NANOANDMORE

Reference Manual

Tuning Fork Sensor Controller

Version 1.4

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Important notes

Operating conditions:

- Indoor use only
- Altitudes below 2000m
- Ambient temperature in the range 5-40°C
- Maximum relative humidity 80% at up to 31°C, linearly decreasing to 50% at 40°C
- Maximum deviations in the power supply up to ±10% from the 100-230V~ 50/60Hz
- Power supply with transient overvoltages category II
- Ambient atmosphere with rated pollution degree 2

Installation instructions:

- The device must be connected to a 100-230V~ 50/60Hz power supply with protective grounding.

Operation manual:

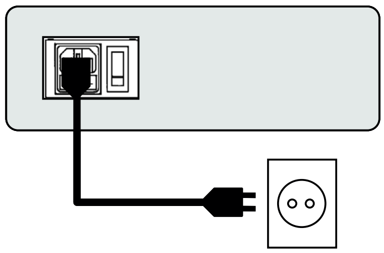
- The device must be positioned in such a way that the connectors at both ends of the power supply cable are easily accessible.
- The external surface of the device can be cleaned with a dry piece of soft cloth only. Do not use corrosive or easily combustible solvents!
- Never use the device for other than its intended purpose! NanoAndMore will assume no responsibility for accident or malfunction caused by improper use.

Maintenance:

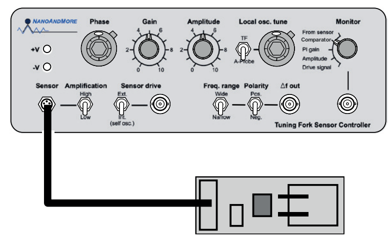
- No periodic maintenance by the manufacturer or an appointed repair representative is required.
- The fuse is F 2.0A 250V

Quick and simple training

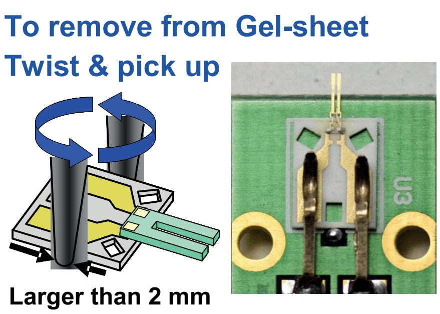
This simple training is for new users to become familiar with the Tuning Fork Sensor Controller. In this example, a tuning fork sensor from NanoAndMore is used.



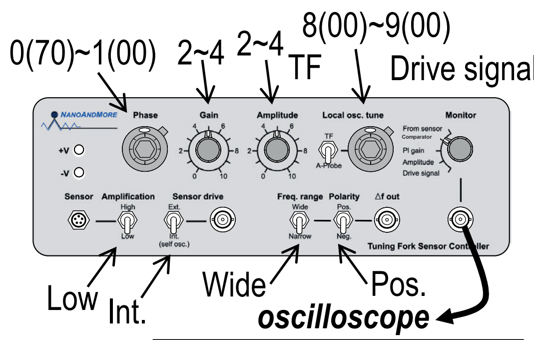
(1) Power connection



(2) Preamp connection



(3) Sensor in the holder



(4) Set knobs and power ON

1) Obtain a sine wave

Please follow the steps above in the described order. Normally, a sine wave should appear on the oscilloscope. If not, please follow the main part of this manual.

2) Experience how the oscillation changes by turning the knobs

The next step is to play with the "Phase", "Gain", and "Amplitude" knobs and to look how the oscillation changes. The knobs have to be turned one after the other as described below.

- "Phase": Amplitude of the sine wave on the oscilloscope visibly changes. There is a minimum amplitude point, which is the resonance of the sensor and the optimum setting.
- "Gain": If the gain is increased too much, the oscillation becomes unstable.
- "Amplitude": Amplitude of the sine wave visibly changes. Depending on the amplitude setting, the optimum position of the "Gain" knob is different.

3) Gently stimulate the TF sensor

Gently stimulate the TF sensor, e.g., by blowing on the sensor, and watch how the oscillation changes.

Next steps: To use the frequency measurement function and/or to know more about the controller, please read the main part of the manual.

Table of contents

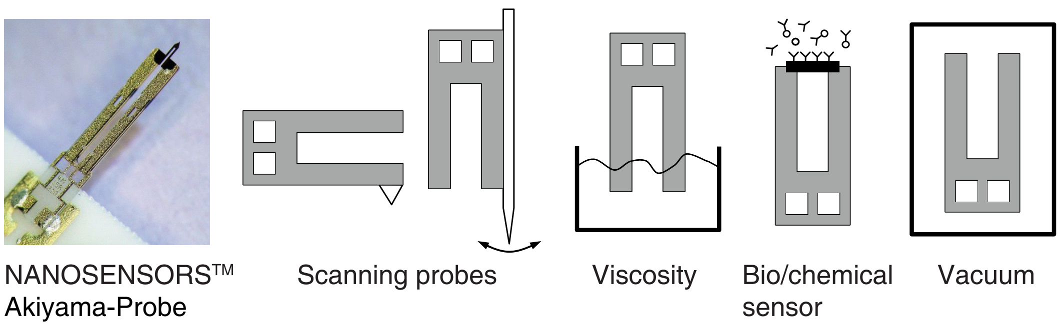
Content of package

- Tuning Fork Sensor Controller
- Preamplifier board with sensor holder
- Controller-to-preamplifier cable
- Controller-to-power supply cable
- Printed version of this manual

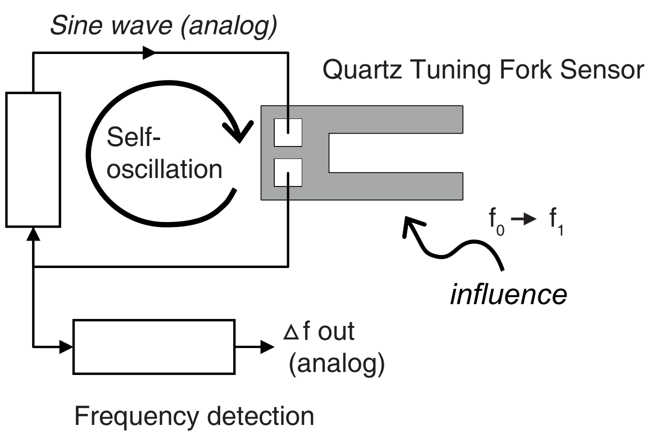
**This product is an electrostatic sensitive device.
Please adopt maximum countermeasures to avoid ESD (Electrostatic Discharge).**

1. Introduction

Commercially available “watch crystals”, with a resonance frequency of 32.768 kHz, are of great interest for various sensing applications such as Scanning Force Microscope (SPM), Atomic Force Microscope (AFM), viscosity/vacuum measurements, bio/chemical sensing, e.t.c.



Most of these sensors are based on a simple working principle: A quartz tuning fork is self-oscillating at its resonance frequency. As soon as an external force, an “influence”, or an environmental change is applied on the tuning fork, the self-oscillation frequency changes. By measuring the frequency shift, one can obtain quantitative information of the analyte.



