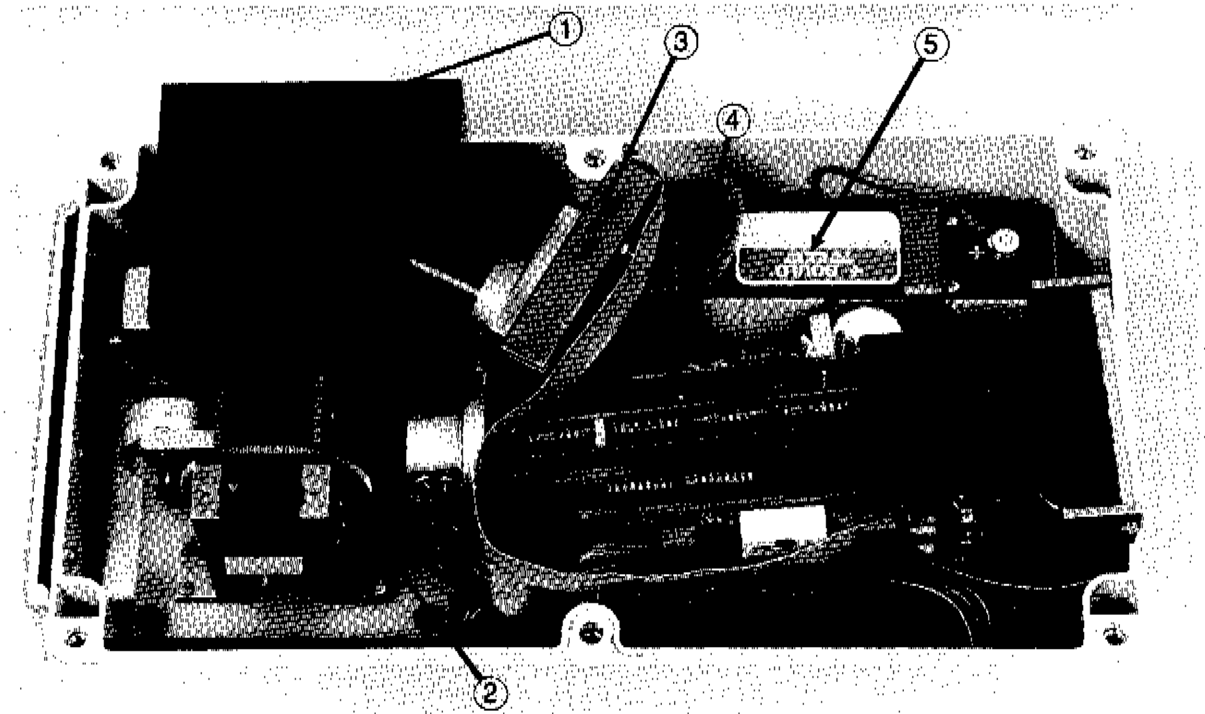
Section II
Theory of Operation

This section gives a brief description of how the LI-1800 works and an overview of the theory of operation. For a more detailed discussion of spectroradiometry, several references are given in Appendix D.

2.1 System Description

The LI-1800 Portable Spectroradiometer is designed to obtain spectral radiation data quickly and easily. Spectral data is fundamental to radiation measurement in that it provides "quality" as well as "quantity" information about a light source.

The major components of the LI-1800 are shown in Figure 2-1.



The LI-1800 is a completely self-contained, battery-operated, microprocessor-controlled spectroradiometer for rapid acquisition of spectroradiometric, radiometric, and photometric data. The standard optical receptor of the LI-1800 is a PTFE-dome cosine receptor with a 180° (2π steradian) field of view. The monochromator is a holographic grating, motor-driven scanning type (typically 35 nm s^{-1}) which disperses the radiation into its spectral components. At the entrance to the monochromator is a filter wheel with seven filters and an opaque target. The filters reject out-of-band energy (including higher spectral orders) to reduce stray light. The opaque target is placed over the entrance slit before and after each scan to provide dark-signal monitoring. The dark signal is automatically subtracted from the measured signal after each scan. The detector, located at the exit slit of the monochromator, is a silicon photodiode operating in the photovoltaic mode. The internal computer handles all collection, storage, communication and manipulation of data files. A block diagram of the LI-1800 operation is given below.

