nanoSurf

easyPLL

DIGITAL FM-DETECTOR

Reference Manual

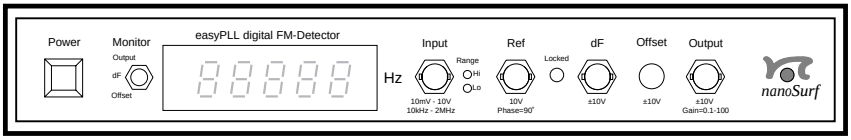


Table of Contents

About this manual

This easyPLL digital FM detector reference manual should be read by anyone who wishes to set up and operate the easyPLL digital FM-Detector. It applies to version 2.5 of the easyPLL software. Users who want to control the easyPLL FM-Detector using external software should refer tot the easyPLL FM-Detector programmers manual, which is delivered in PDF-format on the easyPLL software installation CD.

The easyPLL digital FM-detector

Introduction

The easyPLL digital FM-Detector (short FM-Detector) is an electronic measurement device that outputs an analog voltage which depends on the frequency of a sinusoidal input signal.

The FM-Detector can be used to detect the Frequency Modulation (FM) of the oscillation of a resonating sensor with respect to a fixed reference frequency. The sensor can for example be a quartz tuning fork or an AFM cantilever. The output voltage of the detector can then be used to control an AFM system produced by third parties.

Its patented design that combines analog signal processing with a digital Phase Locked Loop (PLL) allows it to measure this frequency with higher speed, resolution and stability than conventional measurement devices. Moreover, all functionality of the easyPLL is controlled through the easyPLL software, which is installed on a PC with a MS Windows operating system.

Several Nanosurf easyPLL products can be used in conjunction with the FM-detector:

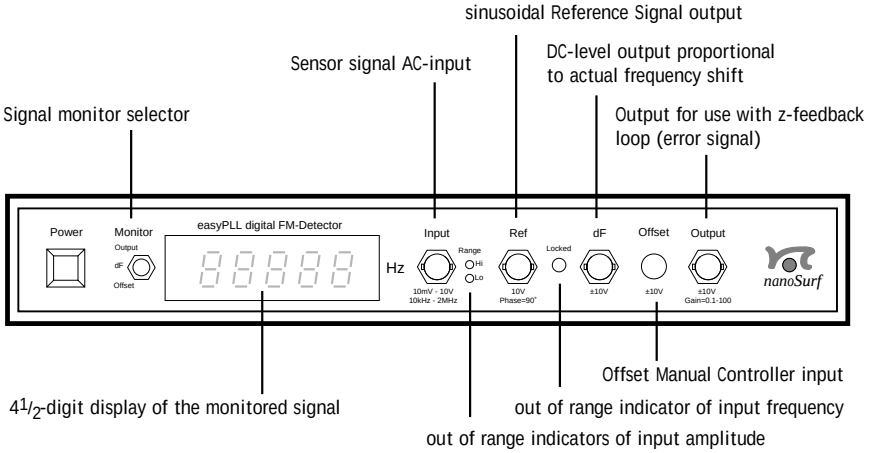
- The 'easyPLL FM Sensor Controller' controls the oscillation of the sensor. The Sensor Controller can either be used when no controller was delivered with the original AFM system, or when you want to increase ease of use and the number of available operating modes: The Sensor Controller uses the 'Ref' output of the FM-Detector to add 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.
- The 'easyPLL UHV preamplifier' was built for amplifying the signal from a Tuning fork sensor that is mounted inside an Ultra High Vacuum (UHV) chamber.
- The 'easyPLL Manual Controller' allows you to change the reference frequency without using the PC.

Technical Data

• Input frequency range.:	10kHz - 2MHz
• Input signal range:	10mV - 10V peak
• Output signal:	±10V / ±1V
• Demodulation resolution:	max 5.5mHz
• Demodulation range:	183.10Hz@5.5mHz resolution 366.21Hz@11mHz resolution 732.42Hz@22mHz resolution
• Demodulation bandwidth:	1.2kHz
• Phase measurement:	0° - 180° ±2.7m° (resolution @90°)
• Output noise level:	$0.3mV_{rms}$ - $3.3mV_{rms}$ (@Gain=1)
• Output sensitivity:	183 mHz/V - 732Hz/V
• Temperature coefficient:	3.5mHz/°C
• Reference output:	10V peak (sine), 90° phase with respect to the input frequency.
• Offset input:	differential ±10V input, 3dB@27kHz Pin1: +10V reference voltage output Pin2: + Offset input Pin3: - Offset input Pin4: -10V reference voltage output Shield: ground
• Power supply voltage:	100 - 230V AC, 50/60Hz
• Power consumption:	13VA
• Control computer:	PC with MS Windows 95 or newer operating system

Connectors and Indicators

The front panel has several BNC connectors for input and output as well as LEDs for quick status overview.



