

# SE1201 Digital Lock-in Amplifier

## User Manual



**The document applies to following models:**

- SE1201 DSP Lock-in Amplifier (50 mHz to 120 kHz)

**Standard Pack:**

- 1 × Main Machine
- 1 × Power Cord
- 1 × USB Cable
- 2 × BNC Connection Cable
- 1 × Spare Fuse (2A, 250VAC)
- 1 × U Disk or CD (for User Manual and PC Software)

## Preface

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## 1 Lock-in Amplifier Basics

### 1.1 Introduction

The Lock-in amplifier is a device used to detect very small signals, which are always obscured by noise sources many thousands of times larger. The lock-in amplifier can extract these small signals from noises and measure their values accurately.

The lock-in amplifier is a weak signal detection method based on the coherence. Lock-in amplifiers use a key technique known as phase-sensitive detection (PSD) to single out the required component of the signal. This component has the same frequency with the reference signal and has a fixed phase differences with the reference signal. Noise signals at other frequencies are rejected and do not affect the measurement.

The basic processing of small signals is amplification. Traditional amplifiers will amplify both the noise signals and the required signals. If there is no band limiting or filtering, amplification will decrease the signal to noise ratio (SNR). Therefore, filtering is needed to purify the signal and increase the SNR in order to measure the weak signal accurately.

PSD can be seen as a band-pass filter with a very narrow bandwidth. The basic modules of PSD include a multiplier module and a low-pass filter (LPF) module, as shown in Fig.1. Sometimes PSD is described as a multiplier module without a LPF.

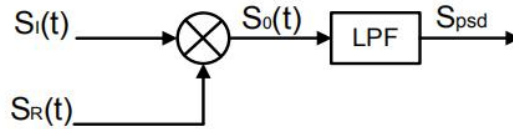


Fig.1 PSD diagram

In Fig.1,  $S_i(t)$  is the input signal plus noise in the time region,  $S_R(t)$  is the reference signal, which has a fixed frequency with the test signal.

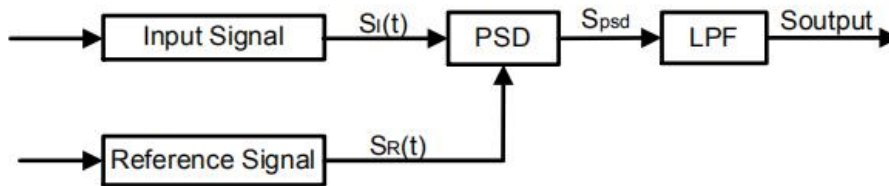


Fig.2 Single-phase amplifier diagram

In Fig.2, the input signal  $S_i(t)$  is defined as:  $S_i(t) = A_i \sin(\omega t + \varphi) + B(t)$ , where  $\omega$  is the frequency of input signal,  $A_i \sin(\omega t + \varphi)$  is the test signal,  $B(t)$  is the total noise.

The reference signal  $S_R(t)$  is defined as:  $S_R(t) = A_R \sin(\omega t + \delta)$ .

These two signals enter the PSD module for multiplication simultaneously, and the output of the PSD is defined as:

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

In the time region, the output of the PSD consists three parts:

- The first part is a DC signal. If  $A_I$ ,  $A$  and the phase difference  $(\varphi - \delta)$  between the input signal and the reference signal are constants, this part is a DC signal.
- The second part is the frequency-doubled reference AC signal.
- The third part is the result of multiplication of the noise and the reference. Because the sine signal is periodic and there is no relevance between the noise signal and the reference signal. The integral of this part is zero.

In the frequency region, we can redraw these three parts:

- The first part is at 0Hz, which is known as the DC component of one signal.
- The second part is at  $2f_{ref}$  Hz.
- The third part is a random signal at all the frequencies, such as white noise. The frequency spectrum of white noise does not change after any frequency drifts.

To sum up, the LPF output is defines as:  $S_{Output} = \frac{1}{2} A_I A_R \cos(\omega - \delta)$

Although we can determine the amplitude the amplitude of the input signal through adjusting the phase difference  $(\omega - \delta)$ , the accuracy is unsteady and insecure. In order to solve this problem, the dual phase lock-in amplifier was invented, see Fig.3.

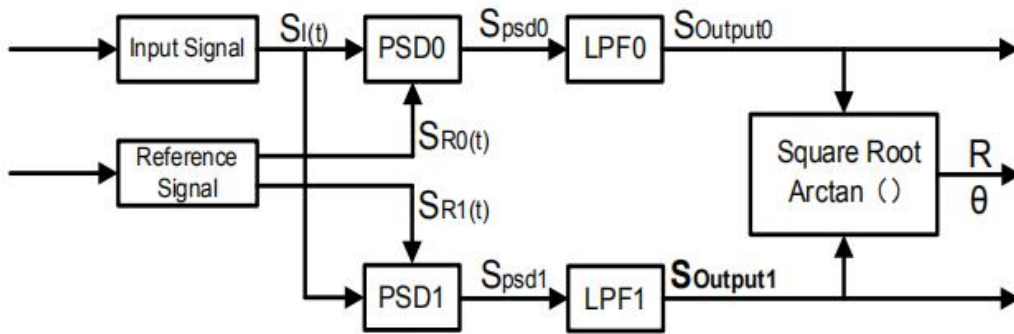


Fig.3 Dual Phase Lock-in Amplifier diagram

Now, we define the phase difference  $\theta = \omega - \delta$ , the LPF0 output  $X = S_{Output0}$  and LPF1 output  $Y = S_{Output1}$ . Then we calculate the amplitude  $R$  which is independent of  $\theta$ :

$$R = \frac{A_I}{\sqrt{2}} = \frac{\sqrt{2(X^2 + Y^2)}}{A_R}$$

The phase difference is defined as:  $\theta = \tan^{-1}(Y / X)$ .

## 1.2 Functional Diagram

The functional block diagram of the SE1201 DSP Lock-In Amplifier is shown in Fig.4. On the whole, the SE1201 includes signal conditioners, reference signal generators, an algorithm module and a system control module and so on.

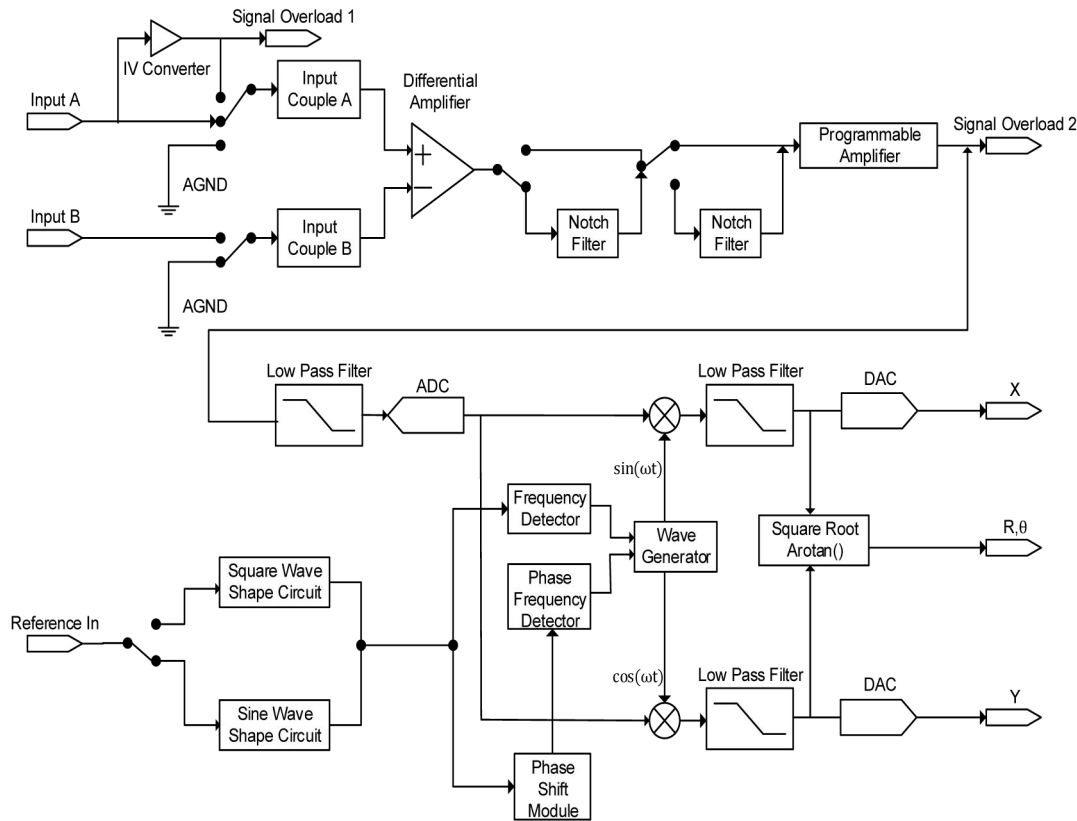


Fig.4 Functional Block Diagram of SE1201

## 1.3 Reference Channel

The reference channel is used to provide control signal which is associated with the detected signal. The SE1201 reference input can trigger on an analog signal such as a sine wave or a TTL logic signal. The input is AC coupled and the input impedance is  $1M\Omega$ .

Generally, both the sine wave and the TTL signal can be used as the reference signal. However, the generator's sine output has a small and varying amplitude. Meanwhile, many function generators provide a stable TTL SYNC output which can be used as the reference. Therefore, for frequencies below 1Hz, a TTL reference signal is required.

The SE1201 lock-in amplifier has two reference signal modes: internal reference mode and external reference mode.

In internal reference mode, the internal oscillator generates a digitally synthesized sine wave which is used to multiply with the input signal. The phase-locked-loop (PLL) is not used since the lock-in reference provides the excitation. The phase noise will not affect the internal reference signal. The phase noise is extremely low. This mode can work normally from 50mHz to 120kHz.



In external reference mode, an external sine wave or TTL logic signal can be used as the external reference signal. PLL will be used in this mode, but it will generate a little phase jitter which may cause measurement errors.

The phase jitter means that average phase shift is zero but the instantaneous phase shift has a few milli-degrees of noise. The phase jitter makes the reference signal plus noise at different frequencies. According to the coherence principle of PSD, the output is not a single frequency, but a distribution of frequencies about the true reference frequency.

In fact, phase noise in the SE1201 is very low and generally has no effect. In applications that requiring no phase jitter, the internal reference mode should be chose. Since there is no PLL in internal mode. The internal oscillator and the reference sine waves are directly linked and there is no jitter in the measured phase.

## 1.4 Phase Sensitive Detectors

The PSD in the SE1201 acts as a digital multiplier as is shown in Fig.5. The input signal amplified and filtered is converted to digital signal by a 24-bits A/D converter and then goes into the PSD. The reference sine wave is computed to 24 bit of accuracy, and the accuracy of the whole PSD is 48 bit.

The PSD module in lock-in amplifier is mainly used to implement the coherent modulation of the input signal and reference signal. Generally, there are two kinds of phase-sensitive detectors (PSD's): digital PSD's and analog PSD's. Traditional PSD's use an analog multiplier to multiply the input signal with the reference signal. There are many problems associated with these, including harmonic rejection, output offsets, limited dynamic reserve and gain error. It will limit the accuracy of PSD's and bring in various noises.

The digital PSD multiplies the digitized signal with a digitally computed reference sine wave. Because the reference sine wave is computed to 24 bit of accuracy, the harmonics have -120 dB roll off. That is to say, the harmonics do not affect the products of the PSD.

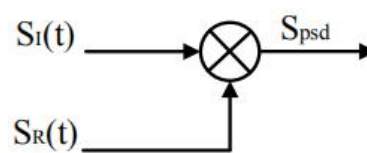


Fig.5 PSD diagram

Because the PSD based on analog method has temperature drift, there are always some deviation between the output and actual result that is the uncertain system error. While the PSD based on digital method has a precise amplitude and never change, so it will not generate any system errors. This eliminates a major source of gain error in a linear analog lock-in. Considering that the inputs of analog multiplier are analog quantity, the reference signal will be affected by temperature drift. This will cause errors in the reference and greater errors in the results of coherent modulation.

The dynamic reserve of an analog PSD's is limited to about 60 dB, because there are always many background noises. When there is a large noise signal present, 1000 times or 60dB greater than the full-scale signal, the analog PSD measures the signal with an error. Because the lock-in amplifier is mainly used to detect weak signals, when the amplitude of background noise is similar to or larger than the signal amplitude, the results of coherent modulation will be wrong.

To the digital PSD's, the dynamic reserve is limited by the quality of the A/D conversion. Once the input signal is digitized, no further errors are introduced. Practically, the dynamic reserve of SE1201 can exceed 120dB.

The performance of a lock-in amplifier is largely determined by the performance of its PSD's. Almost in all respects, the digital PSD outperforms the analog one. Besides, the digital PSD is also more convenient to modify.

## 1.5 Time Constants and DC Gain

The output signal of the PSD contains many signals of various frequency, such as the sum or difference between the input signal frequency and the reference frequency. Only the signal whose frequency is exactly equal to the reference frequency will result in a DC output.

The low pass filter (LPF) at the PSD output removes all the AC signals that unwanted, including the 2F (sum of the signal and the reference) and the noise signals. This filter is what makes the lock-in such a narrow band detector.

### Time Constants

The bandwidth setting of the low pass filter is the same as the conventional low pass filter. They are both determined by the time constants. The calculation of the time constant is defined as:

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

Here f is the -3dB frequency of the low-pass filter. For example, to a one-order low pass filter of RC type, a 1s time constant means its -3dB point occurs at 0.16Hz.

In fact, where there is an input noise, there is an output noise. By increasing the time constant, the output becomes more stable and measurement becomes more reliable. The time constant reflects not only the stability of the system and the accuracy, but also the respond time of the output.

The time constant also determines the equivalent noise bandwidth (ENBW). The ENBW isn't the filter -3dB pole, it is the effective bandwidth for Gaussian noise.

### Digital Filters vs Analog Filters

Analog filters have many limitations in performance. The temperature drift and non-linearity are two important problems that limit the rolloff performance of an analog filter. A two-stage analog filter provides about a maximum rolloff of 12 dB/oct at high frequency points.

Space and expense are also limitations. Each filter needs to have many different time constant settings. These different settings require different components and switches to select. Each setting is costly and space consuming. A large quantity of analog devices also bring quite complexity to the device debugging.

Considering these limitations, we choose a 47 bits digital filter to accomplish narrow band filtering. The DC amplitude is exactly 0 dB and the equivalent value of Q exceeds 145dB.

### Synchronous Filters

Another advantage of digital filtering is to do synchronous filtering. Even if the input signal has no noise, the PSD output always contains a component at  $2F$  (sum frequency of the signal and the reference) whose amplitude may exceed the difference frequency component that we want. At low frequencies, increasing the time constant can attenuate the  $2F$  component.

In SE1201, synchronous filters are available at detection frequencies below 200 Hz. At higher frequencies, the filters are not required because the  $2F$  component is easily removed without using long time constants. The output of the synchronous filter is followed by two more stages of normal filters. This combination of filters can eliminate the harmonics of the reference signal and attenuate other noise signals.

### **Long Time Constants**

Time constants above 100s are difficult to accomplish by using analog filters. This is simply because the capacitors required for the RC filters are prohibitively large in value and size. Why would you use such a long time constant? Sometimes you have no choice. If the reference is below 1 Hz with a lot of noise at low frequency, the PSD output will contain many low frequency components. Nevertheless, the synchronous filter only filters out the harmonic component of the reference frequency, and the followed filters filter the noise.

The SE1201 provides time constants as long as 3000s when the reference frequency is below 200 Hz, which can satisfy most requirements of measurements.

### **DC Output Gain**

How big is the DC output from the PSD? It depends on the dynamic reserve. With a 60 dB dynamic reserve, a noise signal can be 1000 times (60 dB) greater than a full scale signal. At the PSD, the noise cannot exceed the input range of PSD. For example, in an analog lock-in, the PSD input range might be 5 V. With 60 dB dynamic reserves, the signal will be only 5 mV at the PSD input. The PSD typically has no gain so the DC output from the PSD will only be a few millivolts. Even if the PSD had no DC output errors, amplifying this millivolt signal up to 10 V is error prone. An offset as small as 1 mV will appear as 1 V at the output. This is one of the reasons why analog lock-in does not perform well at high dynamic reserve.

The digital lock-in does not have an analog DC amplifier, and has no DC output offset. Likewise, the digital DC amplifier has no input offset. The output of the digital DC amplifier is simply the product of the input signal and the required gain.

This allows the SE1201 to operate with 100 dB of dynamic reserve without any outputs offset or zero drift.

## **1.6 DC Outputs and Scaling**

The SE1201 has Channel 1 and Channel 2 outputs (CH1 and CH2) on the front panel.

### **CH1 and CH2 Outputs and Display**

The output range of CH1 and CH2 is from  $\pm 5V$ .

The output signal is proportional to the value of the test signal and the setting scale. Otherwise, the SE1201 shows the

values of CH1 and CH2 on the front panel, including the value of X, Y, R,  $\theta$  of the test signal. The display interface of SE1201 is shown in Fig.6.

SE1201 can display the value of CH1 and CH2 through bars in addition to numbers. To discover the changes of data, you can observe the data in the time region.

Sens: 100mV	Filter: 24dB/oct	Notch: NONE	Input
TC: 300mS	DR: Normal	Sync: OFF	Filter
Cpl: AC	Src: A		Ref
R = 45.456mV			Phase
$\theta = -0.456^\circ$			Gain
X = 45.456mV			TC
Y = 0.456mV			Disp
Channel			Output
Overload: NONE	NONE	Freq: 1000.000Hz	Utility
Ref. Source: External	PLL: LOCKED		

Fig.6 [Disp] Submenu

### X, Y and R Output Offset and Expand

The SE1201 has the ability to offset the X, Y and R outputs, which is useful when measuring deviations in the signal around some nominal value. The output can be offset to zero by setting the offset. Then changes in the output can be read directly from the display or output voltages. The offset is specified as a percentage of full scale. Offsets can be set up to 100% of full scale. When the sensitivity is changed, the percentage does not change.

The X, Y and R outputs can be expanded. It's realized by multiplying the output with an expansion factor. Thus, a signal which is only 10% of full scale can be expanded to provide 10 V rather than 1 V. The general use for expansion is to increase the measurement resolution around some value which is not zero.

When the output does not exceed the full scale, the SE1201 can expand the output by multiplying with the expansion factor from 1 to 256. The output with offset and expand is:

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

Where <Offset> can be set up to  $\pm 100\%$  by the digital keyboard and the minimal step is 0.01%. <Expand> can be set from +1 to +256 by the digital keyboard and the minimal step is 1. Related display interface is shown in Fig.7.

For example, there is:

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

R = 12.456 mV	$\theta = 0.46^\circ$	Input Filter
X = 12.456 mV	Y = -0.456 mV	Ref Phase
CH Output: CH1		Gain TC
Source: R		Disp
Offset: + 0.00%		Channel Output
Expand: 1		Utility
Sine Output: 1.000V		
Overload: NONE NONE	Freq: 1000.000Hz	
Ref. Source: External	PLL: LOCKED	

Fig.7 [Channel Output] Submenu

## 1.7 Dynamic Reserve

The definition of dynamic reserve is the ratio of the largest tolerable noise signal to the full scale signal, expressed in dB, which is defined as:

$$\text{Dynamic reserve} = 20\text{Lg}(\text{OVL/FS})(\text{dB})$$

Here OVL is the total dynamic range of the input signal. FS is the dynamic range of the output signal. If the dynamic reserve is 100 dB, the tolerable noise can be  $10^5$  times the input.

The 'tolerable' means that the noise at the dynamic reserve limit should not cause an overload anywhere in the instrument. Overload might appear at the input of the pre-amplifier and the output of DC amplifier. We can adjust the distribution of the gain to achieve high dynamic reserve. This means that the input signal gain at the pre-amplifier should be set very low so the noise is not likely to overload. Then the low pass filter removes the large noise component from the PSD output which allows the remaining DC components to be amplified to reach 10 V full scale.

This gain is distributed between AC gain before the PSD and DC gain following the PSD. The total gain is the product of the AC gain and the DC gain. Suppose the total gain is a constant. If the AC gain increases and the DC gain decreases, the input noise is easy to overload after AC gain. Thus, the dynamic reserve and the DC drifts decrease. In contrast, if the AC gain decreases and the DC gain increases, the dynamic reserve increases. In this case, the output stability will decrease and the accuracy of measurement will be lower.

The noise frequencies and amplitudes affect the accuracy of the DC output signal. Noise at the reference frequency with large amplitude becomes part of the DC signal after the PSD. This enlarges the output error of the lock-in amplifier.

The dynamic reserve is related to noise frequency. The dynamic reserve is 0dB at reference frequency and increases when the noise frequency moves away from the reference frequency. It reaches a maximum value when the frequency is far enough. The dynamic reserve near the reference frequency is important to noise tolerance of the instrument. Providing more low pass filter stages can improve the performance of the filters and then increase the dynamic reserve close to the reference frequency. The dynamic reserve far from the reference frequency is generally high but has little

influence.

The dynamic reserve of SE1201 is greater than 120dB. High dynamic reserve will increase output noise and drift. When the dynamic reserve is high, output noise will be increased due to the A/D converter. There is background noise at any signal. When the signal is amplified by PSD, the output signal will contain noises. If the noise is very high, it will result in large output noise. Otherwise, if the external noise is very low, the output is mainly affected by the noise of SE1201. Reducing dynamic reserve and DC gain can decrease the error. Therefore, low dynamic reserve should be chosen firstly in actual application.

In fact, the minimum reserve changes with the sensitivity (gain) of the instrument. At high gains, the minimum dynamic reserve increases with the increase of the sensitivity. In analog lock-in amplifiers, low dynamic reserve means low output error and drift. In SE1201, high dynamic reserve increases output noise, but not increases output error and drift. However, if the gain of analog amplifier is high enough, the amplified intrinsic noise will be greater than the noise generated by the A/D converter. In this case, increasing the analog gain cannot decrease the output noise. At high sensitivity, decreasing the gain will increase the dynamic reserve.

## 1.8 Signal Input Amplifier and Filters

A lock-in amplifier can measure signals as small as a few nanovolts. The gain of the low noise signal amplifier should be large enough so that the output signal can be digitized by the A/D converter without degrading the signal to noise ratio (SNR). The analog gain of the SE1201 ranges from roughly 7 to 1000 times. Higher gains do not improve the SNR.

The overall gain (AC plus DC) is determined by the sensitivity and the distribution of the gain is set by the dynamic reserve.

### Input Noise

In SE1201, the input noise is about  $10nV_{rm}/\sqrt{Hz}$ . If an amplifier has  $10nV_{rm}/\sqrt{Hz}$  of input noise and a gain of 1000, the output will have  $10\mu V_{rm}/\sqrt{Hz}$  of noise. Suppose the output of the amplifier is low-pass filtered by a single RC filter (6 dB/oct rolloff) with 100ms time constant.

Input noise of lock-in amplifier and Johnson noise of resistors are both Gaussian in nature. That is to say, the amplitude of noise is proportional to the square root of the noise bandwidth. A single-stage RC filter has an ENBW of  $1/4T$  where T is the time constant ( $R \times C$ ) which means that Gaussian noise is filtered with an effective bandwidth equal to ENBW. In this case, the filter sees  $10\mu V_{rm}/\sqrt{Hz}$  of input noise and has an ENBW of  $1/(4 \times 100ms)$  or 2.5 Hz. The voltage noise at the filter output will be  $10\mu V_{rm}/\sqrt{Hz} \times \sqrt{2.5Hz}$  or 15.8  $\mu V_{rms}$ .

For Gaussian noise, the peak-peak noise is about 5 times the rms noise. Thus, the output noise will be about 79  $\mu V_{rms}$ . Input noise works in the same way. For sensitivities below 5  $\mu V$ , the value of input noise determines the output noise.

ENBW depends on the time constant and filter roll off. For example, suppose the SE1201 is set to <5  $\mu V$ > full scale, <100 ms> time constant and <6dB/oct> roll off. Thus, ENBW is 2.5 Hz. This leads to 7.9nVrms input noise. At the output, this

causes about 0.16% of full scale ( $7.9\text{nV}/5\mu\text{V}$ ). The peak to peak noise will be about 0.8% of full scale.