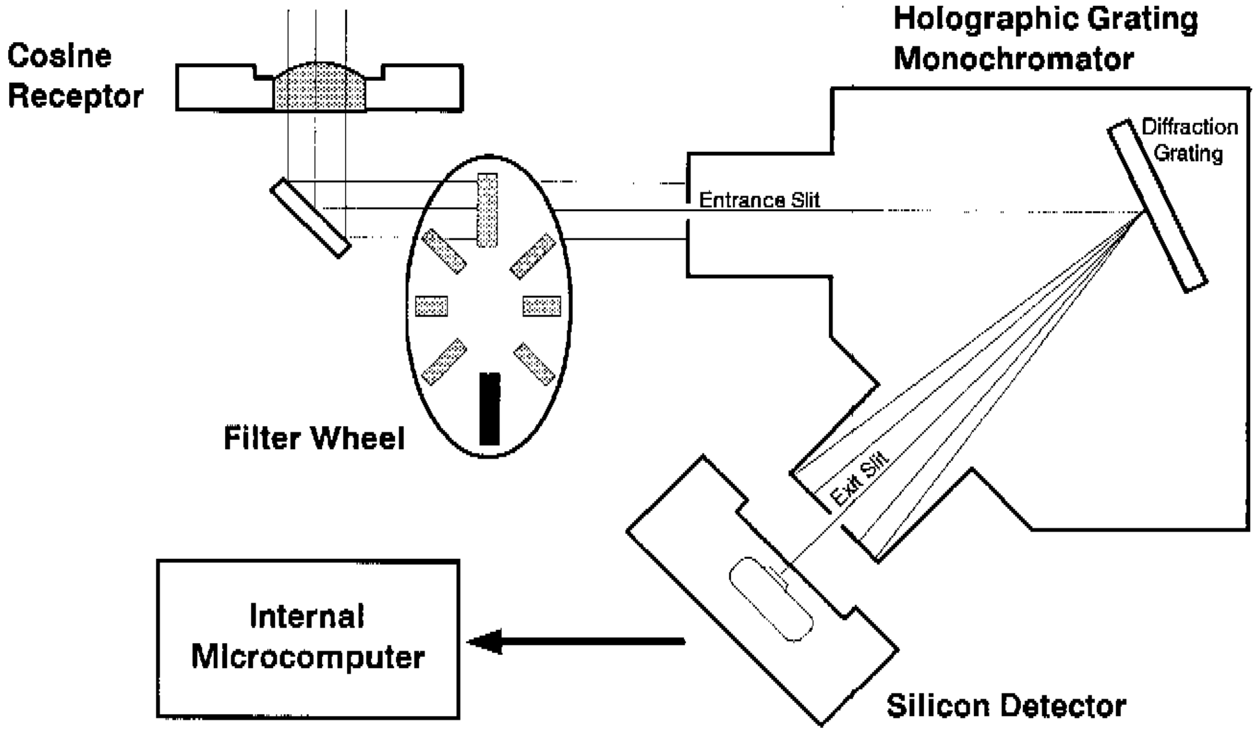


Figure 2-2. LI-1800 operational diagram.

A major feature of the LI-1800 is the "on-board" computer/electronics package which controls the wavelength drive, digitization of the analog signal, storage of the digital data, and file management operations; it also monitors battery voltage, filter wheel operation, and communications to the terminal. Internal RAM capacity is 512 K bytes total, in sixteen 32 K byte banks. Scan limits are 300 to 850 nm (optional 1100 nm), with selectable scan intervals of 1, 2, 5, or 10 nm. Approximately 600 scans from 350 to 850 nm with 2-nm step size fills the memory. All operations are implemented through the use of two-letter commands, supplemented by a series of prompts for limits, intervals, file names, remarks, etc. The data reduction software includes routines for the conversion to quantum (photon flux) units, photosynthetically active radiation, illuminance, linear combinations of files, and ratios and products of files. Data may be sent (via RS-232) to a printer in digital format, plotted on a dot-matrix printer, or downloaded to mainframe or personal computers for further analysis or archival purposes.

2.2 LI-1800 Optical System

Light quality refers to how light is distributed with respect to wavelength. Some light sources, such as lasers, have an extremely narrow distribution. The He-Ne laser only emits at 632.8 nm, and it appears red to the eye. The setting sun can also appear red, but its spectral distribution is very broad and irregular.

The LI-1800 measures the spectral concentration of radiant power by first dispersing the radiation with a diffraction grating monochromator, and measuring the energy in each narrow waveband of the resulting spectrum with a silicon detector.

COSINE RECEPTOR

The standard cosine receptor is a translucent (PTFE) collector which samples radiant flux according to the cosine of the incident angle (follows Lambert's cosine law), and will accept radiation from all angles of a hemisphere. This allows the spectroradiometer to measure flux densities per unit area (m^2). A spectroradiometer which lacks an accurate cosine correction can have significant error under diffuse radiation conditions which occurs, for example, when measurements are made under plant canopies or in the air at low solar elevations. A more complete description of the cosine relationship as well as typical cosine and azimuthal response data for the LI-1800 standard cosine receptor is given in Section IX.

FILTER WHEEL

The collected radiant power must first pass through the filter wheel before it enters the monochromator. The LI-1800 only measures at one location in the spectrum at a time; light at other wavelengths is not needed, and indeed is not even wanted, since it will induce errors if it finds its way to the detector. The filter wheel serves to reduce this "stray" light by filtering out light that is not in the same region of the spectrum as that being measured. The operation of the filter wheel is totally automatic, and is controlled by the internal computer. Sequential filter positions correspond with the following wavelength intervals: 1-298 (open, no filter); 299-348; 349-418; 419-558; 559-678; 679-775; 776-938; 939-2598; 2599 and up (open, no filter).

