Lightwave Communication: Why now is the best time to try it

By Warren Ferber – WF0T & Rob Jahnke – K0XL

How it all started

In 2016, I presented a new idea for Lightwave Communication at the Northern Lights Radio Society's Aurora conference. Up to this point, the state of the art was high-power LED's attached to unusually complex modulation schemes, using Fresnel lenses mounted in heavy square wooden enclosures, and mountain tops. These systems work really well, see Clint Turner's (KA7OEI) site modulatedlight.org and you'll read about his work in setting a U.S. distance record of 273Km using visible red light.

I wanted to try something different, I wanted to experiment with IR light. I found a 5mm IR LED at Digikey that had a built in 3-degree half beam width lens for under 60 cents. I decided to start with this LED as the basis for my testing. Modulation would use a small microcontroller called an ATTiny85, prepackaged on a circuit board from Digispark. These can be programmed using the Arduino IDE. I wrote a simple program to send my callsign and grid square via CW then a series of tones that I used to test the audio response of my receivers.

I built an 850nm (352 THz) 4 LED beacon. I ran various tests including straight distance and cloud bounce with it and had positive results.

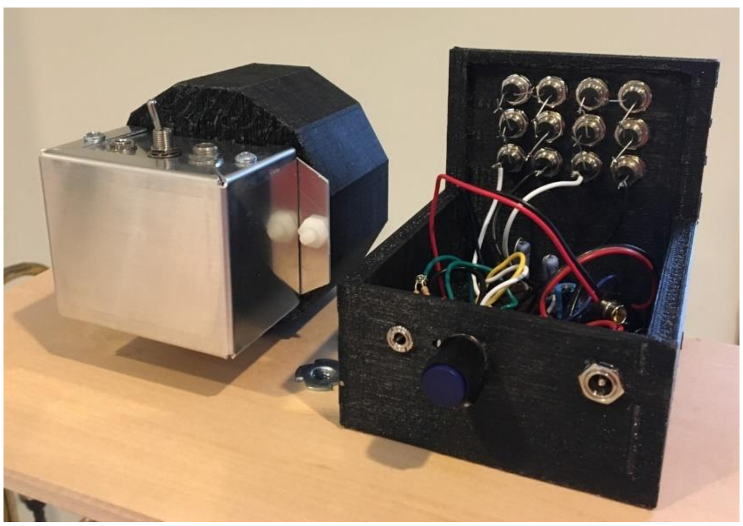
4 LED IR Beacon

- SFH4550 IR LED's
- Digispark ATTiny85 microcontroller board
- Modulated at 50% duty cycle
- Callsign, Grid locator, and tones from 23hz to 4.6Khz
- Radio Shack plastic project box
- 9volt supply

With a 5-inch glass lens and Clint's v3.10 optical receiver I successfully received my reflection off clouds up to 7000 feet and overdrove my receiver from 1.5Km in direct testing. It was fun and exciting, and I wanted to take this experiment to the next level and create a working Transmitter and Receiver.

I purchased a 3D printer “kit” based on a review in Maker magazine, called the Cetus3D mk2. This kit came mostly built. I screwed down the print plate, attached the cables connecting the 3 motors and print head, and attached the vertical slider for the Z axis. I decided the best way to learn 3D printing was to jump in the deep end. I designed a lens enclosure first. When that design failed, I decided maybe wading in the pool was a better idea. I designed and printed some simple shapes, combined a few until I got the settings where things looked good, then went back to designing a lens enclosure. That was successful, so I went on to the transmitter box.

The results can be seen below.



Transmitter and Receiver

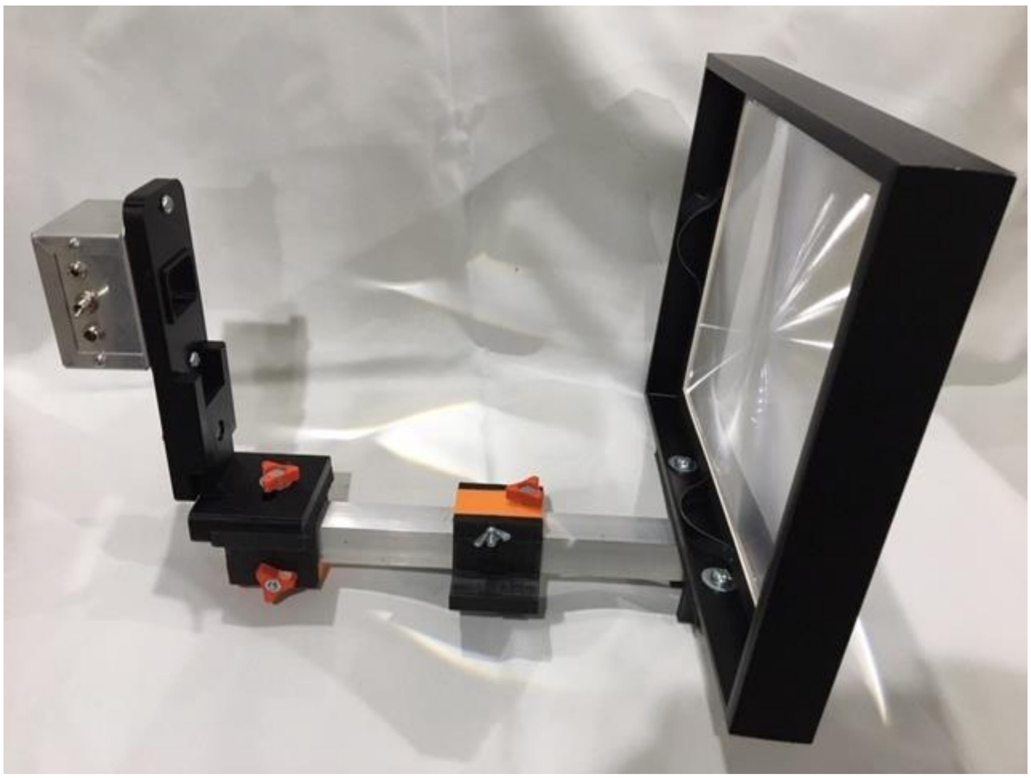
- 555 timer PWM modulator
- 50% duty cycle
- LM833 based audio amplifier
- 12 – SFH4550 IR LEDs wired in 2 parallel blocks of 6 LEDs in series
- K7RJ circuit board of KA7OEI’s v3.10 optical receiver
- 3D printed lens holder and transmitter box
- 90mm Fresnel lens with a 50.8mm focal point

This was a repeatable build. I printed a couple of these and used them for multiple tests. It produced a significantly brighter (in IR light) rectangle that allowed me to; receive music reflected off clouds at over 9000 feet, complete my first voice lightwave contact with Donn WA2VOI, and a water tower bounce test. This was an inexpensive build, $2.20 in PLA filament and 3 hours of print time. Unfortunately, it was not a stable platform for long range communication, but was good enough for distances found in Minnesota. This is an easy to build and aim system for getting your feet wet in lightwave communication.

Back to the drawing board

It was about a year of work to get to the current design. After exhausting several different designs, I was starting to think that large wooden boxes may be the way to go for a stable platform. I was cleaning up my workspace when I ran across my large format rail camera.

This was a stable photography platform that has many adjustments including focusing the lens with the film board. Maybe this is what I was looking for, so I got to work designing an Optical Rail Receiver. The results are below. This is actually version 2 as it includes some of the improvements that Rob K0XL made. They are noted below.



From left to right; Optical receiver, K0XL 3-axis receiver mount, tripod mount with rail tensioner, and the fresnel lens mount, all mounted on a 1-inch square aluminum boom

There have been several iterations of the various parts, the rest of this white paper will cover the build process to create your own Optical Rail System for transmitting and receiving.

After settling on a set of parts, assembling them, and waiting for dark it was time to test it out.

Success! The platform was stable at multiple angles up to 85 degrees, the maximum my tripod can go. There was no change in the focus between the lens and receiver. I was always able to keep my test LED with its tiny spot centered on the optical sensor at all times. Testing continued throughout the evening, including bouncing IR light off various trees, garages, and street signs up and down the blocks near my home. In every test the light from my optical transmitter reflected onto the optical sensor as expected. It was time to share this design with my optical colleague Rob Jahnke, K0XL to get his opinion of this new design.

