KATHMANDU UNIVERSITY

SCHOOL OF ENGINEERING

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

MINI-PROJECT REPORT

GAMEPAD HAPTIC FEEDBACK

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JULY 2021

ABSTRACT

We interact with input devices primarily through our sense of touch. Gamepad controllers are one of the most involving portable things we can directly interact with today. They allow for a comfortable way to interact with a game on any gaming Console/PC. But such a one-sided experience isn't as immersive. To induce a feeling of being touched by the computer, haptic or vibration feedback technology was developed and this small report explores one such design.

ACKNOWLEDGEMENT

I would like to take this small opportunity to thank Dr. Samundra Gurung for making such a mini-project a part of our evaluation. I truly believe that such a method fosters the learning process for us students and allows us to learn about the design process by direct involvement.

LIST OF FIGURES

ABBREVIATIONS

SN.	Abbreviation	Full Form	First Used in Page
1.	RPM	Revolutions Per Minute	6
2.	A/D	Analog-to-Digital Converter	7
3.	KVL	Kirchoff's Voltage Law	14

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1. INTRODUCTION & PROBLEM DEFINITION

The first of such haptic feedback controllers were commercially introduced by Nintendo™ in 1997 in the N64™ console which was shortly followed by Sony's DualShock™ technology. Haptic feedback was primarily developed for racing games to make a player feel the effects of accelerating their in-game cars to higher RPM levels. This effect mimicked the effects of racing cars being in a similar situation in real-life. Over-revving the engines & cornering in fast cars generate huge amount of vibrations especially felt at the steering wheel making it harder for the driver to control it. Mimicking this exact action was the primary goal of haptic feedback technology in order to create better immersion and introducing an aspect of intensity. The vibrations were software controlled in order to make sure haptic feedback wasn't introduced at the wrong points in time. For example: A gamepad vibrating when you are driving the car at very low speeds in-game is a discrepancy that purely hardware based control introduces. This allowed game developers program the trigger into their games when specific conditions were satisfied. For example: The gamepad vibrates when the acceleration & gear variable both exceed a certain value. A small unbalanced load was attached to the rotor of the gamepad's motors to create vibrations.

The problem associated with such a technology is to correctly map the position of the analog stick to provide an accurate response. As an estimation, if the analog stick lies in the region between the inner and outer circle of the upper semi-circle, the unbalanced load must rotate, causing vibrations.

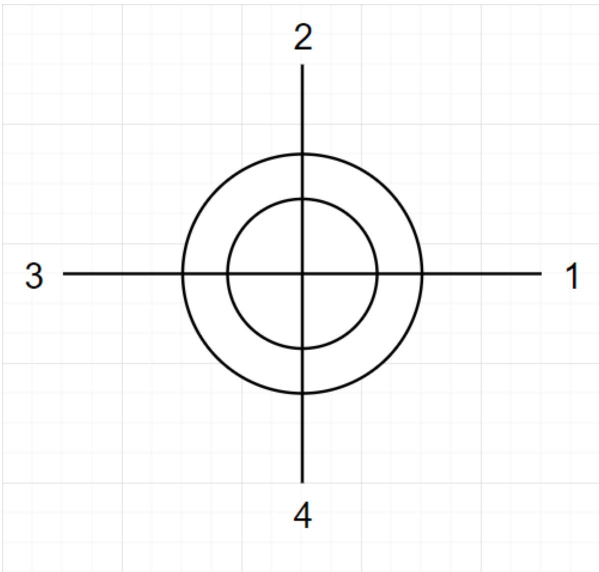

Fig 1: Possible Positions of the Analog Stick

2. OBJECTIVES

1. Select a sensor to detect changes in position
2. Develop a signal conditioning circuit around the sensor behaviour
3. Design circuitry to react appropriately to the signal conditioning circuit's output
4. Create a control point to enable digital control & accommodate A/D conversion

