EE 316 - Electronic Design Project

Project 1
Group 3

Optical Angular Encoder

Final Project Report
11 June 2021

Objective

A component is added to the shaft assembly which name is optical angular encoder. Optical angular encoders allow the angular displacement to be converted directly into a digital form, whereby the shaft's position is determined. In this project, we have an infrared light source and a disc that rotates between us and this light source. Our goal is to estimate the position of the disc by finding the angle of light passing through the rotating disc. Thanks to our two photodedectors, which reach the light passing through the disc, we get two current sources with a phase difference of 90 degree. Then, we convert the current source to the voltage source using the transimpedance amplifier. We digitalize our sinusoidal voltage source using opamp comparator.After that, we design a logic circuit in which we use the phase difference to determine the direction. Accordingly that, we perform the counting process using the Up-Down counter and display rotation degree with direction.

Group Members

Korkut Emre Arslantürk: Shaft Design, Conversion from Light Source to Voltage Signal, Counting.

Melek Tuğçe Çüçen: Rotation, Displaying.

Berke Eren: Digitalize of Analog Signal, Counting, Limiting of Counter, Displaying.

Revision History

Week-3: We have determined the frequency value as 50 Hertz. We did the Shaft design.

Week-8: We switched to 1 Flip-flop and 2 or GATE design, instead of using 2 flip flops and XOR GATE for direction determination.

Week-12: About counting process, we decided solved the problem more simply by using an integrated 40192, which does the Up-Down difference counting instead of increasing the counters and subtracting the two from each other when counting forward and backward.

1. Introduction

1. **Current to Voltage Conversion Process:** We obtain the light coming from the invisible light source and passing through the disc as two current sources with a 90 degree phase difference between them thanks to the photodetectors. In order to perform the necessary operations in the continuation of the circuit, we need to convert the current source to the voltage source. A trans-impedance amplifier can be used for this process. In order not to affect the values of the rest of the circuit (Rtot and accordingly changing values), we can perform this operation using trans-impedance amplifier.

2. **Digitalize of Analog Signal** : We have an analog signal as a voltage. We have to digitize the analog voltage we get and integrate it into the counter process. We get a digital signal with outputs of 0 and 5 V by using Analog to digital to converter. Since we only need one bit of information, we used comparator operational amplifer as an analog to digital converter.

3. **Determining the Position and Direction of the Shaft:** Based on the difference in phase relative to each other in the currents formed on photodiodes, we determine the direction of rotation of our shaft. According to this direction, we can find its position by performing the counting process from the beginning. We decided to use an integrated that can do up-down difference counting. We proposed this idea because instead of complicating the circuit by using 4 different integrated separately for adder and substract operations, we can thus achieve it in a simpler way.

The background information for the primary technologies employed in this project is summarized in the following paragraphs.

1.1 Quadrature Encoder Principles

A quadrature encoder is an encoder with two out-of-phase output channels that is used to identify movement direction in many general automation applications. An incremental rotary encoder is another name for it. The phase relationship of one channel leading or lagging the other channel detects motion direction, and each channel has a predetermined number of evenly spaced pulses per revolution. (PPR). Quadrature encoders are used in applications such as bidirectional position length and sensing measurement. [1] This encoder measures the rotational speed and position of a rotating shaft. Optical and hall effect sensors are the most common types of sensors used in quadrature encoders. [15]

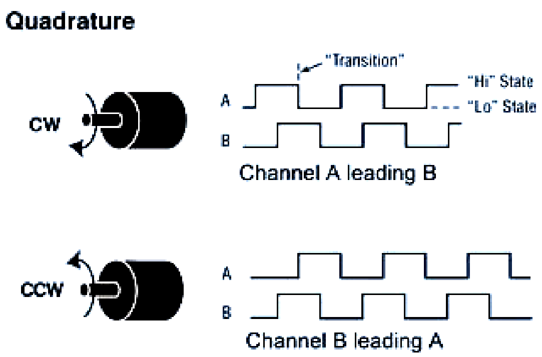


Figure 1: Quadrature encoder working principle[1]

The code disk of a quadrature encoder has two channels, which are commonly referred to as Channel A and Channel B. As seen in the picture side, these tracks or channels are coded ninety electrical degrees out of phase. In applications involving direction sensing, a controller can determine the direction of travel based on the phase relation between Channels A and B. When shown in the sample optical encoder below, the signal will display Channel A ahead of Channel B as the encoder turns clockwise, and vice versa as the quadrature encoder rotates counterclockwise. [1]

1.2 Light Source and Detection

Light-emitting diodes (LEDs) and laser diodes are two forms of light sources that are commonly employed. LEDs are less expensive and easier to use than laser diodes in general, however they have low performance. Since a laser diode can couple more light power to an optical fibre than an LED, and an LED's spectral linewidth is significantly wider than that of a laser diode, the output of an LED differs from that of a laser diode. The lower power coupling from an LED is due to the fact that LEDs emit less light power than laser diodes, as well as the fact that LED light spreads out over a wider beam.[3]

Another situation, the detector is a photodiode, which is a semiconductor device that produces an electrical current proportional to the intensity of light falling on it. Through an optical transmission system, a device that detects an optical signal produced by a light source and propagated in the environment.

