Assembly and Operating Manual

Introduction

The SDL-1 Solar Data Logger is a self-contained solar energy meter that measures the sun's irradiance at regular intervals for up to 170 days at a time. It has a weatherproof enclosure that allows it to function reliably in a wide variety of weather conditions. It is powered by a standard 9V alkaline battery and has a typical battery life in excess of two years. A USB interface allows data to be offloaded to a computer for analysis. The communications program HyperTerminal (standard on Windows based computers) or any serial capture program can be used to capture logged data to a text file. The data can then be analyzed and plotted using a spreadsheet program.

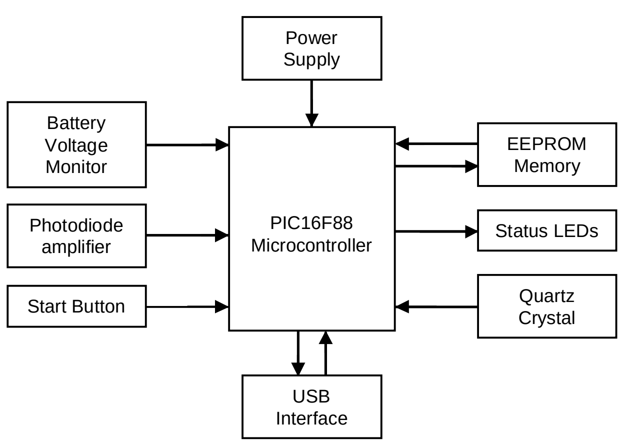
The SDL-1 quantifies the amount of solar resource available at a given location by continuously measuring and recording solar insolation. While historical insolation data is available at various locations, it is usually reported as an average value taken over a long period of time. The SDL-1 provides actual solar insolation data for a specific site for the time period over which the data logger is deployed. The logged data quantifies how much energy could be produced by a solar power system. The data can also help determine the best location and optimal tilt for an array of solar panels. Once a system is installed, the SDL-1 is further useful for monitoring system performance.

Features

- Measures solar irradiance (W/m^2)
- Measures cumulative incident solar energy (kWh/m^2)
- Logs data for up to 170 days
- Irradiance measurement accuracy: ± 5%
- Simple operation
- Weatherproof enclosure
- USB interface
- Long battery life (2 years at 25ºC)
- Built-in battery voltage monitor

Circuit Description

The core of the data logger consists of a PIC16F88 microcontroller from Microchip which contains the firmware that handles computation, timing, and input/output functions. The microcontroller contains an internal oscillator, several digital input and output lines and a multiple channel 10-bit A/D (analog-to-digital) converter. Peripheral components connect to the microcontroller as shown in the diagram below.



Block diagram of the SDL-1 solar data logger.

Each section of the circuit will now be described. Refer to the SDL-1 schematic on pages 20 and 21.

The mode switch (SW1) selects the operating mode as well as the power source. With SW1 in the LOG position the circuit is in data logger mode and is powered by the 9V battery B1. The battery powers the LM2936M-5.0 voltage regulator (U3) to provide a stable 5V output voltage for the microcontroller and peripherals. The battery voltage must be above 6V to maintain proper regulation. A new battery should be installed when the battery voltage falls below 6V. With SW1 in the XFER position, the circuit is in data transfer mode and power is derived from the USB port.

The battery voltage monitor circuit consists of op-amp U2B and several resistors. This circuit keeps track of battery voltage while the data logger is in operation. R4 and R5 form a voltage divider that divides the battery voltage by two. Resistor R6 protects the non-inverting input of the op-amp. Op-amp U2B is configured as a unity gain buffer to convert the high-impedance input to a low-impedance output. The output of the op-amp is connected to the microcontroller's AN0 A/D input. The battery voltage is computed as $V_{BATT} = 2 * V_{AN0}$.

The BPW34 silicon photodiode (D1) measures the intensity of incident solar radiation. This photodiode is a good detector of sunlight because its range of spectral sensitivity is from 400nm to 1100nm and overlaps the solar radiation spectrum from about 300nm to 1800nm. Also, the short-circuit current of the photodiode is directly proportional to the intensity of incident radiation. When the incident radiation intensity is 1000 W/m^2 photodiode D1 produces a short circuit current of approximately 2.64 mA. This current is applied to current sense resistors R30 and R31 to produce a voltage of 81.8 mV. This voltage is too small to be read directly by the microcontroller's A/D converter so it is first amplified by non-inverting op-amp U2A. The end result is that the incident solar radiation intensity is related to the voltage at the microcontroller's AN1 A/D input by

$$P_{sun} = 303.7 * V_{AN1}$$

where P_{sun} is the solar radiation intensity in W/m^2 and V_{AN1} is the AN1 A/D input voltage in volts. The upper limit for V_{AN1} is 5 volts which corresponds to a maximum measurable solar radiation intensity of 1520 W/m^2.

With the mode switch in the LOG position, pressing the start button (SW2) starts the data logger. The data logger continues to take readings at regular intervals until either the memory is full or the mode switch is changed to XFER.

The 24LC256 serial EEPROM (U5) provides 32 kbytes of non-volatile memory for the storage of radiation intensity readings. This device connects to the microcontroller by way of a 2-wire serial interface using the I^{2}C^{TM} protocol. Each reading occupies 2-bytes of memory and up to 16,320 readings can be stored.

Two status LEDs are provided to indicate various states of the data logger. While in data logger mode, pressing the start button causes the red LED (D21) to blink five times to indicate the start of data logging. While in data transfer mode the green LED (D31) turns on to indicate that the USB port is connected. Also, the red LED turns on when USB data transfer is occurring.

Accurate timing is provided by the 32.768 kHz quartz crystal X1 and associated load capacitors C11 and C12. This crystal provides a one second time base with an accuracy of +/- 20ppm, allowing the microcontroller to keep track of elapsed time in seconds.

The USB interface is handled by the FT232RL USB to serial UART integrated circuit (U1). This IC is compatible with both USB 1.1 and USB 2.0. A standard USB A-B cable is used to connect the SDL-1 to a host computer. With this interface, data is transferred at a rate of 57,600 baud, allowing quick transfer of logged data. The USB interface is also used to configure the various SDL-1 setup parameters.

In operation, the FT232RL first initializes the USB connection and then turns on the p-channel MOSFET (Q1) to power the rest of the circuit. Transistor Q4 and resistors R12 and R13 make up a "USB detect" circuit that monitors the status of the USB connection. Transistors Q2 and Q3 invert the transmit and receive signals between the microcontroller and the FT232RL.

Kit Assembly (kit version only)

The following tools will be needed to assemble this kit:
- Soldering iron (25 to 30 Watt)
- Solder (see guidelines above)
- Tweezers (to handle surface mount Devices)
- Diagonal cutters

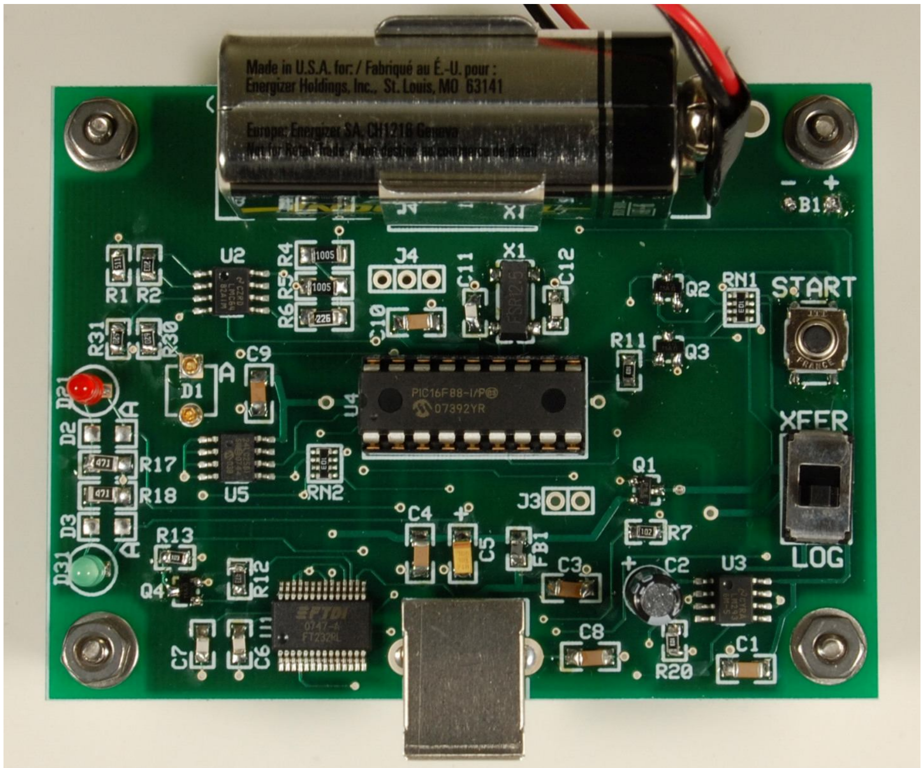
The following tools are also useful:
- Magnifying glass
- Digital multimeter
- Desolder braid (for removing solder if necessary)
- Needle-nose pliers