3. SYSTEM ANALYSIS

There are various ways of sensing movements and translating them to axial data but the simplest and at the same time, reliable sensing mechanism can be designed using trimmer pots (Potentiometers). We can use two of any such easily available pots of typical values to act as axial data collectors. In this design, we choose two such 10 kΩ pots and name them R_x & R_y to represent resistance along the x & y-axes respectively. The pots are used in unison with a comparator i.e. just a differential amplifier. The lower peak voltage must be 0V & the higher peak 5V. Writing the required conditions as a set of linear equations:

(R_x+R_y) can have a minimum value of 0 Ω & a maximum value of 20000 Ωs

Using this fact, we can derive the required linear equations to be satisfied as:

$$0 = V_{in} \cdot 0 + V_{bias} \tag{1}$$

$$5 = V_{in} \cdot 20000 + V_{bias} \tag{2}$$

Where V_{in} is the input voltage & V_{bias} is the required bias voltage

Solving (1) & (2)

$$V_{bias} = 0$$

$$V_{in} = 2.5 \cdot 10^{-4}$$

∴ Eq^n for the resulting circuit is: $V_o = V_{in} \cdot (R_x+R_y) + V_{bias}$

$$V_o = 2.5 \cdot 10^{-4} \cdot (R_x+R_y) + 0$$

$$\mathbf{V_o = 2.5 \cdot 10^{-4} \cdot (R_x+R_y)} \tag{3}$$

The outputs of both the pots are kept in a negative feedback loop in a non-inverting configuration to satisfy the result obtained in eq^n **(3)** with a small acceptable discrepancy,

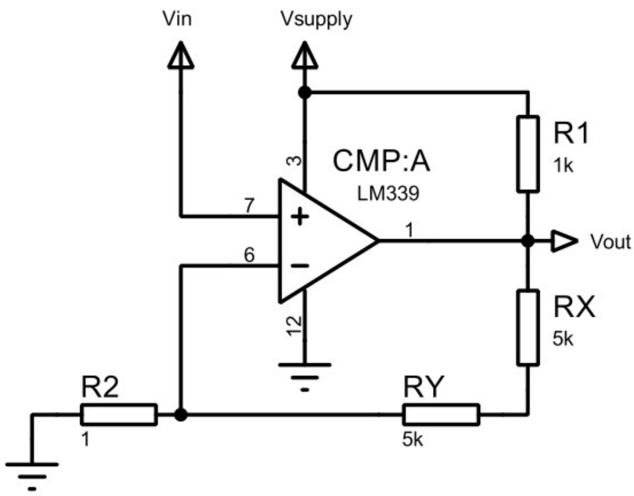

Fig 2: Signal Conditioning Circuit

Eq^n of the circuit:

$$\mathbf{V_{out} = V_{in} \cdot (1 + R_x + R_y)} \quad \mathbf{(4)}$$

It's seen that the output of this circuit has $(1 + R_x + R_y)$ which has the effect of **shifting eq^n (3) to the left by a value of 1**. This effect is so small that it can be easily ignored. The following graph plotted in MATLAB™ shows the performance of this circuit as $(R_x + R_y) = 0\ \Omega$ to $20000\ \Omega$s.

