Adventures in optical communication

Part 3 – Beacons and a LED transceiver

RECAP. So far we have made transmitters and receivers for AM, FM, CW and SSB. Now we'll look at some alignment aids – small and large – and a novel transceiver that uses the same LED to receive as well as transmit.

DESKTOP BEACON. It is useful to have a small beacon transmitter that can output a signal for bench testing. Mine is nothing more complicated than a pair of 555 timer ICs, as shown in **Figure 14**. The right hand 555 oscillates at about 25kHz and drives a red LED via a resistor. 1k gives a bright light for long distance testing up to 500m or so; 10k is quite dim and suitable for indoor use. This beacon tunes in as a carrier a little above 3.605MHz on the FT-817. The left hand 555 is optional; when in use (connected via the switch) it frequency shift keys the 25kHz oscillator, making the signal more easily identified.

I still have not produced a soldered version of this, to date; it languishes on a plug-in breadboard. The (un)finished article is shown in **Photo 10**.

EXTREME BEACON. One of our longer distance contacts, at 65km, was nearly a failure because we could not locate each other for some considerable time. White light from powerful torches looks just like car headlamps; red lights look like car tail lamps. Then Peter, G8POG tried his strobe: identification is much easier with a regularly flashing lamp but, understandably, it was looking a little dim at 65km. Enter the extreme beacon, **Figure 15**. In principle, it's similar to the desktop beacon described above, but uses a power FET on the output to drive a 20W LED. Yes, you can get a 20W LED: it has 25 individual LED chips arranged in a 5 by 5 matrix on a substrate. It runs on about 12V at nearly 2A. The LED does require a substantial heatsink – reckon on dissipating about 15W as heat.

With this LED and its heatsink at the focus of a 100mm lens in the optic tube (**Photo 11**), it produces a 2° wide pattern of light flashing at either 2.5Hz (for visual identification) or 25 kHz for receiver alignment. Do not look directly into the beam: the intensity is enough to cause eye damage, even at some considerable distance.

THE LED TRANSCEIVER. Tim Toast, who runs the Optical Links website, regularly scans the web for optical communication-related material. In October 2010 he provided a link to a paper, *LED used as APD*, written by a team at the University of Salerno, Italy. They had discovered that some GaP and GaAsP/GaP power LEDs, when reverse biased to large voltages, acted as photo sensitive diodes and as avalanche photo diodes. If you are not aware of the significance of this discovery, go and find the price of an avalanche photodiode!

After reading this paper, I set about to repeat their experiments for myself. I used the little beacon on the bench, several power supply units, a few R's and C's, a selection of red LEDs and an oscilloscope. I found that I could recover a signal from a particular high brightness 5mm LED without any reverse bias; as I increased the reverse bias to over 30V, the recovered signal was enhanced. So was I, enhanced enough to rapidly put together another receive head, with a relay to switch the LED from forward bias (so that I could use it as a transmit head), then to reverse bias it in an attempt to use it as a photodiode. When discussing this with my local group of opto-enthusiasts, it was Nick, G4KUX who said it would be 'cool' if you could use the same LED, forward biased for transmit and reverse biased on receive. Since the word cool had never been applied to me ever before, I thought it worth a try, just this once.

There is also one very obvious advantage of needing to aim only one set of optics: if you can hear the other station; you are ready to work the other station.

TESTING. I tried the hurriedly-constructed transceiver on transmit first and it was fine. I switched to receive, without yet connecting any reverse bias. To my great surprise and joy, I could already hear a strong signal, I had forgotten to turn off my beacon, which was still running some feet away – and activating the receive side of the transceiver with no bias at all. One of my mottoes is, "if it ain't broke, don't fix it", so I left well alone until I could give it a field test.

At around this time, Keith, G4MSF had joined the local opto group and had just completed the transverter, Rx and Tx heads. He wanted a test QSO. This we arranged over my favourite 6.5km path across the Tyne valley. I lined up my normal rig and Keith saw the signal immediately, receiving me and replying on light with strong signals both ways. This was fine for a first QSO. I then asked him to wait a moment while I switched rigs. He guessed what was going to happen next. I had my first transceiver ready; it only had the high brightness 5mm LED and its optical output was way down on that of the power LEDs I had been running. It also had no reverse bias for receive. Amazingly, Keith immediately reported that this rig was brighter than the much more powerful one and my signal was crashing out of his HF rig. He then replied on light and I received him at excellent signal strength. This was my first QSO using the same LED on both receive and transmit. (It later transpired the reason this rig was brighter was that my normal rig was not aimed correctly). I then went on to use some attenuators I had made out of cardboard, 4 inch discs to cover the lens with a 2 inch hole for 6dB attenuation, and a 1 inch hole for 12dB attenuation. These simulate the light level at double and quadruple the present distance. The result was that we carried on the QSO with the 1 inch hole in front of the 4 inch lens, so this is the signal strength we would have had at four times

