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DEPARTMENT OF COMPUTER AND ELECTRICAL ENGINEERING

MEASURING ATMOSPHERIC AND AEROSOL PROPERTIES WITH A MULTI-WAVELENGTH POLARIMETER

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ABSTRACT

Ozone depletion and the greenhouse effect have been two environmental concerns in the scientific community, and recently in the public community as well. A *Multi-wavelength Polarimeter* has been constructed to measure incoming ultraviolet solar radiation intensity and atmospheric aerosol content in hopes of collecting data that would help researchers gain insight into the two phenomena. By tracking the sun and measuring the solar radiation, the *Multi-wavelength Polarimeter* can measure the Earth's atmospheric properties, by quantifying UV radiation intensity and aerosol content. The device is able to accomplish this task by measuring solar radiation flux in the UV spectrum and the level of depolarization due to multiple scattering effects in the atmosphere. The intensities of dangerous UVA (321 nm to 400 nm) and UVB (280 nm to 320 nm) radiation levels reaching the Earth's surface are recorded and stored for long-term monitoring of the ultraviolet radiation flux hazard penetrating through the Earth's atmosphere to the surface. Also, the recording of levels of depolarized sunlight due to optical scattering in the atmosphere will provide information on the role of aerosols in determining the radiation transfer through the atmosphere. An instrument has been prepared and tested which will begin to gather a long term data base on ultraviolet radiation reaching the Earth's surface.

INTRODUCTION

Changes in the Earth's atmospheric conditions are of great importance to everyone and everything that inhabits the planet's surface. The Earth's atmosphere blankets the living organisms on the surface from harmful radiation and preserves the necessary balance of conditions conducive to life. For some years now, there has been much concern about human impact an damage to the Earth's atmosphere via fossil fuel burning, chemical pollutants, and aerosols. This leads to concerns that ozone depletion and the greenhouse effect will begin and cause devastating effects on the Earth. With the *Multi-wavelength Polarimeter*, a method of long term monitoring of the atmosphere will hopefully be achieved in which information about the ozone layer depletion and the greenhouse effect can be quantified and thus analyzed to better understand our options and future decisions. This paper will detail background theory, technical aspects, system operation, and future improvements of the *Multi-wavelength Polarimeter*.

BACKGROUND THEORY

The Ozone Layer

Above the stratosphere there is a small, yet, significant amount of ozone in the Earth's atmosphere. Known as the ozonosphere, this concentration of ozone protects life on the planet from harmful solar ultraviolet radiation. This thin layer of ozone reduces the level of harmful solar UV radiation and together with other molecules of the upper atmosphere removes nearly 100% of the incoming solar extreme ultraviolet (EUV) radiation that would otherwise reach the Earth's surface and devastate life as we know it. [1].

It is the molecular absorption of ozone that makes it so effective in blocking the sun's UV radiation. The greatest importance of ozone comes from the electronic transitions that produce Hartly bands centered at 255 nm, which extend from 200 nm to 300 nm absorbing EUV and UVB radiation [2]. Just above the Hartly bands in wavelength lie the Huggins bands which extend out to 340 nm, and together these are primarily responsible for absorbing most of the UV radiation from 200 nm to 340 nm that would otherwise reach the Earth's surface [2]. All of the shorter wavelength, higher energy solar radiation below 200 nm is blocked by N_2 and O_2 in the upper levels of the atmosphere.

The level of UV radiation between 200 nm to 300 nm at the Earth's surface is therefore strongly dependant upon the thickness of the ozonosphere, commonly known as the ozone layer. Monitoring optical transmission through the atmosphere at these UV wavelengths will provide information about the layer and allow researchers to see if the ozone layer is in fact depleting. Figure 1 illustrates the solar spectral irradiance at the top of the Earth's atmosphere and at the Earth's surface. This figure shows how ozone absorbs solar radiation completely up to 300 nm while drastically lowering the intensities in all other wavelengths.

Solar Irradiance from LOWTRAN 7

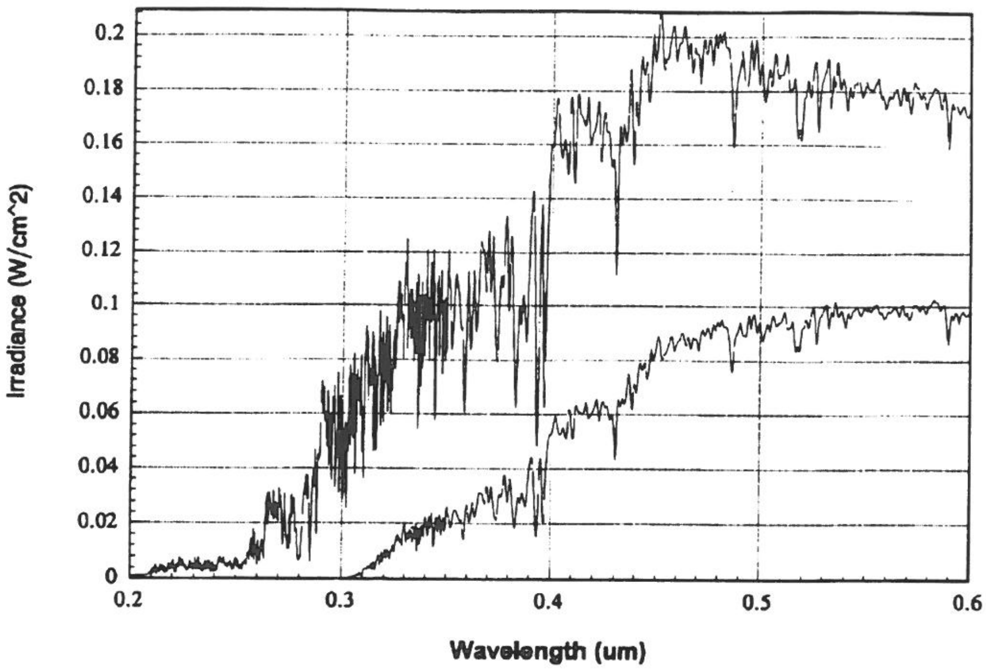

Figure 1. Solar spectral irradiance at the top of the atmosphere (top curve) and at the Earth's surface (bottom curve) from LOWTRAN 7 using a model atmosphere.

Ozone Depletion

Clorofluorocarbons (CFC's) have been linked to the destruction of atmospheric ozone, which in turn has caused an increase of UV radiation flux reaching the Earth's surface. This is because with a thinning of ozone concentrations, there is a direct decrease in UV radiation absorption. The effect is particularly noticeable in high Southern latitudes, but the same effect is of global extent. CFC's are extensively used as refrigerants (such as Freon) and propellants in aerosol sprays. These gases react with ozone to produce a catalytic cycle where chlorine fragments repeatedly destroy ozone molecules before some other chemical process removes the fragment from the stratosphere [3]. Even with regulations which freeze and reduce the use of CFC's and other ozone destructive gases, stratospheric ozone levels would continue to fall since the atmospheric retention time for most chlorine compounds is on the order of one hundred years [3]. Thus ozone depletion must be continuously measured over a long period to monitor the effects as the optical thickness of the ozone layer shrinks and allows higher intensities of harmful UV radiation to reach the planet's surface.

The Greenhouse Effect

The term greenhouse effect is used to described the scenario of global warming due to radiation trapped by water vapor, methane, and carbon dioxide in the atmosphere. These "greenhouse" gases act as the glass of a greenhouse. They allow light to pass through the atmosphere heating the Earth's surface while trapping the heat radiated from the Earth's surface within the layers of these gases in the atmosphere. The burning of fossil fuels, destruction of forests, conversion of land to agriculture and cattle grazing has resulted in the increase of the gases, airborne particulates, and aerosols. While the increase of greenhouse gases leads to the possibility of global warming, it also may be possible that the airborne particulates and aerosols might lead to reversing global warming and negating the greenhouse effect. This is because the particulate and aerosols might, in effect, scatter the sun's light and reflect the incoming radiation which would have otherwise heated the Earth's surface and atmosphere.

Atmospheric Aerosol and Particulate Concentration

The content of aerosols and particulate matter in the atmosphere will affect incoming sunlight by reflecting and absorbing it. As it turns out, there is a band of skylight 90 degrees from the line of the observer and the sun, which is nearly perfectly polarized by single scattering from molecules. Since the optical scattering from particles does not preserve the polarization and multiple scattering effects cannot maintain the polarization, it is then possible to monitor aerosol and particulate content in the atmosphere. Polarization due to aerosol and molecular scattering is dependent on wavelength of light, solar altitude, and angular distance of the observing direction from the sun [4]. Maximum polarization occurs near 90 degrees from the sun. The unpolarized light of the sun's rays is linearly polarized by scattering of molecules at an angle of 90 degrees from the sun to observer reference line. Molecular scattering causes the diffuse clear sky light to be linearly polarized in the direction perpendicular to the propagating light and is illustrated in Figure 2 [5].

Since the multiple scattering, and the resulting depolarization, increases with a rise in aerosol and particulate content the resulting depolarization is a measure of aerosol and particulate density. Two dichroic polarizer films have been be used to measure relative intensities, oriented perpendicular to each other in the plane perpendicular to the sun's rays. Therefore, if the sky is clear of aerosol and particulate scattering, there will be strong polarization and a large difference in the relative intensities; otherwise, the intensities will be similar, which would indicate the degree of depolarization due to non-molecular scattering. The altitude dependence of the atmospheric aerosols and particulates is determined by measuring the intensity from horizon to horizon in the plane perpendicular to the rays of the sun.

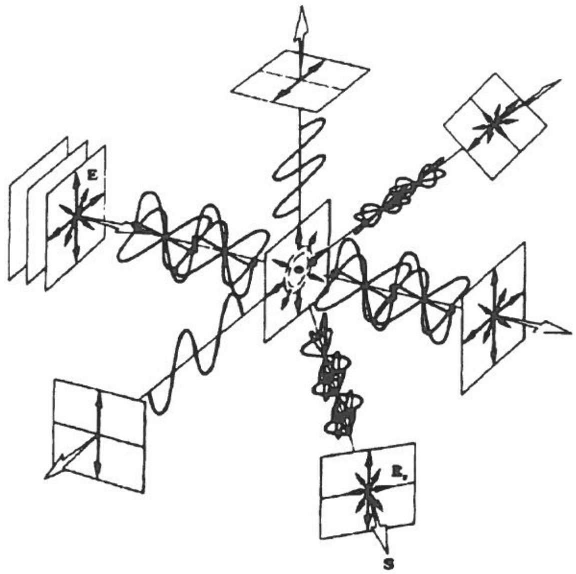

Figure 2. Scattering of unpolarized light by a molecule.

TECHNICAL ASPECTS OF THE *MULTI-WAVELENGTH POLARIMETER*

The *Multi-wavelength Polarimeter* is a device that monitors the Earth's atmospheric optical properties. It gathers data on the ozone layer depletion by measuring the intensities of multiple wavelengths of UV radiation and data on aerosol content by measuring the level of depolarization of light due to multiple scattering effects. There are four main components of the device that provide the necessary functions that are needed to track the sun, collect the data, and then store the data. The block diagram below labeled as Figure 3, illustrates the *Multi-wavelength Polarimeter*'s main components: the detector unit, a drive system, a microprocessor controlled data acquisition circuit, and a data storage computer [6].

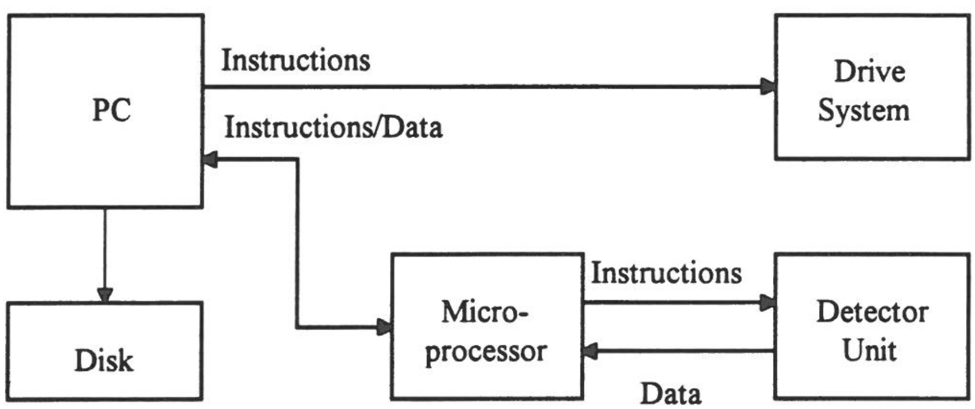

Figure 3. System diagram of the Multi-wavelength Polarimeter

Detector Unit

The *Multi-wavelength Polarimeter* consists of a bank of six detector tubes and a quadrant detector tube. There are four detector tubes devoted to measure levels of four different wavelengths of UV radiation, two detector tubes are fitted with dichroic polarized screens to measure the intensity of polarized light, and one detector tube with a quadrant detector is used to track the sun. These three different types of detector tubes will be explained in the following sections. Figure 4 shows the arrangement of the detection unit.

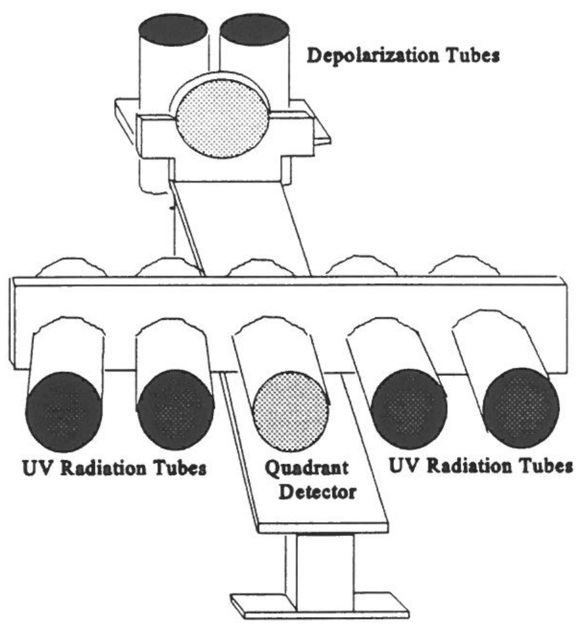

Figure 4. Detection Unit Arrangement on Mounting Bracket.

UV Radiation Flux Detection Tube

There are four UV radiation flux detection tubes as mentioned above that measure solar radiation intensities. With the use of narrow band optical filters, the desired wavelengths of UV radiation can be passed through the tubes to the photo detectors located at the ends of the tubes to measure the relative intensities. Figure 5 depicts the layout of the UV radiation tubes.

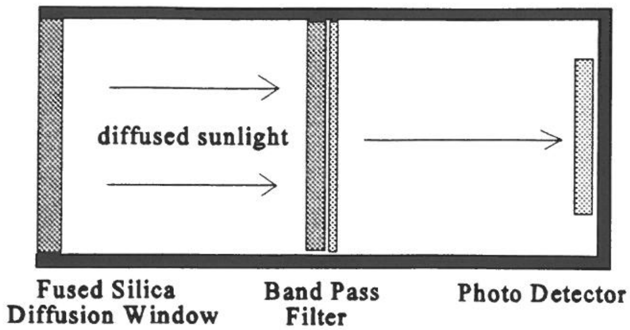

Figure 5. UV Radiation Detector Tube.

The fused silica window is finely ground to produce a surface to diffuse the incoming light from the sun. The narrow band optical filter is used to pass only the desired wavelength of light. Table 1 lists the center wavelengths and passbands of the four filters.

Table 1. Center wavelengths and passbands of the optical filters

Center	Passband
300.7 nm	10.3 nm
351.2 nm	10.6 nm
400 nm	10 nm
545 nm	9 nm

Finally, located at the end of the tube is a photo detector and amplifies circuit used to measure the intensity remaining in the pass band. The center wavelengths that the band pass filters allow through are shown in Figure 6. From the figure, the wavelength of 300 nm was chosen to indicate the cut-off of UVB radiation that ozone should block, wavelengths of 350 nm and 400 nm were chosen to indicate the lower and upper ranges of UVA radiation, and finally the wavelength of 550 nm was chosen to represent a controlled reference at mid-visible light near the peak of the solar spectrum.

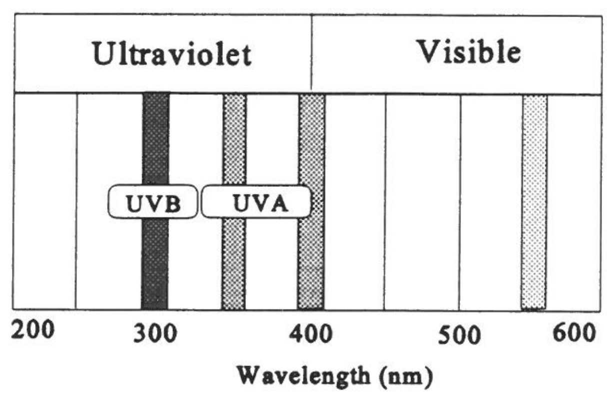

Figure 6. Approximate location and bandwidth of the wavelengths monitored by the detectors as indicated by shaded regions.

The solar radiation detectors are mounted on a bracket system attached to the drive system in a manner that aligns them directly at the sun. Manufacturer information concerning the photo detectors and the actual response curves of the pass band filters can be found in Appendix B.

Depolarization Detector Tube

There are two depolarization detector tubes that are used to measure the intensity of sunlight at a scattering angle perpendicular to the sun-observer reference line. These two tubes are constructed with two polarized filters and the photo detectors used in the UV detector tubes. Figure 7 shows a diagram of the depolarization detector tube.

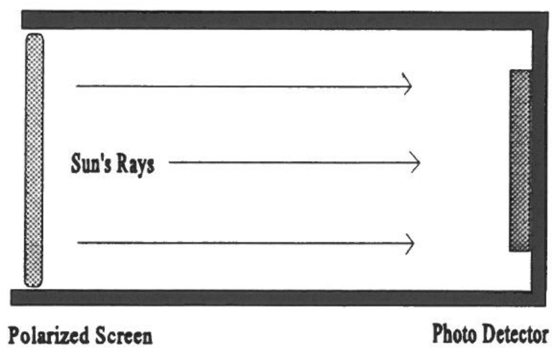

Figure 7. Depolarization detector tube diagram.