'Monitor' selector

The switch selects the signal to be displayed on the 4½-digit display. The positions correspond to the correspondingly named connectors.

Content of delivery

When first unpacking the instrument, check for the following items:

1 - easyPLL digital FM detector electronics

2 - Software installation CD

3 - Parallel cable for connecting the control electronics to the PC

4 - Mains cable

5 - This manual

Installing the FM-detector

This section gives instructions on the installation of the easyPLL digital FM-detector.

Installing the easyPLL Software

You need a PC with MS Windows 95 or newer operating system in order to install the easyPLL software:

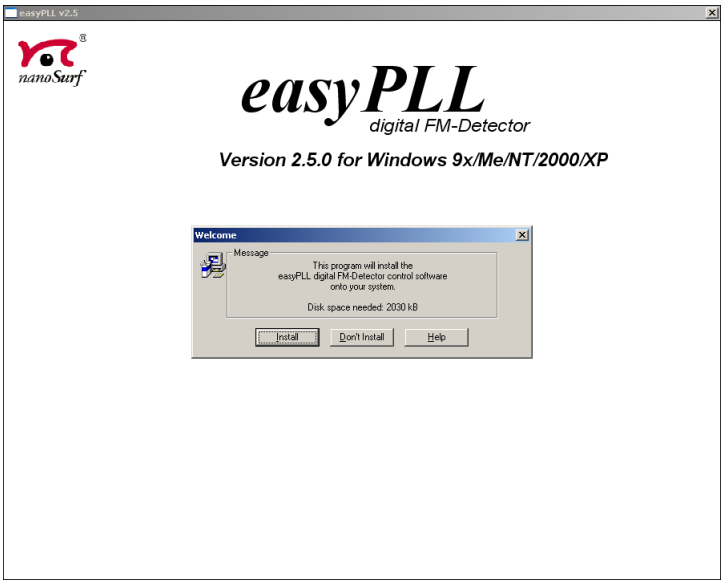
- Turn on your computer and start Windows if necessary.

Important!

- Log in with Administrator rights when your are using Windows NT, 2000, XP or newer.
- Insert the (backup copy of your) installation CD into the drive.

An installation menu should now appear. If this not happen:

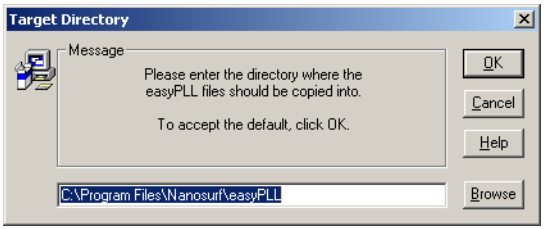
- Open the CD and start the programme 'StartCDMenu.exe'.
- Select 'Install easyPLL software'.



The installation screen now appears.

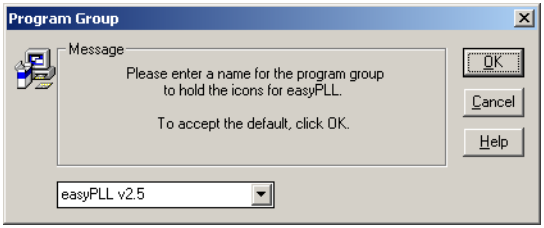
- Click [Install], to install the 'easyPLL' software.

The setup will ask for the directory in which the program files are to be copied:



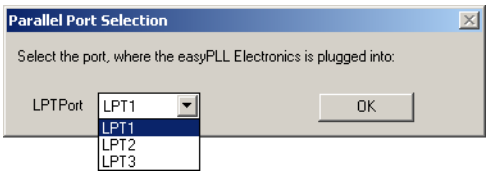
- We recommend putting them in the directory 'Program Files\Nanosurf\easyPLL' by pressing 'OK'.

Afterwards, the setup will ask for the program group in which 'easyPLL' is to be placed:

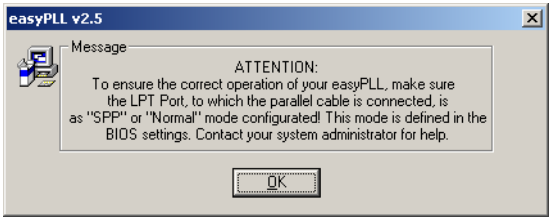


- Accept the program's proposition by pressing 'OK' or type in another name.

