Sunlight and Solar Cells: Teaching digital design and communication through the development of a simple monitoring station

By Nathan Downs and Alfio Parisi

A method is described for building a cost effective digital circuit capable of monitoring the solar radiation incident upon a remote solar cell. The circuit is built in two sections, the first, digitises the analogue voltage produced by the solar cell at a remote location and transmits the received signal to the second receiver circuit which relays the information to a computer for storage. The activity introduces students to simple programming techniques required to communicate with a computer serial interface, and to analyse binary signals for accurate interpretation of the induced solar cell voltage resulting from exposure to sunlight. The activity can be extended by investigating the influence of solar cell tilt angle with respect to solar position, studying the effect of seasonal solar altitude differences and noting the effect of cloud on the radiation received. The completed project provides schools with their own solar radiation monitoring station which can be used for future studies of weather and climate.

Introduction

Solar cells are specialised semiconductor devices. The physics of a simple solar cell is very similar to that of an ordinary signal diode operated in the reverse bias condition. Like diodes, the simple solar cell consists of n-type semiconductor material that contains an excess of electrons and a p-type material which has excess space for electrons or positive 'holes' which can be occupied by electrons. The holes of a p-type semiconductor effectively represent free positively charged regions that can move about the p-type semiconductor material. When p-type and n-type semiconductor materials are joined together, they create a junction which experiences a charge distribution between the two layers. When connected over a potential difference or voltage source like a battery, the p-n junction is said to be forward biased when excess electrons can pass through the p-n junction from the n-type material to the p-type material (Cutnell & Johnson 1998). If a p-n junction is connected to a battery or voltage source so that the free electrons of the n-type material and holes of the p-type material move apart from one another, the junction is said to be reversed biased. Solar cells are designed to operate under this condition. The p-n junction of a simple solar cell consists of n-type semiconductor material underlying a thin p-type material. In the presence of sunlight, solar radiation can ionise atoms creating additional 'holes' in the p-type material setting up a potential difference between the n- and p-type semiconductor materials. This potential difference operates as a voltage source in a similar manner to a battery when connected into a circuit. Typically the potential or voltage produced by a solar cell is very small, therefore several individual cells are connected in series to develop solar cell arrays capable of producing greater voltages than can be produced individually (Cutnell & Johnson 2004).

The power generated by a solar cell array is dependent upon the sunlight energy that is normally incident upon the solar cell array per unit time. The power produced by the solar cell is also affected by the intensity of the sunlight, which is a measure of the sunlight power per unit area (W m^{-2}). The energy captured by the solar cell array per unit time (power), provided the solar cell is resting on a horizontal plane can be expressed as (Giambattista et al. 2004):

$$P = A\, I \sin \theta \qquad (1)$$

where, P is the power of the sunlight captured by the solar cell array of surface area, A. I is the intensity of the incoming sunlight, and θ is the incident angle of the incoming sunlight relative to the horizontal plane (figure 1). In reality however, solar cells do not convert all sunlight energy incident upon the cell into electrical energy. Solar cell efficiencies are typically in the order of 10-15%, with the efficiency decreasing with rising temperature (Meneses-Rodríguez et al. 2005) and reaching a maximum of approximately 25% for most types of high performance cells (Green et al. 2006). Recent modifications to the traditional p-n junction cell including variations in p-n material layer thickness, chemical makeup, layer stacking and local light concentrators (Goetzberger et al. 2002) have resulted in increasing solar cell efficiencies, making the use of solar cells more economically viable for the production of electricity.

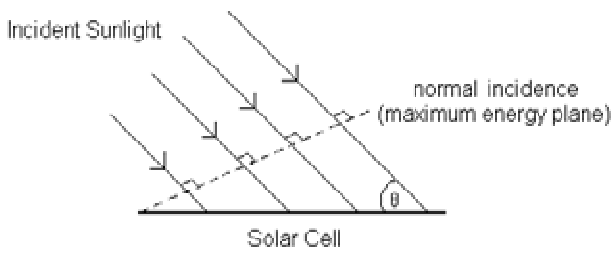

Figure 1: The energy captured by a solar cell depends on the intensity of the sunlight and the angle at which sunlight is incident upon the cell. The maximum energy is received when the sunlight is normally incident to the solar cell. The plane of maximum energy capture moves throughout the day as the sun traverses the sky.

