OE2022
DSP Lock-In Amplifier
User Manual

Revision 1.1.2, 2026-06-17

Contents

Revision History

Version Revision 1.1.2 Update, 2026-06-17

Corrected the effective conditions for the SYNC synchronous filter and revised the descriptions of several remote commands, including RSLP, AMSR, FMSR, PMSR, COUT/FOUT, AXOS, and *PLL?; only the command descriptions are corrected, while the corresponding command parameters remain unchanged.

Revision 1.1.1, 2026-05-14

Added the range/gain relationship table for the voltage and current ranges. See Section 2.7 for details.

Revision 1.1.0, 2026-03-06

1. Adjusted part of the document formatting. The OE2012 and OE2022 user manuals were separated. The PC Software platform was upgraded to SSI Lucid Suite, and the PC Software operation instructions were updated.

2. Changed the typical current noise value at 1 kHz to 15 fA/$\sqrt{\text{Hz}}$.

3. Updated the remote communication commands and programming section. See Chapter 6 for details.

1) The starting value of all channel-number parameters in communication commands was changed from 0 to 1.

2) AUXOUT now supports output-type selection for parameters such as X, Y, and R. The related AXOS, AXDC, AXSN, AXOF, and AXEX commands were added.

3) The Equation function was upgraded to the FreqComb function. The corresponding commands were changed from DARF, DEQU, and DEAF to DMFR, FCMB, and FCMF, and the related parameters were updated.

4) The internal frequency command for the Sineout modulation mode was changed from MARF to SMFR, with the corresponding parameters unchanged.

Revision 1.0.4, 2025-06-18

Added descriptions for clock and trigger signal configuration commands.

Revision 1.0.3, 2025-03-11

Changed the programming command DARB to DARF.

Revision 1.0.2, 2025-02-06

Updated the Input Range settings.

Updated the parameter description of the *PLL programming command.

Modified some setting parameters in the performance test procedure.

Updated figure numbering.

Revision 1.0.1, 2025-01-25

Merged the OE2012 and OE2022 user manuals.

Revision 1.0.0, 2024-10-29

First release of the user manual.

Chapter 1 Technical Specifications

1.1 Signal Channel

• Number of channels	2
• Input mode	
Voltage input	Single-ended (IN+) or differential (DIFF)
Current input	Transimpedance input (I)
• Sensitivity	
Voltage range	1 nV to 5 V_{rms}
Current range	1 pA to 5 mA
• Current transimpedance gain	1 kΩ, 1 MΩ, 100 MΩ
• Input impedance	
Voltage input	10 MΩ || 25 pF
Current input	100 Ω or 1 kΩ || 10 pF
• Input coupling	AC (>1 Hz) or DC coupling
• Shield grounding	Ground or float (10 kΩ)
• CMRR	>110 dB @ 1 kHz
• Dynamic reserve	>130 dB
• Gain accuracy	0.5% (typ.), 1% (max.)
• Voltage noise	
At 1 kHz	3.3 nV/$\sqrt{Hz}$ (typ.)
At 10 kHz	3.0 nV/$\sqrt{Hz}$ (typ.)
At 100 kHz	2.5 nV/$\sqrt{Hz}$ (typ.)
At 1 MHz	2.5 nV/$\sqrt{Hz}$ (typ.)
• Current noise	
At 97 Hz	20 fA/$\sqrt{Hz}$ (typ.)
At 1 kHz	15 fA/$\sqrt{Hz}$ (typ.)

1.2 Reference Channel

• Input	
Number of channels	2
Frequency range	10 μHz to 1.5 MHz
Supported waveform	Square wave or sine wave
Input impedance	1 MΩ
Square ref. level	$-0.1\,V < V_L < 0.5\,V$, $3\,V < V_H < 5\,V$
Sine ref. signal	Frequency > 1 Hz
	$300\,mV < V_{PP} < 10\,V$

- Phase

Resolution	1 µ°
Phase error	0.5° (typ.), 2° (max.)
Temperature coefficient	<200 ppm/°C

- Harmonic detection: 1~10 000 (nF < 1.5 MHz)
- Acquisition time

Internal reference	Immediate
External reference	100 cycles (> 1 kHz); 10 cycles (< 1 kHz)

1.3 Demodulator

- Number of demodulators: 8
- Demodulator resolution: 64 bit
- Stability

Digital output	No zero-drift
Display	No zero-drift
Analog output	< 200 ppm/°C

- Filter bandwidth: 50 µHz to 1.6 MHz
- Filter time constant: 100 ns to 3 ks
- Filter roll-off: 6, 12, 18, 24, 30, 36, 42, and 48 dB/oct selectable
- Synchronous filter: Available below 250 kHz and roll-off above 18 dB/oct

1.4 Internal Oscillator and Output

- Internal oscillator

Number	2
Accuracy	0.3 ppm
Temperature stability	0.5 ppm/°C
Aging	< 1 ppm/year
Phase noise	−145 dBc/Hz (@ 1 kHz)

- Output frequency

Range	DC to 1.5 MHz
Accuracy	2 ppm + 1 µHz
Resolution	1 nHz

- Harmonic distortion: −80 dBFS (f < 100 kHz); −60 dBFS (f > 1 MHz)

- Sine-wave output
  - Number of channels: 2
  - Amplitude: 0.1 µV_{rms} to 5 V_{rms}
  - Accuracy: 0.5% (typ.) (f < 100 kHz), 2% (max.) ± 1 µV_{rms}
  - Resolution: 0.1 µV_{rms}
  - Drive capability: ± 80 mA max
  - Temperature stability: <200 ppm/°C
  - Output impedance: 50 Ω
- Internal DC offset: −5 V to 5 V DC adjustable, 1 mV resolution
- Sync output: 3.3 V TTL/CMOS (50 Ω)
- Additional functions: AM/FM/PM signal modulation output

1.5 Display

- Screen
  - Screen size: 5.6 inches, 640×480 TFT-LCD
  - Screen format: Dual-column graph / full-data display
  - Displayed values: X, Y, R, and θ
  - Display type: Data display formats
  - Color style: Yellow / green

1.6 Auxiliary Inputs and Outputs

- AUX Inputs
  - Function: 4-channel input
  - Amplitude: ± 10 V, 0.3 mV resolution, 0.5% + 10 mV accuracy
  - Impedance: 1 MΩ
  - Sampling rate: 150 kSa/s
- AUX Outputs
  - Function: 4-channel output
  - Amplitude: ± 10 V, 0.3 mV resolution, 0.5% + 10 mV accuracy
  - Drive current: ± 30 mA max
  - Output rate: 500 kSa/s
- CH Outputs
  - Function: 2-channel output
  - Amplitude: ± 10 V, 0.3 mV resolution, 0.5% + 10 mV accuracy
  - Drive current: ± 30 mA max
  - Output rate: 1 MSa/s
- Clock Input
  - Function: External 10 MHz clock input port
  - Logic level: 3.3 V TTL/CMOS

- Clock Output
  - Function: 10 MHz clock output port
  - Logic level: 3.3 V TTL/CMOS
- Trigger Input
  - Function: Trigger signal input port for the lock-in amplifier
  - Logic level: 3.3 V TTL/CMOS
- Trigger Output
  - Function: Trigger signal output port for external equipment
  - Logic level: 3.3 V TTL/CMOS
- Monitor Output
  - Function: Mirror signal output before the ADC in the analog signal chain
  - Drive current: ± 40 mA max

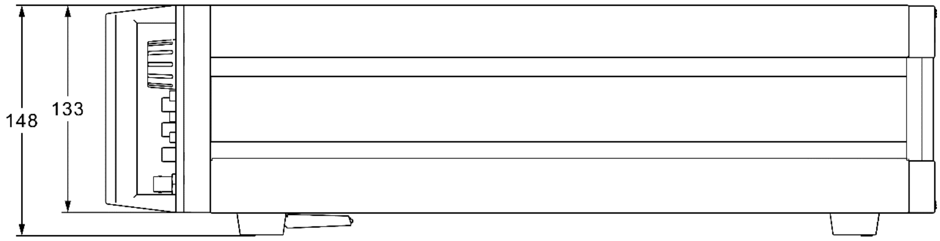
1.7 Communication Interfaces

- RS-232: 9-pin female connector
- USB2.0: USB2.0 High-Speed
- Ethernet: RJ45,1000Mbps
- WIFI: 2.4GHz
- GPIB: IEEE-488.2

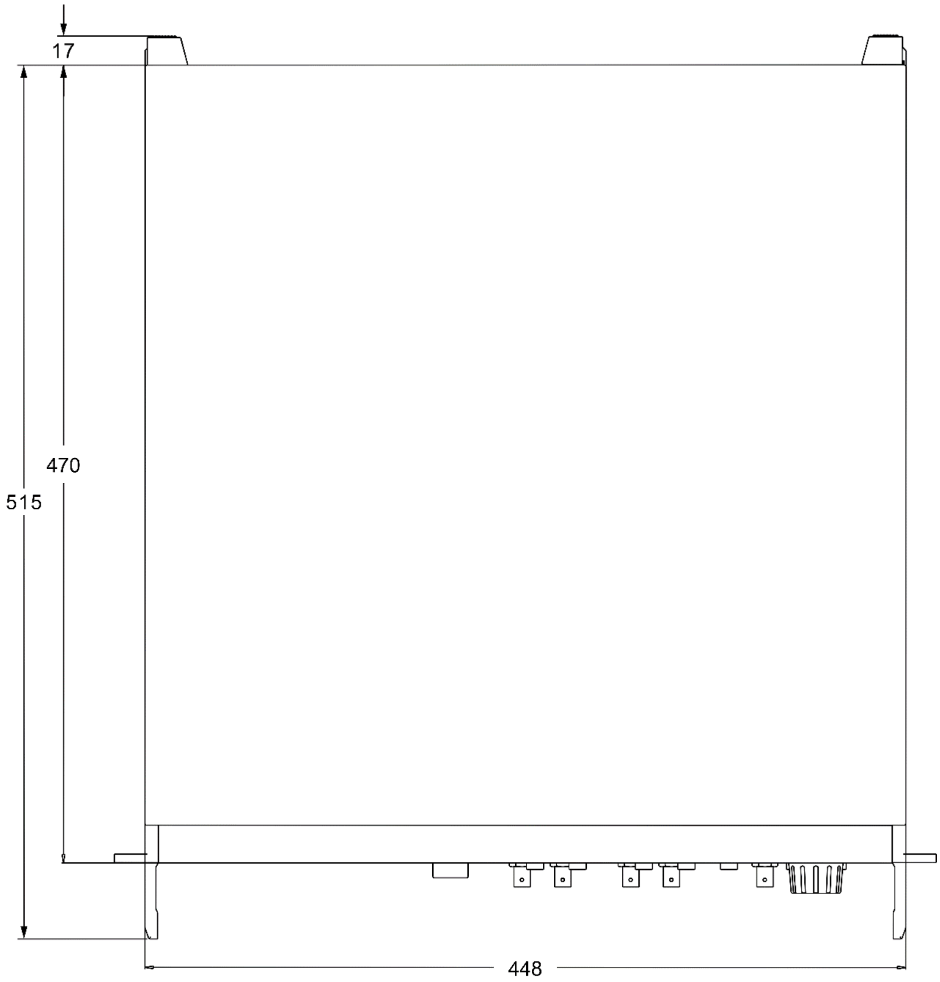
1.8 Others

- Power requirements
  - Voltage: 100~240 V AC
  - Frequency: 50 Hz / 60 Hz
  - Power: Typical 50 W, max< 70 W
- Power noise rejection: 70 dB @ 1 MHz
- Ground terminal: Banana jack / M6 screw terminal
- Weight: 8 kg
- Dimensions
  - Width: 448 mm
  - Depth
    - Including handle: 532 mm
    - Excluding handle: 470 mm
  - Height
    - Including feet: 148 mm
    - Excluding feet: 133 mm

- Product dimension diagram, side view



- Product dimension diagram, top view



Chapter 2 Lock-in Amplifier Fundamentals

2.1 Introduction to Lock-in Amplifiers

A lock-in amplifier is an instrument used for weak-signal detection. Weak signals are often buried in various types of noise. A lock-in amplifier can extract a weak signal from the noise and measure it accurately, as shown in Figure 1. Lock-in amplification is a weak-signal detection method based on cross-correlation. Its core technique is phase-sensitive detection (PSD), which uses a reference signal with the same frequency as, and a fixed phase relationship to, the signal under test as the basis for detection. The instrument extracts the signal component that is correlated with the reference signal and rejects noise components outside the reference frequency.

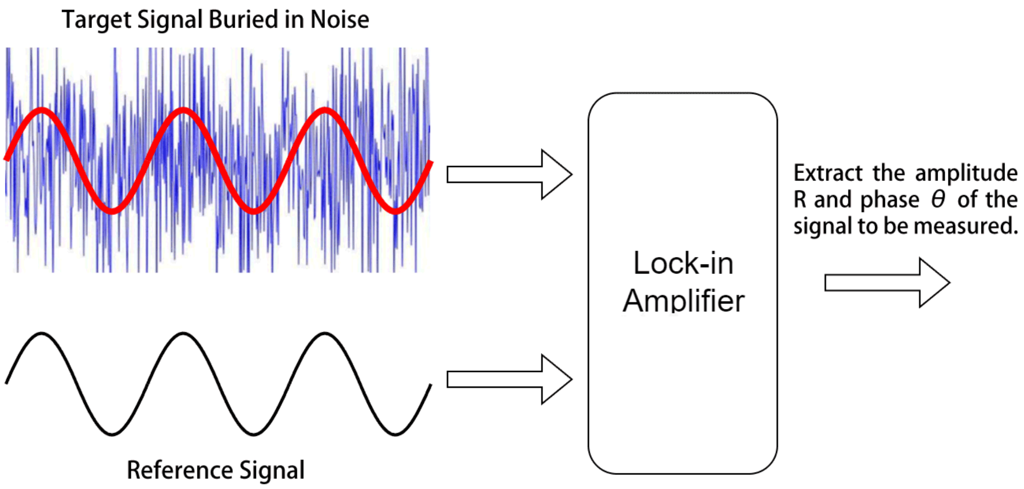


Figure 1. Schematic diagram of a lock-in amplifier

The most basic processing method for a weak signal is amplification. Conventional amplification amplifies the noise together with the signal. In addition, without bandwidth limiting or filtering, any amplification operation will reduce the signal-to-noise ratio. Therefore, filtering must be used to purify the signal and improve the signal-to-noise ratio so that weak signals can be measured accurately. The best choice among filters is a band-pass filter. However, it is often very difficult to implement a band-pass filter with an adjustable center frequency, high stability, and a high Q factor.

A phase-sensitive detector (PSD) can replace a high-Q band-pass filter. Its basic structure includes a multiplier module that multiplies the input signal by the reference signal, and a filter module that low-pass filters the multiplier output. In some contexts, PSD specifically refers to the multiplier module only, excluding the filter module, as shown in Figure 2.

$S_I(t)$ is the time-domain input signal mixed with noise, and $S_R(t)$ is the reference signal that has the same frequency relationship as the signal under test. A PSD combines the measured signal channel and the reference signal channel to form a complete lock-in amplifier architecture, which is referred to as a single-phase lock-in amplifier. Its structural block diagram is shown in Figure 3.

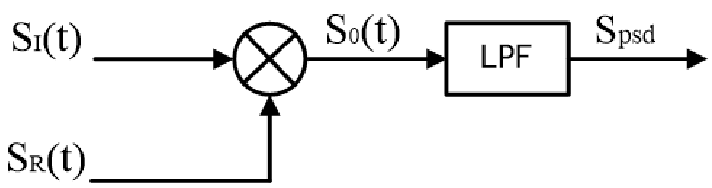


Figure 2. Schematic diagram of phase-sensitive detection

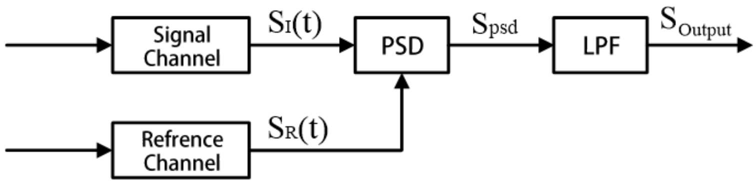


Figure 3. Structure of a single-phase lock-in amplifier

The signal entering the PSD module from the signal channel can be defined as:

$$S_I(t) = A_I \sin(\omega t + \varphi) + B(t)$$

where ω is the frequency of the signal under test, $A_I \sin(\omega t + \varphi)$ is the signal under test, and $B(t)$ is the mixed noise.

The standard reference signal generated by the reference signal channel can be defined as:

$$S_R(t) = A_R \sin(\omega t + \delta)$$

The two signals are simultaneously input to the PSD module and multiplied. The output is:

$$\begin{aligned} S_{psd} &= S_I(t) S_R(t) \\ &= A_I A_R \sin(\omega t + \varphi) \sin(\omega t + \delta) + B(t) A_R \sin(\omega t + \delta) \\ &= \frac{1}{2} A_I A_R \cos(\varphi - \delta) - \frac{1}{2} A_I A_R \cos(2\omega t + \varphi + \delta) + B(t) A_R \sin(\omega t + \delta) \end{aligned}$$

The result contains three terms. The first term contains the signal amplitude A_I, the reference signal amplitude A_R, and the cosine of the phase difference $(\varphi - \delta)$ between the input signal and the reference signal. When both the useful part of the input signal and the reference signal are stable, this term can be regarded as a constant, namely a DC signal. Similarly, the second term is an AC signal at twice the original reference frequency. The third term is the product of the noise signal and the reference signal. According to the orthogonality of sinusoidal signals, a random signal is not correlated with the reference signal, and its integral result is zero.

From the frequency-domain perspective, the first term is located at DC, the second term is located at twice the reference frequency, and the third term is the original random signal shifted in frequency by ω. Taking white noise as an example, the shifted result is still white noise. Therefore, by feeding the result into a low-pass filter, the DC component can be obtained as follows:

$$S_{Output} = \frac{1}{2} A_I A_R \cos(\varphi - \delta)$$

The frequency-domain spectral shifting process of a lock-in amplifier is shown below:

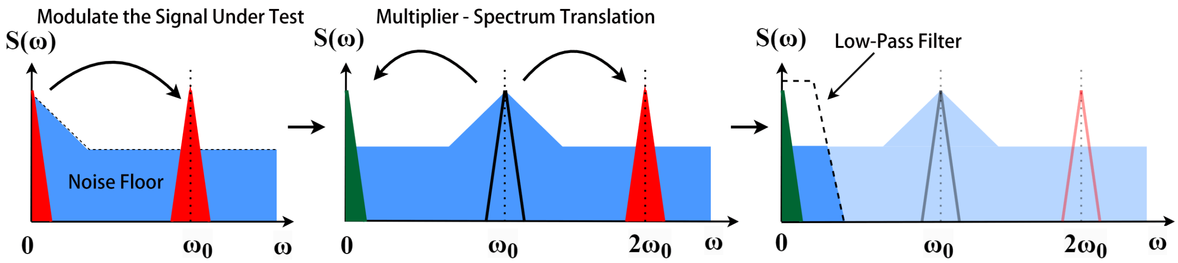


Figure 4. Spectral shifting process in a lock-in amplifier

The amplitude of the signal under test can be determined by adjusting the phase difference $(\varphi - \delta)$ between the measured signal and the reference signal. However, the accuracy of this adjustment is difficult to guarantee. The dual-phase lock-in amplifier provides an effective solution to this problem. Figure 5 shows the operating architecture of a dual-phase lock-in amplifier.

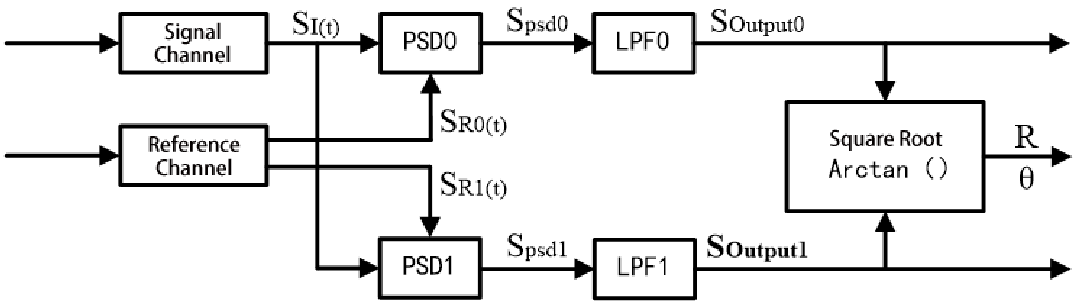


Figure 5. Structure of a dual-phase lock-in amplifier

Let the phase difference be $\theta = \varphi - \delta$. The reference channel generates two sinusoidal signals with a phase difference of 90°:

$$S_{R0}(t) = A_R \sin(\omega t + \delta),\ S_{R1}(t) = A_R \cos(\omega t + \delta),$$

The calculated output results are $S_{Output0} = \frac{1}{2} A_I A_R \cos\theta$ and $S_{Output1} = \frac{1}{2} A_I A_R \sin\theta$.

Define $X = A_I \cos\theta$ and $Y = A_I \sin\theta$. The output amplitude that is independent of the phase difference can therefore be calculated as:

$$R = \sqrt{X^2 + Y^2} = A_I = \frac{2 \times \sqrt{S_{Output0}{}^2 + S_{Output1}{}^2}}{A_R}$$

The phase difference between the reference signal and the measured signal can be obtained by:

$$\theta = \tan^{-1}(Y/X)$$

2.2 Functional Block Diagram of OE2022

The functional block diagram of the OE2022 digital lock-in amplifier is shown below:

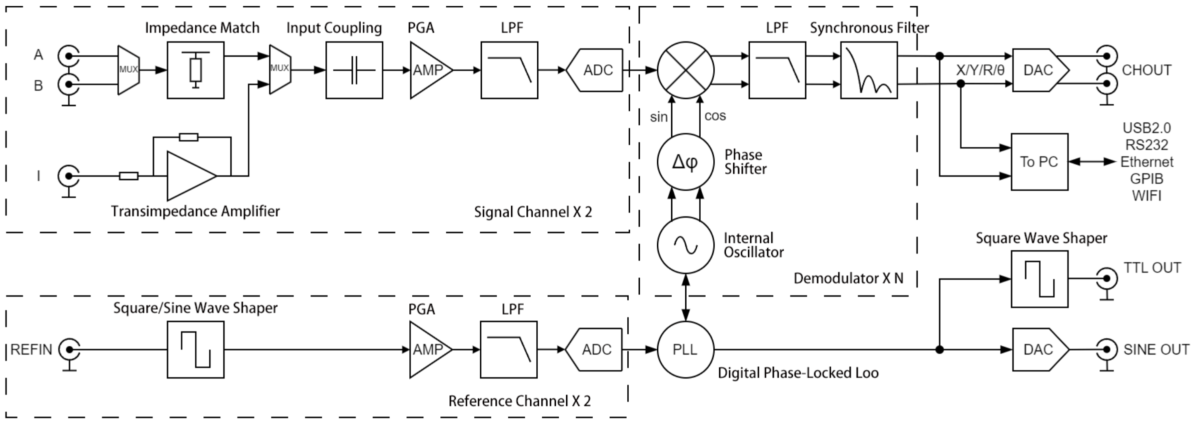


Figure 6. Functional block diagram of OE2022

As illustrated in the functional block diagram, the functional modules of OE2022 include the signal conditioning channel, reference signal processing channel, demodulator module, system controller, and other sections. The interfaces on the left are input interfaces, and the interfaces on the right are output interfaces.

When the signal under test is connected to the voltage or current input of the lock-in amplifier, it is amplified to an appropriate range and then digitized by an analog-to-digital converter (ADC), becoming a digital signal. The digitized measured signal is sent to eight demodulator channels for demodulation processing. The demodulation results are output to the CHOUT interface, where users can observe them with an oscilloscope or other instruments. The results can also be output to a PC Software through the communication interface and viewed with the SSI Lucid Suite software supplied with the instrument.

OE2022 has two digital phase-locked loops that can lock to two reference/synchronization signals simultaneously. The phase-locked loop results can be routed to the Sineout and TTLout interfaces to control other instruments and devices conveniently.

2.3 Reference Channel

The function of the reference channel is to provide a control signal coherent with the detected signal for the phase-sensitive detector. The reference signal of OE2022 can be selected as either a sine wave or a square wave according to the actual application, and its input impedance is 1 MΩ. OE2022 provides two REF IN reference signal input channels, allowing users to demodulate two frequency components simultaneously or to demodulate sum-frequency/difference-frequency signals.

In general, both reference waveforms can be used. For a TTL reference, the high level must be greater than 3 V, and the low level must be less than 0.5 V. A sine-wave reference is AC-coupled and is valid when the sine-wave amplitude is greater than 0.3 V_{pp}. **However, when the frequency is lower than 1 Hz, TTL-level signal mode must be used.** Because a sine-wave signal has a lower signal-to-noise ratio and more amplitude jitter when its output amplitude is small, and because most function generators can generate stable TTL synchronization signals, a square-wave signal is recommended as the reference signal.

The OE2022 lock-in amplifier has two reference source modes: internal reference mode and external input mode.

When internal reference mode is selected, the high-precision oscillator and synthesis algorithm inside the instrument generate the sine-wave signal used for multiplication with the input signal. In this case, no phase-locked loop is required, and the internal reference signal is almost unaffected by phase noise. The internal reference mode can operate normally over the frequency range from 10 µHz to 1.5 MHz. Because there is a certain frequency deviation between the internal oscillator and the oscillator of the external signal source, and because no phase-locked loop is used for tracking and locking, there will be a certain frequency difference between the internally generated sine-wave signal and the signal under test, and phase stability between the two signals cannot be guaranteed.

OE2022 can also use external reference signal mode. Sine-wave signals and TTL logic levels can be used as external reference signals. When external reference signal mode is used, the internal oscillator automatically tracks the external reference signal to maintain the same frequency and phase. In actual operation, the phase-locked loop introduces a certain amount of phase jitter, which may cause measurement error. Phase jitter introduces noise at different frequencies into the reference signal. According to the coherence principle of PSD, the output signal contains not only the measured signal at the same frequency as the reference signal, but also noise components at other frequencies present in the reference signal. In practice, phase jitter is usually small and does not cause measurement problems. For jitter-free measurement, internal reference mode can be selected. Since this mode does not use the phase-locked loop and the internal oscillator is directly connected to the reference signal path, no additional phase jitter interference is introduced.

2.4 Phase-Sensitive Detector

The phase-sensitive detector (PSD) of OE2022 is implemented by a digital multiplier. After the input signal is amplified and filtered, it is converted into a digital signal by a 24 bit A/D converter and then input to the phase-sensitive detector. The phase-sensitive detector module of this product has a precision of 64 bit.

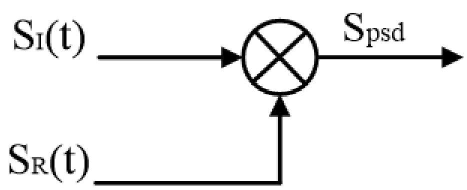


Figure 7. Core part of coherent detection

The phase-sensitive detector module of a lock-in amplifier mainly performs coherent modulation of the input signal and the reference signal. Traditional lock-in amplifiers implement this function with an analog multiplier. However, coherent modulation implemented using analog technology has many drawbacks. It greatly limits the accuracy of the phase-sensitive detector and introduces substantial background noise, both of which are highly unfavorable for weak-signal measurement.

Based on these considerations, this product uses digital technology to implement coherent modulation. Because the reference signal generated by the internal signal generator is a 24 bit digital signal, it can greatly reduce the influence of harmonic components on coherent modulation. In practice, harmonic suppression can reach −120 dB, which means that harmonic components have almost no influence during coherent modulation.

In addition, analog phase-sensitive detectors have temperature drift and DC offset, so their output often deviates from the actual result. This deviation is a systematic error and is often uncertain. A phase-sensitive detector implemented with digital technology avoids this issue. Under normal system operation, almost no corresponding systematic error is generated. Since the inputs of an analog multiplier are analog quantities, its reference signal is also affected by temperature drift, which causes reference-signal deviation and further increases the systematic error in coherent modulation.

The dynamic reserve of a phase-sensitive detector implemented with analog technology is generally limited to below 60 dB, because analog systems usually contain a large amount of background noise. Since lock-in amplifiers are mainly used for weak-signal detection, if the amplitude of the background noise is close to or greater than that of the signal, the coherent modulation result may become incorrect. A digital phase-sensitive detector does not have this type of problem. Its dynamic reserve is mainly limited by the quality of A/D conversion. Once the input signal has been digitized, no additional error is introduced during coherent modulation. In practice, the dynamic reserve of OE2022 can reach more than 120 dB.

In summary, a phase-sensitive detector implemented with digital technology outperforms one implemented with analog technology in many aspects. It also provides advantages such as easier debugging, making it the best choice for this product.

2.5 Filter, Time Constant, and DC Output Gain

The output of the phase-sensitive detector contains signal components at multiple frequencies, including the sum-frequency component and the difference-frequency component of the input and reference signals, as well as noise. Only when the input signal and the reference signal have the same frequency does the difference-frequency signal become a DC signal. The low-pass filter behind the phase-sensitive detector, as shown in Figure 8, removes the noise signal and the sum-frequency signal other than the DC component, allowing the lock-in amplifier to function as a high-quality band-pass filter.

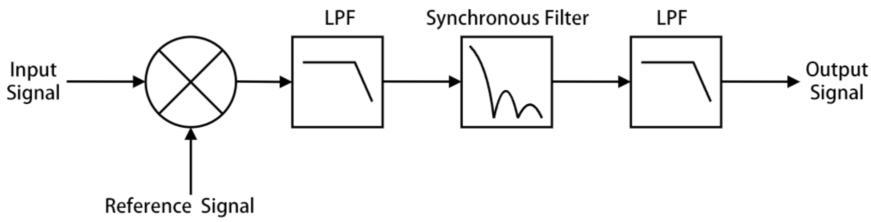


Figure 8. Filter structure of the phase-sensitive detector

Time Constant

The bandwidth of the low-pass filter behind the phase-sensitive detector is set in the same way as that of a conventional low-pass filter, namely by setting the time constant. The time constant TC is calculated as:

$$TC = \frac{1}{2\pi f}$$

where f is the cutoff frequency at −3 dB. For example, for a first-order RC low-pass filter, a time constant of 1 second means that its −3 dB cutoff frequency is 0.16 Hz.

In general, when noise is present at the system input, noise will also appear at the output. Increasing the time constant can make the system output more stable and reduce the influence of input noise on the output. In addition to affecting system stability and accuracy, the time constant also affects the response time. For a first-order RC low-pass filter, the output must be allowed to settle for more than five time constants before the result becomes stable. The step responses of low-pass filters with different orders are shown in Figure 9.

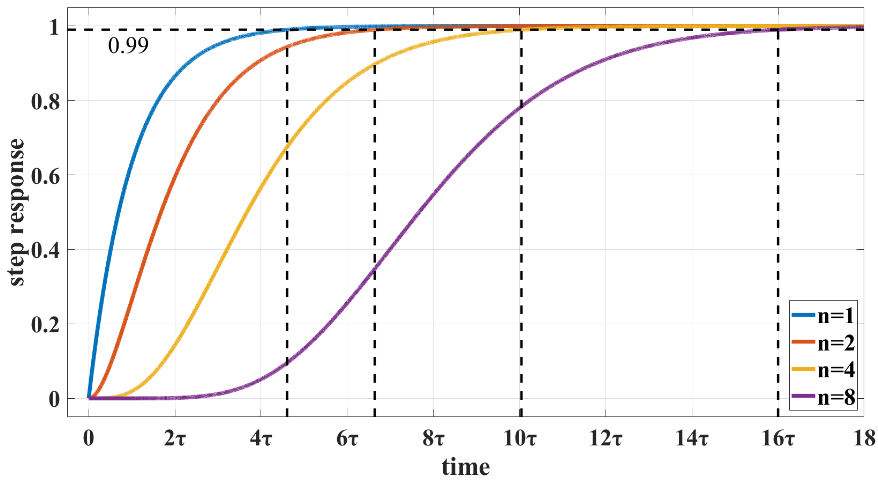


Figure 9. Step response of low-pass filters

The time constant also determines the equivalent noise bandwidth (ENBW) for noise measurements. It should be noted that the equivalent noise bandwidth is not the −3 dB bandwidth of the filter. Instead, it refers to the effective bandwidth for Gaussian noise.

The equivalent noise bandwidth and response settling time of RC low-pass filters of different orders are listed in Table 1.

Table 1. ENBW and response settling time of RC low-pass filters of different orders

Filter order	Roll-off	ENBW	Time required for the output to reach 99% settling
1	6 dB/oct	0.25 ÷TC	4.6 ×TC
2	12 dB/oct	0.125 ÷TC	6.6 ×TC
3	18 dB/oct	0.09375 ÷TC	8.4 ×TC
4	24 dB/oct	0.07813 ÷TC	10.0 ×TC
5	30 dB/oct	0.06836 ÷TC	11.6 ×TC
6	36 dB/oct	0.06152 ÷TC	13.1 ×TC
7	42 dB/oct	0.0564 ÷TC	14.6 ×TC
8	48 dB/oct	0.05237 ÷TC	16.0 ×TC

Comparison Between Digital and Analog Filters

To maximize the performance of the lock-in amplifier, this product uses digital filters to implement low-pass filtering of the coherent modulation result. As in most comparisons between analog and digital systems, digital systems offer many advantages that analog systems do not. First, the inherent temperature drift and nonlinearity of analog devices greatly limit the roll-off performance of the filter. Second, building a low-pass filter with a large time constant and high quality using analog components requires a considerable amount of PCB area. This not only increases the instrument cost, but also makes future debugging more difficult due to the large number of analog components.

The low-pass filter implemented digitally in this product is a narrowband filter with a 64 bit data width, a DC gain of 0 dB, and an equivalent Q value of more than 145 dB.

Synchronous Filter

Another advantage of digital filters is that a synchronous filter can be implemented easily. Even if the input signal contains no noise, the output of the phase-sensitive detector still includes the sum-frequency component of the input and reference signals, namely the second-harmonic component. The amplitude of this sum-frequency component may be larger than that of the desired difference-frequency component. At low frequencies, a very large time constant is required to filter out the second-harmonic component. For example, if the input signal has a frequency of 1 Hz, the second-harmonic component is 2 Hz. Even with a second-order RC filter with a 10-second time constant, the attenuation at 2 Hz is only slightly over 40 dB.

The synchronous filter averages all data over one complete period of the reference frequency. It can effectively reject all harmonic components of the reference frequency and is equivalent to a sinc filter whose zero frequency is located at the reference frequency. In the example above, if a synchronous filter is used, only 1 second of waiting time is required to achieve better performance than a 10-second-time-constant RC filter.

In OE2022, the synchronous filter setting is effective only when the detection frequency is lower than 250 kHz. At higher frequencies, the sum-frequency component can be removed with a smaller time constant, so long waiting times are not required and the synchronous filter is unnecessary. A multi-order filter is also designed after the synchronous filter. This filter combination can remove both harmonic components of the reference signal and other noise signals.

Large Time Constants

It is difficult for analog filters to achieve time constants greater than 100 s, because the required capacitors become too large both in value and in physical specifications. Why are such large time constants needed? In some cases, there is no alternative. For example, when the reference signal frequency is below 1 Hz and substantial low-frequency noise interference is present, the output of the phase-sensitive detector contains many low-frequency interference components. The synchronous filter can remove only the harmonic components of the reference signal, while the remaining noise signals must be removed by the subsequent filter.

Using digital technology, OE2022 can provide a time constant of up to 3000 s, satisfying the requirements of most measurements.

Selection of Time Constant and Filter Slope

Whether the goal is fast signal measurement or a more stable signal display, the desired result can be achieved by adjusting the combination of time constant and filter roll-off. Under the same measurement accuracy requirement, choosing a higher filter roll-off and reducing the time constant accordingly can significantly improve the measurement response speed. Conversely, when the stability of the measurement result needs to be further improved, both the time constant and the filter roll-off can be increased.

For a specific application, the time constant and filter roll-off should be configured flexibly according to the actual conditions. A practical rule is that if the stability of the measurement result is satisfactory, there is no need to excessively increase the time constant or the filter roll-off, as this will only extend the waiting time unnecessarily. If a smoother measurement result is desired, the time constant and filter roll-off can be increased appropriately.

DC Output Gain

How large can the DC output of a phase-sensitive detector be? It depends on the dynamic reserve. When the dynamic reserve is 60 dB, the noise signal may be 1000 times larger than the full-scale signal. In a phase-sensitive detector, the noise signal must not exceed the input range of the phase-sensitive detector. In an analog lock-in amplifier, suppose that the maximum input amplitude of the phase-sensitive detector is 5 V. When the dynamic reserve is 60 dB, the signal at the input of the phase-sensitive detector is only 5 mV. Since the phase-sensitive detector itself does not amplify the signal, its output is only a few millivolts. Even if the DC output of the phase-sensitive detector has no error, the following amplifier can easily distort the signal when it directly amplifies the signal 1000 times to 5 V. If the PSD has an offset of 1 mV, this offset becomes 1 V at the output. This is why analog phase-sensitive detectors cannot achieve very high dynamic reserve.

Because a digital lock-in amplifier does not use an analog DC amplifier, it does not have DC output offset. A digital DC amplifier also has no input offset. The digital DC amplifier simply multiplies the received data by a preset gain and outputs the result. This is why OE2022 can remain unaffected by offset even when its dynamic reserve reaches 130 dB.

2.6 Dynamic Reserve

Dynamic reserve is defined as the ratio between the maximum tolerable noise signal and the full-scale signal. It indicates the lock-in amplifier's tolerance to noise and is usually expressed in dB.

$$\text{Dynamic reserve} = 20 \lg \frac{\text{OVL}}{\text{FS}} \text{ (dB)}$$

where OVL denotes the total input dynamic range, and FS denotes the maximum range, namely the output dynamic range. If the dynamic reserve is 100 dB, the system can tolerate noise that is 10^5 times larger than the useful signal.

In practice, the dynamic reserve setting should ensure that overload does not occur throughout the experiment. Overload may occur at the input of the preamplifier or at the signal output of the DC amplifier. The system input gain is inversely related to the dynamic reserve, because noise is also amplified with the input gain. Therefore, **high dynamic re-**

serve can be achieved by reducing the input gain. The preamplifier gain should be set to a reasonable range to prevent noise overload. After the PSD and low-pass filter remove most of the noise, the DC output gain is set to a larger value to amplify the signal to full scale.

Before PSD processing, the input signal of the lock-in amplifier requires AC amplification. After PSD processing, only DC amplification is required. When the total gain remains unchanged, increasing the AC gain and reducing the DC output gain makes it easier for input noise to overload the PSD, thereby reducing the dynamic reserve, while also reducing the DC drift at the output. Conversely, increasing the DC output gain and reducing the AC gain improves the dynamic reserve and gives the lock-in amplifier better interference immunity, but this comes at the cost of output stability and reduced measurement accuracy.

The accuracy of the DC amplified output is affected by the frequency and amplitude of the noise. Noise with a large amplitude and the same frequency as the signal is also converted into a DC signal after the PSD. When it passes through the low-pass filter, it is directly superimposed on the output and affects the output result.

Dynamic reserve is related to noise frequency. At the reference frequency, the dynamic reserve is 0 dB. As the noise frequency moves away from the reference frequency, the dynamic reserve increases. When the noise frequency is sufficiently far from the reference frequency, the dynamic reserve can reach its maximum value. The dynamic reserve near the reference frequency is extremely important to the instrument's noise tolerance. Increasing the order of the low-pass filter can improve filtering performance and thereby increase the dynamic reserve near the reference frequency. The dynamic reserve far away from the reference frequency is generally larger, but it usually has little effect on the measurement.

The dynamic reserve of OE2022 can exceed 130 dB. A high dynamic reserve may increase output noise and drift. When the dynamic reserve is high, output error increases due to noise in the analog-to-digital converter. All signal sources have a noise floor, so noise is mixed into the signal extraction process of the PSD. If the noise is large, a high-dynamic-reserve measurement may produce a large output error. If the external noise is small, the output is mainly affected by the intrinsic noise of OE2022. In this case, the output error can be reduced by lowering the dynamic reserve and DC output gain. Therefore, in practical applications, a lower dynamic reserve, namely a higher input gain, should be used whenever possible.

2.7 Signal Input Amplification and Filtering

A lock-in amplifier can measure weak signals down to the nanovolt level. An analog-to-digital converter can digitize analog signals, but the signal must be strong enough to be identified. Therefore, the low-noise signal amplifier must provide sufficient gain to amplify the signal to a level that can be directly converted by the analog-to-digital converter without reducing the signal-to-noise ratio. The frontend AC gain of OE2022 is approximately 0.2 to 1200. However, no matter how large the gain setting is, it does not improve the signal-to-noise ratio of the input signal.

Input Noise

Assume that the amplifier input noise is 10 $\mathrm{nV_{rms}}/\sqrt{\mathrm{Hz}}$ and the gain is 1000. The amplifier will then output 10 $\mathrm{\mu V_{rms}}/\sqrt{\mathrm{Hz}}$ of noise. Suppose the amplifier output is followed by a first-order RC low-pass filter with a roll-off of 6 dB/oct and a time constant of 100 ms. The input noise of the amplifier and the Johnson noise of the resistor have Gaussian noise characteristics, and the amount of noise is proportional to the square root of the noise bandwidth. The equivalent noise bandwidth (ENBW) of a single-pole RC filter is $1/(4 \times TC)$. This means that when Gaussian noise at the filter input is filtered, its effective bandwidth is equal to the ENBW. In this example, the filter input has 10 $\mathrm{\mu V_{rms}}/\sqrt{\mathrm{Hz}}$ of noise, and the equivalent noise bandwidth is 2.5 Hz. The output voltage noise of the filter is $10\,\mathrm{\mu V_{rms}}/\sqrt{\mathrm{Hz}} \times \sqrt{2.5\,\mathrm{Hz}} = 15.8\,\mathrm{\mu V_{rms}}$. For Gaussian noise, the peak-to-peak value is approximately 6.6 times the RMS value. Therefore, the output has about 104 µV peak-to-peak noise.

The input noise of a lock-in amplifier follows the same principle. When the gain is set to 1000, the input gain reaches its maximum, and the input noise determines the output noise. The equivalent noise bandwidth of the low-pass filter also affects the amount of output noise.

The equivalent noise bandwidth depends on the time constant and filter roll-off, as described in Section 2.5. For example, when OE2022 is set to the 1 mV range, whose gain is 1000, and the time constant is set to 100 ms with a roll-off of 6 dB/oct, the equivalent noise bandwidth is 2.5 Hz. The input noise of OE2022 is about 2.5 $\mathrm{nV_{rms}}/\sqrt{\mathrm{Hz}}$. Under this setting, the total noise at the filter output is 3.9 $\mathrm{\mu V_{rms}}$, and the equivalent input-referred noise is 3.9 $\mathrm{nV_{rms}}$. The noise-to-full-scale ratio is 3.9 ppm, namely 3.9 nV/1 mV.

Assume that the signal is generated by a low-impedance source. The Johnson noise of a resistor is approximately $0.13 \times \sqrt{R}$. Taking a 100 Ω resistor as an example, its Johnson noise at room temperature is 1.3 $\mathrm{nV_{rms}}/\sqrt{\mathrm{Hz}}$. The Johnson noise of a 10 kΩ source is 13 $\mathrm{nV_{rms}}/\sqrt{\mathrm{Hz}}$, which is already greater than the intrinsic input noise of OE2022. The total system noise is calculated by taking the square root of the sum of the squares of all noise sources. For example, when a 10 kΩ source is connected to the lock-in amplifier, the Johnson noise of the source and the input noise of OE2022 combine to give a total noise of $\sqrt{2.5^2 + 13^2} = 13.2\,\mathrm{nV_{rms}}/\sqrt{\mathrm{Hz}}$. It can be seen that when the input noise is large, more than one order of magnitude greater than the instrument's own input noise, the effect of the input noise of OE2022 on the total system noise can be ignored.

At low gain, the amplified noise signal remains below the intrinsic noise of the analog-to-digital converter. In this case, the system output noise is mainly ADC noise. However, since the DC gain after the filter is very low under this condition, the output noise is negligible relative to the useful signal.

Anti-aliasing Filter

After passing through the notch filter and amplifier circuit, the input signal passes through an anti-aliasing filter. This must be completed before the signal is digitized. According to the Nyquist theorem, the sampling frequency must be at least twice the signal frequency in order to fully preserve the information in the original signal. For example, if the signal frequency is 100 kHz, a sampling frequency of at least 200 kHz is required. The sampling frequency of the A/D converter in OE2022 is 4 MHz. The A/D converter cannot convert signals with frequencies higher than 2 MHz. Signals above 2 MHz violate the Nyquist theorem and cause undersampling. The result of undersampling is that high-frequency signals appear in the low-frequency part of the digital stream output by the A/D converter, causing aliasing and measurement errors.

To avoid undersampling, the analog signal is first low-pass filtered to remove high-frequency components above 1.5 MHz. The low-pass filter has a flat passband from 0~1.5 MHz, and signals in this frequency range are not affected. High-frequency signal components above 1.5 MHz are gradually attenuated. The range from 1.5 MHz to 2.5 MHz is the transition band, and signals and noise above 2.5 MHz are attenuated by more than 100 dB.

Input Impedance

The input impedance of OE2022 is 10 MΩ. If a higher input impedance is required, the OE400X series preamplifier supplied for use with OE2022 can be used. The OE400X series preamplifier provides an input impedance of 100 MΩ or higher, meeting the requirements of various application scenarios.

Current Input

OE2022 can directly measure current signals. The user only needs to connect the current signal to the current input port of OE2022 and switch to the corresponding current range to perform the measurement. The current measurement principle is to convert the current signal into a voltage signal through a precision transimpedance amplifier circuit, and then measure it with the lock-in amplifier. The gain setting for current input differs from that for voltage input. Users can select an appropriate range according to actual needs to ensure measurement accuracy and stability.

Range Selection and Gain Settings

OE2022 provides seven input ranges in both voltage mode and current mode. Different input ranges correspond to different gain settings. Users can select an appropriate range according to the amplitude of the signal under test, so that the signal can be effectively amplified to the input range of the analog-to-digital converter while avoiding overload or excessive dynamic reserve.

The gain settings corresponding to the voltage input ranges are listed in Table 2.

Table 2. Gain settings corresponding to voltage input ranges

Voltage range	Gain
5 V	0.2
1 V	0.8
200 mV	8
50 mV	32
10 mV	120
2 mV	480
1 mV	1200

The gain, transimpedance resistor, and -3 dB bandwidth settings corresponding to the current input ranges are listed in Table 3.

Table 3. Current input range settings

Current range	Total current-to-voltage gain	Transimpedance resistor	DC input resistance	-3 dB bandwidth
5 mA	2×10^2 V/A	1 kΩ	100 Ω	>1.5 MHz
500 µA	2×10^3 V/A	1 kΩ	100 Ω	>1.5 MHz
50 µA	2×10^4 V/A	1 kΩ	100 Ω	>1.5 MHz
5 µA	2×10^5 V/A	1 MΩ	100 Ω	50 kHz
500 nA	2×10^6 V/A	1 MΩ	100 Ω	50 kHz
50 nA	2×10^7 V/A	100 MΩ	1 kΩ	800 Hz
5 nA	2×10^8 V/A	100 MΩ	1 kΩ	800 Hz

2.8 Input Connection

Noise exists in all circuits. Even when the signal amplitude is large, noise reduces measurement accuracy. To obtain the best measurement accuracy, attention must be paid to reducing avoidable noise sources in the experimental environment. In addition to intrinsic system noise, the effects of other noise sources, such as mains noise, signal generator noise, and spatially distributed electromagnetic fields, as well as ground-potential differences and ground loops between instruments, can be reduced through proper input wiring.

The instrument provides two input connection methods: single-ended connection and differential connection. Single-ended connection is very convenient, while differential connection can effectively reduce the influence of noise.

Single-Ended Connection Mode (IN+)

In single-ended connection mode, the IN+ input is used. The lock-in amplifier measures the voltage difference between the center conductor and the shield conductor of the IN+ input connector.

Ground potential is generally considered to be a constant of 0 V; however, the ground potentials of different instruments may differ slightly. When the ground of the signal source is directly connected to the ground of the measuring instrument, the difference in ground potential can cause a large current, namely a ground loop. In this case, the current of the instrument at the higher ground potential returns to earth through the instrument at the lower ground potential. This causes two serious problems. First, the noise of the instrument at the higher ground potential is directly introduced into the instrument at the lower ground potential. Second, the instrument at the lower ground potential may be damaged by excessive current. This problem can be solved by connecting a resistor between the grounds at different potentials. In OE2022, two resistor modes are available: Float and Ground. Float uses a 10 kΩ resistor, while Ground uses a 10 Ω resistor as a short connection.

In addition, single-ended connection has relatively weak noise immunity. A single signal cable behaves like an antenna and is affected by electromagnetic noise in the environment. The shield absorbs this noise. Since single-ended connection measures the voltage difference between the center conductor and the shield, this noise is introduced into the lock-in amplifier.

Differential Connection Mode (DIFF)

In differential connection mode, two signal cables are connected to the signal source, and each cable is connected to the corresponding input terminal, IN+ or IN-. In this mode, the voltage difference between the center conductors of the IN+ and IN- connectors is measured. Noise absorbed by the outer shield layers of the two connectors is not acquired by the lock-in amplifier.

One point should be noted when using differential connection mode: the cables of the two input terminals should be tightly twisted and should not form a loop, in order to avoid electromagnetic induction and measurement errors.

AC Coupling and DC Coupling Modes

OE2022 provides two input coupling modes: AC coupling and DC coupling. In AC-coupled mode, a first-order RC high-pass network with a −3 dB cutoff frequency of 0.16 Hz is inserted to attenuate DC and very low-frequency components. AC coupling should be used when the signal frequency is greater than 10 Hz, so that passband flatness is ensured. For signals below 10 Hz, DC coupling mode should be used. DC coupling mode has no effect on the input signal.

If the input signal contains a DC component and it is not removed, several problems may occur. In the amplifier circuit, the DC component is also amplified. If it is amplified beyond the input range of the A/D converter, the measurement result will contain errors, and the A/D converter may even be damaged. In addition, after the DC component is quantized into a digital value by the A/D converter, it is multiplied by the reference sine signal in the PSD. A more powerful low-pass filter is then required to remove it, resulting in a longer measurement time.

