A low-cost and highly optimized Analog circuit design to interface negative voltages to Single Ended ADC

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Research Article

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Abstract

Interfacing negative(inverted) voltages to micro controller ADC is always challenging. On the fly solution available of using external ADC is expensive and pin compatible chips from different manufacturers is another test. High range of input signal interfacing needs reduced gain circuits, which is an additional task to generate on board negative power source for OpAmp Circuits. To avoid an external ADC chip and optimizing the cost, a dual OpAmp with some discrete and General-purpose comparators, analogue switches is added.

This paper discusses about step-by-step design of circuitry to interface negative voltages to single ended ADC, and consideration on optimizing along with calculations.

Introduction

In motor controls, analogue feedback devices such as AC Tacho/DC Tacho used to measure actual speed gives bidirectional voltage as feedback based on the motor direction shown in Fig1. Traditional Temperature sensors (not PTC/NTC) which are in use also gives negative voltage for negative temperature range shown in Fig2. Microcontrollers have inbuilt ADC on some of ports which can measure single ended and positive directional voltages up to the Vmax or VRef or VAdcMax. Controllers Operate at voltages 3.3/5V, but sensors can give voltages upto Supply voltage of the ECU, in many cases which is higher than microcontroller Vcc. To interface such and adding filters with external ADC on ECU increases the complexity. The proposed solution eliminates complex circuitry and usage of external ADC if resolution of the Microcontroller ADC is serving the need of signal range.

Examples Of Tacho And Temperature

Speed:

Tacho are general DC/AC generators which provides a fixed voltage on the terminals, based on the shaft speed connected to the armature. It multiplies by back EMF constant with the Speed. Tacho having 5mV/RPM gives 10V at 2000RPM and -10V on the other direction with same speed.

Temperature:

Available Solutions

Available solution on the fly is adding an EXT ADC which can read negative input voltages. In needs additional circuitry like external reference, Supply source and Filtering. EXT ADC will be interfaced on Parallel Port or Serial communication which forces additional SW development.

Overview of Proposed Solution

On Mixed signal ECU, having different sources of supply induces noise on sensitive signals and on analog signals which are transduced from physical parameters have an impact over the results. To avoid these noise issues and eliminate EXT ADC as described, proposed solution is shown in figure 3.

It's a 5 staged circuit with 3 chips and includes a DC/DC converter for OpAmp Power supply.

Circuit Design Considerations

To interface the sensor data to ADC of microcontroller, following data shall be taken into consideration.

1. Range of the Signal - To Add gain
2. Max Voltage of the Signal - To select the OpAmp
3. Accuracy of the Signal - To select the OpAmp
4. Noise level on the Signal - To Design Filter

Steps involved in Design

Filtering

A RC Low pass filter is the best discrete filter to eliminate the noise, and which is economical despite cost, easy to construct, easy in stocking and easy to modify for change in parameters.

Filter Design Steps

1. Fix the Capacitor value in µF
2. Calculate the Resistor Value from

R = 1/ (2 x π x F x C)

R = Resistance in Ohms

F = Noise Frequency level to be suppressed in Hz

C = Capacitance in Farads

Figure 4 are the results of filter simulation. Filter is designed to allow a frequency less than 1kHz and above will be suppressed.

All discrete components shall be used with least tolerance (1%) for best performance.

Gain

Most of the Controller ADC are capable to take input voltages up to 5V/3.3V or 2.5V. To match the input signal level to VAdc Max, signal shall be reduced with gain factor. Gain of the circuit shall be calculated to reduce the given max signal voltage to Max ADC Input. Dual OpAmp which is configured both in inverted mode can reduce additional components and reduces the gain as needed.

Gain = Vmax of ADC/ Vmax of Input Signal

Gain = Ri/Rf

Rf = Feedback Resistor

Ri = Input Resistor

DC-DC Regulator Selection

As Operational amplifier requires negative supply sources to convert the signal positive and negative, on board non isolated DC-DC inverted regulator is needed. As the circuit is having single OpAmp it won't take much current, hence designing a flyback, buck-boost is much space occupied and using isolated supplies is expensive. A simple CMOS capacitor switch inverter supply is better in performance and pin compatible.