Studies of renewable energy and energy sustainability are common in senior and junior school science. Studies of solar energy and an understanding of electrical energy produced from solar cells are particularly well suited to renewable and sustainable energy topics, especially in Australia which experiences a high number of sunshine days at low geographic latitude, increasing the solar energy received due to the high incidence angles of the sun for much of the year. Geographic latitude strongly influences the energy received by a solar cell, especially when that cell is placed on a horizontal plane. Sunlight that is incident from a low elevation angle is subject to absorption from an increased atmospheric path and is therefore influenced more strongly by cloud, air, aerosols, dust and other particulate matter which can absorb and scatter the direct incoming beam. Although some energy can be received by a solar cell array from scattered skylight, solar cells employed for the production of electrical energy are typically oriented toward the northern sky (southern hemisphere) and tilted where possible to receive the greatest proportion of normally incident sunlight.

Students completing the activity described here will build their own inexpensive solar cell monitoring station which can be used in the study of renewable energy and for monitoring local cloud conditions over daily and seasonal cycles. The activity integrates studies of digital electronics, communications and environmental science.

Materials

Students will need to have some technical competency in manufacturing circuits, using soldering irons, reading integrated circuit pinouts and resistor labels etc in order to assemble their solar cell monitoring station. Having a solid foundation in computer programming would also be of advantage although is not necessary to gain the maximum benefit from the activity. All computer code, written in *Qbasic*, is provided as an appendix to this article. Building electronic circuits requires patience and a great deal of care in order to achieve the desired result. Students should thoroughly test for the correct operation of the circuit indoors using a lamp to monitor digital output signals to ensure correct operation once the circuit has been assembled and connected to a computer serial port. Students should also check each connection carefully for loose wiring, short circuits or loose joints before locating the solar cell monitoring station outdoors.

The activity requires the following materials:

Monitoring station and receiver circuit

- Solar cell OR solar cell array OR photodiode
- Project box (with optional clear window) for storing electronics outside
- Small project box for storage of indoor electronics
- 2 x 9 V batteries OR 6 x 1.5 V batteries in triple battery packs OR alternative 2 x 5 V power source for electronics
- Electronic kit breadboard and wire OR project-board, wire and soldering kit
- 4 strand cable (long enough to connect to the remote monitoring station)
- 548 Analogue to Digital Converter (548 ADC) integrated circuit (IC)
- PIC08 programmable IC OR 555 astable timer OR suitable oscillator
- 2 x DS8921 RS422 line driver ICs
- 2 x 7805 voltage regulator if using 9 V batteries
- 8 pin computer serial port connector
- Electrolytic capacitors (2500 μF, 0.22 μF)
- 1% tolerance resistors (47 Ω, 120 Ω , 22 k Ω , 10 k Ω, 3 x 100 Ω)

Other materials

- Computer terminal with available serial port
- Qbasic
- Multimeter

The materials required to build the solar cell monitoring station are inexpensive and readily available from electronics suppliers. Components of the monitoring station including the project boxes, breadboard, wire, resistors, capacitors and solar cell array were sourced from Dick Smith Electronics (2009); the DS8921 line drivers and 548 ADC were sourced from Farnell (2009). A PIC08 starter pack including the PIC08 chip and development board was purchased from Wiltronics Research Pty Ltd (2009) for $35. The complete monitoring station was built for under $65 with the most expensive components being the solar cell array at $15 and the PIC08 starter pack and development board. The cost of building a solar cell monitoring station can be reduced if schools have an existing PICAXE development proto board or use an alternative microcontroller clock source including a 555 timer or crystal oscillator circuit. The solar cell itself may also be replaced with a photodiode to reduce costs. A photodiode version of the solar cell monitoring station is currently used to monitor cloud cover changes at the University of Southern Queensland.

Circuit Design

The circuit diagram of the remote solar cell transducer and digital receiver is shown in figure 2. Both circuits are connected by 4-strand cable extending the required length from the storage computer to the remote solar cell monitoring station. The RS232 connection shown for the logger computer serial interface circuit is a three strand wire connecting the receiver circuit to the logger computer. Single connecting wires are shown as either straight or connected lines. Where wires cross over each other on the diagram, a half loop is shown. Resistors are labelled and shown as small rectangular boxes in the figure. The larger figure boxes are the circuit ICs inside which are the pin leg numbers for respective connecting wires. Those not familiar with reading IC pinouts should refer to the IC data sheets typically supplied with the IC chips when ordered, otherwise pinouts are labelled leg 1 through leg 4 top to bottom on the left side of the chip and 5 through 8 from the bottom to the top on the right side of the chip, where the chip top is normally defined by a small groove or cavity cut into the IC.