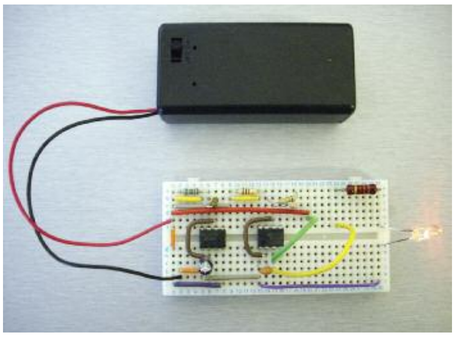


PHOTO 10: The desktop beacon, still on its prototyping board.

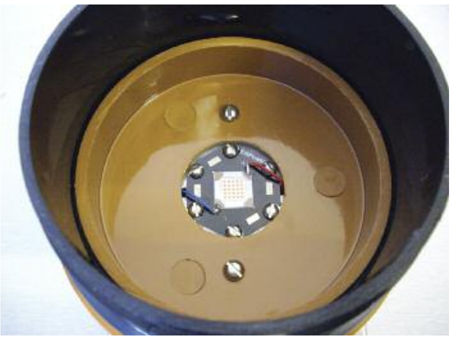


PHOTO 11: The extreme beacon LED mounted in one of our now-standard housings.

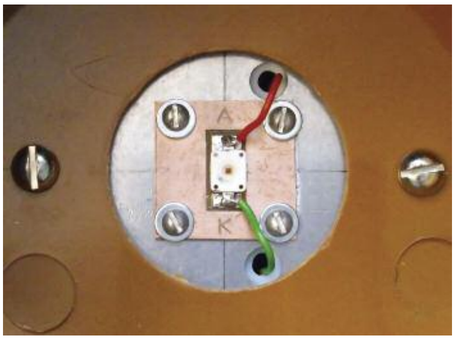


PHOTO 12: Transceiver LED mounted on the head assembly.

FIGURE 14: Circuit diagram of the desktop beacon.

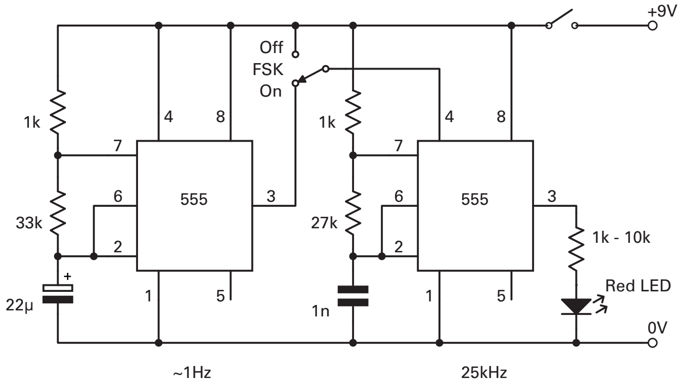
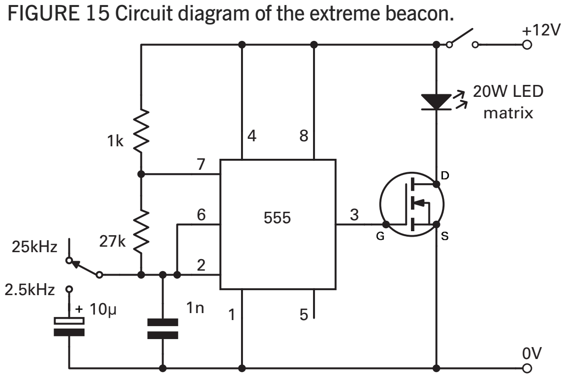


FIGURE 15 Circuit diagram of the extreme beacon.



the distance, 26km. Signal strengths were still S9.

WORLD FIRST? I later got round to investigating the reverse bias situation and achieved a further 12dB improvement in receive sensitivity by using 33V bias across the LED. Raising the bias further increased the output signal but also increased the noise. This first receiver that I had rushed together as a proof of concept was capable of some serious distance on receive! Incidentally, when I reported this in to Tim of Optical Links, he said that although he had heard of some lab bench trials, he thought I might be the first to receive a free space optical signal over a distance of several kilometres using an LED in this way.