The filter wheel also serves as a dark reference. One of the slots in the filter wheel is blocked by a black surface. When the wheel is in this position, there is no light reaching the detector, and any output by the detector is considered the true zero level. *The dark reading is automatically checked before and after each scan.* If the difference in dark readings is more than 3 mV, a warning message (xx MV DRIFT) is displayed on the terminal. The most likely cause of differing dark readings is a temperature difference of the detector before and after the scan. When the drift error message is displayed after a scan, the scan should be retaken if possible.

MONOCHROMATOR

The monochromator disperses the polychromatic radiation transmitted through the filter wheel into narrow wavebands and passes each to the detector. It does not isolate truly monochromatic radiant power. Essential components of the monochromator include the entrance slit, grating and exit slit.

The entrance slit is a rectangular opening through which radiation must pass to get into the monochromator. The smaller the entrance slit, the more spectrally "pure" the resulting dispersed radiation will be.

The holographic grating is the actual wavelength dispersing component in the monochromator. As radiation from the entrance slit strikes the grating, it is diffracted toward the exit slit. The net result of this diffraction is that different wavelengths are projected at slightly different angles toward the exit slit. By changing the angle between the entrance slit and the face of the grating (accomplished by rotating the grating with a calibrated reproducible drive mechanism), selected wavelengths of light can be made to pass through the exit slit, while the rest are absorbed by the blackened interior of the monochromator.

The purpose of the exit slit is to restrict and define the waveband of radiation which reaches the detector. Since radiation directed at the exit slit has been spectrally dispersed by the grating, the width of the exit slit directly determines the spectral width of the waveband that reaches the detector. For example, when the 1/2 mm slits are used with the LI-1800's visible range monochromator (300-850 nm), the half power bandwidth is 4 nm, and the total bandwidth is 8 nm. Thus, when the grating is set at 500 nm, the detector senses 496 through 504 nm; it "sees" all of the radiation at 500 nm, half the radiation at 498 and 502 nm, and no radiation below 496 or above 504 nm (Figure 2-3).

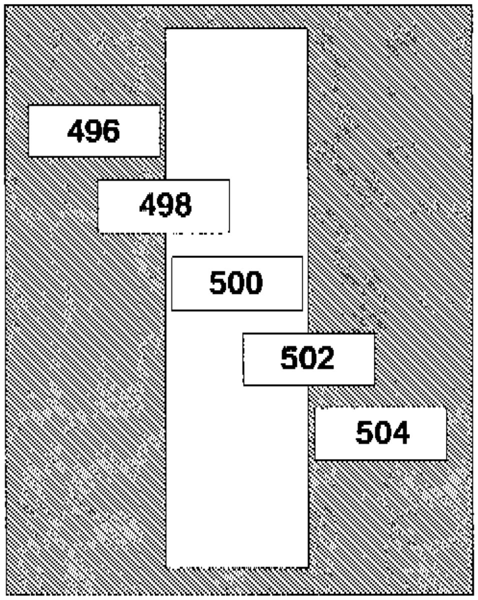


Figure 2-3. Monochromator exit slit. The radiant power passing through the exit slit is proportional to the fractional area of each rectangle that is not blocked by the side walls of the exit slit (assume equal power at each wavelength).

Entrance and exit slits are usually the same size. With narrower slits greater resolution is possible, but the total amount of radiation reaching the detector is reduced. Selection of slit size is a trade-off between wavelength resolution and signal-to-noise ratio. Additional information on monochromator slits as well as a procedure for changing slits is given in Section VIII.

DETECTOR

After emerging from the monochromator, the radiant power is received by the detector which produces a current proportional to the amount of radiation. This current signal is amplified, converted to a voltage, passed through an analog-to-digital converter, and is made available to the internal microcomputer.

The detector in the LI-1800 is a silicon photodiode. Silicon has several advantageous properties: it is mechanically rugged, it does not fatigue, and it has good temperature and long term stability. The temperature stability is best at wavelengths between 400 and 950 nm. Beyond these wavelengths, the silicon's temperature stability degenerates markedly. This is not a problem as long as measurements are taken at about the same temperature at which the instrument was calibrated.

The LI-1800 is calibrated at approximately 25 °C. The temperature dependence of the detector is:

-0.1% / °C, at 350 nm
0.05% / °C, from 400 - 950 nm
0.5% / °C at 1000 nm
1-2% / °C at 1100 nm

If the LI-1800 is to be used at temperatures greatly different from 25 °C it is best to calibrate at, or near the operating temperature. This is particularly true if high accuracy is desired in the 1000-1100 nm waveband.