How to Build Your Own Light Meter!!!

Intro : This simple, cheap, robust light meter is great for teaching labs for students to learn about light. And, it's easy to make.

Features :

- Parts cost around $10.00 US.
- Gain switch has 5 positions, each an order of magnitude more sensitive from very dim room light to very bright sunlight. (Slight modifications allow extends sensitivity an extra factor of 1000, and neutral density filters can be used for bright light.)
- Sensitive from mid-IR to mid-UV. With filters can look only at UV, IR, Visible, individual colours, polarization, etc.
- Easy to build with tools at home – just use a drill, saw and soldering iron.
- Works with any cheap multimeter
- Permits quantitative measurements for an enormous number of existing experiments (eg. $1/R^2$ law, efficiency of different light sources, polarization of light sources, emission spectra etc.)

Parts and Tools

Circuit :

Photo diode – VTS3082 or VTS3085 from VACTEC PHOTO or similar.
LM324 Quad Op Amp
14 Pin Chip mount (recommended by not essential)
100, 1K, 10K, 100K, 1M Ohm resistors (1/4 or 1/8 Watt)
Rotary Double-Pole Six Position Switch - C&K Supplies - Type A20615RNZQ
Knob for Switch
General Purpose Power Diode – 1N4007
9 Volt Battery
9 Volt Battery Clip
BNC Connector
Coloured connection wire
2 (or 3) pin connector

Case :

3.5 inch long pipe (Diameter 2, 2.5 or 3 inches)
Straight coupling.
End cap.
Sheet of 1/32" inch (or similar) aluminium plate (large enough to cover the pipe end – eg. 3"*3")
Velcro-Adhesive tape strips.
5 minute epoxy glue.
Black Paint (spray can works well)
Small piece of white card-board and pen.
2 Number 3 (or similar) self-tapping screws.

Tools :

Soldering iron, solder, flux, wire clippers, pliers
Hack Saw, file, bench clamp, drill, drill bit set (5/64",1/8",3/8", rose), screw driver, punch, tin snips

Notes :

See the end of the document if you want supplier information.

Most photodiodes will do the trick (eg. broken solar calculators). Just hook it up to your multimeter. It should give a voltage of at least 0.25 V when exposed to light. If you've got a sensitive multimeter (or you shine a bright flashlight on the cell) you should be able to get 100 micro to 10 milliAmps out of it when measuring the DC current. Note, if the photodiode has a coating on it this may absorb UV or IR radiation. The VACTEC PHOTO one has no coating, but SILONEX and other manufacturers make similar ones.

Most OP AMPs that can run in single-rail mode will do.

Any multi-position switch will do. We waste one pole of the DP as a power switch, but you could easily use two switches (SinglePole/SingleThrow Power Switch + Gain)

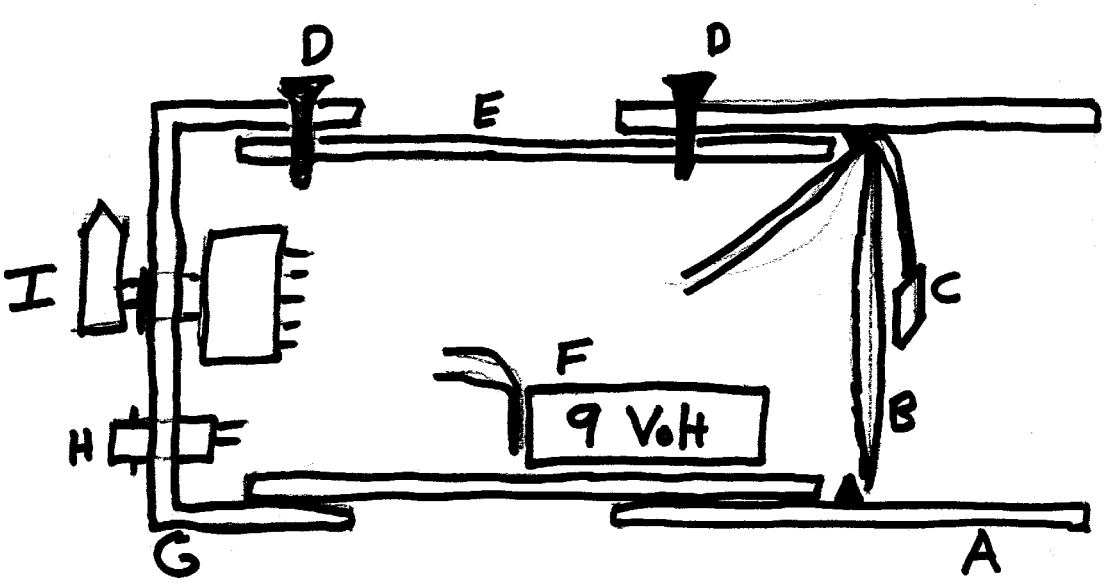
For piping, go with Schedule 40 or Drainage. 2 inches is a bit of a squeeze, but it works fine. 2.5 inches is probably optimal. Almost any hardware store carries suitable piping.

