Adventures in optical communication

A small group of amateurs are doing amazing things in the terahertz bands.

PHOTO 1: Original AM receive head. The switch adjusts bandwidth between CW and voice.

INTRODUCTION. I have been interested in optical communication, on and off, for most of my life. In the 1960s it was with audio amplifiers, phototransistors and 6V filament lamps. With the advent of bright, narrow-angle LEDs in the 80s, the idea of optical communication briefly rose again. This time I combined my hobbies of radio and astronomy by fitting an 8° LED instead of the eyepiece to my telescope, using it as a projector. The receiver was little more than an audio amplifier connected to a reverse biased photodiode placed at the focus of a small lens. The LED was driven by a 555 timer IC producing an audio frequency square wave, keyed in Morse. I got about a mile if my memory serves me right.

Early in 2008 I found myself reading the microwave section of the 8th edition of the *RSGB Radio Communication Handbook*. I was interested to read the article on laser communication by David Bowman, G0MRF. This was a life-changing event as, since that day, I have steadily evolved better and better optical communication systems. My initial experiments were with AM, progressing to FM and later all-mode operation (including SSB via light!). This article describes what I've been up to.

THE AM SYSTEM. G0MRF's system had separate head units for transmission (a laser) and reception (an expensive OPT301 opto IC). I decided that a cheaper SFH2030 photodiode and a low-noise NE5534 op-amp would suit my experiments. David also generated a precise 488Hz Morse tone and a very narrow filter in the receiver. I used this outline, adding a few little innovations of my own such as a 20kHz pulse width modulator (PWM) for voice communication and a switch in the receiver filter circuit to broaden the bandwidth to something suitable for voice communications. The photodiode and amplifier were mounted in a 4 x 2 x 1 inch diecast box (**Photos 1** and **2**), acting as a receive head. The final stage of the receiver, a standard LM386 audio amplifier IC, volume control and loudspeaker, were contained in a separate box. A 3.5mm stereo jack plug, socket and lead were used to connect the boxes, carrying power, signal and ground. The transmitter circuit also had its own separate box, although there is no reason why it could not be accommodated in the receive audio amplifier and speaker box. **Figure 1** shows the circuit diagram of the receive head.

The transmitter circuit mentioned earlier borrowed ideas from David's circuit but I introduced the PWM voice circuit. I also altered the Morse circuit to give maximum light output on key up, which helps when aligning over a distance. The driver transistor produced an output of 3V at around 30mA, ideal for the average laser pen, laser pointer or laser spirit level. I also included an output for a front panel LED so that it would not only indicate when switched on, but it would act as a low power transmitter beacon for short range testing (which turned out to be very useful). **Figure 2** shows the CW/PWM transmitter circuit diagram and **Photo 3** shows the completed unit.

At this stage I was working alone, setting up the transmitter at home (I am lucky enough to have a good view over the surrounding countryside) and going out to the spot where I aimed the laser. I discovered that I could receive the tone 6km away with no lens on the receiver; at 15km, a one inch lens was required.

FIRST DEMONSTRATION. A group of amateur friends meet occasionally at my QTH: Brian, G8KPD, Gordon, G8PNN, Peter, G8POG and Tony, G8NPP (who is sadly no longer with us: he was killed in a traffic accident driving up to my QTH in December 2008 and the group as a whole wish to dedicate this project to his memory). I decided to demonstrate the optical comms

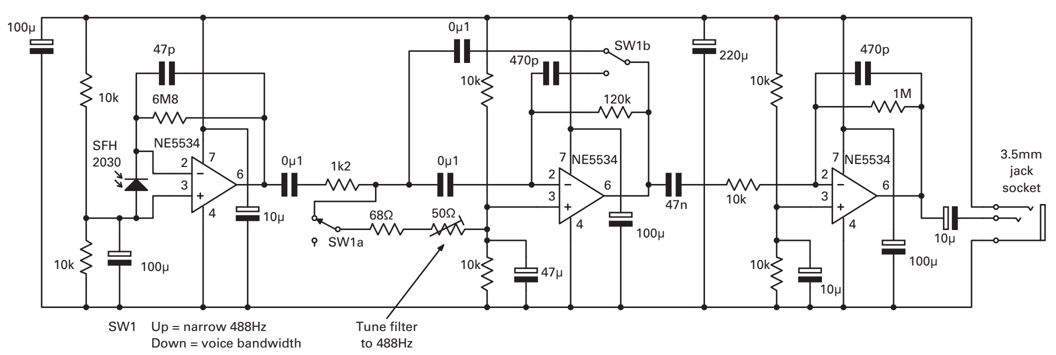


FIGURE 1: Circuit diagram of the AM receive head.