When the frequency of the signal under test is greater than 10 Hz, AC coupling mode is recommended.

2.9 Intrinsic Noise

Noise

From a subjective point of view, any input or influence that is undesired or that interferes with accurate measurement can be regarded as noise. Noise is transient, random, and unpredictable. In almost all measurement fields, the ultimate limiting factor in detecting weak signals is noise. Even when the signal to be measured is not very weak, the presence of noise reduces measurement accuracy. Some forms of noise are unavoidable, such as jitter in the signal under test, and can only be overcome by techniques such as signal averaging and bandwidth reduction. Other forms of noise, such as RF interference and ground loops, can be eliminated or reduced by many techniques, including filtering, proper wiring structure, and appropriate component layout. The amplifier itself also generates noise during operation, which can be reduced by low-noise amplifier design techniques.

Electronic systems contain many types of intrinsic noise sources, each with its own physical meaning.

Johnson Noise (Thermal Noise)

In any passive component, the electrons in the conductor are always in random motion, producing a noise voltage across its terminals. This is Johnson noise, also known as white noise or thermal noise. It exists in all electronic components and transmission media. It is affected by temperature, but not by frequency. In the frequency domain, thermal noise has a uniform power spectral density over the entire frequency range, similar to a white spectrum. It cannot be eliminated and is therefore one of the factors that determines the upper limit of electronic system performance. At temperature T, the actual noise voltage generated by a resistor R is calculated as:

$$V = \sqrt{4kTRB}$$

where k is Boltzmann's constant, $k = 1.38 \times 10^{-23}$ J/K; T is the thermodynamic temperature in kelvin, with the conversion relation $K =^{\circ} C + 273.16$; and B is the bandwidth in hertz.

Nyquist later used thermodynamic reasoning to mathematically describe the statistical characteristics of thermal noise and proved that the power spectral function of thermal noise is:

$$St(f) = 4KTR(V^2/Hz)$$

For example, at room temperature, if a 10 kΩ resistor is connected to the input of a high-fidelity amplifier and a voltmeter is connected to the output, using a filter with a bandwidth of 10 kHz to measure its open-circuit RMS voltage gives a result of 1.3 µV.

The instantaneous amplitude of thermal noise voltage is generally unpredictable under any condition, but it follows a Gaussian distribution. Its significance is that it represents the lower limit of the noise voltage of any detector, signal source, or amplifier. The impedance part of the source resistance generates thermal noise, as do the bias and load resistors of the amplifier.

Shot Noise

Electric current is actually a flow of discrete charges, not a true continuous fluid. The finite nature of charge causes statistical fluctuations in current. If the charges do not interact with each other, the current fluctuation is given by:

$$I_{noise} = \sqrt{2qIB}$$

where q is the electron charge (1.6×10^{-19} C), I is the RMS current in the circuit, and B is the measurement bandwidth. For example, a stable 1 A current measured over a 10 kHz bandwidth has an RMS fluctuation of 57 nA, corresponding to a fluctuation of about 0.000006%. For smaller currents, the relative fluctuation is larger: a stable 1 µA current measured over 10 kHz has an RMS current noise of 57 pA, corresponding to a 0.006% fluctuation. For a 1 pA current, the RMS current noise is 56 fA over the same bandwidth, corresponding to a 5.6% fluctuation.

It has also been proven that shot noise current is a type of white noise, and its power spectral density function is:

$$S_{sI}(f) = 2qI(A^2/Hz)$$

The shot-noise formula above assumes that the charge carriers in the current do not interact with each other. This assumption is valid when charge passes through a potential barrier, such as current diffusion through a point-contact diode. However, it is not valid for the most common metal conductors, in which the charge carriers are closely correlated.

1/f Noise (Flicker Noise)

In 1925, Johnson first discovered 1/f noise in the current of vacuum tubes. Its distinguishing feature is that its power spectral function is proportional to 1/f. The lower the frequency, the more severe the noise, so it is also called low-frequency noise. Its microscopic mechanism is that when the contact between two conductors is imperfect, the contact resistance fluctuates randomly and causes noise.

Although 1/f noise has been studied for decades, its applicable situations vary and many descriptive models exist. Its current amplitude follows a Gaussian distribution, and its power spectral density is inversely proportional to the operating frequency. Its power spectral density function is expressed as:

$$S(f) = \frac{KI_d^2}{f}(V^2/Hz)$$

1/f noise, also called flicker noise, is generated by random fluctuations in the carrier density of active devices. It modulates the center-frequency signal and forms two sidebands around the center frequency, reducing the Q factor of the oscillator. Since 1/f noise is the dominant noise near the center frequency, its influence must be considered when designing device models.

Shot noise and thermal noise are unavoidable noises caused by physical characteristics. For resistors of the same resistance value, a well-made resistor and an inexpensive carbon resistor generate exactly the same thermal noise. In addition, practical devices have various excess noise sources. Actual resistors have resistance fluctuations, which generate an additional noise voltage that is superimposed on the ever-present thermal noise and is proportional to the DC current flowing through the resistor. This noise is related to many factors associated with resistor construction, including the resistor material and especially the packaging technology. Taking solid carbon resistors, carbon-film resistors, metal-film resistors, and wire-wound resistors as examples, wire-wound resistors have the lowest noise, followed by metal-film resistors, then carbon-film resistors, and solid carbon resistors have the highest noise.

2.10 External Noise Sources

Intrinsic noise is difficult to avoid and can only be minimized as much as possible. Compared with intrinsic noise, external noise appears in many forms, and most external noise sources are asynchronous. External noise sources mainly affect measurement time by increasing the requirements for dynamic reserve and time constant. A small number of noise sources are closely related to the reference signal and can add to or subtract from the actual measured signal, causing incorrect measurement results. Fortunately, external noise sources can be minimized through various methods.

Capacitive Coupling

Mutual capacitance always exists between conductors. Because this mutual capacitance behaves like a parasitic element between conductors, it is called parasitic capacitance or stray capacitance. Capacitance also exists between electrodes and surrounding objects, including various components and even the human body. AC voltage signals near the lock-in amplifier can be coupled into the equipment through these parasitic capacitances. Although the parasitic capacitance may be very small, the coupled voltage signal may still be larger than the weak signal under test.

The influence of parasitic capacitance can be calculated as:

$$I = \omega C_{stray} V_{noise}$$

where ω is 2π times the noise frequency, C_{stray} is the stray capacitance, and V_{noise} is the noise amplitude.

As the frequency of the noise source increases, the coupled noise also increases. If the noise source has the same frequency as the reference frequency, it will have a large influence on the measurement result. This is because the lock-in amplifier rejects noise at other frequencies, but treats noise at the same frequency as the reference as a measured signal.

Methods for reducing capacitive coupling include:

- Remove the noise source, or keep the noise source as far away as possible from the instrument and signal cables.
- Use a low-impedance experimental setup so that the coupled noise current produces only a small noise voltage.
- Use capacitive shielding, for example by placing the entire experimental setup inside a metal enclosure.

Inductive Coupling

A magnetic field is induced near an AC current. If a device is placed near an AC current, the induced magnetic field can couple into the circuit and affect it. A changing AC current produces a changing magnetic field, and the changing magnetic field induces an electromotive force. The induced electromotive force affects the current and voltage of the circuit, causing measurement deviation. The magnitude of the electromotive force is related to the frequency of the magnetic field variation. The faster the frequency, the larger the electromotive force and the greater the influence on the measurement.

Methods for reducing inductive coupling include:

- Remove noise sources near the instrument as much as possible.
- Use twisted-pair cables or two tightly twisted coaxial cables to reduce loop effects.
- Use magnetic shielding for the instrument to prevent magnetic fields from entering and

penetrating the measurement area.

Resistive Coupling and Ground Loops

A ground loop can also become an interference source. It can generate a noise voltage between the grounds at the two ends of a transmission path. If the noise voltage is large enough, measurement errors will occur. A ground loop is a physical loop in the system grounding scheme that arises from multiple ground paths between circuits. These ground paths can act as a large loop antenna, capturing environmental noise and thereby generating voltage in the grounding system. The 50 Hz magnetic field from the AC mains is a common noise source captured by ground loops. Similarly, in a distributed grounding system, a ground voltage originating from one location can cause ground current to flow through the ground loop. Since ground is a low-impedance path, the noise current is often quite large. Noise of several hundred millivolts may cause several amperes of current to flow through a ground loop.

Methods for eliminating ground-loop current include:

- Connect all grounds to the same point.
- Make the ground bus as thick as possible to reduce the impedance of the ground connection.
- Avoid sharing the small-signal ground path with high-current ground return paths.

Microphonic Noise Effect

Most noise sources affect circuits electrically. However, mechanical vibration can also be converted into electrical noise through the microphonic effect. Micro-vibrations of transmission cables or the signal under test can produce electrical noise with varying frequency.

Methods for eliminating the microphonic effect include:

- Reduce mechanical vibration as much as possible during measurement.
- Tie down and fix transmission lines carrying weak signals to reduce their vibration.
- Replace ordinary cables with low-noise cables to reduce the microphonic effect.

Thermocouple Effect

The thermocouple effect refers to the potential difference generated between two different metals when they are in contact with each other. The contact potential difference is caused by: (1) different work functions of the two metals; (2) different electron concentrations in the two metals. If the work functions of metals A and B are V_a and V_b, and their electron concentrations are N_a and N_b, the contact potential difference between them is:

$$V_{ab} = V_a - V_b + \frac{kT}{q} \times \ln\left(\frac{N_a}{N_b}\right)$$

where k is Boltzmann's constant, $k = 1.38 \times 10^{-23}$ J/K. T is the thermodynamic temperature in kelvin, with the conversion relation $K = ^\circ C + 273.16$, and q is the electron charge (1.60×10^{-19} C). The above equation shows that the contact potential is determined by the properties of the metals and the temperature of the contact surface. It is generated because different metals have different work functions, meaning different amounts of work are required for electrons to escape from the metal surface.

When two different metals are in contact, the electromotive force generated at the contact point adds a slowly varying millivolt-level voltage to the original level. This noise is closely related to temperature. Since temperature changes slowly, the frequency of this noise is also very low. The thermocouple effect increases as the detector output increases, and it has a greater influence at low frequencies, especially in mHz-level measurements.

Methods for eliminating the thermocouple effect include:

- Keep the measuring instrument at a constant temperature as much as possible.
- Use junctions with compensation characteristics.

2.11 Noise Measurement

OE2022 provides a noise measurement function, which can measure the noise of the input signal at the reference frequency. Some noise sources are frequency-dependent, and the lock-in amplifier can measure such noise sources.

According to the bandwidth of the RC filter set by the user, the lock-in amplifier can be regarded as a band-pass filter whose center frequency is the reference frequency and whose passband bandwidth is twice the RC filter bandwidth. Therefore, noise near the reference frequency remains at the output. When the input signal itself is a noise source, the lock-in amplifier can measure its noise value at the set frequency. If the frequency is swept, the noise power spectrum of the noise source can also be obtained. The PC Software of OE2022 includes a Sweeper parameter-sweep function, which can be used to measure noise spectra.

OE2022 measures noise near the reference frequency using total in-band noise integration. First, the X-component data from the demodulator output is acquired over a specified time and its root mean square (RMS) value is calculated. This value represents the total noise amplitude within a specific bandwidth near the reference frequency. The total noise value must then be normalized to eliminate the influence of the digital filter bandwidth. Specifically, the RMS value calculated above is divided by the square root of the equivalent noise bandwidth (ENBW) of the digital filter, namely $\sqrt{ENBW}$. The resulting value is the noise spectral density, with the unit $V/\sqrt{\text{Hz}}$. For details on calculating equivalent noise bandwidth and selecting parameters, refer to Table 1 in Section 2.5 of this manual.

2.12 Channel Output and Gain (CHOUT/AUXOUT)

OE2022 has six auxiliary output channels on the rear panel: CHOUT1 ~ CHOUT2 and AUXOUT1 ~ AUXOUT4.

Output and Display of CHOUT1 to CHOUT2

The output range of CHOUT1 to CHOUT2 is −10 V to 10 V, the update rate is 1 MSa/s, and the digital-to-analog converter resolution is 16 bit. The output can be scaled proportionally according to the ratio between the current signal measurement result and the currently selected measurement range. In addition, OE2022 can display the data sources of CHOUT1 to CHOUT2 on the front-panel screen, including the X, Y, R, and θ values of the measured signal.

Output and Display of AUXOUT1 to AUXOUT4

The output range of AUXOUT1 to AUXOUT4 is −10 V to 10 V, the update rate is 500 kSa/s, and the digital-to-analog converter resolution is 16 bit. The function of this interface is similar to that of CHOUT1 to CHOUT2. Users can select data such as the X, Y, R, and θ values of the measured signal for output.

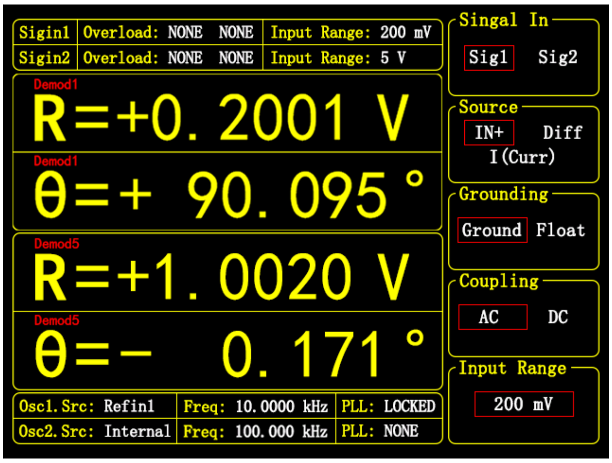


Figure 10. Output setting interface of OE2022

Output Offset and Gain of X, Y, and R

OE2022 can compensate for measurement errors by setting an offset. This is extremely useful when the measured value has an error around a nominal value. Since the offset can be set arbitrarily within the range, the output offset can be considered almost zero. Output changes can be read directly from the display screen or from the output terminals on the panel. The offset is expressed as a percentage of the full-scale output, and this ratio does not change with sensitivity. The offset can be set up to ±100% of full-scale output.

The system can also amplify the output values of X, Y, and R. This feature is implemented by multiplying the output data by a specified gain factor. As a result, even if the signal is only one-tenth of full scale, its output can be increased from 1 V to 10 V after amplification. The main function of output signal gain is to significantly improve measurement accuracy and resolution around a specific nonzero value.

As long as the full-scale output is not exceeded, OE2022 can provide multiple output gain settings from +0.001~+10 000. The output is calculated as:

$$\text{Output} = \left(\frac{Signal}{Sensitivity} + Offset \right) \times Expand \times 10\ \text{V}$$

<Offset> can be set between −100~100 %. It can be entered directly using the numeric keypad, with a minimum step of 0.01%. <Expand> can be set between +0.001~+10 000. It

can be entered directly using the numeric keypad, with a minimum step of 0.001. For example:

$$\text{Output} = \left(\frac{0.1\,\text{mV}}{1\,\text{mV}} + 0.2\right) \times 2 \times 10\,\text{V} = 6\,\text{V}$$

2.13 Auxiliary Analog Inputs (AUX IN)

OE2022 includes four 16-bit high-precision auxiliary AUX IN input channels. The input voltage range is ±10 V, the minimum resolution is 0.3 mV, and the sampling rate is 150 kSa/s. These four ADC channels provide input signal clamp protection and internal differential amplification. With an input impedance of 1 MΩ, they can acquire signals simultaneously and are used to measure low-speed analog signals or DC signals obtained from an experiment, such as signals from temperature or pressure sensors, for PID calculation and transmission to the control computer.

The AUX IN interface uses standard BNC connectors and is integrated on the rear panel of OE2022. AUX IN value display is configured in the [DISPLAY] submenu.

2.14 Signal Generator

OE2022 can select the internal oscillator OSC1 or OSC2 as the signal source to output a sine-wave signal with an arbitrary amplitude. The amplitude range is 100 nV ~ 5 V_{rms}, the output impedance is 50 Ω, and the drive current capability reaches 80 mA. The phase of the output signal remains synchronized with the internal oscillator of the instrument, and an independent phase offset can be set.

For external devices that require a bias voltage, such as electro-optic modulators, OE2022 can directly drive the device without an additional level-shifting amplifier due to its excellent drive capability. A DC bias voltage in the range of ±5 V can be superimposed internally by OE2022.

The signal generator of OE2022 supports AM/FM/PM modulation, making it convenient for users to perform modulation control of the system.

2.15 Multi-harmonic Measurement

Harmonics are components of a periodic function or periodic waveform that can be expressed as a linear combination of constants and sine and cosine functions having the same fundamental period as the original function. According to Fourier series theory, a periodic function can be expanded into a constant plus a set of sine and cosine functions with a common period. In the expansion, the constant term is called the DC component; the component whose minimum positive period is equal to the period of the original function is called the fundamental or first harmonic; and the components whose minimum positive periods are integer multiples of the original period are called higher-order harmonics.

In traditional lock-in amplifiers, only the fundamental signal or one harmonic component can be measured at a time. In many practical applications, multiple harmonics often need to be measured and recorded simultaneously. In such cases, conventional lock-in amplifiers are often unable to meet the requirement.

OE2022 provides an innovative multi-harmonic simultaneous measurement function. Its eight independent demodulator channels can measure up to six harmonic components simultaneously. Tasks that previously required eight lock-in amplifiers can now be completed by a single OE2022.

Multi-harmonic measurement is configured in the [DEMOD REF] menu.

In addition to multi-harmonic measurement, OE2022 also provides arbitrary-frequency demodulation and frequency-combination demodulation functions.

Chapter 3 Interface Overview

3.1 Front Panel

Figure 11. OE2022 Front Panel

3.1.1. Display

The OE2022 uses a 5.6-inch TFT display for data presentation and user interaction. The display resolution is 640×480. Eight background-brightness levels are available and can be configured in the [SYSTEM] submenu.

The large area on the left side of the screen is used to display measurement results of the input signal. It supports dual-column dynamic plots and full data display. The dual-column dynamic plots support numeric and bar-graph display modes, while the full data display supports all measurement parameters. These options can be configured using <Display Mode> in the [DISPLAY] menu.

The area on the right side of the screen is used to select and modify measurement control settings.

3.1.2. Softkeys

There are five Softkeys on the right side of the display. Their functions vary depending on the current menu. In general, the Softkeys have two main functions: selecting different setting items, and highlighting specific parameters so that they can be edited using the knob or keypad. In either case, the Softkeys only operate on the parameters adjacent to them on the right side of the screen.

3.1.3. Knob

The knob is used to adjust parameters highlighted by the Softkeys. Most parameters can be adjusted using the knob. Turn the knob clockwise to increase the parameter value, and counterclockwise to decrease it.

3.1.4. Keypad

The keypad consists of three groups of keys. The ENTRY area is mainly used to enter numerical values for parameters highlighted by the Softkeys. The MENU area changes the parameter list on the right side of the screen and provides ten different function menus. The ARROW area is used to select certain highlighted parameters, such as setting the input range or modifying an individual digit of a frequency value.

3.1.5. BNC Connectors

The front panel has eight BNC connectors. From left to right, they are SINE OUT 1, SINE OUT 2, REF IN 1, REF IN 2, SIGNAL IN 1 IN-, SIGNAL IN 1 IN+/I, SIGNAL IN 2 IN-, and SIGNAL IN 2 IN+/I.

SINE OUT 1/2

The signal generator provides a programmable sine-wave output with a maximum amplitude of 5 V_{rms} and an output impedance of 50 Ω. When an external reference signal is used, the signal generator source is phase-locked and synchronized to the reference signal through the phase-locked loop.

REF IN 1 / 2

The reference signal input can be driven by either a sine wave or a TTL square wave. The input impedance is 50 Ω or 1 MΩ. The sine-wave input is AC-coupled and supports signals greater than 1 Hz. For low-frequency applications below 1 Hz, a TTL square-wave reference signal is recommended.

SIGNAL IN 1 IN- / IN+ / I and SIGNAL IN 2 IN- / IN+ / I

The signal input supports single-ended voltage input through IN+, differential voltage input through DIFF, which is the difference between IN+ and IN-, and single-ended current input through I. The SIGNAL IN+ and I inputs share the same BNC connector. When measuring voltage signals, the input impedance of both IN- and IN+ is 10 MΩ||25 pF. When measuring current signals, the input impedance of the I input is 100 Ω or 1 kΩ.

3.2 Rear Panel

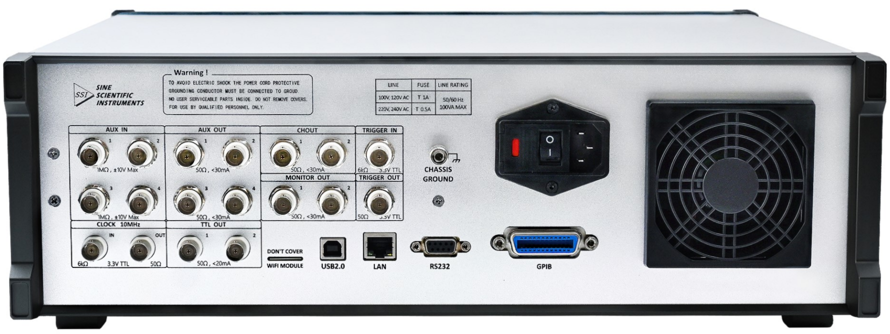


Figure 12. Rear Panel

As shown in Figure 12, the rear panel of the OE2022 includes the cooling fan, power inlet, ground terminal, USB2.0 interface, RS-232 female connector, Ethernet interface, GPIB interface, Digital I/O interface, and extended auxiliary function interfaces. The extended auxiliary function interfaces include AUX IN/OUT, CH OUT, CLK IN/OUT, TRIGGER IN/OUT, and MONITOR OUT.

3.2.1. Power Inlet

The power inlet supplies power to the entire instrument. It accepts 100~240 V, 50 Hz/60 Hz AC mains input, includes an internal fuse, and also provides filtering for high-frequency noise interference.

3.2.2. USB2.0

The USB2.0 high-speed interface allows the OE2022 lock-in amplifier to communicate with a PC. The instrument can be controlled from the PC, and measurement data can also be read by the PC.

3.2.3. RS232

The RS232 interface is a standard 9-pin RS-232 female connector. It allows the OE2022 to communicate with other devices.

3.2.4. GPIB

The standard GPIB female connector complies with the IEEE-488.2 standard and allows the OE2022 to communicate with other devices.

3.2.5. Ethernet Interface

The Ethernet interface supports communication speeds up to 1000 Mbit/s, enabling fast communication with a PC.

3.2.6. AUX IN

The four-channel AUX IN auxiliary input interface has an input range of ±10 V and a minimum resolution of 0.3 mV.

3.2.7. AUX OUT/CH OUT

The four-channel AUX OUT and two-channel CH OUT auxiliary output interfaces have an output range of ±10 V and a minimum resolution of 0.3 mV.

3.2.8. TTL OUT

The TTL OUT connector outputs a 3.3 V TTL square-wave signal with the same frequency and phase as the Sineout signal.

3.2.9. CLK IN & OUT

CLK IN is the external clock input interface. It accepts a 10 MHz, 3.3 V TTL/CMOS-level clock signal and is used to synchronize the clock with external instruments.

⋆ Note: if the external clock source has poor stability, the performance of the OE2022 may degrade.

CLK OUT provides a 10 MHz clock output interface with a 3.3 V TTL/CMOS operating level.

3.2.10. TRIG IN & OUT

The trigger input and output interfaces are used to acquire the signal under test according to an external reference signal. They can also be used for synchronization between multiple OE2022 instruments.

3.2.11. MONITOR OUT

MONITOR OUT provides the conditioned analog signal directly prior to ADC sampling, that is, an analog monitor copy of the signal path after analog amplification and filtering. Because analog amplification also amplifies noise, the MONITOR OUT signal is not suitable for observing the original signal when the signal amplitude is very small.

3.3 Main Interface

The main interface of the OE2022 can be divided into four parts.

3.3.1. Status Bar

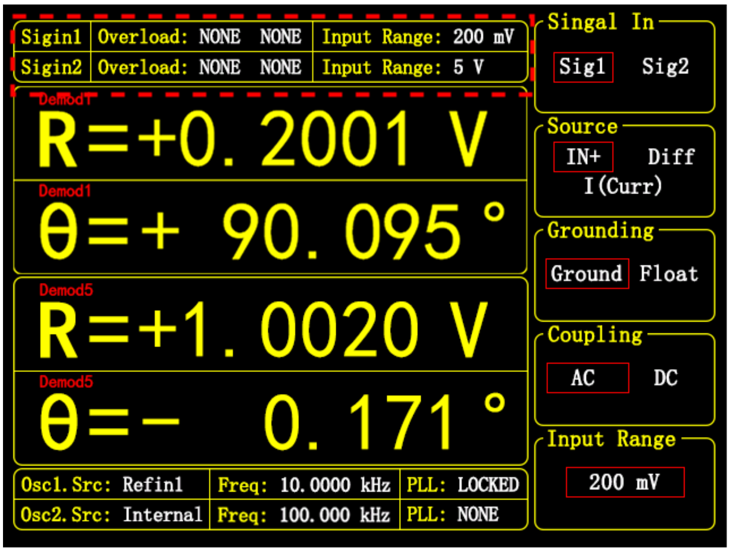


Figure 13. Main Interface–Status Bar 1

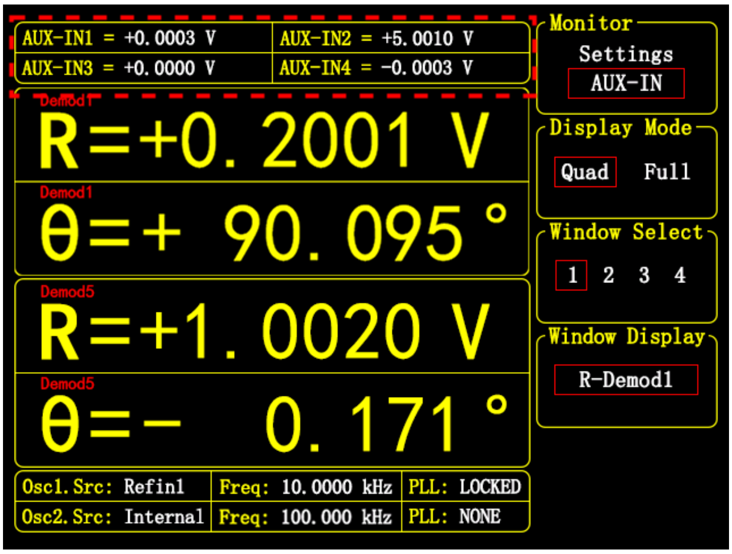


Figure 14. Main Interface–Status Bar 2

The status bar is located in the red boxed area shown in Figure 13 and Figure 14. It indicates the current system settings and measured values, and its displayed items can be switched in the [DISPLAY] submenu. This area displays the following information:

<Overload>: Indicates the input overload or overflow status. It can indicate whether the front-end input or gain stage has overflowed. If no overflow occurs, it displays Overload: NONE NONE. If the front-end input overflows, determined by a voltage threshold of ±7 V; that is, when the input voltage is higher than 7 V or lower than −7 V, corresponding to the peak level of 5 V_{rms}, it displays Overload: INPUT NONE. If the gain stage overflows, it displays Overload: NONE GAIN. If both overflow conditions occur, it displays Overload: INPUT GAIN. In any overflow condition, reduce the input signal and gain as soon as possible to prevent overvoltage damage to the instrument.

<Input Range>: Input range. The input signal must not exceed this range.

<AUX-IN1>: Input amplitude of the AUX-IN1 connector.
<AUX-IN2>: Input amplitude of the AUX-IN2 connector.
<AUX-IN3>: Input amplitude of the AUX-IN3 connector.
<AUX-IN4>: Input amplitude of the AUX-IN4 connector.

3.3.2. Data Bar

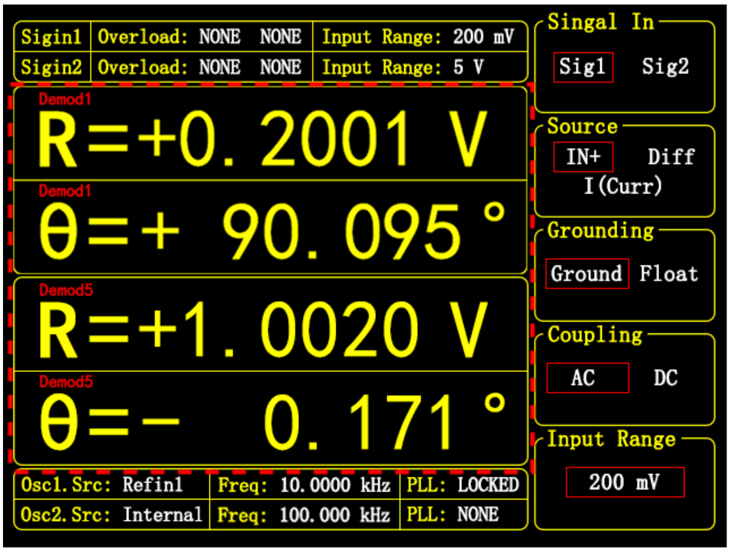


Figure 15. Main Interface–Data Bar

The data bar is located in the red boxed area shown in Figure 15. In the [DISPLAY] sub-menu, the displayed values can be selected from <X>, <Y>, <R>, and <θ>. The display mode can be selected as a four-panel dynamic plot or a full data display. For details on the setting method, see the [DISPLAY] submenu.

3.3.3. Monitor Bar

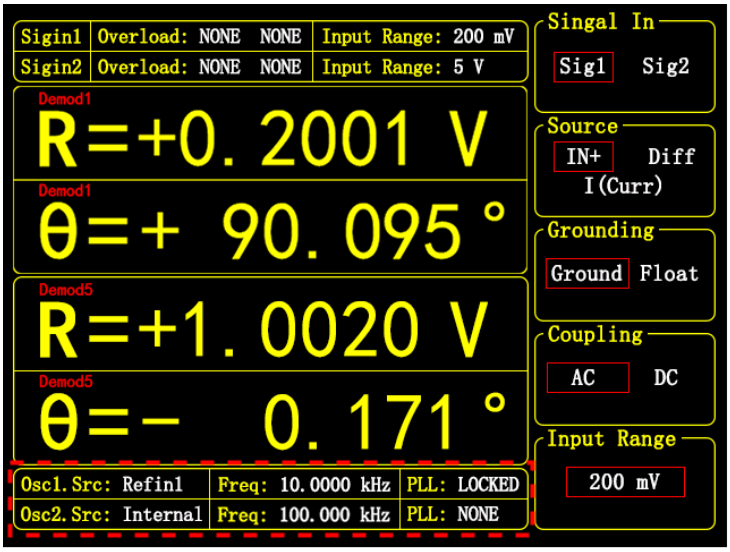


Figure 16. Main Interface–Monitor Bar

The monitor bar, located in the red boxed area in Figure 16, displays three items:

<Osc.Src>: Oscillator input source. This item indicates whether the selected reference signal source is internal or external.

<Freq>: Input signal frequency. This item displays the frequency of the input signal.

<PLL>: Phase-locked loop lock indicator. This item indicates whether the phase is locked. When the phase-locked loop is locked, it displays PLL: LOCKED. When there is no reference signal or the phase-locked loop is not locked, it displays PLL: UNLOCKED. When the internal reference is used, it always displays PLL: NONE.

3.3.4. Function Bar

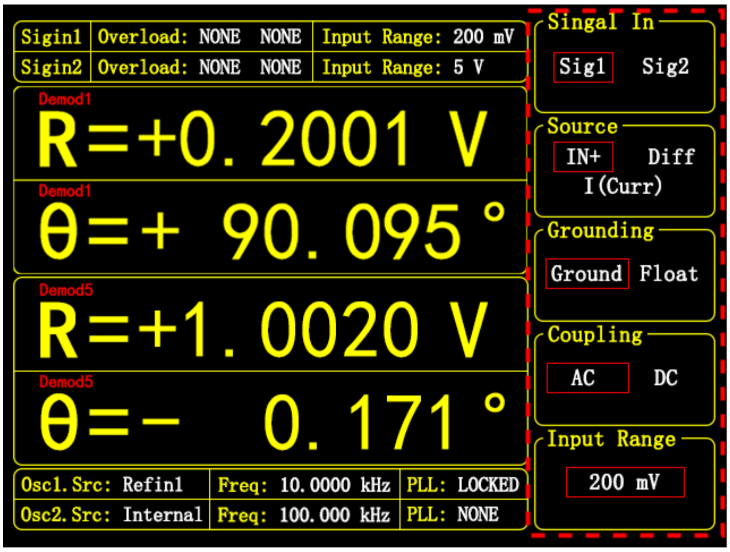


Figure 17. Main Interface–Function Bar

The function bar is located in the red boxed area shown in Figure 17. The function setting box contains multiple function selections corresponding to the five dark-gray keys on the front panel. These keys have different functions in different submenus and are the main means of controlling the instrument.

Chapter 4 PC Software Introduction

4.1 PC Software Overview

The OE2022 is supplied with the SSI Lucid Suite PC Software. SSI Lucid Suite is a next-generation graphical user interface developed on the QT platform. It presents the functional configuration of the lock-in amplifier through a lock-in amplifier flow diagram. Compared with the on-screen instrument interface, SSI Lucid Suite is easier to use and understand. In addition, SSI Lucid Suite supports high-speed data transfer and local data storage, making it convenient for users to perform post-processing and analysis. The SSI Lucid Suite interface is shown in Figure 18.

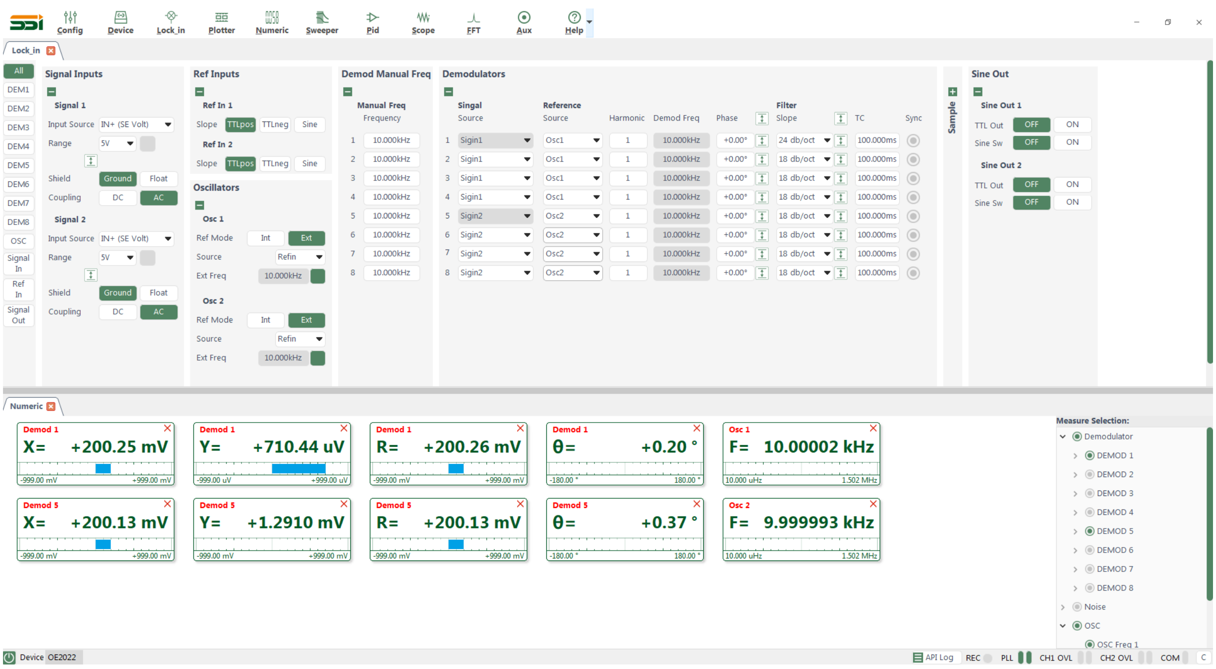


Figure 18. SSI Lucid Suite Software Interface

SSI Lucid Suite is mainly divided into four tab areas: the function menu area, the upper configuration area, the lower configuration area, and the status bar area. The functions of each area are as follows:

Function menu area: This area is used to select different instrument functions. When a function is selected, the corresponding tab interface is created in the configuration area.

Upper and lower configuration areas: The configuration area is divided into upper and lower sections. Each configuration section can contain tab interfaces for different functions, and their positions can be swapped freely. By default, the upper configuration area displays the Lock_in function interface, which is used to configure the core functions of the lock-in amplifier demodulators. The lower configuration area displays the Numeric function interface, which presents measurement results in numerical form.

Status bar area: This area displays the basic status of the lock-in amplifier, including the command-setting history log, data recording status, Overload status, and communication status.

The locations of these areas are shown in Figure 19.

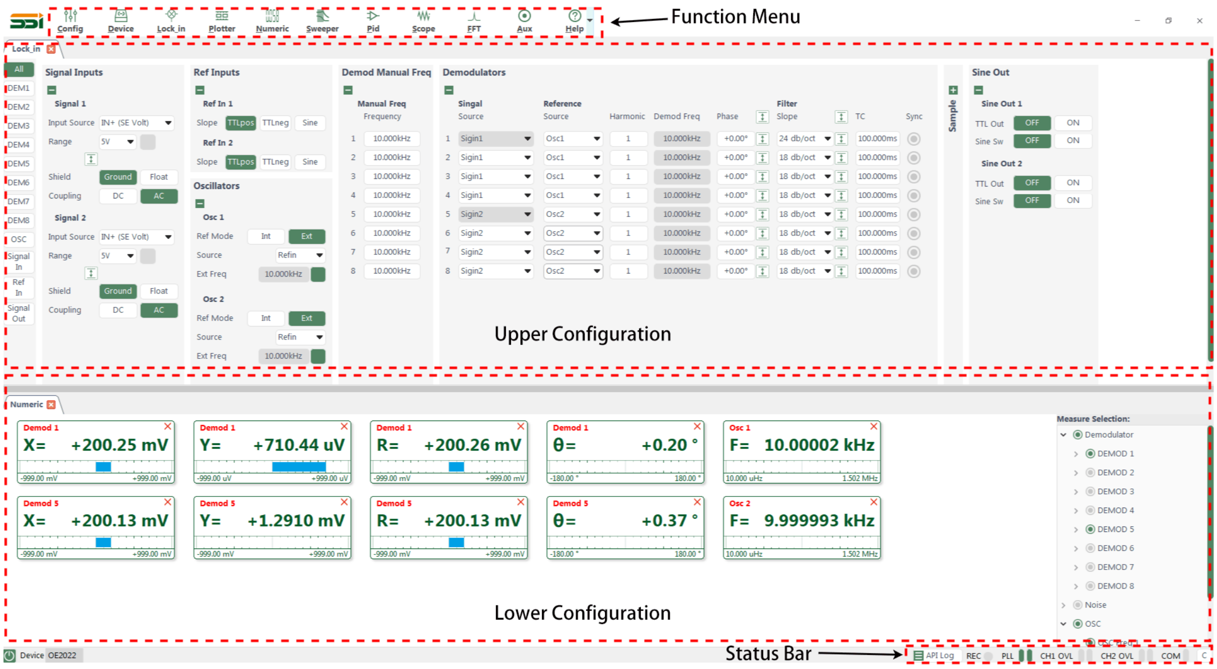


Figure 19. SSI Lucid Suite Area Layout

4.2 Connecting to the PC Software

The OE2022 is supplied with a USB flash drive. Insert the USB flash drive into the PC to obtain the SSI Lucid Suite software. After connecting the PC and the OE2022 using a USB cable or an Ethernet cable, run the “SSI Lucid Suite.exe” file. After the software starts, wait for a few seconds; the software will automatically identify the instrument connected to the PC, as shown in Figure 20.

Figure 20. SSI Lucid Suite Startup Interface

Click the ⏻ button to connect to the instrument. After the connection is established, the SSI Lucid Suite interface changes to the interface shown in Figure 21.

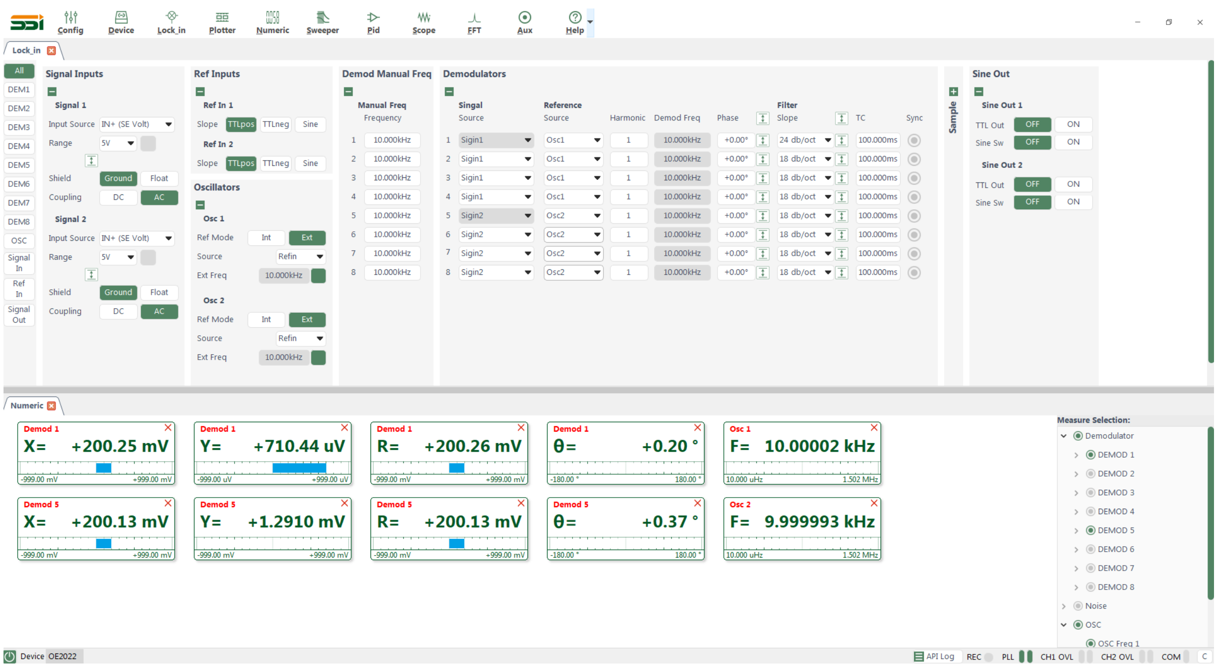


Figure 21. SSI Lucid Suite Interface

4.3 PC Software Function Overview

4.3.1. Function Menu

Figure 22 shows the function menu area of the SSI Lucid Suite PC Software. The functions from left to right are as follows:

Config: Instrument connection menu, used to disconnect or reconnect the instrument.

Device: Displays basic information such as the instrument model, serial number, version number, and interface status.

Lock_in: Sets and queries the configuration related to the core functions of the lock-in amplifier.

Plotter: Displays curves of the demodulator measurement results.

Numeric: Displays numerical values of the measurement results from each demodulator and oscillator.

Sweeper: Internal sweep function of the instrument. It supports frequency/amplitude sweep modes. The Sweeper can sweep instrument parameters over a specified range, making it convenient for users to measure system response curves.

PID: Built-in PID module of the instrument. The OE2022 has two PID modules and can control multiple variables of the lock-in amplifier.

Scope: Oscilloscope function. A virtual oscilloscope is implemented using the high-speed ADC inside the instrument, helping users observe the waveform of the signal under test.

FFT: Displays the FFT frequency-domain waveform corresponding to the oscilloscope data.

Aux: Queries the measured values of the instrument AUX IN channels and sets the output formulas of the AUX OUT channels.

Help: Displays company information and provides functions such as instrument firmware upgrade.

Figure 22. Function Menu Area

4.3.2. Lock_in Tab

The Lock_in configuration tab, shown in Figure 23, contains detailed configuration items for the core functions of the lock-in amplifier, including the demodulators and phase-locked loop. Various variables can be configured in this area. In the left sidebar, the ALL, DEM 1 ~ 8, Osc, Signal In, and other tabs can be selected to switch between the parameter-table view and the flow-diagram view. The parameter-table view displays detailed parameter information, while the flow-diagram view illustrates the instrument's internal hardware and algorithmic architecture, as shown in Figure 24, helping users understand the function of each parameter.

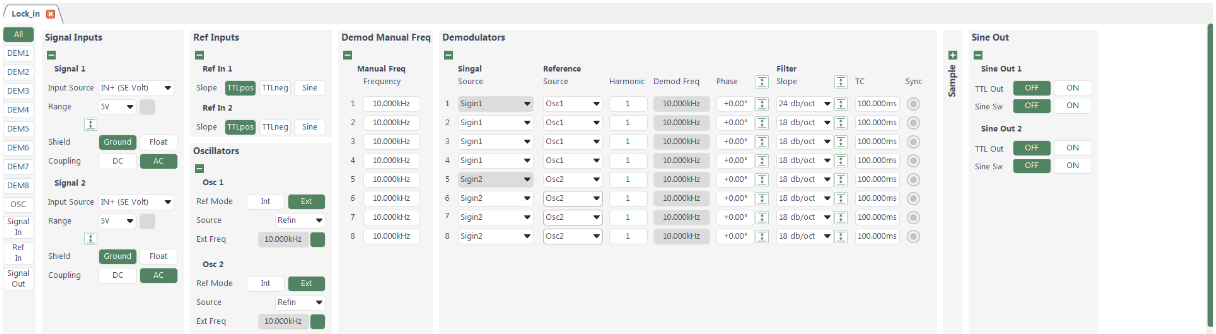


Figure 23. Lock_in Configuration Tab, Parameter-Table View

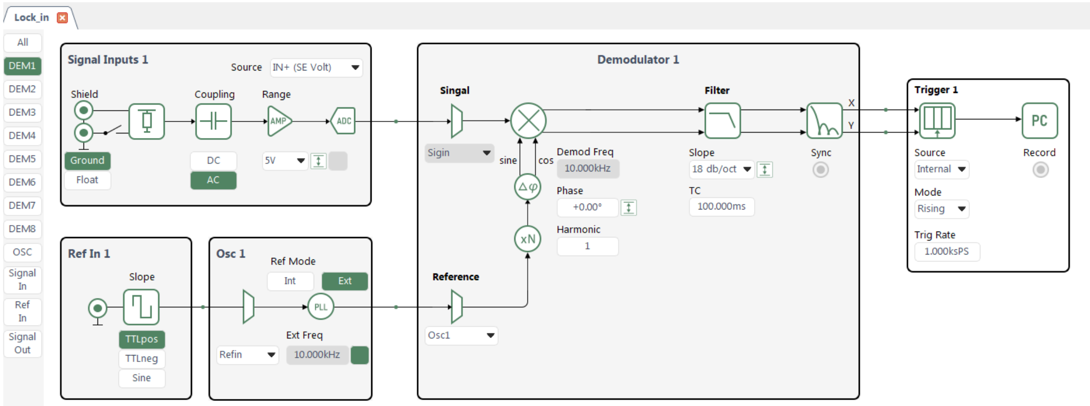


Figure 24. Lock_in Configuration Tab, Flow-Diagram View

4.3.3. Plotter Tab

The Plotter tab, shown in Figure 25, can scroll and display time-domain data trends. It supports flexible scaling of the horizontal and vertical axes, adding different measured values for display, switching between linear and logarithmic coordinates, and displaying the maximum and minimum values of the current waveform. It also allows the current waveform data to be saved separately for subsequent analysis and processing.

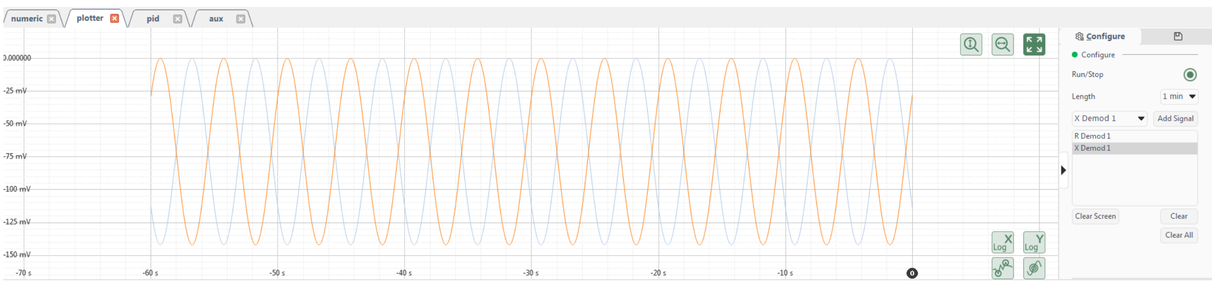


Figure 25. Plotter Tab

4.3.4. Scope Tab

The Scope tab, shown in Figure 26, implements a virtual oscilloscope using the high-speed ADC inside the instrument and can display the waveform of the current measured signal in real time. It supports flexible scaling of the horizontal and vertical axes and provides common oscilloscope functions such as waveform measurement statistics, cursor functions, and trigger functions. The current waveform data can also be saved separately for subsequent analysis and processing.

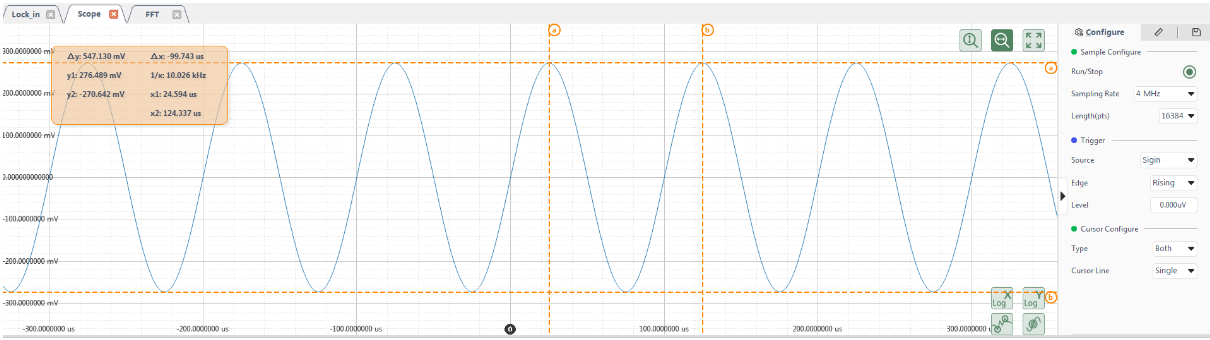


Figure 26. Scope Tab

4.3.5. FFT Tab

The FFT tab, shown in Figure 27, performs a fast Fourier transform on oscilloscope data and converts it into a frequency-domain plot. This helps users analyze the effective components of the input signal and identify harmonic and interference components.

