nanoSurf

easyPLL

FM SENSOR CONTROLLER

Reference Manual

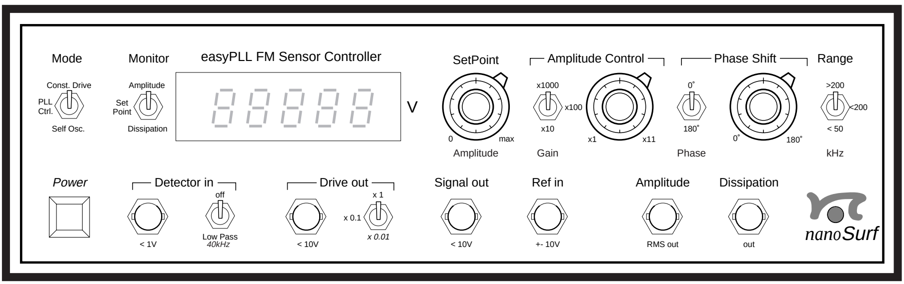


Table of Contents

About this manual

This ‘easyPLL FM sensor controller reference’ manual should be read by anyone who wishes to set up and operate the easyPLL FM sensor controller.

The easyPLL FM sensor controller

Introduction

The Nanosurf easyPLL FM sensor controller (short: Sensor Controller) is an electronic device for controlling a sensor that detects changes in its environment by changing its resonance frequency.

The Sensor controller is generally used to control the resonance of an Atomic Force Microscope (AFM) sensor. This sensor can for example be a quartz tuning fork or an AFM cantilever. The Sensor Controller is meant to be used as part of an easyPLL system that also contains the Nanosurf easyPLL digital FM-Detector (short: FM-Detector) for measuring the resonance frequency . The easyPLL system can be configured for four different operating modes that differ in the way the system regulates the vibration frequency and amplitude. In addition to changes in resonance frequency, the system can also measure changes in vibration amplitude, phase shift or dissipation, depending on the system's configuration.

Although many AFM systems already contain some form of sensor controller, and could therefore be operated using the FM-detector alone, the combination of the Nanosurf easyPLL digital FM-Detector with the easyPLL FM Sensor Controller improves ease of use, and adds three additional operating modes (PLL Oscillation with controlled vibration, PLL Oscillation with constant drive, and Lock-in mode) to the standard Self Oscillation operating mode.

Several other Nanosurf easyPLL products can also be used in conjunction with the easyPLL system:

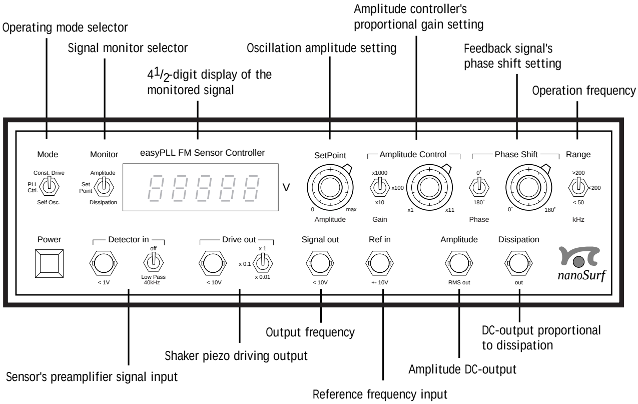
- The 'easyPLL UHV preamplifier' amplifies the signal from the oscillating sensor, when mounted inside an Ultra High Vacuum (UHV) chamber.
- The 'easyPLL Manual Controller' allows you to change the reference frequency without using a PC.

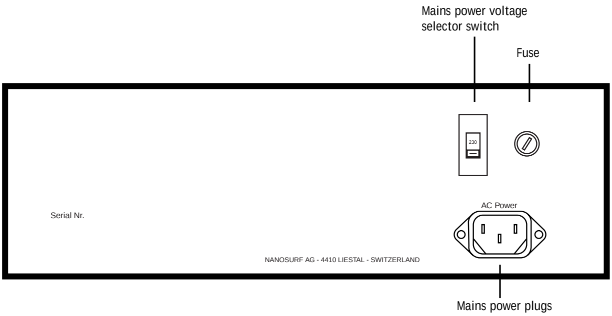
Technical Data

• Operation frequency range	10kHz - 1MHz
• Detector input	max 1 V peak
• Detector filter	40 kHz, on/off, 80dB/Dec
• Drive out range	0 - 10 V / 0 - 1 V / 0 - 0.1 V
• Drive out noise	1.3 mV_{veff} / 0.3 mV_{veff} / 0.2 mV_{veff}
• Drive out phase	0 - 360°
• Signal out noise	0.7 mV_{veff}
• Amplitude setpoint	0 - 1 V
• Amplitude control gain	x10 - x11'000
• Amplitude control bandwidth	1 kHz
• Amplitude output noise	0.4 mV_{veff}
• Dissipation output	-10 - +10V
• Dissipation output noise	0.3 mV_{veff} / 1.5 mV_{veff} / 8 mV_{veff}
• Power supply voltage	220-240 VAC ±10%, 50/60Hz 100-130 VAC ±10%, 50/60Hz
• Power consumption	13 VA
• Fuse	0.40 AT (220 - 240 VAC) 0.80 AT (100 - 130 VAC)

Specifications are subject to change without notice

Connectors and Indicators





Content of delivery

After unpacking the instrument case check for the following items:

1 - easyPLL sensor controller

2 - Mains cable

3 - Two 25cm long BNC cables

4 - This manual

Installing the easyPLL system

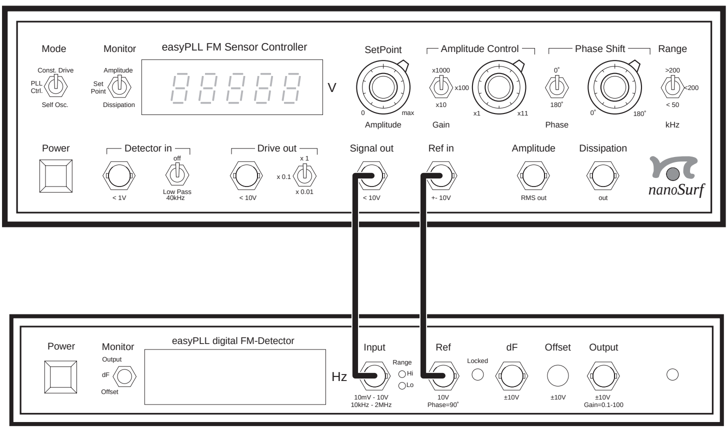
This section gives instructions for installing the easyPLL Sensor Controller.

Important!

- First install the easyPLL digital FM-detector according to the instructions in the *easyPLL digital FM-detector reference* manual.
- Before connecting the electronics, check that the voltage indicated on the 'Mains power voltage selector switch' on the rear panel of the sensor controller corresponds to your mains voltage. Using the wrong setting will blow the fuse or may even damage the electronics.

- Connect the control electronics to the mains using the mains cable (*2*).

- Use the two BNC cables (*3*) to connect the Sensor Controller to the FM detector, as is shown in the figure below:



The other connections depend on both the operating mode (see chapter *Operating the Sensor Controller*) and the AFM you are using.

Connecting to a generic system

Cables

Use 50Ω BNC cables to make all connections.

