Solarbotics BEP Application 3:

The *Wilf Rigter* Solar Power Smart Head (SPSH) v.3

The following instructions detail how to build a Solar Power Smart Head version 3. The Head will seek light and when it finds the brightest source it will go into a low current standby mode. This version also comes with an low power FLED circuit to indicate when the head is active.

So How does it Work?

The Power Smart Head circuit was designed by BEAM-list guru Wilf Rigter, and since its introduction, the circuit has gone through many iterations, each improving on the previous. This latest version has been tweaked, tuned and optimized... for now! We've taken our Bicore Experimenter's PCB, and used a MD2 and BC1 module to construct this project.

Wilf also suggests: *Current passing through the LDRs in bright light is wasted energy. A solution to reduce the current through the eyes is to add some sunglasses. This can be done by darkening the surface of the LDRs with a felt pen. Add one layer at a time and measure.the resistance of the LDR under a bright light with an ohmmeter. The resistance should be about 1K for each LDR. Now the amount of energy wasted when the light is bright is negligible.* Be forewarned: This will also reduce sensitivity of the eyes a bit.

The Eyes / Voltage Divider

The Solar Power Smart Head uses a pair of photoresistors as a voltage divider. By tapping the signal from between them, a voltage is read that varies from 1/2 the system voltage (if running from 5V, aimed directly at the light is 2.5V). The greater the eyes are off balance, the greater the voltage will stray from the "ideal" 1/2 voltage. If it turns one way, voltage climbs. If it turns the other way, voltage drops.

You might notice that the eyes are arranged so that they're wired in series from Vcc, through the eyes, and to ...a output gate? Well, it's like this: In bright sunlight, the CdS cells (the eyes) have a resistance of only about 150 ohms each, for a total of 300 ohms. If you wired these eyes up across Vcc and ground, you'd have a HUGE load on the solar cell when you want it as efficient as possible. So, by terminating the ground connection of the eyes to a gate output, the eyes are "turned off" during charge. When the circuit activates, the gate output snaps low and acts practically as a ground connection, which is good enough for the eyes to do their thing.

The High / Low Oscillator

This varying voltage from the eyes is fed into what is called a "high / low / oscillate" circuit with three types of output states: 1) high 2) low 3) pulsing. When all is right, it spends as much time being high as it does low. When the voltage input from the eyes is introduced, it influences the "high / low" circuit to pulse longer on the high or low side (depending if the input voltage is higher or lower than ideal). When the eyes receive unequal light, the output is a steady high or low, and the motor turns left or right until the light on the eyes become close to balanced.

Nv / Nu Deadband

This rapid chain of off-kilter highs and lows is streamed to another circuit called a "bipolar monostable / delay circuit" (cool technophrase to baffle common folk with, eh?). This circuit is also known as a Nv / Nu driver. The Nv / Nu driver is set up so that it will only send a *dissimilar* signal to the motor driver if it's "so much" out. A dissimilar signal is important, because to get a motor to rotate, you have to feed a high signal to one side, and a low to the other to get a flow of power. If both sides of a motor's inputs are high or low, there's no difference - no power flows; no motion happens. The "so much" portion of the Nv / Nu circuit is called *deadband*, and means the area in which the circuit thinks the signal is close enough to ignore. If the input signal strays outside of the deadband, it's time for the circuit to take action!

The Nv / Nu deadband works by "living" off of equal, but opposite polarity signals. When the SPSH is aimed at something, the signal train feeding the Nv / Nu is 50/50 - half the time on, half the time off. In this situation, the capacitor sitting in the Nv / Nu acts as a wire, passing the same signal through it to the other motor input. As one of the motor inputs is sitting behind a 10M resistor, this capacitor-passed signal can easily over-ride it. The result is that the motor inputs are now both the same, and *nothing* happens. When the signal train strays too far from balanced, the Nv / Nu capacitor finally charges up, and can't "stomach" any more signal. A signal difference passes through the 10M resistor, and BOOM! We have movement!

