AFM / SPM Components

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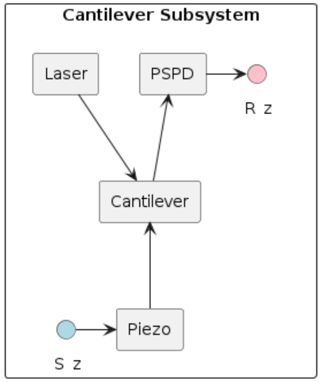
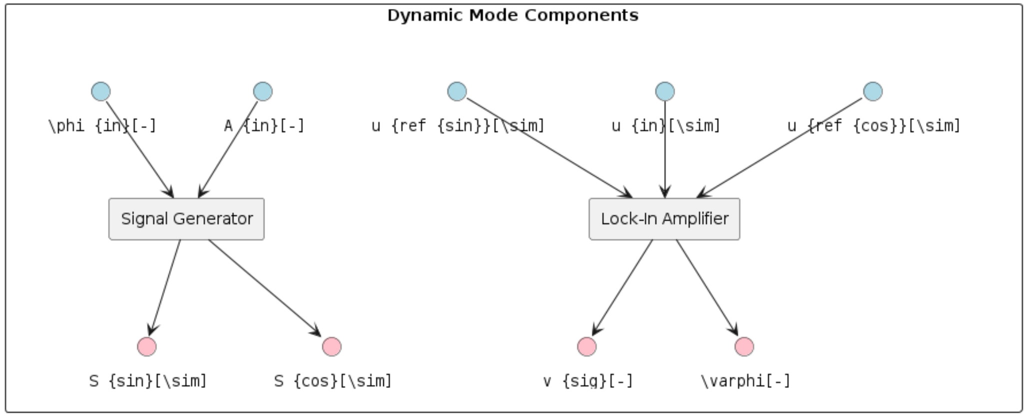
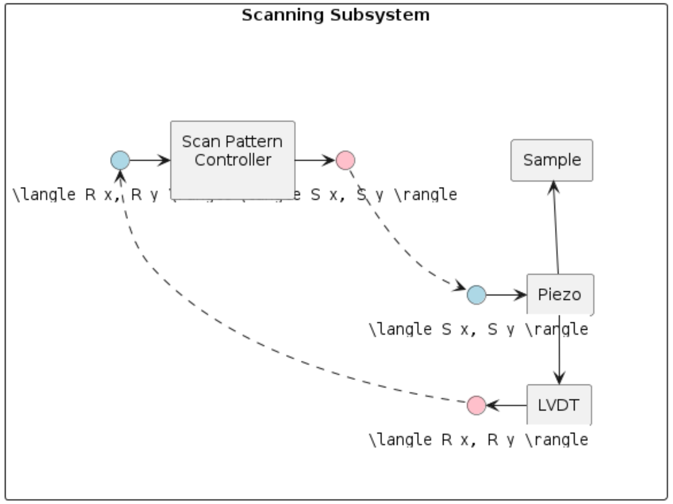
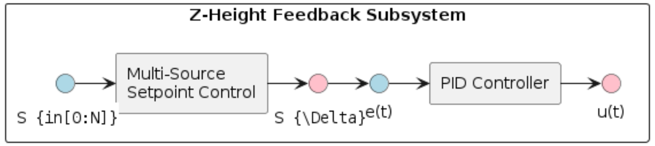
Overarching Diagram