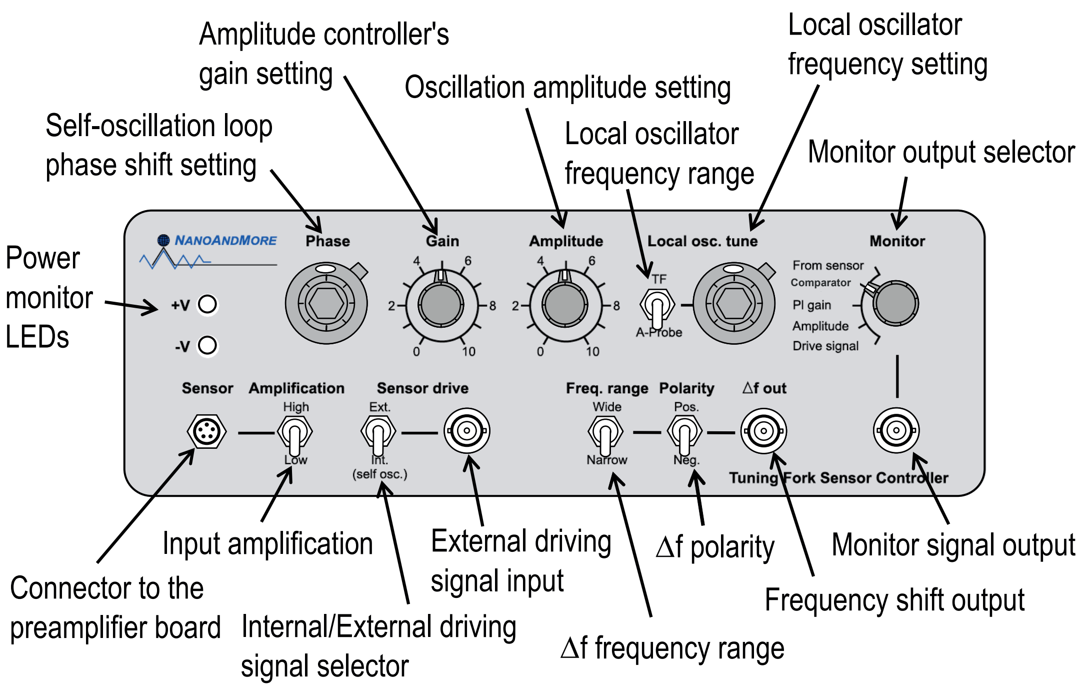
The ***NanoAndMore Tuning Fork Sensor Controller*** is an electronic device to (i) control the self-oscillation of a quartz tuning fork based sensor and to (ii) measure its frequency.

The circuit parameters are particularly optimized for AFM applications with the NANOSENSORS™ Akiyama-Probe (see photo above). However, the ***NanoAndMore Tuning Fork Sensor Controller*** can be applied for other sensors based on the same type of quartz tuning fork.

The ***NanoAndMore Tuning Fork Sensor Controller*** in conjunction with the preamplifier included in the package can self-excite a quartz tuning fork sensor at its resonance frequency. The sensor is driven by an analog signal (normally a sine wave), and the vibration amplitude of the tuning fork is kept at a setpoint by a feedback loop. The phase-locked loop (PLL) of the ***NanoAndMore Tuning Fork Sensor Controller*** measures the self-oscillation frequency and yields an analog output.

2. Knobs and connectors

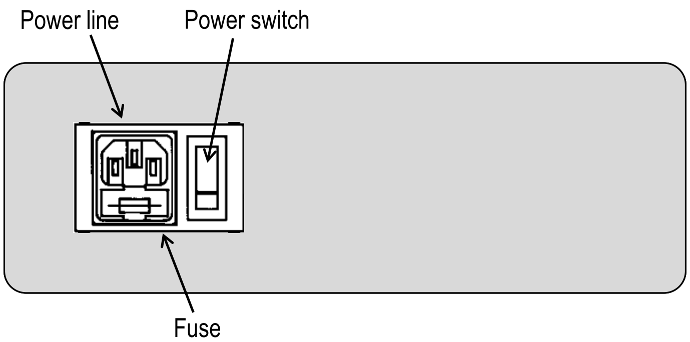
The front panel



- +V, -V : monitor of DC power on the board
- Sensor : Terminal to be connected to the preamplifier board with the provided cable.
- Amplification : Set amplification for the signal from the sensor, High (×10) or Low (×2.4)
- Sensor drive : Select the driving signal to the sensor, either an external signal supplied to the BNC on the side or an internal signal for self-oscillation. (Important: The signal applied on the terminal should be limited between -10 V to +10 V.)
- Phase : Control the phase shifter in the self-oscillation loop
- Gain : Control gain of the amplitude controller in the self-oscillation loop
- Amplitude : Set the signal amplitude to be maintained in the self-oscillation loop
- Local osc. tune: Set the local oscillator frequency, The selector changes the tunable frequency range: TF (27.4 kHz ~ 37.9 kHz), A-Probe (37.6 kHz ~ 60.4 kHz) (± 1 kHz variations in different units)
- Δf out : Frequency shift output terminal. The output range is from -10V to +10V.
- Freq. range : Demodulation frequency range, Wide = ± 2077 Hz (± 150Hz variations in different units), Narrow = ± 405 Hz (± 30Hz variations in different units)
- Polarity : Pos. (sensor frequency UP-> Δf out UP), Neg. (sensor frequency UP -> Δf out DOWN)
- Monitor : Select one of the signals at different points in the self-oscillation loop. The output range of the monitor terminal is from -10V to +10V.

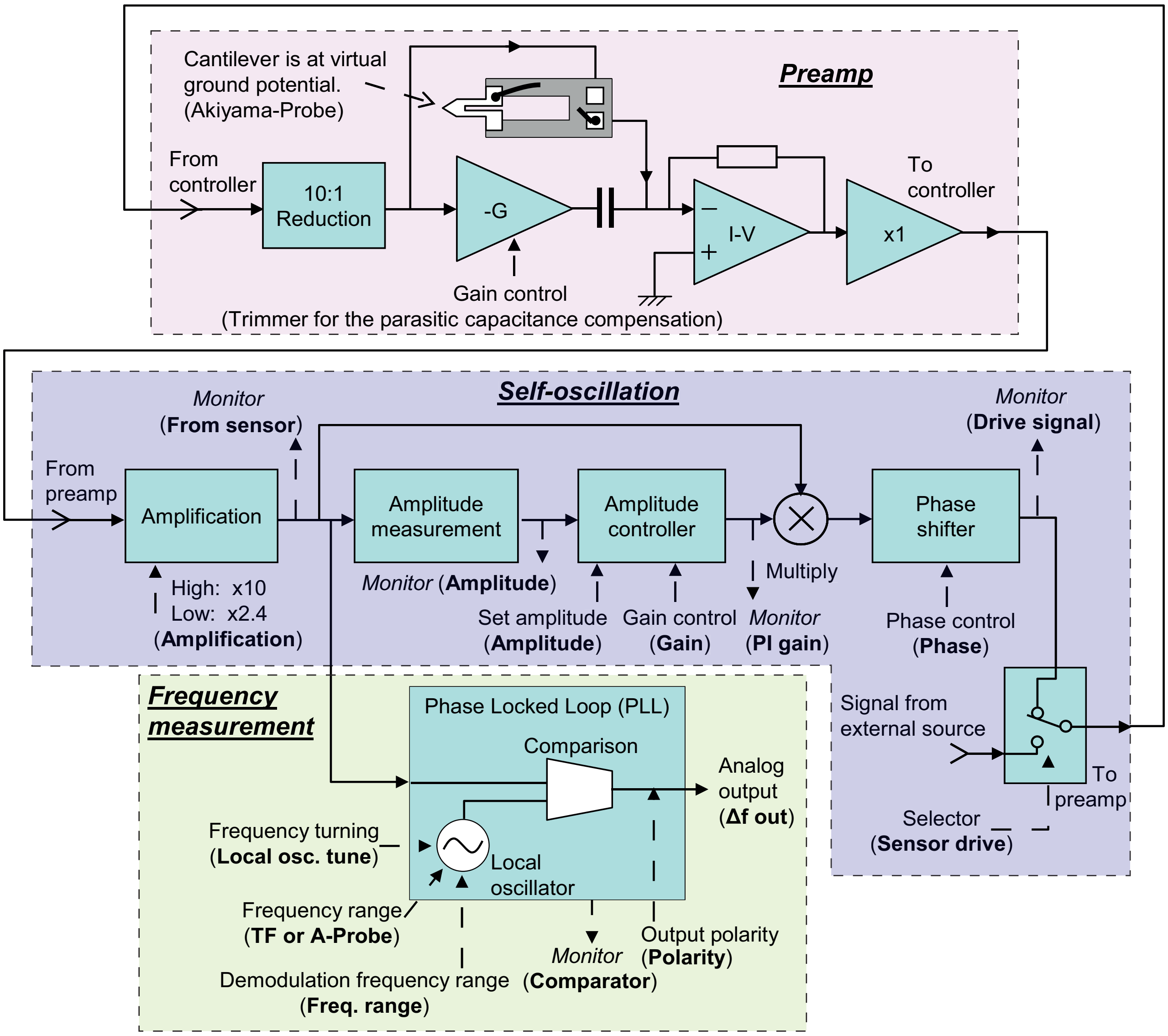
The back panel

On the back panel, there are the power entry socket, the fuse box, and the power switch. The AC power supply should be 100-230V~ 50/60Hz. The fuse is F 2.0A 250V. When the proper DC power is supplied on the internal circuit board, the LEDs on the front panel illuminate.