Circuit Board Assembly

Guidelines for circuit board assembly

- Place components on the top side of the printed circuit board (identified by the white markings).
- Use a fine-tip 25 to 30 W soldering iron.
- Use IC-grade solder – good choices are: Kester #44 (small diameter, e.g. 0.031”) or Radio Shack No. 64-005. **IMPORTANT: Do not use acid flux solder.**
- A solder joint should not be heated for more than 5 seconds at a time to avoid overheating the component.
- For components with long leads, trim excess lead length using diagonal cutters after soldering.
- Avoid electrostatic discharge. The semiconductor components in this kit are static sensitive. As a minimum precaution, touch bare metal before handling these components. A conductive wrist strap provides even better anti-static protection.

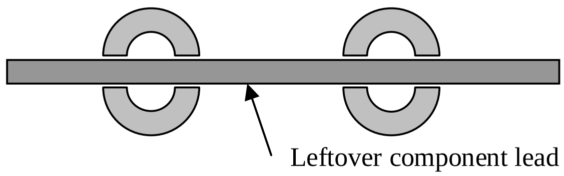
In the following assembly steps “install” means to place the component at the location marked on the circuit board and solder its leads. Components that must be installed with a specific orientation will be specified. If a step does not specify the orientation to install the part then it can be assumed that the part orientation does not matter. The finished Solar Data Logger circuit board is shown below. The schematic and component layout are on pages 19-21.



- ❑ 1. Perform an inventory of all parts in the kit (see Parts List on page 18).

- ❑ 2. The following part is orientation dependent. Locate the electrolytic capacitor marked “47uF, 25V” to be installed at C2. One side of the capacitor has a thick bar shaped feature printed on it and this side is the “-“ or negative lead. Install C2 with the “-” lead facing away from the “+” mark on the circuit board.

- ❑ 3. The following posts will be installed on the bottom side of the board (the bottom side is opposite the component side and has no component outlines). Locate the two gold plated posts to be installed next. On the bottom side of the board, insert the cup end (the non-split end) of each post into the holes at D1. **Refer to the figure below step 8.** With each post perpendicular to the board, place a leftover component lead through the pronged end of each post as shown in the figure below. Make sure the posts are parallel to each other and perpendicular to the board and solder them to the circuit board. After soldering, remove the leftover component lead from the posts. Note: photodiode D1 will be installed in a later step.



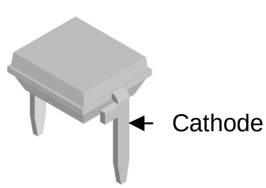
- ❑ 4. Install the USB jack at J1 on the top side of the board. Do not trim leads.

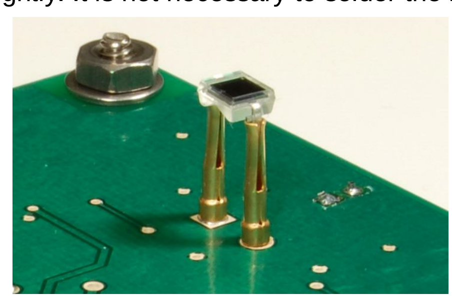
- ❑ 5. Locate the holes at B1. Install the 9V battery snap on the bottom side of the board with the black lead in the hole marked “-” and the red lead in the hole marked “+”.

- ❑ 6. The PIC16F88 microcontroller IC will be installed next. Locate the 18-pin socket at U4 on the circuit board. The notch at one end of the IC must be aligned with the notch on component outline. Also, it may be necessary to bend the leads of the IC inward slightly to fit the socket. Press the PIC16F88 into the socket. Confirm that the notch in the component outline is aligned with the notch in the PIC16F88.

- ❑ 7. Mount the 9V battery holder on the top side of the board at the location marked 9V BATT using (2) 2-56 x 3/16” machine screws, (2) #2 lock washers, and (2) 2-56 nuts.

- ❑ 8. The photodiode D1 will be installed next. Be careful not smudge the top surface of the photodiode. The lead with the notch is the cathode (see figure below). With the cathode lead facing toward the USB jack (J1), insert the photodiode into the mounting posts as shown below. If the photodiode is loose remove it temporarily and gently bend the prongs of each post together using needle-nose pliers. Reinstall the photodiode and verify that it fits tightly. It is not necessary to solder the leads.





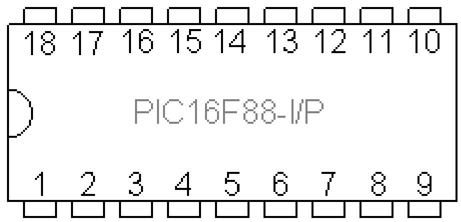
Preliminary Testing

Before installing the battery, check over the circuit board to ensure that all components are installed correctly. Verify that the electrolytic capacitor C2 has “-” in the correct position (i.e. opposite the “+” sign on the circuit board). Also verify that surface mount capacitor C5 is installed with the banded end toward the “+”

sign. Check that U4 and the diodes are installed with the correct orientation, and that the resistors and capacitors match the component outlines. Also examine all solder connections closely to look for any solder bridges or cold solder joints.

After checking over the board visually, measure the resistance between pins 14 and 5 of U4 (see pin outline for U4 below) with the slide switch in both positions (use a high-impedance ohmmeter and connect the common lead to pin 5).

U4 Pin Outline (top view)



The following table indicates the proper range of resistance values.

Mode Switch Position	Resistance between Pins 14 and 5 of U4
LOG	> 200kΩ
XFER	10KΩ (+/-1KΩ)

If a lower resistance is measured, check over the solder connections and confirm that all resistors are in the proper locations.

After verifying proper assembly as outlined above, set SW1 to XFER, install a 9V battery and then set SW1 to LOG. While watching the red LED, press the START button. The red LED should blink 5 times to indicate the start of data logging. If the LED does not blink, refer to the troubleshooting section below.

Enclosure Assembly

Pictures of the assembled SDL-1 and enclosure are on page 17. Locate the gray PVC enclosure base and cover and the remaining hardware. Place a rubber o-ring on each of the four 3/4-inch machine screws. Insert the screws into the 4 holes of the enclosure cover with the threads facing inward. On the inside of the cover, place a 3/8" metal spacer over each screw. Place a flat washer over each of the metal spacers that were just installed. Examine the 1X1 inch glass window attached to the cover. Remove any tape from both sides of the glass window. **Important:** in the next step the circuit board must be positioned so that the photodiode D1 lines up with and is facing toward the glass window on the cover. Position the circuit board over the 1-inch machine screws and spacers, making sure the photodiode is lined up with the glass window. Attach the circuit board using 4 flat washers and 4 nuts over the 3/4-inch machine screws. Tighten the nuts enough to compress the rubber o-rings by about 50 percent. Do not attach the cover to the base yet (the USB interface will be tested next).

Testing the USB Interface

The USB interface on the SDL-1 emulates a conventional RS-232 style serial port, and a driver for this interface will be installed and the program HyperTerminal will be configured. Refer to *Initial Installation* on page 14 to install the driver and configure HyperTerminal.

