Transmitting And Receiving Information Wirelessly Through Electromagnetic Waves

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Introduction:

Internet, WiFi, telecommunication systems and electronic devices are taken for granted these days. Although they could seem complicated, the physics principles behind these technologies are simpler than what most people might expect.

Our aim was to make a wireless network of multiple devices. Upon further research, the scope of the project was altered to establishing a one-way wireless communication system which can then in theory be extended to achieve the original goal. Our telecommunication system utilized a microcontroller to generate signal of data encoded in binary which was transmitted through and received by antennas.The received signal was subsequently filtered, amplified, recorded and sent to a computer where it was decoded.

Encoding Information:

Modern information technology relies on the fact that virtually any information including images, text and videos can be translated into numbers (↔ binary). The figure below shows how each pixel can be represented with 3 numbers and each character 'A' and 'B' has a unique assigned number in Ascii code.

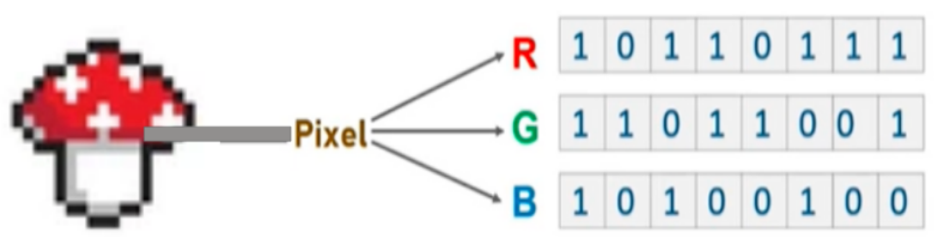


Figure 1: Every colour can be expressed as a combination of red, green, and blue. Consequently, a pixel can be represented using three sets of binary numbers that indicate the intensity of red, green, and blue components.

A → 1000001

B → 1000010

Figure 2: In the ASCII system of encoding, a text character is represented by a sequence of 8 binary numbers.

The data transfer protocol we chose is: 11.5 MHz EM wave is used for our signal; '1' and '0' are represented by ON and OFF of the signal; each bit is transmitted for 0.1 s.

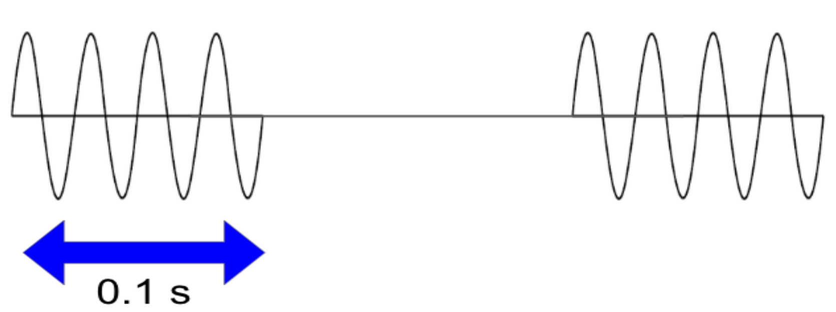
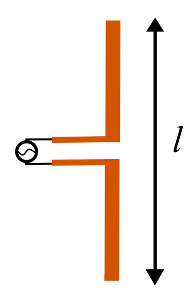


Figure 3: Example of a wave profile representing '101' . This signal is generated by a microprocessor and transmitted by an antenna.

Signal Transmission:



To transmit our data we constructed two antennas which act as a transmitter and receiver. The simplest antenna design is a dipole antenna which consists of 2 L-shaped pieces of metal. We chose copper since it is a good conductor. The optimal length (l) for such an antenna is half the wavelength (λ) of the wave we want to transmit. For a frequency of 11.5 MHz the ideal length would be 13 m, due to space constraints our antenna length was only 3 m.

An electric field shows the direction of the total electric force exerted on a positive charge. Thus the electric field direction is away from regions of positive voltage and towards negative voltage. If that voltage changes, then the electric field produced will also change. Changes in electric fields travel with the speed of light c. If the voltage of a source changes at t=0 then the electric field at a distance d from the source will change at t=d/c.