Assume that the signal input is from a low impedance source. The Johnson noise of resistors equals to  $0.13 \times \sqrt{R}$ . Take a  $100\Omega$  resistor for example, its noise is greater than the input noise of SE1201. The overall noise of multiple noise sources is determined by the square root of the sum of the squares of the individual noise figures. For example, if a  $1\text{k}\Omega$  source impedance is used, the Johnson noise will be  $4.11\text{nV}_{\text{rms}}/\sqrt{\text{Hz}}$ .

At low gains (sensitivities above  $50\mu\text{V}$ ), the gain is not high enough to amplify the input noise to a level greater than the noise of the A/D converter. In these cases, the output noise is mainly the A/D noise. At these sensitivities, the DC gain is low and the noise at the output is negligible.)

### Notch Filters

There are two notch filters in the signal amplifier chain in SE1201. They are pre-tuned to the line frequency and twice the line frequency. When the largest noise signals are at the power line frequencies, these filters can remove noise signals at these frequencies. Removing the largest noise before the final gain stage will reduce the dynamic reserve required to perform a measurement.

To prevent such a situation, it is necessary to improve the signal amplifier chain. If the required dynamic reserve without these notch filters is below 60 dB or if the minimum reserve is sufficient, then these filters do not improve the measurement obviously.

Do not use notch filters when making measurement near the notch frequencies. Notch filters have a finite range of attenuation, generally about 10 Hz. Thus, if the lock-in is measuring at 90Hz, do not use the 80 Hz notch filter. Otherwise, the signal will be attenuated and the measurement will be wrong. Besides, notch filters also have effect on phase shifts measurements.

### Anti-aliasing Filters

After signal filtering and amplification, there is an anti-aliasing filter, which is required by the signal digitization process. According to the Nyquist criterion, the sampling frequency of signal must be at least twice the highest signal frequency. For example, the highest signal frequency is 100 kHz, then the sampling frequency is 312.5 kHz. However, signals above 156 kHz cannot reach the A/D converter. These signals would violate the Nyquist criterion and be under-sampled. The result of under-sampling is to make the higher frequency signals appear as lower frequency signal in the digital data stream. This would make the measurement wrong.

To avoid under-sampling, the analog signal is filtered to remove signals above 154 kHz. This filter has a flat pass bandwidth from DC to 120kHz so that it would not affect measurements in the operation range of the lock-in. The filter rolls off from 120 kHz to 154 kHz and achieves an attenuation of at least 100dB above 154 kHz.

### Input Impedance

The input impedance of SE1201 is  $10\text{M}\Omega$ . If a higher input impedance is desired, the SE1201 remote preamplifier must be used so that the SE1201 has the maximum input impedance of  $100\text{M}\Omega$ .



## 1.9 Input Connections

Noises always exist in all circuits. Even if the signal is not very weak, noises exist and decrease the accuracy of measurement. There are many methods to reduce noise. Minimizing the various noise sources can increase the accuracy of the measurement. Besides, the effect of noise sources in the laboratory and the problem of the differential grounds between the detector and the lock-in can be minimized by careful input connection.

There are two basic methods for input connection - the single-ended connection is more convenient while the differential connection eliminates spurious pick-up more effectively.

### Single-Ended Connection (A)

In the first method, the lock-in uses the A input in a single-ended mode. The lock-in detects the signal as the voltage between the center and outer conductors of the A input only. However, there are two disadvantages of this mode.

Generally, the low level is a constant of 0V. However, grounds of different instruments may be at different potentials. When the shield of the A cable is connected to the lock-in's ground directly, different potentials will result in a high current, that is the ground loop. Thus, connecting via a resistor between them can avoid ground loop problems. In general, float uses 10 k $\Omega$  and ground uses 10 $\Omega$ .

Besides, this mode is not sensitive to noise. The signal cable is just like an antenna. The lock-in lets the shield 'quasi-float' in order to sense the experiment ground and pick up the activities of the electronic in environment. In this case, the noise came up. Unfortunately, the single-ended connection mode cannot distinguish the noise and actual signal.

### Differential Connection (A-B)

The second method of connection is the differential mode. This mode has two signals cables which connect the signal source and the lock-in's inputs. There are two high impedance power amplifiers in the lock-in. The lock-in measures the voltage difference between the center conductors of the A and B inputs, which can avoid common voltage problems since the shields are ignored.

In this mode, take care that the two cables travel the same path between the experiment and the lock-in. There should not be a large loop area enclosed by the two cables. Otherwise, measurement is susceptible to magnetic pickup.

## 1.10 Intrinsic Noise Sources

Noise is defined as any negative factors which will affect the result of measurement. Noise is random, unpredictable and temporary. Good experimental design should reduce the noise and improve the stability and accuracy of measurement.

There are various intrinsic noise sources which are present in all electronic signals. Some of them are unavoidable which only can be decreased by signal averaging and a narrower bandwidth. Others can be decreased by filtering and perfect line structures and component layout. Meanwhile, amplifier itself also produces noise at work, which can be solved by low noise amplifier design techniques.

### Johnson Noise



Every resistor generates a noise voltage across its terminals due to thermal fluctuations in the electron density within the resistor itself. This is Johnson noise. The spectrum of the Johnson noise is flat, so the noise power is almost the same in different frequency band (of course there is an upper limit frequency). In this case, the noise is called white noise. The fluctuations give rise to an open-circuit noise voltage,

$$V = (4kTRB)^{1/2}$$

Where  $k=1.38 \times 10^{-23} \text{J/}^\circ\text{K}$  is the Boltzmann's constant. T is the temperature in  $^\circ\text{Kelvin}$ , which can be transformed to  $^\circ\text{Celsius}$ :  $^\circ\text{K} = ^\circ\text{C} + 273.16$ . R is the resistance in Ohms, and B is the bandwidth of the measurement in Hz.

Harry Nyquist's mathematical studies of Johnson noise revealed that the power spectrum function of Johnson noise is:

$$St(f) = 4kTR(V^2 / \text{Hz})$$

At  $300^\circ\text{K}$ , a resistor of  $10 \text{ k}\Omega$  is connected to the input of the amplifier. The voltmeter is connected to the output of the amplifier. The open-circuit effective voltage of the filter which has a  $10 \text{ kHz}$  bandwidth is  $1.3 \text{ }\mu\text{V}$ .

The amplitude of Johnson noise is unpredictable in normal cases. It follows the Gaussian distribution. Johnson noise is the minimum value of the noise voltage of any devices including detectors, signal sources and amplifiers with resistors. Johnson noise is a typical case of wave dissipation.

### Shot Noise

Because of the finite nature of the charge carriers, electric current has noise. Noise generates in the current since there is always some non-uniformity in the electron flow. This noise is called shot noise. It appears as voltage noise when current is passed through a resistor, or as noise in a current measurement.

If the effect between carriers is ignored, the shot noise or current noise is given by:

$$I = (2qI_{dc}B)^{1/2}$$

where q is the electron charge of  $1.6 \times 10^{-19} \text{ Coulomb}$ ,  $I_{dc}$  is the DC current and B is the bandwidth. If  $I_{dc}$  is  $1 \text{ A}$  DC current and B is  $10 \text{ kHz}$ , then, I is  $57 \text{ nA}$  which is about  $0.000006\%$  of  $I_{dc}$ . At a smaller current, the fluctuation is larger. For example, if  $I_{dc}$  is  $1 \text{ }\mu\text{A}$  and B is still  $10 \text{ kHz}$ , then, I is about  $0.006\%$  or  $-85 \text{ dB}$ . If  $I_{dc}$  is  $1 \text{ pA}$ , then, I is about  $5.6\%$  or  $56 \text{ fA}$ .

In fact, shot noise is one kind of the white noise. Its power spectrum density is given by:

$$S_{sl}(f) = 2qId(A^2 / \text{Hz})$$

The formula is based on the assumption that carriers in the current do not affect each other. This assumption exists, such as the diffusion current in the junction diode. However, for general metal, this formula cannot be used because the cross effect between carries cannot be ignored.

### Flicker Noise (1/f Noise)

In 1925, Johnson first found  $1/f$  noise in in tube currents. The power spectrum function of this noise is proportional to  $1/f$ . The lower the frequency, the more serious the noise. Thus, it is also called low frequency noise. Microscopically,  $1/f$  noise

is caused by the random value of contact resistance between two conductors. The current amplitude of 1/f noise follows the Gaussian distribution, and the power spectrum density is proportional to 1/f which is given by:

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

1/f noise is also called flicker noise due to the random fluctuation of the power spectrum density in active devices. It broadens the bandwidth near the center frequency and reduces the value of Q of oscillators. 1/f noise must be considered near the center frequency.

### Total Noise

Johnson noise and shot noise are unreducible. Any resistors with a same resistance have the same Johnson noise. Shot noise relies on the special manufacture of resistors, including its material and package technology and so on. For example, among winding resistor, metal film, carbon resistor and pure carbon, the winding resistor has the minimum resistance. The metal film resistor and carbon resistor have larger resistances. The pure carbon resistor has the maximum resistance of these four. All of these noises are incoherent. The total random noise is the square root of the sum of the squares of all the incoherent noise sources.

## 1.10 External Noise Sources

In addition to the intrinsic noise sources discussed previously, there are different kinds of external noise sources. Most of these noise sources are asynchronous and not related to the reference. They do not occur at the reference frequency or its harmonics. These noise sources affect the measurement mainly by increasing the requirement of dynamic reserve or lengthening the time constant. However, some external noise sources are related to the reference. If they are picked up in the signal, noise will add or subtract from the actual signal and cause errors in the measurement. Fortunately, external noise sources can be reduced through various ways.

### Capacitive Coupling

The mutual capacity between wires is often called stray capacity  $C_{\text{stray}}$ . An AC voltage from a nearby piece of apparatus can couple to a detector via  $C_{\text{stray}}$ . Although  $C_{\text{stray}}$  may be very small, the coupled noise may still be larger than a weak experimental signal and cause severe instability for the detector. The noise current is given by:

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

Where  $\omega$  is  $2\pi$  times the noise frequency,  $V_{\text{noise}}$  is the amplitude of noise, and  $C_{\text{stray}}$  is the stray capacitance.

When the noise sources' frequency become larger, the coupling noise will be larger. If the noise source is at the reference frequency, the noise will be quite large. The lock-in rejects noise at other frequencies, but pick-up at the reference frequency appears as signal.

Cures for capacitive noise coupling include:

- 1) Remove or turn off the noise source.
- 2) Design the experiment to measure voltages with low impedance for most of low frequency noise sources.
- 3) Install capacitive shielding by placing the experiment and detector in one metal box.

### **Inductive Coupling**

An AC current in a nearby piece of apparatus can couple to the experiment via a magnetic field. A changing AC current gives rise to a changing magnetic field which induces voltage. The larger the frequency, the larger the electromotive force, the greater the measurement error.

Cures for inductively coupled noise include:

- 1) Remove or turn off the interfering noise source.
- 2) Reduce the area of the pick-up loop by using twisted pairs or coaxial cables.
- 3) Use magnetic shielding to prevent magnetic field from crossing the area of measurement.

### **Resistive Coupling or Ground Loops**

The ground loop is an interference source which can generate noise voltage between the grounds. If the noise voltage is large enough, it will cause measurement errors. Ground loop is a physic loop, which generates from many ground methods. These grounding methods can act as a big loop wire. They pick up noises from the environment and generate voltages in the grounding system. The 50 Hz magnetic field of the AC power is a normal noise source that the ground loop always pickup. For distributed grounding systems, the ground voltage can cause the ground current flow in the ground loop. Since the ground is with low impedance, noise current is always very high.

Cures for ground loop problems include:

- 1) Connect all grounds to the same physical point.
- 2) Use a heavy ground bus to reduce the resistance of ground connections.
- 3) Remove sources of large ground currents from the ground bus.

### **Microphonics**

Not all noise source are electrical in origin. According to microphonic effects, mechanical noise can be transformed into electrical noise. Physical changes in the device or cables (due to vibrations for example) will cause electrical noise over the whole bandwidth of the lock-in.

Solutions to minimize microphonic signals:

- 1) Eliminate mechanical vibrations near the experiment.
- 2) Tie down cables carrying sensitive signals.
- 3) Use a low noise cable that is designed to reduce microphonic effects.

### **Thermocouple Effects**

When two dissimilar metals contact, there will be potential difference between them. The reason for potential difference

includes: (1) different electronic work function of two metals. (2) different electron concentration of two metals.

Suppose that metal A and metal B have work functions  $V_a$  and  $V_b$  respectively. The electromotive force (emf) between A and B is:

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

Where  $K=1.38 \times 10^{-23} \text{J/K}$  is Boltzmann's constant. T is the temperature in °Kelvin; q is the elementary charge of  $1.60 \times 10^{-19}$  Coulomb. It's found that from the formula, the contact potential depends on the nature of the metal and the temperature of the contact surface.

If two dissimilar metals contact, the electromotive force at the contact point will plus a slowly changing millivolt level. This kind of noise is sensitive to temperature. This noise is typically at very low frequency because the temperature of the detector and experiment generally changes slowly. This effect is large on the scale of many detector outputs and can be a problem for low frequency measurements, especially in the mHz range.

Solutions to minimize thermocouple effects:

- 1) Hold the temperature of the detector or experiment constant.
- 2) Use a compensation junction.

## 1.11 Harmonic Detection

Harmonics represent waves at multiple frequencies. Periodic function can be described as the linear combination of one constant and many sine or cosine functions with the base frequency and the multiple frequencies. The constant is the DC component. The base frequency component is the base wave. The multiple frequencies are harmonics.

The SE1201 can only measure the base wave or one component of the harmonics at one time. The settings of harmonic detection are at <Harmonic> in [REF/PHASE] menu.

## 2 Interfaces

### 2.1 Front Panel

The front panel of SE1201 is shown in Fig.8.



Fig.9 Front Panel of SE1201

#### Display

The SE1201 uses 3.5-inch TFT-LCD for display and interactive control. Display resolution is 320\*240.

8 levels of background brightness are available, which is set in [Utility] in [SYSTEM]. When in the [Display] menu, the left of the screen displays the measurement results of the input signal. Otherwise, the left of the screen displays the corresponding submenu currently.

#### Spin Knob

Press the spin knob to highlight or exit the current parameter.

If a parameter is highlighted now, spin the knob to change its value. If no parameter is highlighted, spin the knob to select different submenu.

#### Keyboard

There are two groups of keyboards: MENU and two buttons under the spin knob which are called the left button and the right button. The six buttons at MENU correspond to six different menus. The left and the right buttons are used to adjust the highlighted parameter at current menu.

#### BNC Connectors

##### REF IN

The reference input can be a sine wave or a TTL pulse. When input is a sine wave, the input impedance is 1MΩ AC coupled. For low frequencies (<1Hz), it is necessary to use a TTL reference signal.

##### SIGNAL IN

There are two signal input modes, single-ended A and differential, A-B. The input A can be current signal. When measuring voltage, the input impedance of A and B are both 10 MΩ/25pF. When measuring current, the input is connected to the ground via a 1kΩ resistor.

### 2.2 Rear Panel

The rear panel of SE1201 is shown in Fig.9. It includes a cooling fan, a power connector, a power switch, an USB interface, a RS232 interface and four BNC connectors. The four BNC connectors are named [SINE OUT], [CH1 OUT], [CH2 OUT] and [TTL OUT] respectively.



Fig.9 Rear Panel of SE1201

<b>Power Connector</b>	The power connector is used to provide power for the instrument. This power connector with a built-in fuse receives 220 V, 50 Hz AC power. And it can filter high frequency noise.
<b>USB</b>	The SE1201 lock-in amplifier communicates with the PC through a USB interface so that the PC can control the SE1201 and read data directly from it.
<b>RS232</b>	The SE1201 can communicate with the PC or another SE1201 through a RS232 interface. If it is connected with the PC, the PC can control the SE1201 and read data directly from it. If it is connected with another SE1201, the master SE1201 can read data from the slave SE1201.
<b>BNC Connectors</b>	
SINE OUT	The internal oscillator provides a programmable output signal with the maximum amplitude 1Vrms. The output impedance is 50Ω. If the external reference signal is used, the oscillator is phase-locked to the input signal by PLL.
TTL OUT	The TTL output is synchronous with [SINE OUT]. When the amplitude of [SINE OUT] is so small, [TTL OUT] can be used to make a sync phase lock.
CH1&CH2 OUTPUT	The output voltage of [CH1 OUT] and [CH2 OUT] can be configured from -5V to +5V proportional to X or Y or the CH1 and CH2 display.

## 2.3 Main Display

The main display is divided into 4 parts, including status bars, function bar, monitoring bar and menu bar.

### (1) Status Bars

The Status bars indicate the current settings of the system or the results of measurement. When the current menu is [Display], it shows status bar 1, see Fig.10. Otherwise, it shows status bar 2, see Fig.11.

Status bars can show the following parameters:

<Sens>	The value of sensitivity
<Filter>	The value of the filter roll-off.
<Notch>	The status of notch filter.
<TC>	The value of time constant.

<DR>	The status of dynamic reserve.
<Sync>	The status of synchronous filter.
<Cpl>	The couple mode.
<Src>	The input mode.
<X>	The X value of input signal.
<Y>	The Y value of input signal.
<R>	The R value of input signal.
<θ>	The θ value of input signal.

Sens: 100mV	Filter: 24dB/oct	Notch: NONE	Input Filter
TC: 300mS	DR: Normal	Sync: OFF	
Cpl: AC	Src: A		Ref Phase
R =	45.456mV		Gain TC
θ =	- 0.456°		Disp
X =	45.456mV		
Y =	0.456mV		Channel Output
Overload: NONE	NONE	Freq: 1000.000Hz	Utility
Ref. Source: External	PLL: LOCKED		

Fig.10 Status Bar 1

R =	12.456 mV	θ =	0.46°	Input Filter
X =	12.456 mV	Y =	-0.456 mV	
Source: A				Ref Phase
Current Gain: 1M				Gain TC
Grounding: Float				Disp
Coupling: AC				
Line Notches: None				Channel Output
Overload: NONE NONE		Freq: 1000.000Hz		Utility
Ref. Source: External		PLL: LOCKED		

Fig.11 Status Bar 2

## (2) Function Bar

When the current menu is [Display], it shows function bar 1, see Fig.12. It displays the values of <X>, <Y>, <R>, <θ>.

When the current menu is a menu other than [Display], it shows function bar 2, which displays the submenu of the



current menu.

Sens: 100mV	Filter: 24dB/oct	Notch: NONE	Input
TC: 300mS	DR: Normal	Sync: OFF	Filter
Cpl: AC	Src: A		
R =	45.456mV		Ref
$\theta$ =	- 0.456°		Phase
X =	45.456mV		Gain
Y =	0.456mV		TC
			Disp
			Channel
			Output
Overload: NONE NONE	Freq: 1000.000Hz		Utility
Ref. Source: External	PLL: LOCKED		

Fig.12 Function bar 1 in [DISPLAY] menu

R = 12.456 mV	$\theta$ = 0.46°	Input
X = 12.456 mV	Y = -0.456 mV	Filter
Source: A		Ref
Current Gain: 1M		Phase
Grounding: Float		Gain
Coupling: AC		TC
Line Notches: None		Disp
		Channel
		Output
Overload: NONE NONE	Freq: 1000.000Hz	Utility
Ref. Source: External	PLL: LOCKED	

Fig.13 Function bar 2 in [Input Filter] menu

### (3) Monitoring Bar

The monitoring bar is at the bottom of the screen as is shown in Fig.14.



Sens:100mV	Filter:24dB/oct	Notch: NONE	Input
TC: 300mS	DR:Normal	Sync:OFF	Filter
Cp1:AC	Src: A		
R =	45.456mV		Ref
$\theta =$	- 0.456°		Phase
X =	45.456mV		Gain
Y =	0.456mV		TC
			Disp
			Channel
			Output
Overload: NONE NONE	Freq: 1000.000Hz		Utility
Ref. Source: External	PLL: LOCKED		

Fig.14 The highlighted [Disp] bar

#### <Overload>

To indicate an input overload or amplification overload.

If there is no overload, it shows <Overload: NONE NONE>;

If an input overload, it shows <Overload: INPUT NONE>;

If an amplification overload, it shows <Overload: NONE GAIN>;

If there are both an input overload and amplification overload, it shows <Overload: INPUT GAIN>. In this case, reduce the input as soon as possible to prevent over-voltage damage to the instrument.

#### <Freq>

Display the frequency of input signal.

#### <Ref. Source>

The mode of the reference signal: Internal or External.

#### <PLL>

The status of PLL.

If the internal reference is used, it shows <PLL: UNLOCK>.

If the external reference is used, it shows <PLL: LOCKED>.

If <Harmonic> is greater than 1, it shows <PLL:LOCKED HARM>.

#### (4) Menu Bar

As is shown in Fig.15, menu bar is at the right of the main display. There are 6 menus in the menu bar which correspond to the 6 buttons at MENU on the front panel. The current menu will be highlighted. For example, the current menu in Fig.15 is [Disp].

Sens: 100mV	Filter: 24dB/oct	Notch: NONE	Input
TC: 300mS	DR: Normal	Sync: OFF	Filter
Cpl: AC	Src: A		Ref
R =	45.456mV		Phase
$\theta =$	- 0.456°		Gain
X =	45.456mV		TC
Y =	0.456mV		Disp
Channel			Output
Overload: NONE NONE	Freq: 1000.000Hz		Utility
Ref. Source: External	PLL: LOCKED		

Fig.15 The Menu bar at the left portion of the main display

### 3 Menus

The MENUs consists of six parts: [INPUT/FILTERS], [REF/PHASE], [GAIN/TC], [DISPLAY], [CHANNEL OUTPUT] and [UTLITY].

#### 3.1 [INPUT/FILTERS]

When press the [INPUT/FILTERS] button, you will enter this following submenu, as is shown in Fig.16. There are 5 function settings in this submenu, including <Source>, <Current Gain>, <Grounding>, <Coupling> and <Line Notches>.

R = 12.456 mV	$\theta$ = 0.46°	Input Filter
X = 12.456 mV	Y = -0.456 mV	
Source: A		Ref Phase
Current Gain: 1M		Gain TC
Grounding: Float		Disp
Coupling: AC		Channel Output
Line Notches: None		Utility
Overload: NONE NONE	Freq: 1000.000Hz	
Ref. Source: External	PLL: LOCKED	

Fig16. [INPUT/ FILTERS] submenu

##### 3.1.1 <Source>: Setting the Input Signal Mode

<A> Single-ended voltage input mode.

<A-B> Differential voltage input mode.

<I> Current input mode.

Note that when choose mode <A> and mode <A-B>, the amplitude of the input signal must be less than 1Vrms.

##### 3.1.2 < Current Gain >: Setting the Current Gain

<1M> The input current is amplified by the gain of  $10^6$  V/A.

<100M> The input current is amplified by the gain of  $10^8$  V/A.

##### 3.1.3 < Grounding >: Setting the Ground Mode

<Float> The connector shields are isolated from the chassis ground by 10k $\Omega$ .

<Ground> The connector shields are isolated from the chassis ground by 10 $\Omega$  and chassis ground is connected to the earth directly.

Generally, choose <Ground> when the current of the input signal is not large. It prevent signal drift caused by floating. Choose <Float> when there is a large potential difference between the signal ground and chassis ground and a strong current injection. This can limit the current and protect the system circuit.

### 3.1.4 < Coupling >: Setting the Coupling Input Mode

<AC> AC coupling input mode. In this mode, the DC component of the input signal will be eliminated. If the signal frequency is greater than 200 Hz, <AC> should be selected.

<DC> DC coupling input mode. In this mode, the AC component of the input signal will be eliminated. If the signal frequency is less than 200 Hz, <DC> should be chosen.

### 3.1.5 < Line Notches >: Setting the Status of the Notch Filters

<None> Turn off all notch filters.

<Line> Turn on the 50\60 Hz notch filter to suppress the power line interference.

<2xLine> Turn on the 100\120 Hz notch filter to suppress the second harmonic interference of power.

<Both> Turn on the 50\60 Hz and the 100\120 Hz notch filter.

Generally, if the signal frequency is greater than 200Hz, choose <Both>, <Line> or <2×Line>.