Load HyperTerminal using the shortcut that was created in *Initial Installation*, and type the single character command "?" in the HyperTerminal window. The SDL-1 should respond with a list of commands and other SDL-1 information. This indicates that the USB link to the SDL-1 is working and completes preliminary testing of the SDL-1. Note: a list of SDL-1 commands can be found on page 13. The operating instructions on page 6 describe how to use the SDL-1.

Troubleshooting

If the SDL-1 doesn't seem to be working, check the following:

- ❑ Check that U4 is installed correctly with the notch on the IC aligned with the notch on the circuit board. Also make sure that the IC is seated firmly in the socket and all pins are making contact.

- ❑ Make sure the USB cable is disconnected when switching from transfer mode to log mode.

- ❑ Confirm the battery voltage is at least 7V. Replace the battery if necessary.

- ❑ In log mode, check that +5 V is present between pins 14 and 5 of U4.

- ❑ In log mode, measure the current drain of the battery. The current should measure less than 20uA most of the time. When logging, the current will very briefly rise to 2 to 3 mA and then fall back to below 20 uA.

- ❑ Check the connection of crystal X1 and confirm that the correct capacitors (18 pF) have been installed at C11 and C12.

Operating Instructions

IMPORTANT:

▪ Before first use, carry out the *Initial Installation* on page 14.

▪ When the data logger is not in use, be sure to keep the mode switch in the XFER position to prevent battery drain.

▪ See page 13 for a summary of commands used to control the SDL-1.

Required Tools and Equipment:
❑ Windows based computer with USB port, USB cable, and internet connection
❑ 9V Battery
❑ Phillips head screwdriver

Overview
The Solar Data Logger is designed for easy setup and use. Data logger setup is accomplished by running the SDL-1 through a simple setup routine while it is connected to a host computer. After setup, the data logger is activated by pressing the start button and logging proceeds at regular intervals until either the memory fills up or until logging is stopped. Data is stored in non-volatile memory. If the data logger memory becomes full, the unit powers down automatically without loss of data. Data can be off-loaded to a computer at a later time. The SDL-1 has room for up to 16,318 irradiance readings (standard version) or 8,158 irradiance and temperature readings (SDL-1-TEMP version).

The SDL-1 measures solar irradiance in W/m^2 and logs this data at regular intervals. The logging interval is selectable to accommodate the desired duration of deployment. The table below shows the available logging intervals and corresponding maximum deployment durations.

Table of Maximum Deployment Duration

Logging Interval (seconds)	Max. Duration Standard SDL-1	Max. Duration SDL-1-TEMP Version
10	45.3 hours	Not available
60	11.3 days	Not available
150	28.3 days	Not available
300	56.6 days	Not available
900	170.0 days	85.0 days

The data logger reads solar irradiance every 10 seconds and computes the average irradiance over the selected logging interval. The SDL-1 can log either the average value or the instantaneous “sample” value of irradiance (selected in logger setup). The time stamp in seconds for each logged reading (relative to the first reading) is determined manually by multiplying the data index by the logging interval.

SDL-1 Controls and Indicators

▪ Mode Switch (switch labeled LOG / XFER) - controls the two basic modes of operation of the SDL-1.

LOG - *Data Logger Mode:*
This mode is used to log solar insolation data. The SDL-1 is powered by the battery in this mode.

XFER - *Data Transfer Mode:*
This mode is used to transfer data to and from the SDL-1. Single character commands are used to control the data logger. A summary of the commands are on page 13. The SDL-1 is powered by the USB port in this mode.

▪ Start Button (labeled START) – used to start data logging.

▪ Red LED – when in LOG mode, blinks five times when the start button is pressed to indicate the start of data logging. When in XFER mode, turns on to indicate when USB data transfer is occurring.

▪ Green LED – indicates that the USB port is connected.

SDL-1 Operation

<u>Step 1: Logger Setup</u>

Follow these steps to set up the data logger before deployment.

1. Remove the SDL-1 cover from its base by removing the 4 cover screws.

2. Set the mode switch to XFER. Install a 9V battery if not already installed.

3. Connect the SDL-1 to a USB port.

4. Open HyperTerminal (or other serial capture program). Use the settings described page 14.

5. Setup the SDL-1 logging parameters by typing “s” in the HyperTerminal window. (Note: the SLD-1-TEMP version has a fixed logging interval of 15 minutes and the “s” command is not necessary). Refer to the table of maximum deployment duration (above) to decide on a setting for the logging interval. Follow the prompts to set up the logging interval and data reporting type. The data reporting type should be set to “Average” for most applications. The “Sample” setting allows single reading non-averaged data to be logged.

6. Keep the mode switch in the XFER position and then disconnect the USB cable from the SDL-1. *(The mode switch must always be in the XFER position before unplugging the USB cable to prevent battery drain.)*

7. Close the HyperTerminal window.

<u>Step 2: Logging Data</u>

Follow these steps to deploy and log insolation data.

1. With the SDL-1 cover removed and the USB cable disconnected, confirm that the green LED is off. *(If the green LED is on, set the mode switch to the XFER position.)*

2. Set the mode switch to LOG.

3. Make a note of the **start time** and **date** and then press the start button. The red LED should blink five times to indicate that data logging has started. *(The start time and date will be used later to determine the time stamp for each data point logged.)*

4. Attach the cover to the base using 4 screws.

5. Deploy the data logger in the desired location.

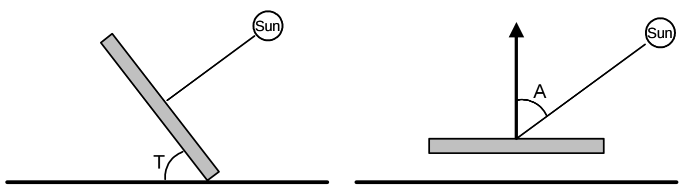
   Notes:

   Data logging proceeds until either the memory is full or the data logger is stopped. Logging is stopped by moving the mode switch from “LOG” to “XFER”. Logging will also stop if the battery is depleted. For long deployment durations it is best to use a new battery. A battery that reads less than 7V should be replaced.

   To reset the data logger without saving previously logged data, set the mode switch from LOG to XFER and back to LOG. Press START when ready to begin logging new data.

   Important: *After the data logger has been activated, data logging proceeds continuously as long as the mode switch remains in the “LOG” position. Setting the mode switch to “XFER” ends the data logging session. To avoid loss of data, the user must transfer the previously logged data to a computer before starting a new logging session.*

   The SDL-1 can be deployed horizontally flat (zero tilt angle) where logged data represents solar radiation intensity falling on a horizontal surface. Alternatively, a non-zero tilt may be used. For example, the SDL-1 can be set up with a tilt that matches that of a solar array to log the amount of solar radiation incident on the solar array.



Tilted Collector   Horizontal Collector

Step 3: Transferring Logged Data

Follow these steps to transfer logged insolation data to a computer.

1. Remove the SDL-1 cover from its base by removing the 4 cover screws.

2. Set the mode switch to XFER. *(This ends the current data logging session.)*

3. Connect the SDL-1 to a USB port. *(The green LED should light up.)*

4. Open HyperTerminal or other serial capture program. (*See pages 14-16 if necessary).*

5. On the HyperTerminal tool bar, select: Transfer > Capture Text

6. At the prompt, enter a file name and location and click on START. *(Tip: use ‘.csv’ as the filename extension, this allows the data file to be loaded easily into Excel.)*