The depolarization detectors are mounted on a stepper motor axis oriented perpendicularly to the rack of UV radiation detector tubes. The stepper motor rotates the axis of the tubes from horizon to horizon in the plane 90 degrees to the sun's ray in order to quantify the altitude dependence of depolarization.

Quadrant Detector Tube

Solar tracking and position information of the device is determined by the quadrant detector that is mounted exactly in the center of the array of detection tubes mounted on the drive system. The illustration of the quadrant detector tube is shown in the Figure 8. A focal length of 100 mm was chosen so that the image of the solar disk would have a diameter size of 2 mm on the 9.65 mm quadrant detector surface [7].

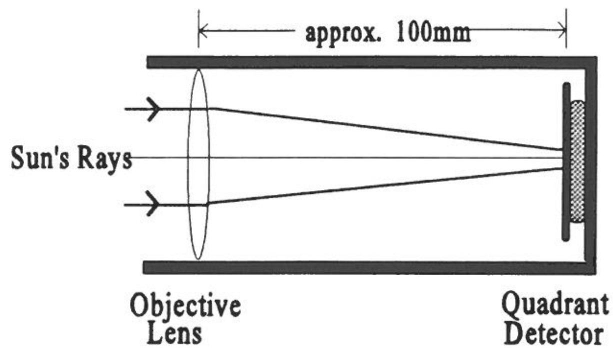

Figure 8. Diagram of Quadrant Detector Tube.

A lens focuses the incoming sunlight into an intense tight solar disk on the quadrant detector's sensitive surface. With periodic readings of the data from the quadrant detector, corrections can be made to guarantee that the *Multi-wavelength Polarimeter* is tracking the motion of the sun. Figure 9 shows the sensitive silicon surface of the quadrant detector.

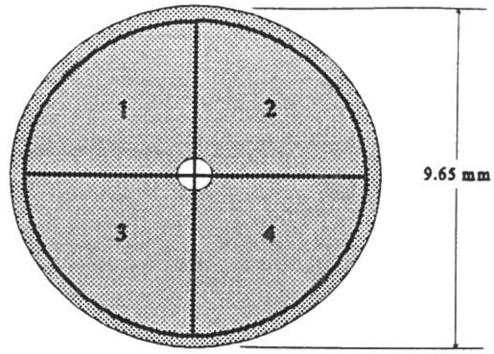

Figure 9. Quadrant detector surface with the solar disk image focused to the center of the detector.

When the image of the solar disk is centered equally among the four sections of the detector, as seen in the figure above, equal voltages are measured from each quadrant indicating correct alignment with the sun. As soon as the motion of the sun moves the image of the solar disk away from the center of the detector, the unbalanced signal from the quadrant detector instructs the device to adjust its position accordingly to recenter the solar image.

In the event that the sun's rays are blocked by cloud cover and the voltage magnitude of the quadrant detector falls below a set threshold, the *Multi-wavelength Polarimeter* will use the "equation of time" to guide the detection tube mounts. With the use of several equations to calculate the coordinates of the sun using the time, date, and observer's location it is possible to track the position of the sun. For the purpose of this document, a description of how the equation of time is used should be all that is necessary. A comprehensive discussion of the equation of time are available (see for example in reference [7]).

A subroutine, nested within the main program, coordinates the operation of the *Multi-*

wavelength Polarimeter, calculates the Right Ascension and Declination of the sun for the day in question. This information is sent to the drive system, a dual axis motor driven telescope, which automatically determines the horizon coordinates of the sun from the time of day. Therefore, as long as the sun is covered by existing weather conditions, the tubes should still be aligned to the approximate location of the sun with the use of the equation of time and the telescope drive system. Once the sun's rays are again "seen" by the *Multi-wavelength Polarimeter,* control of tracking the sun is returned to the quadrant detector.

Drive System

The *Multi-wavelength Polarimeter* uses a Meade 10" LX200 computer operated telescope as its drive system in moving its detector tubes toward the sun. The LX200 possess a heavy duty mount with four-speed altitude-azimuth axis drives that provide precision tracking and stability. The telescope possesses sophisticated capabilities because of its powerful electronic controller: a 16MHz 68000 microprocessor with 64K bytes of program memory, 16K bytes of RAM, and 512K bytes of non-volatile memory in EEPROM [8]. With such characteristics, the telescope was chosen to be the drive system of the *Multi-wavelength Polarimeter* because of its ability to cover every possible contingency of telescope positioning. We make use of its ability to calculate altitude and azimuth coordinates given right ascension and declination.

The control of the telescope is achieved remotely by the PC via RS-232 serial communications. Instructions for telescope motion and the setting of right ascension and declination for the telescope are sent by the computer after it accesses either information on the sun's position or an alignment signal from the quadrant detector. When the *Multi-wavelength*

Polarimeter cannot track the sun with the quadrant detector and must use the equation of time to rack solar position, the telescope moves autonomously with altitude and azimuth coordinates updated by its own microprocessor every few seconds. Otherwise, the telescope is directly under the control of the PC and no other component of the device.

The detector unit is mounted on the top of the telescope by a mounting bracket designed for easy installation and removal without affecting the calibration of the telescope or the detection tubes. This allows the telescope to be free to perform other functions, such as being fitted with a solar filter and charged coupled device (CCD) camera for solar observation while the *Multi-wavelength Polarimeter* operates. Furthermore, the telescope can be used at night for astromonical purposes while the *Multi-wavelength Polarimeter* is not in operation. Technical information and specifications about the Meade LX200 telescope is listed in Appendix B.

Data Acquisition Interface Circuit

The data acquisition interface circuit, encased in a metal "black box", is the heart of the *Multi-wavelength Polarimeter* and is supervised by a Motorola MC64HC11EVB microcontroller board. The data accession interface circuit consists of amplifiers and multiplexers which allow each detection tube's data to be converted from analog to digital form and sent to the PC for storage on disk. Thus the component allows the PC to interface with the detectors to store the data retrieved from it. There are two boards that accomplish the task of conditioning and converting signals from the detector tubes to readable forms for the PC. All incoming data lines from each of the detector tubes are connected to the interface board, where the analog photo detector voltages are multiplexed to the desired amplifier gain value so that the voltage is between 0 and

5 volts required for the A/D port of the microprocessor [9]. When the PC sends the instruction to retrieve data from the detector tubes, it relays the instruction to the second board. The microprocessor is the interface between the PC and detector unit. The microprocessor interprets the instruction and reads the data from its A/D port and sends it back to the PC. The voltage of the detectors are applied to an LF1306 digitally programmable gain set, which selects the appropriate gain so that it is readable to the A/D port of the microprocessor. Appendix B contains the schematics of the circuit.

Microprocessor

The *Multi-wavelength Polarimeter* uses a Motorola MC68HC11EVB microcontroller board to control the data acquisition interface circuit, stepper motor, transmission of data to the PC, and retrieval of instructions from the PC. The microprocessor communicates with the PC via RS-232 serial communication through its P2 Terminal Port Connector. The microprocessor holds two EPROM chips, one contains code that outlines the basic operation that is expected of the microprocessor and the other contains code to translate the coded firmware (Basic 11) to machine language. Listed in Appendix A is the firmware code (Basic 11) burned onto an EPROM chip. Found in Appendix B are details covering I/O connections, serial communication connections, and block diagrams of the MC68HC11EVB.

Stepper Motor Circuit

Located with the metal case containing the data acquisition interface circuit, microcontroller, and their power supplies is the stepper motor circuit. This circuit uses a common unipolar stepper motor with four step sequence and a 7.5 degree step angle. The stepper motor circuit utilizes optical isolation to prevent potential damage to its control circuit. Operation of the motor is managed by sending binary signals to four stepper coils within the motor. Table 2 illustrates the sequence of the binary signals needed to step the motor forward. To step the motor in reverse, the binary signals sent to the stepper coils are applied in reverse order. The stepper motor driver circuit was adapted from reference [6]. Further technical data can be found in Appendix B.

Table 2. Stepper motor step sequence for forward motion.

	Coil Number				
	1	2	3	4	
Step					Decimal Value
1	1	0	1	0	10
2	1	0	0	1	9
3	0	1	0	1	5
4	0	1	1	0	6

Computer

The personal computer is the last integral component of the *Multi-wavelength Polarimeter.* The computer that is used is an IBM compatible 386 machine. The PC is used for supervising system operation consisting of managing data collection, storage and display, as well as controlling the drive system. The PC runs a MS-DOS QBasic program, SUN.BAS which begins the operation of the *Multi-wavelength Polarimeter* and stores the data as strings in the file DATA.DAT. Listing of the Basic code is found in Appendix A. The format of the data string is as follows in Table 3.

Table 3. Sample of data to show its format.

```
07-31-1994,14:32:44,0,0,34,1,28,2,130,3,8,4,7,5,0,6,0,7,0!
07-31-1994,14:32:54,8,0,31,1,9,2,120,3,2,4,0,5,0,6,0,7,0!
07-31-1994,14:33:12,16,0,33,1,21,2,126,3,3,4,0,5,0,6,0,7,0!
07-31-1994,14:33:18,24,0,39,1,10,2,133,3,1,4,0,5,0,6,0,7,0!
07-31-1994,14:33:27,32,0,39,1,24,2,126,3,8,4,0,5,0,6,0,7,0!
07-31-1994,14:33:39,40,0,63,1,29,2,120,3,0,4,0,5,0,6,0,7,0!
```

As illustrated in Table 3 the format consists of a date and time group, current stepper motor angle, detector 0, digital voltage value of detector 0, detector 1, its digital voltage value, ..., detector 7, its digital voltage value, and the end of the string is demarcated with an exclamation point.

SYSTEM OPERATION

The operation of the *Multi-wavelength Polarimeter* is based on a hierarchical structure of the PC-microprocessor system described in the previous sections. Through RS-232 serial communications between the PC and microprocessor , the *Multi-wavelength Polarimeter* will measure and store four different wavelengths of UV radiation intensities and level of depolarized light by continuously tracking the sun. The main program controlling the operation of the device is executed by the PC and its instructions are communicated through a menu format to the microprocessor. For example, if the program called for reading data from the detector tubes, the instruction sent out from the program would be a number signifying what subroutine the microprocessor should perform from its menu option. The menu options are coded and burned in an EPROM placed on the microcontroller board. The microprocessor waits for a menu selection from the PC and performs it when the PC sends an instruction. The system outline which links the PC and microprocessor and supervises the device's operation is given below in Figure 10 and Figure 11.

1. Initialization:
   a. establish data storage disk drive
   b. establish timer period
   c. find position of sun

2. Wait until timer, when timer on go to 3

3. Get data:
   a. measure and store UV radiation flux at 4 specified wavelengths
   b. measure and store depolarization values
   c. record stepper angle

4. Correct position of detector unit based on quadrant detector values then go to 6, else if readings are too low because of cloud cover then goto 5

5. Use Equation of Time to track position of sun

6. Move stepper motor in appropriate direction one step

7. Check if any error in status of program execution:
   a. Yes, then go to 1
   b. No, then go to 8

8. Check if "Q" is entered on keyboard of PC
   a. No, then go to 2
   b. Yes, then END program

Figure 10. Outline of PC program operation for SUN.BAS program.

0. Initialization:
   a. define ports
   b. initialize stepper vector
   c. clear stepper clear stepper flip-flops
   d. define menu options: 1,2,3
   e. send "ok" to PC after successful RS-232 connection
   f. wait for PC instruction: 1, 2, or 3
   g. anytime error arises in communication send command to PC to reinitialize

1. Move stepper motor:
   a. forward or backward
   b. return to menu and wait

2. Read intensities from detector tubes:
   a. apply gain
   b. read data
   c. send to PC
   d. return to menu and wait

3. Read quadrant detector:
   a. read data
   b. send to PC
   c. return to menu and wait

Figure 11. Outline of microprocessor operation.

From the outlines in Figures 10 and 11, it must be noted that the *Multi-wavelength Polarimeter* will operate autonomously once the device is turned on and PC program executed. At dusk, the operator of the *Multi-wavelength Polarimeter* would then shut down the system and remove the data disk for analysis. In Appendix C, documentation of setup procedure and shutdown is provide for operators of the apparatus.

Future Work

A working program and functional *Multi-wavelength Polarimeter* has been constructed. Nevertheless, improvements and modifications are never far from the horizon. A list of possible and perhaps needed future work on hardware and software is described below.

Hardware:

1. Position circuitry for the stepper motor needs to be implemented. Presently, the depolarization tubes do not possess the hardware to locate and know its position relative to the device. The operator must currently by hand, position the tubes on the 0 degree mark on the horizon before power is turned on and operation started. The program then "knows" the tubes position only through the software's angle increments. Opto-electronic switches could be added on the 0 and 180 degree location on the horizon to tell the device when each position is reached and home position is found.

2. More detector tubes can be made. Presently, two additional unused input ports are available on the *Multi-wavelength Polarimeter*. Therefore, through the removal of the grounded signal lines of detector number 6 and 7 on the data acquisition interface circuit, the device can now measure two new wavelengths of UV radiation.

3. Weatherproofing the system might be a future option that deserves research. Presently, the device must be removed from its station as the signs of inclement weather approach. During rain and snow, the device must be shut down and stored in safe condition otherwise damage to the system is inevitable. The benefits of weatherproofing the system is that it would then be possible to use the device during the winter and spring months of the year when there would be snow or precipitation on the ground.

Software:

1. With the addition of stepper motor switches, changes in the initialization subroutine must be made. The routine must then be able to locate the home position of the stepper motor and move it there before operation begins.

2. Gain selection is another subroutine that needs to written. From an examination of the present firmware there seems to be a slight discrepancy in being able to select an optimal gain for each tube reading. Either a complex subroutine must be written in which multiple readings must be taken of the each tube before the optimal gain can be found and applied to the different tubes, or the firmware burned on the EPROM must be changed.

3. Graphic displays can be implemented so that real-time analysis can be accomplished. Presently, the data is stored on disk and must be post processed. A subroutine for the real-time graphics can be implemented by storing the detector values in an array and plotting the readings versus time updating with every new reading.

4. Write a subroutine to convert the digital voltage readings of the detectors to the number of photons during a period of time. By converting the present readings, the operator would have a better sense of what they would mean.

5. Many opportunities exist for improvements of software options and additions. Software for data processing, graphics, error-checking, and file storage are all desirable, and possible, to make the *Multi-wavelength Polarimeter* a more powerful and easier to use system.

CONCLUSION

The *Mutli-wavelength Polarimeter* is a conceptually simple device with great potential in accomplishing serious, long baseline research to measure variations in UV radiation flux at the Earth's surface and atmospheric aerosol content. Ozone depletion and parameters related to the greenhouse effect can be monitored and studies can be made in the phenomenon with this apparatus. The *Multi-wavelength Polarimeter* consists of four major components: a detector unit with four UV radiation flux tubes, two depolarization tubes, and one quadrant detector; a drive system which is a Meade LX200 computer aided four speed two axis telescope; a data acquisition interface circuit which is the heart of the device's operation in sending and receiving data and instructions to the rest of the system; and finally the PC computer which stores the data and runs the main executive program supervising the system. It is expected that the data collected by the *Multi-wavelength Polarimeter* will shed insight in the role of how aerosols interact in the greenhouse effect and allow an effective and simple method of measuring the UV flux hazard at the Earth's surface.

