Infrared Waves for Switch Activated Toys

Chloe Chen, Sabrina Sanchez, Kimi Hiji, Maymon Naing, and Inika Shakya
Bioengineering Department
UC San Diego
La Jolla, USA

***Abstract* - Many families of children with disabilities face a lot of difficulties finding cheap accessible adaptive toys. This is usually a result of many off-the-shelf toys not being very accessible or the available toys being extremely expensive. This project aimed to create a cheap external infrared LED switch that will turn any toy on using an infrared LED receiver that would be inserted into the battery pack of the toy. Utilizing infrared waves would allow an easy solution by having a wireless button that can activate modified toys. The design for the switch consists of three main components: an amplifier, a bandpass filter, and a comparator. These components would work together to filter different types of lights, pick up the infrared light waves, and turn on the toy.**

I. Introduction

The most observed problem of accessible and adaptive toys on the market currently is the insufficient supply of switch-adapted toys due to the high cost, the lack of knowledge surrounding this field, and the inaccessible designs. Therefore, in order to tackle this problem, we have decided to create a low-cost switch that can be universally attached to any toy, making the toys switch-adapted. Included in this design is an infrared receiver system that allows the user to operate the toy remotely using a switch, which is the focus of our project and report. The infrared receiver will detect the wavelength of an infrared LED from the switch through a photodiode, then through a bandpass filter that is defined by and designed to select the target frequency[4]. The output will thereafter go through a comparator to be checked against the threshold frequency, and thereby turn on the toy if passed the desired threshold. In our model of this system, we include an input wave that represents the infrared light of the remote-controlled switch, another input wave that describes the sunlight as a model of potential noises, a transfer function that represents the bandpass filter, and an oscilloscope that represents the output that is consequently used to turn on the toy if applicable.

II. Background

Addressing the growing demand for adaptable toys and the existing deficit in the market, various organizations have emerged with a mission to provide a resource for families through toy lending libraries and modify toys to be external-switch-activated. Typically, these modifications involve altering the internal circuitry of toys to enable them to be activated through an external switch, making them more accessible to children with disabilities. However, a notable challenge looms large, as observed by families of children with disabilities and professionals or organizations working with them: the frustrating high cost and limited availability of these assistive technologies. The intricate nature of the alterations required for recircuiting or adapting these toys renders them unsuitable for mass production, leading to the scarcity of affordable options for children who need them most.

III. Specific Aims

The primary aim of this specific report is to model an infrared receiver that detects the wave from an infrared LED from a switch and turns on a toy. In order to accurately model the detection of infrared light, we will base the input of our model on the frequency and wavelength of a typical infrared light used for remote controls. Our subsequent aim is to create a transfer function that represents the bandpass filter we utilize in our system. The bandwidth produced by the transfer function should be small, allowing only the specific desired wavelength and frequency to pass. The final aim of our project is to analyze the output of our system and verify it matches the goal of our design – the irrelevant input noises are filtered out of the system, leaving only the frequency of the infrared LED to be passed through the rest of the circuit.

IV. Assumptions and Limitations

For the application of our infrared receiver model, we would need the signal from the infrared LED through an amplifier, through a bandpass filter, through a comparator, and then finally presenting an output. The setup of our project is described in the block diagram in Figure 1.

We have several assumptions in the setup of our project in order to simplify the system to be analyzed. We understand that the assumptions may not perfectly describe reality, and we have identified the important limitations of our simplified system.

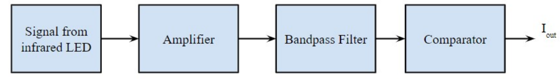

Figure 1. Block diagram of model needed for application of infrared receiver model.

A. Assumptions:

1. The system (transfer function in the Simulink model) only describes the infrared receiver, and does not take into account any other part of the switch circuit or system.
2. The bandpass filter, through our implementation of the quality factor, is assumed to be selective to infrared light only[7].
3. The comparator as described in the block diagram is not included in the Simulink model. The comparator compares the input frequency against the set threshold frequency; when the frequency is above the threshold, the comparator would allow for the current to pass through, whereas if the frequency falls below the threshold, the comparator would stop the current from going through. The current passed through would then be activating the toys.