- Connect the (amplified) sensor signal to the 'Detector In' input of the Sensor Controller.
- Connect the 'Drive Out' output of the Sensor Controller to the excitation input of the sensor.
- If you have an Oscilloscope available:
  - Connect the sensor signal to Channel 1 on the Oscilloscope as well.
  - Connect 'Drive out' to Channel 2 on the Oscilloscope as well.
- Connect the 'Output' of the FM-Detector to the Z-feedback error signal input of the scan electronics.
- Connect the 'Dissipation' output of the Sensor Controller to an auxiliary ADC input of the scan electronics.
- Connect the 'Amplitude' output of the Sensor Controller to an auxiliary ADC input of the scan electronics.
- Connect the 'dF' output of the FM-Detector to an auxiliary ADC input of the scan electronics.

easyPLL software settings

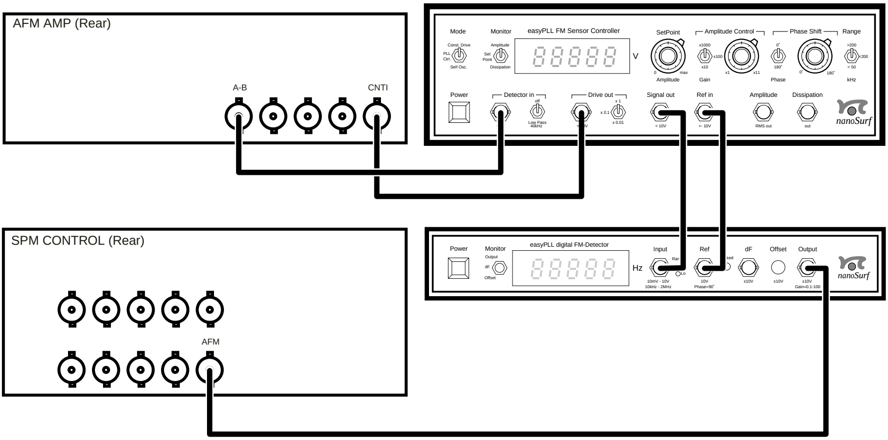
Refer to the section *The easyPLL main window, advanced settings* of Chapter *the easyPLL software* reference for a description of the parameters that should be set.

Connecting to a JEOL SPM 4500 system

Cables

- Connect the 'A-B' output of the 'AFM AMP' to the 'Detector In' input of the Sensor Controller.
- Connect the 'CNTI' input of the 'AFM AMP' to the 'Drive Out' output of the Sensor Controller

- If you have an Oscilloscope available:
  - Connect the ‘A-B’ output to Channel 1 on the Oscilloscope as well.
  - Connect the ‘Drive Out’ to Channel 2 on the Oscilloscope as well.
- Connect the ‘AFM’ input of the ‘SPM CONTROL’ to the ‘Output’ output of the FM-Detector



easyPLL software settings

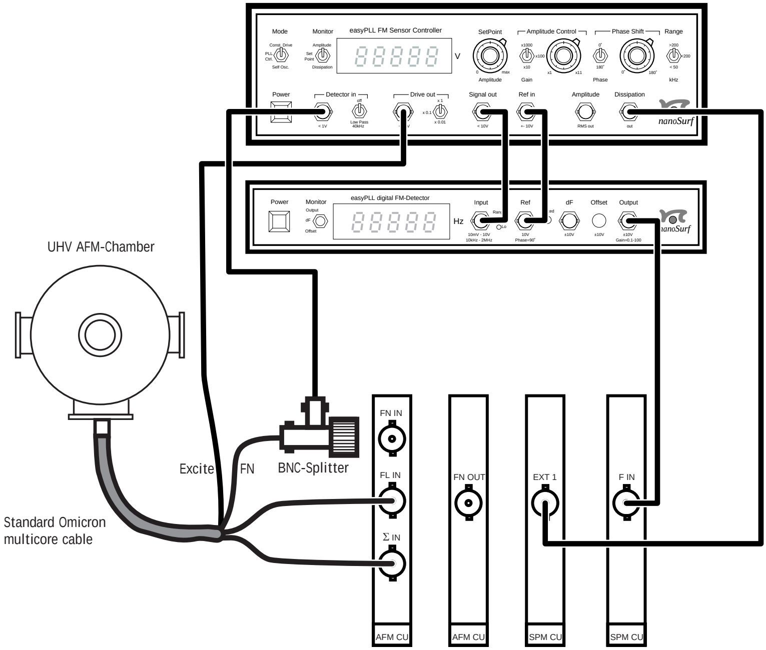
Input	Setting
LockRange	+-732Hz
AutoRange	on
Output:	
Positive Polarity	off
Gain	x1
TipGuard:	
Retract Tip if Unlocked	on
Positive Direction	off

JEOL WinSPM software settings

- In the ‘Advanced’ dialog, set the ‘STM/AFM box’ to ‘FM’.

Connecting to an Omicron system

Cables



- Insert a BNC -T between the ‘FN’ cable from the UHV system to the ‘FN’ input of the AFM CU.

- Connect the ‘FN’ signal of the AFM CU to the ‘Detector In’ of the Sensor Controller.

- Connect the ‘Drive out’ output of the Sensor Controller to the ‘Excite’ cable from the UHV system.

- If you have an Oscilloscope available:
    - Connect the ‘FN’ signal to Channel 1 on the Oscilloscope as well.
    - Connect the ‘Drive Out’ to Channel 2 on the Oscilloscope as well.

- Connect the ‘Output’ of the FM-Detector to the ‘F IN’ input on the SPM CU.

- Depending on the operation mode, connect the ‘Amplitude’ or ‘Dissipation’ output of the Sensor Controller to the ‘EXT 1’ Input of the SPM CU.

easyPLL software settings

Input	Setting
LockRange	+-732Hz
AutoRange	on
Output:	
Positive Polarity	off
Gain	x1
TipGuard:	
Retract Tip if Unlocked	on
Positive Direction	off

Omicron ScanControl settings

- Select the mode ‘AFM non contact’ in the menu ‘Topography Preset’.

The Button ‘Feedback set’ in the Panel ‘Measurement Control’ is now useless. The corresponding value is now set either digitally with the easyPLL control software with the value ‘OffsetFrq’ or manually with the optionally available easyPLL analog offset controller.

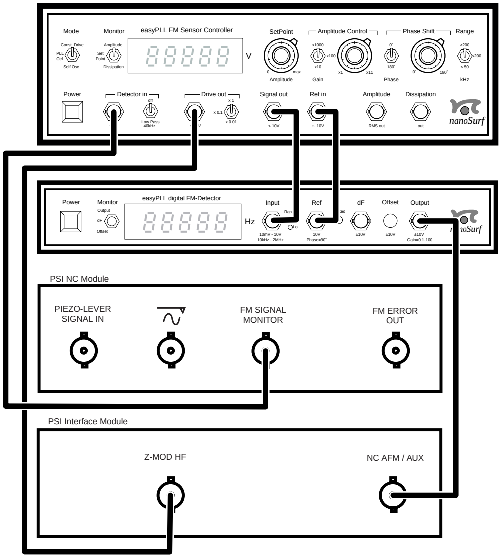
When measuring the ‘Amplitude’ or Dissipation’ signal using ‘EXT 1’:

- Open the calibration settings via the menu ‘Setup/Edit Hardware/Miscellaneous Calibration’.