The setup will now ask for the 'LPT-Port':

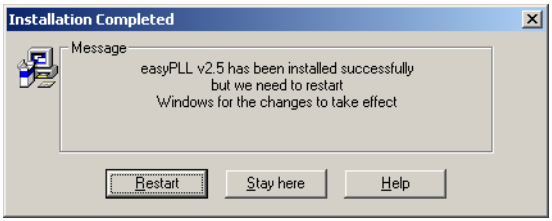


- Select the parallel port to which you have connected the PLL electronics (3). (See section *Assembly*)



Make sure that the parallel port of your PC is configured to either 'SPP-Mode' or 'normal Mode'. This configuration can be set in the BIOS of your PC. Please refer to your PC documentation for help.

- Press 'OK'.



After successful installation you will get this confirmation and find the control program 'easypll.exe' in the directory 'Program Files\Nanosurf\easyPLL'.

Installing the Hardware

This section instructs you on how to set up your FM-Detector. It starts with general instructions, and then continues with instructions for connecting the FM-Detector to the following systems: JEOL, Omicron, PSI, RHK. Software settings are also given for each instrument. If you have another instrument, or have found better settings, please contact Nanosurf or your local distributor.

- Turn off your computer.

- Connect the easyPLL electronics (*1*) to a free parallel port (LPT-Port) on your computer with the parallel cable (*3*).
- Connect the control electronics to the mains with the mains cable (*4*).

Important!

When using the FM-Detector in conjunction with the easyPLL FM Sensor Controller, first install the Sensor controller as described in the *easyPLL FM Sensor Controller*.

Connecting to a generic system

Cables

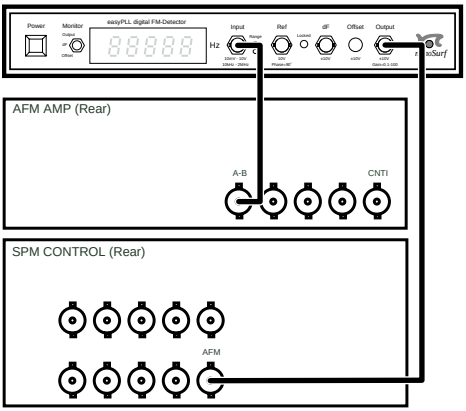
- Connect the (amplified) sensor signal to the 'Input' of the FM-Detector using a 50Ω BNC cable.
- Connect the 'Output' of the FM-Detector to the z-feedback error signal input of your scan control electronics using a 50Ω BNC cable.

easyPLL software settings

Refer to the section *The easyPLL main window, advanced settings* in chapter *the easyPLL software* 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 'Input' of the FM-Detector.
- Connect the 'Output' of the FM-Detector to the 'AFM' input of the 'SPM CONTROL'.

easyPLL software settings

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

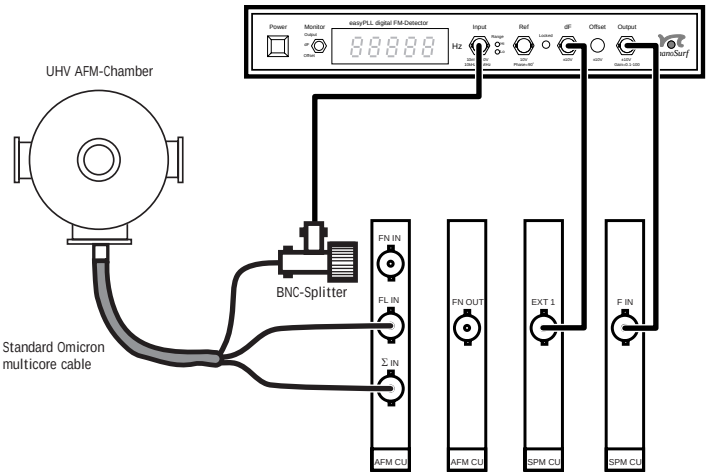
JEOL WinSPM software settings

In the dialog 'Advanced', set the 'STM/AFM box' to 'FM'.

Connecting to an Omicron system

Cables

- Insert a BNC -T connector between the ‘FN’ cable from the UHV system to the ‘FN’ input of the AFM CU.
- Connect the ‘FN’ signal of the BNC-T connector to the ‘Input’ of the FM-Detector.
- Connect the ‘Output’ of the FM-Detector to the ‘F IN’ input on the SPM CU.
- Optionally, you can connect the ‘dF’ output of the FM-Detector 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.

