Transmitting And Receiving Information Wirelessly Through Electromagnetic Waves

Project Team Code MJ4: A. Irakleous, I. Abdelmonem, S. Hwang and P. Patiwetphinyo

Supervisor: Michael McCann

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Abstract

A one-way wireless communication system is implemented by sending high-frequency EM waves. A 1-frequency scheme with a frequency of 11.5 MHz is chosen with a voltage peak to peak of 9.52 V, where binary digit 1 is represented by transmitting a continuous signal for 0.1s and for binary digit 0 no signal is transmitted. The signal was filtered and amplified after it was received by using a high-pass filter to remove 50 Hz interference and a non-inverting amplifier to get a gain of 4. As a result, the reception of the signal was clear with a voltage peak-to-peak of 0.613 V. The input text is encoded in binary, sent wirelessly, and received as a wave profile which is decoded into binary and subsequently to text. The maximum bitrate achieved is 10 bit/s transmitting and the maximum size of the received signal was 40 bits.

I. Background

The main concept for the project was to craft a wireless telecommunication system. Watching a YouTube video [1] about DIY radio inspired us to make a programmable signal-generating radio transmitter and receiver. Initially, we planned to extend the system by making a small-scale network by connecting three or more devices; however, our supervisor suggested concentrating on sending and receiving signals through two devices and extending the system later. The microcontroller of the radio transmitter is programmed to generate two discrete wave frequencies corresponding to either binary digit '1' or '0'. Then the bijection between binary numbers to data allows us to send any form of information, including text and video, wirelessly.

The initial goals were:

- to optimize the antenna design.
- to test the transmitted and received signal by the antennas.
- to decide on two frequencies representing each binary digit.
- to implement a receiver filter design that removes noise and amplifies the signal.

Extended goals were:

- to design the low pass filter for changing the square wave generated by the microcontroller to a sine wave for smoother signalling.
- to design two active band-pass filters to pick up only the desired frequency.
- to investigate the error-detecting algorithm to improve the accuracy of data received.

II. Description of Project Work

A. *Project start-up*

Discussion about the project idea started on the 24th of February 2023 with different ideas being discussed, a shared Word document was created for recording meeting notes. After receiving feedback from Prof. Uchida the final idea was chosen on the 21st of March 2023 as "DIY electromagnetic wave communication system" proposed by S. Hwang. The first meeting with the project supervisor, Dr McCann, occurred on the 12th of May 2023 where the implementation of the idea was discussed. Over the next one and a half weeks the idea was refined with research being done on: circuit design (I. Abdelmonem), coding (S. Hwang), and wave transmission (P. Patiwetphinyo and A. Irakleous). For generating and receiving oscillating voltage, we initially considered using an Arduino microcontroller but after conducting further research we chose the "Teensy 4.0 Development Board" (proposed by I. Abdelmonem) which has a processing speed of 600 MHz as opposed to Arduino's 8 MHz while using the same language as Arduino. Sending a sine wave using Teensy was not possible for high frequencies which we were considering, so we decided to generate square waves that get converted to sine waves by a low pass filter. We decided to use a 2-frequency scheme for sending binary information (a signal of one frequency corresponds to 1 and a signal of a different frequency corresponds to 0). The signal received would go to 2 bandpass filters, each connected to a different I/O port of the microcontroller of the receiver. The bandpass filters would ensure that only the 2 discrete frequencies would be received, and background interference would be blocked. Thus, computational work would be minimized as the microcontroller would only have to detect voltage in the 2 I/O ports. It was decided that all team members will work on the project during the timetabled sessions in the lab. Two weeks after the lab commenced, we started having meetings of around an hour for planning before each lab session. Additional independent research was conducted when necessary (approximately 20 hours/week cumulatively).

B. Choosing frequencies

Working with high frequencies has several benefits. The size of the antennas of the transmitter and receiver needs to be comparable to half the wavelength of the wave sent to have good reception, so our antenna will be compact if the frequency is high. Which means we can send more waves per second. Thus, we can have a higher bitrate. There are very few bandwidths which we are allowed to use legally for low frequencies. The latter proved to not be an issue since after some testing, we found that our signal is undetectable beyond the lab proximity, so all frequencies can be used. We settled for one of the frequencies to be around 13.5 MHz since higher frequencies proved to be hard to implement with Teensy. Lab work commenced on the 18th of May 2023 with an oscillating voltage of 13 MHz produced by an oscilloscope being successfully transmitted and received by DIY dipole antennas made from copper with a length of 1.5 m (design and test by **P. Patiwetphinyo**). We also tried to make an antenna of approximately the same size as the DIY antenna but made from steel instead for more rigidity. The signal of the new antenna was weaker because copper is a better conductor. Thus, we designed a new simple dipole antenna taped to the bench table for rigidity. Ideally, for a frequency of 13.56 MHz, the antenna should be around 11m, but due to space limitations, the total length was 3 m. Sending signal using Teensy was successful and a low pass filter in the transmission stage was not required since the generated signals had the waveform of a sinewave. This occurred because Teensy approached its frequency generation limit (Teensy code written by **S. Hwang**). Initially, a bit was to be represented by 1 or 2 full waves i.e., the bit rate was going to be comparable to the frequency of our wave. Due to limitations with how fast Teensy could start or stop sending signals a bit will be represented by a continuous signal of at least 1μs (**S. Hwang**).