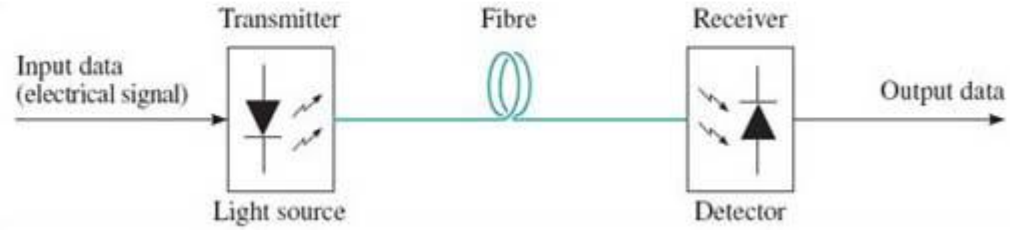


Figure 2: An optical-fibre link [3]

1.3 Trans-impedance Amplifier

A circuit component that converts an input current into an output voltage is known as a trans-impedance amplifier. Using an op-amp and a feedback resistor, the transimpedance amplifier provides an output voltage equal to the input current. The circuit's transfer function is inverted because the size of the gain is proportional to the input resistance. [4].

$$V_{out}= I_{IN}*R_F$$

A trans-impedance amplifier transforms current to voltage as a resistor does, but unlike a resistor, it has low input and output impedance, even at high gain. A transimpedance amplifier is the most significant current signal measuring instrument for light sensing operations. In the transimpedance circuit, there may be interference and noise, therefore choosing the proper amplifier boosts the effect.

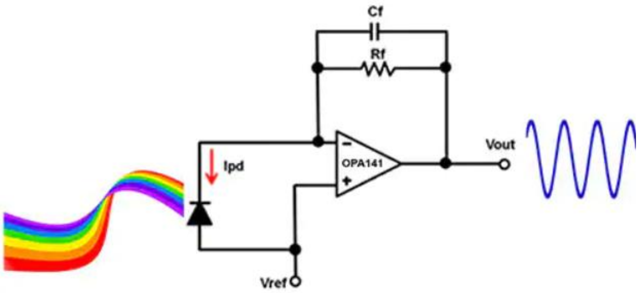


Figure 3: TransImpedance Amplifier[5]

1.4 Analog-to-Digital Converter

Analog signals can be found in a lot of natural phenomena. In nature, analog signals are endless. As a result, processing and storing these signals is difficult. Infinite signals, on the other hand, do not exist in digital signals. Analog signals, for example, have an infinite number between 1 and 3, whereas digital signals only have '2'.[8] An analog to digital converter transfers a signal from analog to digital. In other words, it converts a continuous-time signal to a discontinuous-time signal. As a result of the conversion, a little amount of inaccuracy and noise may occur. This transformation is carried out on a regular routine. [7]

Analog signals work at a continuous and infinite number of voltages, whereas digital signals work in binary. To put it another way, digital signals can only have two values: '0' or '1.' Simply said, an analog to digital converter captures an analog signal and generates digital code to represent it. The amount of bits used for this code is determined by the resolution of the ADC.[8]

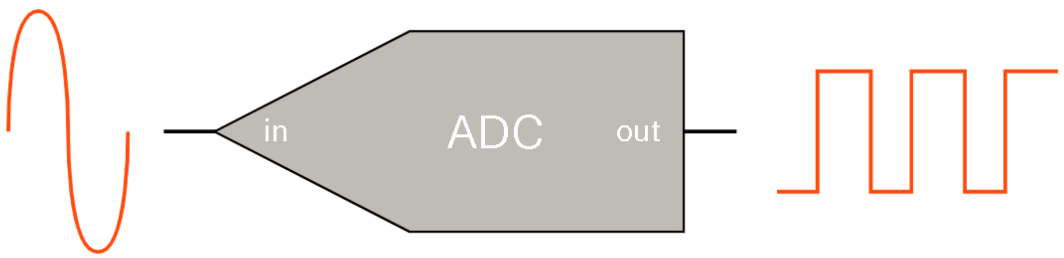


Figure 4: Analog to Digital Converter[8]

We only need 1-bit information to convert our analog signal to a digital signal, therefore instead of utilizing a complex converter, we may use a comparator operational amplifier. There are two input voltages and one binary digital output voltage in the comparator operational amplifier. The comparator operational amplifier compares two input voltages and produces a result. [7] We select a reference voltage level for one input voltage. We get digital output by comparing the reference voltage and the output of the trans-impedance amplifier. We may clear the output of the comparator from noise using the Hysteresis loop.

1.5 Counting and Displaying

Counter is a device that keeps particular processes in memory and shows how many times particular operations occur in relationship to a clock. Sequential digital logic circuits are the most common type of counters. The binary or BCD number system is represented by the values on the output lines. Increasing or decreasing the number in the counter is done by applying to the clock input. Counters are a common component in digital circuits, and they are available as separate integrated circuits as well as parts of larger integrated circuits. [13] Electronic counters may be classified as asynchronous (ripple) counters and synchronous counters. Each flip-flop in synchronous counters share a joint clock flip-flops are connected, and state is changed at the same time. On the other hand, in asynchronous counter flip-flop has its own clock and the state is changed at different times. Up/down counters are one type of synchronous counters. [16] These counters are also known as bidirectional counters. [17]

A counter circuit is often made up of a series of flip-flops linked in series. [16]

Direction of counting is important. When output A and output B of comparators come to D flip flop rotation direction is determined with helps to OR gates. For counterclockwise (CCW) direction is considered as positive and for clockwise (CW) direction it is considered negative [19].

For counting part 40192 counter circuit was used for 4-bit up down counter and 7447 was used as BCD to 7-Segment. 40192 integrated can do up-down difference counting.

Calculators, digital counters, digital clocks, measuring instruments, and other electronic devices typically employ the seven-section display. Typically, displays such as LEDs and LCDs are used to display both characters and numerical numbers.So that, we convert 4-bit output to 8 bits using 7447.[18]

2. Technical Description

Angular position is calculated according to phase difference between photodiodes A and B and according to them we do counting process clockwise rotation or counterclockwise rotation. Clockwise means rotations in the positive direction, and counterclockwise means rotations in the negative direction. Finally, we obtain the angular position to do subtraction process between two counters. We decided to use a counter component that does the up-down difference counting when counting according to the direction determination. In this way, we have achieved the result we want by using a simpler circuit without adding components for the substrate process. On the other hand, we had to limit our counter because the output we wanted to achieve was in the range of 0 and 90 degrees. When doing this limitation operation, we performed it by resetting when we see 9 in the tens digit for counting forward, when we see 9 in the tens digit and 9 in the unit’s digit for counting down.

