EE 2-2
2020

A Visible Light Communication System

EE214 – TERM PROJECT

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İçindekiler

Motivation

In this information era, digital communication has a crucial point in transferring messages, sensor measurements, smart home applications, i.e., any kind of data. In the case of increasing IoT devices, there is a need for a local communication channel. In this project, my purpose is to design a system that uses visible light communication channel to deliver predefined messages. This system can be applied to from smart home IOT applications to any variety of multi-casting transmission applications.

Introduction

This project consists mainly of four parts, namely, user input block, transmitter, receiver sides, and indication block. Users can deliver four types of predefined messages by push buttons, each dedicated for one message. The design supports one message at a time. After being encoded, the message is sent via a flashing LED to the receiver side. The receiver side handles the decoding of the transmitted message. A decoded message is indicated by flashing the dedicated LED for the message in indication block.

User Input Block

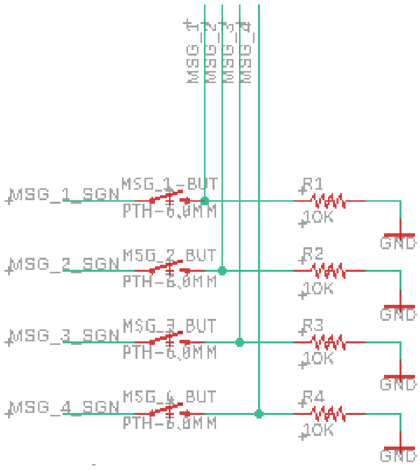


Figure 1 - User Input Block Circuit Diagram

The user input block allows the selection of the message to be delivered by push buttons. When pressed, each button establishes assigned predefined message connection, which is going to be discussed in [Message Encoding](#) section.

Pull-Down resistors are selected to be 10kΩ to prevent ending up a comparable impedance in the line. Any line of not pressed buttons is pulled down to the ground, helping the stabilizing the circuit behavior. Moreover, the effects of sparks appearing due to buttons' physical nature are inhibited by pull-down resistors.

In conclusion, we expect only one line, whose button is pressed to be activated, whereas others are pulled down to the ground.

Transmitter Block

This block has a variety of duties, like, creating carrier signals, encoding the selected message, and transmitting via the LED. Therefore, it has its subblocks, namely, square wave generators, encoding, and processing of the encoded signal, then finally transmitting the message.

Fundamental (Carrier) Square Wave Generators

The encoding of the message has been handled with a square wave with four different frequencies. Base carrier frequencies are 10 Hz, 30 Hz, 50 Hz, and 70 Hz.

The first objective is obtaining square waves. For this purpose, Op-Amp is used. The resistor and capacitor values are calculated to satisfy both frequency and accessibility in the market.

$$T = 2R_5C_1 * \ln\left(1 + \frac{2R_6}{R_7}\right)$$

An example of a 10 Hz square wave generator is shown in Figure 2.

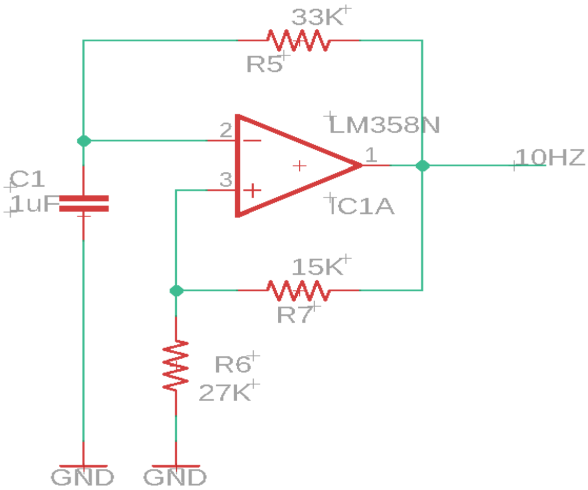


Figure 2 - Square Wave Generating Circuit Diagram

Message Encoding

The message is encoded in terms of multiple square waves with different frequencies. After obtaining square waves with four different frequencies, we mix them according to the encoding diagram, represented in Figure 3.

The encoding process is the summation of two square waves. To be more explicit, for instance, the case of message 1 is selected results in the encoded signal, which is the summation of both 10 Hz and 50 Hz square waves generated built-in.

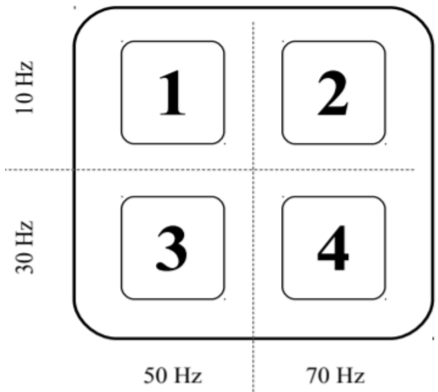


Figure 3 - The Encoding Diagram

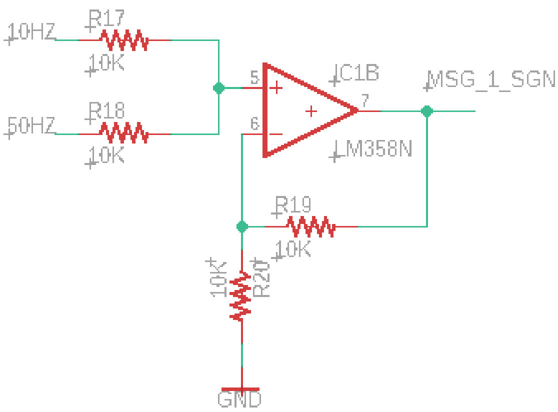


Figure 4 - Summing Op-Amp Circuit

The summing process is handled with Op-Amp. The summing combination is for non-inverting summation to obtain positive output for square waves having the same behaviors of inputs. The R_{17}/R_{18} ratio is selected to be 1 to adjust weights equally. The R_{19}/R_{20} ratio is adjusted to compensate voltage division so that we precisely get the sum with no amplification.

$$V_{out} = \left[1 + \frac{R_{19}}{R_{20}}\right]\left(\frac{R_{17} * V_1 + R_{18} * V_2}{R_{17} + R_{18}}\right) = V_1 + V_2$$

Selection of the Message

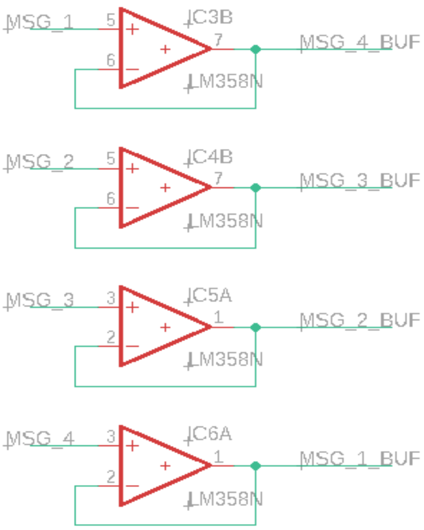


Figure 5 - Buffering the Signals

The encoded messages are forwarded to the [user input block](), where the user selects the desired message to send. After selecting the message and eliminating others, we need to buffer each for further applications. Since there are pull-down resistors each line in the user block circuit shown in Figure 1, when they connected parallelly, they may interfere without buffering.

The next process is reducing the four message lines to one transmission line. Hence, we need to buffer each message line before summing all.

Merging into One Transmission Line

In this stage, we have four message line; only one of them is carrying the encoded message. We must merge them into one transmission line to use this for further processes.

For this purpose, the non-inverting summing Op-Amp configuration, shown in Figure 6, is used. The negative feedback voltage division is adjusted to compensate for the attenuation.

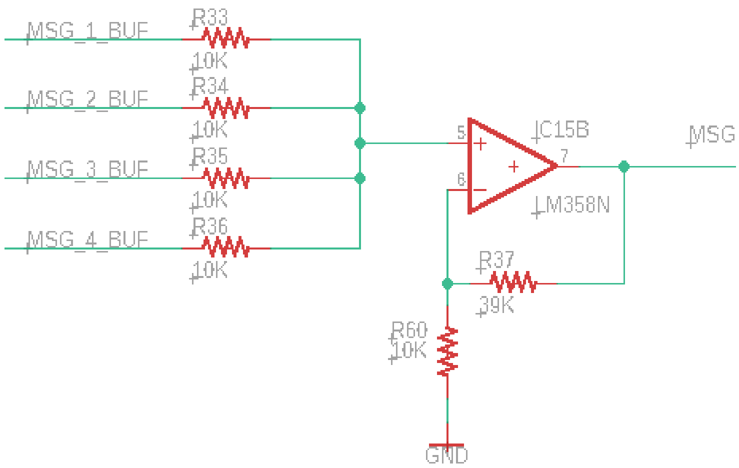


Figure 6 - The Line Reduction Process with Summing Op-Amp

Level Shifting

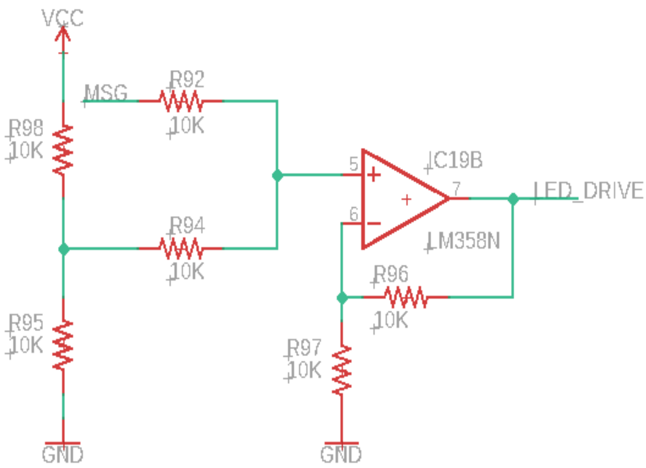


Figure 7 - Level Shifting by +Vcc/2

After combining all four messages, which only one of them selected by user input buttons, we obtain only the selected message signal, lying between $-V_{cc}$ and $+V_{cc}$ levels.

We need to remap this signal in a way that we have ON, IDLE and OFF modes for the transmitter LED. Therefore, the signal is added by $V_{cc}/_2$ so that, we have ON mode with $+V_{cc}$, IDLE mode with $+V_{cc}/2$ and OFF mode with $-V_{cc}/2$ levels.

Transmitting the Message

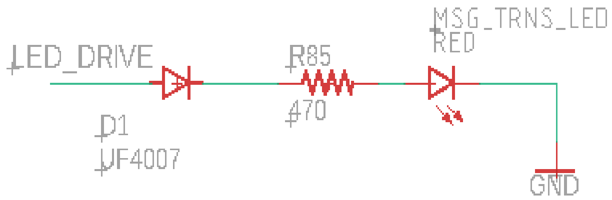


Figure 8 - Driving the Transmission LED

At the final stage of the transmitter block, we have a driving signal that has three voltage level, namely, $V_{cc}/2$, $+V_{cc}$ and $-V_{cc}/2$ to represent GND, $+V_{cc}$ and $-V_{cc}$ levels of encoded message signal, respectively.