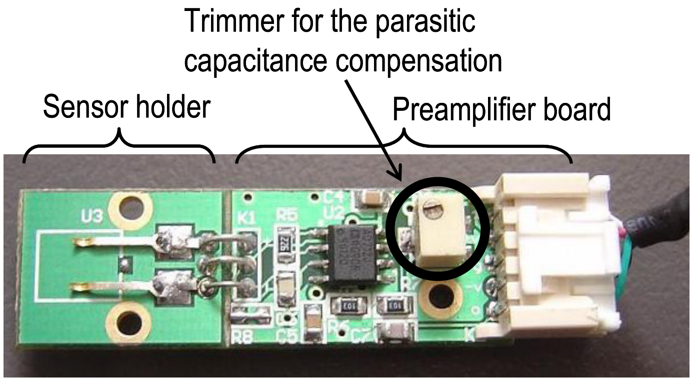
3. Description of Tuning Fork Sensor Controller system

The following figure shows the overall system of the NanoAndMore Tuning Fork Sensor Controller (TFSC). The electronics in the TFSC box consist of two circuit blocks. One is a self-oscillation block which forms an electrical loop together with the preamp (separate unit) to enable a self-oscillation of a quartz tuning fork (TF) at its resonance frequency with constant amplitude. The other block is a frequency measurement unit including a Phase-Locked Loop (PLL) circuit.



Sensor holder

The preamplifier board and the sensor holder are fabricated on a single PCB. The sensor holder is designed for mounting the ceramic plate of the NanoAndMore TF sensor and NANOSENSORS™ Akiyama-Probe. The sensors with the ceramic plates can be easily slipped in the slot and held on the spot. The two spring pins provide the in/out signals to/from the TF. The sensor holder can be separated from the preamplifier board by cutting the PCB and mounted apart, if this is preferable. The three electrical connections, however, should be as short as possible.



--- Preamplifier board and sensor holder ---

In order to perform an accurate measurement with a TF sensor, only the piezoelectric current must be measured. The base current flowing through a parasitic capacitance related to the sensor must be compensated. This is done by adjusting the trimmer on the preamplifier board.

> **!!! Important note !!!**
>
> The preamplifier and sensor holder board are not shielded from external electromagnetic disturbances. They should be used inside of an electromagnetically shielding enclosure.

Preamplifier board

At the first stage of the preamplifier board, the TF driving signal coming from the TFSC is attenuated by a factor of ten. The signal is then supplied to the TF sensor as well as the parasitic capacitance compensation line. The outputs from both lines are summed such that only the piezoelectric-current of the TF is amplified by current-voltage converter. The output is buffered at the final stage on the board and fed to the TFSC.

In case of the Akiyama-Probe, the silicon cantilever and tip are electrically connected to the left pad of the ceramic plate through one of the electrodes of the TF. Upon mounting the Akiyama-Probe on the sensor holder, the left pad is connected to the virtual ground terminal of the current-voltage convertor. Consequently, the cantilever and tip have the virtual ground potential.

Self-oscillation block

A signal from the preamp is amplified at the first stage. The amplification can be set either High (×10) or Low (×2.4). The first choice should be Low. If the Q factor of the sensor is very low and a self-oscillation cannot be obtained, one needs to select the high amplification. The amplified signal can be monitored from the monitor terminal, by selecting “From sensor.”

At the second stage, the amplitude of the amplified signal is measured. The measured value can be monitored as “Amplitude.” The amplitude controller at the following stage includes a proportional-integral (PI) regulator and maintains the measured amplitude at a constant value set by the “Amplitude” knob. The gain of the amplitude controller is set by the “Gain” knob. The output from the amplitude controller can be monitored from the monitor terminal, by selecting “PI gain.”

The amplified signal at the first stage and the amplitude controller output are multiplied and fed to a phase shifter. A certain phase shift controlled by the “Phase” knob is applied to the signal. The yielded signal can be monitored as “Drive signal.” Finally, the signal is fed to the preamp through the “Sensor drive” switch.

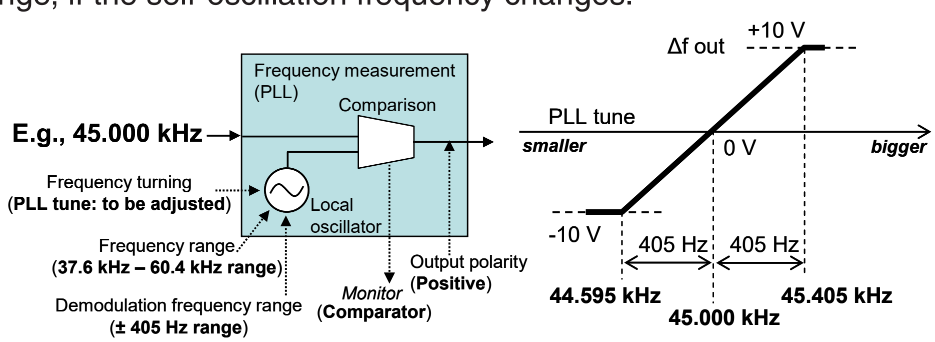
It is possible to apply an external driving signal to the sensor through the “Sensor drive” terminal.

Frequency measurement block

The frequency measurement block includes a Phase-Locked Loop (PLL) circuit. It measures the self-oscillation frequency and generates an analog signal proportional to a difference between the self-oscillation frequency and an internal reference. The frequency of the internal reference is set by the “Local osc. tune” knob and the range selector.

This frequency measurement block is independent from the self-oscillation loop. It does not influence the self-oscillation of the sensor.

Example (the self-oscillation frequency is 45.000 kHz):
The range selector should be set on the position “A-Probe.” By turning the “Local osc. tune” knob, one can find the point where the analog output at the Δf out terminal is 0V. With these settings, the output will follow the change up to the demodulation frequency range selected by “Freq. range,” if the self-oscillation frequency changes.



In this example, “Freq. range” is set “Narrow (± 405 Hz)”. A frequency change from 44.595 kHz to 45.405 kHz can be measured and the corresponding output at the Δf out terminal is from -10 V to +10 V. The output polarity can be inversed by “Polarity” selector setting.

4. Practical operations

In this chapter, practical steps to setup/optimize the TFSC for measurements are described. There are three steps which have to be followed: Step 1 -> Step 2 -> Step 3 -> measurements.

Step 1, Set the trimmer on the preamplifier board.

Step 2, Start the self-oscillation and optimize parameters.

Step 3, Set up the frequency measurement function and obtain an analog output.