- Enter the following values in the row for EXT 1:
  Name: ‘Amplitude’ or ‘Dissipation’
  Min: -10
  Max: +10
  Unit: V
  Min: -10.0
  Max: +10.0

Connecting a PSI UHV system

Cables



- Connect the ‘FM SIGNAL MONITOR’ output of the PSI NC Module to the ‘Detector in’ input of the Sensor Controller.
- Connect the ‘Drive out’ of output the Sensor Controller to the ‘Z-MOD HF’ input of the PSI Interface Module.
- If you have an Oscilloscope available:
    - Connect the ‘FM SIGNAL MONITOR’ output to Channel 1 on the Oscilloscope as well.
    - Connect the ‘Drive Out’ to Channel 2 on the Oscilloscope as well.
- Connect the ‘Output’ of the FM-Detector to the ‘NC AFM / AUX’ input of the PSI Interface Module.

easyPLL software settings

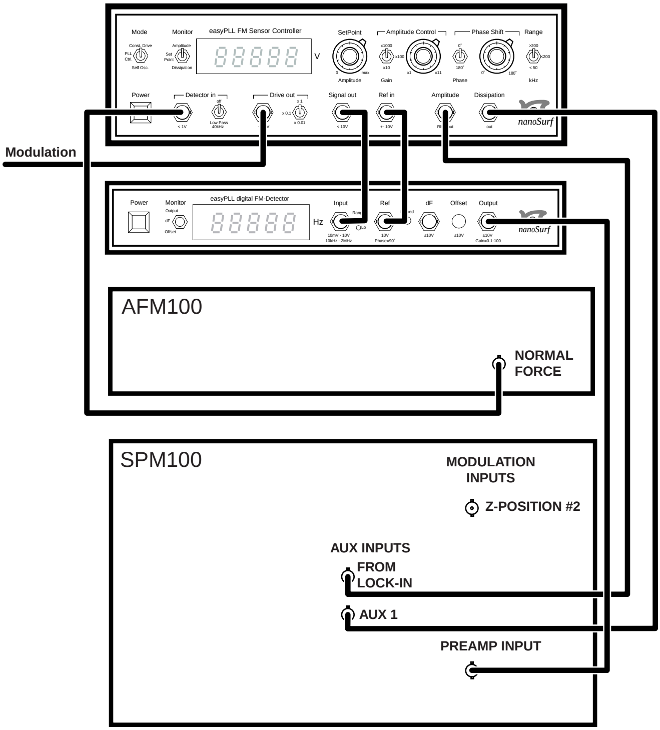
Input	Setting
LockRange	+-366Hz
AutoRange	on
Output:	
Positive Polarity	off
Gain	x1
TipGuard:	
Retract Tip if Unlocked	on
Positive Direction	off

Connecting to an RHK SPM1000 system

The settings and connections given here are optimised for using the RHK SPM1000 system in combination with the RHK UHV350 system. For other systems, those settings marked as UHV350 may have to be different.

Cables

- Connect the 'NORMAL FORCE' output on the AFM100 to the 'Detector in' Input on the Sensor Controller.
- Connect the 'Drive out' output of the Sensor Controller to the cable marked 'Modulation' (UHV350), or to 'Z POSITION #2' on the SPM100.
- If you have an Oscilloscope available:
  - Connect 'NORMAL FORCE' to Channel 1 on the Oscilloscope as well.
  - Connect 'Drive out' to Channel 2 on the Oscilloscope as well.
- Connect the 'Output' on the FM-Detector to the 'Preamp Input (external)' input on the SPM100.
- Connect the 'Amplitude' output of the Sensor Controller to the 'FROM LOCK-IN' input of the SPM100.



Depending on whether you are using one of the PLL modes or the Lock-in mode, make the following connections

- For PLL mode, connect the ‘Dissipation’ output on the Sensor controller to the ‘AUX 1’ input on the SPM100.
- For Lock-in mode, connect the ‘dF’ output on the Sensor conroller to the ‘AUX 1’ input on the SPM100.

Switches on the SPM1000 electronics

SPM 100:

Feedback	Linear
Input Polarity	SPM
Polarity	Normal

easyPLL software settings

Input	Setting
LockRange	+-732Hz
AutoRange	on
Output:	
Positive Polarity	off
Gain	x1
TipGuard:	
Retract Tip if Unlocked	on
Positive Direction	off

RHK software settings

- Go to the menu ‘Settings / I/O’
- Choose ‘User Defined’ for the operation ‘mode’,
- Enter ‘dF’ for ‘name’ and ‘Hz’ as ‘unit’.
- Copy the calibration from the DeltaF monitor in the easyPLL software, and add a ‘-’ sign (UHV350).

Operating the easyPLL system

In the following, it is assumed that you are using the easyPLL FM Sensor Controller in combination with the easyPLL digital FM-detector.

Choosing an operating mode

The easyPLL supports four modes for working with a frequency modulated sensor: one self oscillating operation mode and three driven operation modes:

1. Self Oscillation (SC: ‘Self Osc.’, FM-Detector: ‘PLL FM Detector’): The FM-Detector is used as frequency measuring device. The sensor oscillation is excited by the Sensor Controller by feeding the sensor signal back to the excitation signal. The Sensor Controller simultaneously regulates the sensor vibration amplitude.
2. PLL Oscillation, controlled vibration (SC: ‘PLL Ctrl.’, FM-Detector: ‘PLL FM Detector’): The sensor oscillation is measured and excited by the FM-Detector. The phase shift between the sensor oscillation and the excitation is set by the Sensor Controller, which also regulates the vibration amplitude.
3. PLL Oscillation, constant drive (SC: ‘Const. Drive’, FM-Detector: ‘PLL FM Detector ‘): The sensor oscillation is measured and excited by the FM-Detector. The drive amplitude and the phase shift between the sensor oscillation and the excitation are set by the Sensor controller, which also measures the vibration amplitude.
4. Lock-in (SC: ‘Const. Drive’, FM-Detector: ‘Const. Frequency and Phase Measurement’): The FM-detector excites the sensor at a constant frequency, and measures the phase shift of the vibration. The Sensor Controller determines the excitation amplitude and measures the vibration amplitude.

For more detailed information about the different operating modes please refer to chapter *Theory of the FM Method*.

First choose between one of the resonant oscillation modes or the Lock-in mode. Normally choose one of the resonant oscillation modes. Choose the Lock-in mode for operation of sensors with very low Q factors (for example AFM cantilevers in air).

The choice between the resonant oscillation modes depends on several factors. On the one hand, the PLL oscillation modes feature the best signal to noise ratio. On the other hand, the Self Oscillation mode is more robust against large changes in resonance frequency and amplitude when used with high Q sensors. Therefore, we suggest choosing the operation mode depending on to the sensor's Q:

- Q > 100'000: The S/N ratio difference between the Self Oscillation and PLL Oscillation modes becomes negligible. Then, it is simplest to work in the Self Oscillation mode.
- 500 < Q < 100'000: It is advisable to start in the Self Oscillation mode, and then switch to PLL Oscillation mode, because it is easier to find the best Sensor Controller settings for 'Phase', 'P-Gain', 'SetPoint' or excitation frequency in the Self Oscillation mode.
- Q < 500: The PLL Oscillation modes should be used, because it becomes difficult to sustain self oscillation when the Q factor is low.

The relative advantages of the controlled vibration mode and the constant drive mode are still a matter of scientific debate. The measurement results for controlled vibration mode are easier to understand theoretically, whereas the operation of the constant drive mode is more reliable. The controlled vibration mode is generally preferred in European countries and the USA, whereas the constant drive mode is preferred in Japan.