We designed a logic circuit to determine the direction. This circuit has an output of 0 or 1 and this output determines the direction. When Logic circuit output is 1, our clockwise counter is activated and counter starts counting forward, when output is 0, our counterclockwise counter is activated, and counter starts counting down.

Also, our circuit works with logic inputs 2V and 0V these meaning 1 and 0 but we obtained a current source in our photodiodes with rays passing through the disk. Therefore, we need to convert these two current sources into voltage sources. we used the trans-impedance amplifier to perform this operation. The trans-impedance amplifier circuit we have installed, receives current as input and gives analog voltage at the desired level as output. We need to give digital inputs to Logic circuit. For this reason, we must digitalize our analog voltage using analog to digital converter.

Finally, after all the above processes, we calculated the angular position and displayed the result using the BCD-to-7 segment.

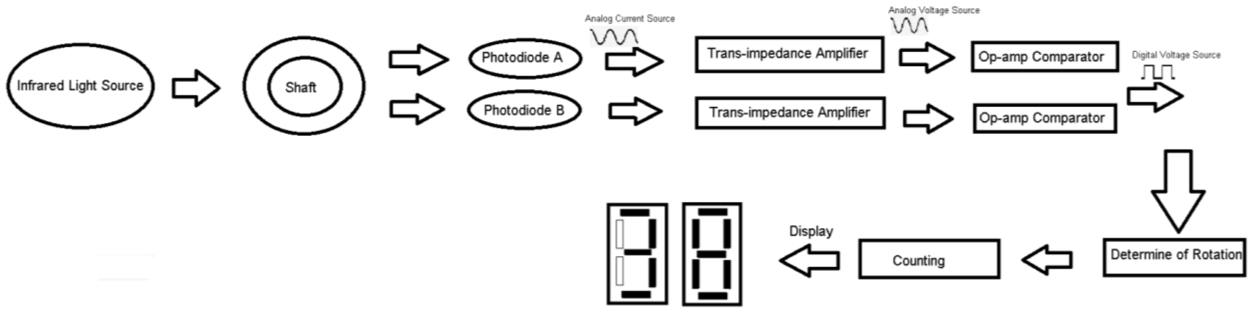


Figure 5: Block diagram of optical angular encoder design.

2.1. Conversion from Light Source to Voltage Signal

We discussed our circuit in 3 main parts. In first part we have infrared light source, 2 photodiodes and trans-impedance amplifier. There is a shaft between us and the light source that makes a rotational motion. Using 2 photodiodes, we obtain the rays passing through the shaft as two current sources with a phase difference of 90 degrees between them. Then we convert the analog current sources to the analog voltage sources using the transimpedance amplifier.

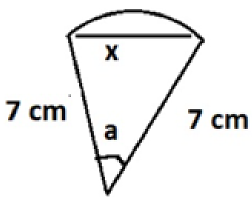
A transimpedance amplifier transforms current to voltage in the same way as a resistor does, but unlike a resistor, it has low input and output impedance, even when the gain is quite high. Stability is ensured in photodiode applications by connecting a compensating capacitor in parallel with the feedback resistor.[6]

Light Source and Detection

We use infrared light for photodiode and detectors to work compatible each other and prevent to noise from the daylight. We used TSAL6100 as a infrared light source with 940 nm peak wavelength value [9]. Also, we used two BPV10NF as photodiodes. BPV10NFA has minimum 30 µA and typical 60 µA reverse light current at 940 nm peak wavelength sensitivity and for sensitive are of the photodiodes, we can say it is recorded like 4.4mm x(5±0.15mm) [10].

Shaft Design

The number of pulses per revolution (PPR) or bits output by the encoder during one 360-degree rotation of the encoder shaft or bore is known as encoder resolution. If an encoder's resolution is insufficient, it will not send accurate feedback to the controller, and the system will not function properly. [14]. In our circuit our resolution is 8 and our clock signal is 1x. To determine frequency value we can use ratio between rpm and frequency. Revolutions per minute(Rpm) is the number of turns in one minute. We can say a normal person can turns the shaft 300 times in a minute and Servo Motor has 6000 RPM. If take them one for minimum and other one is maximum, so we can take our frequency value between 5 Hertz and 100 Hertz. We chose the frequency 50 Hertz within these limits. In addition, if we have to perform this design in real life, we can specify a radius of 7 cm.



a= 4 degree

The length of the arc = (a*x* π*7cm) = 4.88mm

The length of the gap = x = $\sqrt{6^2 + 6^2 - 2 * 6 * 6 * \cos(4)} = 4.2mm$

Current to Voltage Transform

Photodiodes produce a current in proportion to the light coming on them. During this process there is a small leakage current called Dark Current. The dark current rises as the reverse voltage across the photodiode rises. As a result, it should be lowered in order to obtain more precise values. We will transform this light beam into electricity by using the infrared BPV10NF photodetector to detect the light emitted from the light source. The low dark current is one of the reasons we chose this photodetector which is equal to 1nA [10]. The current we acquire will have little fluctuations. To use an analog digital converter, we must convert electrical power to a voltage source. To do so, we need to create a custom trans-impedance amplifier circuit. In photovoltaic mode, the trans-impedance amplifier is utilized to reduce dark current [11]. So, we connect the anode side of the photodiode to the ground. When creating a custom Trans-impedance amplifier circuit, we use LT1001 as an operational amplifier due to the need for Low Input Bias Current compared to 60 µA [11].

We connected a capacitor parallel to the feedback resistance to ensure stability at frequency. We designed the circuit as seen below. The resistance(R1) and Feedback Capacitor(C1) values were important to us when designing the circuit, the calculations are mentioned below. Because the disk is rotating, the photodiode's reverse light current is described as an oscillatory signal. By supplying a 10 V reverse voltage to the photodiode, the dark current is equal to the current on R1, which is 2nA, as expected from the datasheet [11].