The initial preparations before the three steps are as follows:

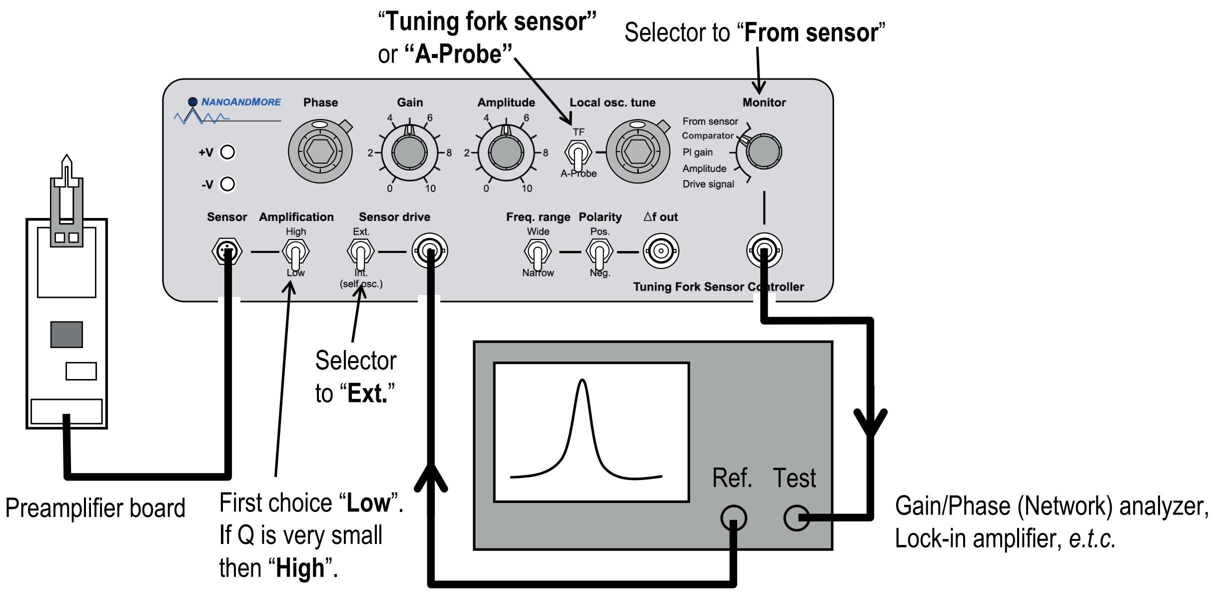
- Fix the sensor holder and the preamplifier board.
- Connect the preamplifier board and the TFSC with the provided cable.
- Connect the AC power cable. The power switch is OFF at this moment.
- Mount a TF sensor on the sensor holder.

Step 1: Adjusting of parasitic capacitance compensation

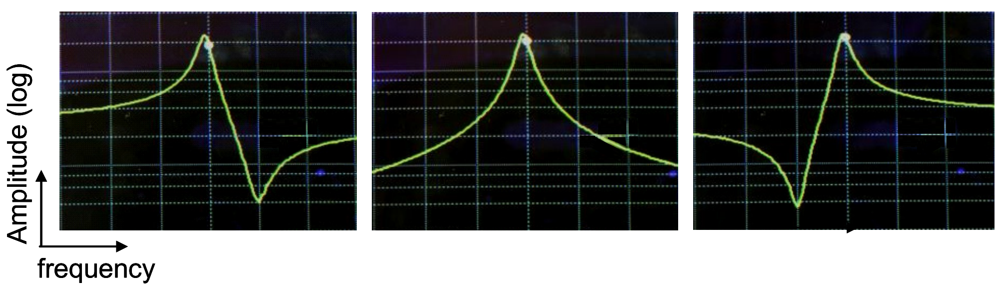
There are three options for adjusting the parasitic capacitance compensation by tuning the trimmer on the preamplifier board. Choose one of the options according to the available external instruments. This procedure must be carried out each time after the TF sensor is exchanged.

Option 1:

If a parameter analyzer (Gain-phase, Network, Lock-in amplifier, etc.) is available.

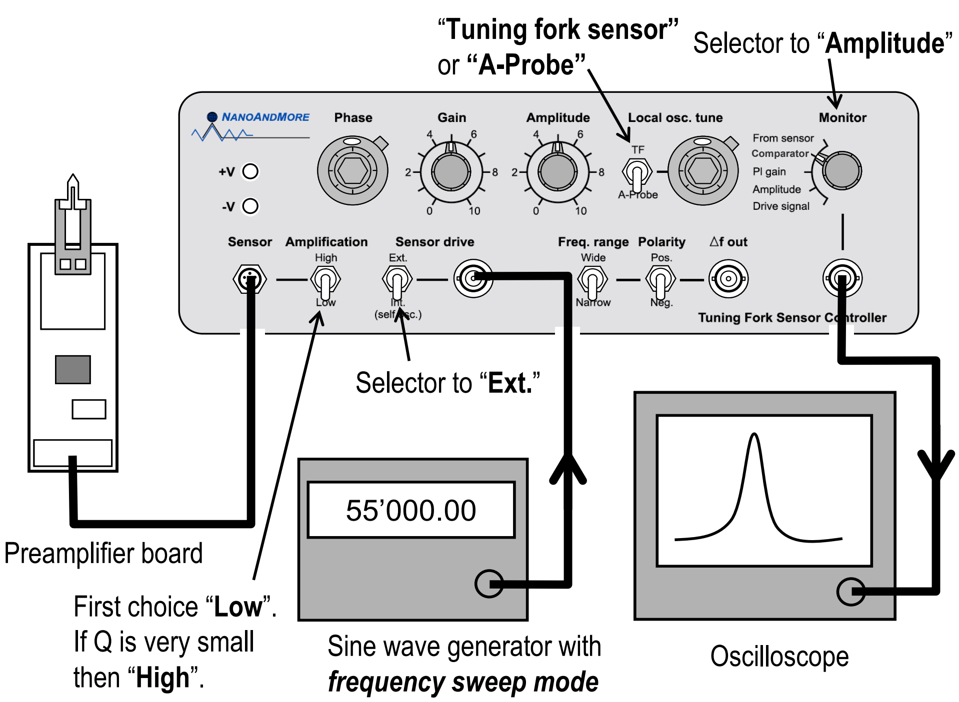


- Set “Sensor drive” switch to “Ext.” and “Monitor” selector to “From sensor”
- Set the selector of “Local osc. tune” depending on the sensor type.
- Set “Amplification” switch to “Low” (this is the first choice. If Q of the sensor is very small, this switch would need to be “High”.)
- Connect the reference output channel of the parameter analyzer and “Sensor drive” input with a 50Ω BNC cable.
- Connect the test channel of the parameter analyzer and “Monitor” output with a 50Ω BNC cable.
- Turn power switch ON, make sure both +V and –V power LEDs are on.
- Start a frequency sweep function of the parameter analyzer. The amplitude is set e.g., 1 V peak-peak.
- Find a resonance peak and make the sweep range narrower, e.g., 1 kHz.
- Turn the small screw of the trimmer on the amplifier board (see “Preamplifier board and sensor holder” on p. 9) with a screwdriver so that the amplitude curve becomes symmetric around the resonance peak. The middle picture below shows the optimum setting.



Option 2:

