CHAPTER 2

SOLAR ULTRAVIOLET RADIATION MONITORING SYSTEM

This chapter contains the details of a solar UV-B radiometer mounted on a single axis sun tracker for monitoring the direct component of the radiation received at the ground. The systems being used by various workers for measuring UV and total ozone are discussed. The need for an ideal system is indicated.

This radiometer has been operational at Trivandrum (8°29′N. 76°57′E) collecting data on solar ultraviolet-B (UV-B) radiation at the central wavelengths 290, 300, 310 and 320 nm. A multi filter technique based on the principle of UV absorption photometry of atmospheric ozone is used here. The UV-B radiation measured is the direct component of the solar UV radiation received by the detector of the system mounted on a sun tracker. The sun tracker (essentially functions as a heliostat) helps the detector to receive the solar radiation at normal incidence.

The block diagram of the ground based solar UV-B system is given in the Fig.2.1. The system consists of three major parts. (1).Sun tracker, (2).Detector and (3).Operation Console.
Fig. 2.1. Block diagram of the solar UV-B system.
2.1. SUN TRACKER:

A. Necessity of a heliostat:

Sun tracker enables a plane to be always oriented perpendicular to the incoming solar radiation. The zenith angle of the sun at any point on the surface of the earth depends on the latitude of that location and the solar declination (i.e., the angular deviation of the sun in the north south direction (maximum $\pm 23.5^\circ$) also called the azimuth).

The sun tracker designed here is a single axis type and is, therefore, semi-automatic in function. The tracker follows the sun in the zenith direction only and the tracker has to be set once a day in the azimuthal direction manually. Since the daily solar shift in the azimuthal direction is well within a quarter degree of arc, the setting for the maximum output once in a day would hold good for that day. The duration of data collection being less than 8 hours the shift in the azimuth will be less than 0.08 degree of arc in that duration of data collection. Since the look angle of the optics is comparable to the planar angular solar diameter, the error induced by the single axis tracking of this kind will be minimal.

Sun trackers are designed with either open loop or closed loop concepts. In the closed loop design, a feedback loop helps to optimize the output of the system by constantly orienting the system towards the sun. When a cloud interferes between the sun and the system, the feedback loop
goes out of control and the system goes haywire. Therefore, such a closed loop system is not favourable in tropics where the cloudiness is relatively more. In the open loop system, the sun tracker moves with the same speed as the sun and hence acts as a heliostat. An open loop system has been used here.

B. Mechanical Assembly:

Fig 2.2 gives the outline of the tracker. The essential part of the sun tracker consists of a cylindrical shaft with a gear wheel at one end. This shaft is mounted horizontally on three supporting posts attached to a platform. Suitable bearings are used for mounting this cylindrical shaft on the posts to reduce friction. A rectangular frame mounted on the shaft away from its drive end, houses the detector. The detector assembly as a whole can be manually tilted to accommodate the annual azimuthal variation of the sun.

The horizontal level of the platform and hence that of the shaft can be adjusted with the help of four leveling screws fitted to the platform. The shaft of the tracker is to be kept parallel to the geographic north-south direction, in order to facilitate the detector assembly track the sun from the east to the west. The rotation of the detector assembly covers a planar angular range of more than 180° in the vertical plane. The arrangement enables the detector to receive the normal incidence of insolation over the entire length of the day at this latitude.

A stepper motor, with 10 kg-cm output torque and 1.8° step angle, fixed to the platform, is used to rotate the shaft through a 10:1 reduction gear coupling. This motor
Fig. 2.2 Schematics of the photometer mounted on a single axis suntracker
takes about 3 amperes of current at 12 V d.c. to produce the rated output torque. The 10:1 gear coupling enables fairly smooth tracking of the sun. Synchronous motors can also be used to track the sun through appropriate gear coupling. This will be a cumbersome procedure. Since the stepper motor is programmable in terms of speed, direction and number of steps, stepper motor driven sun tracker scheme has become attractive in terms of simplicity, flexibility and cost.

