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Modification and calibration of a solar spectroradiometer system

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MODIFICATION AND CALIBRATION OF A SOLAR SPECTRORADIOMETER SYSTEM

by

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STATEMENT BY AUTHOR

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APPROVAL BY THESIS DIRECTOR

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ABSTRACT

A solar spectroradiometer is an instrument used for measuring the transmitted solar radiation on a quasi-continuous basis. An existing computer controlled solar spectroradiometer system has been modified and made operable. Test measurements have shown that the signal to noise ratio (which is time of day and wavelength dependent) is at an acceptable level. The chief use of the spectroradiometer will be for atmospheric transmittance studies, which will require calibration of the instrument. Strategies for calibrating the instrument have been discussed.

CHAPTER 1

INTRODUCTION

The atmosphere consists of different types of gases and aerosols. Aerosols are much larger than gas molecules, and range in diameter from about 0.01 micron to several microns. They consist of air-borne particles such as dust, pollen, and pollution. Both gas molecules and aerosols affect the passage of solar radiation through the atmosphere. Attenuation (or extinction) of the incoming radiation is due to scattering and absorption by these atmospheric components. While attenuation in the visible spectrum is mostly due to molecular and aerosol scattering, attenuation in the ultra-violet and infrared regions is predominated by gaseous absorption. Ozone and oxygen are the gases of primary concern in the ultraviolet, while water vapor and carbon dioxide have greater influence in the infrared. Atmospheric transmittance is a measure of attenuation of the solar radiation passing through the earth's atmosphere. It can be determined by taking the ratio of the transmitted solar flux at the earth's surface to the incident solar flux at the top of the atmosphere. Figure 1.1 shows the spectrum of solar radiation at the top of the atmosphere, together with the spectrum of solar radiation at the earth's surface.

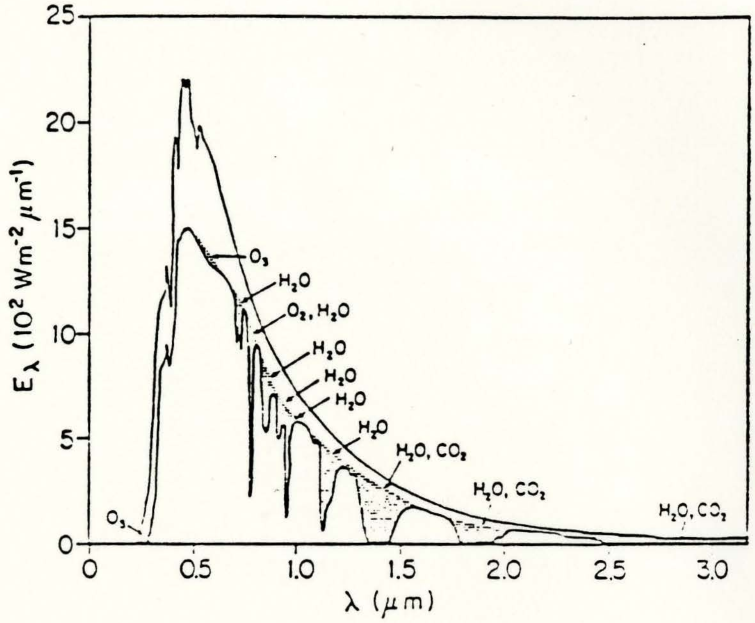

Figure 1.1. The Unattenuated and Attenuated Solar Spectrum (Wallace and Hobbs, 1977)

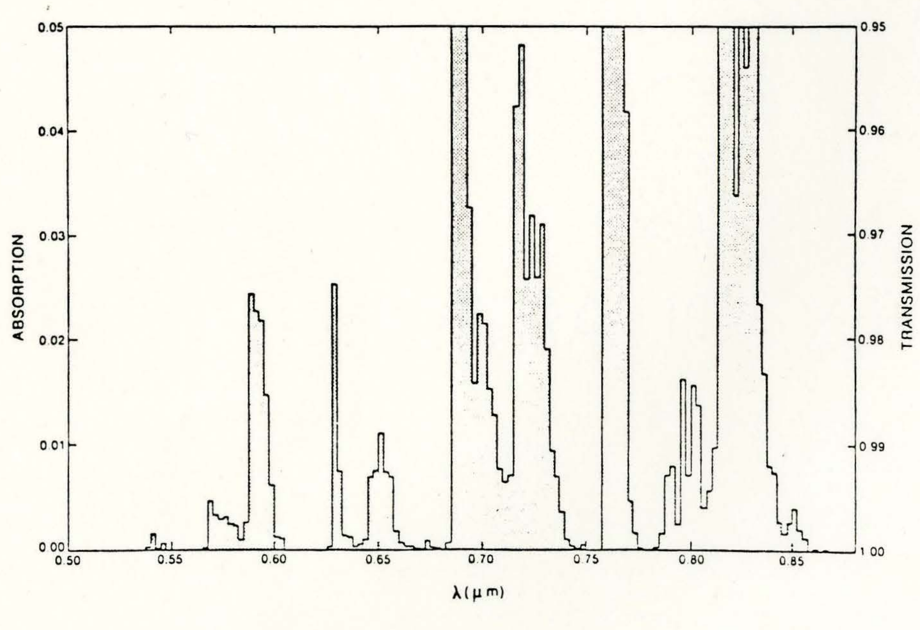

Figure 1.2. Windows in the Attenuation Spectrum (King et al., 1980)

Investigations have been conducted for many years at the University of Arizona into the influence of gases and aerosols on atmospheric extinction (Shaw et al., 1973, King et al., 1980, etc.). These investigations utilized portable filter-wheel radiometers, instruments designed to measure the incoming flux of direct solar radiation within selected, relatively narrow spectral intervals. Selected wavelength intervals are isolated by means of bandpass interference filters arranged in a rotating filter wheel. The center wavelengths of the filters are chosen to correspond to windows in the attenuation spectrum of the atmosphere (see Figure 1.2).

The number of wavelengths of observation for a filter wheel radiometer is limited by the number of filters the radiometer can accommodate. An instrument with a higher spectral resolution is required when measurements of atmospheric transmittance are desired on a finer spectral basis. Such an instrument is a solar spectroradiometer. A spectroradiometer system is shown in Figure 1.3; it consists of the following basic elements:

1) A receiver with some field of view (Ω_R).
2) A wavelength selection system to define a spectral bandwidth ($\Delta\lambda$) about the wavelength of interest (λ). It requires an instrument to disperse the source radiation into its spectrum components for measurement.

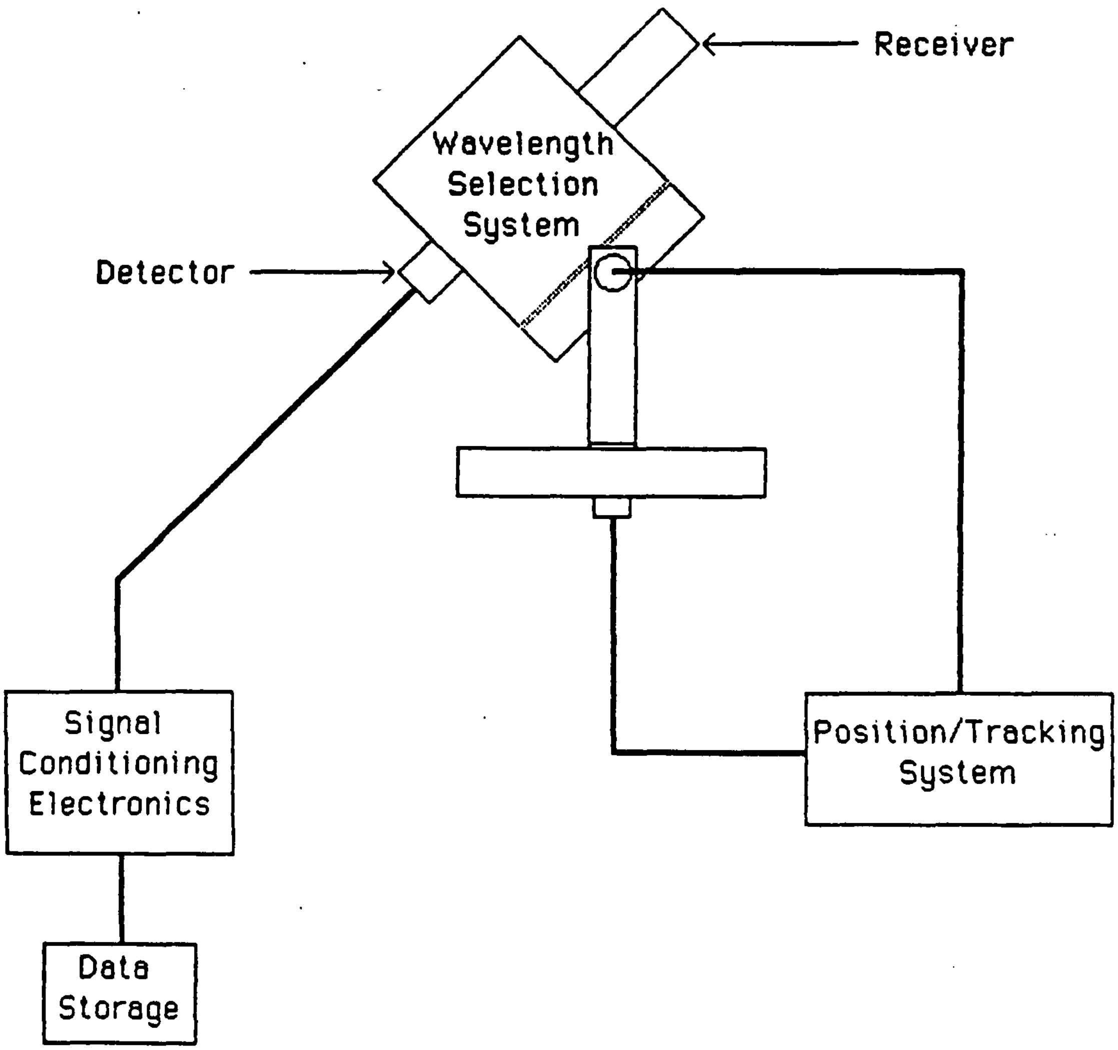

Figure 1.3. Basic Spectroradiometer System

3) A detector to convert collected radiation into an electrical signal.

4) A positioning or tracking system to point the receiver field-of-view in the desired direction.

5) Signal conditioning electronics to provide the necessary gain, electrical filtering (with frequency bandwidth of Δf), A/D, etc.

6) A data storage system to record the measurements.

The Institute of Atmospheric Physics (IAP) operates a spectroradiometer system which is located in the observatory on top of the Physics and Atmospheric Sciences building. The instrument was designed in the mid 1970's by Pamela Davila, a graduate student at the Optical Sciences Center. Dave Perry, an electrical engineer employed by the Center, incorporated all of the hardware components into a working system in the late 1970's and early 1980's. He also wrote all of the original system operating software. Several other people had also worked on the instrument since its initial completion, but no one had worked with it enough to determine how well it really performed. Specific problems/questions with the instrument remained to be solved/answered before it could be usefully employed in atmospheric transmittance studies. These include assuring wavelength repeatability, characterizing system performance, and establishing radiometric calibration of the system. The author was brought into the project to deal with these problems and make the system operable.

This work discusses the author's efforts with regard to dealing with the above noted problems and questions concerning the IAP solar spectroradiometer system. The major thrust of the thesis can be summarized in six parts as listed below:

1) Atmospherics: The Bouger-Lambert Law and the problem of measuring solar radiation are discussed in Chapter 2.

2) Original Hardware and Software: Upon the author's entry into the project, all that was made available to him were schematic drawings of the electronics, a program listing of the operating software, instructions on how to operate the instrument, and various owner/operator manuals for the commercially produced components in the system. Chapter 3 attempts to describe the system hardware as it was originally configured, the original system software, and general operation of the instrument. This is done to give future users of the system a better understanding of the instrument including necessary information for hardware troubleshooting.

3) System Modifications: Problems with the temperature controller and temperature acquisition circuitry necessitated their modification. Optical encoders were added to the wavelength selection system to

allow reading of the wavelength drive setting. The software was modified to accommodate the hardware changes and enhance system performance. Chapter 4 describes the changes that were made to the hardware and software.

4) System Performance: The purpose of Chapter 5 is to characterize the system performance which includes an investigation of the output dark (bias level) signal, a demonstration of the system signal to noise ratio, and a discussion of the best operating parameters for the instrument.

5) System Calibration: Strategies for the calibrating the instrument are examined in Chapter 6. The Langley technique for retrieving the exoatmospheric signal levels of an instrument is introduced, methods for transferring calibration to the spectroradiometer from calibrated devices at discrete wavelengths are discussed, and the problem of interpolating between these calibration points, is explored.

6) Conclusions and Recommendations: Chapter 7 ends the thesis with concluding remarks and suggestions for future work.

CHAPTER 2

ATMOSPHERICS

This chapter introduces the Bouguer-Lambert Law (or Beer's Law) and takes a brief look at the measurement of solar radiation. The monochromatic solar spectral irradiance (units of W/m^2-nm) directly transmitted through the atmosphere may be described by the Bouguer-Lambert Law given by

$$F_\lambda(\theta) = (R_m/R)^2 F_{o\lambda} e^{-m\tau_\lambda} = F_{o\lambda}' e^{-m\tau_\lambda}, \quad (2.1)$$

and $F_{o\lambda}' = (R_m/R)^2 F_{o\lambda}$,

where $F_\lambda(\theta)$ is the spectral irradiance at the earth's surface,

θ is the solar zenith angle,

$F_{o\lambda}$ is the zero airmass solar spectral irradiance,

m is the relative solar ray path-length through the atmosphere (airmass),

τ_λ is the total atmospheric spectral optical depth for a zenith path where $m=1$,

R_m is the mean earth-sun separation

R is the earth-sun separation for the day in question.

This expression relates the direct, normal irradiance at the earth's surface to the irradiance at the top of the atmosphere (i.e., irradiance unattenuated by the atmosphere). Irradiance is the amount of light (radiant flux) at a surface divided by the area of the surface, i.e., a flux density. The term "spectral" indicates a monochromatic quantity, a value at a given wavelength. The equation states that the irradiance falls off exponentially, the argument of the exponential being proportional to the amount of attenuation along the path. Because of the elliptical orbit of the earth around the sun, the spectral solar constant (the spectral solar irradiance at the top of the atmosphere) varies from day to day. This effect is compensated for by the term $(R_m/R)^2$ in equation (2.1)

Airmass is the relative increase in path length over the zenith length. The zenith length is measured from the point of observation on the earth's surface to the point at the top of the atmosphere directly overhead. Airmass is approximately equal to the secant of the zenith angle (the angle between the light ray being measured and the local zenith) for zenith angles less than about 60°. In practice, airmass is usually calculated from one of the airmass models (e.g., Kasten's Model (Kasten, 1966)), which take other factors into account such as the spherical geometry of the earth-atmosphere system and refraction effects.

Optical depth is a quantity which defines how much attenuation a light ray experiences as it passes through a medium. The total atmospheric spectral optical depth is comprised of three optical depth components; $\tau_{Rayleigh}$, $\tau_{aerosol}$, and $\tau_{gaseous}$ such that

$$\tau_{\lambda} = \tau_{Rayleigh} + \tau_{aerosol} + \tau_{gaseous}$$

The Rayleigh optical depth is the result of molecular scattering and is a function of atmospheric pressure and wavelength (Wallace and Hobbs, 1977). The Rayleigh optical depth, which varies as $1/\lambda^4$, is the dominant component at shorter wavelengths. Aerosol optical depth results from airborne aerosols or particulates, such as dust, smog, etc., that are ever present in the atmosphere Gaseous optical depth results from absorption at certain wavelengths of light by different gases. As mentioned in the introduction, the gases in the atmosphere of primary concern are water vapor and ozone, with oxygen and carbon dioxide being important in this regard also. Both aerosol and gaseous optical depths dominate at the longer wavelengths.

Equation (2.1) gives an expression for the solar flux density reaching the earth's surface, but, in practice, this flux density is measured with a detector which outputs a current or voltage proportional to the spectral flux impinging upon it. If the detector outputs a current, as it does in the IAP system, the analog of equation (2.1) in terms of the signal current, I, may be expressed by

$$I_\lambda = I_{o\lambda}' e^{-m\tau_\lambda} \qquad (2.2)$$

The terms I_λ and $I_{o\lambda}'$ are not true spectral quantities because spectroradiometer systems must always have some finite spectral bandwidth to obtain a measurable signal. They are related to F_λ and $F_{o\lambda}'$ by the equations

$$I_\lambda = A_R \int_{\Delta\lambda} S_\lambda F_\lambda R_\lambda d\lambda \qquad (2.3)$$

and

$$I_{o\lambda}' = A_R \int_{\Delta\lambda} S_\lambda F_{o\lambda}' R_\lambda d\lambda \qquad (2.4)$$

where A_R is the area of the receiver,

S_λ is the slit function (bandpass function) of the system,

R_λ is the responsivity of the system.

However, if the bandwidths are small enough, equation (2.2) still holds true outside of gaseous absorption regions.

If the wavelength of interest is in a gaseous spectral absorption region, the solar radiation transmitted through the atmosphere does not follow the Bouguer-Lambert Law. However, if $\Delta\lambda$ is relatively small, then I_λ can be expressed (Reagan et al., 1987) in the form

$$I_\lambda = I_{o\lambda} e^{-m\tau_\lambda} \hat{T}_{\lambda g} \qquad (2.5)$$

where,

$$\hat{T}_{\lambda g} = \frac{\int_{\Delta\lambda} R_\lambda S_\lambda F_{o\lambda}' e^{-m\tau_{\lambda g}} d\lambda}{\int_{\Delta\lambda} R_\lambda S_\lambda F_{o\lambda}' d\lambda}$$

where $\hat{T}_{\lambda g}$ is the band weighted transmittance determined by the spectral absorption properties of the gas and the relative spectral characteristics of $F_{o\lambda}$ and $S_\lambda R_\lambda$ (the overall system responsivity). The necessity of including $\hat{T}_{\lambda g}$ is primarily due to the strong spectral variation of τ_λ normally exhibited in gaseous absorption bands. Good results have been obtained in the water vapor bands by modelling $\hat{T}_{\lambda g}$ as an exponential with a negative argument proportional to the square root of the total path absorber amount for the case where individual absorption lines are fairly narrow compared to their spectral separation distances. In this case, $\hat{T}_{\lambda g}$ is approximated by

$$\hat{T}_{\lambda g} = e^{-k\sqrt{mu}} \qquad (2.6)$$

where, m is airmass,

u is the columnar absorber amount,

k is a constant.

In (2.6), k depends on the absorption structure of the band and the form of the instrument's responsivity over the band.

Practical use of the material contained within this chapter will be discussed in more detail in chapter 6, the chapter on calibration. Having provided sufficient back-ground on solar radiation and its measurement, this work continues with a description of the spectroradiometer system.

CHAPTER 3

DESCRIPTION OF ORIGINAL SYSTEM

This chapter describes the spectroradiometer system hardware and software as it was originally designed. The general operation of the instrument will be outlined first. Various hardware components of the system will be described next. Finally, an overview of the system operating software will be presented.

3.1 General Operation

The IAP solar spectroradiometer is a computer controlled, fully automated system. User input is allowed for predetermined operating parameters. A computer does the rest, including automatic positioning and tracking, wavelength selection, data collection and storage.

To begin operation, the user first runs a peripheral checking program to verify that the computer's peripherals are operating properly. Once the peripherals check is complete, the program loads and runs an initialization and self-check program . It makes sure that the computer is communicating with the system hardware components and initializes those devices which require initialization. Once all of the procedures have been executed, the program then loads and runs the system operating (data collection) program. This program locates the sun to bring sunlight into the system, locks onto the sun, scans across the wavelength range, and records the data onto tape. At the end of the data run (which may consist of several wavelength scans), the program executes shut-down procedures, which cause the computer to record all of the data onto disk, and the day's operating parameters onto tape.

3.2 Hardware

A block diagram of the spectroradiometer system is shown in Figure 3.1. The figure shows all of the hardware components except the light gathering elements. The next few sub-sections describe the functions of these various hardware components.

3.2.1 Computer and Peripherals

At the heart of the system is a Hewlett-Packard 9845A Desktop Computer with 62.5K bytes of RAM, 2 tape drives, and a programmable real-time clock. It runs the software which controls the spectroradiometer. The 9845A computer controls the spectroradiometer through the Hewlett-Packard 6940B Multiprogrammer. This unit controls the bidirectional transfer of data between the computer and peripherals via plug in cards. The multiprogrammer expands a single 16-bit input/output register of the computer to control up to 15 12-bit input/output channels. The type of plug in card used depends on the application.

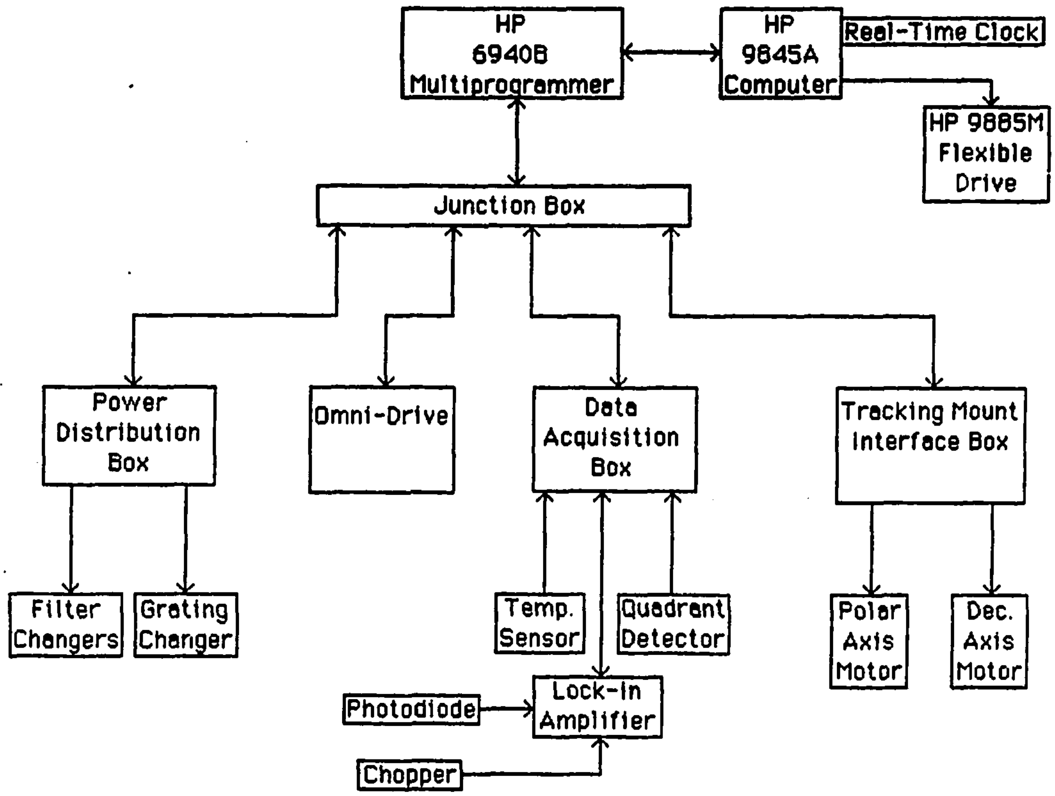

Figure 3.1. System Block Diagram

Table 3.1 lists the cards currently employed in the system, including their designated slots in the multiprogrammer, and their function.

Table 3.1

Multiprogrammer Plug-In Cards

Card-Description	Slot	Function
69331A-Digital Output	0	controls tracking mount motors
69431A-Digital Input*	1	reads encoder 1
69331A-Digital Output	2	sets lock-in sensitivity,selects A/D channel, selects MUX address
69431A-Digital Input*	3	reads encoder 2
69431A-Digital Input	4	reads A/D converter, reads MUX for lock-in
69431A-Digital Input	6	reads monochromator status, reads lock-in status, reads tracking mount limit switches
69380A-Breadboard	8	contains circuitry for omni-drive control
69435A-Pulse Counter	10	lower 12-bit counter for omni-drive
69435A-Pulse Counter	12	upper 12-bit counter for omni-drive
69433A-Relay Output	14	controls filters, gratings, and detector select

* recently added (see Chapter 3)

Data is stored temporarily on magnetic tape as measurements are taken. At the end of the day, all of the data is stored on an 8" floppy disk. The particular disk drive used in the system is the Hewlett-Packard 9885M Flexible Disc Unit.

3.2.2 Receiver System

The tracking mirror on top of the roof of the IAP observatory directs sunlight through an opening in the roof into the room where the spectroradiometer is located. After reflecting off of two mirrors, the sunlight then enters the system's receiver. The receiver for the instrument is a Newtonian reflecting type telescope. It consists of a concave paraboloidal primary mirror (4.5 inches in diameter) followed by a plane mirror which brings the beam out at a right angle to the telescope axis. The telescope (and thus the system) has a field of view which depends on the exit field stop diameter. Currently, the field stop has a diameter of 0.3054", which defines a field of view of 1° for the system. The light from the telescope is then directed onto a $BaSO_4$ covered diffusion block, and light reflected from the block illuminates the entrance slit of the wavelength selection system. A diagram of the entire optical system is shown in Figure 3.2.

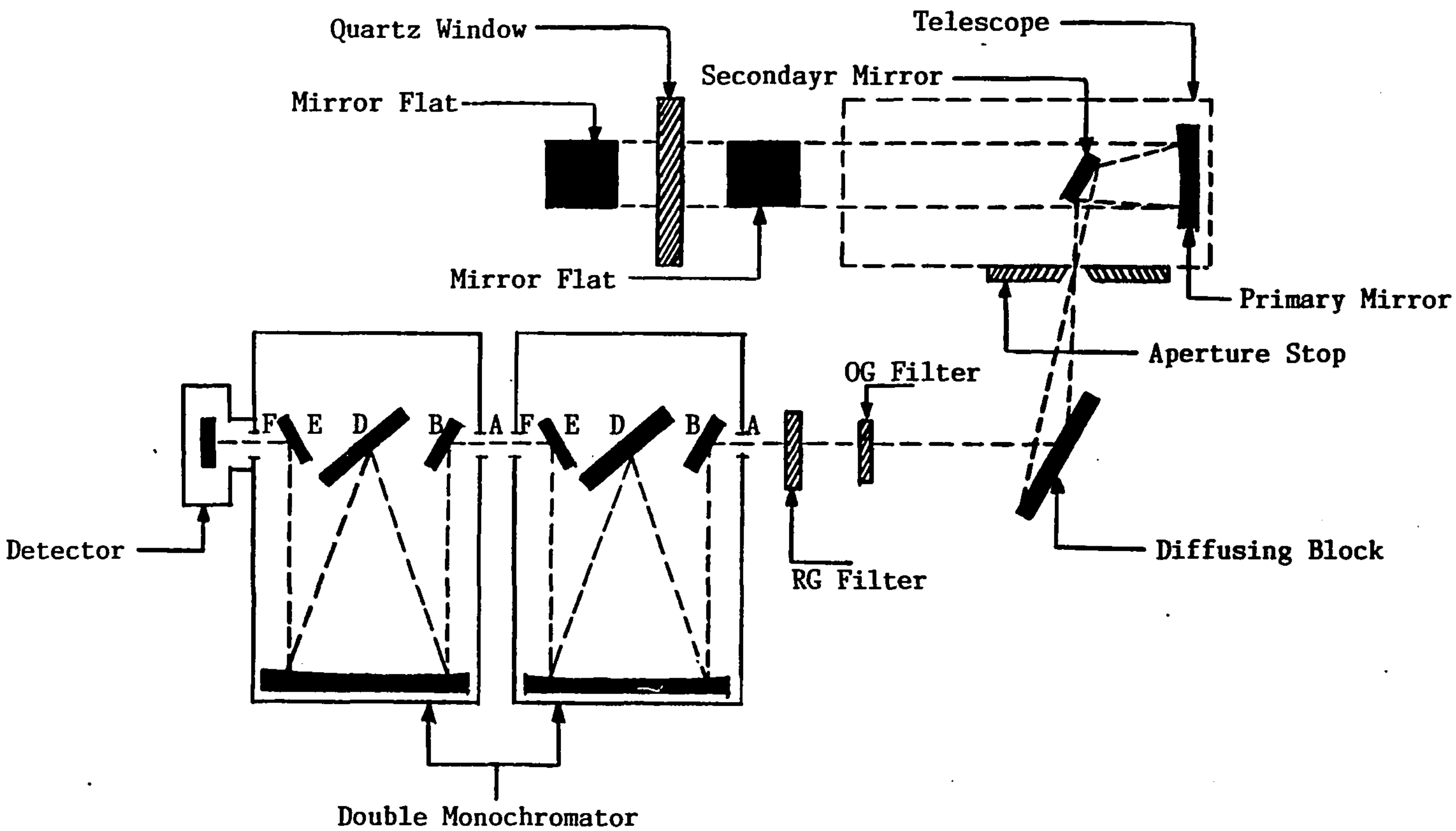

Figure 3.2. Optical System

3.2.3 Wavelength Selection System

The wavelength selection system utilizes two wavelength selective filters and two Jarrel Ash 0.25 meter Ebert grating type monochromators. An orange glass filter is used to pass wavelengths from 550 nm to 999 nm, and a red glass filter is used to pass all wavelengths longer than 999 nm. These are order sorting filters, which are used to block out light with second and higher order components for the monochromator gratings. For wavelengths shorter than 550 nm, no filter is required. The filters are placed in or out of the optical path by actuators operated by the computer via the Relay Output Card in the Multiprogrammmer.

