AFM / SPM Components

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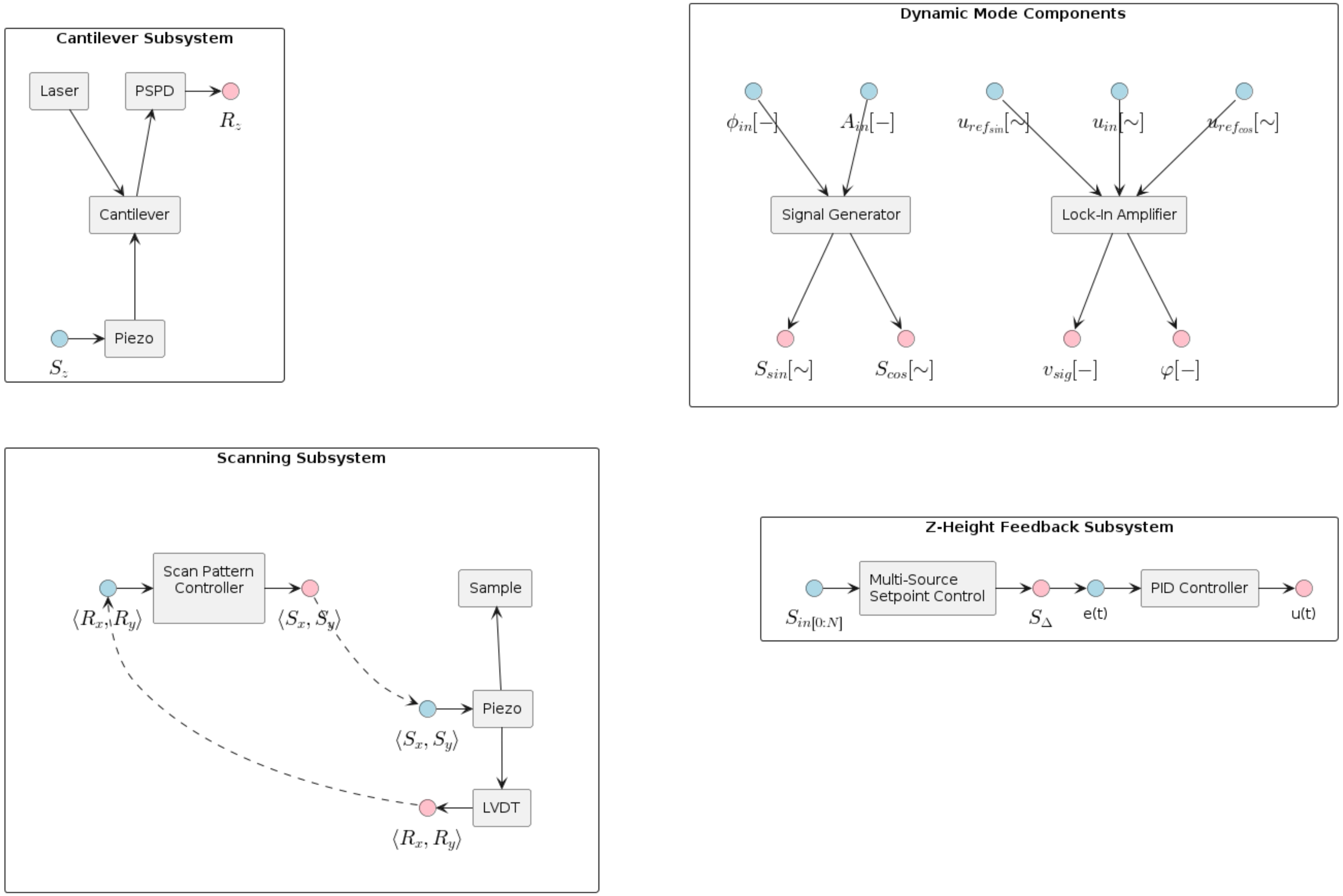
Overarching Diagram