Building the Case

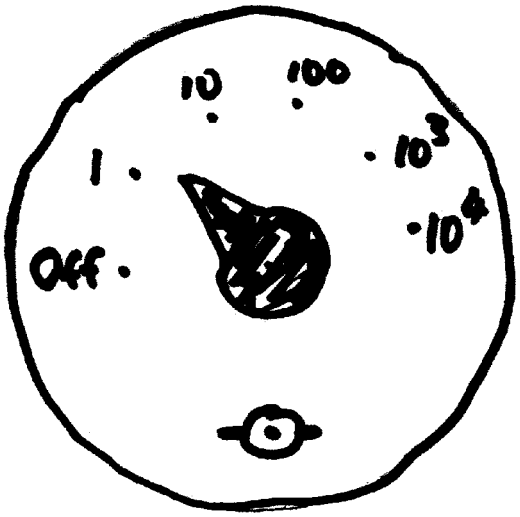
Plans : The sketch below gives a pretty good idea of how it goes together.

Figure One : Side View Schematic

(A – Straight Connector, B – Aluminium Face Plate, C – Photo Diode, D – Self Tapping Screws, E – Piping, F – 9 Volt Battery, G – End Cap, H – BNC Connector, I – Multi-position switch)



- A circle of aluminium is glued into the straight connector to hold the photo-diode.
- The 9 Volt Battery is held inside the tube with Velcro.
- The switch and BNC connector are mounted into the end cap.
- Number 3 wood screws keep the end cap and straight connector from sliding off the tube.



Steps for Building the Case

Pipe :

- Cut the pipe to about 3.5 inches in length
- File the ends smooth and rounded so they don't jam into the connectors

Connector Piece and Face Plate :

- Push the pipe a comfortable distance into the straight connector piece (don't push really hard or it will be a nuisance to slide in and out) and clamp the connector piece.
- Punch the position for, and then drill a hole for the wood screw (5/64" works well for a number 3) to hold the connector piece (about a ½" from the bottom of the straight connector). Rose the hole to make sure the screw won't protrude. Check it fits nicely before pulling out the pipe.
- Using the tin snips, cut out a circle from the aluminium sheet so that it just fits into the front section of the straight connector piece. A good way to start is to use the end of the pipe to mark out a circle.
- The photo diode glues onto the front of this piece. Cut a notch in the perimeter of the face plate to let the photo diode leads through.
- Insert the face plate and glue it in place with 5 minute epoxy.
- Paint the connector piece black. It may take a couple of coats.
- Glue the diode in the center of the face plate with the leads threaded through the notch.

End Cap

- The end cap joins to the pipe with a wood screw in the same way as the connector piece. Drill the hole, rose it and check the screw fits.
- The selector switch and BNC stick out the back of the end cap. With the end cap in a vice, punch the position of each. Both have to be far enough from the edge to fit into the pipe. In addition, they can't be too close to each other or there isn't room for wiring them together. Putting the switch at the center and the BNC 1" down works well for the 2.5" tubing.
- Drill each hole out to a final diameter of 3/8". If you're working with a hand-held drill you may want to work through a range of drill-bits.
- Check the BNC and switch fit comfortably.
- For our switch, there's a stub that prevents it from freely rotating. Measure and drill a hole for it too (1/8" or so). Our switch is also a bit short (for the 2.5" Schedule 40 PVC piping) so we just filed the top of the hole until it was a bit thinner.
- Cut out a piece of card-board to fit around the selector switch and mark on the labels for each position. Epoxy it in place (smear plenty over the card too and the writing is protected).

Battery and Nob

- The 9 volt battery is secured via adhesive Velcro. Cover at least one side of the battery with Velcro. Stick the other type of Velcro into the tube near the photo diode end.
- With the switch screwed in place, cut the switch handle to the right length to fit the knob.