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'
'
'   This program performs three functions:
'
' 1. Instructs the MC68HC11 microprocessor in one of its four functions
'
'   a. Instruction 0-
'   return the string "go". To initialize, send "0"
'   until the string "go" is received. This procedure
'   will ensure that the microprocessor is waiting at
'   the top of its menu system.
'   b. Instruction 1-
'   step the motor one step. When instruction 1 is issued,
'   the microprocessor will query the PC. To step forward,
'   send the sub-instruction 1, or send sub-instruction 2
'   to step backward.
'   c. Instruction 2-
'   read the intensity detectors and the depolarization
'   detectors. When using this instruction, the micro-
'   processor will query the PC. The PC should then send
'   the gain desired and read the resulting voltages.
'   d. Instruction 3-
'   read the quadrant detector voltages. When using this
'   instruction, the microprocessor will query the PC.
'   The PC should send the gain desired and read the
'   resulting voltages.
'
' 2. Writes the intensity and deplorization detector voltages, the date and
'   the time group, and the stepper angle as reported by the microprocessor
'   to the file data.dat .
'
' 3. Plots the data in a time series (this function is not installed yet at
'   this time.
'
' System Operation:
'
' The program waits in a loop until the timer interrupts. Then, the program
' jumps to the subroutine GetData which performs the data recording.
'
' Important Notes:
'
' 1. Communication between processors is accomplished by opening and closing

```
' files.  If the communications subroutines are modified,  keep in mind
' that the file must be opened and closed every time communication is estab-
' lished.  This is necessary to keep the stack (PC's) from overflowing.
'
' 2. The string "go" and "nogo" are used to indicate proper operation and
' improper operation repesctively.  Therefore, additional subroutines should
' check for the string "nogo" when ever receiving data from the microprocessor
' If the string "nogo" is received,  then the system should be reinitialized
' This procedure is necessary in the event of that the RS-232 signal is
' corrupted by interference.
'
' 3. The timer subroutine should not be set for less than seven seconds. Any
' values less than this will cause communication errors.
'
' 4. The subroutine names have been written such that their function is
' obvious.  This is true for variable names as well.
'
' 5. Subroutines marked with "2" at the end of the names signify code that
' needs to be used when the new,  fully operational quadrant detector is in
' place.
'
'
' Gregory A. Babich                          EE 494H
' Started:      13 AUG 92                     PSU
' Last revision: 18 APR 93
'
' Janson Wu                                EE 494H
' Additional Code                           PSU
' and Revision   : 02 JUN 94
'

DECLARE SUB WriteDataToDisk (Disk$, FileName$, data$)
DECLARE SUB StepperAngle (LastAngle%, NewAngle%)
DECLARE SUB Initialize (Disk$, OutputFileName$, data$, LastAngle%, angle%, ok%)
DECLARE SUB WriteOutput (Disk$, OutputFileName$, data$, angle%)
DECLARE SUB ReadSerialPort (data$, ok%)
DECLARE SUB Strip (data$)
DECLARE SUB SendSerialPort (TransmitData%)

DECLARE SUB QuadReadTeleMove ()
DECLARE SUB QuadReadTele2 ()
DECLARE SUB Delay ()
```

```
DECLARE SUB NewDay (alpha$, declination$)
DECLARE SUB Telemetry (TimeCount&, alpha&, declination#, Altitude&, Azimuth&)
DECLARE SUB MoveTelescope (direction%)
DECLARE SUB MoveTelescope2 (direction%)
DECLARE FUNCTION YearDays% ()
DECLARE FUNCTION DayValue% ()
DECLARE FUNCTION ArcSin# (declination#)
DECLARE FUNCTION ArcCos# (declination#)


'Start Operations.

CLEAR
CALL Initialize(Disk$, OutputFileName$, data$, LastAngle%, angle%, ok%)

ON TIMER(15) GOSUB GetData
TIMER ON
DO
' If the string nogo is recieved,  assume error in communications and reinitialize
IF ok% = 0 THEN CALL Initialize(Disk$, OutputFileName$, data$, LastAngle%, angle%,
ok%)

' Enter "Q" to stop the program
IF UCASE$(INKEY$) = "Q" THEN SYSTEM
LOOP
END
```

```
'
' This routine is the heart of the operation.  On the timer interval as
'established in the main program,  this routine is executed.  Currently this
'routine is not finished.  There are several variables which are constants.
'These are for demonstration and debugging.  They should be removed and
'replaced by subroutines.  Comments indicate which variables to be removed.
'

GetData:

IF ok% = 1 THEN
30     instruction% = 2          'Replace when subroutine is developed.
     CALL SendSerialPort(instruction%)
     Gain% = 56                  'Replace with subroutine that chooses gain.
     CALL SendSerialPort(Gain%)
     CALL Delay
     CALL ReadSerialPort(data$, ok%)
     IF ok% <> "1" THEN GOTO 30

     IF ok% = 1 THEN
          CALL WriteOutput(Disk$, OutputFileName$, data$, angle%)
          PRINT data$                'This is for demonstration only.
          LastAngle% = angle%
     END IF

     CALL StepperAngle(LastAngle%, angle%)
     CALL QuadReadTeleMove
END IF
RETURN
```

```
'
' This function is used in computing the RA and Dec of the sun from the equation of time.
'
FUNCTION ArcCos# (declination#)


CONST pi = 3.14592653#

IF ABS(declination#) <> 1 THEN
temp = (pi / 2) - ATN(declination# / SQR(1 - (declination# * declination#)))
ELSEIF declination = -1 THEN
temp = 180
ELSEIF declination# = 1 THEN
temp = 0
END IF
ArcCos# = temp

END FUNCTION
```

```
'
' This function is used in computing the RA and Dec of the sun from the equation of time.
'
FUNCTION ArcSin# (declination#)


CONST pi = 3.141592653#

IF ABS(declination#) <> 1 THEN
temp = ATN(declination# / (SQR(1 - declination# * declination#)))
temp = temp * 180 / pi
ELSEIF declination# = -1 THEN
temp = 270
END IF
ArcSin# = temp

END FUNCTION
```

```
'
'  This function computes the number of days for Jan 1, 1975 to the present
'

FUNCTION DayValue%

'local variable definitions:

DIM DAYS AS INTEGER
DIM YEAR AS INTEGER
DIM i AS INTEGER

DAYS = 0
YEAR = VAL(MID$(DATE$, 9, 2))

FOR i = 75 TO (YEAR - 1)
   IF (i MOD 4) = 0 THEN DAYS = DAYS + 1
   DAYS = DAYS + 365
NEXT i

DayValue% = DAYS + YearDays%

END FUNCTION
```

```
'
' This subroutine moves the telescope in the direction given by the quadrant detector
'readings. This particular version of this code is for the defective quadrant detector which
'has only 3 out of the 4 quadrants active. When new quad. detectors comes in, replace this
'code with MoveTelescope2 (direction%).
'
SUB MoveTelescope (direction%)

OPEN "com2:9600,n,8,1,cd0,cs0,ds0,rs," FOR RANDOM AS #1
a$ = "#:RM#": PRINT #1, a$
IF direction% = 0 THEN GOTO 1

IF direction% = 1 THEN
    a$ = "#:Mn#": PRINT #1, a$
    FOR X = 1 TO 5000
    NEXT X
    b$ = "#:Qn#": PRINT #1, b$
    a$ = "#:Mw#": PRINT #1, a$
    FOR X = 1 TO 5000
    NEXT X
    b$ = "#:Qw#": PRINT #1, b$
END IF

IF direction% = 2 THEN
    a$ = "#:Mw#": PRINT #1, a$
    FOR X = 1 TO 5000
    NEXT X
    b$ = "#:Qw#": PRINT #1, b$
END IF

IF direction% = 3 THEN
    a$ = "#:Ms#": PRINT #1, a$
    FOR X = 1 TO 5000
    NEXT X
    b$ = "#:Qs#": PRINT #1, b$
    a$ = "#:Mw#": PRINT #1, a$
    FOR X = 1 TO 5000
    NEXT X
    b$ = "#:Qw#": PRINT #1, b$
END IF


IF direction% = 4 THEN
```

```
        a$ = "#:Ms#": PRINT #1, a$
        FOR X = 1 TO 5000
        NEXT X
        b$ = "#:Qs#": PRINT #1, b$
END IF

IF direction% = 5 THEN
        a$ = "#:Mn#": PRINT #1, a$
        FOR X = 1 TO 5000
        NEXT X
        b$ = "#:Qn#": PRINT #1, b$
END IF

IF direction% = 6 THEN
        a$ = "#:Mn#": PRINT #1, a$
        FOR X = 1 TO 5000
        NEXT X
        b$ = "#:Qn#": PRINT #1, b$
        a$ = "#:Me#": PRINT #1, a$
        FOR X = 1 TO 5000
        NEXT X
        b$ = "#:Qe#": PRINT #1, b$
END IF

IF direction% = 7 THEN
        a$ = "#:Me#": PRINT #1, a$
        FOR X = 1 TO 5000
        NEXT X
        b$ = "#:Qe#": PRINT #1, b$
END IF

IF direction% = 8 THEN
        a$ = "#:Ms#": PRINT #1, a$
        FOR X = 1 TO 5000
        NEXT X
        b$ = "#:Qs#": PRINT #1, b$
        a$ = "#:Me#": PRINT #1, a$
        FOR X = 1 TO 5000
        NEXT X
        b$ = "#:Qe#": PRINT #1, b$
END IF
1 'return because no change needed.
END SUB
```

```
'
' This subroutine calculates the Right Ascension and Declination for the day
' that just begun. Ascension (Alpha&)is returned in seconds,  while Declin-
' ation (Declination#) is returned is decimal degrees.
'

SUB NewDay (alpha$, declination$)

'local constant and variable definitions:

CONST Eg# = 4.870192401#          'Ecliptic Longitude {in radians}
CONST Wg# = 4.930736581#          'Ecliptic Longitude of perigree {rads}
CONST Beta# = 0                   'Ecliptic Latitude of Sun
CONST Epsi# = .40898821#          'Obliquity of the elliptic
CONST Ecc# = .1672#               'Eccentricity of Earth-Sun orbit
CONST pi = 3.141592653#
DIM DAYNUM AS DOUBLE
DIM temp AS DOUBLE
DIM M AS DOUBLE
DIM X AS DOUBLE
DIM DELT AS DOUBLE
DIM DELX AS DOUBLE
DIM ETA AS DOUBLE
DIM LAM AS DOUBLE
DIM DELTA1 AS DOUBLE
DIM DASCN AS DOUBLE
DIM Q AS INTEGER


'Subroutine code:

DAYNUM = CDBL(DayValue%)          'DAYNUM = number of days since Jan. 1,  1975
temp = 360 * DAYNUM / 365.25
WHILE temp > 360
    temp = temp - 360
WEND

temp = temp * pi / 180
M = temp + Eg# - Wg#
IF M < 0 THEN M = M + 2 * pi
X = M
```

```
DO
  DELT = X - (Ecc# * SIN(X)) - M
  DELX = DELT / (1 - Ecc# * COS(X))
  X = X - DELX
LOOP UNTIL ABS(DELT) < .0000017

ETA = 2 * ATN(TAN(X / 2) * SQR((1 + Ecc#) / (1 - Ecc#)))
LAM = ETA + Wg#
IF LAM > (2 * pi) THEN LAM = LAM - (2 * pi)
IF LAM < 0 THEN LAM = LAM + (2 * pi)

DELTA1 = (SIN(Beta#) * COS(Epsi#)) + (COS(Beta#) * SIN(Epsi#) * SIN(LAM))
Declin# = ArcSin#(DELTA1)
IF Declin < 0 THEN Declin# = Declin# + 360

d$ = STR$(Declin#)
de$ = LEFT$(d$, 3)
dec$ = LEFT$(d$, 6)
decl$ = RIGHT$(dec$, 3)

y$ = LEFT$(de$, 1)
IF y$ = " " THEN
w$ = RIGHT$(de$, 2)
de$ = "+" + w$
END IF
declination$ = de$ + decl$

DASCN = ATN((TAN(LAM) * COS(Epsi#)) - (TAN(Beta#) * SIN(Epsi#) / COS(LAM)))
IF DASCN < 0 THEN DASCN = DASCN + (2 * pi)
DASCN = (DASCN * 180 / pi)

IF LAM < (2 * pi) THEN Q = 4
IF LAM < (1.5 * pi) THEN Q = 3
IF LAM < pi THEN Q = 2
IF LAM < pi / 2 THEN Q = 1

IF (Q = 1) AND (DASCN > 270) THEN DASCN = DASCN - 270
IF (Q = 2) AND (DASCN > 270) THEN DASCN = DASCN - 180
IF (Q = 2) AND (DASCN < 90) THEN DASCN = DASCN + 90
IF (Q = 3) AND (DASCN < 90) THEN DASCN = DASCN + 180
IF (Q = 3) AND (DASCN > 270) THEN DASCN = DASCN - 90
IF (Q = 4) AND (DASCN < 90) THEN DASCN = DASCN + 290
```

```
DASCN = DASCN / 15

s$ = STR$(DASCN)
s1$ = LEFT$(s$, 3)
s2$ = LEFT$(s$, 6)
s3$ = RIGHT$(s2$, 2)
s4$ = LEFT$(s$, 7)
s5$ = RIGHT$(s4$, 1)

z$ = RIGHT$(s1$, 1)
IF z$ = "." THEN
s1$ = LEFT$(s$, 2)
END IF

alpha$ = s1$ + ":" + s3$ + "." + s5$


OPEN "com1:9600,n,8,1,cd0,cs0,ds0,rs," FOR RANDOM AS #1

a$ = "#:Sr" + alpha$ + "#": PRINT #1, a$
b$ = "#:Sd " + declination$ + "#": PRINT #1, b$
CALL Delay
c$ = "#:MS#": PRINT #1, c$
PRINT a$
PRINT b$

CLOSE (1)
CALL Delay

END SUB
```

```
'
'    This subrountine reads and compares the signals from the quadrant detector to track the
'sun.  Presently,  QuadReadTeleMove is the routine that is used in the program.  When the
'new detectors arrives,  the appropiate subroutines noted by the number "2" must replace the
'existing ones.
'
SUB QuadReadTele2


50 CALL SendSerialPort(3)
   CALL SendSerialPort(4)
   CALL Delay
   CALL ReadSerialPort(data$, ok%)

IF ok% = 0 THEN
200      CALL SendSerialPort(0)
      CALL Delay
      CALL ReadSerialPort(data$, ok%)
      IF data$ <> "go" THEN 200
      ELSE IF data$ = "go" THEN GOTO 50
      END IF
END IF

'Compare the 4 quadrant voltages for unbalanced readings (data$)

LET n = LEN(data$)
X = n / 2
s$ = LEFT$(data$, X)
s1$ = LEFT$(s$, 4)
a1$ = RIGHT$(s1$, 2)

IF RIGHT$(a1$, 1) = "," THEN a1$ = LEFT$(a1$, 1)

s2$ = RIGHT$(s$, 4)
a2$ = RIGHT$(s2$, 2)
IF RIGHT$(a2$, 1) = "," THEN a2$ = LEFT$(a2$, 1)
IF LEFT$(a2$, 1) = "," THEN a2$ = RIGHT$(a2$, 1)

s$ = RIGHT$(data$, X)
s3$ = RIGHT$(s$, 9)
a3$ = RIGHT$(s3$, 2)

IF LEFT$(a3$, 1) = "," THEN a3$ = RIGHT$(s3$, 1)
```

```
s4$ = RIGHT$(data$, 4)
a4$ = RIGHT$(s4$, 3)
IF LEFT$(a4$, 1) = "," THEN a4$ = RIGHT$(s4$, 2)


q1 = VAL(a1$)
q2 = VAL(a2$)
q3 = VAL(a3$)
q4 = VAL(a4$)
PRINT q1, q2, q3, q4

'If quadrant voltage is less than the allowable sunlight threshold,
'then assume there is cloud cover and call Equation of Time routine
'to calculate the approxiamte location of the sun to move the telescope.

IF q1 = q2 = q3 = q4 < 10 THEN
      CALL NewDay(alpha$, declination$)

      GOTO 10000
END IF

'If voltages are unbalanced, then move telescope in the appropriate direction
'and compare again until the volatges are equal in all 4 quadrants.

IF q1 > q2 AND q1 > q3 AND q1 > q4 THEN
      direction% = 1
      CALL MoveTelescope2(direction%)
      GOTO 50
ELSEIF q1 > q2 AND q1 > q4 AND q1 = q3 THEN
      direction% = 2
      CALL MoveTelescope2(direction%)
      GOTO 50
ELSEIF q3 > q1 AND q3 > q2 AND q3 > q4 THEN
      direction% = 3
      CALL MoveTelescope2(direction%)
      GOTO 50
ELSEIF q3 > q1 AND q3 > q2 AND q3 = q4 THEN
      direction% = 4
      CALL MoveTelescope2(direction%)
      GOTO 50
ELSEIF q2 > q3 AND q2 > q4 AND q2 = q1 THEN
      direction% = 5
      CALL MoveTelescope2(direction%)
```

```
        GOTO 50
ELSEIF q2 > q1 AND q2 > q3 AND q2 > q4 THEN
        direction% = 6
        CALL MoveTelescope2(direction%)
        GOTO 50
ELSEIF q4 > q1 AND q4 > q3 AND q4 = q2 THEN
        direction = 7
        GOTO 50
        CALL MoveTelescope2(direction%)
ELSEIF q4 > q1 AND q4 > q2 AND q4 > q3 THEN
        direction = 8
        CALL MoveTelescope2(direction%)
        GOTO 50
END IF

IF q1 = q2 = q3 = q4 THEN
        direction% = 0
ELSE GOTO 50
END IF


10000 'go back to get data
END SUB
```

```
'
' This routine will read the quadrant detector and move the telescope accord-
' ing to the necessary direction to track the sun.  If the quadrant voltages
' are not sufficient to meet the determined sunlight threshold level,  then
' the PC will proceed to calculate the position of the sun with the Equation
' of Time algorithm.   *Replace with QuadReadTele2.*
'

SUB QuadReadTeleMove

500 CALL SendSerialPort(3)
    CALL SendSerialPort(4)
    CALL Delay
    CALL ReadSerialPort(data$, ok%)

IF ok% = 0 THEN
20      CALL SendSerialPort(0)
        CALL Delay
        CALL ReadSerialPort(data$, ok%)
        IF data$ <> "go" THEN 20
        ELSE IF data$ = "go" THEN GOTO 500
        END IF
END IF

'Compare the 3 quadrant voltages for unbalanced readings (data$)

LET n = LEN(data$)
X = n / 2
s$ = LEFT$(data$, X)
s1$ = LEFT$(s$, 4)
a1$ = RIGHT$(s1$, 2)
IF RIGHT$(a1$, 1) = "," THEN a1$ = LEFT$(a1$, 1)

s2$ = RIGHT$(s$, 4)
a2$ = RIGHT$(s2$, 2)
IF RIGHT$(a2$, 1) = "," THEN a2$ = LEFT$(a2$, 1)
IF LEFT$(a2$, 1) = "," THEN a2$ = RIGHT$(a2$, 1)

s$ = RIGHT$(data$, X)
s3$ = RIGHT$(s$, 9)
a3$ = RIGHT$(s3$, 2)
IF LEFT$(a3$, 1) = "," THEN a3$ = RIGHT$(s3$, 1)
```

```
q1 = VAL(a1$)
q2 = VAL(a2$)
q3 = VAL(a3$)
q4 = 0
PRINT q1, q2, q3

'If quadrant voltage is less than the allowable sunlight threshold,
'then assume there is cloud cover and call Equation of Time routine
'to calculate the approxiamte location of the sun to move the telescope.

IF q1 = q2 = q3 < 15 THEN
      CALL NewDay(alpha$, declination$)
      CALL Delay
      GOTO 1000
END IF

'If voltages are unbalanced, then move telescope in the appropriate direction
'and compare again until the volatges are equal in 3 quadrants.

IF q1 > q2 AND q1 > q3 THEN
      direction% = 1
      CALL MoveTelescope(direction%)
      GOTO 500
ELSEIF q1 > q2 AND q3 > q2 AND q1 = q3 THEN
      direction% = 2
      CALL MoveTelescope(direction%)
      GOTO 500
ELSEIF q2 < q3 AND q1 < q3 AND q1 <> q2 THEN
      direction% = 3
      CALL MoveTelescope(direction%)
      GOTO 500
ELSEIF q1 < q2 AND q2 > q3 AND q1 = q3 THEN
      direction% = 4
      CALL MoveTelescope(direction%)
      GOTO 500
ELSEIF q1 < q2 AND q2 > q3 AND q1 <> q3 THEN
      direction% = 5
      CALL MoveTelescope(direction%)
      GOTO 500
ELSEIF q1 = q2 AND q1 > q3 AND q2 > q3 THEN
      direction% = 6
      CALL MoveTelescope(direction%)
      GOTO 500
```

```
ELSEIF q1 < q3 AND q2 < q3 AND q1 = q2 THEN
       direction = 7
       CALL MoveTelescope(direction%)
       GOTO 500
END IF

IF q1 = q2 = q3 THEN
       direction% = 0
ELSE GOTO 500
END IF

1000 PRINT "go back to get data"
END SUB



'
' This subroutine is used to communicate with the microprocessor.  This
'program is used to read all output from the microprocessor.
'

SUB ReadSerialPort (data$, ok%)

data$ = ""
count% = 0
CarriageReturn$ = CHR$(26)

OPEN "com2:9600,n,8,1,ASC,CD0,CS0,DS0,OP0,RS" FOR INPUT AS #2
DO
       count% = count% + 1
       data$ = data$ + LTRIM$(RTRIM$(INPUT$(LOC(2), #2)))
       IF INSTR(data$, CarriageReturn$) THEN EXIT DO
       IF count% > 5000 THEN EXIT DO
LOOP

CLOSE (2)
IF count% > 5000 THEN
       ok% = 0
ELSE
       CALL Strip(data$)
       ok% = 1
END IF
END SUB
```

```
'
' This subroutine is used to communicate with the microprocessor.  This
'program is used to send all inputs to the microprocessor.
'

SUB SendSerialPort (TransmitData%)
OPEN "com2:9600,n,8,1,ASC,CD0,CS0,DS0,OP0,RS" FOR OUTPUT AS #2
PRINT #2, TransmitData%
CLOSE (2)

END SUB



'
' This subroutine controls the stepper motor.
'
SUB StepperAngle (LastAngle%, NewAngle%)

IF LastAngle% = 360 THEN LastAngle% = 0

IF LastAngle% < 180 THEN
      NewAngle% = LastAngle% + 7.5
      CALL SendSerialPort(1)
      CALL SendSerialPort(1)
      CALL Delay
      CALL ReadSerialPort(data$, ok%)
END IF
IF LastAngle% >= 180 THEN
      NewAngle% = LastAngle% + 7.5
      CALL SendSerialPort(2)
      CALL SendSerialPort(2)
      CALL Delay
      CALL ReadSerialPort(data$, ok%)

END IF
END SUB
```

```
'
' This subroutine is used to strip all non-printable ASCII characters from
'the microprocessors output.  This is necessary to write the data to disk in
'the most efficient manner
'

SUB Strip (data$)

predata$ = ""
length = LEN(data$)

FOR i = 1 TO length
      temp$ = MID$(data$, i, 1)
      IF ASC(temp$) = 13 OR ASC(temp$) = 26 OR ASC(temp$) = 10 OR ASC(temp$) =
63 THEN
      MID$(data$, i, 1) = ""
      ELSE
            predata$ = LTRIM$(RTRIM$(predata$ + temp$))
      END IF
NEXT i
data$ = predata$

END SUB
```

```
'
' This subroutine writes the data time group, stepper angle, and detector
'voltages to disk.
'

SUB WriteOutput (Disk$, FileName$, data$, angle%)

data$ = DATE$ + "," + TIME$ + "," + LTRIM$(STR$(angle%)) + data$
OPEN Disk$ + FileName$ FOR APPEND AS #2
PRINT #2, data$
CLOSE (2)

END SUB
```

```
'
' This function computes the number of days from the start of the present
' year.
'          Note:  January 1 is day 1.
'

FUNCTION YearDays%

'local variable definitions:

DIM i AS INTEGER
DIM MONTH AS INTEGER
DIM DAYS AS INTEGER
DIM YEAR AS INTEGER

YEAR = VAL(MID$(DATES$, 9, 2))
MONTH = VAL(MID$(DATE$, 1, 2))
DAYS = 0

FOR i = 1 TO (MONTH - 1)
 IF i = 1 THEN DAYS = DAYS + 31
 IF i = 2 THEN DAYS = DAYS + 28
 IF (i = 2) AND ((YEAR MOD 4) = 0) THEN DAYS = DAYS + 1
 IF i = 3 THEN DAYS = DAYS + 31
 IF i = 4 THEN DAYS = DAYS + 30
 IF i = 5 THEN DAYS = DAYS + 31
 IF i = 6 THEN DAYS = DAYS + 30
 IF i = 7 THEN DAYS = DAYS + 31
 IF i = 8 THEN DAYS = DAYS + 31
 IF i = 9 THEN DAYS = DAYS + 30
 IF i = 10 THEN DAYS = DAYS + 31
 IF i = 11 THEN DAYS = DAYS + 30
NEXT i
YearDays% = DAYS + VAL(MID$(DATE$, 4, 2))

END FUNCTION
```