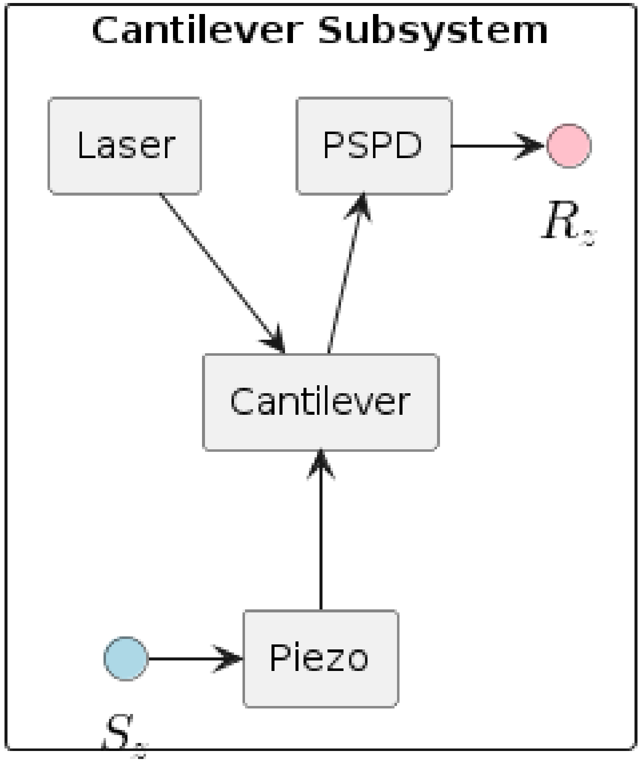


Components

Main Hardware

Cantilever Subsystem

1. Diagram

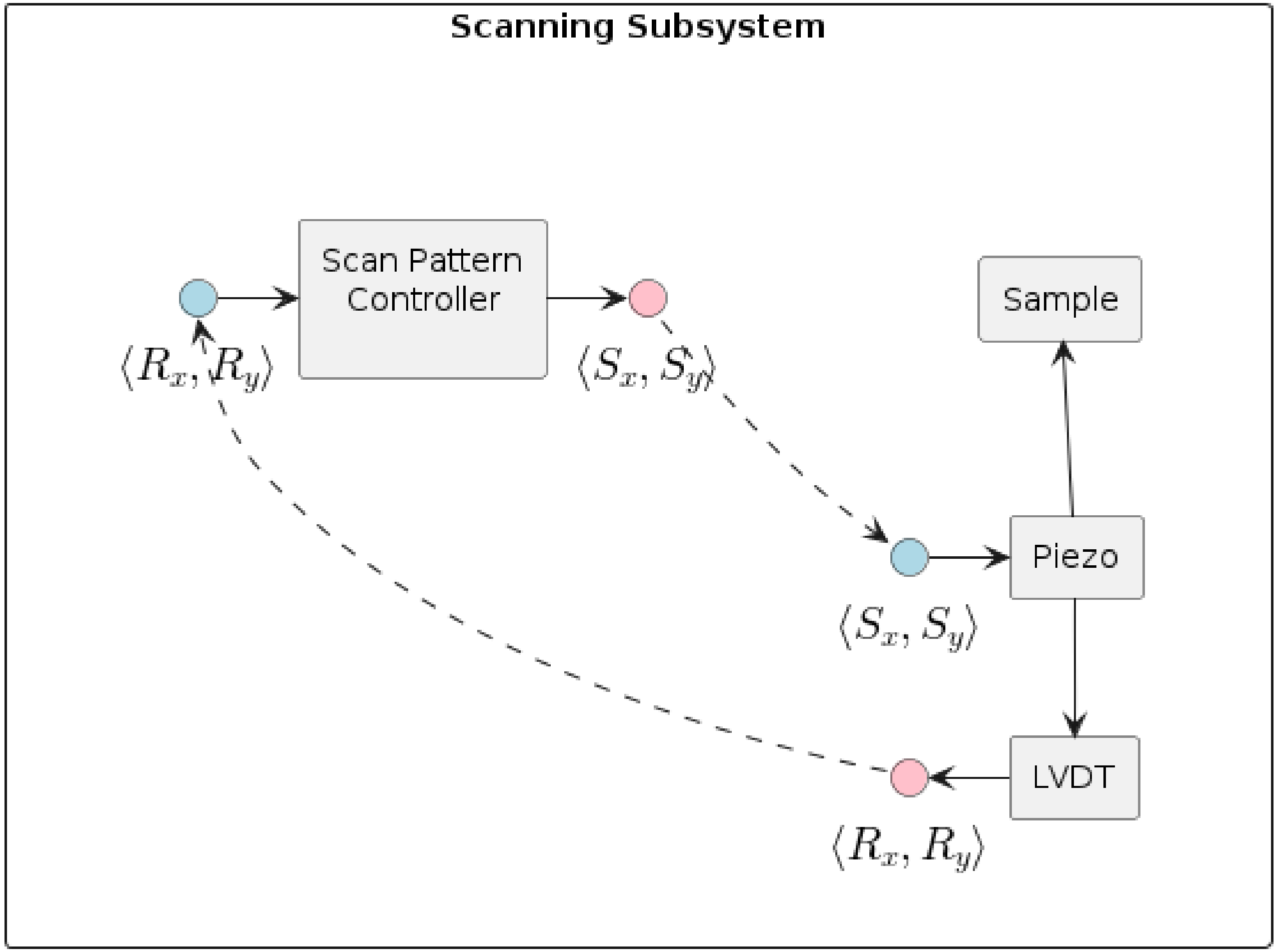


2. Parameters

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
$\langle R_x, R_y \rangle$
$\langle S_x, S_y \rangle$
Sample
Piezo
$\langle S_x, S_y \rangle$
LVDT
$\langle R_x, R_y \rangle$