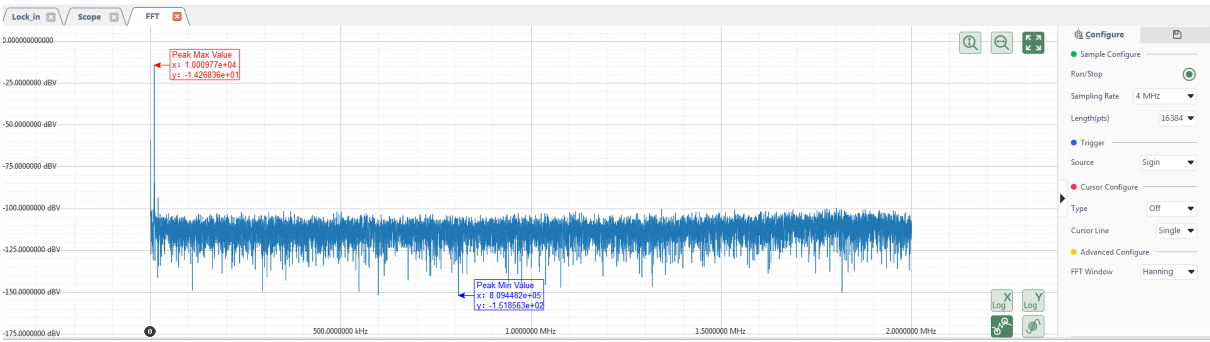


Figure 27. FFT Tab

4.3.6. Sweeper Tab

The Sweeper tab, shown in Figure 28, sweeps instrument parameters within a defined range to measure system frequency response. It can be used to characterize amplitude-frequency response, phase-frequency response, noise power spectra, and amplitude linearity.

The Sweeper can select frequency or amplitude sweep modes and supports linear and proportional step sweeps. Each sweep captures all measurement data of the OE2022, allowing the results to be analyzed from multiple dimensions.

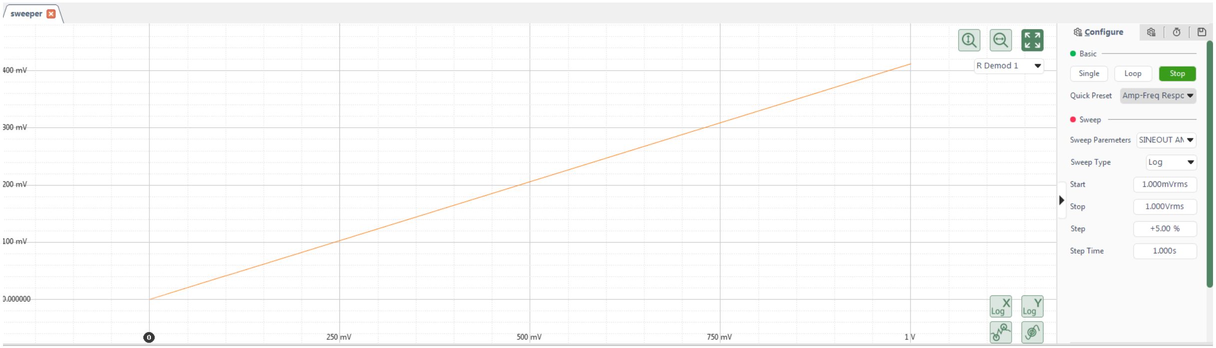


Figure 28. Sweeper Tab

4.3.7. PID Tab

The OE2022 has a built-in two-channel PID controller, as shown in Figure 29. The PID controller supports a maximum sampling rate of 4 MHz. The PID input and output signals can be selected from multiple instrument parameters, making the controller suitable for a wide range of applications, such as laser synchronization frequency locking or high-speed SPM. All available input and output sources are shown in Figure 30.

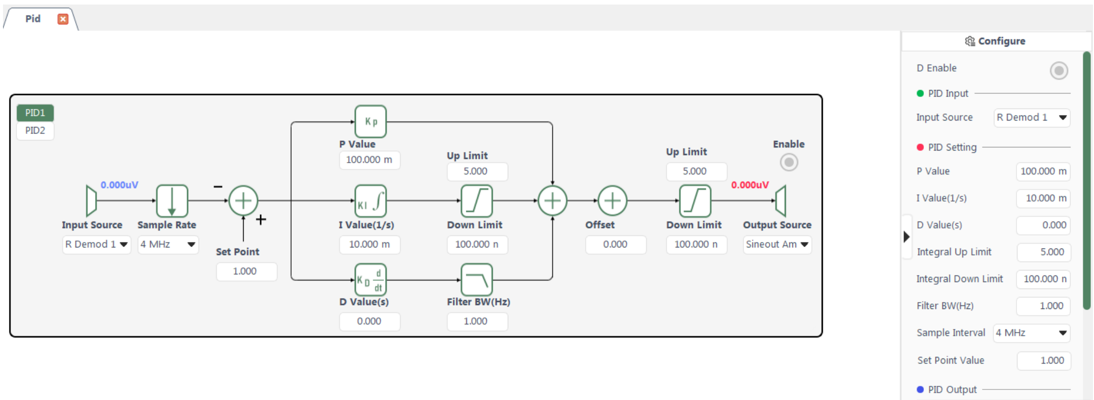


Figure 29. PID Tab

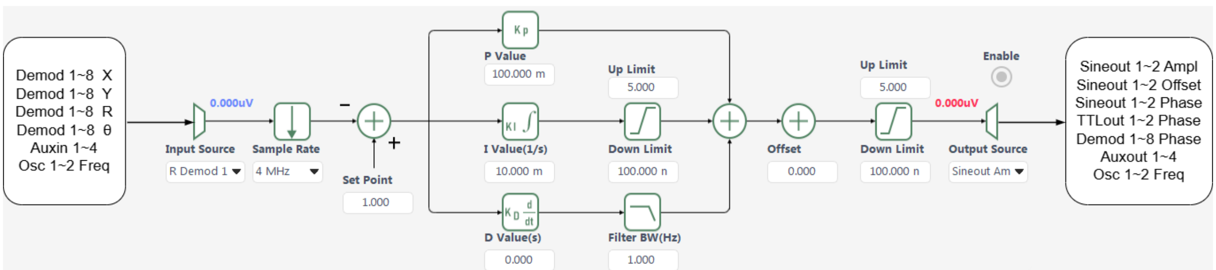


Figure 30. PID Controller Input and Output Source Selection

Some settings in the PID tab are shared with settings that can be accessed from other tabs. If the PID output controls a variable, such as Sineout Amplitude, that variable will be displayed as read-only in the corresponding tab, in this example the Lock-in tab, and the PID output value will override the original parameter configuration.

4.4 Software Usage Example

This example briefly demonstrates how to use the OE2022 PC Software to configure lock-in amplifier parameters and observe and record R, X, Y, and θ values.

First, connect the OE2022 to the PC successfully according to the instructions in Section 4.2. After the connection is established, configuration can begin.

Assume that the user needs to configure the function generator and lock-in amplifier according to Table 4 and save the data.

Table 4. Example Configuration Table

Input signal type	Single-ended voltage input
Input signal amplitude	40 mV
Input coupling	AC
Input gain	100 mV
Reference signal input	External reference, 1000 Hz
Reference trigger mode	TTL rising-edge trigger
Demodulator phase shift	0°
Low-pass filter time constant	100 ms
Filter roll-off	24 dB/oct
Data sampling rate	100 Sa/s

To complete the settings above, perform the following steps:

1. According to the configuration in Table 4, modify the input signal type, input coupling, and input range in the input signal configuration area. Keep the other options at their default values. As shown in Figure 31 and Figure 32, select either method to make the changes.

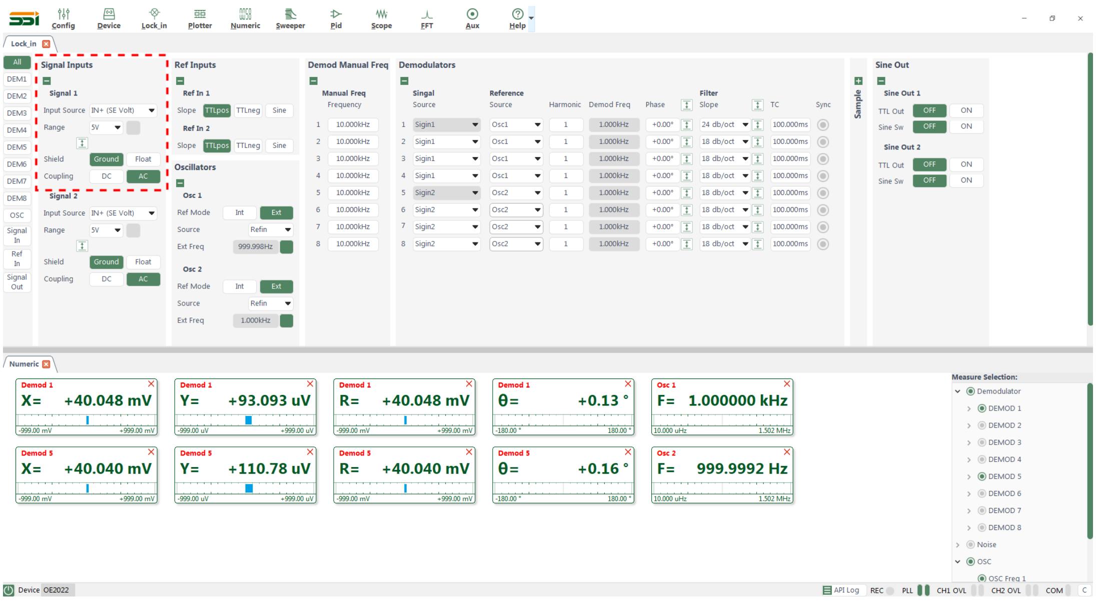


Figure 31. Input Signal Configuration Area

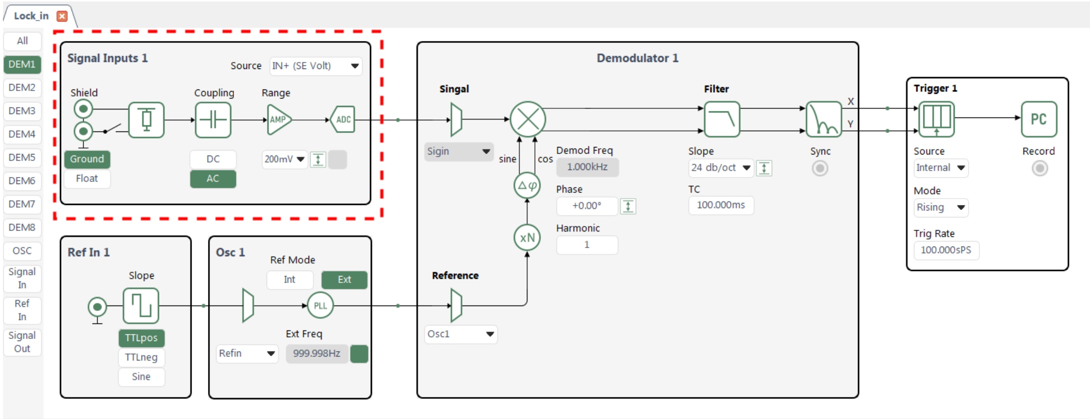


Figure 32. Input Signal Configuration Area in the Flow Diagram

2. According to the configuration in Table 4, select the reference signal source type and external reference in the reference signal configuration area. Keep the other options at their default values. As shown in Figure 33 and Figure 34, select either method to make the changes.

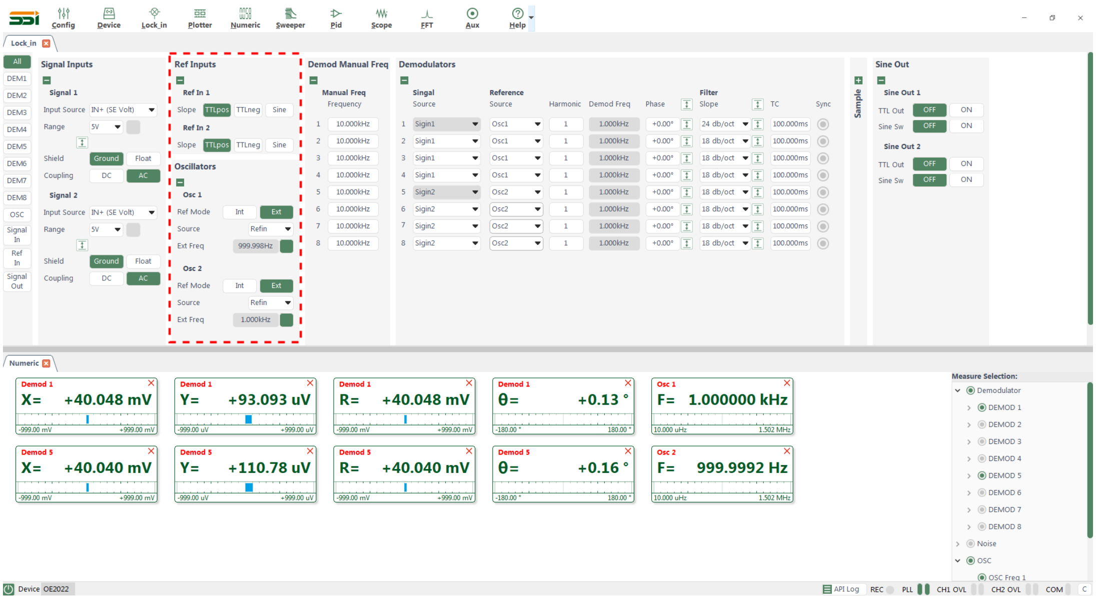


Figure 33. Reference Signal Configuration

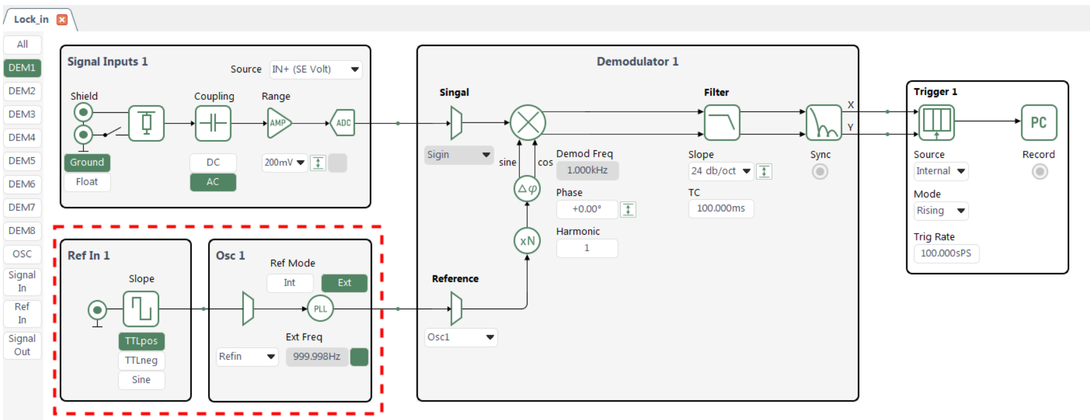


Figure 34. Reference Signal Configuration Area in the Flow Diagram

3. According to Table 4, select the demodulator time constant, filter roll-off, and phase adjustment value in the filter configuration area. Keep the other options at their default values. As shown in Figure 35 and Figure 36, select either method to make the changes and complete the configuration.

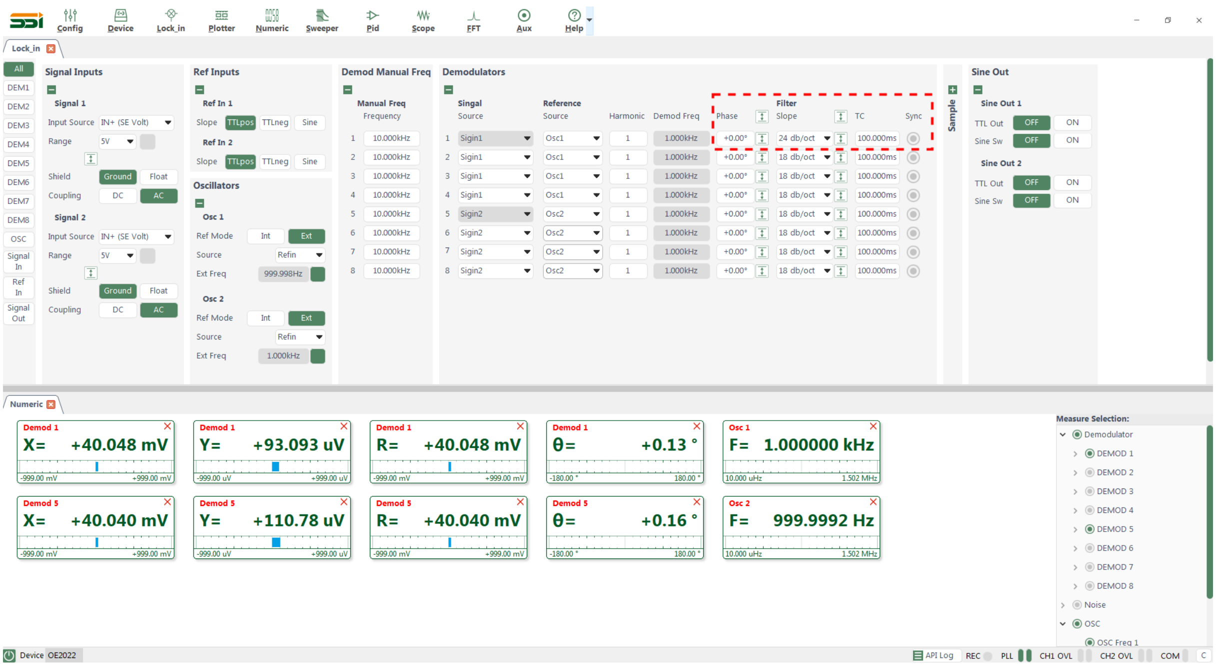


Figure 35. Filter Configuration

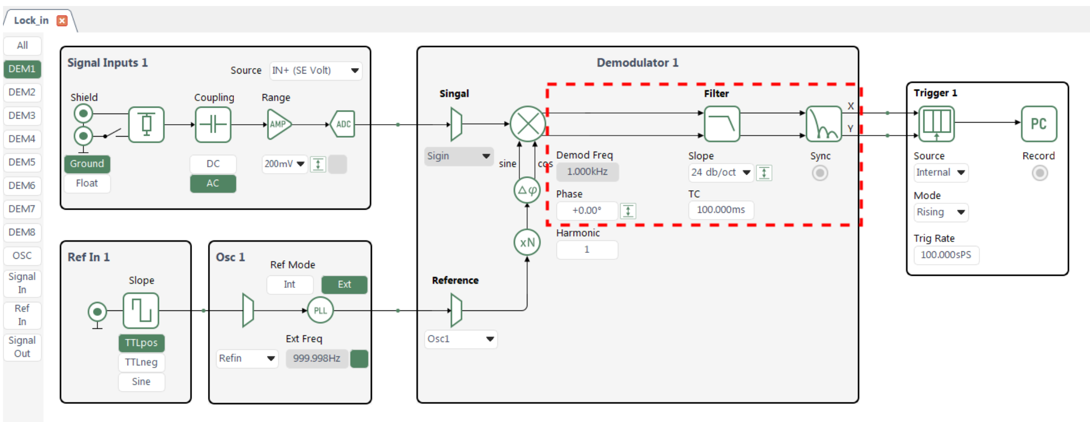


Figure 36. Filter Configuration Area in the Flow Diagram

4. To configure another demodulator, use the red boxed area shown in Figure 37 to set the harmonic order of Demodulator 2 to 3 and enable the display of the Demodulator 2 measurement result. In this way, the fundamental component and the third harmonic component of the input signal can be measured at the same time.

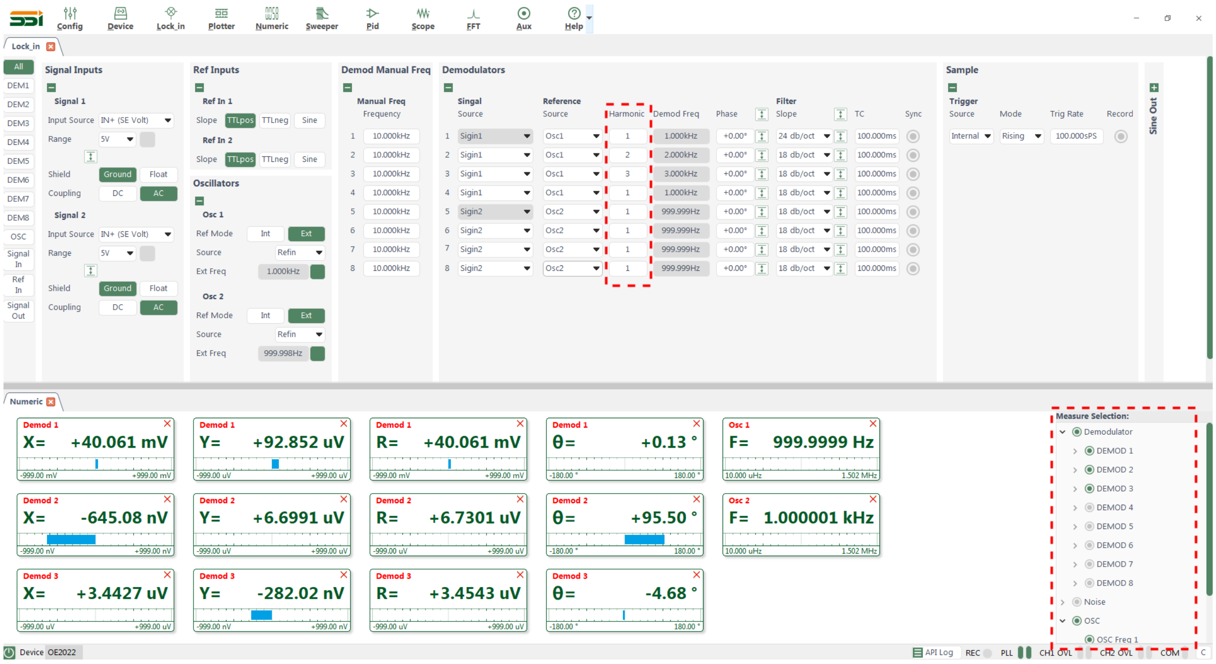


Figure 37. Additional Demodulator Configuration

5. After completing Steps 1–4, the OE2022 has been configured as required. Keep the other options at their default values. Data acquisition and saving can now begin.

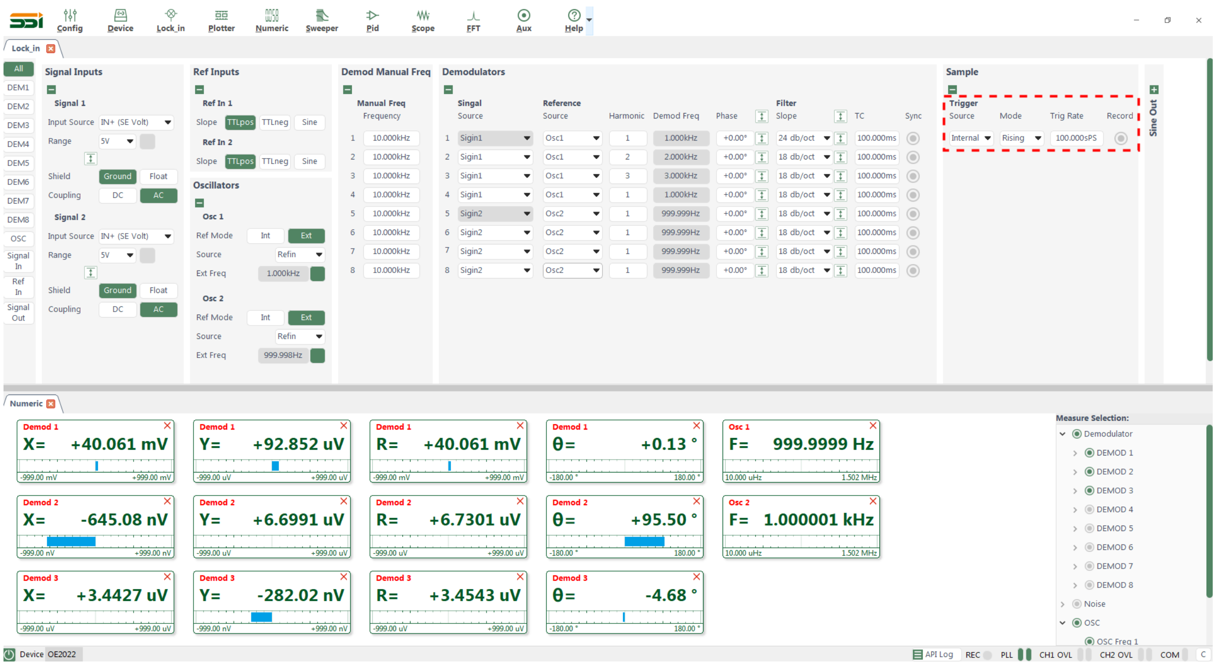
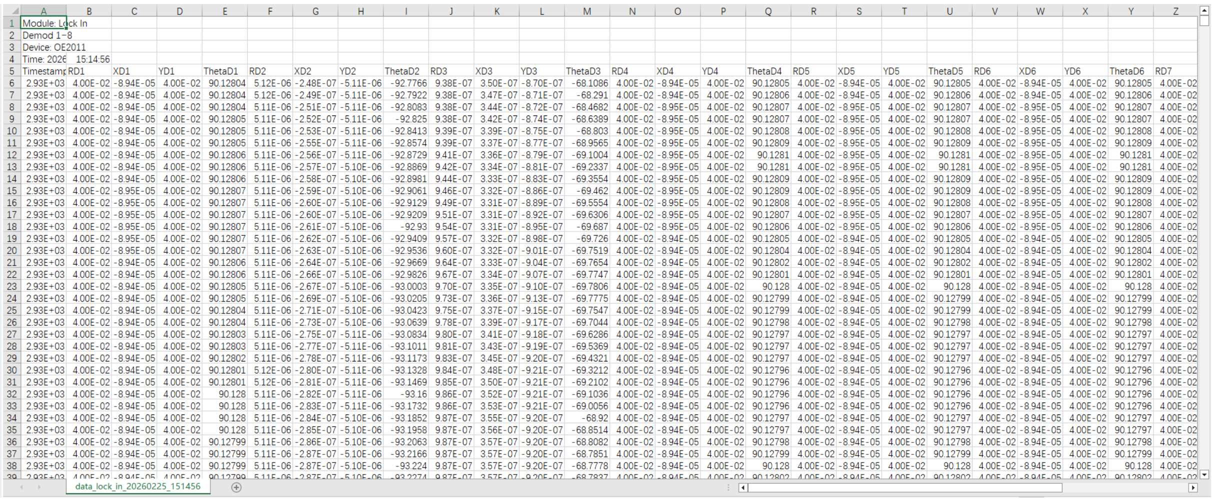


Figure 38. Data Recording in Progress

As shown in Figure 38, click the “Record” button inside the red box. When the button is selected, it indicates that the currently acquired data is being saved.

The data is saved as an Excel-compatible table in the program directory. The file name is “data_lock_in_xxxxx.csv”. The file stores the data from eight demodulators, as shown in Figure 39.



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Module: Lock In												
2	Demod 1~8												
3	Device: OE2011												
4	Time: 2026	15:14:56											
5	Timestamp	RD1	XD1	YD1	ThetaD1	RD2	XD2	YD2	ThetaD2	RD3	XD3	YD3	ThetaD3
6	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12804	5.12E-06	-2.48E-07	-5.11E-06	-92.7766	9.38E-07	3.50E-07	-8.70E-07	-68.1086
7	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12804	5.12E-06	-2.49E-07	-5.11E-06	-92.7922	9.38E-07	3.47E-07	-8.71E-07	-68.291
8	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12804	5.11E-06	-2.51E-07	-5.11E-06	-92.8083	9.38E-07	3.44E-07	-8.72E-07	-68.4682
9	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12805	5.11E-06	-2.52E-07	-5.11E-06	-92.825	9.38E-07	3.42E-07	-8.74E-07	-68.6389
10	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12805	5.11E-06	-2.53E-07	-5.11E-06	-92.8413	9.39E-07	3.39E-07	-8.75E-07	-68.803
11	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12805	5.11E-06	-2.55E-07	-5.11E-06	-92.8574	9.39E-07	3.37E-07	-8.77E-07	-68.9565
12	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12806	5.11E-06	-2.56E-07	-5.11E-06	-92.8729	9.41E-07	3.36E-07	-8.79E-07	-69.1004
13	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12806	5.11E-06	-2.57E-07	-5.10E-06	-92.8869	9.42E-07	3.34E-07	-8.81E-07	-69.2337
14	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12806	5.11E-06	-2.58E-07	-5.10E-06	-92.8981	9.44E-07	3.33E-07	-8.83E-07	-69.3554
15	2.93E+03	4.00E-02	-8.95E-05	4.00E-02	90.12807	5.11E-06	-2.59E-07	-5.10E-06	-92.9061	9.46E-07	3.32E-07	-8.86E-07	-69.462
16	2.93E+03	4.00E-02	-8.95E-05	4.00E-02	90.12807	5.11E-06	-2.60E-07	-5.10E-06	-92.9129	9.49E-07	3.31E-07	-8.89E-07	-69.5554
17	2.93E+03	4.00E-02	-8.95E-05	4.00E-02	90.12807	5.11E-06	-2.60E-07	-5.10E-06	-92.9209	9.51E-07	3.31E-07	-8.92E-07	-69.6306
18	2.93E+03	4.00E-02	-8.95E-05	4.00E-02	90.12807	5.11E-06	-2.61E-07	-5.10E-06	-92.93	9.54E-07	3.31E-07	-8.95E-07	-69.687
19	2.93E+03	4.00E-02	-8.95E-05	4.00E-02	90.12807	5.11E-06	-2.62E-07	-5.10E-06	-92.9409	9.57E-07	3.32E-07	-8.98E-07	-69.726
20	2.93E+03	4.00E-02	-8.95E-05	4.00E-02	90.12807	5.11E-06	-2.63E-07	-5.10E-06	-92.9536	9.60E-07	3.32E-07	-9.01E-07	-69.7519
21	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12806	5.11E-06	-2.64E-07	-5.10E-06	-92.9669	9.64E-07	3.33E-07	-9.04E-07	-69.7654
22	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12806	5.11E-06	-2.66E-07	-5.10E-06	-92.9826	9.67E-07	3.34E-07	-9.07E-07	-69.7747
23	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12805	5.11E-06	-2.67E-07	-5.10E-06	-93.0003	9.70E-07	3.35E-07	-9.10E-07	-69.7806
24	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12805	5.11E-06	-2.69E-07	-5.10E-06	-93.0205	9.73E-07	3.36E-07	-9.13E-07	-69.7775
25	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12804	5.11E-06	-2.71E-07	-5.10E-06	-93.0423	9.75E-07	3.37E-07	-9.15E-07	-69.7547
26	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12804	5.11E-06	-2.73E-07	-5.10E-06	-93.0639	9.78E-07	3.39E-07	-9.17E-07	-69.7044
27	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12803	5.11E-06	-2.75E-07	-5.11E-06	-93.0834	9.80E-07	3.41E-07	-9.18E-07	-69.6286
28	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12803	5.11E-06	-2.77E-07	-5.11E-06	-93.1011	9.81E-07	3.43E-07	-9.19E-07	-69.5369
29	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12802	5.11E-06	-2.78E-07	-5.11E-06	-93.1173	9.83E-07	3.45E-07	-9.20E-07	-69.4321
30	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12801	5.12E-06	-2.80E-07	-5.11E-06	-93.1328	9.84E-07	3.48E-07	-9.21E-07	-69.3212
31	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12801	5.12E-06	-2.81E-07	-5.11E-06	-93.1469	9.85E-07	3.50E-07	-9.21E-07	-69.2102
32	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.128	5.11E-06	-2.82E-07	-5.11E-06	-93.16	9.86E-07	3.52E-07	-9.21E-07	-69.1036
33	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.128	5.11E-06	-2.83E-07	-5.11E-06	-93.1732	9.86E-07	3.53E-07	-9.21E-07	-69.0056
34	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.128	5.11E-06	-2.84E-07	-5.10E-06	-93.1852	9.87E-07	3.55E-07	-9.20E-07	-68.92
35	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.128	5.11E-06	-2.85E-07	-5.10E-06	-93.1958	9.87E-07	3.56E-07	-9.20E-07	-68.8514
36	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12799	5.11E-06	-2.86E-07	-5.10E-06	-93.2063	9.87E-07	3.57E-07	-9.20E-07	-68.8082
37	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12799	5.11E-06	-2.87E-07	-5.10E-06	-93.2166	9.87E-07	3.57E-07	-9.20E-07	-68.7851
38	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12799	5.11E-06	-2.87E-07	-5.10E-06	-93.224	9.87E-07	3.57E-07	-9.20E-07	-68.7778
39	2.93E+03	4.00E-02	-8.94E-05	4.00E-02	90.12799	5.11E-06	-2.87E-07	-5.10E-06	-93.2274	9.87E-07	3.57E-07	-9.20E-07	-68.7837

	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1													
2													
3													
4													
5	RD4	XD4	YD4	ThetaD4	RD5	XD5	YD5	ThetaD5	RD6	XD6	YD6	ThetaD6	RD7
6	4.00E-02	-8.94E-05	4.00E-02	90.12805	4.00E-02	-8.94E-05	4.00E-02	90.12805	4.00E-02	-8.94E-05	4.00E-02	90.12805	4.00E-02
7	4.00E-02	-8.94E-05	4.00E-02	90.12806	4.00E-02	-8.94E-05	4.00E-02	90.12806	4.00E-02	-8.94E-05	4.00E-02	90.12806	4.00E-02
8	4.00E-02	-8.95E-05	4.00E-02	90.12807	4.00E-02	-8.95E-05	4.00E-02	90.12807	4.00E-02	-8.95E-05	4.00E-02	90.12807	4.00E-02
9	4.00E-02	-8.95E-05	4.00E-02	90.12807	4.00E-02	-8.95E-05	4.00E-02	90.12807	4.00E-02	-8.95E-05	4.00E-02	90.12807	4.00E-02
10	4.00E-02	-8.95E-05	4.00E-02	90.12808	4.00E-02	-8.95E-05	4.00E-02	90.12808	4.00E-02	-8.95E-05	4.00E-02	90.12808	4.00E-02
11	4.00E-02	-8.95E-05	4.00E-02	90.12809	4.00E-02	-8.95E-05	4.00E-02	90.12809	4.00E-02	-8.95E-05	4.00E-02	90.12809	4.00E-02
12	4.00E-02	-8.95E-05	4.00E-02	90.1281	4.00E-02	-8.95E-05	4.00E-02	90.1281	4.00E-02	-8.95E-05	4.00E-02	90.1281	4.00E-02
13	4.00E-02	-8.95E-05	4.00E-02	90.1281	4.00E-02	-8.95E-05	4.00E-02	90.1281	4.00E-02	-8.95E-05	4.00E-02	90.1281	4.00E-02
14	4.00E-02	-8.95E-05	4.00E-02	90.12809	4.00E-02	-8.95E-05	4.00E-02	90.12809	4.00E-02	-8.95E-05	4.00E-02	90.12809	4.00E-02
15	4.00E-02	-8.95E-05	4.00E-02	90.12809	4.00E-02	-8.95E-05	4.00E-02	90.12809	4.00E-02	-8.95E-05	4.00E-02	90.12809	4.00E-02
16	4.00E-02	-8.95E-05	4.00E-02	90.12808	4.00E-02	-8.95E-05	4.00E-02	90.12808	4.00E-02	-8.95E-05	4.00E-02	90.12808	4.00E-02
17	4.00E-02	-8.95E-05	4.00E-02	90.12807	4.00E-02	-8.95E-05	4.00E-02	90.12807	4.00E-02	-8.95E-05	4.00E-02	90.12807	4.00E-02
18	4.00E-02	-8.95E-05	4.00E-02	90.12806	4.00E-02	-8.95E-05	4.00E-02	90.12806	4.00E-02	-8.95E-05	4.00E-02	90.12806	4.00E-02
19	4.00E-02	-8.94E-05	4.00E-02	90.12805	4.00E-02	-8.94E-05	4.00E-02	90.12805	4.00E-02	-8.94E-05	4.00E-02	90.12805	4.00E-02
20	4.00E-02	-8.94E-05	4.00E-02	90.12804	4.00E-02	-8.94E-05	4.00E-02	90.12804	4.00E-02	-8.94E-05	4.00E-02	90.12804	4.00E-02
21	4.00E-02	-8.94E-05	4.00E-02	90.12802	4.00E-02	-8.94E-05	4.00E-02	90.12802	4.00E-02	-8.94E-05	4.00E-02	90.12802	4.00E-02
22	4.00E-02	-8.94E-05	4.00E-02	90.12801	4.00E-02	-8.94E-05	4.00E-02	90.12801	4.00E-02	-8.94E-05	4.00E-02	90.12801	4.00E-02
23	4.00E-02	-8.94E-05	4.00E-02	90.128	4.00E-02	-8.94E-05	4.00E-02	90.128	4.00E-02	-8.94E-05	4.00E-02	90.128	4.00E-02
24	4.00E-02	-8.94E-05	4.00E-02	90.12799	4.00E-02	-8.94E-05	4.00E-02	90.12799	4.00E-02	-8.94E-05	4.00E-02	90.12799	4.00E-02
25	4.00E-02	-8.94E-05	4.00E-02	90.12799	4.00E-02	-8.94E-05	4.00E-02	90.12799	4.00E-02	-8.94E-05	4.00E-02	90.12799	4.00E-02
26	4.00E-02	-8.94E-05	4.00E-02	90.12798	4.00E-02	-8.94E-05	4.00E-02	90.12798	4.00E-02	-8.94E-05	4.00E-02	90.12798	4.00E-02
27	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02
28	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02
29	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02
30	4.00E-02	-8.94E-05	4.00E-02	90.12796	4.00E-02	-8.94E-05	4.00E-02	90.12796	4.00E-02	-8.94E-05	4.00E-02	90.12796	4.00E-02
31	4.00E-02	-8.94E-05	4.00E-02	90.12796	4.00E-02	-8.94E-05	4.00E-02	90.12796	4.00E-02	-8.94E-05	4.00E-02	90.12796	4.00E-02
32	4.00E-02	-8.94E-05	4.00E-02	90.12796	4.00E-02	-8.94E-05	4.00E-02	90.12796	4.00E-02	-8.94E-05	4.00E-02	90.12796	4.00E-02
33	4.00E-02	-8.94E-05	4.00E-02	90.12796	4.00E-02	-8.94E-05	4.00E-02	90.12796	4.00E-02	-8.94E-05	4.00E-02	90.12796	4.00E-02
34	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02
35	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02	-8.94E-05	4.00E-02	90.12797	4.00E-02
36	4.00E-02	-8.94E-05	4.00E-02	90.12798	4.00E-02	-8.94E-05	4.00E-02	90.12798	4.00E-02	-8.94E-05	4.00E-02	90.12798	4.00E-02
37	4.00E-02	-8.94E-05	4.00E-02	90.12799	4.00E-02	-8.94E-05	4.00E-02	90.12799	4.00E-02	-8.94E-05	4.00E-02	90.12799	4.00E-02
38	4.00E-02	-8.94E-05	4.00E-02	90.128	4.00E-02	-8.94E-05	4.00E-02	90.128	4.00E-02	-8.94E-05	4.00E-02	90.128	4.00E-02
39	4.00E-02	-8.94E-05	4.00E-02	90.12802	4.00E-02	-8.94E-05	4.00E-02	90.12802	4.00E-02	-8.94E-05	4.00E-02	90.12802	4.00E-02

data_lock_in_20260225_151456

Figure 39. Example Contents of the Data Record File

Chapter 5 Interface and PC Software Functions

The main menu of the OE2022 is located in the MENU key area on the front panel. The MENU main menu contains ten submenus: [SIGNAL INPUT], [OSC REF], [DEMOD FILTER], [DEMOD REF], [DISPLAY], [SIGNAL OUTPUT], [AUTO SET], [CHANNEL OUTPUT], [SYSTEM], and [AUX OUTPUT]. Pressing each key switches the instrument to the corresponding submenu interface.

The OE2022 can also be controlled from the PC Software, and measurement data can be read through the PC Software.

5.1 [SIGNAL INPUT] Submenu

5.1.1. Front-Panel Configuration

Select [SIGNAL INPUT] from the front-panel menu bar to enter this submenu. This menu is used to configure the hardware settings of the signal input channel, as shown in the right-side panel of Figure 40.

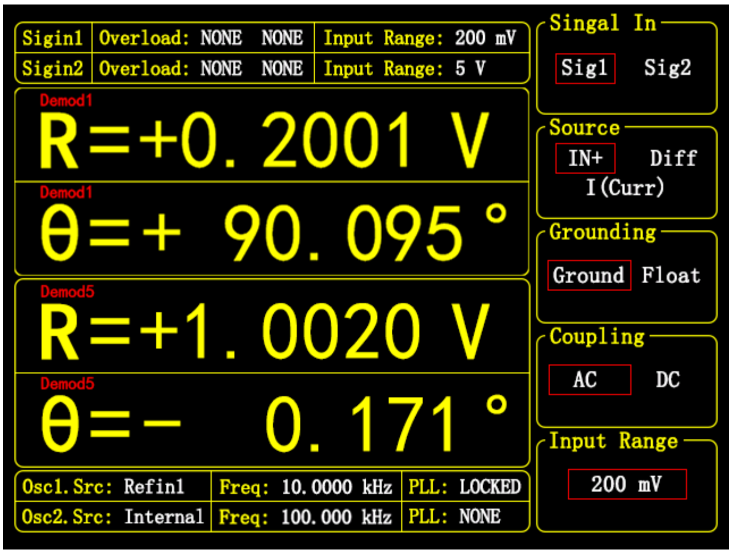


Figure 40. [INPUT/FILTERS] submenu

This submenu includes five function settings: <Signal In>, <Source>, <Grounding>, <Coupling>, and <Input Range>.

- <Signal In>: input channel selection

Press the corresponding key to switch the parameter display and configuration between the two input channels, <Sig1> and <Sig2>. For example, when <Sig1> is selected, the settings of <Source>, <Grounding>, <Coupling>, and <Input Range> all correspond to the current configuration of <Sig1>. Changing these settings at this time does not affect the configuration of <Sig2>.

- <Source>: input signal type setting

<IN+> : Single-ended voltage signal input mode.

<Diff> : Differential voltage signal input mode. In this mode, connect one side of the differential signal to IN+ and the other side to IN-. The measured signal is the differential voltage between IN+ and IN-.

<I> : Single-ended current signal input mode.

☆ **Note: Regardless of whether the voltage or current range is used, the amplitude of the maximum input signal must not exceed the <Input Range> setting.**

- <Grounding>: input shield grounding setting

<Float> : The shells of the IN+ / IN- input connectors are isolated from instrument ground through a 10 kΩ resistor.

<Ground> : The shields of the IN+ and IN- input connectors are connected to instrument ground through a 10 Ω resistor (near-short). Instrument ground is bonded to protective earth (PE).

In general, if the signal source cannot inject a large current into the instrument, or if it is confirmed that the signal ground and instrument ground are at the same ground potential, <Ground> can be selected to short the signal ground and system ground together. This prevents signal drift caused by a floating signal ground. If the absolute potential difference between the signal ground and instrument ground is large, and the signal ground is capable of injecting a large current, use <Float> to float the signal ground and provide current-limiting protection.

☆ **When measuring weak signals (<1 mV), <Ground> mode is recommended, provided that the signal ground and the instrument ground are at the same ground potential.**

- <Coupling>: input coupling setting

<AC> : AC-coupled input. The cutoff frequency of AC coupling is 0.16 Hz. It is used to block the DC component in the input signal. If the signal frequency is above 10 Hz, <AC> coupling is recommended.

<DC> : DC-coupled input. DC coupling does not block any input signal component. If the signal frequency is below 10 Hz, <DC> coupling is recommended. Note that the offset component of the input signal may cause signal overflow.

- <Input Range>: input range setting

When <Signal Type> is set to <Voltage>, the available <Input Range> settings are as follows:

<5 V> : The maximum allowed RMS input voltage is 5 V_{rms}.
<1 V> : The maximum allowed RMS input voltage is 1 V_{rms}.
<200 mV> : The maximum allowed RMS input voltage is 200 mV_{rms}.
<50 mV> : The maximum allowed RMS input voltage is 50 mV_{rms}.
<10 mV> : The maximum allowed RMS input voltage is 10 mV_{rms}.
<2 mV> : The maximum allowed RMS input voltage is 2 mV_{rms}.
<1 mV> : The maximum allowed RMS input voltage is 1 mV_{rms}.

When <Signal Type> is set to <Current>, the available <Input Range> settings are as follows:

<5 mA> : The maximum allowed RMS input current is 5 mA_{rms}.
<500 µA> : The maximum allowed RMS input current is 500 μA_{rms}.
<50 µA> : The maximum allowed RMS input current is 50 μA_{rms}.
<5 µA> : The maximum allowed RMS input current is 5 μA_{rms}.

<500 nA> : The maximum allowed RMS input current is 500 nA_{rms}.
<50 nA> : The maximum allowed RMS input current is 50 nA_{rms}.
<5 nA> : The maximum allowed RMS input current is 5 nA_{rms}.

For general measurements, the gain should be selected based on the absence of overload indication in the monitor bar. As long as no overload occurs, selecting a range closer to the signal amplitude improves the stability and accuracy of the measurement result.

When the automatic gain setting function <Auto Range> is used, the system automatically adjusts the input range to the closest appropriate range according to the maximum amplitude of the input signal, ensuring measurement accuracy.

5.1.2. PC Software Configuration

As shown in the red box in Figure 41, the highlighted area in the PC Software is the [SIGNAL INPUT] configuration area. The user can configure the signal input channel either in the parameter table or in the flowchart area. The configuration information for <Signal Type>, <Input Port>, <Grounding>, <Coupling>, and <Input Range> can all be modified and confirmed in the red-boxed area.

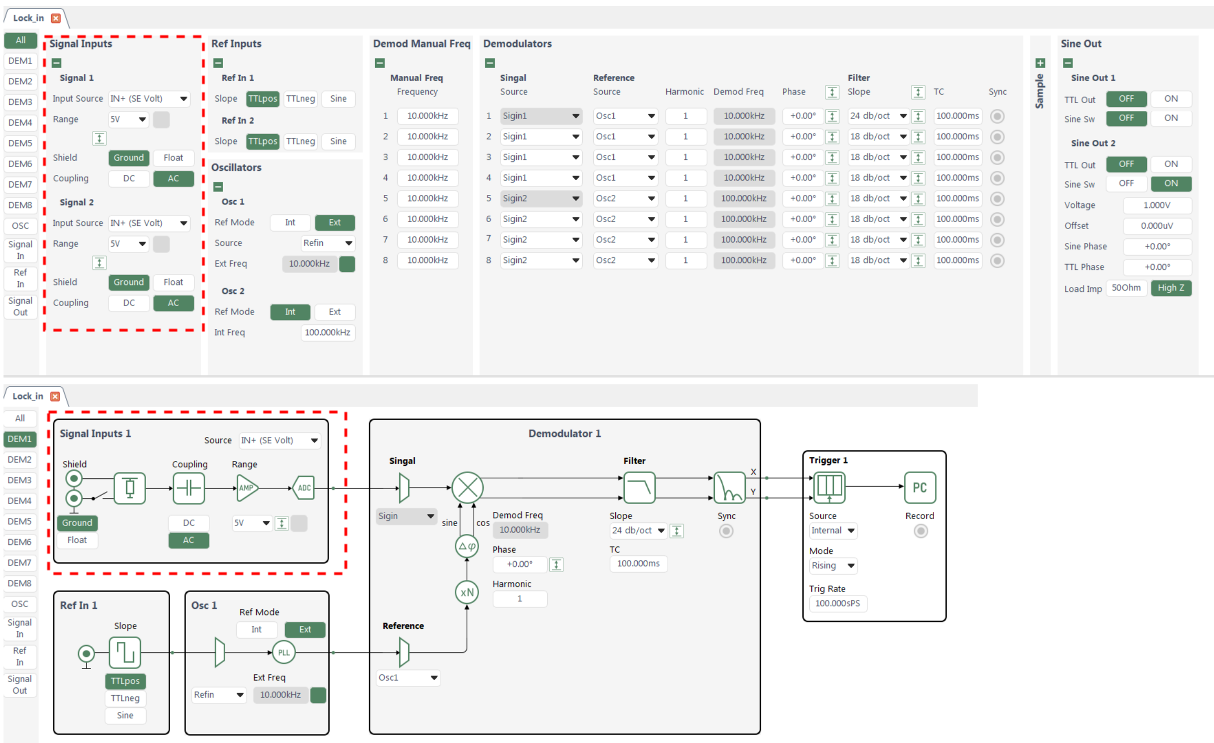


Figure 41. [SIGNAL INPUT] configuration area

5.2 [OSC REF] Submenu

5.2.1. Front-Panel Configuration

Select the [OSC REF] submenu from the front-panel menu bar. This menu is used to configure the hardware settings of the reference input channel and the operating modes of the two oscillators, OSC1 and OSC2. Different configuration modes display different interfaces, as shown in Figure 42 and Figure 43.