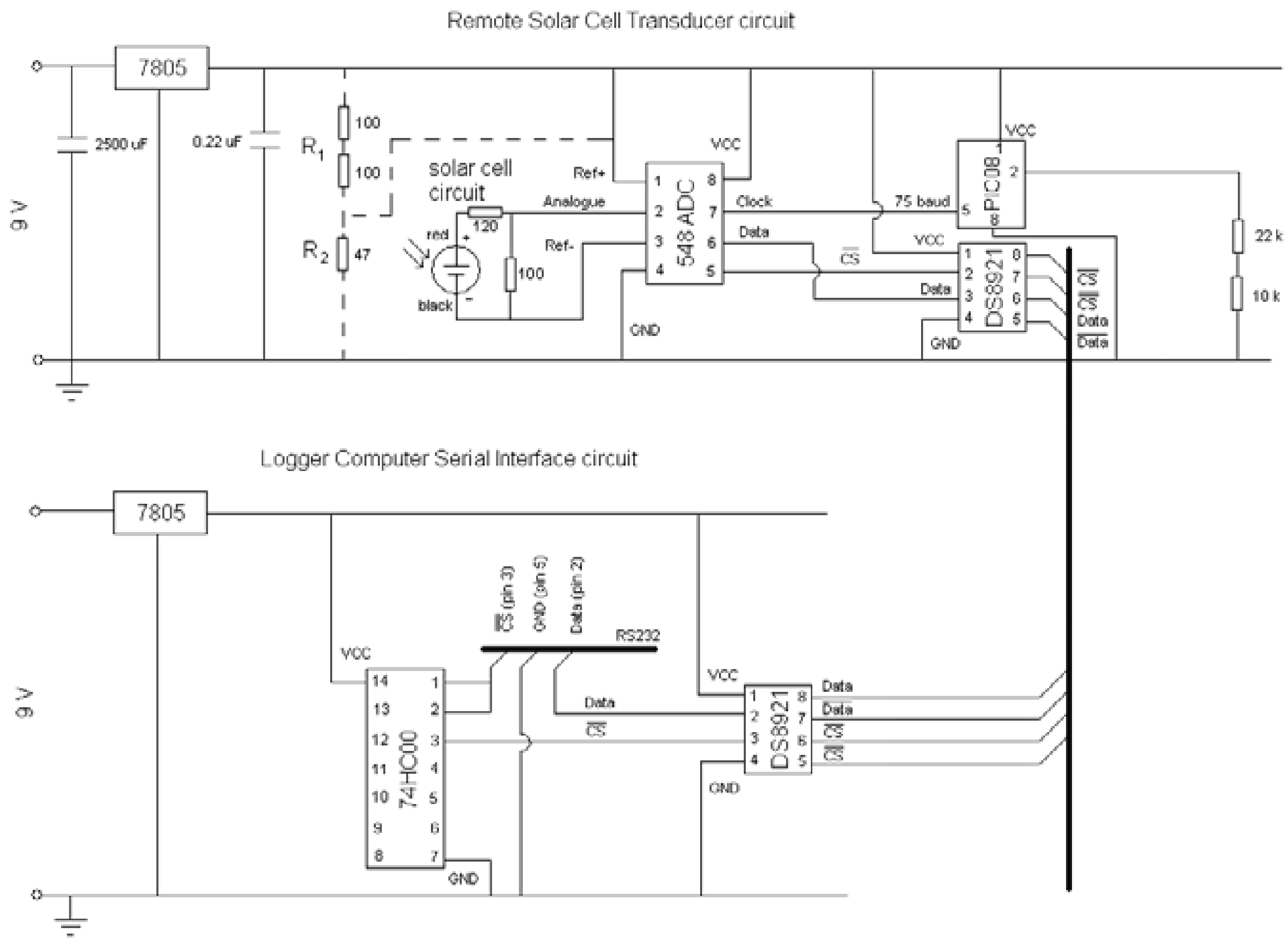

Figure 2: Circuit design and wiring diagram of the solar cell monitoring station.