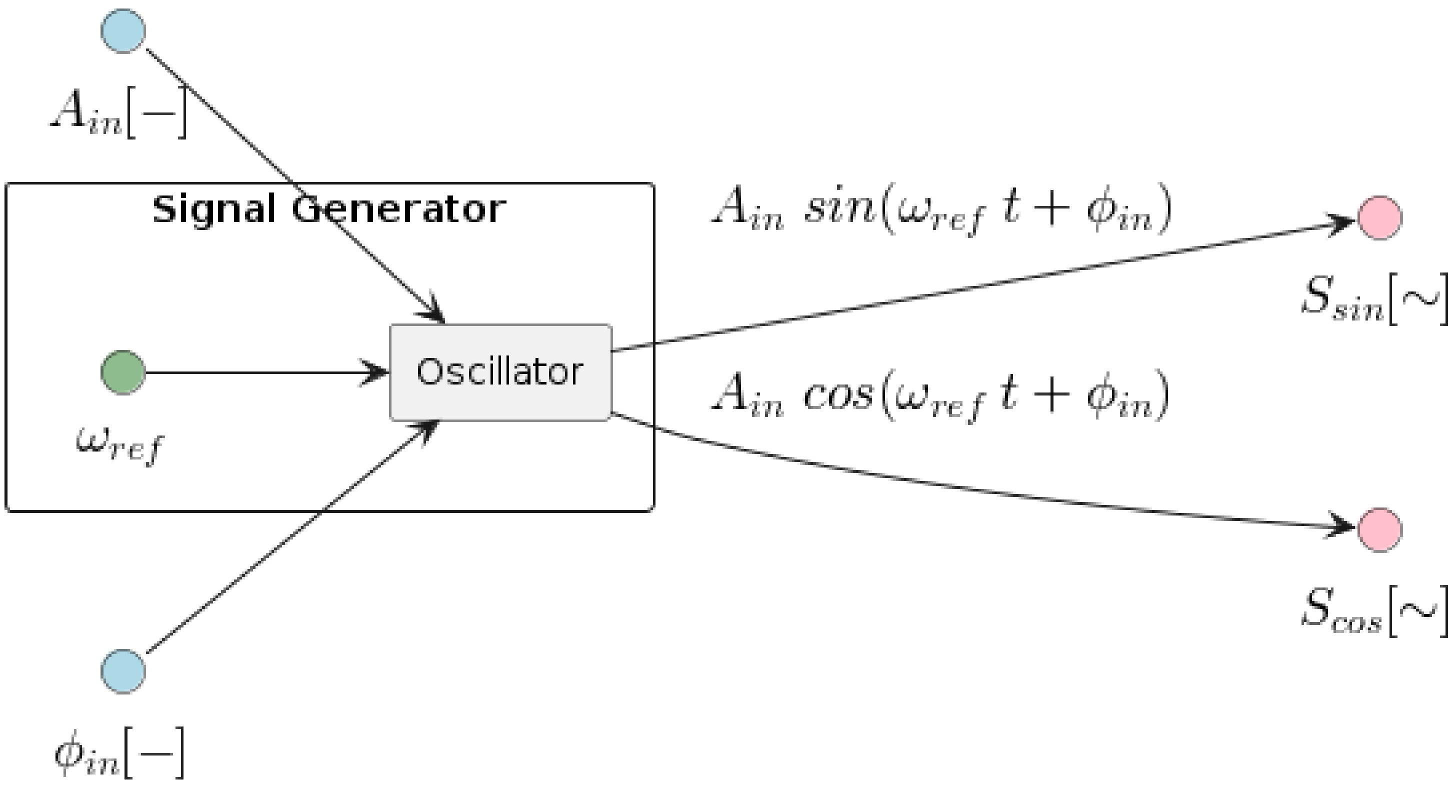
2. Parameters

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

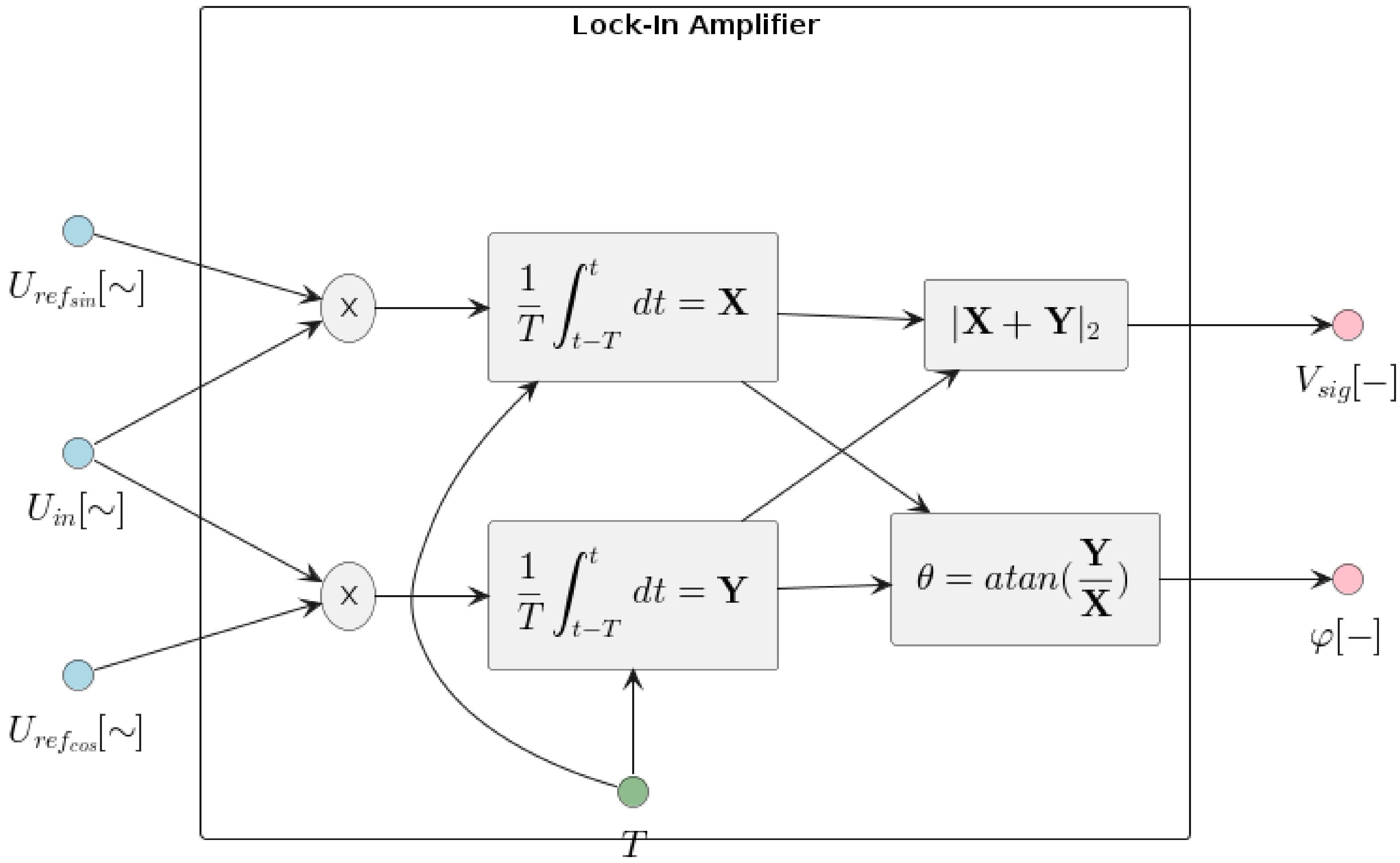


2. Parameters

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

Lock-In Amplifier

1. Diagram


Lock-In Amplifier
$U_{ref_{sin}}[\sim]$
$U_{in}[\sim]$
$U_{ref_{cos}}[\sim]$
×
×
$\frac{1}{T}\int_{t-T}^{t} dt = \mathbf{X}$
$\frac{1}{T}\int_{t-T}^{t} dt = \mathbf{Y}$
$|\mathbf{X}+\mathbf{Y}|_2$
$\theta = atan(\frac{\mathbf{Y}}{\mathbf{X}})$
$V_{sig}[-]$
$\varphi[-]$
T