LED TRANSCEIVER MK 2. The concept of the LED transceiver was proved, but the light level on transmit was way down on that from the power LEDs. So, I looked again at the Golden Dragon LED I was using in my separate transmitter. It is an InGaAlP device, a type not covered in the original research paper. Also, it could not operate in reverse bias due to the presence of a protection diode in reverse-parallel with the LED chip. There is even a warning in its data sheet that the LED is not intended for reverse bias operation. But I wanted to experiment! I noticed that both diodes were set in a silicone gel and the minute gold leads to both diodes were separately visible within the gel. Enter the concept of "microsurgery" on the LED…

Using a sharp knife I cut through the gold wire to the protection diode. Checking with my multimeter on the diode range on told me I had been successful: with the meter leads one way round the LED lit up and the meter indicated about 1.6V; the other way round was now open circuit, having previously indicated the 1.065V forward voltage drop of the protection diode. In short, when the LED woke up after the operation, it discovered it now had a 'split personality': one way round it was a LED, the other way round it was now a functioning photodiode! I have since performed several operations and I have not lost a patient yet. **Figure 16** shows the LED, diode and cut point.

This LED encouragingly developed a photovoltaic output of over 1.1V when strongly illuminated. Using my little beacon as a signal source, it gave an enhanced output voltage when reverse biased to 43V. This was then the centre of a redesigned front end which incorporated the same modified KA7OEI circuit as before, plus relay switching to use the LED on transmit as well, as shown in **Figure 17**. The LED series resistors were also included on the board design to make the complete transceiver head. This has been tested so far up to 46km distance in a QSO with Brian, G8KPD, where no difference was noted on either receive or transmit from the standard separate Tx and Rx, two-lens setup. Signals were still end-stopping at this distance.

The transceiver LED is mounted on a *thin* fibreglass PCB, this time in a design to minimise capacitance to ground on receive while retaining adequate heat conductivity on transmit. Use heatsink paste as before.

I think the exact value of reverse voltage will be an 'adjust on test' item, as one version of the transceiver required 48V to bring it to optimum performance. The bias current is extremely low (about 100nA) and is switched off by the relay when not in use. We used a combination of 12V keyfob batteries and/or button cells to achieve the best voltage for the particular transceiver. You can adjust the actual voltage by placing 1N4001 diodes in series to drop the voltage if required: it seems that you need to hit the optimum voltage to an accuracy of about half a volt. Do not use Zener diodes, as they would generate noise.

My batteries are contained within a piece of 15mm copper water pipe attached inside the box using Terry clips, as can be seen in **Photo 13**. Others have used N cell holders, which are a good match for the keyfob batteries. Don't try to use an inverter or voltage multiplier to supply the bias voltage; noise would drown out the wanted opto signal.

The PTT line can be connected to the FT817 (which grounds a pin on transmit) as well as the transverter PTT input and it should operate as required.

THE FRESNEL LENS RIG. Also known as 'the big rig', this uses flat A4 page magnifiers made from acrylic sheet. They are available from stationery shops or, rather cheaper, from many pound shops. They are actually Fresnel lenses which are of quite good quality. They are not quite the same size as an A4 sheet of paper, being about 21cm by 28cm. Compared to the Blue Spot lenses that fit the plumbing pipes, they have over 8dB further gain when used on receive or transmit. This figure was arrived at by simple calculation of the increased area and confirmed using the FT-817 S-meter on receive and a light meter on transmit. The transmit beamwidth of the Fresnel lens system works out at about a fifth of a degree – which is sharp, but not impossible to aim. It is however too sharp to aim if you do not know exactly where the other station is, hence the extreme beacon (with its 2° spread) described earlier.

I started using these Fresnel lenses before I developed the LED transceiver, so my version has two lenses side by side (**Photo 14**). This makes it simpler to operate because the separate Rx and Tx, aligned side by side, automatically look at the same point in the distance. It is simply necessary to line up the receiver on at a distant (beacon) signal and you're ready to transmit back. With the advent of the transceiver, it is only necessary to use a single lens.