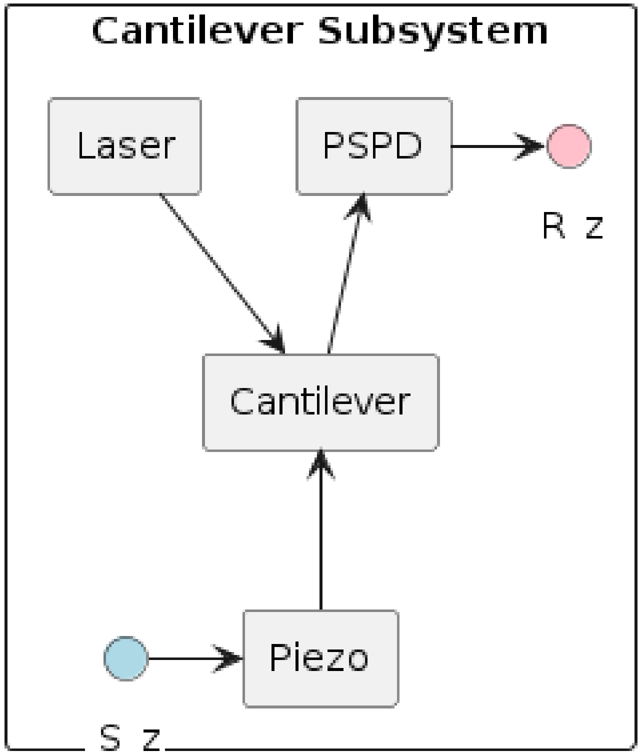


Components

Main Hardware

Cantilever Subsystem

1. Diagram

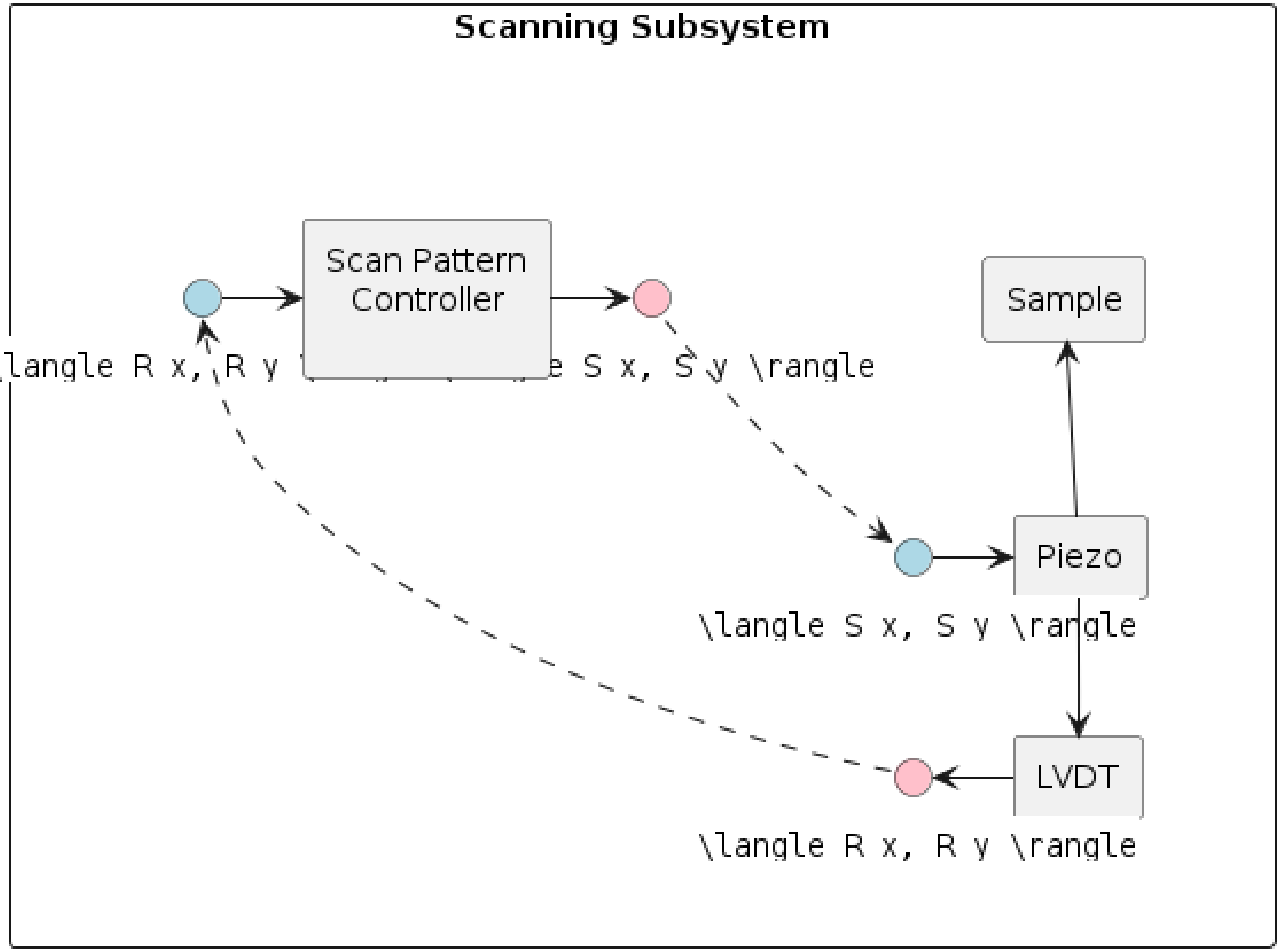


2. Parameters

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

Scanning Subsystem

1. Diagram



Scanning Subsystem
Scan Pattern Controller
Sample
Piezo
LVDT
\langle S x, S y \rangle
\langle S x, S y \rangle
\langle R x, R y \rangle