This type of a stepper motor driven sun tracker is an open loop system based on the principles of incremental control system. As discussed earlier, a closed loop control system using a solar position sensor is not a desirable proposition especially in the tropics where the clouds are frequent in the sky. The cloud conditions can introduce error signals similar to that of the position error. Since it is difficult to distinguish between the two types of error signals, the system becomes highly unstable. This consideration led to the choice of an open loop system using stepper motor for sun tracking here.

C. Electronic Control Circuits:

The schematic block diagram of the sun tracker control circuit is shown in Fig.2.3. A two phase clock generates the required sequence of pulses to drive the stepper motor. These pulses are further amplified before they are used to drive the switching power transistors connected to the four windings of the stepper motor. A forward/reverse switch is used to alter the relative phase of the two phase clock, in order to change the direction of rotation of the
Fig. 2.3. Schematic block diagram of the sun tracker control circuit.
tracker. There is a mode selector switch to select either synchronous or asynchronous modes of operation of the tracker. In the synchronous mode, the adjustable clock generator-I together with a 14 stage ripple counter generates a train of pulses, which are used to trigger the two phase clock generator. This, in turn, causes the stepper motor to drive the detector optics at near sun synchronous speed (~15°) in order to make it essentially a single axis heliostat.

In the asynchronous mode of operation, another clock generator-II, at the instance of a manual command, given through a push button switch, triggers the two phase clock generator. This in turn rotates the detector system at a faster rate, at about 800 times faster than the sun synchronous speed. This mode of operation is used in conjunction with the forward/reverse switch to position manually the detector optics to look at the sun. Detailed block diagram of the sun tracker using CMOS integrated circuits is shown in Fig.2.4.

2.2. DETECTOR:

The detector consists of (a) detector optics and (b) detector electronics. The sectional view of the detector optics is given in Fig 2.5 (a).

2.2.1. Detector Optics:

The optical components of the detector consist of apertures, a UG-5 Colour glass filter, a phototube and the
Fig. 2.4. Detailed diagram of the sun tracker control circuit.
four interference filters fitted to a circular wheel.

Sunlight falls normally on the aperture kept on top of a colour glass filter, UG-5 (Uviol Glass of Schott Glass). This filters most of the visible and IR (infra red) components from the incident solar radiation. The radiation thus filtered falls on an interference filter fitted to a wheel as shown in Fig. 2.5(b). The interference filter selects the wavelength central to its transmission and transmits through it. This radiation falls on a phototube situated directly below the interference filter and generates photoelectric current.

Since solar UV radiation in absolute units have to be measured, for passive collimation, a pair of apertures one below the other is used. The aperture disks are aluminium disks with central holes ranging from 1mm to 8 mm. If a single aperture is used, for a given separation between the photo tube and the aperture, (here, 70 to 78 mm), the look angle, defined as the maximum planar angle subtended by the aperture diameter at the extreme ends of the photo cathode of diameter (8mm), will be very large. However, the flux is governed by the pencil of the direct beam incident on the photo cathode material. For a passive collimation like this, the simple geometric area of the beam mainly decides the current generated. The solid angle subtended at the centre of the photo cathode is quite small, of the order of a few millisterradian, for an aperture of 2mm, the typical one used. The use of a passive collimation effectively increases the directivity of the system to the insolation. Apertures of
Fig. 2.5. Sectional view of the detector assembly.

1, 2, 3. Positions of filters 280, 300 & 320nm
4. Reference closed position

Fig. 2.6. Filter wheel configuration.
various sizes can be utilized to alter the look angle of the photo cathode. With the appropriate passive collimation using 2mm aperture, the look angle can be limited well within about 5° and the planar angle at the cathode centre within 1° without the geometry not affecting the measurement.

The UV interference filters have central wavelengths, 320, 310, 300, 290 and 280 nm each with a pass band of ± 5nm. The filters used were at 320, 300 and 280 nm and later changed to 320, 310, 300 and 290 nm, since the 280 filter did not have sufficient flux to measure. These interference filters have been mounted on the circular wheel in the descending order of wavelength, 320 to 280 nm, with a reference blank position intervening the 320 and 280 nm filter position. The filters are sequentially rotated from the blank position to each filter position. Each filter stays in position for about 2 minutes in the automatic mode. One photo tube is time-shared among the filters used.