Rob saw it and agreed that this was the stable platform that we needed for serious optical light work around the area. He liked it so much that he made some modifications and improvements that are incorporated in my build.

Rear view showing K0XL designs

This view shows the optical rail tensioner and modified receiver mount designed by Rob. This view also shows how the receiver box is mounted to the rear of the vertical slider.

Rear view; Optical Rail Receiver showing mounting of Hammond Manufaturing box #1411FBBU

WF0T 3-axis receiver mount

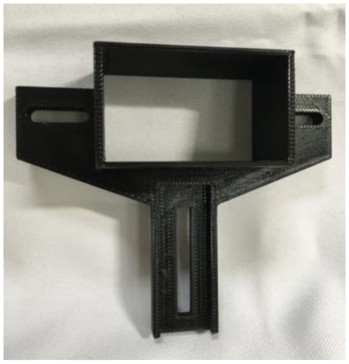
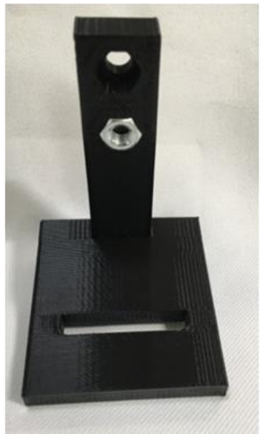
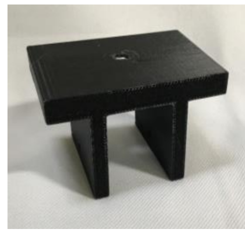
I wanted to build-in the ability to set the appropriate focal length for the lens while retaining finer adjustments to the vertical and horizontal axis. This would allow us to quickly and easily insure that the incoming light through the fresnel lens could be centered on the optical sensor.

During testing in the field, it was surprisingly easy to make focus adjustments. During the water tower testing, the red beacon on the top of the water tower made a fine red dot that could be minimized to the smallest size and centered on the sensor. This also could be peaked for maximum desensing of the audio output from the receiver.

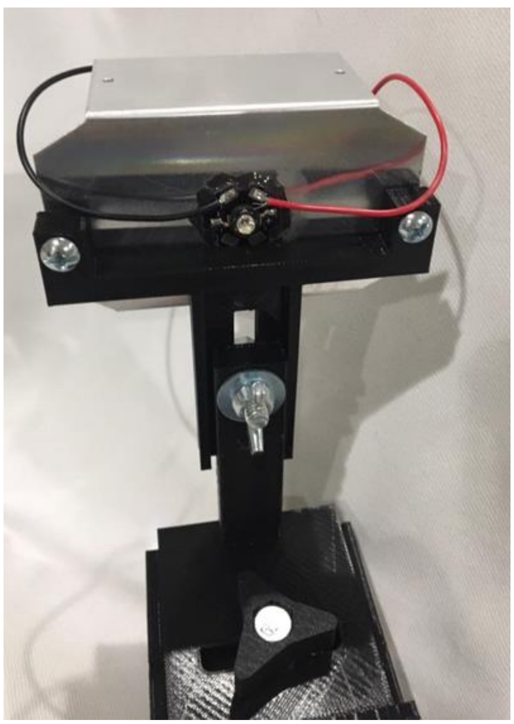
The mount is designed for boxes with mounting between 3 ¼” to 4 ¾”. This is Version 3.1 and includes a light shield to block sunlight and nearby street lights.

Front view of WF0T v3.1, 3-axis mount with receiver

Here are the individual parts for WF0T v3.1, 3-axis mount.


Vertical slider w/light shield   Horizontal slider   Tripod base mount   Fully assembled



Front view of WF0T v1, 3-axis mount with transmitter

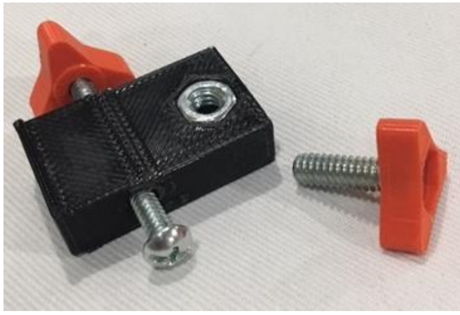
WF0T Transmitter option

The v1 3-axis mount can be used for the transmitter and LED. The Hammond box used for the receiver is perfectly sized to hold the microphone amplifier and my new ATTiny25 modulator for the transmitter or the older 555 timer based modulator.

Fine tuning adjustments can be made to focus the LED beam using an appropriate Fresnel lens mounted to the lens mount.

This allows for various tests you will want to do because it is fun! Cloud bounce, water tower bounce, snow bounce, etc.

Both versions of the 3-axis mount use ¼ inch hardware for mounting the sliders to each other as well as to the tripod base mount. A 1-inch hex bolt will press-fit into the tripod base mount. Tightening the horizontal slider can be secured with a simple wingnut.



K0XL Optical Rail Tensioner

One part that has proved valuable was one that Rob created due to a problem he was having with my original rail mounts. The lens mount was tippy. He solved it by creating these little tensioners that slip in the mounts.

It was a month later that I found out why he was having this problem. He was printing with 30% fill, while I was printing with 65%. My mounts were just solid enough to hold. As soon as I started printing with 20% fill (my printer's setting) I saw the same problem Rob noticed. I now use these as well.

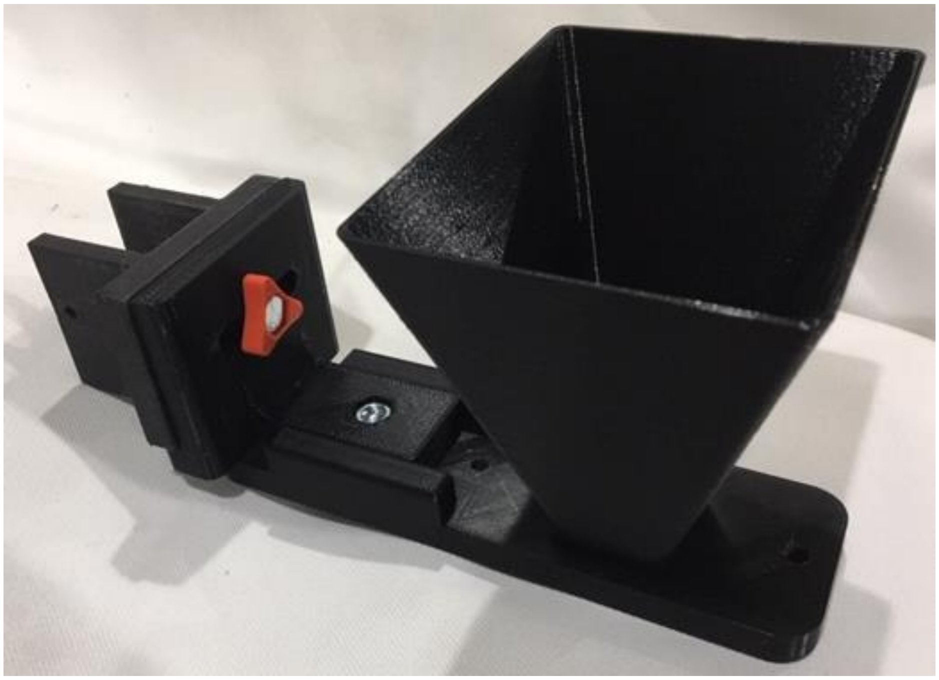
K0XL 3-axis Receiver Mount

This is Rob's version of the receiver mount. His design was based on wanting a way to shield the receiver sensor from outside light sources. The added benefit is that this form appeals to the NLRS membership due to its 10 GHz-like form.