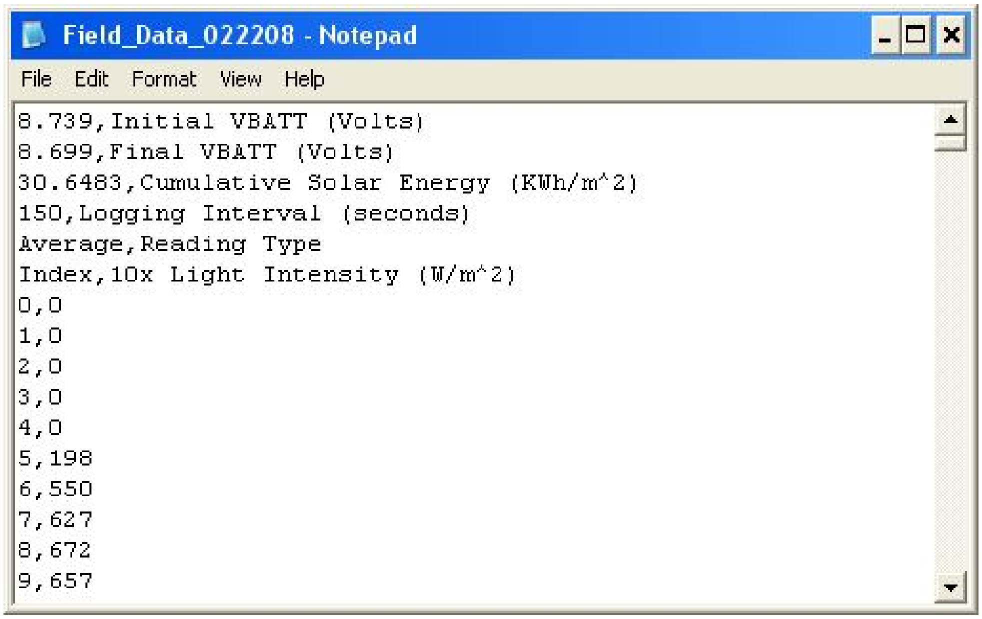
7. In the HyperTerminal window, type "t" to transfer the logged data. The data will scroll by in the HyperTerminal window and the red LED will light up during data transfer.

8. After all the data has been transferred, on the HyperTerminal toolbar, select: Transfer > Stop. The data file is now stored in the file with the name entered above. The SDL-1 can now be unplugged and HyperTerminal window can be closed.

Notes:
The data file is formatted as comma separated values and can be imported into a spreadsheet program for plotting and analysis. For easy plotting, an Excel template file is available on the SDL-1 web page at http://www.microcircuitlabs.com/SDL-1.htm. An example data file is shown below. The file consists of the following:

- ❑ Initial and final battery voltage
- ❑ Cumulative solar energy collected throughout the logging session
- ❑ Logging interval in seconds
- ❑ Logging reading type
- ❑ Index number and logged irradiance data

