Experiment 8

Op Amp Design Project

Rocket Probe Signal Conditioning and Interfacing Circuits

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section:6

INTRODUCTION

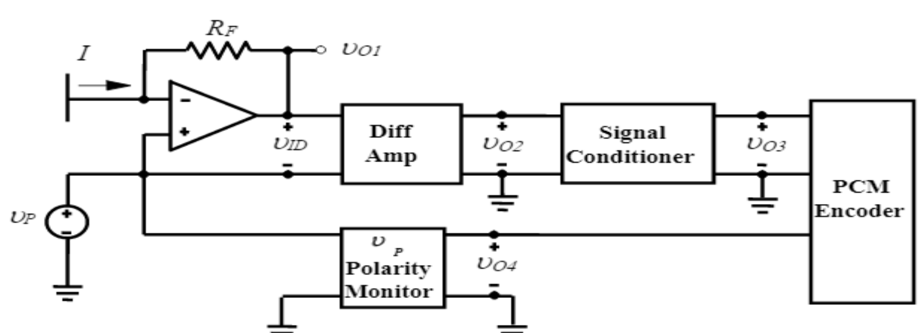
During this experiment, we are going to design a rocket probe that will convert the current to a voltage and remove an unwanted common-mode signal to ensure compatibility with the input to a telemetry system (PCM encoder).

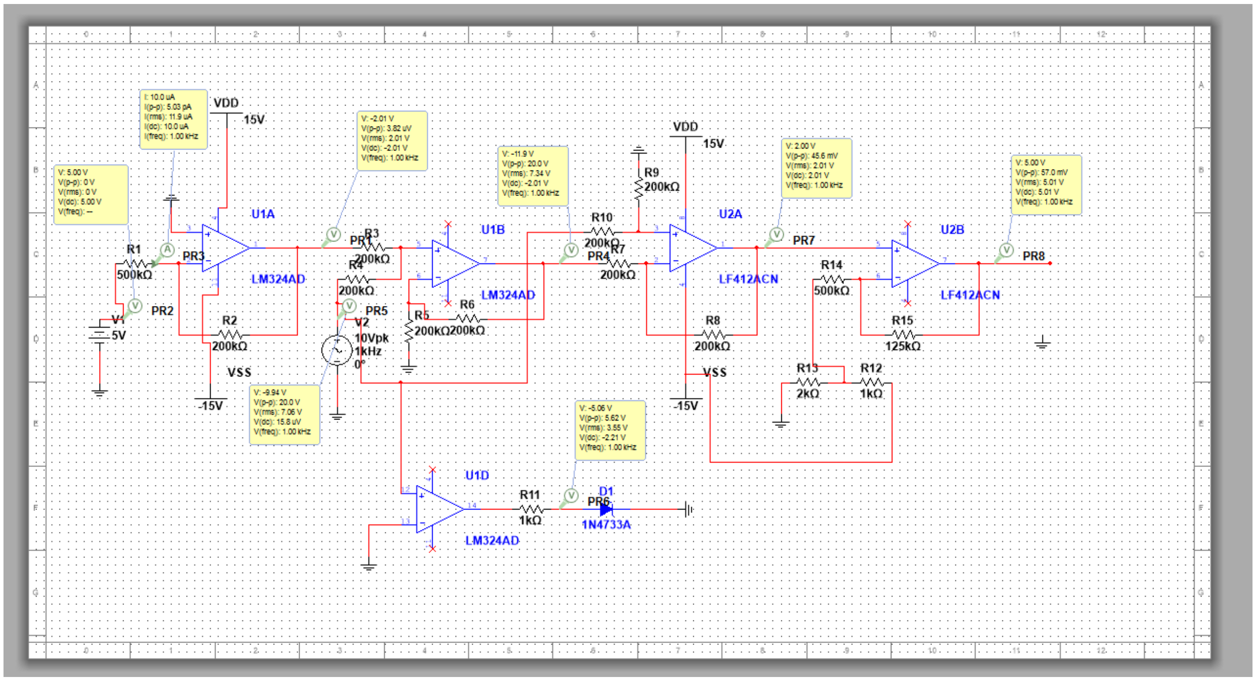
In our design, we will consider our initial current to be < 10 µA. Then, we will design an op amp to convert the current to a voltage (V_{o1}). Also, we expect that the voltage Vpp which will be a 20-V_{pp} triangular waveform and a frequency of 10 Hz will be added to V_{o1} because the probe needs to be biased and it will need to be subsequently removed. However, we want to cancel out the V_{pp} for the output voltage, so the subsequent voltage (V_{o2}) is referenced to system ground, to be of either polarity.