We need a diode other than the LED to prevent the possible damage due to high reverse bias of $-V_{cc}/2$ in OFF mode. Moreover, the output of the Op-Amp has very low impedance; thus, we need a current limiting resistor in series. Also, we use a fast diode to prevent undesired behavior. UF4007 satisfies time requirements. (See Table 1, below)

ELECTRICAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)											
PARAMETER	**TEST CONDITIONS**		**SYMBOL**	**UF4001**	**UF4002**	**UF4003**	**UF4004**	**UF4005**	**UF4006**	**UF4007**	**UNIT**
Maximum instantaneous forward voltage	1.0 A		V_F (1)	1.0				1.7			V
Maximum DC reverse current at rated DC blocking voltage		T_A = 25 °C	I_R	10							μA
		T_A = 100 °C		50							
Maximum reverse recovery time	I_F = 0.5 A, I_R = 1.0 A, I_{rr} = 0.25 A		t_{rr}	50				75			ns
Typical junction capacitance	4.0 V, 1 MHz		C_J	17							pF

Note

(1) Pulse test: 300 μs pulse width, 1 % duty cycle

Table 1 - Electrical Characteristics of UF4007 fast diode

Receiver Block

The receiver block has multiple jobs, like the reception of the transmitted message via LED, filtering, then decoding.

Reception of the Message

The message transmitted via light; therefore, we need a photodetector or an equivalent system to solve the content of the signal. There are three leading possible solutions.

The first approach is using LDR to sense the light. An example of LDR based Light Detection is shown in Figure 9. However, LDR may not compensate for the timing requirements. The electrical characteristic of LDR can be found in its datasheet.

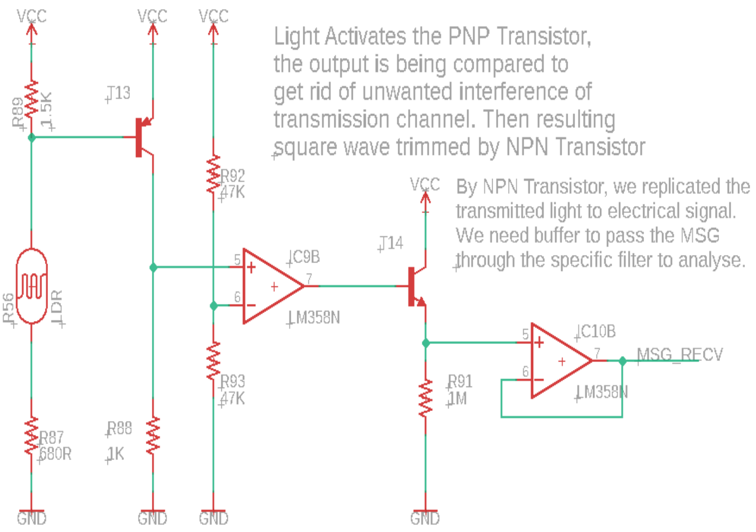


Figure 9 - LDR based Light Detection

Parameter	Conditions	Min	Typ	Max	Unit
Cell resistance	1000 LUX 10 LUX	- -	400 9	- -	Ohm K Ohm
Dark Resistance	-	-	1	-	M Ohm
Dark Capacitance	-	-	3.5	-	pF
Rise Time	1000 LUX 10 LUX	- -	2.8 18	- -	ms ms
Fall Time	1000 LUX 10 LUX	- -	48 120	- -	ms ms
Voltage AC/DC Peak		-	-	320	V max
Current		-	-	75	mA max
Power Dissipation				100	mW max
Operating		-60	-	+75	Deg. C

Figure 10 - LDR Electrical Characteristics in the Datasheet

The official datasheet used to analyze behavior can be found here. Here, we can see Rise and Fall Time in dark and bright conditions, in Figure 10.

After frequency conversion, even the maximum capacity of LDR is not enough for this data transmission system.

The second possibility is using a phototransistor. The datasheet of a phototransistor (BPW77NB) can be found here. The time and frequency behavior of BPW77NB is easily fulfilling our requirements.

BASIC CHARACTERISTICS

PARAMETER	TEST CONDITION	SYMBOL	MIN.	TYP.	MAX.	UNIT
Collector emitter breakdown voltage	$I_C = 1$ mA	$V_{(BR)CEO}$	70			V
Collector emitter dark current	$V_{CE} = 20$ V, E = 0	I_{CEO}		1	100	nA
Collector emitter capacitance	$V_{CE} = 5$ V, f = 1 MHz, E = 0	C_{CEO}		6		pF
Angle of half sensitivity		φ		± 10		deg
Wavelength of peak sensitivity		λ_p		850		nm
Range of spectral bandwidth		$\lambda_{0.1}$		450 to 1080		nm
Collector emitter saturation voltage	$E_e = 1$ mW/cm², $\lambda = 950$ nm, $I_C = 1$ mA	V_{CEsat}		0.15	0.3	V
Turn-on time	$V_S = 5$ V, $I_C = 5$ mA, $R_L = 100\ \Omega$	t_{on}		6		µs
Turn-off time	$V_S = 5$ V, $I_C = 5$ mA, $R_L = 100\ \Omega$	t_{off}		5		µs
Cut-off frequency	$V_S = 5$ V, $I_C = 5$ mA, $R_L = 100\ \Omega$	f_c		110		kHz

Figure 11 - The Characteristic of BPW77NB phototransistor

The third approach is using a photodiode. A reverse-biased photodiode passes current according to optical excitation addition to reverse drift-current. This can be used to replicate the message from incoming light stream by turning on and off. The datasheet of a photodiode (BPW34) can be found here.

BASIC CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)

PARAMETER	TEST CONDITION	SYMBOL	MIN.	TYP.	MAX.	UNIT
Breakdown voltage	I_R = 100 μA, E = 0	$V_{(BR)}$	60			V
Reverse dark current	V_R = 10 V, E = 0	I_{ro}		2	30	nA
Diode capacitance	V_R = 0 V, f = 1 MHz, E = 0	C_D		70		pF
	V_R = 3 V, f = 1 MHz, E = 0	C_D		25	40	pF
Open circuit voltage	E_e = 1 mW/cm^2, λ = 950 nm	V_o		350		mV
Temperature coefficient of V_o	E_e = 1 mW/cm^2, λ = 950 nm	TK_{Vo}		- 2.6		mV/K
Short circuit current	E_A = 1 klx	I_k		70		μA
	E_e = 1 mW/cm^2, λ = 950 nm	I_k		47		μA
Temperature coefficient of I_k	E_e = 1 mW/cm^2, λ = 950 nm	TK_{Ik}		0.1		%/K
Reverse light current	E_A = 1 klx, V_R = 5 V	I_{ra}		75		μA
	E_e = 1 mW/cm^2, λ = 950 nm, V_R = 5 V	I_{ra}	40	50		μA
Angle of half sensitivity		φ		± 65		deg
Wavelength of peak sensitivity		λ_p		900		nm
Range of spectral bandwidth		$\lambda_{0.1}$		430 to 1100		nm
Noise equivalent power	V_R = 10 V, λ = 950 nm	NEP		4 x 10^{-14}		W/√Hz
Rise time	V_R = 10 V, R_L = 1 kΩ, λ = 820 nm	t_r		100		ns
Fall time	V_R = 10 V, R_L = 1 kΩ, λ = 820 nm	t_f		100		ns

Figure 12 - The Basic Characteristics of BPW34 Photodiode

From the datasheet information above, we can conclude that BPW34 can satisfy our timing requirements. However, its reverse current is in μA level, and increasing under increasing light density, as shown in Figure 13. In conclusion, we need to amplify its effect for practical purposes. We can use Op-Amp to amplify this current effect.

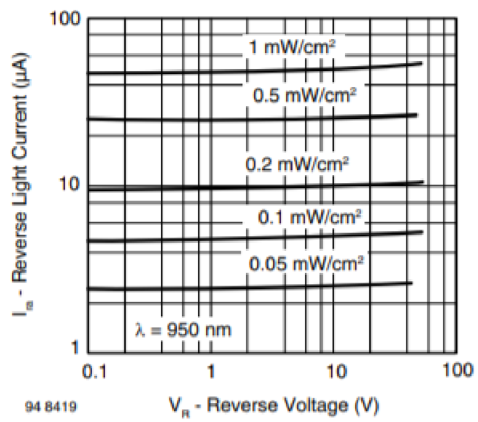


Figure 13 - Reverse Light Current under Light intensity

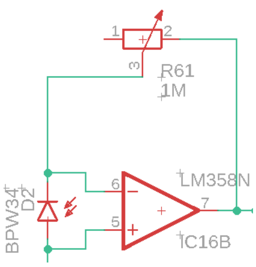
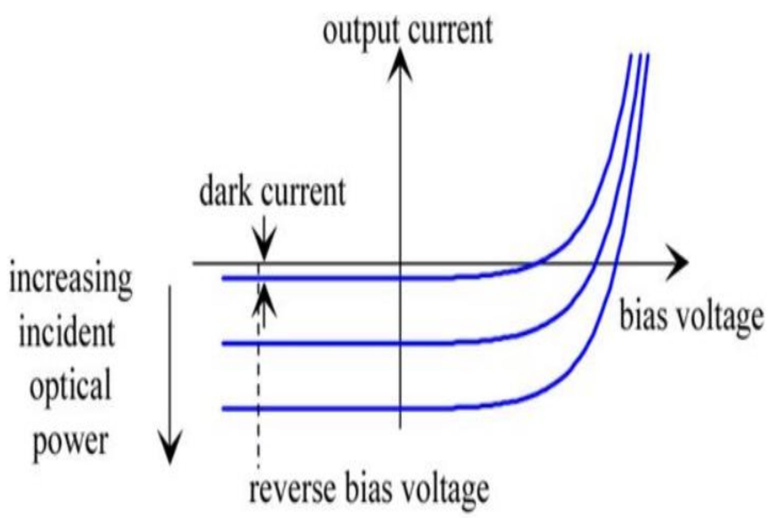


Figure 14 - Amplifying of photodiode reverse current

In Figure 14, there is a simple Op-Amp circuit to amplify the μA current effect. When the photodiode is excited, current passes through resistor and photodiode in reverse direction, creating a positive output voltage, linearly related to current. The amplification rate, i.e., sensitivity, is related with the value of the potentiometer, connected as negative feedback. Ideal potentiometer value 500 kΩ to get 5 V, under 0.2 mW/cm^2 light density, according to datasheet. However, since we use Op-Amp, it is important to be sure that it can handle the time requirements.



While designing the photodiode amplifying circuit shown in Figure 14, we use the characteristic of the reverse-biased diode, indicated in Figure 15.

Even there is no reverse voltage applied; the diode has its built-in drift current causing reverse current, which increases under optical excitation.

Figure 15 - i vs V Characteristic of Reverse Biased Diode under Optical Excitation

The planned Op-Amp is LM358. The official datasheet can be found here. The slew rate of the LM358 must satisfy the on/off timing.

Typical	Single	Dual	Quad
Slew Rate	0.4 V/μs	0.3 V/μs	0.5 V/μs
Bandwidth	0.8 MHz	0.7 MHz	1.2 MHz

Table 2 - The Slew Rate of the LM358 Op-Amp

As indicated in Table 2 above, - information in the datasheet - the slew rate is sufficient for this purpose.