Otherwise, choose <None> to avoid the amplitude damage due to small slope of the notch filter.

## 3.2 [REF/PHASE]

Press [REF/PHASE] and enter its submenu, see Fig.17. There are 5 function settings in the submenu, including <Phase>, <Ref.source>, <Freq>, <Slope> and <Harmonic>.

R = 12.456 mV	$\theta$ = 0.46°	Input Filter
X = 12.456 mV	Y = -0.456 mV	
Phase: + 0.00°		Ref Phase
Ref. Source: External		Gain TC
Freq: 1000.000Hz		Disp
Slope: TTL		
Harmonic: 1		Channel Output
Overload: NONE NONE	Freq: 1000.000Hz	Utility
Ref. Source: External	PLL: LOCKED	

Fig.17 The [REF/PHASE] Submenu

### 3.2.1 < Phase >: Setting the Reference Phase

Users can set the phase shift between two orthogonal reference signals through the keyboard. The accuracy of phase is  $0.01^\circ$  and the range is from  $-180^\circ$  to  $+180^\circ$ .

For phase, it's meaningful only when there is a reference. In the system, the default reference phase is the phase of REF IN after locked by a high precision PLL. Other phases are relative to this reference phase.

### 3.2.2 <Ref. source>: Setting the Reference Source

<External> The external reference signal.

<Internal> The internal reference signal. In this mode, the reference signal is from the internal oscillator. The [REF IN] signal is useless

### 3.2.3 <Freq>: Setting the Internal Reference Frequency

When <Internal> is chosen in <Ref. source>, this setting can access. The frequency range is from 10mHz to 120 kHz and the default frequency is 1.000 kHz. Users can set frequency through the knob and the left and right buttons. The minimum resolution of frequency is 1mHz.

### 3.2.4 <Slope>: Setting the External Signal Mode

When <External> is chosen in <Ref. source>, this setting can access. Choose the corresponding signal type according to the actual external reference signal.

<TTL> Choose TTL when the external reference signal is a square wave.

<Sine> Choose Sine when the external reference signal is a sine wave.

If the external reference signal is TTL logic, choose <TTL>. Pay attention that, even if the REF IN is a square wave, it may still obtain an unsteady trigger because the level does not satisfy the threshold condition of the TTL logic. Thus, it is beneficial to choose <Sine> to trigger. Moreover, choose TTL signal if the signal frequency is very low ( $<1\text{Hz}$ ).

If the input reference signal is sine wave, choose SINE to trigger. In this mode, the instrument will do precision truing for the REF IN input and then detect the frequency and phase information.

Otherwise, the system has no requirement on the signal duty cycle no matter what the trigger way is. It is kind to use common 50% duty cycle.

### 3.2.5 <Harmonic>: Setting the Harmonic Detection

Spinning the knob and press the left and right buttons under the knob to set the harmonic order required. The range of harmonic order is from 1 to 32767 with default 1. The harmonic order is limited by  $(\text{Harmonic} * \text{Freq}) \leq 120\text{kHz}$ . Here, Freq indicates the frequency of reference. Once beyond the limit, the system will not be able to continue to increase the harmonic order.

For example, the input signal is 1kHz square wave. Suppose that the signal's amplitude is A. Set <Harmonic> as 1, 3, 5, 7..., the R will be 0.45A, 0.15A, 0.09A, 0.064A...respectively. This sequence is A times higher the coefficient sequence of the square wave Fourier Series.

### 3.3 [GAIN/TC]

Press [GAIN/TC] button, then enter the submenu as is shown in Fig.18. There are 5 function settings in the submenu, including <Sens>, <DR>, <TC>, <Filter> and <Sync>.

R = 12.456 mV	$\theta$ = 0.46°	Input
X = 12.456 mV	Y = -0.456 mV	Filter
Sens: 100 mV		Ref
DR: Normal		Phase
TC: 300 mS		Gain
Filter: 24 dB/oct		TC
Sync: OFF		Disp
Overload: NONE NONE		Channel
Freq: 1000.000Hz		Output
Ref. Source: External		Utility
PLL: LOCKED		

Fig.18 [GAIN/TC] Submenu

#### 3.3.1 <Sens>: Setting the Full Scale Sensitivity

Choose an appropriate full-scale sensitivity according to the amplitude of the input signal. Adjust the value through the soft keys or spin knob.

Table 1. Full Scale Sensitivity

2 nV/fA	500 nV/fA	100 $\mu$ V/pA	20 mV/nA
5 nV/fA	1 $\mu$ V/pA	200 $\mu$ V/pA	50 mV/nA
10 nV/fA	2 $\mu$ V/pA	500 $\mu$ V/pA	100 mV/nA
20 nV/fA	5 $\mu$ V/pA	1 mV/nA	200 mV/nA
50 nV/fA	10 $\mu$ V/pA	2 mV/nA	500 mV/nA
100 nV/fA	20 $\mu$ V/pA	5 mV/nA	1 V/ $\mu$ A
200 nV/fA	50 $\mu$ V/pA	10 mV/nA	

The change of <Sensitivity> will change the dynamic range of the system. Besides, it will impact the output of CH1&CH2. If the measure signal is current, the full scale acts as the corresponding current unit, <100mV/nA> in default.

#### 3.3.2 <DR>: Setting the Dynamic Reserve Mode

<Low> Low dynamic reserve mode

<High> High dynamic reserve mode.

<Normal> Normal dynamic reserve mode. Generally, this mode is recommended.

### 3.3.3 < TC >: Setting the Time Constants

The range of time constant is from 10  $\mu$ s to 3000 s. Adjust the value through the left and right buttons and the spin knob.

The greater the time constant, the smaller the ENBW, the longer the system response and the higher the measurement accuracy.

Table 2. Time Constants

10 $\mu$ s	3 ms	1 s	300 s
30 $\mu$ s	10 ms	3 s	1000 s
100 $\mu$ s	30 ms	10 s	3000 s
300 $\mu$ s	100 ms	30 s	
1 ms	300 ms	100 s	

### 3.3.4 < Filter>: Setting the Roll off Slope of the Low Pass Filter

<6dB/oct> The roll off slope is 6 dB/oct.

<12dB/oct> The roll off slope is 12 dB/oct.

<18dB/oct> The roll off slope is 18 dB/oct.

<24dB/oct> The roll off slope is 24 dB/oct.

At the same measurement accuracy, a greater roll off slope can reduce the time constant, making a faster response.

### 3.3.5 < Synchronous >: Setting the Status of the Synchronous Filter

<OFF> Close the synchronous filter.

<200Hz> Open the synchronous filter. It's useful at a low reference frequency (< 20 Hz). When the input signal frequency is very low, the low pass filter can't get stable results or it needs a long time to do that. At this time, synchronous filter helps.

## 3.4 [DISPLAY]

Press [DISPLAY] button and enter the submenu as is shown in Fig.19. It displays the results of measurement, including the values of <R>, < $\theta$ >, <X> and <Y>.



Sens: 100mV	Filter: 24dB/oct	Notch: NONE	Input
TC: 300mS	DR: Normal	Sync: OFF	Filter
Cpl: AC	Src: A		
R =	45.456mV		Ref
$\theta$ =	-0.456°		Phase
X =	45.456mV		Gain
Y =	0.456mV		TC
			Disp
			Channel
			Output
Overload: NONE	NONE	Freq: 1000.000Hz	Utility
Ref. Source: External		PLL: LOCKED	

Fig.19 [Disp] Display Submenu

### 3.5 [CHANNEL OUTPUT]

Press [CHANNEL OUTPUT] button and enter the submenu as is shown in Fig.20. The two BNCs CH1 and CH2 can output R, X, Y and  $\theta$  that users wanted by setting in the [CHANNEL OUTPUT] submenu. The output offset and expand is set in <Offset & Expand>.

R = 12.456 mV	$\theta = 0.46^{\circ}$	Input Filter
X = 12.456 mV	Y = -0.456 mV	
CH Output: CH1		Ref Phase
Source: R		
Offset: + 0.00%		Gain TC
Expand: 1		
Sine Output: 1.000V		Disp
		Channel Output
Overload: NONE NONE		Utility
Freq: 1000.000Hz		
Ref. Source: External		
PLL: LOCKED		

Fig.20 [Channel Output] Submenu

The calculation equation of output signal is:

1. When source is <R>, <X>, <Y>:

$$\text{Output} = \left( \frac{\text{Signal}(\text{source})}{\text{Sens}} + \text{offset} \right) \times \text{Expand} \times 5V$$

2. When source is < $\theta$ >:



$$\text{Output} = \frac{\text{Signal}(\text{source})}{180^\circ} \times 5V$$

### 3.6.1 < CH Output >: Setting the Output Channel

<CH1> Setting CH1 as the output channel

<CH2> Setting CH2 as the output channel

### 3.6.2 < Source >: Setting Output Source

<X>: the corresponding analog level of the channel output X

<Y>: the corresponding analog level of the channel output Y

<R>: the corresponding analog level of the channel output R

<θ>: the corresponding analog level of the channel output θ

### 3.6.3 < Offset >: Setting the Output Offset

It is set through the knob and the left and right buttons. The adjustable range is -100% to +100%. The minimal step is 0.01% and 0.00% is default.

### 3.6.4 < Expand >: Setting the Output Expand Factor

It is set through the knob and the left and right buttons. The adjustable range is 1-256 and 1 is default. If the setting value of Expand causes the calculation result over ±5V, the output will be seriously affected.

The settings of <Offset> and <Expand> will not affect the data display in dynamic area.

### 3.6.5 < Sine Output >: Setting the Sine Output Amplitude

SE1201 provides a sine from 0V to ±1V through the “SINE OUT” BNC on the rear panel. The sine out amplitude is adjusted through the knob and the left and right buttons. The available range is from 0.100Vrms to 1.000Vrms with the resolution of 0.001Vrms.

When using the <External> reference, <Sine Output> provides a sine signal which locks phase with external reference. When using the <Internal> reference, the reference signal is generated by the oscillator in SE1201. The “TTL OUT” BNC connector on rear panel will output TTL signal which is synchronous with the <Sine Output>.

## 3.6 [UTILITY]

Press [UTILITY] on the front panel and enter the submenu in Fig.21. There are 5 settings in this submenu, including <StoreRecall>, <USB>, <RS232>, <System> and <Info>.

R = 12.456 mV	$\theta = 0.46^\circ$	Input Filter
X = 12.456 mV	Y = -0.456 mV	
StoreRecall		Ref Phase
USB		Gain TC
RS232		Disp
System		Channel Output
Info		Utility
Overload: NONE NONE	Freq: 1000.000Hz	
Ref. Source: External	PLL: LOCKED	

Fig.21 [Utility] Submenu

### 3.6.1 <StoreRecall>: Store or Recall the Settings of Parameters

Choose <StoreRecall> in <UTILITY> and enter the submenu in Fig.22. There are 3 function settings in this submenu, including <StoreRecall>, <Channel> and <Execute>.

R = 12.456 mV	$\theta = 0.46^\circ$	Input Filter
X = 12.456 mV	Y = -0.456 mV	
StoreRecall: Store		Ref Phase
Channel: S1		Gain TC
Execute: NO		Disp
Menu Return		Channel Output
Overload: NONE NONE	Freq: 1000.000Hz	Utility
Ref. Source: External	PLL: LOCKED	

Fig.22 [StoreRecall] Submenu

<StoreRecall>	<b>Store or recall settings</b>
<Store>	The current operation is to store the settings.
<Recall>	The current operation is to recall the settings.
<Channel>	<b>Archive number</b>
<S1>	The first archive.
<S2>	The second archive.
<S3>	The third archive.
<S4>	The fourth archive.

<Default> The default archive. Valid only for <Recall>.

### <Execute> Settings of executing

<YES> Executes the current setting

Always off (It switches to <NO> automatically when complete executing the current setting.)

<NO> Do not execute the current setting.

## 3.6.2 <USB>: USB serial Communication Settings

Choose <USB> in <UTILITY> and enter the submenu in Fig.23 There are 2 function settings in this submenu, including <Baud Rate> and <Parity>.

R = 12.456 mV	$\theta$ = 0.46°	Input Filter
X = 12.456 mV	Y = -0.456 mV	Ref Phase
Baud Rate: 921600 bd		Gain TC
Parity: None		Disp
		Channel Output
Menu Return		Utility
Overload: NONE NONE	Freq: 1000.000Hz	
Ref. Source: External	PLL: LOCKED	

Fig.23 [USB] Submenu

### <Baud Rate> Baud rate setting

Set the baud rate through the knob and the left and right buttons. The available rate is <600>, <1200>, <2400>, <4800>, <9600>, <19200>, <38400>, <43000>, <56000> <57600>, <115200>, <230400>, <380400>, <460800> and <921600>.

The default baud rate is <921600>.

### <Parity> Parity mode setting.

<Even> Even mode.

<ODD> Odd mode.

<NONE> None mode.

## 3.6.3 <RS232>: RS232 Communication Settings

R = 12.456 mV	$\theta$ = 0.46°	Input Filter
X = 12.456 mV	Y = -0.456 mV	Ref Phase
Baud Rate: 115200 bd		Gain TC
Parity: None		Disp
Remote: Master		Channel Output
Menu Return		Utility
Overload: NONE NONE	Freq: 1000.000Hz	
Ref. Source: External	PLL: LOCKED	

Fig.24 [RS232] Submenu

Choose <RS232> in <UTILITY> and enter the submenu in Fig.24. There are 3 function settings in this submenu, including <Baud Rate>, <Parity> and <Remote>.

#### <Baud Rate>

##### Baud rate setting.

Set the baud rate through the knob and the left and right buttons. The available rate is <600>, <1200>, <2400>, <4800>, <9600>, <19200>, <38400>, <43000>, <56000> <57600>, <115200>, <230400>, <380400>, <460800> and <921600>. The default baud rate is <921600>.

#### <Parity>

##### Parity mode setting.

<Even>	Even mode.
<ODD>	Odd mode.
<NONE>	None mode.

#### <Remote>

##### Master and slave settings.

<Master>	The local SE1201 is set as the master.
<Slave>	The local SE1201 is set as the slave.

Note that use <USB> and <RS232>, the local SE1201 can communicate with another SE1201 or the PC. More details are talked at 'CHAPPER 4 REMOTE PROGRAMMING'.

### 3.6.4 <System>: Systems Settings

Choose <System> in <UTILITY> and enter the submenu in Fig.25. There are 3 function settings in this submenu, including <Beep>, <Color> and <Backlight>.

R = 12.456 mV	$\theta$ = 0.46°	Input Filter
X = 12.456 mV	Y = -0.456 mV	Ref Phase
Beep: NO		Gain TC
Color: Style1		Disp
Backlight: Level4		Channel Output
Menu Return		Utility
Overload: NONE NONE	Freq: 1000.000Hz	
Ref. Source: External	PLL: LOCKED	

Fig.25 [System] Submenu

### <Beep>

**Setting the beep mode.**

<ON> Turn on the beep.

<OFF> Turn off the beep.

### <Color>

**Setting the background color.**

<Style1> Yellow background.

<Style2> Green background.

### <Backlight>

**Setting the level of the background brightness.**

Spin the knob to change the brightness from <Level1> to <Level8>.

## 3.6.5 <Info>: Information View

Choose <info> in <UTILITY> and enter the submenu in Fig.26. It shows the version, serial number of this SE1201 and the R&D units' contact information.

R = 12.456 mV	$\theta$ = 0.46°	Input Filter
X = 12.456 mV	Y = -0.456 mV	Ref Phase
SE1201 DSP LOCK-IN AMPLIFIER		Gain TC
Version: V1.3		Disp
SN: L130189		Channel Output
Menu Return		Utility
Overload: NONE NONE	Freq: 1000.000Hz	
Ref. Source: External	PLL: LOCKED	

Fig.26 [Info] Submenu

## 4 Remote Programming

### 4.1 Command Syntax

Computers use ASCII characters to communicate with SE1201. Commands must be in upper case. A command consists of a four-character command mnemonic, arguments if necessary, and a command terminator. The terminator must be a linefeed <lf> or carriage return <cr> on RS232 to USB. No command processing occurs until a command terminator is received. Commands may require one or more parameters. Multiple parameters are separated by commas (,).

Multiple commands may be sent on one command line by separating them with semicolons (;). The difference between sending several commands on the same line and sending several independent commands is that when a command line is parsed and executed, the entire line is executed before any other device action proceeds.

The SE1201 has an input buffer that can store up to 50 instructions and processes commands in the order received. When the input buffer is full, errors may occur. Thus, it is better to use no more than 50 commands.

SE1201 allows users to query the current value of internal parameters through commands. A query is formed by appending a question mark "?" to the command mnemonic and omitting the desired parameter(s) from the command. Values returned by the SE1201 are sent as a string of ASCII characters terminated by a corresponding terminator. If multiply queries are sent on one command line (separated by semicolons), the answers will be returned individually, each with a terminator.

When in cascade mode, add an 'S' character at the end of the command in the communication between master and slave. More details are in "chapter 3.6 [UTILITY]- [RS232]".

Examples of Command Formats:

FMOD 1 <cr>	Set the master reference source to internal
FMOD 1 S <cr>	Set the slave reference source to internal
FREQ 10E3 <cr>	Set the master internal reference frequency to 10 kHz
FREQ 10E3 S <cr>	Set the slave internal reference frequency to 10 kHz
OUTP? 1 <cr>	Queries the output value of CH1 of the master SE1201
OUTP? 1 S <cr>	Queries the output value of CH1 of the slave SE1201

### 4.2 Detailed Command List

The parameters in each command sequence specify the command. Multiple parameters are separated by commas. Parameters shown in {} are optional. Commands that may be queries have a question mark in parentheses (?) after the mnemonic. Do not send () or {} as part of the command.

The variables are defined as follows.

i, j, k, l, m, n, o, p, q, r, s, t, u	integers
x	real numbers
f	frequency

Note that all numeric variables can be expressed in integer, floating point or exponential formats (i.e., the number five can be 5, 5.0, or .5E1). Strings are sent as a sequence of ASCII characters.

#### 4.2.1 Reference and Phase Commands

PHAS(?) {x}	The PHAS command sets or queries the reference phase shift. The parameter x refers to the phase (real number, unit: °). The PHAS x command will set the current phase shift to x°. The value of x is rounded to 0.01°. The phase can be programmed from -180° to +180°. For example, send command “PHAS -179.0” and the phase shift will be set to -179°. The PHAS? command queries the phase shift.
FMOD(?) {i}	The FMOS command sets or queries the reference source. The parameter i selects external reference (i=0) or internal reference (i=1).
FREQ(?) {f}	The FREQ command sets or queries the reference signal. The FREQ? command will return the current reference frequency (internal or external).
RSLP(?) {i}	The RSLP command sets or queries the trigger way of reference signal when in external reference mode. The parameter i selects <TTL> rising edge (i=0) or <Sine> zero crossing (i=1). When the frequency is less than 1 Hz, the <TTL> reference must be used.
HARM(?) {i}	The HARM command sets or queries harmonic detection. The parameter i is an integer from 1 to 32767. The HARMi command will set the lock-in to detect at the ith harmonic of the reference frequency. The value i is limited by $i \cdot f \leq 120 \text{ kHz}$ . If the value of i and f exceeds 120 kHz, then i will be set to the maximum value that meets $i \cdot f \leq 120 \text{ kHz}$ .

#### 4.2.2 Input and Filter Commands

ISRC(?) {i}	The ISRC command sets or queries the input configuration. The parameter i selects A (single input mode) (i=0), A-B (differential voltage input mode) (i=1), I (1 MΩ) (current input and the expand is 10 <sup>6</sup> V/A) (i=2) or I (100 MΩ) (current input and the expand is 10 <sup>8</sup> V/A) (i=3).
IGND(?) {i}	The IGND command sets or queries the input shield grounding. The parameter i selects Float (i=0) when the input ground is connected to the instrument ground with a 10 kΩ resistor or Ground (i=1) when the input ground is connected to the instrument ground with a 10 Ω resistor.
ICPL(?) {i}	The ICPL command sets and queries the input coupling. The parameter i selects AC (i=0)



	or DC (i=1).
ILIN(?) {i}	The ILIN command sets and queries the notch filter status. The parameter i selects to close notch filters (i=0), open the 50Hz notch filter (i=1), open the 100Hz notch filter (i=2) or open the 50Hz and 100Hz notch filter at the same time (i=3).

#### 4.2.3 Sensitivity and Time Constants Commands

SENS(?) {i}	<p>The SENS command sets or queries the sensitivity. The parameter i is used to select a different range.</p> <table><tr><td>i</td><td>sensitivity</td><td>i</td><td>sensitivity</td><td>i</td><td>sensitivity</td></tr><tr><td>0</td><td>2 nV/fA</td><td>9</td><td>2 μV/pA</td><td>18</td><td>2 mV/nA</td></tr><tr><td>1</td><td>5 nV/fA</td><td>10</td><td>5 μV/pA</td><td>19</td><td>5 mV/nA</td></tr><tr><td>2</td><td>10 nV/fA</td><td>11</td><td>10 μV/pA</td><td>20</td><td>10 mV/nA</td></tr><tr><td>3</td><td>20 nV/fA</td><td>12</td><td>20 μV/pA</td><td>21</td><td>20 mV/nA</td></tr><tr><td>4</td><td>50 nV/fA</td><td>13</td><td>50 μV/pA</td><td>22</td><td>50 mV/nA</td></tr><tr><td>5</td><td>100 nV/fA</td><td>14</td><td>100 μV/pA</td><td>23</td><td>100 mV/nA</td></tr><tr><td>6</td><td>200 nV/fA</td><td>15</td><td>200 μV/pA</td><td>24</td><td>200 mV/nA</td></tr><tr><td>7</td><td>500 nV/fA</td><td>16</td><td>500 μV/pA</td><td>25</td><td>500 mV/nA</td></tr></table>	i	sensitivity	i	sensitivity	i	sensitivity	0	2 nV/fA	9	2 μV/pA	18	2 mV/nA	1	5 nV/fA	10	5 μV/pA	19	5 mV/nA	2	10 nV/fA	11	10 μV/pA	20	10 mV/nA	3	20 nV/fA	12	20 μV/pA	21	20 mV/nA	4	50 nV/fA	13	50 μV/pA	22	50 mV/nA	5	100 nV/fA	14	100 μV/pA	23	100 mV/nA	6	200 nV/fA	15	200 μV/pA	24	200 mV/nA	7	500 nV/fA	16	500 μV/pA	25	500 mV/nA
i	sensitivity	i	sensitivity	i	sensitivity																																																		
0	2 nV/fA	9	2 μV/pA	18	2 mV/nA																																																		
1	5 nV/fA	10	5 μV/pA	19	5 mV/nA																																																		
2	10 nV/fA	11	10 μV/pA	20	10 mV/nA																																																		
3	20 nV/fA	12	20 μV/pA	21	20 mV/nA																																																		
4	50 nV/fA	13	50 μV/pA	22	50 mV/nA																																																		
5	100 nV/fA	14	100 μV/pA	23	100 mV/nA																																																		
6	200 nV/fA	15	200 μV/pA	24	200 mV/nA																																																		
7	500 nV/fA	16	500 μV/pA	25	500 mV/nA																																																		
RMOD(?) {i}	<p>The RMOD command sets or queries the mode of dynamic reserve. The parameter i selects &lt;Low Noise&gt; (i=0), &lt;Normal&gt; (i=1) or &lt;High Reserve&gt; (i=2).</p>																																																						
OFLT(?) {i}	<p>The OFLT command sets or queries the time constant of filters. The parameter i selects a time constant below.</p> <table><tr><td>i</td><td>time constant</td><td>i</td><td>time constant</td><td>i</td><td>time constant</td></tr><tr><td>0</td><td>10 μs</td><td>7</td><td>30 ms</td><td>14</td><td>100 s</td></tr><tr><td>1</td><td>30 μs</td><td>8</td><td>100 ms</td><td>15</td><td>300 s</td></tr><tr><td>2</td><td>100 μs</td><td>9</td><td>300 ms</td><td>16</td><td>1 ks</td></tr><tr><td>3</td><td>300 μs</td><td>10</td><td>1 s</td><td>17</td><td>3 ks</td></tr><tr><td>4</td><td>1 ms</td><td>11</td><td>3 s</td><td>18</td><td>10 ks</td></tr><tr><td>5</td><td>3 ms</td><td>12</td><td>10 s</td><td>19</td><td>30 ks</td></tr><tr><td>6</td><td>10 ms</td><td>13</td><td>30 s</td><td></td><td></td></tr></table>	i	time constant	i	time constant	i	time constant	0	10 μs	7	30 ms	14	100 s	1	30 μs	8	100 ms	15	300 s	2	100 μs	9	300 ms	16	1 ks	3	300 μs	10	1 s	17	3 ks	4	1 ms	11	3 s	18	10 ks	5	3 ms	12	10 s	19	30 ks	6	10 ms	13	30 s								
i	time constant	i	time constant	i	time constant																																																		
0	10 μs	7	30 ms	14	100 s																																																		
1	30 μs	8	100 ms	15	300 s																																																		
2	100 μs	9	300 ms	16	1 ks																																																		
3	300 μs	10	1 s	17	3 ks																																																		
4	1 ms	11	3 s	18	10 ks																																																		
5	3 ms	12	10 s	19	30 ks																																																		
6	10 ms	13	30 s																																																				
OFSL(?) {i}	<p>The OFSL command sets or queries the low pass filter slope. The parameter i selects &lt;6dB/oct&gt; (i=0), &lt;12dB/oct&gt; (i=1), &lt;18dB/oct&gt; (i=2) or &lt;24dB/oct&gt; (i=3).</p>																																																						
SYNC(?) {i}	<p>The SYNC command sets or queries the status of synchronous filter. The parameter i selects Off (i=0) or On (i=1). The synchronous filtering is turned on only when the reference frequency is less than 20 Hz.</p>																																																						