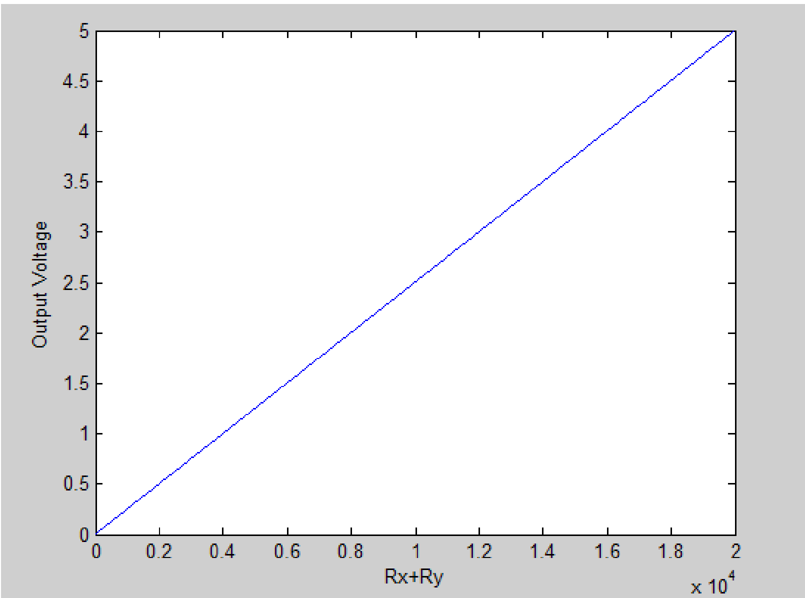

Fig 3: The behaviour of Eq^n (4)

The signal is now conditioned. Two more graphs keeping $R_x = 0$ once & $R_y = 0$ next are plotted in order to monitor the maximum voltage contribution by each trimmer pot.

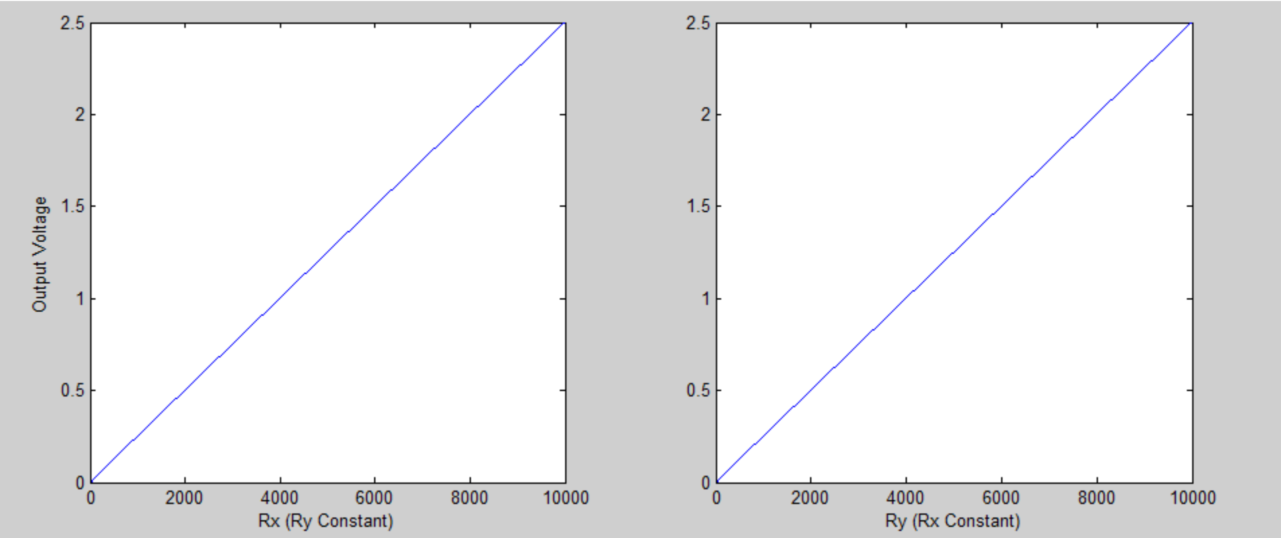

Fig 4: The behaviour of Eq^n (4) increasing R_x once & R_y next

Each trimmer pot contributes a maximum of 2.5 V to the output voltage. Another point to note is that each trimmer pot is not at 0 Ω in the normal position. Because of the way analog sticks must be configured (to be at the middle at times when not being touched by the user) using a spring mechanism, the nominal values of the trimmer pots at the normal position are 5 kΩs each.

$$\therefore \text{nominal } V_{out} = 2.5 \text{ V} \qquad [\because (1 + R_x + R_y) \approx 10 \text{ k}\Omega\text{s}]$$

The next problem to solve is explained by *Fig 2*. The analog sticks must be enclosed by a small circular compartment in order to allow only one trimmer pot to reach it's min. or max. value at a time, particularly to keep the analog sticks from breaking off from the circuit. All manufacturers enclose their analog sticks by such compartments for the same reason.