Self Oscillation mode

In the Self Oscillation mode, the Sensor Controller excites the sensor resonance frequency by feeding the sensor deflection signal back to the excitation device (e.g. piezo). With the appropriate amplification and phase shift settings in the feedback loop, the sensor will start to self-oscillate. An amplitude controller keeps the oscillation amplitude constant by varying the amplification of the feedback loop. The frequency of the self oscillation is converted into a DC signal by the FM-Detector, and can then be used for Z-feedback.

To find the optimum settings for a new or unknown sensor perform the following procedure:

- Set the Sensor Controller controls as follows:

Control	Setting
Mode	Self Osc.
Monitor	Dissipation
SetPoint Amplitude	1V
Amplitude Control Gain:	
switch	x100
potentiometer	x1
Phase Shift:	
switch	0°
potentiometer	0°
Range	expected frequency shift range in kHz
Low pass	off
Drive out Gain	x0.1

- Check that the sensor is oscillating: The oscillation should be visible on the oscilloscope and the 'Monitor' display: The Dissipation voltage should not have the maximum voltage of about 13V.

When the sensor is oscillating, continue with section *Optimising the excitation*. Otherwise, monitor the dissipation to check the result of each of the following steps and continue with section *Optimising the excitation* when the sensor starts oscillating.

Sweep the phase shift from 0° to 360°:

- Turn the 'Phase' potentiometer to search for the operating point of the oscillator.

- If adjusting the 'Phase' potentiometer up to 180° does not result in oscillation, switch the 'Phase' switch to '+180' and turn the 'Phase' potentiometer back again (360° -> 180°).

When the oscillation does not start, increase the Amplitude Control gain:

- Turning the Amplitude Control potentiometer to x5 - x8 and increase the Amplitude SetPoint to 5 V.
- Sweep the phase from 0° to 360°.

When the oscillation does not start, increase the excitation:

- Set the ‘Drive out’ switch to x1.
- Sweep the phase from 0° to 360°.

When the oscillation does not start, increase the Amplitude Control Gain and the Set Point Amplitude even further.

If all these steps fail to start an oscillation, measure the amplitude and phase diagram of the sensor to check whether there really is a resonance using the Phase/Frequency plot dialog of the easyPLL software.

PLL Oscillation modes

The PLL Oscillation operation modes use the phase controlling properties of the phase locked loop to follow the resonance frequency of the cantilever: The reference signal from the FM-Detector is phase shifted and amplified/ weakened by the Sensor controller, and then applied to the excitation device. The resulting sensor deflection signal is passed through the Sensor Controller to the input of the FM-Detector. The phase locked loop in the FM-Detector adjusts the reference frequency until the phase shift between the sensor signal and the reference signal is equal to 90°. When the additional phase shift of the Sensor Controller is set properly, the frequency of the reference signal will follow the resonance frequency of the sensor. The frequency of the self oscillation is converted into a DC signal by the FM-Detector, and can then be used for Z-feedback.

In the regulated amplitude mode, an amplitude controller keeps the oscillation amplitude constant by varying the amplification of the reference signal. In the Constant excitation mode, the amplification is constant.

There are two methods for setting up the oscillation. One method uses the Self Oscillating mode to start the oscillation, the other method uses the Phase/Frequency Plot dialog of the easyPLL software. Do not use the self oscillation mode sensors with a Q factor smaller then approximately 500.

Starting the oscillation using the Self Oscillating mode

Use the self oscillation mode to find the appropriate settings for the Sensor Controller:

- Follow the steps in section *Self Oscillating mode*.

Now lock the FM-Detector to the oscillation:

- Start the easyPLL software and click Search.

The PLL should now lock to resonance frequency, indicated by the lighting up of the green ‘Lock’ LED.

- Set the ‘Mode’ switch to ‘PLL Ctrl.’ for the Amplitude Controlled mode, or set the ‘Mode’ switch to ‘Const. Drive’ for the constant drive mode.

The easyPLL FM-Detector may now unlock, which is normal when the phase shift is not yet properly set.

- Sweep the phase until the easyPLL locks in again.

- Continue with the instructions in section *Optimising the excitation*, paying special attention to the proper phase settings.

Starting the oscillation using the Phase/Frequency Plot dialog

Use the following settings on the sensor controller:

Control	Setting
Mode	PLL Ctrl.
Monitor	Dissipation
SetPoint Amplitude	1V

Amplitude Control Gain:

switch	x100
potentiometer	x1

Phase Shift:	
switch	0°
potentiometer	0°
Range	expected frequency shift range in kHz
Low pass	off
Drive out Gain	x0.1

- Start the easyPLL software.
- Open the Phase/Frequency plot dialog by clicking [Phase Plot...].
- Set the Frequency Range from approximately 60% to 140% of the expected resonance frequency, and set an appropriate number of ‘Samples’ and ‘Time/Sample’. High Q sensors need a more samples and a longer measurement time than Low Q sensors.
- Perform the measurement by clicking [Start].
- Select the point where the phase shift changes most using the mouse, and click [Use as CenterFrq].
- Close the Phase/Frequency plot dialog.
- Set the ‘LockRange’ to +- 720Hz.
- Set the ‘Monitor’ switch on the easyPLL FM detector to ‘dF’.

When the sensor is oscillating, continue with section *Optimising the excitation*. Otherwise monitor the green Locked LED to check the result of each of the following steps. When the PLL has locked, continued turning of the ‘Phase Shift’ potentiometer will sweep the ‘dF’ signal through its range. Continue with section *Optimising the excitation* when the sensor starts oscillating.

Sweep the phase shift from 0° to 360°:

- Turn the ‘Phase’ potentiometer to search for the operating point of the oscillator.
- If adjusting the ‘Phase’ potentiometer up to 180° does not result in oscillation, switch the ‘Phase’ switch to ‘+180’ and turn the ‘Phase’ potentiometer back again (360° -> 180°).

When the oscillation does not start, increase the Amplitude Control gain:

- Turning the Amplitude Control potentiometer to x5 - x8 and increase the Amplitude SetPoint to 5 V.
- Sweep the phase from 0° to 360°.

When the oscillation does not start, increase the excitation:

- Set the 'Drive out' switch to x1.
- Sweep the phase from 0° to 360°.

When the oscillation does not start, increase the Amplitude Control Gain and the Set Point Amplitude even further.

When all these steps do not start the oscillation then the sensor has a resonance outside the lock range of the PLL. The PLL can only lock to a frequency $f_{resonance}$ within the following range:

$$CenterFrq - LockRange < f_{resonance} < CenterFrq + LockRange$$

- Set the center frequency to a new value and repeat the steps above in this chapter.

Optimising the excitation

When the resonant oscillation has been successfully established, the Sensor Controller should be optimally adjusted to the resonance of the sensor. The Sensor Controller's setting are optimal when the sensor dissipation is minimal. This is the case when the driving amplitude used by the oscillator circuitry has been minimized (amplitude controlled modes), or when the vibration amplitude has been maximized (constant drive mode).

In the amplitude controlled 'Self Oscillation' and 'PLL Oscillation, controlled vibration' modes:
- Set the 'Monitor' switch on the Sensor Controller to 'Dissipation'.

In the 'PLL Oscillation, constant drive' mode:
- Set the 'Monitor' switch on the Sensor Controller to 'Amplitude'.
- Turn the 'Phase Shift' potentiometer until the monitor displays minimal dissipation.