The above physics principle is utilised to produce electromagnetic waves by applying an oscillating voltage across the antenna. In the first image, one can see a set of electric field lines going from the positively charged side of the antenna to the negatively charged side. As the voltage applied across the antenna changes, the electric field around the antenna will also change but not instantaneously, it propagates with the speed of light c, resulting in the shape seen in the second panel. The voltage applied across the antenna eventually changes its polarisation; the upper end of the antenna becomes negative and the lower end becomes positive, as a result the electric field around the antenna now has the opposite direction as shown in panel 3. Looking at panel 4 we can see that maximum voltage is reached again but the signs are the opposite compared to panel 1. This process repeats and thus, continuous transmission of electromagnetic waves is achieved.

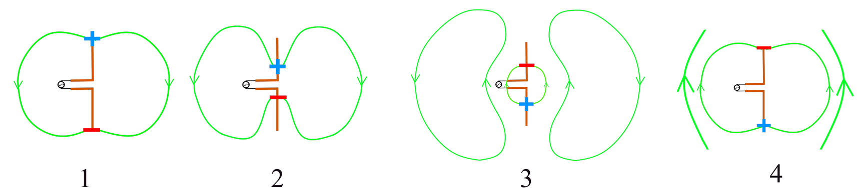


Figure 4: shows the propagation of a changing electric field generated by an antenna

Signal Reception:

The above mechanism is reversible, i.e. when the electric field of the transmitter reaches the receiver, voltage is produced in the receiver. Since the transmitter's electric field changes with time the voltage in the receiver will also be oscillating. However, we have to keep in mind that in the real world our transmitted signal is not isolated and that the receiver will pick up signals from other sources.

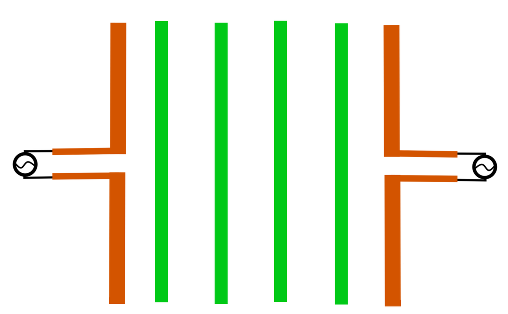


Figure 5: demonstrates the transmission of a signal from the antenna on the left, while the receiver antenna on the right captures the signal.

Signal Filteration:

After the signal is received by the receiver it needs to be filtered and amplified so that it can be analysed by the microcontroller. Initially, the signal received is superposed by the signals from the environment and the source. The largest interference comes from the 50Hz alternating current of the UK power grid as captured in Figure 11. Signals from the external environment vary from 1-15 V peak to peak, having a significant impact on the received signal.

$$f_c = \frac{1}{2\pi RC} \qquad (1)$$

High-pass filters are made from passive components which determine the cut-off frequency that can be calculated from equation 1. The gain is -3.01dB, 1/√2, at the cut-off frequency. The high pass filter used passes frequencies above 725kHz as it is constructed from a 220Ω resistor and 1nF capacitor connected in series as shown in figure 7. The signal used in this project is 11.5MHz, so it would not be attenuated by the high pass filter.