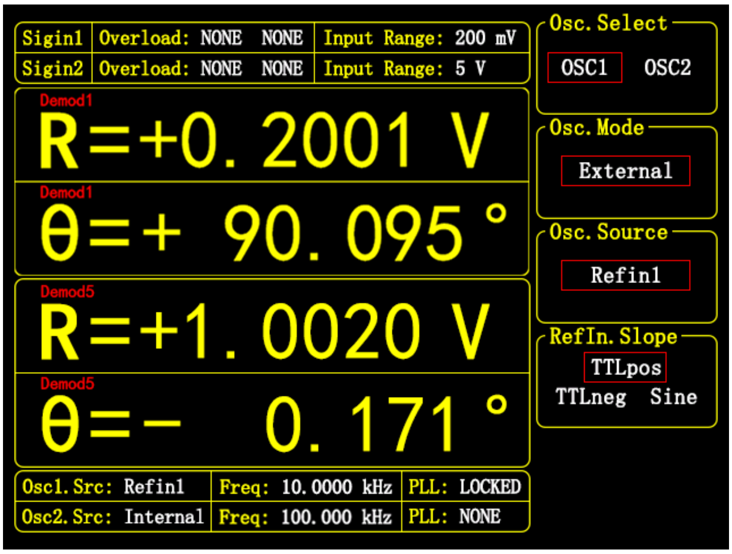


Figure 42. [OSC REF] submenu–<External>

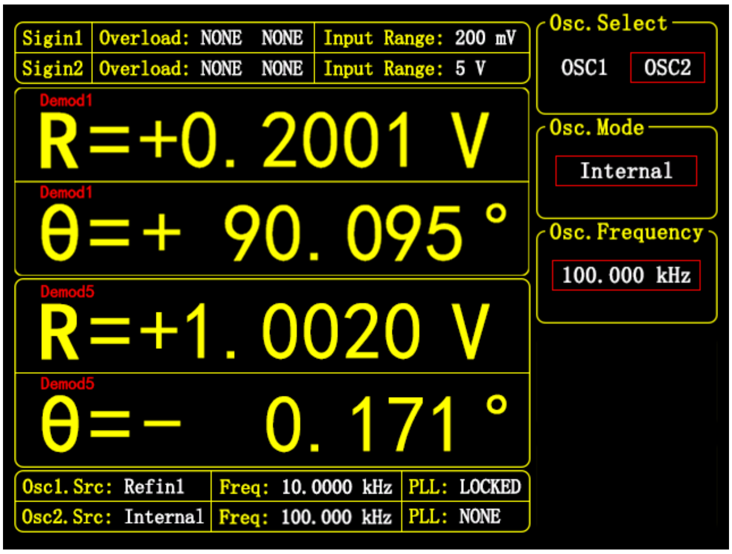


Figure 43. [OSC REF] submenu–<Internal>

This submenu includes five function settings: <Osc.Select>, <Osc.Mode>, <Osc.Source>, <Osc.Fre-quency>, and <RefIn.Slope>.

- <Osc.Select>: OSC channel selection

Press the corresponding key to switch the parameter display and configuration between the two oscillators, <OSC1> and <OSC2>. For example, when <OSC1> is selected, the settings of <Osc.Mode>, <Osc.Source>, and <Osc.Frequency> all correspond to the current configuration of <OSC1>. Changing these settings at this time does not affect the configuration of <OSC2>.

- <Osc.Mode>: oscillator mode setting

<External> : External mode. The OE2022 sets the current oscillator to external mode. In this mode, the reference signal input through the REFIN BNC connector is connected to

the oscillator and phase-locked inside the instrument. Due to the phase-locked loop, the oscillator output signal tracks the external reference signal in real time. The interface in this mode is shown in Figure 42, where <Osc.Source> can be configured.

<Internal> : Internal mode. The OE2022 sets the current oscillator to internal mode. In this mode, the oscillator is connected to the internal crystal oscillator of the instrument, and the reference signal is generated internally. The REF IN input signal is not used. The interface in this mode is shown in Figure 43, where <Osc.Frequency> can be configured.

- <Osc.Source>: reference signal source setting

<Refin1/2> : Sets the reference input source in oscillator external mode to REF IN. In this case, the waveform type of the REF IN signal can be set through <Ref.Slope>. Note that <OSC1> corresponds to the <Refin 1> reference connector, and <OSC2> corresponds to the <Refin 2> reference connector.

<Sigin1> : Sets the reference input source in oscillator external mode to the SIGNAL IN 1 interface.

<Sigin2> : Sets the reference input source in oscillator external mode to the SIGNAL IN 2 interface.

<Auxin1> : Sets the reference input source in oscillator external mode to the AUX IN 1 interface.

<Auxin2> : Sets the reference input source in oscillator external mode to the AUX IN 2 interface.

<Auxin3> : Sets the reference input source in oscillator external mode to the AUX IN 3 interface.

<Auxin4> : Sets the reference input source in oscillator external mode to the AUX IN 4 interface.

<Trigin> : Sets the reference input source in oscillator external mode to the TRIGGER IN interface.

- <Ref.Slope>: reference signal type setting for the REFIN interface

This item is available when <Osc.Mode> is set to <External> and <Osc.Source> is set to <Refin 1/2>. Select the corresponding signal type according to the type of the external reference signal.

<TTLpos> : Select this option when the external input signal is a square wave. The reference signal is phase-locked to the rising edge.

<TTLneg> : Select this option when the external input signal is a square wave. The reference signal is phase-locked to the falling edge.

<Sine> : Select this option when the external input signal is a sine wave. The reference signal is phase-locked to the rising zero crossing.

When the input reference signal is at TTL logic level, TTL triggering is recommended. Note that if the reference signal input to REF IN is a square wave but its voltage levels do not satisfy the TTL logic high/low threshold conditions ($3\,V < V_{IH} < 5\,V$, $-0.1\,V < V_{IL} < 0.5\,V$), stable triggering may not be obtained, and the expected measurement results may not be achieved. In this case, SINE triggering is recommended. In addition, TTL reference must be used for very low frequencies (<1 Hz).

When the reference signal input to REF IN is a sine wave, SINE triggering is recommended. In SINE triggering, the REF IN input is precisely shaped inside the system before frequency and phase information is detected.

In addition, regardless of whether <TTL> triggering or <SINE> triggering is used, the system has no requirement on the signal duty cycle. However, a conventional 50% duty cycle is recommended. A smaller duty cycle results in more severe high-order harmonics and stronger external radiated interference.

- <Osc.Frequency>: internal reference signal frequency setting

This item is available when <Osc.Source> is set to <Internal>. The frequency range is 10 μHz to 1.5 MHz, and the default value is 10.000 kHz. The frequency can be entered using the keypad, and the minimum frequency resolution is 1 nHz. In addition, when <Ref.frequency> is selected, the four arrow keys in the [ARROW] area can be used for digit-by-digit frequency tuning. For example, to quickly change 1000 Hz to 1100 Hz, first select <Ref.frequency>, move the digit cursor to the hundreds place using the [→] and [←] keys, change the hundreds digit to 1 using the [↑] and [↓] keys, and then press <Enter> to confirm the operation. This is shown in Figure 44.

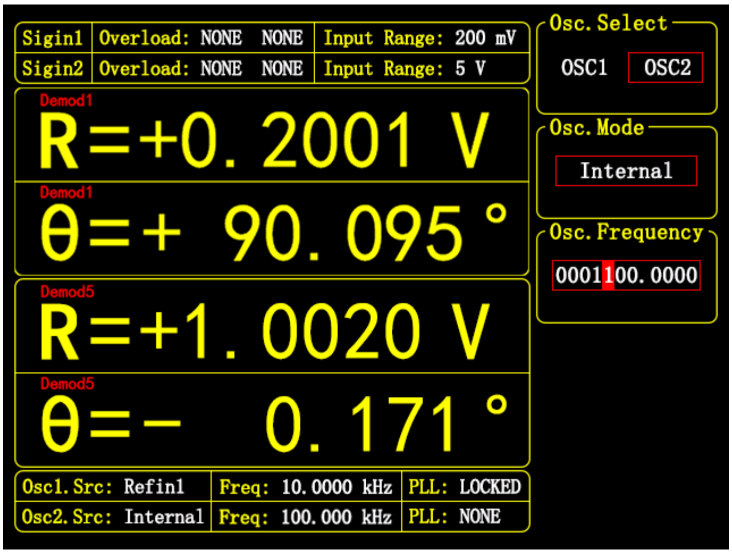


Figure 44. Frequency adjustment using the [ARROW] keys

5.2.2. PC Software Configuration

As shown in the red box in Figure 45, the highlighted area in the PC Software is the [OSC REF] configuration area. The user can configure the hardware settings of the reference input channel and the internal oscillator settings either in the parameter table or in the flowchart area. The configuration information for <Osc.Select>, <Osc.Mode>, <Osc.Source>, <Osc.Frequency>, and <RefIn.Slope> can all be modified and confirmed in the red-boxed area.

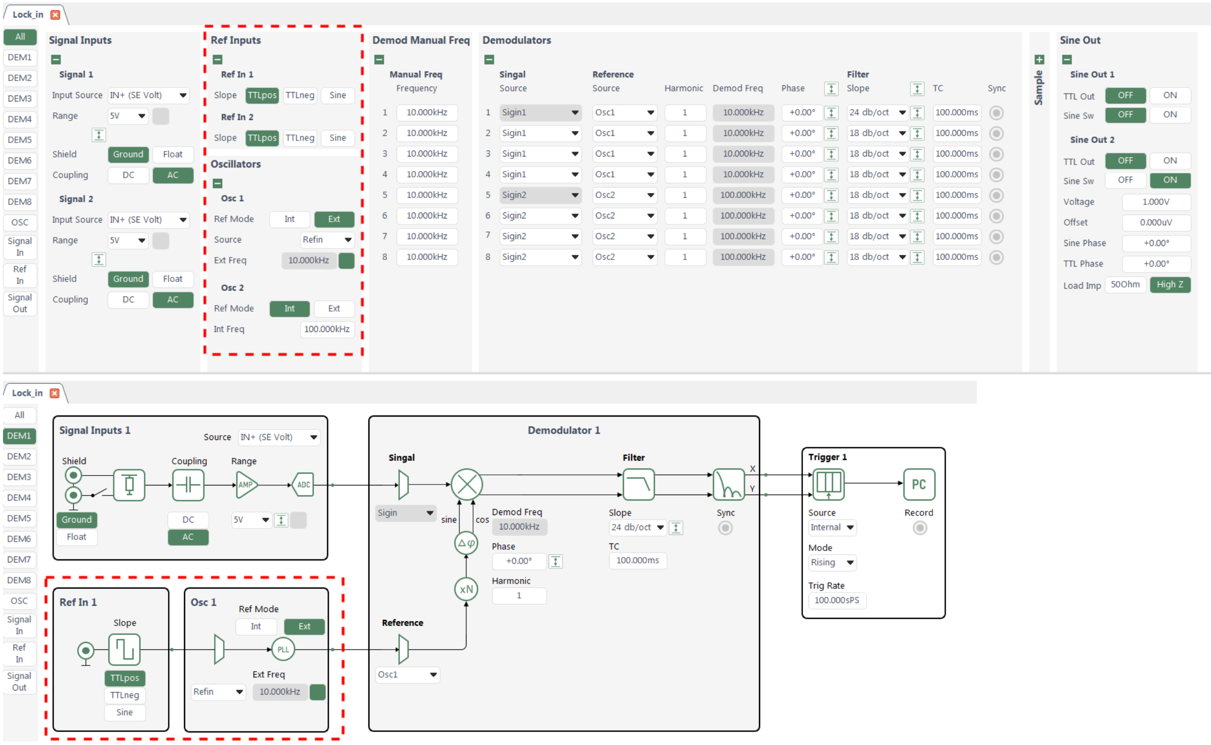


Figure 45. [OSC REF] configuration area

5.3 [DEMOD FILTER] Submenu

5.3.1. Front-Panel Configuration

Select [DEMOD FILTER] from the front-panel menu bar. This menu is used to configure demodulator filter parameters, as shown in the right-side panel of Figure 46.

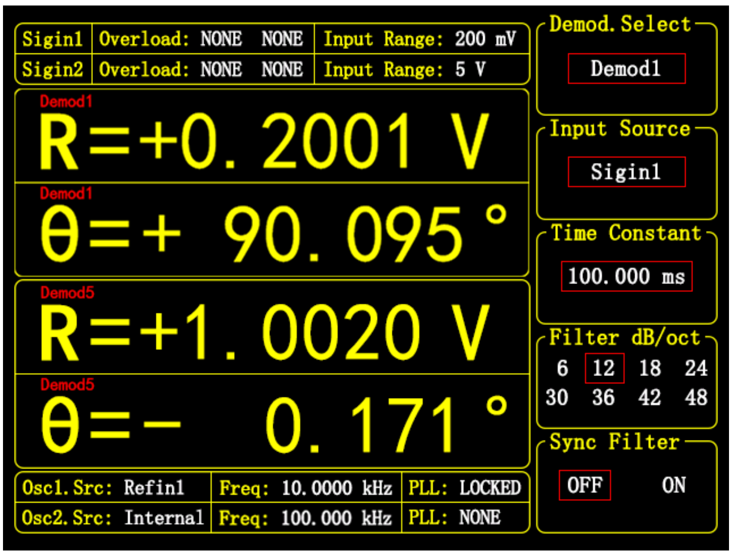


Figure 46. [DEMOD FILTER] submenu

This submenu includes five function settings: <Demod.Select>, <Input Source>, <Time Constant>, <Filter dB/oct>, and <Sync Filter>.

- <Demod.Select>: demodulator channel selection setting

The knob and the ARROW keys can be used to switch the parameter display and configuration among the eight demodulators from <Demod1> to <Demod8>. For example, when <Demod1> is selected, the settings of <Input Source>, <Time Constant>, <Filter dB/oct>, and <Sync Filter> all correspond to the current configuration of <Demod1>. Changing these settings at this time does not affect the configurations of the other demodulators.

- <Input Source>: demodulator signal input source selection

<Sigin1> : Sets the signal input source of the current demodulator to the SIGNAL IN 1 interface.

<Sigin2> : Sets the signal input source of the current demodulator to the SIGNAL IN 2 interface.

<Auxin1> : Sets the signal input source of the current demodulator to the AUX IN 1 interface.

<Auxin2> : Sets the signal input source of the current demodulator to the AUX IN 2 interface.

<Auxin3> : Sets the signal input source of the current demodulator to the AUX IN 3 interface.

<Auxin4> : Sets the signal input source of the current demodulator to the AUX IN 4 interface.

<X-Demod1> : Sets the signal input source of the current demodulator to the X output value of Demod1.

<Y-Demod1> : Sets the signal input source of the current demodulator to the Y output value of Demod1.

<R-Demod1> : Sets the signal input source of the current demodulator to the R output value of Demod1.

<Theta-Demod1>: Sets the signal input source of the current demodulator to the Theta output value of Demod1.

<X-Demod5> : Sets the signal input source of the current demodulator to the X output value of Demod5.

<Y-Demod5> : Sets the signal input source of the current demodulator to the Y output value of Demod5.

<R-Demod5> : Sets the signal input source of the current demodulator to the R output value of Demod5.

<Theta-Demod5>: Sets the signal input source of the current demodulator to the Theta output value of Demod5.

When the signal input source of a demodulator is set from <X-Demod1> to <Theta-Demod5>, the OE2022 enters cascade demodulation mode. This mode can perform secondary demodulation on modulated signals to recover carrier and modulation components.

☆ **Note: Demod1 is fixed to use Sigin1 as its input source, and Demod5 is fixed to use Sigin2 as its input source.**

- <Time Constant>: time constant setting

The time constant can be set from 100 ns to 3 ks. The value can be entered using the keypad or modified using the ARROW keys.

A longer time constant results in a smaller equivalent noise bandwidth, a longer measurement response time, and higher measurement accuracy.

- <Filter dB/oct>: low-pass filter roll-off setting
  <6 dB/oct> : First-order low-pass filter, 6 dB/oct roll-off.
  <12 dB/oct> : Second-order low-pass filter, 12 dB/oct roll-off.
  <18 dB/oct> : Third-order low-pass filter, 18 dB/oct roll-off.
  <24 dB/oct> : Fourth-order low-pass filter, 24 dB/oct roll-off.
  <30 dB/oct> : Fifth-order low-pass filter, 30 dB/oct roll-off.
  <36 dB/oct> : Sixth-order low-pass filter, 36 dB/oct roll-off.
  <42 dB/oct> : Seventh-order low-pass filter, 42 dB/oct roll-off.
  <48 dB/oct> : Eighth-order low-pass filter, 48 dB/oct roll-off.

For the same measurement accuracy, a steeper filter roll-off can reduce the required time constant and make the measurement response faster. The appropriate combination of time constant and filter roll-off must be selected according to the actual application. A practical criterion is that, as long as the stability of the measurement result is satisfactory, the time constant and filter roll-off do not need to be set excessively high, to avoid unnecessarily long waiting time. If a smoother result is desired, the time constant and filter roll-off can be increased as needed.

- <Sync Filter>: synchronous filter setting
  <OFF> : Disable the synchronous filter.
  <ON> : Enable the synchronous filter.

The synchronous filter can effectively remove signals at the reference frequency and its harmonics, reducing the requirement on the low-pass filter. The synchronous filter can be enabled or disabled in any state, but it is effective only when the demodulation reference frequency is below 250 kHz.

At low input signal frequencies, the low-pass filter may fail to obtain a stable result or may require a long time to do so. In this case, enabling the synchronous filter can improve the result. The effect is shown in Figure 47.

☆ **Note: When the synchronous filter is enabled, it is effective only when <Filter dB/oct> is greater than <18 dB/oct> and <Demod Frequency> is lower than 250 kHz!**

Figure 47. Effect of enabling the synchronous filter

5.3.2. PC Software Configuration

As shown in the red box in Figure 48, the highlighted area in the PC Software is the [DEMOD FILTER] configuration area. The user can configure demodulator-related settings either in the parameter table or in the flowchart area. The configuration information for <Input Source>, <Time Constant>, <Filter dB/oct>, and <Sync Filter> can all be modified and confirmed in the red-boxed area.

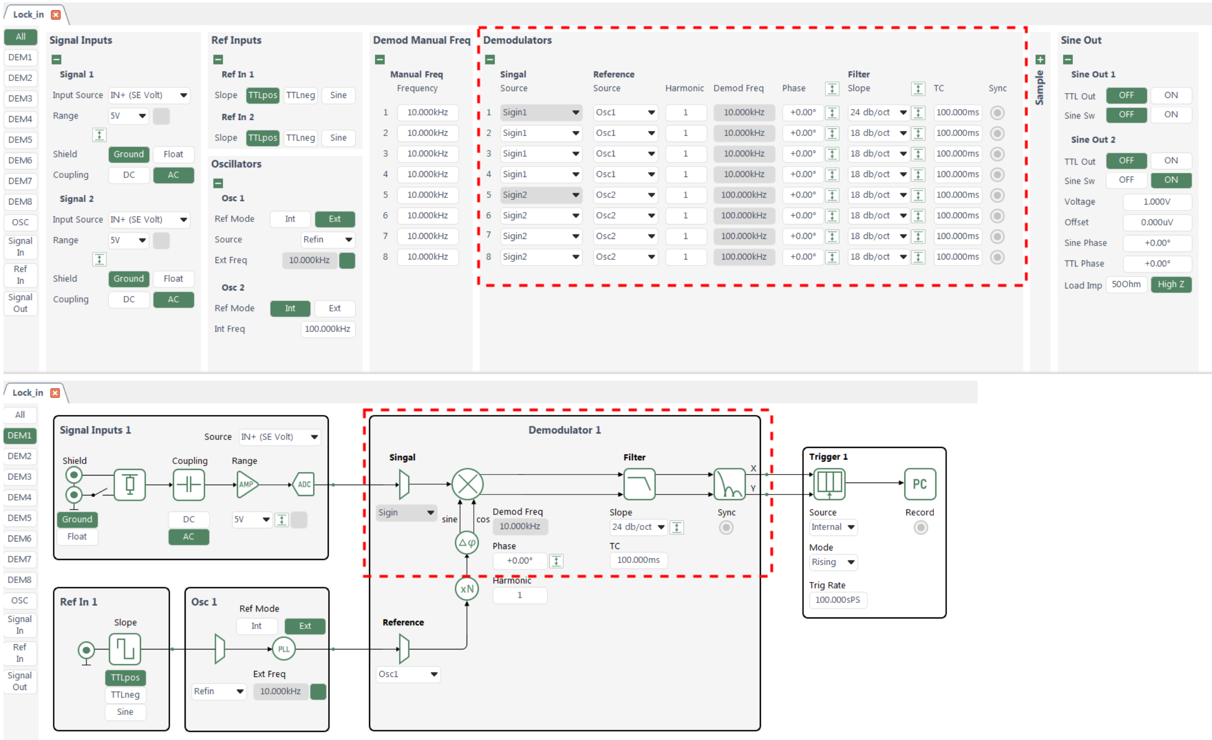


Figure 48. [DEMOD FILTER] configuration area

5.4 [DEMOD REF] Submenu

5.4.1. Front-Panel Configuration

Select the [DEMOD REF] submenu from the front-panel menu bar. This menu is used to configure the reference source of the demodulator, as shown in the right-side panel of Figure 49.

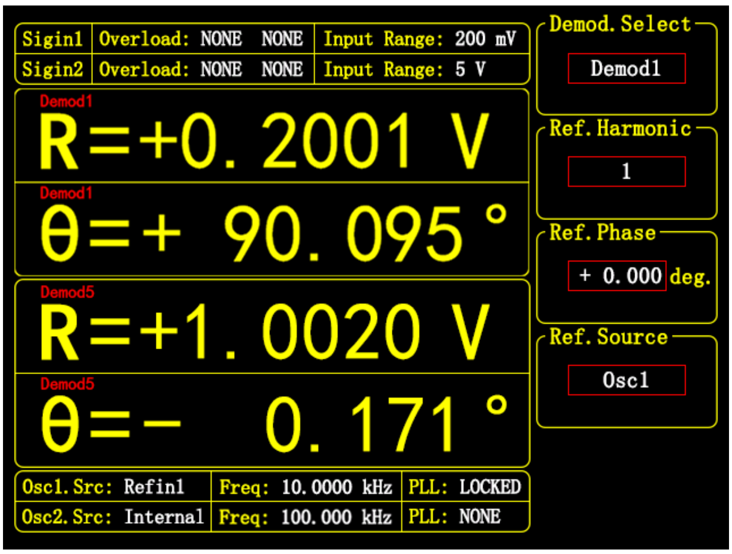


Figure 49. [DEMOD REF] submenu

This submenu includes function settings such as <Demod.Select>, <Ref.Harmonic>, <Ref.Phase>, <Ref.Source>, <Frequency Set>, and <FreqComb Set>.

- <Demod.Select>: demodulator channel selection setting

The knob and the ARROW keys can be used to switch the parameter display and configuration among the eight demodulators from <Demod1> to <Demod8>. For example, when <Demod1> is selected, the settings of <Ref.Harmonic>, <Ref.Phase>, <Ref.Source>, and <Frequency Set> all correspond to the current configuration of <Demod1>. Changing these settings at this time does not affect the related configurations of the other demodulators.

- <Ref.Harmonic>: harmonic order setting of the demodulator reference

The setting range is an integer from 1~10 000. Enter the harmonic order to be measured using the numeric keypad. The default value is 1, indicating first-order harmonic detection, that is, fundamental detection. The <Ref.Harmonic> setting is valid only when Harmonic × reference signal frequency ≤ 1.5 MHz. If the upper frequency limit is exceeded, the system does not prevent the setting, but the measurement result will be incorrect. The user must therefore control the harmonic setting appropriately.

For example, if the input signal is a square wave with a frequency of 1 kHz and a peak-to-peak value of A, then when <Ref.Harmonic> is set to 1, 2, 3, 4, 5, 6, ..., the expected R values are 0.45 A, 0, 0.15 A, 0, 0.09 A, 0, ... This sequence is exactly A times the coefficient sequence of the Fourier series of the square-wave signal.

☆ **Note: To display the measurement results of multiple demodulators at the same time, select <Full> in the <Display Mode> option of the [DISPLAY] submenu. See the [DISPLAY] submenu section for details.**

- <Ref.Phase>: phase offset setting of the demodulator reference

The numeric keypad can be used to set the phase shift angle of the two quadrature reference signals used in the PSD algorithm. The input range of the phase shift angle is −180° ~ 180°, and the resolution is 0.001°.

Phase is meaningful only when a basis or reference is defined. In the system, the rising zero crossing of the internal oscillator is used as the default phase reference, and all other phase values are based on this reference. When the signal source of the internal oscillator is set to REF IN, the internal oscillator locks its phase through a high-precision phase-locked loop, and the system phase reference tracks the REF IN signal to satisfy the lock-in requirement. The phase offset affects the phase difference between the demodulator reference and the internal oscillator. As shown in Figure 50, if no phase offset is required, keep <Ref.Phase> at 0°. In this case, the demodulator reference remains in phase with the internal oscillator.

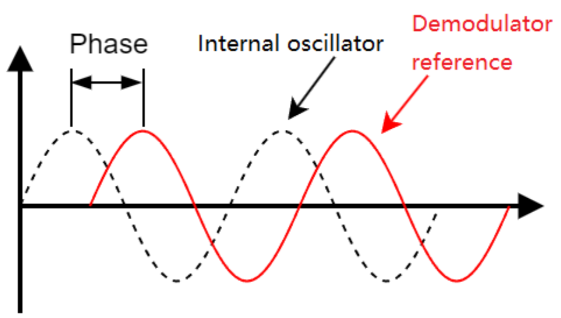


Figure 50. Effect of phase offset on the reference basis

- <Ref.Source>: demodulator reference source setting

<Osc1> : Sets the reference source of the current demodulator to internal oscillator OSC1.

<Osc2> : Sets the reference source of the current demodulator to internal oscillator OSC2.

<Frequency> : Sets the reference source of the current demodulator to an independent demodulation frequency. The interface for this mode is shown in Figure 51.

<FreqComb1> : Sets the reference source of the current demodulator to linear-combination sideband demodulation. The interface for this mode is shown in Figure 52. In this mode, press <Menu Enter> to enter the secondary menu for setting the linear-combination formula. The frequency-combination mode provides four channels, <FreqComb1> to <FreqComb4>, which are independent of the demodulator channels. Each demodulator can be configured independently or can reuse the same <FreqComb> channel.

<FreqComb2> : Same as above.

<FreqComb3> : Same as above.

<FreqComb4> : Same as above.

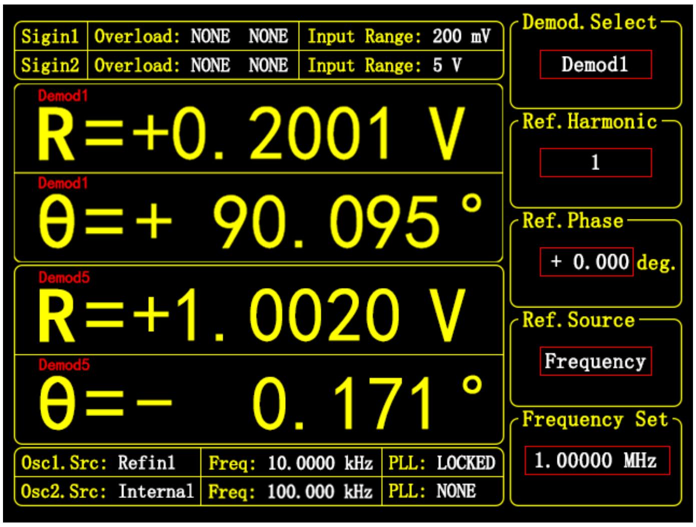


Figure 51. <Frequency> mode interface

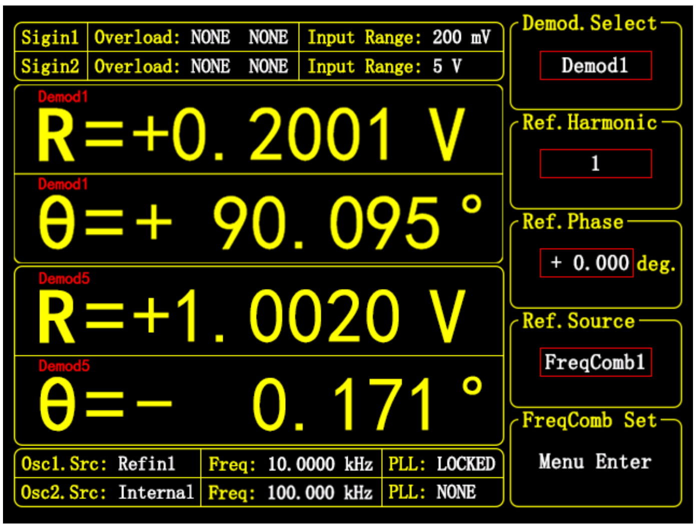


Figure 52. <FreqComb> mode interface

- <Frequency Set>: demodulator reference frequency setting

This item is available when <Ref.Source> is set to <Frequency>. Its setting rules are the same as those for <Ref.Frequency> in [OSC REF]. When <Frequency> is set to a specific frequency, the demodulator uses that frequency as the reference frequency to demodulate the signal.

This mode is especially useful when the input signal contains multiple frequency components and the user needs to extract them separately. The eight demodulators can be set to different demodulation frequencies and can demodulate eight frequency components simultaneously.

- <FreqComb Set>: linear-combination formula setting

This item is available when <Ref.Source> is set to <FreqComb1> to <FreqComb4>. Press <Menu Enter> to enter the secondary menu for setting the frequency-combination formula, as shown in Figure 53. The calculation formula for <FreqComb> is:

$$FreqComb = A \times F_1 + B \times F_2$$

where:

A and B are signed real numbers with a range of -10000 ~ +10000 and a resolution of 0.001;

F_1 and F_2 can be selected from the frequency output result of OSC1 or OSC2, or from any internal frequency of Demod1 to Demod8;

If the calculated result of FreqComb is 1500 Hz, the demodulator uses 1500 Hz as the reference frequency for the phase-sensitive detection algorithm. This mode is effective in AM, FM, and related signal-demodulation applications, such as sum-frequency and difference-frequency sideband demodulation.

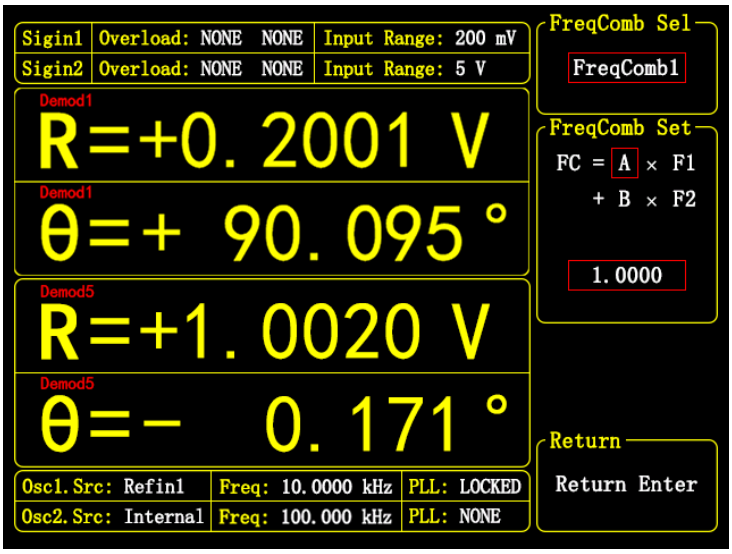


Figure 53. <FreqComb> secondary-menu setting interface

5.4.2. PC Software Configuration

As shown in the red box in Figure 54, the highlighted area in the PC Software is the [DEMOD REF] configuration area. The user can configure the demodulator reference source either in the parameter table or in the flowchart area. The configuration information for <Ref.Harmonic>, <Ref.Phase>, <Ref.Source>, <Frequency Set>, and <FreqComb Set> can all be modified and confirmed in the red-boxed area.

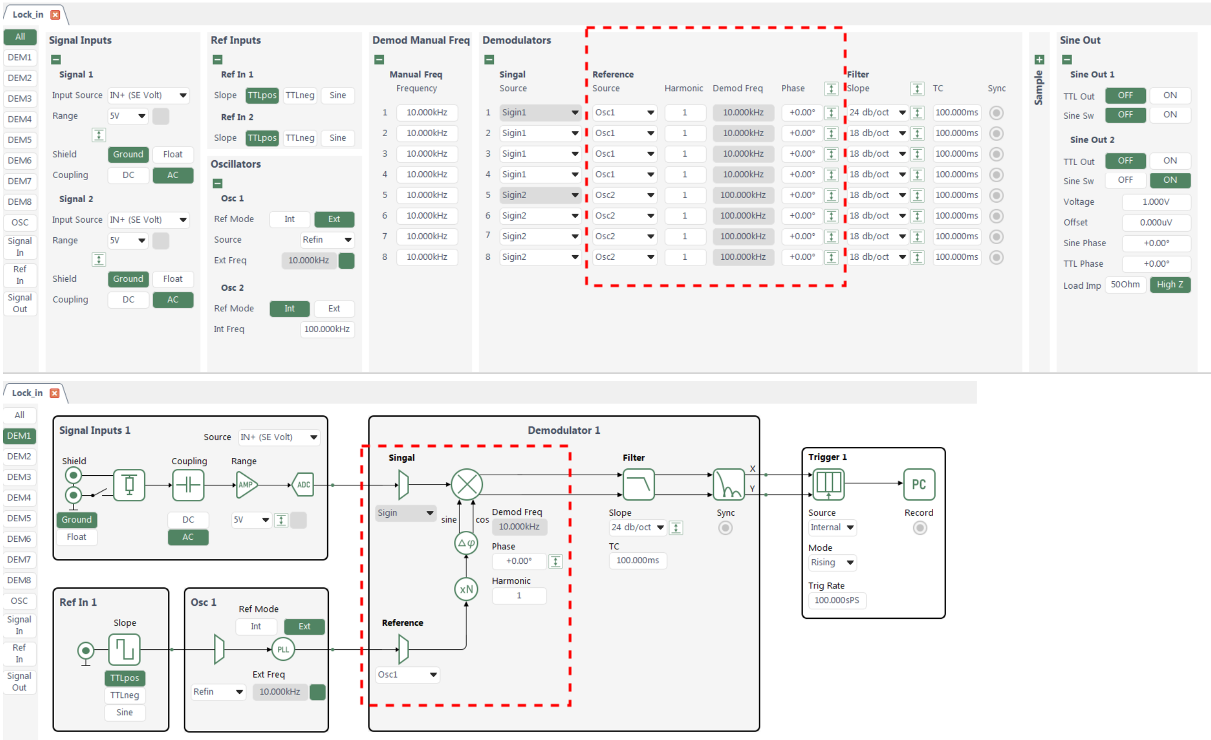


Figure 54. [DEMOD REF] configuration area

The formula configuration interface for <FreqComb Set> is shown in Figure 55. The user can set the frequency-combination calculation formula in the flowchart area of the PC Software. The configuration information for A, B, F_1, and F_2 can all be modified and confirmed in the red-boxed area.

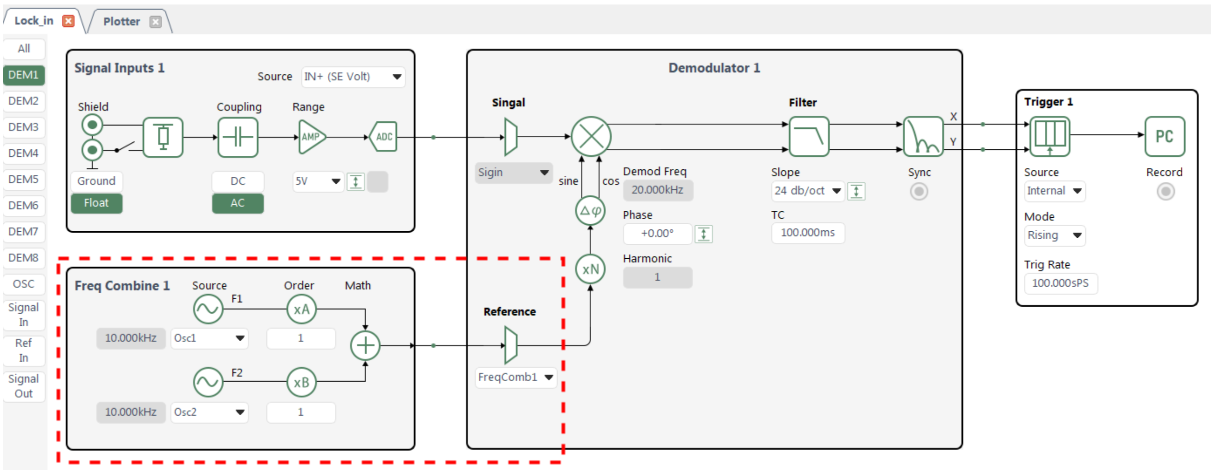


Figure 55. FreqComb formula configuration area in [DEMOD REF]

5.5 [DISPLAY] Submenu

5.5.1. Front-Panel Configuration

Select the [DISPLAY] submenu from the front-panel MENU bar, as shown in the right-side panel of Figure 56.

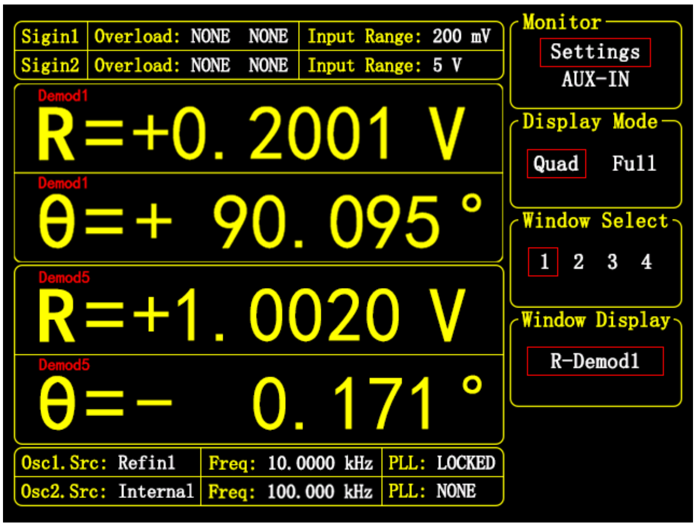


Figure 56. [DISPLAY] submenu

The [DISPLAY] submenu mainly includes five function settings: <Monitor>, <Display Mode>, <Window Select>, <Window Display>, and <Full Window>. These settings can be selected and configured using the corresponding Softkeys beside the submenu.

- <Monitor>: status bar display setting

<Settings> : Displays multiple current setting parameters and status items, such as <Input Source> and <Overload>, in the status bar at the top of the LCD screen.

<AUX-IN> : Displays the real-time input voltage amplitudes of the four AUX-IN BNC connectors on the rear panel in the status bar at the top of the LCD screen. The interface is shown in Figure 57.

- <Display Mode>: dynamic area display mode setting

The <Display Mode> option is mainly used to set the display type of the data bar. Two display types are available:

<Quad> : Four-window display mode, displaying four measurement values at the same time. This mode is shown in Figure 56.

<Full> : Full-data display mode, displaying the measurement values of eight demodulators at the same time. This mode is shown in Figure 58.

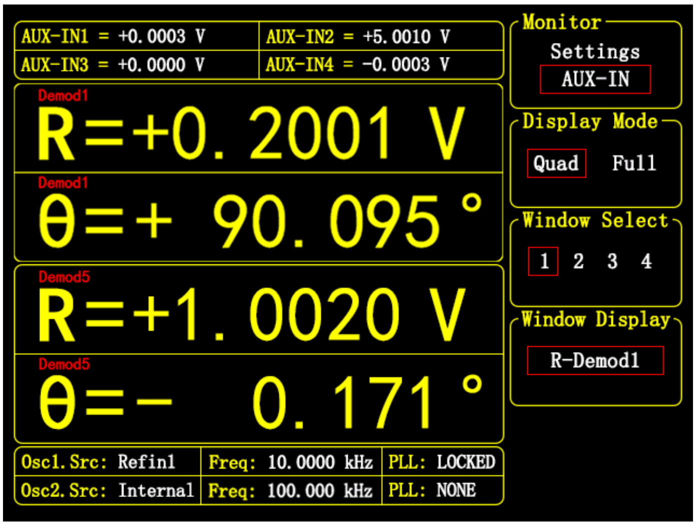


Figure 57. <AUX-IN> interface

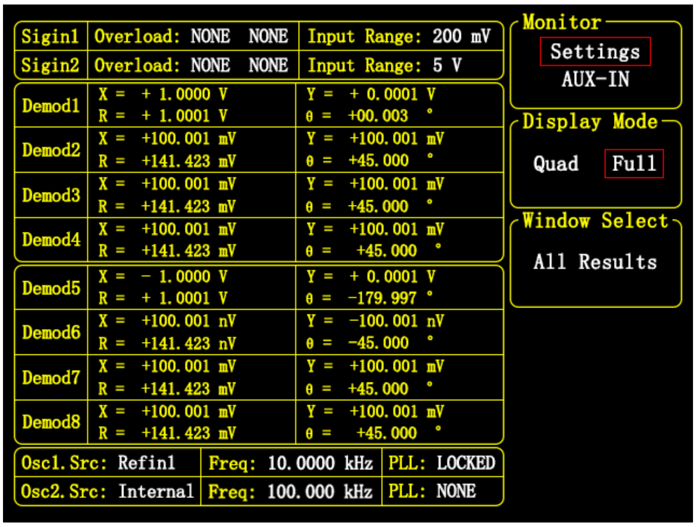


Figure 58. <Full> display mode

- <Window Select> & <Window Display>: split-window display content setting

These two configuration items are available when <Display Mode> is set to <Quad>. <Window Select> selects the split window to be configured, and <Window Display> sets the measurement value displayed in that split window. The available measurement values are:

<X-Demod1> : X value of the demodulation result of Demod1.
<Y-Demod1> : Y value of the demodulation result of Demod1.
<R-Demod1> : R value of the demodulation result of Demod1.
<θ-Demod1> : θ value of the demodulation result of Demod1.
<X-Demod2> : X value of the demodulation result of Demod2.
<Y-Demod2> : Y value of the demodulation result of Demod2.
<R-Demod2> : R value of the demodulation result of Demod2.
<θ-Demod2> : θ value of the demodulation result of Demod2.
<X-Demod3> : X value of the demodulation result of Demod3.
<Y-Demod3> : Y value of the demodulation result of Demod3.
<R-Demod3> : R value of the demodulation result of Demod3.
<θ-Demod3> : θ value of the demodulation result of Demod3.

<X-demod4> : X value of the demodulation result of Demod4.
<Y-demod4> : Y value of the demodulation result of Demod4.
<R-demod4> : R value of the demodulation result of Demod4.
<θ-Demod4> : θ value of the demodulation result of Demod4.
<X-Demod5> : X value of the demodulation result of Demod5.
<Y-Demod5> : Y value of the demodulation result of Demod5.
<R-Demod5> : R value of the demodulation result of Demod5.
<θ-Demod5> : θ value of the demodulation result of Demod5.
<X-Demod6> : X value of the demodulation result of Demod6.
<Y-Demod6> : Y value of the demodulation result of Demod6.
<R-Demod6> : R value of the demodulation result of Demod6.
<θ-demod6> : θ value of the demodulation result of Demod6.
<X-Demod7> : X value of the demodulation result of Demod7.
<Y-Demod7> : Y value of the demodulation result of Demod7.
<R-Demod7> : R value of the demodulation result of Demod7.
<θ-Demod7> : θ value of the demodulation result of Demod7.
<X-Demod8> : X value of the demodulation result of Demod8.
<Y-Demod8> : Y value of the demodulation result of Demod8.
<R-Demod8> : R value of the demodulation result of Demod8.
<θ-Demod8> : θ value of the demodulation result of Demod8.
<XNoise-Demod1> : X-Noise value of the demodulation result of Demod1.
<YNoise-Demod1> : Y-Noise value of the demodulation result of Demod1.
<XNoise-Demod5> : X-Noise value of the demodulation result of Demod5.
<YNoise-Demod5> : Y-Noise value of the demodulation result of Demod5.

The four split display windows can be flexibly configured to show the desired content. By default, they display the <X>, <Y>, <R>, and <θ> values of Demod1.

5.5.2. PC Software Configuration

The [DISPLAY] submenu only configures the display results on the front-panel interface and does not affect the configuration information in the PC Software. The data measurement results in the PC Software can be configured and displayed independently. As shown in Figure 59, the Numeric tab allows the measurement result of any demodulator to be selected for display. Compared with the front-panel interface, the PC Software configuration is more flexible and convenient.

In addition, the PC Software provides a waveform display mode. Select the Plotter tab to observe one or more output results as waveforms.

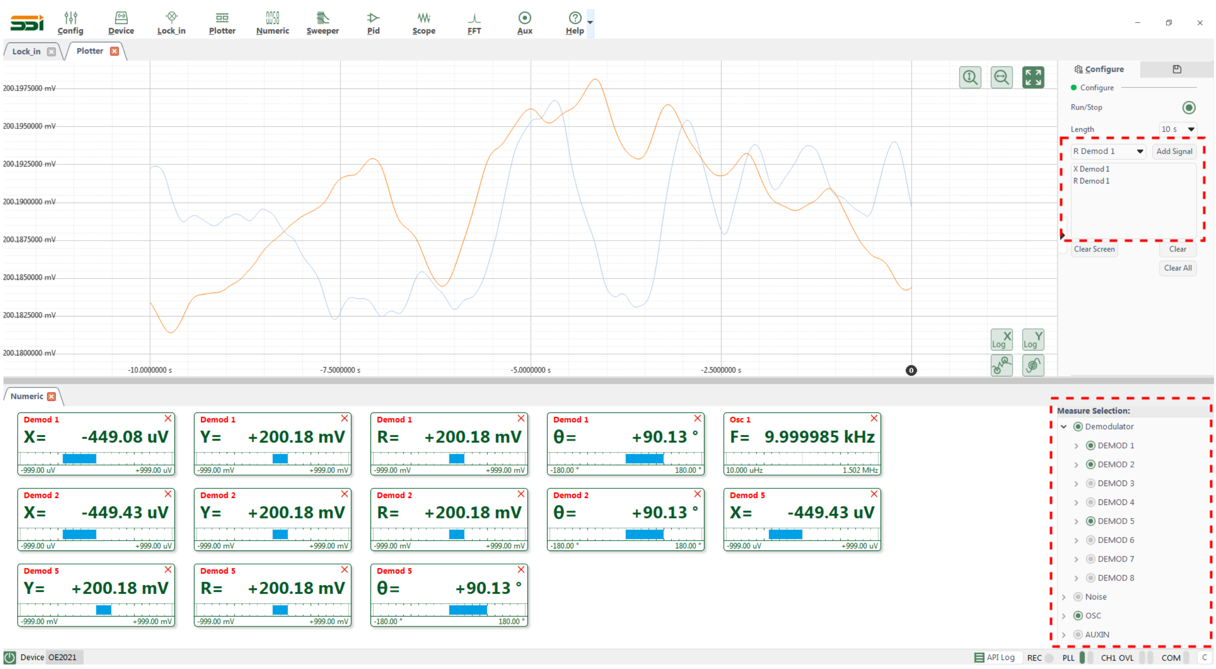


Figure 59. PC Software settings related to [DISPLAY]

5.6 [SIGNAL OUTPUT] Submenu

5.6.1. Front-Panel Configuration

Select the [SIGNAL OUTPUT] submenu from the front-panel MENU bar. This menu is used to configure the parameters of the Sine Out and TTL Out interfaces, as shown in the right-side panel of Figure 60.

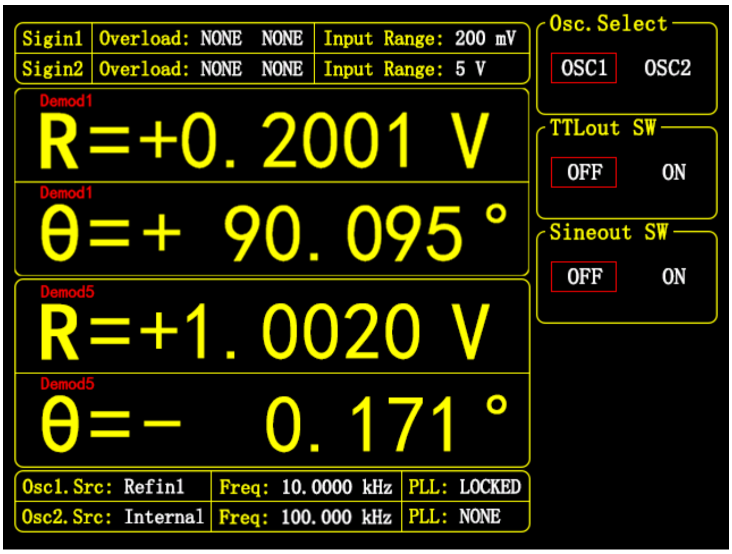


Figure 60. [SIGNAL OUTPUT] submenu

This submenu includes five function settings: <Osc.Select>, <TTLout SW>, <Sineout SW>, <Amplitude>, and <Offset>.

The OE2022 can output sine-wave signals with amplitudes from 100 nV_{rms} to 5 V_{rms} through the front-panel “Sine Out 1” and “Sine Out 2” BNC connectors. Their reference sources follow the internal oscillators, equivalent to adjustable-amplitude outputs of the internal oscillators. The frequency reference sources of “Sine Out 1” and “TTL Out 1” follow OSC1, while the frequency reference sources of “Sine Out 2” and “TTL Out 2” follow OSC2.

When <Osc.Mode> uses <External> external reference, “Sine Out” outputs a sine signal with the same frequency and phase as the external reference. When <Internal> internal reference is used, the signal is generated by the instrument’s internal oscillator.

The “TTL OUT” BNC connector on the rear panel outputs a TTL signal with the same frequency and phase as “Sine Out”.

- <Osc.Select>: SIGNAL OUTPUT channel selection

Press the corresponding key to switch the SIGNAL OUTPUT parameter display and configuration between the two oscillators, <OSC1> and <OSC2>. For example, when <OSC1> is selected, the settings of <TTLout SW>, <Sineout SW>, <Amplitude>, and <Offset> all correspond to the current configuration of <OSC1>. Changing these settings at this time does not affect the configuration of <OSC2>.

- <TTLout SW>: output mode setting for the TTL OUT interface

<OFF> : Disable TTLout output. TTLout outputs a constant 0 V.
<ON> : Enable TTLout output. TTLout outputs a 3.3 V TTL square-wave signal.

- <Sineout SW>: output mode setting for the SINE OUT interface

<OFF> : Disable Sineout output. Sineout outputs a constant 0 V.
<ON> : Enable Sineout output. The amplitude and offset of the output sine wave can then be set using <Amplitude> and <Offset>, as shown in Figure 61.