Now, the sensor oscillates at its resonance frequency with a phase shift between the exciting amplitude and the vibration amplitude of exactly 90°.

It is advantageous when the PLL internally works with relatively high voltages. In the controlled vibration mode, this can be improved by decreasing the ‘Drive out’ gain until the dissipation signal becomes larger than 1V.

Now optimise the speed of the amplitude control.

- Increase the ‘Amplitude Control’ P-gain until the oscillation becomes unstable.

- Reduce the P-gain by about a quarter turn .

We recommend you use the 40 kHz filter on the ‘Detector in’ when using a sensor with a resonance frequency lower than 30 kHz:

- In the ‘Self Oscillation’ mode, a better signal to noise ratio is achieved because the high frequency part of the signal back is not fed back to the sensor.
- In the ‘PLL Oscillation’ nodes, the PLL will not lock to higher order resonances of the sensor.

Important!

The 40 kHz filter causes a slight additional phase shift, therefore optimise ‘Phase Shift’ of the Sensor Controller again after turning on the filter.

Preparing the system for approach / scan

When you have only exchanged cantilevers of the same type between two tip-sample approaches, you can generally use a shorter procedure:

- Start the easyPLL software and click Search to find the ‘CenterFrq’.
- Select a frequency shift as the set point for your experiment using the field ‘OffsetFrq’.
- Minimize the sensor dissipation by changing the ‘Phase shift’ using the procedure in section *Optimising the excitation*.

Now the system is ready to approach and scan.

Lock-in mode

In the Lock-in mode, the sensor is excited by a signal with constant frequency and amplitude. The sensor vibration amplitude and phase are measured, and can be used for Z-feedback. This mode is commonly called tapping or intermittent contact mode. Using the Lock-in is recommended for sensors with low Q factors. With high-Q cantilevers, the amplitude changes very slowly and the scan speed has to be greatly reduced.

When you want to perform Z-feedback on the vibration amplitude:

- Connect the ‘Amplitude’ output of the sensor controller to the error input of the Z-feedback instead of the ‘Output’ of the FM-detector (see Chapter *Installing the easyPLL system*).

- If it was not already connected, connect the ‘dF’ output of the FM-Detector to an Auxiliary input of your scan electronics.

Control	Setting
Mode	Const. Drive
Monitor	Amplitude
SetPoint Amplitude	1V
Amplitude Control Gain:	
switch	x100
potentiometer	x1
Phase Shift:	
switch	0°
potentiometer	0°
Range	expected frequency shift range in kHz
Low pass	off
Drive out Gain	x0.1

- Start the easyPLL software.

- Select ‘Const. Frequency’ using the radio button

The signal at the BNC plug ‘dF’ and ‘Output’ of the easyPLL FM detector should now be interpreted as phase information and no longer as frequency deviation.

- Enter the sensor resonance frequency in the field ‘CenterFrq’
- Set ‘OffsetFrq’ to 0Hz.
- Switch the Sensor Controller’s monitor display to ‘Amplitude’ to show the sensor’s amplitude response at the present frequency.
- Change the value of ‘CenterFrq’ until the amplitude shows a maximum. Thus, the generator frequency is synchronized with the sensor’s resonance. Alternatively, you can use the Phase/Frequency Plot dialog to find the frequency where the phase shift changes most rapidly.
- Set the ‘Monitor’ switch on the FM-detector to ‘Output’ It now shows the sensor signal’s phase shift with regard to the reference signal.
- Turn the ‘Phase Shift’ potentiometer on the Sensor Controller until the Monitor display on the FM-detector shows ‘0.0’.

For your measurment with feedback on vibration amplitude, you can use an operating frequency that is different from the resonance frequency:

- Enter the desired offset from the resonance frequency in ‘OffsetFrq’. Usually a positive frequency shift is set. The offset is chosen so, that the measured sensor vibration amplitude falls to around 90% from its value at resonance.
- Define a set point for the amplitude in your scan software and start the approach.

The Z-feedback loop now uses the amplitude as control input. Additionally the phase can be measured using an ADC channel in your data acquisition hardware.

Troubleshooting

The sensor does not oscillate

This could be due to the amplitude characteristic of the sensor. When the quality factor Q is too small to generate self-oscillation. In this case, use the Lock-in mode

This could also be due to the phase characteristic of the sensor. When this characteristic has more than one 90° transit within the lock range, the lock in may switch between the frequencies at which this transit occurs. This may for example happen when two different torsional vibration modes are coupled to a normal vibration mode.

The approach process stops at once

Check that the polarity of the easyPLL output is set correctly.

The FM-detector unlocks during approach

If possible, operate your system in ‘Self Oscillation’ or the ‘PLL Oscillation, Constant excitation’ mode during approach. If this is not possible, you can write a software procedure that uses the COM-interface of the easyPLL software to automatically search for a resonance frequency after the system has unlocked (see *easyPLL FM-Detector programmers manual*).

Theory of Operation

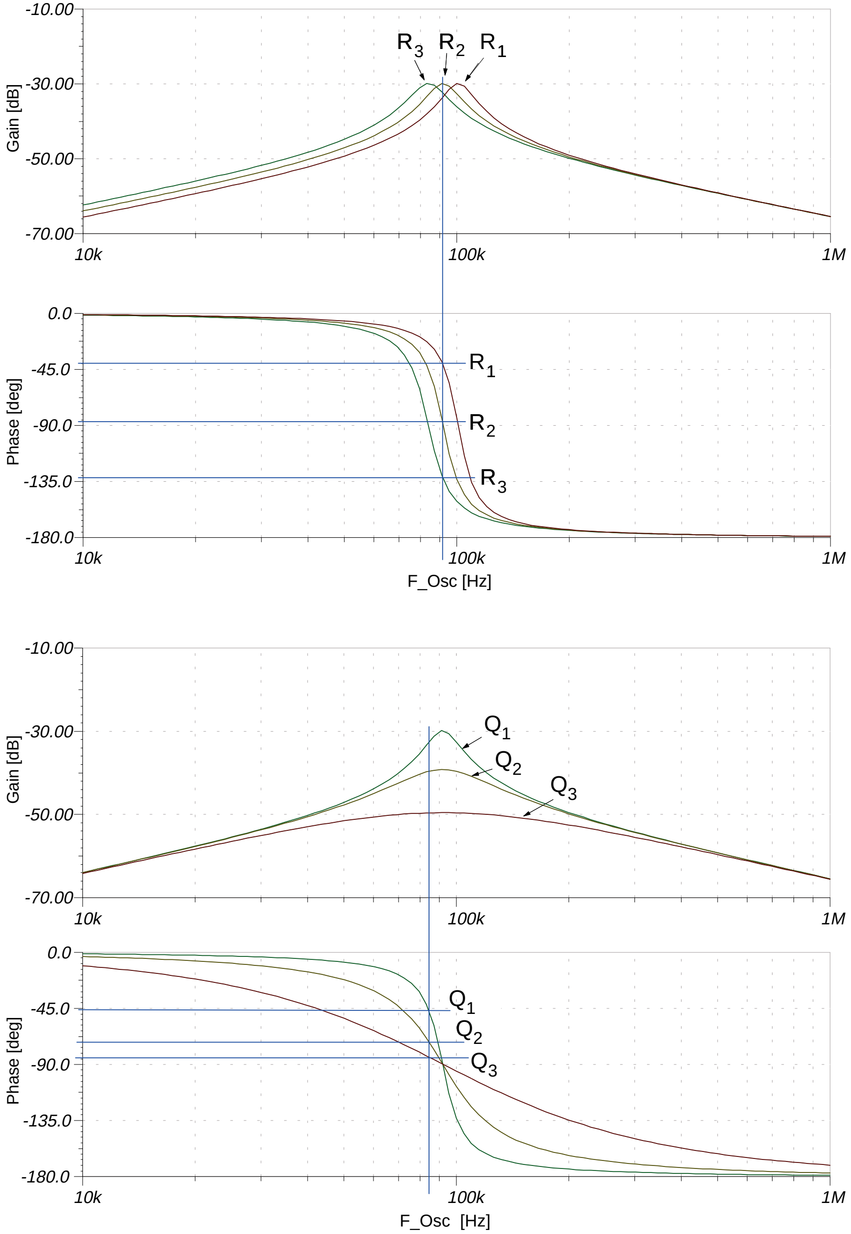
Advantages of the Resonant Oscillation modes