Keeping the nominal values contributed by each trimmer pot as origin of the circle in *Fig 2*, a small script was written to obtain 4 different range of possible values at each quadrant in *Fig 2*.

The ranges were obtained to be:

1st Quadrant: **3.75 V - 4.27 V**

2nd Quadrant: **3.75 V - 1.25 V**

3rd Quadrant: **1.25 V - 0.80V**

4th Quadrant: **1.25 V - 3.75 V**

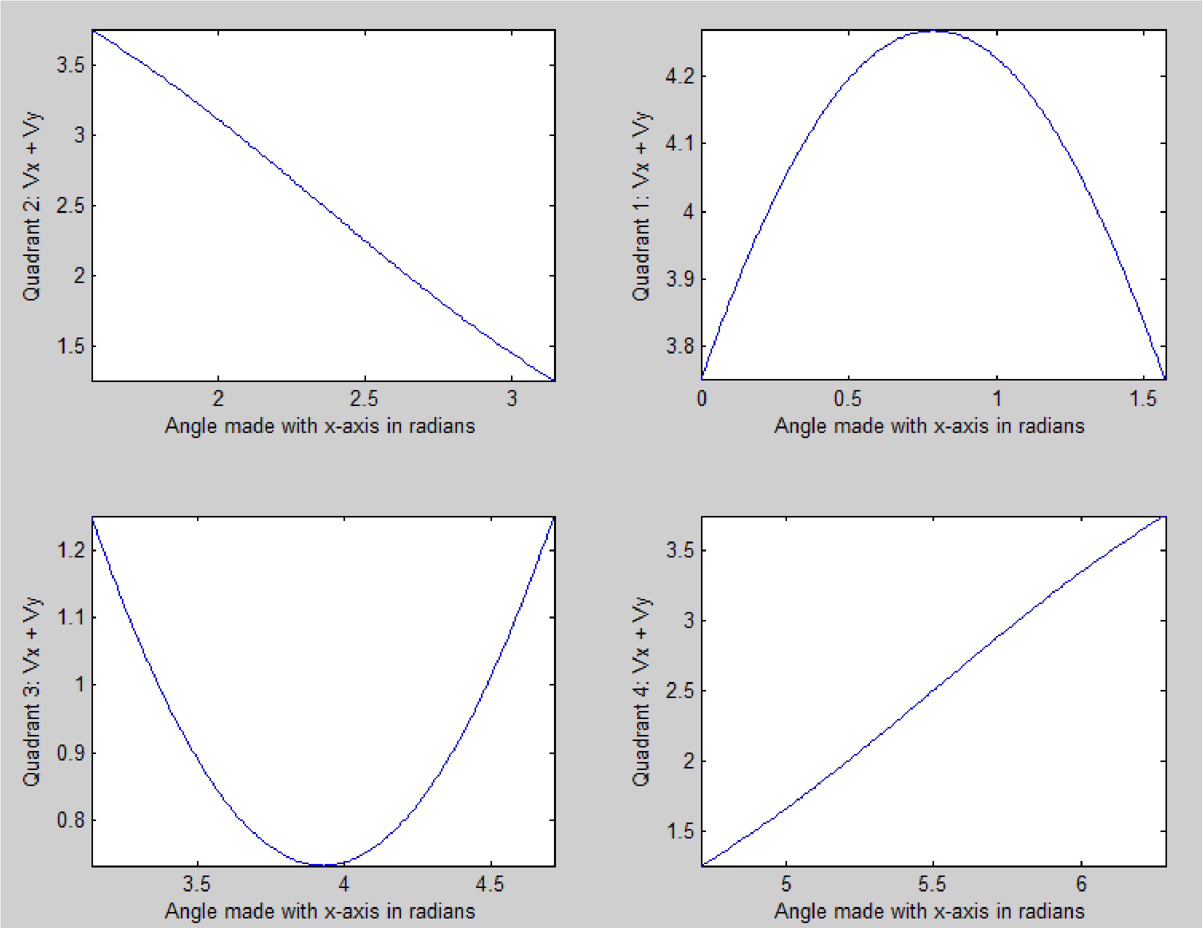

Fig 5: Sum of max. voltages as the stick rotates(anti-clockwise) along the circular compartment

This small analysis allows us to proceed with a good knowledge of the voltage ranges seen at each of the position extremes of the analog stick. *Fig 6* provides a visual aid.

Fig 6: Analog Stick tilted towards the 3rd Quadrant. [Courtesy of Parallax Inc.]

This final solution brings us to the project's main goal, a haptic feedback system. As seen from the quadrant separation of the stick's position in *Fig 2,* we can assume that haptic feedback must be provided as the stick moves around the max. values from position 1 to 2 & 2 to 3 since these positions correspond to the player turning their in-game car while accelerating. This is the exact point where we need to provide a powerful haptic feedback for maximum immersion.

A simple on-off control system must be designed to appropriately respond to V_{out} of the signal conditioning circuit. From quadrant voltage data of the 1st & 2nd quadrants, we discover that haptic feedback must be provided whenever V_{out} > 3.75 V or whenever V_{out} decreases to 1.25 V after attaining 3.75 V first. The latter situation seems counter-intuitive but it is models a practical situation. The player must put their car on full-throttle before turning it to experience vibrations in reality. This criteria simulates that exact situation. The rough circuit must look as shown:

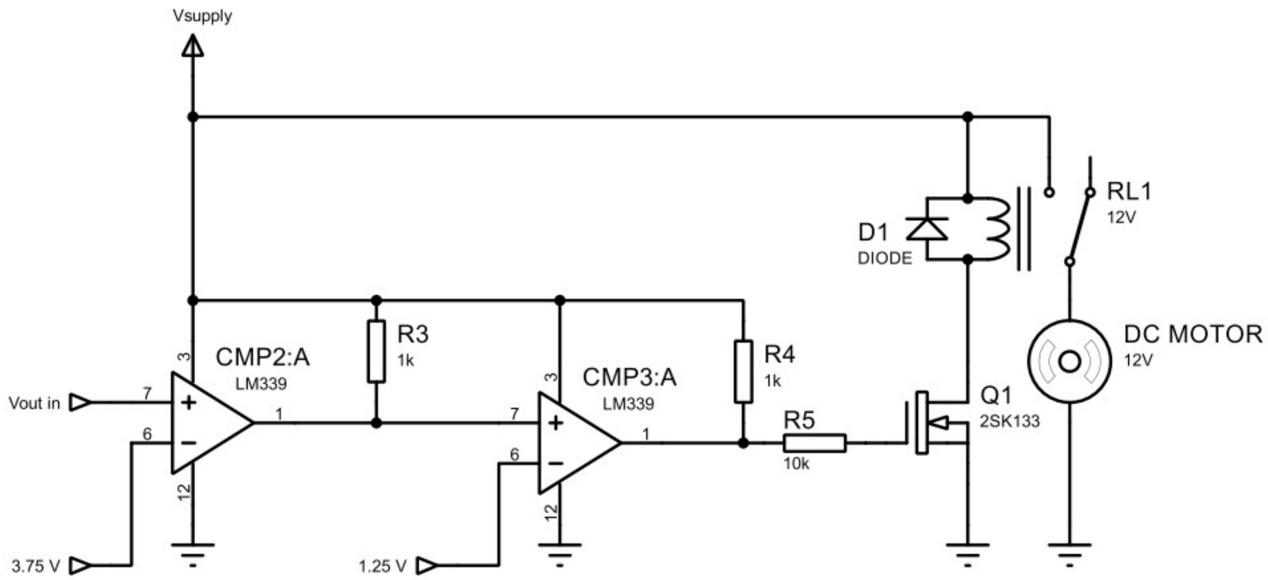

Fig 7: Haptic-Feedback Control Circuit General Simplified Layout

This design completes the design aspect of required control circuits. The following sub-section will explore features of the circuit along with important calculations that allow it's proper operation. An SR Latch was added