Calculation

To find R_f value we can use I_{in} and V_{out} values for this calculation I_{in} equal to 0.12mA and V_{out} equal to 2V.

$$V_{out} = I_{In} * R_f \Rightarrow Rf = \frac{2Vp-p}{0.12mAp-p} = 16.66\text{KOhm}$$

Maximum value of feedback capacitor:
Fp is equal to LT1001 bandwith of typical value which is equal to $0.8\text{x}10^9$

$$C \leq \frac{1}{2*\pi*Rf*fp} \Rightarrow C \leq \frac{1}{2*\pi*16.66*0.8*10^9} \Rightarrow C \leq 11.9\text{pF}$$

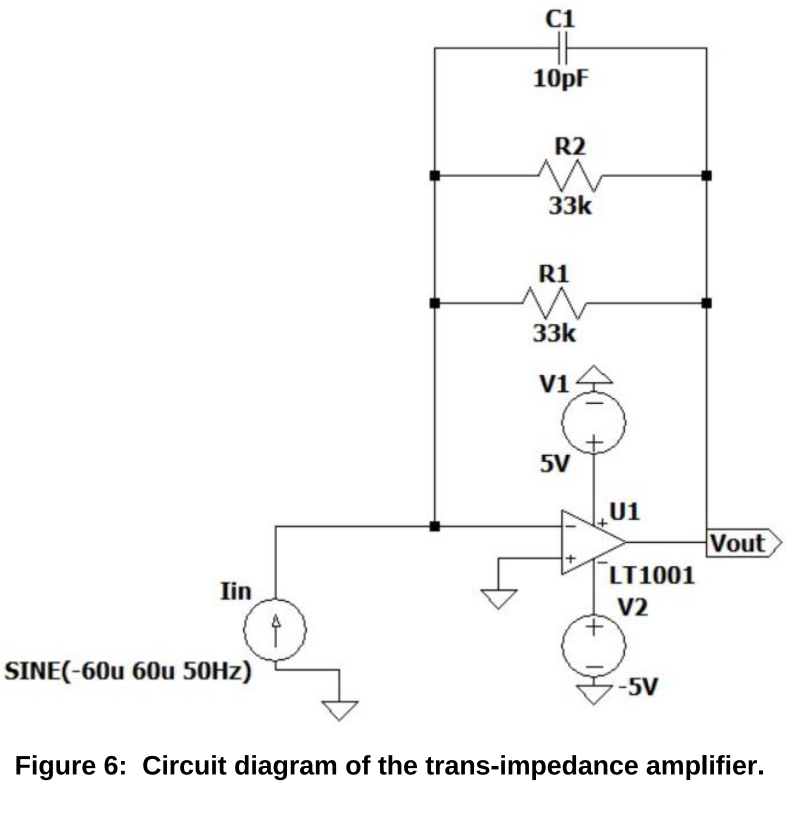


Figure 6: Circuit diagram of the trans-impedance amplifier.

Input current voltage amplitude is 60u. We gave -60u offset to switch our signal from negative cycle to positive side and change its phase by 180 degrees.

We have two current sources with a 90-degree phase difference between them. Since the only change in the circuit is the phase difference in our current source, we showed one of our circuits on schematic, calculation, and design targets.

Trans-Impedance Amplifier Design Targets			
Description of design target	**Min.**	**Max.**	**Unit**
Input High current	**-0.05**	**0.05**	**uA**
Input Low current	**-126**	**-114**	**uA**
Output Low Voltage	**-0.05**	**0.05**	**V**
Output High Voltage	**1.9**	**2.1**	**V**
Resistor	**15.827**	**17.49**	kΩ

Table 1: Design targets for trans-impedance amplifier.

2.2. Digitalize of Analog Signal

In the second part, we have comparator operational amplifier. As the output of the trans impedance amplifier, we get an analog signal. We have to digitalized our analog voltage signal because we will use logic circuits in the next parts for determine direction and counting. At this point, we just require 1-bit information when converting our analog signal to a digital signal, therefore instead of employing a complex converter, we should use a comparator operational amplifier.

There are two input voltages and one binary digital output voltage in the comparator operational amplifier. The comparator operational amplifier compares two input voltages and produces a result[7].

We choose an input voltage as the reference voltage. We get digital output by comparing the reference voltage and the output of the trans-impedance amplifier. Trans-impedance amplifiers have a range of output voltages between 0 and 2V, thus we choose our reference value is 1V. Furthermore, in the next parts, the logic circuits use 5V as logic high and 0 V as logic low.

We may clear the output of the comparator from noise using the Hysteresis loop. This hysteresis is achieved by incorporating a positive feedback loop between the output and one of the inputs, which sets the switching threshold as the input signal increases and falls. As the input signal grows, noise on the input signal might cause repeated transitions in a comparator circuit.[13] This problem can be overcome by employing two threshold voltages instead of one reference voltage. V_{TH} and V_{TL} are the two threshold voltages we have. The output receives the positive saturation voltage if the input voltage is larger than the V_{TH}. If the input voltage is between these two threshold values, the output maintains its previous value. Finally, output receives the negative saturation voltage if the input voltage is less than the V_{TL}

According to our circuit we can say resistor Rh sets the hysteresis level, Rx connect with V_{cc} and R_y connect with ground, Vth is equal to 1.05 and Vtl is equal to 0.95. This means that if input voltage is greater than 1.05 we get 0V on output and R_h is in parallel with R_y, if input voltage is less than 0.95V we get 5V on output and R_h is in parallel with R_x.

