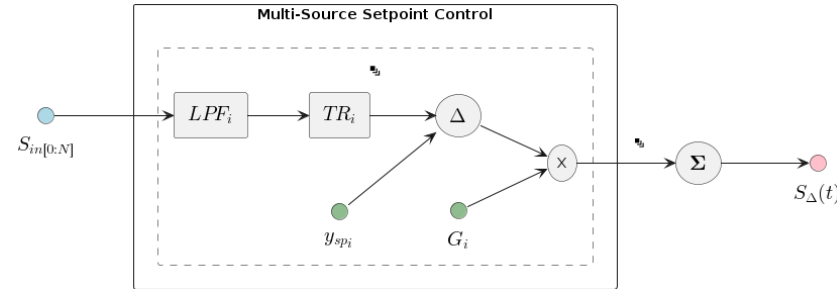
Parameters

Grouping	Parameter	Description	Units
Input	fb_input_{#}_units_to_v_factor	Units-to-V conversion (Input represents x as DC V)	x/V
	fb_input_{#}_gain	Gi: gain applied to signal i (before summing)	
	fb_input_{#}_setpoint	Reference Set-Point	V
Low-Pass Filter	fb_input_{#}_low_pass_freq	Cut-off Frequency	Hz
	fb_input_{#}_low_pass_adaptive_fmin	Min. F0 (if adaptive)	Hz
	fb_input_{#}_low_pass_adaptive_fmax	Max. F0 (if adaptive)	Hz
	fb_input_{#}_low_pass_adaptive_current	Current Crossover (if adaptive)	A
Transform	fb_input_{#}_transform_mode	Mode: 0:Off, 1:On, 2:Log, 4:IIR, 8:FUZZY	n/a
	fb_input_{#}_transform_fuzzy_threshold	Fuzzy-Mode Threshold Level (FUZZY Only)	V

2.3.2 PID Controller

Diagram
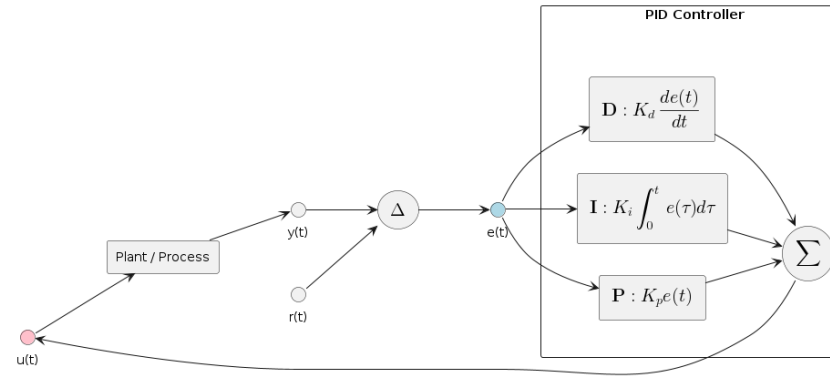
Parameters

Grouping	Parameter	Description	Units
PID	pid_gain_p	Proportional Gain	V/V
	pid_gain_i	Integral Gain	V/V
	pid_gain_d	Derivative Gain	V/V
	pid_ref_freq	Reference Frequency	Hz

3 AFM / SPM Setups

3.1 Contact Modes
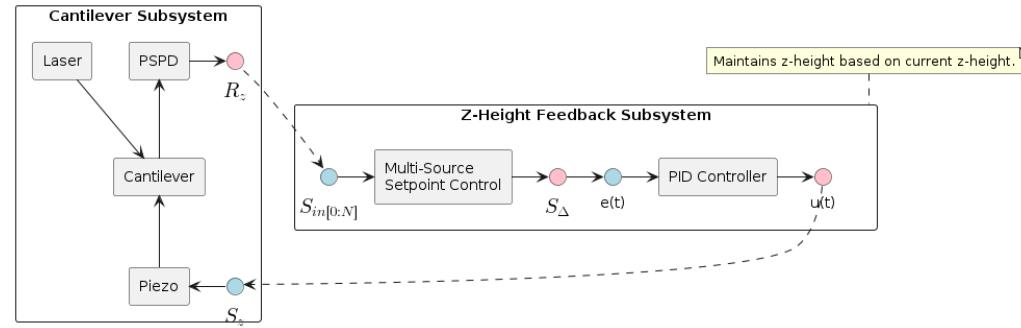
Approach:

Scan over a region with a static tip, while maintaining a constant force on the tip. This is achieved by a feedback loop, where the z-height (i.e. cantilever deflection) is kept constant. This achieves a constant-force scan.

Alternatively:

Set the z-height constant and scan with the feedback control off. This achieves a constant-height scan.