To better understand why the resonant oscillation, or frequency modulation (FM), method is increasingly used, we should first discuss the conventional measurement method.

In conventional AFMs, measurements are performed with constant excitation frequency (e.g. tapping or intermittent contact mode). A sinus generator is used to excite the sensor (cantilever) and the resulting vibration is measured.

The force interaction between the sensor and the sample causes the resonance frequency to shift, and the resulting change in amplitude and the phase response of the sensor can be measured using a Lock-in amplifier. The advantages of this approach are its simple design and application. Nevertheless it has severe drawbacks:

- To increase the sensitivity, sensors with higher quality factors are used. With these sensors, the response time of the amplitude to resonance frequency changes is increased, decreasing the maximum possible scan speed. The response time of the phase is also fast with high quality factors but is not clearly assignable to changes in tip-sample distance and hence is difficult to use for controlling of the tip-sample distance.
- Both the amplitude and the phase signal are a mixture of two pieces of information: firstly the tip sample interaction (distance) and secondly the quality factor of the resonator. Thus a variation of the tip sample distance or a change in the quality factor can’t be distinguished; both may alter the phase response (see figures on the facing page).



Lock-in mode: Changes in resonance frequency and Q factor influence both the measured amplitude and the measured phase.

The resonant oscillation method eliminates these drawbacks. The concept is based on two key elements:

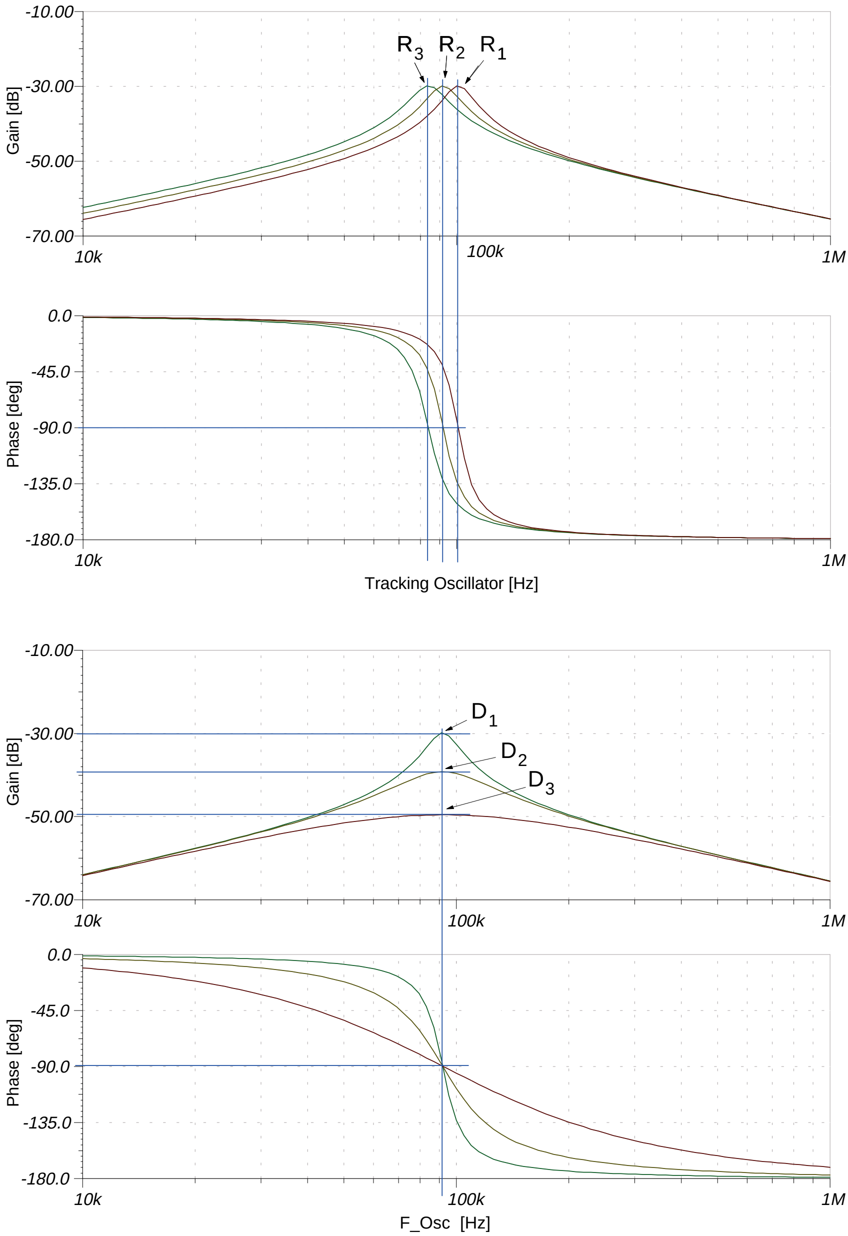
- keeping the phase response constant at exactly 90° using a variable excitation frequency
- controlling the sensor's amplitude

The excitation frequency is a measure for the tip sample distance and the sensor's amplitude damping an independent measure for the sensor's quality factor.

With the FM method, the phase response of the sensor is measured and used for the control of the excitation frequency. The controller sets the excitation frequency so that the sensor always has a 90° phase shift (see figure *Resonant oscillation)*. This is independent of the sensor's quality factor because the resonance curves at different quality factors all intersect at the resonance frequency at a 90° phase shift (see figure *Resonant oscillation*).

The current resonance frequency can now be used as a measure of the tip sample distance and fed into the z-distance controller of the scan electronics. Now the scan speed can be high even with high quality factors because the sensor's phase response for controlling the excitation frequency is very fast also with high quality factors.

An additional amplitude controller measures the sensor's amplitude and keeps it constant by varying the excitation amplitude. When the quality factor changes during scanning, the amplitude controller must also alter its excitation amplitude. Thus, the magnitude of the excitation is a measure for the sensor's quality factor, hence local material properties can be distinguished by recording the output of the amplitude controller.