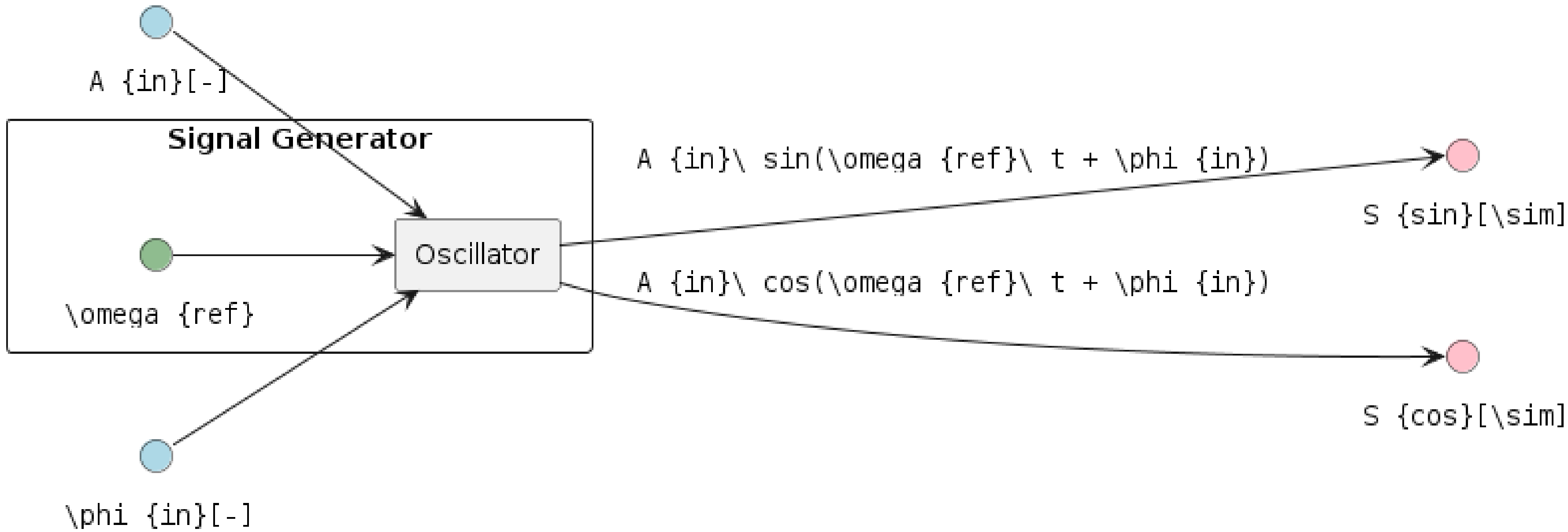
2. Parameters

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

Dynamic Mode Components

Signal Generator

1. Diagram

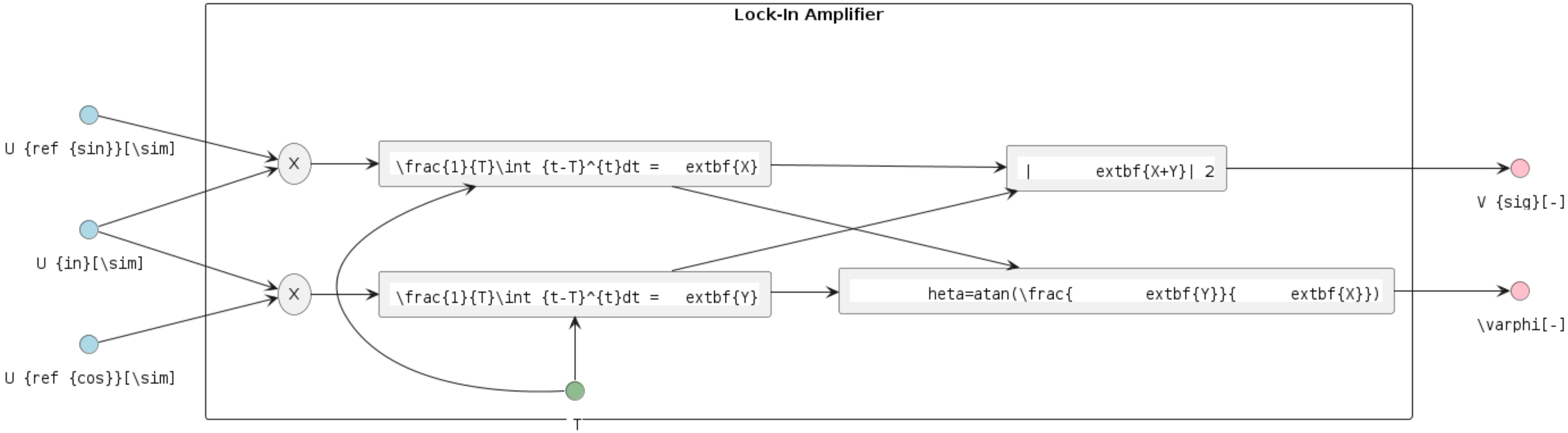


2. Parameters

