UNDERWATER OPTICAL COMMUNICATIONS

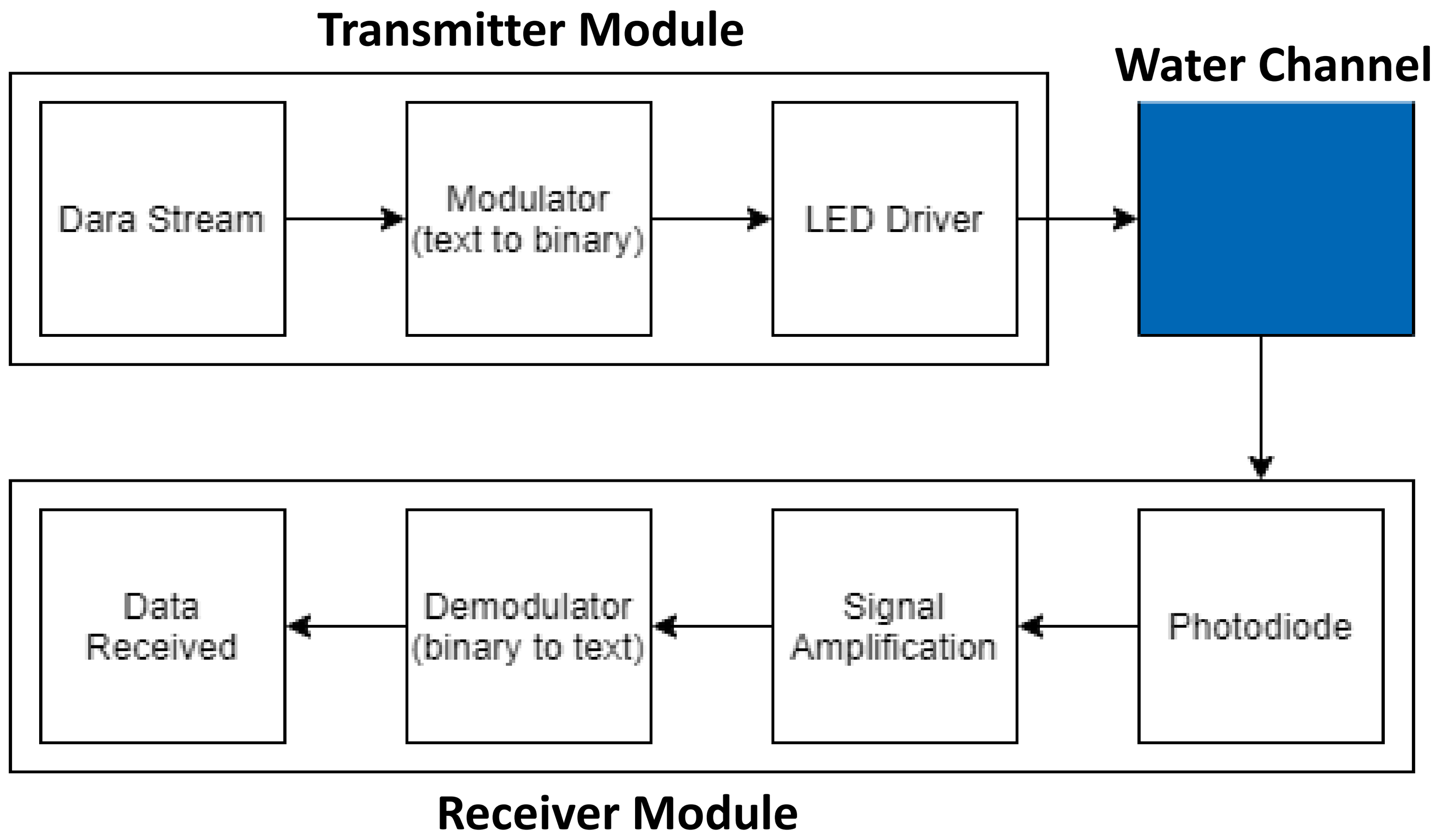
By Thomas Miller

Motivation

Today, most underwater wireless communications are carried out using acoustics. This is due to their very low attenuation in water and can be seen in nature given aquatic life such as whales and dolphins as they communicate using echolocation. However, these waves can not travel at very fast speeds when compared to visible light. If you compare the speed of light to the speed of sound underwater it is equivalent to a ratio of $\frac{1480 m/s}{22500 km/s}$, which is much slower given the speed of electromagnetic radiation is $3 \times 10^8 m/s$ and visible light is apart of this spectrum. Therefore, there exists a need for further research in this field which could lead to exciting prospects for high speed wireless data transfer underwater using visible light as a source.