The raw irradiance data must be divided by 10 for the proper units of W/m^2. The index number can be used to determine the time in seconds for each logged data point (i.e. multiply the index number by the logging interval).




```
8.739,Initial VBATT (Volts)
8.699,Final VBATT (Volts)
30.6483,Cumulative Solar Energy (KWh/m^2)
150,Logging Interval (seconds)
Average,Reading Type
Index,10x Light Intensity (W/m^2)
0,0
1,0
2,0
3,0
4,0
5,198
6,550
7,627
8,672
9,657
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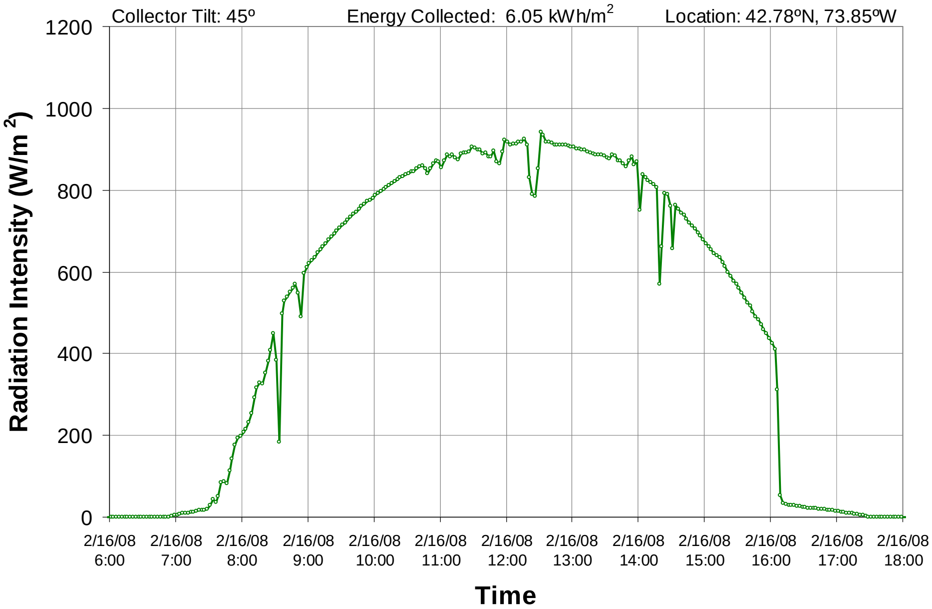
An example of logged data taken by the SDL-1 is shown in the plot below. The data shown is for a mostly sunny day with the data logger facing due south and tilted by 45º.



Solar Power Basics

The Earth receives an enormous amount of energy from the sun and even a small fraction of this energy could supply much of the energy demand of the human population. The cumulative global photovoltaic capacity was 5,000 MW in 2006 and is growing by about 22 percent each year. The appeal of photovoltaic power stems from the fact that it is a reliable and non air polluting source of electric power with very low operation and maintenance costs. The availability of solar power depends on the solar resource which varies greatly depending on geographic location.

Solar Cells

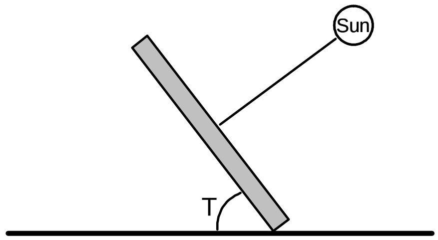
The first usable solar cell was announced in 1954 and had an efficiency of 6%[1]. Today, commercial solar cells are available with efficiencies as high as 22% and costs ranging from 4 to 7 dollars per Watt. A solar module consists of an array of series connected solar cells, usually silicon based. The table below shows a comparison of an assortment of solar modules available as of late 2007. The most common materials used today are polycrystalline and mono-crystalline silicon. Solar cells made from other materials are also available. A typical residential solar array consists of a number of modules connected together (e.g. in parallel) to produce a useable amount of power, typically from 2 kW to 4 kW of peak power. The cost of such a system can range from $10,000 to $30,000.

Manufacturer	Module	Rated Power (W)	Conversion Efficiency (%)	Cell Type	Cost ($/W)
Kyocera	KC200GT	200	14.2	Poly	4.50
Sharp	ND-208U1	208	12.8	Poly	4.59
Day4 Energy	Day4 48MC 180	180	13.9	Poly	4.65
Sunwize	SW160	160	15.0	Mono	4.72
Sharp	NT-180U1	180	13.8	Mono	4.94
GE	GEPVp-200-MS	200	13.7	Poly	5.00
Sanyo	HIP-200BA3	200	17.0	Mono, a-Si	6.44
SunPower	SPR-210-WHT	210	16.9	Mono	NA
SunPower	SPR-315-WHT	315	19.3	Mono	NA

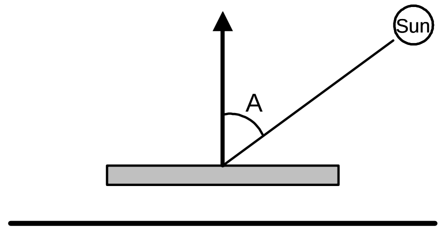
The output power of a solar module degrades over time due to UV degradation of the protective layers that cover the solar cells. The modules listed above are all specified for at least 80% of the initial rated output power after 25 years of operation. Solar module degradation can be monitored by measuring the conversion efficiency over time. The conversion efficiency of a solar module is defined as the ratio of the output electrical energy to the input light energy under standard test conditions (i.e. at a temperature of 25ºC and solar irradiance of 1000 W/m^2). Solar module efficiency can be determined by measuring the output electrical energy and the input light energy. Light energy can be measured by a solar insolation meter such as the SDL-1 Solar Data Logger and electrical energy can be measured by a conventional electrical energy meter.

Collecting Sunlight

A solar collector receives maximum radiation when the incoming sunlight has normal incidence to the collector's surface as shown in Figure 1 below. When light is incident on a collector at an angle other than 90º, the amount of energy collected is reduced by a factor equal to the cosine of the incident angle. Figure 2 shows a collector positioned horizontally flat with sunlight falling on the collector at an incident angle of A.



Tilted Collector
Fig. 1



Horizontal Collector
Fig. 2

In addition to the angle of incidence, the amount of sunlight collected at the Earth's surface depends on the amount of absorption in the atmosphere as well as changes in the radiant intensity of the sun. Atmospheric absorption depends on the amount of dust, water vapor and turbidity in the atmosphere. Other factors being equal, the sun's irradiance will be higher on a dry still day compared to a windy humid day. Also, the path distance through the atmosphere affects the amount of sunlight that reaches the Earth's surface. Sunlight from directly overhead will be stronger than sunlight reaching the Earth at a small angle to the horizon. The radiant intensity of the sun also varies throughout the year as shown in Figure 3 due to the changing distance between the Earth and sun.

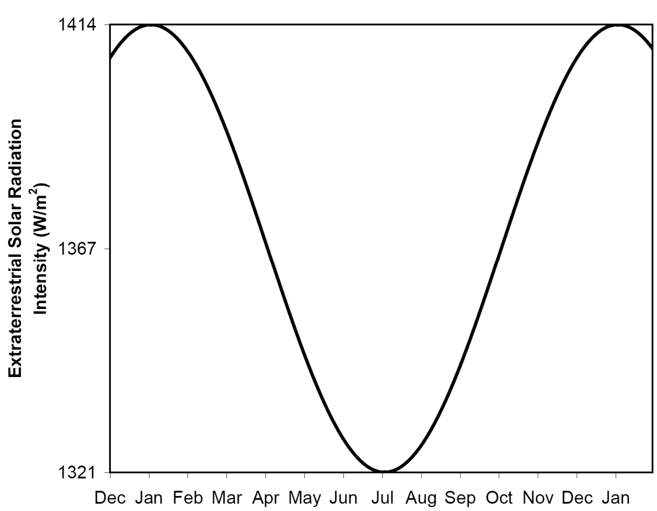


Fig. 3 The Solar Constant

The average solar radiation intensity present just above the Earth's atmosphere is referred to as the solar constant and has an average value of about 1367 W/m^2. The actual radiation intensity of sunlight just above Earth's atmosphere varies throughout the year as shown to the left.

The sunspot cycle causes an additional ± 0.75 percent variation in the sun's output on an approximately 11 year cycle (not shown). The sun's output power reaches a maximum at the peak of the sunspot cycle.

Noon-time Solar Irradiance