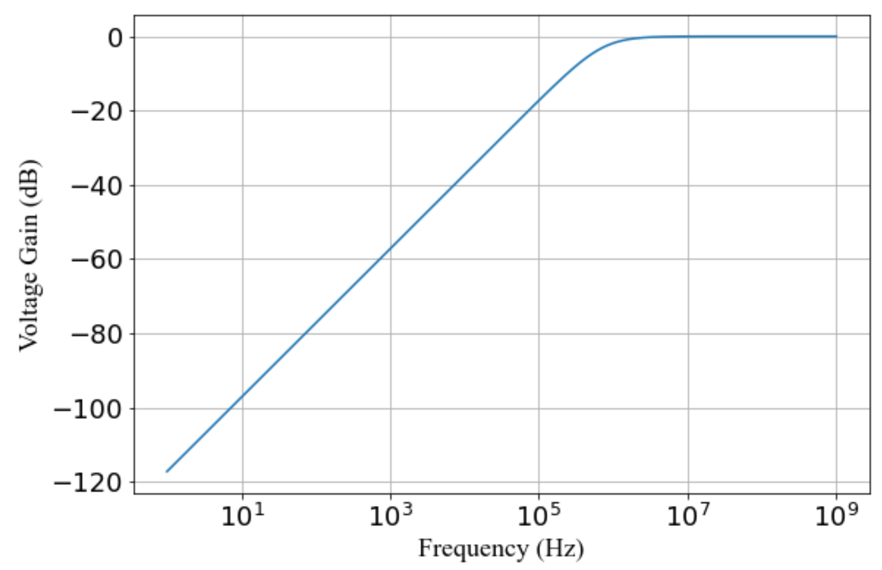


Figure 6: Bode plot of the high pass filter with a cut-off frequency of 725kHz.

$$Gain = 20\log\left(\frac{V_{out}}{V_{in}}\right) \qquad (2)$$

Figure 6 shows a bode plot of the frequency (Hz) vs voltage gain (dB). Both the x and y axes are on a logarithmic scale. The y-axis shows the gain in decibels which is calculated by equation 2. The frequencies below the cut-off frequency of 725kHz are attenuated by more than 30%. At very low frequencies, such as a 50Hz signal, the signal has a significantly large negative gain as it is attenuated by almost 100%. Thus, the external signal would not affect the filtered signal. At a frequency of 11.5MHz, the voltage gain is 0dB, and so the signal is unaffected by the filter as output voltage equals the input voltage.

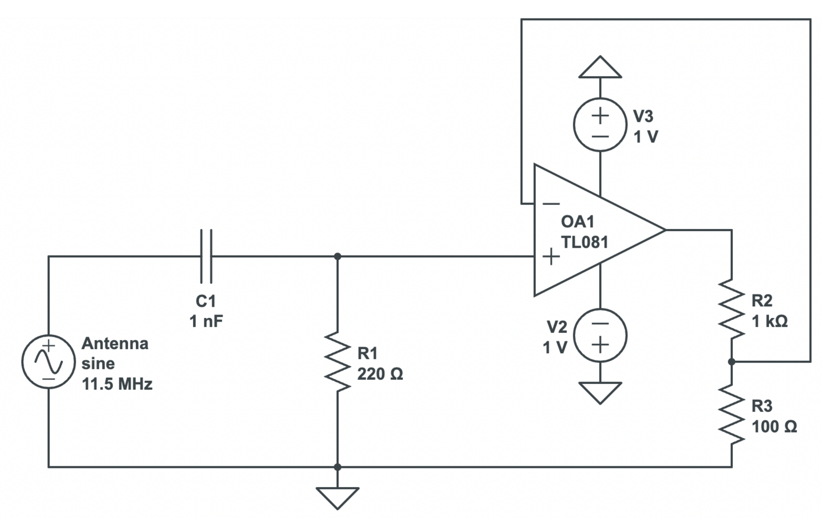


Figure 7: Schematic diagram of the circuit used in the receiver.

Signal Amplification:

During the process of transmitting and receiving the signal, the signal gets attenuated due to inefficiencies in the system. The received signal has a voltage peak-to-peak (Vpp) of 177mV compared to the transmitted signal of 9.5V, only 1.8% of the original signal is recovered. With such a low voltage signal it is not possible to analyze and interpret the received signal by the microcontroller. The microcontroller measures the voltage detected using an analogue-to-digital converter (ADC) where an analogue signal is given by digital readings. Arduino Uno has a 10-bit resolution, resulting in it converting every 4.9mV to an integer. Thus, with such high steps, amplification is required to enable us to decode the signal.

$$Gain = 1 + \frac{R_3}{R_2} \qquad (3)$$

An operational amplifier (op-amp) is used to amplify the signal. The op-amp is an active device that is constructed from a series of transistors and passive components, having several uses such as amplifying a signal. Non-inverting amplification is the design used to amplify the signal by a gain of 3.8. The amplifier's gain depends on the ratio of resistance of R3 to R2 as in equation 3. To amplify the signal with a gain of 11, the non-inverting amplifier is designed using R3=1kΩ and R2=100Ω as illustrated in Figure 7. However, the Vpp is measured to be 613mV compared to the unamplified signal with Vpp=177mV as shown in figure 13, resulting in a total gain of 3.5.