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

Lock-In Amplifier

1. Diagram



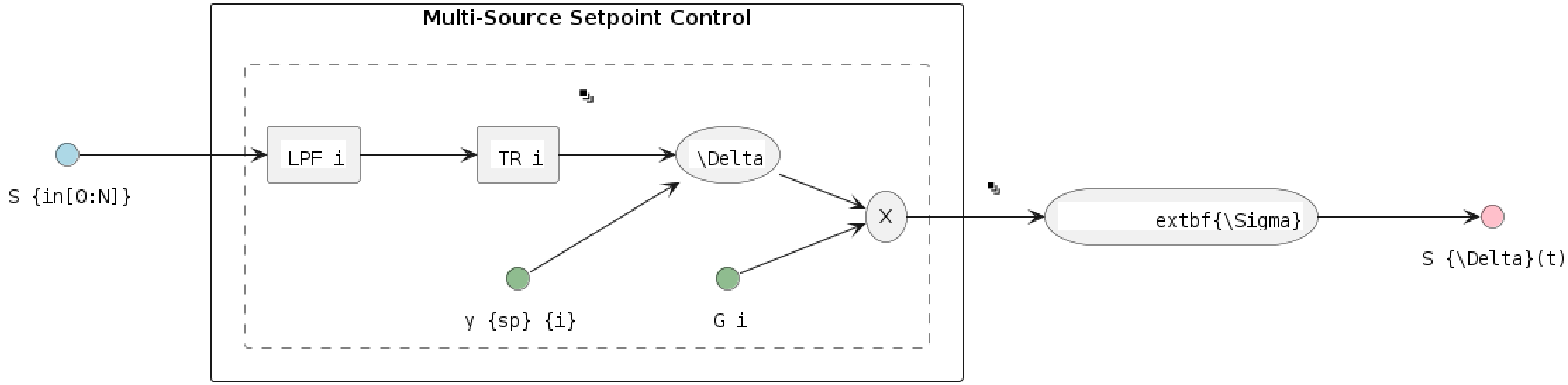
2. Parameters

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

Feedback Subsystem