Methods

Following are the steps required to manufacture the complete solar cell monitoring station:

1. The external solar cell circuit

In order to convert the analogue output of a solar cell into a digital signal, the maximum output voltage of the cell needs to be determined. Typically, the maximum output voltage will be stated by the manufacturer of the solar cell, however individual cells will produce slightly different voltages depending on their individual characteristics. Furthermore, different solar cells will output different maximum voltages (and currents) under the same lighting conditions depending upon the semiconductor design, the number of individual cells in each array and in the case of output current, the load that the cell is required to drive. For the project outlined here, the solar cell is not required to drive a current thirsty load, but simply provide an output signal that can be monitored. To maximize the sensitivity of the solar cell receiver, the solar cell can be set up to an external circuit that drives a nominal 100 ohm load resistor (figure 2 and 3). The voltage produced by this external circuit will depend upon whether cloud is covering the sun and the position of the sun in the sky relative to the solar cell.

The solar cell monitoring station can be tuned to the maximum level of solar radiation it will receive in order to monitor the daily incident solar radiation, providing a daily solar energy curve. The maximum output voltage of the solar cell array will depend on the physical light conditions at the time of testing, therefore it is suggested the voltage of the solar cell array be measured near midday and with the solar cell pointed directly toward the sun while unobstructed by cloud. This voltage can be measured by placing a voltmeter in parallel with the external solar cell circuit (figure 3). For the solar cell monitoring station developed for this article, the maximum voltage was measured at 0.95 V near midday.

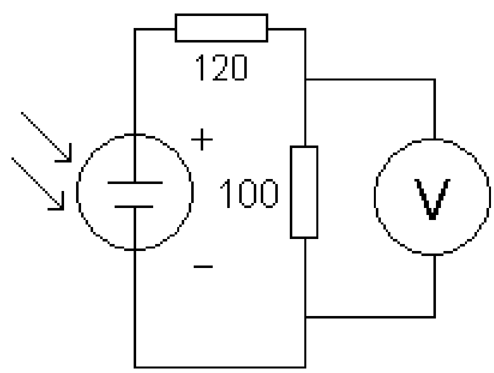

Figure 3: The maximum output of the external solar cell circuit is first measured by placing a voltmeter in parallel with the load resistor. Placing your hand over the cell should show that the cell is working correctly by noting an immediate drop in the output voltage.

2. Building a reference voltage divider

Once the maximum output voltage of the chosen solar cell has been determined, a fixed maximum reference voltage needs to be supplied to an analogue to digital converter (ADC) so that the ADC has a maximum reference level. This maximum reference level is made by building a simple voltage divider. The receiver circuit of the solar cell monitoring station is powered by a regulated 5 V supply. The voltage divider is simply 2 resistors connected in series across the 5 V supply, whereby the reference level is set to the maximum voltage measured by the solar cell circuit in step 1. Using the voltage divider formula (equation 2), two resistors of the appropriate resistance can be selected to closely match the maximum reference level produced by the external solar cell circuit:

$$V_{ref} = \frac{R_2}{R_1 + R_2} V_{cc} \qquad (2)$$

where V_{ref} is the reference voltage of the external solar cell circuit, Vcc is the supply voltage which is set at 5V, R_1 is the resistor connected to the supply line and R_2 is the resistor connected to ground. The divider designed for the tested solar cell has values of 47 Ω for R_2 and 200 Ω for R_1. The value of each resistor can be chosen by trial and error until the reference value of the divider matches as closely as possible the maximum output voltage of the solar cell. Alternatively, the exact resistances required in the voltage divider can be built up by connecting additional resistors in series to make the desired values of R_1 and R_2. The voltage divider shown in figure 2 with the ADC reference line connected between R_1 and R_2 uses a single 47 Ω resistor for R_2 and two resistors of 100 Ω each to make the required resistance for R_1 such that the output reference is set at 0.95 V. Variations in the tolerance of each resistor will also affect the voltage divider reference level, therefore a little trial and error may be required to tune the reference level to the exact maximum solar cell output if so desired. However, for the purposes of the overall circuit design it is not essential to match the reference level exactly to the maximum solar cell output. The maximum reference line of the ADC can be connected to the 5V supply rail. This will limit the 0 to 255 digital range of the ADC but will be sufficient to show changes in solar energy caused by changing solar elevation and passing cloud. Step 2 therefore is not necessary for the correct operation of the solar cell monitoring station but demonstrates one practical use of the voltage divider law, commonly applied in senior physics courses. The optional voltage divider is shown by hatched lines in figure 2.

