EXPERIMENT – 4

PROGRAMMABLE GAIN AMPLIFIER

GROUP NO : W 11

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OBJECTIVE:

To design and implement a programmable gain amplifier (PGA) with the given specifications using analog switch CD4066.

SPECIFICATIONS:

(i) one analog input
(ii) one analog output
(iii) Two TTL control inputs (S_1 and S_2) decide the gain of PGA as follows:

S_1	S_2	Gain
0	0	1
0	1	15
1	0	80
1	1	100

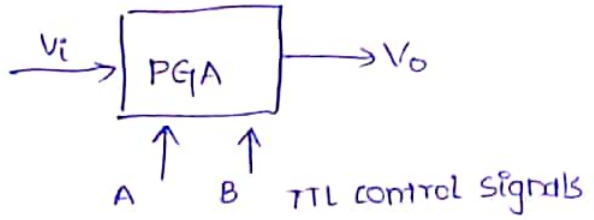
Components needed:

(i) opamp
(ii) Resistances of adequate values
(iii) CD4066 switch
(iv) 2N2222A PNP and NPN transistors (2 each)
(v) wires
(vi) power supply.

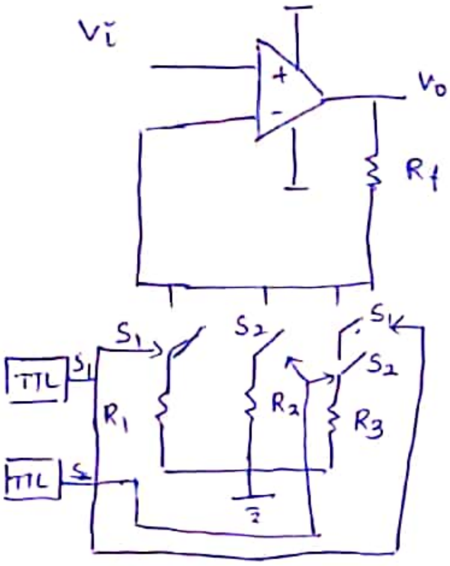
Theory:

- Block diagram of PGA unit with Analog input (V_i), Analog output (V_o) and TTL control inputs (A, B) are provided below.

- changing the TTL control inputs changes the effective gain (V_o/V_i) making it act like a programmable unit.



- The opamp can be used to design the system with control signals representing switches as shown below.



- The resistances R_1, R_2, R_3 and R_f are designed such that the gain of the system changes as switch S_1, S_2 are turned ON (signal = 1) and OFF (signal = 0).

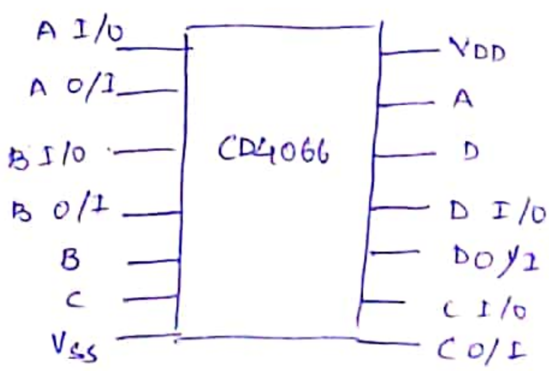
- The switch S_1, S_2 and S_3 (combination of S_1 and S_2) are designed using CD4066 switch

- The CD4066 contains four independent switches. The control signal determines whether switch is 'ON' or 'OFF' when

(i) control = V_{DD} → switch closed

(ii) control = V_{SS} → switch OPEN

Typical R_{ON} of switch ≈ 150 Ω



Here SWA = S_1, SWD = S_2 SWB and SWC together is S_3.

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- One problem with CD4066 switch is that it is bipolar and requires control signal to have both positive or negative value available to it while TTL signal are 0 or 5V and as such it requires a level shifter.

* WORKING OF LEVEL SHIFTER:

TTL input $\rightarrow$ $\boxed{\text{Level shifter}}$ $\rightarrow$ output

In level shifter when TTL input = 5V (Logic = 1), output should be V_{DD} (Here V_{DD} = 5V) and when TTL input = 0 (Logic = 0) output should be V_{SS}. (Here V_{SS} = -5V).