The amount of solar radiation reaching the Earth's surface under clear sky conditions at solar noon is shown in Figure 4. The curves represent the solar radiation intensity for a collector at the Earth's surface receiving sunlight at normal incidence at solar noon for various northern latitudes. These curves represent the direct beam component only and do not include the diffuse or reflected components that can be present in varying degrees. The diffuse component may contribute up to an additional 15% to the total depending on sky conditions and the reflected component may add another 5% or more depending on the reflectivity of the surroundings. For more northern latitudes the intensity of sunlight reaching the Earth's surface decreases because of the greater atmospheric path length at higher latitudes. Also, the variation in solar radiation intensity with latitude is minor in the summer months but very pronounced in the winter months. This is a result of the lower angle of the sun to the horizon during winter months. For a given latitude in the northern hemisphere, solar irradiance decreases in summer months because of the greater Earth to sun distance and increased water vapor content of the atmosphere.

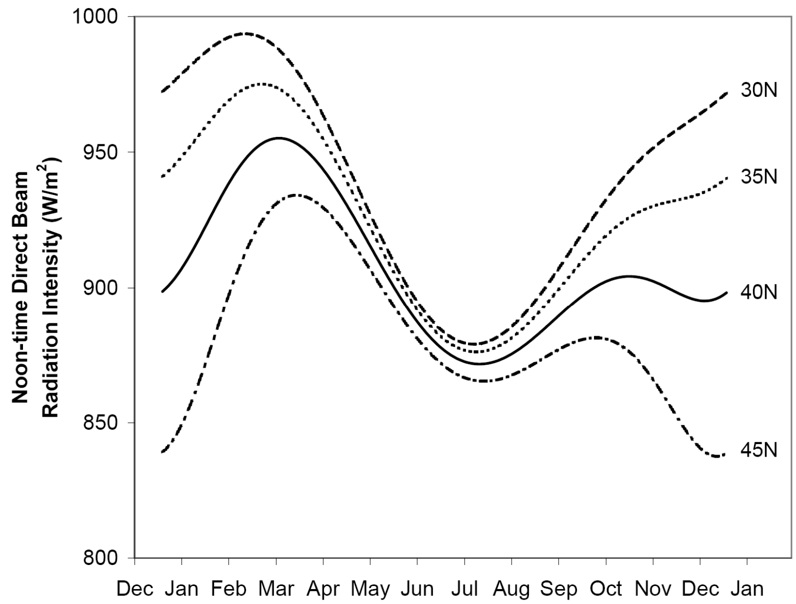


Fig. 4 The sun's irradiance at the Earth's surface on a collector tilted for normal incidence of sunlight.

The results shown in Figure 4 can be used to calculate the incident solar radiation on a horizontally flat collector at the Earth's surface. Figure 5 shows the solar radiation intensity falling on a horizontal collector (tilt angle = 0º) under clear-sky conditions at solar noon for various latitudes. As before, these results do not include the diffuse and reflected components. The received solar radiation intensity is highest during the summer months because of the smaller angle of incidence for these months. Figures 4 and 5 help illustrate the importance of panel tilt where Figure 4 shows the maximum possible solar radiation intensity (with panel angle continuously adjusted for normal incidence) while Figure 5 shows the solar radiation intensity received for a fixed panel tilt of 0º.

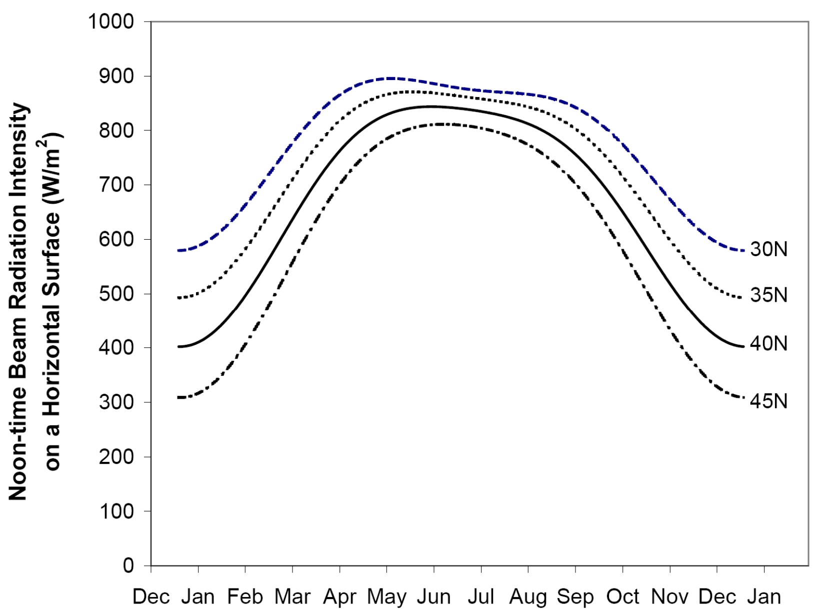


Fig. 5 The sun's irradiance at the Earth's surface on a horizontal collector.

Calculating the Energy Produced by a Photovoltaic System
A photovoltaic system produces energy by converting a fraction of the incident radiant energy (sunlight) into electrical energy. The power rating of a photovoltaic module is specified under a set of standard test conditions. These conditions include a light intensity of 1000 W/m^2 and a solar spectrum corresponding to sunlight passing through the Earth's atmosphere at an angle of approximately 60 degrees from the horizon. Although the actual spectrum of sunlight falling on a solar cell changes continuously, the spectrum used in the standard test conditions represents a characteristic average.

The SDL-1 provides the cumulative energy collected over the entire data logging session. The following expression can be used to determine the amount of energy collected over an arbitrary range of the data:

$$S_{Sun} = (P_1 + P_2 + \ldots P_n) * \Delta t / 3.6x10^6$$

Where S_{Sun} is the energy collected per unit area (kWh/m^2) for data points 1 through n. P_1, P_2,…P_n are the measured light intensity values in W/m^2 and Δt is the data logging interval in seconds.

Assuming the SDL-1 and the photovoltaic system have the same tilt angle, the amount of energy produced by the photovoltaic system can be calculated as:

$$E_{PV} = P_{PV} * S_{Sun} / I_o$$

Where E_{PV} is the electrical energy produced by the photovoltaic system in kWh and P_{PV} is the rated power in kW of the photovoltaic system at the standard light intensity ($I_o = 1\ kW/m^2$).

SDL-1 Commands

The SDL-1 uses a simplistic communications scheme in which single character commands (entered in HyperTerminal) are used to communicate with the data logger when connected to a computer. The available commands are:

Command	**SDL-1 Response**
?	List the available commands, SDL-1 software revision number and data logger setup parameters (logging interval, data reporting type).
E	Read out cumulative solar energy collected and initial and final battery voltage recorded during the most recent data logging session. *Note: the cumulative solar energy and battery voltage data are updated hourly. The cumulative energy reading will not be correct if the data logger was deployed for less than 1 hour.*
S	Set up logging interval (see table on page 6) and data reporting type. Available logging intervals are listed on page 6. Available data reporting types are: Sample - records instantaneous readings at the end of each logging interval Average - records the average value of readings taken every 10 seconds over the logging interval.
T	Transfer logged data as a sequence of comma separated values. See example data file on page 10.
!	Read out all contents of the data logger memory in 16 bit format.

Initial Installation

The following steps are required to install the SDL-1 on a computer for the first time.

Step 1: Install the required driver for the SDL-1.

❑ Using an internet browser, go to ftdichip.com. In the left column, click on “Drivers” and then on “VCP”. Click on the driver version corresponding to the operating system you are using. Save the file to a location such as c:\temp\ and then right click on the file and select “Extract All” to uncompress the file.

❑ Set SDL-1 mode switch to XFER and connect it to the host computer with a USB cable. The driver installation process will start automatically when the SDL-1 is connected. A message box indicating “Found New Hardware” will appear.

❑ At the prompt “Can Windows connect to Windows Update to search for new software” select “No, not at this time.”

❑ At the prompt “What do you want the wizard to do?” select “Install from a list or specific location” and click “Next”

❑ Check the box next to “Include this location in the search”

❑ Click on “Browse” and select the location of the driver files

❑ Click on “Next” to install the driver

Step 2: Configure HyperTerminal on a Windows based computer. Note: if HyperTerminal is not available, any serial capture program can be used. An alternative is described on page 15.

❑ Remove the SDL-1 cover from its base by removing the 4 cover screws.

❑ Set the mode switch to XFER.

❑ Connect the SDL-1 to a USB port.

❑ Open HyperTerminal on a Windows based computer by clicking on:

```
Start > All Programs > Accessories >
Communications > HyperTerminal
```

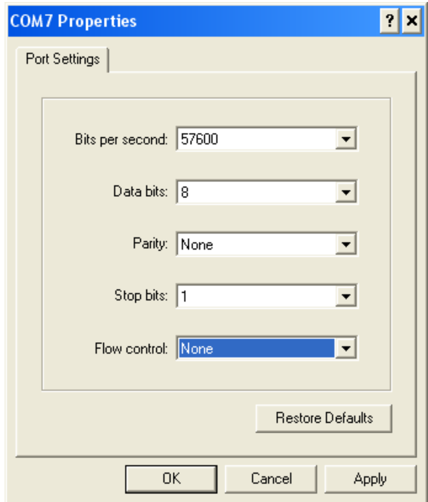
Note: When HyperTerminal is run, Windows may indicate a “TAPI” error message. If this occurs click “ok” and ignore the error message.

❑ In the “New Connection” window, type a name for the connection such as: `sdl-1`

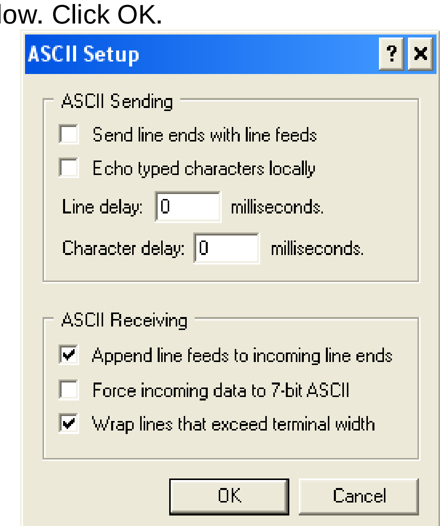
❑ Select the COM number for the connection and click OK. The SDL-1 will be assigned to a COM number higher than 3 (or the highest COM number shown). The COM number may vary depending on which other devices have been previously installed.

Note: *Each SDL-1 uses a unique COM number and if multiple SDL-1’s will be used on the same computer, each unit should have its own HyperTerminal shortcut set with its corresponding COM number.*

❑ In the “COM Properties” window, set the port for 57600 bits per second, 8 data bits, no parity, 1 stop bit and no flow control (57600, 8, N, 1, none) as shown below. Click OK when done.



❑ On the HyperTerminal tool bar, select: `File > Properties` and choose the `Settings` tab. Click on `ASCII Setup`. Under “ASCII Receiving” enable the “Append line feeds to incoming line ends” option. The ASCII Setup window should appear as shown below. Click OK.



❑ In the “Properties**”** window, click OK.

❑ On the HyperTerminal tool bar, select `File > Save As` and set the “Save In” option to “Desktop”. The filename can be “sdl-1” or a file name of your choice. Click on “Save”. This creates a HyperTerminal shortcut called “sdl-1” on the desktop that can be used to communicate with the SDL-1.

This completes initial installation of the SDL-1.

Using RealTerm to communicate with the SDL-1:

RealTerm is an alternate serial capture program to HyperTerminal and can be downloaded for free at:
http://realterm.sourceforge.net/index.html#downloads_Download
(click on the zip file to download)

After loading the FTDI driver for the SDL-1 (described in step 1 above) connect the SDL-1 to the computer's USB port and start RealTerm. Under the "Port" tab, manually enter the port number assigned to the SDL-1. The port number assigned to the SDL-1 by Windows can be determined through the Device Manager (in Windows Vista click on: Start Menu -> Control Panel -> Device Manager -> Ports).

Make sure the baud rate is set to 57600. The other port settings should be fine with their default settings (Parity: none, Data Bits: 8, Stop Bits: 1, Hardware Flow Control: none). Click on the "open" button (to the right of the port number) to open the port. Type for example the "t" command and the SDL-1 will send data to the RealTerm message window.

Capturing data to a file using RealTerm:
To capture data from the SDL-1 to a file, select the "Capture" tab.
Type a file name next to "File" such as `c:\mydata.csv`. Use `.csv` as the file extension to ensure proper formatting. Using `.csv` also allows the file to be opened directly by Excel.