Lastly, we will need to do the signal conditioning for the final analog data signal (V_{o3}) is compatible with the PCM encoder's input to make its range between 0-5V. Moreover, to make the result more reliable, we also would like to know the polarity of the probe voltage V_{pp} by using the device as a comparator to be a voltage polarity monitor.

The following figure shows the brief information for the experiment:

Diagram of Probe Signal Conditioning and Interfacing Circuits





The expected voltage is showing by the table below:

V_{in}	I	V_{o1}'	V_{o1}	V_{o2}	V_{03}
+5 V	10 µA	-2 V	-12 to 8 V	+2 V	5 V
0 V	0 µA	0 V	-10 to 10 V	0 V	2.5 V
-5 V	-10 µA	+2 V	-8 to + 12 V	-2 V	0 V

V_p	V_{o4}
+10 V	5 V
-10 V	0 V

The specifications apply to the design effort:

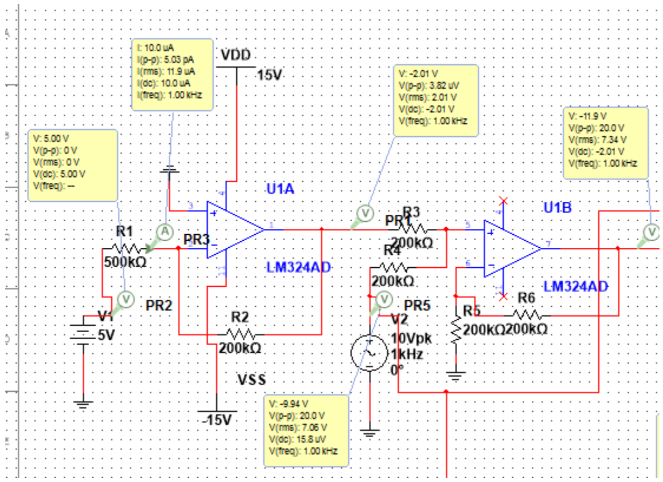
Input current magnitude ($|I|$) $\leq$ 10 µA
Small-signal transresistance gain ($\Delta v_{O3}/\Delta I$) = 200 V/mA
No v_P contribution at output (i.e., essentially perfect common-mode rejection)
Output voltages (v_{O3} and v_{O4}) compatible with PCM encoder's input (0-5 V)
Voltage polarity monitor accurate to ±10 mV
Power supply voltages: ±15 V

CIRCUIT DESIGN AND SUPPORTING ANALYSIS AND CIRCUIT DESCRIPTION, CALCULATION AND DESIGN REASONING

Block 1. Transresistance Amplifier

Schematics:

It is used to get 10 µA current and convert it to voltage signal.



Circuit Description and Design Reasoning:

In this task, our purpose of the transresistance amplifier is to convert the input current of the circuit into a voltage source, which we had told in introduction. We use a non-inverting amplifier circuit by using LM324AD op amp. The resistor value is shown in the figure. As we talk before, the probe needs to be biased, so we use two op amp in this situation.

Calculation:

5V/500kΩ = 10 µA

$V_{o1}' = V_{in} * (200k\Omega / 500k\Omega) = 2$ V

We know that op amp had very big input impendence, so we can assume $V^{-}=V^{+}$ and $I^{-}=I^{+}=0$. Therefore, we could apply KCL @ V^{-}:

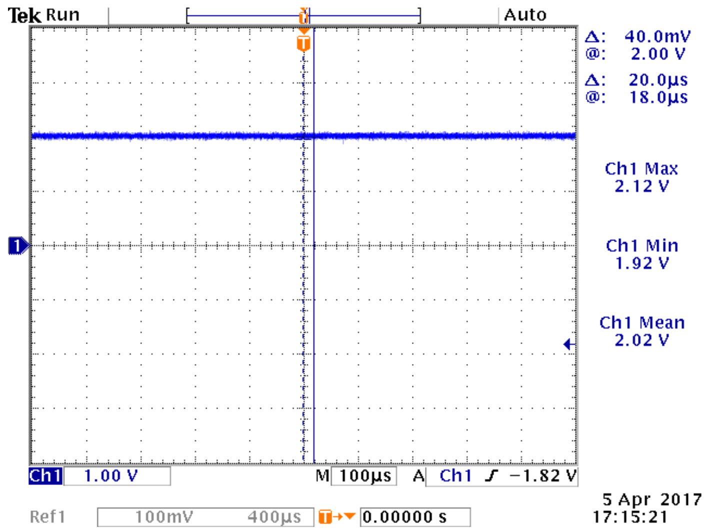
$$\frac{Vpp+Vo1'}{2R5}+\frac{Vpp+Vo1'-Vo1}{2R6}=0$$

$V_{o1} = (V_p+V_{o1})$

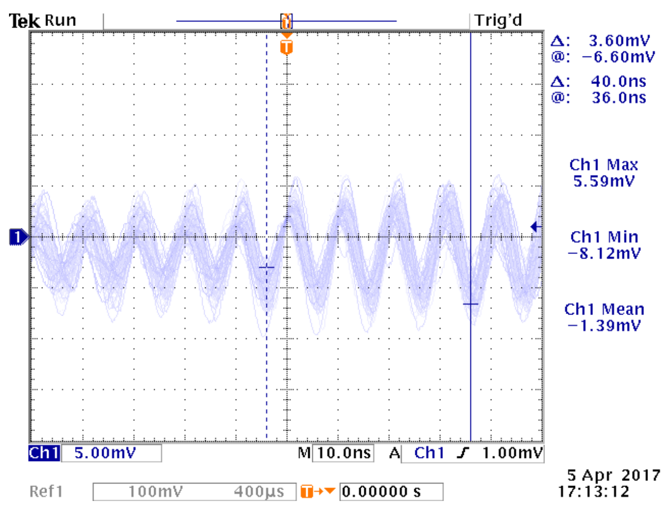
Therefore, we would get 10 µA input current and convert it to a voltage source.

The measurement we got from the real circuit (V_{o1}'), we got 2.02V, -1.39mV and -1.97 V.

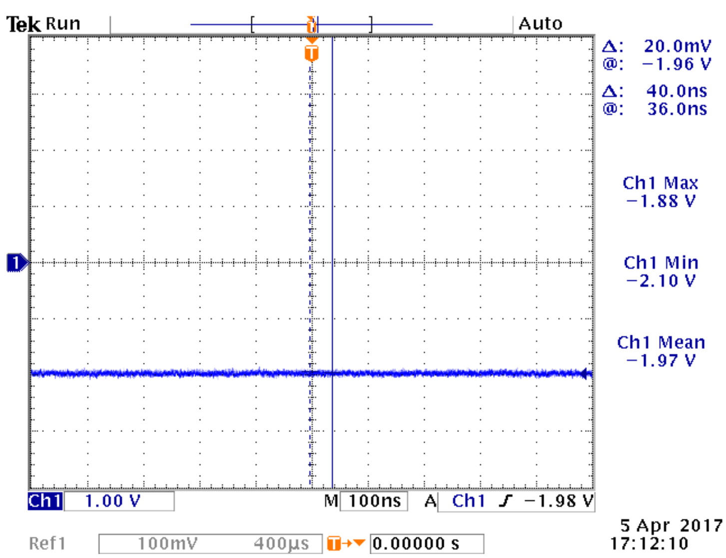
5V:


Tek Run
Auto
Δ: 40.0mV
@: 2.00 V
Δ: 20.0µs
@: 18.0µs
Ch1 Max
2.12 V
Ch1 Min
1.92 V
Ch1 Mean
2.02 V
Ch1 1.00 V
M 100µs A Ch1 ∫ −1.82 V
Ref1 100mV 400µs
0.00000 s
5 Apr 2017
17:15:21

0V:

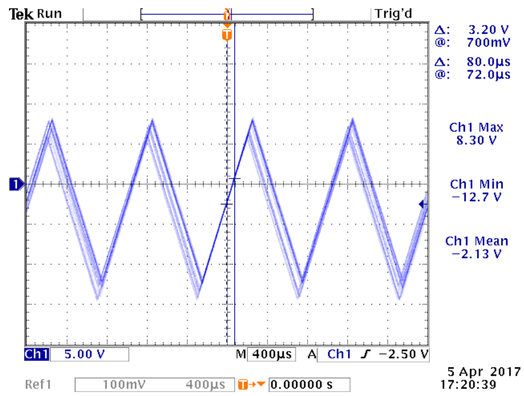

Tek Run
Trig'd
Δ: 3.60mV
@: −6.60mV
Δ: 40.0ns
@: 36.0ns
Ch1 Max
5.59mV
Ch1 Min
−8.12mV
Ch1 Mean
−1.39mV
Ch1 5.00mV
M 10.0ns A Ch1 ∫ 1.00mV
Ref1 100mV 400µs
0.00000 s
5 Apr 2017
17:13:12

-5V:

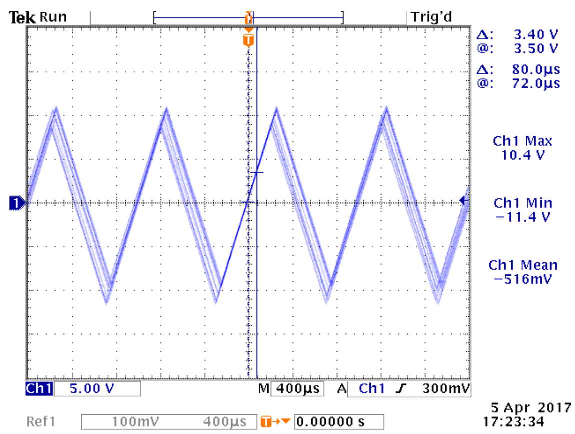

Tek Run
Auto
Δ: 20.0mV
@: −1.96 V
Δ: 40.0ns
@: 36.0ns
Ch1 Max
−1.88 V
Ch1 Min
−2.10 V
Ch1 Mean
−1.97 V
Ch1 1.00 V
M 100ns A Ch1 ∫ −1.98 V
Ref1 100mV 400µs
0.00000 s
5 Apr 2017
17:12:10

The oscilloscope for V_{o1} and the measurement:

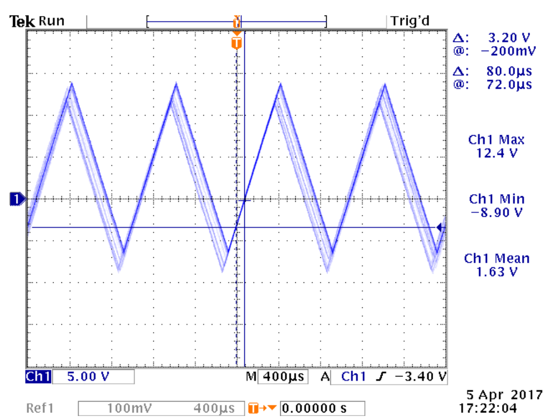
5V:



0V:



-5V:

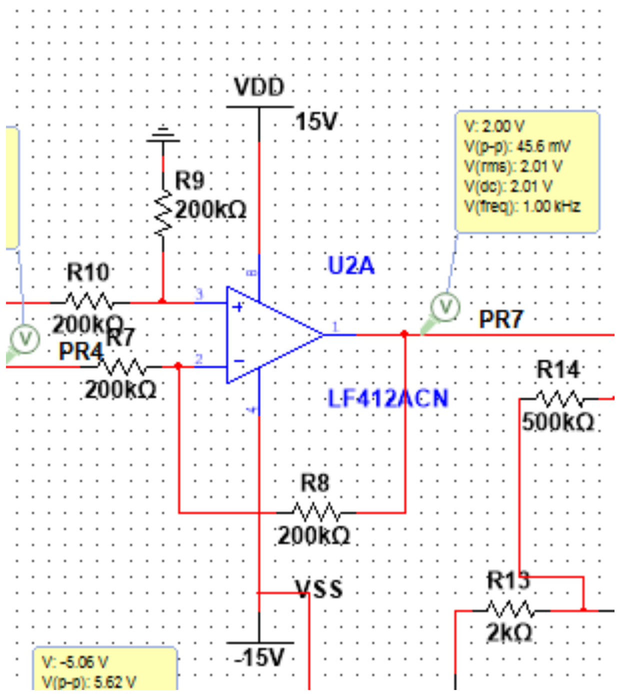


From the figure above, we could see that the current source does convert into the voltage source. We could see that the oscilloscope had some noise because we found out that the wire we used was not in good condition but the value we measured was matched our expectation and we would compare the experimental and theoretical value later.