- Designing level shifter using BJT's:

We will use one PNP and NPN transistor to create level shifter for 1 switch

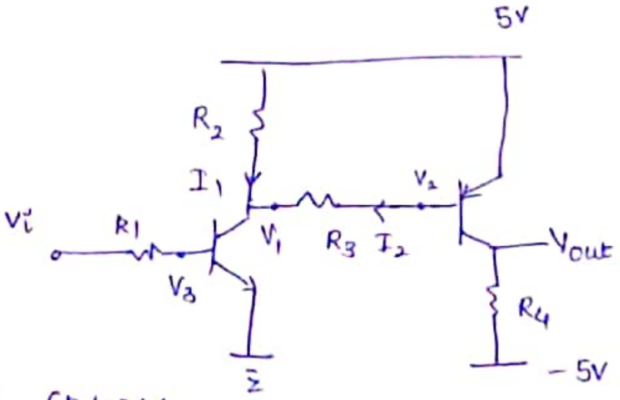
Sat. specifications for PNP transistor used: I_C = 10mA, I_B = 0.5mA β = 20, V_{BE} = 0.7V V_{CE} = 0.2V

Sat. specifications for NPN transistor used: I_C = 150mA, I_B = 15mA, β = 10, V_{BE} = 0.7V, V_{CE} = 0.2V

$V_i \rightarrow$ TTL input

$V_i = \{0, 5\}$ V

V_{out} = output voltage to be used in switch CD4066



- Calculation of R_1 R_2 R_3 and R_4

When $V_i = 5V$ $\quad V_{out} = 4.8V$ $\quad (V_{out} = 5 - V_{CE} \simeq 4.8V)$

$$\frac{V_i - V_3}{R_1} = 15mA \Rightarrow \frac{5-0.7}{R_1} = 15\times10^{3} \Rightarrow \boxed{R_1 = 286\Omega}$$

$$R_4 = \frac{V_{out}}{I_c} = \frac{9.8}{10\times10^{-3}} = 980\Omega \Rightarrow \boxed{R_4 = 980\Omega}$$

$V_1 \simeq 0.2V$, $\quad V_2 = V_{out} - V_{BE} = 4.3V$

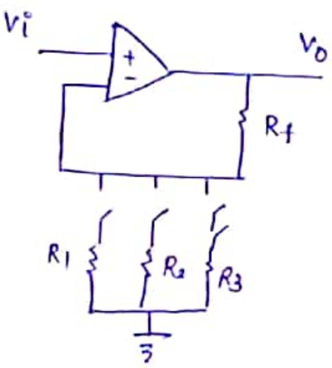
$$R_3 = \frac{V_2 - V_1}{0.5\times10^{-3}} = 8.2k\Omega \Rightarrow \boxed{R_3 = 8.2k\Omega}$$

Also,

$$R_2 = \frac{5-V_1}{I_1} \simeq \frac{5-V_1}{I_c} = \frac{4.8}{150\times10^{-3}} = 32\Omega$$

$$\Rightarrow \boxed{R_2 = 32\Omega}$$

- Designing gain circuit (calculating Resistances for getting desired gain)



Take $R_{ON} = 150\Omega$

Let $R_f = 100k\Omega$

When $S_1 = S_2 = 0$

$$\frac{V_o}{V_i} = 1 + \frac{R_f}{R_i} \simeq 1$$

$(R_i \to \infty)$

When $S_1 = 1, S_2 = 0$

$$1 + \frac{R_f}{R_1 + 150} = 80$$

$$\Rightarrow R_1 = \frac{R_f}{79} - 150$$

$$\Rightarrow \boxed{R_1 \simeq 7k\Omega}$$

When $S_1 = S_2 = 1$

$$\frac{V_o}{V_i} = 100 = 1 + \frac{R_f}{(R_1+150)\,||\,(R_2+150)\,||\,(R_3+150)}$$

