Audio Signal Transmission via 4-20mA Line

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I OBJECTIVE

- Construct a 4-20mA Signal Transmission Line and transmit an Audio Signal.
- At the Receiving end play back the audio signal and display on Oscilloscope.

II INTRODUCTION

The 4-20mA current loop is a simple and effective method for transmitting analog signals over long distances with minimal signal loss. In a typical 4-20mA circuit, the transmitter converts the analog signal into a proportional current in the range of 4 to 20mA, where 4mA represents the minimum value of the signal and 20mA represents the maximum value. This current is then sent over a pair of wires to a receiver circuit that converts the current back into an analog signal.

One of the main advantages of the 4-20mA current loop is its high noise immunity. Since the current signal is independent of the voltage level, it is less susceptible to noise and interference compared to other signal transmission methods. Additionally, the 4-20mA current loop can transmit signals over long distances (up to several kilometers) without the need for signal amplification.

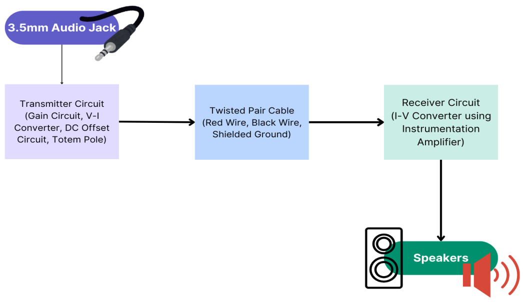

Figure 1: 4-20mA Current Loop Block Diagram

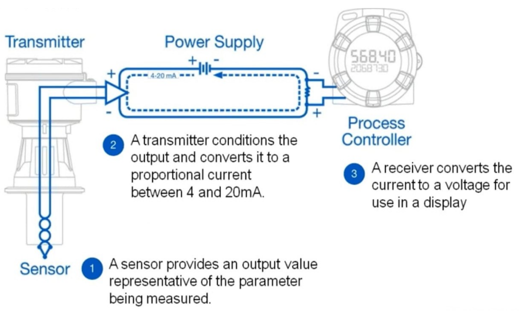

Figure 2: 4-20mA Current Loop Work Flow

III DESIGN

3.1 *Transmitter:-*

- The Transmitter circuit typically consists of a signal conditioning stage, which amplifies and filters the analog signal, and a current driver stage, which converts the analog signal into a proportional current.
- Op-amp Q_2 provides gain to the circuit and Q_4 converts it to a current signal. Q_1 adds a DC bias so that as the sensor voltage varies from -0.5V to 0.5V, the output current varies from 4mA to 20mA. The Offset and Gain can be controlled using Potentiometers R_2 and R_5. To make the offset value independent of the Power Supply voltage we have used Zener Diodes to provide the reference voltage(+5.1V and -5.1V) to the Potentiometer. Both Transistors are driven by the same signal. When the signal is low, the pnp is on; when the signal is high, the npn is on. This creates a push-pull output using just two transistors.

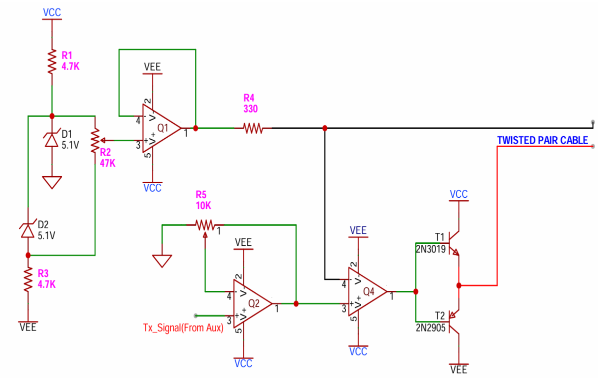

Figure 3: 4-20mA Transmitter Circuit

- At the Transmitter side the Input Voltage to Output Current relation is given by:

$$I_{\text{out}} = (1 + \frac{R_{5a}}{R_{5b}})\frac{V_{\text{Tx}}}{R_4} - \frac{V_{\text{offset}}}{R_4} \qquad (1)$$

Here R_{5a} is the Resistance between Output of Q4 to center tap of the Potentiometer and R_{5b} is the Resistance between Grounded Terminal of Potentiometer to its center tap. Choosing appropriate values of R_{5a}/R_{5b} and V_{offset}, the current output can be tuned to the equation shown below:

$$I_{\text{out}} \approx (16.16 * V_{\text{Tx}} + 12.12)mA \qquad (2)$$

- Above equation is found out by using two point line equation where the two points are (-0.5V, 4mA) and

(0.5v,20mA). Substitute these points into equ(i) using Point-(i) values as V_{Tx} = -0.5V , I_{out} = 4mA and $R_4 = 330\Omega$ and for Point-(ii) use values as V_{Tx} = +0.5V , I_{out} = 20mA. Solve for Gain and V_{offset}. Then adjust the Potentiometers R_2 and R_5, so that the relation (-0.5V, 4mA) and (0.5v,20mA) satisfies. The variation in Output Current with Input Voltage is shown in Table.1 and the same is plotted in Figure 4.