Photos

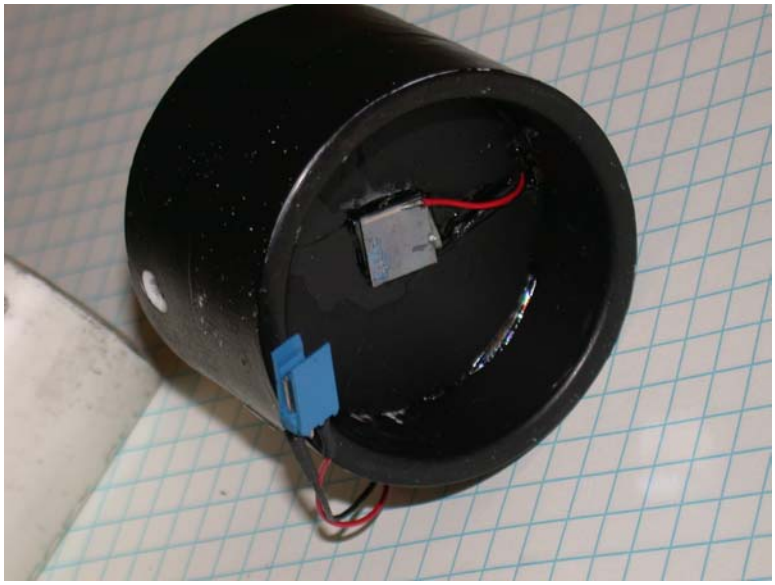
Straight Connector, 3.5 inches length of Pipe and End Cap at start.

Front Connector With Aluminium Face Plate Ready for Gluing.

Illustrating The Position of the Screws in holding the Front and Back on.

Cutting out the Aluminium Face Plate

Finished Straight Connector – Solar Cell glued into place with a 2-pin plug on it.