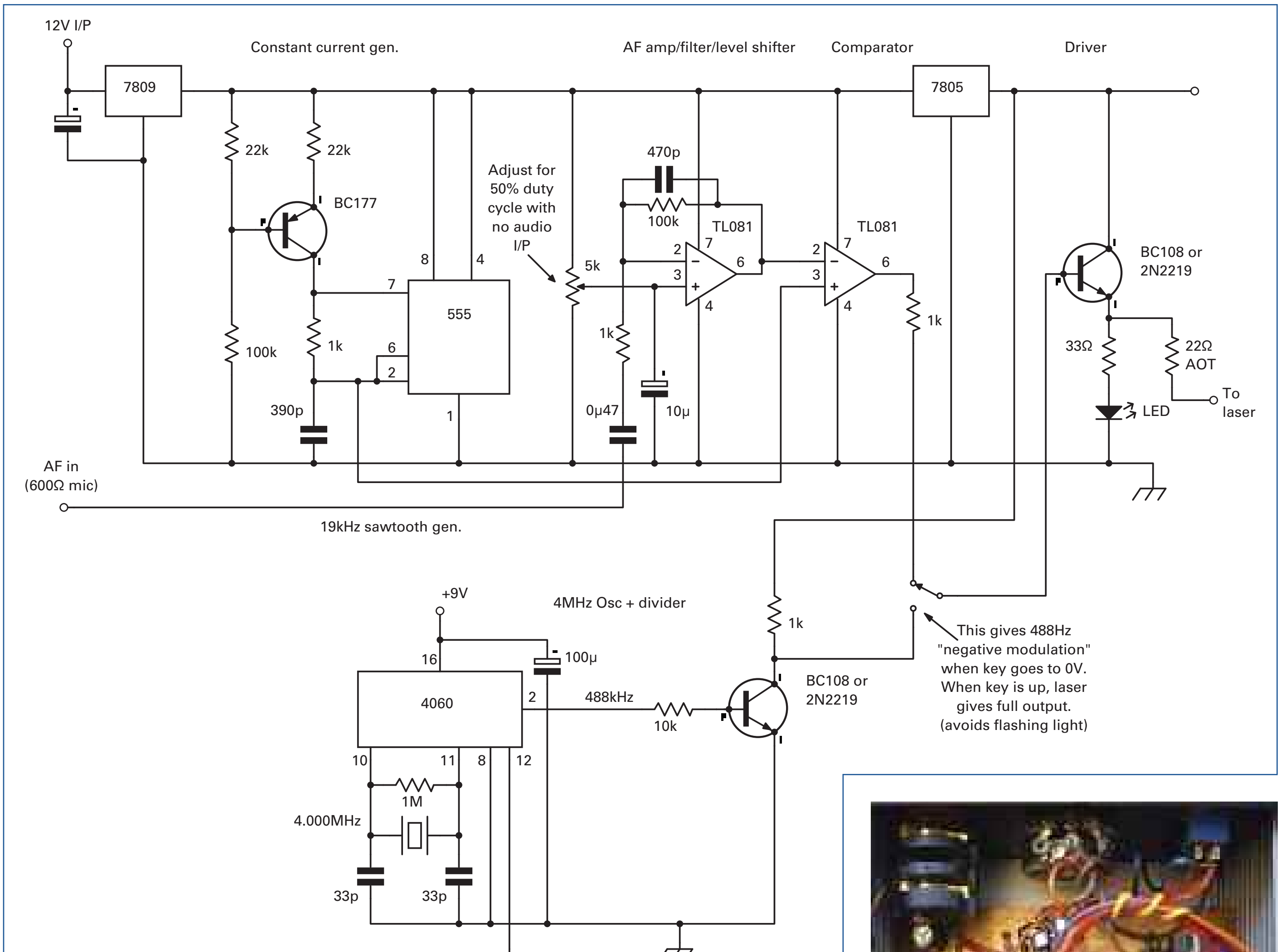


FIGURE 2: Circuit diagram of the CW/PWM (AM) transmitter.

PHOTO 3: Completed CW/PWM transmitter.

PHOTO 2: The completed AM receive head, showing the photo diode and mounting tube.

project to them. For this I aimed the laser about 1m above a hill 1km away, continuing to a second, higher hill 2.5km distant, the beam burying itself safely in a hedge at that point. A word about safety here. Although a 1mW laser is unlikely to do any damage, always make sure there is no chance of someone staring down the beam. At 1km the beam from a cheap laser appears bright although not blinding, but always err on the side of safety.