We used LT1413 as operational amplifier when setting up our comparator circuit.The function of the circuit and the necessary operations are shown below. Although we use LT1413 in our simulation circuit, it should be used LM393 operational amplifier when it is desired to set up this circuit in a laboratory environment. Since it has an open collector output, we have to use pull-up resistor. Pull-up resistors are employed in electrical circuits to guarantee that the inputs of logic systems remain at the expected logic levels when externally attached devices are unplugged. Pull-up resistors can also be employed at the interfaces of several sorts of logic devices.[20]

Calculation

To design hysteresis loop comparator:

Vin = $2V_{p-p}$ so V_h =1.05V V_l=0.95V

$$\frac{Rh}{Rx} = \frac{Vl}{Vh - Vl} = \frac{0.95}{1.05 - 0.95} = 9.5$$

$$\frac{Ry}{Rx} = \frac{Vl}{Vcc - Vh} = \frac{0.95}{5 - 1.05} = 0.241$$

$$Ry = 0.241Rx \qquad Rh = 9.5Rx$$

Let Rx =100KΩ Ry = 24.1KΩ Rh = 950KΩ

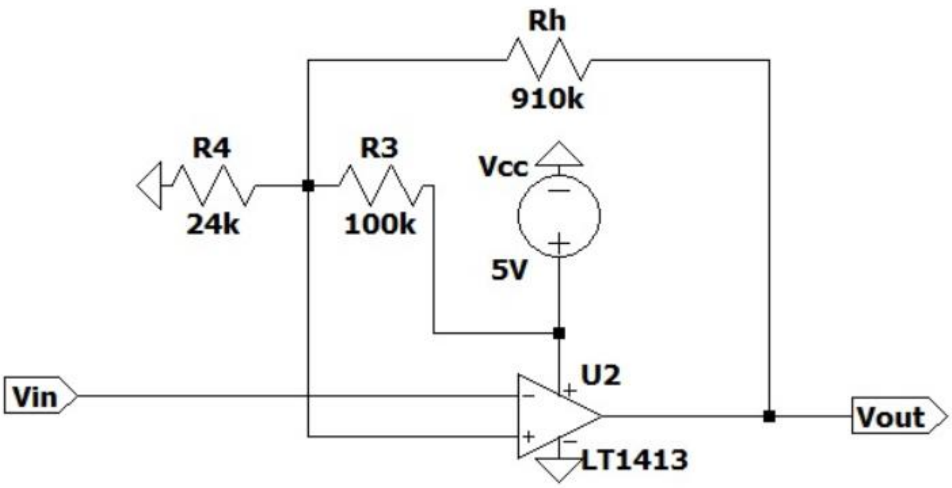


Figure 7: Circuit diagram of the comparator operational amplifier.

Comparator Operational Amplifier Design Targets			
Description of design target	**Min.**	**Max.**	**Unit**
Output Low Voltage	**0**	**0.05**	**V**
Output High Voltage	**4.75**	**5.25**	**V**
Threshold Low Voltage	**0.9025**	**0.9975**	**V**
Threshold High Voltage	**0.9975**	**1.1025**	**V**
Duty Cycle	**47.5**	**52.5**	%

Table 2: Design targets for comparator operational amplifier.

2.3. Counter

Detection of Direction and Counting

Our shaft can rotate clockwise or counterclockwise. We have to take this into account when we do the counting process, so we perform direction determination.

When Channel A leads Channel B, we need to do a clockwise counting operation, that is, the counter increases in a positive direction. When channel B leads channel A, we perform counting in the counterclockwise direction, that is, the counter decreases in the negative direction.

To determine the direction, we use a D type flipflop and two OR gates. In our design, we assigned channel A as a clock signal while giving B channel as a D input for flipflop.

In the direction of Clockwise, the Q output of our Flip Flop is 0. On the other hand, in the direction of counterclockwise, our Q output is 1. To explain this, in the direction of clockwise our Q output gives 0 because Channel B (D input) is low (0) in the rising edges of our channel A(clock).

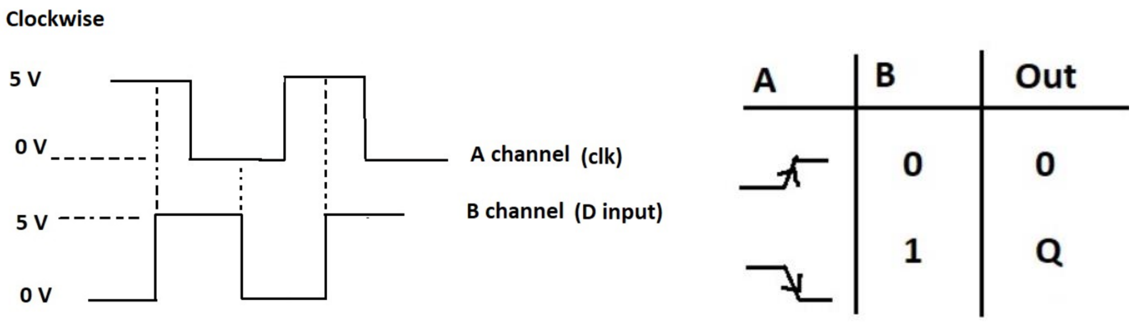


Figure 8: Clockwise Direction Table

On the other hand, in the direction of counterclockwise, during the rising edges of our channel A , our value Q is 1,since our channel B is 1.

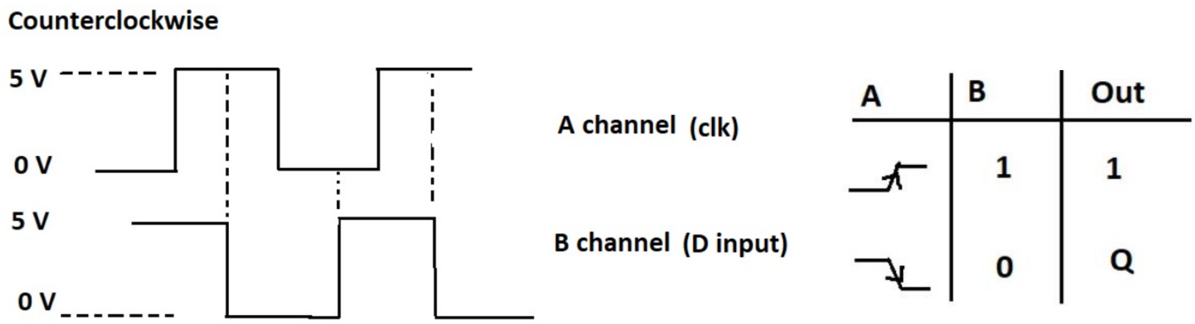


Figure 9: Counterclockwise Direction Table

To perform the counting process, we need to give input to 40192 integrated. After that, we will use the negative direction expressions for counterclockwise, positive direction for the clockwise direction when describing the counting process of the project.