The detector optical assembly is covered using a thin aluminium hood. It is painted white outside to minimize the absorption of radiation and black inside to lower the scattering effects introduced in the measurements. The hood holds the UG-5 filter and the apertures. This assembly is mounted on the sun tracker and they form one unit.

2.2.2. Detector Electronics:

The electronics part of the detector system includes a filter wheel control circuit and an electrometer amplifier circuit. These are detailed below.
A. Filter wheel control circuit:

The filter wheel consists of a circular wheel with the interference filters fitted to it. An indigenous stepper motor is used to rotate the filter wheel in order to position the filters or blank above the photo tube. Both automatic and manual modes of operation of the filter wheel are provided.

In the automatic mode, different filters and blank are periodically positioned above the photo tube for a specified period of time. This time sharing technique has the advantage of using a single photo tube and the associated electrometer amplifier circuits for measuring the UV flux at the different filter wavelengths used.

The stepper motor is basically a two phase a.c. motor with bifilar wound stator and permanent magnet rotor. It has four windings which are sequentially to be energized to produce stepping action. The motor draws a current of about 1.2 amperes at 12 V D.C. to generate the rated 3 kg-cm output torque. However, the filter wheel load on it is very less. The stepper motor has 200 steps to make one revolution so that each step angle is 1.8°. Unlike in the sun tracker, there is no gear reduction.

Fig 2. 6 shows the block schematic of the filter wheel control circuit. A basic clock generator-I with 10 millisecond pulse in conjunction with a divide by 50 counter generates a burst of 50 clock pulses. A timing pulse is used to gate these clock pulses necessary to drive the stepper motor. These are suitably amplified using transistor
Fig. 2.7. Block schematic of the filter wheel control circuit
drives and switching power transistors and fed to the four windings of the stepper motor. Every pulse applied to the two phase clock generator rotates the stepper motor by one step. The filter wheel can rotate in the automatic mode or in the manual mode, which can be selected by a mode switch. Depending on the mode of rotation, appropriate timing pulses are used for gating the clock pulses.

In the automatic mode, a clock generator - II with 5 millisecond period and a 14 stage ripple counter generates a continuous timing pulse with a period of 4 minutes approximately. This interval is programmable to less or more time. The leading edge of the timing pulse triggers the basic clock generator - I to produce a burst of 50 pulses. This will make a 90° rotation of the filter wheel in about 2 seconds and it will remain in that position for about 2 minutes. This process gets repeated in the automatic mode. This was used when three filters and a blank position were used. The system was suitably modified when an additional filter was introduced.

In the manual mode of operation, a single timing pulse of about 5 seconds ON time is produced at the instance of manual command given through a push button switch. This in turn generates a burst of pulses to rotate the filter wheel through a fixed angle, 90° or 60°, depending on the number of filters used. When the manual command is given, the filter wheel turns through a fixed angle and remains in that position. The time of transit between positions is approximately 2 seconds. Fig. 2.7 (a) and (b) details the
Fig. 2.8. Detailed diagram of the filter wheel control circuit. (2)
filter wheel control circuit using CMOS ICs.

Circuits to generate appropriate logic signals for automatic gain switching of the electrometer amplifier and a suitable circuit to interface the digital printer are also included in the control circuitry.

B. Electrometer amplifier circuits:

The phototube operates with a supply of 12 V D.C. to its anode. A sensitive operational amplifier with FET input stage and low bias current is used as the electrometer amplifier (current to voltage converter) to measure the phototube current. The phototube current varies over a wide range due to the change in the incident intensity of the solar UV radiation transmitted through the different filters. If an amplifier with a fixed gain is used to measure the phototube current, it may saturate for one wavelength or be insensitive to the flux at another wavelength. In order to overcome this problem and to increase the dynamic range of the amplifier, automatic gain switching (AGS) is incorporated. This is accomplished by first knowing the flux at each wavelength of interest corresponding to the filter positions. Then two electromagnetic relays with the associated drive circuits are used to connect the respective feedback resistors to get the three different gain stages. Fig 2.8 shows the electrometer amplifier circuit with gain switching. A push button switch is used to reset the automatic gain switching logic circuit.