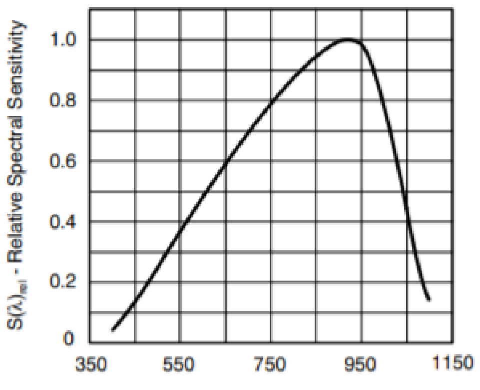


Figure 16 - Wavelength Response of BPW34

The planned component, BPW34, is suitable for visible and near infrared radiation. It successfully operates between 430 to 1100 nm wavelength bandwidth. Since it is more sensitive for higher wavelengths of visible-light-region, we use a red LED (near 800nm) for transmission.

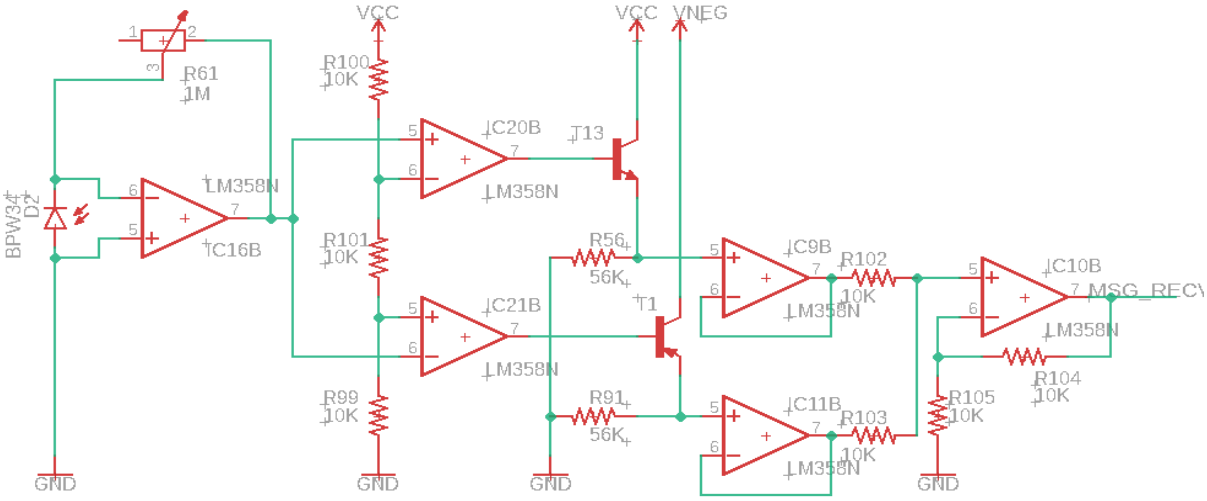


Figure 17 - Reception by using a photodiode

The final receptor circuit is shown as whole in Figure 17. By potentiometer, R61, we can adjust the sensitivity of the amplifier to avoid false triggering due to optic channel noise. The ideal setting for the sensitivity potentiometer is the way that output of the photodiode amplifier Op-Amp – IC16B - is approximately equal to $V_{cc}/2$ in idle mode. The next stage is the detection of levels to determine the $+V_{cc}, +V_{cc}/2\,, GND$ levels of ON, IDLE, OFF modes of transmitting LED. This is done by simple comparing Op-Amp configuration, using a logical information for following BJTs.

The design gives $+V_{cc}$ to the base of the NPN BJT connected to $+V_{cc}$, when the message is HIGH. Similarly, below comparator gives $-V_{cc}$ to the base of the PNP BJT connected $-V_{cc}$, when the message is LOW, i.e. OFF mode of transmitter LED. In IDLE mode, none of the comparators activates the BJTs, hence, we observe 0V representing the GND level of the original message. Please refer to Level Shifting section for clear repetition. The level information is followed by the selection of proper voltage levels to recreate the original massage waveform. After buffering, the resulting signals are added by Summing Op-Amp.

Filter Process

The square waves can be obtained by summing multiple sine waves with portioned frequencies. In other words, the square wave is the form of:

$$
\begin{aligned}
x(t) &= \frac{4}{\pi} \sum_{k=1}^{\infty} \frac{\sin(2\pi(2k-1)ft)}{2k-1} \\
&= \frac{4}{\pi}\left(\sin(\omega t) + \frac{1}{3}\sin(3\omega t) + \frac{1}{5}\sin(5\omega t) + \dots\right), \qquad \text{where } \omega = 2\pi f.
\end{aligned}
$$

Thus, because of the nature of the square wave, it has unique behavior in the frequency domain, as shown in Figure 18 below.

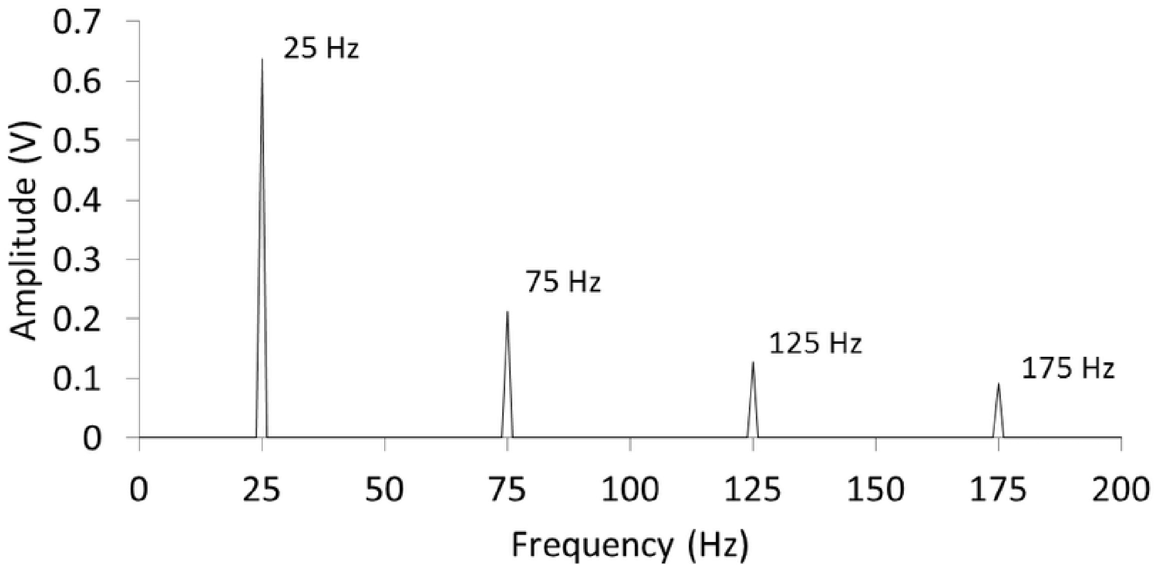


Figure 18 - An example of a square wave in the frequency domain

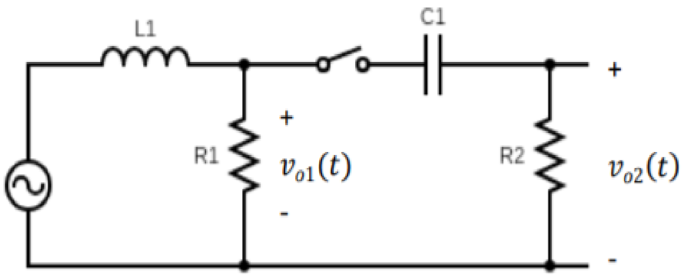


Figure 19 - Low Quality Factor RLC Band pass filter

Since it has a maximum amplitude in its carrier frequency, we can use bandpass filters with resonance frequency is equal to carrier frequencies. Moreover, the bandpass filters must have a high-quality factor, i.e., have a narrow bandwidth. There are two possible solutions for filtering: either passive or active filters. Passive bandpass filters can be constructed as one low pass and one high pass filters in series like in the Figure 19; however, it would have wider bandwidth that we do not want. Another possible passive bandpass filter can be built as an RLC bandpass filter. Depending on its structure, a higher quality factor can be obtained.

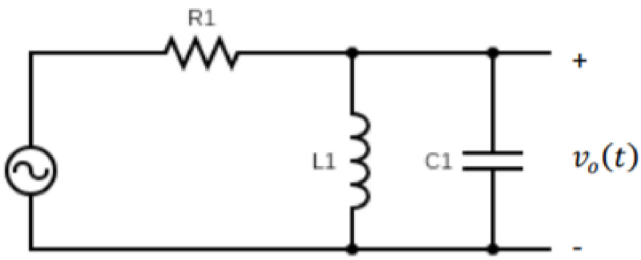


Figure 20 - High Quality Factor RLC Band Pass Filter

However, in passive filter cases, resonance frequency calculations reveal that we need very high values of inductor and capacitor.

$$\omega_0 = \frac{1}{\sqrt{LC}} \qquad f_0 = \frac{1}{2\pi\sqrt{LC}}$$

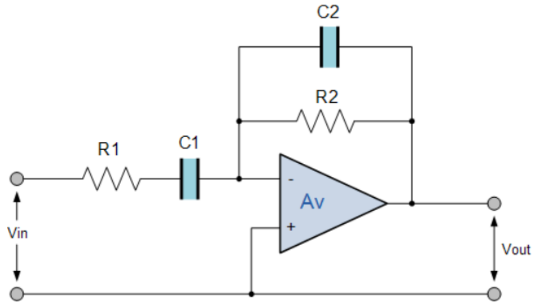
For resonance frequency of 10 Hz, we need to satisfy:

$LC = {}^{1}/_{(2\pi * 10)^2} = 253.3 * 10^{-6}$, We need minimum 16mF and 16mH

Since these inductance and capacitance values are hard to obtain, I consider using active bandpass filters instead of High-Q filters. Not using High-Q filters makes more challenging to figure out what the incoming signal consists of.

One example of an active bandpass filter is shown in Figure 21. This filter inverts the signal, nonetheless, not changing the characteristics of the signal.

The main objective is the get a regulated dc voltage from the filter, that we can use the determine whether it has specific carrier frequency.



$$Voltage\ Gain = -\frac{R_2}{R_1},\quad fc_1 = \frac{1}{2\pi R_1 C_1},\quad fc_2 = \frac{1}{2\pi R_2 C_2}$$

Figure 21 - Inverting Band Pass Filter Circuit

Another combination of an active bandpass filter is shown in Figure 22. In this combination, we can tune gain and quality factors:

$$f_r = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \qquad Q_{BP} = \frac{f_r}{BW_{(3dB)}} = \frac{1}{2}\sqrt{\frac{R_2}{R_1}}$$

$$\text{Maximum Gain, } (Av) = -\frac{R_2}{2R_1} = -2Q^2$$

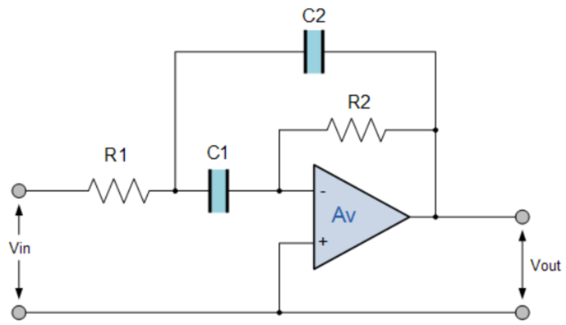


Figure 22 - Infinite Gain Multiple Feedback Active Filter

When we add a resistor Infinite Gain Multiple Feedback Bandpass filter in Figure 22, obtain adjustable gain bandpass filter, shown in Figure 23. This filter is harder to tune, hence, for clear explanations check [Transfer Function] of this filter.

