Table 16.7 Spectral responsivity error sources for measurement of the photocurrent

I. Electrical instrumentation
   A. Current-to-voltage (I to V) converter
      1. Commercial current amplifier, lock-in amplifier or custom amplifier gain, linearity, noise, offset, shunt resistor, calibration, drift, thermovoltages
   B. Signal from I to V converter measured with the following:
      1. Lock-in amplifier calibration, resolution, accuracy, waveform to sine wave correction factor, overloading, noise, dynamic range, time-constant, procedures for using lock-in amplifier
      2. An AC voltmeter gain, offset from noise level, linearity, time-constant

II. PV cell or module
   A. Temperature, response time to periodic light, linearity of PV device, white-light bias spatial uniformity, monochromatic light spatial uniformity, voltage bias of cell being measured, spectral content of bias light, device sensitivity to polarization of light

III. Mechanical
   A. Mechanical movement of optics, mechanical vibration, monochromatic beam wandering with wavelength, chopped stray monochromatic light

with the peak signal. This factor is $\sqrt{2}/2$ for a sine wave, $2\sqrt{2}$ for a square wave, and $2\sqrt{2}\ a\sin(\pi/a)/\pi^2$ for a trapezoid, with the constant π/a being the radian angle at the top of the rising edge of the trapezoidal waveform [156].

The response time of PV devices to chopped light can be a problem for electrochemical cells or those cells with many deep-level recombination centers. Many systems operate with chopping frequencies of 71–93 Hz as a compromise between stability, noise, and deep level response. Chopping frequencies below 4 Hz are required to keep the AC photoresponse independent of frequency [157]. This effect is more pronounced at low light levels and in the infrared. It is important that the light from the bias light source not be allowed to go through the light chopper. A simple procedure to determine if this artifact is present is to turn off the monochromatic light source and measure the test device's response as a function of bias light intensity.

Semiconductor-based calibrations are useful where the photocurrent is known within a multiplicative constant. Their primary limitation is their temperature sensitivity near the energy gap (wavelengths greater than 900 nm for Si) and their limited response range. Calibrated semiconductors are not commercially available for wavelength ranges beyond 300 to 1700 nm (Si-Ge hybrid detector). Accurate calibrations for semiconductor-based detectors are difficult to obtain for wavelengths greater than 1800 nm. If the same amplifier is used to measure the reference and unknown PV devices, then uncertainties in the gain drop out. For semiconductor calibrations, the chopper phase is irrelevant, whereas the electrically calibrated pyroelectric radiometer requires that the chopper be manually adjusted until the phase is correct. Semiconductor-based calibrations allow the test and reference signals to be filtered independently to maximize the signal-to-noise ratio. Various error sources associated with measuring the monochromatic light power are listed in Table 16.8. The measurement of the monochromatic light power can be performed with radiometric detectors or semiconductor detectors. When a quartz slide is used as the beam splitter, errors in the power can arise because of polarization effects. The light off the monochrometer is polarized, and the polarization angle can change with a grating change. The band gap, photoluminescence, and