C. Designing the Receiver circuit

Our received signal was weak compared to the background noise of 50 Hz so even though it was observable on an oscilloscope it was not good enough to be detected by the receiver Teensy. To fix this we initially tried to make simple bandpass filters (**I. Abdelmonem, A. Irakleous, P. Patiwetphinyo**) using capacitors and resistors. Our efforts were not successful because the signal was too weak. Thus, we turned to active filters, which utilized op-amps. Initially, we tried to implement a narrow bandpass active filter (**I. Abdelmonem**) which did not work, and we discovered that the LT1001 op-amp we used was not suitable for our high frequencies. To fix this issue we tried to use low frequencies of the order of 1 kHz which was not limited by the LT1001 op-amp. Unfortunately, even though the filter worked for these low frequencies the transmitted signal was too weak (testing performed by **P. Patiwetphinyo, A. Irakleous**) to be detected because such frequencies would require an antenna length of the order of 10 km. Another solution that we investigated was to isolate the frequencies digitally using Fourier Transforms (**S. Hwang, A. Irakleous**), this endeavour was also unsuccessful because of the high uncertainty in the readings of Teensy. In the end, we decided to order more powerful op-amps (AD845KNZ) that could handle our desired high frequency of 13.5 MHz.

D. Finalizing the Design

Initially, our new narrow pass active filter (designed by **I. Abdelmonem**) with the op-amp (AD845KNZ) was not working since we were implementing an inverting amplification. After changing to a non-inverting design with only a high pass filter, filtering out 50 Hz noise, the op amp (AD845KNZ) managed to successfully amplify the signal and remove the background noise (lab work and testing **I. Abdelmonem, A. Irakleous, P. Patiwetphinyo**). As a result, we had to change to a 1-frequency scheme (proposed by **A. Irakleous**) since having narrow bandpass filters was not feasible. This required changes to our computer code for the receiver (**S. Hwang**). Initially, we read the signal by using Teensy. However, the reading uncertainty was high where Teensy fluctuated between 1 and 0 for any input voltage in the range of

0.3 V to 1.5 V. Thus, we decided to replace the Teensy with Arduino Uno Rev3 and change from digitalRead() to analogRead(). The signal was received successfully but the receiving code needed to be optimized by using an external software [12] to save data from Arduino to PC and measuring the time taken to send 1 bit to be 161 ± 1 loops per bit using a counter algorithm (**S. Hwang**) (testing: **P. Patiwetphinyo**). Due to time limitations, we could not test and optimize our set-up for long ranges.

III. Summary of Results

After transmitting a signal of 11.5 MHz with a peak-to-peak voltage of 9.52 V we received an unfiltered signal of 0.177 V which after filtering and amplification becomes 0.613 V. The distance between the antennas was 10 cm. The maximum bitrate tested was 10 bits per second, and the maximum text length successfully transferred was 40 bits.

IV. Conclusion

The one-way communication system was successful, meeting the purpose of the project. The extended goal of building a small-scale internet with three or more two-way communication devices was not developed due to time constraints. The system accurately transferred 40 bits but failed to transfer larger data sets. Further development of the code would allow larger data to be transferred. The system can be further optimized by increasing the range, accuracy, and bit rate. Investigating microcontrollers with higher processing speeds could help us overcome these limitations. Apart from this, the workflow could be improved through higher productivity. We did not plan thoroughly the tasks that will be conducted in the lab leading to inefficient time management. To address this issue, we decided to meet regularly before lab sessions which allowed us to visualize and organize the tasks required.

V. Purchases And Existing Items

Equipment used and purchased:

The data in this experiment was taken from the oscilloscope that we borrowed to measure the signal of the transmitter and the receiver. Most of the work is done on a breadboard to connect the circuit. In this experiment, we also created an antenna made from a metal bar and a piece of wood. We also bought the microcontroller to transmit and detected the signal for this experiment.

We purchased the following items:

- first thing we used, 2 x Teensy 4.0 (With Pins), type: microcontroller, source: amazon.co.uk and price: £ 65.98.
- Second thing we used, 5 x AD845KNZ, type: Op Amp, source: uk.rs-online.com and price: £ 101.65.

We also made use of these items which were borrowed or already in our possession:

- first thing we used, RTB2004, type: oscilloscope and source: Blackett First Year Laboratory
- second thing we used, copper wire, type: wire and source: Blackett First Year Laboratories
- third thing we used, PB-104, type: 4 x breadboard and source: Blackett First Year Laboratory
- fourth thing we used, resistor and capacitance, type: electric component and source: Blackett First Year Laboratories
- Fifth thing used is an Arduino Uno Rev3, type: microcontroller and source: Blackett First Year Laboratory.
- Sixth thing we used, 2 x MacBook Pro, type: laptop and source: owned by team members.
- Seventh thing we used, 2 x EL301R, type: power supply and source: Blackett First Year Laboratory
- Eight thing we used, 4 x Steel bar, type: bar and source: Blackett First Year Laboratory
- Ninth thing we used, 4 x LT1001, type: Op-amp and source: Blackett First Year Laboratories

VI. Bibliography

The literature that we consulted is listed below, with a brief comment on each item's role in the project.

[1] R.U.F., "How to make the world's easiest Radio! Do it yourself at home!", (How to make the world's easiest Radio ! Do it yourself at home!)

[2] Physics behind antenna https://www.youtube.com/watch?v=ZaXm6wau-jc

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