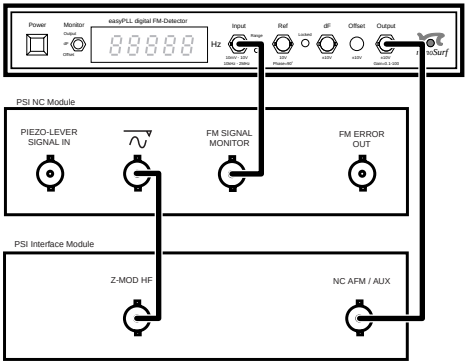
When measuring the dF-Signal using 'EXT 1':

- Open the calibration settings via the menu 'Setup/Edit Hardware/ Miscellaneous Calibration'.
- Enter the following values in the row for EXT 1:
  Name: dF_Digi
  Min: -732
  Max: +732
  Unit: Hz
  Min: -10.0
  Max: +10.0

Connecting to a PSI UHV system

Cables

- Connect the 'FM SIGNAL MONITOR' output of the PSI NC Module to the 'Input' of the FM-Detector.
- 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

You can only use the FM-detector with the RHK SPM1000 system when also using the easyPLL FM-Sensor Controller. Refer to the *easyPLL FM-Sensor Controller Reference* for instructions on setting up the system.

Operating the FM-detector

Important!

Refer to the operating instructions in the *easyPLL FM Sensor Controller reference* manual when the FM-detector is used in conjunction with the easyPLL Sensor Controller.

After installing the easyPLL software, the FM-detector and connecting all necessary cables, you operate the easyPLL as follows:

1. Start the easyPLL software.
2. Start the sensor oscillation:

   Self Oscillation:

   - Proceed according to the instructions of the manufacturer of your sensor controller.

   PLL Oscillation:

   The sensor oscillation is driven using the 'Ref' output. Your electronics must contain a phase shifter between the 'Ref' output and the sensor excitation.

   - Set the 'CenterFrq' in the easyPLL software to approximately the resonance frequency of the sensor.
   - Compensate the phase shift of the sensor by adjusting a phase shifter until the easyPLL locks in and the green 'Locked' LED lights up.
   - Adjust the phase shifter until the amplitude of the sensor excitation signal is minimal, or the sensor vibration amplitude is maximal, depending whether the vibration amplitude is regulated or not.

The system is now ready for approach. Step 3 and 4 should be repeated as part of each approach sequence:

3. Set the center frequency to the free sensor frequency:

   The centre frequency of the easyPLL is normally set to the free resonance frequency of the sensor:

   - Click Search for automatic adjustment, or change the 'CenterFrq' in the easyPLL software manually so, that the value of DeltaF in the Monitor Panel becomes approximately zero.

4. Select a frequency set point for topography imaging:

   Most commercial Z-feedback electronics regulate the tip to sample distance so that the error input of the scan electronics is 0V. If you want to change the set point, You can determine the set point adjust the frequency that corresponds to 0V error voltage. Typical offset values are -30Hz to -1kHz for cantilevers, and -1Hz to -50Hz for tuning forks. The offset can be set either using the easyPLL manual controller or by entering its value in the easyPLL software.

   Manual controller:

   - Set the 'Monitor' switch to 'Offset'. The offset frequency is now shown in the Monitor display.
   - Set the desired offset frequency by turning the knobs on the manual controller.

   Entering the offset in the easyPLL software:

   - Enter the desired frequency shift of the sensor using 'OffsetFrq' in the easyPLL window.

5. Approach the tip and start measuring

6. While measuring, you can adjust the set point as described in step 4.

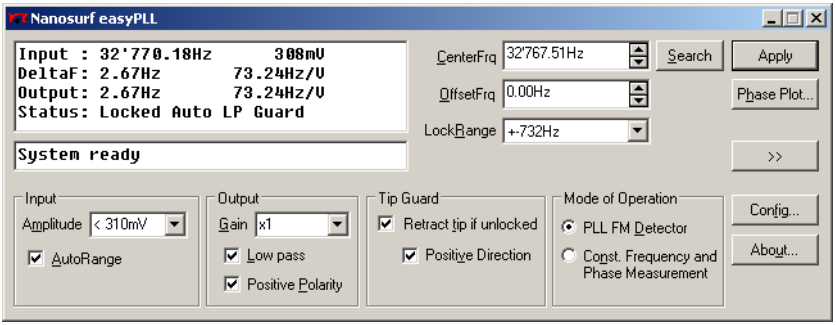
The easyPLL Software

The easyPLL is controlled by the easyPLL software. The functions of this software are described in this chapter.

It is also possible to control the easyPLL Digital FM Detector from other windows software that support 'COM Classes' (in particular the control of 'COM automation server'). This makes it easy to access the full PLL functionality from a customer's home made software, LabView, Visual Basic, Windows scripting, Delphi etc.. The installation includes application examples for LabView and Visual Basic. For more information on how to access the easyPLL functions please refer to the *easyPLL Programmers Manual* which can be downloaded from www.nanosurf.com.