In each monochromator (see Figure 3.2), light enters slit A, strikes mirror B, is reflected to collimating mirror C, is reflected to grating D, is dispersed to collimating mirror C, then is reflected to mirror E and exits out through slit F. The two monochromators are connected in tandem such that the light exiting from the first enters the second. The use of two monochromators in tandem reduces the amount of scattered light that reaches the detector, and, together are called a double monochromator. The entrance slit of this double monochromator is 250 μm wide. The wavelength drive readout covers a range of 0-900 nm (gratings extend the actual range to 1800 nm).

There are two gratings in each monochromator, choice of which depends on the wavelength range. Grating changes are accomplished through the use of d.c. motors coupled to the grating change levers. One grating has 1180 grooves/mm and is blazed at 4000 A. With the 250 μm slit, this gives a spectral bandpass (full width at half maximum) of approximately 8.25 A. The useful wavelength range for this grating is 300-900nm. The other grating has 590 grooves/mm and is blazed at 1.0 μm. With the 250 μm slit, this gives a spectral bandpass of about 16.5 A. The wavelength range for this grating is 900-1800 nm.

A stepper motor (Hurst Model PAS 3206 001) driven "omni-drive" operates the wavelength selection knob, and allows slewing of the wavelength drive in either direction. Limit stops may be set for upper and lower limit wavelengths. Although the drive is currently configured for remote operation, manual operation is also possible. Variable slew speeds from a minimum of 1.56 nm/min to a maximum of 200 nm/min may be set manually or through the computer. The circuitry used to drive the stepper motor is shown in block diagram form in Figure 3.3. Built on an HP 69380 Breadboard card (which plugs into the Multiprogrammer), the circuitry allows the pulsing of the stepper motor. Through computer control, the user can step the motor in a specified direction and vary the rate at which the motor is stepped via the programmable divider circuitry.

Slewing of the drive to a specific wavelength requires determination of the number of pulses needed to

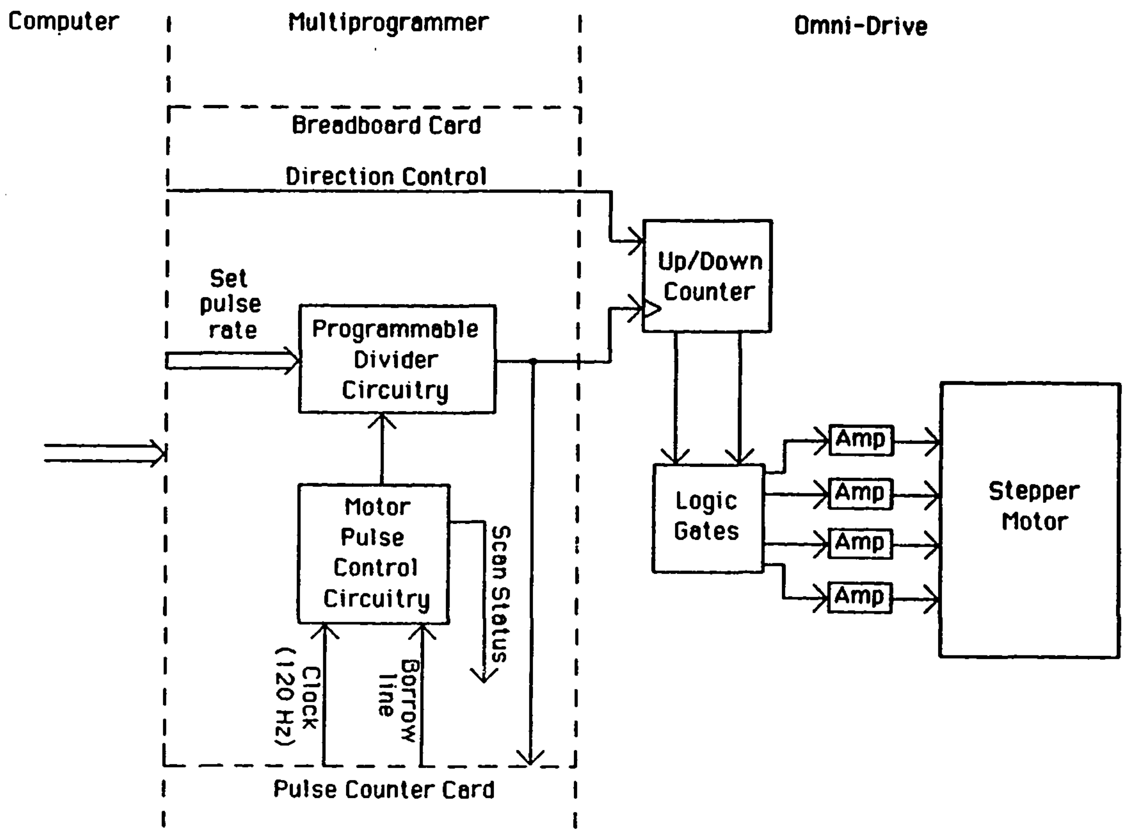

Figure 3.3. Stepper-Motor Driving Circuitry

slew from the current wavelength to the desired wavelength. There are approximately 36 pulses/nm on the short wavelength grating, and 18 pulses/nm on the long wavelength grating. A 24-bit, programmable, count-down counter is used (2 cascaded 12-bit counters) to put out the correct number of pulses. To begin, the counter is first preset with the number of pulses required to step the drive. Next, the control circuitry is set with the speed and direction of the scan and then signaled to start the scan. Through the programmable divider circuitry, the rate at which the stepper motor circuitry is pulsed can be determined. The counter senses the output of the programmable divider circuitry, counting down one value for each pulse received. Once the counter has counted down to zero from the preset value, the borrow line from the counter (which is sensed by the motor pulse control circuitry), flips in value and the pulsing is stopped.

To operate a device such as the omni-drive, the computer sends a command to a specific slot in the multiprogrammer. The slot contains a plug in card which provides control for the peripheral device. A simple program statement sends a 16-bit digital word to the multiprogrammer which specifies the slot and the control word needed to operate a device. In this case, the omni-drive is controlled by a breadboard card in slot 408. A 16-bit word sent to that slot provides control for the omni-drive. Bits

0-4 contain omni-drive control information. Bits 5-11 are not used (are left as "1's"), and bits 12-15 comprise the slot designator. The control bit values are defined in Table 3.2.

Table 3.2

Control Bit Values for the Omni-drive

Function	Bit Value	Definition
scan	0	stop
	1	start
direction	0	up
	1	down
speed	000	fastest
	111	slowest

If, for example, the omni-drive is to be scanned in the "up" direction at the fastest speed, a digital word would be sent (using an output statement in the program) to the multiprogrammer of the form

Bit#:	15	14	13	12	11	12	10	9	8	7	6	5	4	3	2	1	0
	1	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0

The output statement is contained within a subroutine, control variables being set in the calling program.

Whenever a device is to be operated, a simple calling of the subroutine will accomplish this.

3.2.4 Detector

The detector in the IAP spectroradiometer which converts optical radiation at the exit slit of the monochromator to an electrical signal, is an EG&G UV-444B photodiode. The detector is operated in the photovoltaic mode, for which a current is generated that is proportional to the amount of light power falling on it. Features of interest of the detector are listed below:

1) Planar diffused, oxide passivated structure
2) Wide spectral range - 190 to 1150 nm
3) Peak responsivity: .65 amps/watt @ 950 nm
4) UV responsivity: 180 milliamps/watt @ 280 nm
5) Flat noise spectrum to DC - no 1/f noise
6) Noise current - 1×10^{-14} to 7×10^{-14} amp/$Hz^{1/2}$
7) Linearity over wide dynamic range
8) Temperature coefficient of responsivity

   $\leq$ 0.05%/°C @ 900 nm

   $\leq$ 0.18%/°C @ 200 nm
9) Spectral stability - no hysteresis or memory effects

Figure 3.4 shows the spectral responsivity of the detector. This spectral responsivity is temperature dependent as

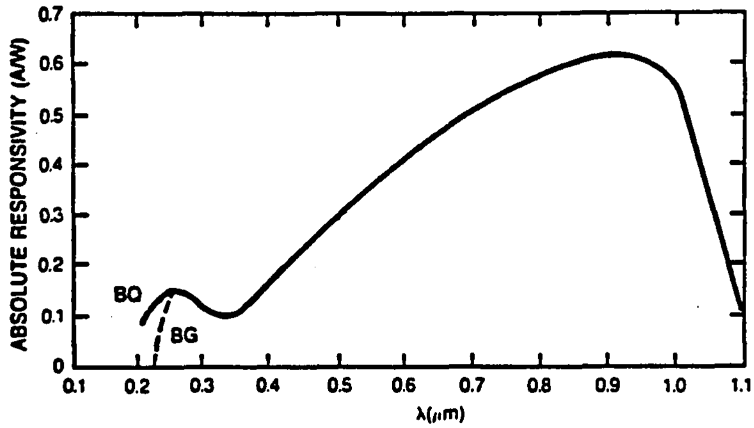

Figure 3.4. Spectral Responsivity of the Detector (EG&G "Photodiodes", 1988)

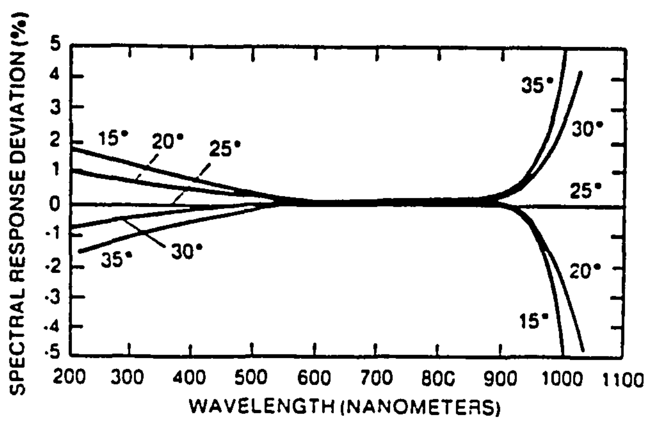

Figure 3.5. Temperature Dependence of the Responsivity (EG&G "Photodiodes", 1988)

demonstrated by Figure 3.5.

3.2.5 Temperature Controller

As evidenced by Figure 3.5, variations in temperature can affect the detector response. Because a change in response is undesirable, the detector must be kept at a constant temperature. The detector is kept at a temperature above the ambient room temperature so cooling isn't required. Constant temperature is achieved through the use of a 10 watt power resistor mounted on the back of the detector which is powered by a proportional temperature controller circuit, a block diagram of which is shown in Figure 3.6. In this closed-loop feedback system, a comparator is used to turn on the heater driver at a constant frequency determined by the triangle wave circuit. Proportional temperature control is achieved through a variable duty cycle. This duty cycle depends on that part of the triangle wave which is above the actual temperature voltage. In other words, for the average value of the triangle wave being kept constant, the heater will be on for those parts of the triangle wave which are above the voltage created by the temperature sensor (see Figure 3.7). The average value of the triangle wave determines the set point temperature, the temperature we wish to obtain for the detector. This set point temperature is set above the ambient room temperature at approximately 35 °C. The temperature sensor is an LM

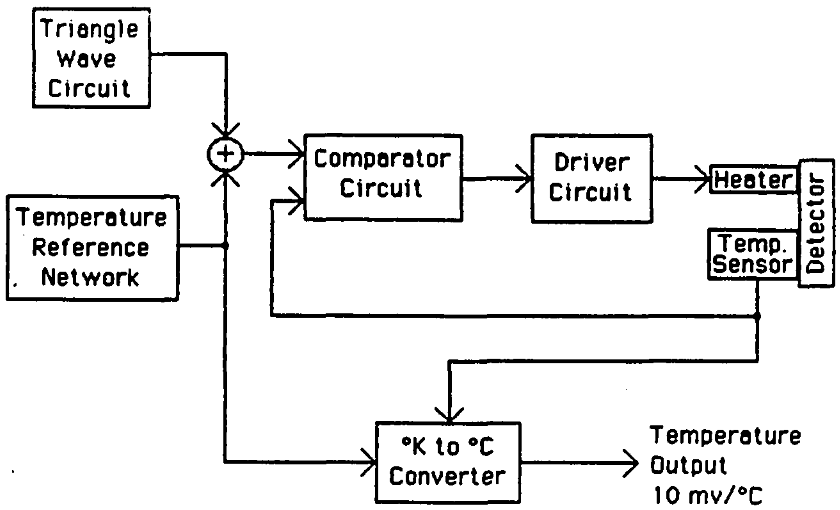

Figure 3.6. Proportional Temperature Controller

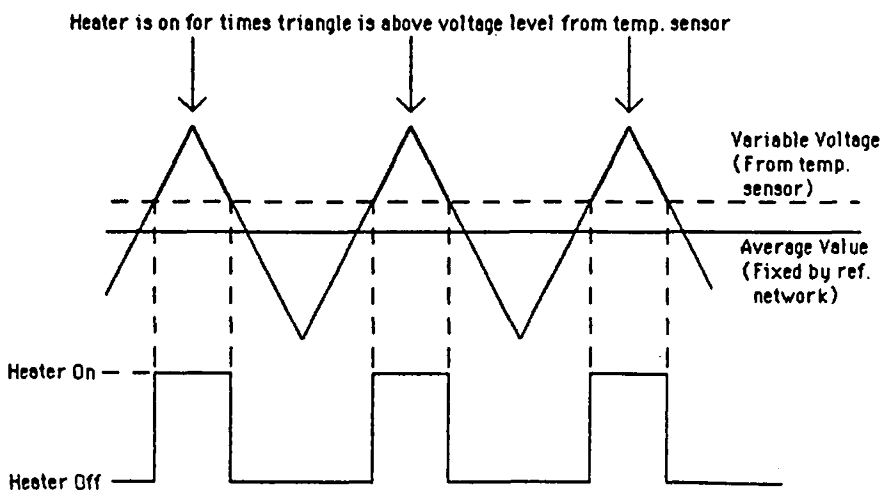

Figure 3.7. Proportional Temperature Control

335H which supplies 10 mv/°K. The temperature controller can only heat, and, therefore, will not provide temperature control (i.e., will not cool) when the detector temperature is above the set point of the reference network.

3.2.6 Tracking/Positioning System

The tracking mirror is on an equatorial tracking mount, which has two axes, namely, the polar and declination axes. The polar axis allows the tracking mirror to move in the east-west direction, while the declination axis allows the mirror to move in the north-south direction. Each axis drive uses a Hurst model ABS 3008-004 stepper motor. The polar axis has a gear reduction of 134:1, and the declination axis has one of 100:1.

Before the tracking mirror can locate the sun, it must be slewed to a reference position, assuming its present position is not known. The tracking mount has no position sensors or encoders, therefore, the position is not absolutely known upon start-up. The reference position is defined as that where the mirror is pointed east and its declination angle is set to 90°. From this position, the computer can point the mirror in any direction in the sky by giving the drives the appropriate number of pulses.

To slew the mirror to its reference position, the mirror is first slewed eastward until the limit switch on its polar axis closes, and it is then slewed slowly westward until the point where the switch just opens. In doing this, the polar axis drive is initialized to its reference position. Next, the mirror is slewed northward until the limit switch on the declination axis is closed. Following this, it is slewed slowly southward until the switch just opens. This puts the declination axis in its reference position. The limit switches are read by a Digital Input Card (DIC).

Once in the reference position, the tracker can locate the sun and track it. It does the former using an open loop tracking routine which calculates the sun's position in the sky (using solar ephemeris data) according to the year, day, time of day and the location of the instrument. It adjusts the angle of the mirror accordingly, matching up with the sun's position, thereby bringing sunlight into the spectroradiometer system. Once locked onto the sun, both a closed loop and open loop tracking routine are used to track the sun.

The closed loop routine utilizes a quadrant detector housed in a telescope to position the tracking mirror. The sun is imaged onto the face of the quadrant detector. Depending on which quadrant(s) the sun's image lies on, the mirror is moved appropriately to move the image to dead-center. The routine determines the relative position of the image on the quadrant detector by measuring the output of each detector quadrant. A higher output results from more image area lying on a detector quadrant. An image at dead-center yields equal outputs from all four quadrants. The field of view of the quadrant detector telescope is about 7.2°. The quadrant detector assembly can detect an angular change of .42 arc-sec. Figure 3.8 shows how the closed loop system is implemented.

The tracker works on an interrupt routine in which the main program is interrupted periodically ~~to~~ update the tracking position. This takes place approximately every six seconds. A flow chart of the tracking routine "Track" is shown in Figure 3.9. The closed loop tracking scheme and the declination axis update are used only once for every 10 times the polar axis update is performed. This is appropriate because the declination position varies much more slowly than the polar position. A block diagram of the motor driving circuitry for the tracking mount is shown in F3.10.

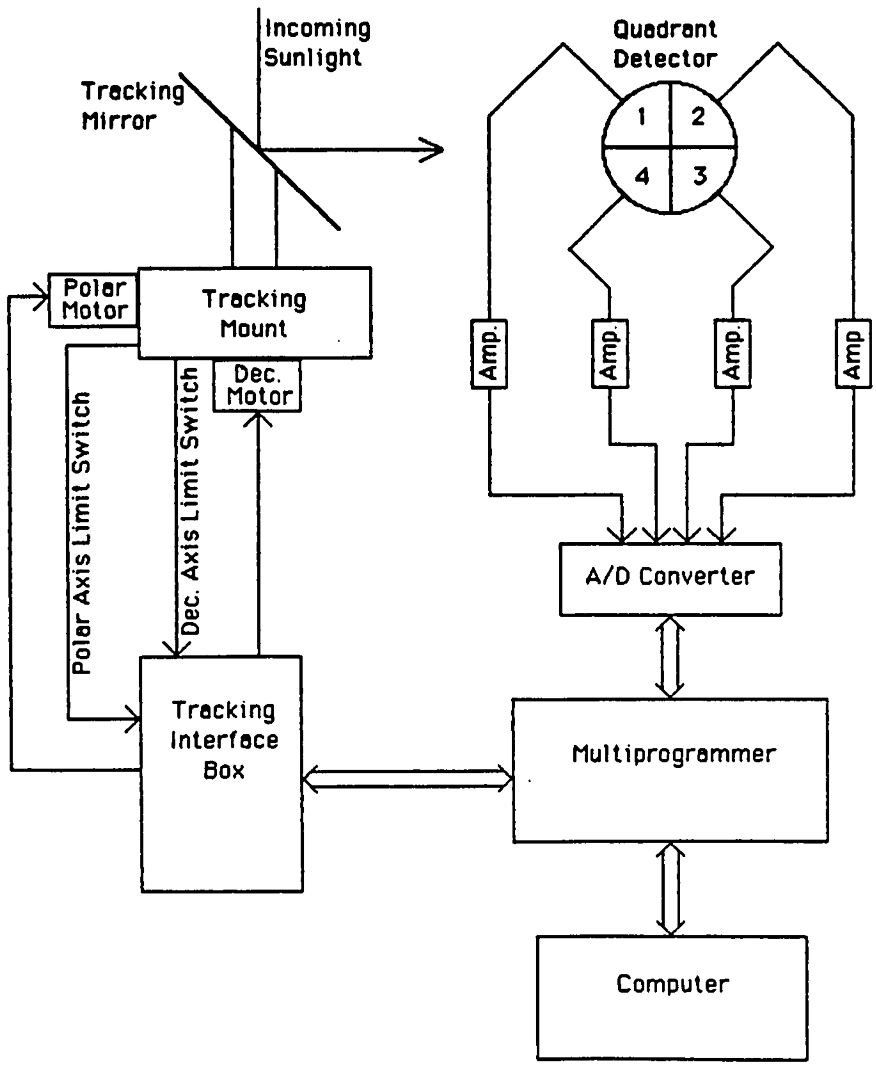

Figure 3.8. Closed Loop Tracking System

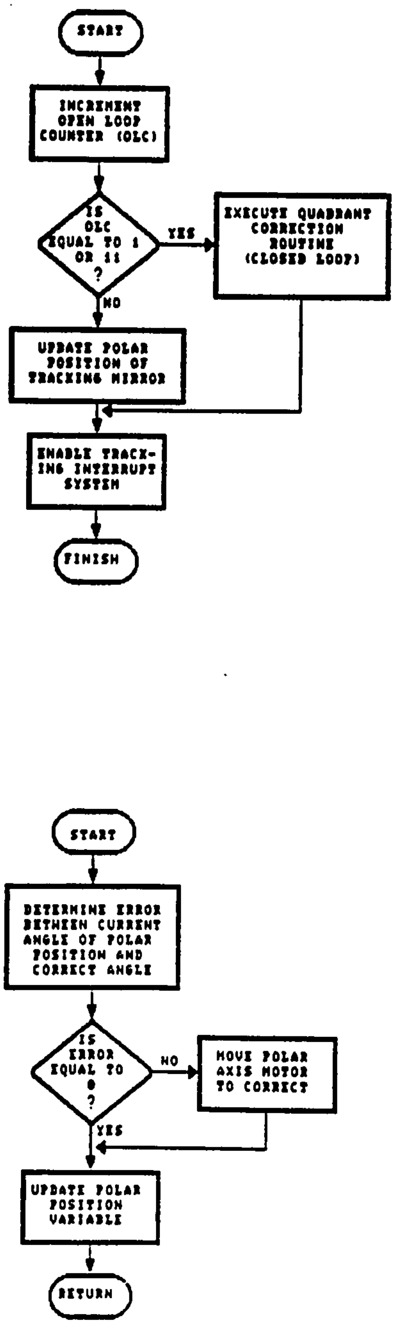

Figure 3.9. Subroutine "Track"

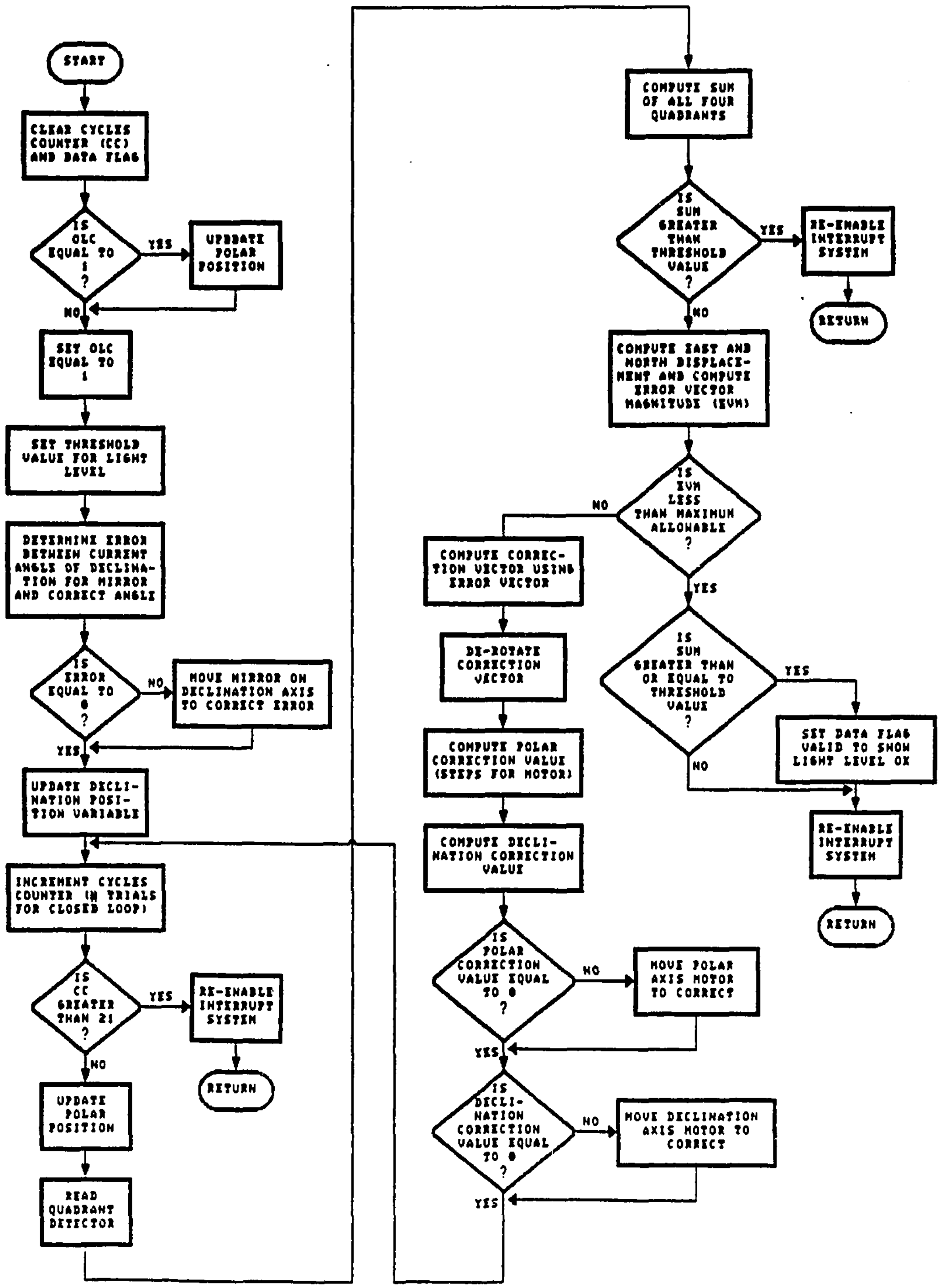

Figure 3.9 (Continued). Quadrant Correction Routine for "Track"

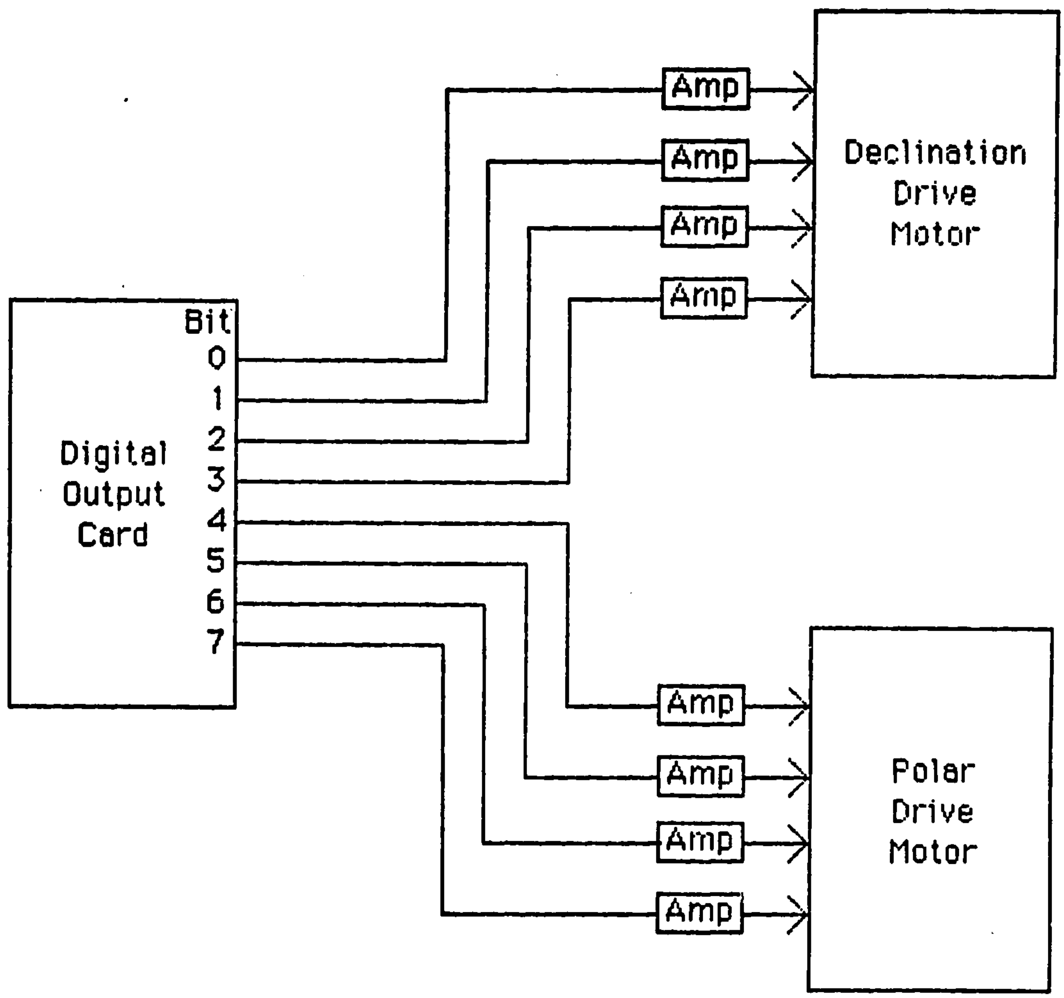

Figure 3.10. Motor Driving Circuitry for Tracking Mount

3.2.7 Signal Conditioning System

Signal conditioning is provided by an Ithaco lock-in amplifier and the Data Acquisition Unit (DAU). The DAU contains the electronics which perform data multiplexing of the lock-in amplifier output and A/D conversion of both the quadrant detector and temperature sensor outputs.

A lock-in amplifier is basically a narrowband filter followed by a rectifier. Its center frequency is controlled by an external reference signal, and its output is a dc level proportional to the amplitude of the input signal which is coherent with the external reference. The lock-in amplifier or synchronous detection technique (Brower, 1968) is an excellent way of recovering a signal buried in noise. It consists of four steps:

1) Moving the signal from zero frequency to an arbitrary frequency by chopping the light.
2) Amplification of the signal at the chopping frequency (170 Hz for the IAP system).
3) Phase sensitive detection and demodulation of the signal.
4) Narrowing the bandwidth around the signal of interest by integration in the low pass filter.