The Fresnel lenses I have tested have a focal length of 350mm, but it would be wise to test each lens individually by measuring the lens to image distance when producing a focused image of a distant streetlamp. The LED (or photodiode) is simply supported at

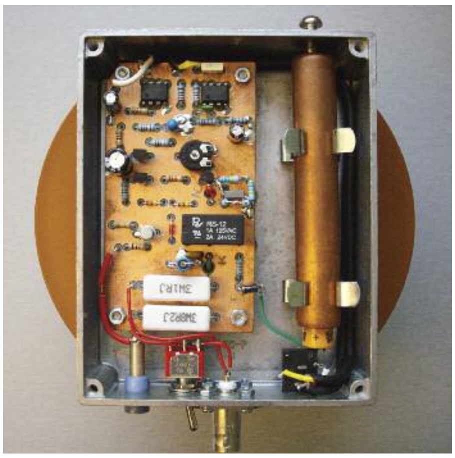


PHOTO 13: General arrangement of the transceiver. The copper tube contains the 43V bias batteries.

FIGURE 16: Where to cut the protection diode wire.

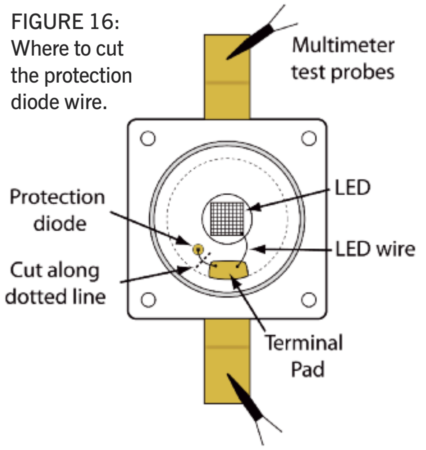


PHOTO 14: The 'big rig' with Fresnel lenses, suitable for a Tx and Rx or a transceiver and beacon (remove the lens on the beacon side).

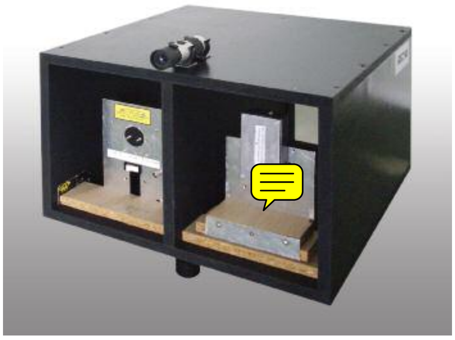


PHOTO 15: LED heating resistors.

this point. The ridged surface of the Fresnel lens must face towards the distant station. All these parts are mounted in a box, shown in Photo 14.

I installed two fixed cabinet feet under the front of my black-painted lens box and one adjustable foot, on a screw thread, centrally at the rear. This gives adjustment in the vertical plane; for horizontal (azimuth) adjustment, I simply move the whole box around on a square of MDF clamped on to my folding workbench. This has proved adequate for contacts up to 66km distance to date. It is stable enough not to have needed further adjustment over a period of nearly one hour as we chatted away. I use a separate table to hold the rig, transverter and batteries so as not to disturb the optics once aligned.

So far, we have not found a distance which we cannot work using the big rig. At 65km, FM is fully quieting and the S-meter sits at the top of its scale. If you can see a little red dot in the distance, a good signal is almost certain once you are aligned. On a recent test at 65km, a mist formed between us and we temporarily lost sight of each other, but the gear kept on working! We are currently looking for longer optical paths over which to test the system.

SSB should ultimately win out over FM when signals get weaker, but we have not yet been able to confirm this, never having had a weak enough signal. This gear seems to be a good addition to those who climb up hills for contests etc, to add 623nm (the wavelength of the red light produced by the LED), to the selection of wavelengths available for communication.