For extremely weak-signal measurements, such as resistance thermal-noise measurement or small-impedance measurement, it is recommended to turn off the Sineout and TTLout outputs to reduce internal same-frequency interference.

- <Amplitude>: Sineout output amplitude setting

The Sineout amplitude can be entered using the numeric keypad and knob. The RMS range is 0.1 μV_{rms} ~ 5 V_{rms}, and the minimum resolution is 0.1 μV_{rms}.

- <Offset>: Sineout output offset setting

The Sineout offset can be entered using the numeric keypad and knob. The range is −5~5 V_{DC}, and the minimum resolution is 0.001 V_{DC}.

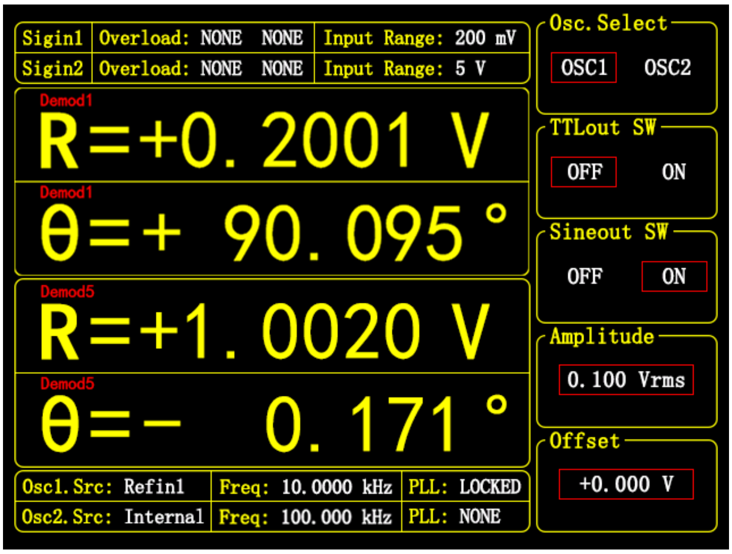


Figure 61. Menu when <Sineout SW> is enabled

5.6.2. PC Software Configuration

As shown in the red box in Figure 62, the highlighted area in the PC Software is the [SIGNAL OUTPUT] configuration area. The user can configure the signal output channel either in the parameter table or in the flowchart area. The configuration information for <Output Source>, <TTLout SW>, <Sineout SW>, <Amplitude>, and <Offset> can all be modified and confirmed in the red-boxed area.

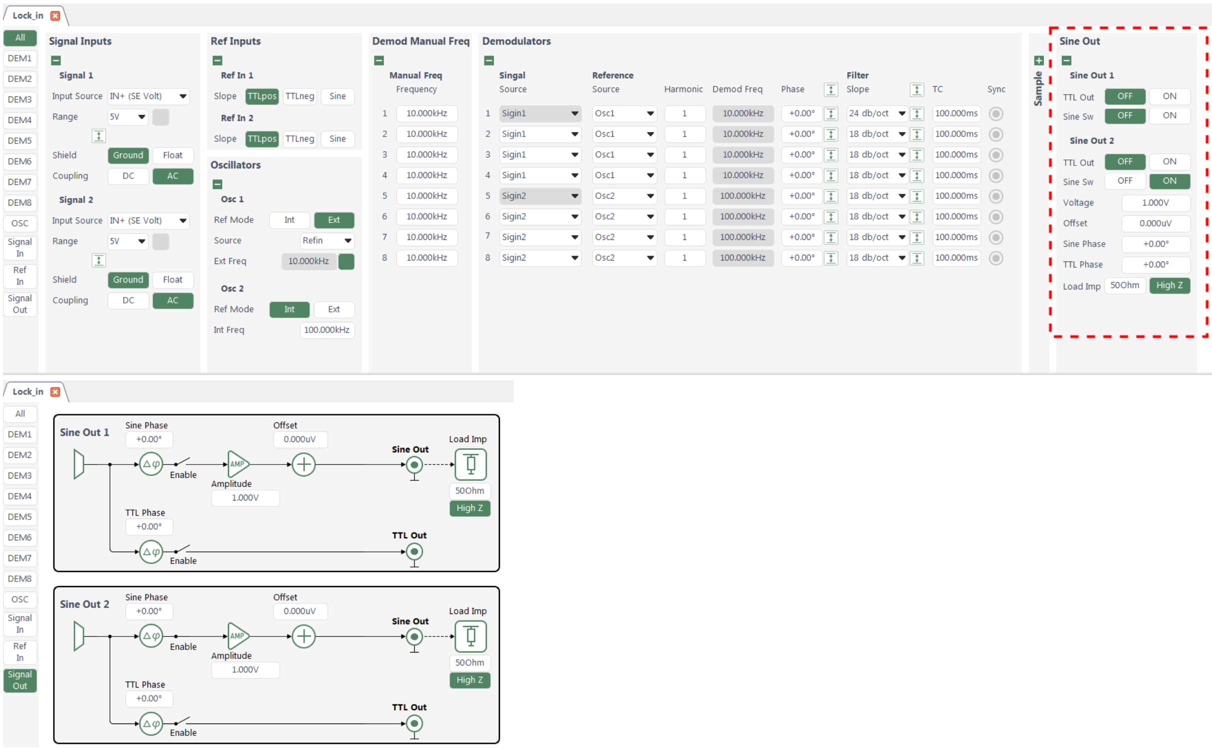


Figure 62. [SIGNAL OUTPUT] configuration area

5.7 [AUTO SET] Submenu

5.7.1. Front-Panel Configuration

The [AUTO SET] submenu includes four automatic setting functions of the OE2022, as shown in the right-side panel of Figure 63.

- <Auto Range>: automatic range setting function

After the <Auto Range> button is pressed, the instrument automatically adjusts the <Input Range> settings of the two input channels according to the amplitude of the current input signal.

Automatic range selection starts from the <5 V> range and switches step by step to lower ranges until the selected range can accommodate the maximum signal amplitude without overflow. The instrument then remains at the current range.

- <Auto Phase>: automatic phase compensation function

After the <Auto Phase> button is pressed, the instrument automatically adjusts the <Ref. Phase> of all demodulators so that the measured input signal phase becomes 0°. This process requires a certain response time, typically less than 5 seconds. If the current signal phase fluctuates significantly, <Auto Phase> may fail. In this case, switch to the [DEMOD REF] submenu and manually set <Ref.Phase>.

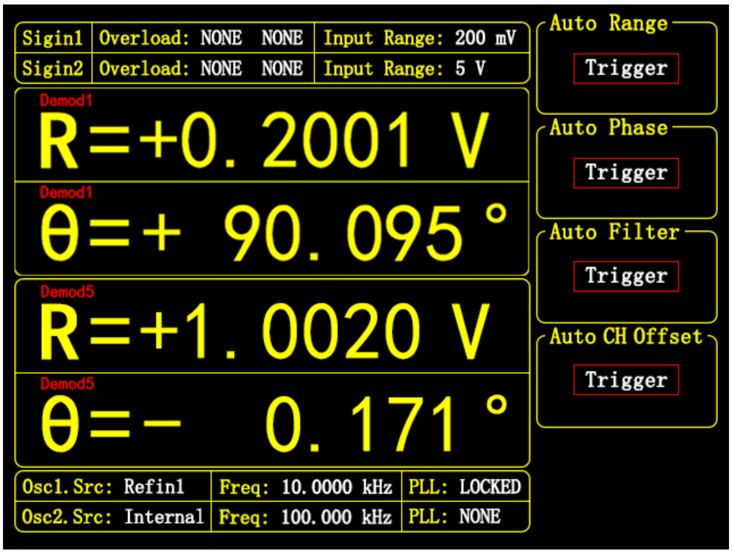


Figure 63. AUTO SET submenu

- <Auto Filter>: automatic demodulator filter setting function

After the <Auto Filter> button is pressed, the instrument automatically calculates the <Time Constant> and <Filter dB/oct> for all demodulators according to the reference frequency of each demodulator. The rules are as follows:

When the reference frequency is greater than 100 Hz, Time Constant = 100 ÷ Frequency, and Filter = 24 dB/oct.

When the reference frequency is less than 100 Hz, Time Constant = 1 s, Filter = 24 dB/oct, and Sync Filter = ON.

When the reference frequency is less than 1 Hz, Time Constant = 1 ÷ Frequency, Filter =

24 dB/oct, and Sync Filter = ON.

For example, if the reference frequency of Demod1 is 10 kHz, after <Auto Filter> is pressed, the filter time constant of Demod1 becomes 10 ms, and the filter roll-off slope is set to 24 dB/oct.

- <Auto CH Offset>: automatic output offset setting function for the CHOUT interface

When the <Auto CH Offset> button is pressed, the instrument automatically adjusts the <Offset> parameter in the [CH OUT] menu so that the formula calculation results of the two current CHOUT channels are zero, thereby implementing automatic DC offset compensation.

5.7.2. PC Software Configuration

As shown in the red boxes in Figure 64, the [AUTO SET] configuration area is located on the right side of the corresponding settings in the PC Software. The user can click the corresponding “” icon as needed to perform automatic configuration.

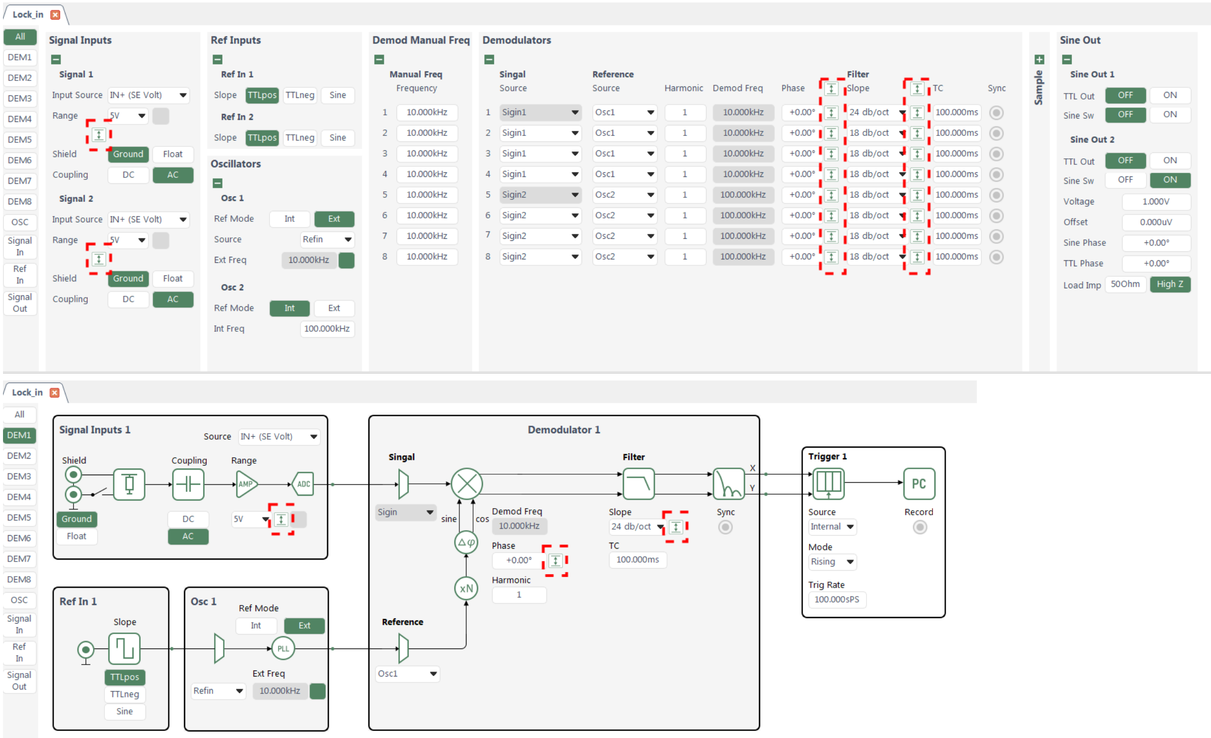


Figure 64. [AUTO SET] configuration area

5.8 [CHANNEL OUTPUT] and [AUX OUTPUT] Submenus

5.8.1. Front-Panel Configuration

Select the [CHANNEL OUTPUT] or [AUX OUTPUT] submenu from the front-panel MENU bar, as shown in the right-side panels of Figure 65 and Figure 66. Because the function configuration items and interface layouts of these two submenus are identical, they are described together in this section.

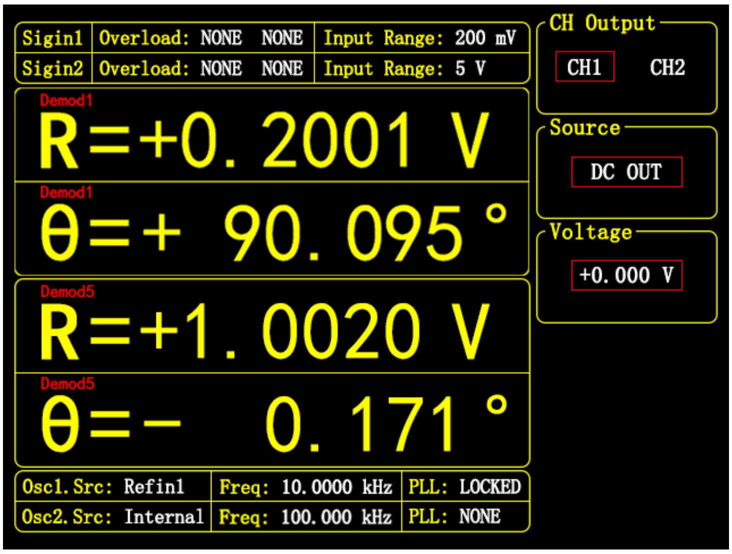


Figure 65. [CHANNEL OUTPUT] submenu

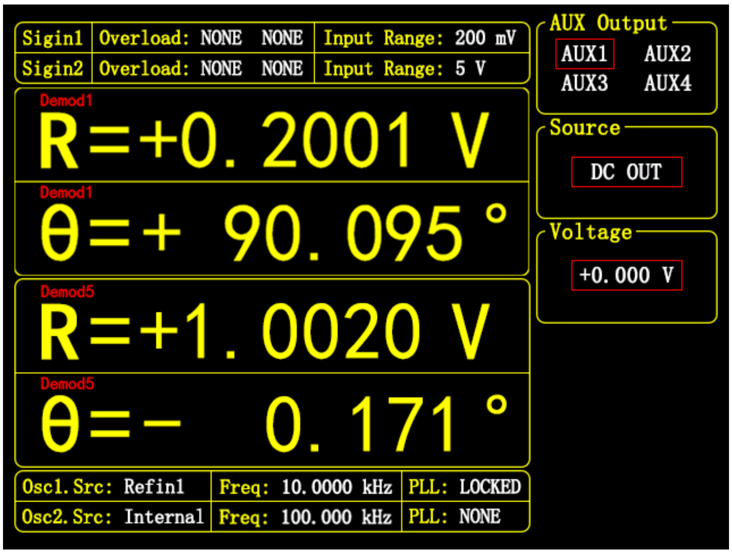


Figure 66. [AUX OUTPUT] submenu

The [CHANNEL OUTPUT] and [AUX OUTPUT] submenus control the six CHOUT / AUX-OUT BNC channels on the rear panel. These channels can output user-defined arbitrary values, the R, X, Y, and θ values of demodulators, and other signals. <Sensitivity> sets the scale factor, while <Offset&Expand> sets the output offset and expansion factor.

The output signal is calculated as follows.

1. When the selected signal is <R>, <X>, or <Y> of Demod1 ~ Demod8:

$$\text{Output} = \left(\frac{\text{Signal(selected signal)}}{\text{Sens}} + \text{Offset}\right) \times \text{Expand} \times 10\ \text{V}$$

2. When the selected signal is <Theta> of Demod1 ~ Demod8:

$$\text{Output} = \left(\frac{Theta}{180°} + \text{Offset}\right) \times \text{Expand} \times 10\ \text{V}$$

In addition to the two cases above, the following options are available:

a) AUXOUT: outputs the user-set voltage value, with a range of −10~10 V_{DC} and a resolution of 1 mV.

b) AUXIN1 ~ AUXIN4: the output equals the input voltage of the corresponding AUXIN interface.

- <CH Output> / <AUX Output>: CH channel or AUX channel selection setting

Selects the channel configuration for CH1 ~ CH2 and AUX1 ~ AUX4 respectively. Each channel can independently select one output source.

- <Source>: channel output source setting

<DC OUT> : The channel outputs the set level. Each channel has an independent <DC OUT> parameter.

<X-Demod1> : The channel outputs the analog level corresponding to the X value of Demod1.

<Y-Demod1> : The channel outputs the analog level corresponding to the Y value of Demod1.

<R-Demod1> : The channel outputs the analog level corresponding to the R value of Demod1.

<θ-Demod1> : The channel outputs the analog level corresponding to the θ value of Demod1.

<X-Demod2> : The channel outputs the analog level corresponding to the X value of Demod2.

<Y-Demod2> : The channel outputs the analog level corresponding to the Y value of Demod2.

<R-Demod2> : The channel outputs the analog level corresponding to the R value of Demod2.

<θ-Demod2> : The channel outputs the analog level corresponding to the θ value of Demod2.

<X-Demod3> : The channel outputs the analog level corresponding to the X value of Demod3.

<Y-Demod3> : The channel outputs the analog level corresponding to the Y value of Demod3.

<R-Demod3> : The channel outputs the analog level corresponding to the R value of Demod3.

<θ-Demod3> : The channel outputs the analog level corresponding to the θ value of Demod3.

<X-Demod4> : The channel outputs the analog level corresponding to the X value of Demod4.

<Y-Demod4> : The channel outputs the analog level corresponding to the Y value of Demod4.

<R-Demod4> : The channel outputs the analog level corresponding to the R value of Demod4.

<θ-Demod4> : The channel outputs the analog level corresponding to the θ value of Demod4.

<X-Demod5> : The channel outputs the analog level corresponding to the X value of Demod5.

<Y-Demod5> : The channel outputs the analog level corresponding to the Y value of Demod5.

<R-Demod5> : The channel outputs the analog level corresponding to the R value of Demod5.

<θ-Demod5> : The channel outputs the analog level corresponding to the θ value of Demod5.

<X-Demod6> : The channel outputs the analog level corresponding to the X value of Demod6.

<Y-Demod6> : The channel outputs the analog level corresponding to the Y value of Demod6.

<R-Demod6> : The channel outputs the analog level corresponding to the R value of Demod6.

<θ-Demod6> : The channel outputs the analog level corresponding to the θ value of Demod6.

<X-Demod7> : The channel outputs the analog level corresponding to the X value of Demod7.

<Y-Demod7> : The channel outputs the analog level corresponding to the Y value of Demod7.

<R-Demod7> : The channel outputs the analog level corresponding to the R value of Demod7.

<θ-Demod7> : The channel outputs the analog level corresponding to the θ value of Demod7.

<X-Demod8> : The channel outputs the analog level corresponding to the X value of Demod8.

<Y-Demod8> : The channel outputs the analog level corresponding to the Y value of Demod8.

<R-Demod8> : The channel outputs the analog level corresponding to the R value of Demod8.

<θ-Demod8> : The channel outputs the analog level corresponding to the θ value of Demod8.

<AUXIN1> : The channel outputs the level corresponding to the AUX-IN1 interface.

<AUXIN2> : The channel outputs the level corresponding to the AUX-IN2 interface.

<AUXIN3> : The channel outputs the level corresponding to the AUX-IN3 interface.

<AUXIN4> : The channel outputs the level corresponding to the AUX-IN4 interface.

- <Voltage>: output voltage value in fixed DC output mode

When <Source> is set to <DC OUT>, <Voltage> can be set, as shown in Figure 65 and Figure 66. The voltage value can be entered using the numeric keypad. The setting range is $-10 \sim 10\ V_{DC}$, and the resolution is 1 mV.

- <Sensitivity>: sensitivity setting

When <Source> selects an input source other than <AUXOUT> and <AUXIN1 ~ 4>, the option menu for <Sensitivity>, <Offset>, and <Expand> appears as shown in Figure 67.

The selectable range of <Sensitivity> is shown in Table 5. Note that when <Source> is set to <θ> of Demod1–Demod8, the <Sensitivity> setting is invalid and is fixed to 180°.

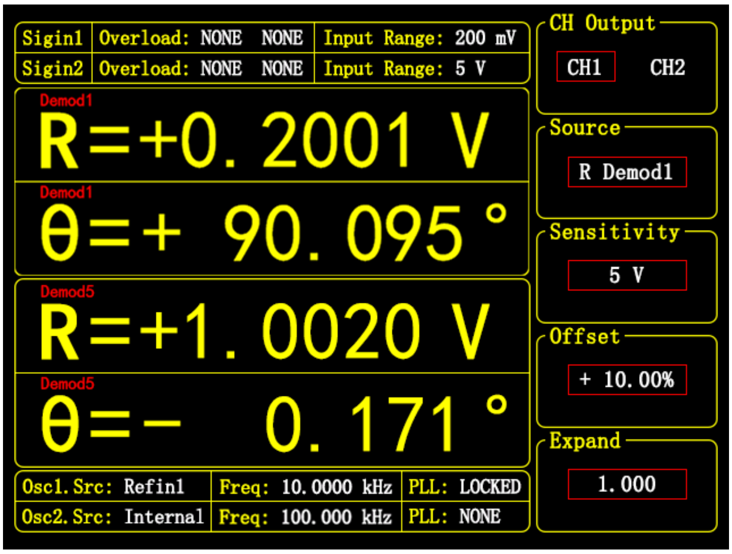


Figure 67. <Offset&Expand> interface

Table 5. Selectable sensitivity settings

1 nV/pA	500 nV/pA	200 μV/nA	100 mV/μA
2 nV/pA	1 μV/nA	500 μV/nA	200 mV/μA
5 nV/pA	2 μV/nA	1 mV/μA	500 mV/μA
10 nV/pA	5 μV/nA	2 mV/μA	1 V/mA
20 nV/pA	10 μV/nA	5 mV/μA	2 V/mA
50 nV/pA	20 μV/nA	10 mV/μA	5 V/mA
100 nV/pA	50 μV/nA	20 mV/μA	-
200 nV/pA	100 μV/nA	50 mV/μA	-

- <Offset>: offset setting

The value can be entered using the numeric keypad. The adjustable range is −100~100 %, the minimum step is 0.01%, and the default value is 0.00%.

- <Expand>: output expansion setting

The value can be entered using the numeric keypad. <Expand> scales the output around the selected <Offset> operating point to increase effective resolution in the region of interest. The adjustable range is a real number from 0.001~10 000, and the default value is 1. If the <Expand> setting causes the calculated value to exceed ±10 V, the output value is limited to ±10 V.

☆ **Note: Each CH / AUX channel has an independent offset value and expansion value.** For example, if <Offset> of CH1 is set to 50% and <Expand> is set to 3, only the output of CH1 is affected. The outputs of other channels remain unchanged.

☆ Note: The settings of <Sensitivity>, <Offset>, and <Expand> do not affect the data displayed in the dynamic-area data box.

5.8.2. PC Software Configuration

As shown in Figure 68, the highlighted area is the [CHOUT AUXOUT] configuration area. This function can be opened from the Aux tab. The configuration information for <Source>, <Voltage>, <Sensitivity>, <Expand>, and <Offset> can all be modified and confirmed in this configuration area.

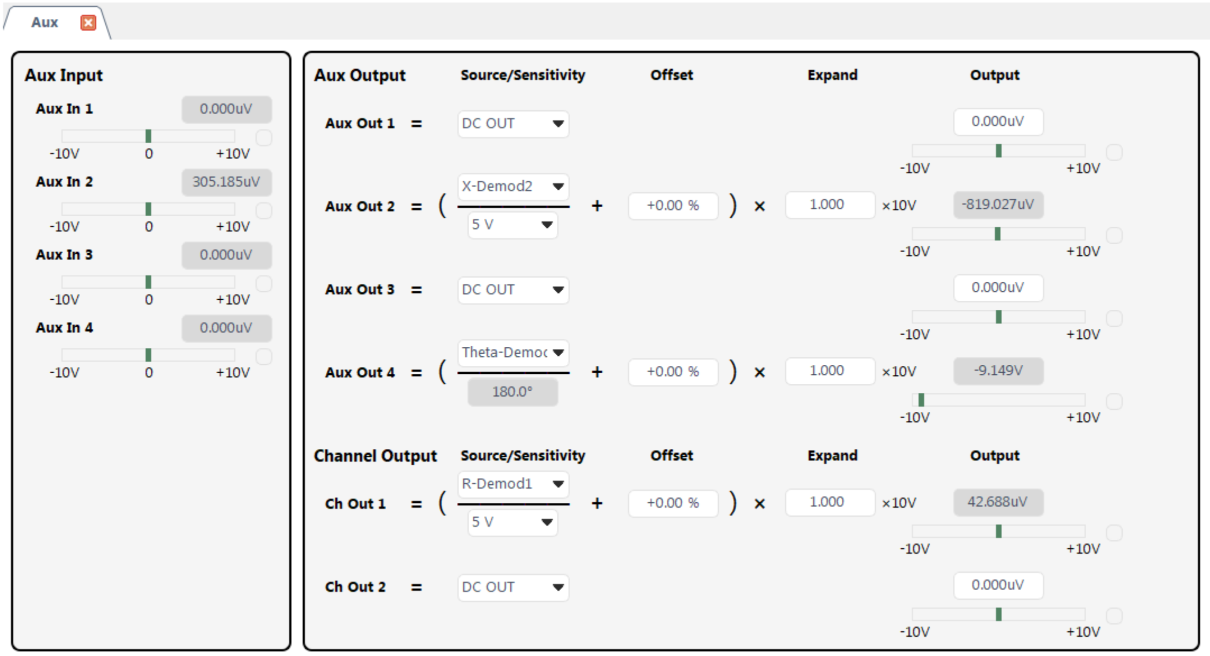


Figure 68. [CHOUT AUXOUT] configuration area

5.9 [SYSTEM] Submenu

5.9.1. Front-Panel Configuration

The [SYSTEM] submenu includes system information and system settings of the OE2022, such as instrument information, screen brightness, and communication settings. The menu is shown in the right-side panel of Figure 69.

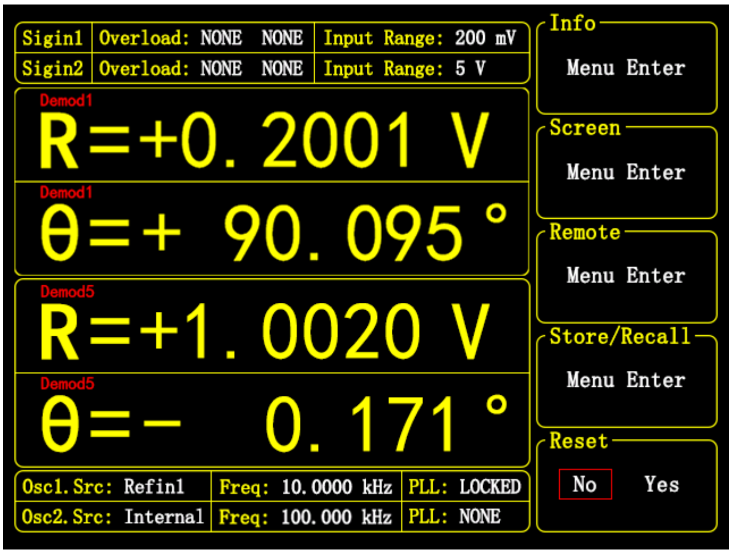


Figure 69. [SYSTEM] submenu

- <Info> secondary submenu

<Info> : This interface displays information such as the R&D organization, after-sales contact information, product serial number, and version number, as shown in Figure 70. The serial number should match the factory label on the rear panel.

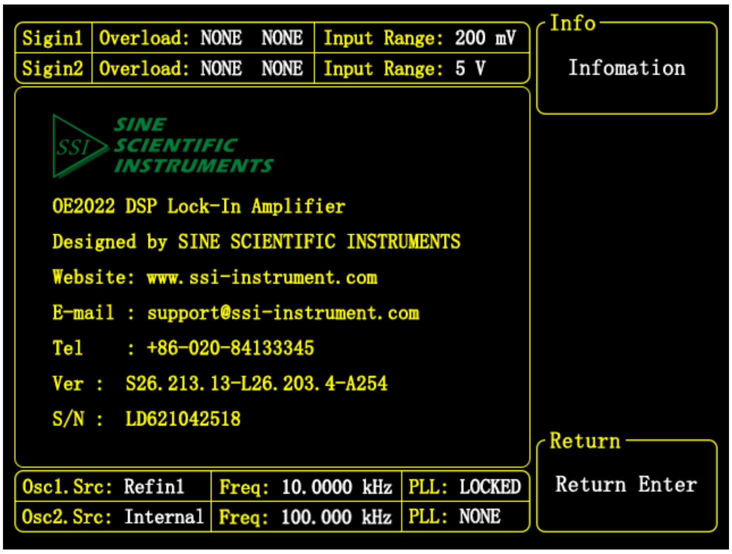


Figure 70. <INFO>–Instrument information

- <Screen> secondary submenu

Select the <Screen> submenu to enter this secondary menu. It includes two function settings: <Window Color> and <Backlight>.

The interface is shown in Figure 71.

<Window Color>: interface color setting

<Yellow>: Sets the main interface color style to yellow, as shown in Figure 71.

<Green>: Sets the main interface color style to green, as shown in Figure 72.

☆ **Note: Only the yellow-style interface is currently available. The green-style interface will be provided in a future OTA update.**

<Backlight>: backlight brightness setting

The brightness can be adjusted using the knob from <Level1> to <Level8>, corresponding to brightness from low to high. The default setting is <Level8>.

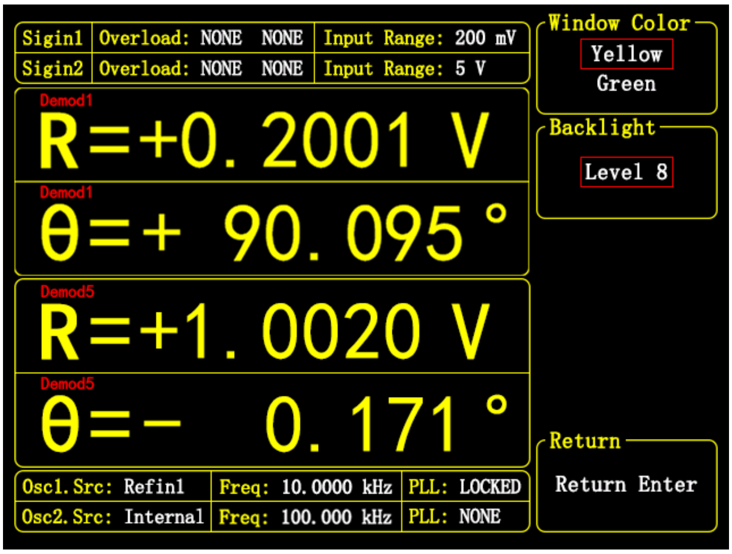


Figure 71. <Screen> submenu–<Yellow> style

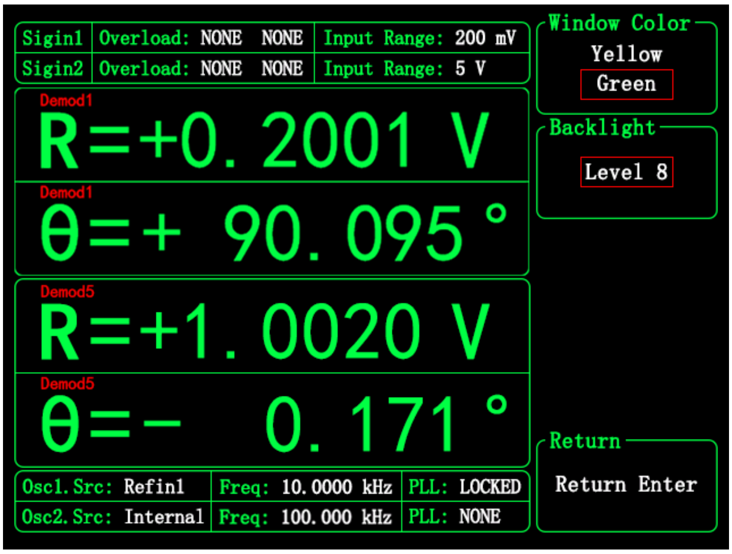


Figure 72. <Screen> submenu–<Green> style

- <Remote> secondary submenu

Select the <Remote> secondary submenu to enter the interface shown in Figure 73.

The OE2022 provides four remote communication interfaces: RS232 serial port, GPIB interface, USB2.0 high-speed interface, and Ethernet interface. The corresponding settings can be configured according to the interface selected in <Remote Mode>.

This menu is used only to modify the configuration of each remote communication interface. Selecting one communication interface in <Remote Mode> does not affect communication through the other interfaces. The instrument supports simultaneous use of multiple communication interfaces.

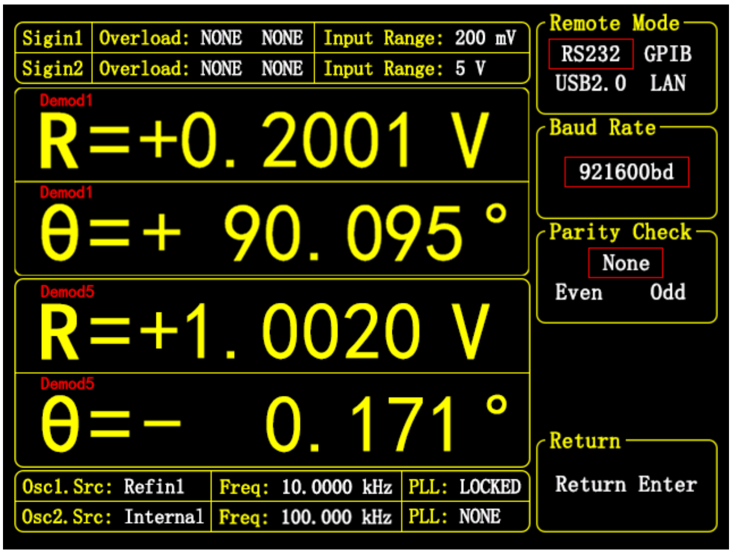


Figure 73. <Remote> submenu–<RS232> option

- <Remote Mode>: remote interface selection

<RS232> : RS232 serial communication interface, using a DB9 female connector. The configuration interface is shown in Figure 73.

<GPIB> : GPIB female connector. Its address configuration interface is shown in Figure 74.

<USB2.0> : USB2.0 high-speed communication interface. The configuration interface is shown in Figure 75.

<Ethernet> : 1000 Mbps Ethernet interface. The port number is 10001. For example, if the OE2022 obtains the network IP address 192.168.1.10, the PC should connect to the OE2022 using 192.168.1.10:10001. The configuration interface is shown in Figure 76.

The PC remote-control software supplied with the instrument must communicate through USB2.0 or Ethernet. RS232 communication is not currently supported by the PC Software.

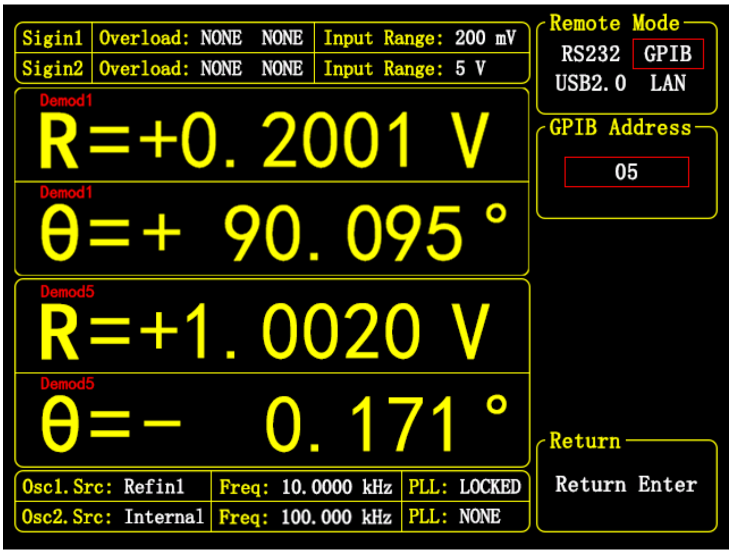


Figure 74. <Remote> submenu–<GPIB> option

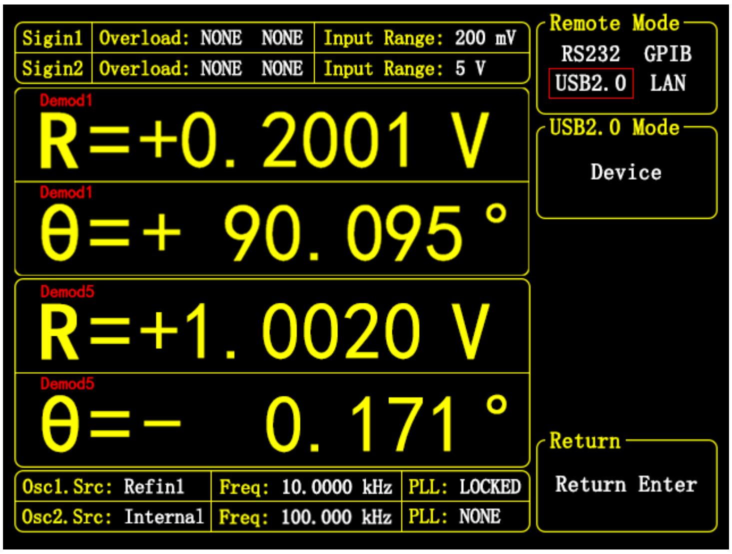


Figure 75. <Remote> submenu–<USB2.0> option

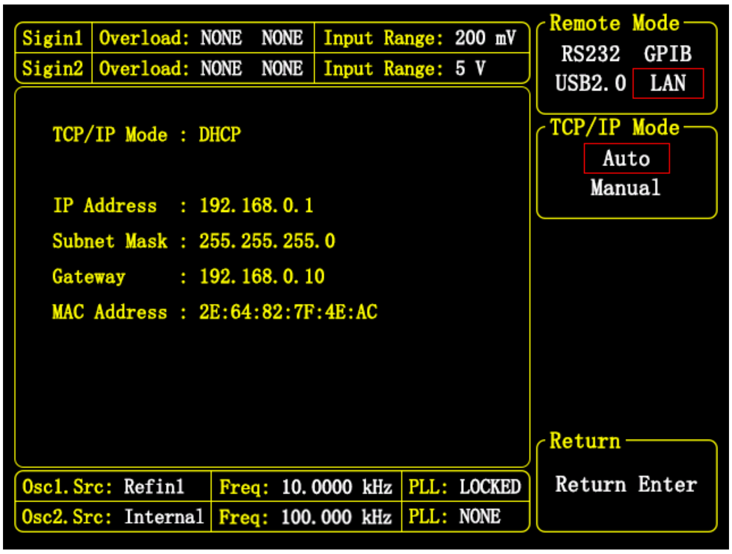


Figure 76. <Remote> submenu–<Ethernet> option

- <Baud Rate>: baud rate setting

This item is available in <RS232> mode. The baud rate can be adjusted using the knob. The available values are <600>, <1200>, <2400>, <4800>, <9600>, <19200>, <38000>, <43000>, <56000>, <57600>, <115200>, <230400>, <460800>, and <921600>. The default value is <921600>.

- <Parity Check>: parity setting

This item is available in <RS232> mode.
<Even> : Even parity.
<ODD> : Odd parity.
<NONE> : No parity.

- <GPIB Address>: GPIB address setting

This item is available in <GPIB> mode. The GPIB address of the instrument can be adjusted using the knob. The available values are <1> to <30>, and the default value is <5>.

- <TCP/IP Mode>: Ethernet TCP/IP mode setting

This item is available in <Ethernet> mode. In general, when the instrument is connected to a router through an Ethernet cable, <Auto> mode can automatically connect it to the Ethernet network.

<Auto> : Automatically configure the TCP/IP protocol.

<Manual> : Manually configure the TCP/IP protocol.

In <Auto> mode, when network access is detected, the interface changes to the "Connecting..." status shown in Figure 77, indicating that the instrument is connecting to the current network. When the network connection succeeds, as shown in Figure 78, the local IP address, subnet mask, gateway, and local MAC address of the current network are displayed.

In <Manual> mode, the IP address, subnet mask, and gateway of the TCP/IP protocol can be configured manually, as shown in Figure 79. Select the IP, subnet, or gateway to be modified in the <IP Select> window, then press the <Excute> key to enter the parameters in the numeric keypad area, as shown in Figure 80. Finally, press <ENTER> to confirm.

After configuration is complete, the OE2022 can be configured and read within the local area network.

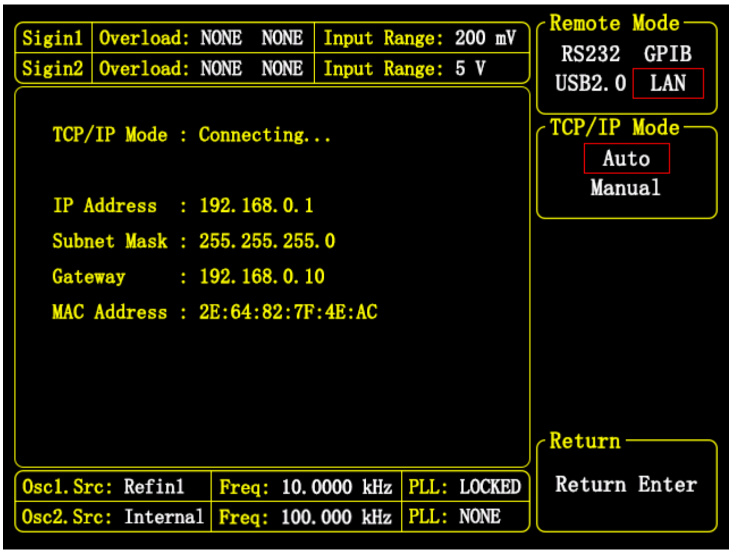


Figure 77. <Auto> mode—Connecting

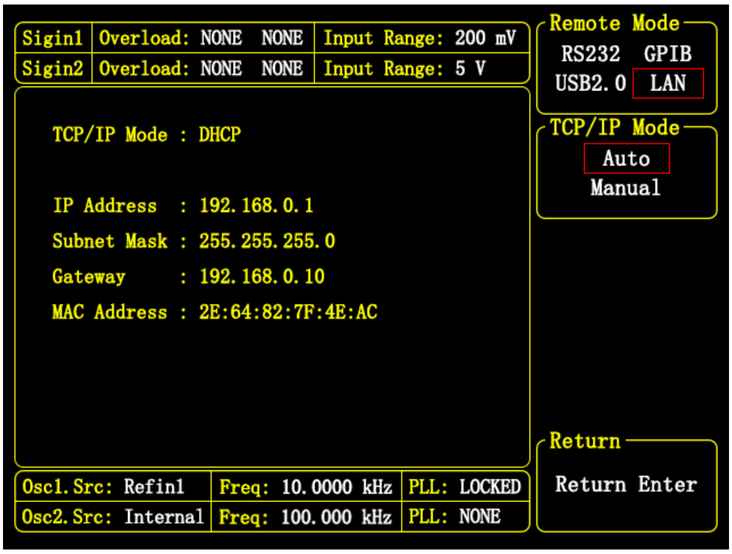


Figure 78. <Auto> mode—Connection successful

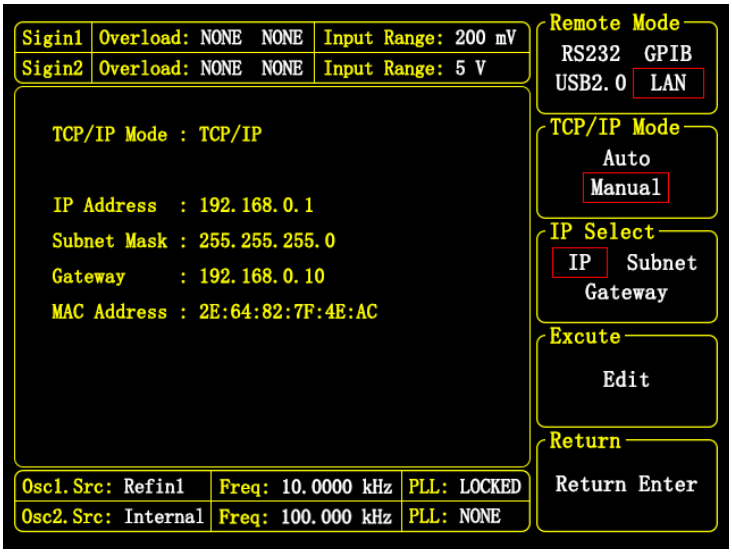


Figure 79. <Manual> mode

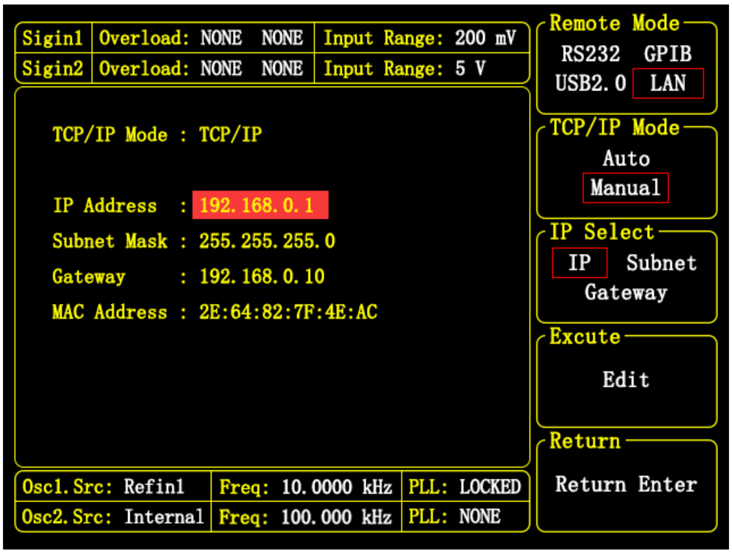


Figure 80. <Manual> mode during modification

- <Store/Recall>: secondary submenu

Select the <Store/Recall> secondary submenu to enter the interface shown in the right-side panel of Figure 81. The <Store/Recall> menu is used to save (Store) or restore (Recall) the current instrument parameter settings and operating status. The instrument has four independent configuration storage areas: <S1>, <S2>, <S3>, and <S4>. Each storage area can save a complete set of parameter configurations, including demodulator settings, filter parameters, output settings, and other settings. When it is necessary to switch to a saved configuration, select the corresponding storage area and execute <Recall> to quickly load the configuration, greatly improving experimental efficiency and flexibility.

<Store> : After entering the <Store/Recall> menu, select <Store> mode, specify the target storage area, such as <S1>, in <Channel>, and then select <Store> in <Execute> to save all current parameters and status to the selected storage area.

<Recall> : To restore a saved configuration, select <Recall> mode, select the corresponding storage area, such as <S1>, in <Channel>, and execute <Recall> in <Execute>. The instrument then loads all settings in that storage area.

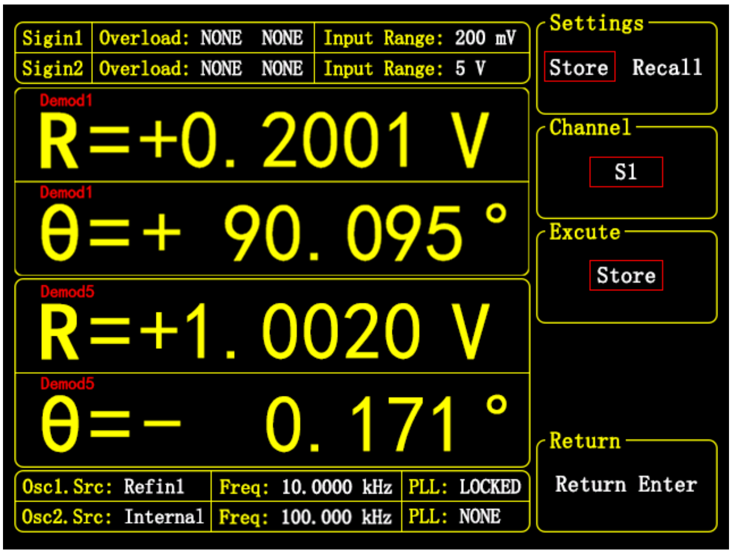


Figure 81. <Store/Recall> submenu

Restore default configuration:

In <Recall> mode, <Channel> also provides the <Default> option. After this option is selected and <Recall> is executed, the instrument restores the factory default configuration and all parameters are reset to their initial states, as shown in Figure 82.

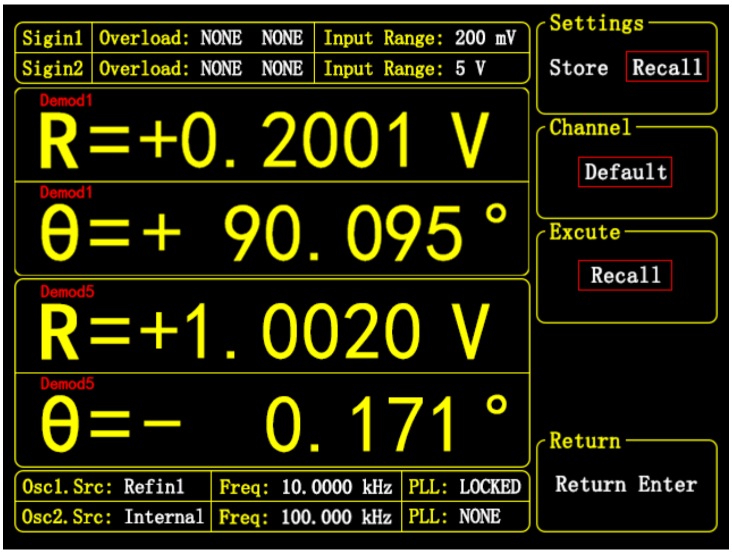


Figure 82. Restore default settings option

- <Reset>: lock-in amplifier soft reset

After the corresponding button is pressed, the system performs a soft reset. The current settings are not changed after the reset and restart.

5.9.2. PC Software Configuration

As shown in Figure 83, the highlighted area is the [SYSTEM] configuration area. This function can be opened from the Device tab. In this tab, the user can view instrument <Info>, view and configure the Ethernet address, perform <Store/Recall> operations, and perform related system settings.