Figure 3.11 shows how the incoming light is chopped by the chopper before entering the monochromators, thereby sending a modulated signal to the detector. Using the reference from the chopper, the lock-in amplifier can then

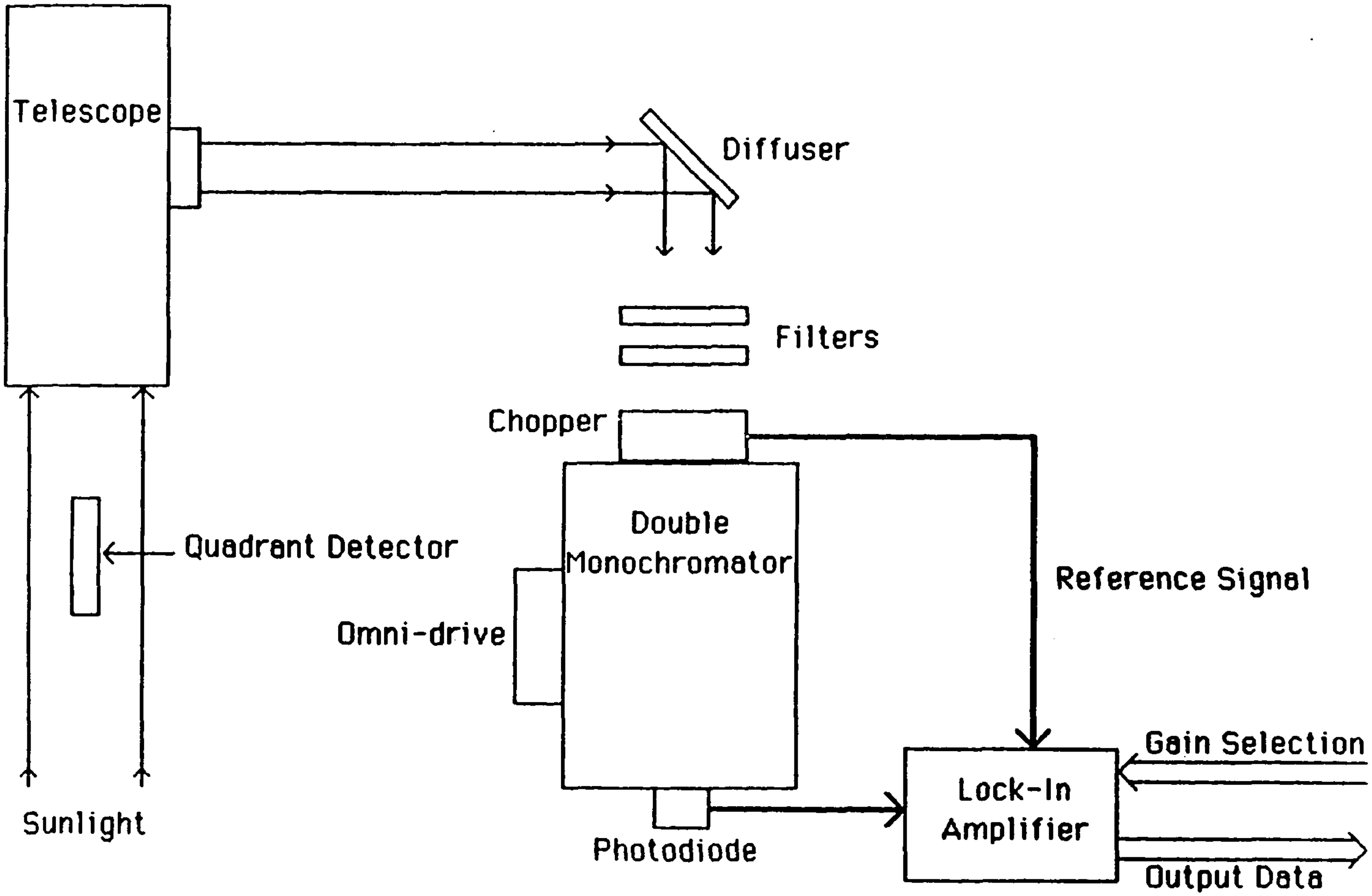

Figure 3.11. Signal Modulation and Detection

amplify and filter the signal at the modulation frequency.

Figure 3.12 shows the block diagram of the circuitry in the DAU. The data acquisition circuitry deals with:

1) Lock-in status check
2) Lock-in amplifier control
3) Transfer of lock-in data
4) Quadrant detector output (for tracking)
5) Temperature sensor output

A total of 5 status lines allow the computer to check if the lock-in amplifier is

1) in local or remote mode
2) in expand mode
3) locked in to the reference signal
4) overloaded
5) outputting valid data

The first 2 status lines go directly to a DIC in the Multiprogrammer. The other 3 status lines are part of the data word sent by the lock-in. Data is displayed by the lock-in amplifier as a 16- bit word. Bits 0-10 and 15 compose the lock-in amplifier signal, and bits 11-14 are status bits. The 16-bit data word is multiplexed in the data acquisition box to four 4-bit words by two 74153 dual 4-line to 1-line multiplexers. Data is retrieved by the computer via a Digital Input Card. Multiplexer addressing is done by the computer through the use of a Digital Output Card (DOC).

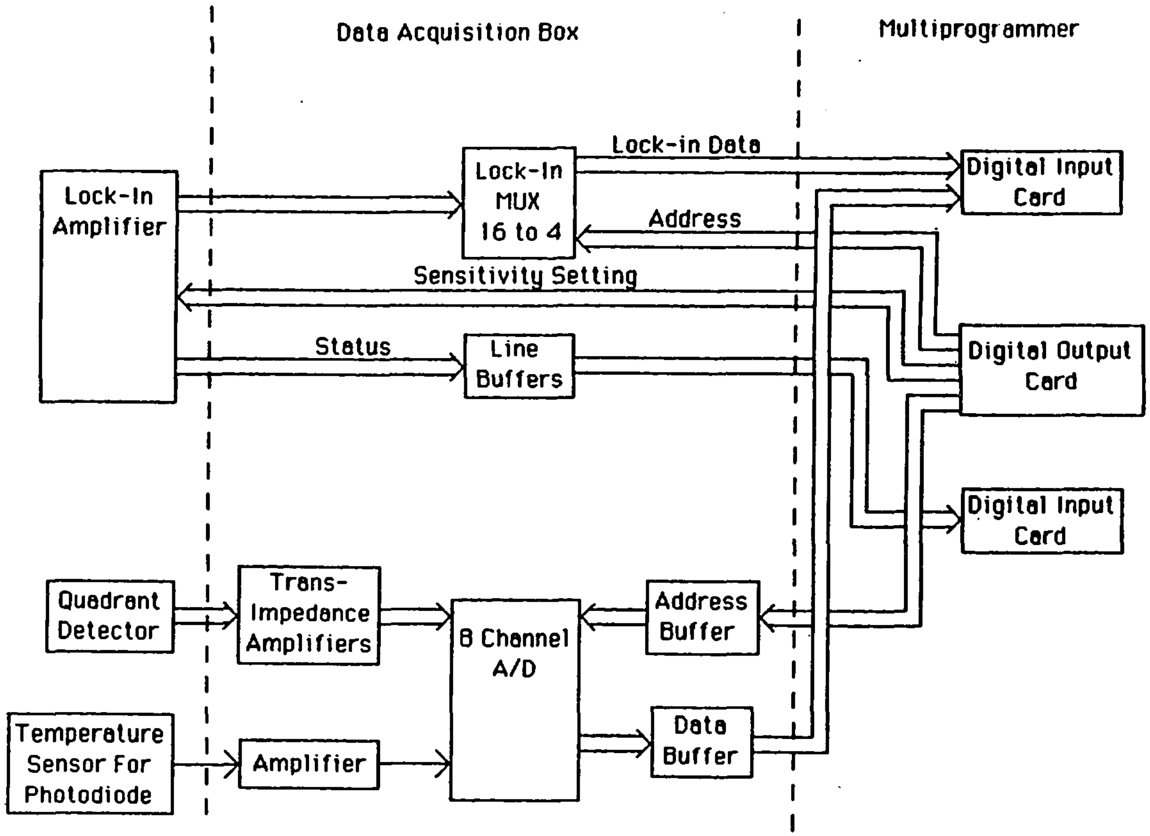

Figure 3.12. Data Acquisition Unit

Lock-in amplifier control involves the setting of the lock-in's sensitivity or gain. A setting is achieved through the use of a DOC in the Multiprogrammer. There are 6 possible settings (maximum range on the amplifier read-out):

1) 10 μV (100 pA)

2) 100 μV (1 nA)

3) 1 mV (10 nA)

4) 10 mV (100 nA)

5) 100 mV (1μA)

6) 1 V (10 μA)

The four quadrant detector outputs, in the form of currents, are converted to voltages by transimpedance amplifiers, which are then digitized by an 8-bit A/D converter. The device used for this is the AD7581, made by analog devices.

The temperature sensor output is in the form of a voltage. This output is amplified and then digitized by the same AD7581 which handles the quadrant detector outputs, but on a different channel. A DIC allows the A/D converter to be read by the computer, and a DOC allows A/D channel selection.

3.3 Software

A listing of the system software, as well as an operator's manual (Scott-Fleming, 1984), is kept with the instrument. The following sub-sections describe programs "Menu", "Perck", "Autost", and "Rad" which comprise the software package that runs the spectroradiometer system.

3.3.1 Programs "Menu" and "Perck"

"Menu" is the program which displays user options for running the spectroradiometer. It executes the procedures corresponding to the special function key pressed by the user. "Perck" initializes and checks the status of the computer and its peripherals. Its flowchart is shown in Figure 3.13. The subroutines for "Perck" are:

"Intro" - displays introductory message and lists tests to be performed

"Setwvl" - reads wavelengths to be scanned by spectroradiometer from a file and allows changing of the wavelengths

"Clkck" - checks clock hardware, asks for verification of time and date

"Clkset" - resets real time clock

"Tapeck" - runs a read-after-write check on auxiliary tape drive

"Multck" - performs echo check on multiprogrammer to verify computer is communicating with it

"Consck" - Displays the solar spectroradiometer's most recent system constants to be approved by the user

"Pause" - allows user to halt program execution

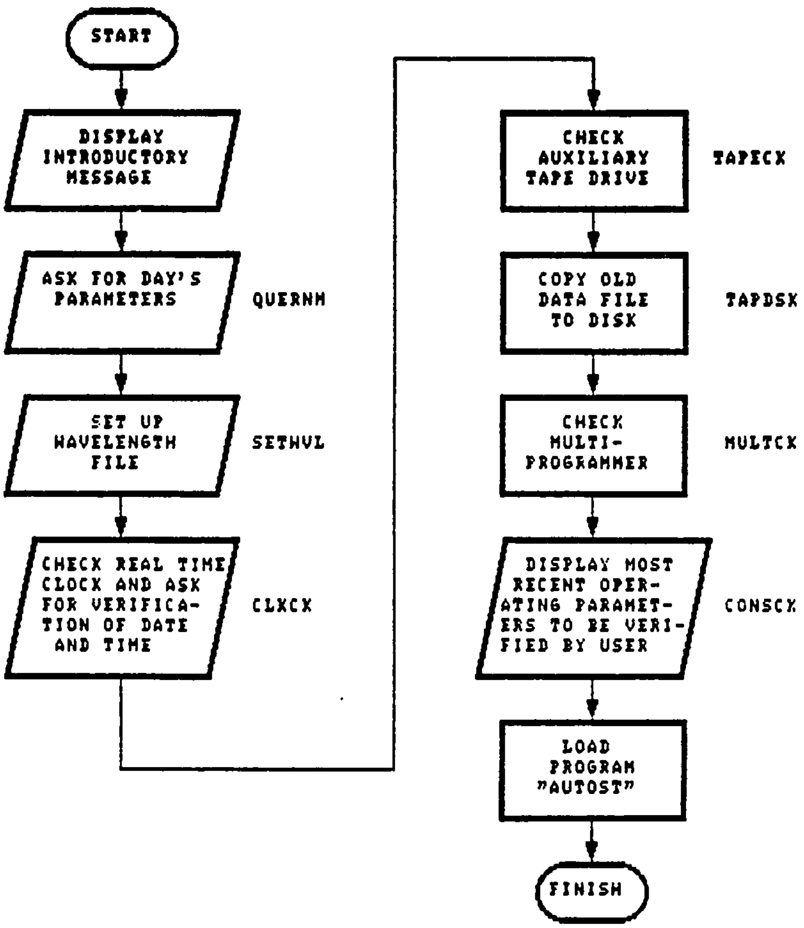

Figure 3.13. Program "Perck"

"Query" - allows alphanumeric input from keyboard

"Quernm" - allows numeric input from keyboard

3.3.2 Program "Autost"

"Autost" performs self-check and initialization procedures on the instrument and then loads program "Rad". Its flowchart is shown in Figure 3.14. The subroutines for "Autost" are:

"Entry" - displays introductory message

"Init0" - turns on power to instrument hardware and performs tests to verify they are operating normally

"Init1" - calls "Polref" to initialize polar axis drive

"Init2" - calls "Decref" to initialize declination axis drive

"Init3" - calls "Monref" to initialize wavelength drive

"Coef" - loads in declination coefficients

"Mertrn" - computes time of local solar meridian transit

"Polref" - initializes polar axis drive

"Decref" - initializes declination axis drive

"Auto" - displays information concerning the automatic start-up option

"Rdsw" - reads limit switches on tracking mount

"Intmsg" - displays introductory message and makes sure the initialization program has been run.

"Poschg" - changes position of tracking mount

"Mpin" - allows non-gated input from multiprogrammer to

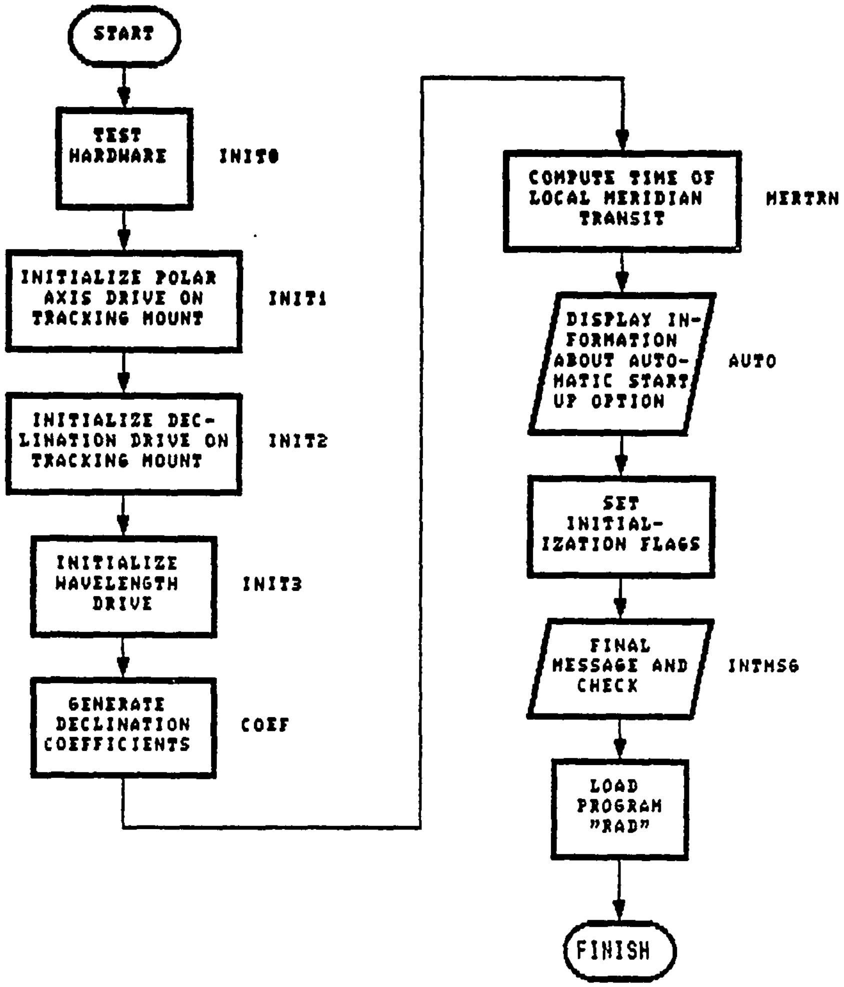

Figure 3.14. Program "Autost"

the computer

"Monref" - initializes wavelength drive

"Frqslw" - slews the monochromator wavelength drive by a specified increment

"Monst" - checks status of the monochromator

"Loadbb" - loads breadboard card in the multiprogrammer to control omni-drive

"Ldcnt" - loads the two 12-bit counter cards in the multiprogrammer for slewing the omni-drive

"Mpout" - allows data transmission to the multiprogrammer

"Time" - reads the real time clock

"Relay" - controls relay output card in multiprogrammer

"Setsen" - sets lock-in amplifier's sensitivity

"Rdlk" - reads lock-in amplifier output data

"Rdatod" - reads the A/D converter

"Chsel" - selects desired channel of A/D converter

"Temprd" - read temperature of the detector

"Pause" - allows user to halt program execution

3.3.3 Program "Rad"

"Rad" is the program which runs the solar spectroradiometer during data collection. The subroutines for "Rad" are shown below:

"Track" - executes open-loop and closed loop positioning of the tracking mirror

"Racor" - determines error between current polar position of tracking mirror and correct polar position

"Deccor" - determines error between current mirror tilt angle and the required mirror tilt angle

"Quadrd" - reads quadrant detector

"Getdet" - takes one reading from lock-in amplifier, determining sensitivity setting automatically

"Setfrq" - sets the wavelength on the monochromators

"Filt1" - places or retracts orange glass filter based on observation wavelength

"Filt2" - places or retracts red glass filter based on observation wavelength

"Grat" - selects proper wavelength gratings in monochromators based on the observation wavelength

"Detsel" - selects proper detector based on observation wavelength (not in use)

"Calfq2" - calculates next observation wavelength

"Timeck" - reads real time clock and shuts down spectroradiometer if not within correct time range

"Settle" - determines when wavelength drive slew is complete and causes a predetermined delay to allow lock-in signal to settle

"Recal" - re-initializes wavelength drive by calling "Monref"

A number of subroutines in "Autost" are also used in "Rad".

These are "Mpin", "Monref", "Frqslw", "Monst", "Loadbb", "Ldcnt", "Mpout", "Time", "Relay", "Setsen", "Rdlk", "Rdatod", "Chsel", "Temprd", and "Pause". A flowchart of "Rad" is shown in Figure 3.15.

This ends the description of the system hardware and software. The next chapter will look at modifications made to the hardware and software.

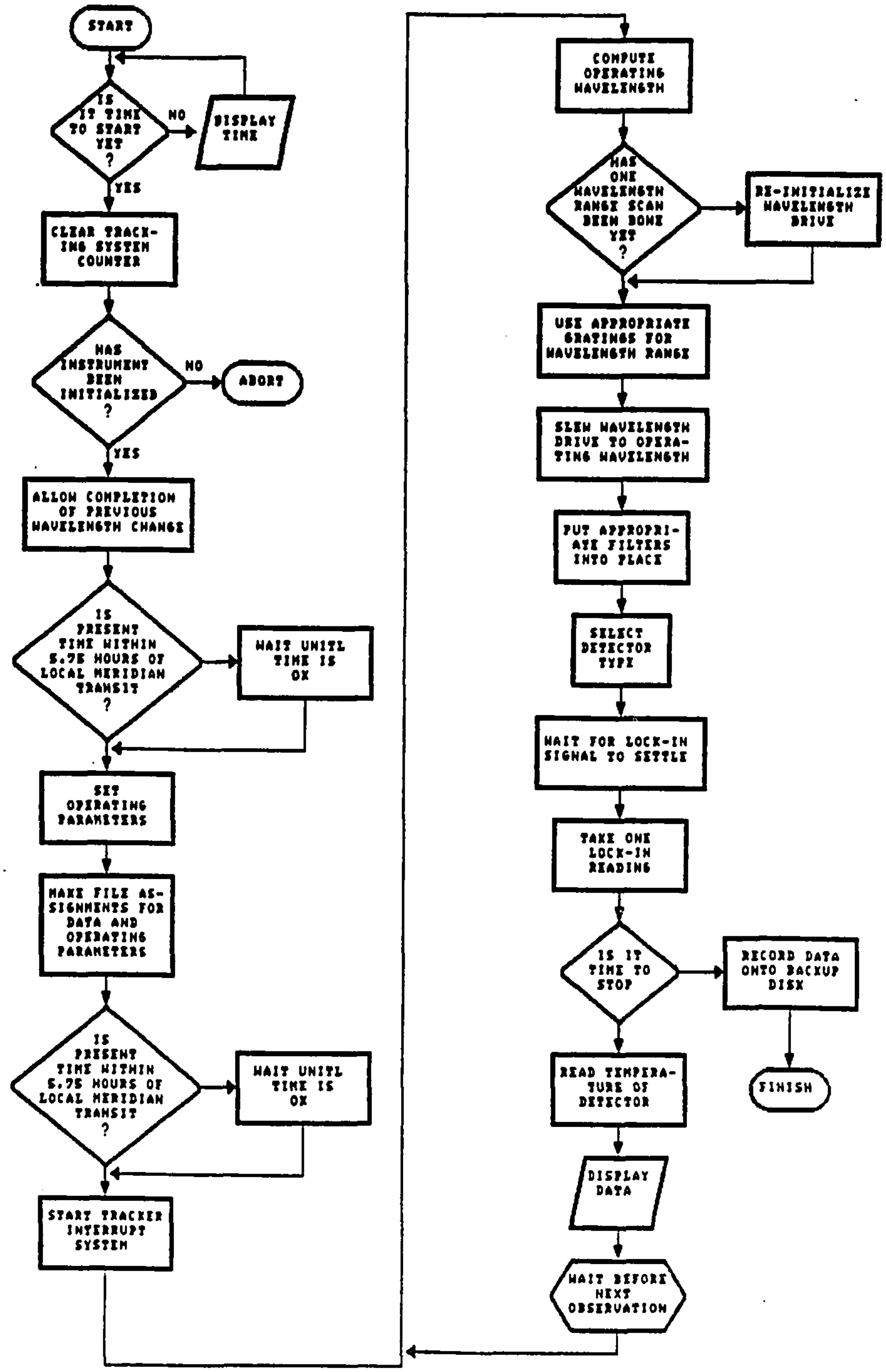

Figure 3.15. Program "Rad"

CHAPTER 4

SYSTEM MODIFICATIONS

This chapter describes modifications that were made to the spectroradiometer system hardware and software. Hardware modifications were necessary to solve problems encountered with the system and upgrade the its capabilities. Software changes were required to accommodate the hardware modifications and enhance system performance.

4.1 Hardware Modifications

This section describes hardware modifications done to the system. First, the modification to the temperature controller will be discussed. Next, changes made to the temperature acquisition circuitry will be described. Finally, the addition of encoders to the wavelength selection system will be examined.

4.1.1 Modification to Temperature Controller

A noise problem existed in the photodiode output to the lock-in amplifier. The noise was periodic, occurring every few seconds, tending to max out the amplifier signal. It was later observed that the noise glitches on the photodiode signal corresponded to glitches on the comparator output of the temperature controller. Noise was coupling into the photodiode output from the temperature controller circuitry.

Through some experimentation, it was found that a 33 μF capacitor across the inputs of the comparator and a 330 μF capacitor from the output of the comparator to ground eliminated the noise on the comparator output and thus the noise on the photodiode signal. The capacitor at the output nullified the periodic nature of the heater signal. The triangle wave oscillator circuit was therefore no longer needed and was removed from the circuit. The resulting heater driving signal was either full on or full off, proportional temperature control no longer being provided. Tests showed that the temperature was still kept within 0.5°C of the set point value.

4.1.2 Modification to Temperature Acquisition Circuitry

The temperature sensor and the circuitry used to amplify its output voltage had been changed from its initial design. Due to this modification, the computer was not able to read the temperature. It was found that the amplifier circuit used to supply the necessary gain was not correctly designed to provide a voltage which matched the A/D converter input voltage range. The AD7581 was set up for "unipolar" (complementary binary) operation (Analog Devices, C575-9-9/80). This means that analog inputs should range between -10V and 0V.

Before undertaking correction of the problem, it was determined that the temperature should be read at a higher resolution than what it had been previously designed to achieve (about ±3.9 °C). The desired resolution was 0.1 °C. The 8-bit A/D converter provides 255 counts, yielding an input voltage resolution of

$$10V/255 = 39.2mv.$$

Recalling that the temperature sensor circuitry has a responsivity of 10mv/°C, for a resolution of 0.1 °C, the temperature sensor output voltage resolution must be

$$0.1\ °C \times 10mV/°C = 1mv.$$

Thus, the gain for the amplifier should be

$$gain = 10/255 \div 0.001 = 39.2 \approx 40.$$

The amplifier input voltage range is then

$$output\ range/40 = 10/40 = 0.25V.$$

The selected set point temperature is 35 °C, which means a temperature sensor output of 0.35V. This value should be in the middle of the input range. By offsetting the amplifier output by 20V, the minimum input voltage becomes 0.25V and the maximum input voltage becomes 0.5V. The amplifier output voltage may be expressed analytically by

$$\text{output voltage} = (40 \times \text{input voltage}) - 20,$$

where,

$$\text{input voltage} = \text{temperature} \times (10\text{mV}/^\circ\text{C}).$$

The equation for the A/D section is

$$A/D_{out} = ((255/10) \times A/D_{in}) + 255.$$

The temperature can then be determined by

$$\text{temperature} = (A/D_{out} + 255)/10.2.$$

It should be noted that the temperature can only be read when it is between 25 °C and 50 °C. Anything lower than 25 °C will yield a temperature reading of 25 °C, and anything higher than 50 °C will give a reading of 50 °C. With the set-point temperature at 35 °C, this should not present a problem. The circuit which was designed to accomplish this and its gain curve is shown in Figure 4.1. The gain curve shows the circuit has a gain of 40, with an offset of 20 volts. Modification of the software to accommodate the hardware changes is discussed in a later.

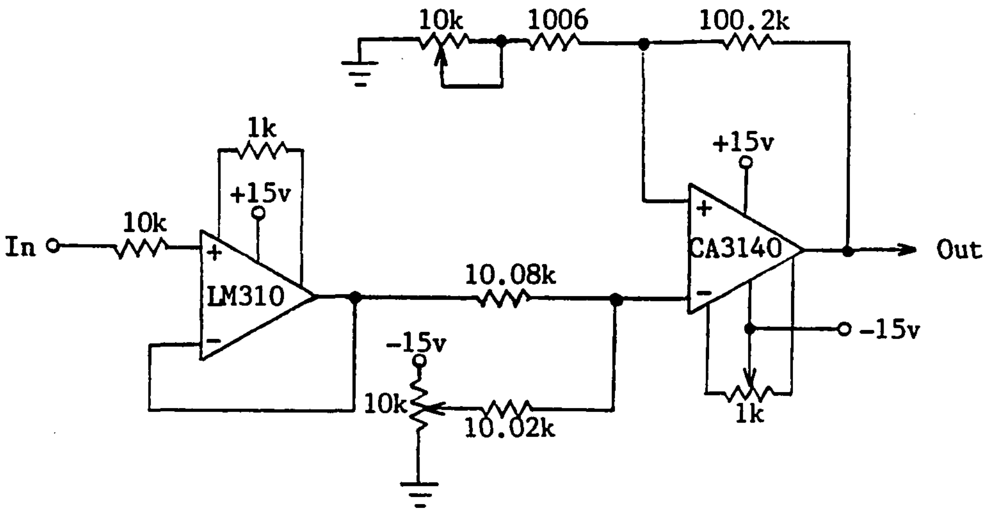

Figure 4.1 a) Modified Circuit

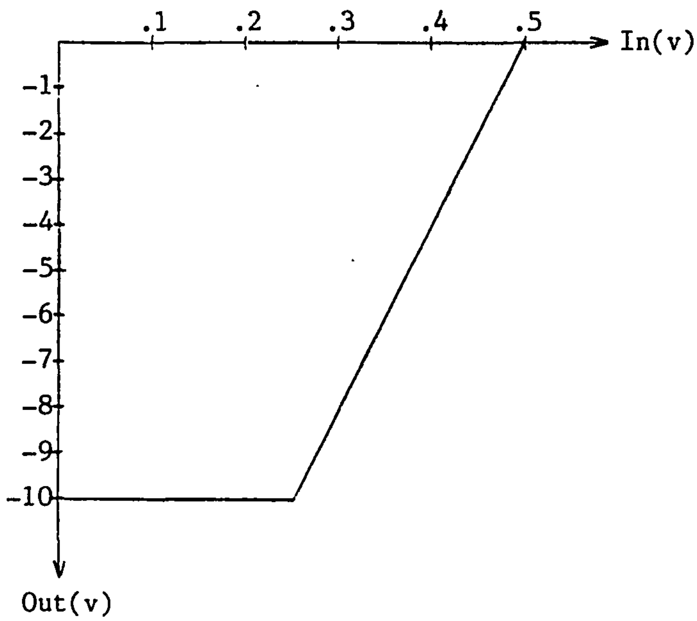

Figure 4.1 b) Circuit Gain Curve

4.1.3 Modification to Wavelength Selection System

As originally designed, the wavelength drive system had no feedback, so there was no accurate way of determining the wavelength setting. Wavelength determination for the monochromators was done by first slewing the drive to a reference position which was below any wavelength of interest, and then stepping the motor of the drive to the wavelength of interest. The resulting wavelength setting was assumed to be correct. Several continuous scans across the spectral line of a HeNe laser showed that this method of inferring the wavelength was very imprecise. The results of this test are shown in Figure 4.2. A considerable drift is evident after only a few runs. In addition, the drift is not uniform for each wavelength. What was needed was an accurate method of determining the wavelength drive setting that could be read through the computer.