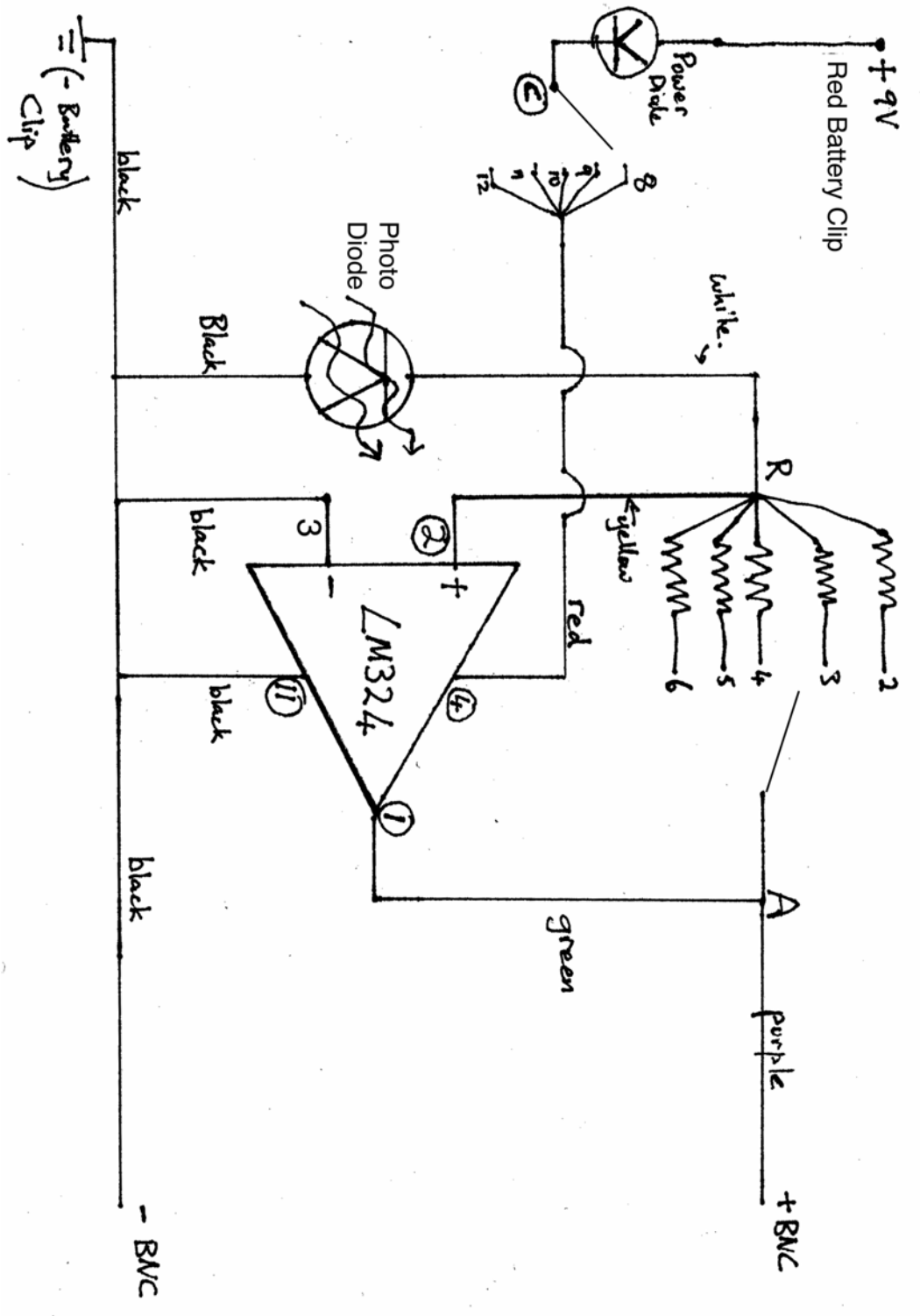
Drilling the holes in the end cap

End Cap Finished with switch and BNC ready to mount.

Covering battery in Velcro and then securing it in the piping.

Building the Circuit

Plans :



Quick Connection Summary

Photo Diode – When plugged into a multimeter the black leg should be positive, white leg negative.

Black Photo Diode -> Black Battery Clip
White Photo Diode -> Point R where all resistors connect and Pin 2 of Op Amp

Power Diode – Connects between Red leg of Battery Clip and Terminal C of Switch. NOTE POLARITY (in right if a multimeter connected between C and black battery terminal gives 8V to 9V.

Switch -

Terminal A selects between 1,2,3,4,5,6
Terminal C selects between 7,8,9,10,11
For us, A selects the gain and C is just a power switch.

A – Purple to +BNC (center of BNC) : Green to Pin 1 of Op Amp
2 – 100 Ohm (Brown Black Brown)
3 - 1K Ohm (Brown Black Red)
4 – 10K Ohm (Brown Black Orange)
5 – 100K Ohm (Brown Black Yellow)
6 – 1M Ohm (Brown Black Green)
Note, all resistors join together at top to form point R.

C - Power diode
8,9,10,11,12 – Joined together by a wire
Connected via a red wire to pin 4 of OP Amp

Op Amp –

Pin 11 – Negative Power – Black Leg of Battery Clip
Pin 3 - Negative Input – Black Leg of Battery Clip
Pin 2 - Positive Input – Connects to R with Yellow Wire
via R connected to white (negative) leg of photo-diode and
via R connected through a resistor to A-> pin 1 of OP Amp
Pin 1 - Amplifier Output – Green Wire to A
via A connected to gain resistor and +BNC (center of BNC)
Pin 4 – Positive Power – single Red wire connection to terminals 8,9,10,11,12 of switch.

BNC –

-BNC – (outer terminal) – Negative (black) side of battery clip with a black wire.
+BNC – (inner terminal) – Purple wire to A.
via A joins to pin 1 of Op Amp.

Battery Clip –

Negative (black) joins with black wires to
pin 3,11 of OP AMP
-BNC terminal
black lead on photo diode.

Positive (red) joins through the power diode to C.

Step by Step Assembly of Circuit

Photo Diode : It's convenient to put a connector on the photodiode so you can unplug it when disassembling the circuit. You might use an earphone jack, or any 2 pin plug. Wire up the connector so the white leg is negative and the black leg positive (I know this seems backwards but there's a reason to this madness). Keep the leads long so you'll have lots of range between the switch and diode.

Battery clip – Wire the power diode into the positive (+) leg of the battery clip. Make sure you get it in the right way so you see a voltage on the multimeter when you attach the battery. It's job is to prevent anyone from burning out the Op Amp if they put the battery in back-to-front.

Connect the power diode to terminal C on the switch (for us, C -> 7,8,9,10,11,12 is the power switch. We just wire 8-12 together so those positions have the meter on).