#### 4.2.4 Output Commands

FPOP(?)i{j}	<p>The FPOP i command sets and queries the output channel on the front panel of SE1201. The parameter i must be set when sending this command. The parameter i selects CH1 (i=1) or CH2 (i=2) as the output channel. The parameter j is used to select the type of output source. More details are as follow.</p> <table><tr><th colspan="2">CH1(i=1)</th><th colspan="2">CH2(i=2)</th></tr><tr><th colspan="2">j Input Type</th><th colspan="2">j Output Type</th></tr><tr><td>0</td><td>R</td><td>0</td><td>R</td></tr><tr><td>1</td><td>X</td><td>1</td><td>X</td></tr><tr><td>2</td><td>Y</td><td>2</td><td>Y</td></tr><tr><td>3</td><td>θ</td><td>3</td><td>θ</td></tr></table>	CH1(i=1)		CH2(i=2)		j Input Type		j Output Type		0	R	0	R	1	X	1	X	2	Y	2	Y	3	θ	3	θ
CH1(i=1)		CH2(i=2)																							
j Input Type		j Output Type																							
0	R	0	R																						
1	X	1	X																						
2	Y	2	Y																						
3	θ	3	θ																						
OEXP(?)i{x,j}	<p>The OEXP i command sets or queries the output offsets and expands. The parameter i must be set and it is used to select the DC output channel. The parameter I selects CH1 (i=1) or CH2 (i=2).</p> <table><tr><th>i</th><th>Parameter</th></tr><tr><td>1</td><td>CH1</td></tr><tr><td>2</td><td>CH2</td></tr></table> <p>The parameter x is used to set the offset and the range is -100 to 100. The parameter j is the output expands with the range of 1≤j≤256.</p> <p>For example, the command OEXP 2,50.00,2 will set the offset to 50.00% and the expand to 2 of the parameter &lt;Y&gt;. The OEXP? i command queries the offset and expand of the parameter corresponding to i. The return strings include the offset and expand and they are separated by comma.</p> <p>For example, the OEXP?2 command returns “50.00,10”. It means the offset of &lt;Y&gt; is 50.00% and expand is 10.</p>	i	Parameter	1	CH1	2	CH2																		
i	Parameter																								
1	CH1																								
2	CH2																								
SLVL (?) {x}	<p>The SLVL command sets or queries the amplitude of the Sine output. The parameter x is the root-mean-square value of the sine output (real number in V). The x is rounded to 0.001V and the range of x is limited from 0.100 to 1.000.</p>																								

#### 4.2.5 Save and Read Settings Commands

SSET i	<p>The SSET i command saves the current setup in setting buffer i (<math>1 \leq i \leq 4</math>). The parameter i selects S1 (i=1), S2 (i=2), S3 (i=3) or S4 (i=4). The setting buffers are retained when the power is off.</p>
RSET i	<p>The RSET i command recalls the saved setup information from buffer i (<math>1 \leq i \leq 5</math>). After executed the RSET i command, the internal parameters will be set as corresponding</p>

	parameter in the setting buffer i. The parameter i selects S1 (i=1), S2 (i=2), S3 (i=3), S4 (i=4) and Default (i=5).
--	----------------------------------------------------------------------------------------------------------------------

#### 4.2.6 Data Read Commands

OUTP(?) {i}	The OUTP? i command queries the value of single parameter. The parameter i selects X (i=1), Y (i=2), R (i=3), $\theta$ (i=4) and Freq (i=5). The value returns in ASCII float number in the unit of volt (V), degree( $^{\circ}$ ) or hertz(Hz).
RALL(?)	The RALL? command queries the values of the five parameters X, Y, R, $\theta$ and Freq. The values return in ASCII float number in the unit of volt (V), degree( $^{\circ}$ ) or hertz(Hz).

#### 4.2.7 Status Read Commands

RSTU(?)	The RSTU? Command queries the status of the gain overload, the input overload and the lock-in sequentially. The result returns sequentially.		
	Status	Return Value	Return Value
	Gain overload	0 (Overload)	1 (None)
	Input overload	0 (Overload)	1 (None)
	Lock-in	0 (Unlock)	1 (Locked)

#### 4.2.8 IDN Commands

*IDN?	The IDN? command queries the ID of the SE1201. The result returns as “SSI LIA-SE1201, SNXXXXXX, VerXXX”. Here, the first is the model name, such as SE1201. The second is the serial number, such as SN000001. The third is the version number, such as Ver1.00.
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## 5 Computer Operation

### 5.1 Install Software

The required software is provided with the CD disk as below in Fig.27.

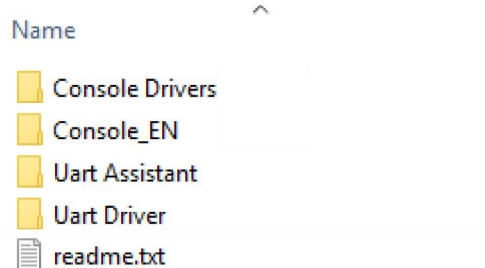


Fig.27 Software files

#### 1. Install the UART to USB Driver

- (1) Double-click "FT232\_drive.exe" in Fig. 28 in the fourth file "Uart Driver" in Fig.27 and then you can see the Fig.29, which shows the installation is running.

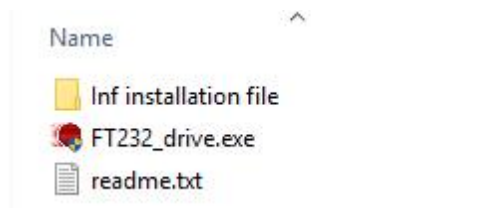


Fig.28 "Uart Driver" files

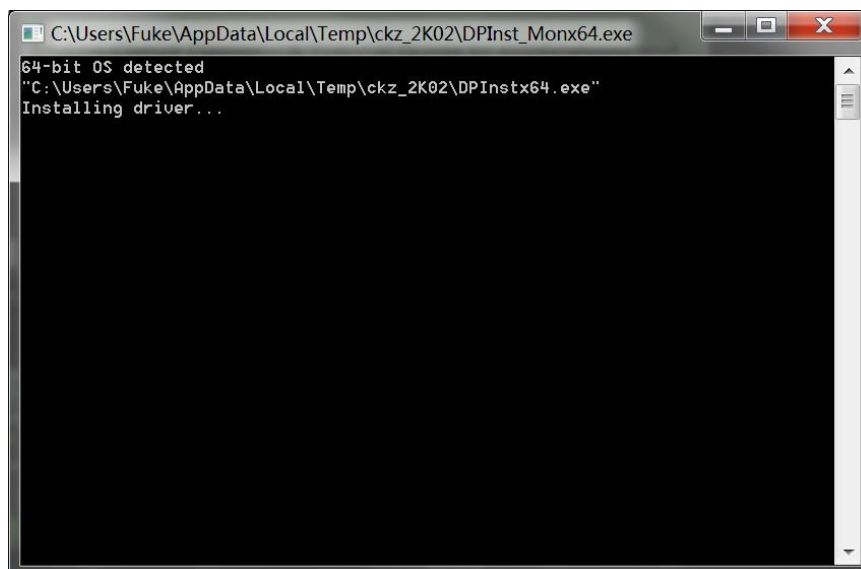


Fig.29 FT232 Driver Installing Interface

- (2) After the installation is finished, you will see the Fig 30. Then press "Enter" key to finish it.

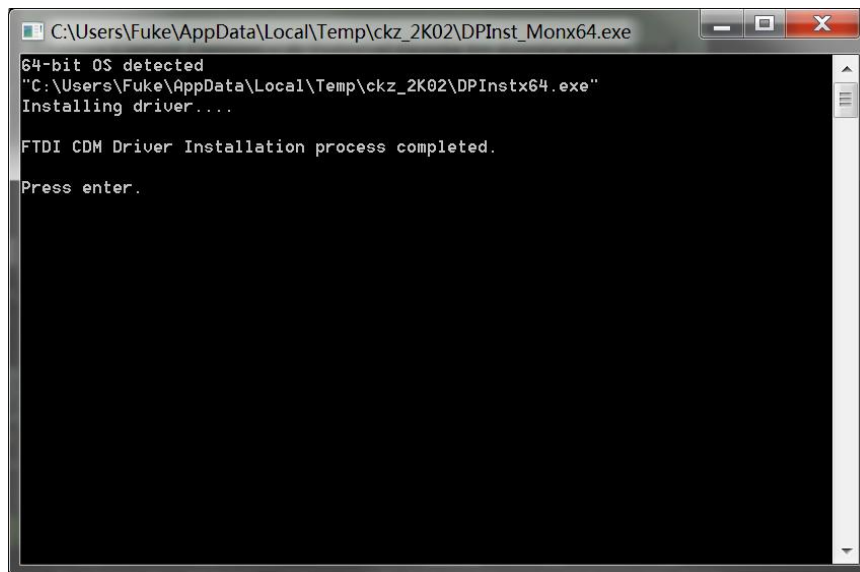


Fig.30 FT232 Driver is installed successfully

Now, use a USB cable to connect the PC and SE1201. If the driver is OK, they will be linked automatically.

Note that if the PC is online, the PC will search the proper driver online when you connect the PC and SE1201. And the installation will run automatically.

If you have already installed the Serial to USB driver, skip this step.

If the installation fails, open “readme.txt” in file “Uart Driver” and use file “inf” to install.

## 2. Install NI LabView 2011 or Higher Version and the VISA Driver

- 1) You need to open the first file “SE1201\_Console Drivers” in Fig.27 and start to install just as shown in Fig 31.
- 2) Double click the file “setup.exe” and start to install the VISA driver of SE1201. Generally, just install it according to the default configuration.
- 3) Note that after the installation is finished, restart the PC to complete the configuration.

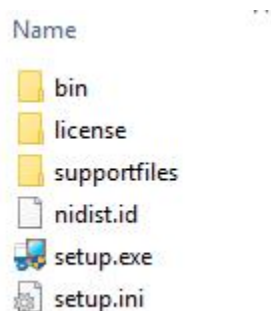


Fig.31 “SE1201\_Console Drivers” File

## 3. Install SE1201\_Console\_EN

- 1) Open the second file “SE1201\_Console\_EN” in Fig 27. This file contains Chinese and English application software and they both can operate in Windows 7/XP.
- 2) Double click the file “SE1201\_Console\_EN.exe” in Fig.32 red box. If the installation is right, and then you will see the Fig.33.
- 3) Now you can configure the SE1201 parameters in PC.



Fig.32 “SE1201\_Console\_EN” File

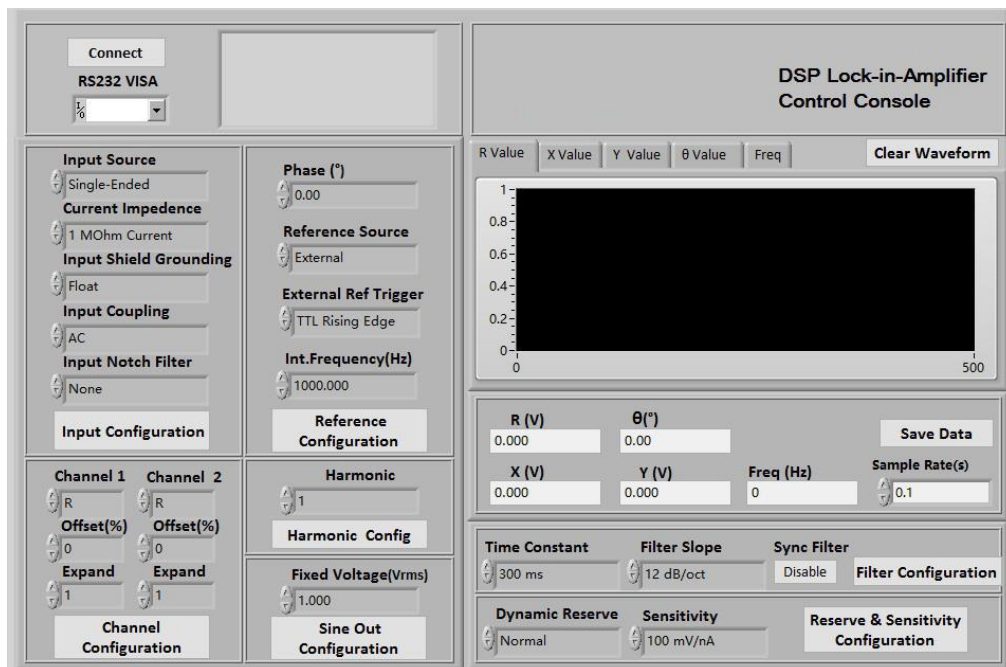


Fig.33 SE1201 Software Interface

## 5.2 How to Use the Software

### 1. Begin to Run

In Fig.34, if you see [Connecting] as (left), it means the program is running. If you see [Connect] as (right), it shows the program is broke down.

You can click the button **Connecting...** to switch between these two statuses.

Note that before the program runs, the Baud rate of the SE1201 should set to 921600bd.



Fig.34 (left) Program is running (right) Program stops

## 2. Connection

This part shows you how to connect the PC and the SE1201.

As is shown in Fig.35, click the button



Fig.35 Current Connection Status

The program begins to run and search for the proper COM automatically. If the connection succeeds, you will see the version information in Fig.36.

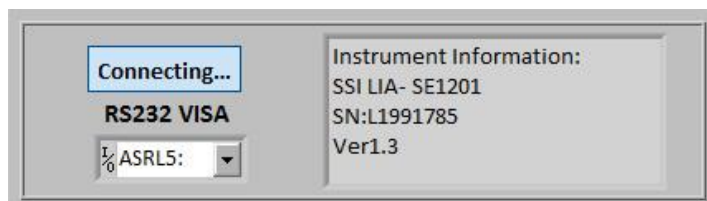


Fig.36 Connection Succeeds

Wait for a few seconds. If the interface pops up a prompt box like Fig.58, it means that the connection between PC and SE1201 fails.

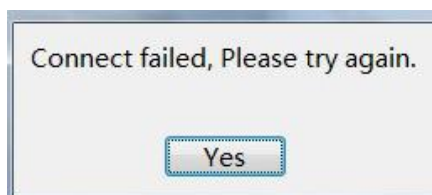


Fig.37 Connection Succeeds

Click the button [YES] to check the status of the connection. Now the right of the status window will display the wrong information, as is shown in Fig.38.

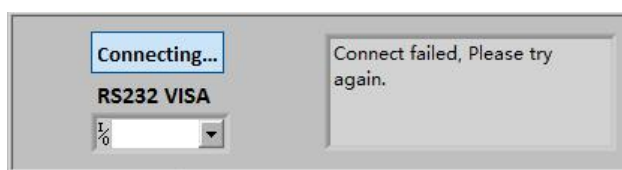







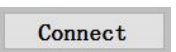
Fig.38 Connection fails and try re-connection

## Two solutions to re-connect:






The first solution:

- Click  at the right side of the option .
  - Click  at the drop-down list.
  - Choose the right COM number. If the COM is right, the connection will success after few seconds.
- Note that when the PC is connected to SE1201 with USB, you can go to “Device Manager” to search “COM and LPT”. In this case, you can know which COM is used to connect currently.
- If the COM is right, wait for a few seconds and the connection status will refresh to Fig.36.

The second solution:

- Click . Wait until it becomes .
- Click  again.
- Repeat the operations 1 and 2 until the connection is successful.

After connection successes, as is shown in Fig.39, the data in red box will be empty and it will restart a new display. It displays the value of R in default.

You can choose      to display the value of X, Y,  $\theta$ , frequency and noise at top of the red box. The software interface will display the parameters of the SE1201 current configuration. You can set other parameters shown on the GUI.

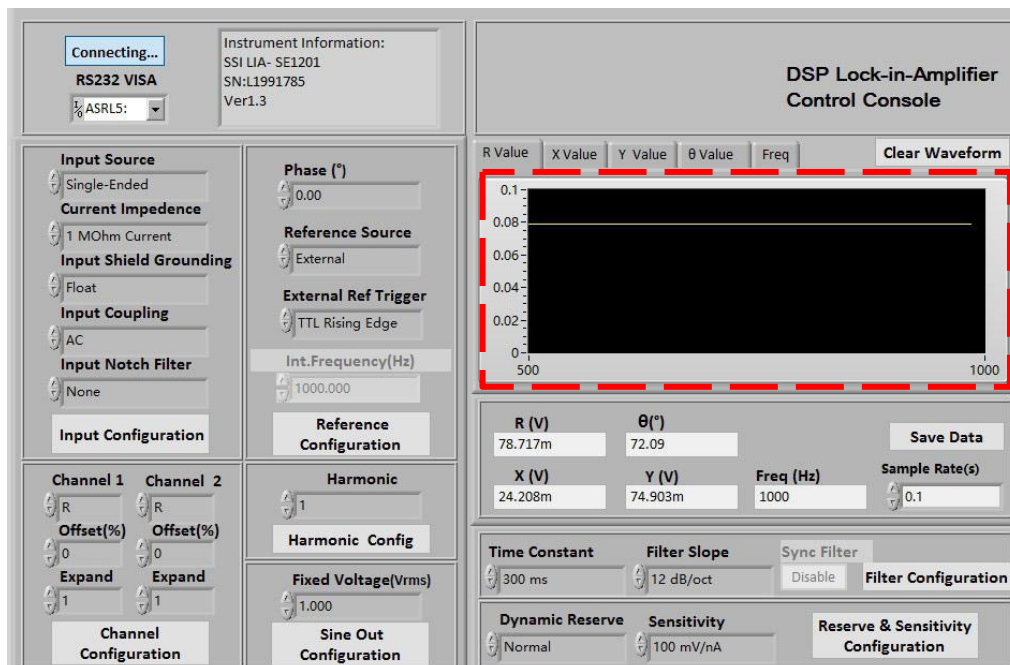


Fig.39 Software Connection Succeeds

## 3. Input Configuration

The program configuration area of input signal is as shown in the red box in Fig.40. The details of the configuration are listed on Table 3.

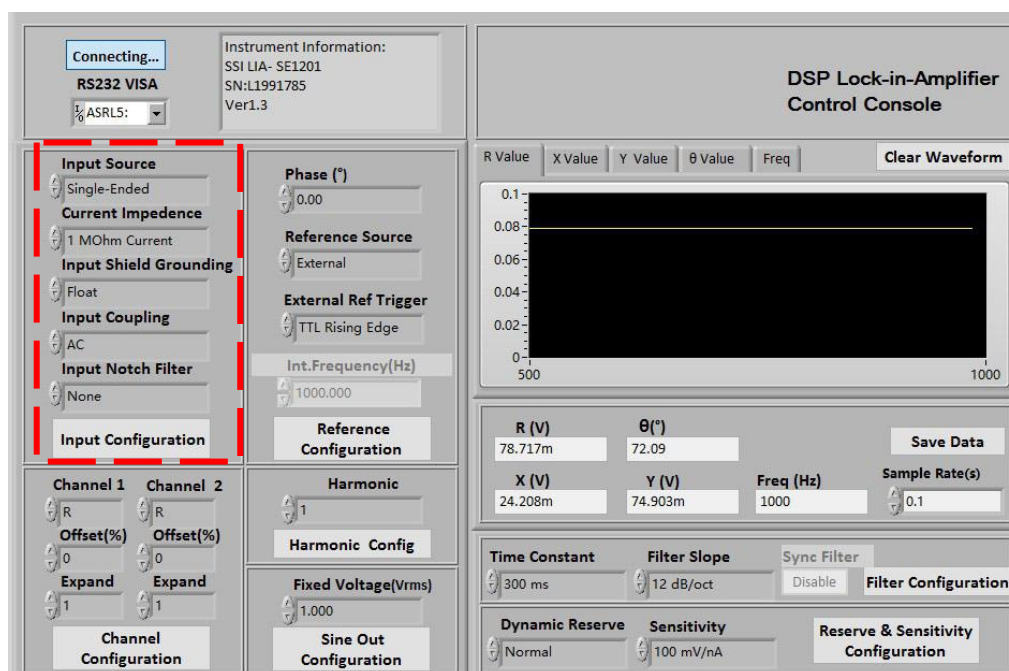


Fig.40 The Configuration Area of Input Signal

Table 3. Input Configuration

Input Source	Single-Ended Voltage
	Differential Voltage
	Current
Current Impedance	1MOhm Current Gain
	100MOhm Current Gain
Input Shield Grounding	Float
	Ground
Input Coupling	AC coupling
	DC coupling
Input Notch Filter	None
	Line Notch
	Both Notch Filters
	2× Line Notch

**Note that:**

- After finishing all the settings, click **Input Configuration** to finish the configuration for input signal. All settings can be changed at the same time and you just need to click this button once.



- After changing the settings, you need to click **Input Configuration** to finish this configuration. Otherwise the settings are void.

#### 4. Reference and Frequency Sweep Configuration

The configuration area of reference signal is shown in the red box in Fig.41. The details of configuration are shown in Table 4.

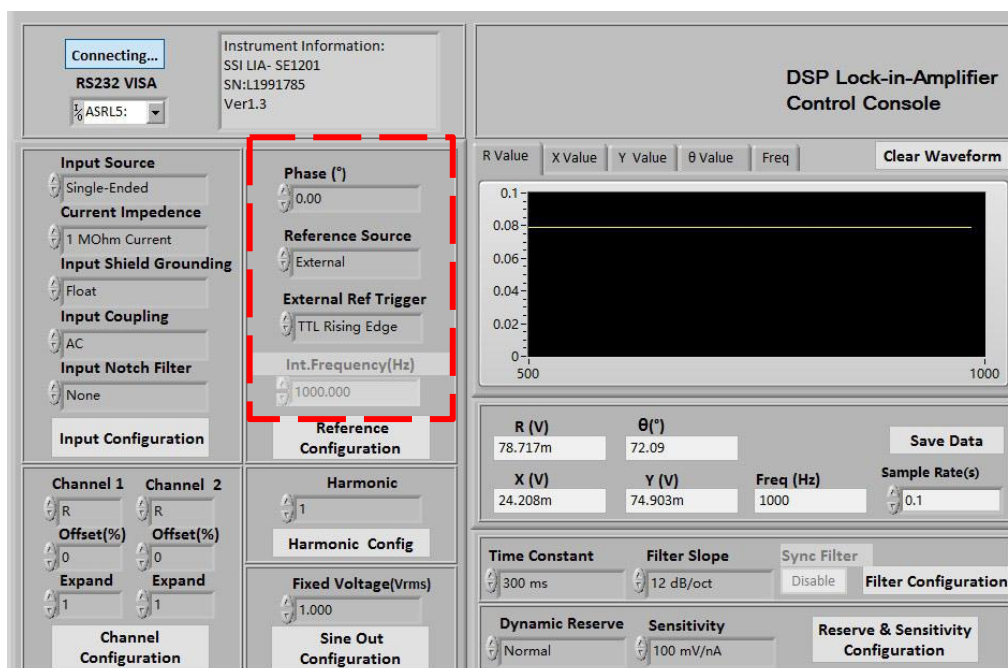


Fig.41 The Configuration Area of Reference Signal

Table 4. Reference Signal Configuration

PHASE	-180° to +180° by one step of 0.01°
Reference Source	External
	Internal
External Ref Trigger	TTL Rising Edge
	Sine Zero Crossing
Int. Frequency	Manually, 1mHz to 120kHz by one-step of 1mHz at least.