"Power Smart" Indicator

Also included is a high efficiency LED flasher that serves the dual purpose of using the regularly unused gates and providing a useful running indicator. *Note:* This is *not* a "lock-on" indicator. It is simply a very efficient blinker that turns on when the SPSH is on (moving or not). When the circuit is charging, it is being "held off" by the rest of the circuit.

Solar Engine

Of course, being a *solar* device, we have it hooked up to a solar cell and a few other components to make it function under light. The SPSH will take a bit to charge up, then (if there's a need to re-align) it will turn every once in a while. If there's no need to move, it'll happily blink an LED at you.

The solar engine powering the SPSH utilizes a 1381 voltage trigger, which outputs a high signal when the supply voltage exceeds its set trigger voltage (in this case for a 1381J, 2.7V) and a low signal when voltage is below the trigger voltage. The high signal when the 1381 triggers is inverted and enables the PSH circuit (enables with a low signal). The +Vcc reference is powered through a regular silicon diode, due to the low current the voltage drop is about 0.3V so the 1381 really sees +Vcc - 0.3V. When the 1381 enables the 1/2 of the 74HC240 chip housing the head circuit, another inverter is to create a "Latch signal" to yank the +Vcc reference of the 1381 up to practically the supply +Vcc. This hysteresis value between the voltage drop of the diode and the output voltage of the inverter gate is what causes this circuit to latch.

For some much more detailed operational analysis check these links:

http://www.solarbotics.net/wilf/PSH/heads101.html

http://www.solarbotics.net/library/circuits/bot_head_pshead.html, particularly the schematic at the bottom of the page, which is the one used as a basis for this project.

A Few Changes to the Original

A few minor changes were made to the original SPSH3 circuit, including the addition of a 0.47µF capacitor, decreasing the power storage capacitor from 1.0F to 0.33F, and using a 22µF capacitor instead of 10µF.

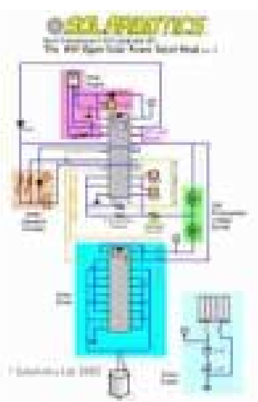
Adding the 0.47µF capacitor helps filter power to the 1381 when the supply voltage sags, preventing false resets. Using 0.33F capacitors for power storage makes the head trigger more frequently, but shortens the running time. Substituting the 10µF for a 22µF capacitor gives a slower, but brighter LED flash.

If you want to adjust the "deadband" try replacing the 510k resistor with a 500k or 1M trimpot feeding from the eyes to the High / Low oscillator. The lower value it is, the more sensitive the headbot will be, up to the point where it will *always* be seeking left and right trying to optimize its aim. Adjusting this resistor is easier than tweaking the actual 10M Nu / Nv resistor. You know how hard it is to find a 10M trim potentiometer?!?

Wilf expresses concerns on how we're running the circuit with "floating inputs" when the chip is deactivated. Although we're not presently having problems with the design, Wilf feels (correctly) that a couple 1M resistors between the inputs and ground (or Vcc) will make it quite robust.

Here's his full review: "*The pin 13 input of the 74HC240 and all the inverter inputs of the74AC240 driver are floating when the SE is off. The trapped voltage at those inputs can be the SE reset voltage and that voltage remains the same while the supply cap is charging. This can cause problems as Vcc is rising and the input is held at a lower voltage. Even though the outputs associated with those floating inputs are tristate, the Vcc leakage current of the chips can greatly increase (>50mA) and hang up the circuit. A couple of 1M resistors between the floating inputs and GND (or Vcc) will take away the uncertainty.*"

Circuit Diagram:



If you find that a wee bit small to read, click on the image for a much larger GIF of the schematic, or click here for a PDF copy of the same schematic.