We walked up the local hill and, at first, could not even see the beam. The receiver was switched on and pointed back to my QTH. Immediately, the tone was audible and I used this as a beacon to find the beam proper. When located, it gave about a 15cm diameter patch of red light. The receiver was driven into overload when placed in the patch of light, even without a lens. We then travelled to the more distant hill, found the beam and marveled at how it could outshine streetlights and headlights. It overloaded the receiver again. It was this demonstration that enthused the others and started the construction of three further sets to investigate how far this would go.

OPTIMUM OPTICS. We had been experimenting with various magnifying lenses to hand. All that is required is to collect as much of the available beam as possible and concentrate it on to the photodiode in much the same way as a microwave dish focuses radio waves on to the feed. Here I am going to cut a long story short and go straight for the optimum system that we have latterly

PHOTO 4: Parts used in constructing the receive optics.

PHOTO 5: The complete receiver.

developed. This system gives the simple PWM equipment a range of some 15km (10 miles).

The optical system that evolved used a length of 110mm waste pipe, an end cap and a joining piece (all available from DIY warehouses). We located a Blue Spot 100mm magnifying glass at a pound shop, cut off the handle and filed off the protrusion where the handle met the rim. This was found to be a tight push fit into the end of the tube. (Be careful at this point: the band around the lens is not parallel. Place it narrow end upwards on a sturdy table and push the tube over it. When the tube rim touches the table top, the lens is properly installed.) **Photo 4** shows the constituent parts.

The cylinder on the end cap was cut down to 20mm and the centre of the blanking disc drilled out to allow light to pass through. We cut a 38mm dia hole with a hole punch. The joining piece was cut exactly in half along its length. One half was used to push the end cap into, the cut end then was slid over the tube on the far end from the lens, making a loose fit that can be improved by using a turn or two of PVC insulating tape on the tube. The length of the tube depends on the lens. You need to be able to produce a focused image of a distant street lamp on the photo diode. The lenses were found to vary in focal length slightly, most required around 285mm from lens centre to the diode surface.

LASERS. Originally we had obtained our lasers from Lidl, where a laser level kit was often available for £10. The kit includes a tripod, adjustable head and a spirit level with the laser in it. The spirit level can be modified to take two connections out to a 3.5mm socket to use it as the transmit head. A second kit provides all you need to mount the receive tube. Simply bolt a section of the aluminum spirit level to two wall clips (also useful for marking an accurate line around the tube before cutting) and slot the tube in place through the hoops. This means that a laser level is sacrificed to science, but this is the cheapest and easiest way. A further wall clip or two can be used to support a finder telescope or, as in my case, half a pair of cheap Lidl binoculars - an essential aid to lining up. This lot then clamps in the adjustable head. A completed unit is shown in **Photo 5**, which also shows some 40mm waste pipe fittings used to hold the receive head. This arrangement also enables different heads to be slid in and out and for fine tuning the focus of the system, although once the focus is set it doesn't normally need adjusting.

I used another half of a joining piece as a lens hood. This also seemed to finish the system off well. It has also proved useful as a holder for irises - cardboard discs with holes in - that act as signal attenuators. These are used to assess how little signal is needed at a given distance, as an aid to calculating the potential range of the system. A 2 inch diameter hole gives 6dB attenuation and a 1 inch hole is 12dB attenuation. Ignoring atmospheric effects, these equate to signal levels at twice and four times the range respectively.

OPERATION. AM works, after a fashion. There are, however, some issues. There is a lot of QRM from street lights. The signal flutters at long distance due to atmospheric scintillation (twinkling), and aiming the laser accurately can be quite difficult. To address the latter point, we started using a high power LED and eventually got this to the point where the signal could be detected 34km away.

POWER LED. The advantage of a LED transmitter is that it is much easier to aim because it has a broader beam than the laser. Also, you cannot be accused of shining a laser over the countryside and, since the power density is much lower, it is safer. That said, a 1W LED using these optics still looks very bright, even when lined up over a distance of several kilometers!

Changing from a laser to a power LED is an easy move. You will need to make another tube and lens system - so there is a use for the second tripod, head and spirit level: to hold the second tube. At the rear of the end cap, a diecast box makes a good mount for the power LED. The completed assembly looks rather like the detector in Photo 4.

The LED drive circuit (**Figure 3**) is an N-channel power MOSFET, which requires a small heatsink. The gate goes to the transmit electronics, the source to 0V and the drain to the LED cathode. The anode goes to +12V.