Comparing Signal

Signal2 is nothing but the reduced gain multiplied input signal. Signal2 can be compared to 0V and output of comparator can be used to select the analog switch. Comparator with a pull up provides a digital LOW or HIGH on input signal from +Ve to -Ve.

Switching the +Ve Signal Always

Signal1 is inverted and reduced Gain, Signal2 is inverted of Signal1. Both signals are connected to SPDT analog switch which is controlled with output of comparator to select signal as output. On input signal -Ve Comparator provides HIGH as output and NO of the analog switch connects to COM, on +Ve LOW as output and NC of the analog switch connects to COM.

Conclusion

Due to elimination of the EXT ADC, and its supporting circuitry, cost of the design and cost of SW development efforts is waived off. Irrespective of EXT ADC, we need to use some filters and gain components which are used in the proposed design.

Board has been designed with the circuit explained above, and tested in the lab, with a DC Tacho. Signal has been successfully interfaced using the design mentioned in this article, and the expected and actual outputs are as per the article.

Declarations

Data availability

All data in this study can be obtained by simulation results.

References

1. https://www.ti.com/lit/an/sboa093a/sboa093a.pdf
2. https://www.analog.com/media/en/training-seminars/design-handbooks/basic-linear-design/chapter1.pdf
3. https://www.baumer.com/asset/197882
4. https://www.ti.com/lit/pdf/sloa049
5. https://www.analog.com/media/en/training-seminars/design-handbooks/basic-linear-design/chapter8.pdf

