# Experiments on an LED-Based Optical Transceiver

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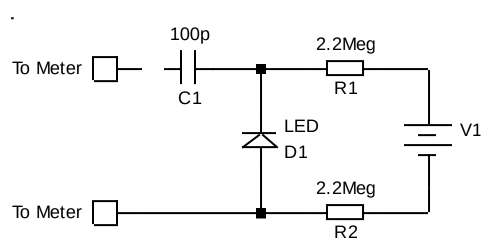
1. LED Used as a Photodiode

The LED was ordered from “dipmicro electronics” on Ebay and is a generic type, manufacturer unknown. Here is the data provided by dipmicro.

| Technical Summary | |
|---|---|
| RoHS | ✓ |
| Package | ø 3mm |
| Packaging | buk |
| Dimensions | ø3mm |
| Lead Spacing | 2.54mm |
| Color | Red |
| Brightness | 4000mcd |
| Wavelength | 615~640nm |
| Lens | Waterclear, White |
| Viewing Angle | 15º |
| Forward Voltage | 1.8~2.6V |
| Current Rating | 20mA |

2. LED Capacitance

The capacitance was measured using the following circuit, using an Almost All Digital Electronics L/C Meter IIB.



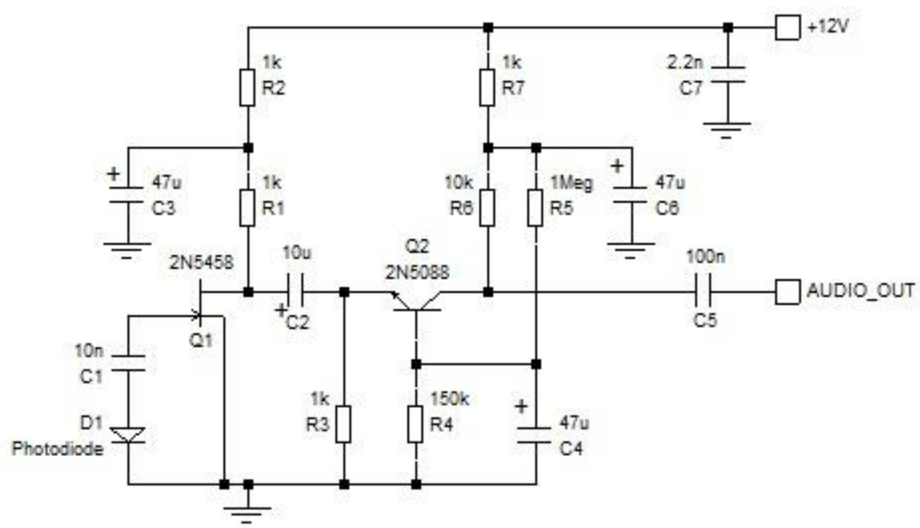

The capacitance was found to be 3.3 pF with V1 = 12 V and 5.0 pF with V1 = 1.4 V.I am unsure if the AC voltage applied by the meter is small enough for accurate measurement.

3. Optics

A 3.5 inch (89 mm) glass lens with about 105 mm focal length was used. This subtends about 46 degrees at the focus so the LED, in theory, should not make use of the aperture very well. However, when powered, the LED lights the lens completely with no significant spillover. Nevertheless, this is an area of uncertainty which may impact the performance.

4. Preamplifier

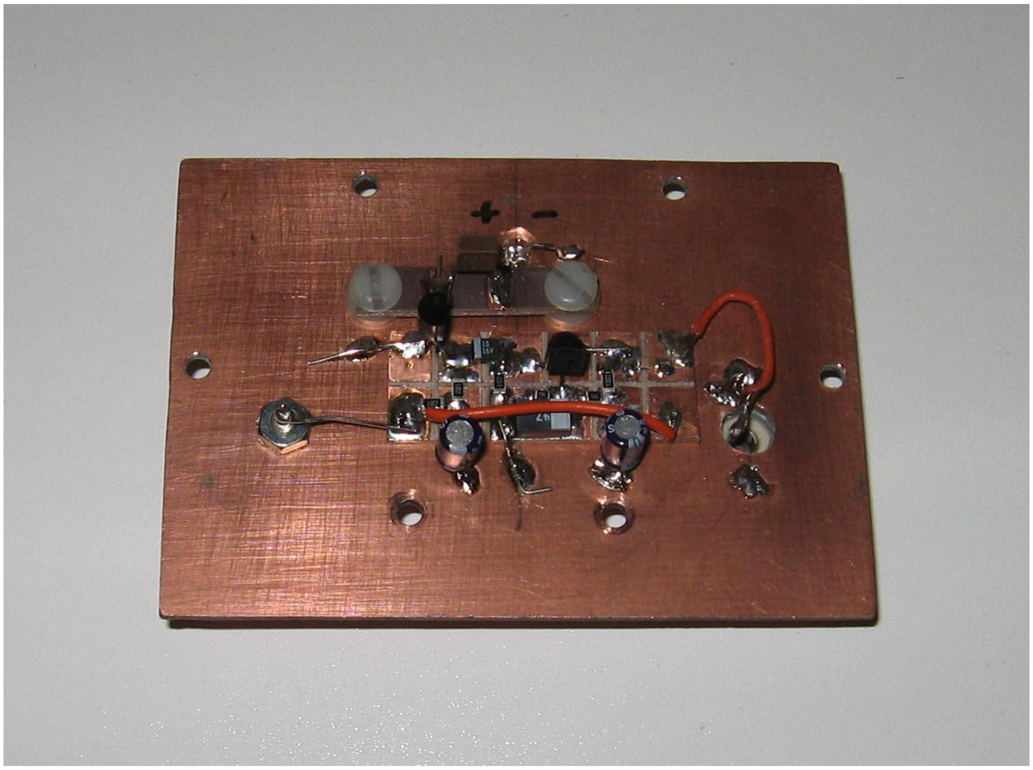
The preamplifier is built according to the following schematic.




The self-biased drain current of Q1 was measured to be 2.7 mA (Idss = 2.2 mA), which places the drain voltage at around 7 V. The collector current of Q2 is less than 1 mA. The preamplifier is designed to operate into a high impedance load (much greater than 10 kΩ).

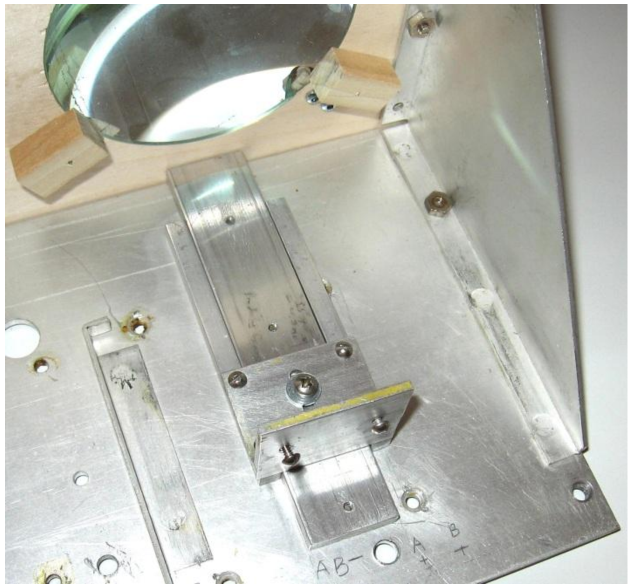
The construction of the preamplifier is shown in the following photograph. The high impedance connections of D1, C1 and the gate of Q1 are made on a piece of Teflon-glass PC board (with no copper on the back side), mounted on Nylon screws and Nylon spacers, in order to try to minimize leakage resistances. The LED sticks through a hole in the PC board base for the preamplifier (at the top of the first photo).