Multi-Source Setpoint Control

1. Diagram

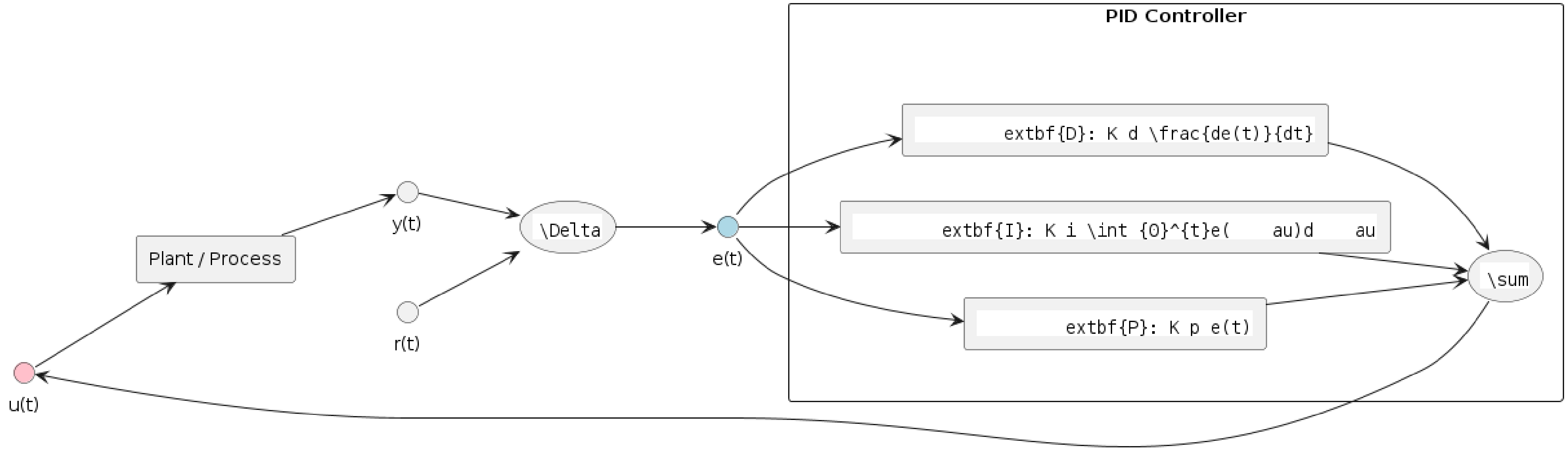


2. Parameters

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

PID Controller

1. Diagram

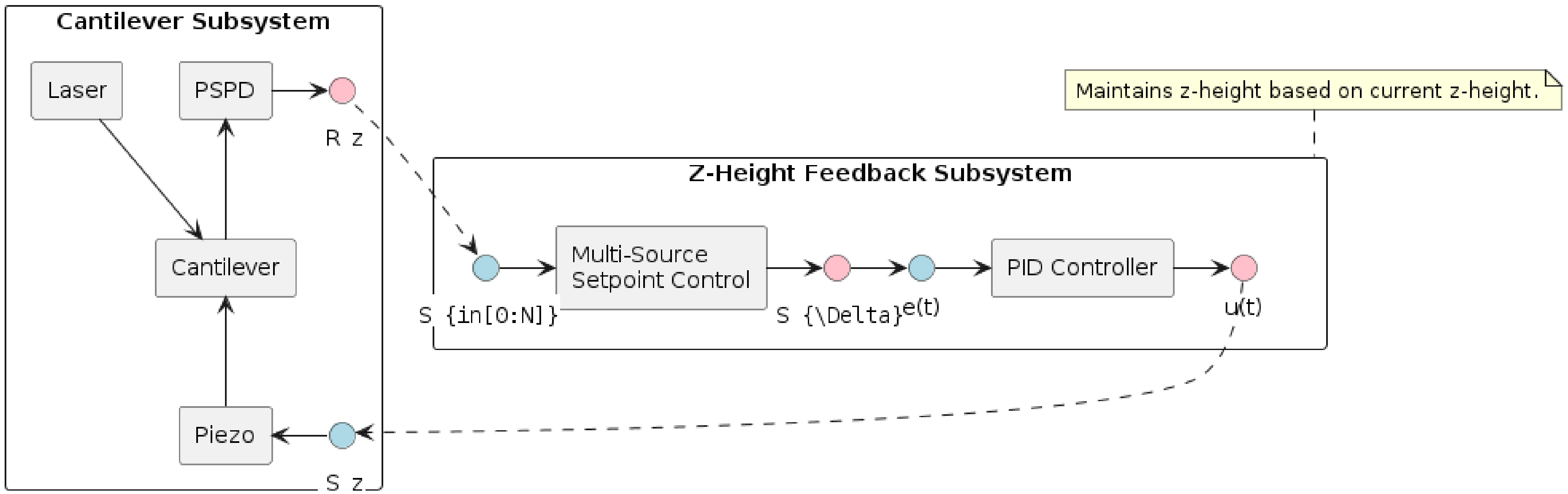