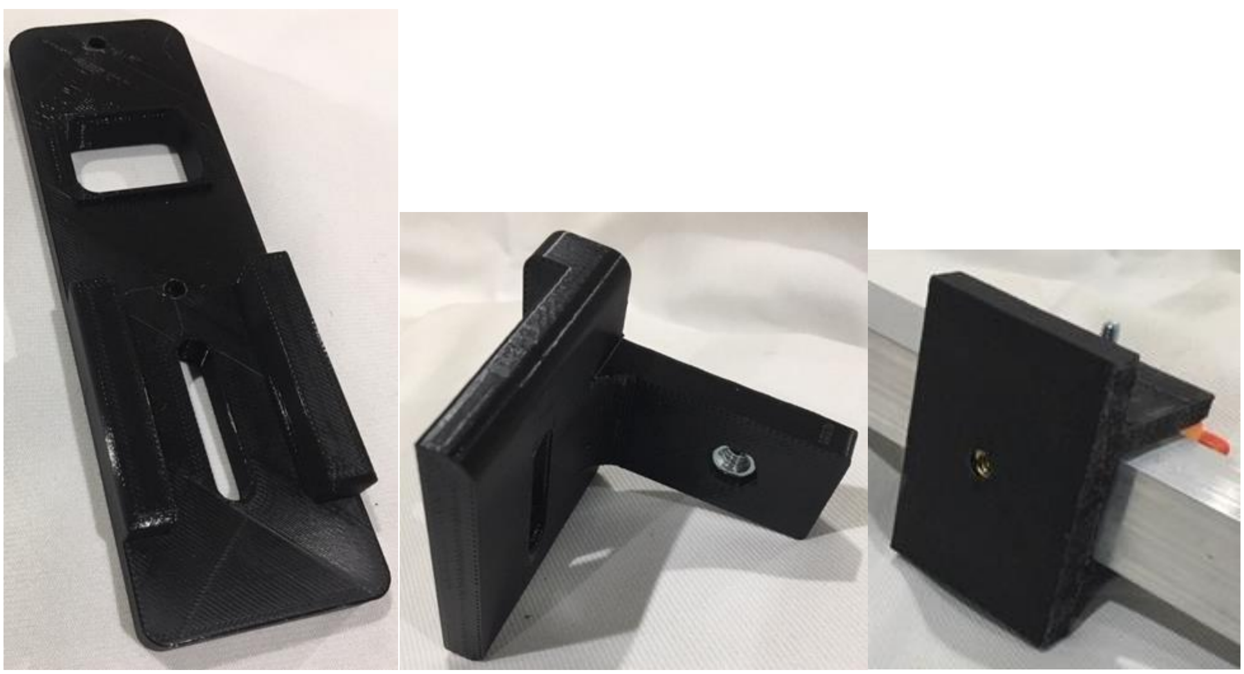
K0XL version of 3-axis receiver mount and light shield

The parts fit together using ¼ inch hex bolts. You can use wingnuts to secure the sliders together and for mounting to the base mount, or you can use the knobs that Rob designed.

The light shield needs to be glued to the receiver opening. The shield was made for a "page-sized" Fresnel lens. These are available at CVS, craft stores, Ebay, etc. Most of these sized lenses have a focal length around 13 inches and the shield is optimized for this.



Fully assembled K0XL 3-axis receiver mount with attached light shield



Individual parts for K0XL 3-axis mount; vertical slider, horizontal slider, base mount

WF0T Lens mount

I wanted to create a lens mount that would be able to support any size lens I had. Over the last few years I have accumulated many different sizes and shapes. What I came up with was a mount that supports a picture frame. The frame can be any size needed to match your lens, within reason. I have tested it with 12-inch x 12-inch frames, down to 5-inch x 7-inch frames with positive results. The lens mount remains solid on the rail with no noticeable wiggle. I have used it outside in winter wind conditions and the test signal remained focused on the center of the sensor.

I used frame kits that I purchased from Michael's crafts and Dick Blick Art supply. The are metal frames that come with two sides, so you can customize your frame to your lens. I then cut a photo mat to size and use that to hold the lens in place. The frame kits come with metal clips.

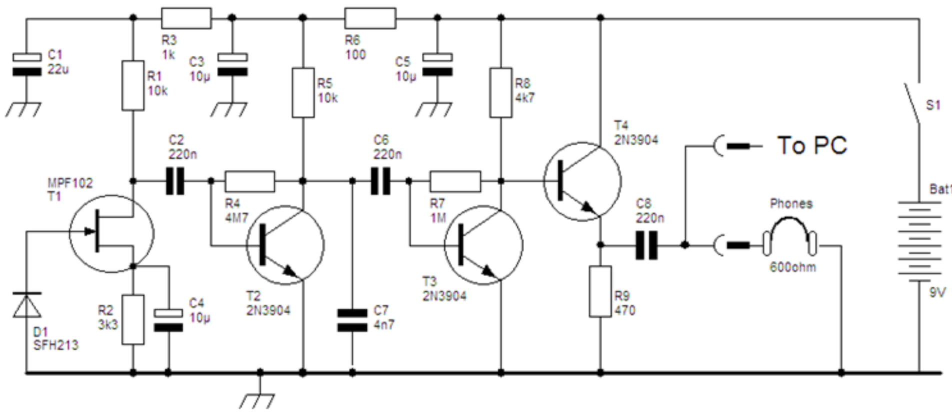
Bottom view of Lens mount attachment

I use ¼ inch hardware to secure the frame to the mount, bolts, washers, and lock nuts. It creates a solid platform for holding the lens as well as making it easy to change the lens size.

Receivers for lightwave communication

There is a lot of information on building optical receivers on the internet, everything from a solar cell connected to an audio amplifier to serious designs for long distance communication. I wanted to include a couple of options that we have tried and have had success with.

The first is a design from G3XBM, it is derived from the original K3PGP optical receiver. I used this schematic to build from which I got from the VE7SL blog.

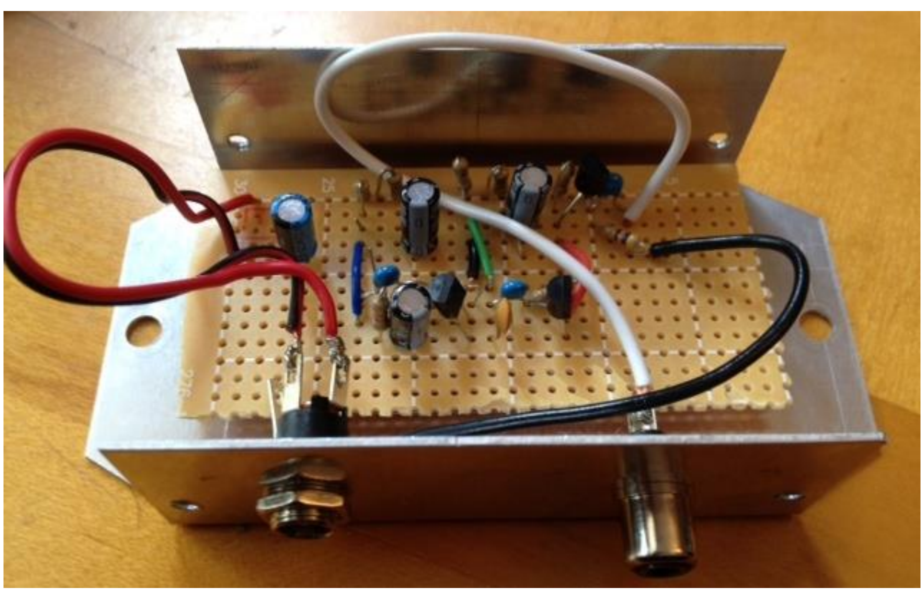


K3PGP derived 481THz receiver

Rev A 10.3.13 G3XBM

I made a couple of parts modifications. I used a BPW34 detector instead of the SFH213, I also replaced the MPF102 JFET with a 2N5457, and used a 1 meg resistor on the base of T2 instead the 4.7 meg.