Block 2. Difference Amplifier

Schematic:

The difference amplifier is used to get $V_{02} = V_{o1}'$.



Circuit Description and Design Reasoning:

We know that the purpose of the difference amplifier is tried to remove the bias voltage from the output voltage of the final signal to make it compatible with the PCM encoder's input. The resistor value is shown in the figure above, which is 200kΩ.

We want to make $V_{o2} = V_{o1}'$

Calculation:

$$V+= \frac{R9}{R10+R9}\, Vp$$

We know V+=V-, so apply KCL @ V-:

$$\frac{V^{-}-Vo1}{R7} + \frac{V^{-}-Vo2}{R8} = 0$$

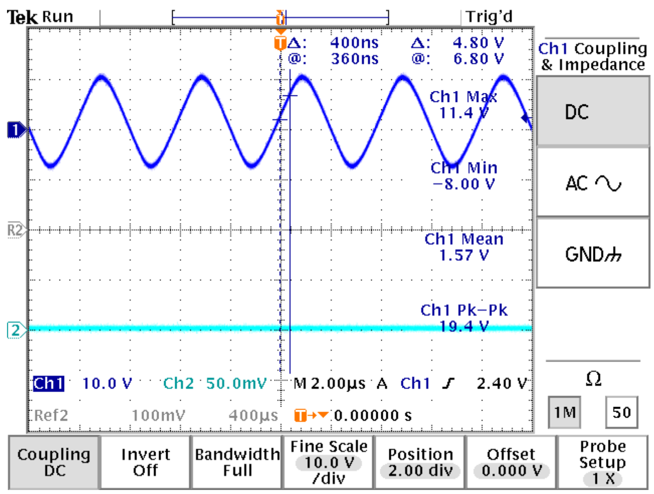
⇨ $$Vo2 = \left(\frac{R8}{R7} + 1\right)\frac{R9}{R10+R9}Vp - \frac{R8}{R7}Vo1$$

So $V_{o2} = V_p - V_{o1} = 2$ V

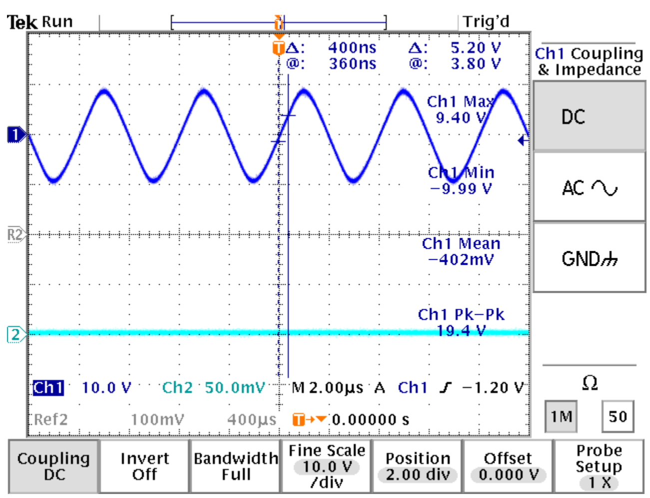
Therefore, we could conclude that we use the difference amplifier to get output voltage equals to difference of V_p and V_{o1}'

In the following, is the real circuit testing oscilloscope:

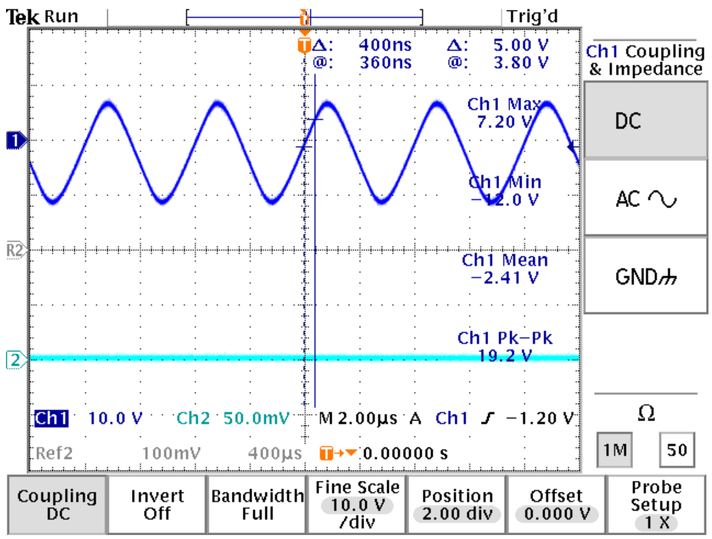
5V:



0V:



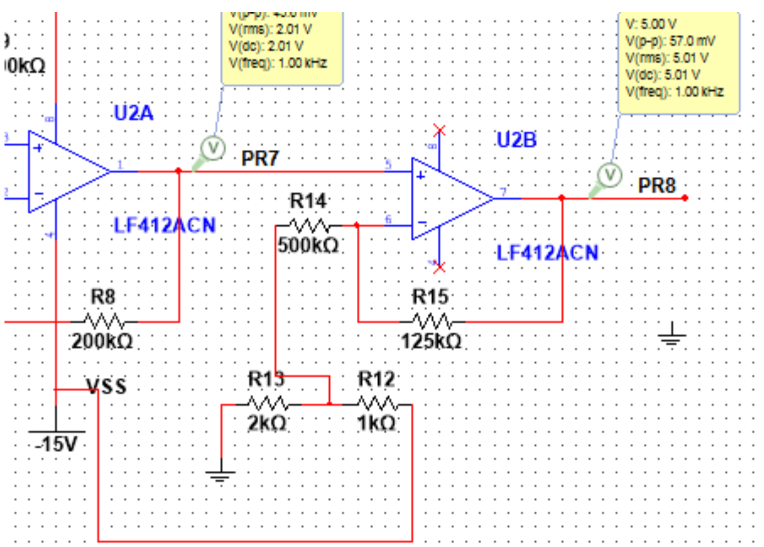
-5V:



From our testing result, we could see that the voltage was same as V_{o1} although there is still some error exist, which we will discuss later. However, we found out that our design does make sense and match the condition due to the oscilloscope above.

Block 3. Signal Conditioner

Schematic:



The signal conditioner is used to get output range in 0-5V.

Circuit Description and Design Reasoning:

Our purpose of the signal conditioner is to take V_{o2} through the conditioner to make the voltage output (V_{o3}) in the range of 0 to 5 V, which is required analog voltage of the PCM encoder. Therefore, we will do the calculation to present our assumption.