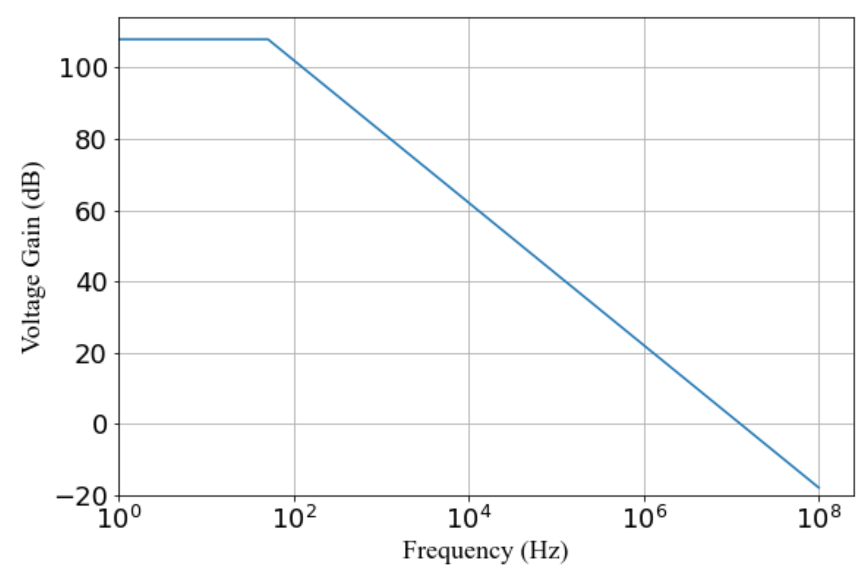


Figure 8: Frequency response graph of AD845 op-amp illustrating trade-off between frequency (Hz) and gain (dB).

The op-amp is limited by an open loop gain of 250V/mV which decreases for increasing frequencies. Figure 8 shows a bode plot of the frequency response of the AD845 op-amp used in this experiment. For very low frequencies, below 3Hz, the op-amp achieves the maximum gain of 250V/m. However, as the frequency increases, the voltage gain drops linearly with increasing frequencies, where the voltage gain drops by 20dB for an increase in frequencies by a factor of 10. This occurs because for high frequencies the op-amp acts as a low-pass filter, attenuating the signal. Thus, there is a trade-off between the maximum possible gain and the frequency of the signal. The transmitted frequency is chosen to be 11.5MHz to achieve a sufficient gain.

Results:

The scatter diagram at the bottom right illustrates the presence of signal against time. We sent an additional '1' before and after the signal in order to distinguish between '0' and no signal. When decoding it, the data is split into time packets of size 0.1 s, where each packet represents 1 bit of information. The data in the zoomed-in diagram, for instance, represents '1101'. We then decoded the binary string to text. The example data was decoded successfully into 'hello', which was what we sent. That means the system was able to accurately transmit and receive text length of 40 bits at a maximum rate of 10 bits per second

Conclusion:

One way communication system was successful meeting the purpose of the project. However, we were unable to create small-scale internet with three or more two-way communication devices due to physical limitation and time constraints. The system transmitted the data using microcontroller which generates alternating voltage to the antenna. Which then was received by the other antenna. The received signal is filtered and amplified. Subsequently, the received signal is recorded by Arduino Uno and is sent to a computer where it is decoded. The signal we received is continuous waves which stop and continue corresponding to 0 and 1.