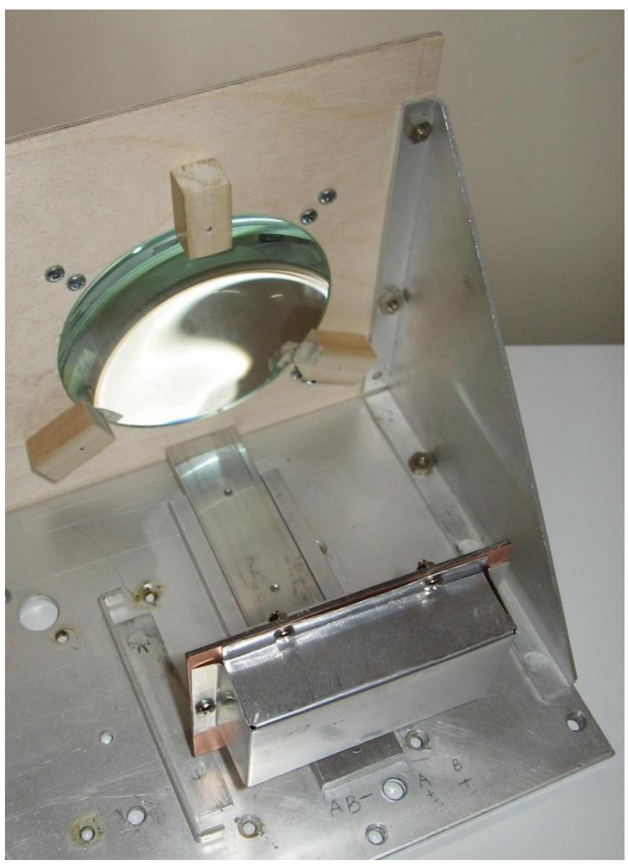
An aluminum shield is used to reduce capacitive pickup of hum from AC power lines, as shown in the second photo on the following page.



5. <u>Focusing</u>

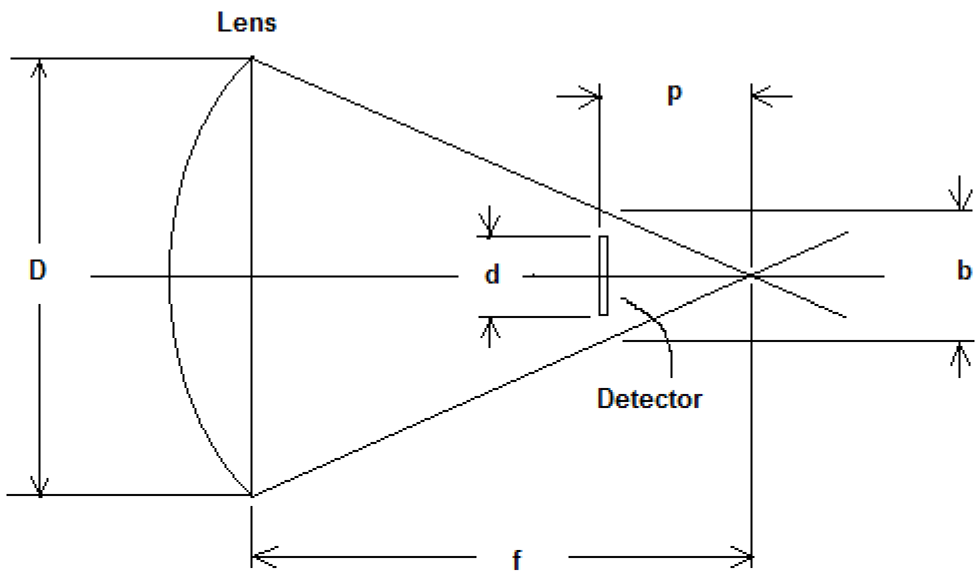
The LED and preamplifier are mounted on a lockable focusing slide, shown in the following photographs.





6. Focusing Sensitivity

Consider this diagram, where D is the lens diameter, d is the detector diameter, f is the focal length, p is the axial position of the detector (measured from the focus) and b is the beam diameter at this position.



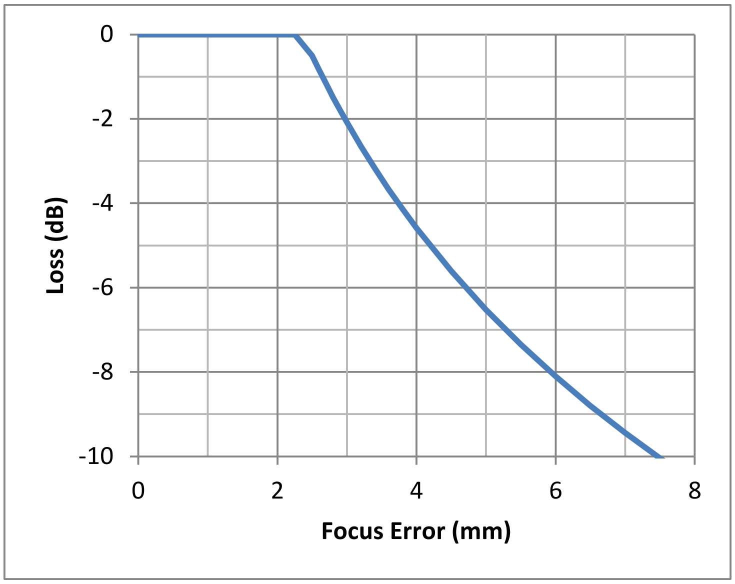

By simple proportion, b = (p/f) D.

The proportion of the available beam power intercepted by the detector is the ratio of the detector area to the beam area, where the beam is larger than the detector, and one where the detector is larger than the beam. So

$$P/Po = d^2/b^2$$
$$= (df/pD)^2 .$$

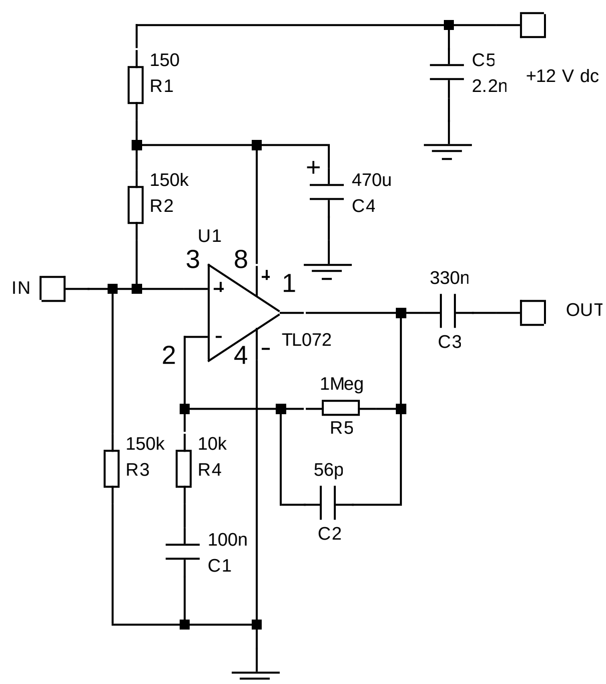
For the LED detector, we need to take a guess at the effective diameter (meanwhile noting that the detector area is probably actually a square !). Let's say 2 mm for the 3 mm diameter LED. For the 89 mm / 105 mm focal length lens, this results in the following curve (where the power ratio has been converted to dB).