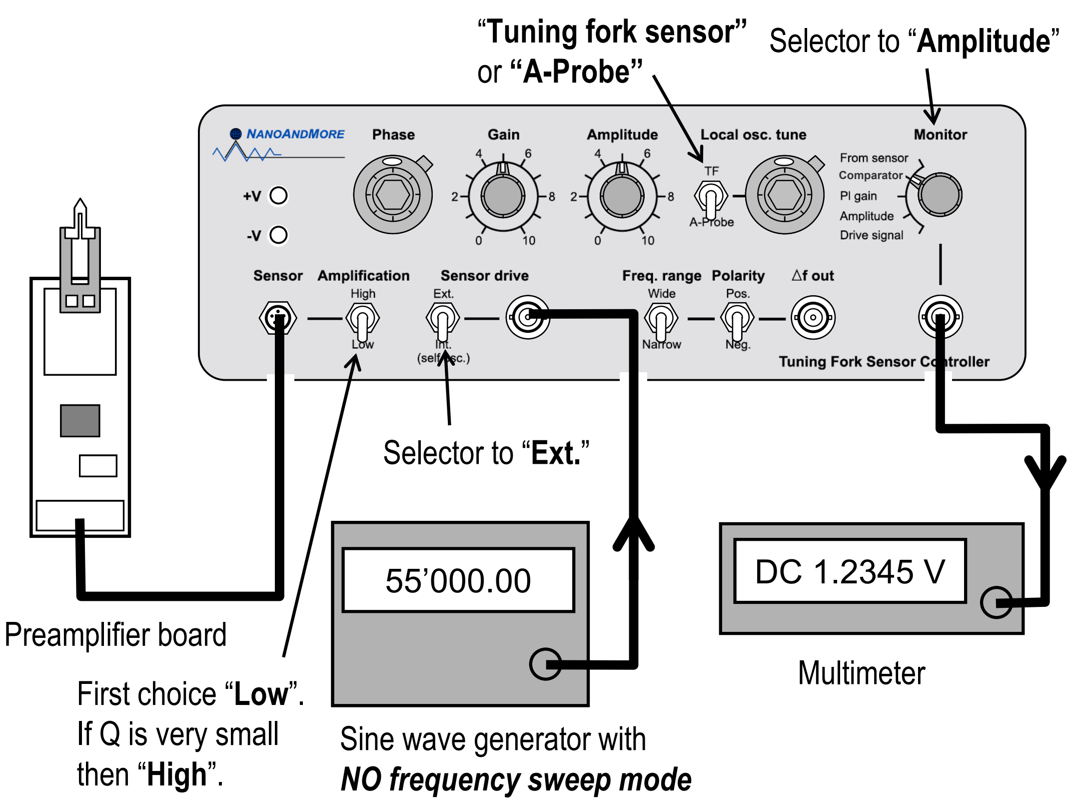
If a sine wave generator **with frequency sweep function** and an oscilloscope are available.



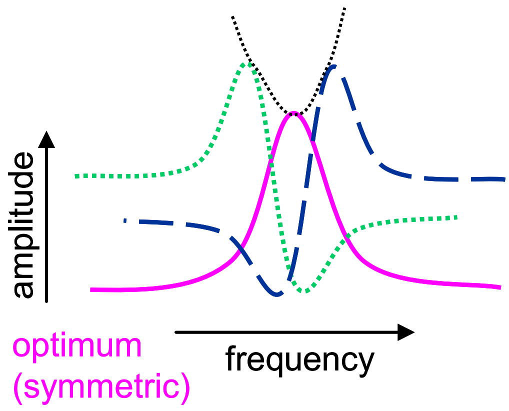
- Set “Sensor drive” switch to “Ext.” and “Monitor” selector to “Amplitude”.
- Set the selector of “Local osc. tune” depending on the sensor type.
- Set “Amplification” switch to “Low”. This is the default position. Only if the Q factor of the sensor is very small, set “Amplification” to “High”.
- Connect the output channel of the sine wave generator and “Sensor drive” input with a 50Ω BNC cable.
- Connect an input channel of the oscilloscope and “Monitor” output.
- Turn power switch ON, make sure both +V and –V power LEDs are on.
- Start a frequency sweep of the sine wave generator: e.g., center frequency = resonance frequency of the sensor, bandwidth = 2 kHz, amplitude = 1 V peak-peak, sweeping time = 5 seconds.
- Set the time axis of oscilloscope, e.g., 500 ms/div, so that one cycle of the frequency sweep can be monitored.
- Normally, a peak can be found in the signal on the oscilloscope. If yes, make the sweep range narrower, e.g., 1 kHz, if not, slightly change the center frequency.
- Turn the small screw of the trimmer on the amplifier board (see “Preamplifier board and sensor holder” on p. 9) with a screwdriver so that the amplitude curve becomes symmetric around the resonance peak.

Option 3:

If a sine wave generator **with NO frequency sweep function** and a multimeter (or an oscilloscope) are available.

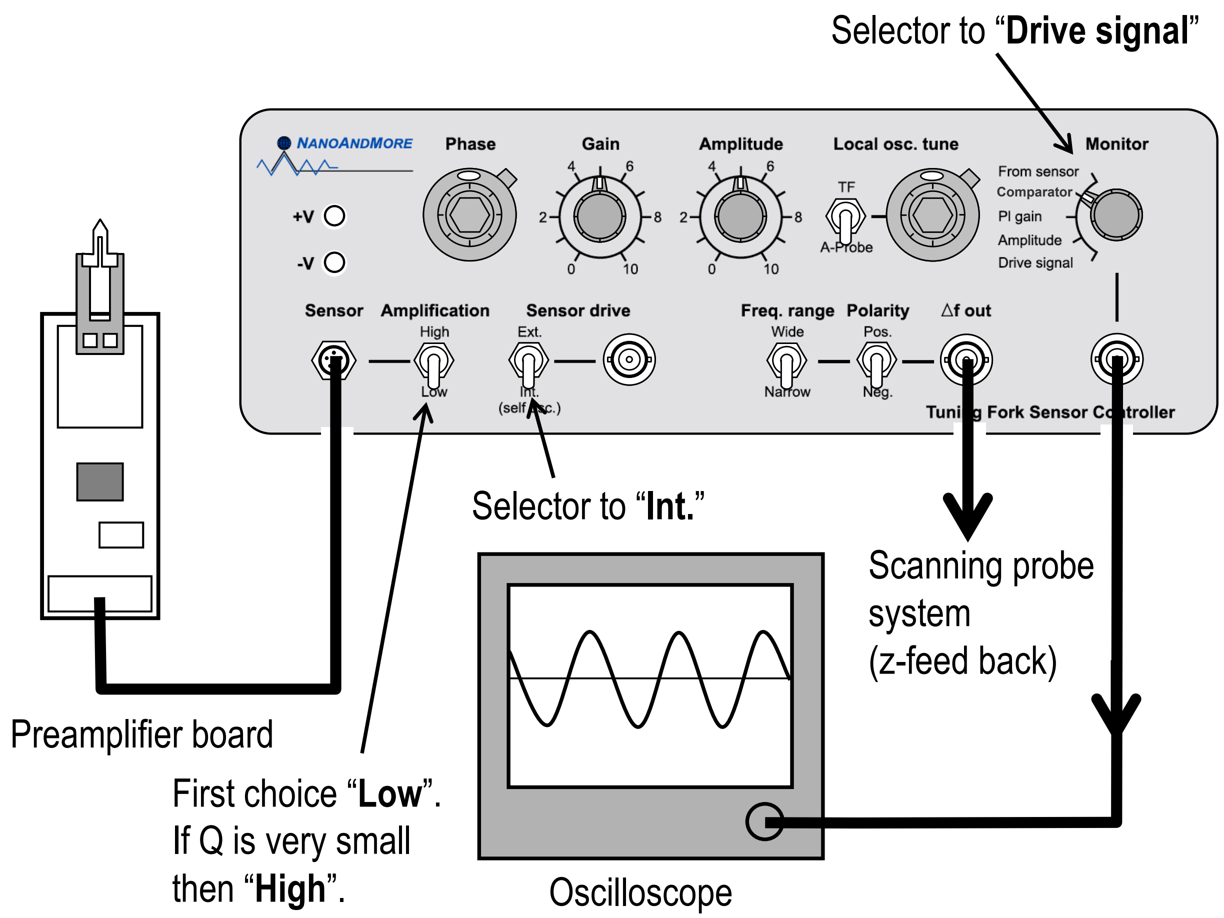


- Set “Sensor drive” switch to “Ext.” and “Monitor” selector to “Amplitude”.
- Set the selector of “Local osc. tune” depending on the sensor type.
- Set “Amplification” switch to “Low”. This is the default position. Only if the Q factor of the sensor is very small, set “Amplification” to “High”.
- Connect the output channel of the sine wave generator and “Sensor drive” input with a 50Ω BNC cable.
- Connect a test channel of the multimeter to “Monitor” output. The multimeter should be set in a DC measurement mode.
- Turn power switch ON, make sure both +V and –V power LEDs are on.
- Start the sine wave generator. Set the frequency several kHz higher than the expected resonance of the sensor, e.g., ~60 kHz in case of the Akiyama-Probe and ~40 kHz for the TF sensor. The amplitude is e.g., 1 V peak-peak.
- Turn the small screw of the trimmer on the amplifier board (see “Preamplifier board and sensor holder” on p. 9) with a screwdriver in order to minimize the amplitude (measure on the multimeter). With these settings, the adjustment of the parasitic capacitance compensation is normally sufficient just to obtain self-oscillation of the sensor. Perform the following steps if you require precise adjustment.
- First, the signal frequency from the generator is set at the expected sensor resonance. Precisely adjust the frequency in order to obtain a maximum amplitude (measure on the multimeter). Take a note of the frequency and the amplitude.
- Slightly change the setting of the trimmer on the preamplifier board to one direction.
- Tune the frequency and find maximum amplitude again. Repeat this step if you obtain a smaller amplitude than before. If the amplitude is increased, turn the trimmer the other direction. The optimum setting is where the amplitude is at its minimum (see the figure below). Note that the amplitude change is usually very small.