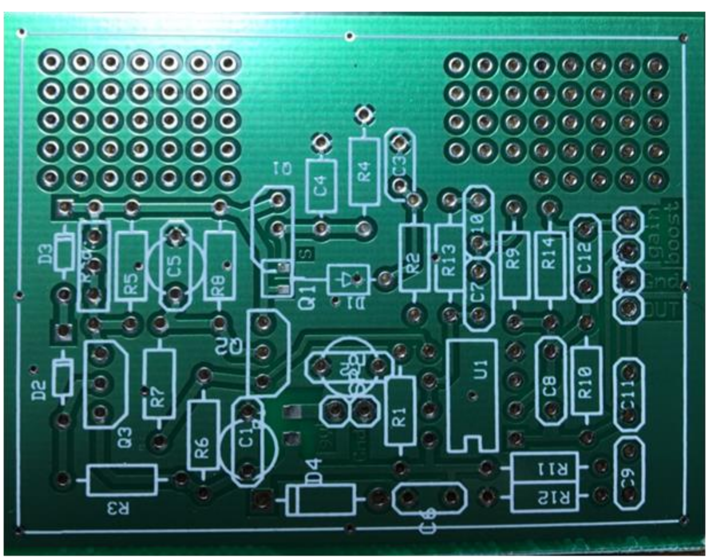
I built the receiver on perf board. All but two of the parts are visible on the top of the board. I mounted the JFET and detector on the bottom of the board facing the front of the enclosure.



This is the finished receiver in the enclosure. I built it in a Hammond Manufacturing aluminum box #1411FBCU. The opening is for the BPW34 detector. It is connected “in the air” to the gate of the JFET. This minimizes the capacitance and increases the sensitivity of the detector. On top are the connectors for power (left) and audio-out (right).

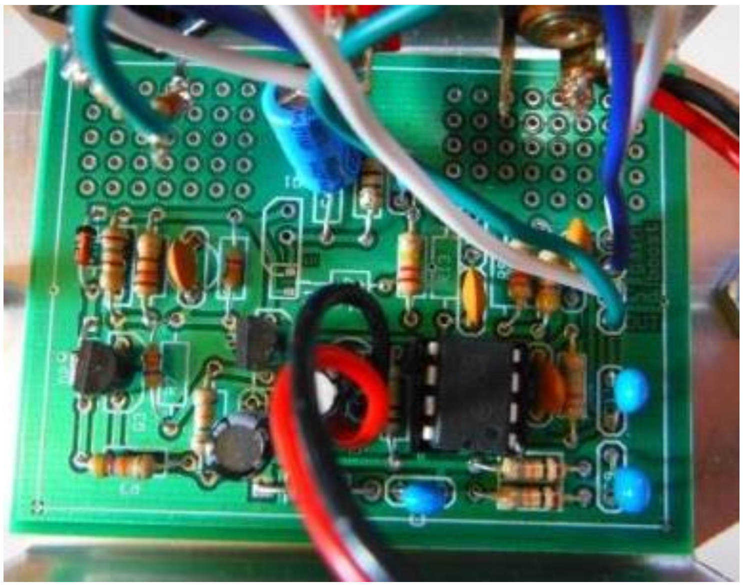
I have received aircraft strobes over the horizon and visible aircraft above 25,000 feet and over 50 miles away. I also did my first cloud bounce tests with this receiver and was able to detect my beacon off of a cloud deck at around 7,000 feet. It is simple to assemble, goes together quickly, and really works. G3XBM designed a super optical receiver!

The second receiver we are using is one designed by Clint (KA7OEI) the v3.10 optical receiver. Available on Clint’s site (modulatedlight.org) is the version that Ron, K7RJ, created a circuit board for. The PCexpress files are available on the site. When Rob saw this he put in an order for 6 boards for us to build and to use in our testing.



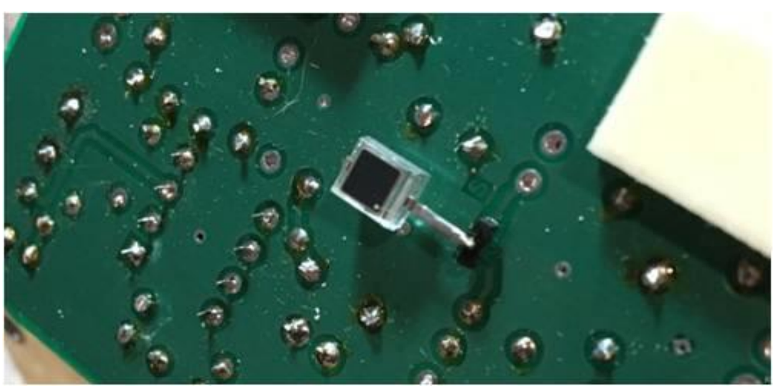
Clint's site has many pages of build hints, so will steer you there for specifics about the design and optimizing your build. I will share some observations on my builds and results of our testing.

There are only a couple of surface mount parts on the board. One is a fuse to protect against applying power to the wrong terminals in the dark, and the JFET. The rest of the parts are standard sizes. The board allows for a pretty quick build, I completed my second board in under two hours, mostly due to trouble getting the FET and detector mounted horizontally to the board. Mounting it into the Hammond box with drilling and aligning took another hour.



Populated circuit board

Mounting the Detector to the JFET can seem daunting; however it isn't as hard as it may seem at the beginning. A magnifying glass, tweezers, good lighting, and decaf were essential for my success in mounting them on the board. I probably spent more time than I needed on it, but I wanted to make sure the JFET was vertical and the detector was horizontal to the board.



Close up view of the smd JFET and the BPW34 detector, the blob upper right is the double-sided mounting tape

The circuit board and wiring fit in the Hammond box like they were made for each other. Even if you can't find the box I used, the WF0T version 3.1, 3-axis mount, will accommodate the box you do use.

Receiver box, from left to right: 9V battery plug, gain boost switch, and audio output

Results of testing the receivers

Both Rob and I built two KA7OEI v3.10 receivers. Rob adhered to Clint's suggestions on building the receiver. I was not so disciplined; I used whatever parts I had on hand, mostly picked up at a local surplus shop. The amazing thing was all of our receivers using the BPW-34 detector were within 1.5 dB of relative output of each other. The best was the one receiver built using the BPW-34S detector which has a built in daylight filter. The G3XBM receiver was also tested and had the highest audio output.

WF0T KA7OEI w/daylight filter	0 dB -57dB	+20 dB gain switch -35dB
WF0T KA7OEI no filter	0 dB -55dB	+20 dB gain switch -37dB
WF0T G3XBM	0 dB -29.5dB	
K0XL KA7OEI receiver #1	0 dB -55.6dB	+20 dB gain switch -37.3dB
K0XL KA7OEI receiver #2	0 dB -54dB	+20 dB gain switch -37dB

Table of receiver relative output testing results

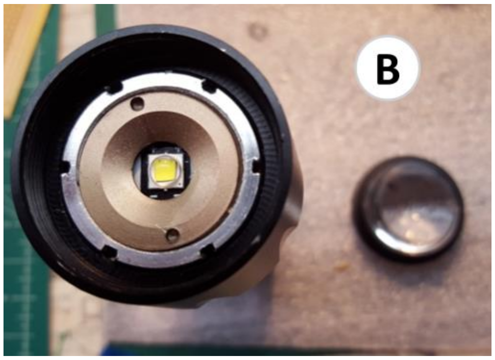
K0XL "Flashlight" Optical Transmitter

This is based on the Atomic Beam CREE "white" LED 5000 lux flashlight.