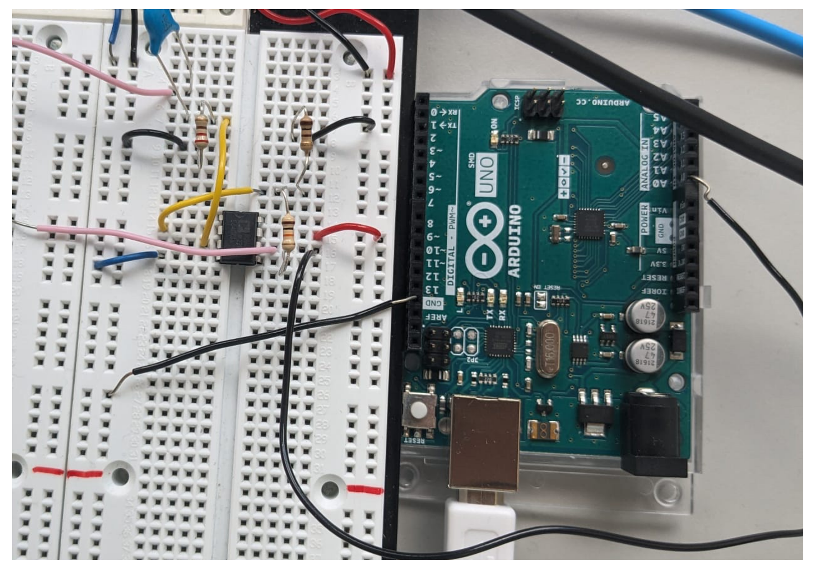


Figure 15: Receiver circuit constructed

Areas of improvement:

Using a microprocessor of higher processing speed would allow to send signal of higher frequencies, optimizing the antenna length. Alternatively, having more available space could enable us to make bigger antennas that are optimal for the frequency we are using.

Due to the nature of the op-amp, where the gain decreases for higher frequency, the amplification of the received signal is limited. Having a more powerful op- amp would allow us to amplify our received signal even further

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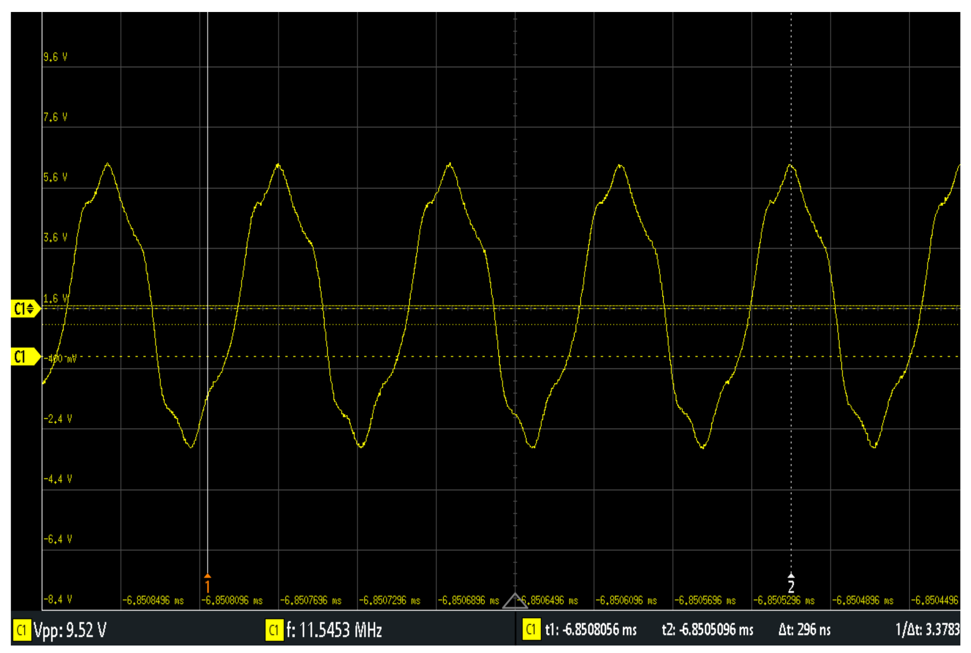

Figure 10: Microcontroller generates an alternating voltage with a frequency of 11.5 MHz and 9.5 Vpp

