Chapter 1
Introduction

Lock-in amplifiers are electronic devices that are often applied in the optical sciences. They represent versatile instruments that can be adapted to a variety of measurement tasks. The purpose of a lock-in amplifier is to recover small or weak signals that would otherwise be lost in noise. This device serves to detect the amplitude of a signal s that is superimposed by noise (Fig. 1.1). The instrument can be considered as a highly selective amplifier that operates as a bandpass filter, the central frequency of which is determined by the reference signal (Fig. 1.2).

A measurement can be affected by white noise and $1/f$ noise. These terms were coined considering the noise spectrum in the frequency domain. White

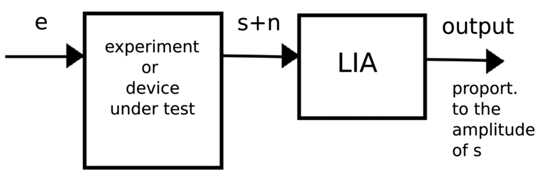

Figure 1.1 An excitation signal *e* serves as input to the experiment or to the device under test. The output signal is superimposed by noise *n*. The lock-in amplifier (LIA) generates an output signal that is proportional to the amplitude of the signal *s*.

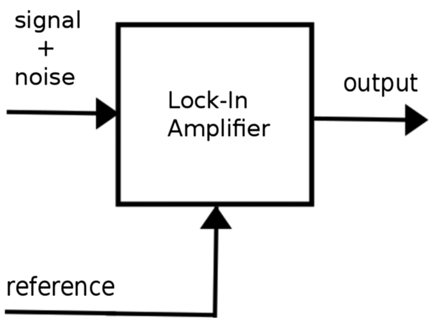

Figure 1.2 To be able to discriminate the signal from noise, it is essential to provide a reference signal to the lock-in amplifier that carries information on the signal *s*.

noise refers to the noise contribution that is constant with respect to frequency, whereas $1/f$ noise shows a steep decrease from low to high frequencies. It is advantageous to have a signal with a frequency outside of the range where $1/f$ noise is predominant. Lock-in detection allows the frequencies at which the amplifier operates to move away from regions dominated by $1/f$ noise. Noise rejection is performed using an electronic unit that mainly consists of a multiplier and an electronic filter, which acts as an integrator. It is essential to the operation of a lock-in amplifier that the signal and the reference be modulated periodically.

Lock-in detection can be applied to the measurement of nonperiodic quantities by introducing an additional device into the measurement setup. In the setup shown in Fig. 1.3, a chopper is used for this purpose. The chopper wheel interrupts the light path periodically. A signal is derived that bears information on the frequency and phase of the modulation. The signal is fed into the lock-in amplifier and serves as a reference (Fig. 1.4).

A lock-in unit detects the signal based on modulation at some known frequency. In a nutshell, a lock-in amplifier is an instrument that receives an input voltage

$$u_{in} = u_0 \sin(\omega t + \phi) + u_{noise} \tag{1.1}$$

and performs the operation of providing a DC output voltage

$$u_{out} \propto u_0 \cos(\phi) \tag{1.2}$$

that is proportional to the amplitude of the sinusoidal signal and the cosine of the phase. The lock-in amplifier serves to extract the signal from noise.

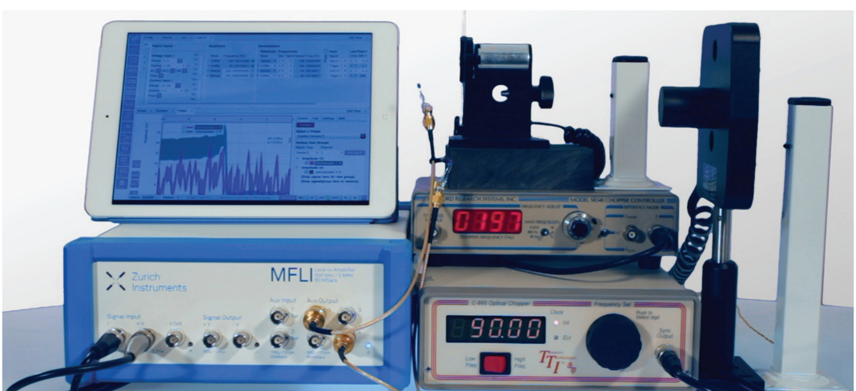

Figure 1.3 Measurement of the intensity of LEDs using lock-in amplifiers. (Courtesy of Zurich Instruments, used with permission.)

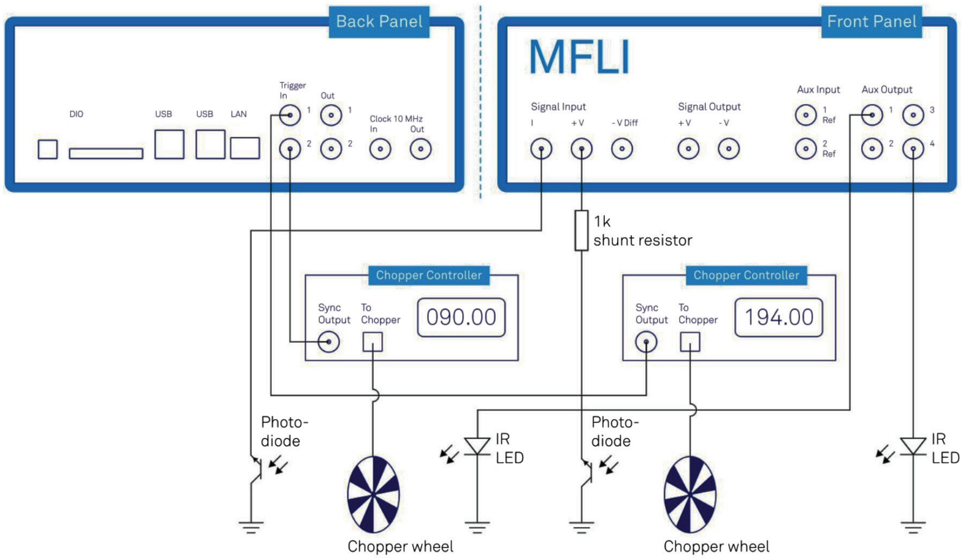

Figure 1.4 The measured signals and the corresponding references are fed into the lock-in amplifiers. (Courtesy of Zurich Instruments, used with permission.)