MC64HC11EVB microprocessor firmware (BASIC 11)

```
50 DIM
60 REM ******************** PORT C AS OUTPUT
70 POKE($1007,255)
80 REM ******************** PORT A7 AS OUTPUT
90 POKE($1026,128)

100    REM ******************** INITIALIZE STEPPER VECTOR
110    X(0) = 80
120    X(1) = 72
130    X(2) = 40
140    X(3) = 48
150    L = X(0)
160    REM ******************** CLEAR STEPPER FLIP-FLOP
170    PORTA = 0
180    PORTA = 128
190    PORTA = 0

200    REM ******************** MENU
210    INPUT I
220    IF I > 4.OR.I<0 THEN 210
230    ON I+1 GOSUB 1000, 2000, 3000, 4000
240    GOTO 210
250    END

1000   REM ********************* SUB FOR INITIALIZATION
1010   GOSUB 5000
1020   PRINT "GO",  CHR$(26)
1030   RETURN

2000   REM ********************* SUB TO STEP MOTOR
2010   INPUT A
2030   IF A = 0 THEN 2050
2040   IF A = 1 THEN 2080
2050   IF A = 2 THEN 2130
2060   PRINT "NOGO", CHR$(26)
2070   GOTO 2350
2080   REM ********************* STEP FORWARD
2090   IF L = X(0) THEN 2230
2100   IF L = X(1) THEN 2260
```

```
2110  IF L = X(2) THEN 2290
2120  IF L = X(3) THEN 2200
2130  REM ********************** STEP BACKWARD
2140  IF L = X(0) THEN 2290
2150  IF L = X(1) THEN 2200
2160  IF L = X(2) THEN 2230
2170  IF L = X(3) THEN 2260
2180  REM ********************** COMMUNICATION ERROR
2190  GOTO 2050
2200  PORTA = X(0)
2210  L = X(0)
2220  GOTO 2310
2230  PORTA = X(1)
2240  L = X(1)
2250  GOTO 2310
2260   PORTA = X(2)
2270  L = X(2)
2280  GOTO 2310
2290  PORTA = X(3)
2300  L = X(3)
2310  PORTA = PORTA + 128
2320  PORTA = 0
2330  GOSUB 5000
2340  PRINT PORTA,  CHR4(26)
2350  RETURN

3000  REM ********************** SUB TO READ INTENSITY DETECTOR
3010  INPUT B
3020  GOSUB 5000
3030  IF B = 0 THEN 3100
3040  FOR I = 0 TO 7
3050      PORTB = B+1
3060      PRINT ",",I,",",ADC(1)
3070  NEXT I
3080  PRINT "!",CHR$(26)
3090  GOTO 3110
3100  PRINT "NOGO",CHR$(26)
3110  RETURN

4000  REM ********************** SUB TO READ QUADRANT DETECTOR
4010  INPUT C
4020  GOSUB 5000
4030  IF C = 0 THEN 4100
```

```
4040  FOR I = 0 TO 3
4050      PORT C= C + I
4060      PRINT ",",I,",",ADC(0)
4070  NEXT I
4080  PRINT "!", CHR$(26)
4090  GOTO 4110
4100  PRINT "NOGO", CHR$(26)
4110  RETURN

5000  REM *************************** SUB TO GENERATE DELAY
5010  FOR I = 1 TO 300
5020      X = ADC(0)
5030  NEXT J
5040  RETURN
```

APPENDIX B
Hardware

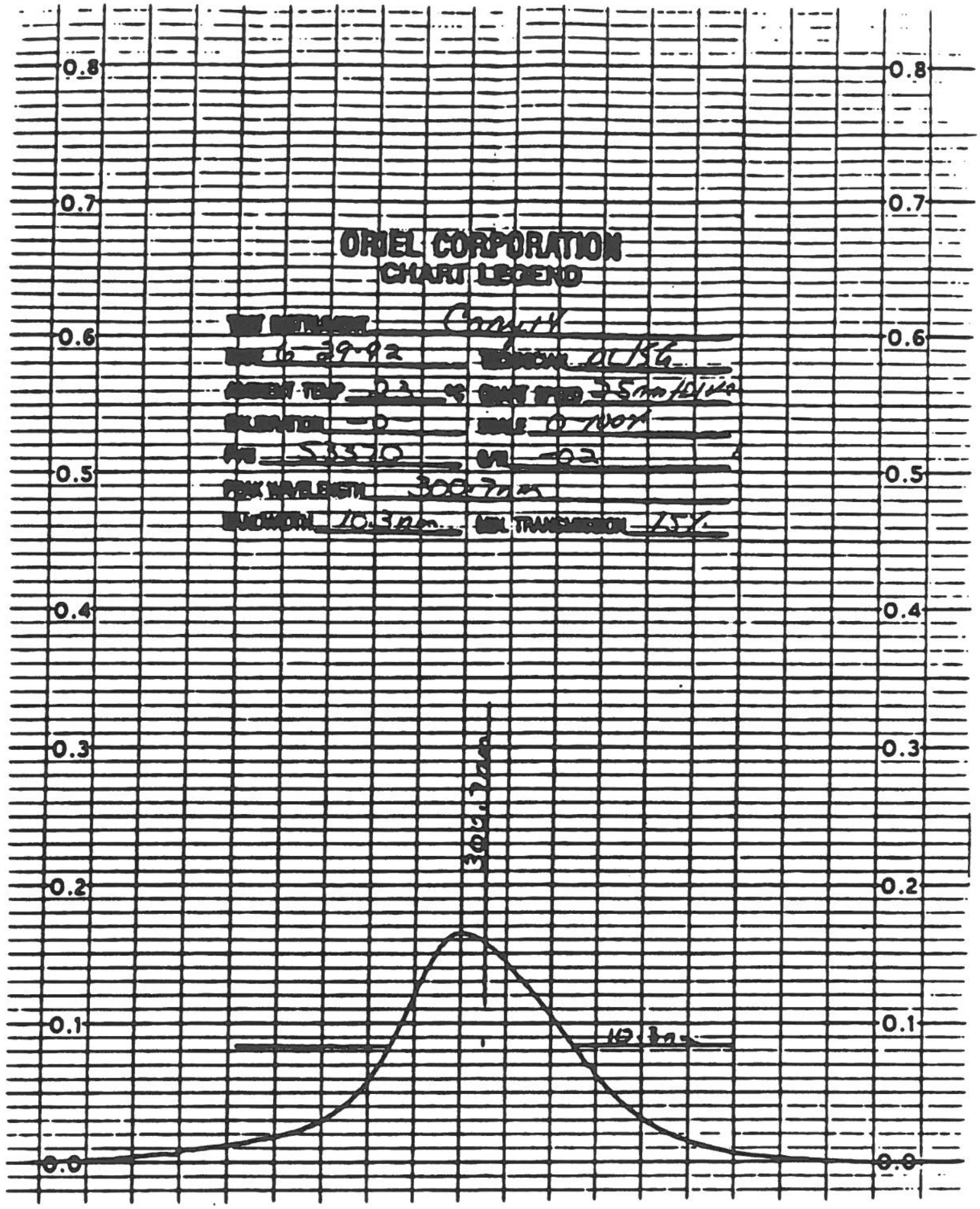


Figure B-1: Actual filter response of 300nm filter.

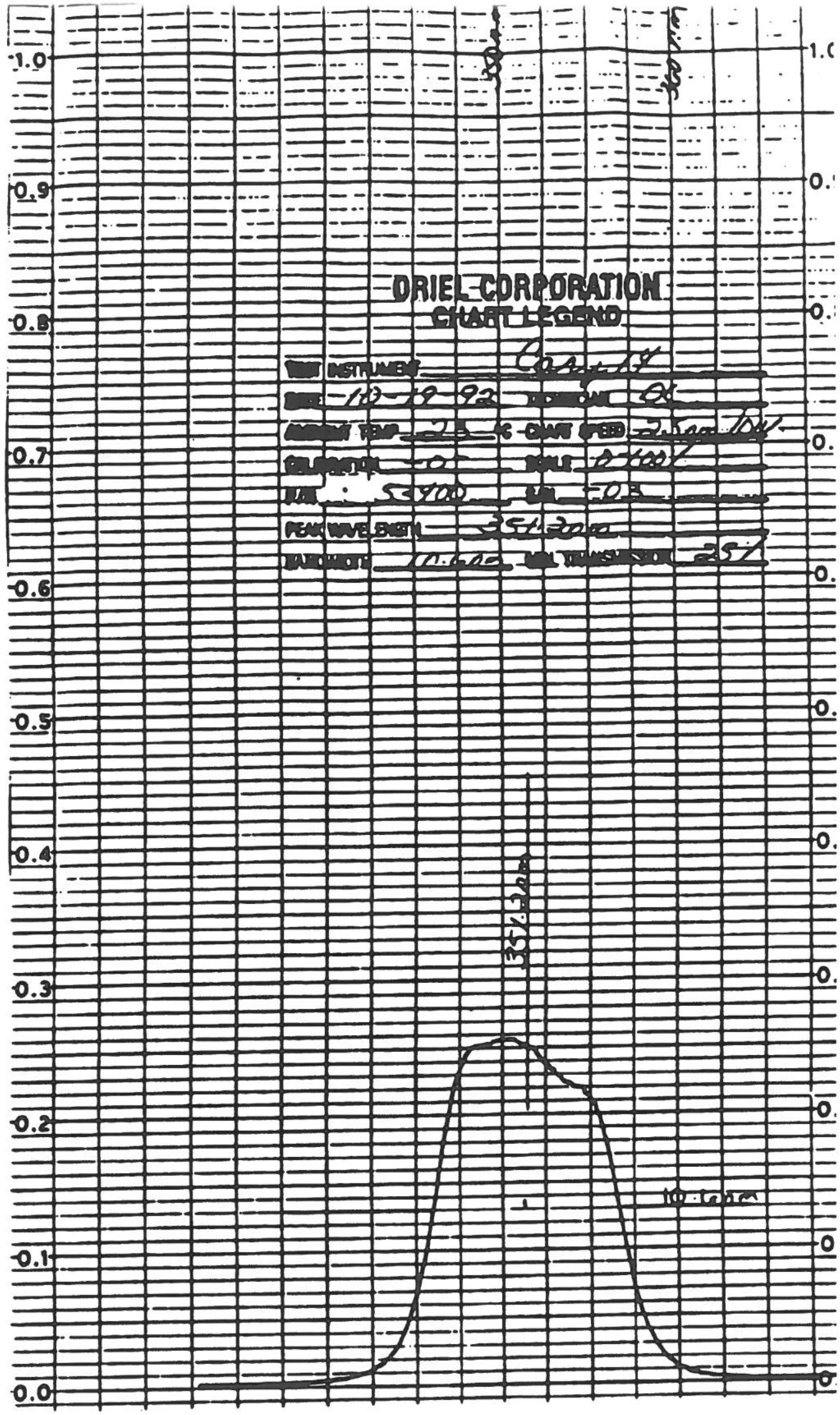


Figure B-2: Actual filter response of 350nm filter.

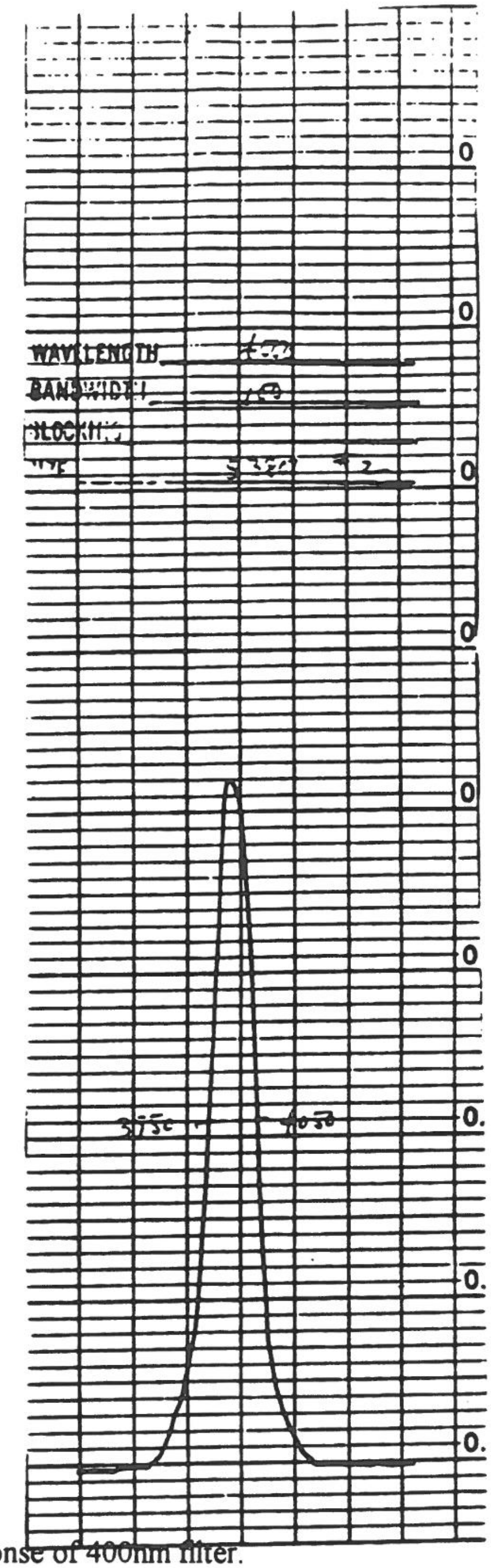


Figure B-3: Actual filter response of 400nm filter.