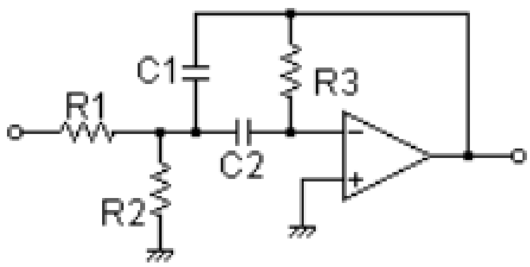


Figure 23 - Multiple Feedback Band-Pass Filter

For the output of the filters, we expect a signal that has higher V_{rms} value for the matching frequency than the case of not matching.

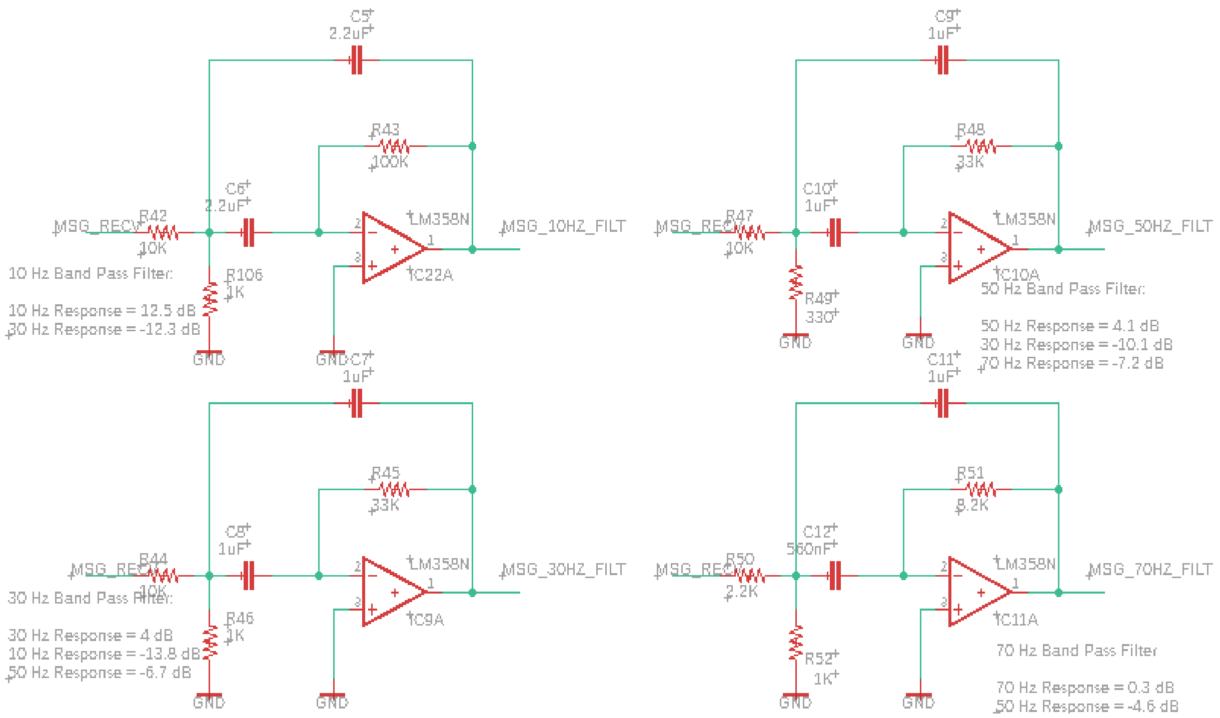


Figure 24 - The Filter Section for Different Carrier Frequencies and Their Relative Responses

The important characteristic of the filters is the attitude to the neighboring frequencies. For an example of worst-case, we need to clearly distinguish between 10 Hz + 50 Hz message and 30 Hz + 50 Hz message. Therefore, 10 Hz and 30 Hz filters should be able to separate these neighboring frequencies. The same worst-case scenario is valid for the 50 Hz and 70 Hz filters. Worst-case simulation results of each filter are shown in the Filter Simulations section. The regulated output of worst-case results is upper bounded below the level of $V_{cc}/_2 = 6\ V$ in the simulations, successfully.

Hence, we can use comparator Op-Amp to finalize the determination whether the message signal has this seeking frequency of the filter.

In Table – 3 below, responses of the filters for each base frequency are listed:

Frequencies \ Filters	10 Hz	30 Hz	50 Hz	70 Hz
10 Hz Filter	12.5 dB	-12.3 dB	---	---
30 Hz Filter	-13.8 dB	4 dB	-6.7 dB	---
50 Hz Filter	---	-10.1 dB	4.1 dB	-7.2 dB
70 Hz Filter	---	---	-4.6 dB	0.3 dB

Table 3 - Filter Responses under specific frequencies

Decoding the Message

In this phase, our purpose is to investigate the message we rebuilt by decomposing with filters. The filter outputs carrier the information of the composition of the message in terms of frequencies. However, to interpret this data we convert it to some leveling function, telling us what the V_{rms} is or any relative ratio. We can utilize regularization to convert AC signal to DC signal holding the level of a ratio of V_{rms}. Since frequencies other than around resonance frequency of the filter are attenuated, we get relatively higher V_{rms} when the message contains the resonance frequency of the filter.

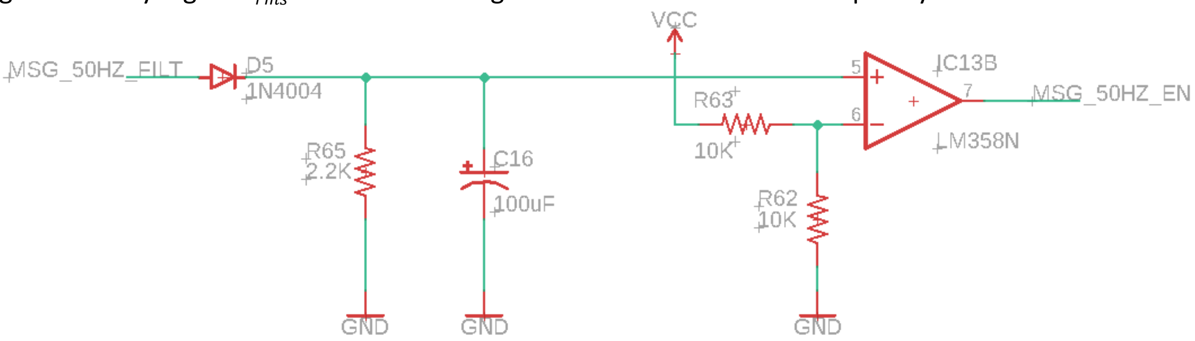


Figure 25 - Regulation and Comparison Process

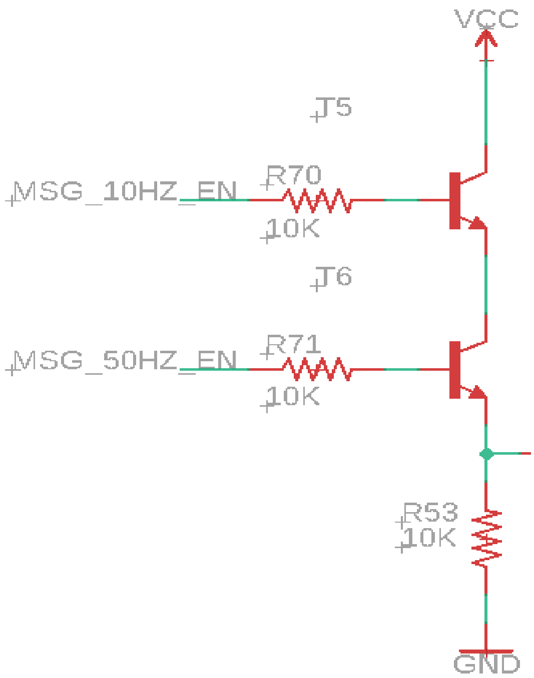


Figure 26 - The Example of Selecting the Transmitted Message

Thus, the rectifiers are adjusted accordingly, so that, we obtain $V_{DC} > V_{cc}/2$ for matching and $V_{DC} < V_{cc}/2$ for other cases. An example design is shown in Figure 25. This fact eases the determination of which carrier frequencies the signal composes of. Obtaining regulated composition information of the message, we can decode the message using NPN transistors.

The NPN Transistor combination, shown in Figure 26, is used for checking the compositions. Enabling lines, i.e., bases of the transistors, are connected to comparison Op-Amps. Therefore, solely ones having the desired message frequencies are activated. However, in this configuration, both encoding frequency check must be satisfied like AND operator. Only one message line, having both frequencies enabled, i.e. logic HIGH for AND operator, is connected to the driving line of the indicator LED. Others are pulled down to the ground by 10 kΩ resistors.

For the response time details, see Important Notes and Filter Simulation sections.

Indicator

After decoding the message, we need to indicate it via a dedicated LED for this specific message. In Figure 27, there is an LED driving circuit. Since the output of the decoding block is pulled low to GND for other messages, the protection diode other than LED is not necessary. Each message has a dedicated LED with different colors.