to this diagram with S (Set) connected to the 1st comparator & R (Reset) connected to the 2nd comparator to satisfy the sequential criterion explained in the paragraph above.

4. CIRCUIT DESIGN

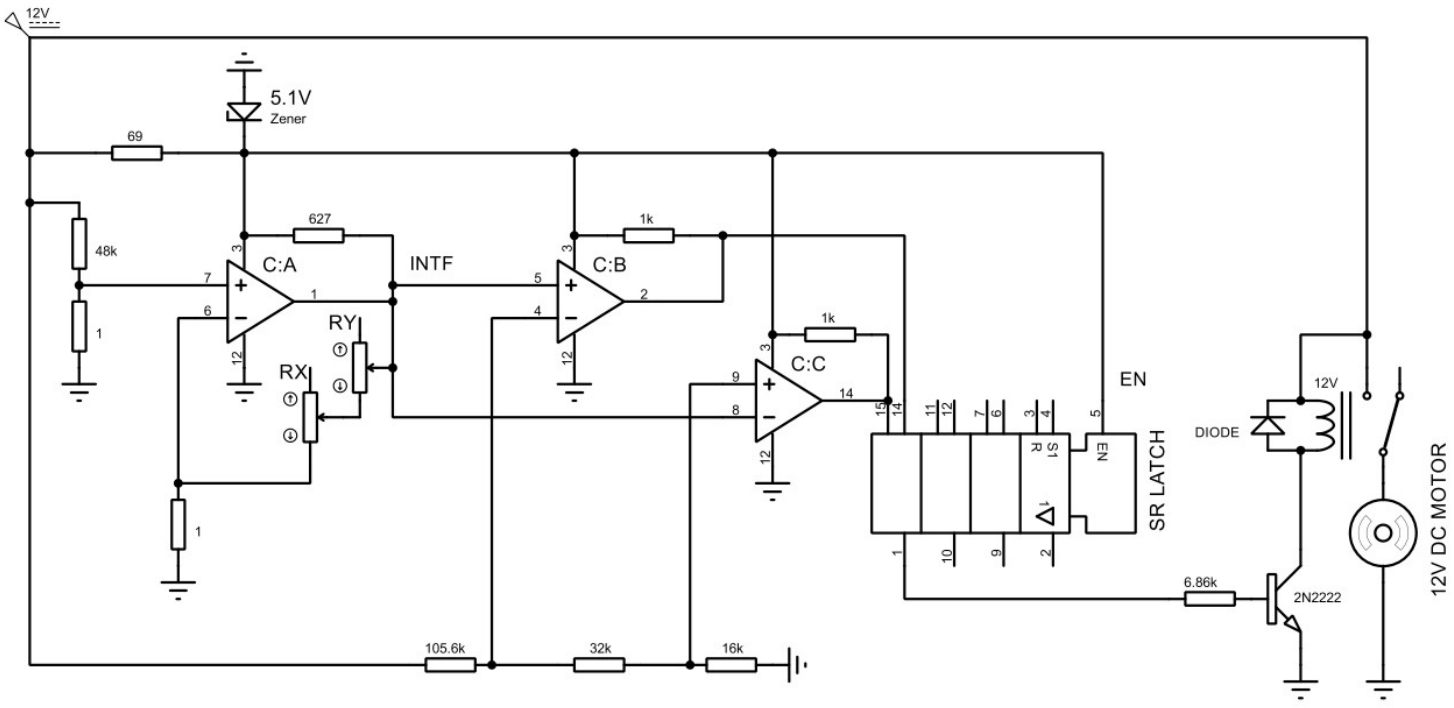

Fig 8: Fully Functional Haptic-Feedback Circuit Module

Primary features of the circuit module:

1. Haptic feedback completely hardwired for racing games, almost no customization required.
2. The label INTF represents the conditioned voltage (0-5V). This output can be directly connected to A/D converters for digital manipulation of the axial data.
3. This is further facilitated by the EN label i.e. the enable pin of the SR Latch which can be linked to a micro-controller to allow for full digital control of the whole circuit through software. EN pin has the ability to turn haptic feedback on or off whenever required. This helps the programmer tailor it to their game, allowing the same circuit to be used not only for racing, but each and every type of game.

The final working circuit has a small modification in implementation as compared to *Fig. 7*. Depending on values of RX & RY, the input voltage is appropriately amplified. The output is fed into non-inverting input of C:B with a 3.75V reference at the inverting input which triggers S of the SR Latch. Reference voltage of 1.25V is fed into the non-inverting input of C:C in order to prevent the R of the SR Latch from being triggered before the conditioned signal goes below 1.25V. This sequential logic doesn't allow the relay to be energized without the conditioned voltage crossing 3.75 V first. Whenever it does cross it, the voltage must go below 1.25 V before resetting the Latch.

List of Components

1. LM339 Quad Differential Comparator
2. Generic Resistors, Diodes
3. 1N5918B 5.1V Zener Diode
4. 12V DC Motor
5. 12V Relay (40mA excitation Current, 240 Ω Coil Resistance R_{Coil})
6. 2N2222 NPN-BJT (800mW, β = 75)
7. Trimmer Potentiometer (0-10 kΩ)
8. 4043 CMOS Quad 3-State R/S Latch

Calculations based on typical component values as listed in respective data sheets:

Transistor & Relay:

Possible outputs at SR Latch pin 1 = 0V or 5V. ∴ The transistor remains off at 0V. The transistor turns on at 5V. For proper biasing of the transistor, writing a KVL (Kirchoff's Voltage Law) along the Emitter-Base loop.

∵ $\beta = 75$, calculating R_B for $I_C = 47\text{mA}$, $V_{Latch} = 5\text{V}$, assuming $V_{BE} \approx 0.7$ V

$$\beta \cdot (V_{Latch} - V_{BE}) = I_C \cdot R_B \qquad (5)$$

$$R_B \approx 6.86\ \text{k}\Omega$$

Power Calculations:

$$P_{Transistor} = I_B^2 \cdot R_B + (I_C + I_B) \cdot [V_S - (I_C \cdot R_{Coil})]$$

$$P_{Transistor} = 37\ \text{mW}$$

$$P_{Coil} = I_C^2 \cdot R_{Coil}$$

$$P_{Coil} = 530\ \text{mW}$$

Zener Reference Circuit: Current (I_Z) = (12 - 5.1) ÷ 69 = 0.1 A

$P_{Zener} = I_Z^2 \cdot 69 = 690$ mW

Resistive Dividers:

(i) Divider for non-inverting input of C:A to generate V according to eq[n] (3)

$R_1 : R_2 = V_S - V_{Out} : V_{Out}$ (6)

$R_1 : R_2 = 47999 : 1$

$R_1 = 48$ kΩ, $R_2 = 1$ Ω

I = 12 ÷ 48000 = 250 μA

$P = I^2 : 48000 = 3$mW

(ii) Divider for Reference voltage generation at the bottom part of *Fig 8* using eq[n] (6)