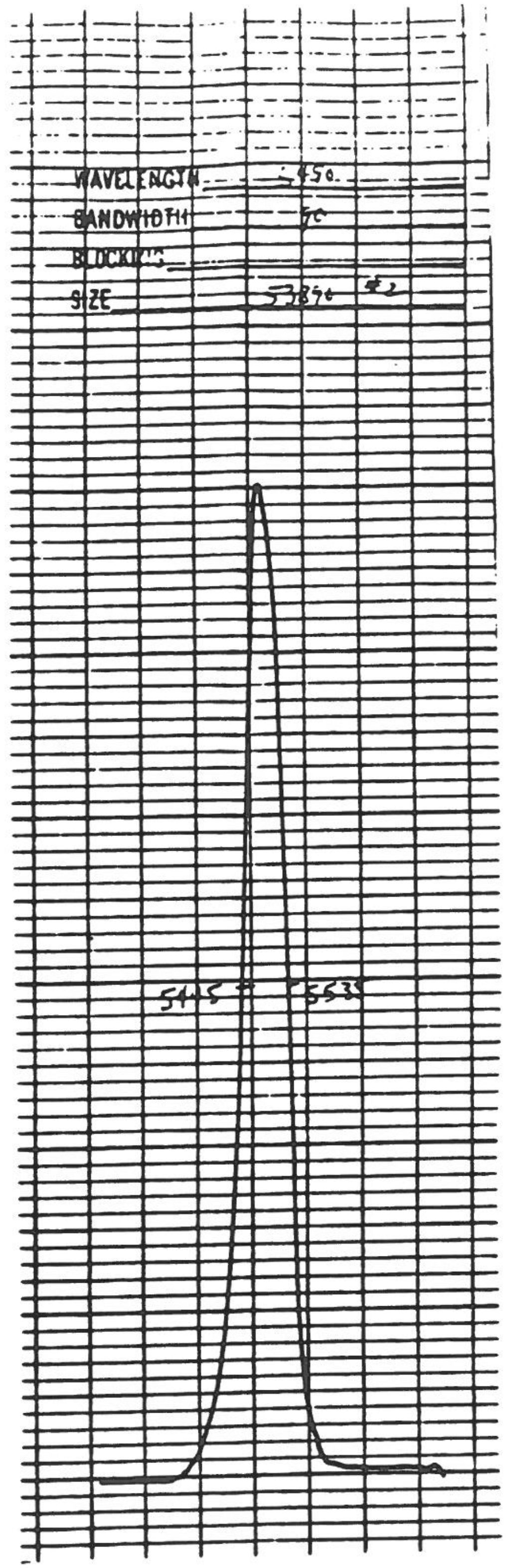


Figure B-4: Actual filter response of 550nm filter.

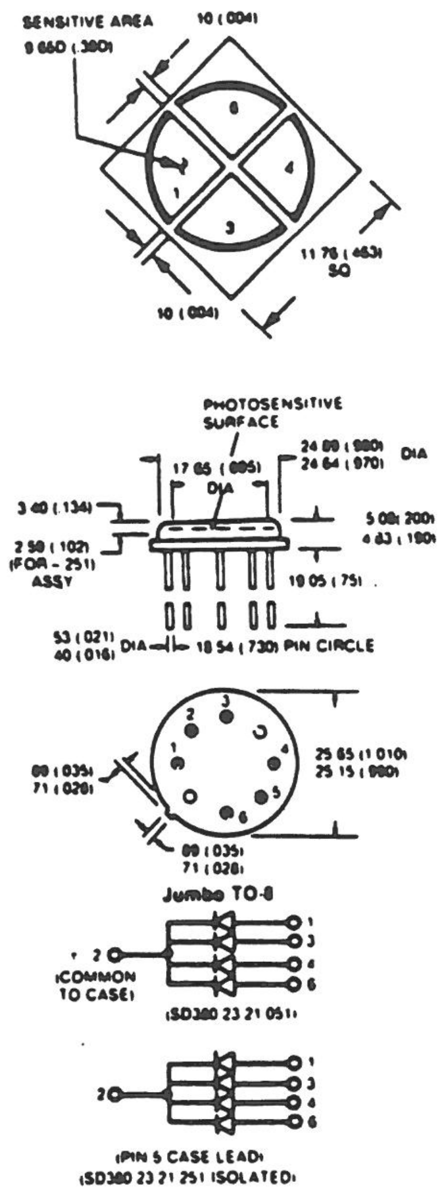


Figure B-7: SD380-23-21-051 Quadrant detector specifications. (From Silicon Detector Corporation catalog, Camarillo, CA 93010)

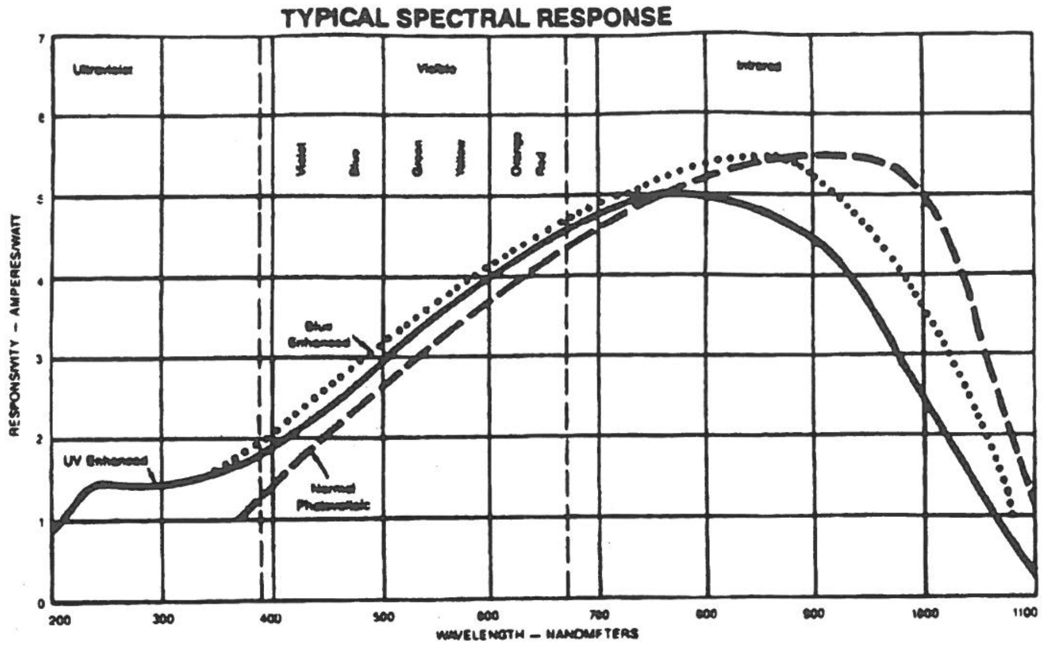


Figure B-5: Photo-detector response curve. Reference [12].

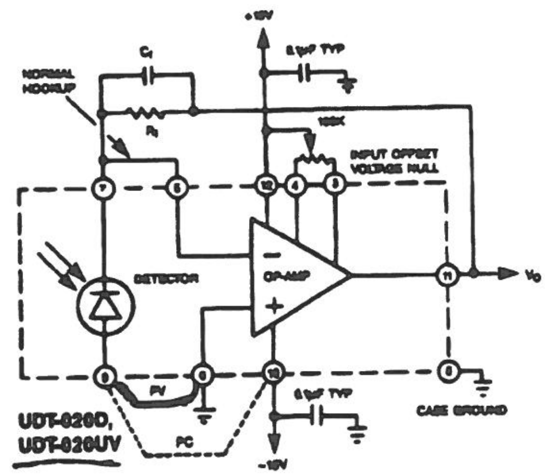


Figure B-6: Schematic diagram of the photo-detector used for both UV intensity and depolarization measurements. Model UDT-020UV is used in its PV mode. Reference [12].

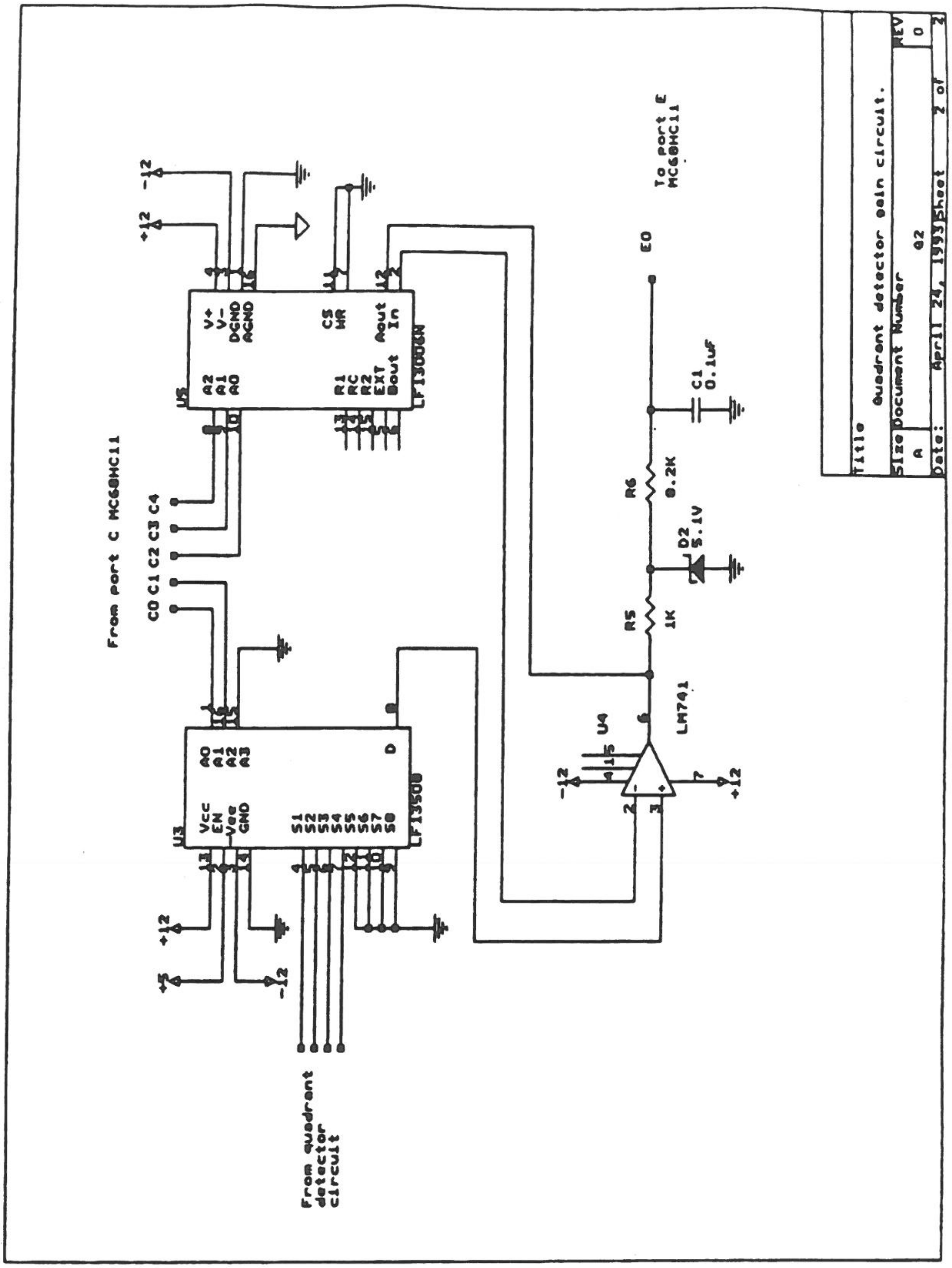


Figure B-9: Schematic diagram of data acquisition circuit (quadrant detector, sheet 2).

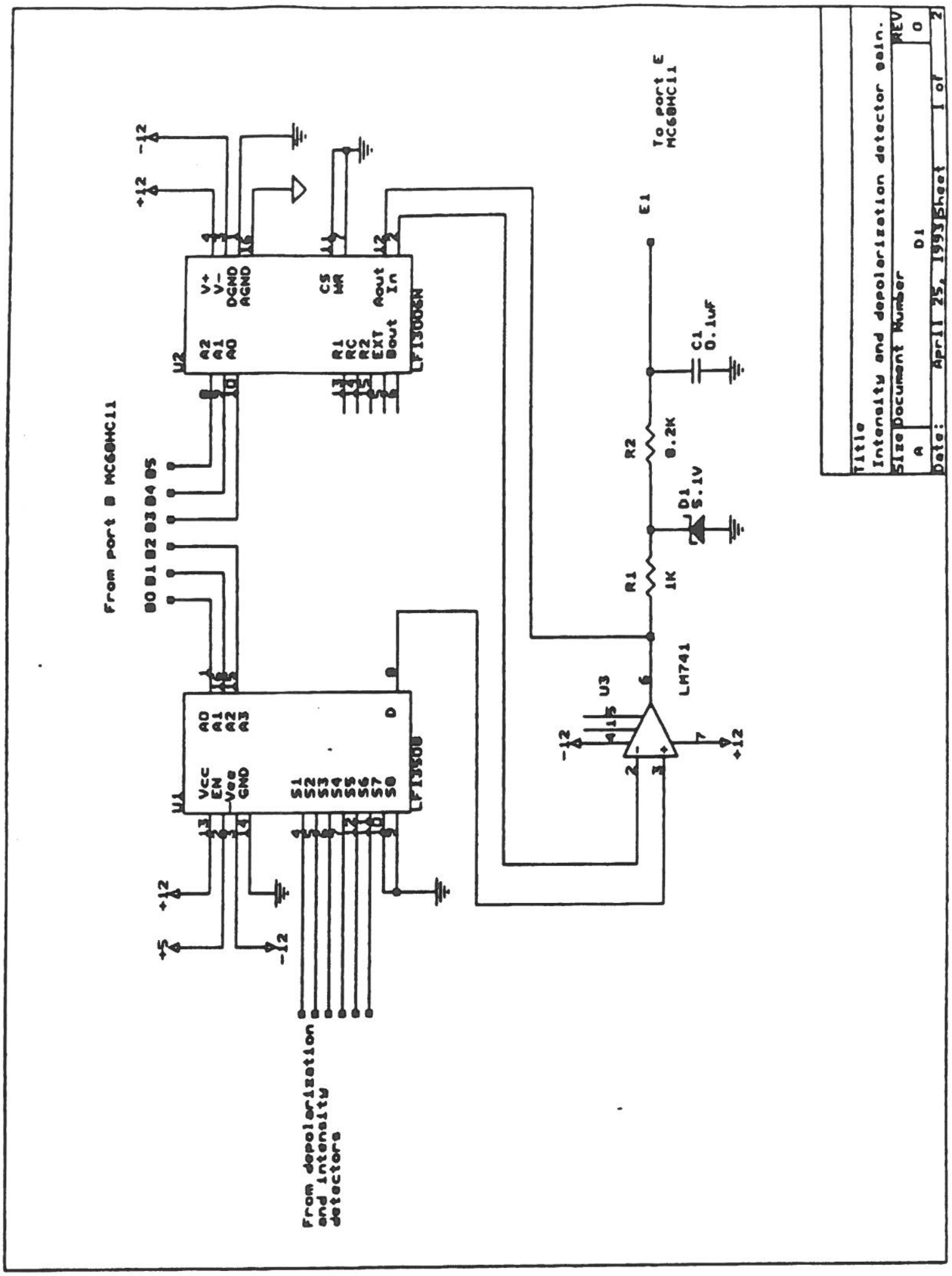


Figure B-10: Schematic diagram of data acquisition circuit (UV intensity/depolar detectors)

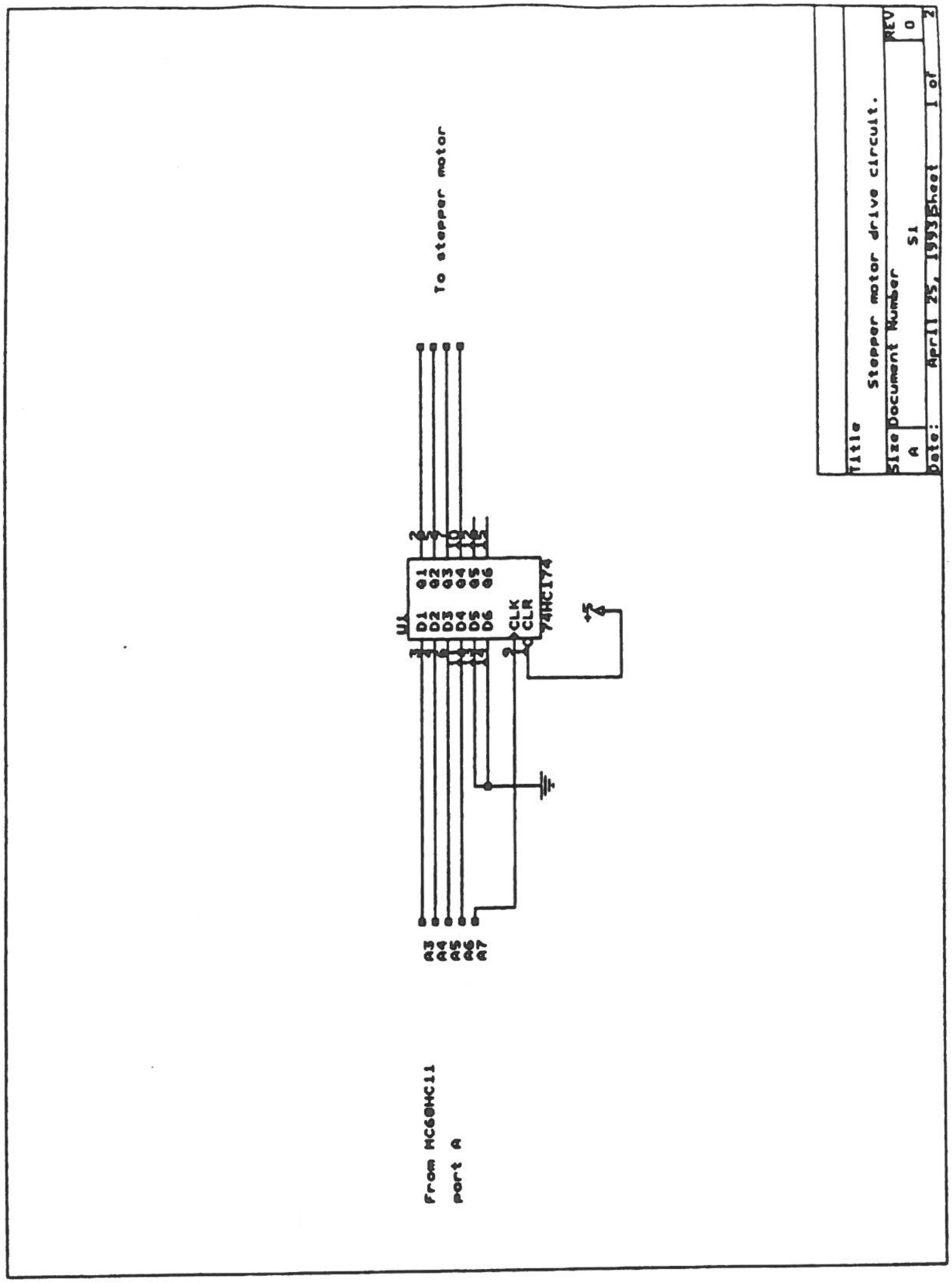


Figure B-11: Stepper motor drive circuit, sheet 1.