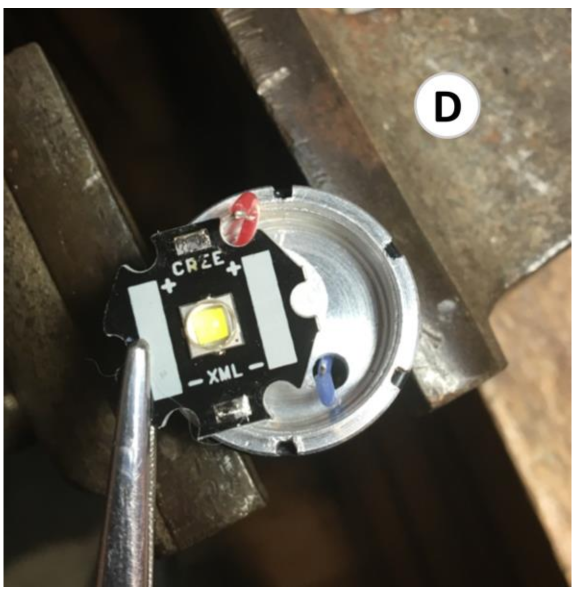

Taking the Atomic Flashlight apart

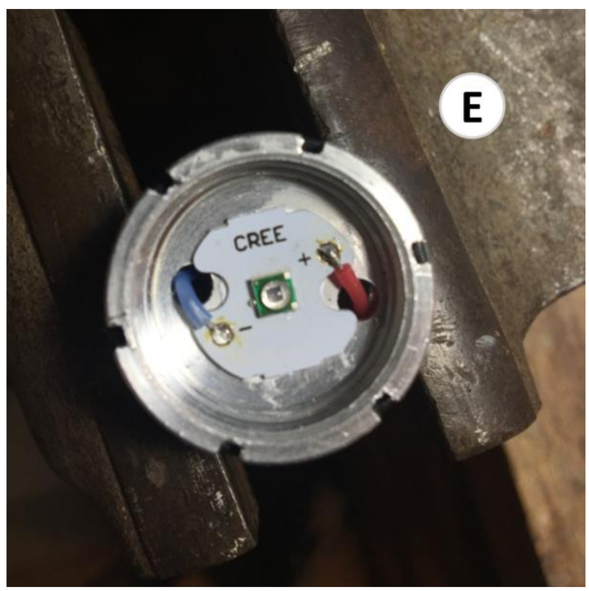
You will need a spanner wrench (or snap ring pliers) to disassemble the flashlight. Start by removing the backend battery cover and removing the battery holder. (A) The switch is press fit into the backend, remove it by pushing on the silicon button.

Unscrew the lens from the lens holder assembly (B). Using the spanner wrench remove the LED assembly (outer aluminum ring) from the flashlight through the lens holder assembly (C).



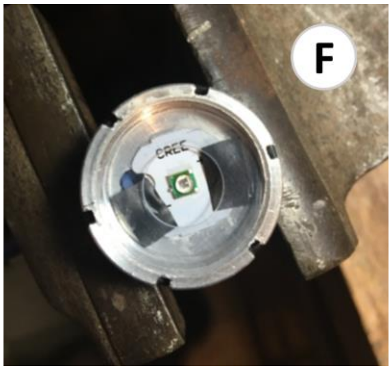
Remove the copper colored (inner ring) LED retaining ring. There is a clear spacer under the retaining ring, keep this as it protects the LED connections from shorting out. The LED and heat sink are now exposed. Unsolder the red (+) and blue (-) wires from the LED base (D). Clean off the LED assembly base and add new heat sink compound and add your new IR or red LED and solder it in place (E).

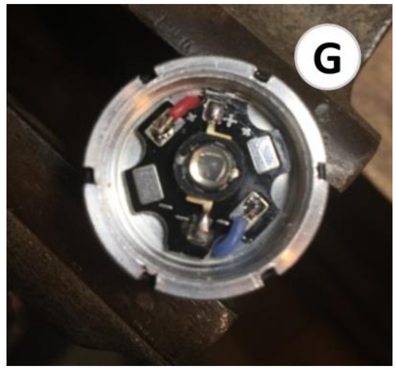


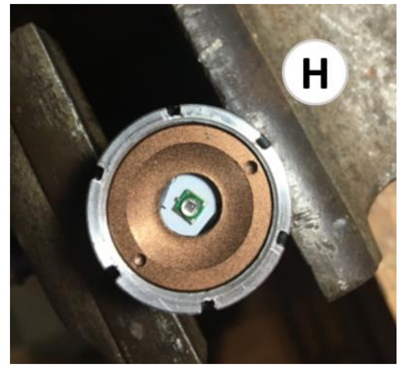


A word of caution is needed at this point. Depending on the LED you are using and the base it is mounted on, you may need to make a small modification to prevent shorting out the LED.

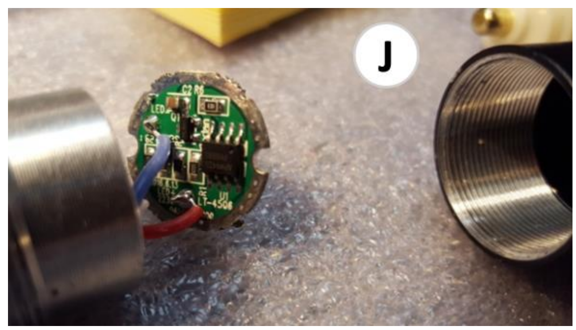
In the first example, my IR LED is mounted on a 16mm Cree base. The positive and negative solder points are slightly exposed under the clear spacer opening. I used small pieces of electrical tape to protect from shorting (F). In the second example, the LED is on an elevated mount with a lens (G). In this case you will need to drill out the copper colored ring to 12mm. This should give you enough clearance to not short out the LED. When you have the LED centered and are happy with the clearance, screw the copper colored LED retaining ring into the LED assembly (H).



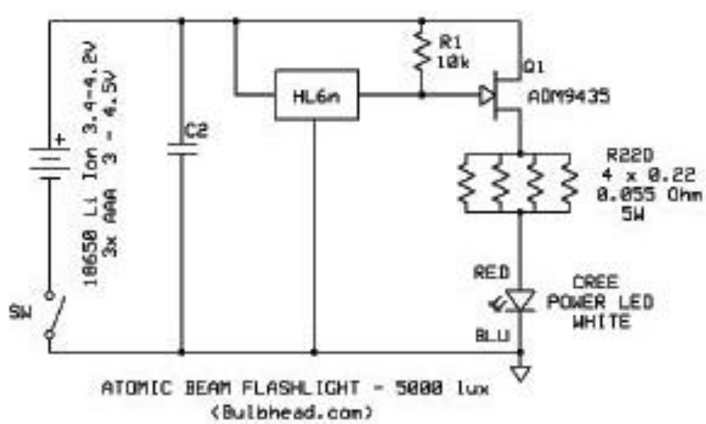




Next, let's modify the LED control board. Turn the LED assembly over. Using a tweezer or one pins on the spanner wrench, insert it into one of the openings between the circuit board and the LED assembly and pry to circuit board out (I).

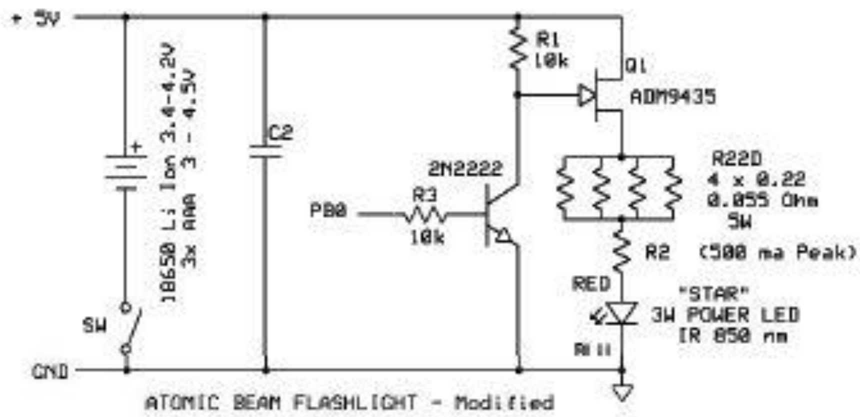


This is the LED control board (J). Part numbers may be different from the schematic; we found part ids were different between shipments. Thankfully it isn't a complicated schematic and the board is easily modified.

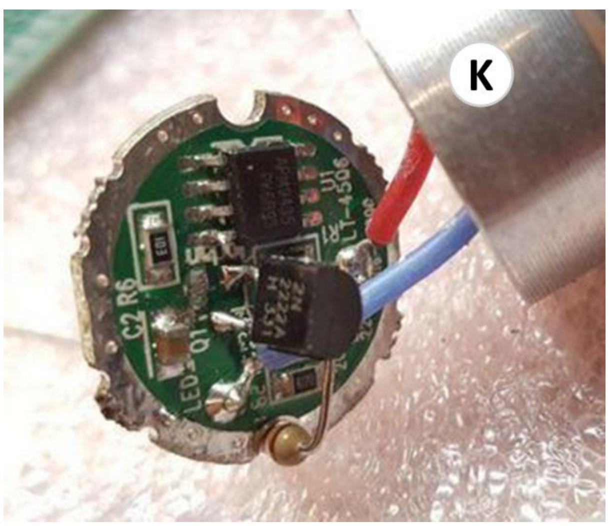


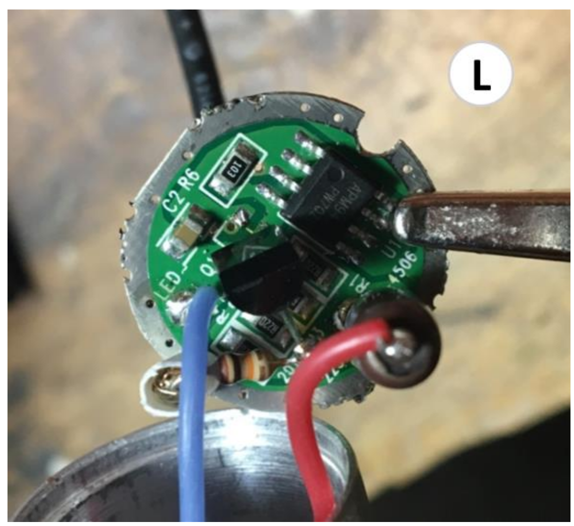
Schematic for the board in the Atomic Beam Flashlight

This is the schematic of the modified board. You'll notice that the 3 pin transistor (HL6N) is removed and replaced with a 2N2222A transistor and a current limiting resistor (R2) is added.