The black lead connects to a stack of wires. Cut 3 fairly short (5cm or 2") black wires and join all three to the black battery clip lead. Then, connect in the black lead from the Photo diode. Solder the lot together.

Switch - Okay, here's the guts of the work.

For the power switch, join terminals 8,9,10,11 and 12 together with a bit of wire (the cut off legs of resistors works well). Cut a short (2" or 5cm) red lead and connect it to the 8-12 combo. This will power the chip.

For the gain selector works by picking out a resistor. Terminal A selects between terminals 1,2,3,4,5 and 6. For each terminal where the circuit is on (2-6) we select a different resistor to control the gain of the op amp. That is, we want to connect the OP AMP to each of the resistors at one end, and the switch will decide which one to pass the current along. Solder one leg of the 100 Ohm onto Pin 2, 1k Ohm to pin 3, 10K Ohm to pin 4, 100K Ohm to pin 5 and 1M Ohm to pin 6 so they stick vertically up from the switch bottom. Bend them towards each other until they all touch. Solder them together. That's point R. Current will flow into point R and then the switch will pick which resistor to send it through.

Join 2 wires to point R. Connect the white lead of the Photo Diode to R and connect a short (2" / 5cm) yellow.

Finally, run short GREEN and PURPLE leads from A.

OP AMP - So now we've lots of little leads sticking out that need to go to the OP AMP. I recommend using a chip holder. That way, if you stuff up a chip (power into the wrong leg, etc.) you don't have so much work to do. Anyway, that's up to you.

Join the green lead to PIN 1 (A on switch)
Join the Yellow to PIN 2 (R on switch)
Join a BLACK from the negative battery clip to Pin 3
Join a BLACK from the negative battery clip to Pin 11
Join the RED from terminals 8-12 of the switch to Pin 4

That should leave two wires hanging loose
Short Black from the negative battery clip.
Short Purple from A.
which are destined for the BNC.

BNC –

Put the switch and BNC into the end cap. Join the PURPLE to the center of the BNC. Join the black to the outside of the BNC.

Testing –

Quickly check all your connections go where they should.
Put the switch into position 1/7.
Connect the multimeter to the BNC.

Connect the battery. Flick the switch to position 2/8. The OP AMP should stay cool and you probably won't see much voltage on the low gain setting. Everything should be working. Crank up the gain.