#### Note that:

- After finishing all the settings, click the button **Reference Configuration** to finish the configuration for input signal. All settings can be changed at the same time and you just need to click the button once.
- After changing the settings, you need to click **Reference Configuration** to finish this configuration. Otherwise, the settings are void.

## 5. Dynamic Reserve and Sensitivity Configuration

The configuration area of Dynamic Reserve and Sensitivity is in the red box in Fig.42. The details of configuration are listed on the Table 5.

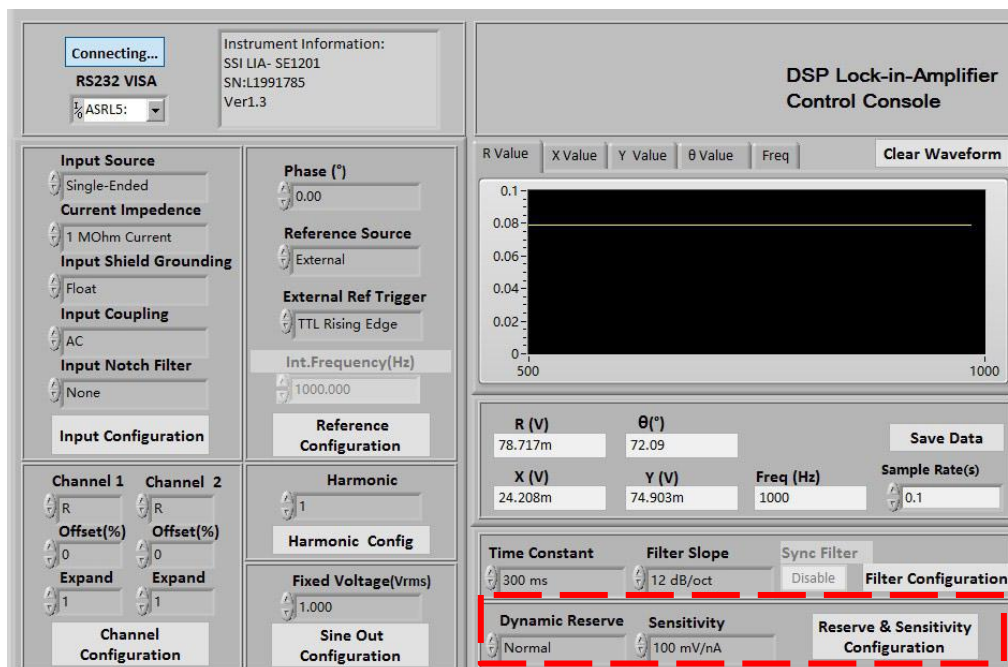




Fig.42 The Configuration Area of Dynamic Reserve and Sensitivity

Table 5. Dynamic Reserve and Sensitivity Configuration

Dynamic Reserve	Low Noise			
	Normal			
	High Reserve			
Sensitivity	2nV/fA	500nV/fA	100μV/pA	20mV/nA
	5nV/fA	1μV/pA	200μV/pA	50mV/nA
	10nV/fA	2μV/pA	500μV/pA	100mV/nA
	20nV/fA	5μV/pA	1mV/nA	200mV/nA
	50nV/fA	10μV/pA	2mV/nA	500mV/nA
	100nV/fA	20μV/pA	5mV/nA	1V/μA
	200nV/fA	50μV/pA	10mV/nA	

### Note that:

- After finishing all the settings, click the button  to finish the configuration for input signal. All settings can be changed at the same time and you just need to click this button once.
- After changing the settings, you need to click  to finish this configuration. Otherwise, the settings are void.

## 6. Harmonic Configuration

The harmonic configuration is in the red box in the Fig.43. The harmonic order is set manually from 1 to 32767. The harmonic frequency is no more than 120 kHz.

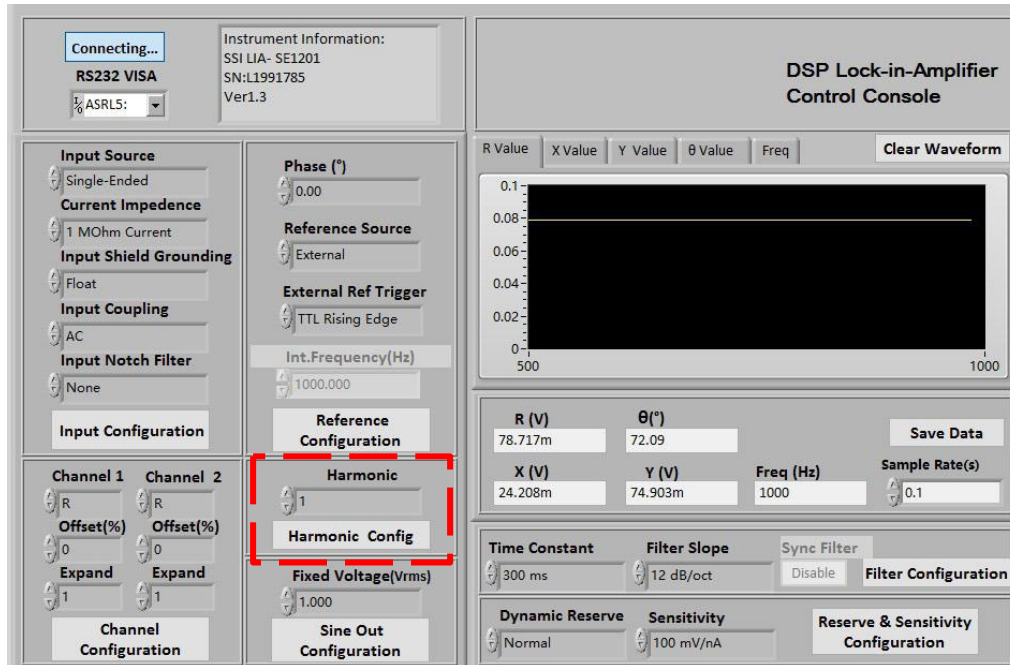


Fig.43 The Configuration Area of Harmonic Configuration

## 7. Filter Configuration

The filter configuration is in the red box in the Fig.44. The details of configuration are shown in Table 6.

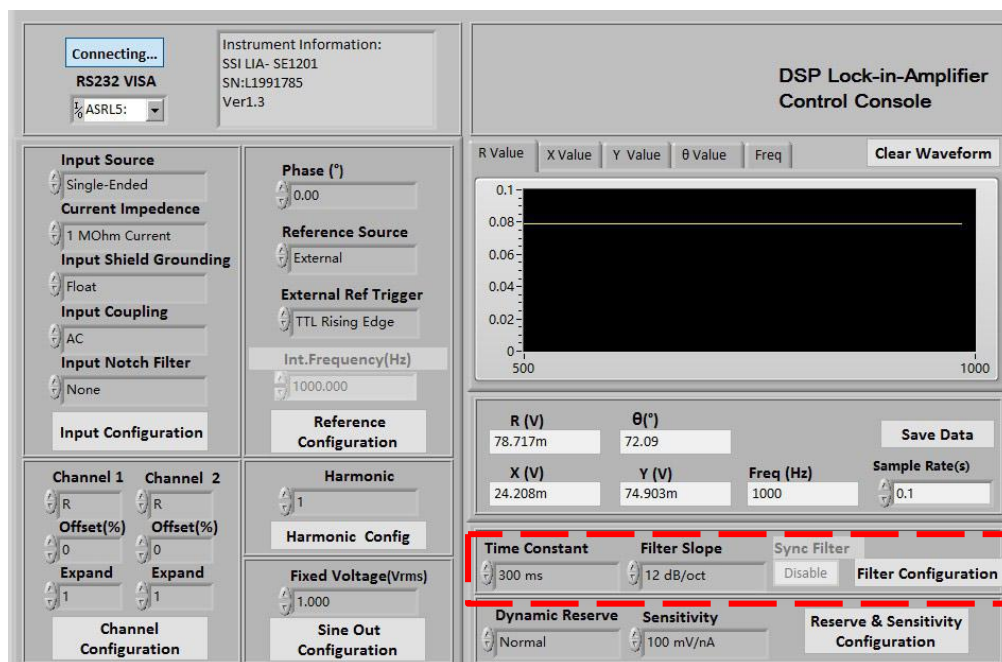

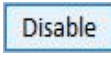


Fig.44 The Configuration Area of Filter Configuration

Table 6. Filter Configuration

Time Constant	10 $\mu$ s	3ms	1s	300s
	30 $\mu$ s	10ms	3s	1000s
	100 $\mu$ s	30ms	10s	3000s
	300 $\mu$ s	100ms	30s	
	1ms	300ms	100s	
Filter Slope	6dB/oct	12dB/oct	18dB/oct	24dB/oct
SYNC Filter	Disable			
	Enable			

Note that:

- The SYNC Filter configuration is controlled by a single button . If you need to turn off the sync filter, click the button and then it changes to  which means the sync filter has been turned off.

## 8. Output Configuration

The output configuration is in the red box in the Fig.45. The details of configuration are shown in Table 7.

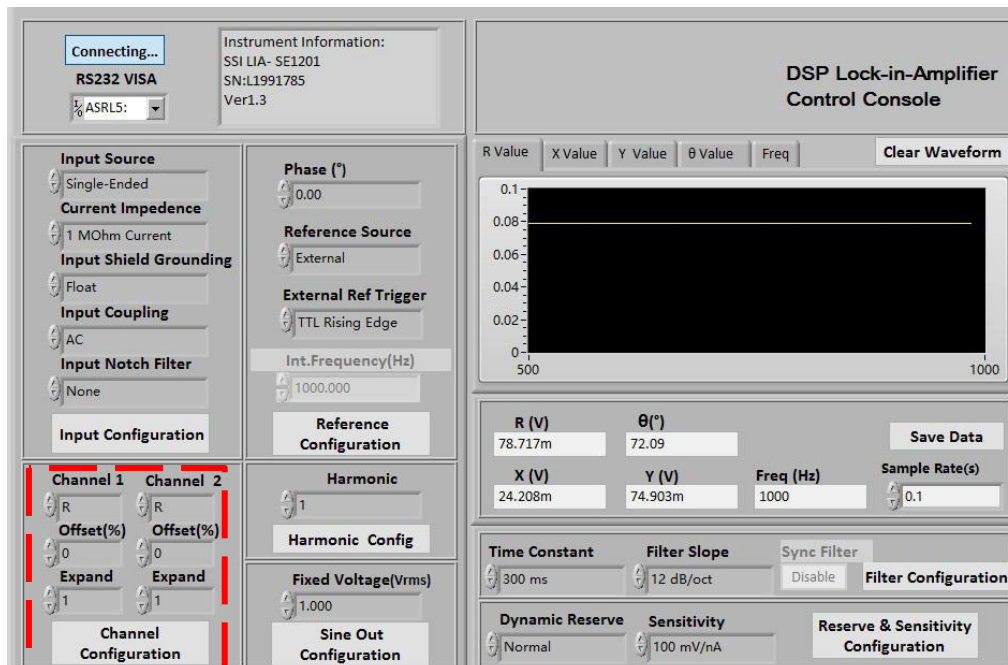


Fig.45 The Configuration Area of Output Channel

Table 7. Output Channels Configuration Options

Channel 1	Choose CH1 to output the required values. The value types contain the X/Y/R/ $\theta$ value of signal.
-----------	--------------------------------------------------------------------------------------------------------

Channel 2	Choose CH2 to output the required values. The value types contain the X/Y/R/ $\theta$ value of signal.
Offset (%)	The range is -100% to +100%, the minimal step is 0.01%, 0.00% in default.
Expand	The range is 1 to 256, 1 in default.

## 9. Sine Out Configuration

The sine out configuration is in the red box in the Fig.46.

The amplitude of the sine out can be set manually from 100 mVrms to 1.000 Vrms. The minimum accuracy is 1 mVrms.

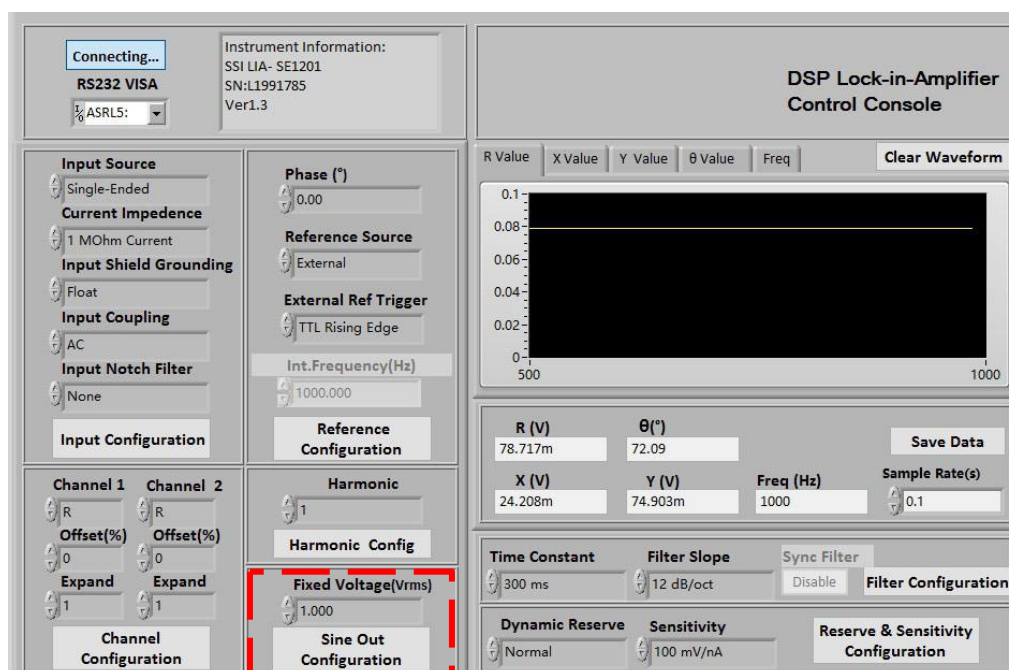


Fig.46 The Configuration Area of Sine Out Channel

## 10. Data Storage

The software has the function of data storage. Users can choose to save the data or not that SE1201 collects in a period. The saved data contains the value of X, Y, R,  $\theta$  and Freq.

The steps for choosing to save data or not:

1. The data is saved in Excel. The file name is "Data\_recorded\_excel.xls". It is saved in the program directory.
2. When the software is executing, click the button **Save Data** in the red box in Fig.47. After clicking this button and it displays **Saving...**. The software is saving the current collected data.



3. Click the button **Saving...** again, and the button status will switch back to **Save Data** again. This means the software stops saving collected data.

4. In box **Sample Rate(s)**, you can modify the sampling rate of the current display and data storage. The input range is 0.1s - 100s.

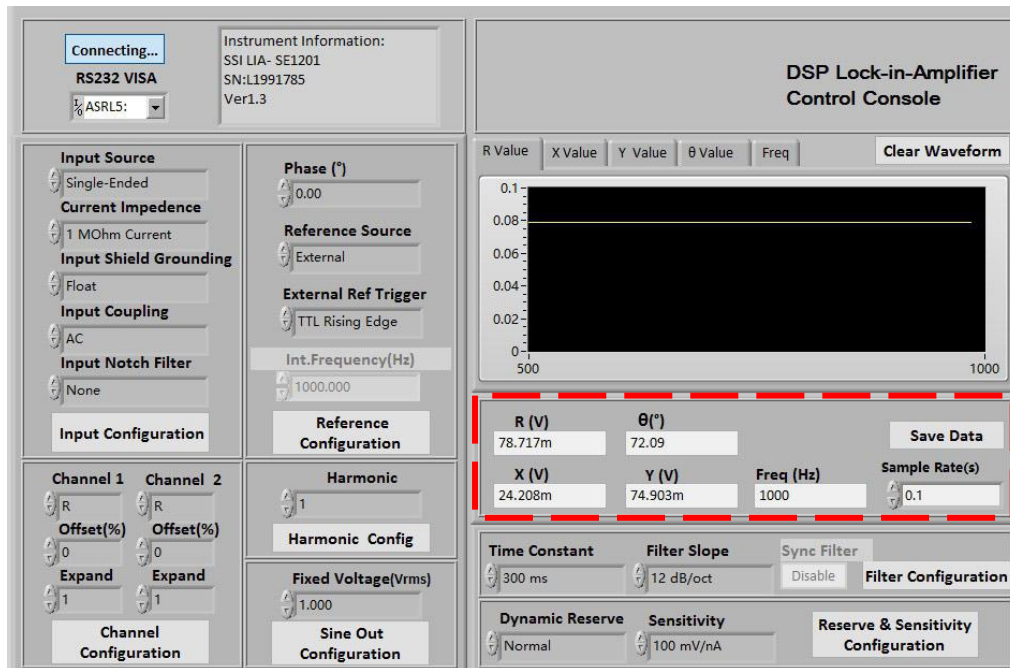


Fig.47 The Configuration Area of Data Storage

### 5.3 Usage Examples

This example will show how to use SE1201 PC software to configure parameters, and observe and record the value of R/X/Y/θ.

First, connect the SE1201 and PC according to the software usage guidance in 5.2 and then you can start to configure.

Suppose that the lock-in amplifier configurations are shown in Table 8.

Table 8. Case Configuration

Input Source	Single-ended voltage input
Input Amplitude	40mV
Input Coupling	AC
Input Notch Filter	None
Dynamic Reserve	Normal
Sensitivity	50mV/nA

Reference Source	External reference, 1000Hz
Reference Signal Trigger Way	TTL rising edge trigger
Phase Shift Angle	0
Time Constant of Low Pass Filter	300ms
Filter Slope	12 dB/oct
Sampling Rate	10Hz

The step to finish the configuration in table 8 are as follows:

1. According to Table 8, choose the following options in “Input Setting”, including “Input Source”, “Input Coupling” and “Input Notch Filter” with other options in default, as is shown in Fig.48. At last, click the button

**Input Configuration** to finish the configurations.

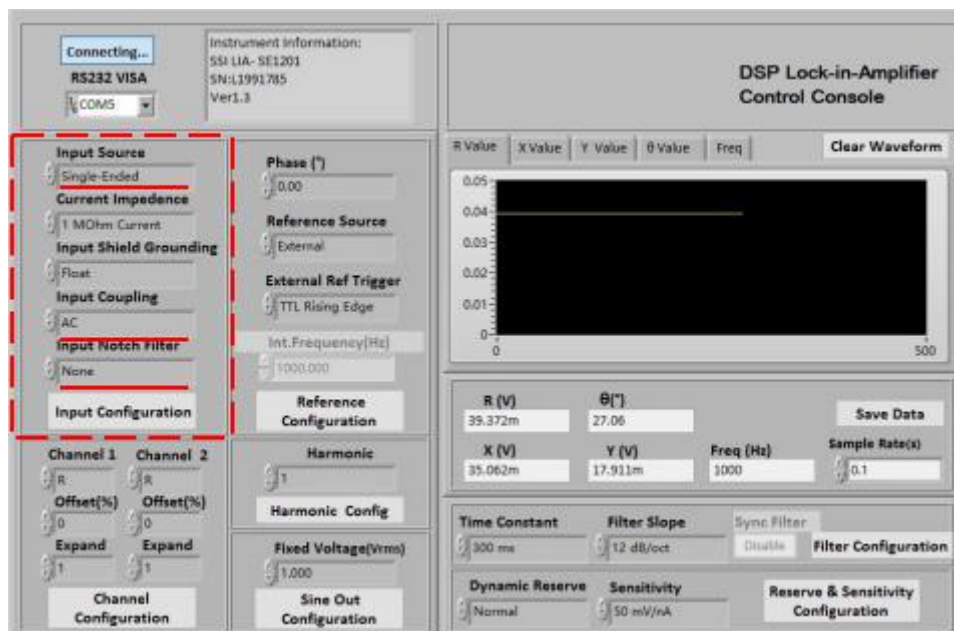


Fig.48 Input Configuration

2. Choose the following options in “Reference Configuration”, including “Phase”, “Reference Source”, “External Ref Trigger” with other options in default, as is shown in Fig.49. At last, click the button **Reference Configuration** to finish the configurations.

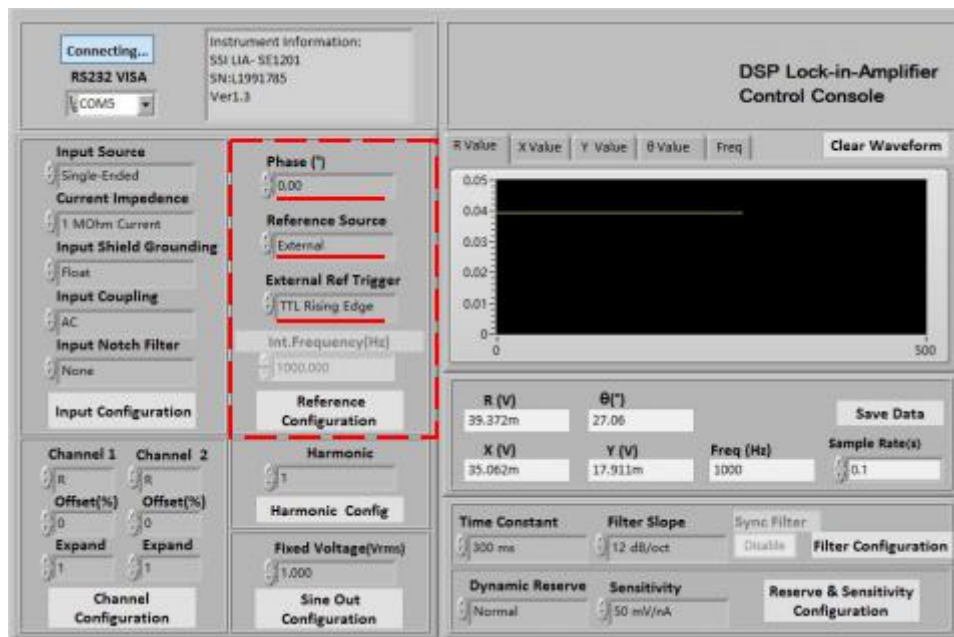


Fig.49 Reference Configuration

3. Choose these two options in “Filter Configuration”, including “Time Constant” and “Filter Slope” with other options in default, as is shown in Fig.50. At last, click the button **Filter Configuration** to finish the configurations.

If you don't use sync filter, do not click the corresponding button [Close] and just keep it. If you use sync filter, click the corresponding button . When this button **Disable** is clicked and it displays “Open”, the SE1201 has started the sync filter function. Click this button again and it will reset to the original status “**Disable**”. This means the SE1201 has closed this function.