The focusing adjustment will need to be set to a precision of around 2 mm.

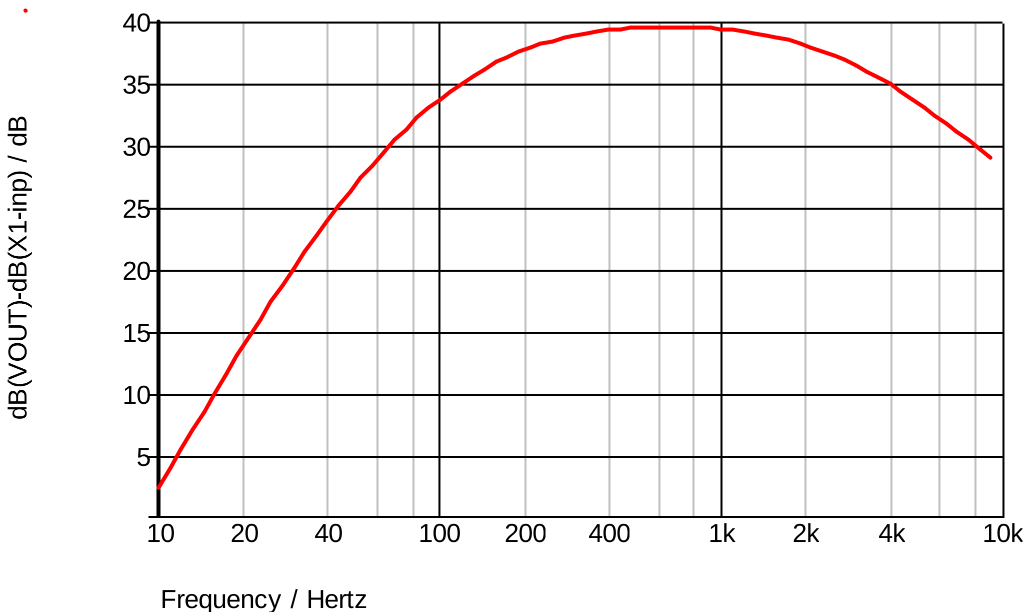



7. Intermediate Amplifier

The next amplification stage uses the following schematic.

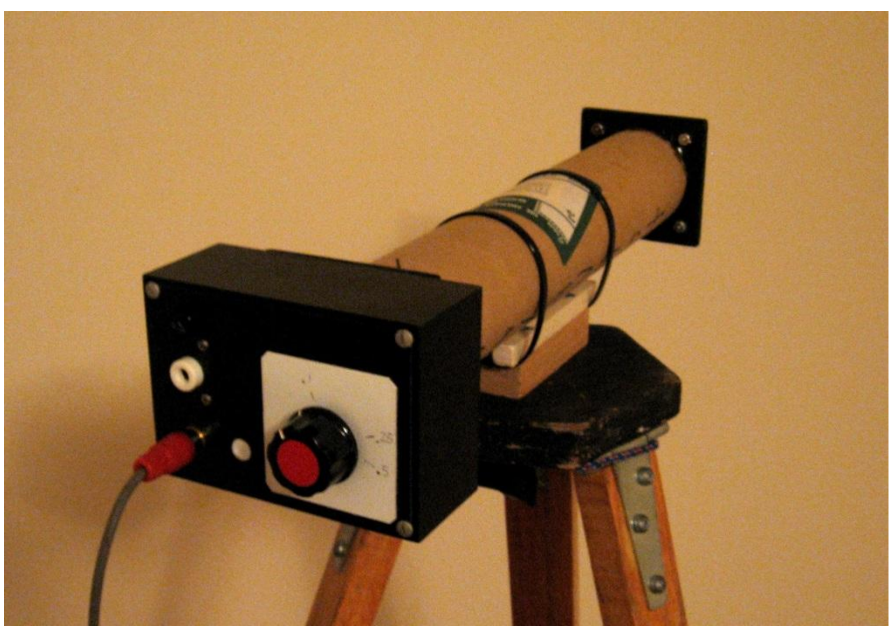


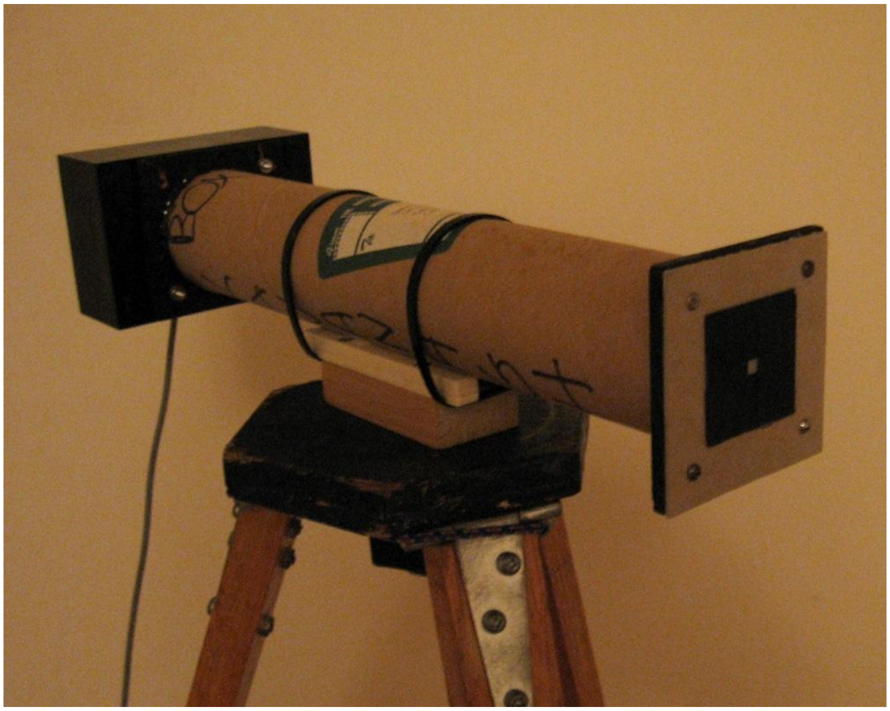

The theoretical voltage gain of this circuit (into a 10 kΩ load) versus frequency is as shown below. This was modelled using SIMetrix SPICE.