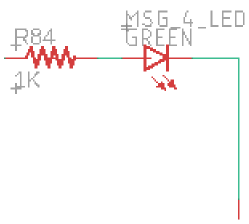
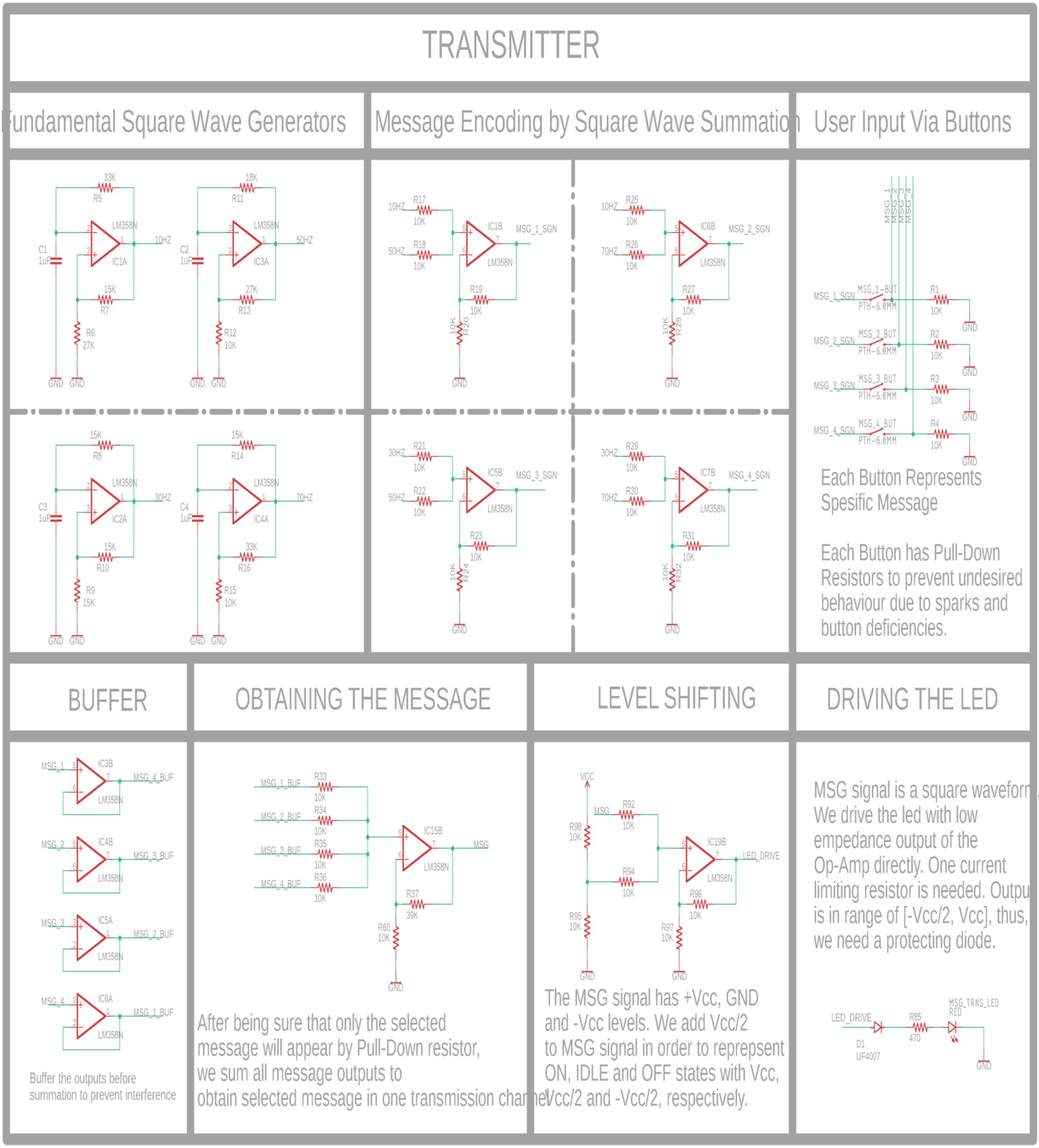
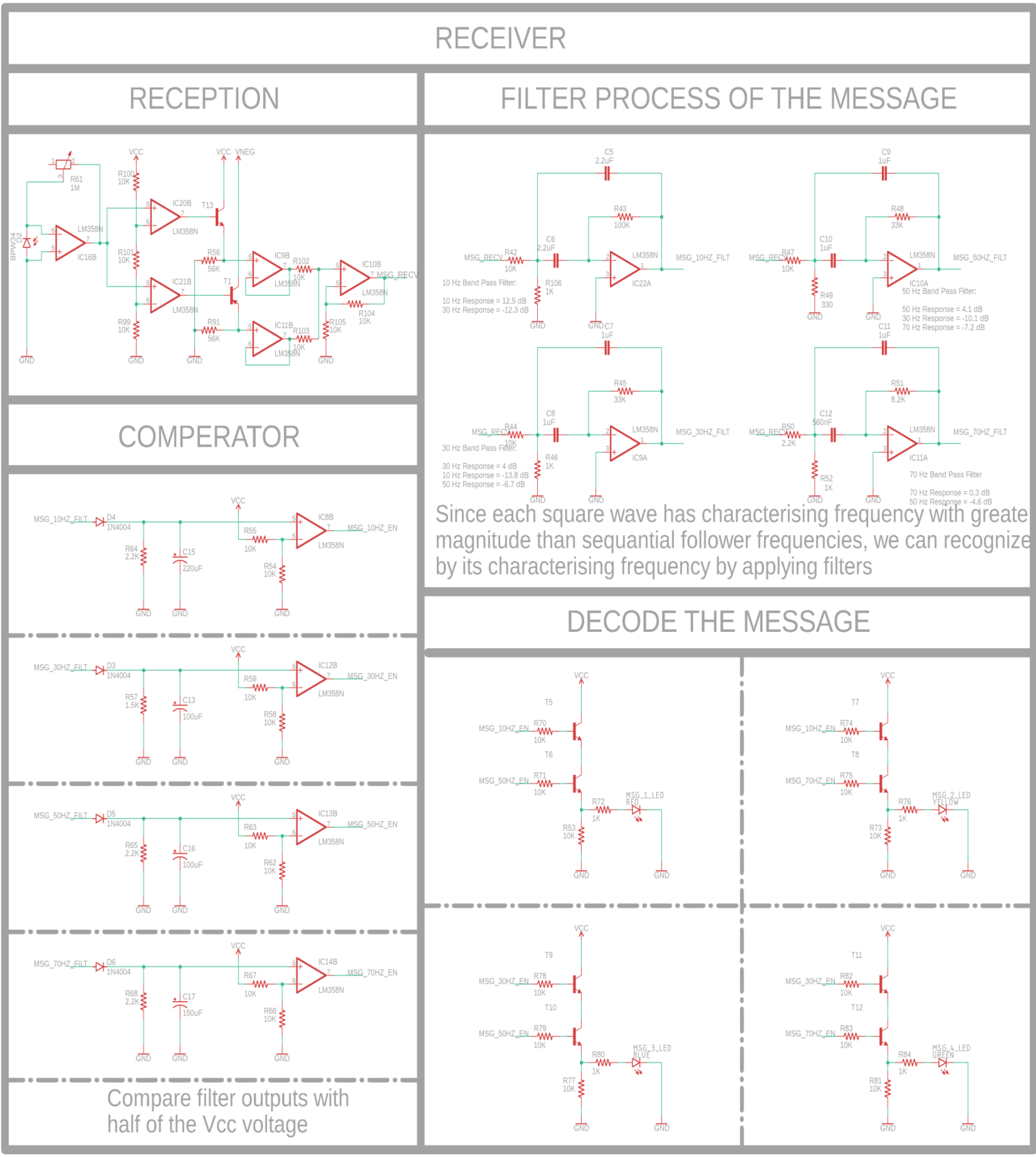


Figure 27 - Indicator

Transmitter Circuit Diagram



Receiver Circuit Diagram



Bill of Materials

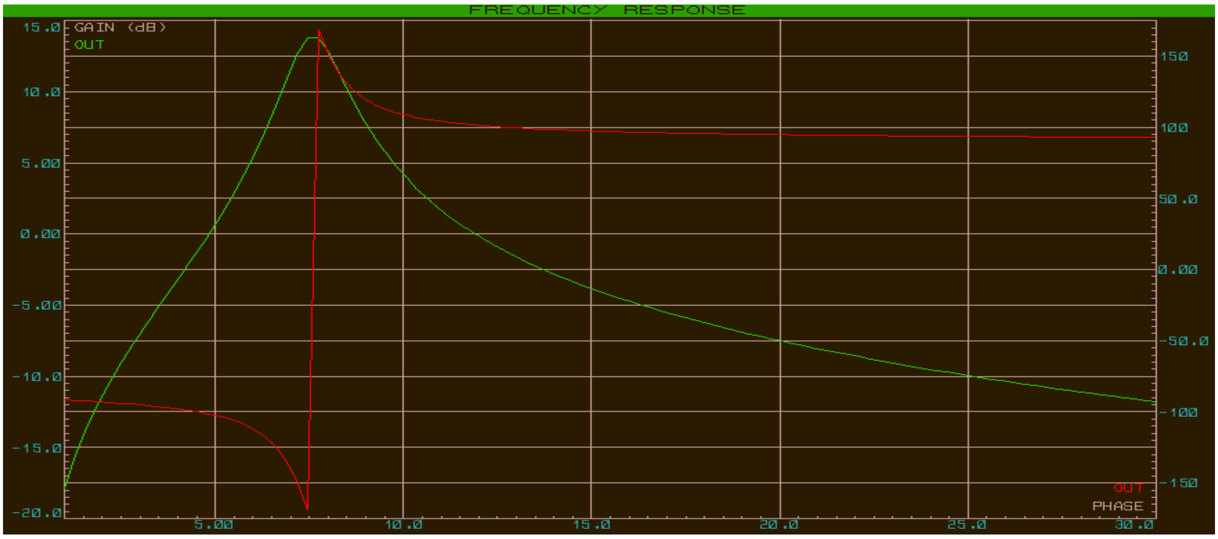
Qty	Value	Device	Parts
9	BC547	NPN-TO92-CBE	T5, T6, T7, T8, T9, T10, T11, T12, T13
1	BC557	PNP-TO92-CBE	T1
1	1.5K	R-US_0207/7	R57
1	100K	R-US_0207/7	R43
2	100uF	CPOL-USE5-10.5	C13, C16
63	10K	R-US_0207/7	R1, R2, R3, R4, R12, R15, R17, R18, R19, R20, R21, R22, R23, R24, R25, R26, R27, R28, R29, R30, R31, R32, R33, R34, R35, R36, R42, R44, R47, R53, R54, R55, R58, R59, R60, R62, R63, R66, R67, R70, R71, R73, R74, R75, R77, R78, R79, R81, R82, R83, R92, R94, R95, R96, R97, R98, R99, R100, R101, R102, R103, R104, R105
1	150uF	CPOL-USE5-10.5	C17
5	15K	R-US_0207/7	R7, R8, R9, R10, R14
1	18K	R-US_0207/7	R11
7	1K	R-US_0207/7	R46, R52, R72, R76, R80, R84, R106
1	1M	POTENTIOMETER_PT-10S	R61
4	1N4004	1N4004	D3, D4, D5, D6
9	1uF	C-EU075-052X106	C1, C2, C3, C4, C7, C8, C9, C10, C11
4	2.2K	R-US_0207/7	R50, R64, R65, R68
2	2.2uF	C-EU075-052X106	C5, C6
1	220uF	CPOL-USE5-10.5	C15
2	27K	R-US_0207/7	R6, R13
1	330	R-US_0207/7	R49
4	33K	R-US_0207/7	R5, R16, R45, R48
1	39K	R-US_0207/7	R37
1	470	R-US_0207/7	R85
1	560nF	C-EU075-052X106	C12
2	56K	R-US_0207/7	R56, R91
1	8.2K	R-US_0207/7	R51
1	BLUE	LED10MM	MSG_3_LED
1	BPW34	BPW32	D2
1	GREEN	LED10MM	MSG_4_LED
20	LM358N	LM358N*	IC1, IC2, IC3, IC4, IC5, IC6, IC7, IC8, IC9, IC10, IC11, IC12, IC13, IC14, IC15, IC16, IC19, IC20, IC21, IC22
4	PTH-6.0MM	MOMENTARY-SWITCH-SPST-PTH-6.0MM	MSG_1-BUT, MSG_2_BUT, MSG_3_BUT, MSG_4_BUT
2	RED	LED10MM	MSG_1_LED, MSG_TRNS_LED
1	UF4007	1N4148DO35-7	D1

