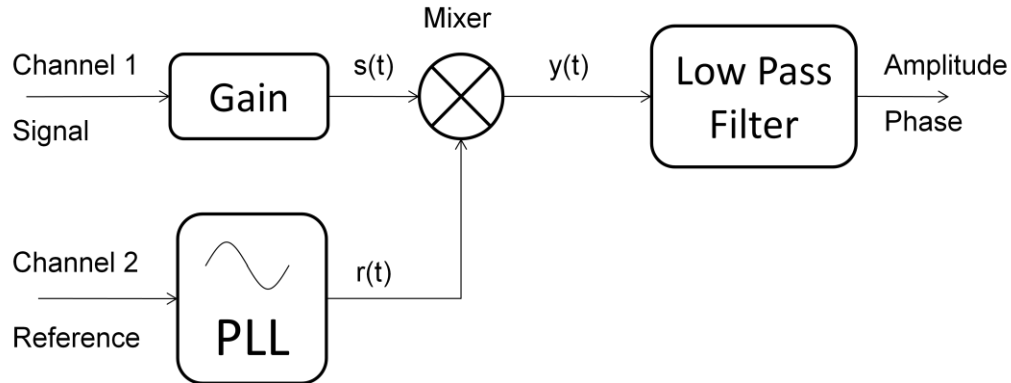# Lock-in Amplifier

Lock-in Amplifier is an instrument that can detect the amplitude and phase of sinusoidal signal with known frequency in extremely low signal to noise environment. The principle of lock-in amplifier can be illustrated in the following diagram.

There are two input channels of Lock-in Amplifier. Channel 1 contains signal to be measured and noise. Channel 2 contains a reference signal that is the same frequency as the signal to be measured. The reference is fed into Phase Locked Loop (PLL) and the output of PLL is a clean sinusoidal wave.

Suppose that input $s(t) = A\cos(\omega t + \varphi) + n$, where A is signal amplitude and φ is phase. n is input noise. The PLL produces reference wave $r(t) = 2\cos(\omega t)$. The mixer multiplies signal with the output of PLL. Thus the output of the mixer can be expressed as

$$y(t) = s(t) \cdot r(t) = A\cos\varphi + A\cos(2\omega t + \varphi) + 2n\cos(\omega t)$$

The output contains a DC component $A cos\varphi$. Then if we apply a low pass filter to the output of the mixer, only DC component $A cos\varphi$ remains.

Usually, phase locked loop can also produce an orthogonal wave $r'(t) = 2\sin(\omega t)$. If we apply this orthogonal wave to mixer and filter, we get DC component $A\sin\varphi$. From $A cos\varphi$ and $A\sin\varphi$, we can recover the amplitude and phase.

The benefit of lock-in amplifier is that it can work in extremely noisy environment. The signal to noise ratio can be as low as -100dB. This is because any noise signal at frequencies other than the reference frequency will not output DC component in mixer. If the pass band of filter is narrow enough, all the noises will eventually be filtered out.

Two important parameters of the low pass filter is time constant and filter rolloff. Time constant determines the filter bandwidth. It is $1/2\pi f$ where f is -3dB bandwidth of filter. Filter rolloff controls sidelobe suppression ability. It is measured as attenuation per octave in stop band.

The performance of Lock-in Amplifier is summarized below.

Hardware:	cRIO 9104 NI 9233
Resolution:	24 bit
Sampling Rate:	50kHz (limited by 9233)
Time Constant:	1ms to 20ks
Filter Rolloff:	20dB, 40dB, 60dB, 80dB
Noise Level	<-100dB, determined by 9233
Dynamic Reserve:	>100dB

PLL type:	Costa Loop
Maximum PLL sampling rate:	850kHz
Low Pass filter:	1-2 stage CIC, 1-4 stage Moving Average