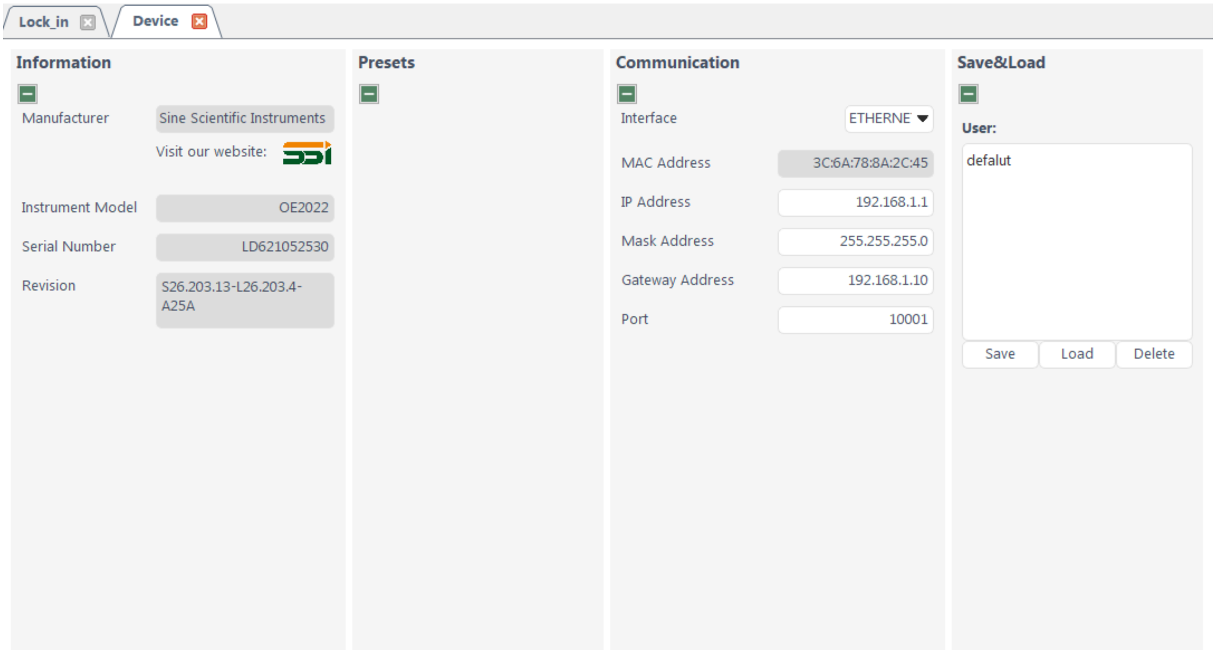


Figure 83. [SYSTEM] configuration area

5.10 PC Software Data Saving

The PC Software of the OE2022 supports data acquisition, logging, and file export. Users can log measurement data over a selected time interval as needed.

5.10.1. Global Data Saving

Global data saving includes the following contents:

- Measurement values R, X, Y, and θ of Demod1 ~ 8;
- X and Y noise values of Demod1 and Demod5;
- Measured frequencies of the two oscillators;
- Signal values of the four auxiliary input AUXIN interfaces.

The steps for global data saving are as follows:

1. When the software is running, click the “Record” button in the red box in Figure 84 to start data acquisition and logging.

2. The data is saved in Excel-compatible CSV format. The file name is “data_lock_in_XXXXXXXX_XXXXXX.csv”, where “XXXXXXXX_XXXXXX” represents the date and timestamp, ensuring that each file name is unique. The file is stored in the program directory by default. An example data format is shown in Figure 85.

3. Click the “Record” button again to stop data acquisition and logging.

4. The current display and saved-data sampling rate can be modified in “

”. The

setting range is 0.1~100 kSa/s.

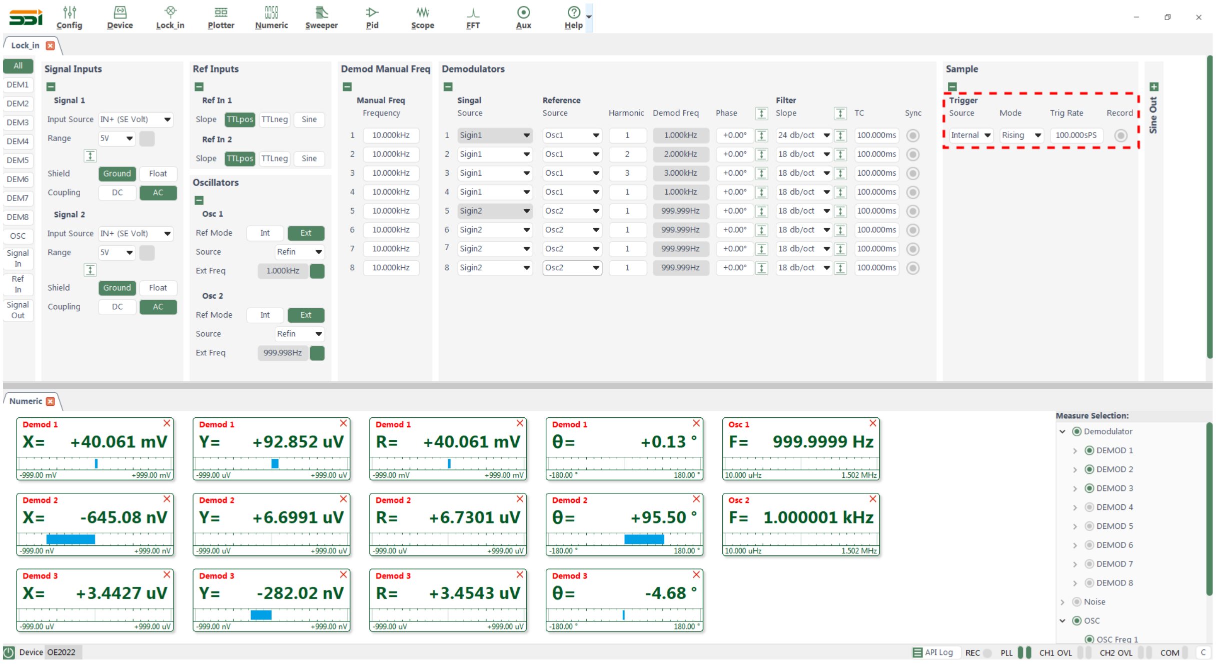


Figure 84. Data saving configuration area

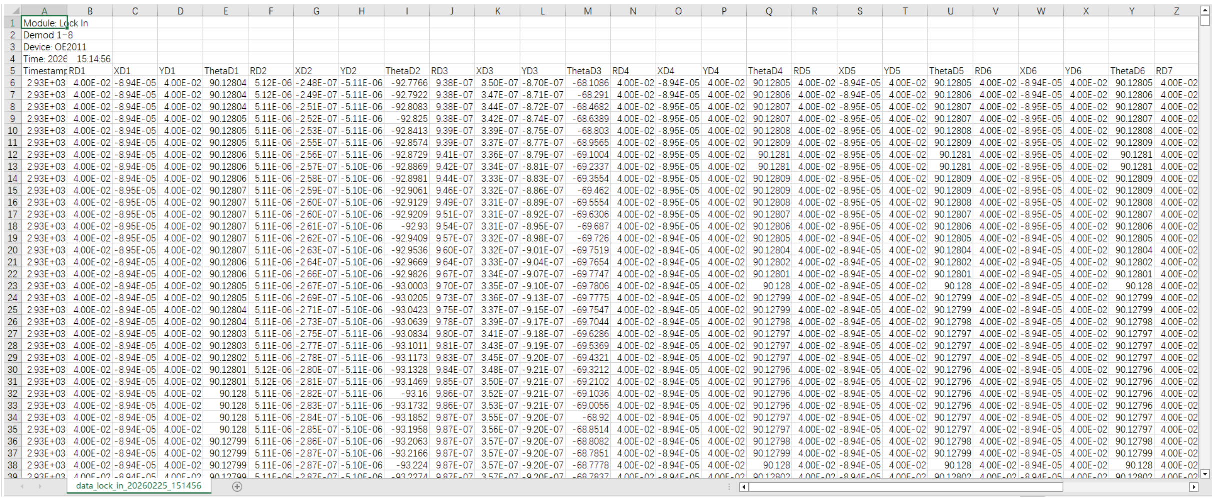


Figure 85. Format of the data_lock_in_XXXXXXXX_XXXXXX.csv file

5.10.2. Plotter Waveform Data Saving

In the Plotter tab, click the “Save” button area shown in the red box in Figure 86, and then click the “Save Data” button to save the data corresponding to the current waveform plot to the local hard disk.

The data is saved in Excel-compatible CSV format. The file name is “data_plotter_XXXXXXXX_XXXXXX.csv”, where “XXXXXXXX_XXXXXX” represents the date and timestamp, ensuring that each file name is unique. The file is stored in the program directory by default. An example data format is shown in Figure 87.

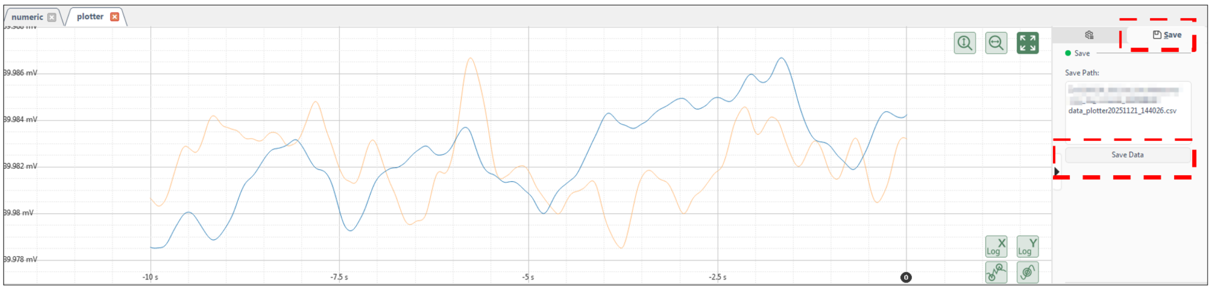


Figure 86. Plotter waveform data saving configuration

	A	B	C	D	E
1	Module: Plotter				
2	Graph	1	2		
3	Device: OE2041				
4	Time: 2025	14:40:26			
5	Timestamp	R Demod 1	Timestamp	Theta Demod 1	
6	1.96E+04	4.00E-02	1.96E+04	-1.41E-01	
7	1.96E+04	4.00E-02	1.96E+04	-1.41E-01	
8	1.96E+04	4.00E-02	1.96E+04	-1.41E-01	
9	1.96E+04	4.00E-02	1.96E+04	-1.41E-01	
10	1.96E+04	4.00E-02	1.96E+04	-1.41E-01	
11	1.96E+04	4.00E-02	1.96E+04	-1.41E-01	
12	1.96E+04	4.00E-02	1.96E+04	-1.41E-01	
13	1.96E+04	4.00E-02	1.96E+04	-1.41E-01	
14	1.96E+04	4.00E-02	1.96E+04	-1.41E-01	
15	1.96E+04	4.00E-02	1.96E+04	-1.41E-01	
16	1.96E+04	4.00E-02	1.96E+04	-1.41E-01	
17	1.96E+04	4.00E-02	1.96E+04	-1.41E-01	
18	1.96E+04	4.00E-02	1.96E+04	-1.41E-01	

Figure 87. Plotter waveform data file format

5.10.3. Scope Waveform Data Saving

In the Scope tab, click the “Save” button area shown in the red box in Figure 88, and then click the “Save Data” button to save the data corresponding to the current waveform plot to the local hard disk.

The data is saved in Excel-compatible CSV format. The file name is “data_oscilloscope_XXXXXXXX_XXXXXX.csv”, where “XXXXXXXX_XXXXXX” represents the date and timestamp, ensuring that each file name is unique. The file is stored in the program directory by default. An example data format is shown in Figure 89.

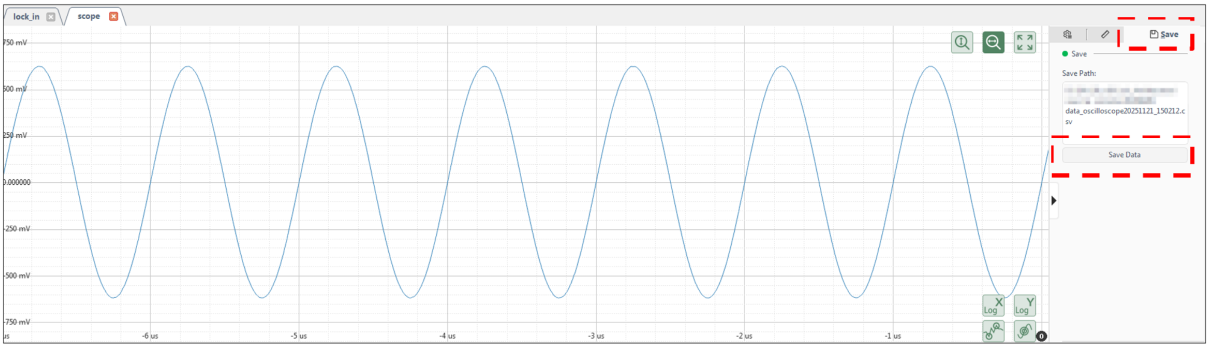


Figure 88. Scope waveform data saving configuration

	A	B
1	Module: Oscilloscope	
2	Osci 1	
3	Device: OE2041	
4	Time: 2025	15:02:12
5	X	Y
6	-6.55E-05	1.37E-01
7	-6.55E-05	1.21E-01
8	-6.55E-05	1.06E-01
9	-6.55E-05	9.14E-02
10	-6.55E-05	7.73E-02
11	-6.55E-05	5.89E-02
12	-6.55E-05	4.29E-02
13	-6.55E-05	2.73E-02
14	-6.55E-05	1.32E-02
15	-6.55E-05	-2.83E-03
16	-6.55E-05	-1.70E-02
17	-6.55E-05	-3.30E-02
18	-6.55E-05	-4.90E-02
19	-6.55E-05	-6.55E-02
20	-6.55E-05	-8.06E-02
21	-6.55E-05	-9.66E-02
22	-6.55E-05	-1.11E-01

Figure 89. Scope waveform data file format

5.10.4. Sweeper Waveform Data Saving

In the Sweeper tab, click the “Save” button area shown in the red box in Figure 90, and then click the “Save Data” button to save the data corresponding to the current waveform plot to the local hard disk.

The data is saved in Excel-compatible CSV format. The file name is “data_sweep_XXXXXXXX_XXXXXX.csv”, where “XXXXXXXX_XXXXXX” represents the date and timestamp, ensuring that each file name is unique. The file is stored in the program directory by default. An example data format is shown in Figure 91.

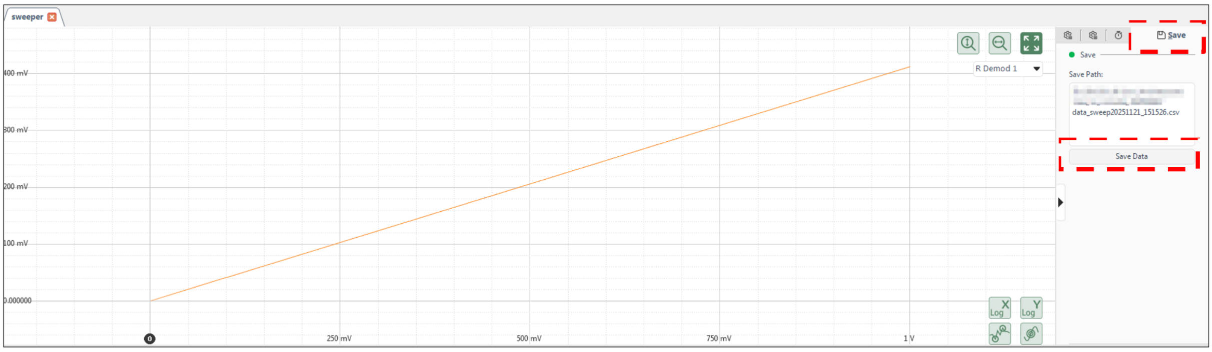


Figure 90. Sweeper parameter-scan data saving configuration area

	A	B	C	D	E	F	G	H	I
1	Module: Sweep								
2	Sweep 0								
3	Device: OE2041								
4	Time: 2025	15:15:26							
5	Timestamp	Demo_1 R	Demo_1 X	Demo_1 Y	Demo_1 Th	Demo_2 R	Demo_2 X	Demo_2 Y	Demo_2 Th
6	4.164E+09	4.16E-04	-4.29E-05	-4.14E-04	-95.91097	4.16E-04	-4.28E-05	-4.14E-04	-95.9069
7	3.886E+09	4.37E-04	-4.46E-05	-4.35E-04	-95.85548	4.37E-04	-4.49E-05	-4.35E-04	-95.89733
8	693618825	4.59E-04	-4.74E-05	-4.57E-04	-95.92161	4.58E-04	-4.70E-05	-4.56E-04	-95.87884
9	750979896	4.82E-04	-4.94E-05	-4.79E-04	-95.88177	4.82E-04	-4.94E-05	-4.79E-04	-95.88909
10	3.083E+09	5.06E-04	-5.23E-05	-5.03E-04	-95.93328	5.06E-04	-5.19E-05	-5.03E-04	-95.88933
11	484492330	5.30E-04	-5.48E-05	-5.28E-04	-95.93057	5.30E-04	-5.44E-05	-5.27E-04	-95.89732
12	822870507	5.57E-04	-5.66E-05	-5.54E-04	-95.83704	5.57E-04	-5.73E-05	-5.54E-04	-95.90161
13	50432454	5.85E-04	-6.09E-05	-5.81E-04	-95.9819	5.84E-04	-5.97E-05	-5.81E-04	-95.85781
14	2.103E+09	6.14E-04	-6.27E-05	-6.11E-04	-95.85966	6.14E-04	-6.30E-05	-6.10E-04	-95.88979
15	1.751E+09	6.46E-04	-6.59E-05	-6.42E-04	-95.86253	6.45E-04	-6.60E-05	-6.42E-04	-95.87214
16	2.99E+09	6.77E-04	-6.92E-05	-6.74E-04	-95.86549	6.77E-04	-6.91E-05	-6.74E-04	-95.85512
17	2.317E+09	7.11E-04	-7.24E-05	-7.08E-04	-95.84578	7.11E-04	-7.24E-05	-7.07E-04	-95.84656
18	3.931E+09	7.47E-04	-7.65E-05	-7.43E-04	-95.88122	7.47E-04	-7.61E-05	-7.43E-04	-95.85421
19	3.5E+09	7.85E-04	-7.93E-05	-7.81E-04	-95.79868	7.85E-04	-8.01E-05	-7.81E-04	-95.85827
20	1.866E+09	8.23E-04	-8.43E-05	-8.19E-04	-95.87627	8.24E-04	-8.39E-05	-8.19E-04	-95.84428
21	647932839	8.64E-04	-8.84E-05	-8.60E-04	-95.87083	8.64E-04	-8.82E-05	-8.60E-04	-95.85408
22	2.836E+09	9.07E-04	-9.23E-05	-9.03E-04	-95.83571	9.07E-04	-9.26E-05	-9.02E-04	-95.85731
23	3.313E+09	9.52E-04	-9.69E-05	-9.47E-04	-95.84378	9.52E-04	-9.72E-05	-9.47E-04	-95.85643
24	2.092E+09	1.00E-03	-1.01E-04	-9.96E-04	-95.80683	1.00E-03	-1.02E-04	-9.95E-04	-95.84283
25	3.508E+09	1.05E-03	-1.07E-04	-1.05E-03	-95.82552	1.05E-03	-1.07E-04	-1.05E-03	-95.83592
26	3.781E+09	1.10E-03	-1.12E-04	-1.10E-03	-95.8494	1.10E-03	-1.12E-04	-1.10E-03	-95.83068
27	309506995	1.16E-03	-1.18E-04	-1.15E-03	-95.8202	1.16E-03	-1.18E-04	-1.15E-03	-95.82474
28	398442314	1.22E-03	-1.24E-04	-1.21E-03	-95.83949	1.22E-03	-1.24E-04	-1.21E-03	-95.83054

	J	K	L	M	N	O	P	Q	R
5	Demo_3 R	Demo_3 X	Demo_3 Y	Demo_3 Th	Demo_4 R	Demo_4 X	Demo_4 Y	Demo_4 Th	Demo_5 R
6	4.16E-04	-4.28E-05	-4.14E-04	-95.9069	4.16E-04	-4.28E-05	-4.14E-04	-95.9069	4.16E-04
7	4.37E-04	-4.49E-05	-4.35E-04	-95.89733	4.37E-04	-4.49E-05	-4.35E-04	-95.89733	4.37E-04
8	4.58E-04	-4.70E-05	-4.56E-04	-95.87884	4.58E-04	-4.70E-05	-4.56E-04	-95.87884	4.58E-04
9	4.82E-04	-4.94E-05	-4.79E-04	-95.88909	4.82E-04	-4.94E-05	-4.79E-04	-95.88909	4.82E-04
10	5.06E-04	-5.19E-05	-5.03E-04	-95.88933	5.06E-04	-5.19E-05	-5.03E-04	-95.88933	5.06E-04
11	5.30E-04	-5.44E-05	-5.27E-04	-95.89732	5.30E-04	-5.44E-05	-5.27E-04	-95.89732	5.30E-04
12	5.57E-04	-5.73E-05	-5.54E-04	-95.90161	5.57E-04	-5.73E-05	-5.54E-04	-95.90161	5.57E-04
13	5.84E-04	-5.97E-05	-5.81E-04	-95.85781	5.84E-04	-5.97E-05	-5.81E-04	-95.85781	5.84E-04
14	6.14E-04	-6.30E-05	-6.10E-04	-95.88979	6.14E-04	-6.30E-05	-6.10E-04	-95.88979	6.14E-04
15	6.45E-04	-6.60E-05	-6.42E-04	-95.87214	6.45E-04	-6.60E-05	-6.42E-04	-95.87214	6.45E-04
16	6.77E-04	-6.91E-05	-6.74E-04	-95.85512	6.77E-04	-6.91E-05	-6.74E-04	-95.85512	6.77E-04
17	7.11E-04	-7.24E-05	-7.07E-04	-95.84656	7.11E-04	-7.24E-05	-7.07E-04	-95.84656	7.11E-04
18	7.47E-04	-7.61E-05	-7.43E-04	-95.85421	7.47E-04	-7.61E-05	-7.43E-04	-95.85421	7.47E-04
19	7.85E-04	-8.01E-05	-7.81E-04	-95.85827	7.85E-04	-8.01E-05	-7.81E-04	-95.85827	7.85E-04
20	8.24E-04	-8.39E-05	-8.19E-04	-95.84428	8.24E-04	-8.39E-05	-8.19E-04	-95.84428	8.24E-04
21	8.64E-04	-8.82E-05	-8.60E-04	-95.85408	8.64E-04	-8.82E-05	-8.60E-04	-95.85408	8.64E-04
22	9.07E-04	-9.26E-05	-9.02E-04	-95.85731	9.07E-04	-9.26E-05	-9.02E-04	-95.85731	9.07E-04
23	9.52E-04	-9.72E-05	-9.47E-04	-95.85643	9.52E-04	-9.72E-05	-9.47E-04	-95.85643	9.52E-04
24	1.00E-03	-1.02E-04	-9.95E-04	-95.84283	1.00E-03	-1.02E-04	-9.95E-04	-95.84283	1.00E-03
25	1.05E-03	-1.07E-04	-1.05E-03	-95.83592	1.05E-03	-1.07E-04	-1.05E-03	-95.83592	1.05E-03
26	1.10E-03	-1.12E-04	-1.10E-03	-95.83068	1.10E-03	-1.12E-04	-1.10E-03	-95.83068	1.10E-03
27	1.16E-03	-1.18E-04	-1.15E-03	-95.82474	1.16E-03	-1.18E-04	-1.15E-03	-95.82474	1.16E-03
28	1.22E-03	-1.24E-04	-1.21E-03	-95.83054	1.22E-03	-1.24E-04	-1.21E-03	-95.83054	1.22E-03

	S	T	U	V	W	X	Y	Z	AA
5	Demo_5 X	Demo_5 Y	Demo_5 Th	Demo_6 R	Demo_6 X	Demo_6 Y	Demo_6 Th	Osc Int Fre	Osc Int Freq 2
6	-4.28E-05	-4.14E-04	-95.9069	4.16E-04	-4.28E-05	-4.14E-04	-95.9069	999999.51	999999.51
7	-4.49E-05	-4.35E-04	-95.89733	4.37E-04	-4.49E-05	-4.35E-04	-95.89733	999999.51	999999.51
8	-4.70E-05	-4.56E-04	-95.87884	4.58E-04	-4.70E-05	-4.56E-04	-95.87884	999999.27	999999.27
9	-4.94E-05	-4.79E-04	-95.88909	4.82E-04	-4.94E-05	-4.79E-04	-95.88909	999999.51	999999.51
10	-5.19E-05	-5.03E-04	-95.88933	5.06E-04	-5.19E-05	-5.03E-04	-95.88933	999999.51	999999.51
11	-5.44E-05	-5.27E-04	-95.89732	5.30E-04	-5.44E-05	-5.27E-04	-95.89732	999999.27	999999.27
12	-5.73E-05	-5.54E-04	-95.90161	5.57E-04	-5.73E-05	-5.54E-04	-95.90161	999999.27	999999.27
13	-5.97E-05	-5.81E-04	-95.85781	5.84E-04	-5.97E-05	-5.81E-04	-95.85781	999999.51	999999.51
14	-6.30E-05	-6.10E-04	-95.88979	6.14E-04	-6.30E-05	-6.10E-04	-95.88979	999999.51	999999.51
15	-6.60E-05	-6.42E-04	-95.87214	6.45E-04	-6.60E-05	-6.42E-04	-95.87214	999999.27	999999.27
16	-6.91E-05	-6.74E-04	-95.85512	6.77E-04	-6.91E-05	-6.74E-04	-95.85512	999999.51	999999.51
17	-7.24E-05	-7.07E-04	-95.84656	7.11E-04	-7.24E-05	-7.07E-04	-95.84656	999999.51	999999.51
18	-7.61E-05	-7.43E-04	-95.85421	7.47E-04	-7.61E-05	-7.43E-04	-95.85421	999999.27	999999.27
19	-8.01E-05	-7.81E-04	-95.85827	7.85E-04	-8.01E-05	-7.81E-04	-95.85827	999999.51	999999.51
20	-8.39E-05	-8.19E-04	-95.84428	8.24E-04	-8.39E-05	-8.19E-04	-95.84428	999999.27	999999.51
21	-8.82E-05	-8.60E-04	-95.85408	8.64E-04	-8.82E-05	-8.60E-04	-95.85408	999999.51	999999.51
22	-9.26E-05	-9.02E-04	-95.85731	9.07E-04	-9.26E-05	-9.02E-04	-95.85731	999999.51	999999.51
23	-9.72E-05	-9.47E-04	-95.85643	9.52E-04	-9.72E-05	-9.47E-04	-95.85643	999999.27	999999.27
24	-1.02E-04	-9.95E-04	-95.84283	1.00E-03	-1.02E-04	-9.95E-04	-95.84283	999999.51	999999.51
25	-1.07E-04	-1.05E-03	-95.83592	1.05E-03	-1.07E-04	-1.05E-03	-95.83592	999999.51	999999.51
26	-1.12E-04	-1.10E-03	-95.83068	1.10E-03	-1.12E-04	-1.10E-03	-95.83068	999999.51	999999.51
27	-1.18E-04	-1.15E-03	-95.82474	1.16E-03	-1.18E-04	-1.15E-03	-95.82474	999999.51	999999.51
28	-1.24E-04	-1.21E-03	-95.83054	1.22E-03	-1.24E-04	-1.21E-03	-95.83054	999999.27	999999.27

Figure 91. Sweeper parameter-scan data file format

Chapter 6 Remote Programming

6.1 OE2022 Command Syntax

The PC software communicates with the OE2022 by using ASCII characters. Command mnemonics must be uppercase. Each command contains four command characters, optional parameters when required, and a command terminator. For RS232, USB2.0, or Ethernet communication, the terminator must be a semicolon <;> or a carriage return <cr>. The OE2022 executes a command only after the command terminator is received. A command may contain one or more parameters, and multiple parameters are separated by commas (,).

Multiple commands can be sent in the same command line. A semicolon <;> must be inserted between commands. Sending multiple commands in one command line provides a faster command response.

The OE2022 has an input buffer with a capacity of 1024 characters and processes commands in the order in which they are received. When the buffer is full, the newest command overwrites the oldest executed command. When entering multiple commands, it is recommended that the total length not exceed 1024 characters.

The OE2022 allows users to query the current values of internal settings through commands. A query command is formed by appending a question mark "?" to the command and omitting one or more parameters required by the setting command. The OE2022 returns the queried parameters as ASCII strings. If multiple queries separated by semicolons are sent in one command line, the responses are returned in sequence. The return value of each command is terminated by a carriage return <cr>.

For parameter settings with multiple channels, such as demodulators and oscillators, a channel parameter must be added for identification. Channel numbers start from 1. For example, "FREQ?1" queries the frequency value of internal oscillator OSC1, and "FREQ1,1000" sets the reference signal frequency of internal oscillator OSC1 to 1 kHz. For parameters with only one channel, such as clock configuration, no channel parameter is required. For example, "OCLK?" queries the enable status of the clock output interface.

In addition, non-channel parameters are indexed from 0 by default. For example, "OCLK0" disables the clock output interface, and "OCLK1" enables the clock output interface.

Command format examples:

FMOD 1,1 <cr>	Set the reference source of internal oscillator OSC1 to internal mode
FREQ 1,10E3 <cr>	Set the reference signal frequency of internal oscillator OSC1 to 10 kHz
OUTP? 1 <cr>	Query the Y output value of Demodulator 1
ISRC? 1 <cr>	Query the single-ended or differential mode of input channel 1
IGND 1 <cr>	Set the input shield grounding mode to GND mode
OCLK? <cr>	Query the enable status of the clock output interface

6.2 Detailed Command List

Command syntax notes:

- Parameters specified in a command must be written strictly in the specified order and separated by English commas “, ”.
- Parameters enclosed in braces { } are optional. Fill them in as needed; not all optional parameters need to be entered.
- A command is executed as a query only when it includes the question mark “?” mnemonic. Without “?”, it is treated as a setting command and does not return measurement or status data.
- In general, setting commands must include the required parameters shown in braces { }. Query commands do not need to include the optional parameters in { }.
- Do not insert spaces between the command name, mnemonic, and parameters. Spaces shown in the examples below are only for readability and should be omitted during actual communication.
- Note: When sending an actual command, parentheses ( ) and braces { } must not be included in the command string. They are used only in this document to explain and mark the command structure.

The variables are defined as follows:

i,j,k,l,m,n,o,p,q,r,s,t,u	Integer
x, y, z	Real number
f	Frequency value

All numeric variables above can be expressed as integers, floating-point numbers, or exponential notation. For example, the number 5 can be written as 5, 5.0, or 0.5E1. Strings are sent as ASCII character sequences.

6.2.1. Input Channel Configuration Commands

OE2022 has two signal input channels, Signal In 1 and Signal In 2. All input-channel commands require an input-channel selection parameter. The signal input channel parameter is represented by i: i=1 selects Signal In 1, and i=2 selects Signal In 2.

<table>
<tr><td>ISRC (?) i {,j}</td><td>ISRC command is used to set or query input configuration mode. Parameter i must be specified when sending this command, Parameter i indicates the signal input channel number, when i=1, select Signal In 1, when i=2, select Signal In 2.
When j=0, select <IN+>(single-ended voltage signal input);
when j=1, select <DIFF>(differential voltage input).
when j=2, select <I>(single-ended current input).</td></tr>
<tr><td>IGND (?) i {,j}</td><td>IGND command is used to set or query input shield grounding mode.
Parameter i must be specified, when i=1, select channel 1, when i=2, select channel 2.
When j=0, select <Float> mode (input connector shell is isolated from instrument ground through a 10 kΩresistor);
when j=1, select <Ground> mode (input connector shell is shorted to instrument ground).</td></tr>
<tr><td>ICPL (?) i {,j}</td><td>ICPL command is used to set or query input coupling mode.
Parameter i must be specified, when i=1, select channel 1, when i=2, select channel 2.
When j=0, select <AC>(AC-coupled input);
when j=1, select <DC>(DC-coupled input).</td></tr>
<tr><td>IRNG (?) i {,j}</td><td>IRNG command is used to set or query input channel range.Parameter i is used to select different ranges.
Parameter i must be specified, when i=1, select channel 1, when i=2, select channel 2.
as follows:
<table>
<tr><th>i</th><th>Input Range</th></tr>
<tr><td>0</td><td>5 V / 5 mA</td></tr>
<tr><td>1</td><td>1 V / 500 μA</td></tr>
<tr><td>2</td><td>200 mV / 50 μA</td></tr>
<tr><td>3</td><td>50 mV / 5 μA</td></tr>
<tr><td>4</td><td>10 mV / 500 nA</td></tr>
<tr><td>5</td><td>2 mV / 50 nA</td></tr>
<tr><td>6</td><td>1 mV / 5 nA</td></tr>
</table></td></tr>
<tr><td>RMOD ? i</td><td>RMOD command is used to query system dynamic reserve, The returned parameter is integer data with the following meaning:
Parameter i must be specified, when i=1, select channel 1, when i=2, select channel 2.</td></tr>
</table>

<table>
<tr><td>RMOD ? i</td><td>
<table>
<tr><th>Returned parameter</th><th>Dynamic reserve</th></tr>
<tr><td>0</td><td>High</td></tr>
<tr><td>1</td><td>Normal</td></tr>
<tr><td>2</td><td>Low</td></tr>
</table>
</td></tr>
</table>

6.2.2. Oscillator Configuration Commands

OE2022 has two oscillators, OSC1 and OSC2. All oscillator commands require an oscillator-channel selection parameter. The oscillator channel parameter is represented by i: i=1 selects OSC1, and i=2 selects OSC2.

<table>
<tr><td>FMOD (?) i {,j}</td><td>The FMOD command sets or queries the reference source mode (internal or external) for oscillator i.
Parameter i must be specified with this command. It identifies the oscillator channel: i=1 selects oscillator OSC1, and i=2 selects oscillator OSC2.
When j=0, select external reference mode;
when j=1, select internal reference mode.</td></tr>
<tr><td>RSRC (?) i {,j}</td><td>RSRC command is used to set or query reference signal source in the oscillator external-reference mode.
Parameter i must be specified with this command. It identifies the oscillator channel: i=1 selects oscillator OSC1, and i=2 selects oscillator OSC2.
Parameter j is used to select different reference signal sources, as follows:
<table>
<tr><th>j</th><th>Reference signal source interface</th></tr>
<tr><td>0</td><td>Ref In</td></tr>
<tr><td>1</td><td>Signal In 1</td></tr>
<tr><td>2</td><td>Signal In 2</td></tr>
<tr><td>3</td><td>Aux In 1</td></tr>
<tr><td>4</td><td>Aux In 2</td></tr>
<tr><td>5</td><td>Aux In 3</td></tr>
<tr><td>6</td><td>Aux In 4</td></tr>
<tr><td>7</td><td>Trig In</td></tr>
</table>
</td></tr>
</table>

FREQ (?) i {,f}	FREQ command is used to set or query oscillator signal frequency in internal reference mode. Parameter i must be specified with this command. It identifies the oscillator channel: i=1 selects oscillator OSC1, and i=2 selects oscillator OSC2. Parameter f can be set in the range $1E^{-5} \sim 1.5E^{6}$, and the minimum resolution is $1E^{-9}$. The command FREQ?i returns the current reference signal frequency. When oscillator i is in internal mode, it returns the signal frequency in internal reference mode; when oscillator i is in external mode, it returns the frequency of the external reference source.
FEXT ? i	FEXT command is used to query oscillator frequency of the reference source in external mode. Parameter i must be specified with this command. It identifies the oscillator channel: i=1 selects oscillator OSC1, and i=2 selects oscillator OSC2. The returned parameter type is a floating-point number, and the parameter range is$1E^{-5} \sim 1.5E^{6}$.
FINT (?) i {,f}	FINT command is used to set or query oscillator reference signal frequency in internal mode. Parameter i must be specified with this command. It identifies the oscillator channel: i=1 selects oscillator OSC1, and i=2 selects oscillator OSC2. Parameter f can be set in the range $1E^{-5} \sim 1.5E^{6}$, and the minimum resolution is $1E^{-9}$. The command FINT?i returns the current oscillator set frequency in internal mode.
RSLP (?) i {,j}	RSLP command is used to set or query edge trigger mode of the REF IN interface. Parameter i must be specified with this command. It identifies the oscillator channel: i=1 selects oscillator OSC1, and i=2 selects oscillator OSC2. When j=0, set TTL rising-edge trigger; When j=1, set TTL falling-edge trigger; When j=2, set sine-wave zero-crossing detection; When the signal frequency is below 1Hz, the two TTL trigger modes are recommended.

6.2.3. Demodulator Configuration Commands

OE2022 has eight demodulators, Demod1 to Demod8. All demodulator commands require a demodulator-channel selection parameter. In the following commands, the demodulator channel parameter is represented by i: i=1 selects Demod1, i=2 selects Demod2, i=3 selects Demod3, ……, and i=8 selects Demod8.

<table>
<tr>
<td>DSRC (?) i {,j}</td>
<td>DSRC command is used to set or query demodulator input signal source.
Parameter i is required when this command is sent. It specifies the demodulator channel number, with a setting range of 1 ~ 8.
Parameter j is used to select different input signal sources, as follows:
<table>
<tr><th>j</th><th>Input signal source</th></tr>
<tr><td>0</td><td>Signal In 1</td></tr>
<tr><td>1</td><td>Signal In 2</td></tr>
<tr><td>2</td><td>Aux In 1</td></tr>
<tr><td>3</td><td>Aux In 2</td></tr>
<tr><td>4</td><td>Aux In 3</td></tr>
<tr><td>5</td><td>Aux In 4</td></tr>
<tr><td>6</td><td>Demod1 X</td></tr>
<tr><td>7</td><td>Demod1 Y</td></tr>
<tr><td>8</td><td>Demod1 R</td></tr>
<tr><td>9</td><td>Demod1 θ</td></tr>
<tr><td>10</td><td>Demod5 X</td></tr>
<tr><td>11</td><td>Demod5 Y</td></tr>
<tr><td>12</td><td>Demod5 R</td></tr>
<tr><td>13</td><td>Demod5 θ</td></tr>
</table>
Note that the input signal sources of demodulator channels 1 and 5 cannot be changed. Regardless of configuration, the input source of Demod1 remains Signal In 1, and the input source of Demod5 remains Signal In 2.</td>
</tr>
<tr>
<td>OFLT (?) i {,x}</td>
<td>OFLT command is used to set or query demodulator filter time constant.
Parameter i is required when this command is sent. It specifies the demodulator channel number, with a setting range of 1 ~ 8.
Parameter x can be set in the range $1E^{-7}$ ~ 3000, and the minimum resolution is $1E^{-7}$.</td>
</tr>
</table>

<table>
<tr>
<td>OFSL (?) i {,j}</td>
<td>OFSL command is used to set or query demodulator low-pass filter roll-off.
Parameter i is required when this command is sent. It specifies the demodulator channel number, with a setting range of 1 ~ 8.
Parameter j is used to select different filter roll-offs, as follows:
<table>
<tr><th>j</th><th>Filter dB/oct</th></tr>
<tr><td>1</td><td>6 dB/oct</td></tr>
<tr><td>2</td><td>12 dB/oct</td></tr>
<tr><td>3</td><td>18 dB/oct</td></tr>
<tr><td>4</td><td>24 dB/oct</td></tr>
<tr><td>5</td><td>30 dB/oct</td></tr>
<tr><td>6</td><td>36 dB/oct</td></tr>
<tr><td>7</td><td>42 dB/oct</td></tr>
<tr><td>8</td><td>48 dB/oct</td></tr>
</table>
</td>
</tr>
<tr>
<td>SYNC (?) i {,j}</td>
<td>SYNC command is used to set or query on/off status of the demodulator synchronous filter.The synchronous filter is effective only when the reference frequency is below 250 kHz.
Parameter i is required when this command is sent. It specifies the demodulator channel number, with a setting range of 1 ~ 8.
Parameter j=0 when disabling the synchronous filter;
when j=1, enable the synchronous filter.</td>
</tr>
<tr>
<td>DMOD (?) i {,j}</td>
<td>DMOD command is used to set or query demodulator reference source mode.
Parameter i is required when this command is sent. It specifies the demodulator channel number, with a setting range of 1 ~ 8.
Parameter j is used to select different reference base sources for the demodulator, as follows:
<table>
<tr><th>j</th><th>Reference base source</th></tr>
<tr><td>0</td><td>oscillator OSC1</td></tr>
<tr><td>1</td><td>oscillator OSC2</td></tr>
<tr><td>2</td><td>Arbitrary-frequency demodulation</td></tr>
<tr><td>3</td><td>frequency combination FreqComb1</td></tr>
<tr><td>4</td><td>frequency combination FreqComb2</td></tr>
<tr><td>5</td><td>frequency combination FreqComb3</td></tr>
<tr><td>6</td><td>frequency combination FreqComb4</td></tr>
</table>
</td>
</tr>
</table>

DMFR (?) i {, f}	DMFR command is used to set or query reference frequency in arbitrary-frequency demodulation mode. Parameter i is required when this command is sent. It specifies the demodulator channel number, with a setting range of 1 ~ 8. Parameter f can be set in the range $1E^{-5}$ ~ $1.5E^{6}$, and the minimum resolution is $1E^{-9}$.
HARM (?) i {, j}	HARM command is used to set or query harmonic order of the demodulator reference signal. Parameter i is required when this command is sent. It specifies the demodulator channel number, with a setting range of 1 ~ 8. Parameter j can be set to an integer from 1 to 10000 and indicates the harmonic order. The HARM i,j command sets the j-th harmonic of the detection reference frequency for the i-th demodulator. The requested harmonic frequency ($j \times f$) must not exceed the maximum demodulation bandwidth of 1.5 MHz. Setting a value higher than 1.5 MHzresults in an out-of-range error or invalid measurement data.
PHAS (?) i ,{x}	PHAS command is used to set or query reference phase shift. Parameter i is required when this command is sent. It specifies the demodulator channel number, with a setting range of 1 ~ 8. Parameter x is the phase value (a real number, in °; the unit does not need to be entered). The input range is −180.000~180.000, and the resolution is 0.001. For example, sending PHAS 1,-179.0 sets the phase shift of Demodulator 1 to −179.000°. The command PHAS?1 queries the phase shift of Demodulator 1.
DREF ? i	DREF command is used to query final reference frequency of the demodulator. Parameter i is required when this command is sent. It specifies the demodulator channel number, with a setting range of 1 ~ 8. The returned parameter type is a floating-point number, and the parameter range is$1E^{-5}$ ~ $1.5E^{6}$.The returned frequency value is the reference frequency multiplied by the harmonic order.

It should be noted that there are four FreqComb frequency-combination channels, which are independent of the demodulator channels. The parameter configuration of the FCMB formula-parameter setting command is relatively complex, as described in the table below:

<table>
<tr>
<td>FCMB (?) i {,x,j,y,k}</td>
<td>
FCMB command is used to set or query formula parameters in the demodulator formula based frequency combination mode.
Parameter i must be specified when sending this command. It corresponds to the frequency-comb channel number, and the setting range is 1 ~ 4.
Parameters x, j, y, and k correspond to A, F_1, B, and F_2 in the formula FreqComb $= A \times F_1 + B \times F_2$.
x and y can be set in the range −10 000~10 000between Real number, and the minimum resolution is 0.001;
j and k can be set to different frequency sources, as follows:
<table>
<tr><th>j, k</th><th>Frequency source selection</th></tr>
<tr><td>0</td><td>oscillator OSC1</td></tr>
<tr><td>1</td><td>oscillator OSC2</td></tr>
<tr><td>2</td><td>Internal arbitrary frequency of Demod1</td></tr>
<tr><td>3</td><td>Internal arbitrary frequency of Demod2</td></tr>
<tr><td>4</td><td>Internal arbitrary frequency of Demod3</td></tr>
<tr><td>5</td><td>Internal arbitrary frequency of Demod4</td></tr>
<tr><td>6</td><td>Internal arbitrary frequency of Demod5</td></tr>
<tr><td>7</td><td>Internal arbitrary frequency of Demod6</td></tr>
<tr><td>8</td><td>Internal arbitrary frequency of Demod7</td></tr>
<tr><td>9</td><td>Internal arbitrary frequency of Demod8</td></tr>
</table>
</td>
</tr>
</table>

6.2.4. Signal Output Channel Configuration Commands

Because OE2022 has two signal output channels, all signal-output commands require a signal-output channel selection parameter. In the following commands, the signal output channel parameter is represented by i: i=1 selects Signal Out 1, and i=2 selects Signal Out 2.

STTL (?) i {,j}	STTL command is used to set or query <TTL Out>interface output state. Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2. When j=0, select disable TTL Out output; when j=1, enable TTL Out output.
SIGO (?) i {,j}	SIGO command is used to set or query <Sine Out>interface output state. Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2. When j=0, select disable Sine Out output; when j=1, enable Sine Out output.
SLVL (?) i {,x}	SLVL command is used to set or query sine-wave voltage amplitude output from <Sine Out>. Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2. Parameter x indicates the amplitude voltage (a real number, in Vrms; the unit does not need to be entered). Parameter x must satisfy $0.1\,\mu V_{rms} \leq x \leq 5\,V_{rms}$, and the minimum resolution is $0.1\,\mu V_{rms}$.
SOFF (?) i {,x}	SOFF command is used to set or query DC offset voltage output from <Sine Out>. Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2. Parameter x indicates the offset voltage value (a real number, in V; the unit does not need to be entered). The range of parameter x is −5~5, and the minimum resolution is 0.001
SPHS (?) i {,x}	SPHS command is used to set or query phase shift of the <Sine Out> sine wave relative to the oscillator reference. Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2. Parameter x is the phase value (a real number, in °; the unit does not need to be entered). The input range is −180~180, and the minimum resolution is 0.001.

TPHS (?) i {,x}	TPHS command is used to set or query phase shift of the <TTL Out> waveform relative to the oscillator reference. Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2. Parameter x is the phase value (a real number, in °; the unit does not need to be entered). The input range is −180~180, and the minimum resolution is 0.001.
SMFR (?) i {,f}	SMFR command is used to set or query internal frequency in <Sine Out> modulation mode. Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2. Parameter f can be set in the range $1E^{-5}$ ~ $1.5E^{6}$, and the minimum resolution is $1E^{-9}$.

SMOD (?) i {,j}	SMOD command is used to set or query output mode of <Sine Out>.
	Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2.
	When j=0, select sine-wave output mode;
	when j=1, select AM modulation mode;
	when j=2, select FM modulation mode;
	when j=3, select PM modulation mode.
	When AM/FM/PM modulation mode is selected, the carrier amplitude and frequency remain the same as in sine-wave mode, while the modulation depth and frequency are controlled by other commands.

AMSR (?) i {,j}	AMSR command is used to set or query frequency source of the AM modulation signal. Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2. When j=0, select oscillator OSC1 Frequency value; when j=1, select oscillator OSC2 Frequency value; when j=2, select the internal frequency of modulation mode, that is, the SMFR-set Frequency value.
AMDP (?) i {,x}	AMDP command is used to set or query modulation depth of the AM modulation signal. Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2. Parameter x is a real number in the range is 0~1 Real number, representing the amplitude ratio of the modulation signal to the carrier signal, for example, AMDP1 means that the modulation signal amplitude is the same as the carrier amplitude.

FMSR (?) i {,j}	FMSR command is used to set or query frequency source of the FM modulation signal. Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2. When j=0, select oscillator OSC1 Frequency value; when j=1, select the frequency of oscillator OSC2; when j=2, select the internal frequency of modulation mode, that is, the SMFR-set Frequency value.
FMDV (?) i {,f}	FMDV command is used to set or query peak frequency deviation of the FM modulation signal. Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2. Parameter f can be set in the range $1E^{-5}$ ~ $1.5E^{6}$, and the minimum resolution is $1E^{-9}$.
PMSR (?) i {,j}	PMSR command is used to set or query frequency source of the AM modulation signal. Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2. When j=0, select oscillator OSC1 Frequency value; when j=1, select oscillator OSC2 Frequency value; when j=2, select the internal frequency of modulation mode, that is, the SMFR-set Frequency value.
PMDV (?) i {,x}	PMDV command is used to set or query phase deviation of the PM modulation signal. Parameter i indicates the signal output channel number, when i=1, select Signal Out 1, when i=2, select Signal Out 2. Parameter x is the phase value (a real number, in °; the unit does not need to be entered). The input range is 0~360, and the minimum resolution is 0.001.

6.2.5. Channel Output Commands

OE2022 provides two CHOUT auxiliary output channels and four AUXOUT auxiliary output channels. All channel-output commands require a CH/AUX channel selection parameter.

The CHOUT commands are described first. In the following commands, the CH channel parameter is represented by i: i=1 selects channel 1, and i=2 selects channel 2.

