The One Hour Photodetector

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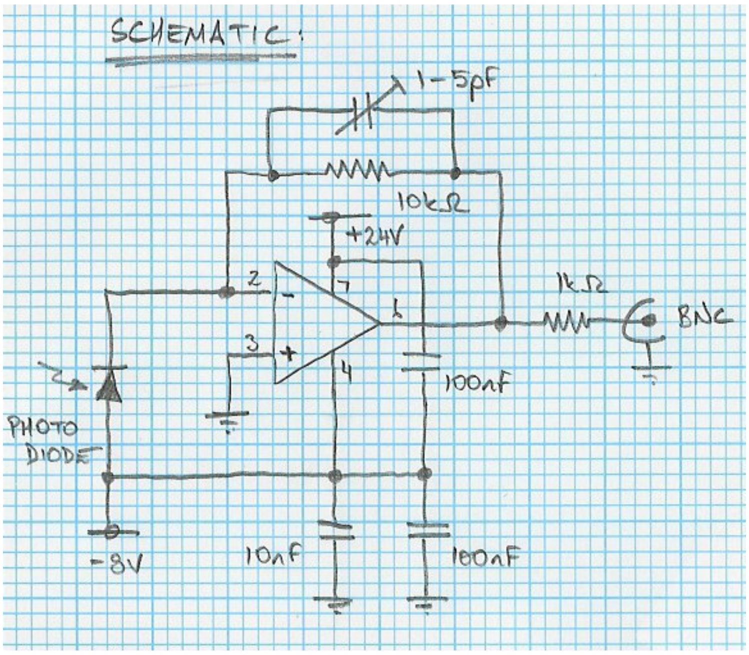
The scenario…

You've painstakingly constructed yet another optical cavity and need to align it. You squirt light into one end, begin sweeping one of the piezo- mounted cavity mirrors and reach for… crud! Who used the last of the photodetectors?!

Substitute the word interferometer, chopper, modulator, unusual wavelength etc and you can see why this project was born – in every optical lab there are dozens of applications for a cheap and simple photodetector. While being cheap, simple and ***quick*** were the primary design goals for the photodetector described herein it was also intended to be genuinely ***useful***, i.e. exhibit a versatile bandwidth, negligible drift and large output swing.

Design

The architecture chosen was a textbook transimpedance amplifier configuration as shown in the schematic below. The photodiode is operated in reverse bias and the op-amp performs a photocurrent-to-voltage translation. Note that the photodiode is connected to the negative supply so that an increasing photocurrent yields an increasing positive output voltage. Things just seemed to make more intuitive sense that way.



The only two components that rate a special mention are the 1-5pF variable feedback capacitor and the 1kΩ output resistor. The feedback capacitor compensates for the parasitic capacitance of the photodiode which serves to decrease the amplifier phase margin and thus decrease the circuit's stability. It serves to increase the negative feedback at high frequencies and restore sensible operation but at the expense of bandwidth. Oh well, it's still plenty fast enough for what I needed!

The output resistor is primarily there to protect the op-amp. It ensures that short circuit output current is limited to no more than 24mA and that the photodetector remains stable when connected to a capacitive load. The caveat is that the output amplitude falls by a factor of 21 if driving a 50Ω load. If this really matters to you, you could substitute a better op-amp or add another stage of amplification, but then it wouldn't be a "One Hour Photodetector"!

None of the component values in the circuit are particularly critical, but here are a few guidelines if you want to substitute parts *you* have to hand:

Photodiode: Any PIN diode that can withstand the 8V of reverse bias used in the above circuit will work in this application. For our 1550 nm application a Perkin Elmer C30641G InGaAs PIN photodiode would be ideal but we actually used the far more expensive C30617 because we happened to have one in the drawer…
Other semiconductors could be used for other wavelength ranges without any problems. Dark (or leakage current) will result in a small positive output voltage – I haven't included any provision to trim this away but it could be tamed by following your op-amp manufacturer's 'offset adjustment' procedure if it really bugs you.