Tx Signal(V_{in})	I_{out}
-500mV	4mA
-400mV	5.92mA
-300mV	7.53mA
-200mV	9.31mA
-100mV	11.01mA
0mV	12.57mA
100mV	14.14mA
200mV	15.80mA
300mV	18.01mA
400mV	19.57mA
500mV	19.98mA

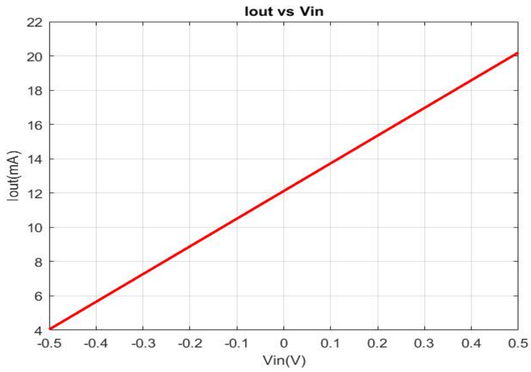

Figure 4: Plot of V_{in} versus I_{out}

3.2 *Receiver:-*

- The Receiver Circuit consists of a Current-to-Voltage Converter, which converts the Current back into a Voltage signal, and a DC Bias Offset to obtain the original Analog Signal.
- At the Receiver, the Current is converted to a Voltage using a 270 ohm resistor. The value of Resistor was chosen so that the Transmitter does not saturate and is able to maintain Closed Loop Feedback. The Instrumentation Amplifier comprising of Q1, Q2 and Q3 provides a gain of 3 and Q4 provides a DC Bias Offset to convert back the Current Signal into original Voltage Output.
- At the Receiver side the Input Current to Output Voltage relation is given by:

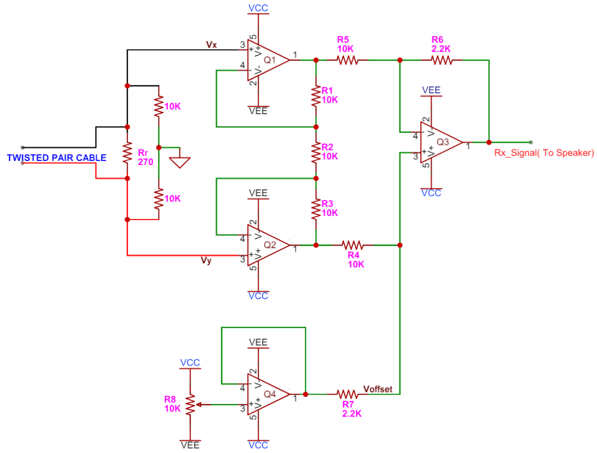

Figure 5: 4-20mA Receiver Circuit

$$V_{out} = (3 * \frac{R_6}{R_5})(V_y - V_x) + V_{offset} \tag{3}$$

Let $\frac{R_6}{R_5} = \beta$. Above equation can be solved by using two point line equation where the two points are ((V_y - V_x) , V_{out}) = (4mA*270 Ω, -0.5V) and (20mA*270 Ω, +0.5V). Substitute these points into equ(iii) using Point-(i) values as (V_y - V_x) = 1.08V , V_{out} = -0.5V and for Point-(ii) use values as (V_y - V_x) = 5.4V , V_{out} = +0.5V. Solve for Gain(β) and V_{offset}. Then adjust the Potentiometer R_8 and Resistors R_5 and R_6, so that the relation (1.08V, -0.5V) and (5.4V, 0.5v) satisfies. The variation in Output Voltage with Input Current is shown in Table.2 and the same is plotted in Figure 6.