Figures

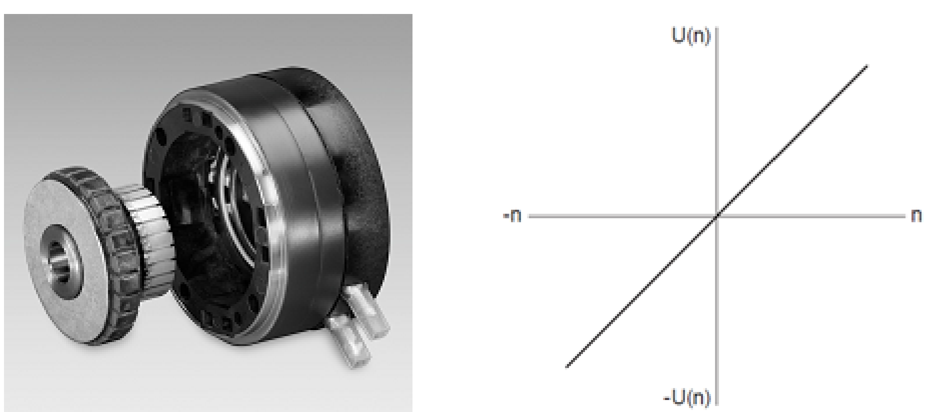

Figure 1

Tacho of a motor

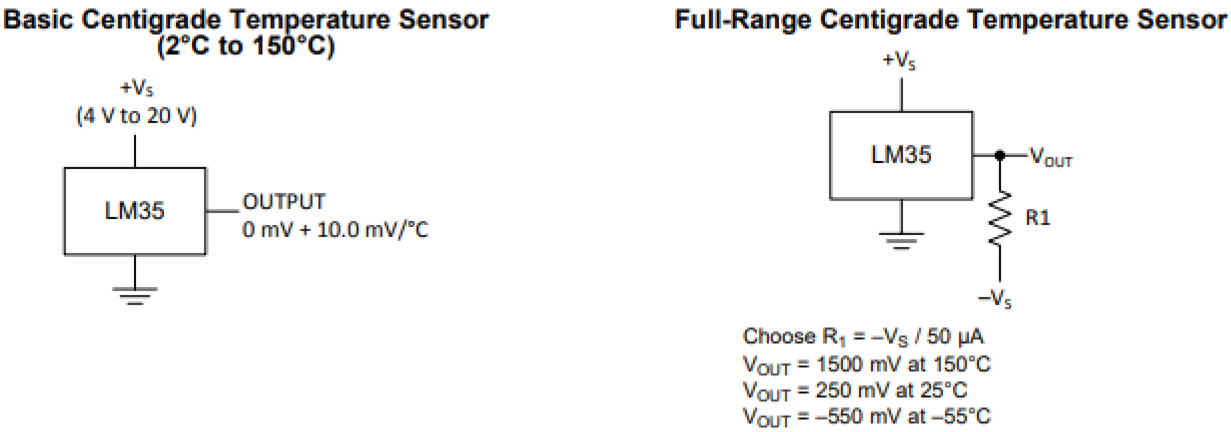

Figure 2