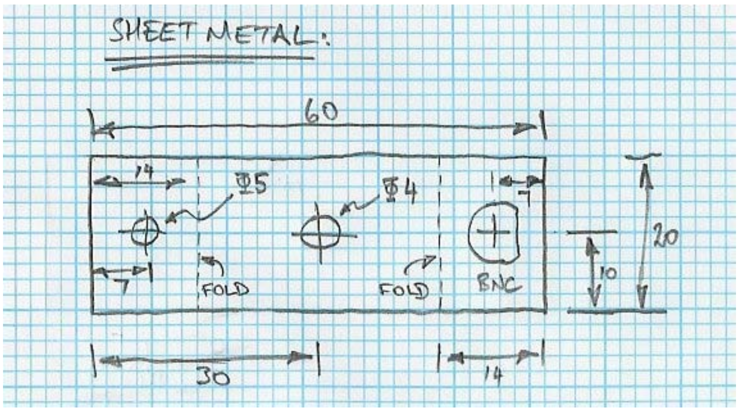
Power supplies: The values of -8V and +24V were used for no other reason than these voltages are readily available in our lab and I wanted to avoid having to include voltage regulators in the design. The values you use will be most strongly influenced by your choice of op-amp and the desired reverse bias for the photodiode. Most cheap op-amps laying around in a parts box won't be able to swing to within closer than a couple of volts of the supply rails, so having a negative supply of at least -2V means that no light in will give zero volts out. Coincidentally, these few volts are also an ideal reverse bias for the photodiode, so check your diode's specs before increasing it too far! The positive supply limits the maximum output voltage of the detector, noting again that the maximum output will typically be a few volts short of the rail. The only practical constraint on this voltage is the maximum operating voltage of the op-amp.

Op-Amp: Pretty much any will do depending upon the speed you require! Don't be fooled into choosing an op-amp based on its' gain bandwidth product alone – the far more important parameter is slew rate, the speed at which it can change its output in response to light level changes. For example, when sweeping a high finesse cavity through its resonances the transmitted intensity rapidly changes from zero to a large value and back again. If the output voltage cannot keep up with the light intensity changes you see a time shifted, filtered, lower amplitude lump on the oscilloscope instead of the thin perky response you expect. You can waste *days* trying to debug problems that aren't really there. Trust me. I used the LM6361 300V/us device in this design and it appears to be fine (I'll actually measure it one day). Please don't even think about using the awful LM741…

Feedback components: The value of the feedback resistor (10kΩ) multiplied by the photodiode's spectral responsivity (in A/W) determines the overall sensitivity of the photodetector in V/W. Decreasing this value may serve to increase the bandwidth of the amplifier at the expense of output voltage swing – you decide. The role of the compensation capacitor was described previously and adjustment is simple; initially set the capacitor to minimum capacitance and the output will most likely oscillate at some frequency determined by your op-amp and photodiode. Gradually increase the capacitance until the oscillation stops and then add little bit more for good measure – all done! If your amplifier doesn't oscillate at all, then adjust the capacitor for maximum speed and responsiveness. If no amount of twiddling stops your detector from oscillating, then increase the value of the feedback capacitor and try again.