It was decided that encoding turns of the wavelength drive shaft using a device called an optical rotary encoder would accomplish this.. There are two types of optical rotary encoders, absolute and incremental. Absolute encoders give a non-ambiguous output corresponding to position. The output is in the form of a binary code (e.g., natural binary, BCD, Gray code, etc.). This code is derived from photodetectors corresponding to independent tracks on a glass disc within the encoder. Outputs from these detectors would then be high or low, depending on the

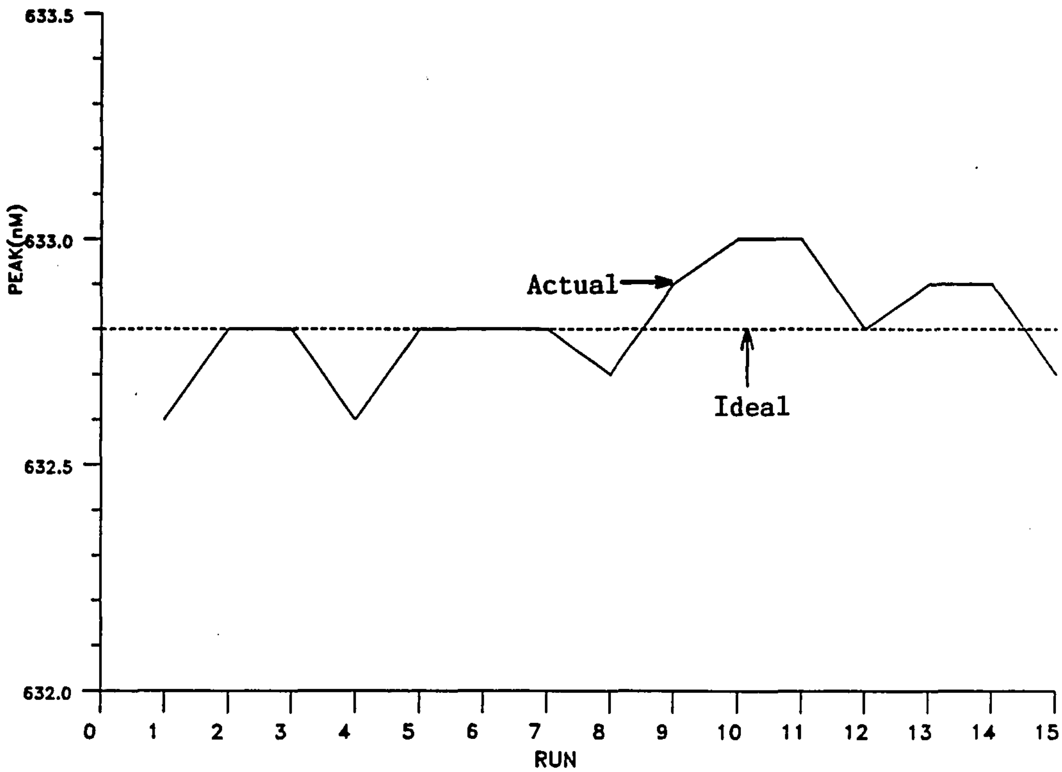

Figure 4.2. Scans Across Laser Line

pattern for that particular position (see Figure 4.3). An 8-bit absolute disk is shown in Figure 4.4. Incremental encoders output a wave form (e.g., square wave, pulse train, etc.) as the encoder shaft is rotated. The amount of rotation on the shaft is determined by counting the number of square waves or pulses which have occurred. Square waves or pulses are produced when lines positioned radially outward on the glass disk pass between the light source and the photodetector within the encoder. Figure 4.5 shows such a disk. The major difference between the two is the fact that with absolute encoders the shaft position is known exactly at all times, whereas with incremental encoders the position can only be determined in a relative fashion.

An absolute encoder was chosen over an incremental encoder. It was decided that the ability to calculate the wavelength setting at start-up and at other times, without having to count pulses, was a definite advantage. For the system, a wavelength range covering the visible spectrum was of primary concern. A resolution of at least .2 nm was desired. If the range is from 150 nm to 900 nm, this means a resolution of 1 in 3750 parts. Although encoders are made with this kind of resolution, they are quite expensive. The author pursued the idea of using two absolute encoders of lower resolution (8-bit, binary output) to act as one with a higher resolution. One encoder was coupled directly to the wavelength drive shaft, and the other encoder was geared to

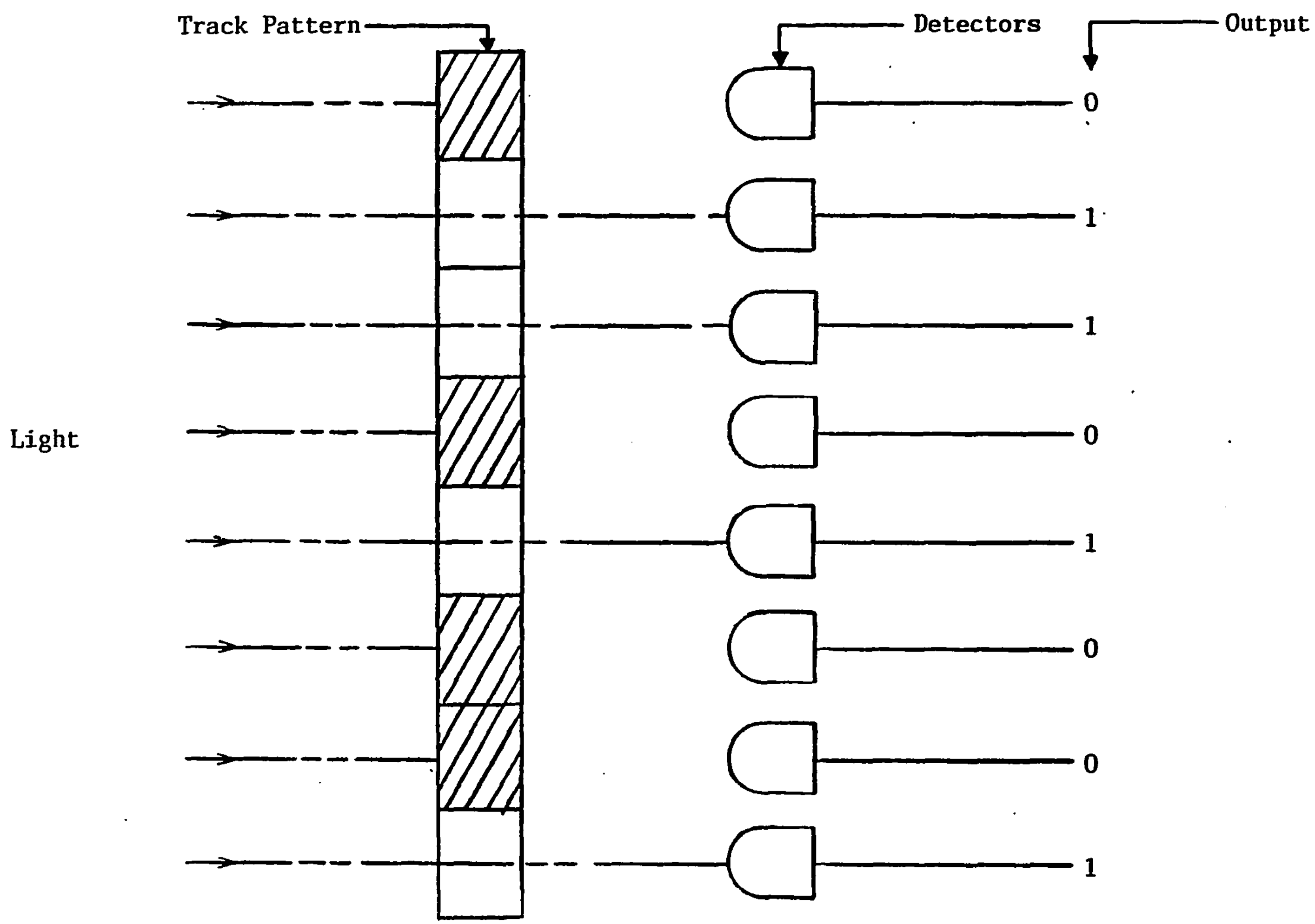

Figure 4.3. Absolute Encoder Output

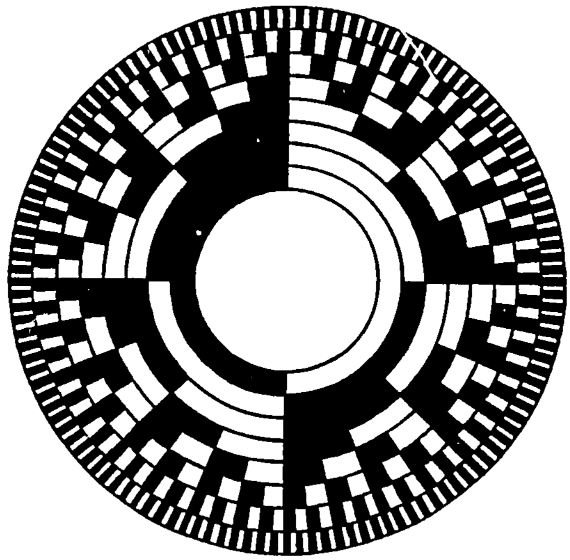

Figure 4.4. 8-Bit Absolute Disk

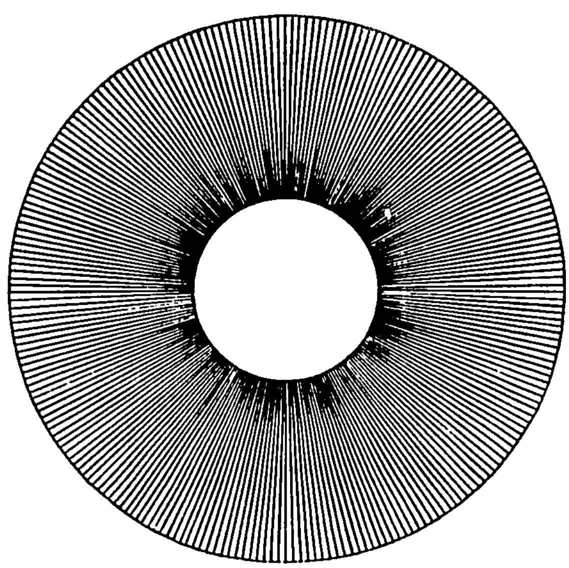

Figure 4.5. Incremental Disk

the first, counting the number of turns the shaft made. The shaft of the monochromator turns 32 times when going through one complete scan, therefore the encoders were geared together with a ratio of 32:1. The set up is shown in Figure 4.6. With the encoder system, the total number of counts for the wavelength range is 8192, so a resolution of 1 in 8192 parts was achieved on the short wavelength range, corresponding to about 0.1nm. The resolution on the long wavelength range is half of this, about 0.2nm.

A DIC was used for each encoder so that the encoder outputs could be read by the computer via the Multiprogrammer. A power supply module was built for the encoders which included LED's to make visual reading of the encoders more convenient (see Appendix A).

When first tested, errors occurred in deriving the wavelength from the encoder outputs. Tests were performed to determine variability in the transition from one count to another. Theoretically, the first encoder should go through 32 counts as the second encoder goes through 1. This was found not to be the case. A defective gear assembly was suspected to be causing the problem. The first encoder's counts varied for each count of the second. Test results are shown in Figure 4.7 for 40 counts of the second encoder. The results can be explained with the aid of Figure 4.8. For encoder 2, the dotted box designates its resolution "window", and the black squares indicate a transition

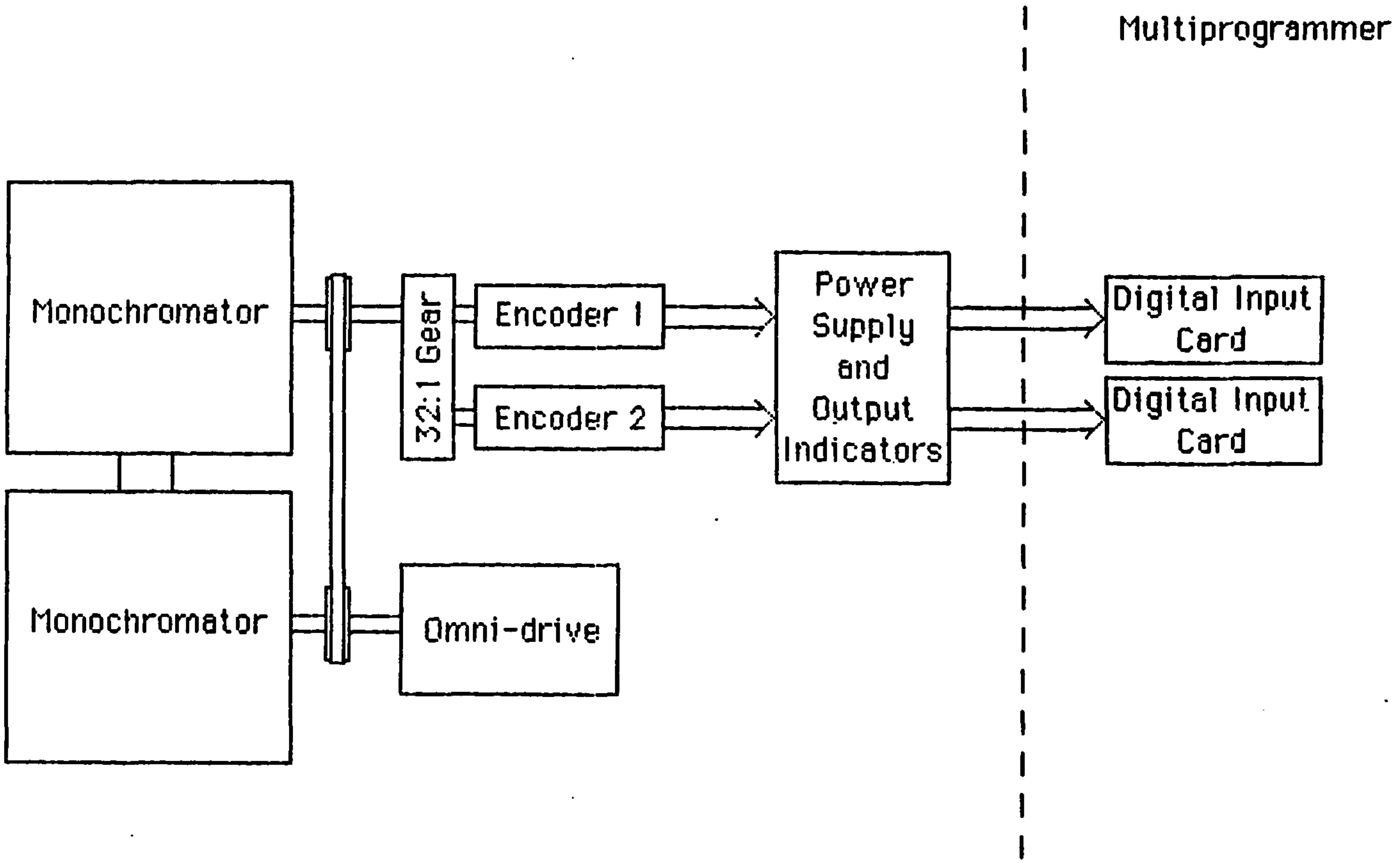

Figure 4.6. Encoder System Set-Up

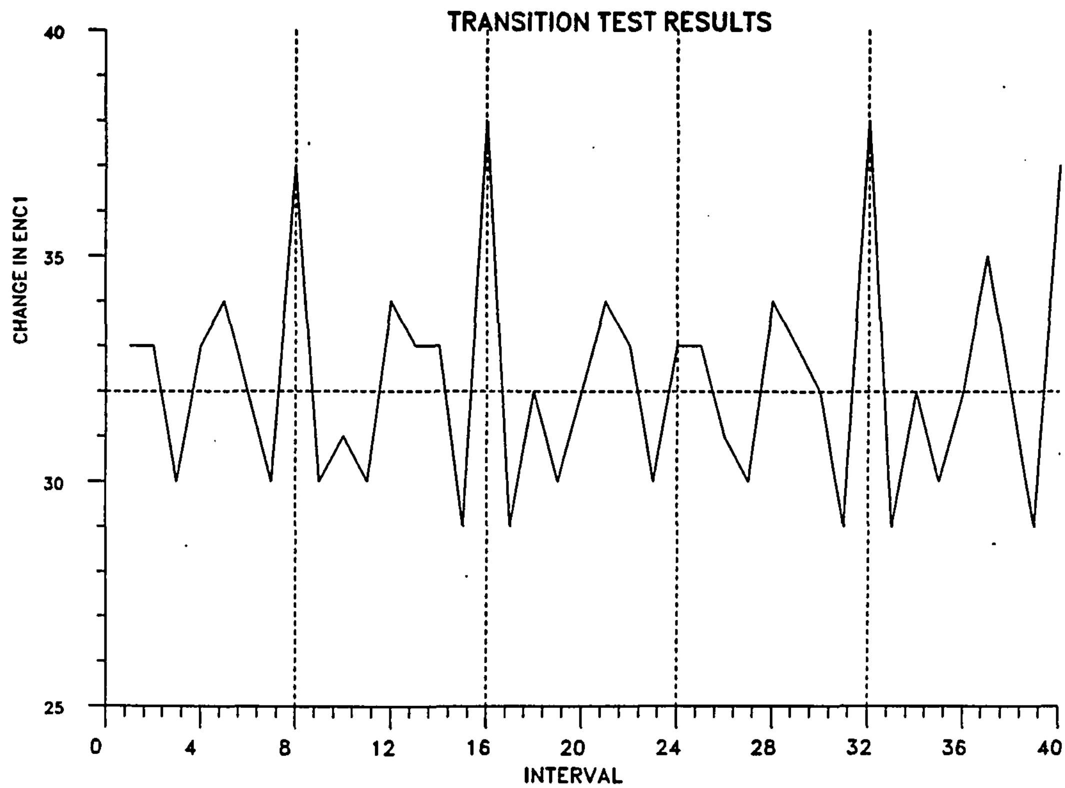

Figure 4.7. Test Run for Encoders

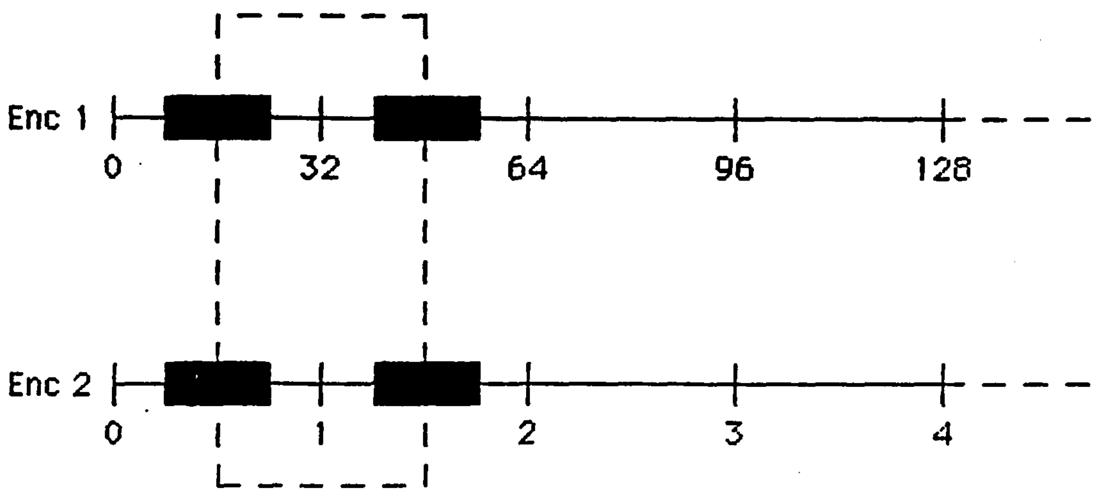

Figure 4.8. Encoder System Resolution

uncertainty where a transition will occur somewhere in the square. For each encoder individually, the uncertainty may be as much as ±1/2 count. However, because of the 32:1 gear ratio, ±1/2 count on encoder 2 will be magnified to ±16 counts. This may seem quite large, but it is not of much concern. For encoder 1, a transition accuracy of ±1/2 corresponds to ±1/2(25/256) = ±0.0488 nm (for the short wavelength grating), because it is directly coupled to the drive shaft. Encoder 2 counts the number of turns, and one must only worry about the transition from one turn to the next. The configuration of the encoder system has a built in safeguard. There is a specific relationship between encoder 2 and encoder 1, which is shown in Figure 4.9. Thus, at a turn transition, a test can be performed to see if the output of encoder 1 corresponds to correct values. For example, if the output of encoder 2 is 7 (right before a turn transition), then encoder 1 should be between 192 and 0 (accounting for the uncertainty). If encoder 1's output is not correct, encoder 2 did not turn when it should have, so 1 can be added to encoder 2's output value to get the correct value. If the output of encoder 2 is 8 (at a turn transition) and encoder 1 is not between 0 and 64, then encoder 2 turned early, so 1 can be subtracted from encoder 2's output to derive the correct value. This process does not work at the maximum/reference position where the output of both encoders should be 0. If the drive is at the high

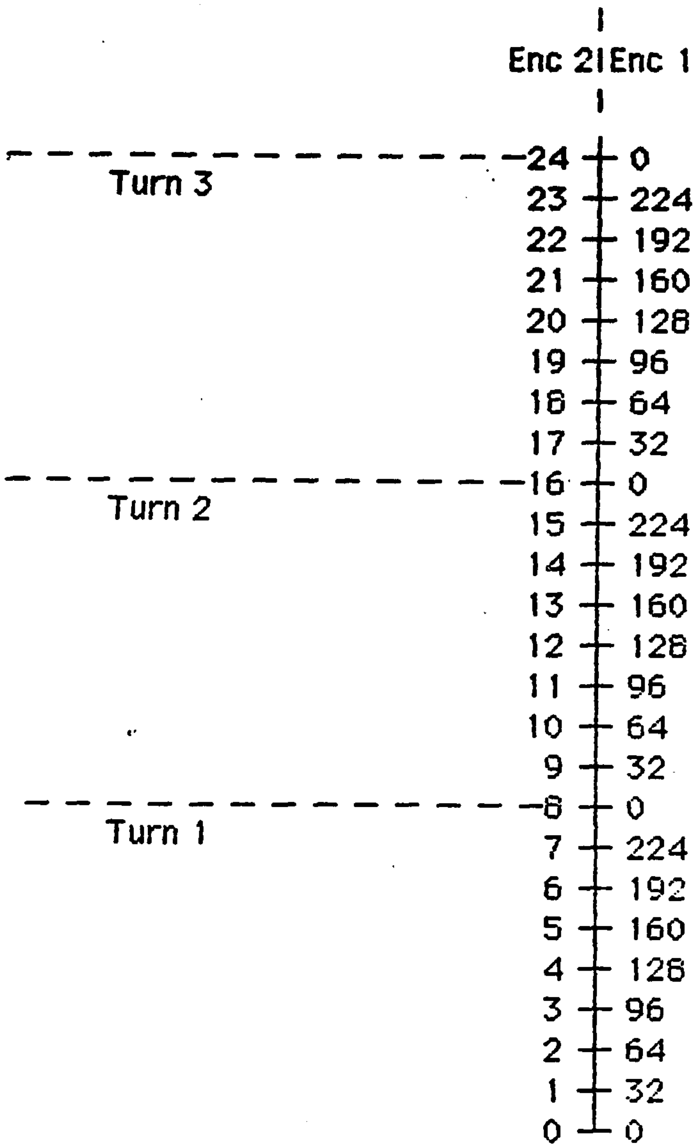

Figure 4.9. Relationship Between Encoders

end of the range and encoder 1 reaches 0 before encoder 2, the computer would calculate a wavelength position at the low end of the range. The problem is solved by setting encoder 2 slightly ahead of encoder 1.

It has been visually verified that the wavelength setting read by the computer is accurate. Additional tests with a HeNe laser have shown that the encoder system is very precise and performs quite satisfactorily.

4.2 Software Modifications

Several changes were made to the system software to accommodate the hardware modifications and enhance the performance of the instrument. This section describes subroutines that were deleted, added, and modified.

4.2.1 Deleted Subroutines

"Monref" was the subroutine in the original software which slewed the monochromator drive to the reference position, from which wavelength settings could be made. The encoder system allowed determination of the wavelength setting exactly. Thus, "Monref" was no longer needed, and it was therefore deleted. Subroutine "Setfrq" in the original software was responsible for slewing the monochromator drive to the desired wavelength. The modified wavelength selection system required a new algorithm for slewing the drive, so "Setfrq" was replaced by "Setwav" (explained in the next section).

4.2.2 Added Subroutines

Subroutine "Setwav"

This subroutine replaces "Setfrq" and slews the wavelength drive of the monochromator to the desired wavelength. It first determines if the wavelength of interest is in the long or short wavelength range (long=900.1 nm to 1800.0 nm and short=150.0 nm to 900.0 nm) and then scales the wavelength of interest appropriately to the monochromator readout. If the wavelength is in the long range, the 0.1 position of the wavelength value is determined to be odd or even. If the 0.1 position is odd, a flag is set so the omni-drive can be used to adjust for this. This is done because the resolution of the encoders is .2 nm for the long wavelength range, instead of the 0.1 nm, as it is for the short wavelength range. If the wavelength is in the short wavelength range, a range flag is set to show this. Once the wavelength range is determined, the difference between the desired wavelength and the current wavelength is calculated (scaled to the readout). If the difference is 0, the program ends. If the difference is negative (the desired wavelength is below the current wavelength) the monochromator is slewed to 1 nm below the desired value (all wavelength settings are approached from the lower side to take care of any backlash in the gearing).

If the desired wavelength is above the current one, but within 0.5 nm, the drive is stepped in fine increments until the desired wavelength is reached. If the desired wavelength is above the current one and within 1 nm (but greater than 0.5 nm) the drive is stepped in medium sized increments until it is within 0.5 nm. Once it is within 0.5 nm, the drive is stepped in fine increments until the desired wavelength is reached. The flowchart of this subroutine is shown in Figure 4.10.

Subroutine "Rdenc"

"Rdenc" reads the DIC's which store and display the outputs of the encoder. The subroutine also and stores the values in memory, so they can be accessed by the calling program. The flowchart is shown in Figure 4.11.

Subroutine "Calwav"

This subroutine is used to determine the wavelength setting of the monochromators. First, both encoders are read using subroutine "Rdenc". Encoder 2 is checked to determine if it is a multiple of 8, or 1 less than a multiple of 8, then encoder 1 is checked for correct values. Encoder 1 values are changed appropriately if necessary. This is done to make sure no errors occur in wavelength determination (see section 4.1.3 on encoders). Once all encoder values are determined to be correct or are cor

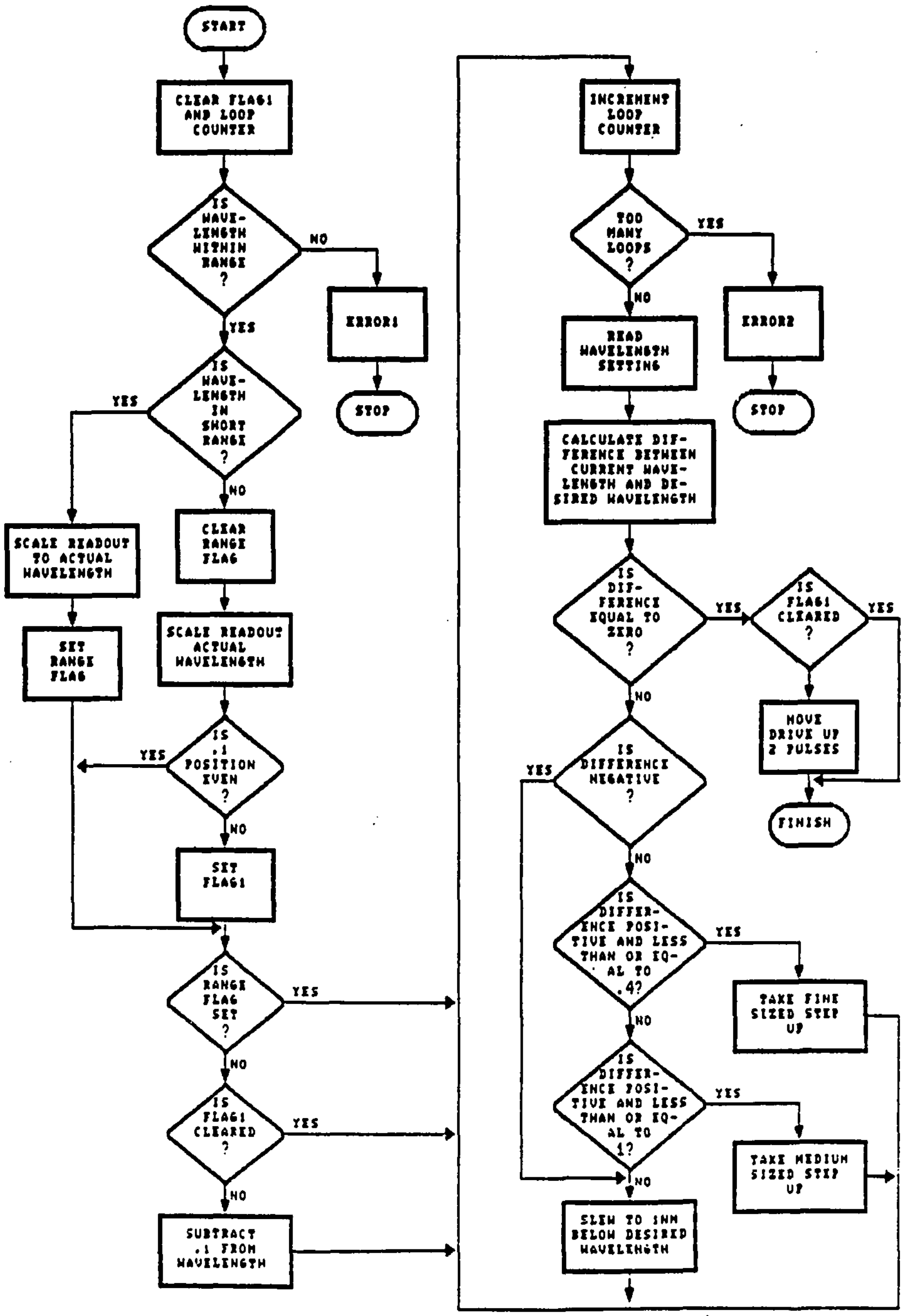

Figure 4.10. Subroutine "Setwav"

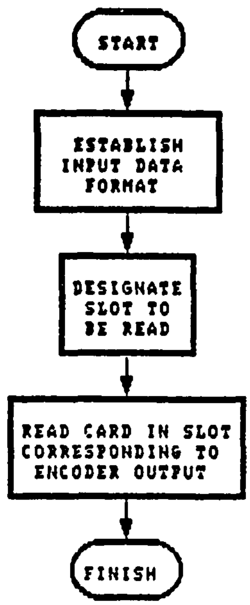

Figure 4.11. Subroutine "Rdenc"

rected, the wavelength setting is calculated. First, the encoder 2 value is used to determine the turn number. Each turn corresponds to 25 nm on the wavelength drive. Then, the fraction of a turn is determined using the encoder 1 value. This fraction of a turn is added to the turn number and the wavelength reference value (150 nm), giving the wavelength drive setting.