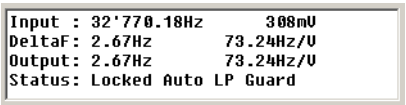
The easyPLL main window

The following window appears when the easyPLL software is started :



easyPLL Panel: main user interface

Status panel



The status panel shows the current values of the most important input and output parameters, and important system messages.

Input: actual input frequency and input range

DeltaF: actual output value of the 'dF' BNC connector and the respective output sensitivity.

Output: actual output value of the 'Output' BNC connector and the respective output sensitivity.

Status: displays the actual system status

- *Locked* - PLL is locked to the input frequency - otherwise 'unlocked').
- *Auto* - if 'Input Autorange' is active
- *LP* - if the output low pass filter is active
- *Neg* - if the output polarity is negative
- *Guard* - if the output 'Tip Guard' feature is on

System Messages:

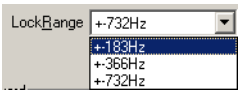
- *System ready* - regular operation
- *Searching...* - appears during frequency sweep.
- *Input amplitude too high* or *...too low*
  The input amplitude exceeds or is under, the value selected in the input section or is over ±10V
- *Input frequency is out of lock range!*
  The input frequency is outside the selected demodulation range around the centre frequency.
- *Hardware not detected*
  The easyPLL has no mains power, the parallel cable is not correctly connected or the wrong parallel port has been selected.
- *Communication down*
  PC has lost communication with the electronics during operation. Either the easyPLL has no main power or the parallel cable is not correctly connected.

General Settings

CenterFrq: To set the centre frequency of the input which is to be measured.

OffsetFrq: To set an offset frequency to be added to the Output signal.

LockRange: The frequency range within which the deviation of the centre frequency is tracked. This also determines the sensitivity of the frequency measurement.



LockRange	Resolution
±183Hz	5.5mHz
±366Hz	11mHz
±732Hz	22mHz

Search: Clicking Search starts a frequency sweep in the search range. The status panel shows 'Searching...'. If the easyPLL could lock in, the message 'System ready' appears. If the easyPLL is not able to find the frequency at all, a Windows dialog box appears with a message to adjust the search range. The search range is defined in the configuration dialog (see below).

Apply: Keyboard entered values have to be confirmed by clicking this button with the mouse pointer, or by pressing the 'Enter' or 'Return' key on the keyboard.

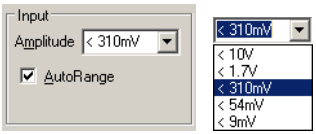
Values altered by using the arrow buttons or the cursor keys on the keyboard are automatically confirmed.

Phase Plot...: Opens the Phase/Frequency plot dialog (see section *Phase/Frequency Plot Dialog*).

>> / << : Shows/Hides the advanced settings part of the easyPLL software.

Advanced Settings

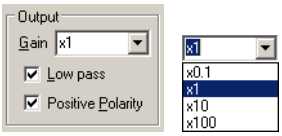
Input



Amplitude: To set the sensitivity of the input amplifier circuit.

AutoRange: To automatically set a suitable sensitivity for the input amplifier circuit.

Output

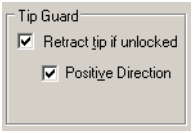


Gain: Sets the sensitivity of the output amplifier circuit (maximum output range is ±10V).

Low Pass: Select this check box to turn on a 2nd order low pass filter at 300Hz.

Positive Polarity: Select this box to determine the sign of the output signal and to adjust it to your feedback system. A positive polarity means that by increasing input frequency the output signal rises.

Tip Guard

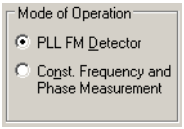


Select the behaviour of the system if the PLL circuit can no longer lock into the input frequency in order to prevent the tip from crashing. In this case the output is set to the maximum to force the z-feedback controller to retract the tip from the surface.

Retract tip if unlocked: Select this check-box to turn on the 'Tip Guard' feature.

Positive Direction: Select this box to ensure the output signal is positive if the system becomes unlocked.

Mode of Operation



PLL FM Detector: Select this mode to set the electronics in the frequency measurement mode. The sine wave's frequency at the 'Ref' BNC follows the input frequency.