Step 2: Setting up the self-oscillation of a tuning fork sensor

The next step after the adjustment of the parasitic capacitance compensation is to setup a stable self-oscillation of the TF sensor.



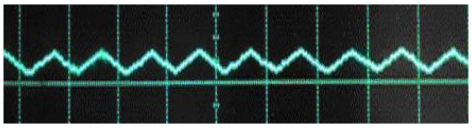
- Turn the power switch OFF.
- Connect an oscilloscope to the "Monitor" output with a 50Ω BNC cable.
- Set the "Sensor drive" switch to "Int." and the "Monitor" selector to "Drive signal".
- Set the "Amplification" switch to "Low". This is the default position. Only if the Q factor of the sensor is very small, set "Amplification" to "High".
- If the tuning knob parameters are not known, set the "Phase" knob to 5(00), the "Gain" knob to 5, and the "Amplitude" knob to 5 for tuning fork sensors and 1(00)/5/5 for A-probes.
- Turn the power switch ON. Make sure both +V and –V power LEDs are on.
- Turn the "Phase" knob until a stable sine wave appears on the oscilloscope. Normally, its frequency is around the resonance frequency obtained in Step 1.
- Fine-tune the "Phase" knob such that the amplitude of the "Drive signal" appearing on the oscilloscope is minimal.

- As the name suggests, the "Amplitude" knob controls the vibration amplitude of the TF sensor. (In case of the Akiyama-Probe, the tip vibration amplitude in a free space is set by this knob.)
- The 'Gain' knob controls the feedback loop gain of the amplitude control circuit. Normally, it should be set as high as possible, but low enough to keep the signal stable. It is recommended to re-tune this knob each time after the amplitude setting was changed.

Step 3: Setting up the frequency measurement function

At this point, the TFSC can be connected to a planned final measurement setup, e.g., SPM/AFM. The terminal "Δf out" provides an analog signal proportional to a difference between the self-oscillation frequency and an internal reference which can be tuned by the "Local osc. tune" knob.

- Connect the "Δf out" terminal to a planned measurement setup, if necessary.
- Set the "Monitor" selector to "Comp. out".
- Turn the "Local osc. tune" knob until the signal at "Δf out" is nearly 0 V and the "Monitor" output shows a triangle (saw) wave. In fact, there are a couple of circumstances where "Δf out" becomes nearly 0V. However, there is only one setpoint which fulfills the above mentioned two conditions simultaneously.



- Finally, the "Local osc. tune" knob is set at a setpoint at which "Δf out" yields a preferable voltage or frequency offset. Please refer to the paragraph "Frequency measurement block" above.

> **!!! Important note !!!**
>
> The preamplifier and sensor holder board are not shielded from external electromagnetic disturbances. They should be used inside of an electromagnetically shielding enclosure.

5. NANOSENSORS™ Akiyama-Probe operation

The best operation mode for NANOSENSORS™ Akiyama-Probe is dynamic mode with frequency modulation (FM) detection, which can be perfectly done using the TFSC. To setup an AFM system with the Akiyama-Probe, only two things have to be done: (i) fixation of the probe on to the AFM head and (ii) electrical connection between the frequency output of the TFSC, "Δf out", and an input terminal for z-feedback loop of the AFM.

For example, some Veeco/Bruker AFMs are equipped with the so called "Break-out box", which is an I/O interface with many BNC connectors for different signals. "In0" of this box is the terminal to which an external signal should be fed for the z-feedback. The "Δf out" terminal of the TFSC can be directly connected to the "Input" terminal of "In0" with a 50Ω BNC cable. The switch of "In0" should be positioned on "Input".

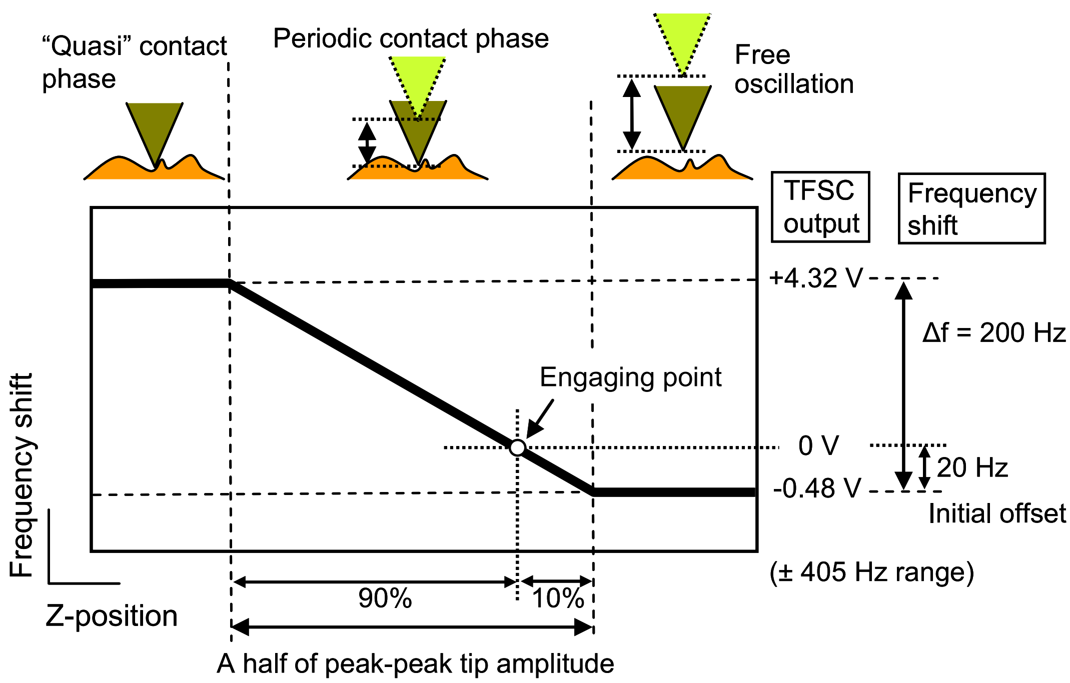
If you don't know how to introduce an external signal for the z-feedback, please contact your AFM manufacturer.

In case of Nanoscope III from Veeco/Bruker, if an external input signal for the z-feedback is negative, the AFM program recognizes that the tip is not touching the sample. In contrast, if the signal is positive, the tip is considered to be already at the sample surface.

When the tip-engaging function (start of scanning) is launched, the program checks the input signal. As long as the signal is negative, the tip is mechanically approached towards the sample. When it becomes 0 V, the approach is stopped and xy-scanning as well as the z-feedback are started. The z-piezo is driven with the feedback loop according to the magnitude of the input signal. A higher input voltage is considered to be a larger cantilever deflection.

The dynamic range of the output of the TFSC is ±10V, which corresponds either to ± 405 Hz or to ± 2077 Hz. The maximum frequency shift (denoted as Δf) of an Akiyama-Probe is approximately 30 Hz ~ 400 Hz (Δf varies depending on temperature and humidity). Normally, the ± 405 Hz range (~24 mV/Hz) is selected for tuning fork sensors and Akiyama-Probe operation.