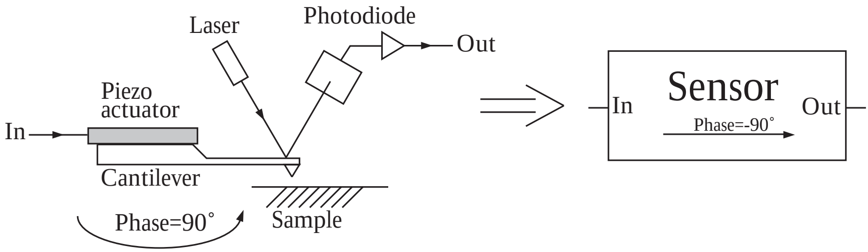
Resonant oscillation: Changes in resonance frequency only influence the tracking, changes in Q factor only influence the amplitude/dissipation

How do the easyPLL modes work ?

In the following, the implementation of the FM method and two different concepts connected to the easyPLL digital FM detector and the easyPLL Sensor Controller are discussed. Each component and its interaction will be explained using simplified block schematics. Complete schematic diagrams of the easyPLL system are provided at the end of this section.

The sensor block acts as a central component which consists of three parts: the excitation that turns the excitation signal into a mechanical vibration, the sensor itself and the detector that converts the sensor's reaction to an electrical signal.

Typical elements used are a shaker piezo as excitation, a silicon cantilever with integrated tip as sensor and a laser deflection system with a split photodiode as detector.



Self Resonance mode

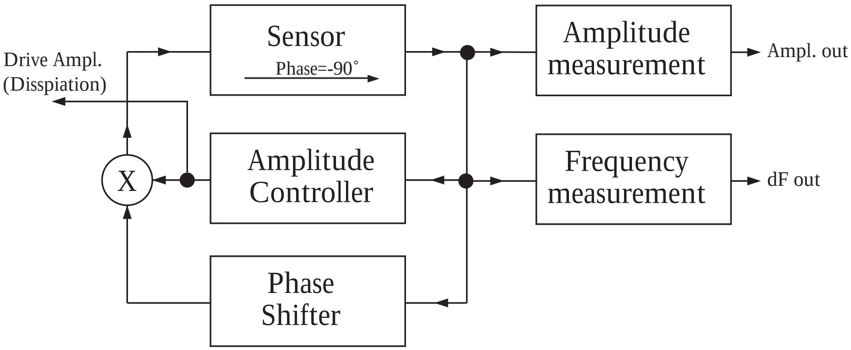
A self resonant oscillator needs no external signal generator for its excitation. The oscillation is generated by feeding the detector's output back to the sensor's excitation. To achieve this, two conditions must be fulfilled: First the multiplied amplification of the sensor element and the feedback element must be equal to 1. Second, the total phase shift of both elements must be 0°.

The feedback element consists of two parts:

- A variable phase shifter which compensates the sensor's phase shift.
- An amplitude controller that keeps the amplification constant by varying the excitation amplitude.

The phase condition of the self oscillator is sustained within a frequency range around the resonance frequency of the sensor.

In order to achieve the desired 90° phase shift of the sensor for the FM-method, the phase shifter in the feedback element must be set so that the amplitude controller can sustain the amplification condition with minimal excitation amplitude. This is because the sensor responds with maximum amplitude to its resonance frequency.



Self Resonance mode

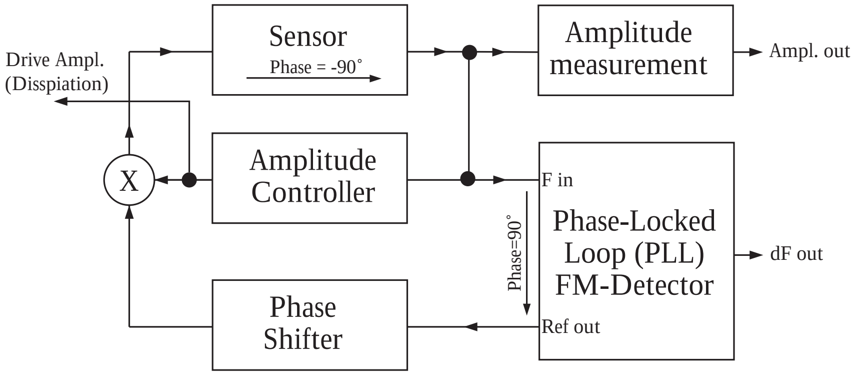
The oscillation frequency changes automatically when the resonance frequency and thereby the phase of the sensor vibration are changed due to tip-sample interactions. With the help of a frequency to voltage converter (e.g. PLL technology) the information for the distance controller can be deduced from the sensor signal. The amplitude controller provides information about the dissipation of the tip-sample interaction.

With high quality factor sensors, the self oscillator will start to oscillate by itself as a result of thermal noise. With systems of low quality factor (like measurements in liquids), starting the self oscillation is a problem, as is the high frequency noise. These drawbacks are solved in the PLL Resonance modes.

PLL Resonance, constant vibration mode

The setup for the PLL controlled resonance with constant vibration amplitude uses a modified Phased-Locked-Loop (PLL) circuit. The PLL frequency measurement device can also supply the excitation signal for the sensor because the input frequency is also generated within the PLL.

This internal frequency signal has a very high spectral purity. It is able to excite the sensor even at low quality factors because of its time integrating characteristics.



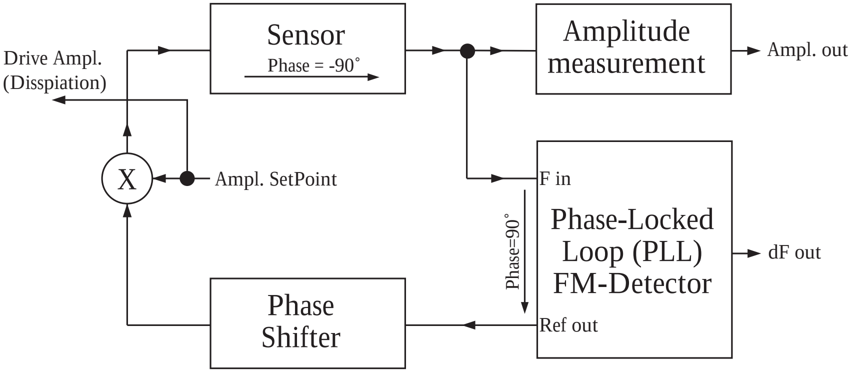
PLL Resonance, constant vibration mode

The frequency generated by the PLL is, on one hand compared to the sensor signal and on the other hand connected via a phase shifter to the excitation device. Additionally, the amplitude of the sensor is kept constant with the amplitude controller.

The PLL controls its output frequency till the phase at the input of the compare circuit equals 90°. The FM method also requires a -90° phase shift in relation to the sensor. To fulfil both conditions the phase shifter has to be set so that the intrinsic phase shifts of the sensor electronics and mechanical components are compensated for. The optimum phase compensation can be deduced from the excitation amplitude. If the amplitude controller operates with minimum driving amplitude then the sensor is oscillating at its resonance frequency and the phase shift equals 90°.

PLL Resonance, constant drive mode

Because amplitude control is neither mandatory nor desired for certain measurements in the PLL operation mode, the amplitude controller in the easyPLL Sensor Controller can be switched off.



