Lab 3.1.A: Putting opamps to 'gainful' use [Negative Feedback]

All question material is in blue. Please put your answers in black color font.
Note on symbols for Gain:
In earlier labs we used the symbol **G** to denote the open-loop gain of an opamp. For the LM741 **G~10^6**(effectively infinite as approximated in most equations).
As discussed in class, the opamp working in open-loop mode is not very useful. Our objective is to design and build an opamp circuit with a finite gain – we will call this gain **G$_f$ i.e. the gain with feedback in place. G$_f$ is a finite number whose value is specified by design**

Part A: Simple Negative Feedback

A.1) Simple negative feedback to set finite voltage gain G$_f$

A.1.1 non-inverting negative feedback

In the pre-lab session, the following scheme of negative feedback was discussed to arrange a circuit with gain $G_f = \frac{1}{x}$:

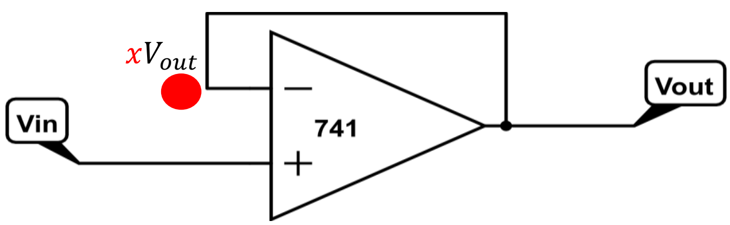


Fig 1: Basic scheme for opamp negative feedback, preserving the sign of V_{in}

A.1.1.1) Design **[2]**

Arrange a resistor divider to feedback a fraction xV_{out} of the output voltage V_{out} back to the V_- input of the opamp.

Work out the design equations to calculate values of the resistor divider for $G_f = +10$ in your circuit design. Justify the choice of particular resistor values you use. Write all steps of the design equation here: Use 'Insert equation' in MS-Word or Libre-Office to format your equations correctly including subscripts. A prototype equation is provided below, which you may copy-paste and reuse. One equation per line looks good!

$$V_{out} = G(V_+ - V_-)$$

$$x = \frac{1}{G} = \frac{1}{10}$$

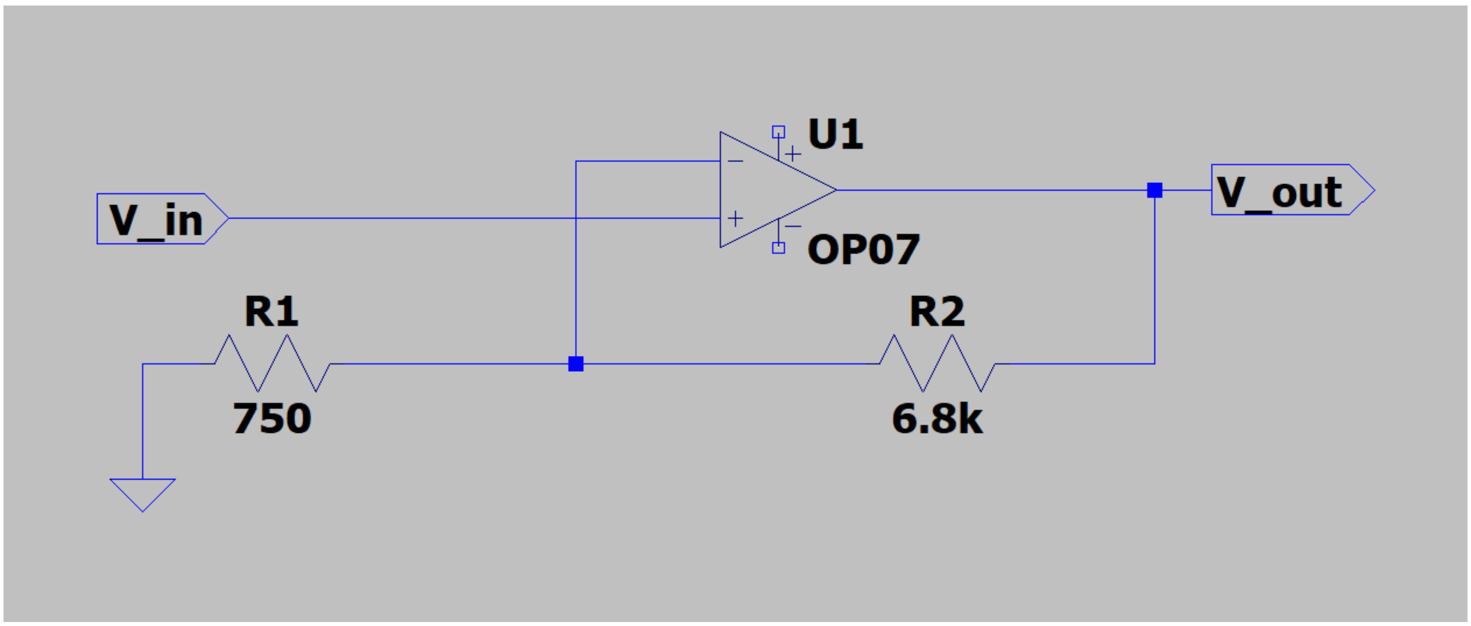
Closed loop gain, $G = 1 + \frac{R1}{R2}$

Therefore, $\frac{R1}{R2} = 9$

A decent choice of R1 and R2 that satisfies the above relation would be 6.8kΩ and 750Ω respectively.