For $V_{Out} = 3.75$ V, $R_1 : R_2 = 11:5$

For $V_{Out} = 1.25$ V with $V_{in} = 3.75$ V, $R_1 : R_2 = 2:1$

$R_2 + R_3 = 48$ kΩ, $R_1 = 105.6$ kΩ

$R_2 = 32$ kΩ, $R_3 = 16$ kΩ

I = 12 ÷ 153600 = 78.1 μA

$P = I^2 \cdot 153600 = 0.94$ mW

Total Power Dissipated by Dividers, (P_{Rz}) = 3.94 mW

Signal Conditioning & Control Circuit

$$P_{Max} = I_Z \cdot V_Z = 0.1 \cdot 5.1 = 510 \text{ mW}$$

Note: Indirect power calculations for control circuit due to dynamic operating modes

Total Power Requirements of the Module:

$$P_{Transistor} + P_{Coil} + P_{Rz} + P_{Zener} + P_{Max} = (37 + 530 + 690 + 3.94 + 510) \text{ mW} = 1770.94 \text{ mW}$$

∴ The circuit requires a minimum power of ~1.7 W for proper operation

4. REFERENCES

1 B. Razavi, Fundamentals of Microelectronics, 2^{nd} Ed, Los Angeles, CA, USA: John Wiley & Sons, Inc., 2014

2 Curtis D. Johnson, "Analog Signal Conditioning", in Process Control Instrumentation Technology, 8^{th} Ed, Edinburgh Gate, Harlow, Essex CM20 2JE, England: Pearson Education Limited, 2014

APPENDIX: USED MATLAB™ SCRIPTS

Fig 3:

```
rx = (0:0.01:10000)';
ry = (0:0.01:10000)';
v = @(x,y) 2.5e-4*(x+y+1);
subplot(1,3,1),
plot(rx+ry,v(rx,ry));
axis([0 20000 0 5]);
xlabel('Rx+Ry');
ylabel('Output Voltage');
```

Fig 4:

```
rx = (0:0.01:10000)';
ry = zeros(1000001,1);
v = @(x,y) 5*(x+y)/20000;
subplot(1,2,1), plot(rx+ry,v(rx,ry));
axis([0 10000 0 2.5]);
xlabel('Rx (Ry Constant)');
ylabel('Output Voltage')

rx = zeros(1000001,1);
ry = (0:0.01:10000)';
v = @(x,y) 5*(x+y)/20000;
subplot(1,2,2), plot(rx+ry,v(rx,ry));
axis([0 10000 0 2.5]);
xlabel('Ry (Rx Constant)');
```

Fig 5:

```
x = 0:pi/360:pi/2;
sum = @(x) (1.25*(sin(x)+cos(x)))+2.5;
subplot(2,2,2), plot(x,sum(x)); %plot voltages sum due to each sensing resistor
axis([0 pi/2 3.75 8.5355/2]);
xlabel('Angle made with x-axis in radians');
ylabel('Quadrant 1: Vx + Vy');

x = pi/2:pi/360:pi;
sum = @(x) (1.25*(cos(x)+sin(x)))+2.5;
subplot(2,2,1), plot(x,sum(x)); %plot voltages sum due to each sensing resistor
axis([pi/2 pi 1.25 3.75]);
xlabel('Angle made with x-axis in radians');
ylabel('Quadrant 2: Vx + Vy');

x = pi:pi/360:3*pi/2;
sum = @(x) (1.25*(sin(x)+cos(x)))+2.5;
subplot(2,2,3), plot(x,sum(x)); %plot voltages sum due to each sensing resistor
axis([pi 3*pi/2 1.4645/2 1.25]);
xlabel('Angle made with x-axis in radians');
ylabel('Quadrant 3: Vx + Vy');

x = 3*pi/2:pi/360:2*pi;
sum = @(x) (1.25*(cos(x)+sin(x)))+2.5;
subplot(2,2,4), plot(x,sum(x)); %plot voltages sum due to each sensing resistor
axis([3*pi/2 2*pi 2.5/2 7.5/2]);
xlabel('Angle made with x-axis in radians');
ylabel('Quadrant 4: Vx + Vy');
```