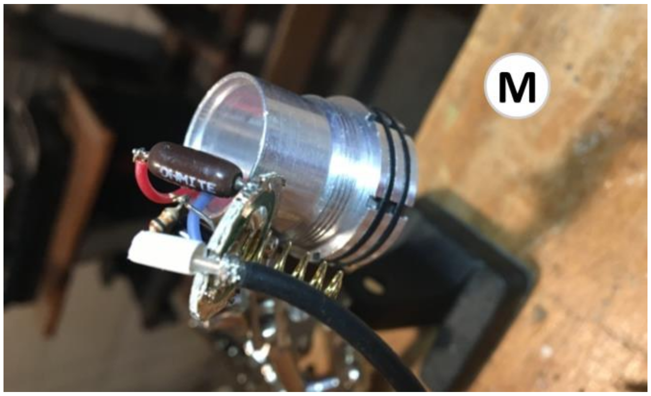


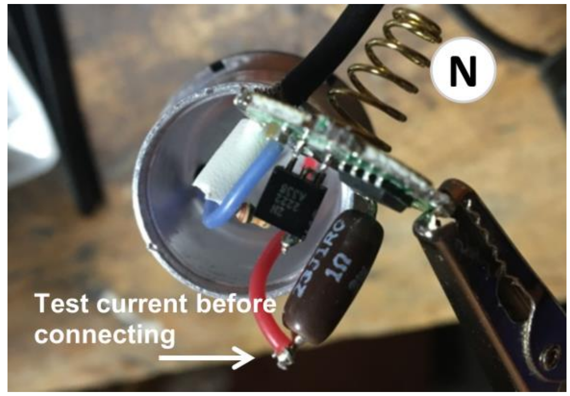
You'll need to remove the 3 pin smd device. After removing it, put a dab of solder on the 2 pads we'll use for 2N2222A transistor's collector pin (left pad) and emitter pin (lower right pad) (K), bend the base pin up to the back of the transistor (L).





The transistor will be used to feed the PWM output to the LED. Connect a 10k resistor to the base pin with the other end routed to the back of the board (K). I attached the resistor horizontally to the base pin (L) and routed a length of RG-174/u to the resistor through the semi-circular opening on the side of the board. Shielded cable is not necessary, however it doesn't hurt either and I figured some shielding on the feed line couldn't hurt. The ground is attached to the ground ring (outer ring) on the backside of the board (M).





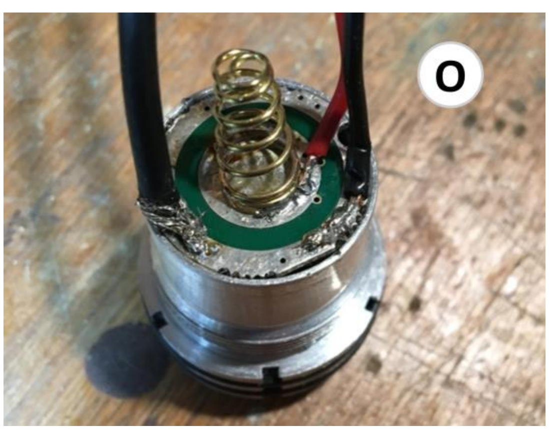
Remove the red (+) wire from the board and attach a current limiting resistor to the positive board pad and reattach the red (+) wire to the other end of the current limiting resistor (N).

Calculating the value of the current limiting resistor is an Ohms law exercise; R = V/I. Since we are using a 50% duty cycle a little explanation is needed. First you will need to know, or at least be able to estimate, the 100% duty cycle or DC current limit of your LED. Then you will need to know the voltage drop across the LED.

The new equation is R = (V – VLED)/(2*ILED). For the Cree 3watt IR LED it came to a resistor value of 1.4 ohms. I have a batch of 1 ohm, 3watt resistors and found one with a 1.2 ohm resistance and used that.

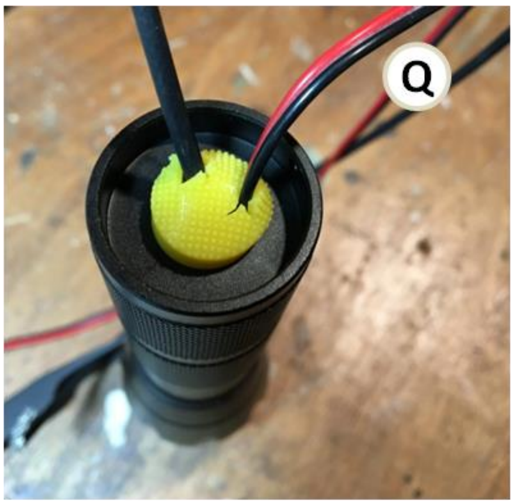
Use the power calculation to make sure your resistor can handle the watts that need to be dissipated by the resistor. Calculate that using P = (V – VLED)^2/R. My power calculated out to 2.75 watts, since we are using a 50% duty cycle, I really only need half that amount (~2watt resistor), so my 3watt resistor will be fine.

Attach your power cable to the backside of the board (O). The inner ring is for V+ and the outer ring is ground. Before fitting the board back into the LED assembly test that everything is working and verify the current draw. Connect the output of your modulator to the feed line attached to the 2N2222A. I checked current by putting my meter between the current limiting resistor and the positive connection to the LED (N).



When you are happy that everything is working as expected it's time to reassemble your new lightwave transmitter. Start by press fitting the board back into the LED assembly (O).

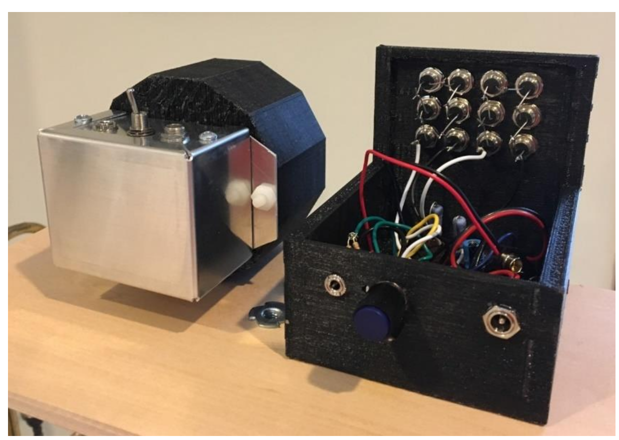
Next, slide the lens holder assembly over the body of the flashlight and using your spanner wrench screw in the LED assembly into the flashlight body. I tied a loose knot in the feed line and power wires to use as a strain relief (P). I then screwed on the backend battery holder. I cut a couple of slits in the silicon button cover and pushed the wire through them, then pushed the button cover into the backend battery holder (Q).



Congratulations! Your new lightwave transmitter is ready.