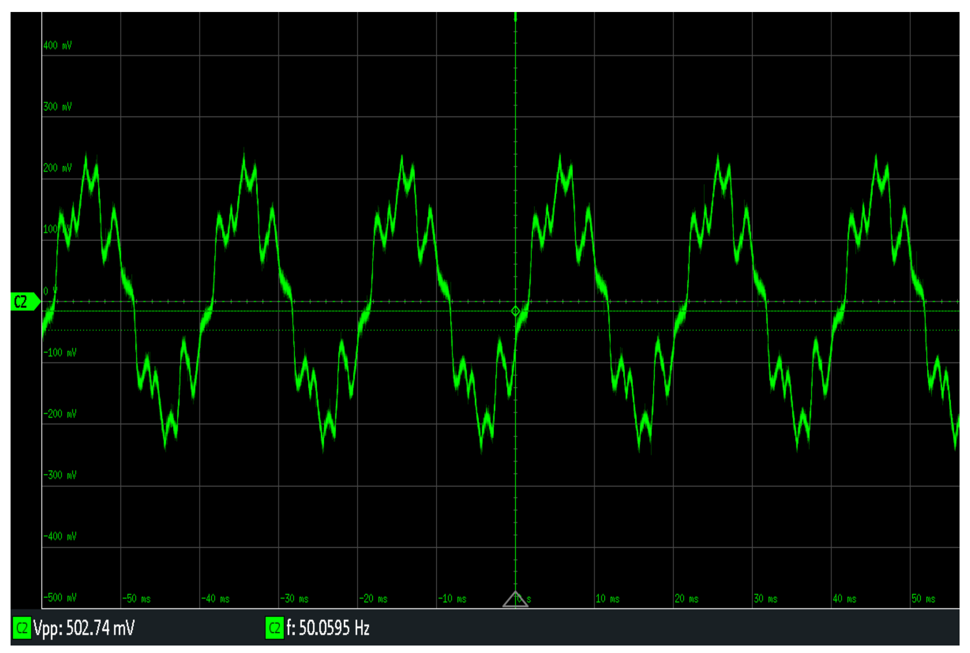

Figure 11: Noise captured on the receiver without signal transmitted

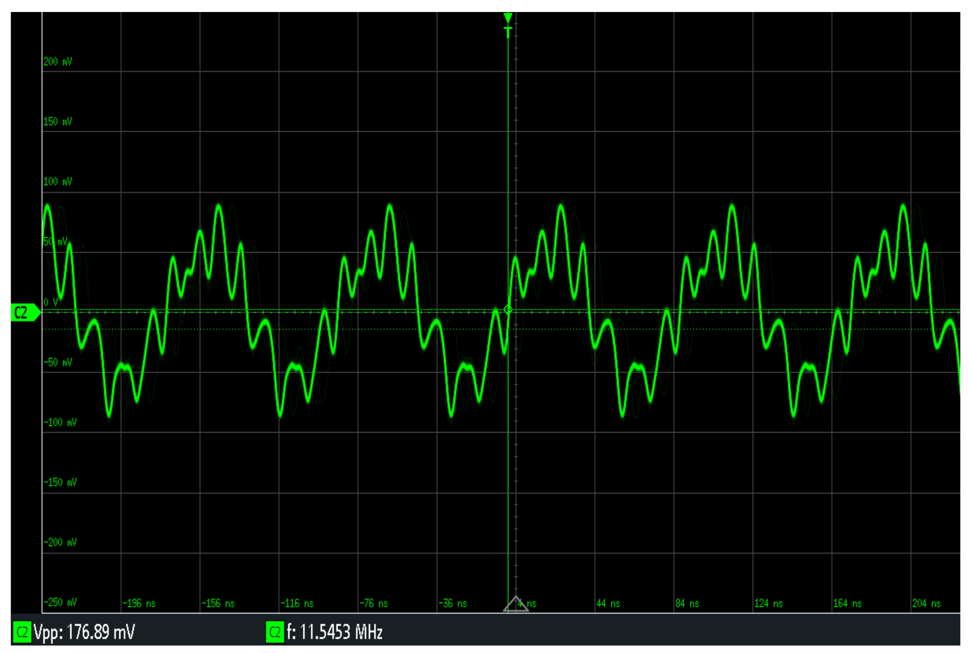

Figure 12: Filtered received signal without amplification, frequency 11.5MHz with 176 mVpp