3. Setting up the ADC

The ADC is required to digitise the analogue solar cell voltage so that it can be read and stored by a computer. The solar cell monitoring station uses an 8-bit ADC. This means that the ADC can convert the solar cell output voltage to levels in the range between 0 and 255. In order to understand why this is so, some knowledge about the structure of a byte and digital communication is required. Essentially, the digital data received by the computer will be read as single bytes of information by the logger computer. A byte of digital information is a series of binary numbers listed from the least significant binary digit (LSD) to the most significant binary digit (MSD). Each digit has a weighting from 1 to 128. As an example, the weighting from the LSD to the MSD of the digital number 191 is shown in figure 4. Each of the digits in the 8-bit byte are sent along the data communication line from the ADC to the computer as pulses (digital 1's) or spaces (digital 0's). An oscilloscope attached to pin 6 of the 548 ADC will show the output data pulses. For the case shown in figure 4, eight pulses are sent in succession, these represent the digital level 191 out of 255 which is calculated by the computer as: (1x1)+(1x2)+(1x4)+(1x8)+(1x16)+(1x32)+(0x64)+(1x128) = 191.

1	1	1	1	1	1	0	1
1	2	4	8	16	32	64	128
LSD							MSD

Figure 4: The 8-bit digital level 191 sent down a communication line as eight pulses from the LSD to the MSD.

From figure 2, the maximum reference level of the ADC was set at 0.95 V (pin 1 REF+) and the minimum level is set at 0 V (pin 4 GND). Therefore if the ADC receives 0.95 V from the solar cell circuit it will convert the cell voltage to the digital level 255. Similarly, if no sunlight reaches the solar cell, the voltage will be converted to the digital level 0. A total of 256 discrete sunlight levels can be recorded by the solar cell monitoring station. To read these levels the logger computer interrogates the ADC at frequent intervals. For the solar cell monitoring station, the ADC is interrogated approximately every second. The ADC responds when interrogated by sending the digital solar cell voltage level stored on the ADC chip from the previous interrogation. Thus there is an approximate 1 second lag in the system, which for most purposes will be acceptable. The digital sunlight level sent from the ADC is sent down pin 6. The signal requesting the sunlight level from the computer is sent to the ADC through pin 5. This is called the 'chip select not' signal and is given the logic notation $\overline{CS}$ which denotes that the ADC chip is selected (or interrogated) to send its stored digital level when the chip select line voltage drops from a logic 1 to a logic 0. This can also be monitored with an oscilloscope attached to pin 5 of the 548 ADC. On the interrogation signal, the ADC sends its digital sunlight level at a pulse rate determined by an external timing chip. This is the clock speed of the data communication line. The clock speed is determined accurately by a PIC08 microcontroller unit set up as an oscillator (figure 2). The clock speed of the solar cell monitoring station is set at 75 baud, which simply means the data is sent down the communication line at the rate of 75 pulses per second. In order to achieve 75 baud, bits need to be clocked out of the ADC at the rate of 75 bits per second, where for this project there are no stop or parity checking bits in the data stream. Therefore, the PIC08 shown in figure 2 is programmed to a pulse frequency of 75 Hz. The PIC08 chip is a versatile unit that can be programmed to do a number of jobs. These chips and the development kit supplied in the PIC08 starter pack are easily programmable and come with good documentation enabling students to develop their own microcontrollers in a relatively short time. They are therefore recommended for this project but are not essential. Alternative oscillation circuits including 555 timers may be designed to operate with the solar cell monitoring station.

4. Line drivers

If the distance between the solar cell monitoring station and the logger computer were small, the output of the ADC could be linked directly to the serial port of the computer. However, most stations will be located well away from their logger computer, therefore a set of communication line drivers need to be employed to boost the ADC and computer control signals along the communication line. The drivers used for the solar cell monitoring station are the DS8921 ICs. These line driver chips are capable of sending and receiving digital information over hundreds of meters of cable length. The line drivers are each connected to four separate strands of a 4 strand communication line. Two lines are dedicated to sending ADC data and another two are dedicated to transmitting the logger computer signal. To ensure no errors have occurred along the communication line, the line drivers send the actual signal and the inverted signal at the same time down the line so that when the signal is received it is checked with the inverted signal line by the receiver in the line driver pair. An error occurs if the signals match and this information is not then transmitted to either the ADC in the case of the $\overline{CS}$ signal or the logger computer in the case of the solar cell digital level.