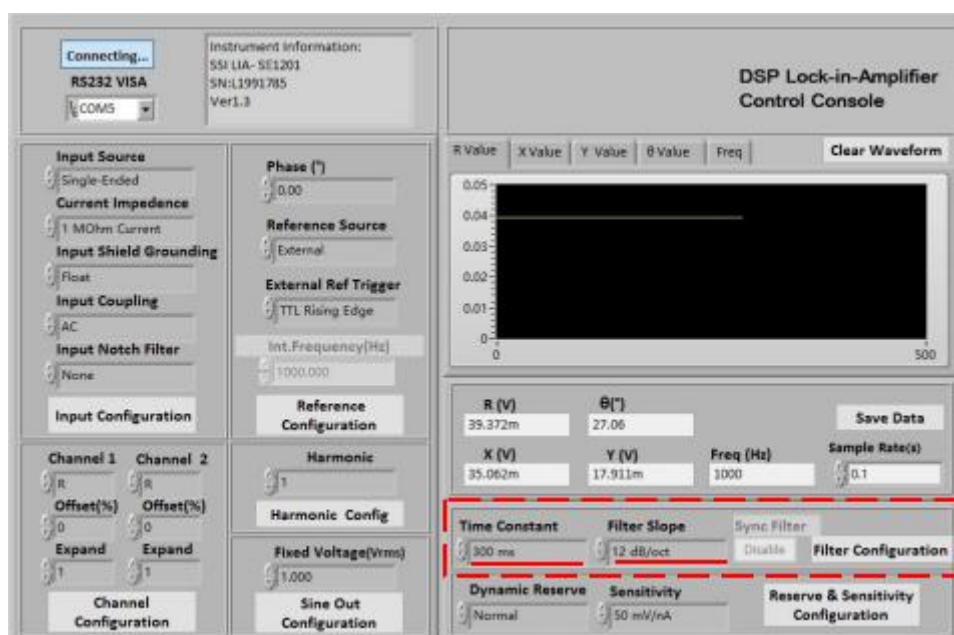


Fig.50 Filter Configuration



4. Choose these two options in “Reserve & Sensitivity Configuration”, including “Dynamic Reserve” and “Sensitivity” with other options in default, as is shown in Fig.51. At last, click the button **Reserve & Sensitivity Configuration** to finish the configurations.

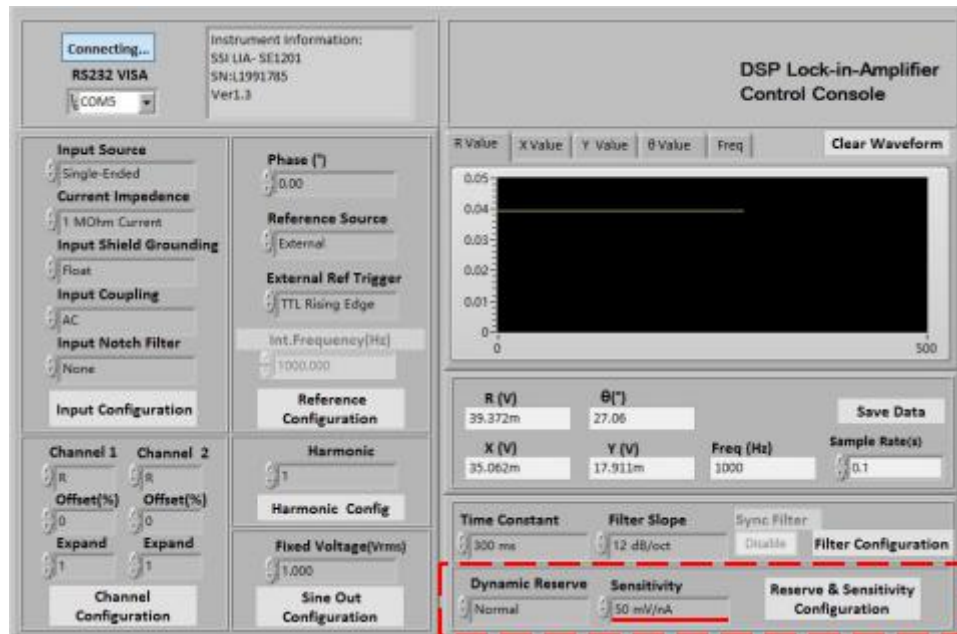


Fig.51 Reserve & Sensitivity Configuration

Compare the two SE1201 interfaces before and after configuration as is shown in Fig.52 and Fig.53, and you will see the configurations are successful.

Sens:100mV	Filter:24dB/oct	Notch: NONE	Input Filter
TC: 300mS	DR:Normal	Sync:OFF	
R = 40.23 mV			Ref Phase
$\theta = -0.95^\circ$			Gain TC
X = 40.22 mV			Disp
Y = -0.67 mV			Channel Output
Overload: NONE	NONE	Freq: 1000.000Hz	Utility
Ref. Source: External	PLL: LOCKED		

Fig.52 <SENS> is 100 mV before configuration

Sens: 100mV	Filter: 24dB/oct	Notch: NONE	Input Filter
TC: 300mS	DR: Normal	Sync: OFF	Cpl: DC
Src: A			Ref Phase
R = 40.23 mV			Gain TC
$\theta = -0.95^\circ$			Disp
X = 40.22 mV			Channel Output
Y = -0.67 mV			Utility
Overload: NONE	NONE	Freq: 1000.000Hz	
Ref. Source: External	PLL: LOCKED		

Fig.53 <SENS> is 50 mV before configuration

5. These configurations of SE1201 are finished. Other options are in default. Then uses can collect and save data.

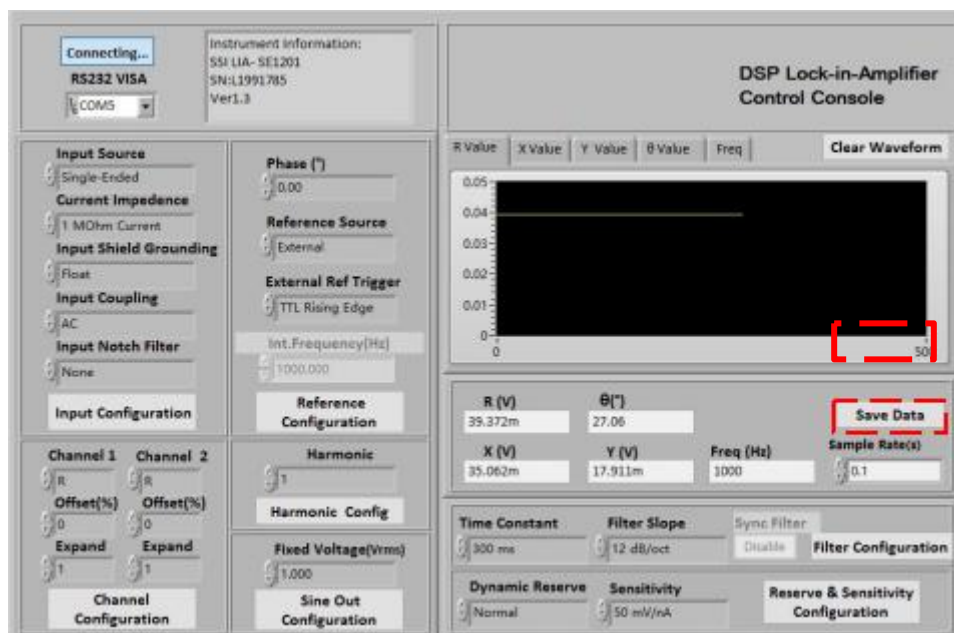


Fig.54 The data saving is paused

As is shown in Fig.54, click the button **Save Data** in the red box. When this button is clicked and it displays " **Saving...** ". This means the SE1201 is saving data, as is shown in Fig.55.



Fig.55 The data saving is executing

## 6 Performance Tests

Introduction	The performance tests are designed for users to prove that the SE1201 can operate normally and enhance users' confidence to our instrument. Each test can be recorded on the Performance Test Record form at the final section of this chapter.
Serial Number	If you have any questions and need to contact us, please offer the serial number of your unit. You can find the serial number on the CD box, the package box or the backside of your unit. You can also check the serial number at <Info> on the screen when the unit is powered on.
Firmware Revision	The firmware revision number is shown at <Info> of <Utility> on the screen when the unit is powered on.
Warm Up	Due to the temperature drift of chips, it is best to warm up the instrument for some time (30-60 minutes) in order to reduce measurement error.
Test Record	At the end of this section, there is a performance test record. It is necessary to make a copy of it before filling in the record. This record will allow you to determine whether the tests pass or fail and also preserve a record of the tests.
If a Test Fails	<p>If a test fails, you should check the settings and connections of any external equipment and internal equipment. If possible, verify its operation with a DVM, scope or other pieces of test equipment. After checking the settings, repeat this test from warm up and make sure that the test is performed correctly.</p> <p>If the test continues to fail, contact us for further instructions. Make sure that you have the unit's serial number and firmware revision code handy. Have the test record on hand as well.</p>
Necessary Equipment	<p>The following equipment is necessary to complete the performance tests.</p> <p>The suggested equipment or its equivalent should be used.</p>

### 1. Function Signal Generator

Freq Range	1 Hz to 1 MHz
Freq Accuracy	Better than 5 ppm
Amplitude Accuracy	0.2 dB from 1 Hz to 120 kHz
Spurious	$\leq -55$ dBc
TTL SYNC	Available
Output Setup	50 $\Omega$ or High Z
Recommended	AGILENT 33250A

### 2. Digital Voltmeter

Voltage Range	$\geq 20$ V, 4 1/2 digits
---------------	---------------------------

Accuracy	$\leq 0.005 \%$
Recommended	KEITHLEY 2100

### 3. DC Voltage Source

Voltage Range	$\geq 10 \text{ V}$
Accuracy	$< 10\text{mVpp}$
Recommended	RIGOL DP831A

### 4. Feedthrough Terminations

Impedance	$50 \Omega$
-----------	-------------

**Front Panel Display Test** First, turn on the power switch on the rear panel to start the device. Second, check whether the display is lighted or not. Third, check whether there are bad pixels on the display. End the display test.

**Keypad Test** After the device is started, press any button and you will hear “Di” sound once. Then, try to press every button to check whether the display change to the corresponding setting. Finally, press <Sensitivity> and spin the knob to check whether the knob is OK.

## 6.1 Self-Test

The self-test checks the lock-in hardware. This test should be done before any other performance tests.

### Device

No external device is required in this test.

### Steps

1. Open the power switch on the rear panel to start the lock-in amplifier.
2. Observe the device, and check whether the screen, keyboard and cooling fan is OK.
3. Record the test results in the Performance Test Record.

## 6.2 DC Offset

This test measures the DC offset of the input.

### Device

Connect a  $50\Omega$  BNC cable to the A/I input. This shorts the input so the lock-in’s own DC offset will be measured.

### Steps

1. Turn the lock-in off and on to restart it.
2. Press the buttons in the following sequence:

<Ref. Source> Set to <Internal>

<Ref. Frequency> Set to 1Hz

<Sensitivity> Set to <1mV> through the spinning knob

3. Wait 10 seconds, then record the value of R.

4. Change the setting:

<Coupling> Set to <DC>

5. Wait 10 seconds, then record the value of R.

6. End the test and fill the result into the performance test form.

### 6.3 Common Mode Rejection

This test measures the common mode rejection of the lock-in.

#### Device

Use the internal oscillator sine output to provide the signal.

Connect the [SINE OUT] to both A and B inputs of the lock-in.

Use equal length cables from A and B to a BNC TEE.

Connect the cable from the [SINE OUT] to the TEE. Do not use any termination.

#### Steps

1. Turn the lock-in off and on to restart it.

2. Press the buttons in the following sequence:

<Sensitivity> Set to <1 V> through the spinning knob

<Sine Output> Set to <1.000 V> through the spinning knob

<Ref. Source> Set to <Internal>

<Ref. Frequency> Set to 100 Hz

3. Wait until <R> is steady and <R> should be 1Vrms (within 3% error)

4. Press the buttons in the following sequence:

<Coupling> Set to <DC>

<Source> Set to <A-B>

<Sensitivity> Set to <200  $\mu$ V> through the spinning knob

5. Wait 10 seconds, and then record the value of R.

6. End the test. The common mode rejection equals to  $20\lg(1/R)$ , where R is in Volts(V). Fill the results in the performance test form.

### 6.4 Amplitude Accuracy and Flatness

This test measures the amplitude accuracy and frequency response.

## Device

Use the function signal generator to provide an accurate frequency and a sine wave.

Use one cable with BNC connector to connect the output of the function signal generator to the A input of the lock-in. Use another cable with BNC connector to connect the reference output of the function signal generator to the REF IN of the lock-in.

Set the function signal generator to:

Function	Sine
Frequency	1 kHz
Amplitude	1 Vrms
Offset	0 V
Output	High Z
Sweep	off
Modulation	none

## Steps

1. Turn the lock-in off and on to restart it.
2. Set <Filter> to 24 dB/oct.
3. Amplitude accuracy is verified at 1kHz and various sensitivities. Set the sensitivity of the lock-in and the amplitude of the function signal generator in the following sequence:

Sensitivity	Amplitude
1 V	1.0000 Vrms
200 mV	200.00 mVrms
100 mV	100.00 mVrms
20 mV	20.000 mVrms
10 mV	10.000 mVrms

- a) Set the function signal generator to the amplitude shown above.
  - b) Set <Sensitivity> of the lock-in.
  - c) Wait 10 seconds, then record <R>, then test the next group of the sensitivity-amplitude.
  - d) Repeat the steps from 3)-a) to 3)-c) until the Sensitivity-Amplitude test is completed.
4. Frequency response is checked at frequencies above 1kHz. Set the frequency in the following sequence:

Test Frequency
24 kHz
48 kHz
72 kHz
96 kHz
120 kHz

- a) Set <Sensitivity> of the lock-in to <200 mV>.

- b) Set the frequency of the function signal generator to 1 kHz and the amplitude to 200.00mVrms.
  - c) Set the frequency of the function signal generator in the upper sequence.
  - d) Wait 10 seconds, then record <R>, then test the next frequency.
  - e) Repeat from 4)-c) to 4)-d) until all the frequencies are tested over.
5. End the test and fill the results in the performance test form.

## 6.5 Amplitude Linearity

This test measures the amplitude linearity. It tests how accurately the lock-in measures a signal smaller than full scale.

### Device

Use a function signal generator to provide an accurate frequency and a sine wave.

Use a cable with BNC connector to connect the output of the function signal generator to the A/I input of the lock-in. Use another cable with BNC connector to connect the reference output of the function signal generator to the REF IN of the lock-in.

Set the function signal generator to:

Function	Sine
Frequency	1 kHz
Amplitude	1 Vrms
Offset	0 V
Output	High Z
Sweep	off
Modulation	none

### Steps

1. Turn the lock-in off and on to restart it.
2. Set <Filter> to <24 dB/oct> and <Sensitivity> to <1 V>.
3. The Amplitude of the function signal generator should be 1kHz at various amplitudes. Set the amplitude in the following sequence:

Amplitude  
1.0000 Vrms  
100.00 mVrms  
10.000 mVrms

- a) Set the output amplitude of the function signal generator.
- b) Wait 10 seconds, then record <R>, then test next amplitude.
- c) Repeat from 3)-a) to 3)-b) until all amplitudes are tested over.



4. End the test and fill the results in the performance test form.

## 6.6 Frequency Accuracy

This test measures the frequency accuracy of the lock-in.

### Device

Use the function signal generator to provide the reference signal.

Use one cable with BNC connector to connect the reference signal of the function signal generator to the REF IN of the lock-in.

### Steps

1. Turn the lock-in off and on to restart it.
2. Set the frequency of the function signal generator to 10 kHz.
3. Wait until <PLL: UNLOCK> changes to <PLL: LOCKED>, then record <Freq>.
4. End the test and fill in the performance test form.

## 6.7 Sine Output Amplitude Accuracy and Flatness

This test measures the amplitude accuracy and frequency response of the internal oscillator SINE OUT.

### Device

Use a 1 meter length cable with BNC connector to connect the SINE OUT to the A/I of the lock-in.

### Steps

1. Turn the lock-in off and on to restart it.
2. Set <Sensitivity> to <1 V> and <Ref. Source> to <Internal>.
3. The frequency of the internal oscillator should be 1kHz steadily. Set <Sensitivity> and the amplitude of the SINE OUT in the following sequence:

Sensitivity	Sine Output
-------------	-------------

1 V	0.800 Vrms
-----	------------

500 mV	0.400 Vrms
--------	------------

200 mV	0.160 Vrms
--------	------------

- a) Set the amplitude of <SINE OUT>.
- b) Set <Sensitivity>.
- c) Wait 10 seconds, then record <R>, then test next group of Sensitivity-Sine Output.

4. Repeat from 3)-a) to 3)-c) until all the Sensitivity-Sine Output are tested over. Frequency response is checked at frequencies above 1 kHz. Set <Ref. Frequency> in the following sequence:

Test Frequencies

24 kHz

48 kHz

72 kHz

96 kHz

120 kHz

- a) Set <Sensitivity> to <1 V>.
- b) Set the amplitude of the SINE OUT to <0.800Vrms>.
- c) Set <Ref. Frequency> in the upper sequence.
- d) Wait 10 seconds, then record <R>, then test next frequency.
- e) Repeat from 4)-c) to 4)-d) until all the frequencies are tested over.

5. End the test and fill results in the performance test form.

## 6.8 DC Outputs

This test measures the DC accuracy of the DC outputs of the lock-in.

### Device

Use a DVM to measure the DC output of the lock-in.

Connect a 50  $\Omega$  BNC termination to the A/I input of the lock-in.

### Steps

1. Turn the lock-in off and on to restart it.
2. Set <Ref.Source> to <Internal>.
3. Use a cable to connect CH1 or CH2 to the DVM and set the full scale of the DVM to 19.999 V.
4. Set <Offset> of <Channel Output> in the following sequence:

Offset (%)

100.00

50.00

0.00

-50.00

-100.00

5. Waiting for 10 seconds and record the reading of the DVM. Then, test next offset.
6. Repeat steps 4) to 5) until all the offset is tested over for CH1 and CH2.

## 6.9 Input Noise

This test measures the input noise of the lock-in.

### Device

Connect a 50  $\Omega$  BNC termination to the A/I input of the lock-in. This grounds the input so the lock-in's own noise is measured.

### Steps

1. Turn the lock-in off and on to restart it.
2. Set the parameters in the following sequence:
 

<Ref. Source>	Set to <Internal>
<Ref. Frequency>	Set to 997 Hz
<Sensitivity>	Set to <100 nV> through the spinning knob
<Reserve>	Set to <Low>
<Filter>	Set to <24 dB/oct>
<Disp>	Check the result
3. Wait until the reading is steady, and then record the maximum value of noise.
4. End the test and fill the result in the performance test form.

<b>SE1201 Performance Test Record</b>	
<b>Serial Number</b>	<b>Tested By</b>
<b>Firmware Revision</b>	<b>Date</b>
<b>Equipment Used</b>	
<b>1. Self Tests</b> <div style="display: flex; justify-content: space-around; margin-top: 10px;"> <span>Pass</span> <span>Fail</span> </div>	

2. DC Offset				
Input Coupling		Reading		Upper Limit
AC				0.500mV
DC				0.500mV
3. Common Mode Rejection				
Frequency		Reading		Upper Limit
100Hz				30μV
4. Amplitude Accuracy and Flatness				
Sensitivity	Amplitude	Lower Limit	Reading	Upper Limit
1V	1.0000Vrms	0.9800V	_____	1.0200V
200mV	200.00Vrms	198.99mV	_____	202.00mV
100mV	100.00Vrms	98.00mV	_____	102.00mV
20mV	20.000Vrms	19.60mV	_____	20.400mV
10mV	10.000Vrms	9.800mV	_____	10.200mV
Sensitivity	Amplitude	Lower Limit	Reading	Upper Limit
200mV	24kHz	196mV	_____	204mV
200mV	48kHz	196mV	_____	204mV
200mV	72kHz	196mV	_____	204mV
200mV	96kHz	196mV	_____	204mV
200mV	120kHz	196mV	_____	204mV
5. Amplitude Linearity				
Sensitivity	Amplitude	Lower Limit	Reading	Upper Limit
1V	1.0000Vrms	0.9900V	_____	1.0100V
	100.00Vrms	0.0990V	_____	0.1010V
	10.000Vrms	0.0099V	_____	0.0101V
6. Frequency Accuracy				
Frequency	Lower Limit	Reading		Upper Limit
10kHz	9.990kHz			10.010kHz
7. SINE OUT Amplitude and Flatness				
Sensitivity	SINE OUT Ampl.	Lower Limit	Reading	Upper Limit
1V	0.800Vrms	0.776V	_____	0.824V
500mV	0.400Vrms	388.00mV	_____	412.00mV
200mV	0.160Vrms	155.20mV	_____	164.80mV
SINE OUT Ampl.	Frequency	Lower Limit	Reading	Upper Limit
0.800Vrms	24kHz	0.776V	_____	0.824V
0.800Vrms	48kHz	0.776V	_____	0.824V

0.800Vrms	72kHz	0.776V	_____	0.824V
0.800Vrms	96kHz	0.776V	_____	0.824V
0.800Vrms	120kHz	0.776V	_____	0.824V
<b>8. DC Outputs</b>				
Output	Offset	Lower Limit	Reading	Upper Limit
CH1	100.00	4.850V	_____	5.150V
	50.00	2.376V	_____	2.625V
	0.00	-0.050V	_____	0.050V
	-50.00	-2.625V	_____	-2.375V
	-100.00	-5.150V	_____	-4.850V
Output	Offset	Lower Limit	Reading	Upper Limit
CH2	100.00	4.850V	_____	5.150V
	50.00	2.376V	_____	2.625V
	0.00	-0.050V	_____	0.050V
	-50.00	-2.625V	_____	-2.375V
	-100.00	-5.150V	_____	-4.850V
<b>9. Input Noise</b>				
Frequency	Sensitivity	Reading	Upper Limit	
997Hz	100nV		15nV/√Hz	

## 7 Operation Examples

### 7.1 Simple Signal Measurements

This example will show how the SE1201 measure the value of R, X, Y,  $\theta$ . You need two BNC cables to input the measurement signal and the reference signal. In this case, we use the function signal generator to generate a 80mVrms, 1kHz sine signal and use the SE1201 to measure it. The steps are below:

#### Measure a Sine Signal

1. Disconnect all cables from the lock-in. Connect the power source and then turn on the power switch. The system is in default now.
2. Use a BNC cable to connect the output of the function signal generator and the A/I input of the SE1201. Use another BNC cable to connect the reference signal of the function signal generator and the REF IN of the SE1201, as is shown in Fig.57.

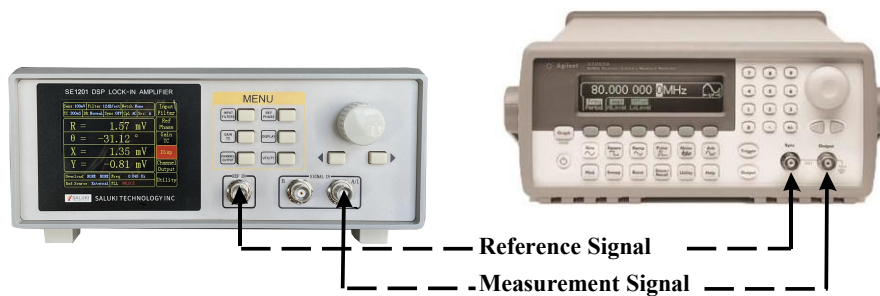


Fig.57 Signal Cable Connection Diagram

3. Turn on the function signal generator and set “Function: Sine”, “Amplitude: 80mVrms”, “Frequency: 1kHz”, “Output Impedance: High Z”, as is shown in Fig.58.

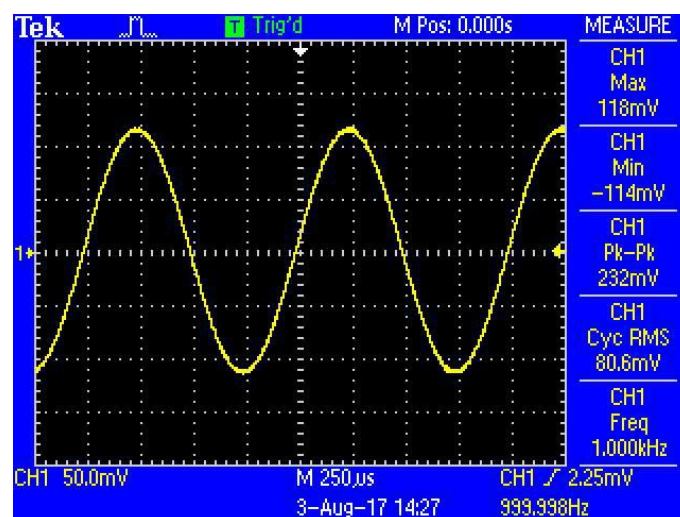


Fig.58 Parameters of Measured Signal

4. Turn on the output of the function signal generator and check whether the scale is overload by watching <Overload> in Fig.59.