For the V^-: 15 V * (1kΩ/(1+2)kΩ) = 10 V

We know that $V_{o3} = V_{o2}*(1+ R15/R14) + (10V)*R15/R14$

$= V_{o2} +(V_{o2}+10)*R15/R14$

So : $V_{o2} = 2V \Rightarrow V_{o3}= 5V$

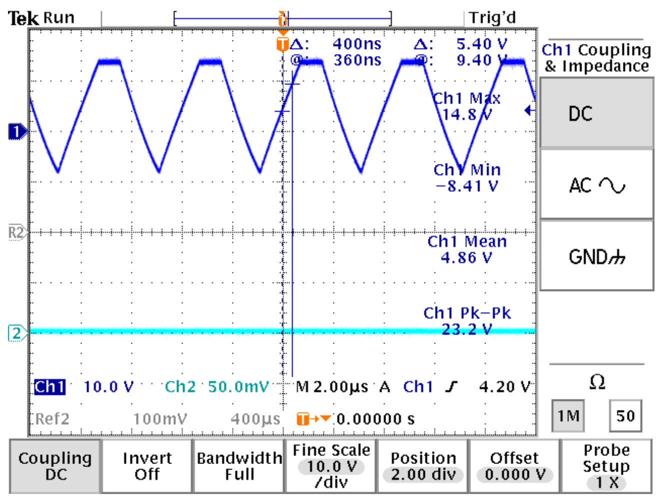
$V_{o2} = 0V \Rightarrow V_{o3}= 2.5$ V

$V_{o2} = -5$ V $\Rightarrow V_{o3}= 0$ V

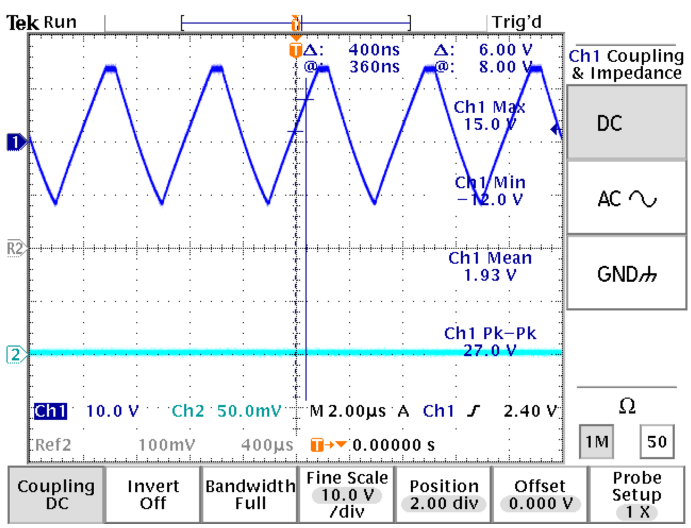
Therefore, from the calculation, our assumption and circuit met the requirement.

In the following, we test our real circuit and find out that the value has not quite if we use the resistor above, so we decide to change R15 in to 330Ω, and the oscilloscope is in the below:

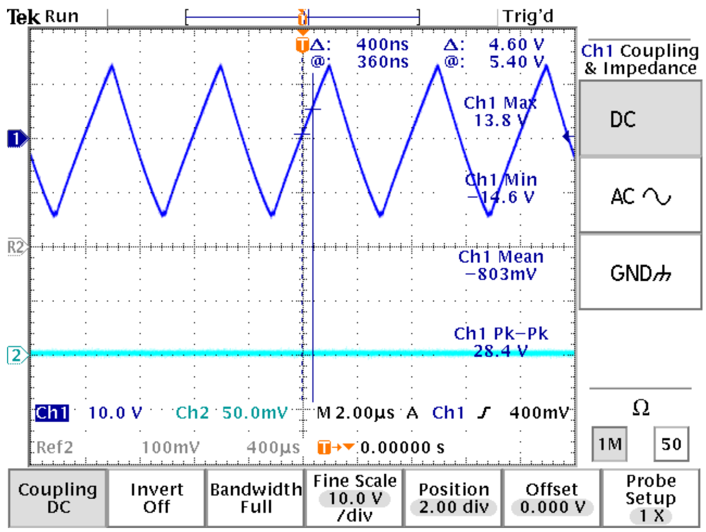
5V:



0V:



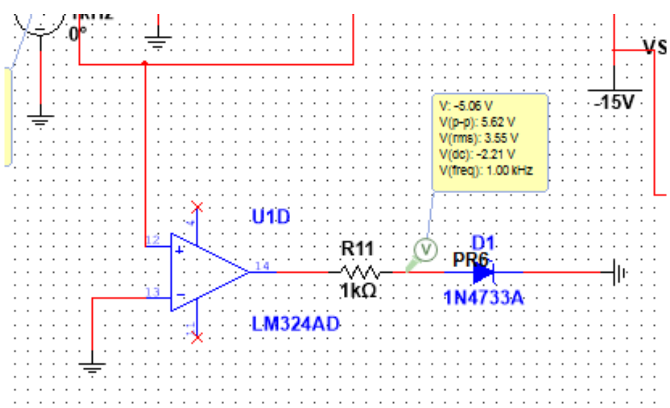
-5V:



We could see that the oscilloscope does support our design and the value does match the requirement for the PCM encoder. Also, we notice that the circuit is in saturation when the V_{o2} is 5V and 0V. We believe that the issue is come from the resistor we have picked, but it doesn't influence a lot in our experiment. We will discuss the value with the theoretical number later.

Block 4. Polarity Monitor subsystem

Schematic:



It tells us the probe collection voltage's polarity.

Circuit Description and Design Reasoning:

Our goal in this block is to determine the polarity of the input voltage using a comparator circuit using voltage divider and op amp, so we could see the polarity of the circuit since we expect positive charge collection to result when the probe has a negative bias voltage, and vice versa.