Click on "Start: Overwrite", click inside the message window and type the "t" command to transfer data. When done, click on "Stop Capture". Please note: when capturing data to a file, the data is sent directly to the named file and the data will not appear in the RealTerm message window.

The captured data can now be used in a spreadsheet program such as Excel for plotting and analysis. For easy plotting, an Excel template file is available on the SDL-1 web page at http://www.microcircuitlabs.com/SDL-1.htm.

References

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2. J. Schwartz, "PV Buyer's Guide," *Home Power*, Oct./Nov. 2007, Issue 121, pp. 70-78.
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4. G.M. Masters, *Renewable and Efficient Electric Power Systems*, John Wiley & Sons, 2004.
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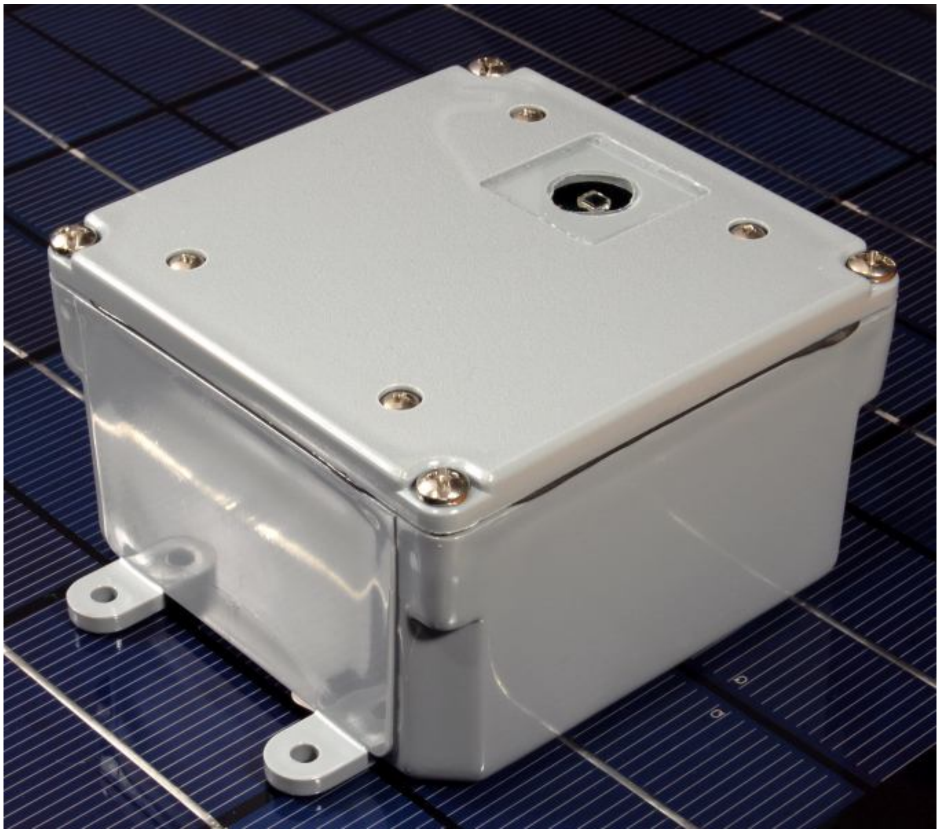
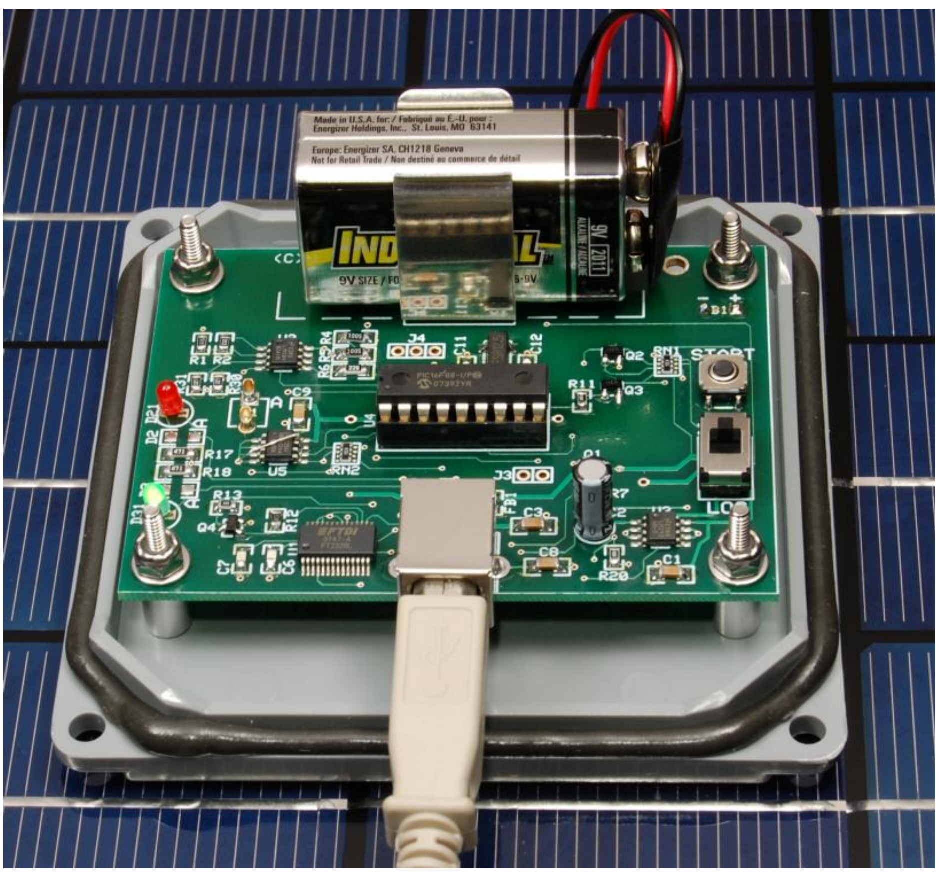
SDL-1 Solar Data Logger



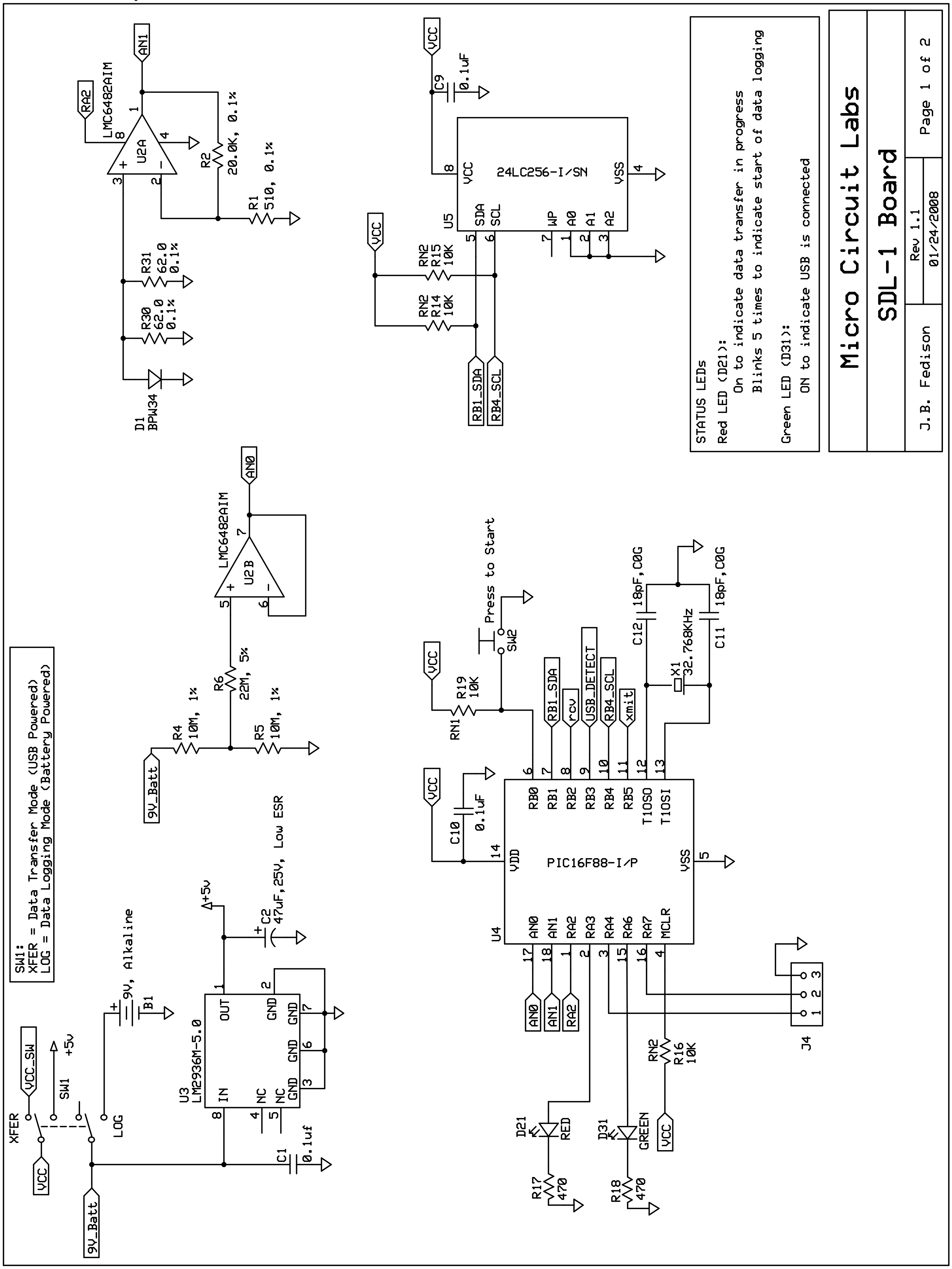


Parts List

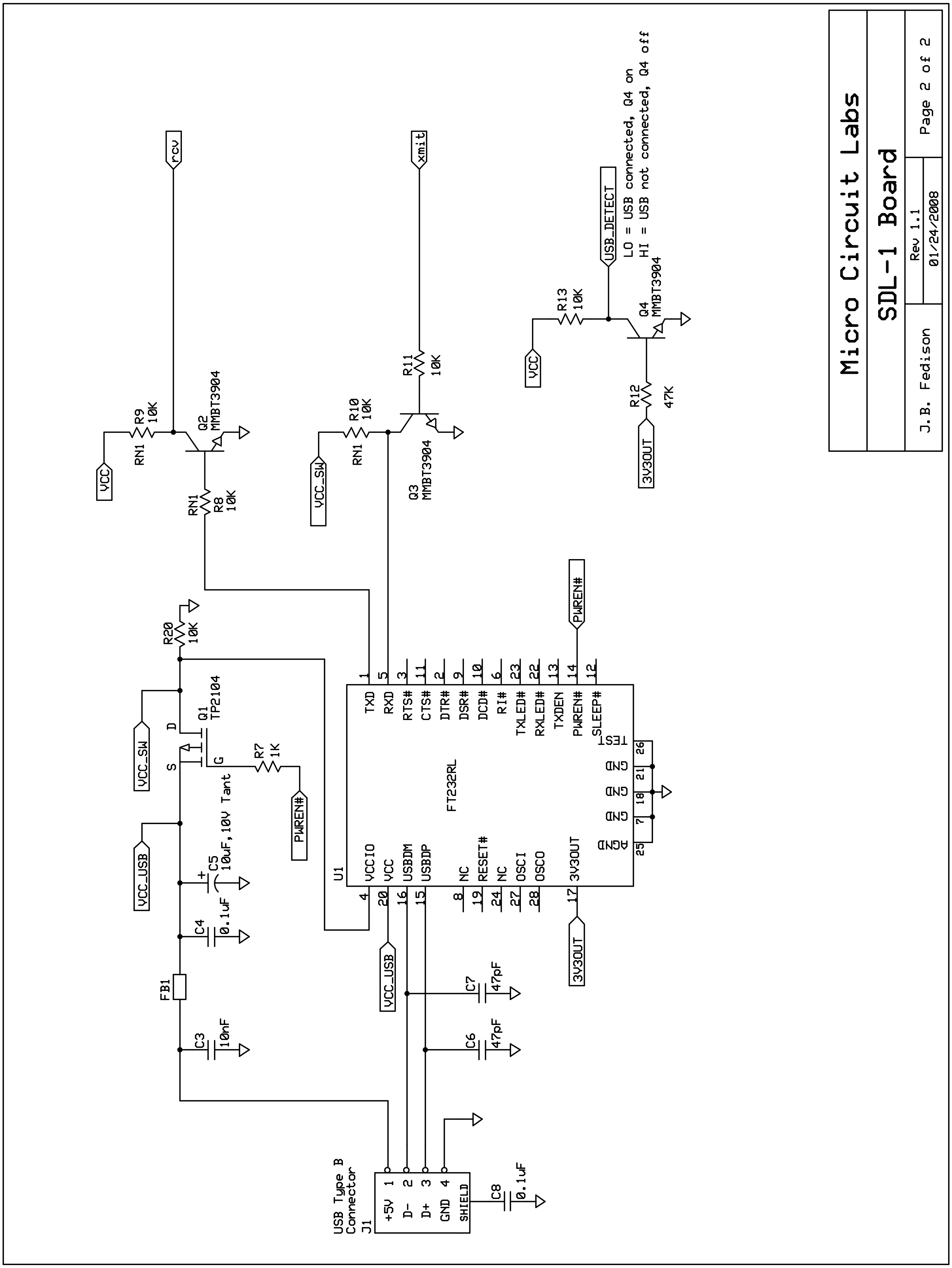
Ref.	Description	Qty	Pre-Installed*
C3	Cap, 0.01uF, SMD 1206 (Green)	1	x
C1, C4, C8, C9, C10	Cap, 0.1uF, SMD 1206 (Orange)	5	x
C6, C7	Cap, 47pF, SMD 0805 (Yellow)	2	x
C11, C12	Cap, 18pF, SMD 0805 (Blue)	2	x
C5	Cap, 10uF, 10V tantalum, SMD 1206	1	x
C2	Cap, 47uF, 25V Al electrolytic	1	
D1	Photodiode, BPW34, clear plastic 2 lead DIP	1	
D21	LED, red	1	x
D31	LED, green	1	x
FB1	EMI ferrite bead, SMD 0805 (Black)	1	x
J1	Connector, USB type B	1	
J2	Connector, 9V battery snap	1	
Q1	MOSFET p-channel, TP2104, SOT-23, “P1LE “	1	x
Q2, Q3, Q4	Transistor , NPN, BT3904, SOT-23, “1An”	3	x
R1	Res, 510 ohm, 0.1%, SMD 0805, “511”	1	x
R2	Res, 20K ohm, 0.1%, SMD 0805, “203”	1	x
R30, R31	Res, 62.0 ohm, 0.1%, SMD 0805, “620”	2	x
R17, R18	Res, 470 ohm, 5%, SMD 1206, “471”	2	x
R7	Res, 1K ohm, 5%, SMD 0805, “102”	1	x
R11, R13, R20	Res, 10K ohm, 5%, SMD 0805, “103”	3	x
R12	Res, 47K ohm 5%, SMD 0805, “473”	1	x
R4, R5	Res, 10M ohm, 1%, SMD 1206, "1005"	2	x
R6	Res, 22M ohm, 10%, SMD 1206, "226"	1	x
RN1, RN2	Resistor network, 10K, 8-lead SMD, “103”	2	x
SW1	DPDT slide switch	1	x
SW2	SPST-NO push switch	1	x
U1	IC, USB to serial interface, FT232RL, SSOP-28	1	x
U2	IC, Dual op-amp, LMC6482AIM, SOIC-8	1	x
U3	IC, Voltage regulator (5 volts) LM2936M-5.0, SOIC-8	1	x
U4	IC, Programmed microcontroller, PIC16F88-I/P, 18 pins	1	x
U5	IC, 256k serial EEPROM, 24LC256-I/SN, SOIC-8	1	x
X1	Crystal, 32.768KHz, 4-lead SMD plastic package	1	x
MISC	SDL-1 printed circuit board	1	
MISC	Posts for photodiode D1	2	
MISC	Socket for U4, 18 pins	1	x
MISC	9V battery holder	1	
MISC	2-56 machine screw, 3/16" length	2	
MISC	2-56 nut	2	
MISC	#2 lock washers	2	
MISC	4-40 machine screw, 3/4" length	4	
MISC	Aluminum spacer, #4 hole, 3/8" length	4	
MISC	4-40 nut	4	
MISC	#4 flat washer	8	
MISC	Rubber O-ring	4	
MISC	#8 sheet metal screws, 5/8” (to attach cover to base)	4	
MISC	#8 sheet metal screws, 3/4" (to mount PVC enclosure)	4	
MISC	PVC enclosure, 4x4x2" (includes cover and base)	1	
MISC	Glass plate, 1x1x0.039"	1	x

* Refers to kit version

Schematic, Sheet 1



Schematic, Sheet 2



Component Layout