In ambient conditions, an engaging point should be in the "periodic contact phase" (see figure below). Here, we suppose that a probe has Δf = 200 Hz and that an engaging point should be at 20 Hz shifted position. In this case, an initial frequency out of the TFSC ("Δf out" terminal) should be set to -0.48 V (24 mV/Hz × 20 Hz = 0.48 V, negative = lower frequency) by adjusting the "Local osc. tune" knob. With this setting, the AFM program starts xy-scanning at the desired engaging point.



For measurements in ambient conditions, it is better to use a relatively large tip vibration amplitude. However, each probe has different factors between "Driving voltage" and "Tip amplitude", e.g., dial "2" at "Amplitude" knob yields 300 nm peak-to-peak for one Akiyama-Probe, but 150 nm- 500 nm for another.

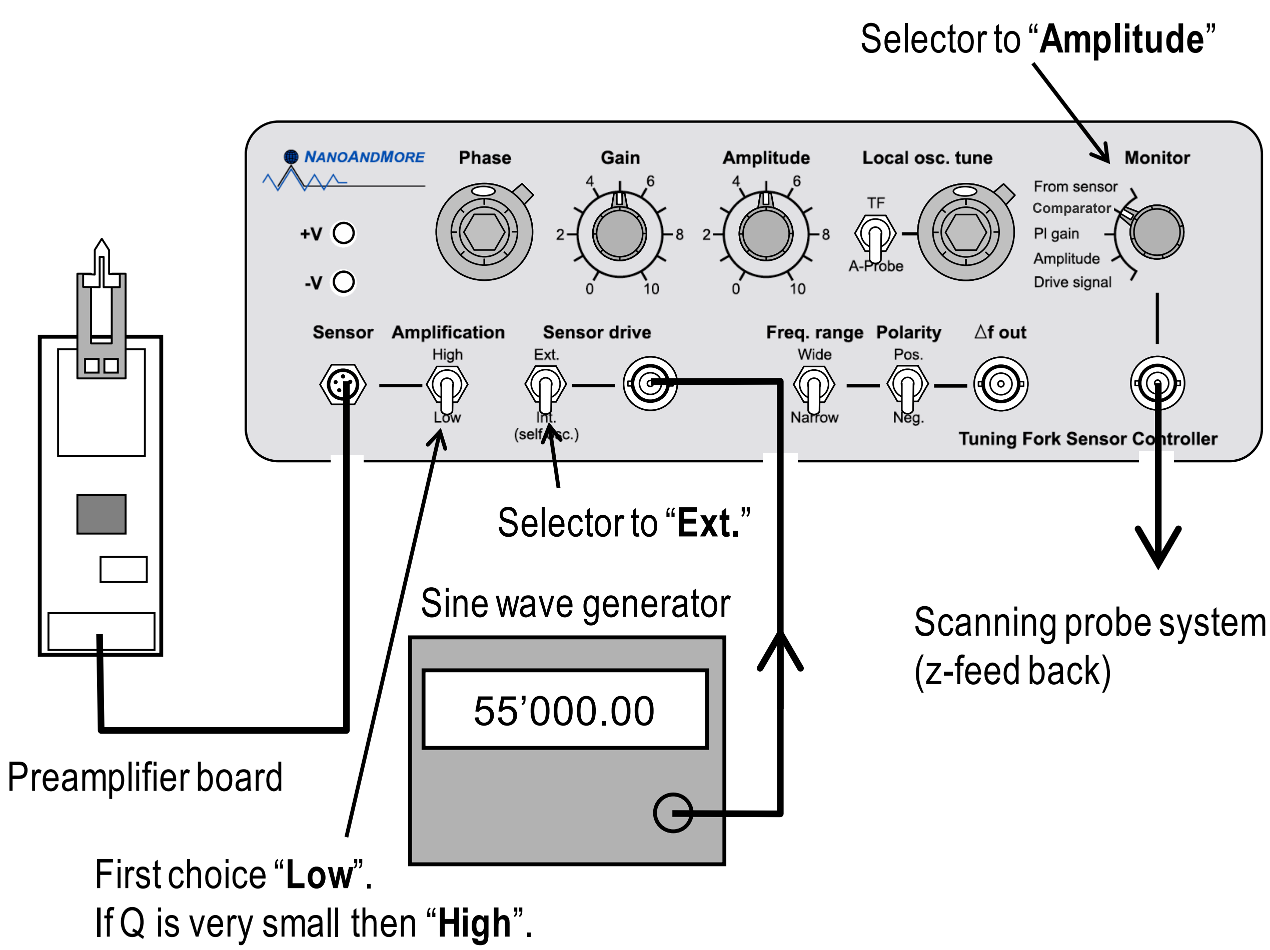
Real amplitude can be estimated from a full stroke approach curve. The z-displacement over which the periodic contact phase is lying corresponds to a half of the peak-peak tip amplitude.

Note that the amplitude of the piezoelectric-current of the TF, which is proportional to the mechanical vibration amplitude of the prongs, is maintained at a set value by the TFSC, but this does not mean that the tip vibration amplitude is also kept at a constant value.

It is recommended to optimize the “Gain” whenever the tip amplitude setting is changed. This is especially important if the probe needs to work with a very small tip amplitude (< 150nm).

For more information about the Akiyama-Probe, please read the references provided by NANOSENSORS™ (www.akiyamaprobe.com).

Although, the TFSC can be configured for the amplitude modulation (AM) detection like shown in the figure below, this mode is not recommended for an operation of the Akiyama-Probe. The reason is that due to the high Q of the Akiyama-Probe, the scan speed would have to be very slow and one would have to compromise the spatial resolution.