LED operation reduces the operating noise somewhat, because the wider (optical) bandwidth doesn't suffer from the 'speckle' that you get with lasers. But we are still using an AM-based system, which has pronounced issues with fluttering signals plus QRM from

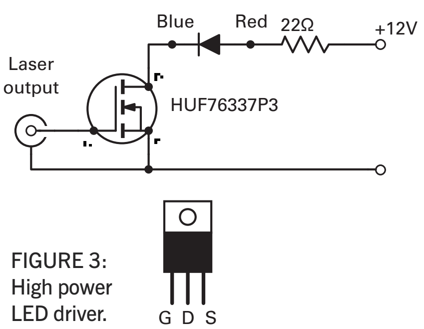
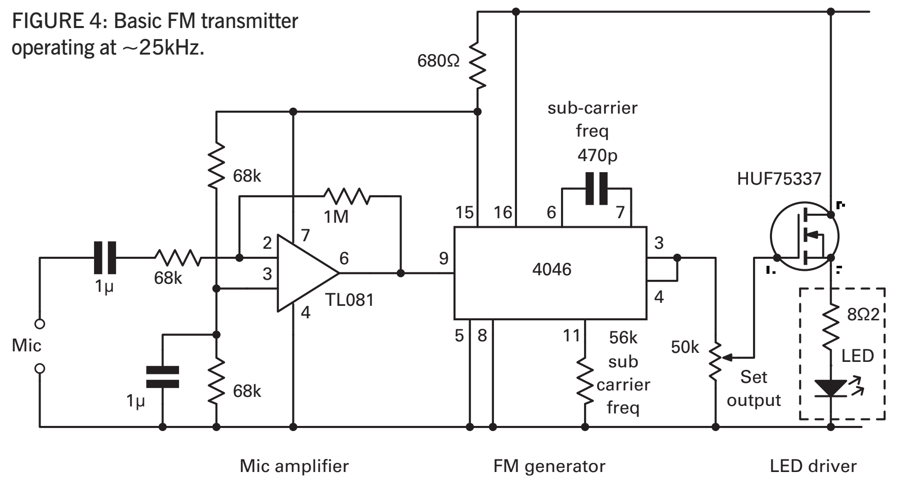
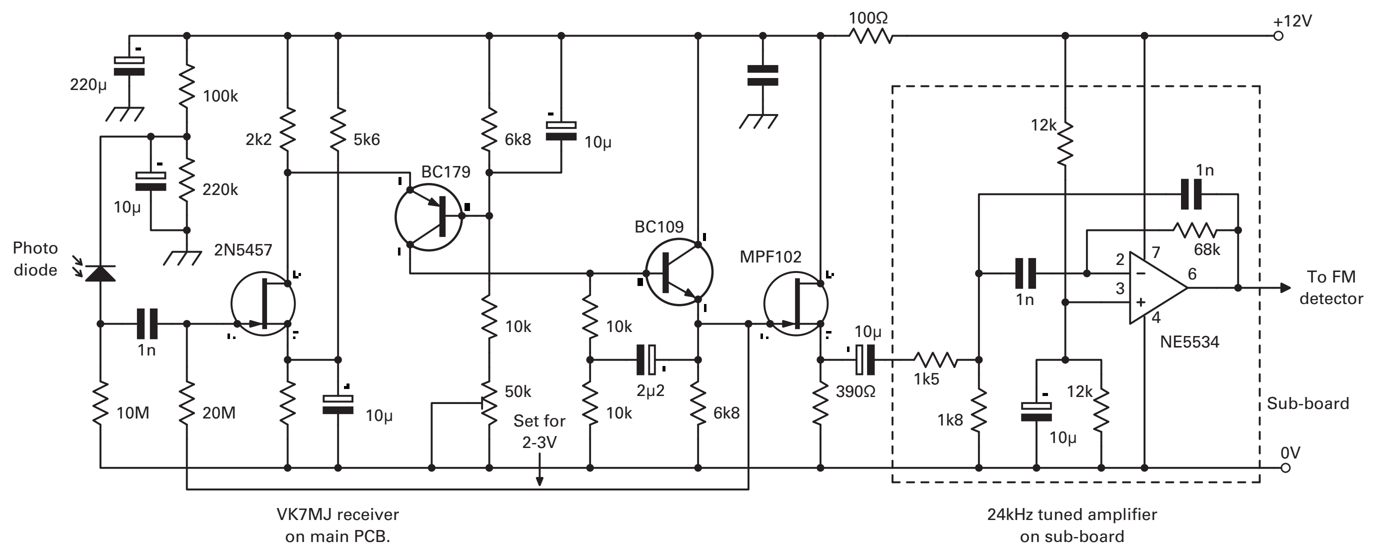


FIGURE 3: High power LED driver.