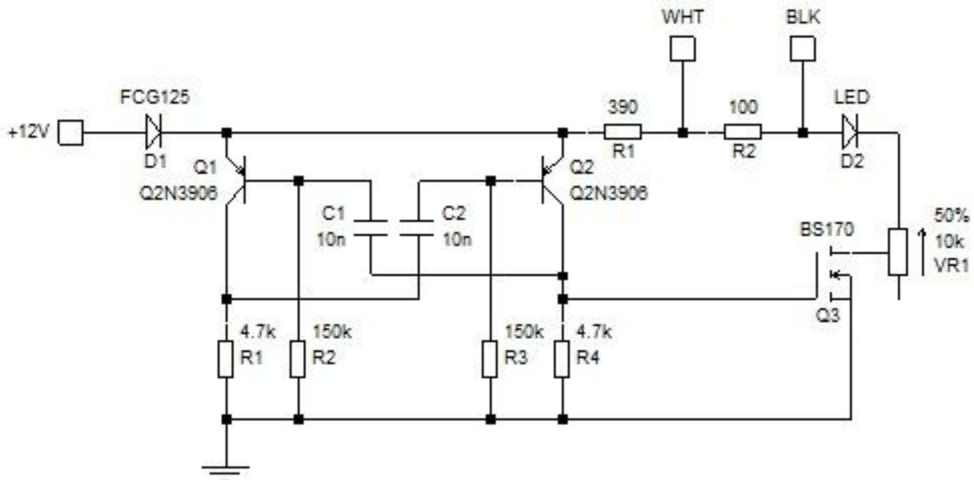

8. Weak Signal Source

A weak signal source for testing was constructed using a mailing tube (painted black inside), with a square-wave modulated LED at one end (with adjustable current) and at the other end a piece of thin clear plastic, sanded with 150-grit sandpaper on both sides and masked with electrical tape to a 4 mm square.  The LED used was the same type as in the receiver.



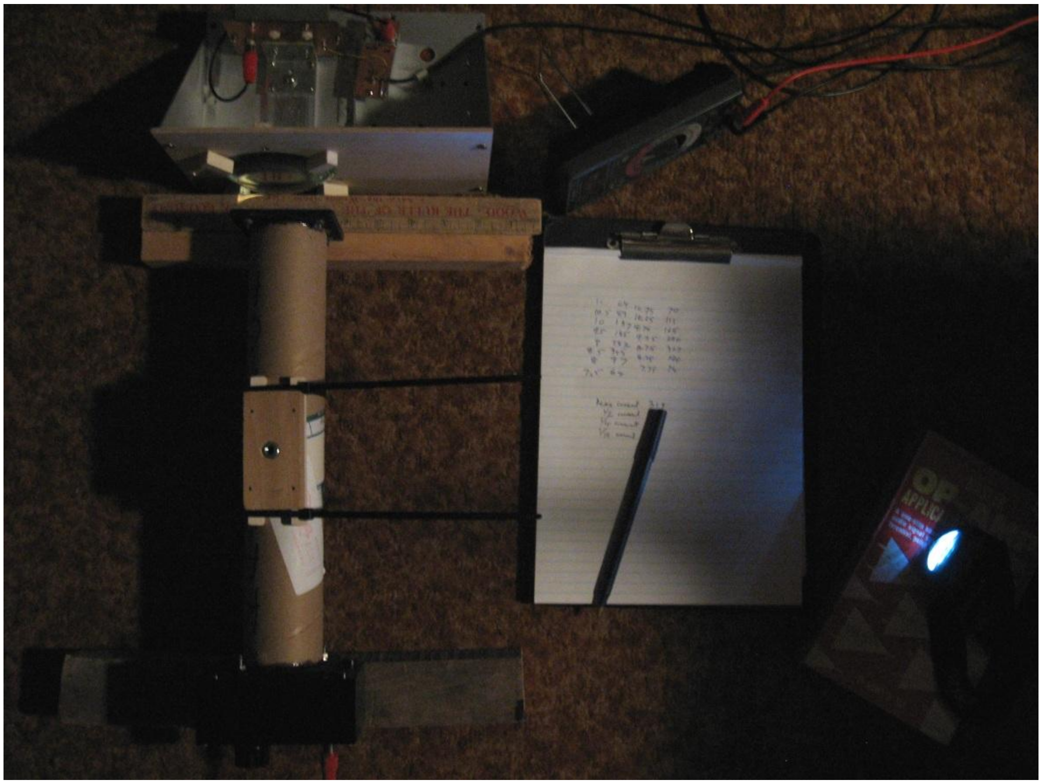


The schematic for the LED modulator used is given below.

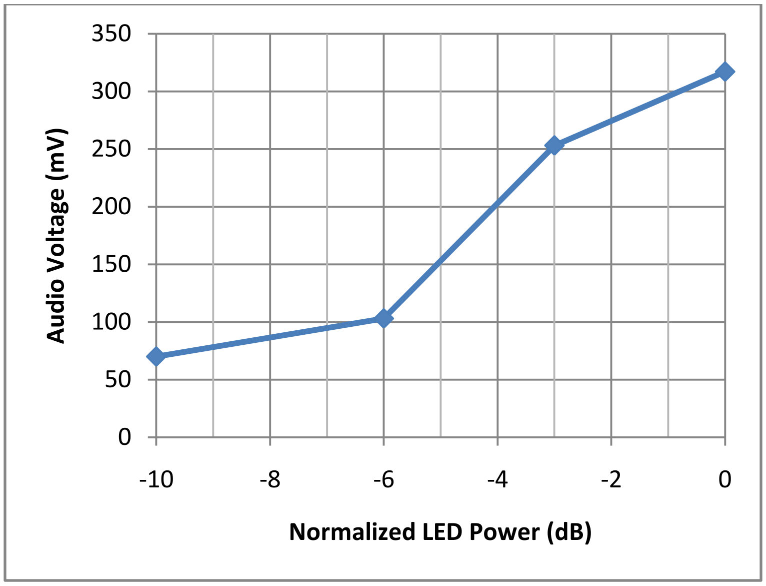


9. <u>Checking the Aperture Distribution</u>

The weak signal source was used to make a rough check of whether or not the LED's narrow beamwidth was resulting in under-use of the full lens aperture. The test setup is shown below.



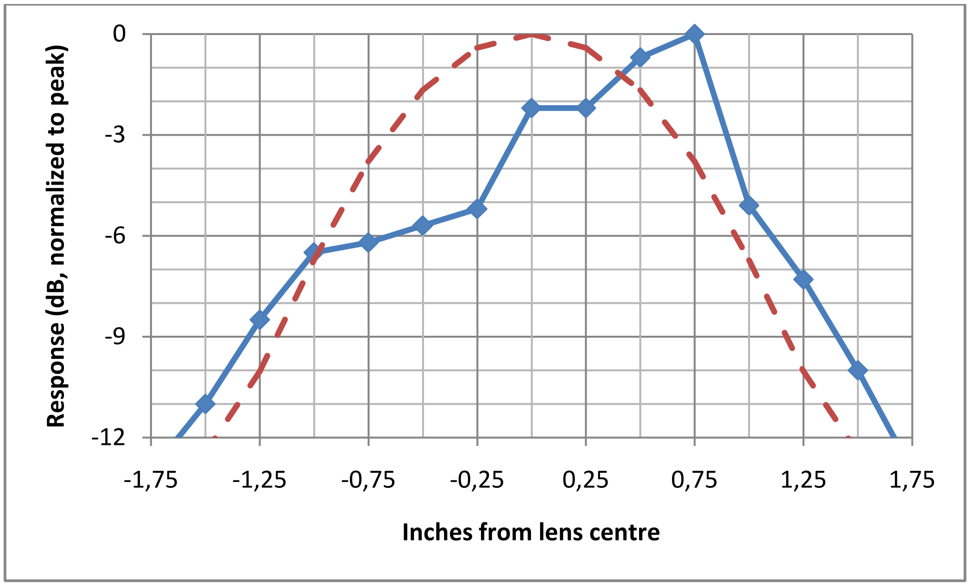
The weak signal source was used to illuminate a small part of the lens at a time, and was moved across the lens from side to side, while monitoring the audio output voltage with a digital multimeter. The current control on the weak signal source was used to calibrate the response, knowing that the LED power output is proportional to current. With the weak signal source near the centre of the lens the audio output versus LED current setting was as follows.