Sens: 100mV	Filter: 24dB/oct	Notch: NONE	Input
TC: 300mS	DR: Normal	Sync: OFF	Filter
Cpl: AC	Src: A		
R =	45.456mV		Ref
$\theta$ =	- 0.456°		Phase
X =	45.456mV		Gain
Y =	0.456mV		TC
			Disp
			Channel
			Output
Overload: NONE NONE	Freq: 1000.000Hz		Utility
Ref. Source: External	PLL: LOCKED		

Fig.59 The Monitoring Bar of Main Interface

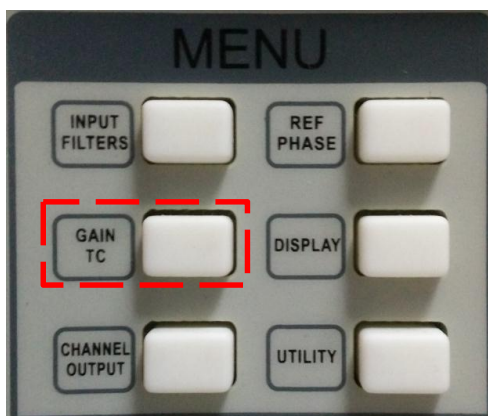
Note that if the input of the preamplifier is overload, it shows <Overload: **INPUT** NONE>. If the output is overload, it shows <Overload: NONE **GAIN**>. If both the input and the output are overload at the same time, it shows <Overload: **INPUT GAIN**>.

### How to Adjust <Sensitivity>

When the input of the preamplifier is overload, you should decrease the output amplitude of the function signal generator. If the output is overload, you should increase the sensitivity of the SE1201. The default sensitivity is <100 mV>. So in this case it will not overload. If you need to adjust the sensitivity, you should take the steps below.

1. Press [GAIN/TC] in front panel and then enter the submenu shown in Fig.60.

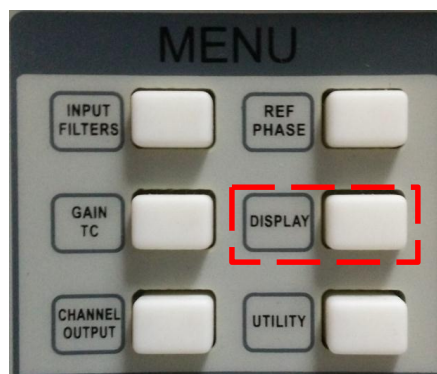
Press [Soft Key 1] to choose <Sensitivity> and then it will be highlighted. Spin the knob to change the value of sensitivity so that there is no overload and the full scale is the maximum. In this case, we set the parameters as Fig.60. Then SE1201 measures the sine signal and the result is  $R=80.08\text{ mV}$ ,  $\theta=0.18^\circ$ .



R = 12.456 mV	$\theta$ = 0.46°	Input Filter
X = 12.456 mV	Y = -0.456 mV	Ref Phase
Sens: 100 mV		Gain TC
DR: Normal		Disp
TC: 300 mS		Channel Output
Filter: 24 dB/oct		Utility
Sync: OFF		
Overload: NONE NONE	Freq: 1000.000Hz	
Ref. Source: External	PLL: LOCKED	

Fig.60 GAIN/TC Menu Interface

2. Press [DISPLAY] as below to see <X>, <Y>, <R> and < $\theta$ > as Fig.61.



Sens: 100mV	Filter: 24dB/oct	Notch: NONE	Input Filter
TC: 300mS	DR: Normal	Sync: OFF	Ref Phase
	Cpl: AC	Src: A	Gain TC
R = 45.456mV			Disp
$\theta$ = - 0.456°			Channel Output
X = 45.456mV			Utility
Y = 0.456mV			
Overload: NONE NONE	Freq: 1000.000Hz		
Ref. Source: External	PLL: LOCKED		

Fig.61 [DISPLAY] Menu Interface

3. Press any other buttons except [DISPLAY] to see <X>, <Y>, <R> and < $\theta$ > at the upper region of the display as Fig.62.



R = 12.456 mV	$\theta = 0.46^\circ$	Input Filter
X = 12.456 mV	Y = -0.456 mV	
Sens: 100 mV		Ref Phase
DR: Normal		Gain TC
TC: 300 mS		
Filter: 24 dB/oct		Disp
Sync: OFF		Channel Output
Overload: NONE NONE	Freq: 1000.000Hz	Utility
Ref.Source: External	PLL: LOCKED	

Fig.62 Monitoring Bar Display

## 7.2 Harmonics Measurements

This example will show how to measure harmonic component of the input signal. You need two BNC cables to input the measured signal and the reference signal. Use the function signal generator to provide a 80mVrms, 1 kHz square wave and then measure the first and third harmonic with the SE1201. The steps are below.

1. Disconnect all cables from the lock-in. Connect the power source and then turn on the power switch. The system is in default.
2. Use a BNC cable to connect the output of the function signal generator and the A/I input of the SE1201. Use another BNC cable to connect the reference signal of the function signal generator and the REF IN of the SE1201, as is shown in Fig.63.

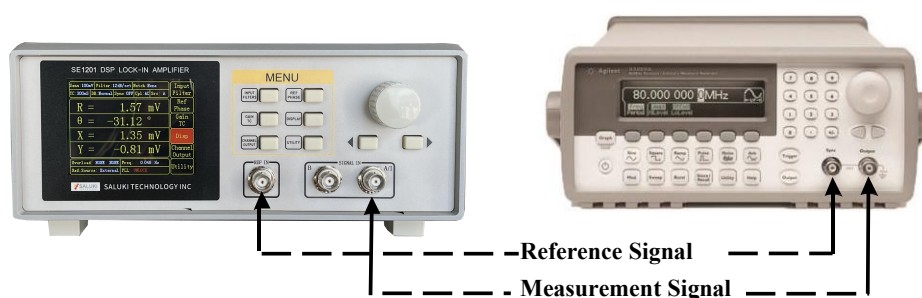


Fig.63 Signal Cable Connection Diagram

3. Turn on the function signal generator and set “Function: Square”, “Amplitude: 80mVrms”, “Frequency: 1 kHz”, as is shown in Fig.64.

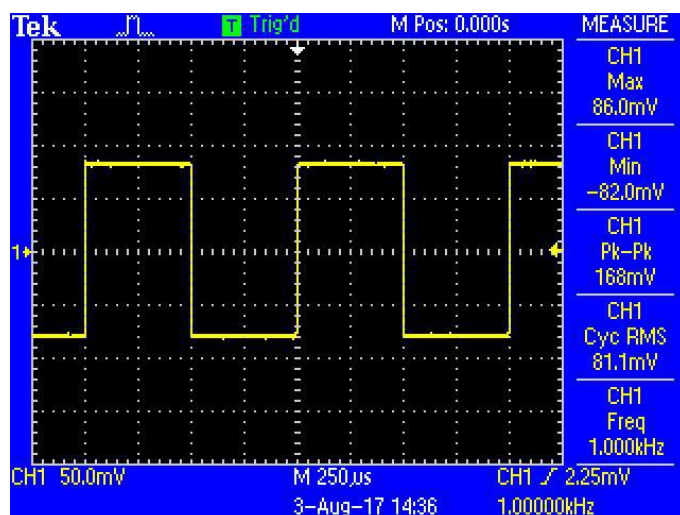


Fig.64 Measured Signal Parameter

4. Press [REF PHASE] in front panel and enter the corresponding submenu, as is shown in Fig.66.

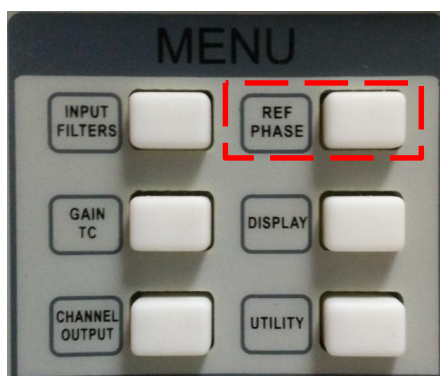


Fig.65 [REF PHASE] Submenu

R = 79.84 mV	$\theta = 0.20^\circ$	Input Filter
X = 79.84 mV	Y = 0.28 mV	Ref Phase
Phase: + 0.00°		Gain TC
Ref. Source: External		Disp
Freq: 1000.000Hz		Channel Output
Slope: TTL		Utility
Harmonic: 1		
Overload: NONE NONE	Freq: 1000.000Hz	
Ref. Source: External	PLL: LOCKED	

Fig.66 [REF PHASE] Submenu

Set the harmonic number in <Harmonic> secondary submenu and use the keyboard to input the required order.

First, press the knob and then spin it to change the harmonic order. For example, the order is set to 3 in Fig.67.

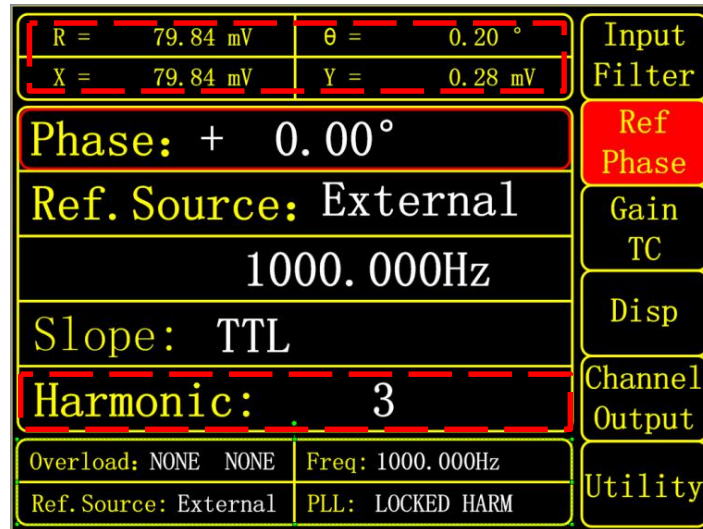


Fig.67 Cubic harmonic measurement of square wave

### How to get the amplitude of the $n^{\text{th}}$ harmonics

How to calculate the harmonic theoretical value of the square wave: suppose that the peak-peak value of square value is  $E$  and the angular frequency is  $\omega$ . After Fourier expand, the result is:

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

Where the  $n^{\text{th}}$  harmonic is a sine wave:

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

Therefore, the valid value of the  $n^{\text{th}}$  harmonic is :

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

We can verify that whether the measured result is close to the theoretical result. In this example, the peak-peak value  $E$  is 160mV, and the calculated value of first harmonic is:

$$R = \frac{\sqrt{2} \times 160}{1 \times \pi} mV \approx 72.025 mV$$

The calculated value of third harmonic is :

$$R = \frac{\sqrt{2} \times 160}{3 \times \pi} mV \approx 24.008 mV$$

Compare the measured result with theoretical result according the above method.

### 7.3 Optical Spectral Measurements

This example will show how to measure a spectral diagram of any light source. You need an optical chopper (such as SIGNAL RECOVERY MODEL 197 Light Chopper), a grating monochromator (such as WDG15-Z) and its control system, a photoelectric detector (such as the S286 series photodiode of Japan Hamamatsu Company), a data collection platform (such as NI cDAQ-9172) and a PC. You should control the monochromator to sweep automatically in the spectral measurement range. Then measure the photo current by the SE1201. The steps are as follows:

1. Disconnect all cables from the lock-in. Connect the power source and then turn on the power switch. The system is in default.
2. Set the corresponding parameters of SE1201.
  - (1) Press [INPUT/FILTERS] and then set the input mode to <I> and <Amplitude: 1M>. Other settings remain the default.
  - (2) Press [REF/PHASE] and then set <Ref. Source: External> and <Type: TTL>.
  - (3) Press [GAIN/TC] and then set <Sensitivity: 1 $\mu$ A> which can be adjusted in measurement, <Reserve: Normal>, <TC: 300ms> and <Roll off: 12dB/oct>. Finally, turn off the SYNC filter.
  - (4) Press [OUTPUT/OFFSET] and then set <CH1>, <Source: R> and <Speed: Fast>.
3. Build up the spectral measurement platform.

Use a BNC cable to connect the output of the photoelectric detector and the A/I input of the SE1201.

Use a BNC cable to connect the Sync out f1 of the optical chopper and the REF IN of the SE1201.

Use a BNC cable to connect the data collection platform and the CH1 OUT of the SE1201. The sketch is shown in Fig.68.

The actual connect figure is shown in Fig.69.

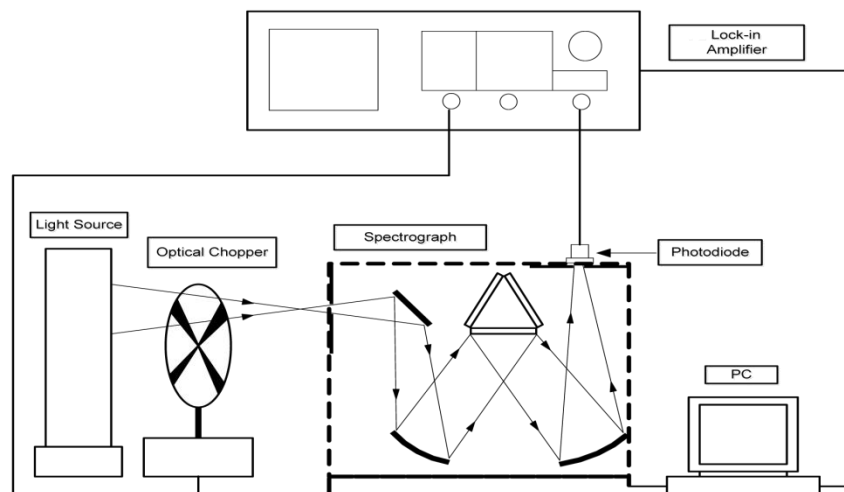


Fig.68 Spectral Measurement Platform Diagram

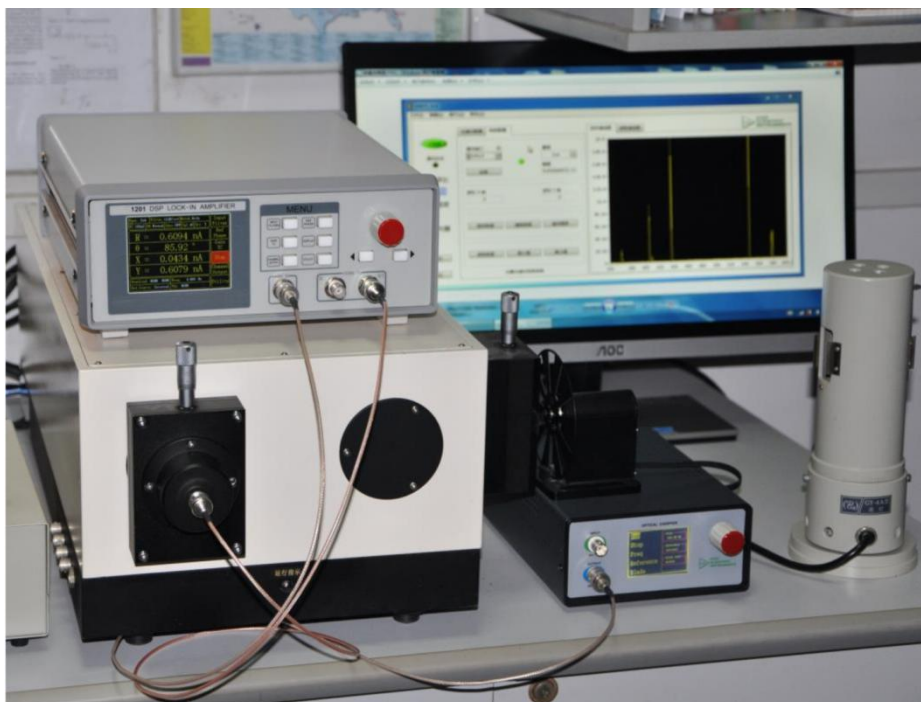


Fig.69 Spectral Measurement Platform Physical Connection

4. Start the spectral measurement and collect data from the data collection platform. Then, you will get an uncalibrated spectral curve as is shown in Fig.70.

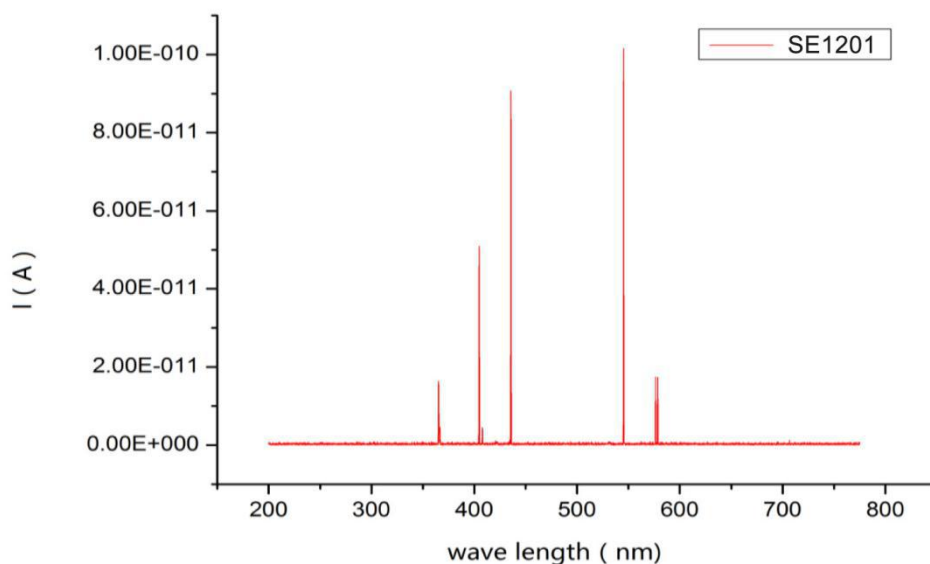


Fig.70 Spectrum Curve measured by SE1201

5. Use the SR830 instead of the SE1201 to measure. Repeat the steps above to run the same experiment. Then you will get another spectral curve as is shown in Fig.71. You can see that these two curves measured by SE1201 and SR830 are almost the same.

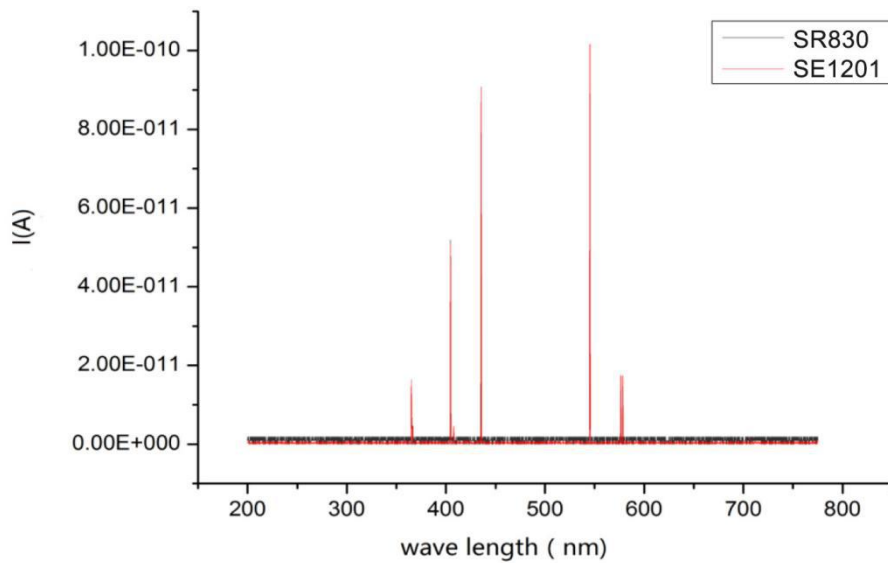


Fig.71 The Contrast Spectrum Curve between SR830 and SE1201

## 7.4 Serial Communication

This example will show how to remotely run the serial communication. You need an USB cable. The steps are as follows:

1. Use an USB cable to connect the USB of the SE1201 to the USB of the PC.
2. The PC will recognize the USB device and remind to install the driver program. If your PC system is WIN7, the PC will do these automatically online. You just need to wait for a few minutes. If the installation fails, you need to install the driver manually according to Chapter 5.2.
3. Open the folder "Uart Driver" in your disk and double click the file UartAssist.exe. It will call out the software interface, as is shown in Fig.72.

Note that this software can set the communication mode, the receiver mode, the transfer mode. The default Baud rate of the SE1201 is 921600. The SE1201 has no parity bit, 8 data bits and 1 stop bit. The port number choose the COM number automatically assigned by the PC. Users can check it at the 'COM and LPT' option in Device Manager of the PC, as is shown in Fig.73.



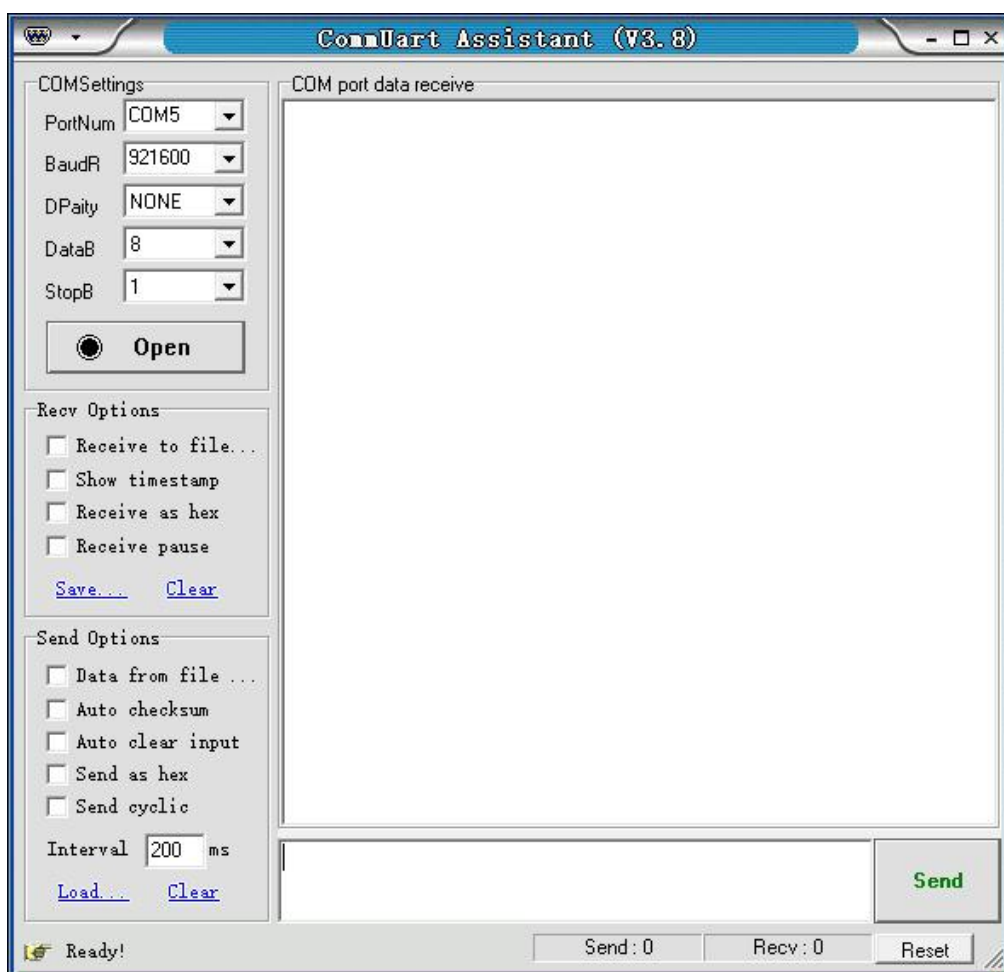


Fig.72 “CommUart Assistant” Software Display

After these settings are completed, if you see a black circle like



, you need to click the button to

make it red like



. If you cannot make it red, please check the port number and repeat the connection.

If the connection id OK, you will see Fig.74.