<table>
<tr>
<td>CHDC(?) i {, x}</td>
<td>CHDC command is used to set or query DC OUT voltage value of the CHOUT channel in DC mode.
Parameter i corresponds to the CH channel, when i=1, select CH1; when i=2, select CH2.
Parameter x sets the output voltage value (a real number, in V; the unit does not need to be entered). The range is -10.000 ≤ x ≤ 10.000, and the minimum resolution is 0.001.
For example, sending CHDC1,5.00 sets the output value of <CHOUT1> in DC OUT mode to 5.00 V.</td>
</tr>
<tr>
<td>SENS (?) i {,j}</td>
<td>SENS command is used to set or query sensitivity of the CHOUT channel.
Parameter i corresponds to the CH channel, when i=1, select CH1; when i=2, select CH2.
Parameter j is used to select different ranges.
as follows:
<table>
<tr><th>j</th><th>sensitivity</th><th>j</th><th>sensitivity</th></tr>
<tr><td>0</td><td>1 nV/pA</td><td>15</td><td>100 µV/nA</td></tr>
<tr><td>1</td><td>2 nV/pA</td><td>16</td><td>200 µV/nA</td></tr>
<tr><td>2</td><td>5 nV/pA</td><td>17</td><td>500 µV/nA</td></tr>
<tr><td>3</td><td>10 nV/pA</td><td>18</td><td>1 mV/µA</td></tr>
<tr><td>4</td><td>20 nV/pA</td><td>19</td><td>2 mV/µA</td></tr>
<tr><td>5</td><td>50 nV/pA</td><td>20</td><td>5 mV/µA</td></tr>
<tr><td>6</td><td>100 nV/pA</td><td>21</td><td>10 mV/µA</td></tr>
<tr><td>7</td><td>200 nV/pA</td><td>22</td><td>20 mV/µA</td></tr>
<tr><td>8</td><td>500 nV/pA</td><td>23</td><td>50 mV/µA</td></tr>
<tr><td>9</td><td>1 µV/nA</td><td>24</td><td>100 mV/µA</td></tr>
<tr><td>10</td><td>2 µV/nA</td><td>25</td><td>200 mV/µA</td></tr>
<tr><td>11</td><td>5 µV/nA</td><td>26</td><td>500 mV/µA</td></tr>
<tr><td>12</td><td>10 µV/nA</td><td>27</td><td>1 V/mA</td></tr>
<tr><td>13</td><td>20 µV/nA</td><td>28</td><td>2 V/mA</td></tr>
<tr><td>14</td><td>50 µV/nA</td><td>29</td><td>5 V/mA</td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr><td>COFP (?) i {, x}</td><td>COFP command is used to set or query output offset value of the CHOUT channel.
Parameter i corresponds to the CH channel, when i=1, select CH1; when i=2, select CH2.
Parameter x sets the offset value (unit: %). The range is -100.00 ≤ x ≤ 100.00, and the minimum resolution is 0.01.</td></tr>
<tr><td>CEXP (?) i {,x}
OEXP (?) i {,x}</td><td>CEXP command is used to set or query output expansion factor of the CHOUT channel. The CEXP and OEXP commands have the same function and are compatible.
Parameter i corresponds to the CH channel, when i=1, select CH1; when i=2, select CH2.
Parameter x sets the output expansion factor, which is a real number in the range 0.001 ≤ x ≤ 10000, with a minimum resolution of 0.001.</td></tr>
<tr><td>COUT (?) i {, j}
FOUT (?) i {, j}</td><td>COUT command is used to set or query OE2022 rear-panel CHOUT output-channel signal source.
The COUT and FOUT commands have the same function and are compatible.
Parameter i must be specified when sending this command, when i=1, select CH1; when i=2, select CH2.
Parameter j is used to select the output value type, as follows:
<table>
<tr><th>j</th><th>CH channel source</th><th>j</th><th>CH channel source</th></tr>
<tr><td>0</td><td>DC OUT</td><td>19</td><td>R-Demod5</td></tr>
<tr><td>1</td><td>X-Demod1</td><td>20</td><td>θ-Demod5</td></tr>
<tr><td>2</td><td>Y-Demod1</td><td>21</td><td>X-Demod6</td></tr>
<tr><td>3</td><td>R-Demod1</td><td>22</td><td>Y-Demod6</td></tr>
<tr><td>4</td><td>θ-Demod1</td><td>23</td><td>R-Demod6</td></tr>
<tr><td>5</td><td>X-Demod2</td><td>24</td><td>θ-Demod6</td></tr>
<tr><td>6</td><td>Y-Demod2</td><td>25</td><td>X-Demod7</td></tr>
<tr><td>7</td><td>R-Demod2</td><td>26</td><td>Y-Demod7</td></tr>
<tr><td>8</td><td>θ-Demod2</td><td>27</td><td>R-Demod7</td></tr>
<tr><td>9</td><td>X-Demod3</td><td>28</td><td>θ-Demod7</td></tr>
<tr><td>10</td><td>Y-Demod3</td><td>29</td><td>X-Demod8</td></tr>
<tr><td>11</td><td>R-Demod3</td><td>30</td><td>Y-Demod8</td></tr>
<tr><td>12</td><td>θ-Demod3</td><td>31</td><td>R-Demod8</td></tr>
<tr><td>13</td><td>X-Demod4</td><td>32</td><td>θ-Demod8</td></tr>
<tr><td>14</td><td>Y-Demod4</td><td>33</td><td>AUXIN1</td></tr>
<tr><td>15</td><td>R-Demod4</td><td>34</td><td>AUXIN2</td></tr>
<tr><td>16</td><td>θ-Demod4</td><td>35</td><td>AUXIN3</td></tr>
<tr><td>17</td><td>X-Demod5</td><td>36</td><td>AUXIN4</td></tr>
<tr><td>18</td><td>Y-Demod5</td><td></td><td></td></tr>
</table></td></tr>
</table>

The AUXOUT commands are described next. In the following commands, the AUX channel parameter is represented by i: i=1 selects channel 1, i=2 selects channel 2, i=3 selects channel 3, and i=4 selects channel 4.

<table>
<tr><td>AXDC(?) i {, x}</td><td>AXDC command is used to set or query DC OUT voltage value of the AUXOUT channel in DC mode.
Parameter i identifies the AUX channel number. The setting range is 1 ~ 4.
Parameter x sets the output voltage value (a real number, in V; the unit does not need to be entered). The range is -10.000 ≤ x ≤ 10.000, and the minimum resolution is 0.001.
For example, sending AXDC1,5.00 sets the output value of <AX-OUT1> in DC OUT mode to 5.00 V.</td></tr>
<tr><td>AXSN (?) i {,j}</td><td>AXSN command is used to set or query sensitivity of the AUXOUT channel.
Parameter i identifies the AUX channel number. The setting range is 1 ~ 4.
Parameter j is used to select different ranges.
as follows:
<table>
<tr><th>j</th><th>sensitivity</th><th>j</th><th>sensitivity</th></tr>
<tr><td>0</td><td>1 nV/pA</td><td>15</td><td>100 µV/nA</td></tr>
<tr><td>1</td><td>2 nV/pA</td><td>16</td><td>200 µV/nA</td></tr>
<tr><td>2</td><td>5 nV/pA</td><td>17</td><td>500 µV/nA</td></tr>
<tr><td>3</td><td>10 nV/pA</td><td>18</td><td>1 mV/µA</td></tr>
<tr><td>4</td><td>20 nV/pA</td><td>19</td><td>2 mV/µA</td></tr>
<tr><td>5</td><td>50 nV/pA</td><td>20</td><td>5 mV/µA</td></tr>
<tr><td>6</td><td>100 nV/pA</td><td>21</td><td>10 mV/µA</td></tr>
<tr><td>7</td><td>200 nV/pA</td><td>22</td><td>20 mV/µA</td></tr>
<tr><td>8</td><td>500 nV/pA</td><td>23</td><td>50 mV/µA</td></tr>
<tr><td>9</td><td>1 µV/nA</td><td>24</td><td>100 mV/µA</td></tr>
<tr><td>10</td><td>2 µV/nA</td><td>25</td><td>200 mV/µA</td></tr>
<tr><td>11</td><td>5 µV/nA</td><td>26</td><td>500 mV/µA</td></tr>
<tr><td>12</td><td>10 µV/nA</td><td>27</td><td>1 V/mA</td></tr>
<tr><td>13</td><td>20 µV/nA</td><td>28</td><td>2 V/mA</td></tr>
<tr><td>14</td><td>50 µV/nA</td><td>29</td><td>5 V/mA</td></tr>
</table></td></tr>
<tr><td>AXOF (?) i {, x}</td><td>AXOF command is used to set or query output offset value of the AUXOUT channel.
Parameter i identifies the AUX channel number. The setting range is 1 ~ 4.
Parameter x sets the offset value (unit: %). The range is -100.00 ≤ x ≤ 100.00, and the minimum resolution is 0.01.</td></tr>
</table>

<table>
<tr>
<td>AXEX (?) i {,x}</td>
<td>AXEX command is used to set or query output expansion factor of the AUXOUT channel.
Parameter i identifies the AUX channel number. The setting range is 1 ~ 4.
Parameter x sets the output expansion factor, which is a real number in the range $0.001 \le x \le 10000$, with a minimum resolution of 0.001.</td>
</tr>
<tr>
<td>AXOS (?) i {, j}</td>
<td>AXOS command is used to set or query OE2022 rear-panel AUXOUT output-channel signal source.
Parameter i identifies the AUX channel number. The setting range is 1 ~ 4.
Parameter j is used to select the output value type, as follows:
<table>
<tr><th>j</th><th>AUX channel source</th><th>j</th><th>AUX channel source</th></tr>
<tr><td>0</td><td>DC OUT</td><td>19</td><td>R-Demod5</td></tr>
<tr><td>1</td><td>X-Demod1</td><td>20</td><td>θ-Demod5</td></tr>
<tr><td>2</td><td>Y-Demod1</td><td>21</td><td>X-Demod6</td></tr>
<tr><td>3</td><td>R-Demod1</td><td>22</td><td>Y-Demod6</td></tr>
<tr><td>4</td><td>θ-Demod1</td><td>23</td><td>R-Demod6</td></tr>
<tr><td>5</td><td>X-Demod2</td><td>24</td><td>θ-Demod6</td></tr>
<tr><td>6</td><td>Y-Demod2</td><td>25</td><td>X-Demod7</td></tr>
<tr><td>7</td><td>R-Demod2</td><td>26</td><td>Y-Demod7</td></tr>
<tr><td>8</td><td>θ-Demod2</td><td>27</td><td>R-Demod7</td></tr>
<tr><td>9</td><td>X-Demod3</td><td>28</td><td>θ-Demod7</td></tr>
<tr><td>10</td><td>Y-Demod3</td><td>29</td><td>X-Demod8</td></tr>
<tr><td>11</td><td>R-Demod3</td><td>30</td><td>Y-Demod8</td></tr>
<tr><td>12</td><td>θ-Demod3</td><td>31</td><td>R-Demod8</td></tr>
<tr><td>13</td><td>X-Demod4</td><td>32</td><td>θ-Demod8</td></tr>
<tr><td>14</td><td>Y-Demod4</td><td>33</td><td>AUXIN1</td></tr>
<tr><td>15</td><td>R-Demod4</td><td>34</td><td>AUXIN2</td></tr>
<tr><td>16</td><td>θ-Demod4</td><td>35</td><td>AUXIN3</td></tr>
<tr><td>17</td><td>X-Demod5</td><td>36</td><td>AUXIN4</td></tr>
<tr><td>18</td><td>Y-Demod5</td><td></td><td></td></tr>
</table>
</td>
</tr>
</table>

6.2.6. Auto-Setup Commands

ARNG i	ARNG command is used to enable the input-channel the auto-range function. This command has the same function as pressing <Auto Range> in the menu. Parameter i corresponds to the input channel, when i=0, select all two input channels, when i=1, select Signal In 1, when i=2, select Signal In 2.
APHS i	APHS command is used to enable demodulator the auto-phase compensation function. This command has the same function as pressing <Auto Phase> in the menu. Parameter i corresponds to the demodulator channel, When i=0, select configure all eight demodulators, when i=1, select Demod1, when i=2, select Demod2...... i=8 selects Demod8. For example, sending APHS 2 automatically adjusts the current phase value of Demodulator 2 to 0, and the phase value is written to Ref.Phase of Demodulator 2. Auto phase setup takes some time. Do not send the APHS command again before the auto setup is complete. In addition, if the phase is unstable, this command is invalid.
AFLT i	AFLT command is used to enable automatic demodulator filter setup function. This command has the same function as pressing <Auto Filter> in the menu. Parameter i corresponds to the demodulator channel, when i=0, select all eight demodulators, when i=1, select Demod1, when i=2, select Demod2...... i=8 selects Demod8.
AOFP i	AOFP command is used to enable auto CHOUT output-offset setup function. This command has the same function as pressing <Auto CH Offset> in the menu. Parameter i corresponds to the CHOUT channel, when i=0, select all two CHOUT channels; when i=1, select CH1; when i=2, select CH2.

6.2.7. Save and Recall Setting Commands

SSET i	The SSET i command is used to save the current OE2022 settings to the configuration storage area, that is, Setting buffer i(1≤i≤4). The configuration information in the setting buffer remains stored after the OE2022 is powered off.
RSET i	The RSET i command is used to recall settings from Setting buffer i (0≤i≤4).where i=0 indicates the <Default> setting, and i=1~4 indicates the <S1> ~ <S4> settings. After a successful recall, OE2022 internal parameters are set to the same values as those in Setting buffer i.

6.2.8. Reset and IDN Commands

*RST	*RST command performs a soft reset of OE2022.During the reset, all internal states and instrument parameters are restored to their default values, and all data in the data buffer is lost. The asterisk is included so that the command mnemonic has four characters.
*IDN?	*IDN? command is used to query the OE2022 ID, with the format "Sine Scientific Instruments, OE2022, SN:XXXXXX, Ver:XXXXX", where the first field is the company name, the second is the model, for an example, OE2022; the third is the serial number, for example, SN:00001; and the fourth is the version number, for example, Ver:1.00-1.10. The asterisk is included so that the command mnemonic has four characters.

6.2.9. Data and Status Read Commands

<table>
<tr><td>OUTP? i</td><td>The OUTP? i command is used to read a single measurement value.Parameter i corresponds to the following table.Parameteri selectas follows:

<table>
<tr><th>i</th><th>Parameter</th><th>i</th><th>Parameter</th></tr>
<tr><td>0</td><td>X-Demod1</td><td>22</td><td>R-Demod6</td></tr>
<tr><td>1</td><td>Y-Demod1</td><td>23</td><td>θ-Demod6</td></tr>
<tr><td>2</td><td>R-Demod1</td><td>24</td><td>X-Demod7</td></tr>
<tr><td>3</td><td>θ-Demod1</td><td>25</td><td>Y-Demod7</td></tr>
<tr><td>4</td><td>X-Demod2</td><td>26</td><td>R-Demod7</td></tr>
<tr><td>5</td><td>Y-Demod2</td><td>27</td><td>θ-Demod7</td></tr>
<tr><td>6</td><td>R-Demod2</td><td>28</td><td>X-Demod8</td></tr>
<tr><td>7</td><td>θ-Demod2</td><td>29</td><td>Y-Demod8</td></tr>
<tr><td>8</td><td>X-Demod3</td><td>30</td><td>R-Demod8</td></tr>
<tr><td>9</td><td>Y-Demod3</td><td>31</td><td>θ-Demod8</td></tr>
<tr><td>10</td><td>R-Demod3</td><td>32</td><td>Xnoise-Demod1</td></tr>
<tr><td>11</td><td>θ-Demod3</td><td>33</td><td>Ynoise-Demod1</td></tr>
<tr><td>12</td><td>X-Demod4</td><td>34</td><td>Xnoise-Demod5</td></tr>
<tr><td>13</td><td>Y-Demod4</td><td>35</td><td>Ynoise-Demod5</td></tr>
<tr><td>14</td><td>R-Demod4</td><td>36</td><td>Frequency-OSC1</td></tr>
<tr><td>15</td><td>θ-Demod4</td><td>37</td><td>Frequency-OSC2</td></tr>
<tr><td>16</td><td>X-Demod5</td><td>38</td><td>AUXIN1</td></tr>
<tr><td>17</td><td>Y-Demod5</td><td>39</td><td>AUXIN2</td></tr>
<tr><td>18</td><td>R-Demod5</td><td>40</td><td>AUXIN3</td></tr>
<tr><td>19</td><td>θ-Demod5</td><td>41</td><td>AUXIN4</td></tr>
<tr><td>20</td><td>X-Demod6</td><td>42</td><td>Timestamp</td></tr>
<tr><td>21</td><td>Y-Demod6</td><td></td><td></td></tr>
</table>

The selected parameter values are returned as ASCII floating-point numbers, in volts (V), degrees (°), or hertz (Hz), but the units are not output. This command is query-only.</td></tr>
</table>

<table>
<tr>
<td>SNAP? i {,j,k,l,m,n,o,p……}</td>
<td>
SNAP? command is used to read up to 20 different measurement values from OE2022 at the same instant.
The SNAP? command is used to query instantaneous values such as <X>, <Y>, <R>, <θ>, or <F> at the same instant. This function is especially important when the time constant is short or the signal changes rapidly. Querying multiple parameters sequentially with the OUTP? command introduces a time offset between returned readings, so the data are not strictly synchronized. In dynamic measurements, this timing skew can introduce significant error. The SNAP? command acquires all specified parameters at the same internal sampling instant, ensuring temporal consistency.
The SNAP? i command requires at least one parameter, and can read up to 20 parameters simultaneously.The parameter selection is as follows:
<table>
<tr><th>i</th><th>Parameter</th><th>i</th><th>Parameter</th></tr>
<tr><td>0</td><td>X-Demod1</td><td>22</td><td>R-Demod6</td></tr>
<tr><td>1</td><td>Y-Demod1</td><td>23</td><td>θ-Demod6</td></tr>
<tr><td>2</td><td>R-Demod1</td><td>24</td><td>X-Demod7</td></tr>
<tr><td>3</td><td>θ-Demod1</td><td>25</td><td>Y-Demod7</td></tr>
<tr><td>4</td><td>X-Demod2</td><td>26</td><td>R-Demod7</td></tr>
<tr><td>5</td><td>Y-Demod2</td><td>27</td><td>θ-Demod7</td></tr>
<tr><td>6</td><td>R-Demod2</td><td>28</td><td>X-Demod8</td></tr>
<tr><td>7</td><td>θ-Demod2</td><td>29</td><td>Y-Demod8</td></tr>
<tr><td>8</td><td>X-Demod3</td><td>30</td><td>R-Demod8</td></tr>
<tr><td>9</td><td>Y-Demod3</td><td>31</td><td>θ-Demod8</td></tr>
<tr><td>10</td><td>R-Demod3</td><td>32</td><td>Xnoise-Demod1</td></tr>
<tr><td>11</td><td>θ-Demod3</td><td>33</td><td>Ynoise-Demod1</td></tr>
<tr><td>12</td><td>X-Demod4</td><td>34</td><td>Xnoise-Demod5</td></tr>
<tr><td>13</td><td>Y-Demod4</td><td>35</td><td>Ynoise-Demod5</td></tr>
<tr><td>14</td><td>R-Demod4</td><td>36</td><td>Frequency-OSC1</td></tr>
<tr><td>15</td><td>θ-Demod4</td><td>37</td><td>Frequency-OSC2</td></tr>
<tr><td>16</td><td>X-Demod5</td><td>38</td><td>AUXIN1</td></tr>
<tr><td>17</td><td>Y-Demod5</td><td>39</td><td>AUXIN2</td></tr>
<tr><td>18</td><td>R-Demod5</td><td>40</td><td>AUXIN3</td></tr>
<tr><td>19</td><td>θ-Demod5</td><td>41</td><td>AUXIN4</td></tr>
<tr><td>20</td><td>X-Demod6</td><td>42</td><td>Timestamp</td></tr>
<tr><td>21</td><td>Y-Demod6</td><td></td><td></td></tr>
</table>
</td>
</tr>
</table>

SNAP? i {,j,k,l,m,n,o,p……}	The returned value is a string, different values in the string are separated by commas (,), and the values are returned in the same order as i, j, k, l, and m in the transmitted command.For example, sendingSNAP?0,1,36,3;returns <X>, <Y>, <Frequency> and <θ> values. All values are placed in a single string, for example: "0.951359,0.0253297,1000.00,1.234". The first value is <X>, the second is <Y>, the third is the frequency value, and the fourth is <θ>.
OAUX? i	OAUX command is used to query input voltage value of the rear-panel AUX-IN interface. Parameter i must be specified, when i=1, read AUX-IN1; when i=2, read AUX-IN2; when i=3, read AUX-IN3; when i=4, read AUX-IN4. The query returns a real number, in volts (V), but the unit is not output.
INOV? i	INOV? command is used to query Input Overload status of the input channel. The query returns 0 or 1.where 0 indicates that currently the input-channel front-end amplifier is not overloaded; 1 indicates that the input-channel front-end amplifier is overloaded, reduce the input signal to protect the instrument from damage. Parameter i must be specified, when i=1, query Signal In 1, when i=2, query Signal In 2.
GNOV? i	GNOV? command is used to query Gain Overload status of the input channel. The query returns 0 or 1.where 0 indicates that currently the input-channel ADC is not overloaded; 1 indicates that the input-channel ADC is overloaded, reduce the input signal or increase the input range to protect the instrument from damage. Parameter i must be specified, when i=1, query Signal In 1, when i=2, query Signal In 2.
*PLL? i	*PLL? command is used to query oscillator phase-locked loop status. Parameter i must be specified, when i=1, read the PLL status of OSC1, when i=2, read the PLL status of OSC2.The query returns 0 or 1, where 0 indicates that currently the PLL is not locked, or is in internal reference mode; 1 indicates that the PLL is locked.

6.2.10. Clock and Trigger Signal Configuration Commands

<table>
<tr><td>TMOD (?) {i}</td><td>TMOD command is used to set or query instrument clock source.
When sending the command, parameter i selects the clock mode:
i=0 means use the internal clock;
i=1 means use an external 10 MHzclock.</td></tr>
<tr><td>TSTA?</td><td>TSTA? command is used to query instrument clock PLL status.
The returned parameter type is an integer:
0 indicates all clock PLLs are abnormal;
2 indicates the internal clock PLL is normal;
7 indicates the external clock PLL is normal.</td></tr>
<tr><td>OCLK (?) {i}</td><td>OCLK command is used to set or query enable status of the instrument 10 MHz clock output interface.
When i=0, disable the Clock out interface, the interface output remains low;
When i=1, enable the Clock out interface, the interface then outputs a 10 MHz, 3.3 V square-wave clock.</td></tr>
<tr><td>TRIG (?) {i}</td><td>TRIG command is used to set or query instrument trigger-source type.
When i=0, use the internal trigger source, all data sampling is determined by the internal instrument clock;
When i=1, use the external trigger source Trigger in.</td></tr>
<tr><td>TRIM (?) {i}</td><td>TRIM command is used to set or query instrument external trigger mode.
The external trigger modes corresponding to parameter i are as follows:
<table>
<tr><th>i</th><th>External trigger mode</th></tr>
<tr><td>0</td><td>Rising edge</td></tr>
<tr><td>1</td><td>Falling edge</td></tr>
<tr><td>2</td><td>Edge trigger</td></tr>
<tr><td>3</td><td>High-level trigger</td></tr>
<tr><td>4</td><td>Low-level trigger</td></tr>
</table>
When rising-edge, falling-edge, or edge-trigger mode is selected, the instrument outputs data at the instant when the trigger signal edge is detected.
When high/low-level trigger mode is selected, the instrument outputs data while the trigger signal is at the corresponding level, continuously outputs data at the user-defined sampling rate, equivalent to applying a window function to limit the data output range.</td></tr>
</table>

TRIO (?) {i}	TRIO command is used to set or query enable status of the instrument Trigger out interface. When i=0, the Trigger out interface is disabled, the interface output remains low; When i=1, enable the Trigger out interface, the interface outputs trigger signals according to the current trigger mode of the instrument.
TRIF (?) {f}	TRIF command is used to set or query sampling rate in internal trigger mode. Parameter f indicates the data sampling rate, which can be set in the range: 0.01~100 000 Hz.

Chapter 7 Performance Test

Introduction

This chapter provides a series of performance tests to help users verify the measurement accuracy of the instrument and gain confidence in its reliability. All test results can be recorded in the performance test record table attached at the end of this chapter for subsequent performance evaluation.

Serial Number

When contacting our technical support team, be sure to provide the instrument serial number so that we can process the issue quickly.

The serial number is clearly marked on the rear panel of the instrument and on the outer packaging box. After the instrument is powered on, this information can also be viewed on the <INFO> interface.

Firmware Version

After the instrument is powered on, the firmware version can be viewed on the <INFO> interface.

Warm-up

Because the internal components of the instrument exhibit temperature drift, allow the instrument to warm up sufficiently before formal testing to ensure accurate test results. A warm-up time of 30 to 60 minutes is recommended so that the system reaches thermal stability and measurement error is effectively reduced.

Test Records

A performance test record table is provided at the end of this chapter for recording system test data. It is recommended to make a backup copy of the record table before filling it in.

After all tests are completed, evaluate whether the instrument performance meets the expected specifications based on the measured data in the record table. Keep the record table properly; it can serve as an important reference when communicating with our engineers in the future.

Test Failure

If any test fails, troubleshoot according to the following steps:

1. Check the settings: carefully verify that the configuration of this instrument and all externally connected devices is correct;

2. Warm up again: after confirming that the settings are correct, fully warm up the instrument and repeat the test;

3. Replace external devices: if possible, use other known-good external devices to elim-

inate peripheral interference factors.

If the test still fails after the above measures, please:

1. Record the instrument serial number and firmware version;
2. Prepare the complete performance test record table;
3. Contact our technical support team promptly for further assistance with diagnosis and handling.

Required Test Equipment

1. Function signal generator

Freq Range	1 Hz to 100 MHz
Freq Accuracy	Better than 2 ppm
Amplitude Accuracy	0.2dB from 1 Hz to 100 MHz
Spurious	≤−55 dBc
TTL SYNC	Available
Output Setup	50 Ω or High Z
Recommended	AGILENT 33600B series

2. Digital multimeter

Voltage Range	≥20 V, 4 1/2 digits
Accuracy	≤0.005%
Recommended	KEITHLEY 2100

3. DC power supply

Voltage Range	≥10 V
Accuracy	<10 mV_{pp}
Recommended	RIGOL DP831A

4. Connectors

BNC resistor	50 Ω
BNC T adapter	

5. Cables

BNC-to-BNC cable	Several cables, 0.5 m long
BNC-to-BNC cable	Several cables, 1 m long

Front-panel LCD Test

Operate the instrument as follows: first, turn on the rear power switch to start the instrument; then carefully observe whether the LCD screen lights up properly; finally, check the screen carefully for any defective pixels.

Keypad Test

After starting the instrument, gently press any key. A clear beep should be heard as feedback.

Next, test all keys one by one and carefully observe the display to confirm that each key operation correctly triggers the corresponding setting change.

Finally, select the <Demod.Select> setting item in the [DEMOD FILTER] menu and rotate the knob to verify that the knob operates normally and responds with the corresponding adjustment.

7.1 Startup Test

Before performing other performance tests, first perform the startup test to comprehensively check the hardware functions of the lock-in amplifier and ensure that it is operating normally.

Equipment

No external equipment is required for this test.

Procedure

1) Turn on the rear power switch to start the lock-in amplifier;

2) Check whether the instrument screen, keypad functions, and rear cooling fan operate normally;

3) Record whether the check passed in the test record table at the end of this chapter.

7.2 DC Offset

This test is used to test the DC offset at the input.

Equipment

Use 50 Ω BNC resistor loads to short the IN+ connectors of Signal In 1 and Signal In 2. After the inputs are shorted, the lock-in amplifier can measure its own DC offset.

Procedure

1) Power off and then power on the rear power switch, and then set <Default> in <Recall>;

2) Modify the settings in the following order:

<OSC 1&2> <Osc.Mode>:	Set to <Internal>
<OSC 1&2> <Osc.Frequency>:	Set to 1 Hz
<Signal In 1&2> <Input Range>:	Set with the knob to <1 mV>

<Demod 1&5> <Time Constant>: Set to 1 s
<Demod 1&5> <Filter dB/oct>: Set to <24 dB/oct>

3) After waiting for 10 seconds, record the <R-Demod1> and <R-Demod5> values;
4) Modify the setting:

<Signal In 1&2> <Coupling>: Set to <DC>

5) After waiting for 10 seconds, record the <R-Demod1> and <R-Demod5> values;
6) This completes the DC offset test. Fill in the data in the test record table at the end of this chapter.

7.3 Common-mode Rejection

This test is used to test the common-mode rejection ratio of the lock-in amplifier.

Equipment

Use the sine wave generated by this instrument as the output signal.

Connect the SINE OUT output of the lock-in amplifier to the IN+ and IN- inputs. Attach a BNC T adapter to the SINE OUT 1 connector, and use two equal-length signal cables (BNC male-to-male) to connect the T adapter to the IN+ and IN- connectors of SIGNAL IN 1 respectively. Then connect SINE OUT 2 to the IN+ and IN- connectors of SIGNAL IN 2 in the same way.

Procedure

1) Power off and then power on the rear power switch, and then set <Default> in <Recall>;
2) Modify the settings in the following order:

<Signal In 1&2> <Input Range>: Set with the knob to <5 V>
<Signal In 1&2> <Coupling>: Set to <DC>
<Osc 1&2> <Osc.Mode>: Set to <Internal>
<Osc 1&2> <Osc.Frequency>: Set to 100 Hz
<Signal Out 1&2> <Amplitude>: Set to 1 V_{rms}

3) Wait until the <R> value is stable. The <R> value should be 1.000 V_{rms} within 1% error;
4) Modify the settings in the following order:

<Signal In 1&2> <Source>: Set to <DIFF>
<Signal In 1&2> <Input Source>: Set with the knob to <5 mV>

5) After waiting for 10 seconds, record the <R-Demod1> and <R-Demod5> values;
6) This completes the common-mode rejection test. Calculate the common-mode rejection ratio as CMRR = 20lg(1.0/R). Fill in the data in the test record table at the end of this chapter.

7.4 Amplitude Accuracy and Flatness

This test is used to test the accuracy of each input range and the frequency response of the lock-in amplifier.

Equipment

Use an external function generator capable of producing a high-accuracy sine-wave signal.

First, use one signal cable (BNC male-to-male) to connect the output connector of the function generator to the IN+ connector of Signal In 1 of the lock-in amplifier, and use another signal cable to connect the sync output connector of the function generator to the REF IN 1 connector of the lock-in amplifier. Then connect the function generator to the IN+ connector of Signal In 2 and the REF IN 2 connector of the lock-in amplifier in the same way.

Set the function generator:

Function:	Sine wave
Frequency:	1 kHz
Amplitude:	1 V_{rms}
Offset:	0 V
Output:	High-Z
Sweep:	off
Modulation:	none

Procedure

1) Power off and then power on the rear power switch, and then set <Default> in <Recall>;

2) First test Channel 1 and modify the settings in the following order:

<Demod 1&5> <Filter dB/oct>:	Set to <24 dB/oct>
<Demod 1&5> <Time Constant>:	Set to 300 ms
<Signal In 1&2> <Coupling>:	Set to <DC>
<Osc 1&2> <Osc.Mode>:	Set to <External>

3) For the amplitude accuracy test, keep the function generator frequency at 10 kHz, and modify the lock-in amplifier <Input Range> and the function generator <Amplitude> in the following order:

Input Range	Amplitude
5 V	2.000 V_{rms}
1 V	0.500 V_{rms}
200 mV	100.00 mV_{rms}
50 mV	25.000 mV_{rms}
10 mV	5.000 mV_{rms}
2 mV	1.000 mV_{rms}
1 mV	1.000 mV_{rms}

a) Set the amplitude of the function generator;

b) After waiting for 10 seconds, record the <R-Demod1> value, and then test the next data point;

c) Repeat steps 3a to 3b until the amplitude accuracy test is completed.

4) The frequency response test is performed at frequencies greater than 1 kHz. Modify the frequency of the function generator in the following order:

Test Frequency
1.2 kHz
12 kHz
120 kHz
1.2 MHz

a) Set the function generator amplitude to 100.00 mV$_{rms}$;
b) Set the lock-in amplifier <Input Range> to <200 mV>;
c) Set the function generator frequency in sequence;
d) After waiting for 10 seconds, record the <R-Demod1> value, and then test the next data point;
e) Repeat steps 4c to 4d until the frequency response test is completed.

5) Move the cable connection to Channel 2, and then repeat the above steps to complete the Channel 2 test. Record the <R-Demod5> value during the test.

6) This completes the amplitude accuracy and frequency response test. Fill in the data in the test record table at the end of this chapter.

7.5 Amplitude Linearity

This test is used to test the amplitude linearity of the lock-in amplifier and verify its measurement capability when the signal is below full scale.

Equipment

Use an external function generator capable of producing a high-accuracy sine-wave signal.

First, use one signal cable (BNC male-to-male) to connect the output connector of the function generator to the IN+ connector of Signal In 1 of the lock-in amplifier, and use another signal cable to connect the sync output connector of the function generator to the REF IN 1 connector of the lock-in amplifier. Then connect the function generator to the IN+ connector of Signal In 2 and the REF IN 2 connector of the lock-in amplifier in the same way.

Set the function generator:

Function:	Sine wave
Frequency:	1 kHz
Amplitude:	1 V$_{rms}$
Offset:	0 V
Output:	High-Z
Sweep:	off
Modulation:	none

Procedure

1) Power off and then power on the rear power switch, and then set <Default> in <Recall>;
2) First test Channel 1 and modify the settings in the following order:

<Demod 1&5> <Filter dB/oct>:	Set to <24 dB/oct>
<Demod 1&5> <Time Constant>:	Set to 300 ms
<Signal In 1&2> <Input Range>:	Set with the knob to <1 V>

<Osc 1&2> <Osc.Mode>: Set to <External>

3) Keep the function generator frequency at 10 kHz, and modify its amplitude in the following order:

Amplitude
1.0000 V_{rms}
100.00 mV_{rms}
10.000 mV_{rms}
1.0000 mV_{rms}

a) Set the amplitude of the function generator;

b) Wait for 10 seconds, record the <R-Demod1> value, and then test the next data point;

c) Repeat steps 3a to 3b until all data measurements are completed.

4) Move the cable connection to Channel 2, and then repeat the above steps to complete the Channel 2 test. Record the <R-Demod5> value during the test.

5) This completes the amplitude linearity test. Fill in the data in the test record table at the end of this chapter.

7.6 Frequency Accuracy

This test is used to test the frequency accuracy of the lock-in amplifier.

Equipment

Use a function generator to provide the reference signal.

First, use one signal cable (BNC male-to-male) to connect the reference signal connector of the function generator to the REF IN 1 connector of the lock-in amplifier. Then connect the function generator to the REF IN 2 connector of the lock-in amplifier in the same way.

Procedure

1) Power off and then power on the rear power switch, and then set <Default> in <Recall>;

2) Set the function generator frequency to 100 kHz;

3) Set <Osc.Mode> of <Osc1> on the lock-in amplifier to <External>.

4) After <PLL> in the lower-right corner of the lock-in amplifier screen changes from <UNLOCK> to <LOCKED>, connect the PC Software and record the <Freq> value of Osc1;

5) Move the cable connection to REF IN 2, and then repeat the above steps to complete the Channel 2 test. Record the <Freq> value of Osc2 during the test.

6) This completes the frequency accuracy test. Fill in the data in the test record table at the end of this chapter.

7.7 Sine Out Amplitude/Phase Accuracy and Flatness

This test is used to test the amplitude and phase accuracy and frequency response of the sine wave generated by the lock-in amplifier (Sine Out).

Equipment

Use a 1 m signal cable (BNC male-to-male) to connect the SINE OUT 1 connector to the IN+ connector of Signal In 1, and then connect SINE OUT 2 to the IN+ connector of Signal In 2 in the same way.

Procedure

1) Power off and then power on the rear power switch, and then set <Default> in <Recall>;

2) Modify the following settings:

<Signal In 1&2> <Input Range>:	Set with the knob to <5 V>
<Demod 1&5> <Filter dB/oct>:	Set to <24 dB/oct>
<Demod 1&5> <Time Constant>:	Set to <300 ms>
<OSC 1&2> <Osc.Mode>:	Set to <Internal>
<OSC 1&2> <Osc.Frequency>:	Set to 10 kHz
<Signal Out 1&2> <Sineout SW>:	Set to <ON>

3) For the amplitude accuracy test, keep the internal reference signal frequency at 10 kHz, and modify <Input Range> and Sine <Amplitude> in the following order:

Input Range	Sineout Amplitude
5 V	1.6 V_{rms}
200 mV	0.160 V_{rms}
50 mV	0.016 V_{rms}
2 mV	0.0016 V_{rms}

a) Set the <Amplitude> values of the two <Sineout> outputs respectively;

b) Set the <Input Range> values of <Signal In 1&2> respectively;

c) After waiting for 10 seconds, record the <R-Demod1>, <θ-Demod1>, <R-Demod5>, and <θ-Demod5> values, and then test the next data point;

d) Repeat steps 3a to 3c until the amplitude accuracy test is completed.

4) The frequency response test is performed at frequencies greater than 1 kHz. Modify the <Osc.Frequency> value in the following order:

Test Frequency
1.2 kHz
12 kHz
120 kHz
1.2 MHz

a) Set the <Input Range> values of <Signal In 1&2> to 200 mV respectively;

b) Set the <Amplitude> values of <Signal Out 1&2> to 0.160 V_{rms} respectively;

c) Set the <Osc.Frequency> values of <OSC 1&2> in sequence;

d) After waiting for 10 seconds, record the <R-Demod1>, <θ-Demod1>, <R-Demod5>, and <θ-Demod5> values, and then test the next data point;

e) Repeat steps 4c to 4d until the frequency response test is completed.

5) This completes the <Sine Out> amplitude, phase accuracy, and frequency response test. Fill in the data in the test record table at the end of this chapter.

7.8 DC Output and Input

This test mainly tests the accuracy of the DC output and input of the lock-in amplifier.

Equipment

Use a linear DC power supply as the DC input. Use a digital multimeter to measure the DC output of the lock-in amplifier.

Procedure

1) Power off and then power on the rear power switch, and then set <Default> in <Recall>;

2) Modify the setting:

<CH Source>:	Set the sources of the two CH channels to <DC OUT>

3) Perform the following steps:

a) Connect a signal cable from the rear-panel CHOUT 1 connector to the digital multimeter; set the multimeter range to 19.999 V.

b) Modify the value in <DC OUT> according to the following list:

DC OUT (V)
10.000
5.000
0.000
-5.000
-10.000

c) After waiting for 10 seconds, record the digital multimeter reading, and then test the next data point;

d) Repeat steps 3b to 3c until the CHOUT 1 test is completed. Then connect CHOUT 2 to the digital multimeter in sequence and continue the test.

4) Perform the following steps:

a) Connect a signal cable from the rear-panel AUXOUT 1 connector to the digital multimeter; set the multimeter range to 19.999 V.

b) Modify the value in <DC OUT> according to the following list:

DC OUT (V)
10.000
5.000
0.000
-5.000
-10.000

c) After waiting for 10 seconds, record the digital multimeter reading, and then test the next data point;

d) Repeat steps 4b to 4c until the AUXOUT 1 test is completed. Then connect AUXOUT connectors 2–4 to the digital multimeter in sequence and continue the test.

5) Perform the following steps:

a) Modify the setting: in the [DISPLAY] submenu, set <Monitor> to <Input>;

b) Use a signal cable to connect the voltage output connector of the DC power supply to the AUX-IN 1 connector on the rear panel;

c) Set the output voltage of the DC power supply in the following order:

Voltage (V)
10.000
5.000
0.000
-5.000
-10.000

d) After waiting for 10 seconds, record the <AUX-IN1> reading at the top of the screen, and then test the next data point;

e) Repeat steps 5c to 5d until the AUX-IN1 test is completed. Then connect the DC power supply output connector to AUX-IN2, AUX-IN3, and AUX-IN4 in sequence to complete the AUX-IN2, AUX-IN3, and AUX-IN4 tests.

6) This completes the DC output and input test. Fill in the data in the test record table at the end of this chapter.

7.9 Input Noise

This test mainly tests the input noise of the lock-in amplifier.

Equipment

After the system is grounded, the lock-in amplifier can measure its own input noise. Use two 50 Ω BNC resistors to short the IN+ connector of Signal In 1 and the IN+ connector of Signal In 2, simulating the case where a signal source with a 50 Ω source impedance is connected to the input in actual use.

Procedure

1) Power off and then power on the rear power switch, and then set <Default> in <Recall>;

2) Modify the settings in the following order:

<Osc 1&2> <Osc.Mode>:	Set to <Internal>
<Osc 1&2> <Osc.Frequency>:	Set to 1 kHz
<Signal In 1&2> <Input Range>:	Set with the knob to <1 mV>
<Demod 1&5> <Time Constant>:	Set to 10 ms
<Demod 1&5> <Filter dB/oct>:	Set to <24 dB/oct>
<Window Display>:	Set Window <2> to <X-Noise-Demod1> and <4> to <X-Noise-Demod5>

3) Allow the reading to settle for approximately 2 min, then record the average X-noise value;

4) Modify the following parameters in sequence:

<Osc.Frequency>
1 kHz
10 kHz
100 kHz
1 MHz

5) This completes the input noise test. Fill in the data in the test record table at the end of this chapter.

7.10 Performance Test Record

OE2022Performance Test Record (1/6)

Serial No.: ____________________ Tested by: ____________________

Firmware Version: ____________________ Date: ____________________

Instrument Purpose: ____________________

____

1.Startup Test

Pass _____ Fail _____

2.DC Offset

	Input Coupling	Reading	Upper Limit
Signal In 1	AC	________	0.500 mV
	DC	________	0.500 mV
Signal In 2	AC	________	0.500 mV
	DC	________	0.500 mV

3.Common-Mode Rejection

	Frequency	Reading	Upper Limit
Signal In 1	100 Hz	________	1 mV
Signal In 2	100 Hz	________	1 mV

4.Amplitude Accuracy and Flatness(Signal In 1)

Input Range	Amplitude	Lower	Reading	Upper
5 V	2.000 V_{rms}	1.980 V	________	2.020 V
1 V	500.0 mV_{rms}	495.00 mV	________	505.00 mV
200 mV	100.00 mV_{rms}	99.00 mV	________	101.00 mV
50 mV	25.000 mV_{rms}	24.75 mV	________	25.25 mV
10 mV	5.000 mV_{rms}	4.950 mV	________	5.050 mV
2 mV	1.0000 mV_{rms}	0.990 mV	________	1.010 mV
1 mV	1.0000 mV_{rms}	0.990 mV	________	1.010 mV

Input Range	Frequency	Lower	Reading	Upper
200 mV	1.2 kHz	99 mV	________	101 mV
Amplitude	12 kHz	99 mV	________	101 mV
100.00 mV_{rms}	120 kHz	99 mV	________	101 mV
	1.2 MHz	99 mV	________	101 mV

OE2022Performance Test Record (2/6)

4.Amplitude Accuracy and Flatness(Signal In 2)

Input Range	Amplitude	Lower	Reading	Upper
5 V	2.000 V_{rms}	1.980 V	________	2.020 V
1 V	500.0 mV_{rms}	495.00 mV	________	505.00 mV
200 mV	100.00 mV_{rms}	99.00 mV	________	101.00 mV
50 mV	25.000 mV_{rms}	24.75 mV	________	25.25 mV
10 mV	5.000 mV_{rms}	4.950 mV	________	5.050 mV
2 mV	1.0000 mV_{rms}	0.990 mV	________	1.010 mV
1 mV	1.0000 mV_{rms}	0.990 mV	________	1.010 mV

Input Range	Frequency	Lower	Reading	Upper
200 mV	1.2 kHz	99 mV	________	101 mV
Amplitude	12 kHz	99 mV	________	101 mV
100.00 mV_{rms}	120 kHz	99 mV	________	101 mV
	1.2 MHz	99 mV	________	101 mV

5.Amplitude Linearity

Signal In 1

Input Range	Amplitude	Lower	Reading	Upper
1 V	1.000 V_{rms}	0.990 V	________	1.010 V
	100.0 mV_{rms}	99.00 mV	________	101.0 mV
	10.00 mV_{rms}	9.900 mV	________	10.10 mV
	1.000 mV_{rms}	0.990 mV	________	1.010 mV

Signal In 2

Input Range	Amplitude	Lower	Reading	Upper
1 V	1.000 V_{rms}	0.990 V	________	1.010 V
	100.0 mV_{rms}	99.00 mV	________	101.0 mV
	10.00 mV_{rms}	9.900 mV	________	10.10 mV
	1.000 mV_{rms}	0.990 mV	________	1.010 mV

6.Frequency Accuracy

	Frequency	Lower	Reading	Upper
REF IN 1	100 kHz	99.999 kHz	________	100.001 kHz
REF IN 2	100 kHz	99.999 kHz	________	100.001 kHz

OE2022Performance Test Record (3/6)

7.Sine Out Amplitude/Phase Accuracy and Flatness

Sine Out 1

Range	SineOut Ampl.	Lower	Reading	Upper
5 V	1.600 V_{rms}	1.568 V	R:________	1.632 V
		−2.000°	θ:________	2.000°
200 mV	160 mV_{rms}	156.8 mV	R:________	163.2 mV
		−2.000°	θ:________	2.000°
50 mV	16 mV_{rms}	15.68 mV	R:________	16.32 mV
		−2.000°	θ:________	2.000°
2 mV	1.6 mV_{rms}	1.568 mV	R:________	1.632 mV
		−2.000°	θ:________	2.000°

Sine Out 2

Range	SineOut Ampl.	Lower	Reading	Upper
5 V	1.600 V_{rms}	1.568 V	R:________	1.632 V
		−2.000°	θ:________	2.000°
200 mV	160 mV_{rms}	156.8 mV	R:________	163.2 mV
		−2.000°	θ:________	2.000°
50 mV	16 mV_{rms}	15.68 mV	R:________	16.32 mV
		−2.000°	θ:________	2.000°
2 mV	1.6 mV_{rms}	1.568 mV	R:________	1.632 mV
		−2.000°	θ:________	2.000°

Sine Out 1

SineOut Ampl.	Frequency	Lower	Reading	Upper
160.0 mV_{rms}	1.2 kHz	1.568 V	R:________	1.632 V
		−2.000°	θ:________	2.000°
	12 kHz	1.568 V	R:________	1.632 V
		−2.000°	θ:________	2.000°
	120 kHz	1.568 V	R:________	1.632 V
		−2.000°	θ:________	2.000°
	1.2 MHz	1.568 V	R:________	1.632 V
		−2.000°	θ:________	2.000°

OE2022Performance Test Record (4/6)

7.Sine Out Amplitude/Phase Accuracy and Flatness(Continued)

Sine Out 2

Range	SineOut Ampl.	Lower	Reading	Upper
5 V	1.600 V_{rms}	1.568 V	R:______	1.632 V
		−2.000°	θ:______	2.000°
200 mV	160 mV_{rms}	156.8 mV	R:______	163.2 mV
		−2.000°	θ:______	2.000°
50 mV	16 mV_{rms}	15.68 mV	R:______	16.32 mV
		−2.000°	θ:______	2.000°
2 mV	1.6 mV_{rms}	1.568 mV	R:______	1.632 mV
		−2.000°	θ:______	2.000°

8.DC Output and Input

Output	Voltage	Lower	Reading	Upper
CH OUT 1	10.000 V	9.940 V	______	10.060 V
	5.000 V	4.965 V	______	5.035 V
	0.000 V	−0.010 V	______	0.010 V
	−5.000 V	−5.035 V	______	−4.965 V
	−10.000 V	−10.060 V	______	−9.940 V

Output	Voltage	Lower	Reading	Upper
CH OUT 2	10.000 V	9.940 V	______	10.060 V
	5.000 V	4.965 V	______	5.035 V
	0.000 V	−0.010 V	______	0.010 V
	−5.000 V	−5.035 V	______	−4.965 V
	−10.000 V	−10.060 V	______	−9.940 V

Output	Voltage	Lower	Reading	Upper
AUX OUT 1	10.000 V	9.940 V	______	10.060 V
	5.000 V	4.965 V	______	5.035 V
	0.000 V	−0.010 V	______	0.010 V
	−5.000 V	−5.035 V	______	−4.965 V
	−10.000 V	−10.060 V	______	−9.940 V

OE2022Performance Test Record (5/6)

8.DC Output and Input(Continued)

Output	Voltage	Lower	Reading	Upper
AUX OUT 2	10.000 V	9.940 V	______	10.060 V
	5.000 V	4.965 V	______	5.035 V
	0.000 V	−0.010 V	______	0.010 V
	−5.000 V	−5.035 V	______	−4.965 V
	−10.000 V	−10.060 V	______	−9.940 V
Output	Voltage	Lower	Reading	Upper
AUX OUT 3	10.000 V	9.940 V	______	10.060 V
	5.000 V	4.965 V	______	5.035 V
	0.000 V	−0.010 V	______	0.010 V
	−5.000 V	−5.035 V	______	−4.965 V
	−10.000 V	−10.060 V	______	−9.940 V
Output	Voltage	Lower	Reading	Upper
AUX OUT 4	10.000 V	9.940 V	______	10.060 V
	5.000 V	4.965 V	______	5.035 V
	0.000 V	−0.010 V	______	0.010 V
	−5.000 V	−5.035 V	______	−4.965 V
	−10.000 V	−10.060 V	______	−9.940 V

Input	Voltage	Lower	Reading	Upper
AUX IN 1	10.000 V	9.940 V	______	10.060 V
	5.000 V	4.965 V	______	5.035 V
	0.000 V	−0.010 V	______	0.010 V
	−5.000 V	−5.035 V	______	−4.965 V
	−10.000 V	−10.060 V	______	−9.940 V
Input	Voltage	Lower	Reading	Upper
AUX IN 2	10.000 V	9.940 V	______	10.060 V
	5.000 V	4.965 V	______	5.035 V
	0.000 V	−0.010 V	______	0.010 V
	−5.000 V	−5.035 V	______	−4.965 V
	−10.000 V	−10.060 V	______	−9.940 V

OE2022Performance Test Record (6/6)

8.DC Output and Input(Continued)

Input	Voltage	Lower	Reading	Upper
AUX IN 3	10.000 V	9.940 V	________	10.060 V
	5.000 V	4.965 V	________	5.035 V
	0.000 V	−0.010 V	________	0.010 V
	−5.000 V	−5.035 V	________	−4.965 V
	−10.000 V	−10.060 V	________	−9.940 V

Input	Voltage	Lower	Reading	Upper
AUX IN 4	10.000 V	9.940 V	________	10.060 V
	5.000 V	4.965 V	________	5.035 V
	0.000 V	−0.010 V	________	0.010 V
	−5.000 V	−5.035 V	________	−4.965 V
	−10.000 V	−10.060 V	________	−9.940 V

9.Input Noise

	Osc.Frequency	Input Range	Reading	Upper Limit
Signal In 1	1 kHz	1 mV	________	6 nV/$\sqrt{Hz}$
	10 kHz		________	4 nV/$\sqrt{Hz}$
	100 kHz		________	4 nV/$\sqrt{Hz}$
	1 MHz		________	4 nV/$\sqrt{Hz}$

	Osc.Frequency	Input Range	Reading	Upper Limit
Signal In 2	1 kHz	1 mV	________	6 nV/$\sqrt{Hz}$
	10 kHz		________	4 nV/$\sqrt{Hz}$
	100 kHz		________	4 nV/$\sqrt{Hz}$
	1 MHz		________	4 nV/$\sqrt{Hz}$

Chapter 8 Operation Examples

8.1 Basic Signal Measurement

This operation example briefly demonstrates how to use the OE2022 to measure the R, θ, X, and Y values of a signal. Prepare two signal cables with BNC connectors, one for the input signal under test and the other for the reference signal. In this example, a function generator is used to generate a sine wave with an amplitude of 100 mV$_{rms}$ and a frequency of 100 kHz, and the OE2022 is used for measurement. The procedure is as follows:

1. Disconnect all signal cables from the instrument chassis, connect the power cord, and turn on the power switch. The system is now in the default state.
2. Use a signal cable with BNC connectors to connect the output connector of the function generator to the IN+ connector of SIGNAL IN 1 on the front panel of the OE2022. Use another BNC signal cable to connect the synchronous reference signal connector of the function generator to the REF IN 1 connector on the front panel of the OE2022, as shown in Figure 92.