Construction procedure:

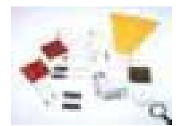
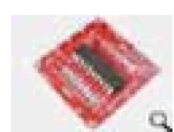
	**1. Gather all your parts:** Parts list: 1 - BC1 BEP board 1 - MD2 BEP board 1 - A 3mm thick Sintra cutout used to make the base for the head 1 - 74HC240 for the BC1. These *should* be the HC versions to work properly. 1 - 74AC240 for the MD2 motor driver. Some motors are efficient enough *not* to use a driver. Ours isn't! 1 - 0.47µF capacitor (Marked 474) 2 - 0.01µF capacitor s (Marked 103) 1 - 22µF capacitor (Substituted from 10µF) 1 - LED 2 - CdS photo cells 2 - 1N914 diodes 1 - 1381 "J" trigger 1 - DC Gearmotor (GM2) with mounting wheel 1 - Solar cell (SC3733) 2 - 0.33F Gold capacitors (Substituted from 1.0F in the picture) Resistors: 1 - 510K resistor 1 - 5.1M resistor 2 - 10M resistors 2 - 100K resistor
	**2. Forming the base** Sintra is a thermoplastic, meaning that when you heat it up you can shape it. A couple of methods work well for heating it up- leave it in boiling water for a minute or use a heat gun. We tend to use the heat gun as it's less messy, but it does require a bit more skill to use. Just heat the Sintra up, bend it to the desired shape, hold it there while it cools and ***voila*** - it holds the shape! Pick a shape that appeals to you, as it's simply a base to mount the head to. If the shape doesn't meet your expectations, you can always re-heat it and try again. Sintra is pretty useful construction stuff.
	**3. Glue mounting wheel on base and insert motor** Superglue- Specifically "Flash" Cyanoacrylate works very well for bonding Sintra to gear motor wheels.
	**4. Solder the 74AC240 into the BEP MD2 "Motor Driver" module** Figure 4.1: Be very careful not to mix up the 74AC240 with the 74HC240. The 74AC240 works best for driving motors because of its higher current carrying capabilities. Solder the 74AC240 chip in place and watch the chip orientation.

Figure 4.1

Figure 4.2

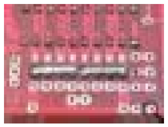


Figure 4.3

Figure 4.4

Figure 4.2: Usually, solder bridges are a bad thing but in this case we are using them to make convenient electrical connections. Run solder bridges across the inputs and outputs to make two groups of four by placing four inverters in parallel for each side of the motor. Teaming up inverters increases the available drive current to the motor.

Figure 4.3: This is a close-up shot of the solder bridges paralleling the two groups of four on the MD2 outputs. Make sure that there is not solder *between* the two bridges or to the free ground pads either. That would be a bad thing as it would be shorting out the outputs!

Figure 4.4: Cut the enable trace isolating it from ground, the enable will be connected to the enable on the BC1 board later. That's basically it for work on the MD2, set it aside for now and begin work on the BC1 board.

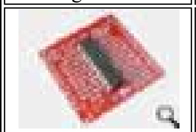


Figure 5.1

Figure 5.2

5. Solder the 74HC240 into the BEP BC1 Module

Figure 5.1: Leave the MD2 for now, as we're going to start on the nitty gritty brains of the Power Smart Head. Start by soldering in the 74HC240 chip. Again, watch the chip orientation.

Figure 5.2: Flip the PCB - we need to enable lines on pin 19 to be isolated. Do this by cutting the trace tying the two enables together and the trace from pin 19 to ground.

6. BC1 solder bridges

As the BC1 is intended to be an "all-purpose" sort of module, there is some custom work to be done. First, we'll have to make four solder bridges to the BC1. Starting at the top right side, run a solder bridge between pin 1 and ground, which will permanently ground this enable line. Remember, you're working on the *bottom* of the chip, so pin numbers start at the **top right** corner and go down, and back up the left side.

Down and to the left of that a solder bridge, connect pins 17, 18 and 19.

Near the bottom left, bridge pins 8 and 9 together.

Lastly, right of the previous step, pins 12 and 13 have a bridge connecting them.