3.2 Dynamic Modes

3.2.1 AM-AFM - Amplitude Modulation

Approach:

Scan over a region with the tip oscillating its z-height at its resonant frequency, while maintaining the oscillation amplitude constant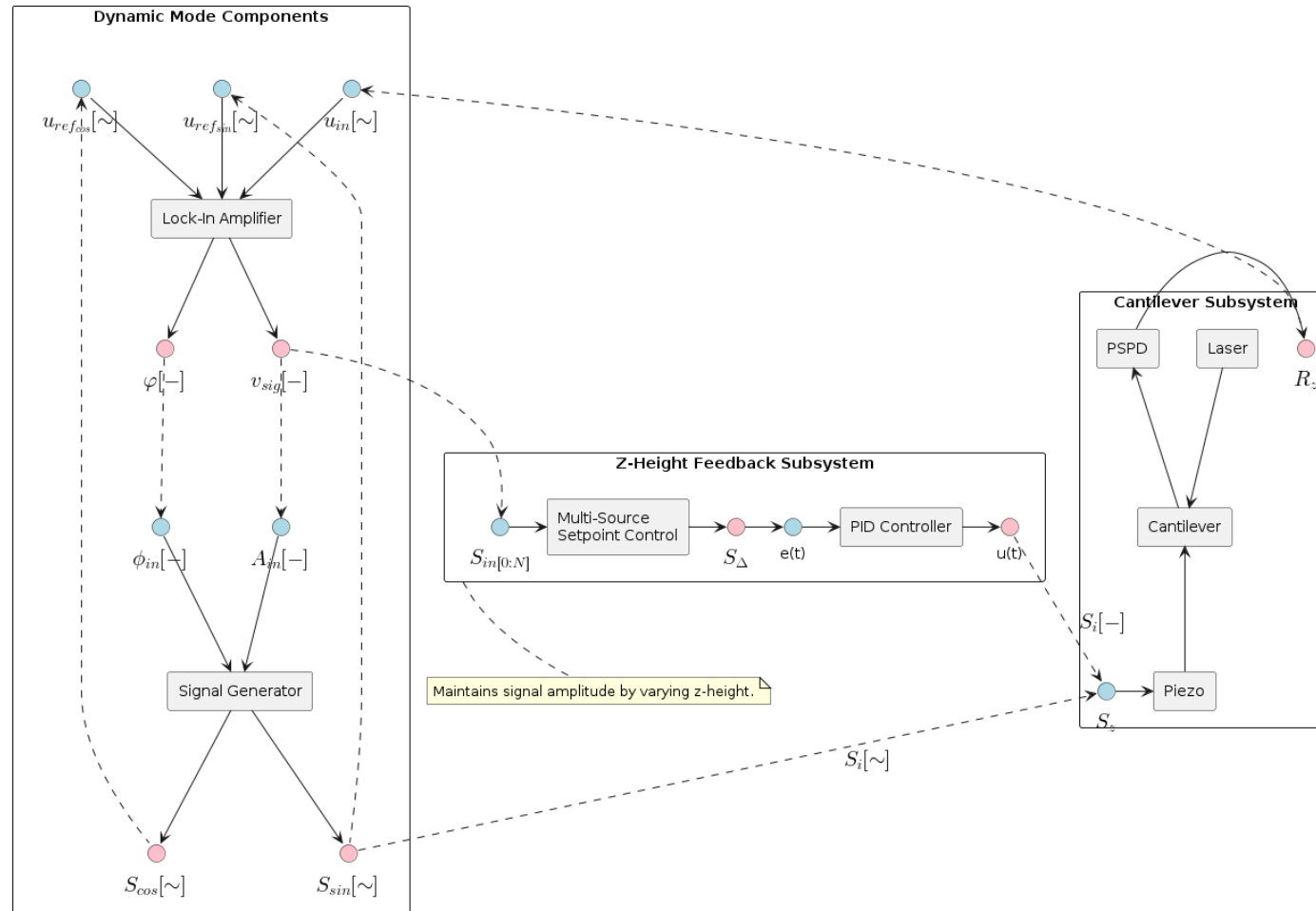. This is achieved by a feedback loop, where the z-height is changed whenever the oscillation amplitude difference between the excitation signal amplitude and resonator signal amplitude varies from a desired difference.

Notes:

- The change in amplitude is due to a change in the system's resonant frequency. You can visualize this as if the amplitude/frequency curve is translating along the frequency axis. Doing so decreases the amplitude; we modify the z-height so that the system's resonant frequency is returned to its initial state (where the amplitude is maximum).