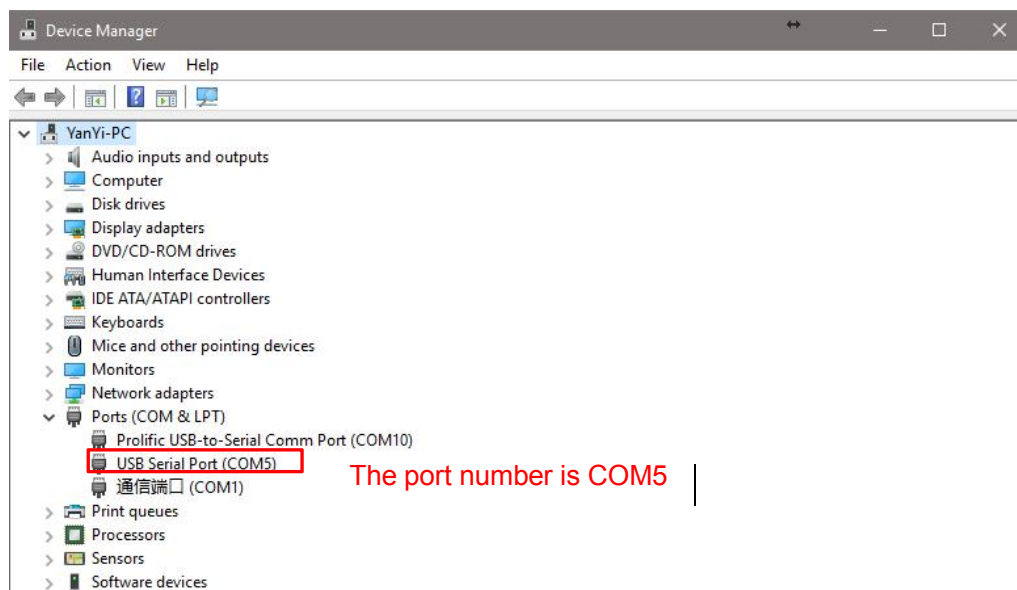


Fig.73 Check the port number at “Device Manager”

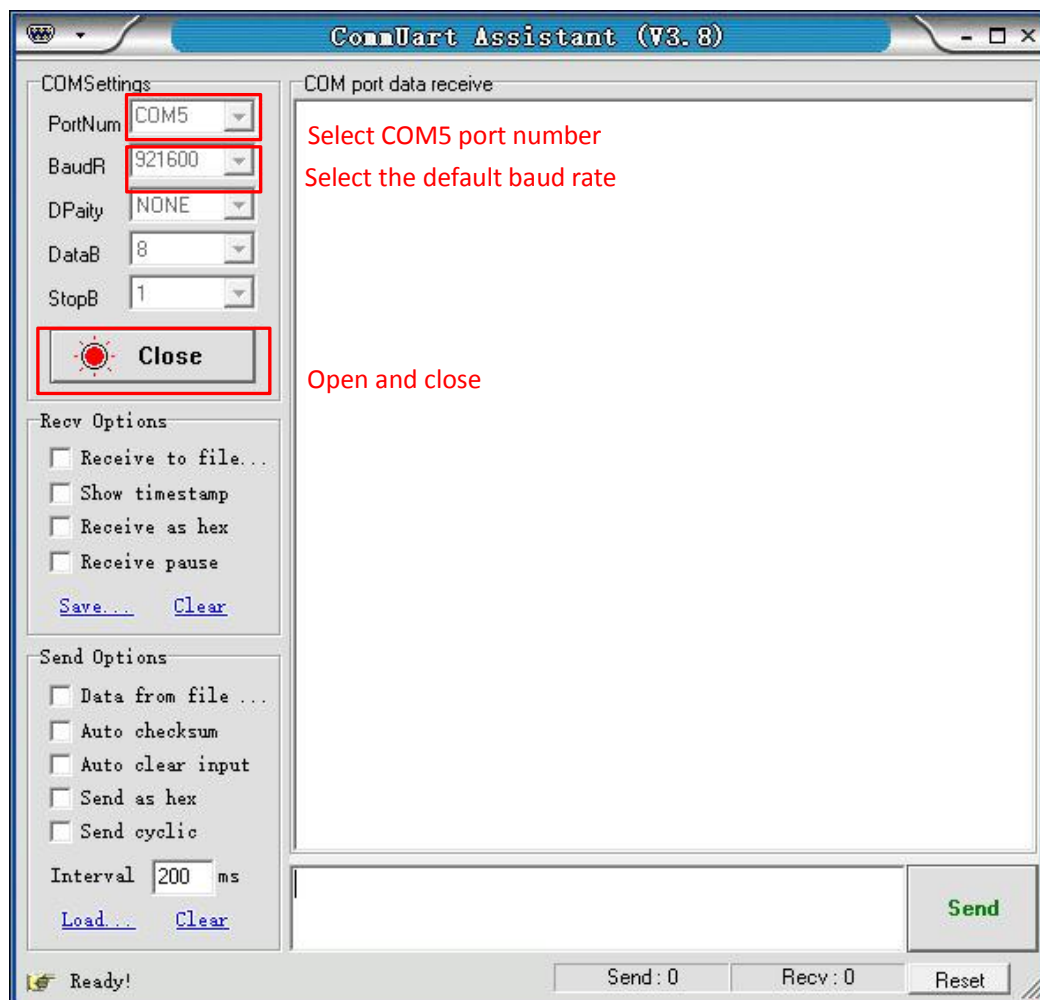


Fig.74 USB connection succeeds

4. Transfer commands to communicate with the SE1201.

(1) The commands consist of four upper mnemonics, option parameters and a terminator. Several commands at the same line are separated by semicolons. More details please see Chapter 4 Remote Programming. The terminator can be a carriage return <cr> or a hexadecimal number 0D. When sending the command, first input the command in the sending area, then press the Enter key, then click the 'Send' button, the command will be sent. As shown in Fig.75 and Fig.76.

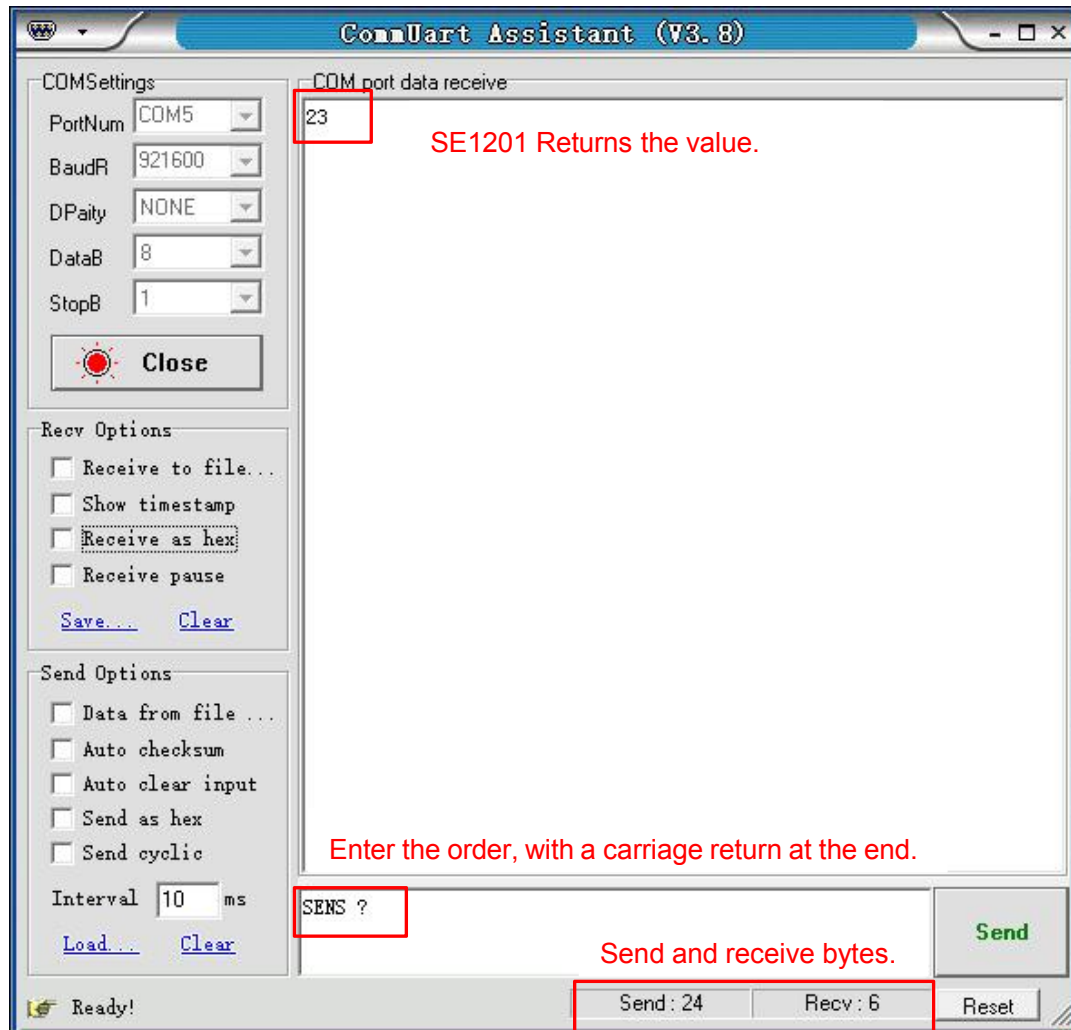


Fig.75 Send and Receive Commands in ASCII Words

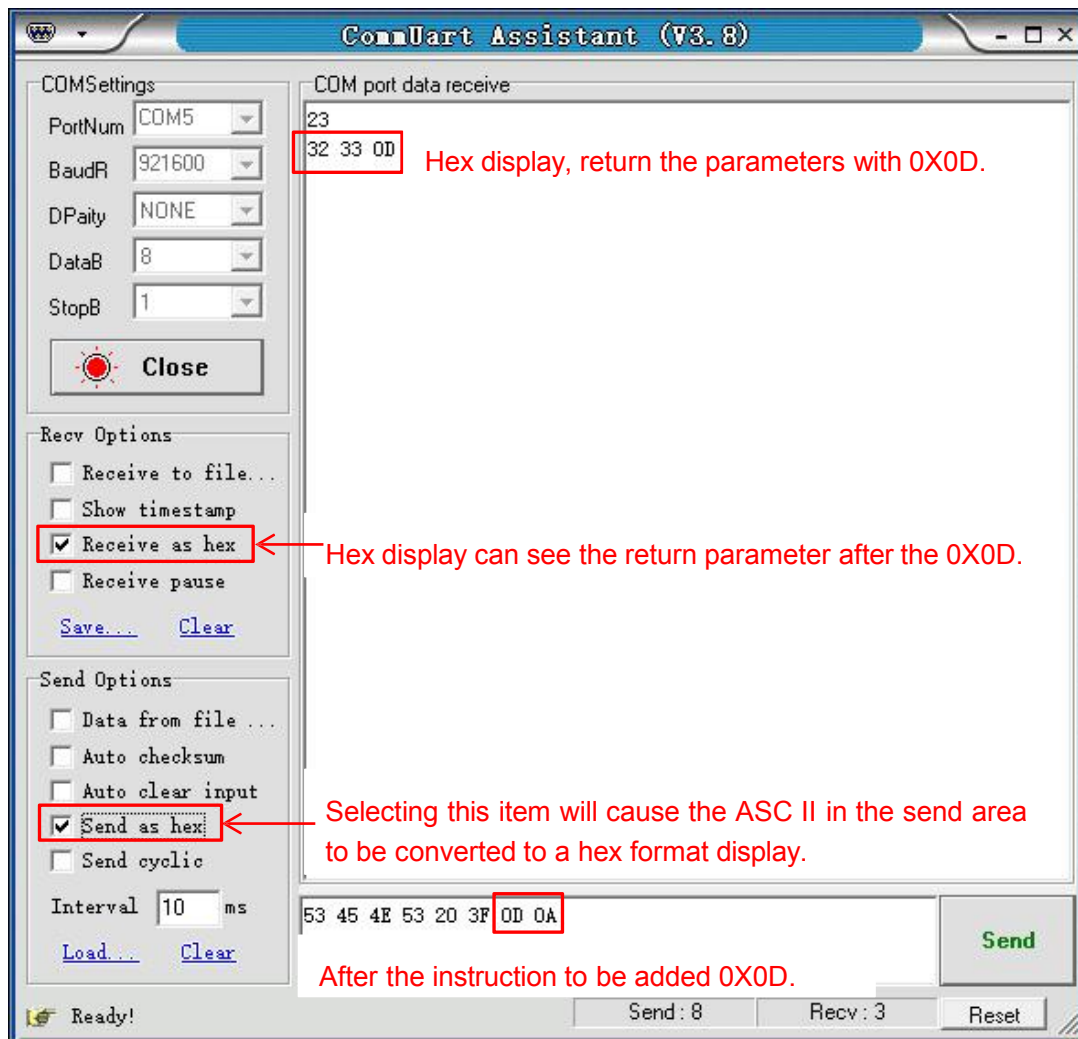


Fig.76 Send and Receive Commands in HEX

(2) The serial assistant can be configured to automatically add carriage return 0X0D. You just need to click

☐ Auto checksum and choose ☐ Fixed Byte Checksum. Finally, set the additional digit to <0D> as Fig.77.

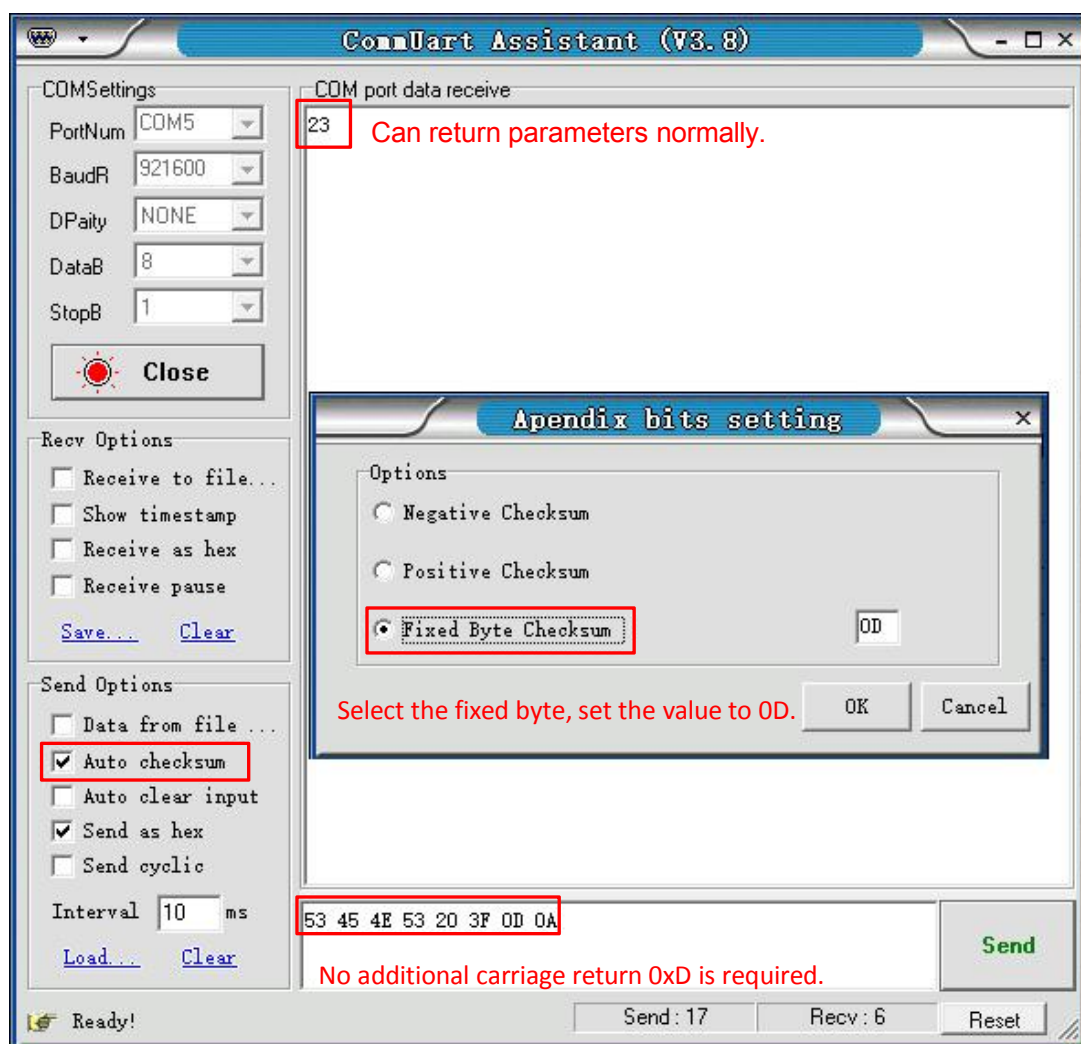


Fig.77 Setting the checksum

(3) Multiple commands are separated by “,”, such as “SENS 24;FMOD 1;FREQ 1000;SENS ?;FMOD ?; FREQ ?”, as is shown in Fig.78.

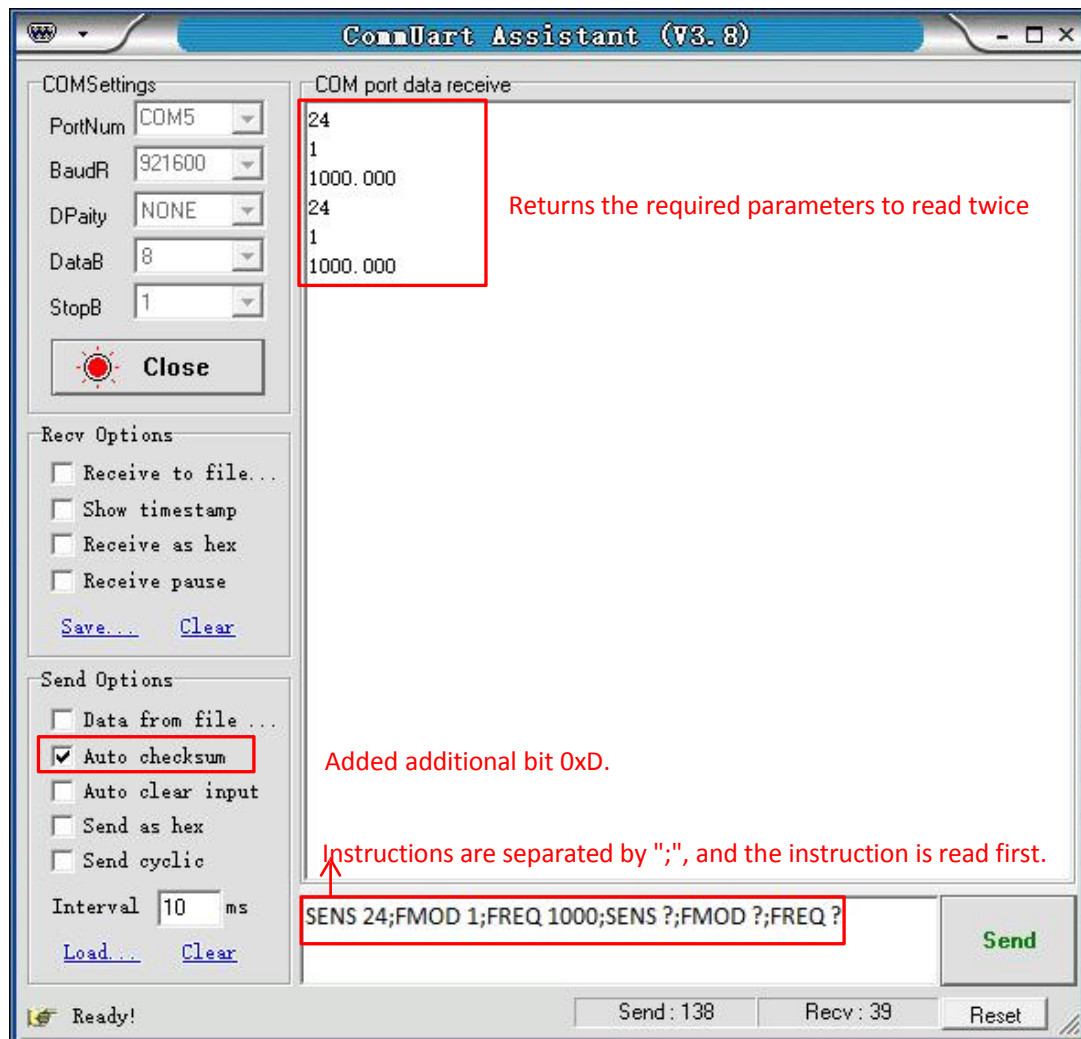


Fig.78 The execution of multiple commands

(4) If you want to read the values of <X>, <Y>, <R>, < $\theta$ > and Freq continuously, you can set the transfer interval time as Fig.79.

Note that when use this software to control the SE1201, the LCD display will refresh at the same time. For example, if <Sens: 100mV> is corresponding to the "25" command. <Sens> will change to <Sens: 50mV> when the SE1201 receives the "24" command.

The SE1201 can use many versions of serial debugging assistant. You can use other software to control the SE1201 remotely.

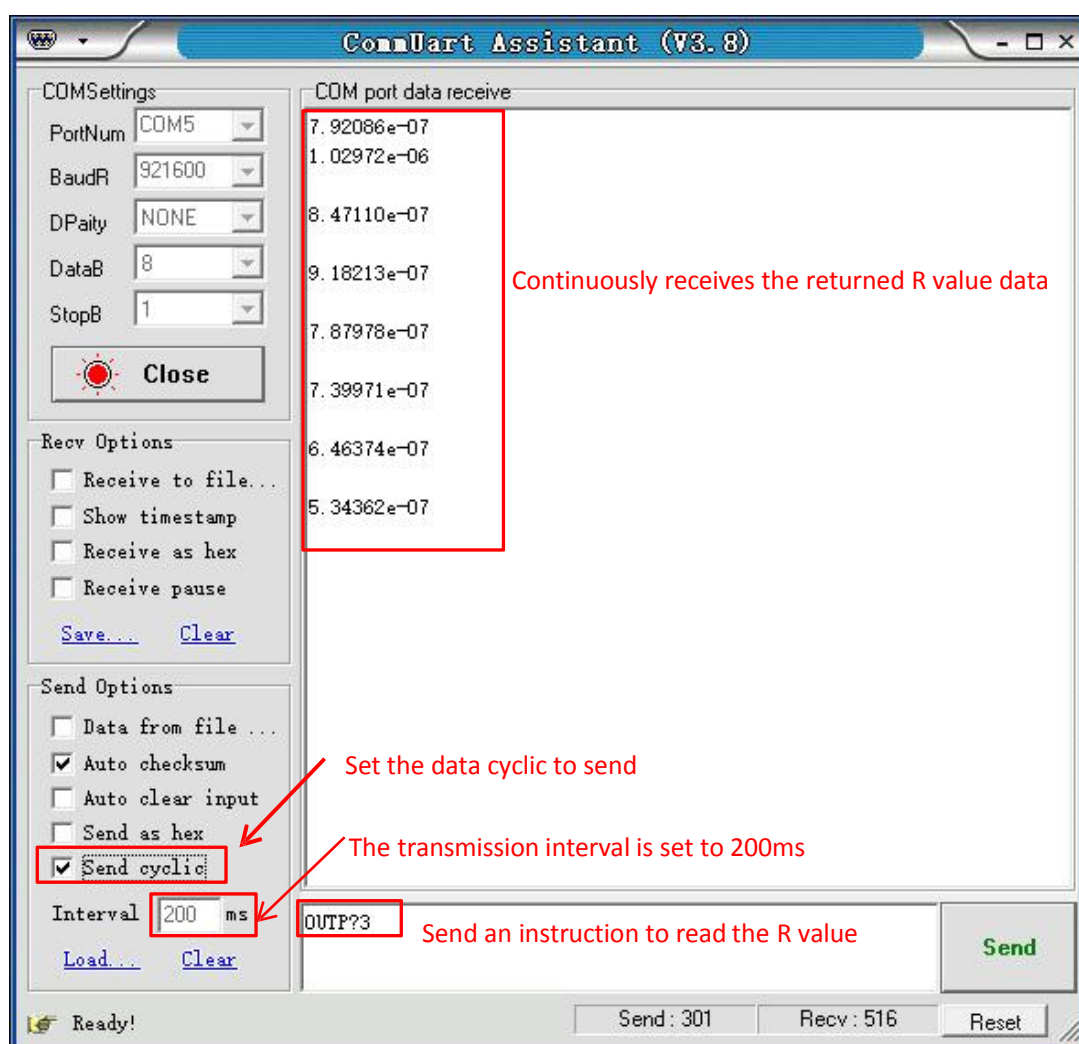


Fig.79 Read the single R value continuously

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