FIGURE 4: Basic FM transmitter operating at ~25kHz.





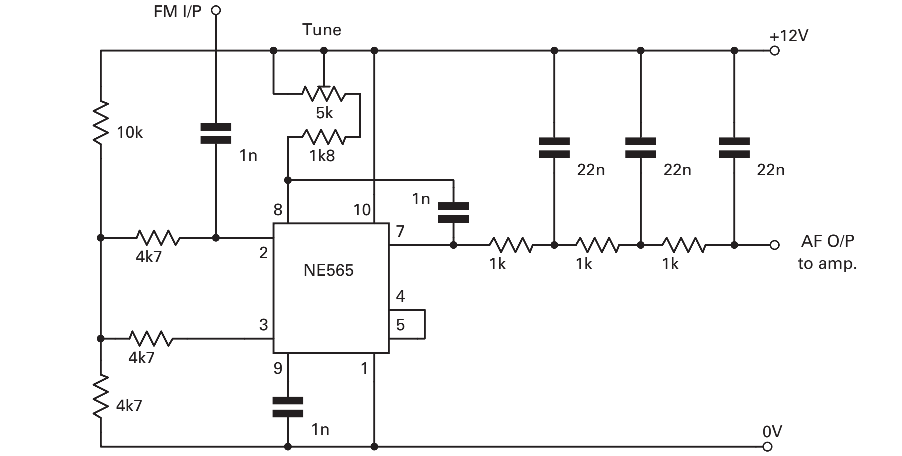


FIGURE 5: 25kHz FM receiver.

PHOTO 6: FM receiver. The stripboard houses the 24kHz amplifier (see Figure 5).

streetlights and road traffic. These issues made me contemplate how could I get round these problems. I began searching the web looking for 'laser dx' and 'optical communication'. I found a wealth of material out there. A great source of information is the Optical Links site run by Tim Toast [1]. You can read all about the progress various groups of optical communication enthusiasts have made mainly in Australia, Czech Republic, Finland, Germany and USA, to name just some of the major contributions. Of special note are VK7MJ and group who have communicated by voice over 160km and KA7OEI and group who have exceeded even this. To date, most have now progressed into weak signal modes and the Australia/Tasmania group have spanned the Bass Strait between Australia and Tasmania by cloudbounce, a distance of some 288km. You should see their 60 LED transmitter in action!

Since in the UK we do not have any huge mountains or dry flat deserts to provide long optical paths and our atmosphere is cloudy and misty most of the time, we cannot really compete on distance, so we re-defined our aims to involve immediate real-time microphone to loudspeaker communications. That's what 'does it' for us.

FM SYSTEM. In my web searches I encountered a receive head design by VK7MJ that had a frequency response from audio to 50kHz and beyond. This made me think that I could use this in an FM subcarrier system, which I decided to centre on approximately 25kHz. At this frequency the QRM from street lights would hopefully be significantly reduced (if not absent) and the effect of the limiter in an FM receiver might help overcome the fluttering of signals. This turned out to be very true.

The FM transmitter shown in Figure 4 uses an opamp based microphone amplifier/ filter connected to a 4046 PLL generator running at 25kHz. The audio signal produces frequency modulation around the main carrier frequency. A MOSFET driver connected directly to the oscillator then provides adequate drive to the power LED head.

The receive head (Figure 5) starts with VK7MJ's design, followed by an amplifier tuned to the sub-carrier frequency feeding a NE566 PLL demodulator. All of this fits into the by now-standard 4 by 2 by 1 diecast box and uses the same 3.5mm stereo jack system for power and signal connections that connect to the audio amplifier/ speaker box from the AM system. All the optics remain as they were for the AM system. A later modification was to make this head switchable between AM and FM by tapping directly into the output of the original VK7MJ circuit. The first dual-mode optical receiver! Just for good measure I then went back to the transmitter box and included a linear (rather than PWM), AM transmitter circuit to complete the dual-mode setup.

RESULTS. Short range tests (our by now favorite 6.5km path across the Tyne valley) showed FM to hold much promise. Very strong signals with no QRM or flutter were achieved. Going on to the 15km path gave similarly good results even in near proximity to powerful lights. We have since used FM over all paths tried up to 34km and always found strong signals and clear communication. We wonder how far this will actually travel… But more of this next month.

WEBSEARCH

[1] http://www.aladal.net/toast/comlinks.html