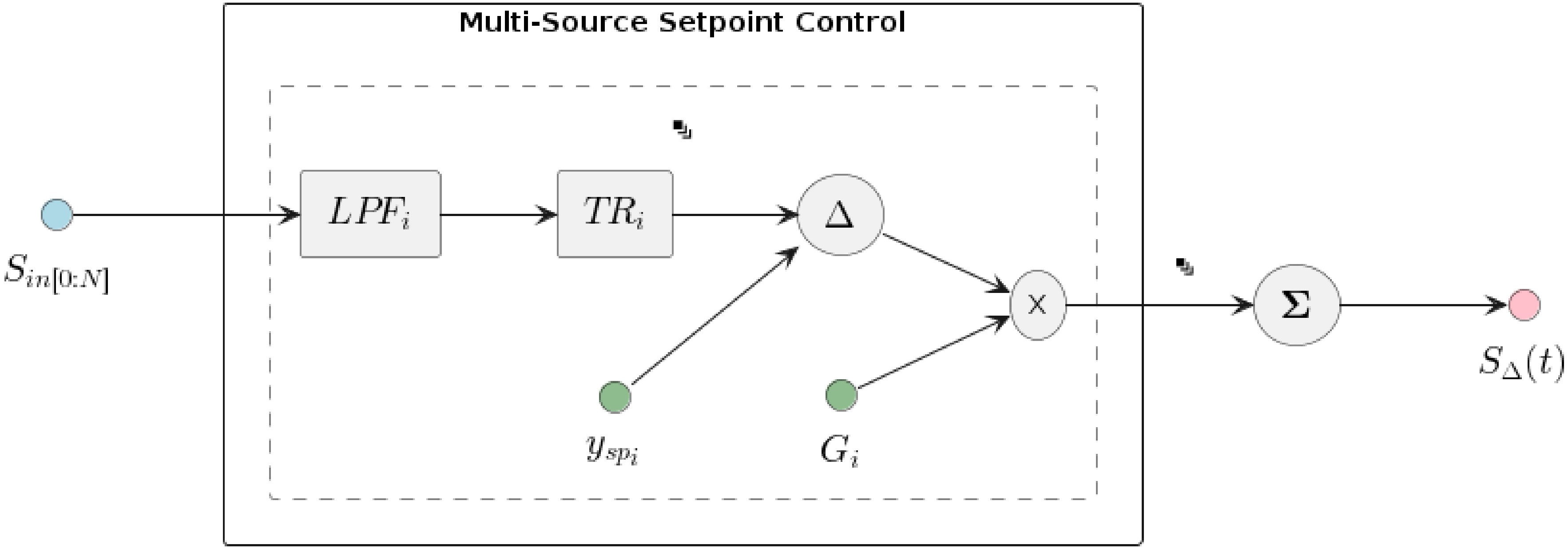
2. Parameters

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

Feedback Subsystem

Multi-Source Setpoint Control

1. Diagram



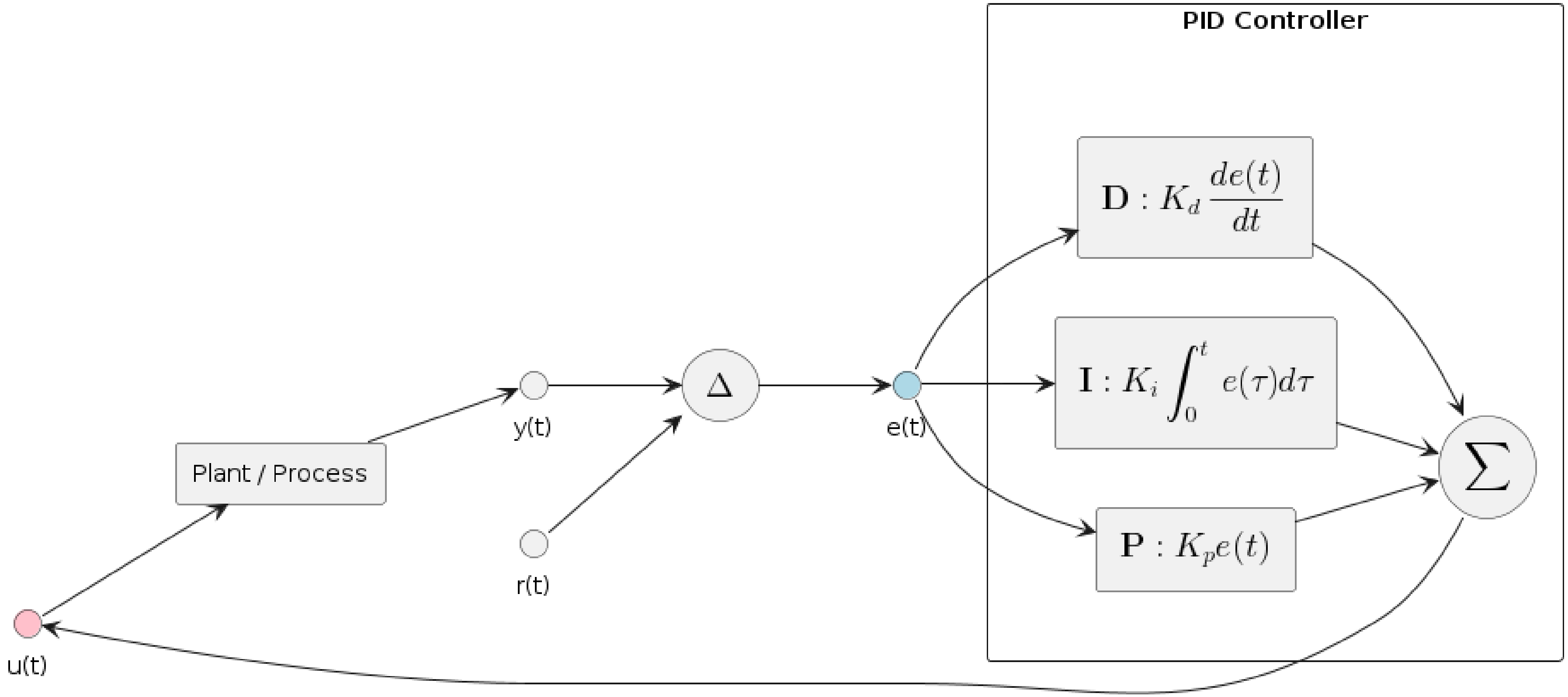
2. Parameters