3.2.2 FM-AFM - Frequency Modulation
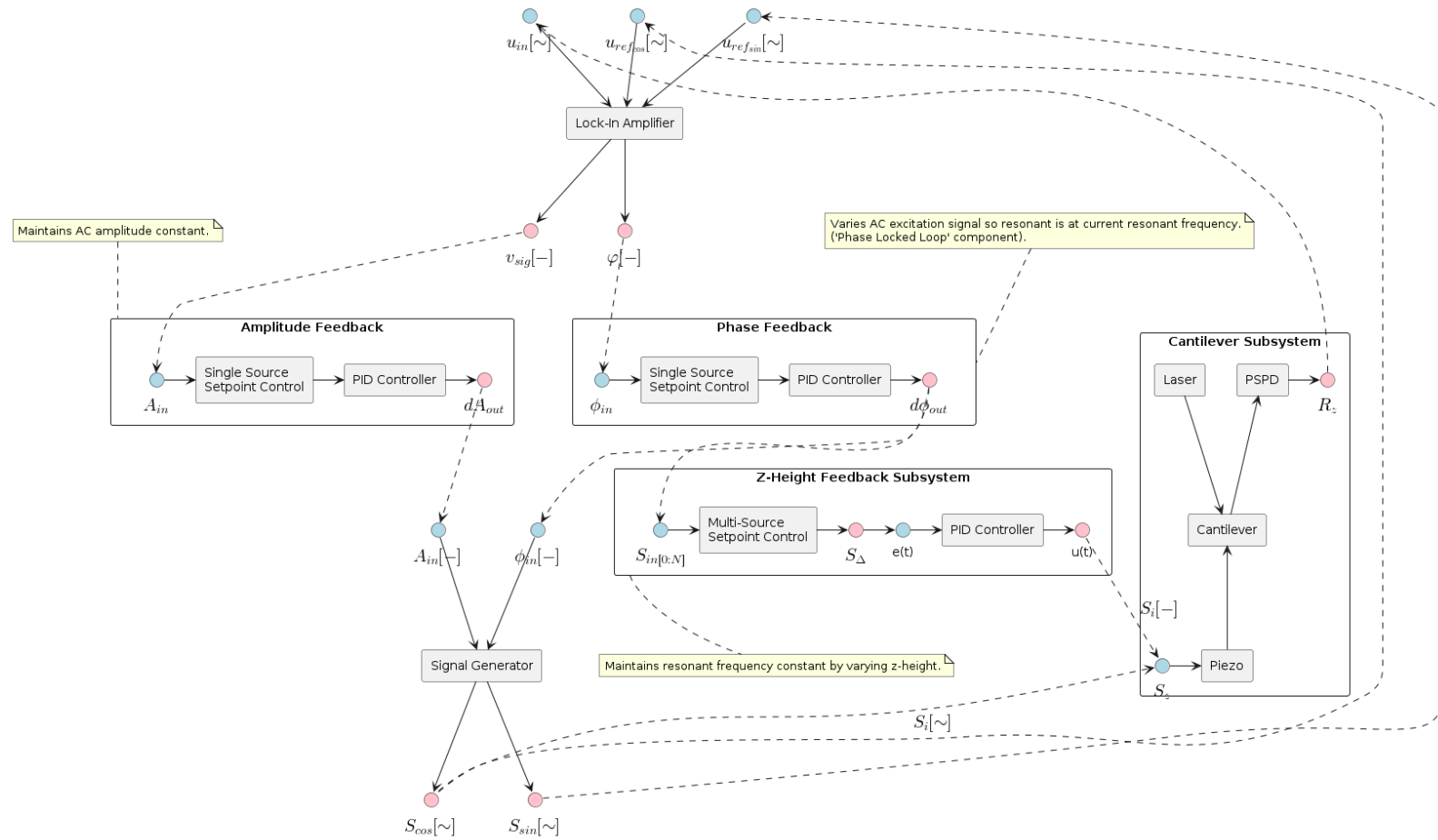

Approach:

Scan over a region with the tip oscillating its z-height at its resonant frequency, while maintaining the resonant frequency constant. This requires 3 different feedback loops:

- The z-height feedback loop, where the z-height is changed whenever the frequency difference between excitation signal frequency and resonator signal frequency varies from a desired difference.

- The phased lock loop component, where the excitation signal phase is changed whenever the phase difference between excitation signal phase and resonator signal phase varies from a desired difference. Since phase and frequency are intricately linked (instantaneous frequency is temporal rate of change of instantaneous phase), maintaining the phase ensures we maintain the frequency. Thus, this feedback ensures that **as the system resonant frequency changes**, we update the **excitation signal** to keep driving the system **on resonance** (i.e. the resonant signal frequency is always at the system's current resonant frequency).