It was found that errors occurred in reading the encoders whenever the interrupt system executed the tracking routine right before the reading of the encoders. The subroutine therefore disables the interrupt system at the start of the subroutine and re-enables it at the end of the subroutine. The flowchart of this subroutine is shown in Figure 4.12.

4.2.3 Modified Subroutines

Subroutine "Init3"

In the original software, "Init3" displayed information concerning the initialization of the wavelength drive, and called subroutine "Monref" to initialize the drive (slew it to a reference position). The original form of "Init3" was no longer needed because of the implementation of the optical encoders. "Init3" was modified to perform a simple test to determine if the encoders and monochromator omnidrive were operating properly and then prompt the user to verify an indicated wavelength setting. Specifically, the

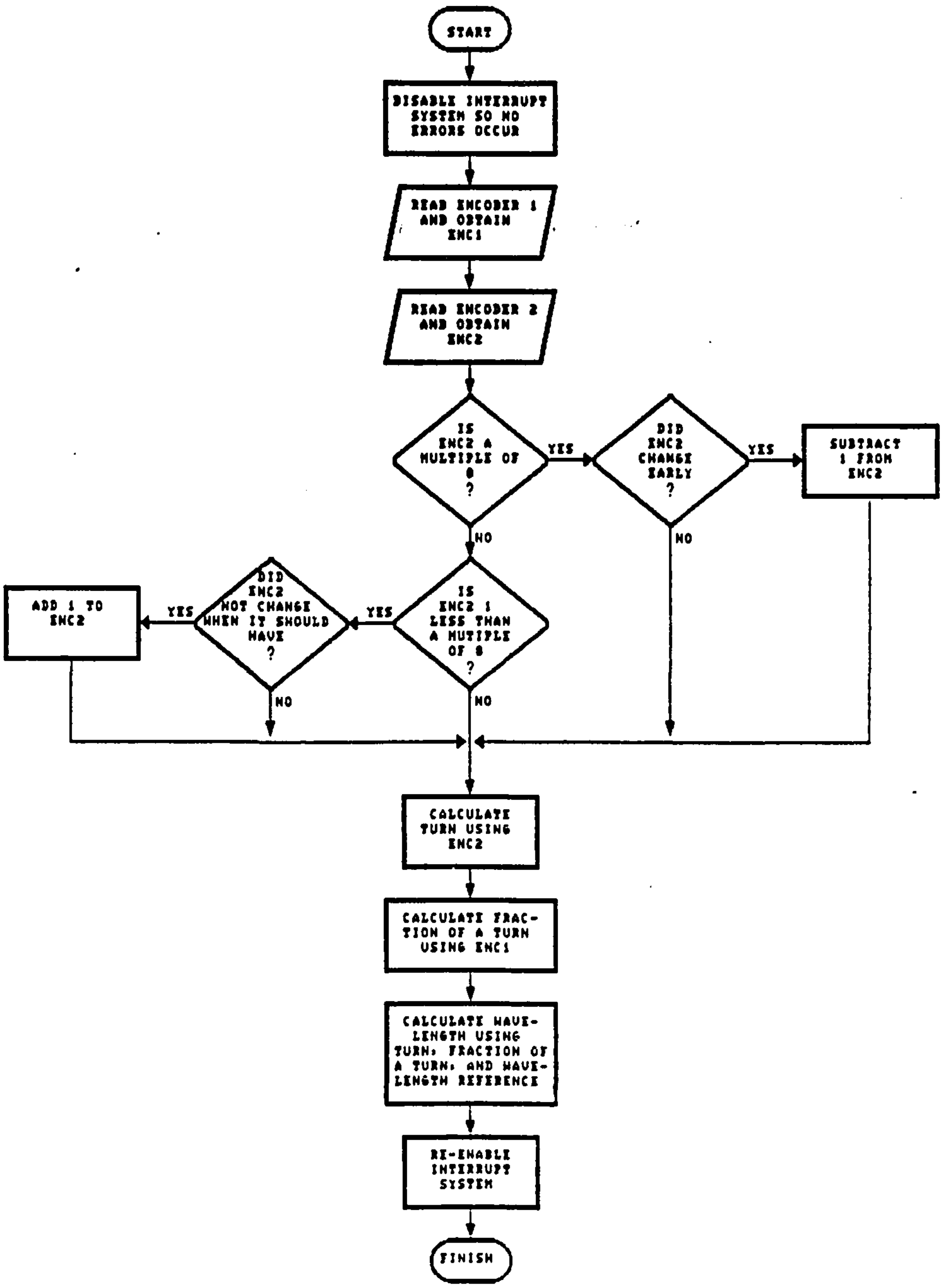

Figure 4.12. Subroutine "Calwav"

subroutine directs the computer to read the current wavelength, then moves the drive up a step at a time until a wavelength change of 1nm is registered. If the change occurs within 100 steps, the test is complete, and the user is asked to visually verify the current wavelength setting. If the change does not occur after 100 steps, then an error message is displayed, and the program is terminated. The flow chart is shown in Figure 4.13. A listing of the subroutine is given in Appendix B.

Subroutine "Temprd"

"Temprd" is the subroutine which reads the digitized value of the temperature sensor output from the A/D converter and determines the temperature from the reading. Modifications to the temperature sensor reading hardware necessitated a change in the software. Basically, only the statement calculating the temperature from the digitized value of the sensor output had to be changed. The statement is given in Appendix B.

Subroutine "Calfq2"

Subroutine "Calfq2" was the subroutine used to extract the desired wavelengths from an array one at a time. Because of the new routines used to determine the wavelength setting and slew the wavelength drive, many of the variables "Calfq2" were unnecessary. It was modified to eliminate

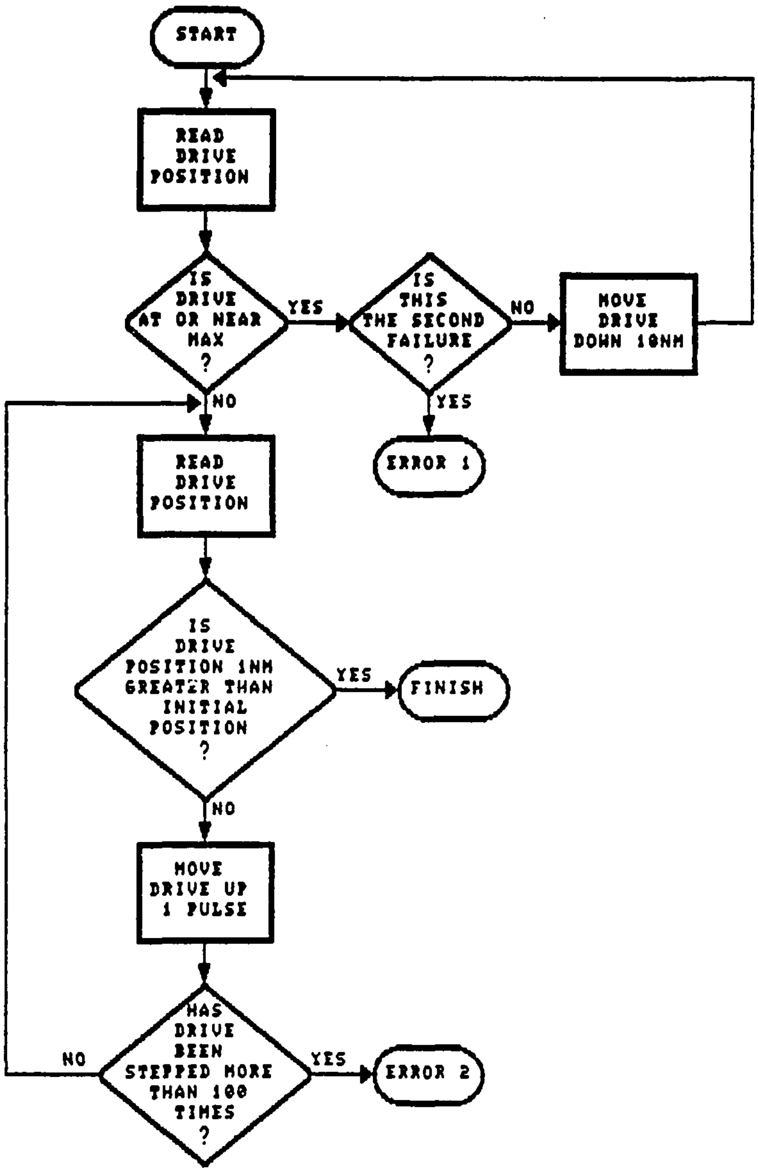

Figure 4.13. Subroutine "Init3"

all unnecessary variables, and its name was changed to "Compwav". The subroutine is listed in Appendix B.

Subroutines "Polref" and "Decref"

These subroutines initialize the tracking mirror mount to their reference positions. Previously, they moved the mount 50 pulses and then checked the limit switches (closure of which indicate the reference positions). This continued in a loop until it was determined that the reference position had been reached. The subroutines were changed so that the limit switches were checked first, and then the mount was moved 50 pulses in a loop. This was done to speed up the initialization procedures and to protect the motors and mount, just in case the mount axes were already at their limits.

Subroutine "Settle"

"Settle" was used to determine when a wavelength drive scan was complete, after which a predetermined delay was executed to allow settling of the lock-in amplifier. Subroutine "Setwav" now determines when a scan is complete and "Getdet" decides when the signal has settled, thus, the function of "Settle" has been altered. It now allows a predetermined delay to be executed before a reading is taken.

Subroutine "Getdet"

A short test program, utilizing the same lock-in and settling routines used in the data collection program, was written to perform consecutive measurements of different input light levels. These measurements were compared with measurements of the input light levels obtained through manual operation of the lock-in amplifier. Results showed that the two set of measurements did not agree (see Figure 4.14). Two problems accounted for this: 1) settling time was set to be a constant, 2) the settling routine was used before a lock-in gain change. In reference to the first problem, actual times for the lock-in signal to settle vary according to the specified time constant, whether the signal is increasing or decreasing, and the magnitude of the signal change from the previous reading. Table 4.1 shows example settling times (found through experimentation) for the various lock-in time constants.

TABLE 4.1

Settling Times for the Lock-in Amplifier

Time Constant	Settling Time (sec) (decreasing signal)	Settling Time (sec) (increasing signal)
.0025	10	8
.008	8	4
.025	5	2
.08	4	3
.25	5	5
.8	14	6
2.5	35	20
8	90	45
25	300	210

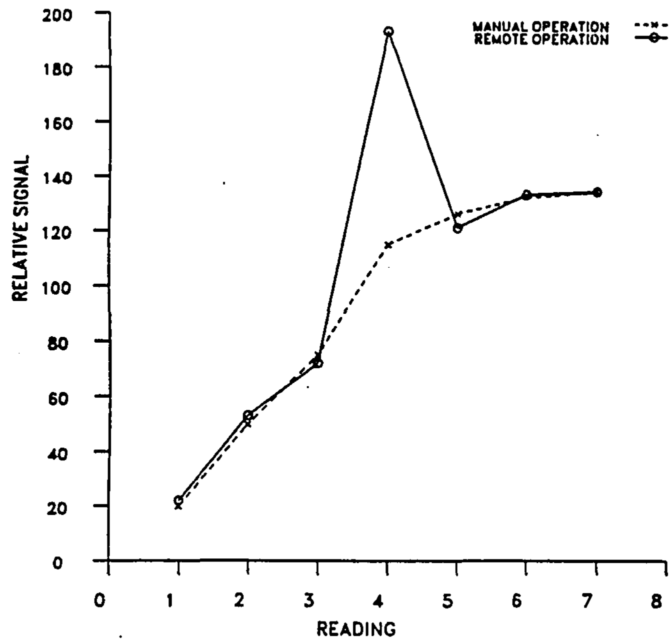

Figure 4.14. Test Measurements Using Original "Getdet"

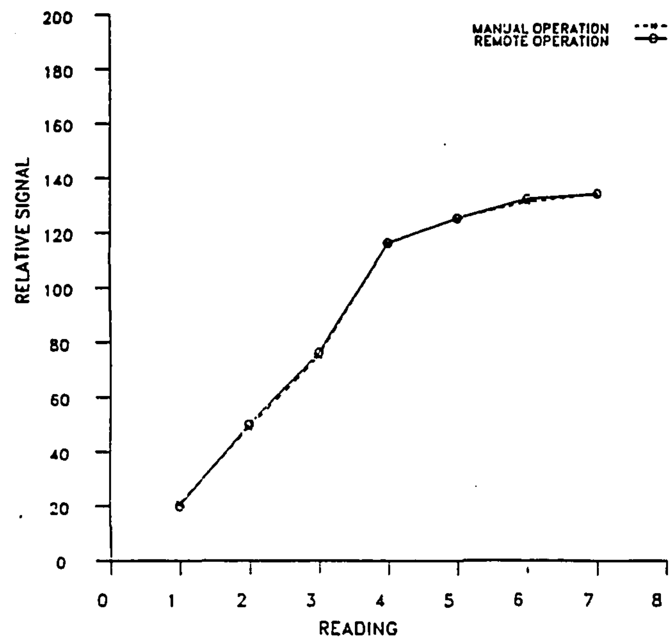

Figure 4.15. Test Measurements Using Modified "Getdet"

With the original software, incorrect results occurred when readings were taken before the signal was allowed to stabilize. The second problem was found to be the most significant of the two problems. The lock-in reading routine deals with the gain selection in addition to recording the lock-in value. Settling time must occur after the gains have been changed and before a reading is taken (i.e., within the lock-in reading routine) in order to get correct results, because after a gain change, the amplifier signal drifts until it reaches a stable value.

There are two ways of executing the correct settling time. One way is to use a pre-determined value, depending on the specified time constant. Although this is a fast and easy implementation, it may not be the best way of solving the problem. For each time constant, the worst case (longest time) would have to be used, which could result in long settling times whether needed or not. This could unreasonably lengthen the time for each data run. It is desirable to minimize the settling time because the primary factors determining the time for each data run should be the wavelength and grating changes. The second way is to use a routine which determines when a signal has settled. It was decided that subroutine "Getdet" should be modified to employ the latter method.

The settling algorithm determines when a signal has settled by first taking a reading, the value of which is assigned to the maximum and minimum variables (Sigmax and Sigmin) as a starting point. After a 0.5 sec delay, another reading is taken. It is then compared with the Sigmax and Sigmin values. If it is larger than Sigmax, Sigmax is set to equal the reading. If it is smaller than Sigmin, then Sigmin is set to equal the reading. This continues in a loop (starting with the .5 sec delay) as long as the Sigmax and Sigmin variables are changed. When the variables remain unchanged for a specified number of loops (0.5 seconds per loop), the signal is assumed to be settled. The routine executes a 1 second wait time after each gain change to overlook any transients which may occur immediately after the change. Transients could cause the range between Sigmax and Sigmin to be exceedingly large. The settling algorithm was incorporated into the original "Getdet" subroutine. Test results, shown in Figure 4.15, show that the settling algorithm performs satisfactorily. The flowchart for the modified "Getdet" is shown in Figure 4.16 and a listing of the subroutine is given in Appendix B.

Program "Rad"

"Rad" is the data collection routine for the spectroradiometer. It was modified to accommodate the subroutine changes just discussed. Further additions were made to "Rad" and are described below.

A reference wavelength value for the encoder system

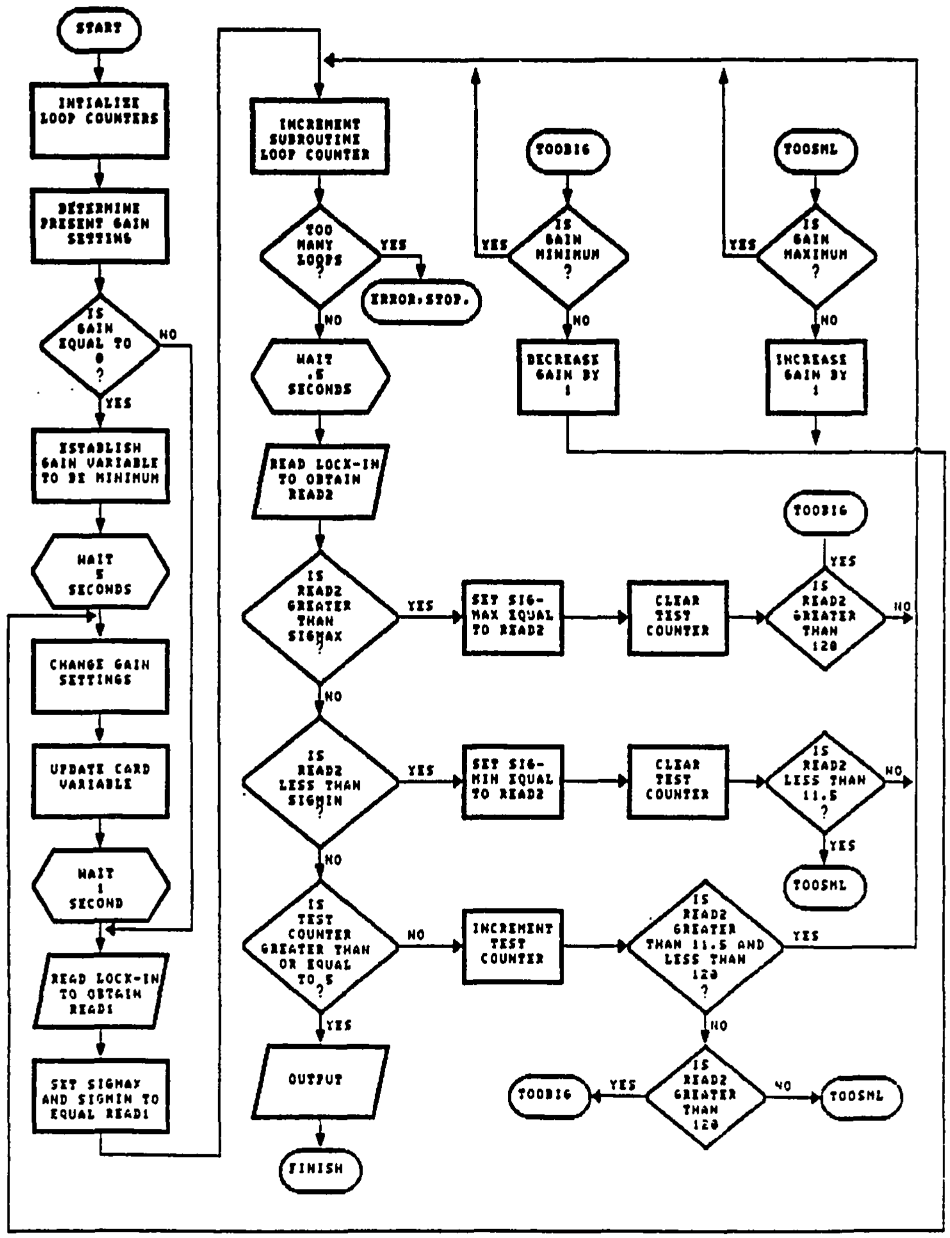

Figure 4.16. Modified Subroutine "Getdet"

was required for wavelength determination. The variable to handle this (Refwav) was placed in "Rad" to allow easy modification. As of this writing, the reference value is 150 nm.

In its original form, "Rad" did not display a message when shut-down procedures were executed. This caused much confusion for the operator. A message added to indicate activation of shutdown procedures.

It was decided that the ability to take repeated readings at one wavelength, and then average the readings, was desirable. This would allow random variations in the signal to be averaged out, and, allow measurement of the signal to noise ratio. A program loop and a short averaging routine were added to accommodate this. The routine also calculates the standard deviation of the measurements. The number of loops and the wait time before each reading can be specified by the user.

Operation of the instrument has shown that the modified system software works satisfactorily. The modified portions of the software are listed in Appendix B. A listing of the software will be kept with the instrument. The next chapter reports on the system performance after the modifications were made.

CHAPTER 5

SYSTEM PERFORMANCE

Once the modifications discussed in chapter 4 had been completed, the system had to be tested and evaluated. This chapter presents results of the tests that were performed on the system. To begin with, the resolution of the lock-in will be examined. This is done because it is often desirable to examine noise in terms of digital counts of an A/D converter. Next, information about the dark signal level of the instrument will be presented. This will include an explanation of what the dark signal is, how it is measured, and how it is used. An assessment of noise in the system, including a demonstration of the signal to noise ratio (S/N), will then be given. Finally, a summary of the best system operating parameters will be provided.

5.1 Lock-In Amplifier Resolution

The lock-in amplifier is configured for BCD output. In this configuration, output data is composed of 13 bits, divided into 4 groups. The first group consists of one bit, and designates the most significant bit. Each of the remaining 3 groups is composed of 4 bits. Each group represents a percentage of full scale on the display of the lock-in, the first group representing 100% of full scale, and the other groups decreasing by orders of 10. This makes the last group, representing the least significant bit, 0.1% of full scale. Recalling that a 1-bit BCD digit can represents a decimal value of 1 or 0, and a 4-bit BCD digit can represent decimal values of 0-9, the resolution of the lock-in A/D is then 1 in 1999 counts. Ideally, the variability in an output signal should be no greater than ± 1/2 count of the A/D, so that any variation in the signal is not resolvable by the lock-in amplifier. Table 5.1 shows the resolution in terms of currents for each sensitivity scale setting.

Table 5.1

Scale	Range	Resolution (1 cnt)
1	100 pA	0.05 pA
2	1 nA	0.5 pA
3	10 nA	5.0 pA
4	100 nA	0.05 nA
5	1 μA	0.5 nA
6	10 μA	5.0 nA

5.2 Dark Signal Levels

The dark signal level of the system is the signal obtained when the detector is shielded, such that no light falls on it. This signal is the result of intrinsic noise sources in the detector itself. Repeated measurements of the dark signal can provide a measure of the detector's precision, and, an indication of the offset of a data reading. However, noise characteristics of a detector can change with time. Therefore, a dark signal measurement run, providing a sample mean and sample variance of the dark signal, should be done before a data run. (Although not covered in this thesis, such a routine has been written and will be implemented before the author's departure).

Tests were performed to determine the magnitude of the dark signal in the system. To do this, the detector was covered, and repeated readings were taken at a rate of about 2 per second. The average value of the dark signal can be considered as a bias level, to be subtracted from an actual data reading. Table 5.2 shows the dark signals and standard deviations for different time constant settings. It is seen from the table that the time constants 0.8 seconds and longer have the lowest standard deviations. Note that the 0.0025 and 0.008 time constant settings have noticeably larger dark signal mean values than the other time constants. This is probably due to the larger noise bandwidths associated with these time constants, which allow higher frequency noise components to pass through the system and appear in the output signal.

Table 5.2

Average Dark Signal Values at Different Time Constants

Time Constant	Mean Signal(pA) (pA)	(Cnts)	Standard Deviation (pA)	(Cnts)
0.0025	15.056	(302.0)	0.238	(4.76)
0.008	5.448	(110.0)	0.218	(4.36)
0.025	3.218	(64.0)	0.352	(7.04)
0.08	3.160	(64.0)	0.293	(5.86)
0.25	3.062	(62.0)	0.208	(4.16)
0.8	3.102	(62.0)	0.082	(1.64)
2.5	3.098	(62.0)	0.059	(1.18)
8.0	3.108	(62.0)	0.040	(0.8)
25.0	3.144	(62.0)	0.050	(1.0)

When choosing a time constant to minimize the variance of the dark signal, the settling times for each time constant must also be considered. Example settling times, given in Section 4.3, are repeated in Table 5.3 for convenience. There is obviously a trade-off, larger time constants are associated with smaller and less variable dark signals, but their settling times are quite long. Other factors, such as the affect of the time constant setting on the S/N, must be taken into account before choosing a settling time. The S/N is the topic of the next section.

Table 5.3

Settling Times for the Lock-in Amplifier

Time Constant	Settling Time (sec) (decreasing signal)	Settling Time (sec) (increasing signal)
0.0025	10	8
0.008	8	4
0.025	5	2
0.08	4	3
0.25	5	5
0.8	14	6
2.5	35	20
8	90	45
25	300	210

5.3 Noise Performance

Several types of noise may contribute to the overall system noise. For a discussion on the different types of noise in electronic systems and their analyses, the reader is referred to books on such topics such as the one by Robinson (Robinson, 1974). Noise is a random statistical process, so it should be discussed in terms of means and standard deviations of signals. If the sample mean of a signal is S (the signal being the actual signal plus dark current), and its sample standard deviation is σ_s, then the criterion for probable error is S ± σ_s. If the sample mean of the dark signal, D, is known, then an expression for the S/N is

$$S/N = (S - D)/\sigma_s. \tag{5.1}$$

This assumes the output of the system is constant (non-periodic).

Test measurements were performed using the three time constant settings which offered the best compromise between settling time and dark signal variance. The source was the sun at midday and in the morning. Results are indicated in Tables 5.3 through 5.9. The ten wavelengths used were chosen because they correspond to the center wavelengths of the filters in the portable filter-wheel radiometers (which will be used for calibration of the spectroradiometer). Higher signals occurred during the midday hours because of the lower airmasses (from Beer's Law). Note that the average signals, in the morning, increase with increasing time constant. This is due to the fact that in the time it took to perform measurements at each time constant setting, the airmass (which was in the range from about 3.0 to 3.5) had changed significantly (A scan through the 10 wavelengths was done for each time constant instead of switching time constants at each wavelength. The rate of data collection was about 2 per second for 40 readings. It is seen from the results that there is an amplitude dependence of the S/N (the signal amplitude is, in turn, airmass and wavelength dependent). Note also that for the signal standard deviation, there isn't as strong a dependence on the amplitude as there is on the time constant setting. The variation of the signal is probably due mostly to instrument noise, although another factor may be fluctuations in optical depth during the measurements.

An acceptable minimum S/N is 100, which gives an error of 1%, allowing data to be reliable to within about 1%. From the tables, it is seen that a S/N of 100 is achieved at all 10 wavelengths for midday (low airmass) observations, and 9 wavelengths for morning (large airmass) observations, for time constants 0.8 sec and 2.5 sec. Only the S/N for 370.0 nm, in the morning, is less than 100 for all three time constants. This is due to a number of factors, including the fact that the transmitted solar flux is relatively low in magnitude (because of the relative magnitude of the exoatmospheric flux, and because of attenuation - recall Figure 1.1), and that the detector responsivity is quite low at that point (recall Figure 3.4). Measurements in the morning should present no problems in terms of S/N if data is taken at wavelengths greater than about 440 nm. For the shorter wavelengths, measurements should be taken at lower airmasses (later in the morning). Midday measurements are significantly better than the morning measurements; therefore, data should be collected toward the midday hours. Insofar as choosing the best time constant, the 0.8 sec setting would probably offer the best compromise between settling time and S/N. This is because the S/N of the readings for the 0.8 sec setting are comparable to the S/N of the 2.5 sec setting, with faster settling times for the 0.8 sec setting.