* Each LM358 consists of two Op-Amp. # of LM358 $= \# \, of \; LM358N/2$

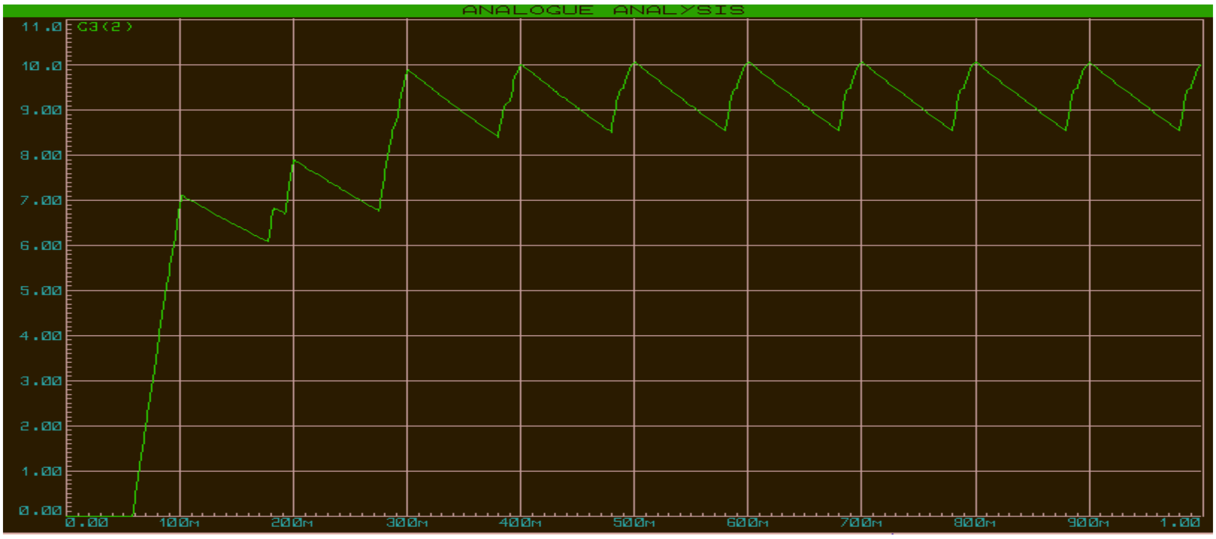
Simulations

10 Hz Filter

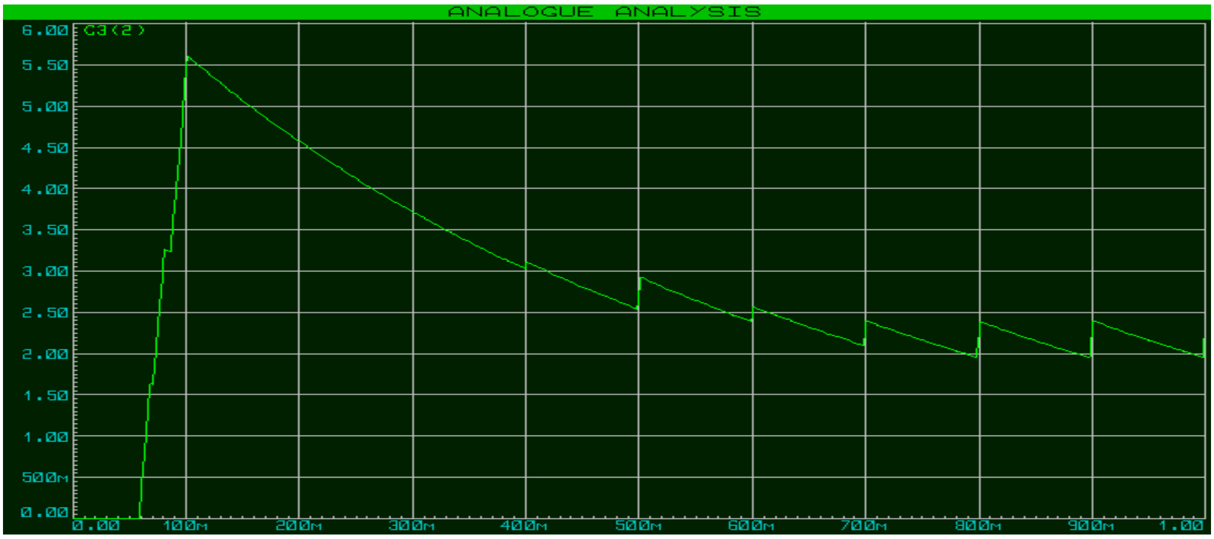
Frequency Response



Regulation Output with matching frequency

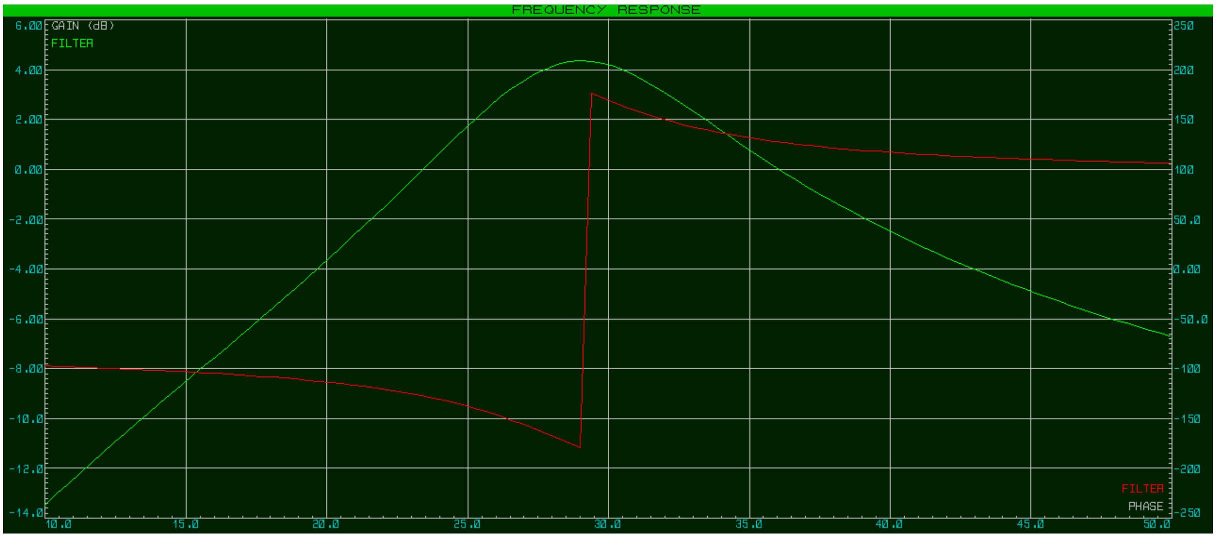


Regulation Output without matching frequency (Worst Case/ 30Hz + 50 Hz)