B. Limitations:

1. The actual frequency of the infrared light is between the range of 3×10^{11} to $4 \times 10^{14} Hz$. The high value of the infrared frequency causes the values of the transfer function to be on the extreme ends, and more specifically affecting the time constant. When modeling the system in Simulink, the input frequency was lowered by a factor of 10^{14} .
2. Distance between the infrared LED light and the receiver is a potential limitation to the sensitivity of our infrared receiver. As the distance increases, the signal may be harder to be detected by the receiver, hence influencing the output of the system.

V. Methods and Equations

A. Parameters and Equations

In order to model our system, research of typical frequency of an infrared light and that of the other light sources were done, as they are sources of noise that can be detected by the photodiode.

Light Sources	**Frequency range**
Fluorescent light (household lightbulb)	50~60 Hz
Sunlight	$1 \cdot 10^{18}$ Hz
General infrared light	$3 \cdot 10^{11} \sim 4 \cdot 10^{14}$ Hz
Typical IR LED used for remote control	$3 \cdot 10^{14}$ Hz

Figure 2. Light sources and their corresponding frequencies[3].

Due to the limitations of Simulink, as discussed earlier, we scaled down all of our variables by a factor of 10^{14}. The following variables are listed below.

The value of the center frequency was determined based on the frequency of infrared light. This scaled-down value is given as

$$F_c = 3\ Hz$$

Tau, the time constant, was then calculated using the center frequency with the following equation

$$F_c = \frac{1}{2\pi\tau} \qquad (1)$$

The τ value is then calculated to be 0.05305.

The quality factor is a dimensionless parameter that describes damping an oscillator[5]. It is the ratio of the initial energy stored to the energy lost in one oscillation. It also stabilizes the system, so less energy is dissipated during each oscillation. The quality factor was calculated using the following equation

$$Q = \frac{center\ frequency}{bandwidth} \qquad (2)$$

This then gave us a quality factor of 30.

As a result, the bandwidth is small, and the filter is more selective. This value is

$$Bandwidth = 0.1$$

B. Transfer Function

The transfer function for our system is then defined as [6]

$$\frac{\tau s}{1+\frac{2\tau s}{Q}+\tau^2 s^2} \qquad (3)$$

The quality factor was added to the equation of a usual transfer function of a bandpass filter, to create an underdamped system, instead of critically damped, which in turn created a narrow bandpass filter[2]. This ensures that the filter is highly selective to only the frequency transmitted by the infrared LED.

C. Simulink Model

Modeling the system on Simulink, we used the transfer function mentioned above (3) along with the variables mentioned in the previous section.

We created two models with the same transfer function (3) but a different set of input frequencies, all scaled down by a factor of 10^{14} and had a square wave frequency response. The models were simulated for the same amount of time: **10 seconds**.

The first model, which is shown below, receives one signal representing an infrared LED.

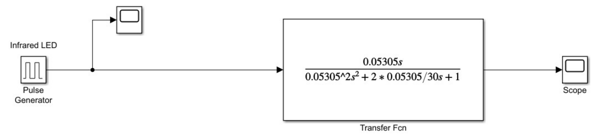

Figure 3. Model of the transfer function of a narrowband bandpass filter with one inputted signal.

The input signal had the scaled frequency of a typical LED (3 Hz) and a period of 0.333 sec.

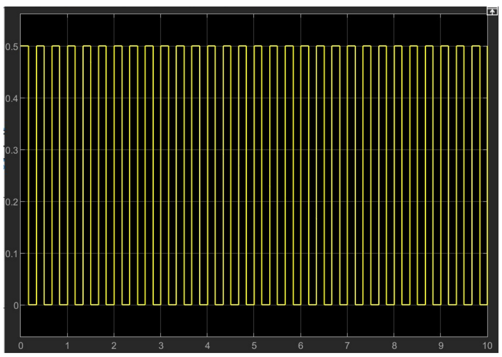

Figure 4. Plot of an Infrared LED Signal

The second model, which is shown below, receives two signals: the frequency of an infrared LED and the frequency of sunlight.