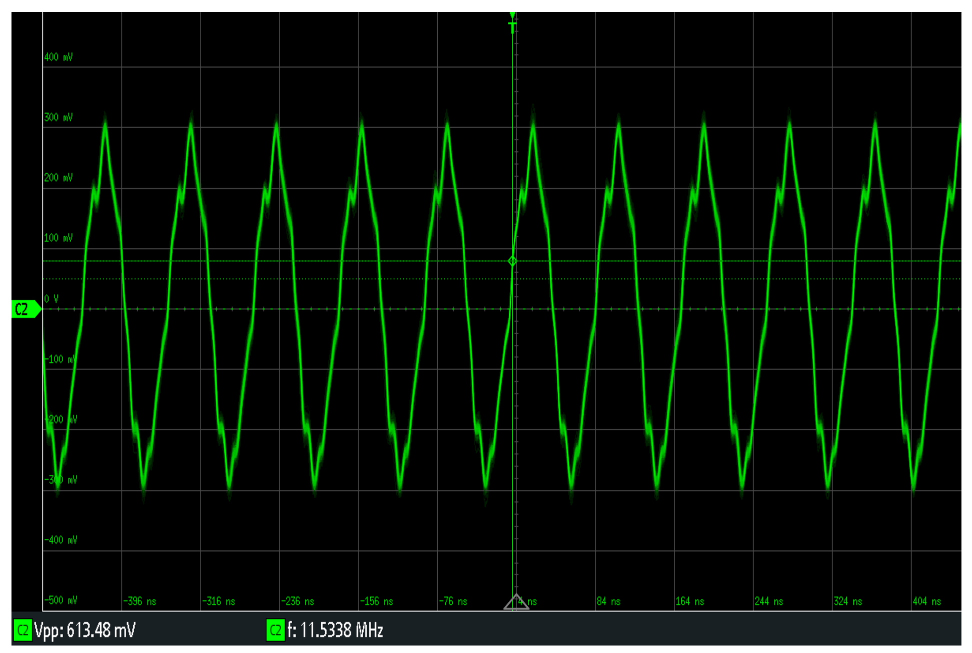

Figure 13: Filtered received signal after amplification, frequency 11.5MHz with 613 mVpp

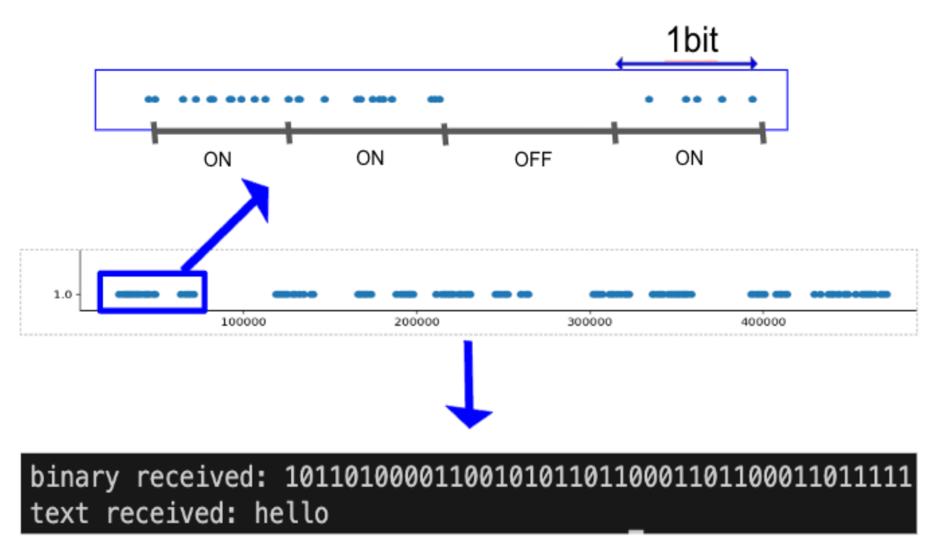

Figure 14: Plot of results recorded by the Arduino