2. Parameters

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

AFM / SPM Setups

Contact Modes

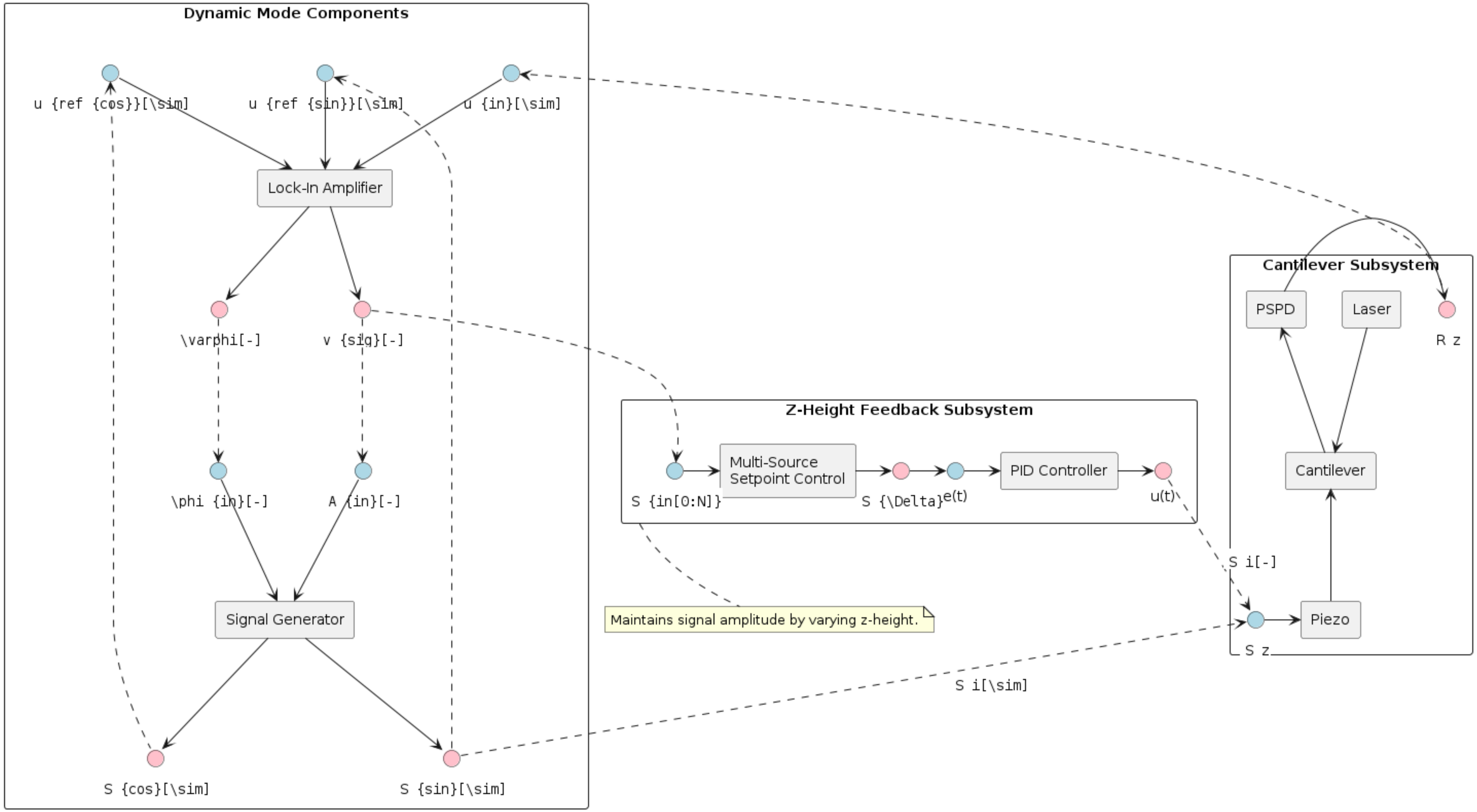


Approach:

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.