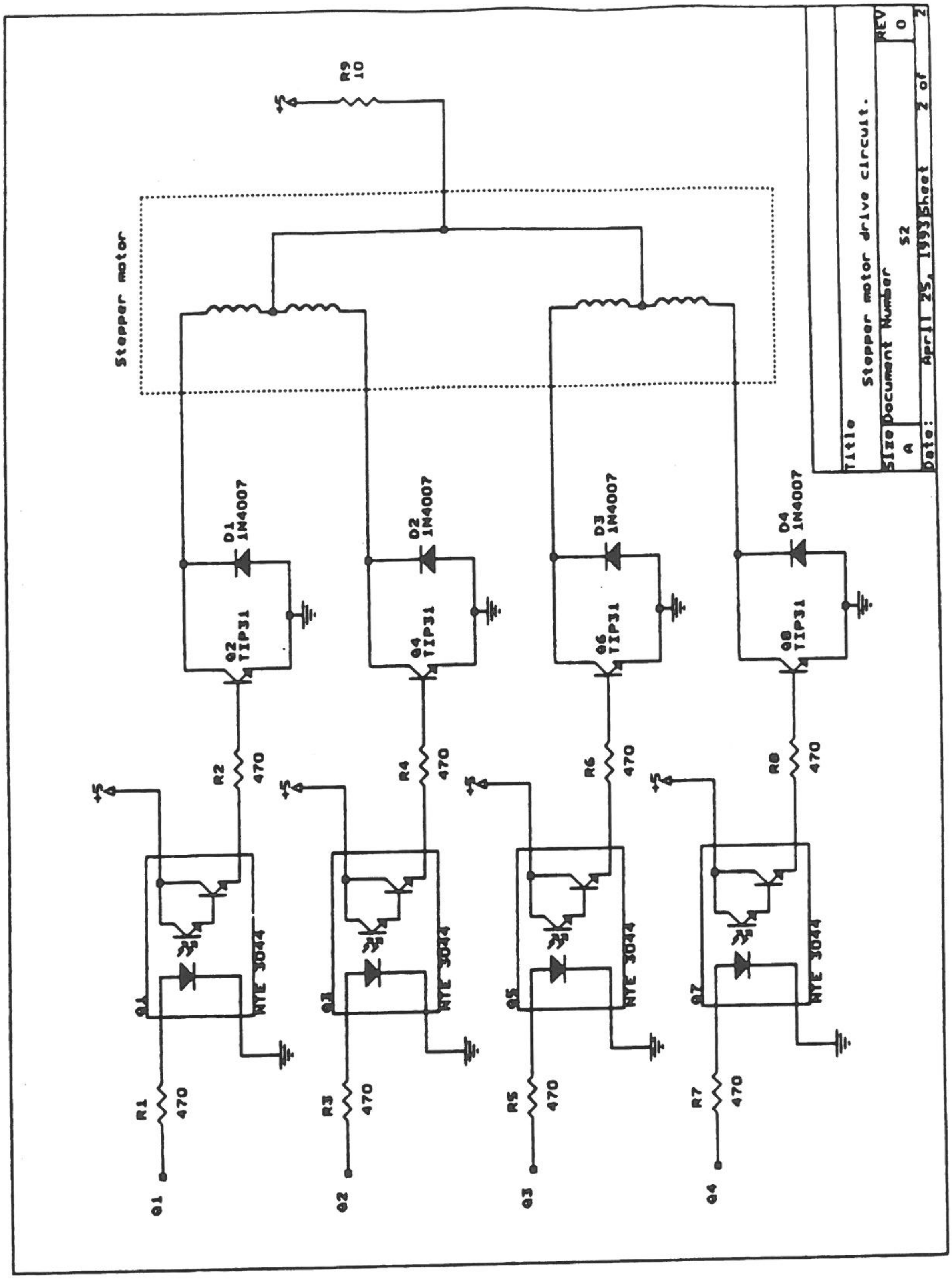


Figure B-12: Stepper motor drive circuit, sheet 2.

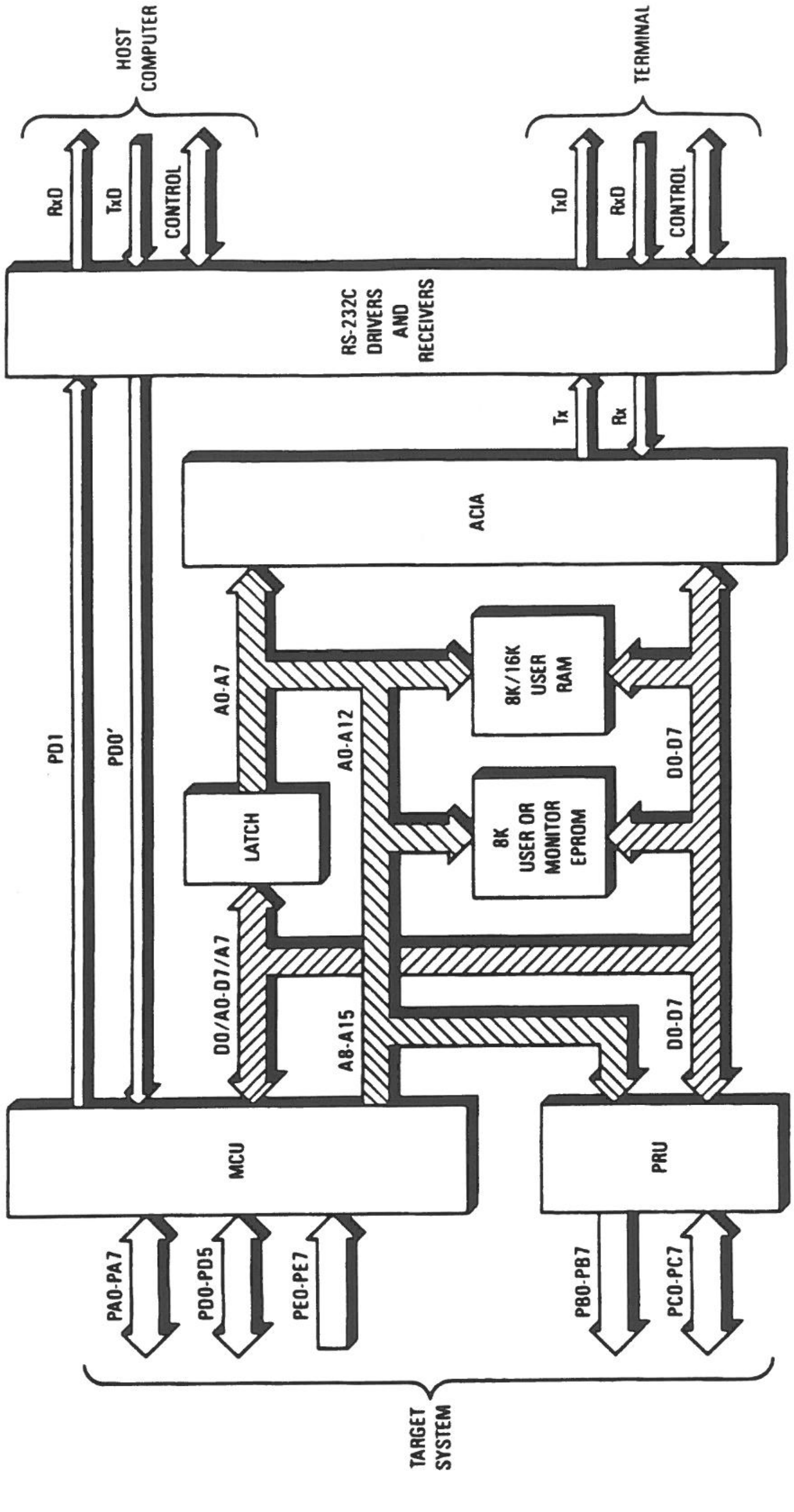


Figure 1-2. EVB Block Diagram

Figure B-13: Block diagram of MC64HC11. Reference [8].

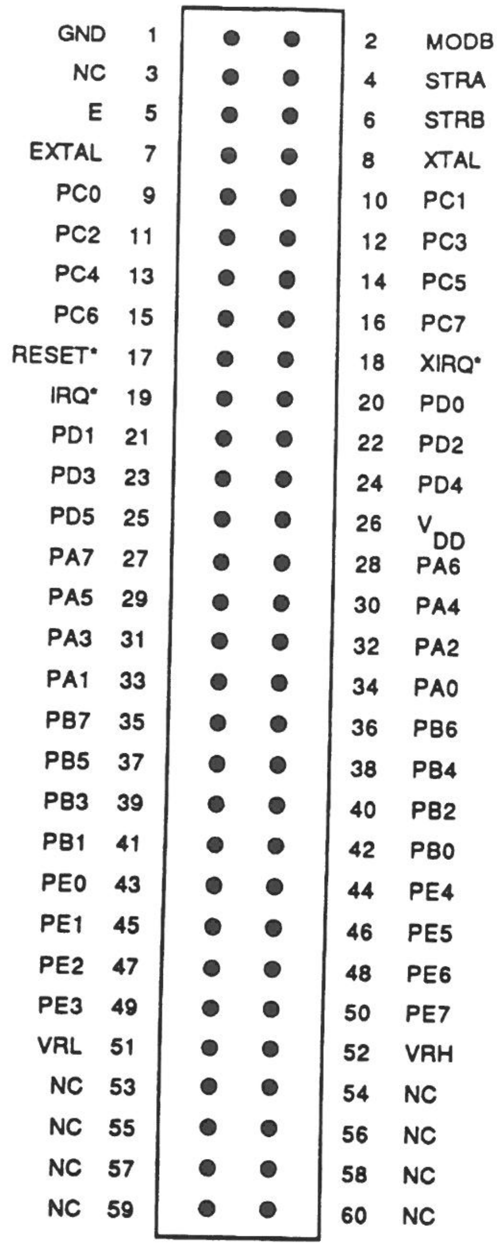


Figure B-14: IO pin assignments of MC64HC11EVB Evaluation Board. Reference [8].

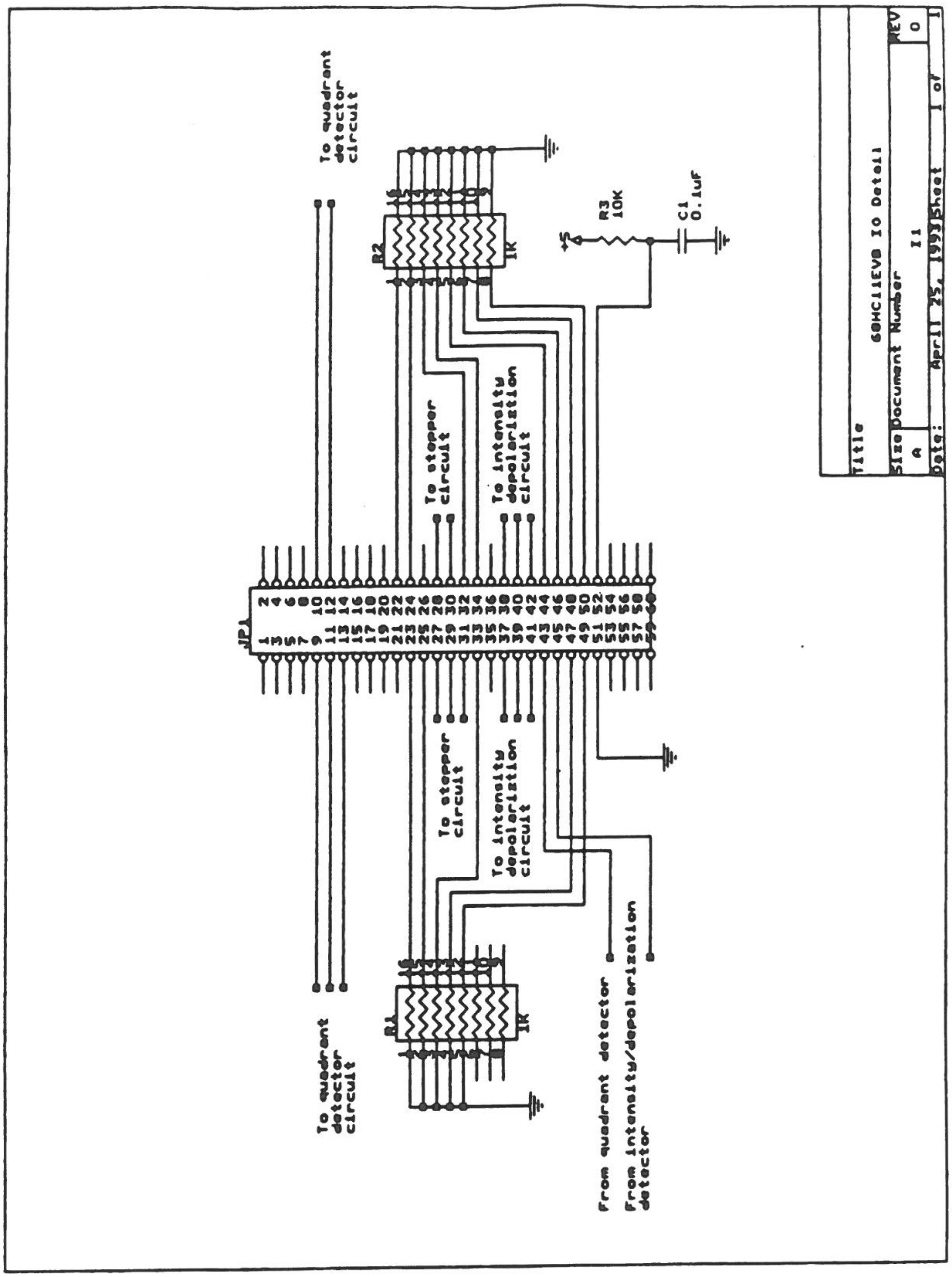


Figure B-17: IO connection of the *Multi-wavelength Polarimeter* and the MC64HC11EVB.

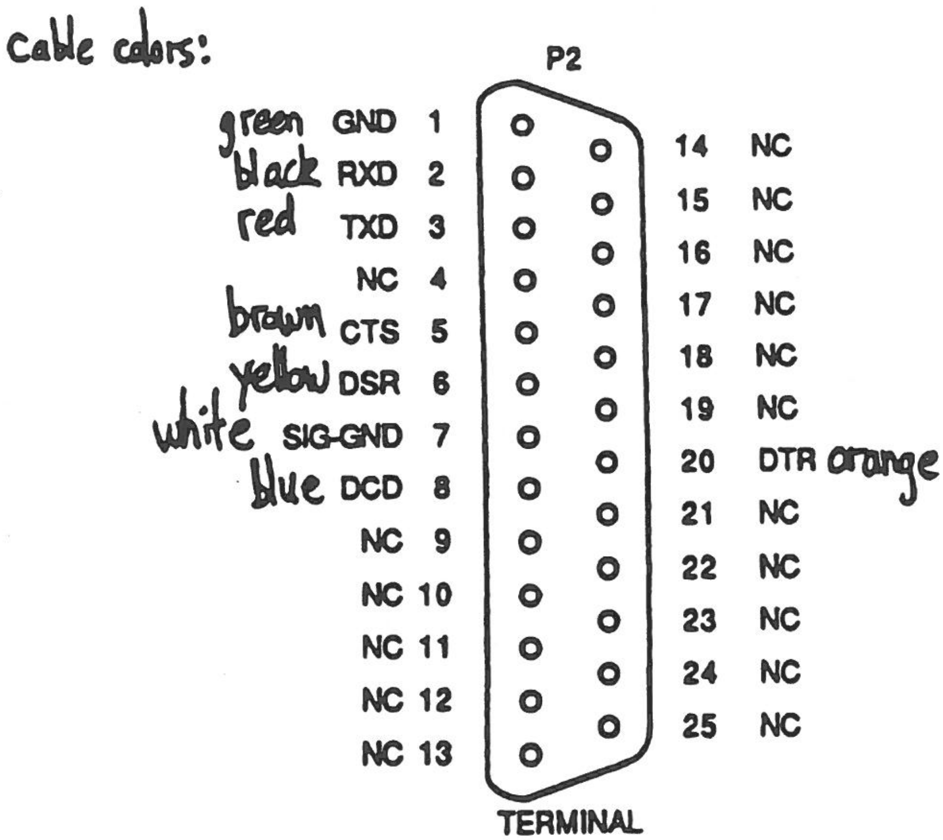
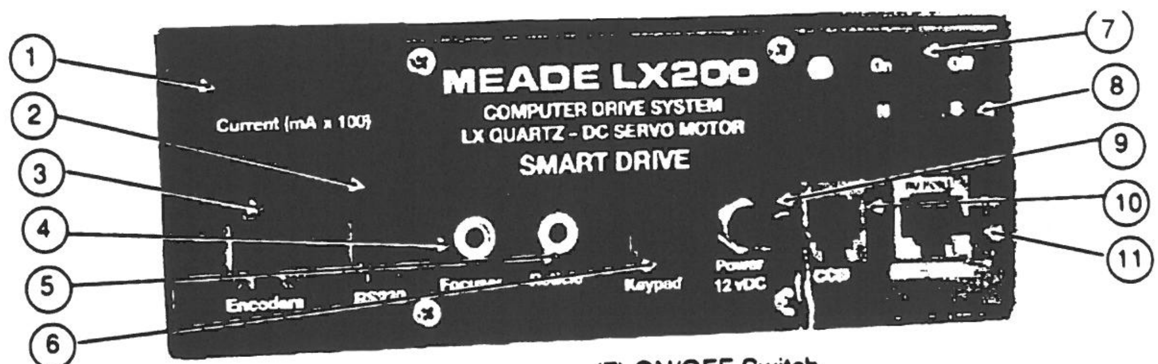


Figure B-18: RS-232 connection, Terminal EVB interconnection to PC. Reference [8].



(1) Ammeter
(2) RS 232 Connector
(3) Encoders Connector
(4) Focuser Connector
(5) Reticle Connector
(6) Keypad Connector
(7) ON/OFF Switch
(8) N/S Switch
(9) 12v DC Power Connector
(10) CCD Connector
(11) DEC Motor Connector

Figure B-20: View of Meade LX200 computer console. Reference [7].