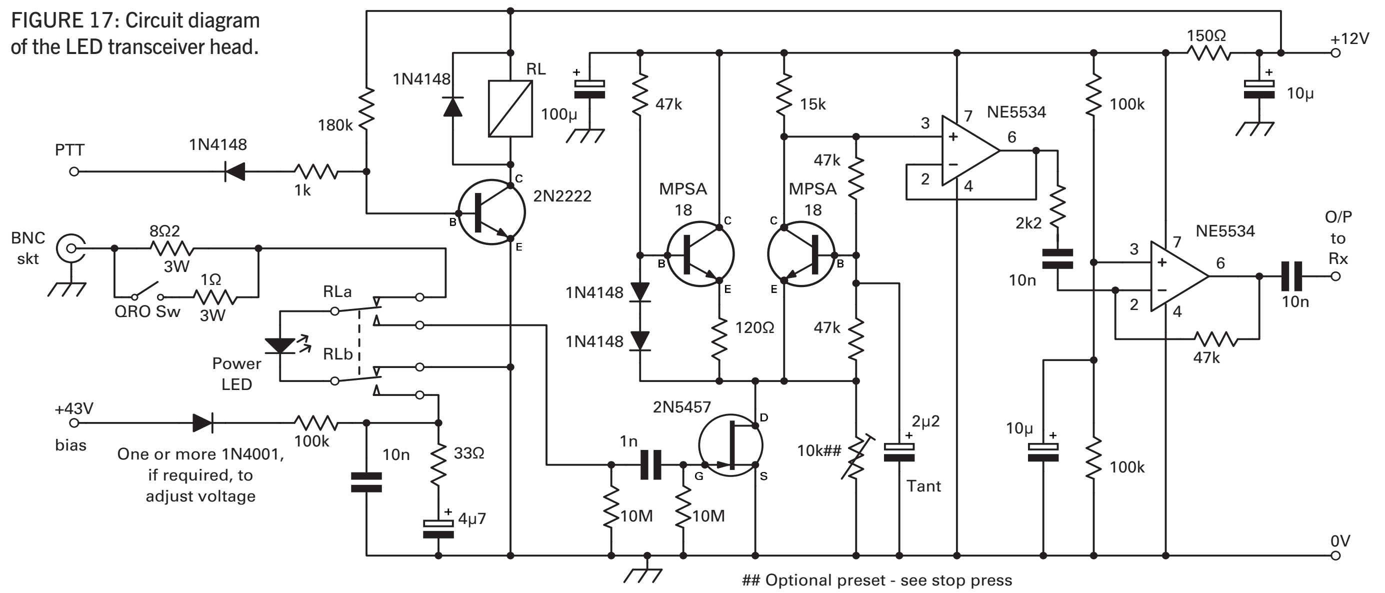
STOP PRES: MATTERS ARISING. As this is a 'live' project, there have been some developments since the article was first submitted. These are noted below in order of importance.

Essential note on 2N5457 FET front end bias. This applies to both the receive head and transceiver head described here. Variations in the characteristics of the 2N5457, bias generator MPSA18 and its diodes can cause an incorrect FET drain voltage. It is vital for maximum sensitivity that the drain voltage sits at around half the power supply voltage. If the drain is higher than 6V, a quick fix is to connect a resistor from drain to 0V, which will greatly improve matters. Some constructors have used a 4.7k fixed resistor whilst others have used a 10k pot and adjusted it until the drain is at 6V. This has affected around half the circuits built so far.

Gain balance and noise figure (important for SSB operation). Several recent tests over long distances revealed an odd situation with receiver response. FM signals were end-stopping on the FT-817 S-meter, but when we switched to SSB, the S-meter would not indicate more than S9 with equally strong signals. This was traced to the receive head (and transceiver, the same circuit on receive) putting out so much signal that it was causing the transverter to limit. Of course this is fine on FM, but it would be nice to have an equal response to SSB. The cure is to reduce the gain in the head by removing the second opamp and connecting the output of the first opamp via a capacitor to the output socket.

In the transverter the Rx output attenuator was modified as follows: change C9 from 47pF to 1nF, remove R25 and swap R26 with R27. If the receiver S-meter is deflected simply by noise after this mod, some of us have fitted a 220Ω pot as a gain control at the point where the Rx signal from the head connects to the transverter board. The signal on the pot wiper is fed to the Rx in port on the board. Adjust the pot to the point where the S-meter show no indication when the head is in total darkness. This mod slightly lowers the noise figure of the receiver and enables the S-meter to have full range on SSB signals.

FIGURE 17: Circuit diagram of the LED transceiver head.



Transceiver head noisy at low ambient temperature. Several times when we have been out portable over this winter, we have noticed that occasionally, the transceiver head produces excessive noise at times when it gets really cold. Keith, G4MSF has got to the root of the problem and has proposed a solution:

When used at temperatures below about 5°C the transceiver can get excessively noisy, with a signal that's normally S7 being unreadable in S9+ noise. Keith, G4MSF discovered this was due to the LED properties changing at low temperature. He added a heater to the LED, consisting of a 10Ω half watt resistor in series with a pair of paralleled 120Ω 2.5W wire wound resistors (**Photo 15**), all fed from 12V. A little heatsink compound is used to couple the resistors to the LED. This heater dissipates about 1.75W and can be left on all the time.