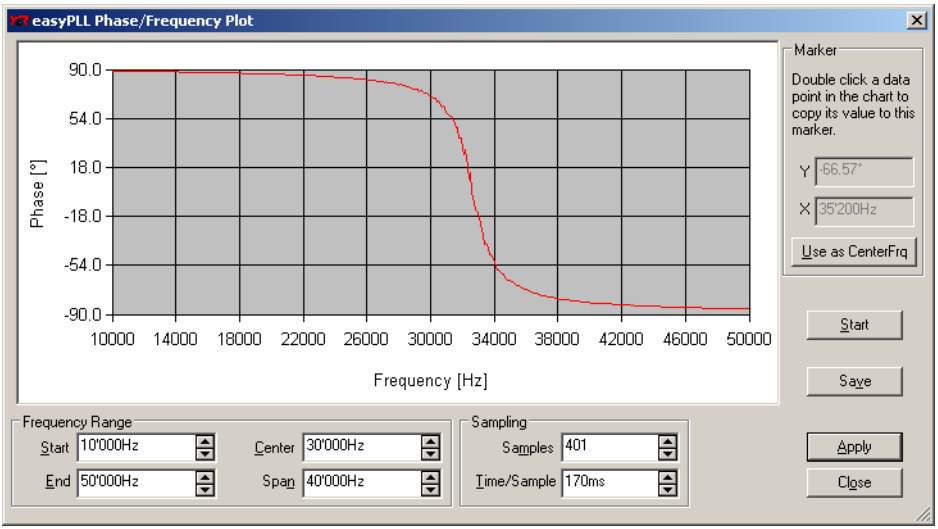
Const. Frequency: Select this mode to set the electronics in the phase measurement mode. The frequency generated at the 'Ref' BNC is the sum of 'CenterFrq' and 'OffsetFrq'.

For more details on the two operation modes, refer to chapter *Function Principle*.

Config...: Opens the configuration dialog (see section *Configuration Dialog*).

About...: Displays the about dialog box. Here you find the version number of your easyPLL software.

Phase/Frequency plot dialog



The Phase/Frequency Plot dialog can be used to measure and plot the phase/frequency spectrum of your sensor. You can use this plot to identify the resonance frequencies of your sensor, and manually select one frequency as Center frequency in the easyPLL main window. This can be used to find the resonance frequency of a high-Q sensor, when it is not found by the automatic search algorithm. This dialog can also be used when your sensor has several resonance frequencies, and you want to use a different resonance frequency to the one found by clicking Search.

General Settings

Start: Start measuring the Phase/Frequency plot.

Save: Save the measured frequency/phase points in a text file.

Apply: Change the settings to the recently entered values

Close: Close the Phase/Frequency plot dialog.

Frequency Range

You can define the frequency range for the plot by either entering the values of 'Start' and 'End', or by the entering the values of 'Center' and 'Span'. The other value pair is adjusted automatically according to the latest entry. Sometimes the both pairs will be adjusted because the entry is physically impossible, for example setting 'Span' larger than half the value of 'Center'.

Sampling

Samples: The number of frequencies at which the phase shift is measured.

Time/Sample: The time that the easyPLL waits between changing the excitation frequency and measuring the phase. Its value should be of the order of the Q factor divided by the resonance frequency of the sensor.

Marker

The Marker allows you to change the CenterFrq in the easyPLL main window:

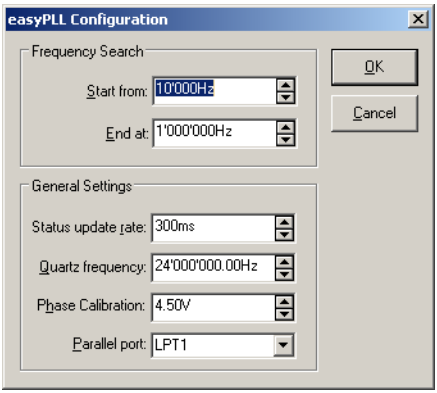
- Move the mouse cursor over the Phase/Frequency plot to the position of the desired CenterFrq. When the cursor is over a measured point, the measured values are displayed in a small window.

- Double-click on the desired measured point. The measured point is now displayed in the X and Y display.

- Click 

to use the displayed point as CenterFrq.

Configuration dialog



Frequency search

The frequency range in which the resonance frequency is searched for when clicking Search. The search range must be within 10kHz and 2MHz.

General settings

Status update rate: Rate at which the PLL's status panel is updated. This rate lies in the range from 10ms to 1000ms.