Temperature sensor

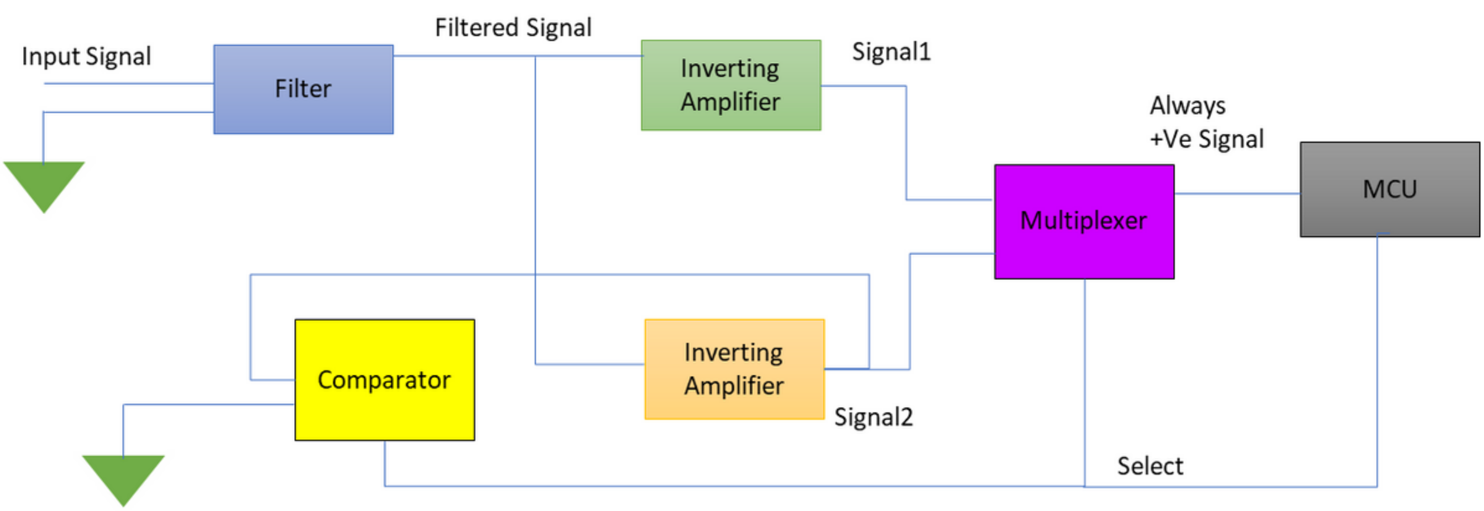

Figure 3

Proposed solution block diagram

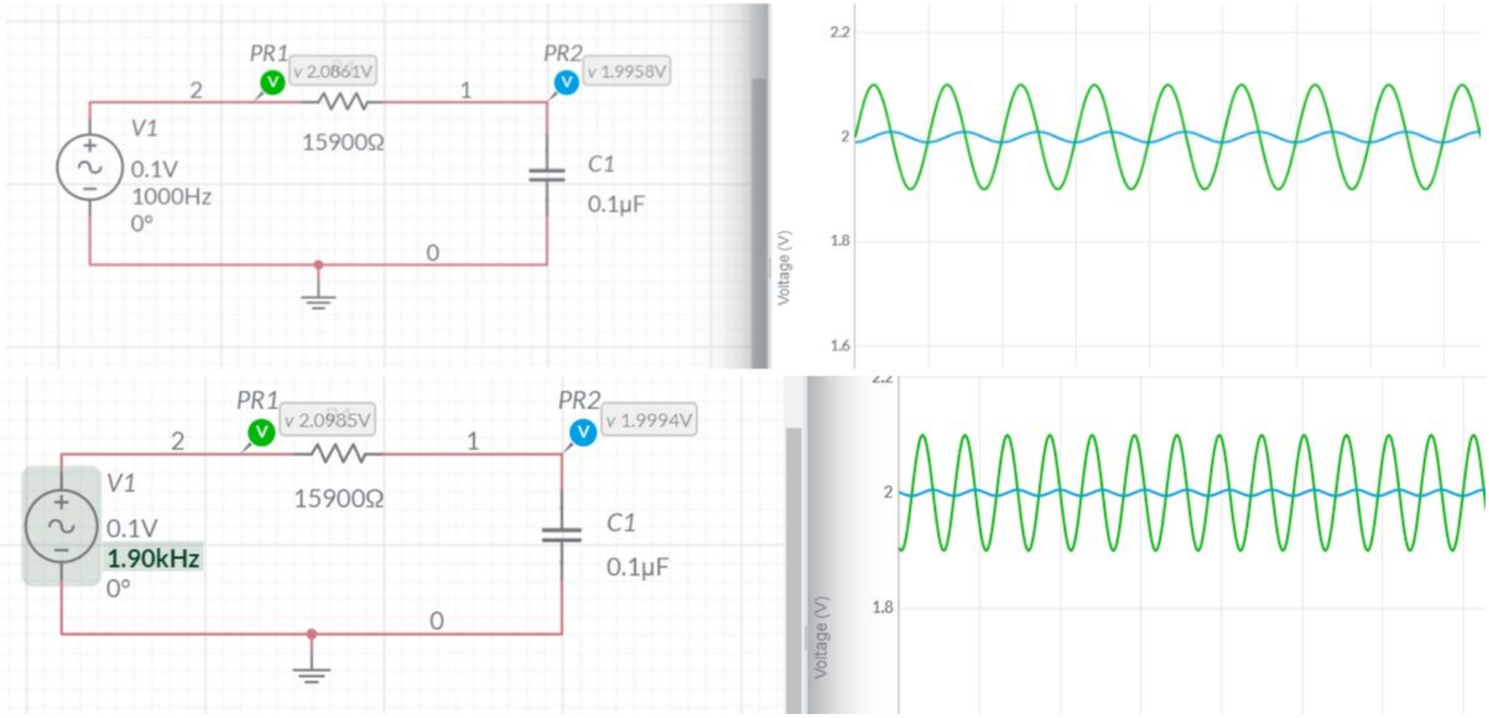