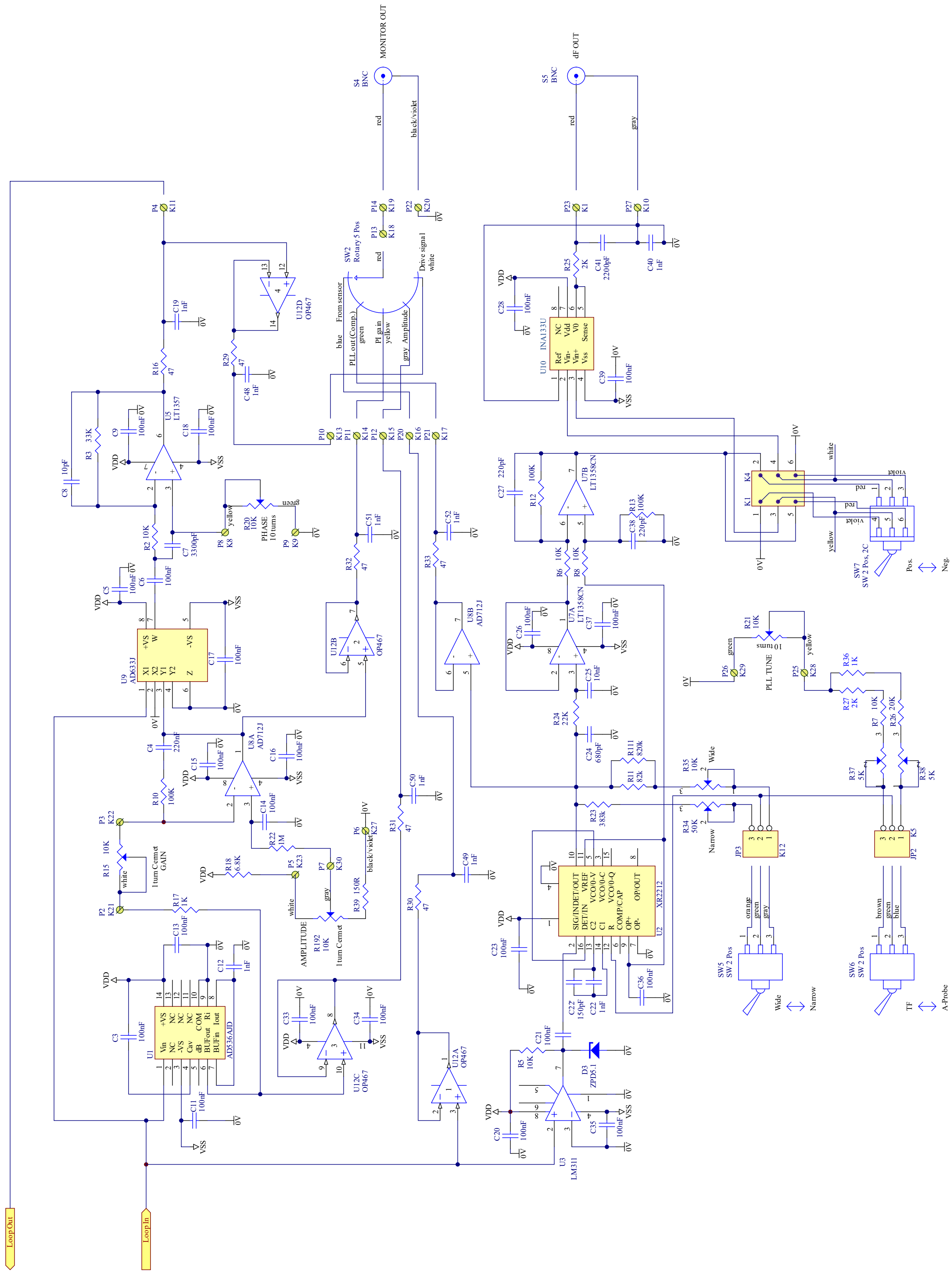
6. Technical data

▪ Self-oscillation frequency range	10 kHz ~ 100 kHz
▪ Frequency measurement range (@ Δf out = 0V)	(a) 27.4 kHz ~ 37.9 kHz*1 (b) 37.6 kHz ~ 60.4 kHz*1
▪ Demodulation output range	± 10 V
▪ Demodulation frequency range	(i) ± 405 Hz *2 (100 mHz resolution) (ii) ± 2077 Hz *3 (510 mHz resolution)
▪ Demodulation bandwidth	~ 400 Hz
▪ Output polarity selection	Yes
▪ Monitor terminal range	± 10 V
▪ Required power supply	100-230V~ 50/60Hz 4VA

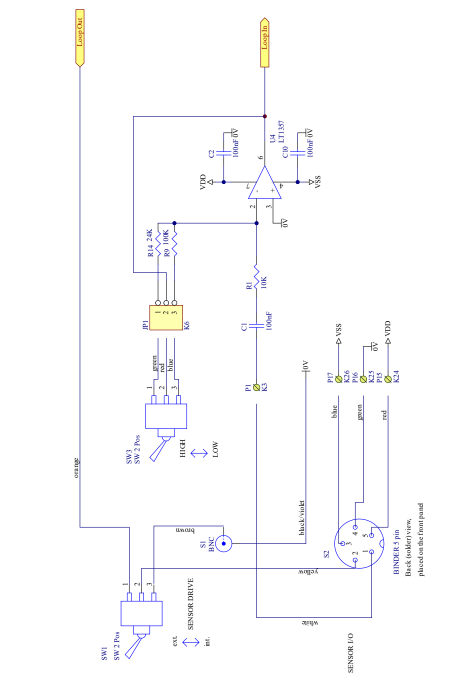
*1 ± 1 kHz variations in different units
*2 ± 30 Hz variations in different units
*3 ± 150 Hz variations in different units

Specifications are subject to change without notice.

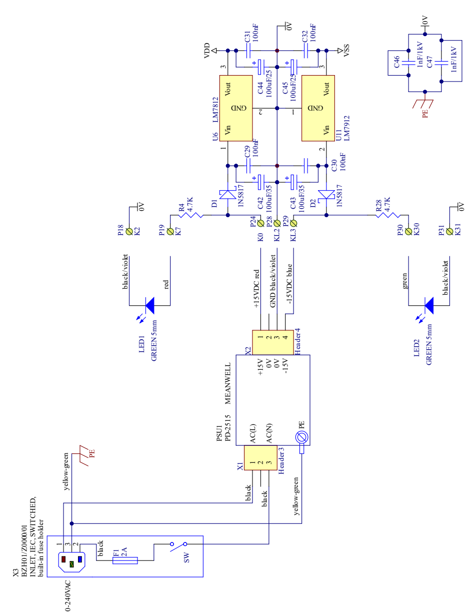
Appendix 1: Circuit Diagrams - Self oscillation and phase-locked loop block



Appendix 2: Circuit Diagrams - Power supply block (A) and Tuning Fork Sensor I/O block (B)

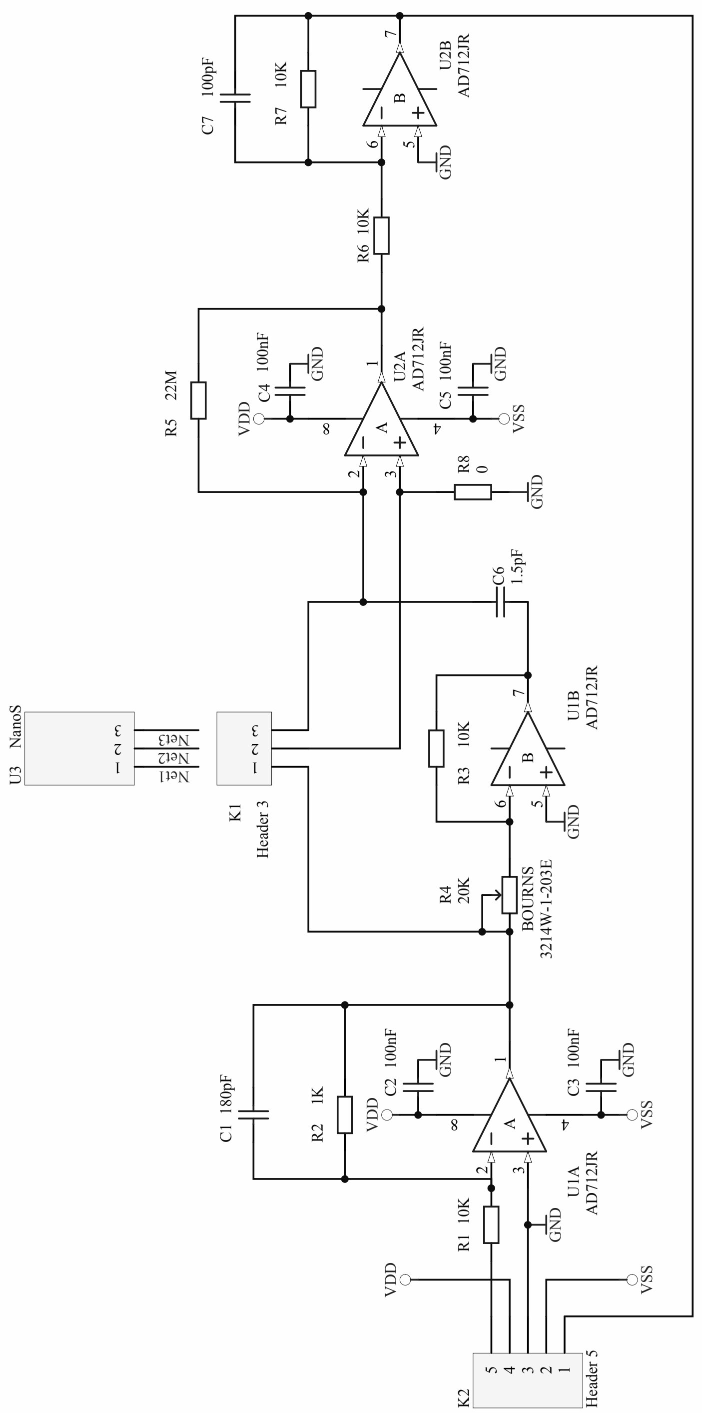


B. Tuning Fork Sensor I/O Block



A. Power Supply Block

Appendix 3: Circuit Diagrams - Preamplifier board



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Reference Manual
Tuning Fork Sensor Controller