When counting in the positive direction, count up input becomes a clock signal, while count down input becomes 1. In order to get the clock signal as Count Up input, we insert the Q output of the flip flop into the OR gate with channel A. Because of the operating principle of the OR gate and the Q output of the flip flop is 0, The Count Up input depends on the A Channel. In order to get 1 as Count Down input, we insert the Q’ output of the flip flop into the OR gate with channel B. Since Q ' is equal to 1, the result from OR gate is 1 under all conditions.

When counting in a negative direction, count up input becomes 1, and count down input becomes a clock signal. In order to get 1 as Count Up input, we insert the Q output with channel A into the OR gate. Since output Q is equal to 1, we get 1 output under all conditions. In order to get the clock as Count Down input, we use B channel and Q’ output. Since Q ' output is 0, we get B channel as clock.

We used two counters in our design. One of them is for units digit, one for tens digit.

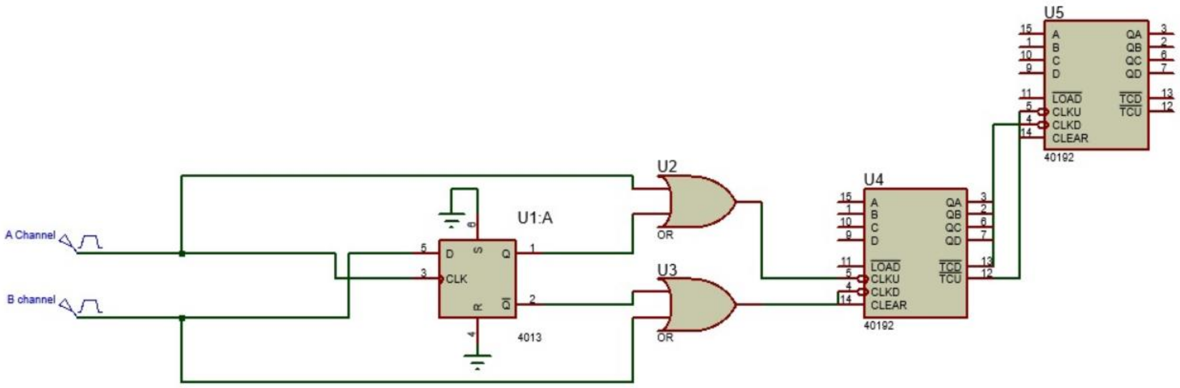


Figure 10: Determine Rotation Circuit

Limiting and Displaying

We use two counters, so that our circuit counts from 0 to 99, but we have to limit our circuit to 90 to determine the angular location of our shaft because our resolution 4. First, we need to reset when we see 9 in the tens digit to avoid counting after 90.

When doing this limitation, we put outputs B and C coming out of the meter in the NOT gate, and then put them in the AND gate along with the other outputs of the same counter.

In order to limit the count forward, we entered the result of the AND gate in a new AND gate with the Q output from the flip flop and we gave result to load and clear inputs of counter.

When counting down, we entered the result of the AND gate with flipflop output Q into the OR gate and we entered the result to the load and clear of counter. Also, when counting down the counter will start from 99, we bring a number of load inputs to 90 by resetting when it is 9, that is, in the case of 1001.

In order to use the Q output of the Flip flop and the output from the limiting circuit again in the OR and AND gates, we applied masking.

Truth Table of Limiting				
A	B	C	D	Output
0	0	0	0	0
0	0	0	1	0
0	0	1	0	0
0	0	1	1	0
0	1	0	0	0
0	1	0	1	0
0	1	1	0	0
0	1	1	1	0
1	0	0	0	0
1	0	0	1	1

Table 3: Truth Table of Limiting

Karnaugh-Map of Limiting				
AB/CD	00	01	11	10
00	0	0	0	0
01	0	0	0	0
11	0	0	0	0
10	0	1	0	0

Table 4: Karnaugh-Map of Limiting

Function of limiting ➔ A.B'.C'.D

Instead of directly displaying our 4-bit output from the counter, we converted the 4-bit information to 8 bits by using the integrated 7447. We suppressed this with 7 segments anode. In real life, we used resistance when displaying 7 segments to avoid damaging the BCD anode integration. We have calculated resistance values that we would use between 7447 and BCD by using forward voltage, forward current values and 5V power that we give for 7 Segment BCD operation in the TDSO5150 integration. We did this to make our circuit integrate into real life.

Resistor values had calculated as 130Ω by R = (Vcc-Vf / If) where VCC is the source voltage, Vf is the forward voltage drop across LED and If is the current through the resistor.