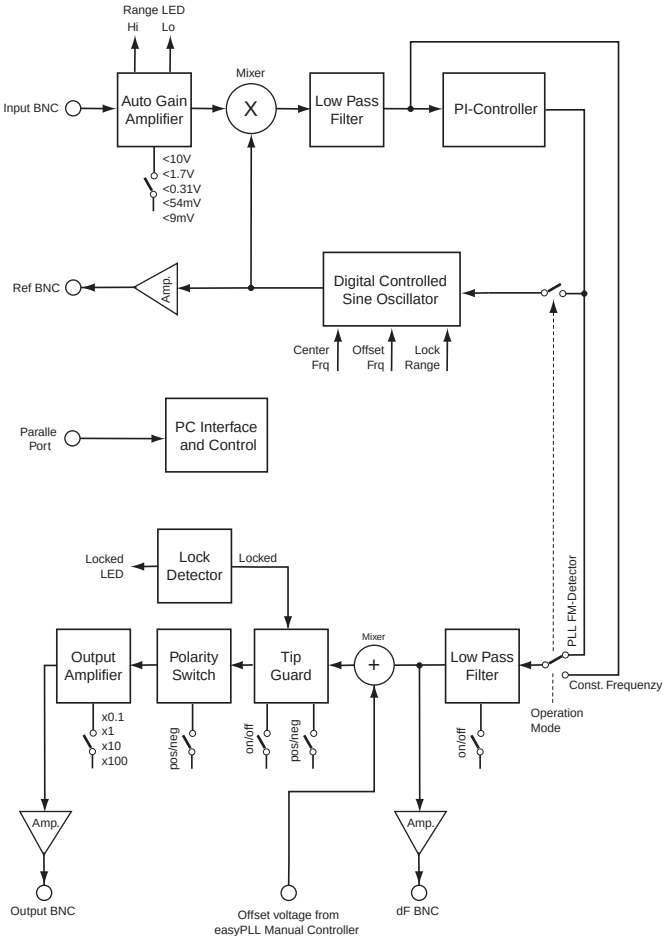
Quartz frequency: The internal reference clock speed. This value is set automatically during installation and rarely needs adjusting. For fine adjustment of the PLL only.

Phase calibration: the internal phase measurement peak value. This value is set automatically during installation and rarely needs adjusting. For fine adjustment of the PLL only.

Parallel port: The parallel port used for the communication between PC and electronics.

Theory of Operation

The radio button ‘Mode of Operation’ determines the operating mode: With the setting ‘PLL FM-Detector’, the electronics is set to operate as Phase Locked Loop to measure the frequency with very high accuracy. With the setting ‘Const. Frequency’, the electronics is configured as a frequency generator with lock-in amplifier for phase measurement.

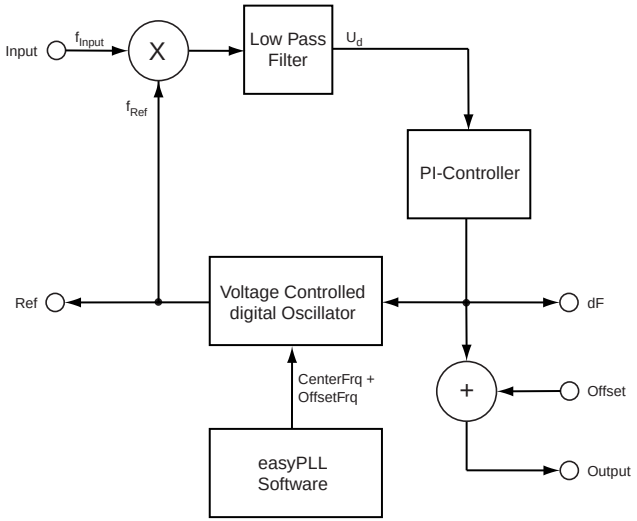


Schematic of easyPLL digital FM detector.

Together with the easyPLL FM Sensor Controller, all common and some uncommon dynamic AFM modes are available.

Operation Mode 'PLL FM-Detector'

The easyPLL is an electronic regulatory circuit which synchronizes the reference signal of frequency f_{Ref} and phase ϕ_{Ref} of a voltage controlled digital oscillator (VCDO) with a sinusoidal input signal of frequency f_{Input} and phase ϕ_{Input} in frequency as well as in phase. In the synchronised or locked state, the phase shift between the reference signal and the input is constant at 90°.



Principle of easyPLL circuit

The multiplier together with the low pass filter form the 'phase detector' device. This measures the phase relation between two input signals. The output voltage, U_d, of the phase detector corresponds to

$$U_d = \cos(2\pi(f_{Input} - f_{Ref})\ t + \phi_{Input} - \phi_{Ref})/K_d \quad .$$

The output of the phase detector is fed back to the reference frequency generator through a PI-controller. The PI-controller is equipped with proportional and integral amplifiers and generates a frequency control

voltage U_{dF} that causes proportional changes in f_{Ref}. The control voltage is stable when the input and the reference signal have the same frequency and a 90° phase difference ϕ_{Input} - ϕ_{Ref}.. When both frequencies are the same, and a 90° has been reached, the loop is 'locked' This function principle is also called Phase-Locked-Loop (PLL).