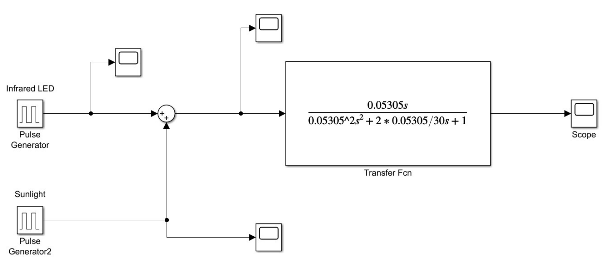

Figure 5. Model of the transfer function of a narrowband bandpass filter with two inputted signals.

The input signal of sunlight had a frequency of 10^4 Hz and a period of 10^{-4} sec.

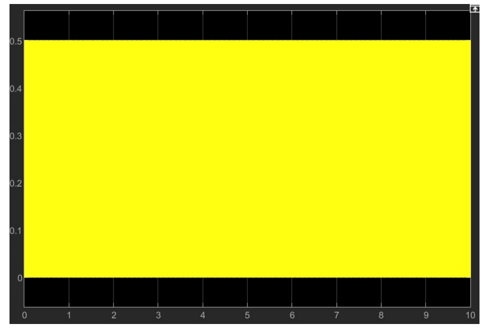

Figure 6. Plot of signal from sunlight.

The combined signal that was imputed into the transfer function is shown below.

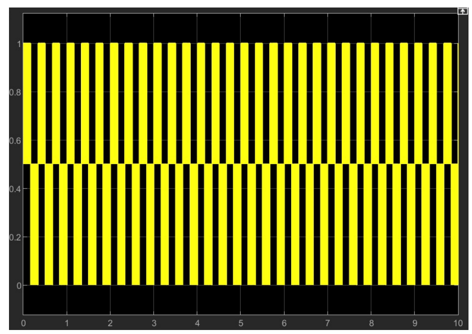

Figure 7. Combined signal of infrared LED and sunlight.

VI. Results

A. Frequency Response

The plot of the model that received just the frequency of the infrared LED is shown below.

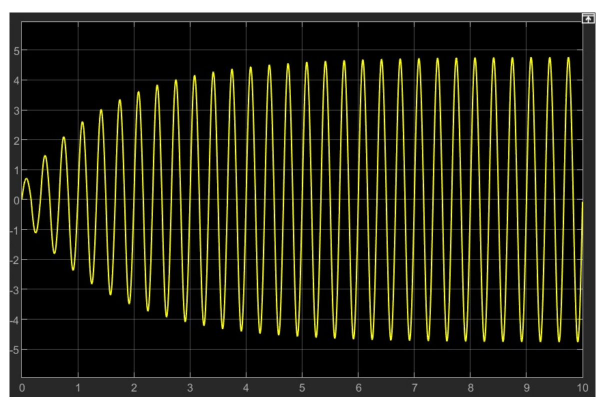

Figure 8. Frequency response of simulation with one inputted signal of 3 Hz.

The plot of the model that received both the frequency of an infrared LED and sunlight is shown below.

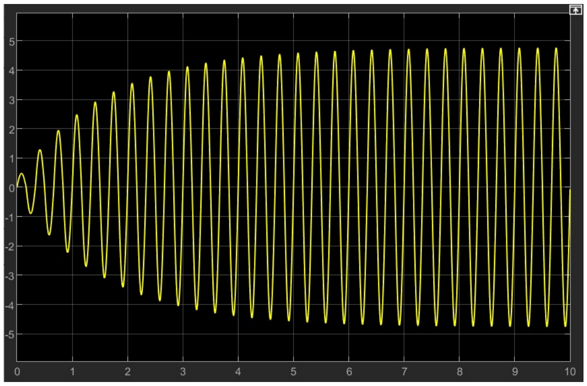

Figure 9. Frequency response of simulation with two inputted signals.

The figures show the same frequency response despite having different imputed signals. This proves the ability of the bandpass filter to filter out the undesired signals, which in our case, the non-infrared LED signals.