Table 5.4

Measurements at Time Constant 0.25 (Midday)

Wavelength (nm)	Mean Signal (pA)	(Cnts)	Standard Deviation (pA)	(Cnts)	S/N
370.0	24.4	(488.0)	0.2	(4.0)	106.7
402.9	100.5	(201.0)	0.9	(1.8)	108.3
442.5	205.9	(411.8)	1.6	(3.2)	126.8
522.1	334.0	(668.0)	1.5	(3.0)	220.6
612.3	202.7	(405.4)	2.3	(4.6)	86.8
671.5	124.0	(248.0)	1.4	(2.8)	86.4
780.0	44.9	(898.0)	0.3	(6.0)	139.5
872.4	27.0	(540.0)	0.5	(10.0)	47.9
942.2	140.2	(280.4)	1.2	(2.4)	114.3
1030.6	311.3	(622.6)	1.9	(3.8)	162.2

Table 5.5

Measurements at Time Constant 0.8 (Midday)

Wavelength (nm)	Mean Signal (pA)	(Cnts)	Standard Deviation (pA)	(Cnts)	S/N
370.0	24.4	(488.0)	0.2	(4.0)	106.5
402.9	101.3	(202.0)	0.3	(0.6)	327.3
442.5	207.0	(414.0)	0.8	(1.6)	254.9
522.1	330.9	(661.8)	1.3	(2.6)	252.2
612.3	204.0	(408.0)	0.9	(1.8)	223.2
671.5	125.4	(250.8)	0.5	(1.0)	244.6
780.0	44.5	(890.0)	0.2	(4.0)	207.0
872.4	26.9	(538.0)	0.2	(4.0)	119.0
942.2	139.4	(278.8)	0.7	(1.4)	194.7
1030.6	310.9	(621.8)	1.8	(3.6)	171.0

Table 5.6

Measurements at Time Constant 2.5 (Midday)

Wavelength (nm)	Mean Signal (pA)	(Cnts)	Standard Deviation (pA)	(Cnts)	S/N
370.0	24.3	(486.0)	0.08	(1.6)	265.0
402.9	101.2	(202.4)	0.3	(0.6)	327.0
442.5	204.9	(409.8)	0.6	(1.2)	336.3
522.1	332.2	(644.4)	0.6	(1.2)	548.5
612.3	204.5	(409.0)	0.5	(1.0)	402.8
671.5	125.2	(250.4)	0.4	(0.8)	305.3
780.0	45.1	(90.2)	0.2	(4.0)	210.0
872.4	26.8	(53.6)	0.1	(2.0)	237.0
942.2	141.2	(282.4)	0.9	(1.8)	153.4
1030.6	317.6	(635.2)	1.1	(2.2)	286.0

Table 5.7

Measurements at Time Constant 0.25 (Morning)

Wavelength (nm)	Mean Signal (pA)	(Cnts)	Standard Deviation (pA)	(Cnts)	S/N
370.0	5.8	(116.0)	0.2	(4.0)	13.7
402.9	30.6	(612.0)	0.7	(14.0)	39.3
442.5	87.9	(1758.0)	1.2	(24.0)	70.7
522.1	197.0	(394.0)	1.2	(2.4)	161.6
612.3	137.0	(274.0)	1.8	(3.6)	74.4
671.5	97.9	(1958.0)	1.1	(22.0)	86.2
780.0	38.3	(766.0)	0.5	(10.0)	70.5
872.4	23.9	(478.0)	0.3	(6.0)	69.5
942.2	41.5	(830.0)	1.0	(20.0)	38.4
1030.6	256.0	(512.0)	1.5	(30.0)	168.6

Table 5.8

Measurements at Time Constant 0.8 (Morning)

Wavelength (nm)	Mean Signal (pA)	(Cnts)	Standard Deviation (pA)	(Cnts)	S/N
370.0	7.5	(150.0)	0.2	(4.0)	22.0
402.9	37.0	(740.0)	0.2	(4.0)	169.5
442.5	99.7	(1994.0)	0.5	(10.0)	193.2
522.1	220.0	(440.0)	0.9	(1.8)	241.0
612.3	149.0	(298.0)	0.8	(1.6)	182.4
671.5	100.7	(201.4)	0.5	(1.0)	195.2
780.0	38.8	(776.0)	0.2	(4.0)	178.5
872.4	25.0	(500.0)	0.2	(4.0)	109.5
942.2	47.9	(958.0)	0.4	(8.0)	149.3
1030.6	277.0	(554.0)	1.4	(2.8)	195.6

Table 5.9

Measurements at Time Constant 2.5 (Morning)

Wavelength (nm)	Mean Signal (pA)	(Cnts)	Standard Deviation (pA)	(Cnts)	S/N
370.0	9.2	(184.0)	0.08	(1.6)	76.2
402.9	43.8	(876.0)	0.3	(6.0)	135.7
442.5	114.9	(229.8)	0.5	(1.0)	223.6
522.1	233.0	(466.0)	0.6	(1.2)	383.2
612.3	165.0	(330.0)	0.5	(1.0)	323.8
671.5	111.1	(222.2)	0.4	(0.8)	270.0
780.0	42.1	(842.0)	0.2	(4.0)	195.0
872.4	26.0	(520.0)	0.1	(2.0)	229.0
942.2	54.7	(1094.0)	0.5	(10.0)	103.2
1030.6	290.0	(580.0)	1.1	(2.2)	260.8

5.4 Summary of Best Operating Parameters

The system may be characterized as far as the best integration times and best wavelengths for S/N. The best time constant setting for the lock-in appears to be 0.8 seconds, which offers the best compromise between settling time and S/N. Longer time constant settings would lengthen the settling times, and hence a data scan. Measurements at midday will give the highest S/N values because of low airmass. Measurements at wavelengths less then 400 nm should only be taken at relatively low airmasses (high sun angle) for improved S/N. At higher wavelengths, the detector responsivity drops off sharply near 1100 nm, so it is recommended that measurements not be taken past 1050 nm, because the S/N will be too small to provide useful data. It should be noted that none of the results showed a signal variation of less than 1/2 count. Therefore, measured signals (in terms of counts) should be 100 times the number of counts of variation, to meet the requirement of a S/N of 100.

In trying to obtain the best operating parameters, a time constant setting of 0.8 sec was chosen as the best compromise between settling time and S/N. The settling time should not be the limiting factor in determining the length of a data scan, rather, the limiting factor should be the wavelength and grating change times. Unfortunately, one drawback of the system is the excessive length of time for omni-drive slewing and grating changes. The top slew speed for the omni-drive is 200nm/min. About 10 seconds should be added for each observation wavelength to calculate the slew time. Grating changes take about 1.5 to 2 minutes, and settling times for the .8 second time constant setting average about 6 seconds. Therefore, when taking readings at 10 wavelengths ranging from 370 nm to 1030 nm, the estimated time for 1 run to the next is about 11.5 minutes, which was confirmed experimentally. It might be desirable to lessen this time, especially when taking readings at low sun angles, where the airmass changes quite rapidly. This could be accomplished by changing the drive motors for the omni-drive (or changing the drive itself) and the grating change mechanism. A stepper motor (which is inherently slow), for the wavelength drive, may not be needed any longer because of the wavelength determination by the encoder system. Perhaps a dc motor could be used. Also, a faster motor could be implemented for the grating changer.

The performance of the system is satisfactory, and, with the modifications that have been implemented, there have been no visible problems with the hardware or software. Test scans were performed on relatively clear days, for both the short (300-900 nm) and long (902-1000 nm) wavelength ranges. The results are shown in Figures 5.1 and 5.2. Figure 5.2 also plots the results from LOWTRAN, a computer program which simulates gaseous absorption of solar radia

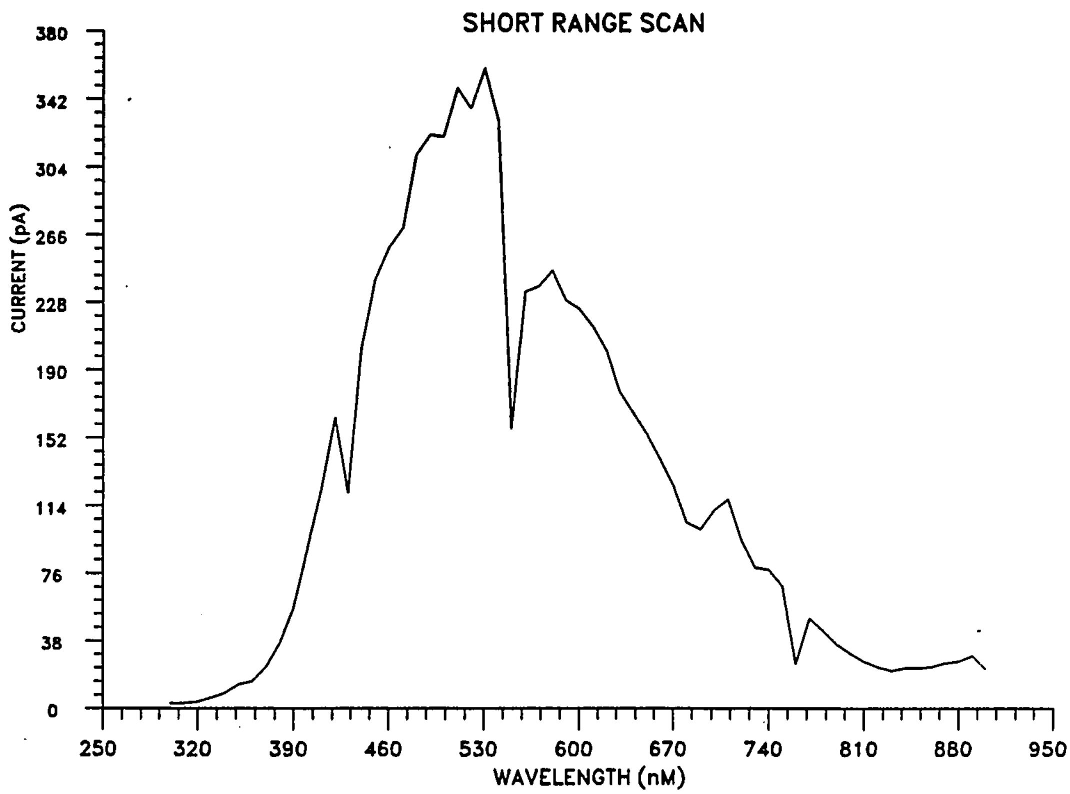

Figure 5.1. Test Scan for Short Wavelength Range

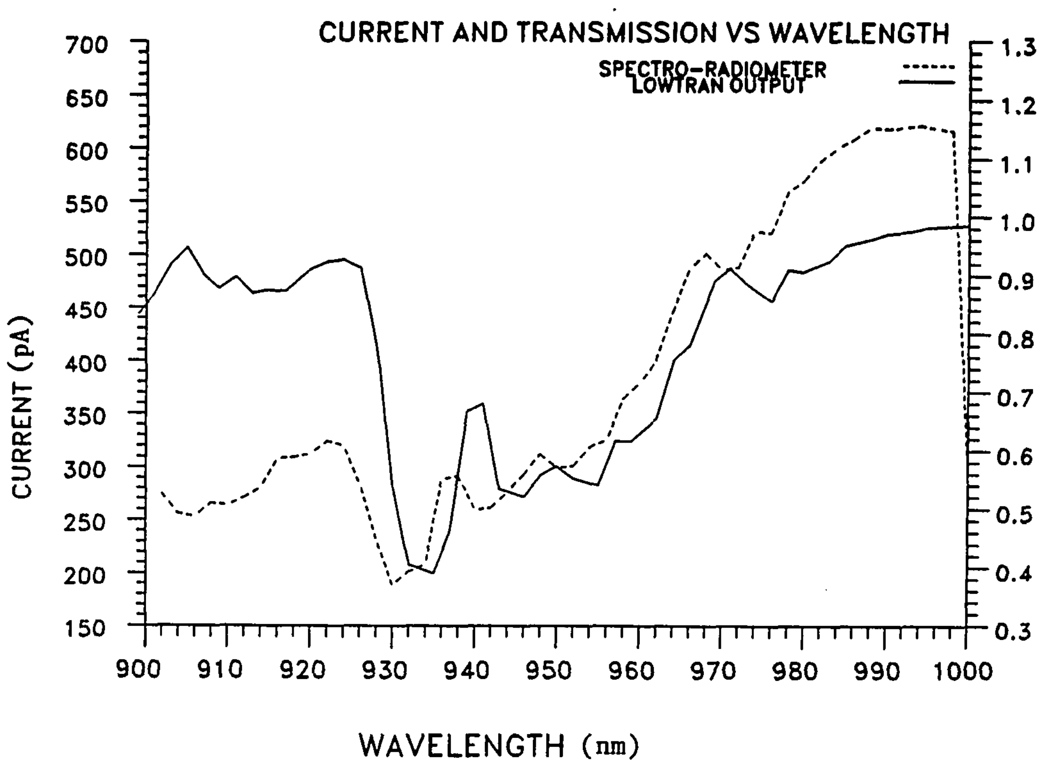

Figure 5.2. Test Scan for Long Wavelength Range Together With Lowtran Output

tion. Note that the two plots agree fairly well, but it appears that the spectroradiometer (monochromators) has become misaligned with respect to wavelength. Alignment can be achieved by calculating the amount of displacement of the peaks and troughs from those obtained with LOWTRAN, and displacing all future measurements by this amount, or, by manually checking alignment with a laser or lamp, and then sending the monochromators back to the manufacturer for realignment. Before measurements collected with the system can be analyzed to extract meaningful information about atmospheric transmittance, the instrument must be calibrated. Calibration strategies for the instrument are discussed in the next chapter.

CHAPTER 6

CALIBRATION STRATEGIES

As stated in the introduction, the primary use for the spectroradiometer will be for atmospheric transmittance studies. Atmospheric transmittance values will be derived, on a quasi-continuous basis, from measurements of the transmitted solar irradiance. To accomplish this, the instrument must be calibrated.

There are two types of calibration, relative and absolute. Both give information about the form of the system responsivity. The responsivity, R_λ, of the spectroradiometer, is defined by the spectral characteristics of the optics, the spectral properties of the diffusing block, the efficiencies of the gratings as a function of wavelength, and, the detector responsivity. For an overall system responsivity, the slit function, S_λ, must also be taken into account. Relative calibration gives only the relative responsivity of an instrument, meaning that responsivity values are referenced to an arbitrary value. THis permits determination of the relative spectral energy distributions of sources, allowing a quantitative intercomparison of data at different wavelengths. Absolute calibration gives an absolute relationship of the output signal to input light power. This allows precise determination of the absolute spectral energy distribution of a source, in addition to the relative spectral energy distribution. Not only does absolute calibration permit intercomparison of data at different wavelengths, but it also allows intercomparison of data from other calibrated instruments as well.

Once calibrated, the instrument may be used in measuring atmospheric transmittance. There are two ways of doing this. One way is to calculate the ratio $I_\lambda/I_{o\lambda}'$, the ratio of the measured signal to the intercept signal level, which, if you will recall from Beer's Law, is $e^{-m\tau_\lambda}$. If this method is used, the exoatmospheric signal level, $I_{o\lambda}'$, must somehow be determined. Determination of $I_{o\lambda}$ at discrete wavelengths, and interpolation of it between these wavelengths, will be discussed in later sections. For now, it suffices to say that interpolation of $I_{o\lambda}$ requires at least a relative calibration of the instrument. The other way of determining atmospheric transmittance is to calculate the ratio $F_\lambda/F_{o\lambda}'$, F_λ being the directly transmitted solar irradiance, and $F_{o\lambda}'$ being the exoatmospheric solar irradiance. Here, $F_{o\lambda}$ is given in tables of solar irradiance, such as those of Neckel and Labs (1983). The value of F_λ must be derived from the measured I_λ, which requires calibration of the instrument. This too will be discussed in a later section.

Ideally, calibration of the system could be achieved using a standard lamp of known spectral irradiance. Unfortunately, the present configuration of the system does not allow easy implementation of a standard lamp calibration set-up, and other calibration strategies must be considered. This chapter will discuss the different calibration strategies currently under consideration for the spectroradiometer. First, an introduction to the Langley method of obtaining exoatmospheric signal levels outside of gaseous absorption bands will be presented. Next, transferring of calibration at discrete wavelengths, using a calibrated portable filter-wheel radiometer, will be discussed. Portables can be calibrated using the Langley technique, or, a standard lamp. Transferring of calibration at discrete wavelengths, using an absolutely calibrated detector (radiometer), will then be considered. An absolutely calibrated detector is one whose responsivity is known absolutely. It allows a check on the stability of the spectroradiometer because of it's implied precision. Finally, the problem of interpolating between discrete calibration points will be discussed.

6.1 The Langley Technique

The Langley technique (Shaw et al., 1973) allows the determination of the exoatmospheric signal levels at wavelengths outside of gaseous absorption bands. Measurements inside gaseous absorption bands will be discussed later. Recall that the Bouger-Lambert Law in terms of the output signal of an instrument is

$$I_\lambda = I_{o\lambda}' e^{-m\tau_\lambda}. \qquad (6.1)$$

Remember, the use of I, a current, in (6.1), is arbitrary. An output voltage can be used in (6.1) if the voltage is proportional to the input flux density. By taking the natural logarithm of both sides of equation (6.1), one obtains

$$\ln(I_\lambda) = \ln(I_{o\lambda}') - m\tau_\lambda. \qquad (6.2)$$

Measurements taken at different airmasses allow $\ln(I_\lambda)$ to be plotted against m. This gives a linear curve of slope $-\tau_\lambda$ and an $\ln(I_\lambda)$ axis intercept of $\ln(I_{o\lambda}')$, which is the natural logarithm of the exoatmospheric signal level. The Langley technique assumes a constant τ_λ, meaning that there should be no spatial or temporal variations in τ_λ during data collection. Variations in the optical depth will yield errors in the determination of the intercepts. These errors can be overcome by averaging values obtained over a long period of time. The effect of variations of τ_λ on Langley analysis has been investigated by Scott-Fleming (1987), and the reader is referred to this work for more on the subject. Once $I_{o\lambda}'$ has been obtained from the Langley plot, the transmittance, $I_\lambda/I_{o\lambda}'$, can be calculated. Also, $I_{o\lambda}'$ can be related to $F_{o\lambda}'$ for calibration purposes.

Calibration of the spectroradiometer using the

Langley technique is not practical. Langley analysis requires a relatively large range of airmasses (from m near unity to m of about 5), and the instrument is physically limited to airmasses less than 4. Also, the time for a wavelength scan is too long. Measurements should be taken at approximately 5 minute intervals at larger airmasses. Currently, the instrument averages about 12 minutes for 10 wavelengths spanning the visible and near infrared regions. Because of these reasons, other calibration methods must be considered.

6.2 Using a Calibrated Portable

Portable filter-wheel radiometers, currently in use in the ECE Atmospheric Remote Sensing Laboratory, have been calibrated at wavelengths outside gaseous absorption bands, using the Langley technique (their intercept voltages have been established). These radiometers use narrow-band interference filters (about 10 nm bandwidth) to make quasi-spectral measurements. For wavelengths in water vapor absorption bands, $V^p_{0\lambda}$ can be obtained using a modified Langley approach (Reagan et al., 1987), which utilizes equations (2.5) and (2.6), restated here (in terms of the portable voltage output) for convenience,

$$V^p_\lambda = V^p_{0\lambda} e^{-m\tau_\lambda} \hat{T}_{\lambda g}, \tag{6.3}$$

and

$$\hat{T}_{\lambda g} = e^{-k\sqrt{mu}}. \tag{6.4}$$

Using (6.4) in (6.3) gives

$$V_\lambda^p e^{+m\tau_\lambda} = V_{o\lambda}^p e^{-k\sqrt{mu}}. \tag{6.5}$$

The term on the left hand side is the effective surface signal if the only atmospheric transmittance loss were due to $\hat{T}_{\lambda g}$. By plotting $\ln(V_\lambda^p e^{+m\tau_\lambda})$ versus $\sqrt{m}$, a modified Langley plot is generated. This yields a straight line of slope $-k\sqrt{u}$, and intercept $\ln(V_{o\lambda}^p)$. Thus, $V_{o\lambda}^p$ can be determined without knowing k or u, although u must remain temporally and spatially constant over the range of airmasses that measurements are made.

The standard lamp technique is another method of calibrating a portable. This technique requires knowing one voltage intercept, $V_{o\lambda 1}^p$, at a wavelength λ_1. From this, voltage intercepts at other wavelengths can be calculated by taking measurements of the standard lamp at λ_1 and the other wavelengths, and by knowing the relative spectral irradiance of the lamp. Consider first, the expression for a voltage intercept of the portable radiometer,

$$V_{o\lambda}^p = A_R^p \int_{\Delta\lambda} T_\lambda^p F_{o\lambda}' R_\lambda^p \, d\lambda \approx A_R^p F_{o\lambda}' \hat{R}_\lambda \tag{6.6}$$

and, $\hat{R}_\lambda = \int_{\Delta\lambda} T_\lambda^p R_\lambda^p \, d\lambda$

where, T_λ^p is the interference filter transmission function,

R_λ^p is the detector spectral responsivity,

A^R_λ is the area of the receiver,

$\Delta\lambda p$ is the bandwidth defined by the filter function

For the wavelengths λ_1 and λ_2, the zero-airmass voltages at the two wavelengths may be related by

$$V_{o\lambda 2}/V_{o\lambda 1} = (F_{o\lambda 2}/F_{o\lambda 1})(\hat{R}_{\lambda 2}/\hat{R}_{\lambda 1}), \qquad (6.7)$$

where the ratio $\hat{R}_{\lambda 2}/\hat{R}_{\lambda 1}$ can be determined from standard lamp measurements, at λ_1 and λ_2. This is accomplished by placing the radiometer in front of the lamp to obtain an output signal of the form

$$V^L_\lambda \approx A^R_R \, F^L_\lambda \, \hat{R}_\lambda, \qquad (6.8)$$

where F^L_λ is the spectral irradiance of the lamp. The ratio $\hat{R}_{\lambda 2}/\hat{R}_{\lambda 1}$ is then

$$\hat{R}_{\lambda 2}/\hat{R}_{\lambda 1} = (F^L_{\lambda 1}/F^L_{\lambda 2})(V^L_{\lambda 2}/V^L_{\lambda 1}). \qquad (6.9)$$

The intercept voltage at λ_2, $V_{o\lambda 2}$, can then be found from

$$V_{o\lambda 2} = V_{o\lambda 1}(F_{o\lambda 2}/F_{o\lambda 1})(F^L_{\lambda 1}/F^L_{\lambda 2})(V^L_{\lambda 2}/V^L_{\lambda 1}). \qquad (6.10)$$

This technique can be used to predict $V^R_{o\lambda}$ at other wavelengths, including those in gaseous absorption bands. They can then be compared to intercepts obtained using the Langley technique.

The intercept values for the spectroradiometer can be obtained by running the portable and the spectroradiometer simultaneously, both viewing the sun. In doing this, instantaneous optical depth values are acquired at each measurement by

$$\tau_\lambda = -\ln(V'_\lambda / V'_{o\lambda})/m. \tag{6.11}$$

By using equation (6.10) in equation (6.1), an expression for $I_{o\lambda}'$ results,

$$I_{o\lambda} = I_\lambda (V'_{o\lambda} / V'_\lambda). \tag{6.12}$$

Thus, knowing τ_λ allows $I_{o\lambda}'$ to be determined from I_λ.

This analysis does not apply to gaseous absorption regions. The standard lamp technique described earlier can be used to derive $I_{o\lambda}'$ in gaseous absorption bands, if a standard lamp can be implemented in the system. This would require measurements with a standard lamp at wavelengths λ_1, outside the band, and, λ_2, inside the band, as well as having the signal intercept, $I_{o\lambda 1}'$, outside of the band. The intercept inside the band, $I_{o\lambda 2}'$, can then be found using the output current counterpart to equation (6.10).

Once $I_{o\lambda}'$ is known, it can be related to the solar spectral irradiance at the top of the atmosphere by,

$$I_{o\lambda}' = A_R \int_{\Delta\lambda} S_\lambda F_{o\lambda}' R_\lambda d\lambda \qquad (6.13)$$

which is the same as equation (2.4). As the spectral bandwidth is relatively small, (6.13) can be approximated by

$$I_{o\lambda}' \approx A_R S_\lambda F_{o\lambda}' R_\lambda \Delta\lambda. \qquad (6.14)$$

By using values of $F_{o\lambda}'$ (e.g., Labs and Neckel, 1983), the product $S_\lambda R_\lambda$, which can be considered as the overall system response, may be determined. However, the product is known only at the discrete wavelengths defined by the filters of the portable radiometer. To obtain $I_{o\lambda}'$ values between these wavelengths, $S_\lambda R_\lambda$ must also be known at these in-between wavelengths. This requires knowledge of the relative spectral variation of $S_\lambda R_\lambda$, which will be discussed in section 6.4.

6.3 Using an Absolutely Calibrated Detector

An absolutely calibrated detector is a detector whose absolute responsivity is known. One such device, the QED-200 silicon photodiode detector, manufactured by United Detector Technology (UDT, 1983), has been acquired for use with the spectroradiometer system. This detector is intended for use in the visible spectrum. Another device, a pyroelectric detector, can be used for measurements at infrared as well as visible wavelengths.

The QED-200 incorporates three large area, inversion layer silicon photodiodes connected electrically in parallel to sum the total generated photocurrent (see Figure 6.1). Light not absorbed by the first detector is reflected to the next detector, and light not absorbed by this detector is reflected to the third. Any light not absorbed by the third is reflected back along the path to the second and first detectors. In this way, almost complete absorption of the radiant flux is achieved. For example, if the reflection off of each surface is .25 (which is relatively high), then the total loss due to reflection is $(.25)^5$ which is less than .1%. Also, this device operates with nearly total internal quantum efficiency.

The responsivity can be calculated from

$$R_\lambda^{QED} = \lambda/(hc/\eta e) = \lambda/1239.5 \qquad (6.15)$$

where, λ is the wavelength in nm,

h is Planck's constant,

c is the speed of light in m/s

η is the quantum efficiency (≈ 1.0),

e is the change of an electron in Coulombs.

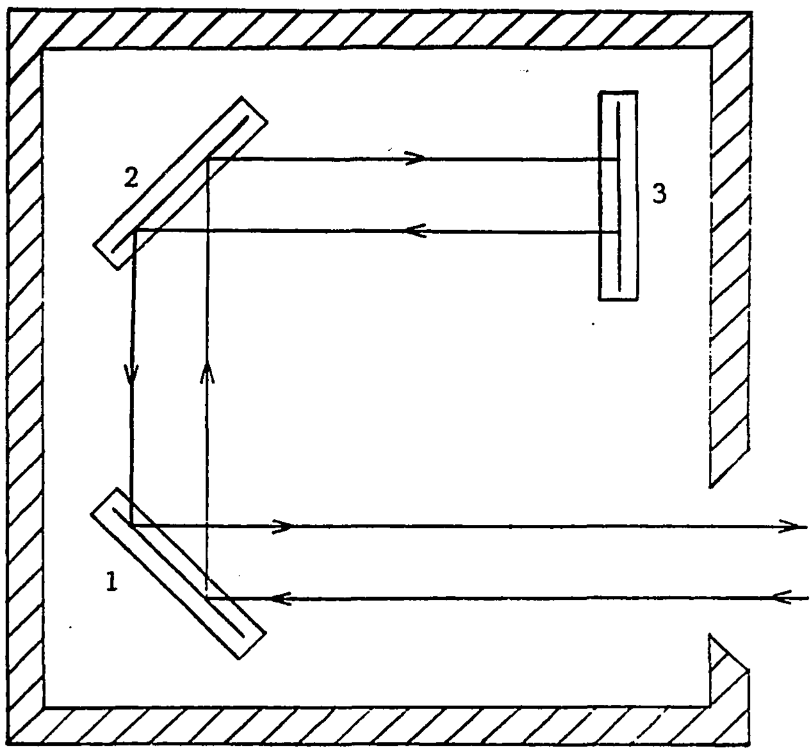

Figure 6.1. QED-200 Configuration

Assuming 100% quantum efficiency, one incident photon generates one electron of photocurrent. It is interesting to note that the device has a linear responsivity as a function of wavelength. For more information on this device, see Zalewski and Duda (1983).

Calibration of the spectroradiometer is achieved by transferring the calibration of an absolute detector to it. To do this, the instruments are run simultaneously, both pointed at the sun. The output of the absolute detector is proportional to the amount of light falling on it such that

$$V_\lambda^{AD} = A_R^{AD}\int_{\Delta\lambda_{AD}} T_\lambda F_\lambda R_\lambda^{AD} d\lambda \approx A_R^{AD} F_\lambda \int_{\Delta\lambda_{AD}} T_\lambda R_\lambda^{AD} d\lambda \qquad (6.16)$$

where, A_R^{AD} is the receiver area,

T_λ is the filter function,

$\Delta\lambda_{AD}$ is the bandwidth defined by the filter function,

R_λ^{AD} is the absolute detector's spectral responsivity (R_λ^{QED} for the QED-200).

If the filter function, T_λ, is characterized, the integral $\int_{\Delta\lambda_{AD}} T_\lambda R_\lambda^{AD} d\lambda$ can be computed because the form of R_λ^{AD} is known. After computing this integral, the solar irradiance, F_λ, can be calculated from V_λ^{AD}. Correspondingly, the output of the uncalibrated spectroradiometer is of the form

$$I_\lambda = A_R \int_{\Delta\lambda} S_\lambda F_\lambda R_\lambda d\lambda \approx A_R S_\lambda F_\lambda R_\lambda \Delta\lambda. \qquad (6.17)$$

By transferring F_λ obtained from the absolute detector to (6.17), the product $S_\lambda R_\lambda$ can be calculated. As discussed earlier, this product is used to infer F_λ values from the output signal values. The product is known only at the discrete wavelengths defined by the filters of the absolute detector. Interpolation of $S_\lambda R_\lambda$ between these wavelengths will be discussed in the next section. It should be noted that the absolute detector radiometer can also be used to calibrate the portable filter-wheel radiometers in much the same way.