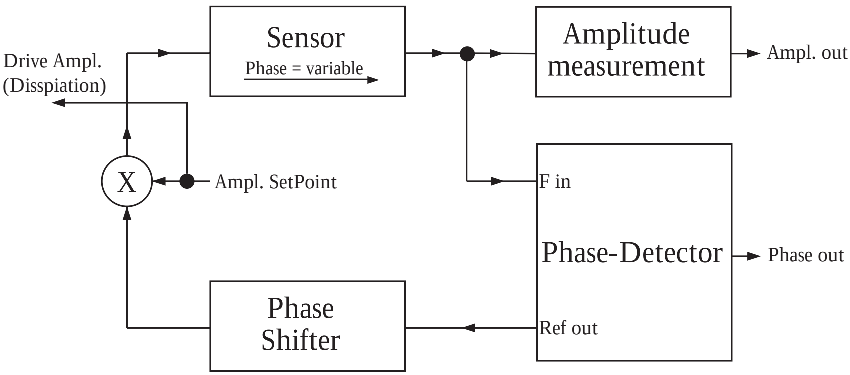
PLL Resonance, constant drive mode

The PLL is simultaneously the excitation generator and the frequency to voltage converter for the z-controller. The amplitude controller provides dissipation information of the tip sample interaction.

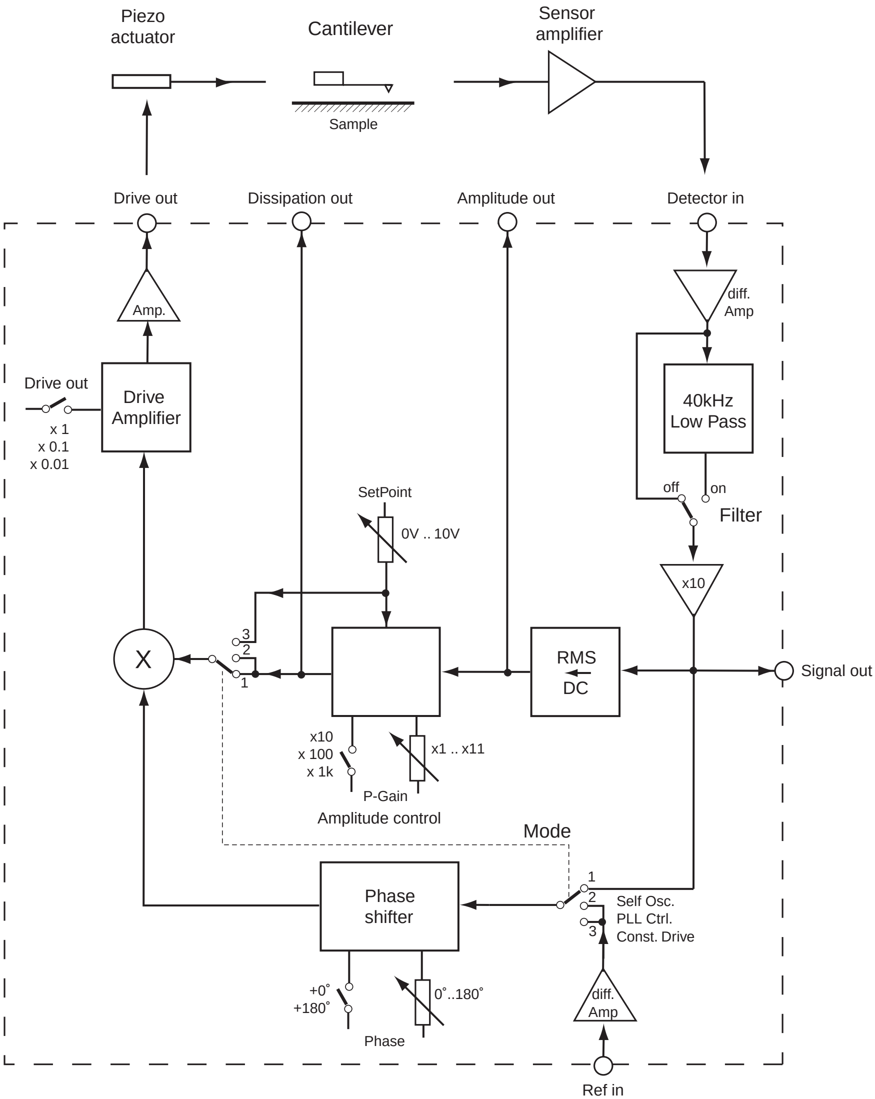
Lock-in mode

To work with low Q sensors the Lock-in mode (also called tapping or intermittent contact mode) with amplitude and phase measurement is useful.

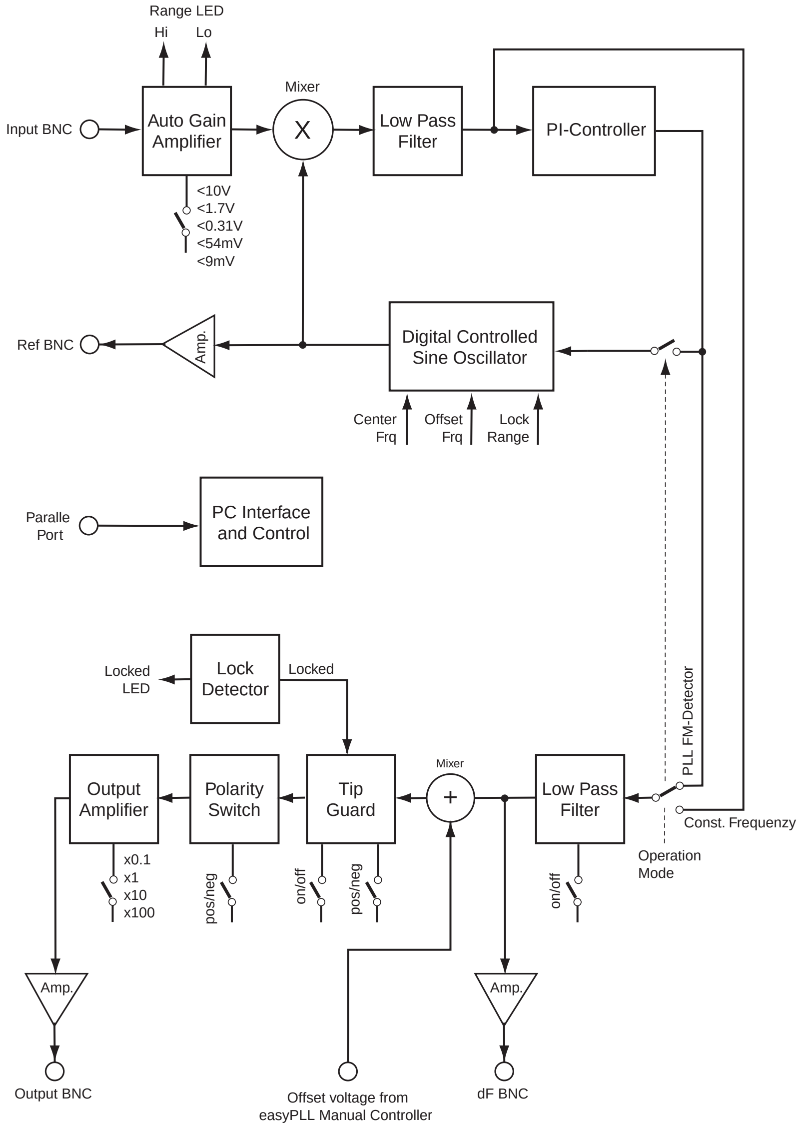
To operate in this mode the amplitude controller is switched off. The easyPLL FM Detector is switched to 'Const Frequency Mode' and acts as a frequency generator to excite the sensor and as a Lock-In Amplifier for measuring the phase response of the sensor.



Lock-in mode



Block diagram of the Sensor Controller



Block diagram of the FM-Detector

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