$$V_{out} = (3 * \frac{0.5}{6.48})(V_y - V_x) - 0.75 \tag{4}$$

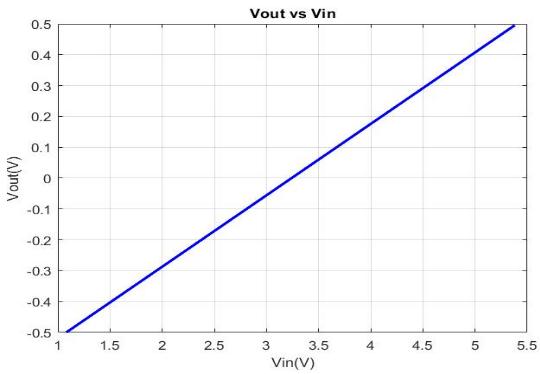

Figure 6: Plot of V_{in} versus V_{out}

Tx Signal(V_{in})	Input Current	V_{out}
-500mV	4mA	-414mV
-400mV	5.92mA	-336mV
-300mV	7.53mA	-259mV
-200mV	9.31mA	-185mV
-100mV	11.01mA	-102mV
0mV	12.57mA	-5.3mV
100mV	14.14mA	-53mV
200mV	15.80mA	-126mV
300mV	18.01mA	-210mV
400mV	19.57mA	-260mV
500mV	19.98mA	-309mV

3.3 *Transmission Cable:-*

- Twisted pair cables have two conductors that are generally made up of copper and each conductor has insulation. These two conductors are twisted together, thus giving the name twisted pair cables.
- The receiver uses the difference of signals between these two conductors. The noise or crosstalk in the two parallel conductors is high but this is greatly reduced in twisted pair cables due to the twisting characteristic.
- In the first twist, one conductor is near to noise source and the other is far from the source but in the next twist the reverse happens and the resultant noise is very less and hence the balance in signal quality is maintained and the receiver receives very less or no noise.
- The quality of signal in twisted pair cables greatly depends upon the number of twists per unit length of the cable.

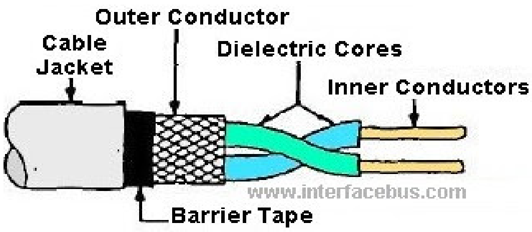

Figure 7: Twisted Pair Cable

- Shielded Twisted Pair Cables have extra insulation or protective covering over the conductors in the form of a copper braid covering. The shielding ensures that the induced signal can be returned to the source via ground and only circulate around the shield without affecting the main propagating signal.
- The Shielded Twisted Pair cables are color-coded as different color pairs are required for analog and digital transmission. These cables are costly and difficult to install.

3.4 *Audio Jack:-*

- Audio jacks, at their core, are standardized connectors designed for the transmission of audio signals. They are made up of a socket (female) and a plug (male) that are joined by metal contacts. The most common audio jack configuration is the TRS configuration, which consists of a tip (T), a ring (R), and a sleeve (S).
- There are many different types of headphones available today, each with its own jack. As a result, it's critical to understand the many types of headphone jacks available.
- **3.5mm Audio Jack (1/8-inch)**:- The 3.5mm audio jack, also affectionately known as the mini-jack or headphone jack, stands as the cornerstone of audio connectivity. Measuring 3.5mm in diameter, it has become the ubiquitous choice for a wide range of consumer electronics. From smartphones and laptops to portable audio players and headphones, this jack serves as the linchpin for countless audio experiences. Its versatility lies in its ability to accommodate both mono and stereo audio signals. This makes it the go-to choice for personal audio enjoyment.
- TRS type jack supports stereo sound but it does not support microphone. You can only listen to music but can not make calls with these type of headphones.

Figure 8: Male 3.5mm Stereo Jack

IV Why 4-20mA instead of 0-20mA signal?

1. **Live Line Detection:-** Electronic Circuit need some current value to flow in the components to stabilize the system. If it is 0mA we cannot find whether the loop is working or not. But at 4mA we can easily check whether the loop is live or is there any problem in the circuit.

2. **Fault Finding:-** At shutdown time if it is 0mA we cannot find out whether loop is working or not. There may be problem in the sensor or cable. If 0 is used instead of 4mA, we cannot differentiate between the actual 0 value of the sensor and the problem in the Transmission of Signal. *Ex*:- Cable cut or damage of the cable.

3. **Easy Calculation:-** The standard should be linear and utilising the maximum of the 3-30mA Band. We have 2 possible options:- 5-25mA or 4-20mA. Since calculations are easy for multiplications of 2, we use 4-20mA. Linearity based on 0,25,50,75 and 100 % of base value, where zero current should be equal to $1/4^{th}$ of Full range. Here 4mA = 0%, 8mA = 25%, 12mA = 50%, 16mA = 75% and 20mA = 100%.