The amplifier output is connected to a strip chart recorder for recording the analogue data. A digital printer with the proper interface is also connected to the
Fig. 2.9. Electrometer amplifier circuit with gain switching.
amplifier output to get the digitized information. A digital multimeter has also been used from a parallel port to read the flux.

2.3. OPERATION CONSOLE:

All the control circuits are housed away from the sun tracking detector optics in a movable rack - mounting cabinet. The upper rack contains electrometer amplifier circuits, filter wheel control circuits and sun tracker control circuits. Various switches for filter wheel and sun tracker control are provided on the front panel. The power supplies are provided in the lower rack. The system operates on a 230 V main supply.

A strip chart recorder having 0.5 sec full scale response and better than 0.3 \% accuracy has been used for recording the amplifier output. There is also provision to display the readings using a 3 1/2 digit, digital panel meter (DPM) having parallel BCD output. Input to the digital panel meter is suitably attenuated to limit to 200 millivolts for full scale read out. A digital printer which accepts data in bits- parallel digits parallel form, connected to the BCD output of the DPM, prints out the data every 20 seconds. However, different data rates can be obtained by internally adjusting the interface circuit for the digital printer. There is provision in the rack mounting cabinet to keep the strip chart recorder, the DPM, and the digital printer. There is a parallel port for checking the DPM output, using a
digital multi meter (DMM).

2.4. OTHER SYSTEMS USED FOR UV AND OZONE MEASUREMENTS:

In this section different systems of total ozone, UV and vertical ozone measuring instruments are presented and discussed.

2.4.1. Dobson Spectrophotometer: G. M. B. Dobson designed a reliable total ozone measuring instrument in the early thirties. In his honour, the unit for measuring the ozone amount in the atmosphere is named as the Dobson Unit (D.U.). It is equal to 1 milli atm-cm (Conversions from D.U. are given in detail in the Appendix). Dobson spectrophotometer is a standard instrument for total ozone measurement (Dobson, 1930, 1957, 1963). It is a double prism spectrophotometer which contains the slits in the common focal plane to isolate wavelengths of interest (usually 4 channels at about 305, 308, 311 and 317 nm) and eliminate as much stray light as possible. The output of the second prism is focused on to a photo multiplier tube which measures the relative intensity of radiation from a pre-selected pair of slits. The ratio of the relative intensities is used to derive the total ozone content. This method needs accurate knowledge of the absorption coefficients of ozone, Rayleigh and particulate matter scattering coefficients at the desired wavelengths, relative optical air mass and the solar zenith angle. In the wavelength intervals chosen, it is assumed that scattering varies linearly with wavelength.
2.4.2. Umkher Method: This method uses the Dobson technique at very large zenith angles to measure the total ozone in different Umkher levels (0 to 5), thus giving a vertical distribution of ozone, however gross. This technique requires the altitude dependant Chapman function to derive the vertical profile of ozone. The Umkher method gives an average picture of the vertical distribution in ozone.

2.4.3. Brewer Ozone Spectrophotometer: This is a modified Ebert grating spectrophotometer which, like, Dobson, uses axial slits to isolate five wavelengths of interest. The relative intensities are measured sequentially using a photomultiplier tube. The five different wavelengths used are 306.8, 310.6, 313.5, 316.6 and 320 nm. The system calibration is maintained using an internal mercury spectral line source. The effective absorption as well as extra terrestrial coefficients - the natural logarithm of the ratio of the intensities outside the atmosphere at the desired pairs of wavelengths- are chosen to yield good agreement between Brewer and Dobson spectrophotometers.

2.4.4. U.S.S.R. M - 83 Ozonometer: This is a two band filter photometer which uses relatively higher bandwidth filters to isolate regions of the near UV spectrum. The central wavelengths of the filters are 399, 324.7 nm with nearly 22.5 and 14 nm width at half power points. These are manually rotated into position between the entrance aperture and the detector, which is a photocell for direct sun measurements and a photo multiplier for zenith measurements. An external lamp source is provided for calibration. The ratio of the meter
readings gives the total ozone content as in the case of Dobson instrument.