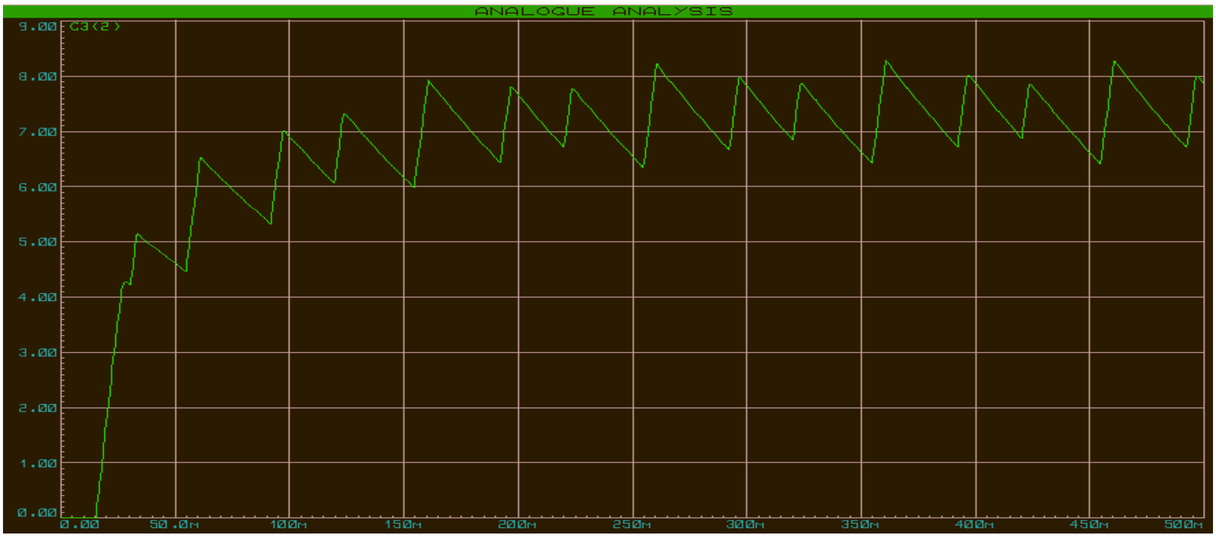


30 Hz Filter

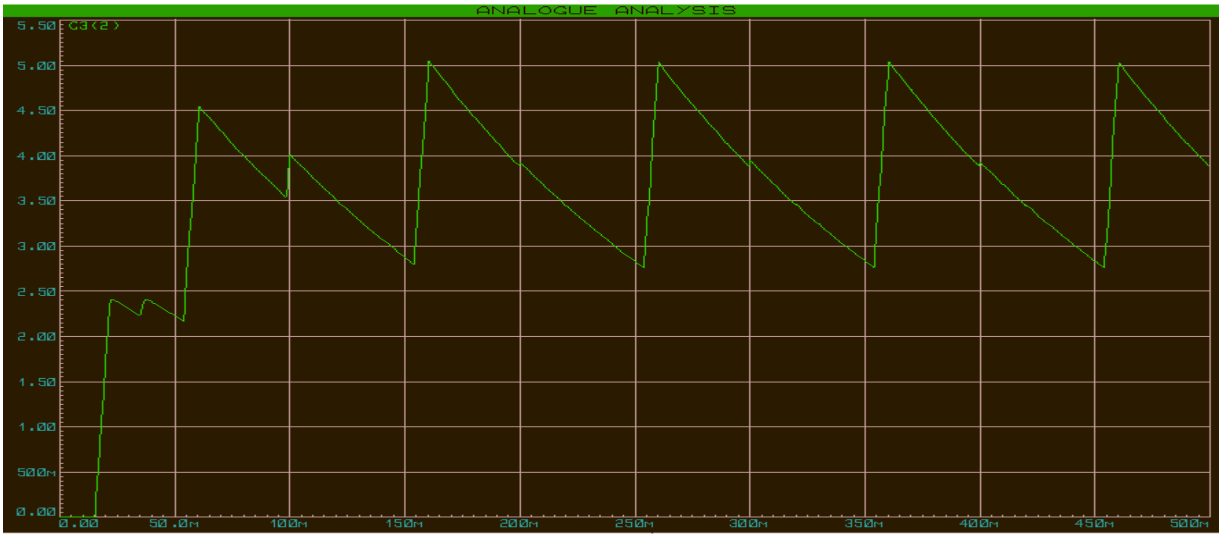
Frequency Response



Regulation Output with matching frequency

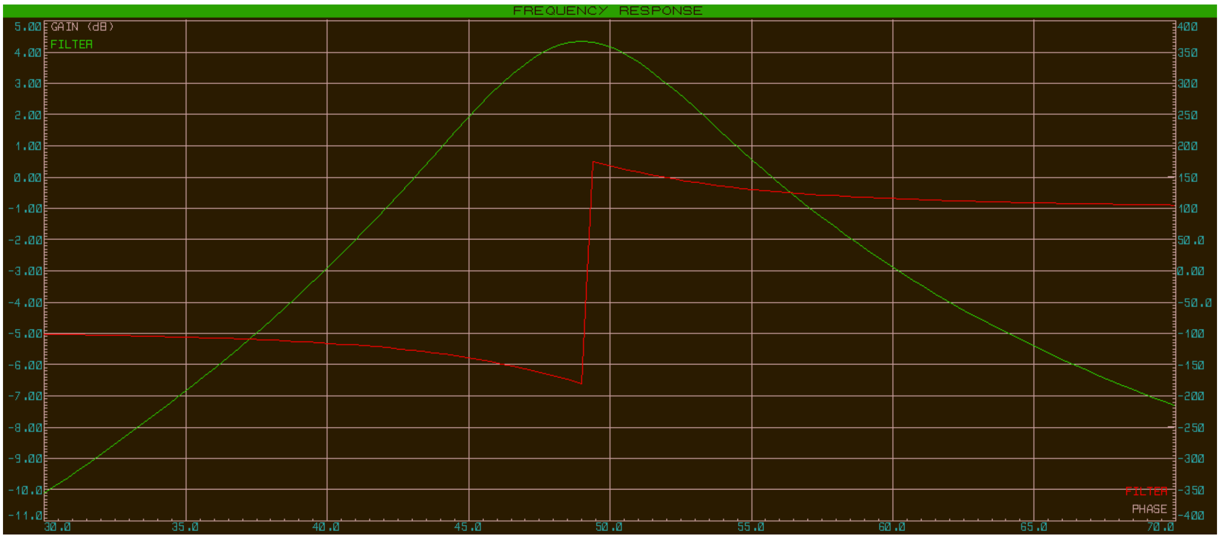


Regulation Output without matching frequency (Worst Case/ 10Hz + 50 Hz)

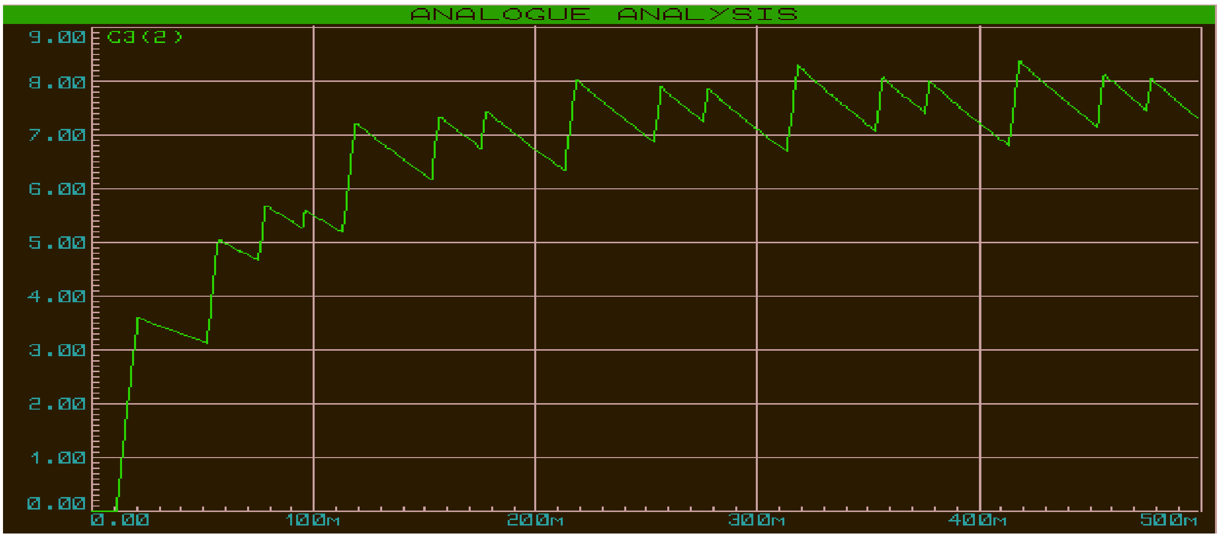


50 Hz Filter

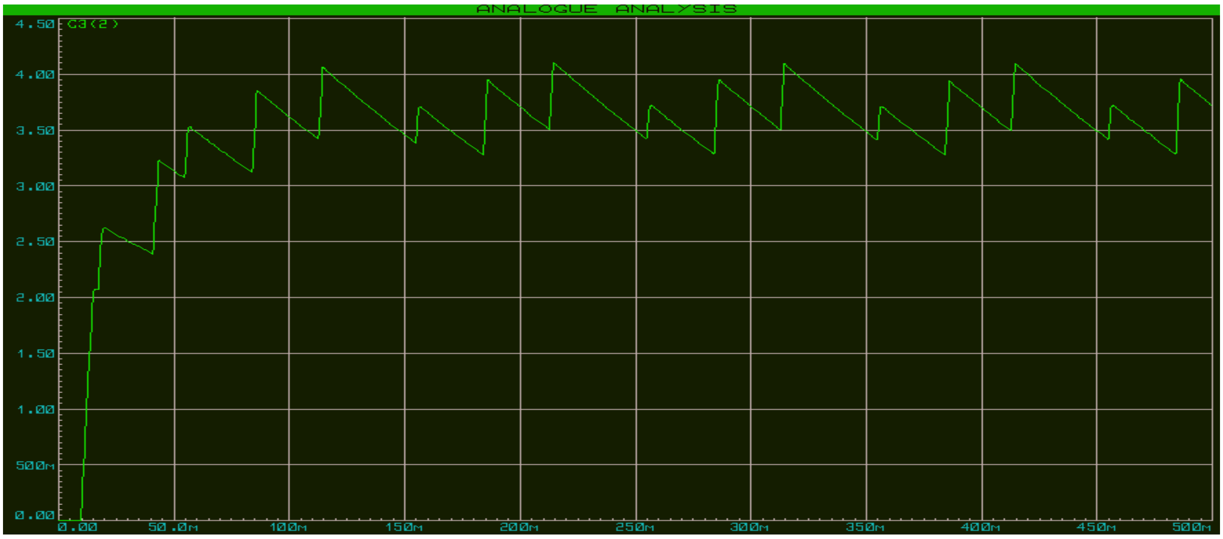
Frequency Response



Regulation Output with matching frequency

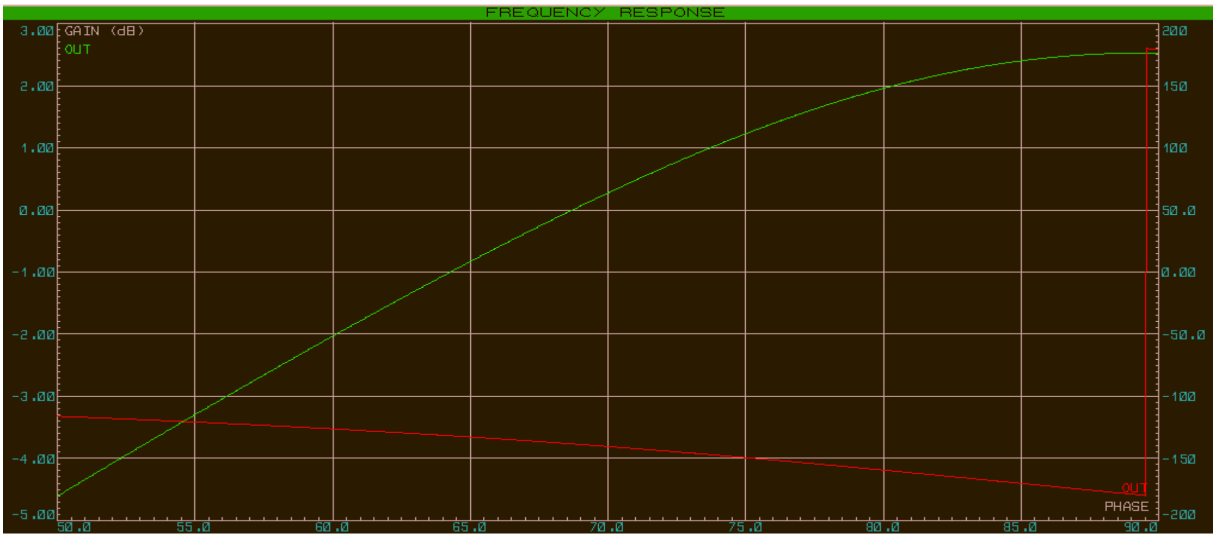


Regulation Output without matching frequency (Worst Case/ 30Hz + 70 Hz)