   Signal corresponding to mA signal =

$$\frac{MeasuredValue - LowerRangeValue}{Span} \tag{5}$$

V Pros and Cons of 4-20mA Current Loop

5.1 Pros:-

- Saves on cable wire because it only needs 2 wires to function. Uses less wire and connections which will reduce installation costs.
- It can be run over long distances with minimal signal losses compared to voltage type signals. Low sensitivity to electrical noises.
- Easy to detect loss of signal or power. Live zero reading verifies sensor is electrically functional.
- A varying current loop load impedance or supply voltage will not significantly affect the signal as long as it does not exceed recommended component limits.

5.2 Cons:-

- Isolation requirements.Supply not isolated from output. Susceptibility to ground loops.
- High power consumption compared to other analogue signal types. One parameter Transmission.
- Increasing circuit load resistance, will reduce the supply voltage available to power the transmitter that is generating the 4-20mA signal.

VI Results

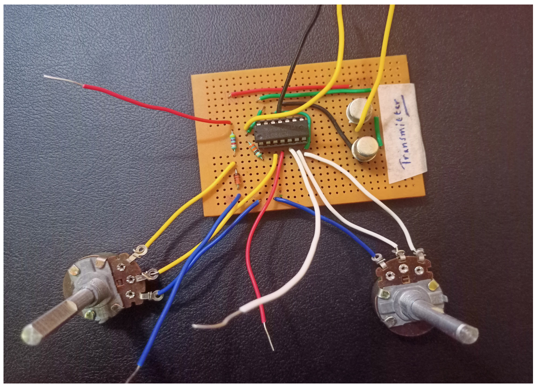

Figure 9: Designed 4-20mA Transmitter Circuit

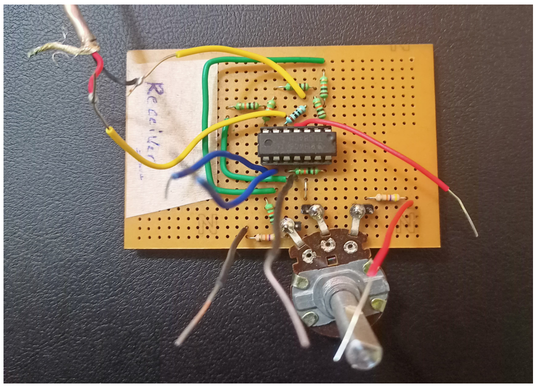

Figure 10: Designed 4-20mA Receiver Circuit

VII Conclusion

The 4-20mA circuit was successful in demonstrating the effectiveness of this circuit in transmitting analog signals for industrial control applications. In this project, audio signal was sent through the 4-20mA circuit to a receiver. The experiment demonstrated the high accuracy and reliability of the 4-20mA current loop in transmitting analog signals over long distances, with minimal signal degradation or interference.

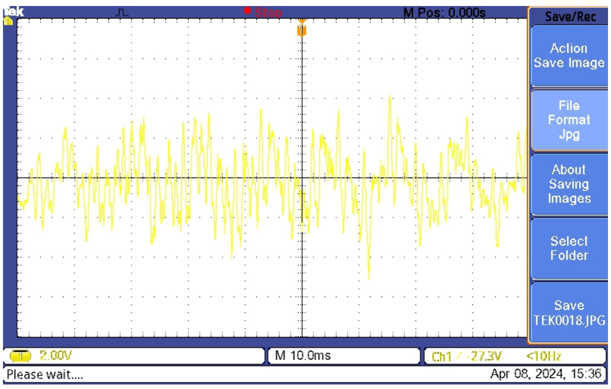

Figure 11: Waveform of Audio Signal Received

Overall, this project highlights the importance of using reliable and accurate analog signal transmission methods in industrial control systems. The 4-20mA current loop provides a robust and stable method for transmitting analog signals, which can be used in a variety of applications, including temperature control, pressure sensing, flow measurement, and level sensing, among others. With its simplicity, high noise immunity, and ease of use, the 4-20mA circuit is a valuable tool in industrial automation and control systems.

References

[1] "The Fundamentals of 4-20 mA Current Loops"

[2] "4-20 mA current Transmitter design by Prof. M.K. Gunasekaran "

[3] "THE SCIENCE OF 4 TO 20 MA CURRENT LOOPS "

[4] "Why Is 4 20mA Used In Sensors?"

[5] "Basics of Twisted-pair Cable"