7. 1381 trigger section

Figure 7.1: The 1381 "J" trigger is soldered into the pads near the power filter capacitor , by

Figure 7.1

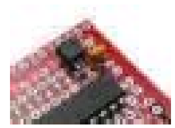


Figure 7.2

Figure 7.3

Figure 7.4

Figure 7.5

the top right of the chip. 1381 pin 1 is soldered into IN1 on the BC1. 1381 pin 2 is soldered to a free pad and pin 3 is soldered to the nearest ground pad.

Figure 7.2: A 0.47µF capacitor is soldered across the 1381 Vcc and ground rails (pin 2 and 3). This capacitor smoothes power to the 1381 and keeps it from prematurely resetting by accident.

Figure 7.3: A 1N914 diode is soldered between Vcc and pin 2 of the 1381. This diode isolates power to the 1381, letting it do it's job when the power sags during motor operation.

Figure 7.4: A 100K resistor is installed between O5 and IN1.

Figure 7.5: It should resemble something like this when you are done.

8. BC1 Jumper

Flip the PCB over and run a jumper wire between O5 and pin 2 of the 1381. This is part of the *enable latch circuit* from the 1381 trigger.

9. LED flasher Section

The following diode, two resistors, capacitor and LED are part of the LED Flasher circuit that blinks the LED when the head is active.

Figure 9.1: Solder the other 1N914 diode with the Cathode pointed towards IN2 and the Anode pointed towards the group of pins 17, 18 and 19.

Figure 9.1

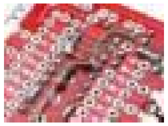


Figure 9.2

Figure 9.2: Add a 10M resistor from pin 4 of the 74HC240, for now just leave the other end of the resistor hanging.


Figure 9.3

Figure 9.3: Solder in a 100K resistor between pin 6 of the 74HC240 and the other end of the 10M resistor.


Figure 9.4

Figure 9.4: Add a 22µF capacitor between the resistor combination and pin 14 of the 74HC240. capacitor + goes to pin 14 as shown by the red lead.

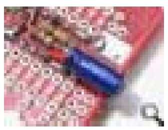


Figure 9.5

Figure 9.5: A different view of the shot above.


Figure 9.6

Figure 9.6: Solder the LED between a pair of free pads near the bottom right of the BC1 board.


Figure 9.7

Figure 9.7: Run a wire between LED Anode to pin 6 of the 74HC240, show by the red wire. The small black wire is connected to the + of the 22µF capacitor and to the Cathode of the LED.

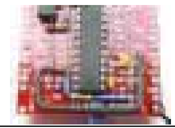

Figure 9.8

Figure 9.8: Details of the black wire connection to the Cathode of the LED.

10. Soldering in 0.01µF caps

The two 0.01µF capacitors are soldered in so one goes between pins 11 and 12, the other

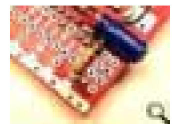
capacitor needs to straddle a pin to go between pins 13 and 15.



11. Add 10M and 5.1M resistors

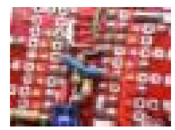
The second 10M resistor is soldered between pin 8 and 15.

The 5.1M resistor goes between pins 9 and 11.



12. The 510K resistor

The 510K resistor goes from pin 11 and a free pad, which will later be connected to the center point of the CdS photoresistor voltage divider.



13. Just one last board jumper wire

Jumper goes between 6 and 16 (blue wire). This is a part of the LED flasher circuit.

That's basically it for work on the PCB!

14. Soldering the 0.33F capacitors together

The two 0.33F capacitors need to be soldered in series to make a 5V 0.165F capacitor.

15. Cutting corners


Figure 15.1

Figure 15.1: The corner of both the MD2 and the BC1 are chamfered. This is done so they fit tightly to the motor body, with the flat of the chamfer resting against the solar cell. Be careful while cutting the chamfer so that *any important traces are not cut*. The outside ground line goes all the way around the board so cutting it *once* does not change it electrically.


Figure 15.2

Figure 15.2: The boards are attached on either side of the motor

16. Putting it together

Everything gets assembled like this. The CdS photoresistor eyes are installed in this figure (but installed in the next step).