Construction

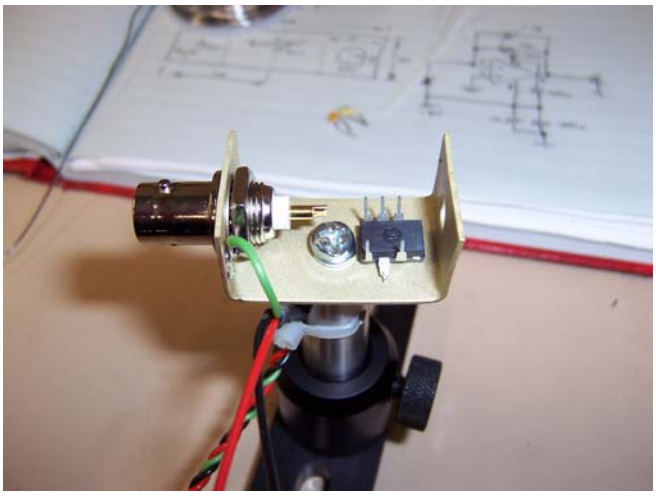
Building a case for any given widget can be terribly time consuming, so the photodetector was designed to be simply constructed 'dead bug' style on a bent piece of solderable metal. Naturally, the exact dimensions are far from critical but the following sketch illustrates the dimensions of the scrap piece of 1mm brass I used. It is easiest to use a punch to make the holes in the sheet as both brass and copper sheet have a tendency to tear and distort when drilling. If you use a drill, be sure to clamp the workpiece down to avoid being shredded – oh, and drill the holes *before* bending it into a U shape!



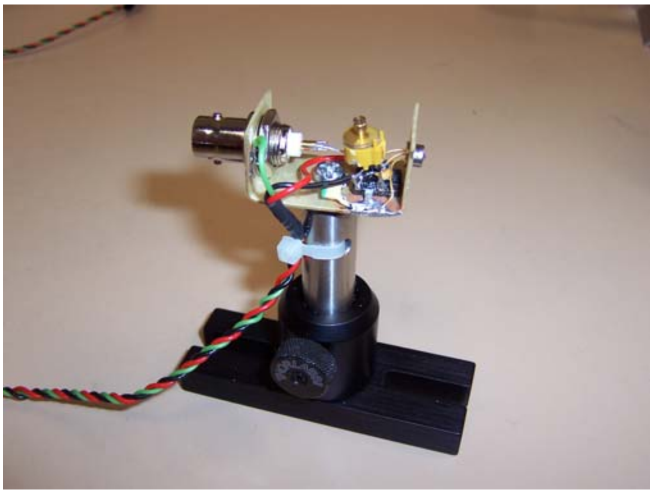
To avoid potentially hazardous specular reflections from the case, sandblasting or beadblasting the finished 'chassis' is highly recommended. The right hand piece below illustrates the final finish achieved and significantly reduces the reflection hazard at 1550nm (other wavelengths? No idea!).

To set the photodetector at the correct height, we mounted our unit atop a Thorlabs post/postholder combination as shown. Use whatever is easiest for you!

'Dead-bug' construction involves mounting the integrated circuits upside-down so that their legs stick up into the air (see where the name comes from?) and soldering directly to the chassis for all ground connections. All other connections are achieved by wiring from point-to-point with short lengths of bare wire.



This photo illustrates the op-amp ready to be soldered, with pin 3 soldered straight down to the chassis. Because of the relatively thick metal I used, this requires a *lot* of heat – be careful not to incinerate the op-amp or your fingers. Note that I clipped off the unused pins of the op-amp to make things a little less cluttered. The wires cable-tied to the post run off to the connector for our power supplies.



Voila! The completed unit! The photodiode can be seen protruding from the hole on the right and the yellow compensation capacitor was placed last to allow easy adjustment – now the moment of truth…

Testing

Testing the unit involves applying power briefly and watching the power supply currents – the meter needles are allowed to twitch, but any more than a few milliamperes (depending upon your op-amp) is a cause for concern. If the current consumption appears excessive, disconnect power and check for short circuits or reversed diode/power supply polarity.

Once all appears well, connect an oscilloscope to the output and apply power. Ideally the output should remain around zero volts – if it commences oscillating at a frequency of a few hundred kilohertz to low megahertz, tweak the compensation capacitor as described previously.

The final test is to illuminate the photodiode – if all is well the output voltage should increase linearly with the intensity. All done! Enjoy ☺.