Outcomes & Objectives

The aim of this project was to transmit and receive lossless, wireless, high speed data using visible light as the communication medium over reasonable distances. These achievable data rates and transmission lengths would first be determined in the free space of air to gain a control and then through a water medium. The challenges here were to firstly figure out how to properly synchronise both the transmitter and receiver for lossless communication and then see how fast these could operate at before data losses occurred or the distances between them became too large for significant detection.



How Light Behaves Underwater

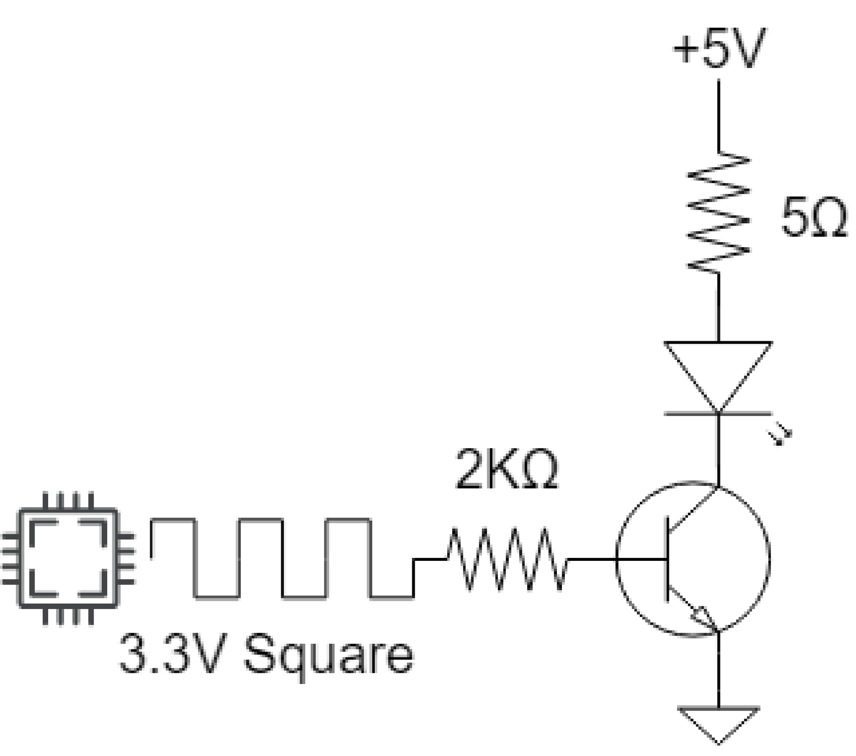
From a point source of visible light its intensity becomes attenuated both quadratically and exponentially underwater according to the Beer Lambert law, see below. This is based on the attenuation coefficient, where in an underwater context this is the light absorption by the water and causes the total propagation of its energy to continuously decrease. Furthermore, light also suffers from heavy scattering of their photons, especially in sea waters due to the large amount of small particles and organic matter such as plankton and microscopic organisms which are often present.

$$I(\lambda) = I_0(\lambda)e^{k(\lambda)d}$$

Due to these principles, light underwater can only travel very short distances of 10-100m depending on the design before it will require boosting by another optical modem. However, light can still be sent at very high data rates up to Gbit/s, making it faster than any other wireless transmission medium.