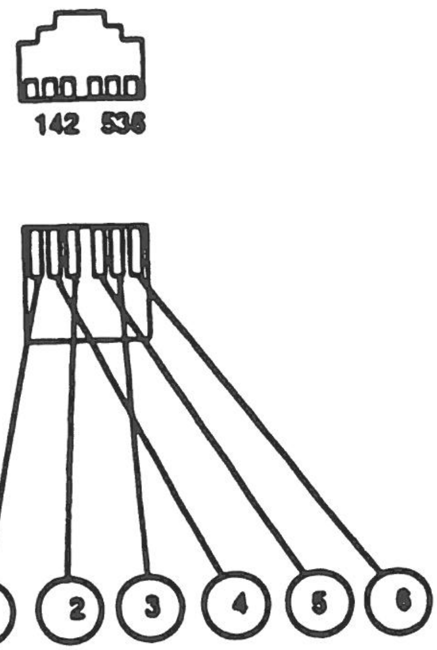


Fig. 29: LX200 Modular Connector

LX200 RS-232 CONNECTOR PIN OUT CODE LEGEND

6 WIRE MODULAR CONNECTOR	DESCRIPTION	TO DB-9 CONNECTOR PIN#***	TO DB-25 CONNECTOR PIN#***
#1	+12 VOLTS DC	NOT USED	NOT USED
#2	MISC. SERIAL OUT	NOT USED	NOT USED
#3	PC TRANSMIT DATA	#3	#2
#4	GROUND	#5	#7
#5	PC RECEIVE DATA	#2	#3
#6	MISC. SERIAL IN	NOT USED	NOT USED

Figure B-21: Diagram of LX200 modular connector and legend. Reference [7].

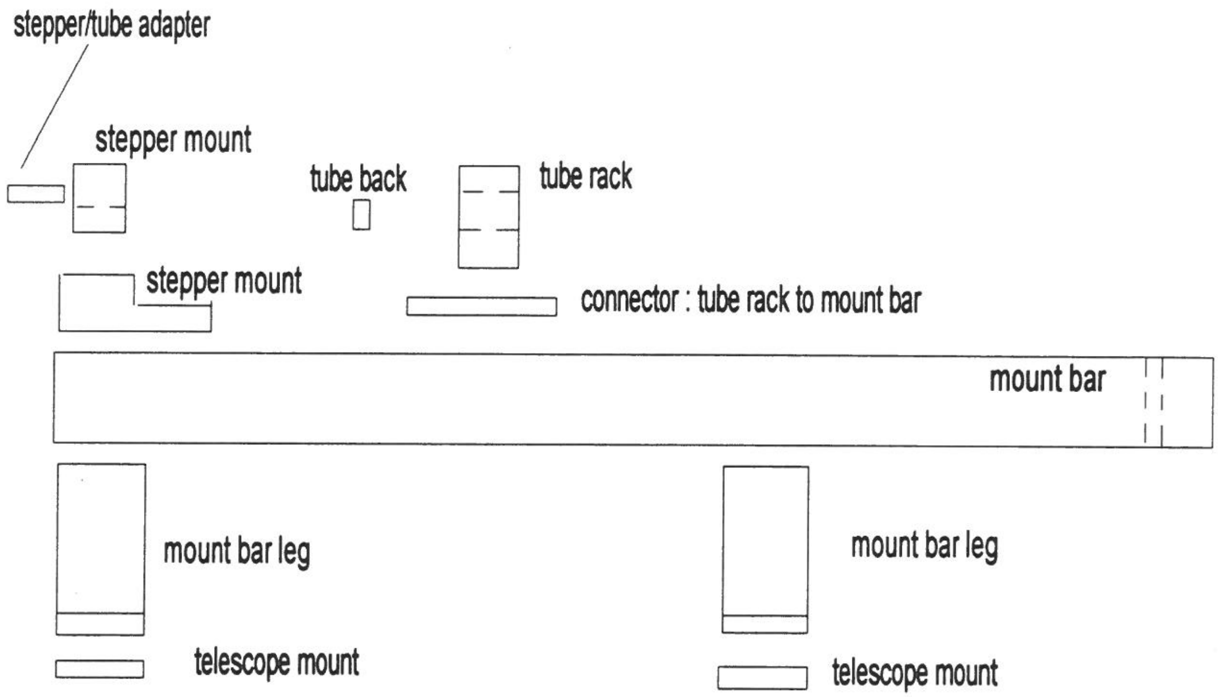


Figure B-22: Assembly diagram of detector unit mounting system.

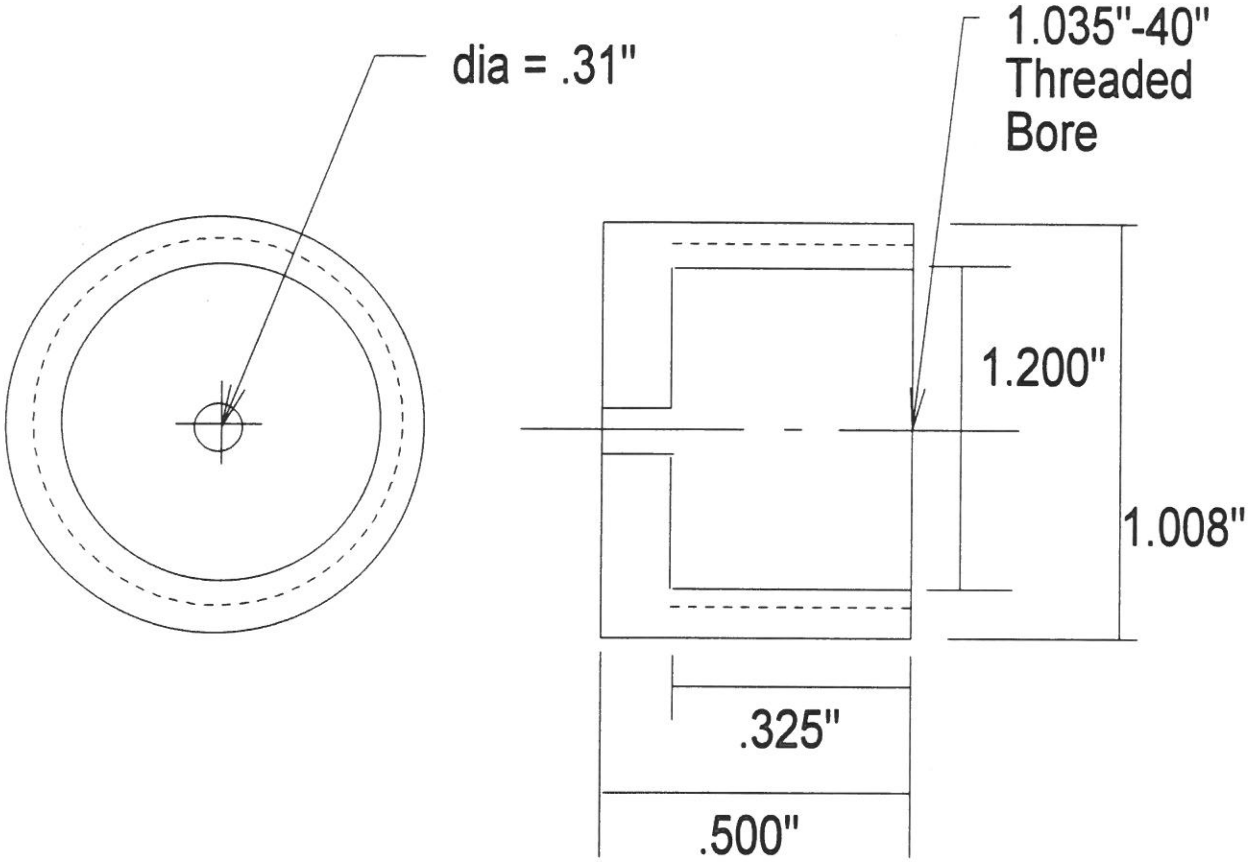


Figure B-23: Diagram of tube backs to the detector tubes.

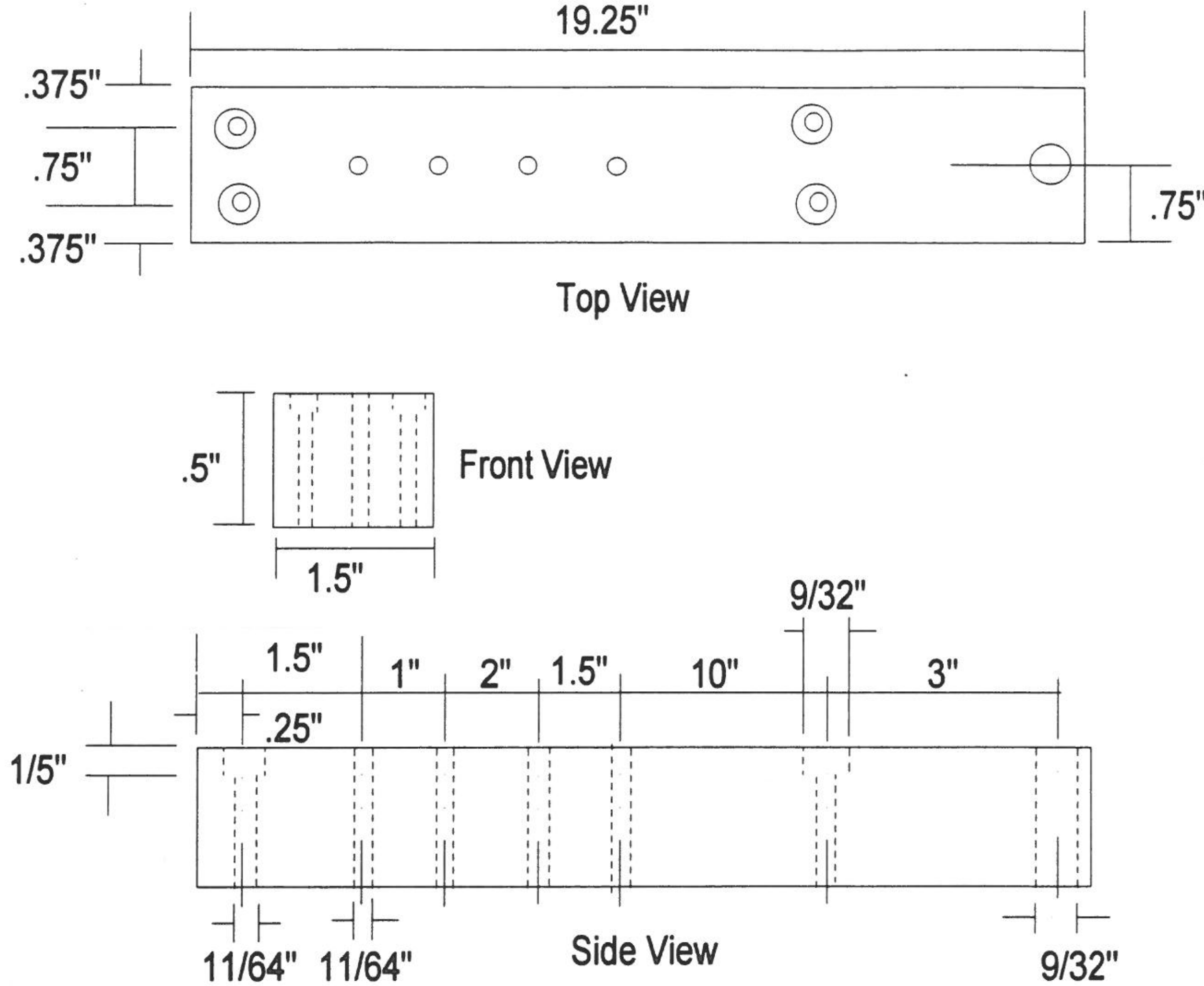


Figure B-24: Diagram of mount bar.

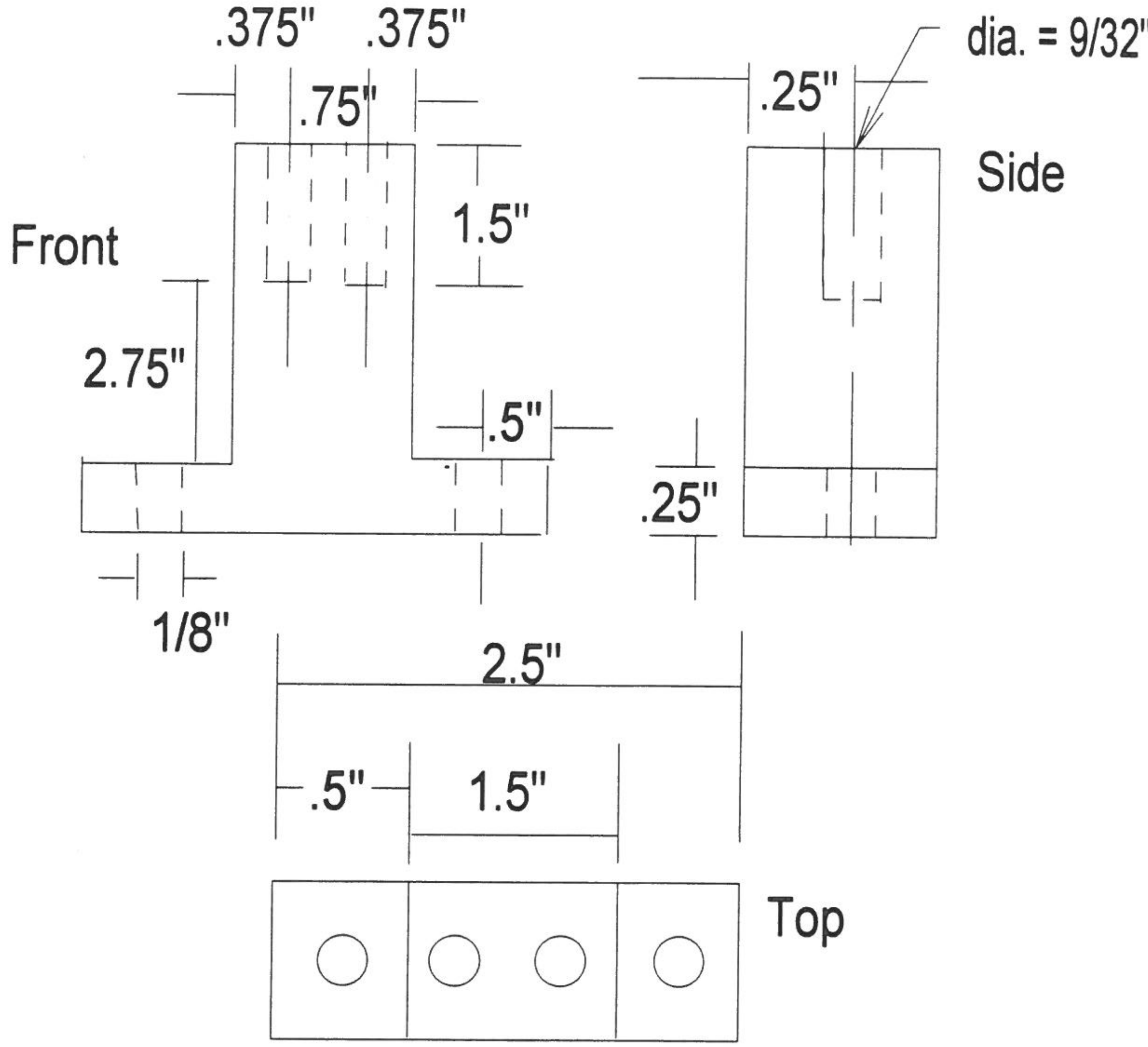


Figure B-25: Diagram of mount bar leg.

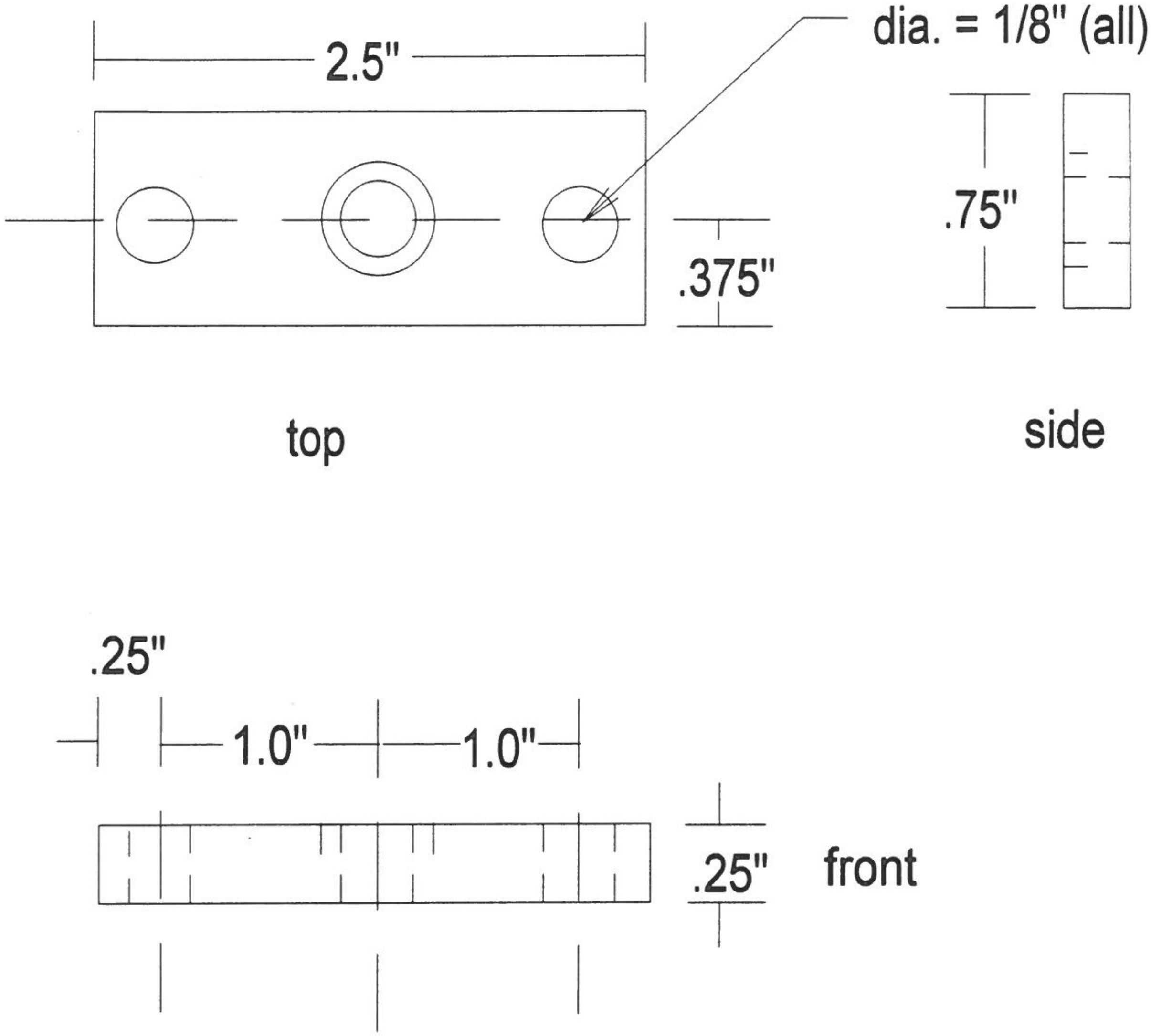


Figure B-26: Diagram of telescope mount.