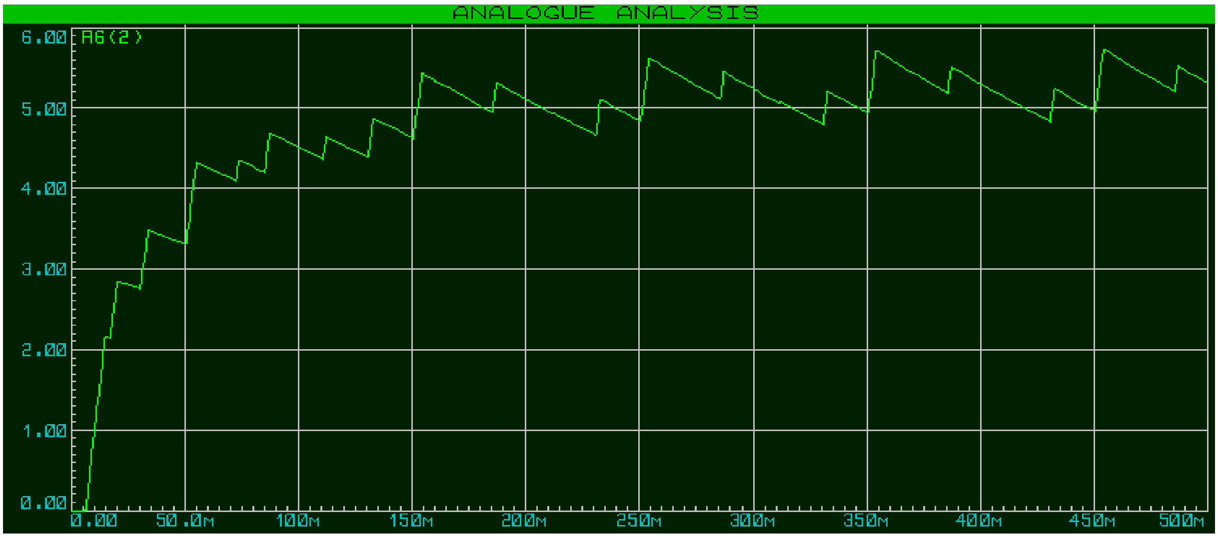
70 Hz Filter

Frequency Response



Regulation Output with matching frequency

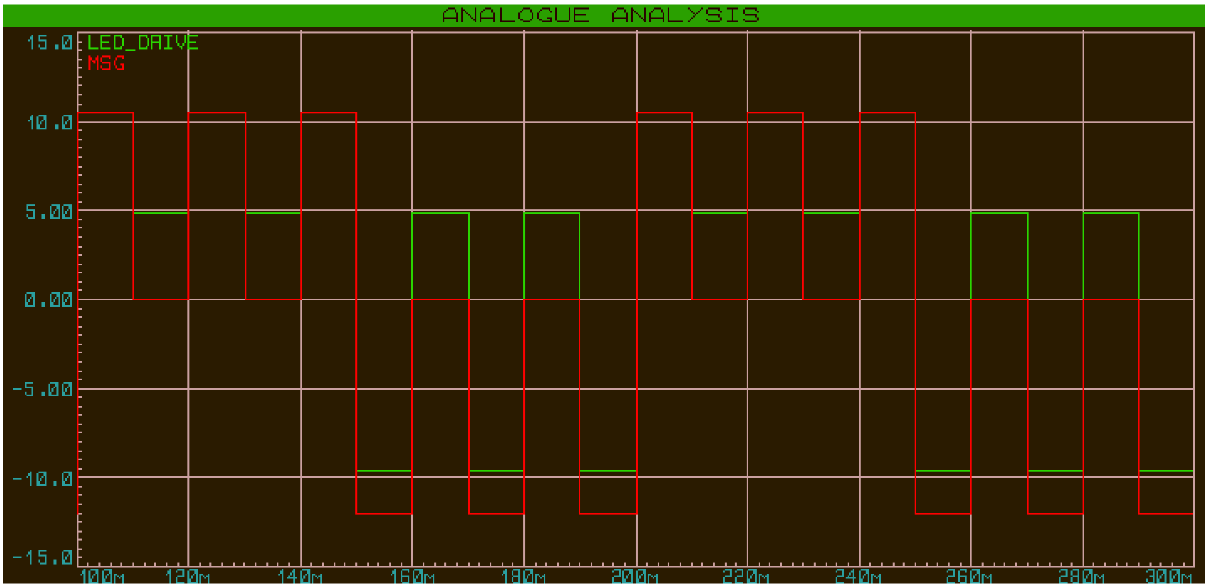
Regulation Output without matching frequency (Worst Case/ 30Hz + 50Hz)



Transmitter LED

LED DRIVE Voltage

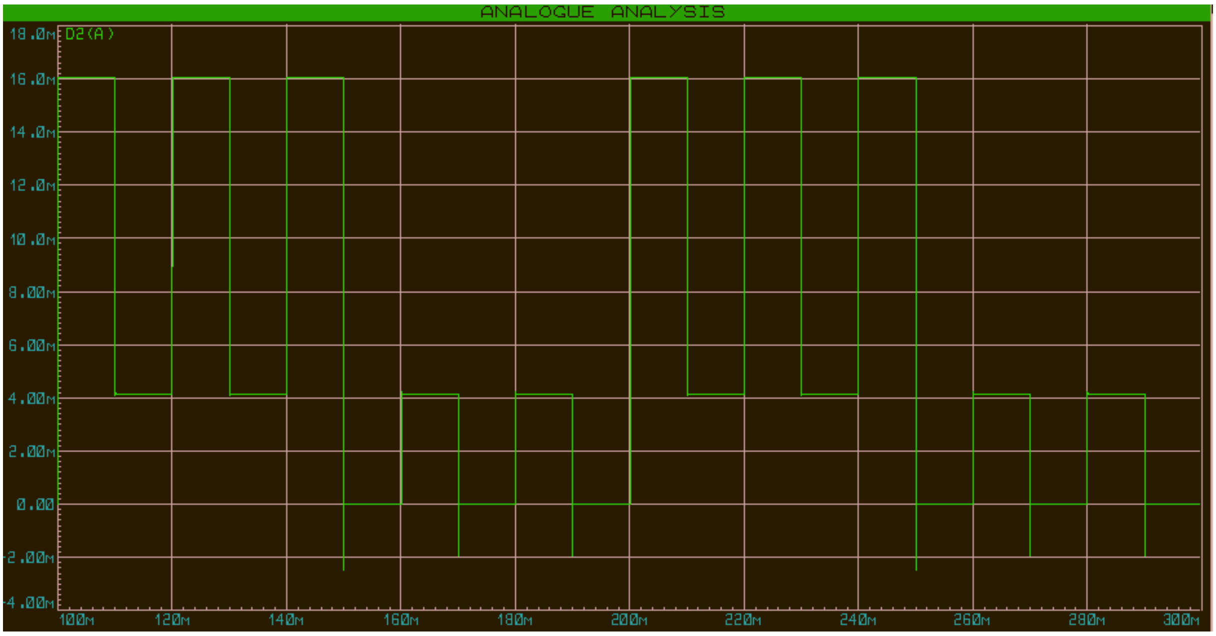
Conditions: MSG is selected to be predefined Message-1. MSG is consists of 10 Hz and 50Hz square waves, whereas the LED_DRIVE signal is defined in Level Shifting and Transmitting the Message sections.



Transmitter LED Current

ON, IDLE and OFF states are clearly distinguishable from the current passing thought the Transmitter LED.

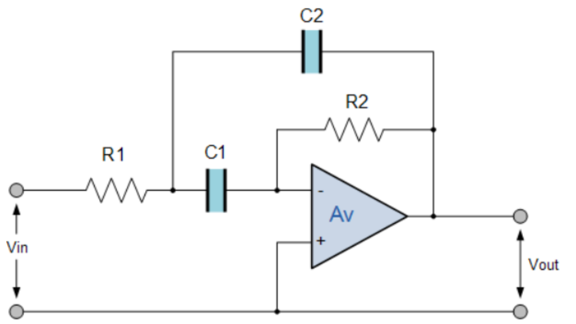
ON Mode: 16mA IDLE Mode: 4.05 mA OFF Mode: No Current



Additional Information

Transfer Functions

Infinite Gain Multiple Feedback Active Filter

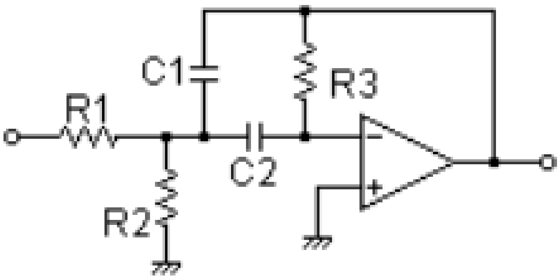


$$H(s) = \frac{-R_2 C_2 * s}{s^2(R_1 R_2 C_1 C_2) + s\,(R_1 C_1 + R_1 C_2) + 1}$$

$$f_r = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \qquad Q_{BP} = \frac{f_r}{BW_{(3dB)}} = \frac{1}{2}\sqrt{\frac{R_2}{R_1}}$$

$$\text{Maximum Gain, } (Av) = -\frac{R_2}{2R_1} = -2Q^2$$

Multiple Feedback Active Filter



$$H(s) = \frac{-\frac{1}{R1C1}s}{s^2 + s\left(\frac{1}{R3C2} + \frac{1}{R3C1}\right) + \frac{1}{R3C1C2}\left(\frac{1}{R1} + \frac{1}{R2}\right)}$$

Product Datasheets

BC547	https://www.sparkfun.com/datasheets/Components/BC546.pdf
LM358	http://www.ti.com/lit/gpn/lm358-n
BPW34	https://www.vishay.com/docs/81521/bpw34.pdf
UF4007	http://www.vishay.com/docs/88755/uf4001.pdf

Important Notes

- Typical $\pm V_{cc}$ for this design and simulations selected to be $\pm 12V$.
- All Op-Amp input and output resistors are calculated to satisfy stabile current and power performance on LM358 electrical characteristics. (* see below, Table 4).
- Pull-Down resistors are selected to reduce power consumption, while considering current noise issues in necessary cases, like Op-Amp, transistor, and diode characteristics.
- Rectifier and regulation calculations of filters are made, so that activation time is $\leq 150ms$ and recover time is $\leq 10ms$ with easily distinguishable voltage difference between on and off states.

* Selection of resistors is based on supply current and input current characteristics of LM358, stated in Table 4 below.

$V^+ = +5.0$ V, See[1], unless otherwise stated

PARAMETER		TEST CONDITIONS	LM358 MIN	LM358 TYP	LM358 MAX	LM2904 MIN	LM2904 TYP	LM2904 MAX	UNIT
Input Offset Voltage		See[2], $T_A = 25°C$		2	7		2	7	mV
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$, $T_A = 25°C$, $V_{CM} = 0$ V, See[3]		45	250		45	250	nA
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0$ V, $T_A = 25°C$		5	50		5	50	nA
Input Common-Mode Voltage Range		$V^+ = 30$ V, See[4] (LM2904, $V^+ = 26$ V), $T_A = 25°C$	0		$V^+ - 1.5$	0		$V^+ - 1.5$	V
Supply Current		Over Full Temperature Range							
		$R_L = \infty$ on All Op Amps							
		$V^+ = 30$ V (LM2904 $V^+ = 26$ V)		1	2		1	2	mA
		$V^+ = 5$ V		0.5	1.2		0.5	1.2	mA
Large Signal Voltage		$V^+ = 15$V, $T_A = 25°C$,							
Gain		$R_L \geq 2$ kΩ, (For $V_O = 1$ V to 11 V)	25	100		25	100		V/mV
Common-Mode Rejection Ratio		$T_A = 25°C$, $V_{CM} = 0$ V to $V^+ - 1.5$ V	65	85		50	70		dB
Power Supply Rejection Ratio		$V^+ = 5$ V to 30 V (LM2904, $V^+ = 5$ V to 26 V), $T_A = 25°C$	65	100		50	100		dB
Amplifier-to-Amplifier Coupling		f = 1 kHz to 20 kHz, $T_A = 25°C$ (Input Referred), See[5]		−120			−120		dB
Output Current	Source	$V_{IN}^+ = 1$ V, $V_{IN}^- = 0$ V, $V^+ = 15$ V, $V_O = 2$ V, $T_A = 25°C$	20	40		20	40		mA
	Sink	$V_{IN}^- = 1$ V, $V_{IN}^+ = 0$ V, $V^+ = 15$V, $T_A = 25°C$, $V_O = 2$ V	10	20		10	20		mA
		$V_{IN}^- = 1$ V, $V_{IN}^+ = 0$ V, $T_A = 25°C$, $V_O = 200$ mV, $V^+ = 15$ V	12	50		12	50		μA

Table 4 - Important electrical characteristics of LM358

Comments and Conclusions

This project requires understanding of semiconductors, RLC and RC filters, and searches about suitable components. It was challenging to build a system to transmit a message via visible light. Although, the transmission and reception parts are not included due to pandemic, I really liked to build - at least try my best to build, these sections to think and improve myself.

In the project, I have realized that it is going to be more challenging than I thought at the beginning of the designing process. I encountered many unexpected theoretically possible but practically harder problems. Therefore, I needed to use both my academic knowledge and trial-error while designing. Surprisingly, designing become harder that I expect when trying to find suitable components and values from the market. Since I want to build this design in real, availability is crucial for me.

The filters are hard to tune and adjust in this availability sense, due to limited choice of values and components. And I wanted to build a system that not requires much pre or runtime settings. It may reduce the applicability of the real project but I consider only one setting – "Amplification Rate" related with environment in the reception section, is sufficient for small projects.

The timing specifications of the components and the circuit itself is another important topic. All components must satisfy the changing rates and frequencies in order to proceed decently. The reaction time of the project is tuned so that we have a meaningful communication.

I think this project is carefully specified a proof-of-concept design. I learned a lot and I may use this knowledge on similar projects. I believe that I can recognize similar procedures, I needed to think, solve, and build, in other external applications. I gained an understanding of receiving and transmitting signals.