5. Serial interface circuit

A small serial interface circuit needs to be built to power the logger computer line driver and logic gates used by the computer serial port. This circuit consists of a 5 V voltage regulator, a series of logic NAND gates, and the logger computer line driver. The logic NAND gates are used to invert the computer ADC interrogation signal into the $\overline{CS}$ required by the ADC at the solar cell end of the monitoring station. All communications between this IC and the line driver are sent through the computer's serial port (COM 1) using the RS232 serial communications protocol. The pinouts of serial plug connectors are labelled clearly with small numbers printed next to their respective pins. In order to use this protocol correctly, the output ADC interrogation signal must be connected to pin 3 of a standard 9 pin serial plug connector. The input ADC data line must be connected to pin 2 and pin 5 should be connected to the negative terminal (ground) of the serial interface 7805 voltage regulator (figure 2). The solar cell monitoring station was also found to perform well if the signal ground was not connected.

Overview of circuit operation

The complete interrogation and data response cycle of the solar cell monitoring station can be followed in seven steps:

1. The controlling software sends an active $\overline{CS}$ through the RS232 serial port on the logger computer as an active high or $\overline{\overline{CS}}$ (Chip Select NOT NOT) to request the solar cell voltage.
2. This ADC control pulse is then inverted to a standard $\overline{CS}$ signal by the cross connected 74HC00 NAND gates of the serial interface circuit.
3. The $\overline{CS}$ control signal is then sent to the line driver pair (which utilise the control signal ($\overline{CS}$) and the inverted control signal ($\overline{\overline{CS}}$).
4. The signal is transferred over the communication line to the solar cell transducer circuit to the 8-bit ADC to request the current solar cell voltage level.
5. The sample taken on the previous control request (which occurs approximately 1 second before the current request) is clocked out on the ADC data line.
6. The 8-bit sunlight level (0-255) is transmitted as a single data byte through the line driver pair at 75 baud (again as a true and inverted signal) which is then received by the serial interface circuit and sent via the RS232 link to the logger computer.
7. The logger computer stores the received sunlight energy as a digital sunlight level.

Monitoring station control and storage software

Sunlight exposure level data is stored on the logger computer as a series of daily text files in the format yyyymmdd.dat. The text files contain the date and time the solar cell level was recorded and the sunlight level from 0-255. To ensure consistency of the data stream the 548ADC ref+ line can be connected to the 5V supply rail rather than a voltage divider. In this way the maximum analogue output of the solar cell will not approach more than half of the 5 V maximum reference level so that if a signal greater than 128 is received by the logger computer, it will be known to have been caused by a communication synchronisation error and can be ignored. Thus, the MSD (128) can be set up to act as an error checking bit. This protocol was used for the solar cell monitoring station *Qbasic* code provided in the appendix to this article. The storage location of the data files produced by the logger computer code is 'C:\Solar'. This directory needs to be created for the computer program listed in the appendix to work correctly. Daily sunlight levels can be opened with spreadsheet software to graph sunlight levels with the time of day.

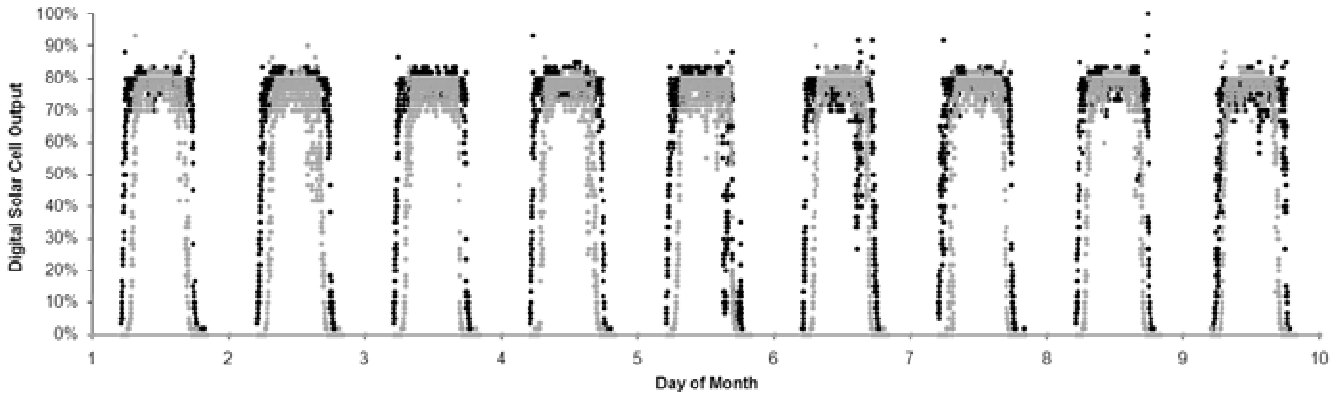

Figure 5: Digital sunlight level measured in Toowoomba and plotted as a percentage of the maximum digital solar cell level for the first 10 days of June 2009 (grey points) and the first 10 days of November 2009 (dark points). Shorter days in June limit the daily period over which the solar energy is received.