The measured audio voltage with the weak signal source LED current set to maximum and then scanned across the receiver lens was as given in the following table.

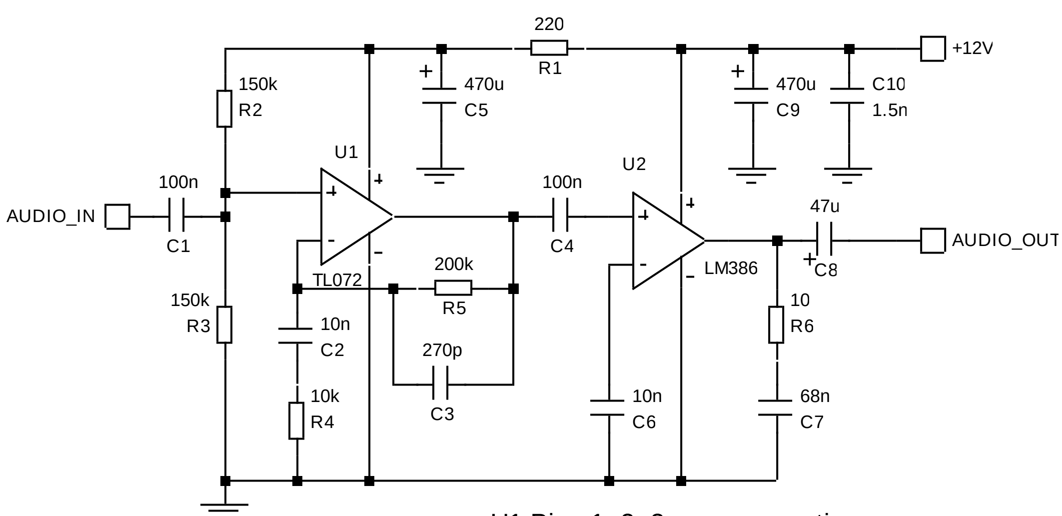
| Position<br>(inches from lens centre) | Audio Voltage<br>(mV) | Audio Level (dB, using<br>above graph to convert) |
|---|---|---|
| -1.75 | 64 | <-10 |
| -1.50 | 70 | -10 |
| -1.25 | 89 | -7.5 |
| -1.00 | 111 | -5.5 |
| -0.75 | 137 | -5.2 |
| -0.50 | 165 | -4.7 |
| -0.25 | 185 | -4.2 |
| 0 | 290 | -1.2 |
| 0.25 | 282 | -1.2 |
| 0.50 | 327 | +0.3 |
| 0.75 | 345 | +1.0 |
| 1.00 | 190 | -4.1 |
| 1.25 | 97 | -6.3 |
| 1.50 | 74 | -9 |
| 1.75 | 64 | <-10 |

The distribution is plotted below in blue, re-normalized to the peak response. It can be seen that the response does taper off markedly towards the edges of the lens and is rather asymmetric. Apparently the LED is somewhat mis-aimed. The edge taper is not more than would be typical in microwave antennas, however, so it cannot be catastrophically bad ! Typically, circular aperture distributions for antennas, with 13 dB edge taper, have only about 1 dB loss compared to a uniformly distribution. For comparison, the dashed red curve is a 13 dB edge taper parabolic-cubed-on-a-pedestal distribution, typically used in antenna analysis to approximate the distribution on a reflector or lens antenna resulting from a real feed horn radiation pattern.




10. Audio Amplifier Output Stages

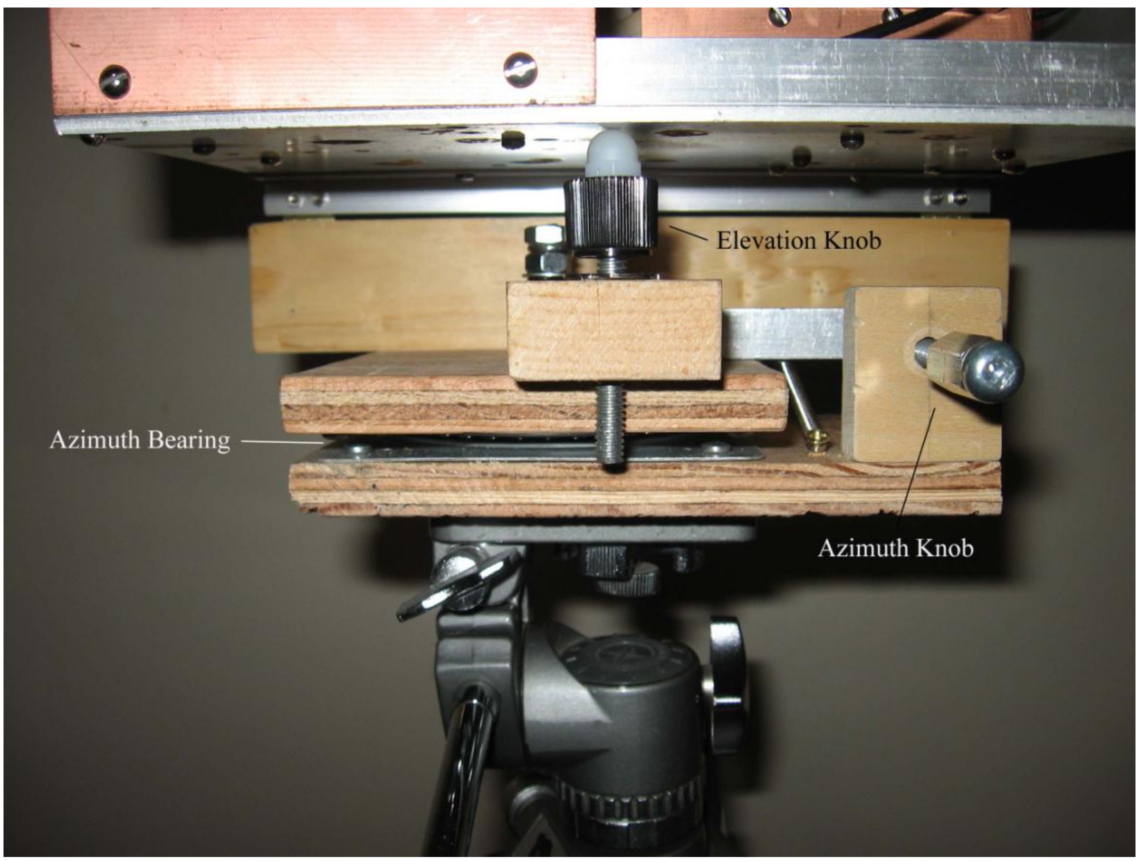
The audio section was completed using a 10 kΩpotentiometer for volume control at the output of the intermediate amplifier described above, followed by another op-amp stage and an LM386 power amplifier. Here is the schematic for the output amplifier stages.