Dynamic Modes

AM-AFM - Amplitude Modulation



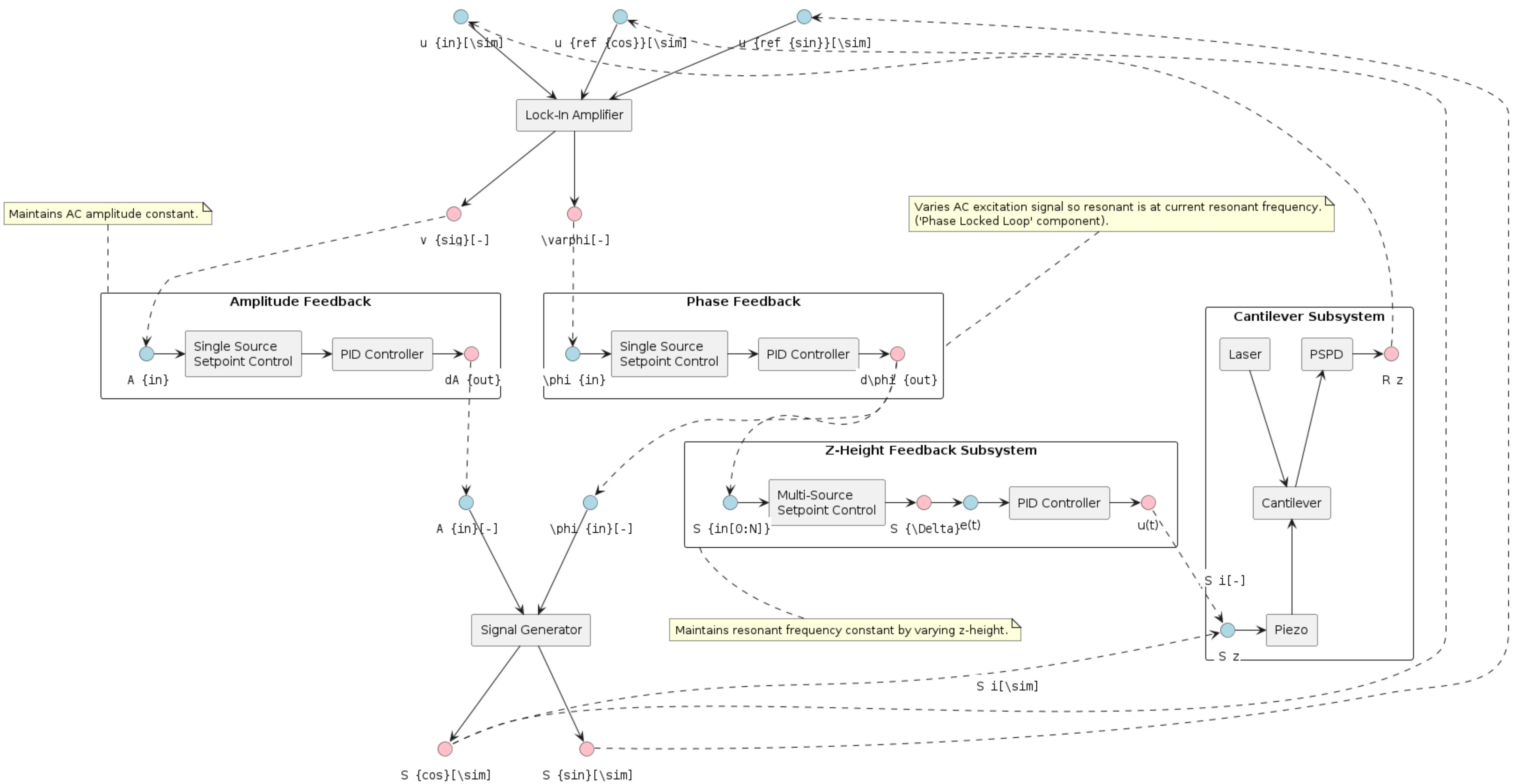
Approach:

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).

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.

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
		`fb_input_{#}_low_pass_adaptive_fmax`	Max. F0 (if adaptive)	Hz

Subsystem	Grouping	Parameter	Description	Units
		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