6.4 Interpolation Between Calibration Points

The techniques previously described calibrate the spectroradiometer only at the wavelengths defined by the filters of the transfer radiometers (either the portable or absolute detector). Interpolation is necessary to be able to measure atmospheric transmittance between these points. It requires using a lamp whose relative spectral output is known. If the relative spectral irradiance of the lamp is F_λ^L, then the output of the spectroradiometer due to this is

$$I_\lambda = A_R \int_{\Delta\lambda} S_\lambda F_\lambda^L R_\lambda d\lambda \approx A_R S_\lambda F_\lambda^L R_\lambda \Delta\lambda. \qquad (6.18)$$

Then, the relative overall system responsivity, as a function of wavelength, can be obtained by dividing the output signal by the relative spectral irradiance of the lamp because

$$S_\lambda R_\lambda \approx I_\lambda/(A_R \Delta\lambda F^s_\lambda) \propto I_\lambda/F^s_\lambda \qquad (6.19)$$

Readings are taken of the lamp, at the wavelengths which atmospheric transmittance measurements are to be made. These values can then be referenced to the absolute responsivity values obtained by one of the calibration techniques, giving an absolute responsivity function. This absolute responsivity function can then be used to find $I_{o\lambda}$ at in-between wavelengths (using (6.14)), and atmospheric transmittance can then be derived from I_λ. Also, the responsivity function will allow F_λ values to be calculated from I_λ values (using (6.17)) during data collection. Atmospheric transmittance, $F_\lambda/F_{o\lambda}$, can then be determined.

Although the system does not have a standard lamp calibration set-up, the author was able to procure a small, portable tungsten lamp (manufactured by Ealing), and used it to obtain a rough estimate of the relative spectral responsivity of the system. The relative spectral output of the lamp was not known, but an estimate was obtained by transferring the relative spectral irradiance from a standard lamp to it via a portable radiometer. This was done by first taking measurements of the standard lamp for each filter, and then taking measurements of the Ealing lamp.

Then, by using the value of spectral irradiance of the standard lamp at the center wavelength of each filter, a relative spectral irradiance of the portable lamp was obtained from

$$F_\lambda^{EL} = K(V_\lambda^{EL}/V_\lambda^{SL})F_\lambda^{SL} \qquad (6.20)$$

where, K is a constant,

V_λ^{EL} is the output of the portable due to the Ealing lamp,

V_λ^{SL} is the output of the portable due to the standard lamp,

F_λ^{SL} is the spectral irradiance of the standard lamp

A standard spline interpolation was done to estimate points in between the 10 wavelengths. From these points, and the output signal at wavelengths between 370 nm and 1030 nm (at intervals of 5 nm), the relative spectral responsivity of the system was obtained and is shown in Figure 6.2. There are some interesting things to note from the figure, namely, the large jump in responsivity at 900 nm, and the sharp dips in the curve at 550 nm and 1000 nm. The large jump at 900 nm is due to the change from short wavelength range grating to the long wavelength range grating, which occurs at that point. The responsivity is much higher for the long range grating compared to the short because the effective spectral

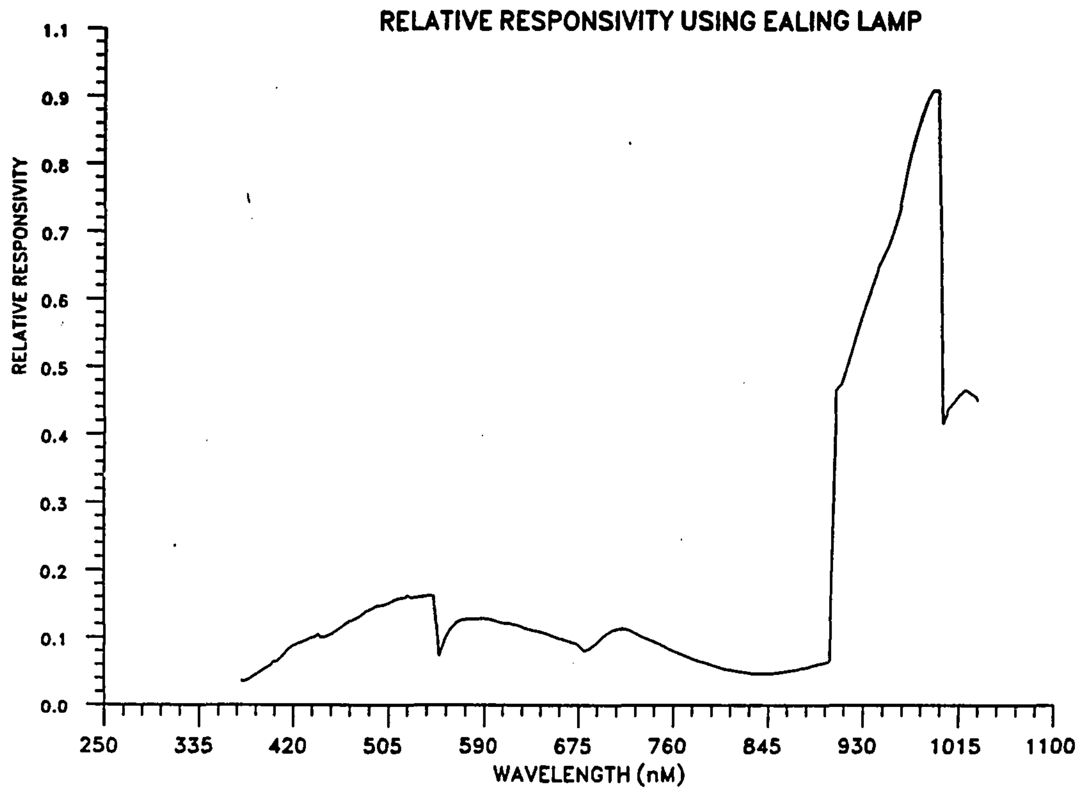

Figure 6.2. Relative Responsivity of the System Derived From Measurements With Ealing Lamp

bandwidth for the long range grating is wider. The sharp dips in the curve are due to the placement of the order sorting filters in the optical path. Remember, this curve is only a rough estimate because the exact shape of the spectral irradiance curve of the Ealing lamp was not known and was assumed smooth. A more permanent lamp system will have to be implemented to accurately and precisely calibrate the system. Only after being calibrated, will the system prove useful in determining atmospheric transmittance.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The IAP spectroradiometer system has been modified and made operable. Modifications were made to the temperature controller and temperature acquisition circuitry. An optical encoder system was added to the wavelength drive to allow the computer to read the wavelength drive setting. Software changes were made to accommodate the hardware modifications, and to enhance system performance.

A test of system performance after the modifications has shown the signal to noise ratio, which is wavelength and time of day dependent, is within acceptable levels. By considering the signal to noise ratio and data scan times, the best system operating parameters have been chosen.

To be useful in atmospheric transmittance studies, the system will have to be calibrated. Calibration strategies for the instrument have been examined. These include transferring the calibration of a calibrated portable or an absolutely calibrated detector, at discrete wavelengths, to the spectroradiometer. Once having calibrated the instrument at these discrete points, the calibration on a quasi-continuous basis can be achieved using a lamp whose relative spectral irradiance is known.

7.2 Recommendations

The system as it now stands is fully operational, and should prove to be a valuable tool in atmospheric transmittance studies. The calibration of the instrument as discussed earlier, should be investigated further and carried out. Also, a number of improvements can be made to allow the instrument to run more efficiently. Several suggested changes or modifications that appear worth making to the system are listed below:

1) Changing the location of the system: The entire system should be moved to a new location, probably to the top of the Gould-Simpson building. Late afternoon data cannot be taken with the instrument because during certain parts of the year, the sun is blocked by Gould-Simpson building in the late afternoon. At other times of the year, other instruments on the PAS observatory roof obstruct the view of the tracking mirror in the afternoon. In the morning hours, a railing on the roof prevent measurements at airmasses greater than about 4.0. Also, a lightning rod obstructs the view of the instrument at certain times in the morning.

2) Standard lamp calibration: The incorporation of a standard lamp into the system for the purposes of radiometric calibration should be considered. This would also allow examination of the long term stability of the system.

3) Tracking mount modifications: Encoders should be added to the tracking mount to allow the computer to determine the position of the tracking mirror. This will speed up tracking, and eliminate the need for tracking mount initialization. It is also suggested that the resolution of the mount be increased through modified gearing or new motors. Currently, the gearing allows an angle of .025° per step. The sun subtends an angle of about .5°, so each step constitutes about 5% of the angle subtended by the sun.

4) Detector assembly: An insulating housing should be built for the detector assembly. The time for the detector to reach set point temperature was found to be quite long during cold weather (cold room temperature). The metal casing housing the detector seems to readily conduct the heat away from the detector. This could be prevented by placing an insulating shell around the metal casing.

5) Grating and filter changers: It may be desirable to add some sort of feedback in the grating and filter changing mechanisms. There have been problems with these mechanisms in the past, including failure of one of the filter mechanisms to retract its filter, and failure of the grating change mechanism. Allowing the computer to read the change of filters or gratings will eliminate bad data runs due to

similar problems in the future. Limit switches already exist on the grating changers, and some additional circuitry (including a Digital Input Card for the Multiprogrammer) would allow the computer to read them. The filter changers have no such switches at the moment, but they could be easily added.

6) IBM PC control: A possible future project might involve changing the system to be run on an IBM PC compatible. This would be a difficult task, but one that may be worth the effort. The 62.4K of memory on the HP 9845A is just not enough to allow large additions to the software. The tape drive system is slow and very limited. Accessories for the system are quite expensive. Also, because a data reduction program written for the PC is used, all data taken by the instrument must be transferred by hand to a PC. Using a PC compatible to control the instrument would allow more programming flexibility, more data storage space, less expensive modifications, and more speed. A serial/parallel interface would have to be built to allow control of the peripheral instrumentation.

APPENDIX A

Encoder System Hardware and Operation

Power Supply Module

The power supply module provides

1) power to operate the encoders,
2) LED readouts of the encoder outputs,
3) interconnections between the main cable to the junction box and the cables to the encoders.

To accomplish this, the module contains

1) a 5 volt power supply,
2) LED's with driver circuitry
3) terminal blocks for interconnects between incoming and outgoing lines.

Figure A.1 and Figure A.2 show the layout in the power supply module.

The LED driver board controls the LED's, corresponding to the outputs of the encoders. One of the driving circuits is shown in Figure A.3. The connector pin connections are shown in Table A.1 through Table A.3.

Operation

To operate the encoder system, first make sure the power cord is connected. If they are not already, connect the cables to Encoder 1 (the one directly coupled to the wavelength drive shaft) and Encoder 2 to the proper connec

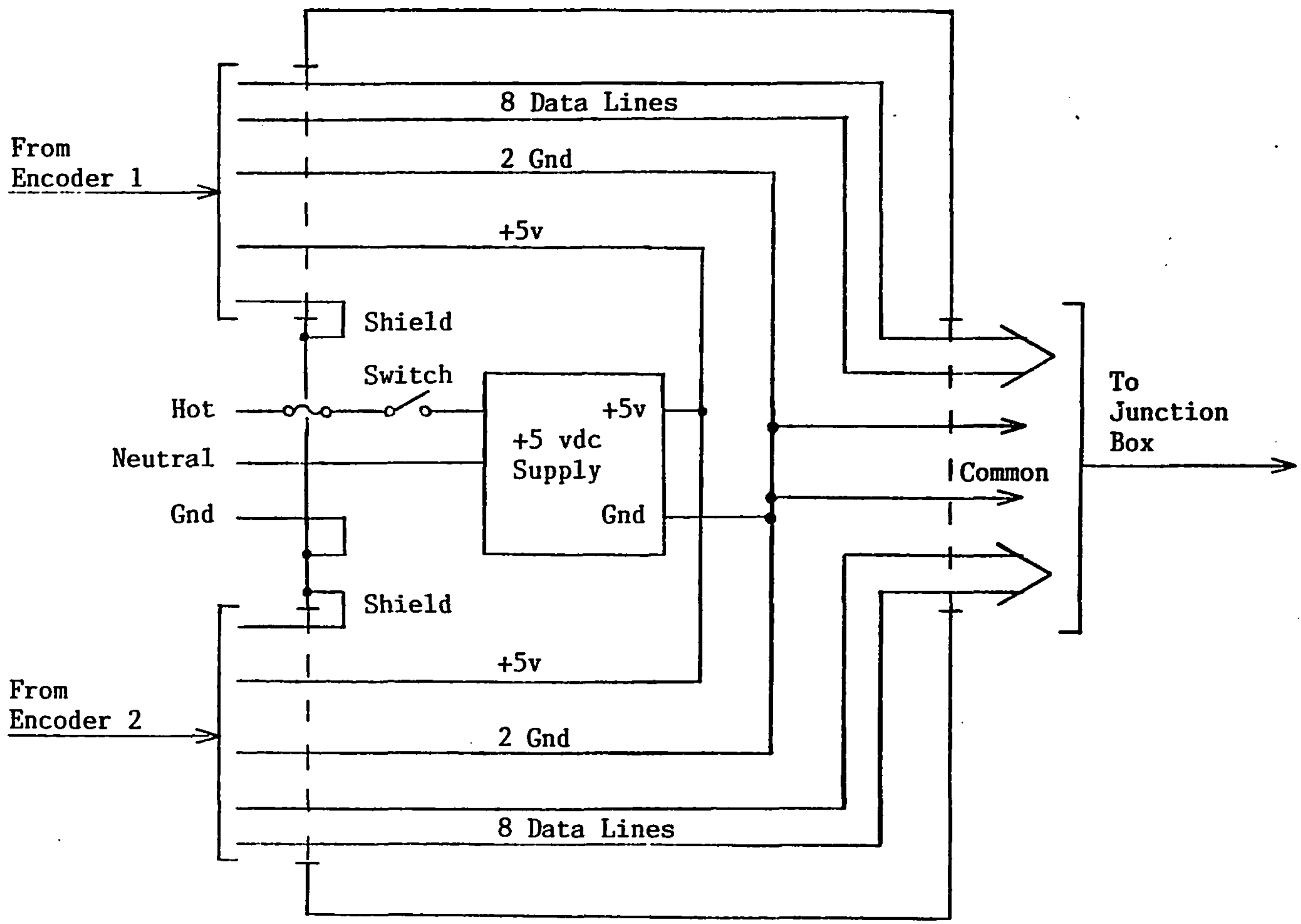

Figure A.1. Power Supply Module Configuration

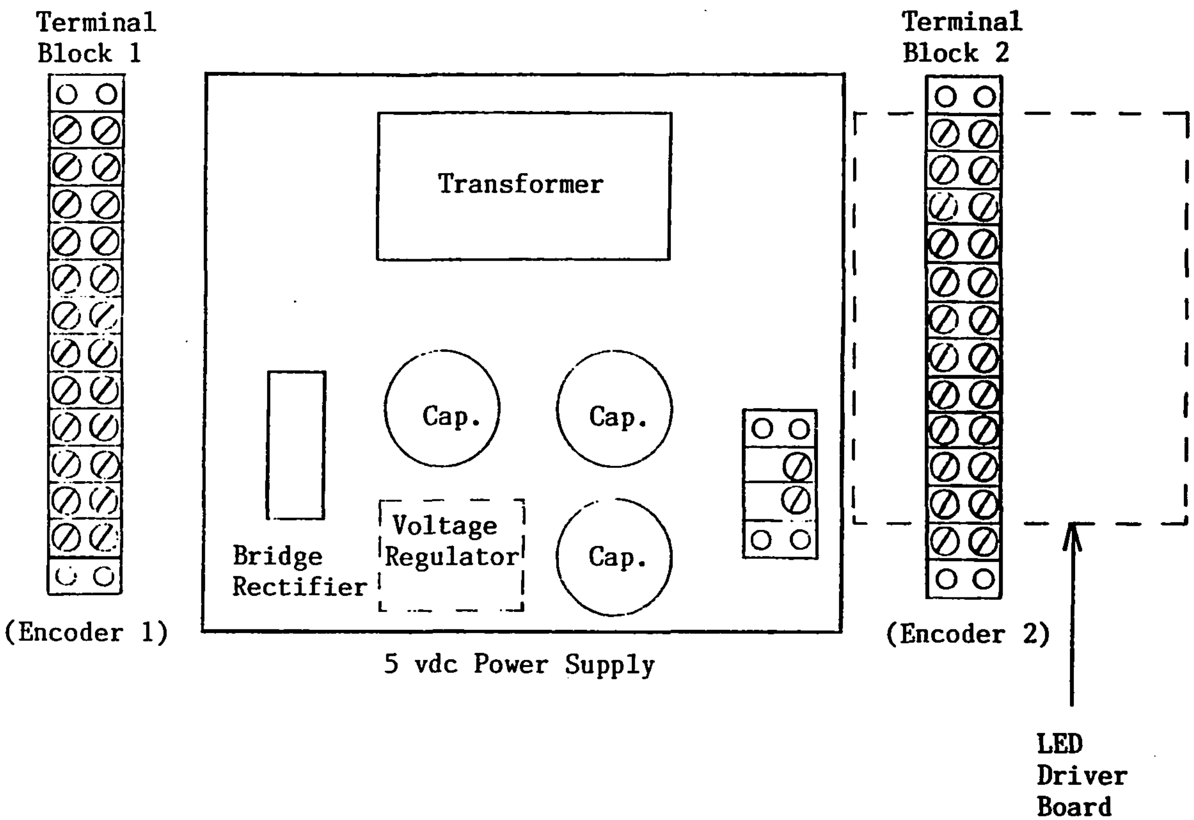

Figure A.2. Power Supply Module Layout

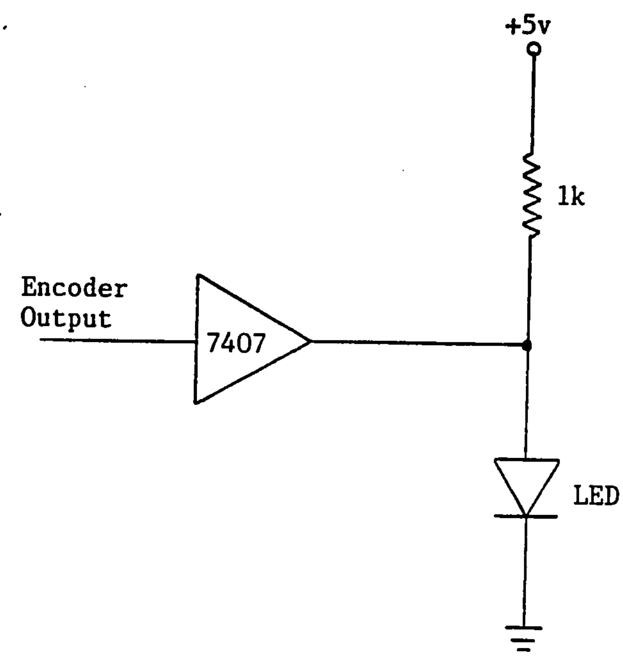

Figure A.3. LED Driver Circuit

Table A.1

Cables from Encoders to Power Supply Module

12 - conductor
24 AWG - shielded

Function	Wire Color	DB-25 pin	MS3106B-4-19S pin
Bit 7	Light Brown	1	J
Bit 6	Black	2	H
Bit 5	Pink	3	F
Bit 4	White	4	E
Bit 3	Grey	5	D
Bit 2	Green	6	C
Bit 1	Orange	7	B
Bit 0	Purple	8	A
GND	Red	15	L
GND	Blue	16	M
+5v	Dark Brown	18	K
Shield	Shield	23	N
not used	Yellow		

Table A.2

Connectors for Power Supply Module

MS3102A-22-14p

Pin	Function
A	Bit 0 (Enc2)
B	Bit 1 (Enc2)
C	Bit 2 (Enc2)
D	Bit 3 (Enc2)
E	Bit 4 (Enc2)
F	Bit 5 (Enc2)
G	Bit 0 (Enc1)
H	Bit 1 (Enc1)
J	Bit 2 (Enc1)
K	Bit 3 (Enc1)
L	Bit 4 (Enc1)
M	Bit 5 (Enc1)
N	Bit 6 (Enc2)
P	Bit 7 (Enc2)
R	Common (Enc2)
S	Bit 6 (Enc1)
T	Bit 7 (Enc1)
U	Common (Enc1)
V	Case Ground

MS3102A-24-19p (1&2)

Pin	Function
A	Bit 0
B	Bit 1
C	Bit 2
D	Bit 3
E	Bit 4
F	Bit 5
H	Bit 6
J	Bit 7
K	+5v
L	GND
M	GND
N	Case Ground

Table A.3

Cables - Junction Box to Digital Input Cards

Function	Color	Card Connector Pin
Bit 0	Purple	1
Bit 1	Orange	2
Bit 2	Green	3
Bit 3	Grey	4
Bit 4	White	5
Bit 5	Pink	6
Bit 6	Black	7
Bit 7	Light Brown	8
Common	Blue	15
not used	Dark Brown	
"	Yellow	
"	Red	

tors on the back of the power supply box. The cable from the junction box should be connected to the connector on the front of the power supply box. Flip the switch on the box to the "ON" position. Some of the LED's should light up, unless both encoders have zero output. If no lights are on, turn off the omni-drive and rotate the wavelength drive shaft 1/2 turn in either direction. Some lights should come on. If not, check all connections, power supply output, and driver circuitry. The encoders should now be ready for use. The LED's display the 8-bit binary outputs of the encoders. Conversion of these into a wavelength drive position is done by a subroutine in the main program. Normally, the cables are left connected and the power switch is left in the "ON" position so the encoders system is ready for use upon start-up.

Encoder adjustments

The encoder system has already been adjusted to provide correct wavelength determination. This section describes how the system can be adjusted if needed. The encoder system can be adjusted in two sections:

1) encoder to encoder,

2) encoder to wavelength drive.

To perform the encoder to encoder adjustments, it is best to remove the encoder assembly. To do this, first disconnect the cables at the encoders. Next, disconnect the flexible coupling from the wavelength drive shaft using an Allen wrench. Finally, remove the encoder assembly from the base plate using an Allen wrench.

The encoder box is used to view the encoders' outputs, so hook the encoders back up to the box. To adjust, loosen the set screw on one of the pulleys so that one moves freely from the other. Turn the shaft of one encoder, keeping the other one stationary, until the desired outputs are achieved. Currently, the encoders are adjusted such that both encoders achieve zero outputs at the same time (actually encoder 2 is slightly ahead of encoder 1). Now the encoder assembly can be put back. Screw the assembly to the base plate, and fit the flexible coupling onto the wavelength drive shaft, but do not tighten it. The encoder to wavelength drive adjustment must now be done.

Encoder to wavelength drive adjustments determine the reference wavelength for the system. This reference wavelength is required to calculate the drive shaft position using the encoder outputs. To do the adjustment, first make sure the encoders are not coupled to the wavelength drive shaft. Next, manually turn the drive to the desired reference wavelength. Then, turn the coupling until the desired reference output is achieved, making sure the drive shaft does not turn while you do this. When the desired output is achieved, tighten the coupling onto the drive shaft, being careful not to disturb the position of either.

This may take a few tries, so be patient. There is a fine adjustment screw on the coupling, but the author has not found it to be useful. The reference wavelength for the system as of this date is 150 nm. The monochromators should not be used below the reference wavelength.