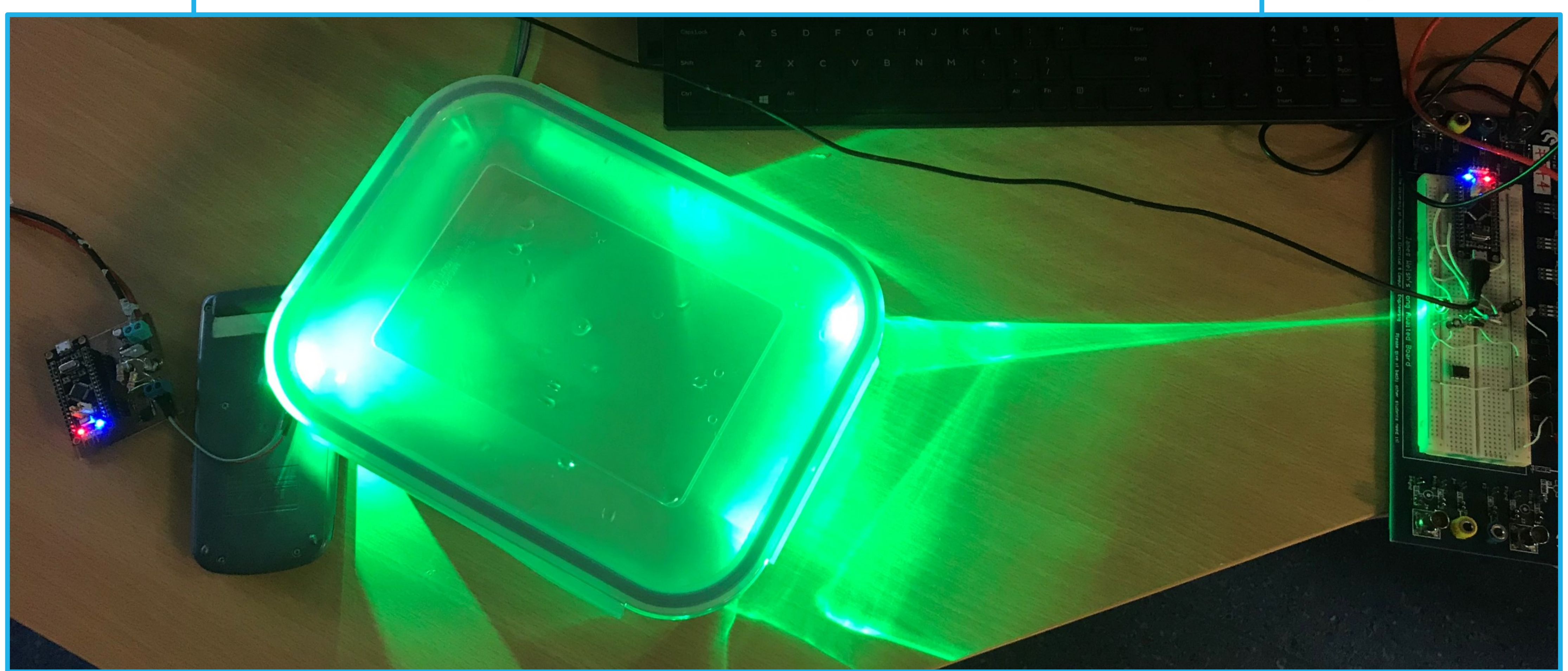
The Transmitter

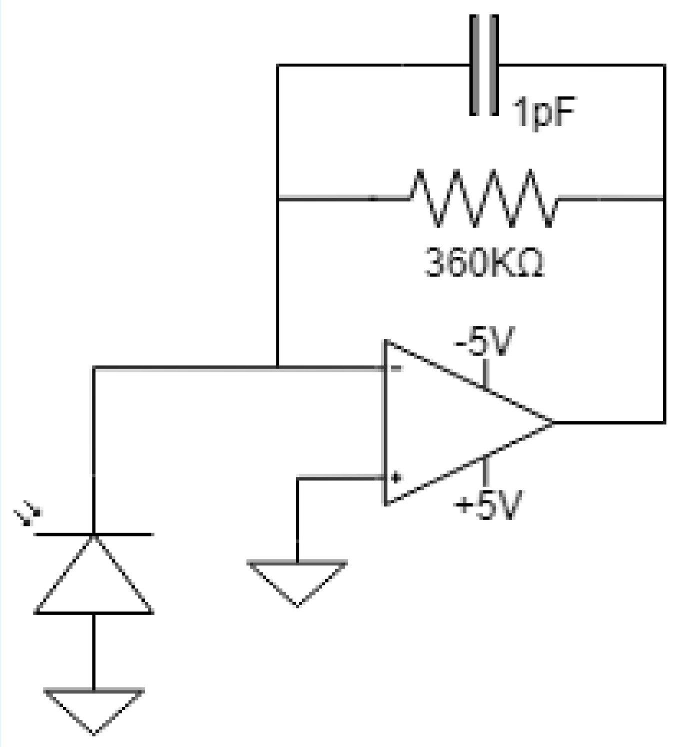
This simple LED driver consists of a transistor acting as a switch to turn off and on the LED based on a HIGH or LOW input from the microcontroller at the base input of the transistor. This causes the transistor to either enter the cut-off or active regions of operation. The higher the frequency the microcontroller is transmitting at will determine how fast the LED switches.