Figure 4

Low Pass Filter

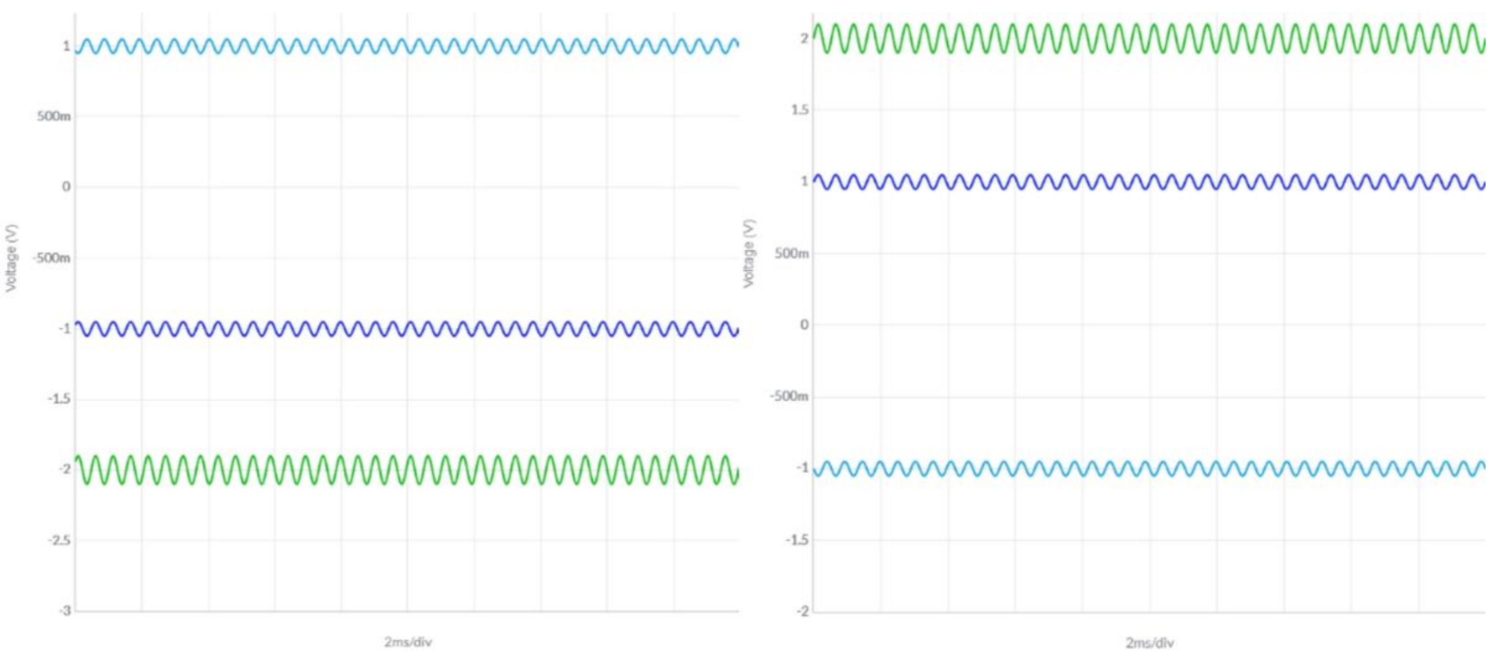

Figure 5

Amplifier Stage Output