Results

Monitoring sunlight level

Digital sunlight levels were recorded over a period of several weeks with the solar cell array placed inside a sealed environment proof box with the solar cell array placed facing directly upward. This information provides a daily record of the change in sunlight level on a horizontal plane provided the solar cell array is placed on a flat outdoor surface (figure 5). The changing position of the sun and cloud cover is also clearly visible for a daily record. Figure 6 shows the plotted sunlight level recorded on 1 February 2010. Low sunlight levels are recorded at the beginning and end of each day due to the low vertical component in the sunlight incident at grazing angles to the solar cell array.

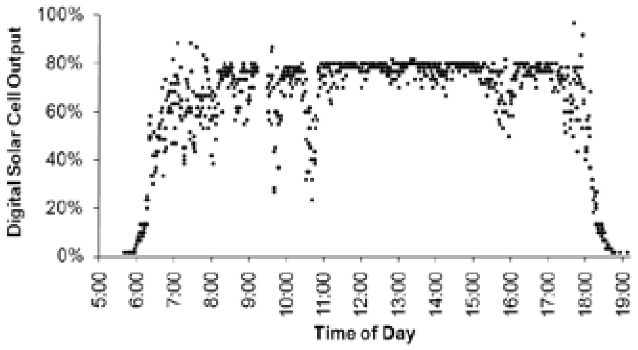

Figure 6: Digital sunlight level measured in Toowoomba and plotted as a percentage of the maximum digital solar cell level for 1 February 2010. Data provided by the solar cell monitoring station can be used to determine periods of maximum sunlight intensity, monitor daily cloud coverage and to study seasonal differences in available sunlight energy. Heavy cloud periods are shown in this daily plot before 10:00 am, 11:00 am and at 4:00 pm.

Optimising the solar cell for maximum power output

Given that the power generated by a solar cell is dependent upon the intensity and angle of incidence of the sunlight, students may find it valuable to optimise the power output of their chosen cell. In order to achieve this, students will need to find the optimum angle at which to face their solar cell with respect to the horizontal so that the cell is exposed to the greatest amount of normally incident solar radiation. For schools located in the tropics the sun will reach the zenith, therefore a solar cell inclination angle of 0˚ will likely produce the best results for much of the year. Schools located further south will find the solar cell will need to be orientated at a steeper angle of inclination to maximise the total energy received throughout the day. A simple experiment that can be performed requires setting the solar cell array at set angles of inclination over several days and recording the daily sunlight level. The total solar energy received by the solar cell is represented by the area under the curve of the digital solar sunlight level versus time. A comparison of several daily sunlight levels each measured at different cell angles of inclination will tell students what the optimum angle of inclination is for their location provided conditions are similar during each successive tested inclination angle. The process could further be repeated for the summer, winter and spring / autumn seasons to determine optimum angles of inclination for each respective season.

Discussion

A method has been described for building a cost effective remote solar cell monitoring station. Additionally, two simple methods have been described for measuring the daily solar cell energy output and optimising this output for different tilt angles of a solar cell. Schools can use the solar cell monitoring station to integrate teaching and learning of digital design and communications to aid studies of environmental science. The complete station will provide a resource which can be mounted in an outdoor environment to monitor the solar radiation for an extended period which will further provide an ongoing scientific data set which may be used to complement other weather and climate monitoring stations. This article is intended as a reference for building a complete solar cell monitoring station. Students and schools may find modifying the hardware or attached code a worthwhile educational exercise and are encouraged to do so to meet their specific needs.

For science teachers, the methods presented in this article provide an opportunity to study solar cell electronics and the physics of radiative energy transfer. Simple experiments can be performed to investigate solar cell output by connecting a multimeter to a cell and noting the influence of tilt angle, cloud cover and general cell shading. The influence of the irradiating solar beam can be studied with respect to the trigonometric sine ratio for sunlight incident at increasing angles to the horizontal plane (equation 1). Comparing the power output of a solar cell placed on a horizontal plane and monitored throughout the day, with the ideal sine response will show the influence of increasing atmospheric absorption. The power converted by a solar cell can be studied with respect to the area of the cell exposed to sunlight (equation 1). These activities can be performed without the need to develop a student's understanding of digital communication electronics. However, the methods presented provide an additional opportunity to integrate studies of electronics and communication technologies with studies of solar cell and atmospheric physics. Often, scientists work as instrumentation engineers, calibrating and maintaining equipment necessary for their chosen field of research. The project presented provides students with the opportunity to develop these practical skills.