The Receiver

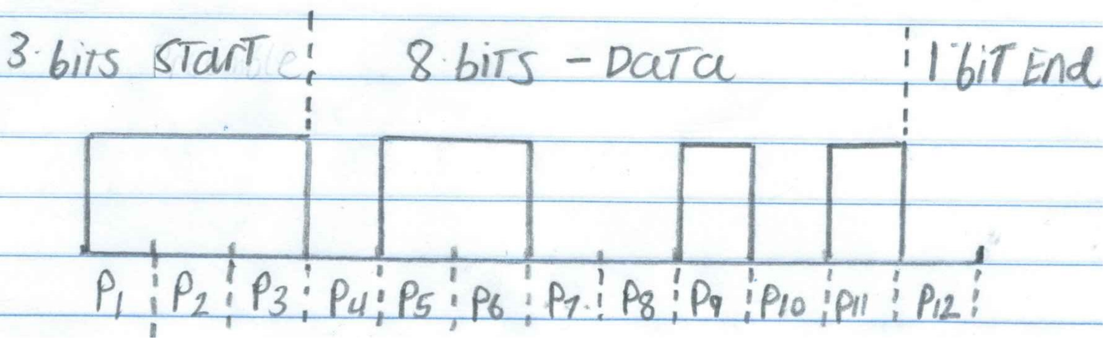
Similar to how a solar panel would work, the receiver uses a photodiode to generate a current proportional to the intensity of light directed upon it. This current is then converted to a readable voltage (approx. 3.3V) using ohms law given the feedback resistor located above the op-amp. A small capacitor is also used to maintain gain stability. Combining all these elements gives this circuit which is commonly known as a transimpedance amplifier.



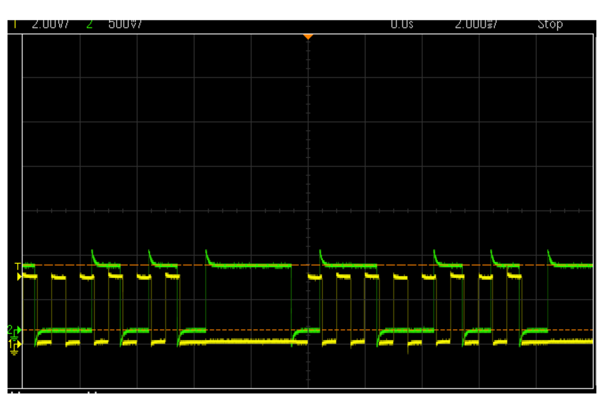


Synchronisation

Synchronisation between the transmitter and receiver clocks was done with the help of start and end flags. These flags were made up of preamble bits. The start flag consisted of 3 HIGH bits while the end flag is one LOW bit. These were detected using a rising edge detector pin located at the receiver end microcontroller. This was activated each time after the last data bit received and then triggered the sampling timer which ran at double the rate of the incoming signal as so to sample in the exact middle of each received bit.



To demonstrate this, the receiver module was setup to produce a pulse every time it was sampling. This was recorded on an oscilloscope and can be seen below. The yellow pulses are when the receiver is determining the status of the 8 bits of data transmission in between the start and end flags and the green pulse is the received signal at the output of the transimpedance amplifier. If the clocks are in near perfect synchronisation like in the recording then the yellow pulses will rise exactly in the middle of the green pulses after each start flag and before the end flags.