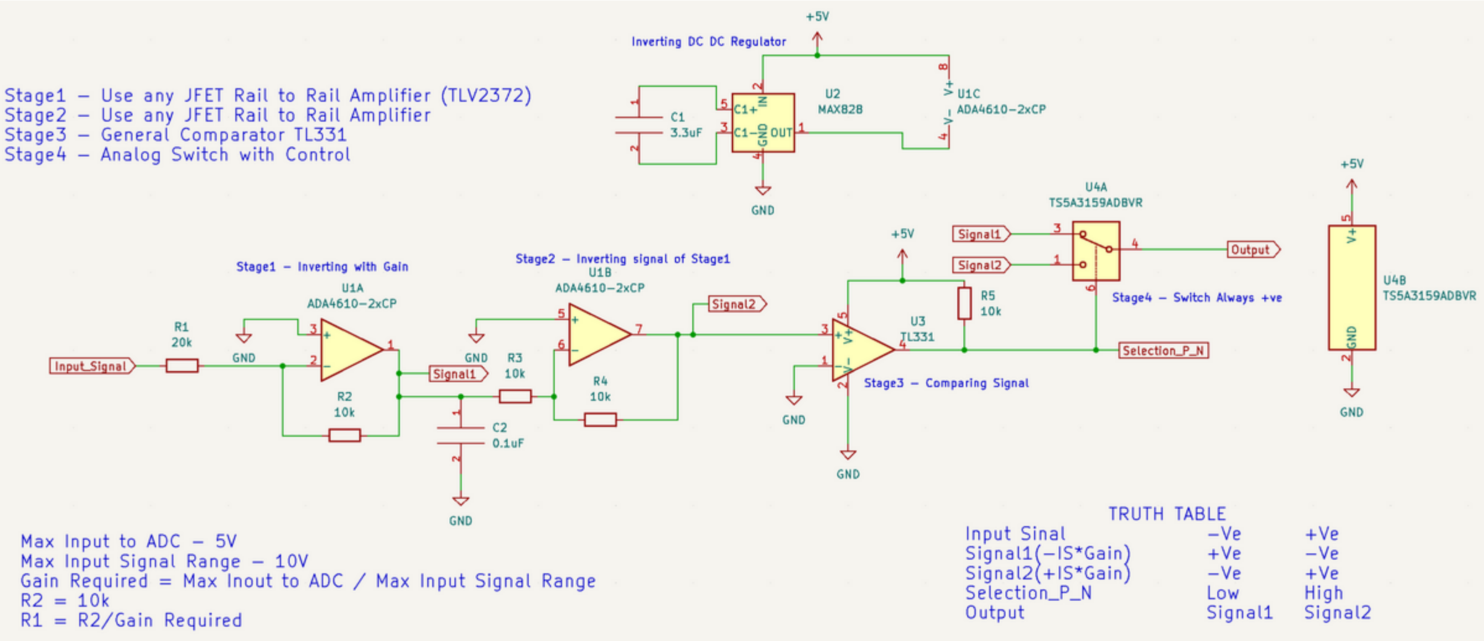

Figure 6

Complete Circuit Diagram

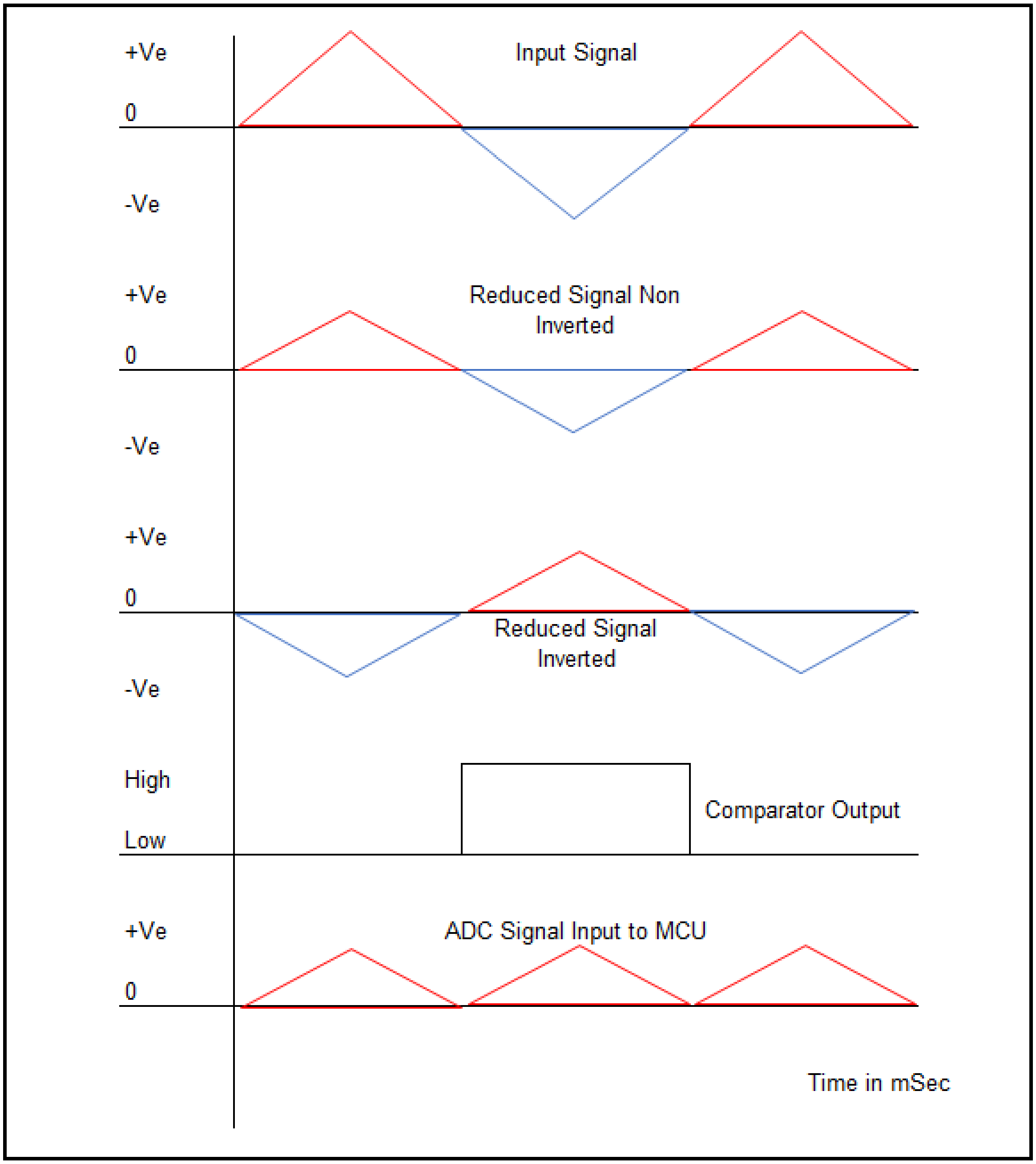

Figure 7

Stage Wise Results