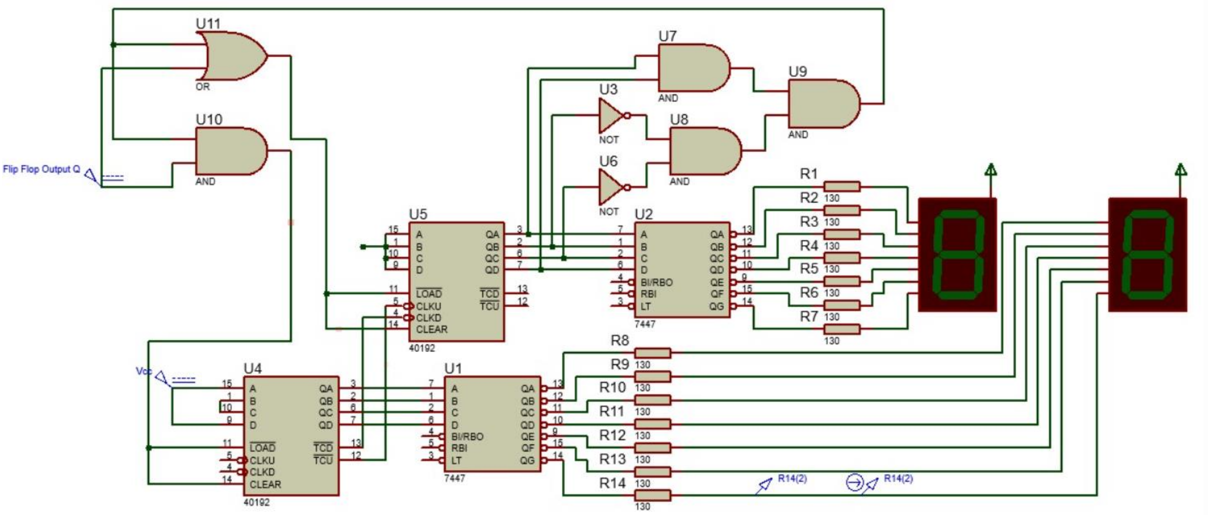


Figure 11: Counting and Displaying Circuit

Display Design Targets			
Description of design target	**Min.**	**Max.**	**Unit**
Forward Voltage	**2.28**	**2.52**	**V**
Segment of current (If)	**19**	**21**	**mA**
Resistors between 7447 and 7 segment BCD	**123.5**	**136.5**	**Ω**

Table 5: Design targets for comparator operational amplifier.

3. Test Results

3.1. Conversion From Light Source to Voltage Signal Test Results

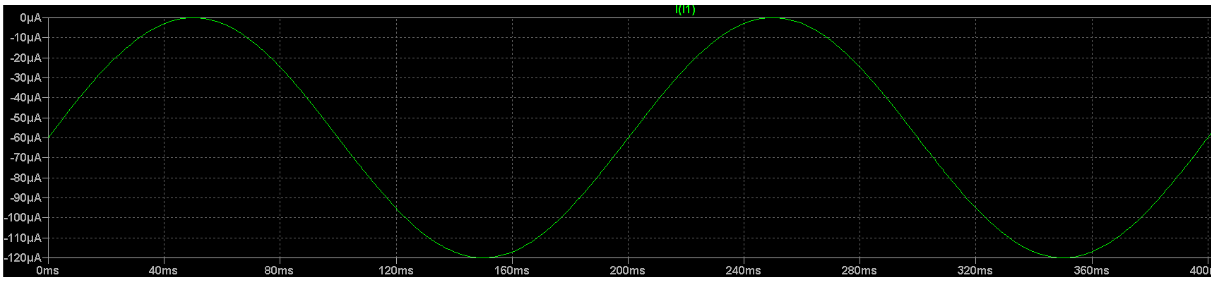


Figure 12: Current Input of Trans-impedance Amplifier

In this figure we can see input current source which generated 5 Hertz,0-2A sinusoidal signal.

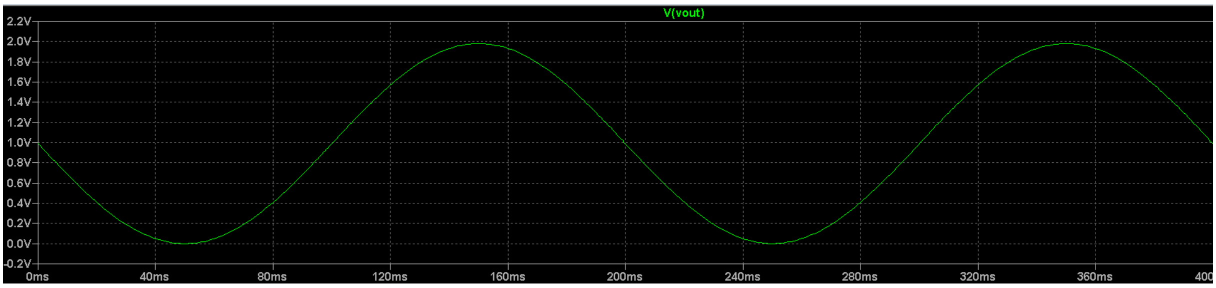


Figure 13: Output Voltage of Trans-impedance Amplifier

In this figure we can see output voltage which generated 5 Hertz,0-2V sinusoidal signal.

Trans-Impedance Amplifier Test Results				
Design target	**Measured value**	**Calculated Value**	**Unit**	**%Error**
Input High Current	**-0.025**	**0**	**uA**	**0.025**
Input Low Current	**-119.97**	**-120**	**uA**	**0.025**
Output Low Voltage	**1.78**	**0**	**mV**	**0.0178**
Output High Voltage	**1.98**	**2**	**V**	**1**
Resistor	**16.5**	**16.66**	**kΩ**	**0.96**

Table 6: Test results for Trans-Impedance Amplifier.

We have to use standard resistor values which is the closest desired value according to calculation. We can say we are in %5 acceptable error range for every target. We have little bit error because of difference between calculated resistor values between standard resistor values.

3.2. Digitalize of Analog Signal Test Results

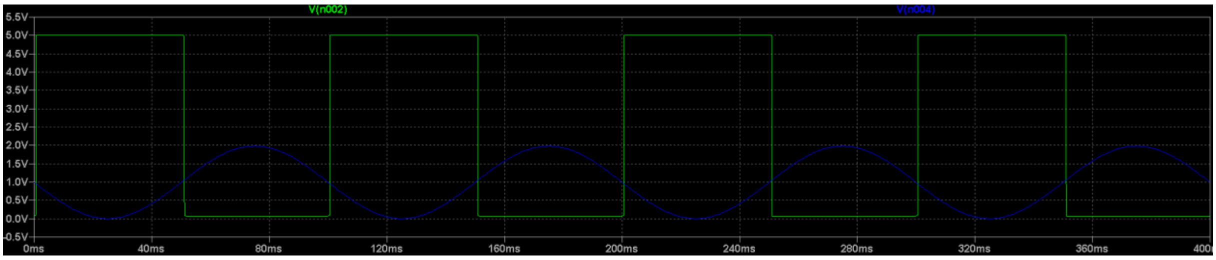


Figure 14: Output Voltage of Comparator Operational Amplifier

In this figure we can see output voltage which generated 0-5V digital signal in green label and input voltage which generated 5 Hertz 0-2V analog signal in blue label.