APPENDIX B

Modified Software Listing

```
5    REM FF**  RUNRAD  **
10   ! PROGRAM Runrad                 29 JULY '82        D. PERRY
15   !
20   !
25   ! THIS PROGRAM IS RESPONSIBLE FOR RUNNING THE SOLAR SPECTRO-
30   ! RADIOMETER.  THIS IS ONLY A RUDIMENTARY PROGRAM DESIGNED
35   ! TO ILLUSTRATE THE WAY IN WHICH THE SYSTEM FOLLOWS THE SUN
40   ! AND OBTAINS DATA.  OPERATING PARAMETER ARE FIXED.  IN THE FUTURE,
45   ! IT MAY BE DESIRABLE TO ADD INTERACTIVE CONTROL OF OPERATING
50   ! PARAMETERS AND STORAGE OF GOOD DATA.  PLEASE NOTE THAT THIS
55   ! PROGRAM MAY NOT BE USED WITHOUT RUNNING THE INSTRUMENT
60   ! INITIALIZATION PROGRAM FIRST.
61   !
62   ! NOTE: THIS PROGRAM MODIFIED BY JON CHANG    8/88
65   !
70   COM Status,Ppos,Tang,Dirslw,Actfrq    ! DO NOT ALTER THESE STATEMENTS
75   COM Bcklsh,A(5),A,B,N,Lmtt            ! THEY MUST MATCH UP WITH THE
80   COM S1400,S1402,S1414,Inflg,Wflg      ! STATEMENTS IN THE PREVIOUS
85   COM Shtflg,Lngflg,Cnt,Opencnt         ! PROGRAM, AS WELL AS Track
90   COM Fcycles,INTEGER Dataflg           ! SUBROUTINE
95   COM Pressure,Nwvl,SHORT Wvl(75)
100   COM Wakeup,Shutdown
105  !
110   SHORT Opfq,Dtvl,T1,Tmp,Dum
115   DIM Time(5),Val(200)
120   !
125   ON KEY #15 GOTO Terminate
130   ON ERROR GOTO Errtrap
135                                         ! WAIT FOR WAKE-UP TIME
140   IF Wakeup=0 THEN 165
145   CALL Time(Time(*))
150   DISP Time(3);":";Time(4);":";Time(5),"WAKE-UP SET FOR ";Wakeup
155   T1=Time(3)*100+Time(4)+Time(5)/100
160   IF (T1<Wakeup-.05) OR (T1>Wakeup+.05) THEN 145
165  !
170   PRINT PAGE;"TO EXAMINE OR CHANGE OPERATING PARAMETERS, PRESS 'PAUSE' AND"
175   PRINT "MODIFY 'Nwvl' AND CONTENTS OF ARRAY 'Wvl()'"
180  !
185   CALL Wait(15)
190  !
195  Nloop=1
200  Settling=0
205  INPUT "NUMBER OF LOOPS FOR AVERAGING? [1]",Nloop
210  INPUT "WAIT TIME BEFORE EACH READING? [0]",Settling
215   Opencnt=0                        ! CLEAR OPEN-LOOP COUNTER USED
220   Wflg=0
225                                    ! BY TRACKING SYSTEM
230 Form: IMAGE 4D.D,X,"nM",1X,2D.7D,X,"uA",3X,2D,":",2D.D,X,"M.S.T.",3X,S2D.D,X
,"Deg. C.",3X,"Sys. Status =",X,D
235   IF Inflg=1 THEN Ckwflg           ! INFLG=0 IF 'RAD' NOT LOADED FROM 'AUTOST
'
240   PRINT PAGE;CHR$(7);"PROGRAM NOT LOADED FROM 'AUTOST'.  RUN ABORTED"
245   STOP
250  !
255 Ckwflg: IF Wflg<>0 THEN CALL Settle(Settling) ! IMPORTANT: ALLOW UNCOMPLETED
260                                    ! WAVELENGTH CHANGE TO BE COMPLETED
265                                    ! IF NECCESSARY
270   CALL Timeck(Lmtt,Time1,Shutdown,Endfil) ! CHECK TIME OF DAY: O.K.?
275   IF Status=0 THEN Files           ! BYPASS INTERACTIVE ENTRY OF
280  !                                 ! PARAMETERS AFTER POWER FAILURE
285  !
290   Pwvl=0                           ! W/L POINTER INTO W/L LOOKUP TABLE AND
295   Spcnt=1                          ! POINTER SPACING, USED IN CALFQ2
300                                    ! TO CALCULATE NEXT FREQUENCY.
305                                    !
310   Dwell=0                          ! TIME FROM LAST READING TO NEXT
```

```
315                                   ! WAVELENGTH CHANGE, SECONDS
320  !
325  ! MAIN LOOP BEGINS HERE
330  !
335 Files: GOSUB Data                 ! MAKE DATA FILE ASSIGNMENTS
340   Status=0                        ! RE-SET Status IN CASE OF RESTART
345  !
350   PRINT PAGE;"NOW SLEWING ROUND TO LOCATE THE SUN"
355   CALL Timeck(Lmtt,Time1,Shutdown,Endfil)! READ TIME AND PAUSE IF TOO EARLY
360   GOSUB Timer                     ! START UP INTERUPT SYSTEM
365  !
370  Refwav=150                       ! REFERENCE VALUE ON HIGH RANGE
375                                   ! READOUT.  (USED FOR DETERMINING
380                                   ! WAVELENGTH)
385 Start1: CALL Compwav(Nwvl,Pwvl,Spcnt,Cnt,Opfrq,Wvl(*))
390                                   ! COMPUTE WAVELENGTH: THIS ROUTINE
395                                   ! COULD BE REPLACED WITH A LOOK-UP
400                                   ! TABLE OF DESIRED WAVELENGTHS
405   Mean=0
410   Vari=0
415   CALL Grat(Opfrq,S1414,Shtflg,Lngflg)       ! CHANGE GRATINGS IF REQ'D.
420   CALL Setwav(Opfrq,Refwav)       ! SET OPERATING WAVELENGTH
425   DISP CHR$(132)&"Press SF key #15 to end data collection routine"&CHR$(128)
430   CALL Filt1(Opfrq,S1414)         ! CHANGE OG 550 FILT IF REQ'D.
435   CALL Filt2(Opfrq,S1414)         ! CHANGE RG1000 FILT. IF REQ'D.
440   CALL Detsel(Opfrq,S1414)        ! SELECT Si OR Ge DETECTOR
445   FOR I=1 TO Nloop                ! LOOP FOR AVERAGING
450    CALL Settle(Settling)           ! WAIT FOR NEXT READING
455   CALL Getdet(Detval,S1402)       ! TAKE 1 LOCK-IN READING
460   Val(I)=Detval                   ! LOAD ARRAY FOR AVERAGING
465   CALL Timeck(Lmtt,Time1,Shutdown,Endfil)! READ TIME AND STOP IF TOO LATE
470   IF Endfil<>0 THEN Closefiles
475   NEXT I
480   FOR I=1 TO Nloop                ! FIND MEAN SIGNAL VALUE
485   Mean=Mean+Val(I)
490   NEXT I
495   Mean=Mean/Nloop
500   FOR I=1 TO Nloop
505   Vari=Vari+(Val(I)-Mean)^2.0
510   NEXT I
515   Vari=SQR(Vari/(Nloop-1))
520   Detval=Mean
525   CALL Temprd(Temp,S1402)         ! READ DETECTOR TEMPERATURE
530   Hours=INT(Time1)
535   Mins=60*Time1 MOD 60
540   Opfq=Opfrq
545   Dtvl=Detval
550   IF Dataflg=0 THEN Dtvl=-Dtvl
555   T1=Time1
560   Tmp=Temp
565   PRINT USING Form;Opfrq;Detval;Hours;Mins;Temp;Dataflg ! DISPLAY NEW DATA
570   PRINT #1;Opfq,Dtvl,T1,Tmp,END   ! SAVE ON MAG. TAPE VIA BUFFER
575   Npts=Npts+1
580   IF Dwell=0 THEN Start1
585   FOR I=1 TO INT(Dwell*10)        ! WAIT TO BEGIN NEXT OBSERVATION
590   WAIT 100
595   NEXT I
600   GOTO Start1
605   STOP
610   REM % FILE CLOSING AND SHUTDOWN
615 Terminate:   PRINT PAGE
620  PRINT "YOU HAVE ACTIVATED SHUT DOWN.  SHUT DOWN"
625  PRINT "PROCEDURES WILL COMMENCE IN 10 SECONDS."
630  CALL Wait(10)
635 Closefiles:    Copied=0             !STORE # OF DATA POINTS IN PARAMETER FIL
E
```

```
640   ASSIGN #1 TO "PARAMS:T14"
645   READ #1;Puvl,Spcnt,Dwell,Settling,Fcycles,Dum1,Dum2,Pressure,Nuvl,Wvl(*),D
um1,Dum2
650   READ #1,1
655   PRINT #1;Puvl,Spcnt,Dwell,Settling,Fcycles,Npts,Copied,Pressure,Nuvl,Wvl(*
),Tang,Ppos,END
660   OUTPUT 7;"B"                    ! SHUT DOWN REAL TIME CLOCK
665   LINK "TAPDSK"                   ! LOAD AND RUN PROGRAM TO BACK UP DATA ONT
O DISK
670   STOP
675   !
680 Errtrap: IF ERRN<>59 THEN Errm
685   INPUT "END OF TAPE. NO MORE ROOM FOR DATA. HIT 'CONT' TO CONTINUE",Inp
690   GOTO Closefiles
695 Errm: PRINT ERRM$
700   PRINT "EXECUTION HALTED"
705   STOP
710   REM FF  SUBROUTINE Data              5 AUG. '82         D. PERRY
715   !
720   ! THIS SUBROUTINE IS RESPONSIBLE FOR MAKING DATA FILE ASSIGNMENTS.
725   ! IF A NEW DATA TAPE IS IN USE, THE ROUTINE WILL CREATE FILES
730   ! DATA1 AND PARAMS.  DATA1 IS THE PRIMARY DATA FILE.
735   ! IN THE EVENT OF A POWER FAILURE, DATA1 IS REREAD TO THE END OF
740   ! THE FILE, AND A MARKER IS SET TO FLAG THE BREAK IN THE DATA.
745   ! PARAMS IS USED TO STORE THE MOST RECENT SYSTEM OPERATING
750   ! PARAMETERS.
755   !
760 Data:                                  !
765   CHECK READ OFF                       ! TURN OFF AUTO-VERIFY IF ON
770   ON ERROR GOTO Dataerr3               ! TRAP TAPE ERRORS
775 Assn3: ASSIGN #2.0 TO "PARAMS:T14"    ! OPERATING PARAMETERS STORAGE
780   ON ERROR GOTO Dataerr1               ! TRAP TAPE ERRORS
785 Assn1: ASSIGN #1 TO "DATA1:T14"        ! DATA1 FOR NORMAL MODE
790   IF (Status=1) OR (Copied=1) THEN 850
795 Restart:     Npts=0                    !RESTART FROM POWER FAILURE OR STOP
800   ON END #1 GOTO Gotnpts               ! GET # OF POINTS ALREADY IN FILE
805   READ #1;Time(1),Time(2.0)
810 Getnpts:    READ #1;Opfq,Dtvl,T1,Tmp
815   Npts=Npts+1
820   GOTO Getnpts
825 Gotnpts:                               !
830   Dum=9999
835   PRINT #1;Dum,Dum,Dum,Dum,END         ! WRITE OUT DUMMY RECORD TO MARK BREA
K
840   Npts=Npts+1
845   !
850   ON ERROR GOTO Errtrap                ! RESTORE ORIGINAL 'BRANCH ON ERROR'
855   CALL Time(Time(*))                   ! GET TODAY'S DATE
860   PRINT #1;Time(1),Time(2.0),END       ! PLACE DATE ON FRONT OF DATA FILE
865   IF Status=0 THEN READ #2.0;Puvl,Spcnt,Dwell,Settling,Fcycles,Opts,Copied,P
ressure,Nuvl,Wvl(*)
870   IF (Tang=0) AND (Ppos=0) THEN READ #2.0;Tang,Ppos
875   IF (Tang=-99999) OR (Ppos=-99999) THEN Lostpos
880                                        ! USE MOST RECENT PARAMETERS AFTER
885                                        ! POWER FAILURE
890   IF Status=1 THEN PRINT #2.0;Puvl,Spcnt,Dwell,Settling,Fcycles,0,0,Pressure
,Nuvl,Wvl(*),-99999,-99999,END
895                                        ! RECORD OPERATING PARAMETERS FOR
900                                        ! FUTURE USE
905   ASSIGN #2.0 TO *                     ! FREE UP SOME MEMORY
910   RETURN
915 Dataerr1:     IF ERRN=56 THEN Create1  ! CREATE DATA1 IF NOT PRESENT ALREADY
920 Msg:    PRINT PAGE,"SYSTEM ERROR ";ERRN;" HAS OCCURED" ! TAPE ERROR MESSAGE
925   PRINT LIN(2.0),"CONSULT HP9845A DOCUMENTATION FOR ERROR MESSAGE LISTINGS."
930   PRINT LIN(3),"PROGRAM EXECUTION HALTED"
935   STOP                                 ! TERMINATE ON ALL ERRORS BUT #56
```

```
940 Create1:   CREATE "DATA1:T14",11000,16 ! CREATE 174K FILE
945   GOTO Assn1                          ! GO BACK; TRY AGAIN
950 Dataerr3:   IF ERRN=56 THEN Create3    ! CREATE PARAMS IF NOT PRESENT ALREAD
Y
955   GOTO Msg
960 Create3:   CREATE "PARAMS:T14",2.0     ! CREATE 1/2K FILE
965   GOTO Assn3                          ! GO BACK; TRY AGAIN
970 Lostpos:  PRINT PAGE,"SYSTEM HAS BEEN RESTARTED WITHOUT INITIALIZATION, AND
THE"
975   PRINT "TRACKER'S POSITION IS UNKNOWN.  PLEASE RE-INITIALIZE SYSTEM AND"
980   PRINT "TRY AGAIN",LIN(2.0),"PROGRAM EXECUTION HALTED"
985   STOP
990  REM FF SUBROUTINE Timer  27 AUG. '82    D. PERRY
995  !
1000 ! THIS SUBROUTINE IS RESPONSIBLE FOR STARTING UP THE PERIODIC
1005 ! RTC INTERUPT USED BY THE TRACKING SYSTEM.
1010 !
1015 Timer:  OUTPUT 7;"A U1P6000"         ! ESTABLISH 6 SEC. PERIOD, UNIT#1
1020  ON INT #7 CALL Track                ! EXECUTE TRACKING ROUTINES ON INT.
1025  CONTROL MASK 7;128                  ! INITIALIZE DEVICE 7 CONTROL MASK
1030  CARD ENABLE 7                       ! ENABLE INTERUPTS FROM DEVICE 7(RTC)
1035  OUTPUT 7;"U1G"                      ! START 6 SEC. TIMER
1040  RETURN
```

```
2320 REM FF**  GETDET  **
2325 ! SUBROUTINE Getdet
2330 !
2335 ! THIS SUBROUTINE MODIFIED BY JON CHANG    4/20/88
2340 !
2345 ! THIS SUBROUTINE IS RESPONSIBLE FOR TAKING ONE
2350 ! READING FROM THE LOCK-IN AMPLIFIER. THE SENSITIVITY
2355 ! SETTING IS CHANGED AUTOMATICALLY, AND ONLY IF
2360 ! THE SENSITIVITY SETTING USED ON THE PREVIOUS
2365 ! READING IS NOT ADEQUATE.  THE OUTPUT VARIABLE
2370 ! Detval IS EXPRESSED IN uA.  THE SUBROUTINE WAS
2375 ! MODIFIED TO ALLOW SETTLING OF THE LOCK-IN SIGNAL.
2380 ! EXECUTION TIME FOR THIS SUBROUTINE WILL VARY.
2385 !
2390  SUB Getdet(Detval,S1402)
2395  DIM Lk(4)
2400  DISP CHR$(132);"WAITING FOR SIGNAL TO SETTLE";CHR$(128)
2405  Cnt1=0
2410  Cnt2=0
2415  Gain=BINAND(S1402,2^6+2^5+2^4)/16        ! DETERMINE CURRENT SENSITIVITY
2420  IF Gain<>0 THEN Read                     ! POWER-UP CHECK
2425  Gain=6                                   ! SET SENSITIVITY TO MINIMUM ON
2430  WAIT 5000                                ! POWER UP AND WAIT FOR SETTLING
2435 Setgn:  CALL Setsen(Gain,S1402)           ! CHANGE SENSITIVITY SETTING
2440 S1402=BINAND(S1402,4095-2^6-2^5-2^4)+Gain*16
2445 WAIT 1000                                 ! ALLOW SOME SETTLING
2450 Read:CALL Rdlk(Lk(*),S1402)               ! READ AMPLIFIER
2455 Read1=BIT(Lk(4),3)*100+Lk(3)*10+Lk(2)+Lk(1)/10
2460 Sigmax=Read1                              ! SET MAXIMUM VALUE
2465 Sigmin=Read1                              ! SET MINIMUM VALUE
2470 Cycle: Cnt1=Cnt1+1
2475 IF Cnt1>800 THEN Error                    ! TAKING TOO LONG?
2480 WAIT 500                                  ! WAIT .5 SECONDS
2485 CALL Rdlk(Lk(*),S1402)                    ! READ AMPLIFIER
2490 Read2=BIT(Lk(4),3)*100+Lk(3)*10+Lk(2)+Lk(1)/10
2495 IF Read2>Sigmax THEN Set1                 ! SET NEW MAX?
2500 IF Read2<Sigmin THEN Set2                 ! SET NEW MIN?
2505 IF Cnt2>=5 THEN Convert                   ! SIGNAL SETTLED?
2510 Cnt2=Cnt2+1
2515 IF (Read2>=11.5) AND (Read2<=120) THEN Cycle  ! SIGNAL WITHIN RANGE?
2520 IF Read2>120 THEN Toobig                  ! SIGNAL TOO BIG
2525 GOTO Toosml                               ! SIGNAL TOO SMALL
2530 Set1: Sigmax=Read2                        ! SET NEW MAX
2535 Cnt2=0
2540 IF Read2>120 THEN Toobig                  ! SIGNAL TOO BIG
2545 GOTO Cycle
2550 Set2: Sigmin=Read2                        ! SET NEW MIN
2555 Cnt2=0
2560 IF Read2<11.5 THEN Toosml                 ! SIGNAL TOO SMALL?
2565 GOTO Cycle
2570 Toobig: IF Gain=6 THEN Cycle
2575 Gain=Gain+1
2580 GOTO Setgn
2585 Toosml: IF Gain=1 THEN Cycle
2590 Gain=Gain-1
2595 GOTO Setgn
2600 Error: PRINT "THERE MAY BE AN ERROR IN THE LOCK-IN SIGNAL."
2605 PRINT "PLEASE CHECK.  PROGRAM TERMINATED."
2610 STOP
2615 Convert: Detval=Read2*10^(Gain-7)         ! CONVERT TO uA
2620 DISP " "
2625 SUBEND
```

```
2630 REM FF**  SETWAV  **
2635 ! SUBROUTINE Setwav
2640 !
2645 ! NOTE: THIS SUBROUTINE REPLACES SUBROUTINE SETFRQ
2650 ! JON CHANG     1/88
2655 !
2660 ! THIS SUBROUTINE IS RESPONSIBLE FOR SETTING THE MONOCHROMATOR
2665 ! WAVELENGTH SETTING.  THE MECHANICAL READOUTS ON THE MONOCHROMATORS
2670 ! WILL READ 1/2 THE ACTUAL WAVELENGTH OF OPERATION IN NANOMETERS.
2675 ! THE HIGH BLAZE READOUT IS ON THE LEFT, AND THE LOW BLAZE READOUT
2680 ! IS ON THE RIGHT.  Deswav IS THE ACTUAL WAVELENGTH OF OPERATION.
2685 ! Rdoutwav IS THE HIGH BLAZE READOUT VALUE.
2690 !
2695  SUB Setwav(Deswav,Refwav)
2700  DISP CHR$(132);"W/L CHANGE IN PROGRESS. PRESS SF KEY #15 TO END DATA RUN";
CHR$(128)
2705  Multflg=0                    ! SET FLAG TO CHECK .1 POS. FOR 2 MULT.
2710  Count=0
2715  IF (Deswav<Refwav+5) OR (Deswav>2*(Refwav+795)) THEN Outrange
2720  IF Deswav<=900 THEN Short
2725 Long:  Rngflg=0                   ! LONG WAVELENGTH RANGE
2730 Rdoutwav=.5*Deswav                ! SCALE READOUT TO ACTUAL WAVELENGTH
2735 Rdoutwav=PROUND(Rdoutwav,-1)
2740 Fracdeswav=FRACT(Deswav)
2745 Number=10*Fracdeswav
2750 Number=Number/2
2755 Fracnum=FRACT(Number)
2760 IF Fracnum=0 THEN Start           ! .1 POSITION IS MULTIPLE OF 2
2765 Multflg=1                         ! .1 POSITION IS NOT MULTIPLE OF 2
2770 GOTO Start
2775 Short: Rngflg=1                   ! SHORT WAVELENGTH RANGE
2780 Rdoutwav=Deswav                   ! READOUT READS ACTUAL WAVELENGTH
2785 Start: IF Rngflg=1 THEN Slew
2790 IF Multflg=0 THEN Slew
2795 Rdoutwav=Rdoutwav-.1        ! SLEW TO "EVEN" WAVELENGTH IF IN LONG RANGE
2800 !
2805 Slew: Count=Count+1
2810 IF Count>50 THEN Error    ! DON'T GO FOREVER
2815 CALL Calwav(Wavelength,Refwav)
2820 Wavinc=Rdoutwav-Wavelength
2825 IF Wavinc=0 THEN Check      ! TEST IF AT DESIRED WAVELENGTH
2830 IF Wavinc<=0 THEN Move      ! TEST IF ABOVE DESIRED WAVELENGTH
2835 IF Wavinc<=.4 THEN Finestep  ! SLOWLY PULSE UP TO WAVELENGTH
2840 IF Wavinc<=1 THEN Step      ! TEST IF WITHIN 1NM OF DESIRED WAVELENGTH
2845 !
2850 Move: Speed=0
2855 Delwav=PROUND((Wavinc-1)*36*1.00179140,0)
2860 CALL Frqslw(Delwav,Speed)
2865 Wait:  CALL Monst(Ref,Rem,Rdy)       ! WAIT FOR MOTION TO STOP
2870 IF Rdy<>1 THEN Sum=0
2875 IF Rdy=1 THEN Sum=Sum+1
2880 IF Sum<3 THEN Wait
2885 GOTO Slew
2890 !
2895 Step: CALL Frqslw(14,0)     ! TAKE MEDIUM-SIZED STEPS
2900 WAIT 800
2905 GOTO Slew
2910 Finestep: CALL Frqslw(1,0)      ! MOVE DRIVE 1 PULSE UP
2915 WAIT 200
2920 GOTO Slew
2925 !
2930 Check: IF Multflg=0 THEN End
2935  CALL Frqslw(2,0)          ! MOVE DRIVE UP 2 PULSES
2940  WAIT 200
2945  GOTO End
2950  !
```

```
2955 Outrange:  PRINT Deswav,"IS OUT OF RANGE.  PROGRAM TERMINATED"
2960 STOP
2965 Error: PRINT "NOT ABLE TO SLEW TO DESIRED WAVELENGTH.  CHECK"
2970 PRINT "MONOCHROMATORS AND ENCODERS. PROGRAM TERMINATED."
2975 STOP
2980 End: DISP " "
2985 SUBEND
```

```
3495 REM FF**  COMPWAV  **
3500 SUB Compwav(Nwvl,Pwvl,Spcnt,Cnt,Opfrq,SHORT Wvl(*))
3505 !
3510 ! SUBROUTINE Compwav
3515 ! EXECUTION TIME: NO MORE THAN 20mS
3520 !
3525 ! NOTE: THIS SUBROUTINE REPLACES 'Calfq2'.
3530 ! JON CHANG   2/88
3535 !
3540 ! THIS SUBROUTINE IS RESPONSIBLE FOR CALCULATING THE NEXT
3545 ! OBSERVATION WAVELENGTH, Opfrq.  IF THE
3550 ! COMPUTED WAVELENGTH IS OUTSIDE THE OPERATING RANGE OF THE
3555 ! WAVELENGTH DRIVE, AN ERROR MESSAGE IS DISPLAYED, AND
3560 ! EXECUTION IS HALTED.  FURTHERMORE, VARIABLE Cnt KEEPS
3565 ! TRACK OF HOW MANY COMPLETE UP/DOWN CYCLES HAVE BEEN
3570 ! PERFORMED.
3575 !
3580  Pwvl=Pwvl+Spcnt
3585  IF Pwvl<=Nwvl THEN Setwav
3590  Pwvl=1
3595  Cnt=Cnt+1
3600 Setwav:Opfrq=Wvl(Pwvl)
3605  IF (Opfrq<290) OR (Opfrq>1850) THEN Fail
3610  SUBEXIT
3615 Fail:  PRINT PAGE,"COMPUTED WAVELENGTH IS OUT OF RANGE"
3620  PRINT LIN(2),"PLEASE CHANGE THE CONTENTS OF ARRAY 'WVL()' SO THAT ALL"
3625  PRINT "WAVELENGTHS ARE >290 nM AND <1850 nM."
3630  PRINT LIN(2),"PROGRAM EXECUTION TERMINATED"
3635  STOP
```

```
3820 REM FF**  SETTLE  **
3825 !
3830 ! THIS ROUTINE EXECUTES A PREDETERMINED DELAY
3835 !
3840 ! NOTE:  MODIFIED BY JON CHANG   2/88
3845 !
3850 SUB Settle(Settling)
3855 FOR I=1 TO INT(Settling*10)          ! DELAY BY PRESCRIBED AMOUNT
3860 WAIT 100
3865 NEXT I
3870 DISP ""                              ! CLEAR DISPLAY
3875 SUBEND                               ! RETURN
```

```
3880 REM FF**  RDENC  **
3885 REM  SUBROUTINE Rdenc
3890 REM
3895 REM  THIS SUBROUTINE READS THE DIGITAL INPUT CARDS WHICH
3900 REM  DISPLAY THE OUTPUTS OF THE OPTICAL ENCODERS USED TO DETERMINE
3905 REM  THE MONOCHROMATOR WAVELENGTH SETTING.
3910 REM
3915 REM  NOTE:  THIS SUBROUTINE REPLACES SUBROUTINE RECAL.
3920 REM  JON CHANG    1/88
3925 REM
3930 SUB Rdenc(Slot,Encout)
3935 OUTPUT 9 WHS USING "#,W";-3936       ! SET FOR NON-GATED READ
3940 CALL Mpin(Slot,Encval)               ! READ DIC FOR ENCODER
3945 Encout=BINAND(Encval,255)
3950 SUBEND
```

```
4210 REM FF**  CALWAV  **
4215 REM  SUBROUTINE Calwav
4220 REM
4225 REM NOTE: THIS SUBROUTINE REPLACES SUBROUTINE MONREF
4230 REM  JON CHANG      1/88
4235 REM
4240 REM  THIS SUBROUTINE READS THE ENCODERS AND DETERMINES THE
4245 REM  WAVELENGTH DRIVE SETTING OF THE MONOCHROMATORS.
4250 REM 'Hireadout' IS THE SETTING ON THE LONG RANGE READOUT.
4255 REM IT IS EQUAL TO THE ACTUAL WAVELENGTH WHEN THE SHORT RANGE
4260 REM GRATING IS IN USE OR 1/2 THE ACTUAL WAVELENGTH WHEN THE
4265 REM LONG RANGE GRATING IS IN USE
4270 REM
4275  SUB Calwav(Hireadout,Refwav)
4280  DISABLE                  ! DISABLE INTERRUPT SYSTEM SO NO ERRORS
4285                           ! OCCUR IN READING ENCODERS
4290  Slot=401                              ! DIC FOR ENCODER1
4295  CALL Rdenc(Slot,Encout)               ! READ ENCODER1
4300  Enc1=Encout
4305  Slot=403                              ! DIC FOR ENCODER2
4310  CALL Rdenc(Slot,Encout)               ! READ ENCODER2
4315  Enc2=Encout
4320  Val=Enc2/8
4325  Fracval=FRACT(Val)
4330  Chkenc=Enc2+1
4335  Chkval=Chkenc/8
4340  Chkfrac=FRACT(Chkval)
4345  IF Fracval=0 THEN Chk_ahead     ! CHECK IF ENC2 IS MULTIPLE OF 8
4350  IF Chkfrac=0 THEN Chk_behind    ! CHECK IF ENC2 IS (MULTIPLE OF 8) - 1
4355  GOTO Calc_wave
4360 Chk_ahead:  IF (Enc1>=0) AND (Enc1<=63) THEN Calc_wave
4365                                  ! CHECK IF ENC2 CHANGED EARLY
4370 Enc2=Enc2-1                      ! CHANGED EARLY, SUBTRACT 1
4375 GOTO Calc_wave
4380 Chk_behind: IF (Enc1>=192) AND (Enc1<=255) THEN Calc_wave
4385                                  ! CHECK IF NO CHANGE WHEN SHOULD
4390 Enc2=Enc2+1                      ! NOT CHANGED, ADD 1
4395 Calc_wave: Correctval=Enc2/8     ! USE CORRECT VALUE
4400 Correctfrac=FRACT(Correctval)
4405 Turn=Correctval-Correctfrac
4410 Frcturn=25/256*Enc1
4415 Hireadout=Refwav+Turn*25+Frcturn
4420 Hireadout=PROUND(Hireadout,-1)
4425 End: ENABLE                        ! RE-ENABLE INTERRUPT SYSTEM
4430 SUBEND
```

```
5970 REM FF**  TEMPRD  **
5975  REM  SUBROUTINE Temprd   25 MARCH '82    D. PERRY
5980  REM  EXECUTION TIME:  110mS
5985  REM
5986  !
5987  ! NOTE: THIS SUBROUTINE MODIFIED BY JON CHANG  2/88
5988  !
5990  REM  THIS SUBROUTINE IS RESPONSIBLE FOR READING THE
5995  REM  TEMPERATURE OF THE DETECTOR MOUNT ASSEMBLY.
6000  REM  THIS TEMPERATURE WILL BE ROUGHLY EQUIVALENT
6005  REM  TO THE INTERNAL AMBIENT TEMPERATURE OF THE
6010  REM  SOLAR SPECTRORADIOMETER.  THE TRANSDUCER OUTPUT
6015  REM  IS SCALED AND DIGITIZED IN THE DATA AQUISION
6020  REM  ENCLOSURE, AND IS READ FROM A TO D CHANNEL NO.
6025  REM  4.  Temp IS EXPRESSED IN DEGREES CELSIUS.
6030  REM  ACCURACY IS ABOUT ± 0.1 DEGREES C.
6035  REM
6040  SUB Temprd(Temp,S1402)
6045  Chan=4                          ! SELECT A TO D CHAN. 4
6050  CALL Rdatod(Chan,Andata,S1402) ! GET A TO D COUNT
6055  Temp=PROUND((255+Andata)/10.2,-1) ! CONV. LSB = .03906V
6060                                  ! 0 TO -58.6mV = 255
6065                                  ! -9.96 TO -10.0 V = 0
6070                                  ! TRANSDUCER SCALE FACTOR
6075                                  ! IS 100mV/DEGREE C.
6080  SUBEND
```

```
1295 REM FF**  INIT3  **
1300 ! SUBROUTINE Init3                  26 JULY'82          D. PERRY
1305 !
1310 ! MODIFIED BY JON CHANG     1/88
1315 !
1320 ! THIS SUBROUTINE PERFORMS A SIMPLE TEST TO SEE IF THE ENCODERS
1325 ! AND THE WAVELENGTH DRIVE ARE OPERATING CORRECTLY AND THEN ASKS
1330 ! THE USER TO VISUALLY VERIFY A WAVELENGTH SETTING.
1335  SUB Init3
1340  ON KEY #15 CALL Pause
1345  PRINT PAGE,"WAVELENGTH DRIVE AND ENCODERS CHECK"
1350  PRINT LIN(1),"PLEASE NOTE THAT THE WAVELENGTH DRIVE SETTING MUST BE IN THE
"
1355  PRINT "RANGE 300 TO 1800 nM.  THE DRIVE SHOULD HAVE BEEN LEFT IN THIS "
1360  PRINT "RANGE IF IT HAS NOT BEEN ALTERED DURING MANUAL OPERATION.  IF YOU"
1365  PRINT "SUSPECT THAT THE DRIVE IS NOT IN THE PROPER RANGE, PLEASE CHECK IT"
1370  PRINT "AT THIS TIME.  REMEMBER, YOU MUST DOUBLE THE READINGS SHOWN ON THE"
1375  PRINT "MONOCHROMATORS TO GET THE CORRECT WAVELENGTH VALUE.  THE RIGHT-HAND
"
1380  PRINT "WINDOW APPLIES TO THE SHORT WAVELENGTH GRATING.  THE LEFT-HAND "
1385  PRINT "WINDOW APPLIES TO THE LONG WAVELENGTH GRATING.  IF THE PRESENT SETT
ING"
1390  PRINT "IS NOT IN RANGE, MANUALLY RESET THE DRIVE TO THE CORRECT RANGE BY"
1395  PRINT "MOMENTARILY TURNING OFF THE OMNI-DRIVE AND ROTATING THE DRIVE BELT"
1400  PRINT "BY HAND.  DON'T FORGET TO TURN THE OMNI-DRIVE BACK ON AFTER RESETTI
NG"
1405  PRINT "THE WAVELENGTH."
1410  CALL Wait(15)
1415  DISP "ENCODERS AND WAVELENGTH DRIVE CHECK IN PROGRESS"
1420 Begin:  CALL Calwav(Wavelength1,150)    !DETERMINE FIRST WAVELENGTH SETTING
1425 IF Wavelength1<=898 THEN Step           !SETTING AT OR NEAR MAX?
1430 Count1=Count1+1
1435 IF Count1>1 THEN Error                  !DON'T DO MORE THAN ONCE
1440 CALL Frqslw(-360,0)                     !MOVE DOWN ABOUT 3NM
1445 WAIT 3500
1450 GOTO Begin
1455 !
1460 Step: CALL Calwav(Wavelength2,150)      !DETERMINE SECOND SETTING
1465 IF Wavelength2-Wavelength1=1 THEN Okay
1470 Count2=Count2+1
1475 IF Count2>100 THEN Error                 !DON'T GET STUCK
1480 CALL Frqslw(1,0)                        !GO UP ONE PULSE
1485 WAIT 200
1490 GOTO Step
1495 !
1500 Error: PRINT PAGE
1505 PRINT "ENCODERS AND/OR MONOCHROMATORS ARE NOT OPERATING"
1510 PRINT "PROPERLY.  PLEASE CHECK.  PROGRAM TERMINATED."
1515 STOP
1520 !
1525 Okay: PRINT PAGE
1530 PRINT "THE WAVELENGTH DRIVE AND ENCODERS HAVE PASSED"
1535 PRINT "CHECK.  AT THIS TIME, PLEASE VISUALLY VERIFY"
1540 PRINT "THAT THE HIGH RANGE READOUT HAS SETTING OF";SPA(1);Wavelength2
1545 PRINT "IF IT DOES, PRESS 'CONT' TO CONTINUE.  IF IT DOES"
1550 PRINT "NOT, STOP THE PROGRAM AND CHECK THE ENCODERS."
1555 PAUSE
1560 SUBEND
```

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