To demonstrate the phase locking capability, lets assume that the input and the reference frequency are the same, but the phase difference is larger than 90°. U_d becomes negative and the controller will increase the reference frequency until the reference has 'caught up' in phase with the input, and the U_d becomes zero.

To demonstrate the frequency synchronising capability, assume that the phase difference is 90°, and f_{Input} becomes larger than f_{Ref}. Again the output U_d becomes negative and the controller will increase the f_{Ref} until the reference is again the same as f_{Input}. In the following, we assume that the PLL is locked, and $f_{Ref} = f_{Input}$.

The signal U_{dF} is output at the BNC connector 'dF'. The relation between U_{dF} and f_{Input} is:

$$U_{dF} = (f_{Input} - \text{'CenterFrq'} + \text{'OffsetFrq'})/ K_{DeltaF} .$$

'CenterFrq' and 'OffsetFrq are entered in the easyPLL software. The values of U_{dF} K_{DeltaF} and the responsivity K_{DeltaF} are displayed in the status message area of the easyPLL software under 'DeltaF'. The value of K_{DeltaF} and thereby the maximum detuning of the reference frequency generator depend on the setting of 'LockRange': The frequencies in the LockRange are mapped to the +/-10V output range.

In addition to the dF connector, the FM-detector has an 'Output' connector that is meant to be used as the error signal for a Z-feedback loop. Its output voltage, U_{Output}, is given by

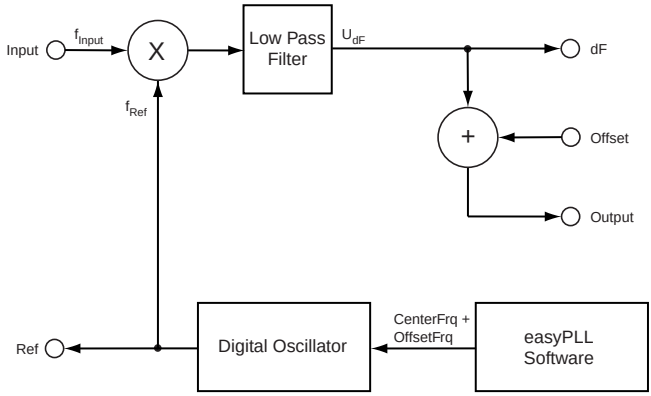
$$U_{Output}=(f_{Input} - \text{'CenterFrq'} + \text{'OffsetFrq'} + \text{'Offset'})/K_{Output} .$$

The responsivity K_{Output} of the output is also displayed in the status message area under 'Output'. The 'OffsetFrq' in the easyPLL software and the signal from easyPLL manual controller, connected to the 'Offset' connector can be used to determine the frequency set point of the Z-feedback loop. Also, the Tip Guard feature can be used to protect the

sensor. For example, when the PLL unlocks due to the AFM touching the sample surface, the Tip Guard will set the Output signal so that the Z-feedback loop pulls away from the sample.

Operation Mode 'Const. Frequency'

In operation mode 'Const. Frequency' the PI-controller loop is opened and the easyPLL FM detector electronics operates as a digital sine wave generator that excites the sensor, and as a Lock-In amplifier that determines changes in the phase shift between the input signal and the excitation signal. Together with the easyPLL FM Sensor Controller, an amplitude and phase measurement system can be set up that can be used for AFM operating modes also known as tapping or intermittent modes with phase contrast.



Principle of const. freq. mode

The feedback loop from the phase shift to the reference frequency can now be disabled, because the signal frequency is the same as the reference frequency: f_{ref} = 'CenterFrq' + 'OffsetFrq'. The output of the phase detector is now directly connected to the 'dF' BNC connector. The voltage at the 'dF' BNC is

$$U_{dF} = \cos(\phi_{Input} - \phi_{Ref})/K_{dF} \quad .$$

For small phase differences around 90° this relation becomes approximately:

$$U_{dF} = (\phi_{Input} - \phi_{Ref})/K_{dF} \quad .$$

The voltage at the 'Output' BNC is then

$$U_{Output} = (\phi_{Input} - \phi_{Ref})/K_{Output} + U_{Offset} \quad .$$

The responsivities K_{DeltaF} and K_{Output} of the output signals in deg/V are displayed in the status message area of the easyPLL software panel of the corresponding output.

The software and the signals at the BNC connectors refer always to a 90° phase shift. Hence 0V or 0° means a phase shift between input and reference of 90°. The input signal may differ ±90° from this reference. When the input signal is within these limits, the 'locked' LED of the easyPLL FM detector is on and the software displays the current phase shift.

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