WF0T 3D Printed Transmitter and Receiver

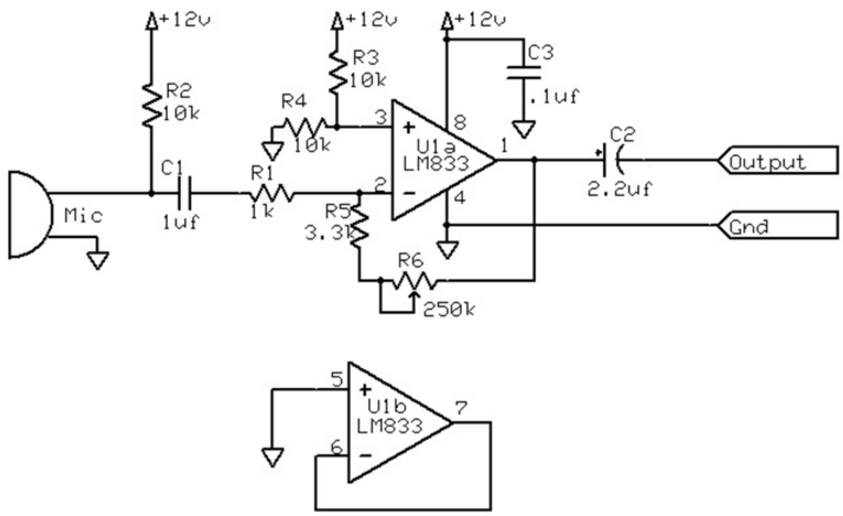
I introduced this set at the beginning of the paper. Here are a few more details about building the transmitter. The receiver is the KA7OEI v3.1 attached to a 3D printed lens housing.



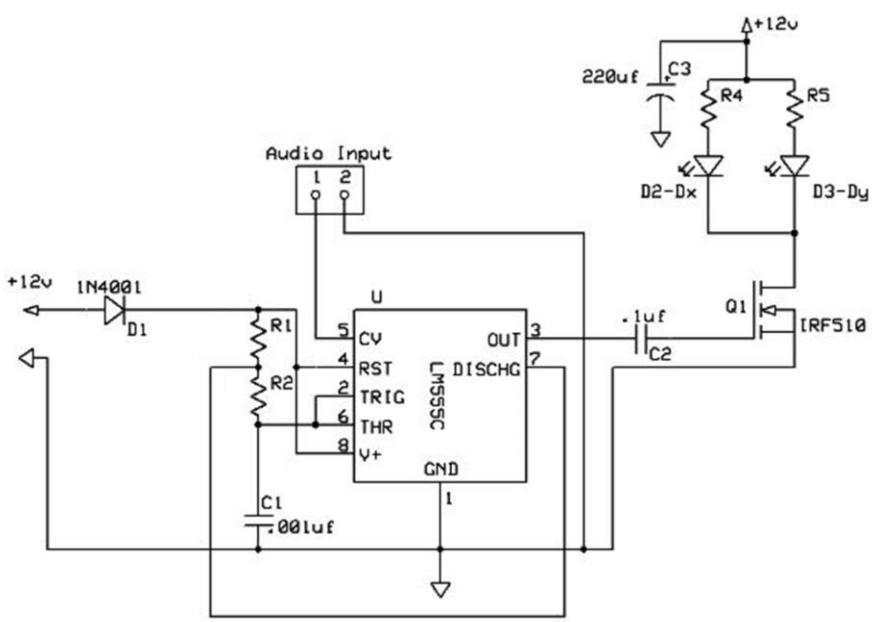
I have uploaded my transmitter and receiver designs to Thingiverse.com.

The Transmitter is at: http://www.thingiverse.com/thing:2751923
The Receiver is at: http://www.thingiverse.com/thing:2765972

I used an LM833 OpAmp in my transmitter, mostly for two reasons; I had a bunch on hand, and I liked the sound it produced. You can substitute any dual OpAmp (TL082, LF353, TL072, etc.) for the LM833 in this schematic and get good results. This is the schematic I drew up for the microphone amplifier.



This is the schematic for the 555 timer modulator. R1 and R2 should be selected to make the duty cycle as close to 50% as possible. I used values of 1.2k (R1) and 56k (R2), they got me really close to 50%.



The 3D printed transmitter uses 2 parallel banks of 6 LEDs in series. I've denoted this on the schematic as D1-Dx for the first 6 and D2-Dy for the second 6 LEDs. R4 and R5 are valued to limit the current to the LEDs based on the voltage drop of the 6 LEDs and the duty cycle of the timer. I'm using 2 - 4 ohm 3 watt resistors. Keep C3 connections as short and direct as possible. If you want to add more bypass for the circuit, you could also add a bypass capacitor after the 1N4001 (mislabeled as D1) directly to ground.

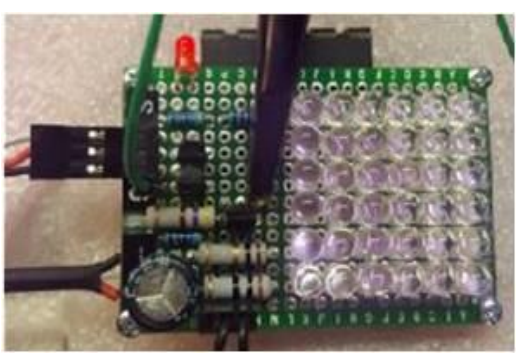
As you can see, it is not the prettiest of builds. Hidden under the wires are three small circuit boards, one for the microphone amplifier, one for the 555 timer modulator, and one for the LEDs driver module. It may be a bit ugly, but it works!

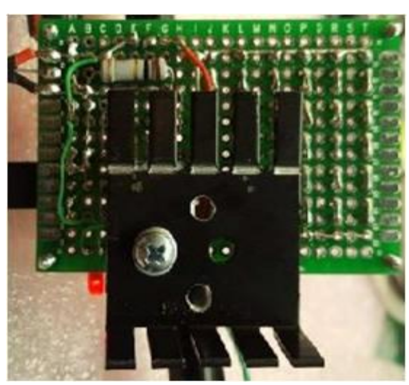
The LED holders are from Radio Shack. Fortunately, they are available on-line from various retailers. They add a finished look and provide some heat sinking for the LEDs.

The LEDs are Osram model SFH4550, they have a 6 degree beam width, which creates a tight pattern of IR light with no external lens required.

K0XL 36 LED Transmitter

Rob extended the idea of a 12 LED transmitter to 36 LEDs. He built it on a perf board and tightly packed the LEDs into a 6x6 square.