2.4.5. Canterbury filter photometer: This photometer developed in Canterbury, New Zealand, uses narrow band UV interference filters to isolate spectral bands of widths comparable to slit band pass widths of Dobson. It uses six such filters rotated sequentially in front of a photomultiplier detector to measure the intensities at each pair of wavelengths centred at Dobson channel bands A (305.5nm), B (308.8nm) and D (317.6 nm). To block the visible and IR radiation, a nickel sulphate hexahydrate crystal sandwiched in Corning CS-75 glass is used. The derivation of total ozone from these measurements follows the Dobson technique. For narrow wavelength selection two filters have been used in place of one.

2.4.6. Sen Tran Company Filter Photometer: This was developed from the rocket ozone sonde (ROCOZ) of Krueger and McBride, 1968 where the ROCOZ filters were replaced by the Dobson A and D channel filters. Parsons et al., 1982 inter compared at Wallops Island, Virginia, USA, the above five instruments for a period in excess of 15 months. The Dobson Spectrometer was used as a standard for comparison of the other four instruments. All the five were found to have some deficiencies and the major findings were: (1) The Brewer instrument with its ease of operation and automatic data recording and processing advantages, produced data in excellent agreement with Dobson. It did suffer from electronic failures. (2) The M-83
photometer results were in acceptable agreement with the Dobson instrument. The variability was due to the combined effects of aerosol scattering fluctuations in the atmosphere and the relatively broad band pass of the M-83 filters. (3) Narrow band filter photometers are capable of good performance for short periods of time, but filter aging and degradation occurs during long periods of data collection.

2.4.7. Robertson Meters: From the standpoint of assessing the UV dosage in the entire band of 290-320 nm where the biological, especially the erythemal efficacy is the highest, development of dedicated instruments with absolute traceability to primary standards in wavelengths have been developed over the years. These have been necessitated by the growing concern over the ill effects of the UV radiation on human skin. The meter has a dye which absorbs the UV radiation and emits (fluoresces) in the visible region which is measured. These have been in wide use in Australia and the USA for the evaluation of the UV-B dosage. Using this instrument the unit for erythema on Caucasian skin has been defined as a sunburn unit.

2.5. OZONE AND UV MEASUREMENTS - THE INDIAN SCENE:

2.5.1. Rocket-borne measurements: With the increasing concern over the possibility of ozone destruction by anthropogenic means and the consequent alterations to the stratospheric chemistry, the need to monitor ozone above the balloon ceiling altitude was felt. Thus the rocket ozone
The ozone sonde programme was initiated in India in the late seventies. A rocket borne solar middle ultraviolet (MUV) photometer to measure ozone from 15 to 70 km was developed at the Physical Research Laboratory (Subbaraya and Shayamal, 1981). Night time ozone vertical profile using a lunar UV photometer were also made by the same group. A rocket borne UV photometer has been developed at the National Physical Laboratory, New Delhi (Somayajulu et al., 1982). A number of ship based rocket launches have been made off the coast of South India by the Central Aerological Observatory (CAO) of the State Committee for Hydrometeorology and Control of Natural Environment (SCHCNE) of the erstwhile USSR for measurement of ozone vertical profiles in the tropics. The ozonesonde intercomparison experiment at Thumba, Trivandrum involving different rocket sensors was conducted during March - April 1983 and the results are summarized by Acharya et al., 1985.

2.5.2 Balloon-borne measurements: The vertical distribution of ozone using balloon borne ozone sonde was initiated in the early seventies in India. Regular balloon soundings are done from New Delhi (28.6°N), Pune (18.5°N) and Trivandrum (8.5°N). However, balloons cover an altitude range of 0 to about 30 km only. The instrument used to measure ozone is a modified miniature version wet electrochemical bubbler used for surface ozone monitoring (Sreedharan, 1973). The same instrument has also been used at the Indian base at Antarctica, Dakshin Gangotri. The balloon sonde were too operational for the low altitude ozone distribution data collection.
2.5.3. **Ground based measurements** - Measurement of total atmospheric ozone in the low latitude regions has been in progress for about three decades in India using a network of Dobson spectrophotometers. The India Meteorological Department monitors surface ozone (Brewer bubbler), total ozone (Dobson) and vertical distribution of ozone with balloons wet bubbler sonde (data collection is ground-based) from various meteorological stations like New Delhi, Poona, Kodaikanal, Varanasi, Srinagar, Ahmedabad etc.