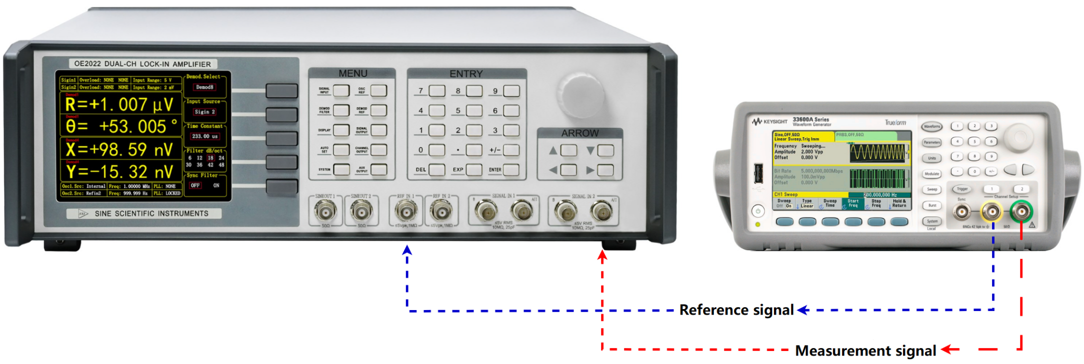


Figure 92. Signal Cable Connection Diagram

3. Turn on the function generator and set the parameters to “Waveform: sine wave”, “Amplitude: 100 mV$_{rms}$”, “Frequency: 100 kHz”, “Output impedance: high impedance”, and “Sync output: on”. The waveforms of the signal under test and the synchronization signal are shown in Figure 93.

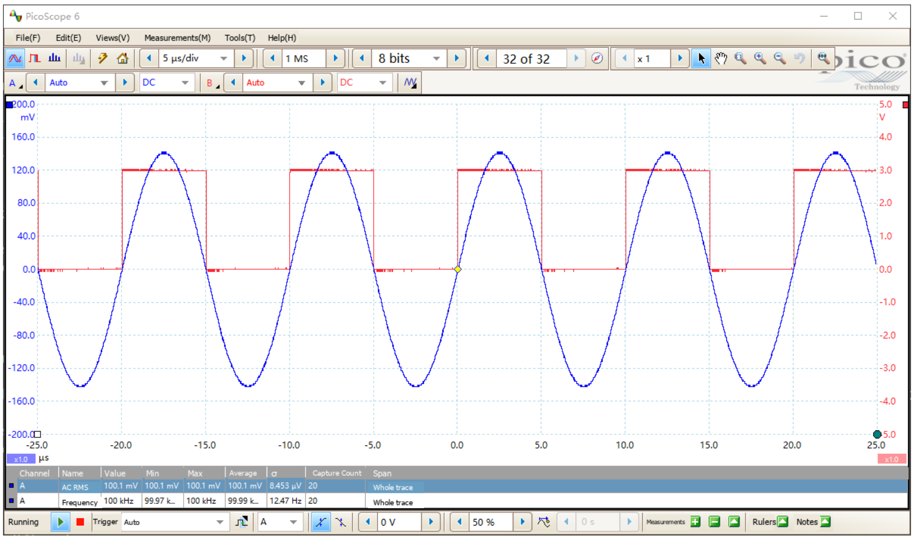


Figure 93. Waveform of the Signal Under Test

4. Enable the output of the function generator and observe whether the <Overload> item in the status bar of the main interface indicates an overflow condition:

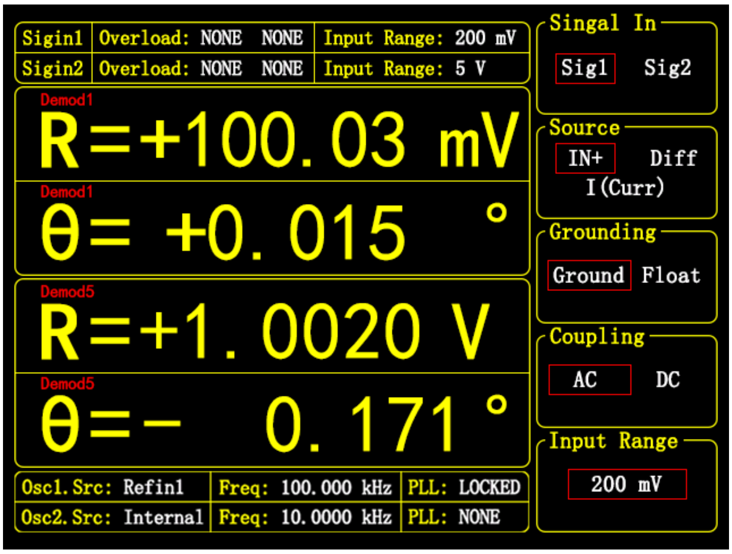


Figure 94. Status Bar on the Main Interface

If the front-end input overflows, Overload: INPUT NONE is displayed. If the gain stage overflows, Overload: NONE GAIN is displayed. If both overflow conditions occur, Overload: INPUT GAIN is displayed.

When front-end overflow occurs, immediately reduce the output amplitude of the function generator. When gain overflow occurs, immediately adjust the gain value. Front-end overflow occurs when the peak value at the OE2022 input is higher than 7 V or the valley value is lower than −7 V, corresponding to the peak and valley levels of the maximum range of 5 V_{rms}. Therefore, in this example, a sine-wave output amplitude of 100 mV_{rms} from the function generator will not cause overflow. However, pay attention to overflow conditions when measuring other signals. The method for adjusting the sensitivity is described below.

5. Adjust the input range. Press the [SIGNAL INPUT] key on the front panel to enter the submenu.

Figure 95. Location of the [SIGNAL INPUT] Menu

The [SIGNAL INPUT] submenu interface is shown below:

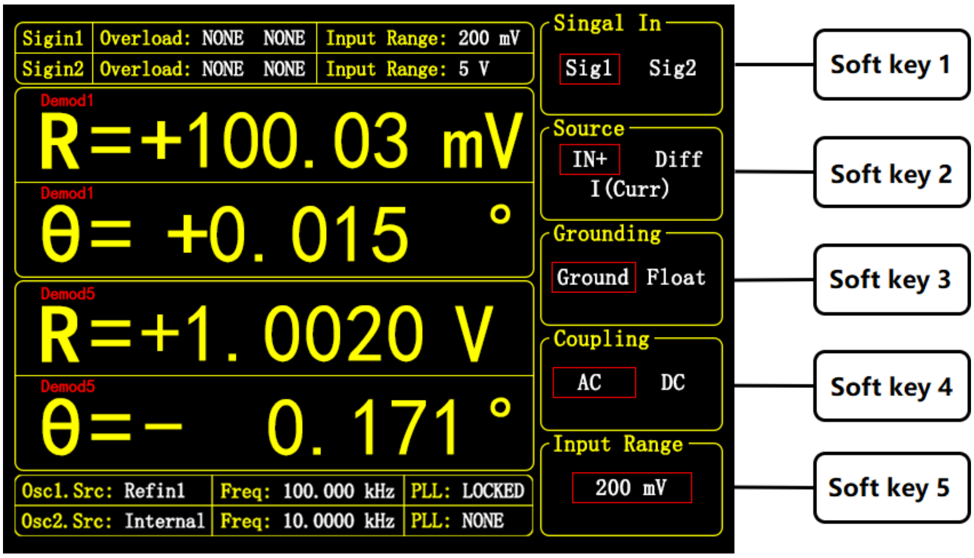


Figure 96. [SIGNAL INPUT] Menu Interface

Press "Soft key 5" to select the <Input Range> function. The selected area is highlighted. Rotate the knob to adjust the <Input Range> value so that the measured signal value is as close as possible to the input range without causing overflow. In this example, set it to <200 mV>. At this point, the sine-wave signal from the function generator has been measured. As shown in Figure 96, the measured data are R = 100.03 mV and θ = 0.015°.

6. Display the <R>, <θ>, <X>, and <Y> values in the data bar of the main interface. Press the [DISPLAY] key on the front panel to enter the submenu.

Figure 97. Location of the [DISPLAY] Menu

The [DISPLAY] submenu interface is shown below:

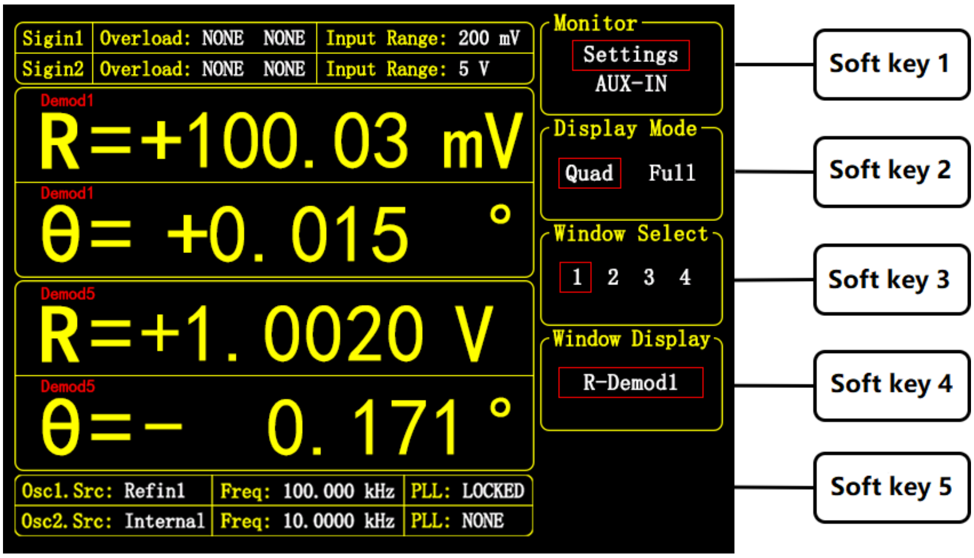


Figure 98. [DISPLAY] Menu Interface

In the default system settings, the four data windows display the <R> and <θ> values of Demod1 and the <R> and <θ> values of Demod5, respectively. The displayed values can be changed using the method described below. In the [Display] submenu, press "Soft key 3" to switch among <1>, <2>, <3>, and <4> in the <Window Select> menu. For example, selecting <2> means that the second window is selected. Then press "Soft key 4" to select the <Window Display> menu, and use the knob to change the displayed value to "R-Demod2". After the modification, the result is shown in Figure 99. This method can be used to view the desired measurement result.

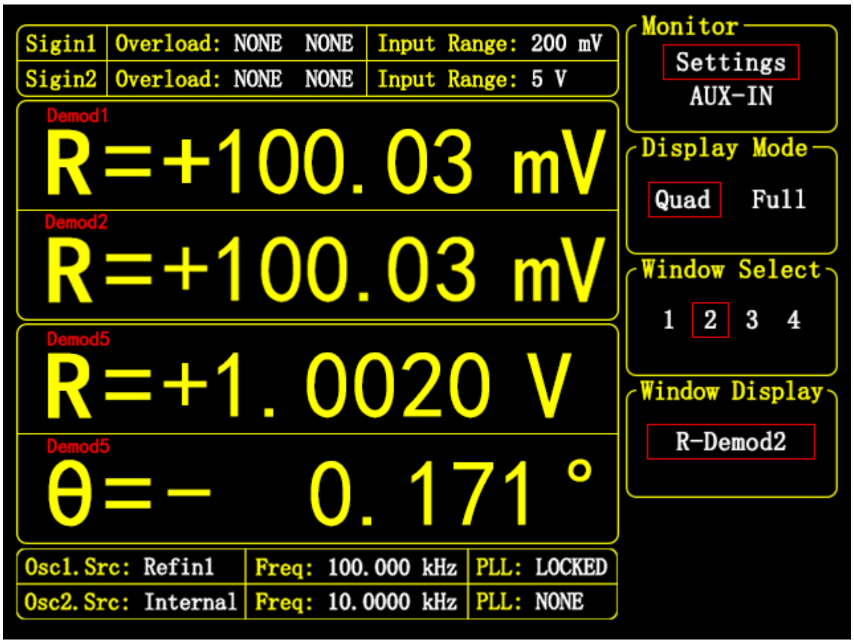


Figure 99. Modified Window Display Result

8.2 Harmonic Measurement

This example demonstrates how to measure the harmonic components of the input signal. Prepare two signal cables with BNC connectors, one for the signal under test and the other for the reference signal. In this example, a function generator is used to generate a square wave with an amplitude of 160 mV$_{pp}$ and a frequency of 1 kHz, and the OE2022 is used to measure its 1st through 8th harmonics. The procedure is as follows:

1. Disconnect all signal cables from the instrument chassis, connect the power cord, and turn on the power switch. The system is now in the default state.
2. Use a signal cable with BNC connectors to connect the output connector of the function generator to the IN+ connector of SIGNAL IN 1 on the front panel of the OE2022. Use another BNC signal cable to connect the reference signal connector of the function generator to the REF IN 1 connector on the front panel, as shown in Figure 100.

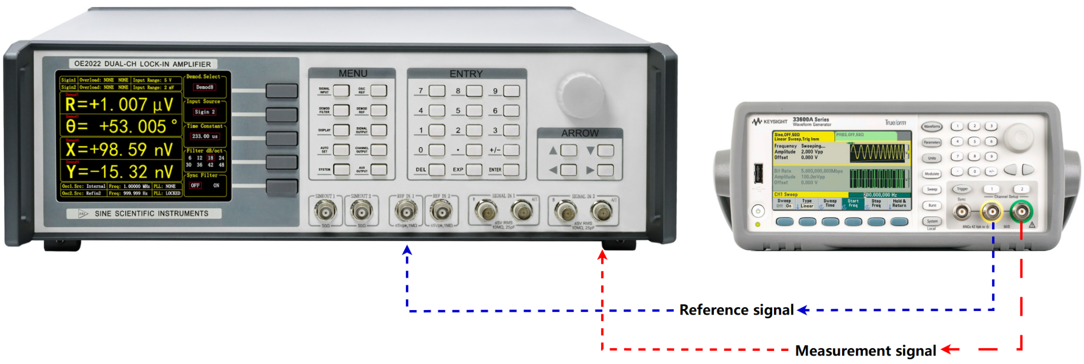


Figure 100. Signal Cable Connection Diagram

3. Turn on the function generator and set the parameters to “Waveform: square wave”, “Amplitude: 160 mV$_{pp}$”, and “Frequency: 1 kHz”. The waveform of the signal under test

is shown in Figure 101.

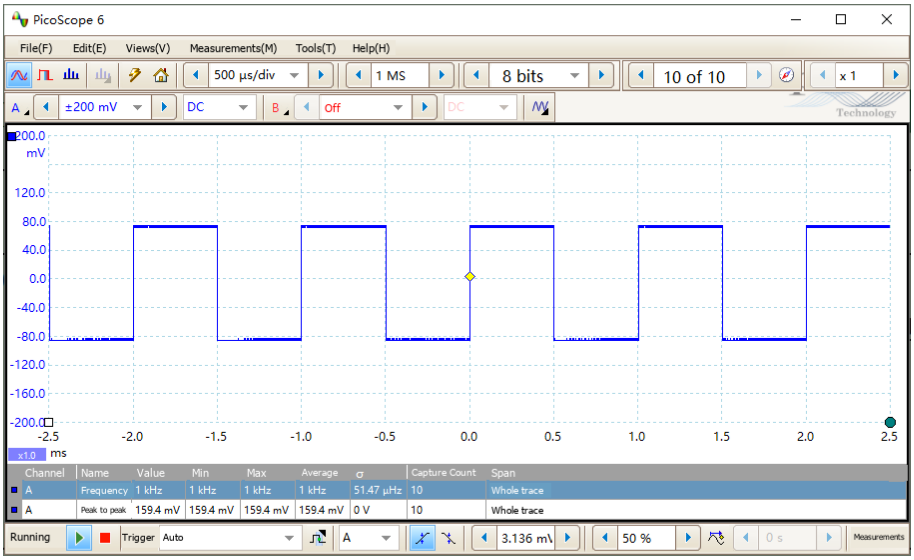


Figure 101. Signal Under Test Parameter Diagram

4. Press the [DEMOD REF] key on the front panel, shown in Figure 102, to enter the sub-menu.

Figure 102. Location of the [DEMOD] Submenu

The [DEMOD REF] submenu interface is shown in Figure 103.

In the <Ref.Harmonic> menu, set the harmonic order measured by each demodulator. Use the keypad to enter the desired harmonic order.

5. To measure the 1st through 8th harmonics of the input square wave simultaneously, operate as follows. In the [DEMOD REF] submenu, press "Soft key 1" to switch among the eight demodulator channels. Press "Soft key 2" to select the harmonic setting window, where the harmonic order of the current demodulator channel can be modified. Set the harmonic orders of Demod1 through Demod8 to 1 through 8, respectively.

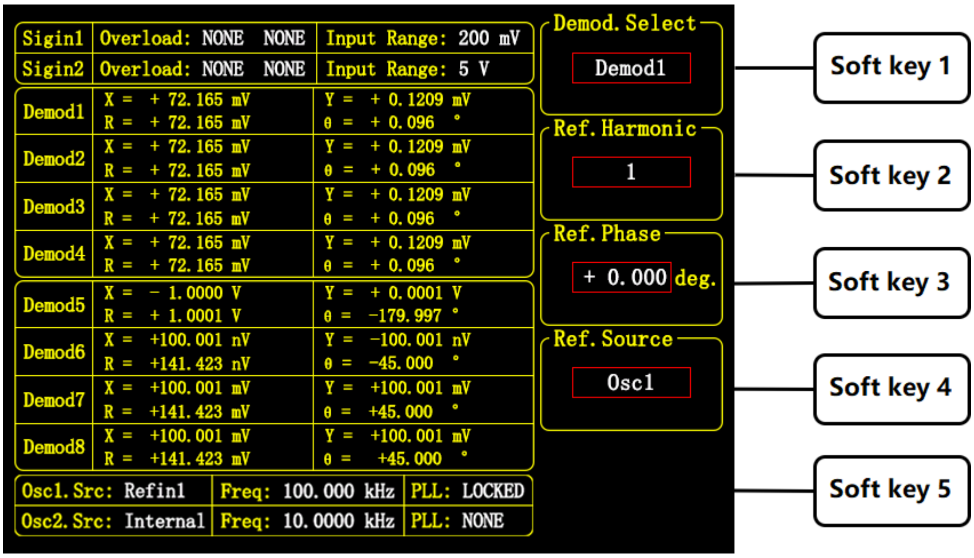


Figure 103. DEMOD REF Submenu

6. Then, in the [DISPLAY] submenu, press "Soft key 2" to set <Display Mode> to <Full>, as shown in Figure 104, so that all fundamental and harmonic measurement results are displayed.

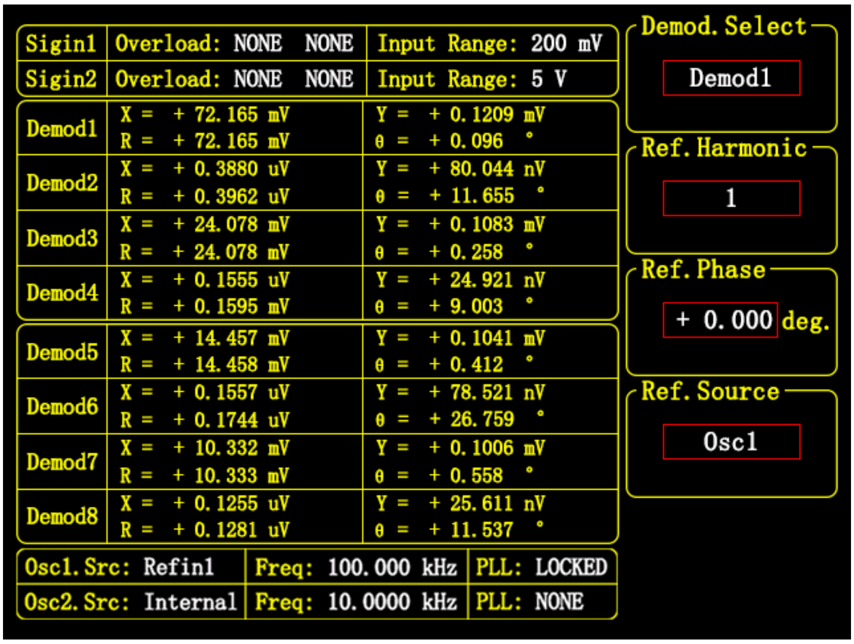


Figure 104. Harmonic Measurement Results of the Square Wave

The theoretical harmonic values of the square wave are calculated as follows. Let the peak-to-peak value of the square wave be E and its angular frequency be ω. After Fourier expansion, the signal is obtained as:

$$f(t) = \frac{2E}{\pi}\left(\sin(\omega t) + \frac{1}{3}\sin(3\omega t) + \frac{1}{5}\sin(5\omega t) \cdots + \frac{1}{n}\sin(n\omega t)\right)$$

The nth harmonic is therefore the sine wave:

$$f(t) = \frac{2E}{n\pi} \sin(n\omega t)$$

Therefore, the RMS value of the nth harmonic is:

$$R = \frac{\sqrt{2}E}{n\pi}$$

In this example, the peak-to-peak value E of the square wave is 160 mV. Therefore:

The calculated value of the 1st harmonic is: $R = \frac{\sqrt{2}\times 160}{1\times\pi}\text{mV} \approx 72.025\,\text{mV}$.

The calculated value of the 3rd harmonic is: $R = \frac{\sqrt{2}\times 160}{3\times\pi}\text{mV} \approx 24.008\,\text{mV}$.

The calculated value of the 5th harmonic is: $R = \frac{\sqrt{2}\times 160}{5\times\pi}\text{mV} \approx 14.405\,\text{mV}$.

The calculated value of the 7th harmonic is: $R = \frac{\sqrt{2}\times 160}{7\times\pi}\text{mV} \approx 10.203\,\text{mV}$.

The theoretical values of the 2nd, 4th, 6th, and 8th harmonics are 0 V.

Using the calculation method described above, the measurement results shown in Figure 104 indicate that the measured values are consistent with the theoretical values.

8.3 AM Demodulation Measurement

Amplitude modulation (AM) is a modulation method in which the amplitude of the carrier varies according to the signal to be transmitted, while the frequency remains unchanged. The modulated signal can propagate over a long distance, but its interference immunity is relatively poor.

Modulating signal: $U_m(t) = A_m * \cos\omega_m t$

Carrier signal: $U_c(t) = A_c * \cos\omega_c t$

The modulated signal is:

$$U(t) = (A_c + A_m \cos\omega_m t) * \cos\omega_c t \quad = A_c * \left(1 + \frac{A_m}{A_c}\cos\omega_m t\right) * \cos\omega_c t$$

where A_c is the carrier amplitude and ω_c is the carrier frequency; A_m is the modulating-signal amplitude and ω_m is the modulating-signal frequency. The modulation depth is defined as $m = \frac{A_m}{A_c}$.

Further conversion gives:

$$\begin{aligned} U(t) &= A_c * (1 + m\cos\omega_m t) * \cos\omega_c t \\ &= A_c * \cos\omega_c t + \frac{mA_c}{2} * \cos(\omega_c - \omega_m)t + \frac{mA_c}{2} * \cos(\omega_c + \omega_m)t \end{aligned}$$

It can be observed that the AM signal contains three frequency components: ω_c, $\omega_c - \omega_m$, and $\omega_c + \omega_m$. By using three demodulators of the lock-in amplifier to demodulate these three frequency components simultaneously, the values of A_c and $\frac{mA_c}{2}$ can be recovered, and thus the amplitude information of the carrier and modulating signal can be obtained.

The actual demodulation procedure is as follows:

1. Set the function generator to AM modulation mode. Set a 100 kHz, 200 mV$_{rms}$ sine wave as the carrier, and set a sine wave with a frequency of 10 kHz and a modulation depth of 100% as the modulating signal. Note that in the AM modulation mode of the function generator, regardless of the modulation depth setting, the carrier amplitude is reduced by half. For example, when the current setting is 200 mV$_{rms}$, the actual amplitude is only 100 mV$_{rms}$. The waveform output from the function generator is shown in Figure 105.

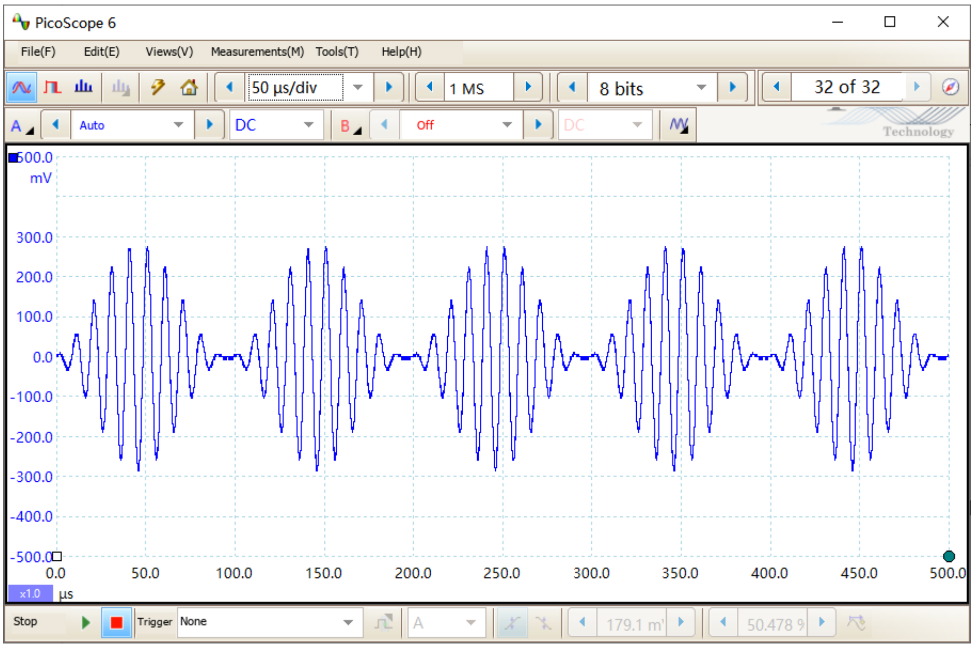


Figure 105. Waveform of the AM Signal

2. Press the [DEMOD REF] key on the front panel of the OE2022 to enter the submenu.
3. Set the following parameters:

   Set <Ref.Source> of Demod1 to <Osc1>.

   Set <Ref.Source> of Demod2 to <Frequency>, and set <Frequency Set> to 90.0000 kHz.

   Set <Ref.Source> of Demod3 to <Frequency>, and set <Frequency Set> to 110.000 kHz.

At this point, the three demodulators of the OE2022 demodulate the frequency components at 100 kHz, 90 kHz, and 110 kHz, respectively. The results are shown in Figure 106.

4. The results are R-Demod1 = 100.4 mV$_{rms}$, R-Demod2 = 49.985 mV$_{rms}$, and R-Demod3 = 49.957 mV$_{rms}$. The converted carrier amplitude is 100.4 mV$_{rms}$, the modulating-signal amplitude is 99.942 mV$_{rms}$, and the modulation depth is 99.54%, which agrees with the theoretical expectation.

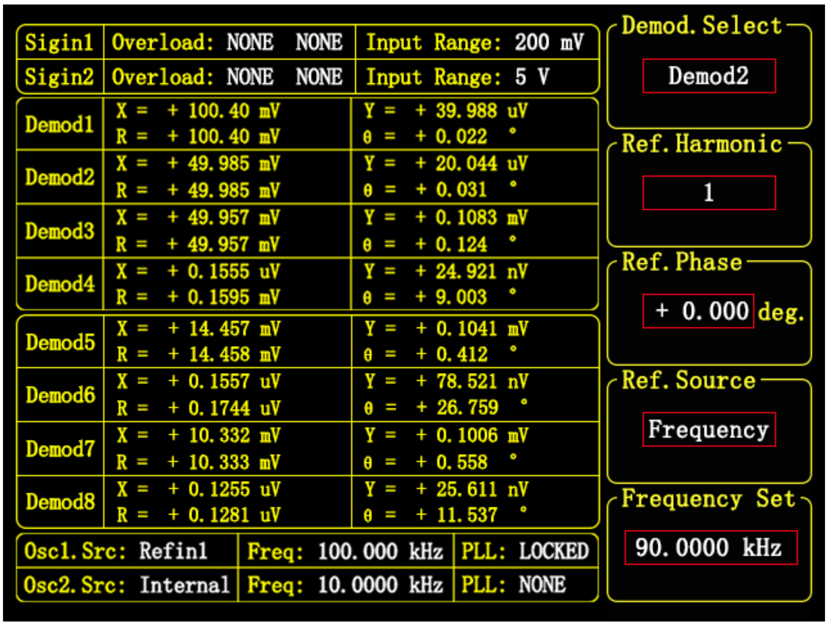


Figure 106. AM Demodulator Measurement Results

8.4 Serial/USB Command Communication

This example demonstrates how to set up and debug the serial/USB2.0 remote-control environment for the OE2022. Prepare a USB2.0 Type-B cable or a USB-to-RS232 male cable. The procedure is as follows:

1. Use a USB cable to connect the USB connector of the OE2022 to any USB port on the computer.
2. The computer automatically detects the USB device and prompts you to install the driver.
3. Open the Uart_Assistant folder on the USB flash drive and double-click UartAssist.exe. The software interface appears as shown in Figure 107.

The serial debugging software includes communication settings, receive-area settings, send-area settings, a receive area, and a send area.

The default serial-port settings of the OE2022 are a baud rate of 921600, no parity, 8 data bits, and 1 stop bit. The baud rate, parity, and other serial settings of the OE2022 can be configured through the RS232 menu option in the front-panel submenu.

Because the USB2.0 driver creates a virtual serial port, the USB2.0 interface, like the RS232 serial port, requires selecting the COM port automatically assigned by the computer to the OE2022. The COM port number can be viewed in Device Manager under Ports (COM & LPT): right-click Computer → Properties → Device Manager → Ports, as shown in Figure 108.

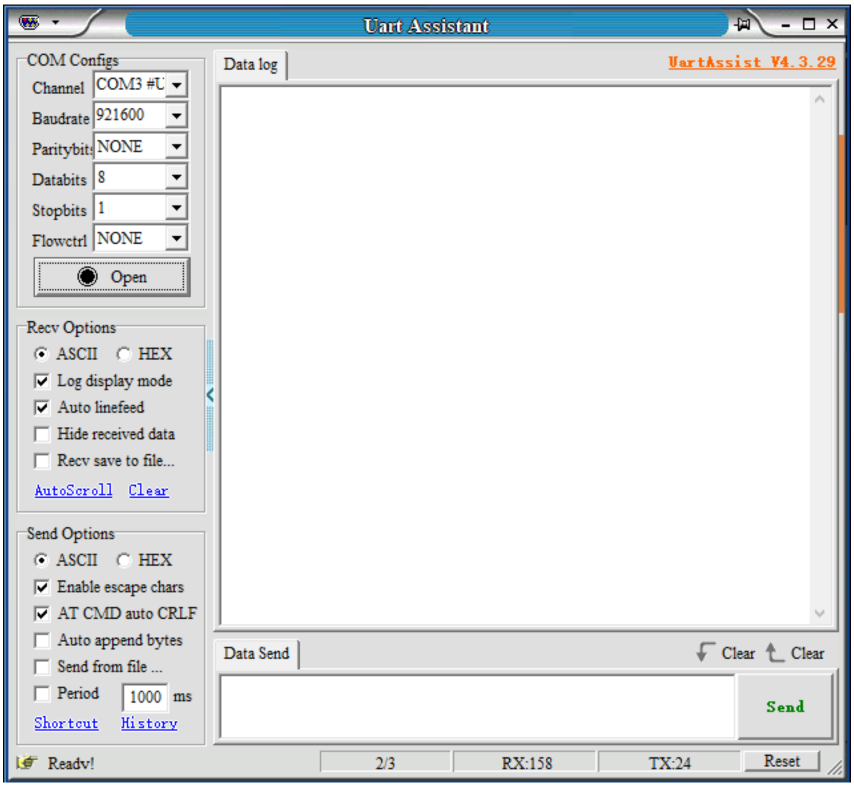


Figure 107. UartAssist Software Interface

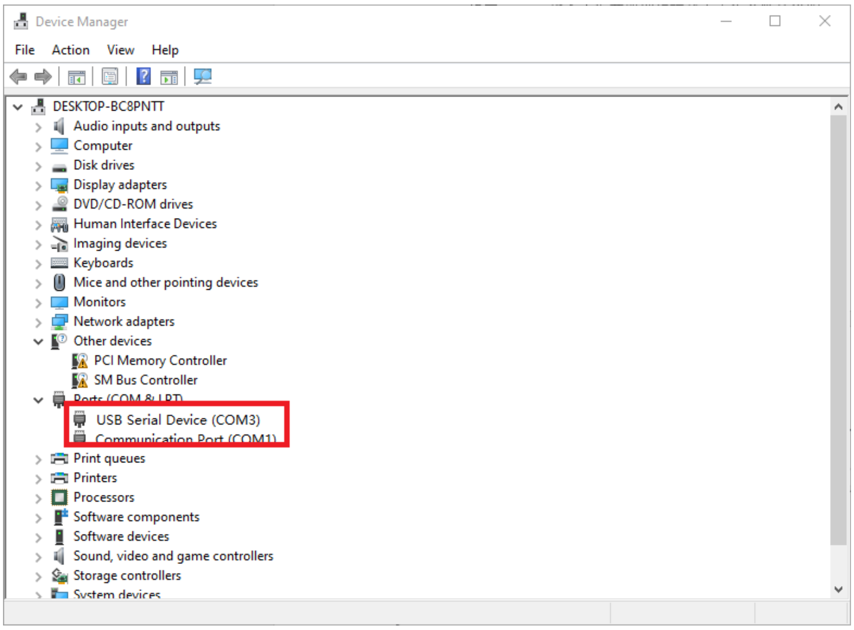


Figure 108. Viewing the Port Number

After the port number, baud rate, parity, data bits, and stop bits are configured, check the connection button. If the small circle on the left side of the connection button is black and unlit (), click it once to change the button status to a red lit state (). If the button is red and lit, the computer has successfully connected to the device on the selected serial port. If repeated attempts to connect fail, check whether the selected port number is correct and try again. A successful connection is shown in Figure 109.

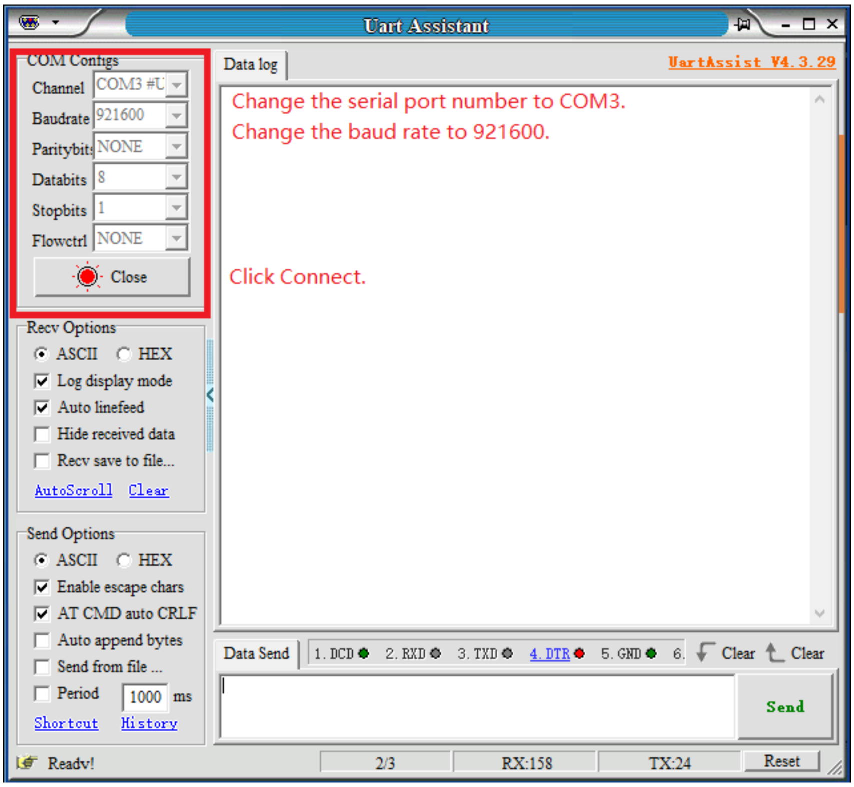


Figure 109. Successful Connection Status

4. After completing the above steps, commands can be sent to communicate with the OE2022:

The OE2022 command format requires a four-letter uppercase mnemonic followed by option parameters. For example, use the command "ISRC1,1;" or "*IDN?" followed by a carriage return character (0D). Multiple consecutive commands can be separated by semicolons ";". The command ending must include either a semicolon ";" or a carriage return character (hexadecimal 0D). For more detailed commands, refer to the chapter on remote programming.

When sending a command, first enter the command in the send area, then enter the semicolon ";", and finally click the send button. The command will then be sent, as shown in Figure 110.

The serial debugging assistant can also be configured to automatically append the carriage return character 0X0D when sending. Select the "Auto Append" option in the send-area settings, choose the fixed-bit option in the appended-bit settings window that appears, and set the appended value to the hexadecimal value "0D". The configuration is shown in Figure 111.

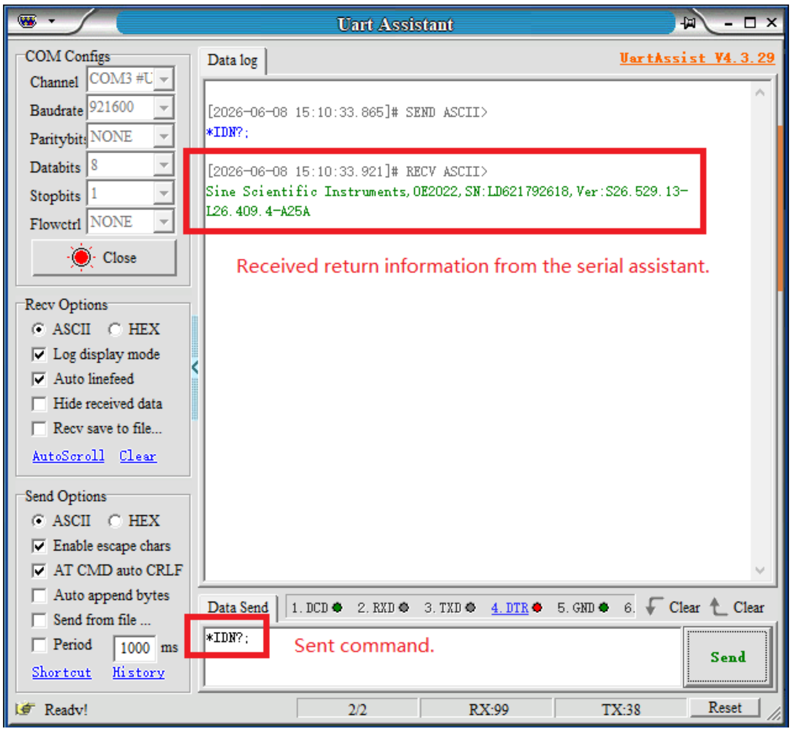


Figure 110. Sending and Receiving Commands in ASCII Format

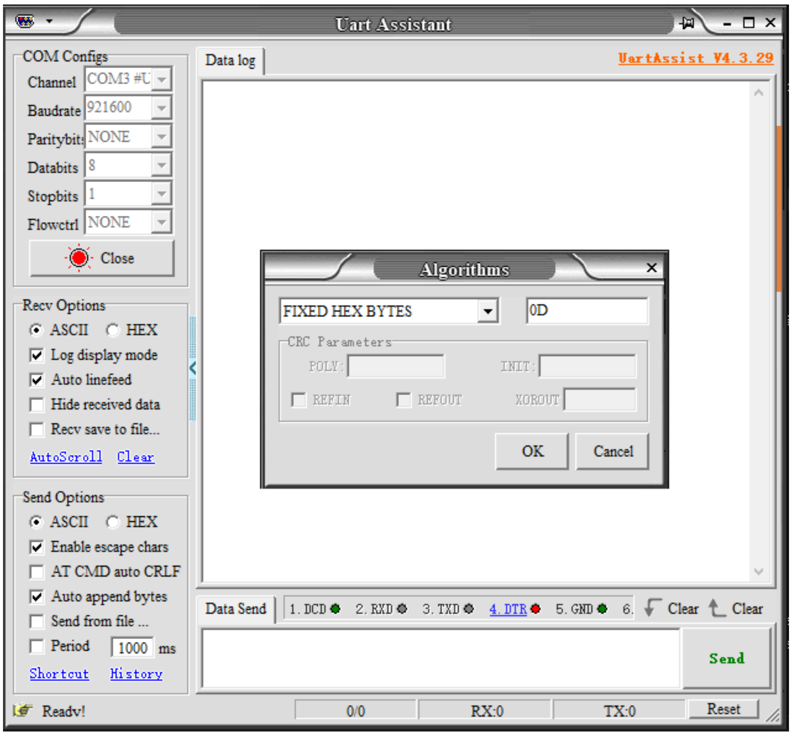


Figure 111. Appended-Bit Setting

When sending multiple commands, semicolons “;” must be used to separate them. For example, sending “IGND1,1;IGND?1;OUTP?2;SENS?0;” produces the result shown in Figure 112.

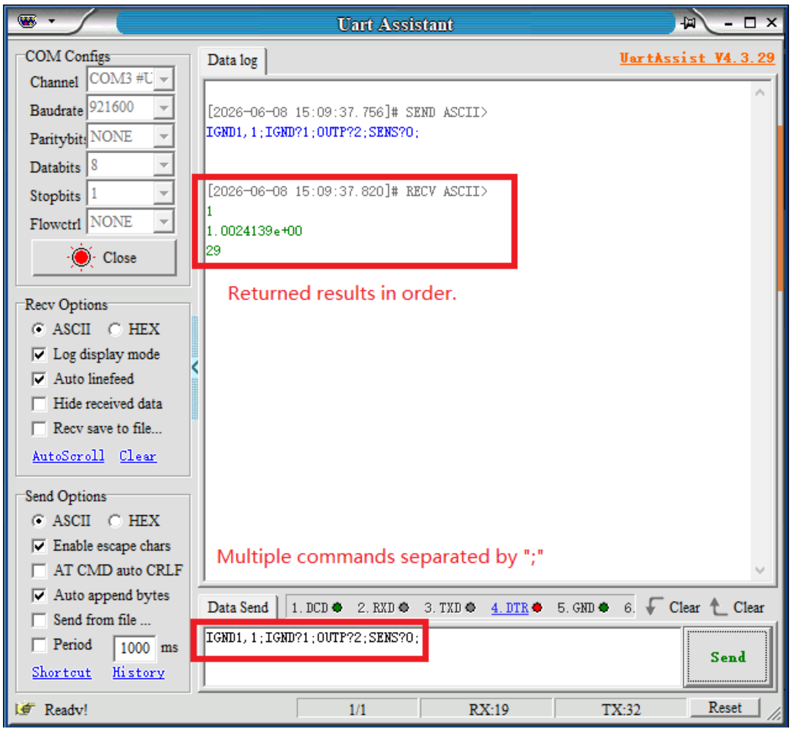


Figure 112. Executing Multiple Commands

To continuously read the X, Y, R, and θ values of the OE2022, configure interval sending in the serial debugging assistant software, as shown in Figure 113 and Figure 114.

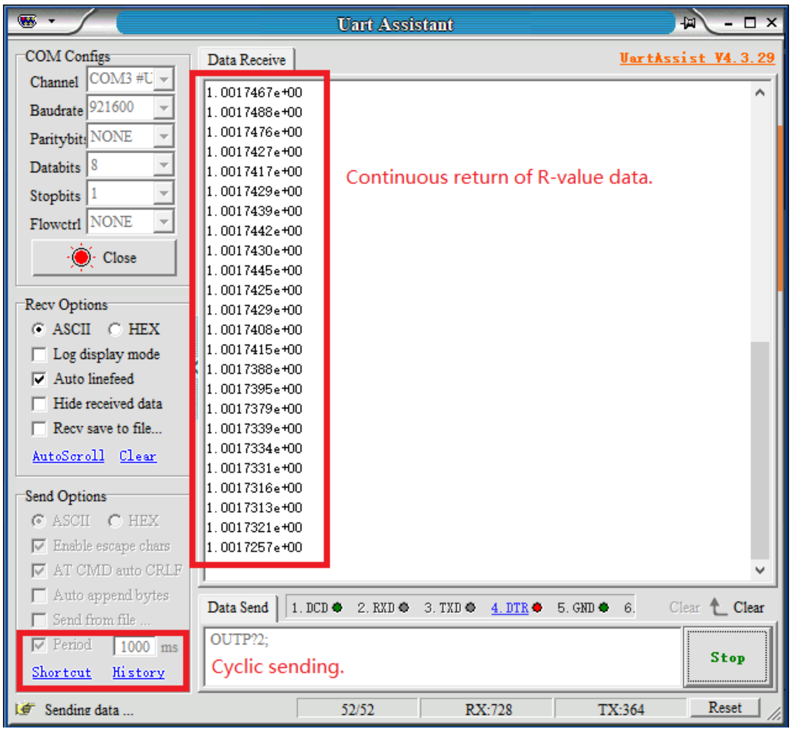


Figure 113. Continuously Reading a Single R Value

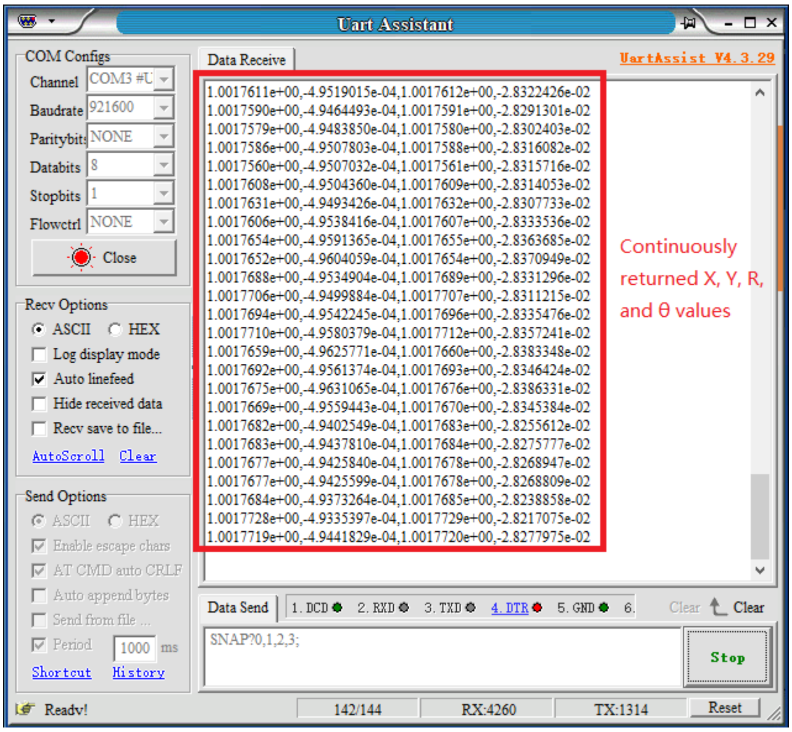


Figure 114. Continuously Reading X, Y, R, and θ Values

When the OE2022 internal parameters are set by sending commands through the serial debugging assistant, the corresponding parameter status on the LCD screen is updated at the same time. For example, if the current <Input Range> value in the status bar of the OE2022 is <5 V>, the corresponding command is IRNG and the parameter is 0. After sending the command "IRNG2,2;", the <Input Range> value in the status bar changes to the value corresponding to the command parameter, <200 mV>. The screen interface is shown in Figure 115.

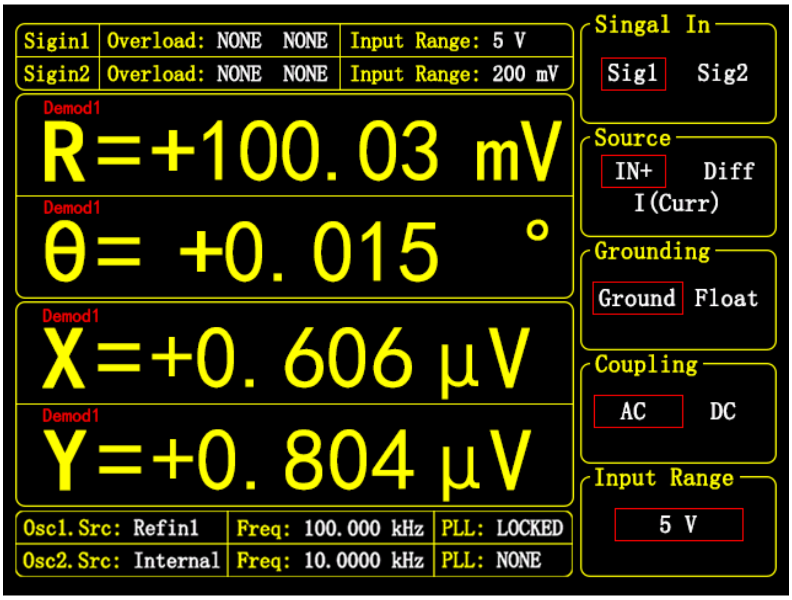


Figure 115. Interface After Modifying the Input Range Value

Other serial debugging tools of the same type can also be used for remote debugging, and the operating steps are similar.