- Traditionally, there is also an amplitude feedback loop, which ensures that the amplitude of resonance is kept constant.

Notes:

- We require the PLL **and** z-height feedback because they function at different frequencies: PLL at ~100 kHz, z-height at ~1 kHz.

- So: the PLL maintains the signal on resonance **much more quickly** than the z-height maintains the resonant frequency constant.

4 Full Table of Parameters

Subsystem	Grouping	Parameter	Description	Units
Cantilever	Cantilever	cantilever_invols	Inverse Optical Lever Sensitivity	m/V
		cantilever_k	Spring Constant	n/a
		cantilever_f0	Resonant Frequency	Hz
		cantilever_q	Q-Factor	n/
	Tip-Surface	tip_bias_voltage	Tip-Surface Bias Voltage	V
		tip_bias_amp_gain	Bias Amplifier Gain	V
		tip_bias_amp_offset	Bias Amplifier Offset	V
Scanning	Piezo	piezo_sensitivity_{3d}	Piezo Sensitivity	Ang/V
		piezo_amp_gain_{3d}	Piezo Amplifier Gain	V/V
		piezo_amp_offset_{3d}	Piezo Amplifier Offset/Bias	V
	LVDT	lvdt_sensitivity_{3d}	LVDT Sensitivity	V/Ang
		lvdt_offset_{3d}	LVDT Offset/Bias	V
	Scan Params	scan_dim_{2d}	Maximum Scan Dimensions	m
		scan_roi_dims_{2d}	Current Scan Dimensions	m
		scan_roi_pos_{2d}	Current Scan Offset (x,y)	m
		scan_origin_pos_{2d}	Coordinate System Origin	m
		scan_roi_angle	ROI Angle (if applicable)	°
		scan_direction	Scan Direction	N/A
		scanning_speed	Scanning Speed	m/s
		moving_speed	Moving Speed (not scanning)	m/s
Main Feedback	Input	fb_input_{#}_units_to_v_factor	Units-to-V conversion (Input represents x as DC V)	x/V
		fb_input_{#}_gain	Gi: gain applied to signal i (before summing)	V/V
		fb_input_{#}_setpoint	Reference Set-Point	V
	Low-Pass Filter	fb_input_{#}_low_pass_freq	Cut-off Frequency	Hz
		fb_input_{#}_low_pass_adaptive_fmin	Min. F0 (if adaptive)	Hz

Continued from previous page

Subsystem	Grouping	Parameter	Description	Units
		`fb_input_{#}_low_pass_adaptive_fmax`	Max. F0 (if adaptive)	Hz
		`fb_input_{#}_low_pass_adaptive_current`	Current Crossover (if adaptive)	A
	Transform	`fb_input_transform_mode`	Mode: 0:Off, 1:On, 2:Log, 4:IIR, 8:FUZZY	n/a
		`fb_input_transform_fuzzy_threshold`	Fuzzy-Mode Threshold Level (FUZZY Only)	V
	PID	`fb_pid_gain_p`	Proportional Gain	V/V
		`fb_pid_gain_i`	Integral Gain	V/V
		`fb_pid_gain_d`	Derivative Gain	V/V
		`fb_pid_ref-freq`	Reference Frequency	Hz
Dynamic Mode	Signal Generator	`oscillator_f_ref`	Oscillator reference frequency	Hz
	Lock-In	`lockin_averaging_period`	Averaging Period	cycles
	Amplitude Feedback	`amp_fb_enabled`	On/Off	n/a
		`amp_fb_input_v_to_v_factor`	V-to-V conversion (represents V-amplitude as DC V)	V/V
		`amp_fb_input_gain`	Gain applied to signal i	V/V
		`amp_fb_input_setpoint`	dAmplitude Set-Point	V
		`amp_fb_low_pass_freq`	Cut-off Frequency	Hz
		`amp_fb_pid_gain_p`	Proportional Gain	V/V
		`amp_fb_pid_gain_i`	Integral Gain	V/V
		`amp_fb_pid_gain_d`	Derivative Gain	V/V
	Phase Feedback	`pll_fb_enabled`	On/Off	n/a
		`pll_fb_input_hz_to_v_factor`	dHz-to-V conversion (represents Hz as DC V)	Hz/V
		`pll_fb_input_gain`	Gain applied to signal i	V/V
		`pll_fb_input_setpoint`	dFrequency Set-Point	V
		`pll_fb_low_pass_freq`	Cut-off Frequency	Hz
		`pll_fb_pid_gain_p`	Proportional Gain	V/V
		`pll_fb_pid_gain_i`	Integral Gain	V/V
		`pll_fb_pid_gain_d`	Derivative Gain	V/V