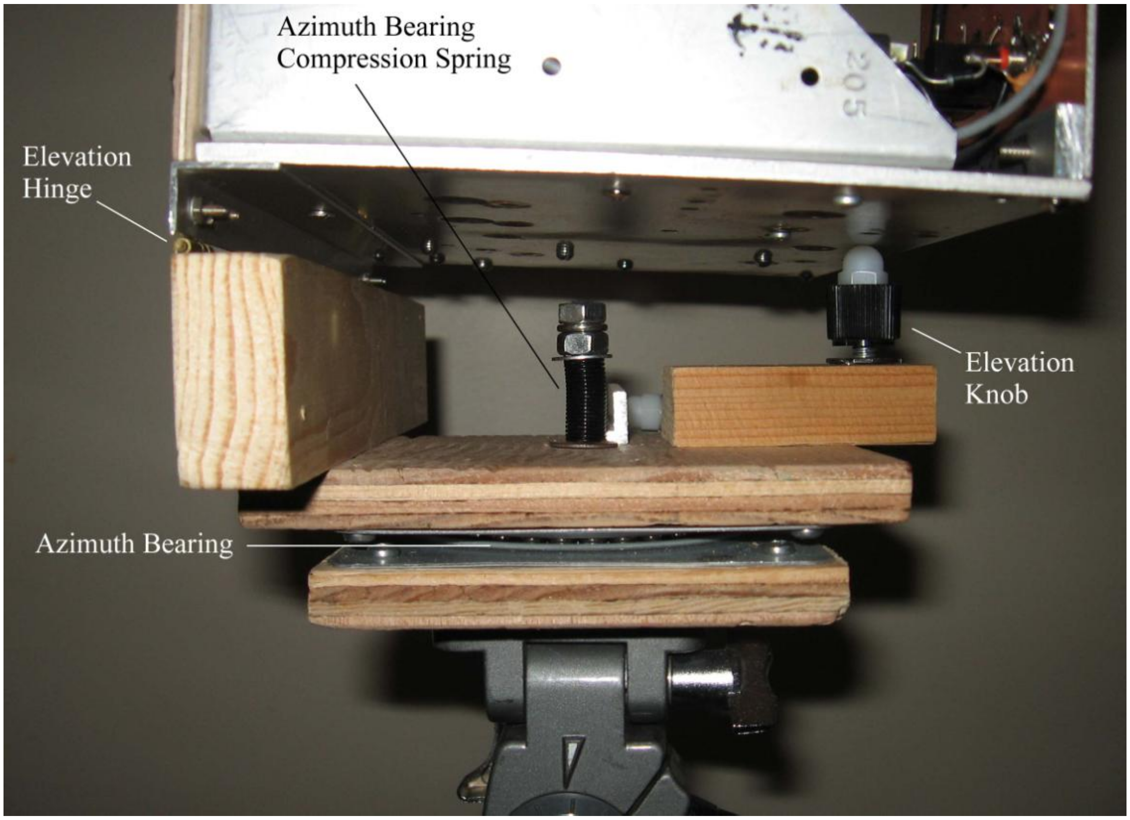


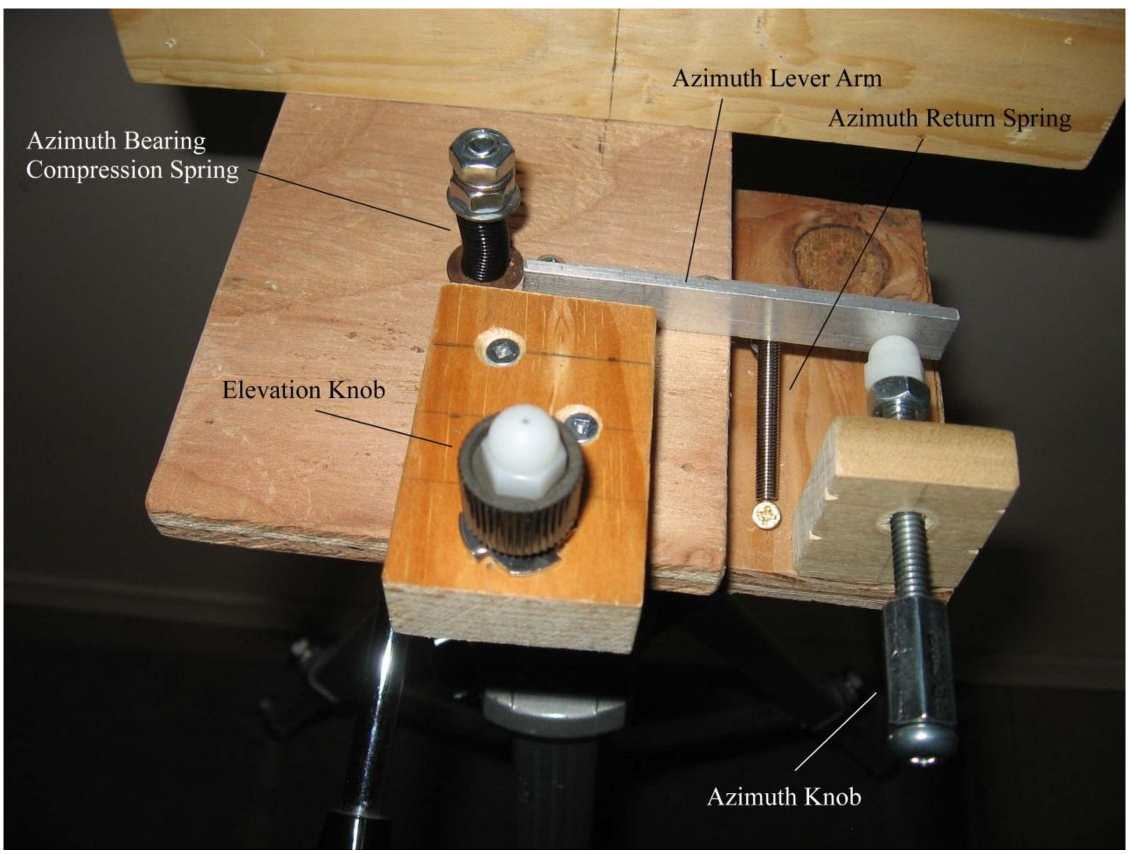

U1 Pins 1, 2, 3 - no connection
U2 Pins 1, 7, 8 - no connection

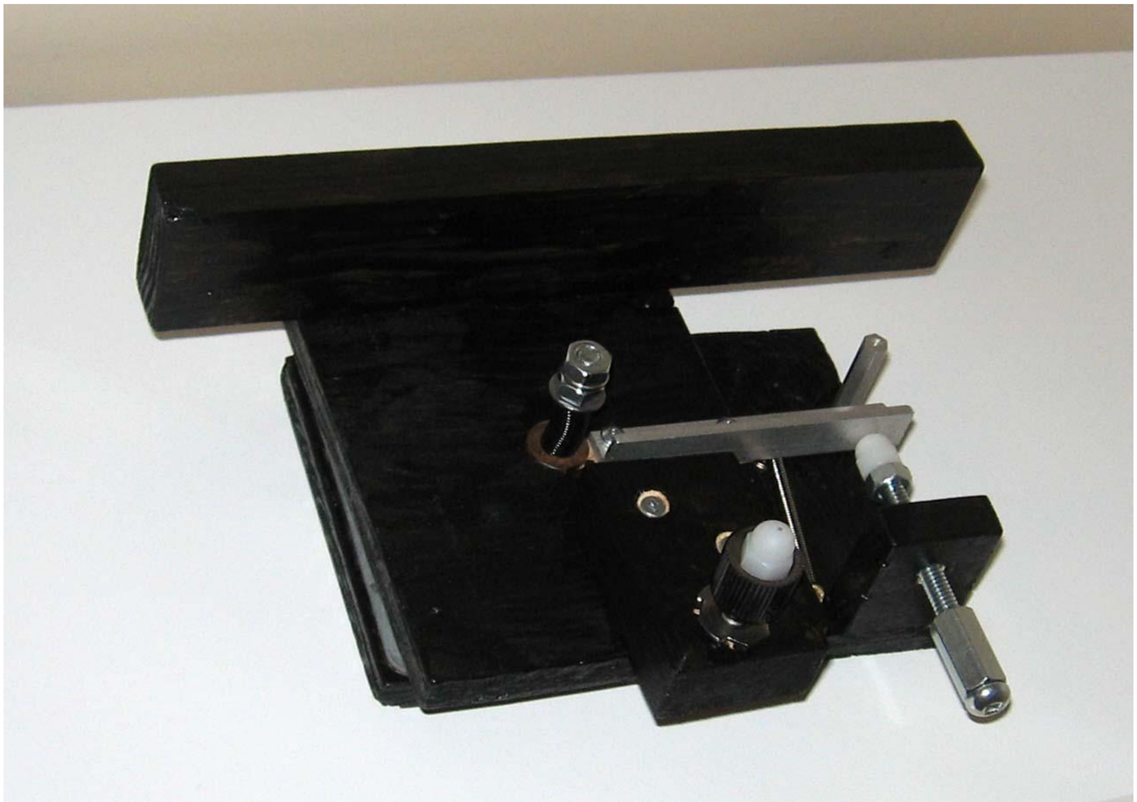
11. Fine Pointing Mechanism

The following photographs show a prototype fine pointing mechanism for a small optical transceiver, which allow more precise pointing than that achievable with a basic tripod head. Nothing requires much precision in machining or assembly, as can be seen from the rough nature of the carpentry! A few degrees of motion is provided in both the azimuth and elevation planes. The base of the mechanism mounts to a ¼-20 stud on the tripod, using a T-nut threaded insert in the plywood base, located between the bolt holding the azimuth bearing compression spring and the inside rim of the bearing. The bearing itself is a ball bearing of the “Lazy Susan” type, but is a bit too wobbly without the compression spring. To minimize wobble in the elevation hinge, the hinges chosen are miniature ones, probably intended for making small wooden boxes, for jewelry or the like. Two items yet to be added when most of the photos were taken were stops in the azimuth plane (to avoid over-stretching the return spring) and in the elevation plane (so the transceiver doesn’t flip right over, possibly damaging the elevation hinges). The last photo shows the mechanism with the azimuth stop added, as well as a coat of paint. The rates of motion with ¼-20 adjustment screws are about 0.9 degree per turn in azimuth and 0.5 degree per turn in elevation.