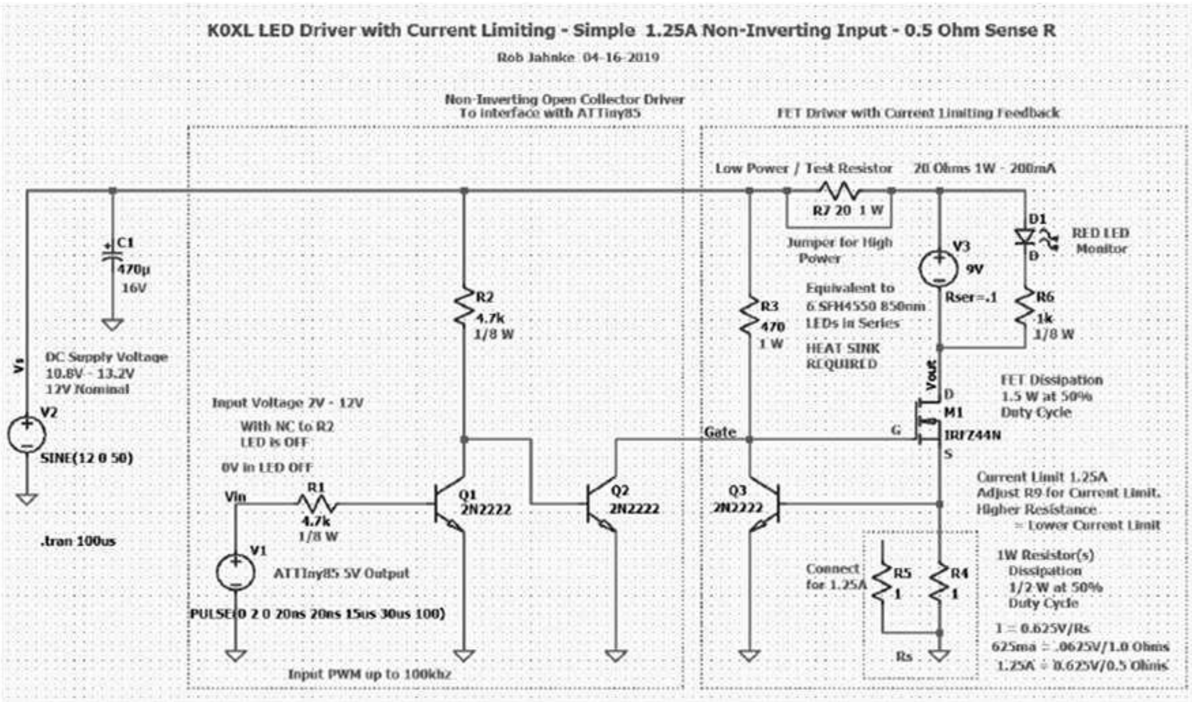




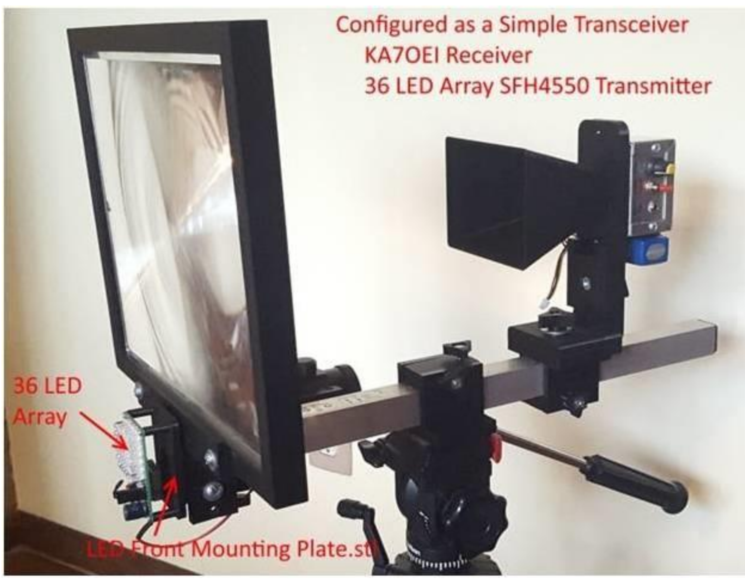
Front side of 36 LED Transmitter with current driver, back of board with FET heat sink view

The LEDs are wired in 6 parallel blocks of 6 LEDs in series. Current to each block is 200ma, driven by Rob's PWM modulator. Heat is the main issue to address with this transmitter. With the LEDs tightly packed airflow needs to be provided. A small PC processor fan will work.

Rob designed a constant current source to power the transmitter. It provides 625ma or 1.2A, individual LED current = array current/6.



Schematic of the LED driver/constant current source used with the 36 LED array



Rob designed 3D parts for mounting the 36 LED array on his receiver set up to create a simple optical transceiver.

The 36 LEDs are the Osram model SFH4550 high power narrow beam width LEDs.

K0XL Receiver with 36 LED array mounted in the 1 inch square aluminum boom

Chart showing the comparison of the “on” power of the various transmitter configuration. Results taken at a distance of 2 meters.

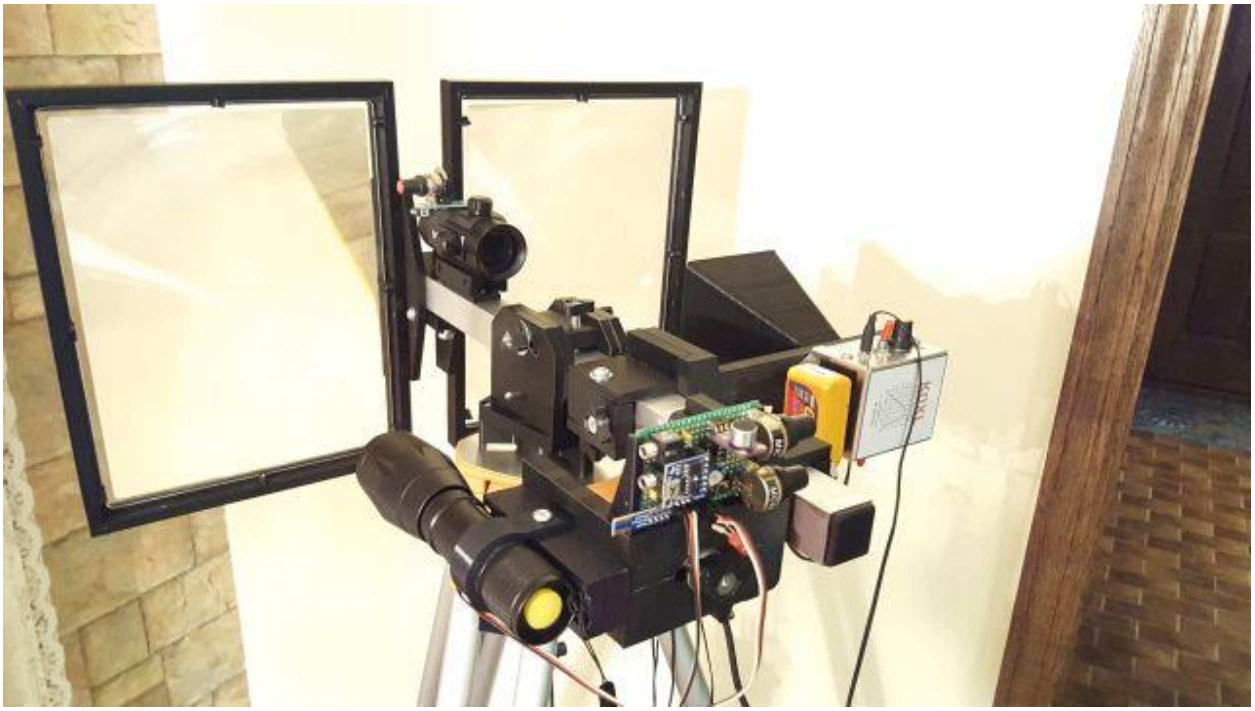
K0XL Red LED Flashlight	600 microwatts	50% duty cycle	500 mA
WF0T IR 12 LED array	2600 microwatts	50% duty cycle	200 mA
K0XL Red LED Flashlight w/Fresnel lens	12400 microwatts	50% duty cycle	500mA

3-watt Flashlight transmitter lighting up the Sartell water tower from 1050 ft.

At this site we tested IR vs. Red light. Even though the Red light has about five times the light power over the 12 LED transmitter, the IR light won. The BPW34 sensor is only 67% efficient at red light and almost 100% efficient at 850nm (IR) which is probably the reason for the result. Rob was sending music to the tower and I was able to hear it just fine until I sent my IR light beam to the tower. With less light power the IR signal blocked out the red light signal so only the music I was playing was audible.

This test taught us that when bouncing light off of an object for communication, we need to aim at different points. When I moved my IR beam to the side of the big red spot, we were able to distinguish between the two signals. Peaking the receivers at the other’s transmitted light beam allowed us to hear each other’s signal with very little QRM from our own light beam.

This will be something we need to be aware of when we start cloud bounce communication testing.



Rob K0XL's Optical transceiver set-up

This is what happens when you can print your own parts! It's really an innovative idea, use the rail mount system to mount an optical transmitter on one side and the optical receiver on the other. Included in this picture are the transmitter mount, his ATTiny85 based modulator, a red-dot aiming device, a tilt mount for the tripod, his design for a lens holder and the lens clips he uses with his frame – along with the other components discussed earlier.

I have all of my 3D printed part files on my blog: wf0t.blogspot.com. I created a post in September called MUD 2019, where you will find the links.

Rob created a Google site where you can download all our 3D files as well as; more pictures, schematics, code used for our modulators, and more detail of some of the testing that's been done.

The link is: sites.google.com/view/k0xl

Note: 3D printer settings vary by manufacturer. I use .3mm layers with 20% infill with a .4mm print nozzle. I print with 3 layers for the top and bottom surface, with raft and support. Prints take from 11 minutes to about 2.5 hours. For the tripod mount and the receiver 3-axis mount I print these parts at 50% and 65% fill. Each print uses between 6 grams to 70 grams of PLA filament. The aluminum rail is 1-inch square.

73,

Warren WF0T & Rob K0XL