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

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 Controller

1. Diagram

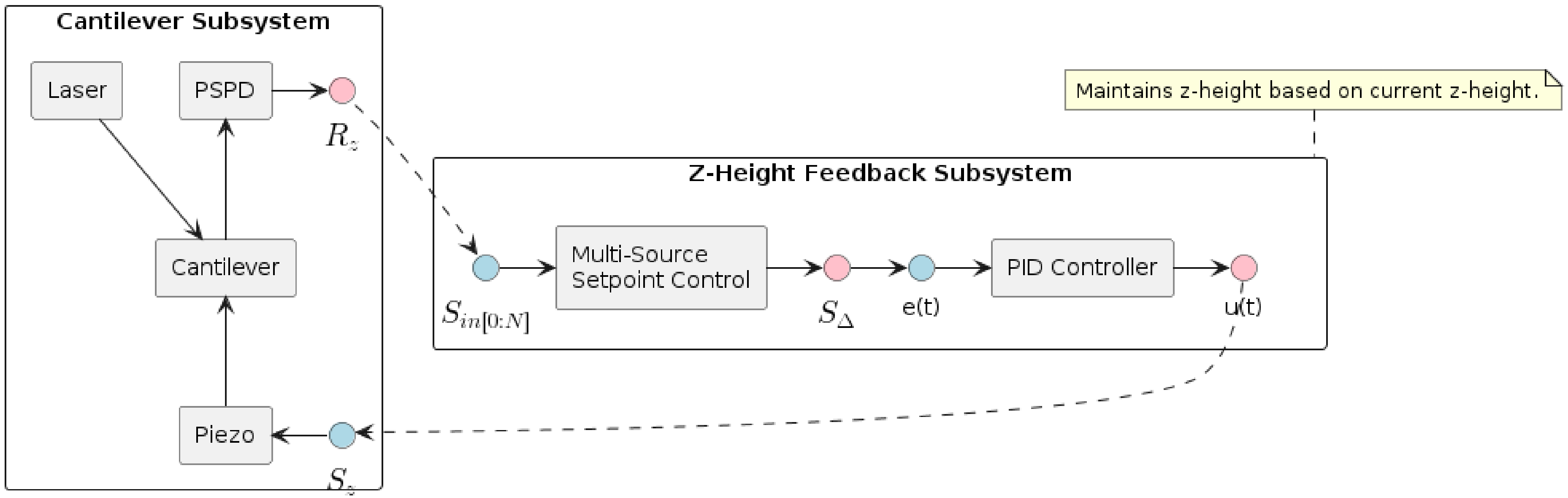


2. Parameters

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:

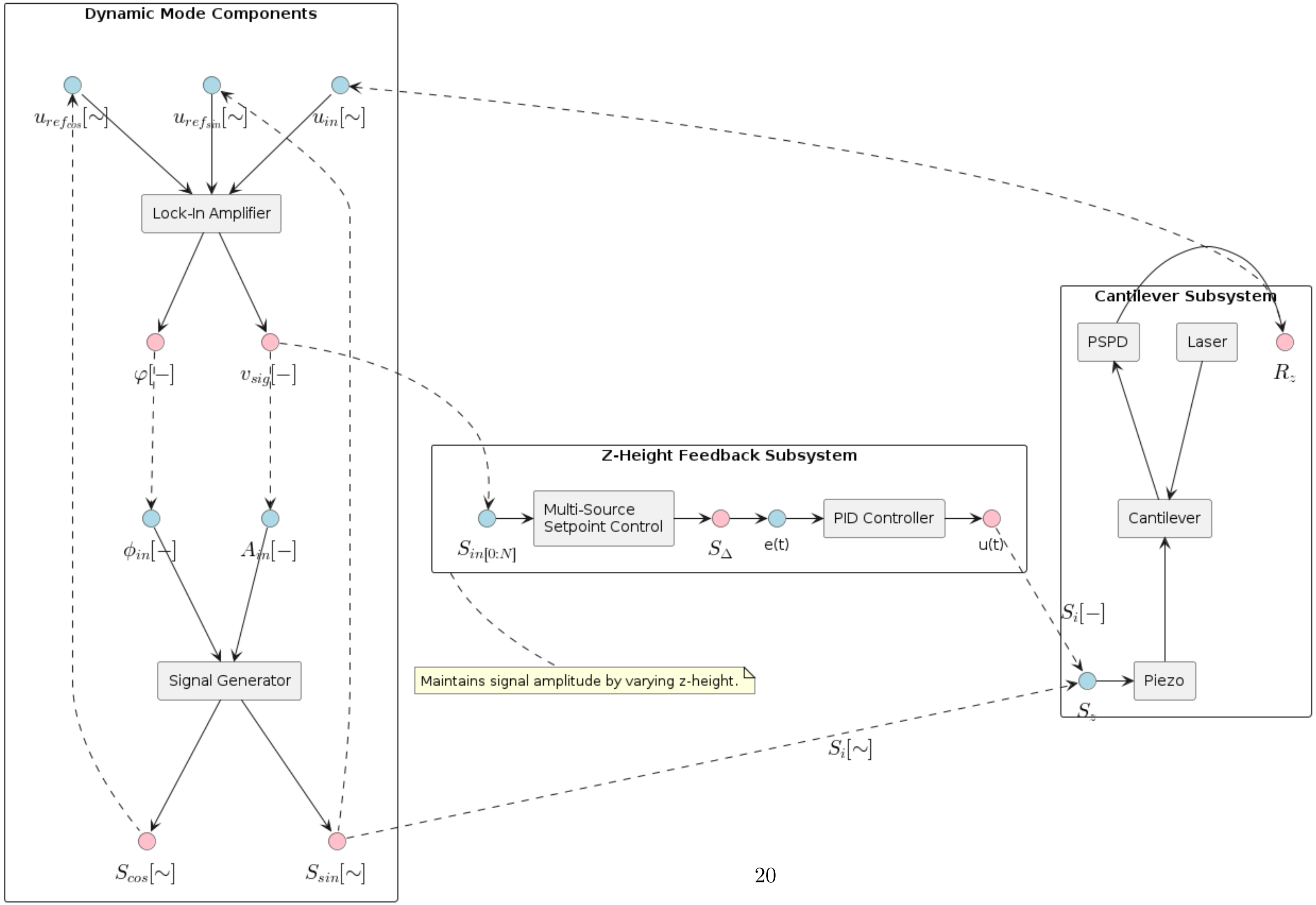
Scan over a region with a static tip, while maintaining a constant force on the tip. This is achieved by a feedback loop, where the z-height (i.e. cantilever deflection) is kept constant. This achieves a constant-force scan.

