in the 300- to 600-nm wavelength region to suppress modes at longer wavelengths and shorter wavelengths (e.g. $\frac{1}{2}\lambda$ and 2λ). The light power of the grating-monochrometer-based system can be focused on a rectangular spot of about 1 mm by 3 mm by imaging the monochrometer exit slits onto the test plane with a magnification of less than 1. Chromatic aberrations in the lens(es) cause the beam size to change with wavelength. This effect can be eliminated by eliminating all lenses and using a spherical or, better yet, a parabolic mirror. Typically, grating-based systems have lower optical throughput (lower intensity) but higher spectral resolution than filter-based systems.

16.4.3 Spectral Responsivity Measurement Uncertainty

Spectral responsivity measurements involve the measurement of the photocurrent produced by light of a given wavelength and power. The spectral responsivity is typically measured with bias light simulating reference conditions, because the device may be nonlinear [74, 77, 80, 81, 147–151, 154]. Typically, the spectral correction factor for efficiency measurements is calculated on the basis of $S(\lambda)$ measurements near 0 V and is assumed to be the same as at the maximum-power point. This assumption is valid for most PV systems and results in a negligible error for amorphous silicon, which has a voltage-dependent spectral responsivity [144, 155] assuming a reasonably well-matched reference cell is used such as a Schott KG5 filtered mono-Si cell.

The photocurrent is measured with a current-to-voltage converter. A power operational amplifier (±40 V, 8 A) with computer-controlled gain resistors (50 to 10 000 Ω) is useful for wide bias ranges and signal levels [147]. A simple current sense resistor may be adequate for systems that measure the same type of PV device all the time. The major limitation is that resistor and thermal noise at the microvolt level limits the measured currents to microamperes. Commercial current preamplifiers typically have a maximum current rating of 1 to 10 mA, limiting their usefulness for measuring the spectral responsivity with bias light (i.e. a 1 cm^2 device with $J_{SC} = 30$ mA cm^{-2} produces 30 mA of DC bias current with a 1 sun bias light). An operational amplifier configured as a current-to-voltage converter allows the insertion of a power supply in series with the PV device, giving a wide range of bias voltages. This feature is critical when measuring modules, multijunction devices, or devices with a voltage-dependent spectral responsivity [105, 147, 153]. Most groups use a lock-in amplifier to detect the periodic AC signal, but this is not required because the intense monochromatic light afforded with interference filters allows the AC signal to be amplified to the range where AC voltmeters are quite accurate [155]. Modern digital lock-in amplifiers have rapid auto-ranging capabilities and will outperform an AC voltmeter for noisy signals because of their large dynamic range. Error sources related to the measurement of the photocurrent are summarized in Table 16.7. If semiconductor-based calibrations are employed with the same electronics used to measure the test and reference device, then all multiplicative errors drop out. For pyroelectric-radiometer-based calibrations, the absolute photocurrent must be measured for absolute $S(\lambda)$ measurements.

For absolute current measurements, the measured lock-in signal must be multiplied by a waveform correction factor that relates the measured root-mean-square (RMS) signal