In India, a solar UV-B radiometer to measure global UV-B was developed at the National Physical Laboratory (NPL), New Delhi (*Srivastava and Sharma, 1979*). Under the Indian Middle Atmosphere Programme, such radiometers have been installed at New Delhi, Poona, Waltair and Mysore. At New Delhi and Poona facility for the direct solar UV-B measurements also exist. A ground based total ozone measuring instrument using absorption in the Chappuis band was developed at the Indian Institute of Tropical Meteorology, Pune (*Poonam, M, 1986*).

So far the instruments in use described above were either total ozone or relative measurements. The system developed here for monitoring the direct component of the solar UV-B radiation has the advantage of secondary calibration with an NBS standard lamp. Since the relationship between the global and the direct components of the solar flux is empirical and the global radiation cannot be made use of for the estimation of ozone and such minor species in the atmosphere, it was decided to measure the direct component of
the radiation. The purpose is to map the solar UV-B flux for examining the long term variability and the derivation of the overburden ozone is secondary. The system is prone to the defects mentioned in the Canterbury photometers. An all absolute UV measuring system is described below.

Solar spectral irradiance measurements have gained a fresh impetus during the recent years. Researchers involved even in many unrelated scientific disciplines have needed to determine the spectral irradiance of the sunlight accurately. A few years before, it has become evident that solar radiation along with the changing levels of its UV component due to changes in concentration of ozone in the stratosphere, is causing a multitude of far reaching problems.

Accurate UV spectral measurements are quite difficult and far more complex than measuring the spectral output of most other types of light sources. The exponential decrease in the spectral irradiance of sunlight with decreasing wavelength and the relatively large amount of irradiance at longer wavelengths puts very stringent requirements on the optoelectronics instrumentation. The UV-B band ranging from 280 to 320 nm has 1.4 % of the total solar radiation outside the atmosphere and about 0.4 % of the total flux reaching the ground. Here the total flux is the sum of the diffuse and direct components.
2.6. NEED FOR AN IDEAL SYSTEM FOR SOLAR UV-B MEASUREMENT:

**Critical parameters in the measurement of UV with a spectroradiometer:**

One of the most accurate methods to measure solar UV radiation is using a spectroradiometer. An internal standard calibration lamp source that has solar simulated output pattern within the radiometer helps to calibrate the system on line and automatically. The output is given in terms of $W/$sq.cm/nm, the absolute units. The dynamic range of the system must be linear over at least 5 decades (orders of magnitude). The half bandwidth of the monochromator must be narrow in the region where the solar flux is changing rapidly with wavelength. Since the spectral output of the sun changes with time, scanning time must be minimized. For the UV-B range, 1 data point per second or per nm is sufficient to have a good resolution.

In order that the spectroradiometer maintains the calibration for both wavelength and spectral irradiance response over prolonged periods, temperature stabilization and auto zeroing of the dark current are essential. For wavelength calibration, it is essential to maintain the lamps irradiance level within $\pm 1\%$ of the standard source.

In the input optics for global solar spectral irradiance, the input and the collecting optics must have a good cosine response. In addition, the diffuse radiation produced by Rayleigh scattering is polarized, with the degree of polarization depending on the scattering angle. Therefore,
the collecting optics must also serve as a depolarizer. Transmitting type cosine diffusers are available commercially. However, integrating sphere is the most efficient. A properly designed integrating sphere with highly diffuse reflection inside will serve as a nearly perfect cosine collector and will also depolarize the incident radiant flux. However, the overall efficiency of throughput of an integrating cosine collector is very low. With or without the integrating sphere attached to the monochromator, the attenuation of the detector signal from a point source may be as high as 1 : 1000.

Since solar spectral measurements are done, as a rule, in a non-laboratory environment, the automated spectroradiometer should be: (1) portable with power backup, (2) capable of field calibration checks for wavelength and electro optical system and (3) a stand alone system.

Without the input optics and the integrating sphere, a double grating monochromator can be used to measure the direct component of the solar radiation reaching the earth's surface. The direct component measurements at close spectral resolution with increasing path (solar zenith) will help to determine minor species in the atmosphere with relatively good accuracy.