Azimuth Bearing
Compression Spring
Elevation
Hinge
Elevation
Knob
Azimuth Bearing


Azimuth Lever Arm
Azimuth Return Spring
Azimuth Bearing
Compression Spring
Elevation Knob
Azimuth Knob



12. Approximate Beamwidth Measurement

Using the weak signal source at a distance of about 5 m, the angular range over which the signal could be heard above the noise was measured, by counting turns and/or partial turns of the fine adjustment knobs. In both axes the beamwidth (as so defined) was found to be about 0.8 degrees. The angular size of the weak signal source'saperture, as seen from the receiver, was about 0.05 degrees (4 mm at 5 m).

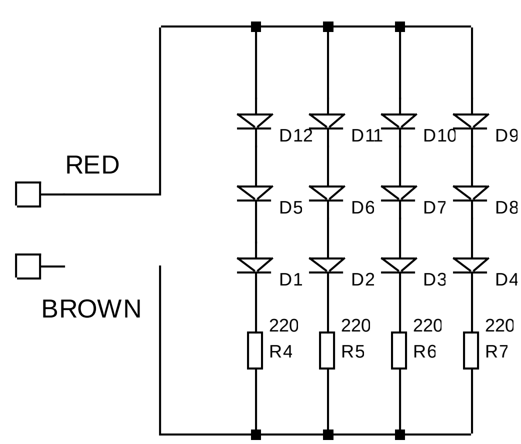
13. Aiming Scope

A Tasco BKRD30/22 "Red Dot" riflescope was mounted to the receiver. This is a 1X scope (i.e. no magnification). I found that, after alignment, it was adequate to find a moderately strong signal just by adjusting the camera tripod head. No search pattern was required. But a few more dB could be had by peaking the signal by ear, using the fine adjustment knobs.



14. <u>Transmitter</u>

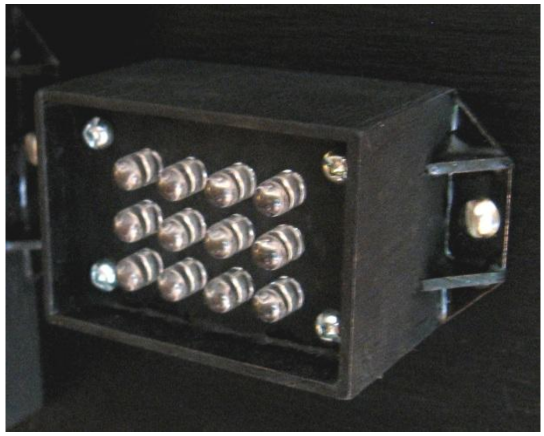
The transmitter uses a module made from 12 Cree high intensity 5 mm diameter LEDs, using the following schematic.