Alternatively:

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

Dynamic Modes

AM-AFM - Amplitude Modulation



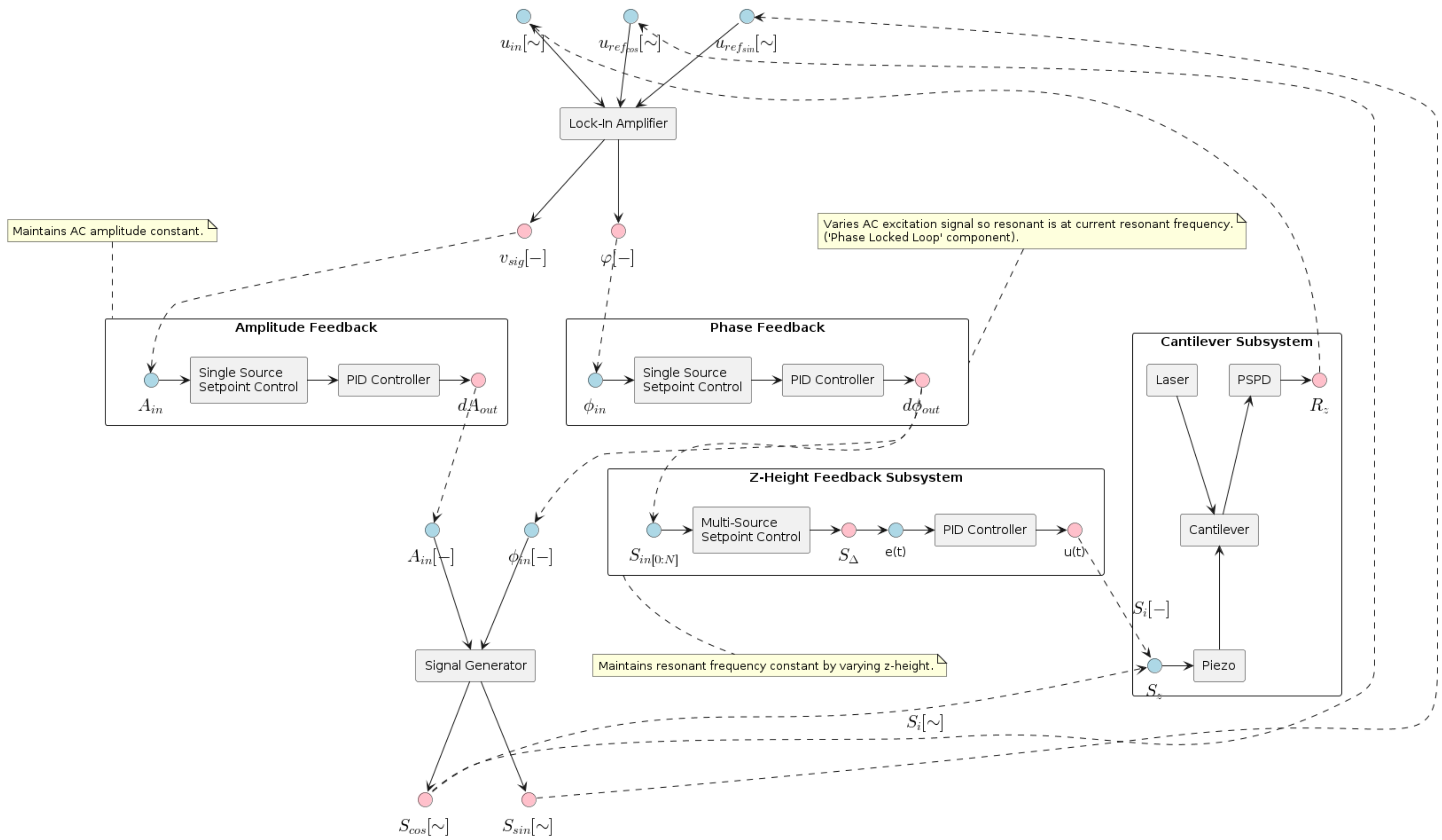
Approach:

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