17. The eyes

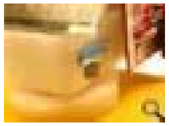


Figure 17.1

Figure 17.1: It is wise to insulate the wires coming from the CdS photoresistors, as it will prevent them from shorting together, as well as giving some surface for the glue to stick to.


Figure 17.2

Figure 17.2: The eyes were angled at approximately 45 degrees.

18. Wiring the eyes

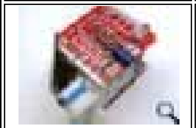


Figure 18.1

Figure 18.1: Wire up the CdS cells

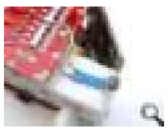


Figure 18.2

Figure 18.2: This yellow wire goes underneath the solar cell and...

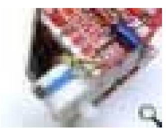


Figure 18.3

...Figure 18.3: gets attached to the 510K resistor, CdS cell point.

19. Adding the power storage caps


Figure 19.1

Figure 19.1: The 0.33F capacitors fit nicely on the rear of the motor. The capacitor + and - are soldered right onto the power filtration capacitor location.

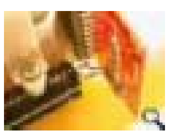


Figure 19.2

Figure 19.2: Another figure of the same, to show that the bare capacitor leads do not touch anything else.

20. Attaching power lines of the boards together

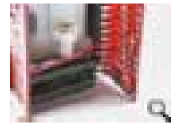


Figure 20.1

Figure 20.1: Image of the ground and Vcc connections to the MD2 board.

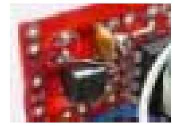


Figure 20.2

Figure 20.2: Detail of the positive connection to the BC1 board.

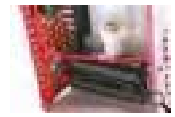


Figure 20.3

Figure 20.3: Detail of the ground wire to the BC1 board.

21. Attach outputs of the PSH to the motor driver.

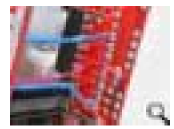


Figure 21.1

Figure 21.1: The blue wires are the outputs of the PSH being connected to the inputs of the motor driver.


Figure 21.2

Figure 21.2: Detail image showing the output connections of the BC1 board. The outputs are labeled O6 and O7.

22. Outputs of motor driver to the motor

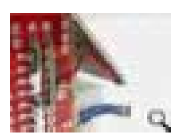

Figure 22.1

Figure 22.1: The green wires are the connections from the outputs of the motor driver to the motor. If the head rotates opposite to what you expect, this is probably the easiest point to correct the behavior.

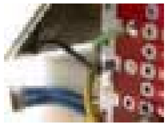

Figure 22.2

Figure 22.2: Detail image showing the output connections of the BC1 board. The outputs are labeled O6 and O7.

23. Lastly, attaching the solar cell



The '+' from the solar cell, wire a connection to any positive trace on the board (the center rail).

Figure 23.1  Figure 23.2	The '-' from the solar cell goes to any ground trace on the PCB (the edge rail).
	**24. All done!** Enjoy.

Troubleshooting:

- To help trouble-shoot, to have a DC power supply and a multimeter. With a 1381 "J", a supply voltage over 3.22V should be sufficient to start the circuit and keep it running continuously. Any voltage source over 3.22V will start the LED flashing and the head tracking light. By attaching a DC supply this help to troubleshoot as it bypasses the solar engine and allows continuous operation.
- If the head only turns one direction the CdS cells may be very un balanced, check this by giving the eyes approximately equal light and measuring the voltage at the center of the voltage divider. The voltage should be close to half the supply voltage. Actually measured value at 1.71V. If the value is way off the best solution is to just replace the eyes.

Hints, tips and useful advice :

- Tuning the head is most easily accomplished by changing the angle the eyes are set at. A potentiometer can be set between the eyes to electrically tune for a left/right bias.
- Adding battery power is a simple matter of wiring a battery is parallel with the storage cap. Just make sure that the battery voltage is sufficient to trigger the 1381. This project **could** be made exclusively battery power by just removing the 1381 trigger stage and have the enable lines permanently grounded.
-