Currently, the solar cell monitoring station is being integrated into the senior physics final year assessment program as a possible extended experimental investigation for students at Hervey Bay state high school, Queensland. These research tasks are open ended investigations intended to provide students with the opportunity to demonstrate technical research investigation and reporting skills. The presented solar cell monitoring station design provides a framework from which senior students can develop electronic design, weather and climate, solar energy, and data analysis investigation techniques.

Acknowledgement

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Appendix

SolarCell.bas:

```
'Solar cell level communication program
'The program reads the solar cell level between 5am and 8pm
'Solar cell levels are read on serial port 1 (COM1)

CLS
count = 0 'total samples received from the solar cell
ini = 0 'a returned solar cell level

OPEN "COM1:75,N,8,1,ASC,CD0,CS0,DS0,OP0,RS,TB2048,RB2048"
FOR RANDOM AS #1

DO
  goi$ = LEFT$(TIME$, 2)
  IF goi$ = "20" THEN
     GOSUB sleepy 'program goes into sleep mode at night
  END IF

     COM(1) ON
     rep = 0
     DO UNTIL rep = 1
       OUT &H3F8, 0 'send a chip select signal to read the ADC
       ON COM(1) GOSUB rit
       FOR k = 1 TO 500000
          REM a simple delay between chip select signals
       NEXT k
  LOOP
LOOP

rit:

 'this subroutine converts the decimal response on the serial port to
a binary solar cell level for error checking
ini = INP(&H3F8)
m1 = ini / 2
m2 = FIX(m1)
IF (m1 - m2) > 0 THEN
  b1 = 1
ELSE
  b1 = 0
END IF

m2 = m2 / 2
m3 = FIX(m2)
IF (m2 - m3) > 0 THEN
  b2 = 1
ELSE
  b2 = 0
END IF

m3 = m3 / 2
m4 = FIX(m3)
IF (m3 - m4) > 0 THEN
  b3 = 1
ELSE
  b3 = 0
END IF

m4 = m4 / 2
m5 = FIX(m4)
IF (m4 - m5) > 0 THEN
  b4 = 1
ELSE
  b4 = 0
END IF

m5 = m5 / 2
m6 = FIX(m5)
IF (m5 - m6) > 0 THEN
  b5 = 1
ELSE
  b5 = 0
END IF

m6 = m6 / 2
m7 = FIX(m6)
IF (m6 - m7) > 0 THEN
  b6 = 1
ELSE
  b6 = 0
END IF

m7 = m7 / 2
m8 = FIX(m7)
IF (m7 - m8) > 0 THEN
  b7 = 1
ELSE
  b7 = 0
END IF

m8 = m8 / 2
m9 = FIX(m8)
IF (m8 - m9) > 0 THEN
  b8 = 1
ELSE
  b8 = 0
END IF

ini = b8 * 1 + b7 * 2 + b6 * 4 + b5 * 8 + b4 * 16 + b3 * 32 + b2 * 64 +
b1 * 128
IF b1 = 0 THEN 'the program will not record solar cell levels > 127
decimal or 0 solar cell levels
  IF ini <> 0 THEN
     REM IGNORE 0 SOLAR LEVEL AS CAN BE A COMMS ERROR
     count = count + 1
     PRINT " ", ini, count
     m5$ = MID$(DATE$, 1, 2)
     d5$ = MID$(DATE$, 4, 2)
     y5$ = MID$(DATE$, 7, 4)
     nameFL$ = "c:\solar\" + y5$ + m5$ + d5$ + ".dat"
     OPEN nameFL$ FOR APPEND AS #2
     WRITE #2, DATE$, TIME$, ini
     CLOSE #2
  END IF
END IF
rep = 1 'mark solar cell circuit ADC response as true
RETURN

sleepy:
'This subroutine sends the communication program to sleep
between 8pm and 5am
TIMER ON
WHILE goi$ <> "05"
  startT = TIMER
  WHILE timerT < 60
     timerT = TIMER - startT
  WEND
  goi$ = LEFT$(TIME$, 2)  'check the time every minute until 5AM
WEND
TIMER OFF
timerT = 0
RETURN
```

TS