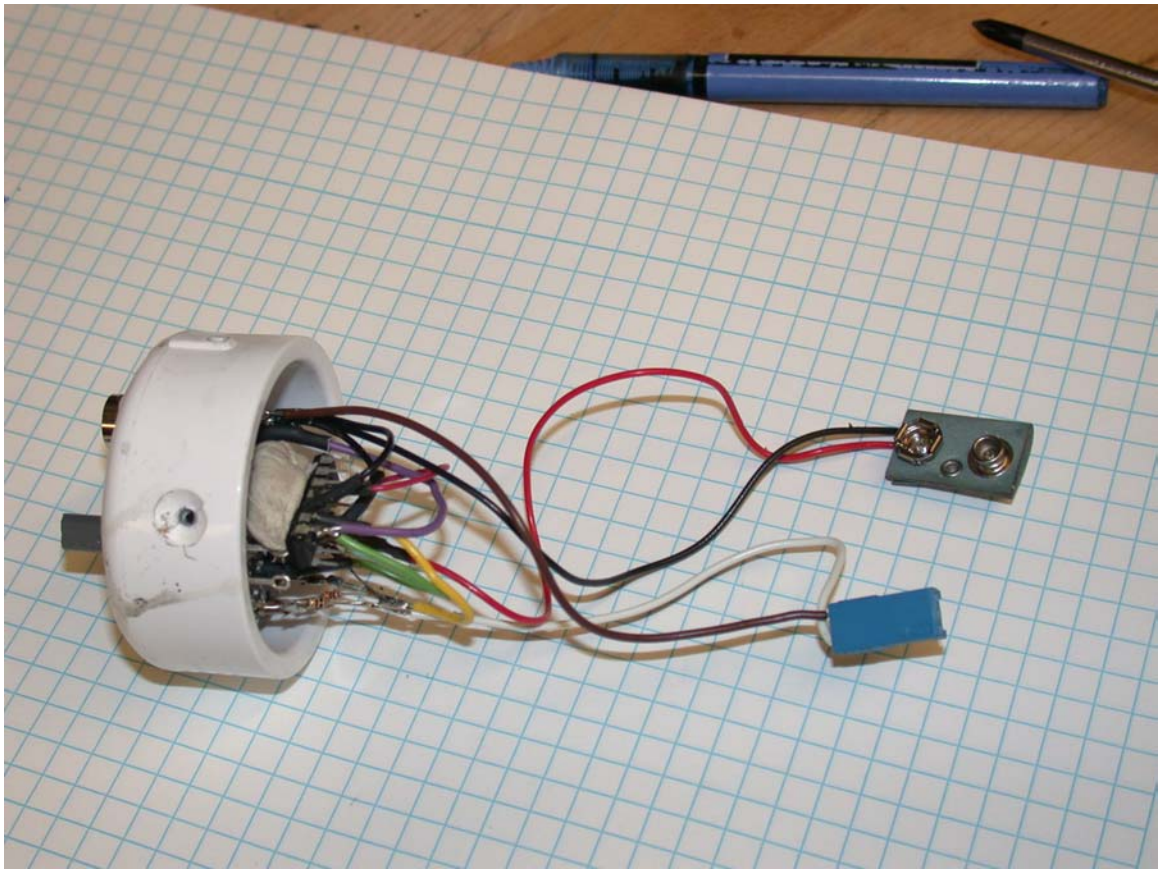
Neatening Up –

Use heat-shrink and electrical tape to eliminate any potential shorts.
A dob of putty or a dab of hot glue can keep the OP-AMP safely secured to the side of the switch.

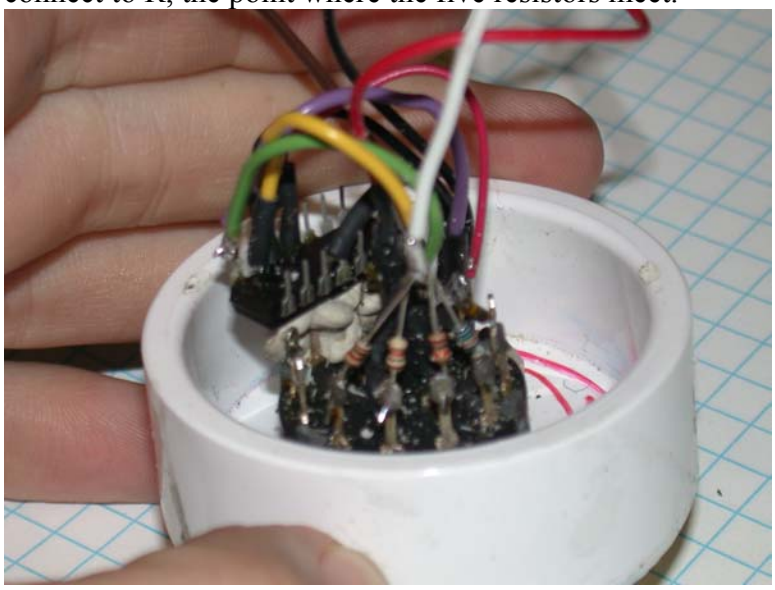
Trouble-Shooting –

1. Is the Op-Amp getting power? You should see 8-9V from pin 11 to pin 4. If you don't feed it power, nothing interesting will happen.
2. Is the photodiode connected? Turn the meter off, or disconnect the battery. You should see a small negative (-0.2 or –0.3V) between the negative battery terminal and R (ie. across the photo diode). This should also be present at Pin 2 of the OP Amp.
3. Is there feedback? Again with the battery disconnected, check the resistance between pin 1 and pin 2. If the gain is set to 100 Ohms you should see 100 Ohms.
4. Is the Op Amp working? If the output is high (>7 V), pin 2 should be more positive than pin 3. If the output is low (effectively 0V) pin 2 should be more negative than pin 1.
5. You did build a test version on a breadboard, didn't you?