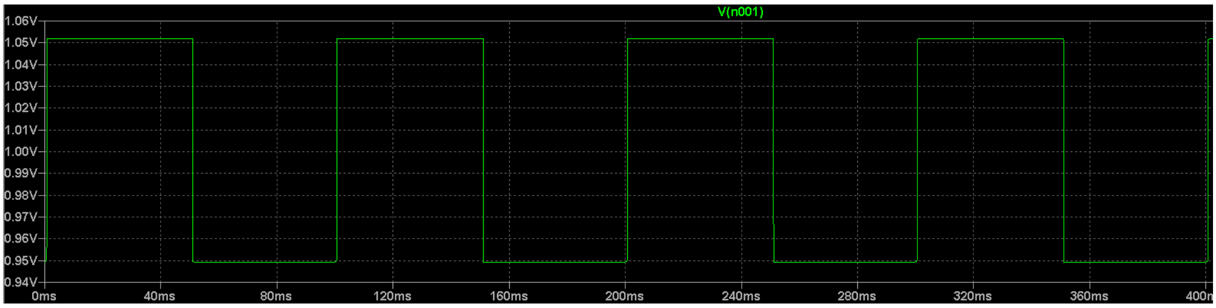


Figure 15: Threshold Voltage.

In this figure we can see our V_{TH} and V_{TL} values which are 1.05V and 0.95V in green label.

Comparator Operational Amplifier Test Results				
Design target	**Measured value**	**Calculated Value**	**Unit**	**%Error**
Output Low Voltage	**64.48**	**0**	**mV**	**0.64**
Output High Voltage	**4.99**	**5**	**V**	**0.2**
Threshold Low Voltage	**949**	**950**	**mV**	**1.05**
Threshold High Voltage	**1.052**	**1.05**	**V**	**0.19**
Duty Cycle	**50.1**	**50**	**%**	**0.2**

Table 7: Test results for Comparator Operational Amplifier.

We have to use standard resistor values which is the closest desired value according to calculation. We can say we are in %5 acceptable error range for every target. We have little bit error because of difference between calculated resistor values between standard resistor values.

3.3. Counter Test Results

OR GATE 1

Q	A channel	Clock up(output)
0	↑	↑
1	↑	1

OR GATE 2

Q'	B channel	Clock down (output)
1	↑	1
0	↑	↑

Counter Truth Table

Clock up	clock down	Reset	Action
↑	1	0	Count up
1	↑	0	Count down

Table 8: Truth Tables for Counting.

According to the counterin working principle, we have established the input and output relationships in the figure to get our outputs.

Displaying Test Results				
Design target	**Measured value**	**Calculated Value**	**Unit**	**%Error**
Forward Voltage	**2.4**	**2.35**	**V**	**2.08**
Segment of current(If)	**20**	**20**	**mA**	**0**
Resistors between 7447 and 7 segment BCD	**130**	**130**	**Ω**	**0**

Table 9: Test results for Displaying.

We can say we are in %5 acceptable error range for every target.

4. Conclusion.

In this project we calculated the position of the shaft by designing an optical angular encoder.

We use infrared light as a light source for photodiode and detectors to work compatible each other. To determine the direction, we use phase difference of two light sources. Because the photodiode is a current source, we obtain current when light strikes the detectors. In order to move forward in a simpler way in the design and operations of the circuit, we need to convert this current to voltage. To ensure that the rest of the circuit and the equivalent resistance do not change, we performed the current-to-voltage conversion using trans impedance amplifier instead of connecting the resistance to the circuit. After this procedure, we got a sinus wave.

To make the counting process, we needed to digitalize this wave. Therefore, we needed to convert sinus wave to square wave. we achieved this process by using comparator operational amplifier in a simpler way instead of using analog to digital converter since we only need one-bit information.

After this step, we determined our rotation direction to using D type flip flop and two OR gates. For counting and displaying part we used 40192 counter circuit and 7447 BCD to 7 segments. We paid attention to the direction, the appearance of an increase or decrease, and the direction. On the other hand, when we performed the counting process, we solved the problem more simply by using up-down difference counting instead of increasing the counters and subtracting these two from each other when counting forward and backward.

In rotation direction part firstly, we considered to implement 2 flip flop and XOR gate, but we could not take results successfully. In order to achieve this problem, we applied 1 Flip flop and 2 OR gate.

For counting part in our first design, we needed to change a connection in the circuit for counting up and counting down, we solved this problem by masking with logic gates.

We did not have the opportunity to test the circuit we created in the laboratory, but we simulated the schematic design using software applications such as LTspice and Proteus, and the design and results we achieved were as expected. Consequently, we implemented an optical angular encoder circuit by passing the light source coming to our disk through certain steps.

5. Component List

Component description	Part Number	Manufacturer	Supplier
High Power Infrared Emitting Diode	**TSAL6100**	Vishay Semiconductors	www.vishay.com
Silicon PIN Photodiode	**BPV10NF**	Vishay Semiconductors	www.vishay.com
Operational amplifier	**LT1001**	Linear Technology	www.digipart.com
Operational amplifier	**LT1413**	Linear Technology	www.digipart.com
Dual D-Type Flip-Flop	**CD4013**	Fairchild	www.direnc.net
CMOS Presettable BCD Up/Down Counter	**CD40192B**	Texas Instruments	www.ti.com
BCD to 7-Segment Decoders/Drivers	**DM7447A**	Fairchild	www.ebay.com
Standard 7-Segment Display	**TDSO5150**	Vishay Semiconductors	www.vishay.com

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