$$\Rightarrow \boxed{R_3 \simeq 16.52k\Omega}$$

When $S_1 = 0, S_2 = 1$

$$\frac{V_o}{V_i} = 1 + \frac{R_f}{R_2 + 150} = 15$$

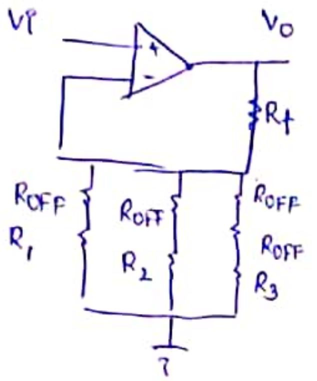
$$\Rightarrow R_2 = \frac{R_f}{14} - 150$$

$$\Rightarrow \boxed{R_2 \simeq 1.2k\Omega}$$

- Calculating R_{ON} (Resistance offered by switch at ON) and R_{OFF} (Resistance offered at OFF position)

We will use experimental gain to calculate R_{ON} and R_{OFF}.

When $S_1 = S_2 = 0$ let $g_{(exp)}$ be experimental (gain $\simeq 1$)

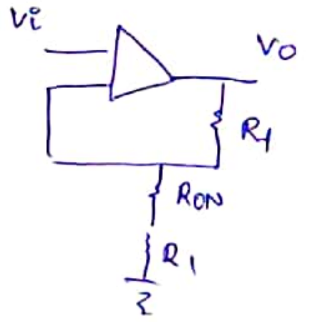


$$1 + \frac{R_f}{(R_{OFF}+R_1) \parallel (R_{OFF}+R_2) \parallel (R_{OFF}+R_3)} = g_{exp}$$

$$\Rightarrow \quad \frac{R_f}{R_{OFF} \parallel R_{OFF} \parallel 2R_{OFF}} = g_{exp} - 1$$

$$\Rightarrow \quad \boxed{R_{OFF} = \frac{R_f}{0.4 \times (g_{exp}-1)}}$$

When $S_1 = 1,\ S_2 = 0$ let g_{exp} be experimental gain



$$g_{exp} = 1 + \frac{R_f}{R_{ON}+R_1}$$

$$\boxed{R_{ON} = \frac{R_f}{g_{exp}-1} - R_1}$$

Department of Electronics & Electrical Engineering

EC207: Analog Circuits Laboratory

Results verification sheet

Experiment No. 4: Programmable Gain Amplifier

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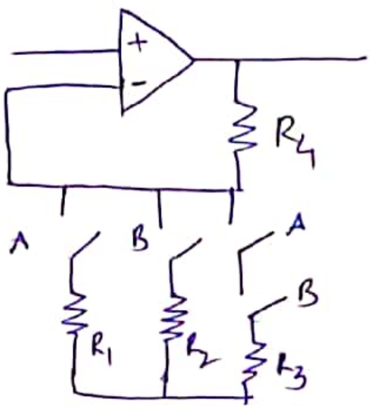
1. **Circuit Diagram:**



2. **Designed value of resistances:**

$R_1 = 7k\Omega$ $R_2 = 1.2k\Omega$ $R_3 = 16.52k\Omega$ $R_4 = 100k\Omega$

3. **Measured value of resistances:**

$R_1 = 6.93k\Omega$ $R_2 = 1.1k\Omega$ $R_3 = 16.48k\Omega$ $R_4 = 99.5k\Omega$

4. Minimum voltage required to turn on the switch = 4.6V

Minimum voltage required to turn off the switch = -2.9V

5. Measured value of ON resistance of an analog switch, R_{ON} = 165Ω

Measured value of OFF resistance of an analog switch, R_{OFF} = $1.1M\Omega$

Control Inputs (TTL)		Analog Input (v_i)	Analog Output (v_o)	Gain (v_o/v_i)	Expected Gain
A	B				
0	0	527 mVpp	549 mVpp	1.03	1
0	1	61.3 mVpp	825 mVpp	13.45	15
1	0	64.1 mVpp	4.94 Vpp	77.34	80
1	1	64.1 mVpp	6.13 Vpp	95.6	100

Signature of the TA Date 19.02.2020