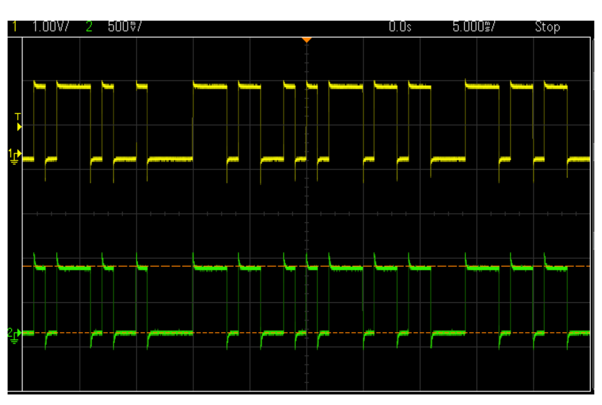


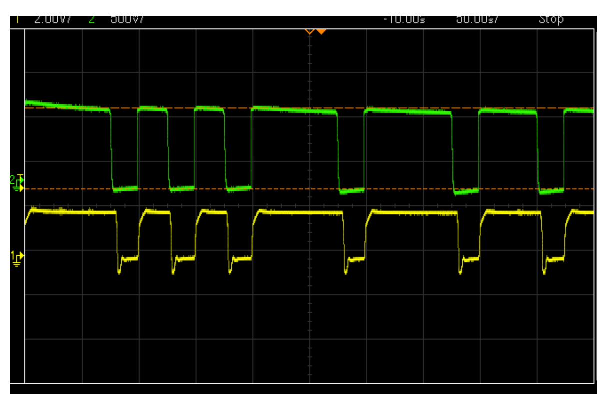
Why Colour and Wavelength Matters

When picking a diode colour for visible light communication, it is recommended to choose a colour which it situated between the wavelengths of 450nm to 550nm in the visible light spectrum. These relate to the colours of green and blue since when used underwater they possess the least absorption and highest transparency when compared to any of the other colours in the spectrum. Moreover, these blue-green bands of the visible light spectrum can also be transmitted at a higher power efficiency since the ocean is mostly transparent to these waves when compared alongside the traditional acoustic waves.

Achieving The Maximum Possible Data Rates And Transmission Distances

Observing the image above, the green light from the transmitter enters a water channel and then exits into a highly focused collimated beam directed towards the photodiode at the receiver end. Using the tub the maximum transmission distance could be extended to 30cm and greater using more or larger tubs. This was due to the corners of the tub acting as convex lenses increasing the total luminous intensity on the photodiode resulting in a greater received voltage. Tests were done at frequencies of 1KHz, to 50KHz and their oscilloscope recordings were taken. Below are two readings taken at the output of the transimpedance amplifier measuring 1KHz (left) and 50KHz (right). It was noted that the receiver can still detect higher frequencies but at the cost of some wave distortion.

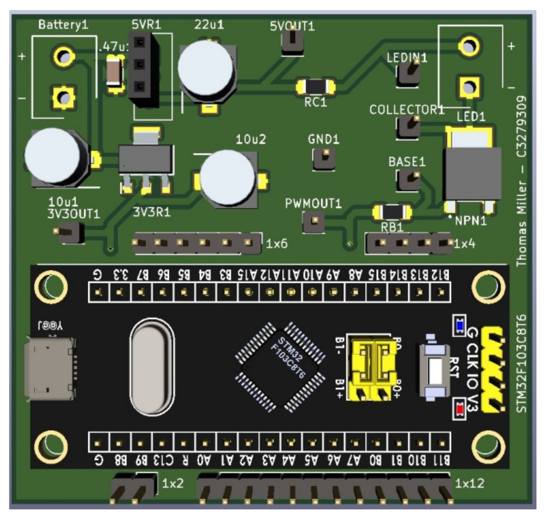


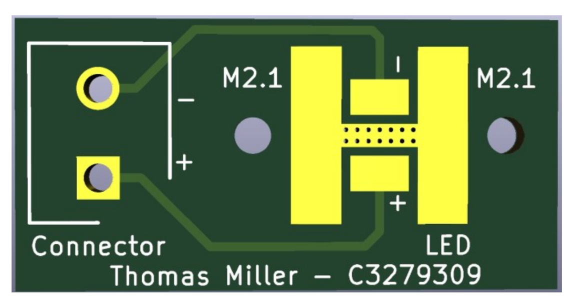


In conclusion, due to potential errors in the synchronisation method used, maximum transmission frequencies of 20KHz were possible, where any higher frequency would cause the clocks to become out of sync. Future work is required to make higher data rates achievable.

PCBs

To make both the circuits portable, they were constructed on separate PCBs which had the bonus effect of a significant reduction in electrical noise and high resistivity which was the issue when using normal breadboards. By using a separate PCB for the LED seen in the right figure, the LED could be extended using longer jumper wires and be able to be specifically placed anywhere against the glass tub. This gave further flexibility in this design.





Hardware Desirables

In order to transmit at higher data rates, larger gain components are required. For example the transistor and op-amp used both had large GWBPs or gain bandwidth products of 300 meaning that they can both support higher frequency transmissions. The op-amp and photodiode had a very low input noise per voltage ratio and a low input capacitance which were very useful for this high sensitive high frequency application. A very high slew-rate or switching rate is also a very desirable feature for the op-amp to have since it allows it to switch faster from LOW to HIGH when reading in fast data rates of high frequencies, improving the overall shape of the received and amplified waveform.