These are the expected graphs of the narrowband bandpass filter for an infrared LED. If the response was simulated after the square wave was no longer imputed, the graphs would eventually decrease toward 0.

B. Bode Plot

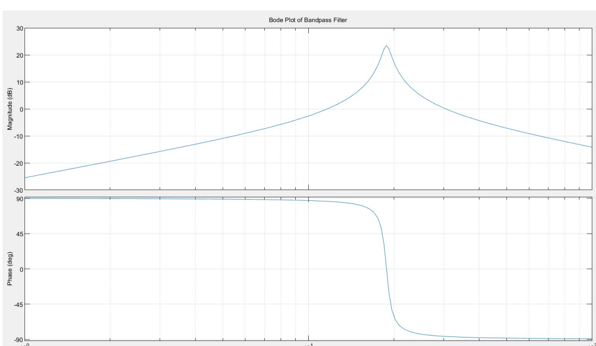

Figure 10. Bode response of narrowband bandpass filter

The bode plot shows the expected magnitude and phase response of the narrowband bandpass filter with our defined parameters and transfer function.

VII. Discussion

The plots, as seen in the previous section, describe the output of a narrow band bandpass filter to square-wave periodic signals, of infrared LED only, and both infrared LED and sunlight. The bandwidth of signal, determined by the quality factor Q, to which we have selected as 30, ensured that the filter is selective to only the frequency transmitted by the infrared switch, and ignores all other irrelevant frequencies.

From Figure 8. and 9., it is evident that the output of the system is identical to one another, meaning that our setup of the bandpass filter functioned as intended, filtering out the undesired frequency and letting the wanted frequency through to activate the adapted toys.

With the results we have gotten, and scaling the results back to match the real frequencies, the activating/threshold frequency on the comparator should be set around $440\ tHz$ for our receiver on our toy. If the captured frequency is above this threshold, meaning that the frequency outputted by the transfer function is that of the infrared LED from the switch, the toy will be activated.

VIII. References

[1] Chen, W.-L., Wagner, J., Heugel, N., Sugar, J., Lee, Y.-W., Conant, L., Malloy, M., Heffernan, J., Quirk, B., Zinos, A., Beardsley, S. A., Prost, R., & Whelan, H. T. (2020). Functional near-infrared spectroscopy and its clinical application in the field of neuroscience: Advances and future directions. Frontiers in Neuroscience, 14. https://doi.org/10.3389/fnins.2020.00724

[2] Electrical4U. (2021, April 16). Band pass filter: What is it? (Circuit, Design & Transfer Function). https://www.electrical4u.com/band-pass-filter/#google_vignette

[3] Fundamentals of IR and RF Remote Control. IR/RF recording/playback. (n.d.). https://www.laser.com/dhouston/ir-rf_fundamentals.html#:~:text=A%20typical%20Consumer%20IR%20receiver,to%20the%20same%20940nm%20wavelengthv

[4] Khoshakhlagh, A., & Gunapala, S. D. (2017). Infrared imaging: a potential powerful tool for neuroimaging and neurodiagnostics. Neurophotonics, 4(1), 011014. https://doi.org/10.1117/1.nph.4.1.011014

[5] Quality factor and bandwidth. Quality Factor and Bandwidth - Filters - Basics Electronics. (2021). https://ecstudiosystems.com/discover/textbooks/basic-electronics/filters/quality-factor-and-bandwidth/

[6] Transfer functions. Transfer Functions - Filters - Basics Electronics. (2021). https://ecstudiosystems.com/discover/textbooks/basic-electronics/filters/transfer-functions/

[7] What is a band pass filter? (2023, June 2). Collimator. https://www.collimator.ai/reference-guides/what-is-a-band-pass-filter

[8] Zhou, S., Xia, X., Gao, Y., Rong, L., Lourenco, M., & Homewood, K. (2021, August 4). A simple integratable silicon photodetector ... - wiley online library. Advanced Photonics Research. https://onlinelibrary.wiley.com/doi/10.1002/adpr.202100091