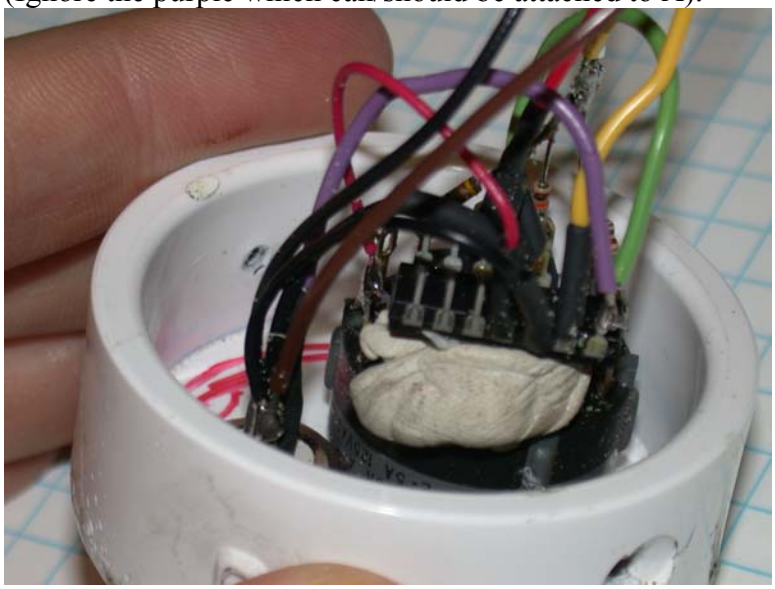
The Final Product



Resistors for selecting gain (See how all 5 resistors are bent over to connect to each other. The white (photodiode), green (Op Amp Output) and purple (BNC +) wires all connect to R, the point where the five resistors meet.



The IC wiring. Red to pin 4, Black to pins 11 and 3, Yellow to pin 2 and Green to pin 1. (Ignore the purple which can/should be attached to A).



Building a Filter

What light meter would be complete without some filters? We haven't done it yet, but here's how you would.

Parts :

Straight PVC connector
Piece of PVC piping just long enough to join two connectors together.
Sheet of filter material.
5 minute Epoxy Glue.

Method :

Cut out a circle of filter material so it is just smaller than the end of the pipe. Glue it on.
Stick the pipe into the connector.
Glue the pipe and connector together.

Additional Suggestions

You can make a lot of modifications to this circuit/package if you desire.

1. More gain : The LM324 has 4 Op-Amps on one chip. We've only used one of those stages. If you feed the normal output into a second stage of amplification, you can easily boost the signal by a factor of 1000. If you go beyond that point "dark current" starts to dominate your output. The only reliable way to beat that is to add a DC offset ("a zero trimmer pot").

2. Make a Spot Meter Attachment : With a short piece of pipe and a lens you can easily focus a scene onto the diode face. Simply using a smaller diode helps.

3. Build an Integrator to measure the light flux from camera flashes.
   Any of the three extra Op Amps on the chip would make a good integrator.

4. Build the pre-amp separately from the diode. We deliberately packaged the amplifier as a single unit so it would be tough and easy to use. However, you could easily put the current-voltage convertor into a box that plugs straight into a multimeter. Now you have a tool not just for a photo-diode, but for any transducer that produces a DC current. For example, put a smoother on the input and it'll work for a speaker as a sound meter.

Suppliers

Newark

Photodiode

Newark Part No.:92F3666
Manufacturer Part No.:VTS3082
Manufacturer Name:VACTEC PHOTO
Product Category:Opto-electronics~LED~IR
Part Description:Photo diode With Solderable Contacts, 0.144 sq in Active Area, 0.33 volt Open Circuit Voltage V oc Typical, 0.2 micro A Dark Current I D Maximum
$9.410

Newark Part No.:92F3665
Manufacturer Part No.:VTS3085
Manufacturer Name:VACTEC PHOTO
Product Category:Opto-electronics~LED~IR
Part Description:Photo diode With Solderable Contacts, 0.032 sq in Active Area, 0.33 volt Open Circuit Voltage V oc Typical, 0.1 micro A Dark Current I D Maximum
$4.010

Op Amp

Newark Part No.:35C0507
Manufacturer Part No.:LM324N
Manufacturer Name:FAIRCHILD SEMICONDUCTOR
Product Category:IC's~Amplifiers
Part Description:Quad operational amplifier, 75 dB CMRR, 4 channel, 1 mA supply current, 3 to 32 V supply voltage, 1.5 mV offset voltage, offset drift 7 uV/C, 14 lead, DIP, operational amplifier, generic part number LM324
$0.525

Switch

C&K Supplies - Catalog Number - 81F1012 - Type A20615RNZQ - Rotary DP 6 Position - $4.02

Resistors, Power Diode, BNC Connector

McMaster

2 inch Schedule 40 Pipe

White 2” Pipe Size , Coupling – 4880K56, End Cap 4880k76,
+ 2 inch tubing.