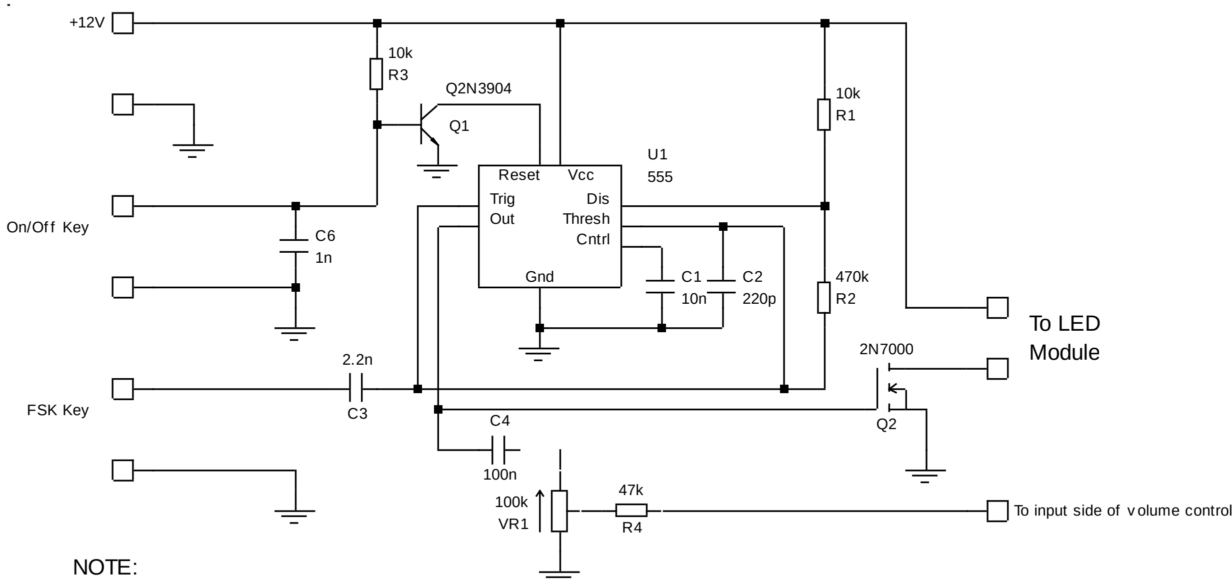


D1-D12: Cree C503B-RAS-CY0B0AA2

These are mounted in an enclosure made of PC board material and bolted to the front panel of the transceiver box as shown below.



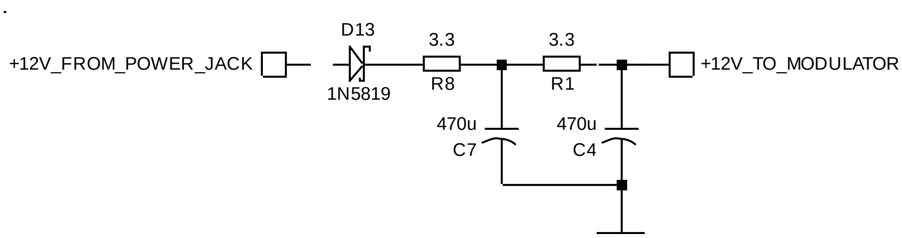
The modulator circuit is according to the following schematic.  The potentiometer is for controlling sidetone level.




NOTE:

1. FSK Key up condition produces modulation at a few kHz.  Key down is close to 650 Hz.

To minimize the disturbance to the +12V rail due to the pulsed current a power filter is used to feed the modulator.  The current drain is about 80 mA.



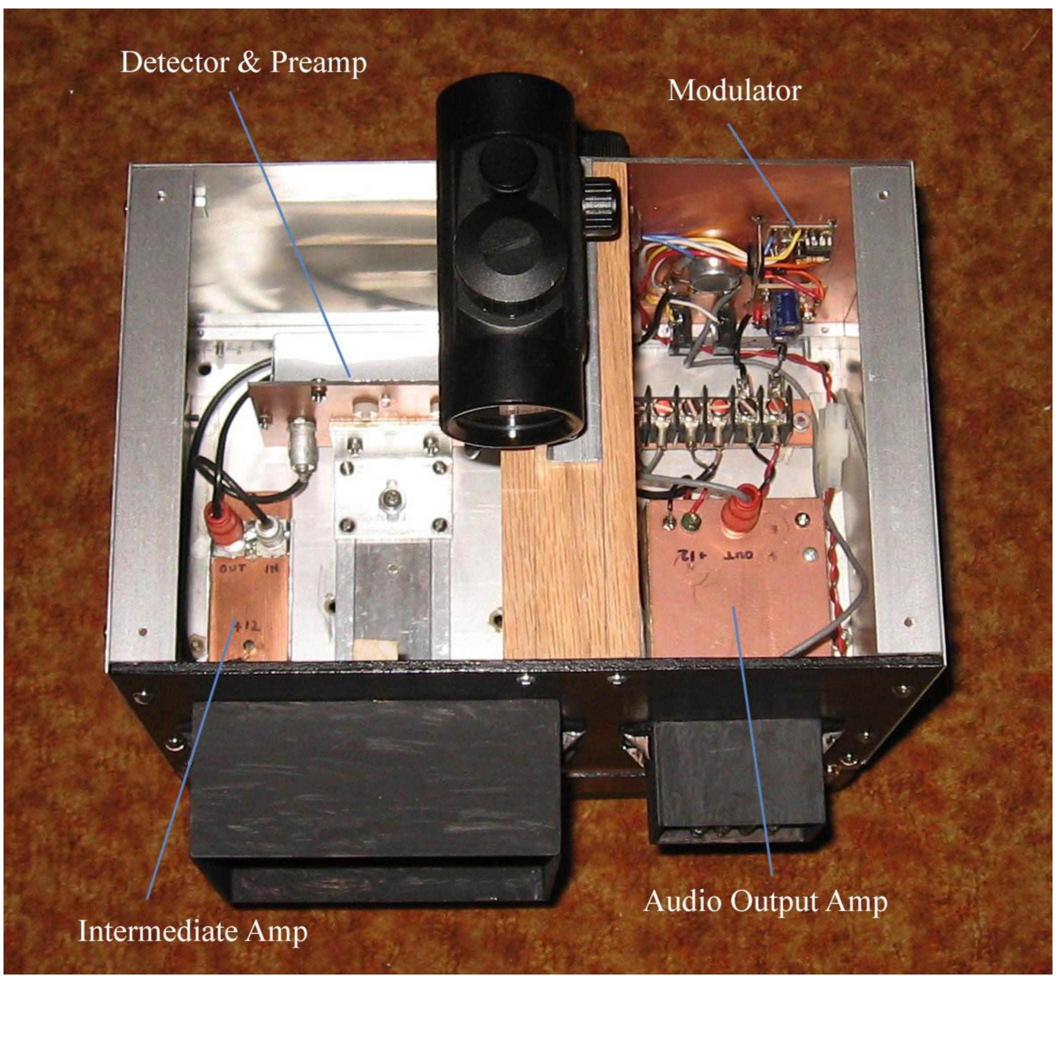
15. The Completed Transceiver

The following photos show the completed transceiver. First is the operator's side. The large knob is the volume control and the small knob is the sidetone level. The jacks are: (left to right) 12V power, on-off keying jack, FSK key jack, headphones. Below the jacks is the piece of string which provides an elevation stop for the fine pointing mechanism.

Next is the optical side.  The receive lens is at the left of the photo, with a shroud to keep local light out, and the transmitter LED array is at the right.

Next is a photo showing the details of how the red dot scope was mounted.


And here is a view of the inside of the box with all the electronics installed.



16. Hearing a Star

The receiver was pointed at a star (Altair, +0.9 magnitude) and a weak “frying” noise was heard. This magnitude seems about the limit for reception (by ear) of the light of a star. It was necessary to adjust the fine pointing knobs every few seconds to track the apparent movement of the star in the sky.

17. First QSO

The first two way contact using this transceiver was made on Aug. 19, 2012, with VE3RKS and VE3KH at the other end. The distance covered was 1.4 km and the contact was made in about 5 minutes from when they arrived at their site. The transmitter at the other end was a frequency shift keyed audio-modulated array of 8 high intensity LEDs (but not as bright as the Cree devices used in this transceiver). The receiver at their end was my older receiver, the schematic for which is available at http://www.qsl.net/ve3sma/LaserSchematics.pdf . That receiver used a detector from a CD-player as the photodiode.