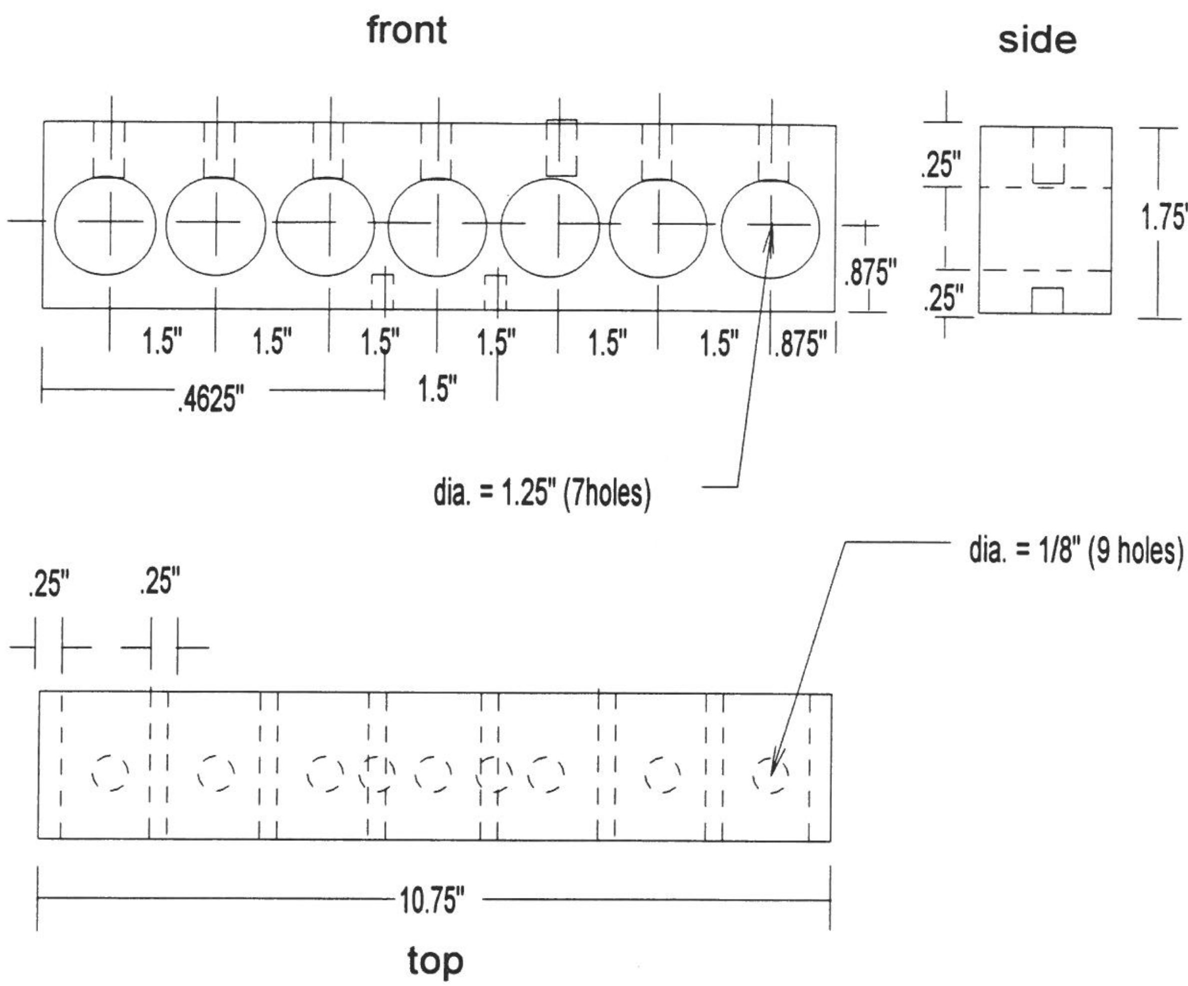


Figure B-27: Diagram of tube rack.

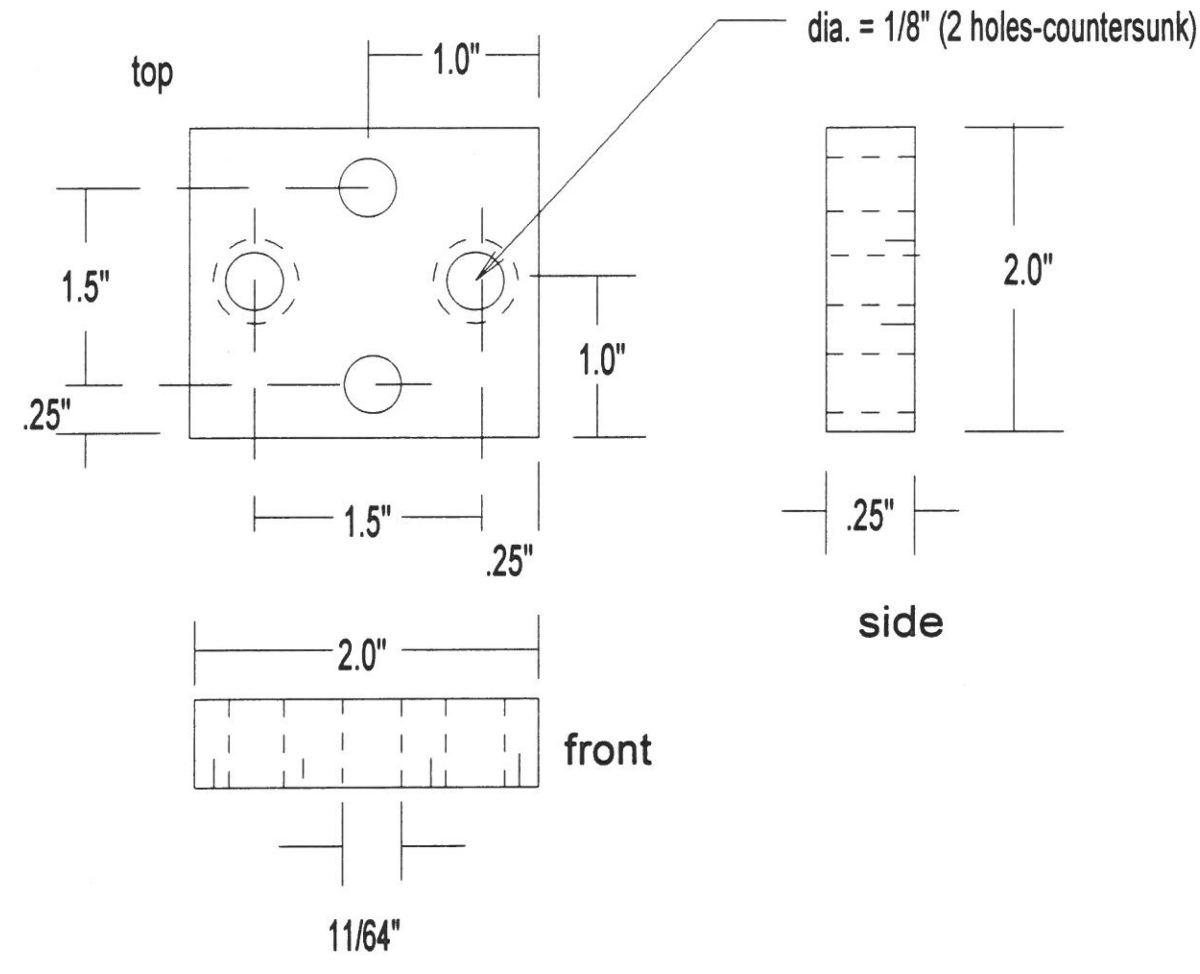


Figure B-28: Diagram of connector between tube rack and mount bar.

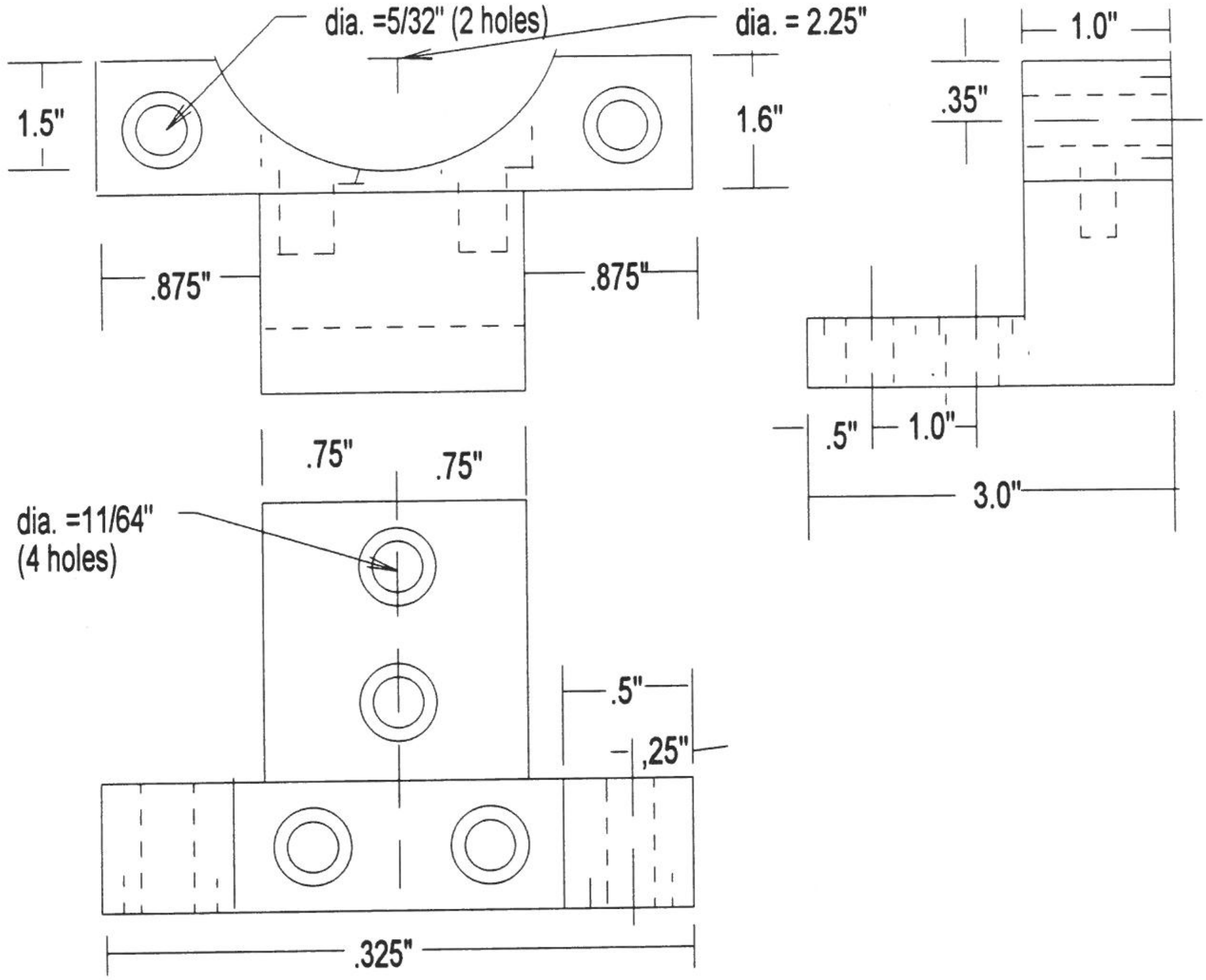


Figure B-29: Diagram of stepper mount.

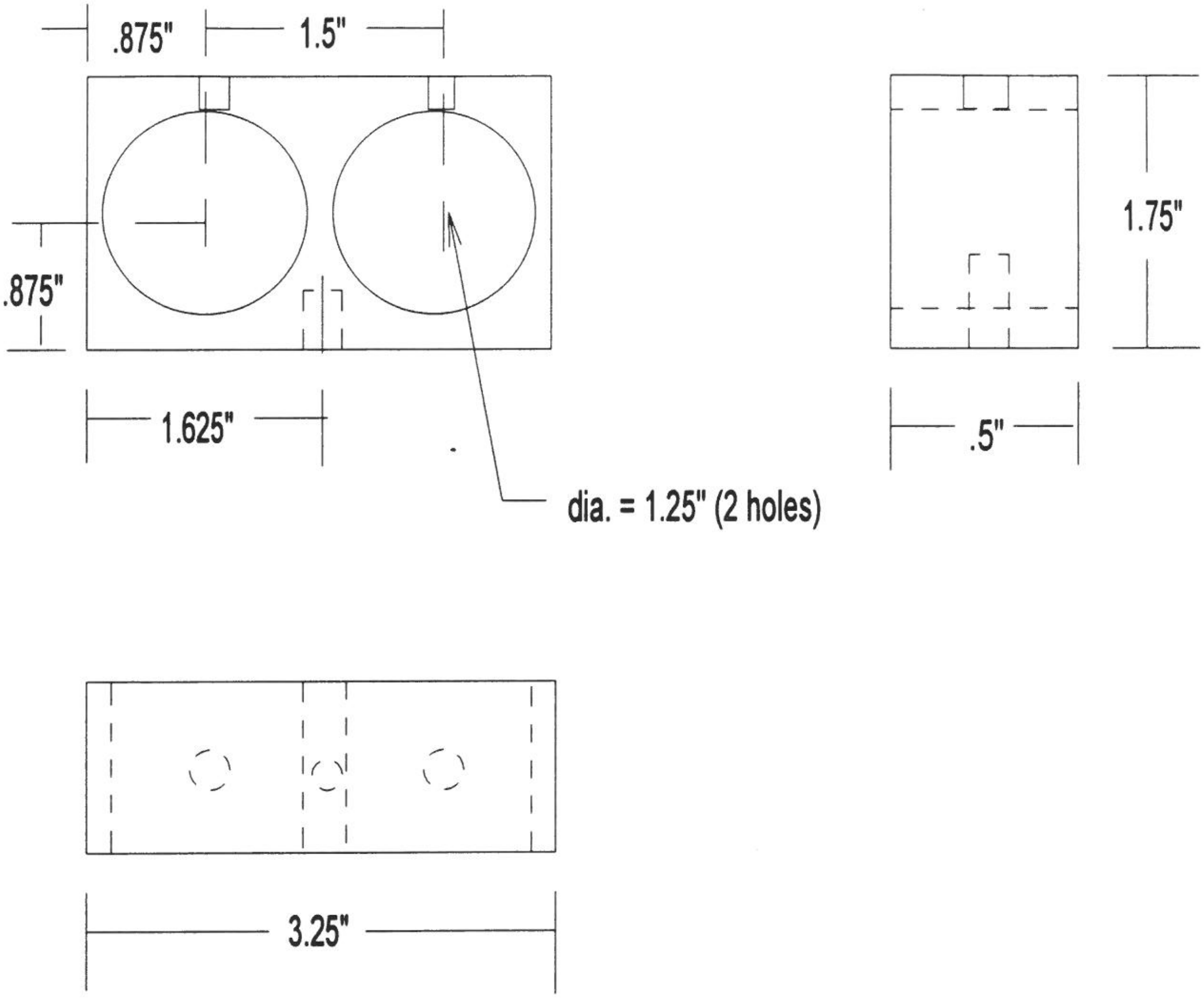


Figure B-30: Diagram of stepper tube adapter.

APPENDIX C

Documentation of System Operation

Documentation of *Multi-wavelength Polarimeter* Operation

*Preparing Telescope and Detector Unit:

1. Set up telescope on top of the roof of Electrical Engineering East.
   a. Refer to pages 11 to 14 of Meade Instruction Manual for telescope assembly.

NOTE: Make sure that the telescope has proper information for LX200 to operate in Altazimuth mode. Refer to pages 17 to 20 in the instruction manual.

2. Connect RS-232 "telephone" cable to PC, run down from roof through window.
3. Connect detector tube lines to the metal box (data acquisition unit)

   QUAD: the quadrant detector

		Order of detectors in data array
0	: UV tube (300nm)	7
1	: UV tube (350nm)	6
2	: UV tube (400nm)	5
3	: UV tube (550nm)	4
4	: Depolarization tube	3
5	: Depolarization tube	2

   STEPPER: the stepper motor cable

NOTE: Make sure that the order of the tubes on the tube rack matches that shown below.

empty	300nm	350nm	Quad	400nm	550nm	empty

4. Connect the RS-232 serial comunication from the metal box on the roof to the PC through the window.

5. Turn on the telescope and the metal box.

*Preparing the PC:

Note: Use Computer "C" in Rm 311 because delays and serial communications are set up for it.

1. Run the cables from the roof to the PC
   RS-232 cable from the telescope to COM1 (9-pin connector)
   RS-232 cable form metal box to COM2 (25-pin connector)
2. enter DOS and run QBasic (type: qbasic)
   - reference of BASIC commands found in [11].
3. open file C:\SUN.BAS
4. place empty data floppy disk in drive B:\
5. run program SUN.BAS
6. enter name of data file.

*Shutdown procedure:

1. On PC type letter "q" to stop program
2. Turn off power to the telescope and metal box.
3. Disconnect all detector tube cables and stpper cable from metal box.
4. Disconnect RS-232 cables from PC.
5. Store telescope and metal box inside building in a safe, dry location.

NOTE: Refer to Meade telescope manual to familiarize yourself with proper handling methods.

6. IMPORTANT: in all case of approaching inclement weather shutdown system and store.