A.1.1.2) LTSpice simulation

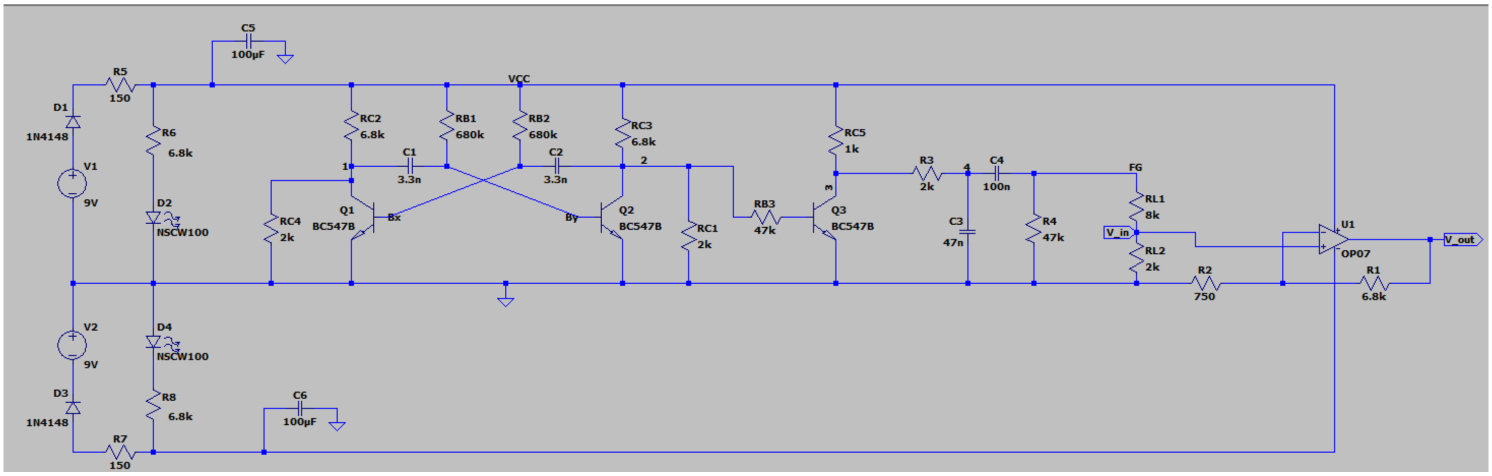
Draw your circuit diagram in LTSpice. **[2]**
For clarity, only put your negative feedback opamp circuit design here (not full design with FG)
You may use the standard opamp available in LTSpice OP07 as a stand-in replacement for LM741

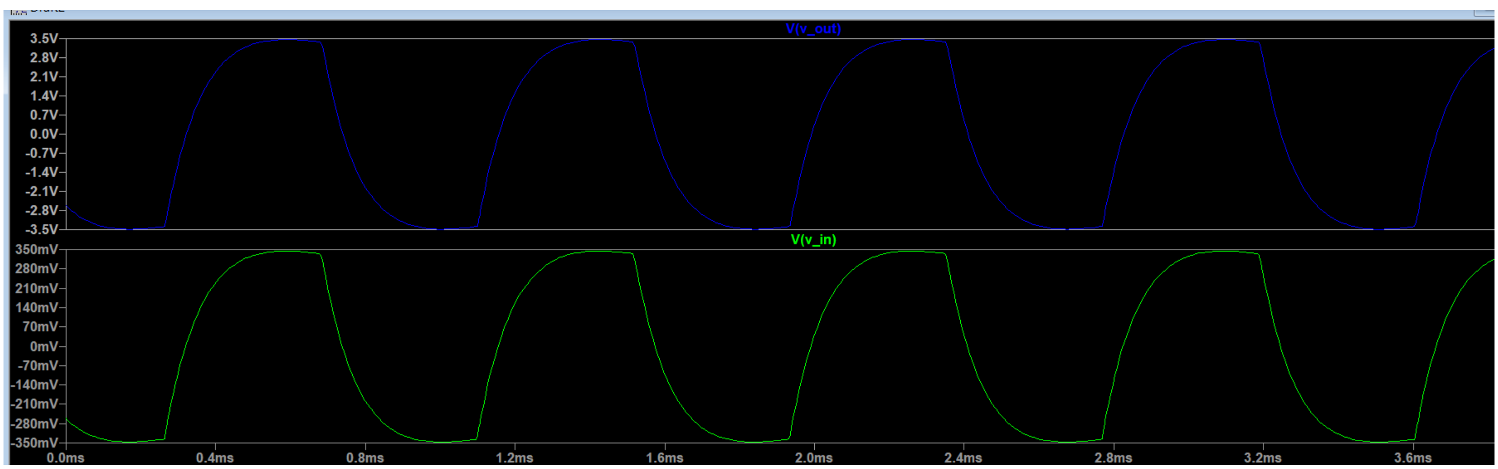


Run the simulation in LTSpice and put below a plot of your simulated $V_{in} \rightarrow V_{out}$ signals.
Now obviously you need to include the FG simulation for this step.

Remember to put large value electrolytic (100μF/47μF/22μF/10μF) power supply bypass capacitors for both FG and opamp power rails. Note that you will be running the opamp with ≈ ±8V V_{CC} rail voltage as setup in Lab 2. From the simulation determine a suitable amplitude of V_{in} such that V_{out} does not hit the opamp saturation voltage limits when you test the circuit experimentally in the next step.Objective of your simulation: Verify the gain and phase difference (if any) in the transfer function $V_{in} \rightarrow V_{out}$

To check the phase difference, you must display both V_{in} and V_{out} with individual scaling on Y-axis: First plot just V_{in} using the voltage probe tool. Then, select the Output window and choose "Add Plot Pane" option from the "Plot Settings" drop-down control. Next, plot V_{out} as the second voltage using the voltage probe tool **[2]**

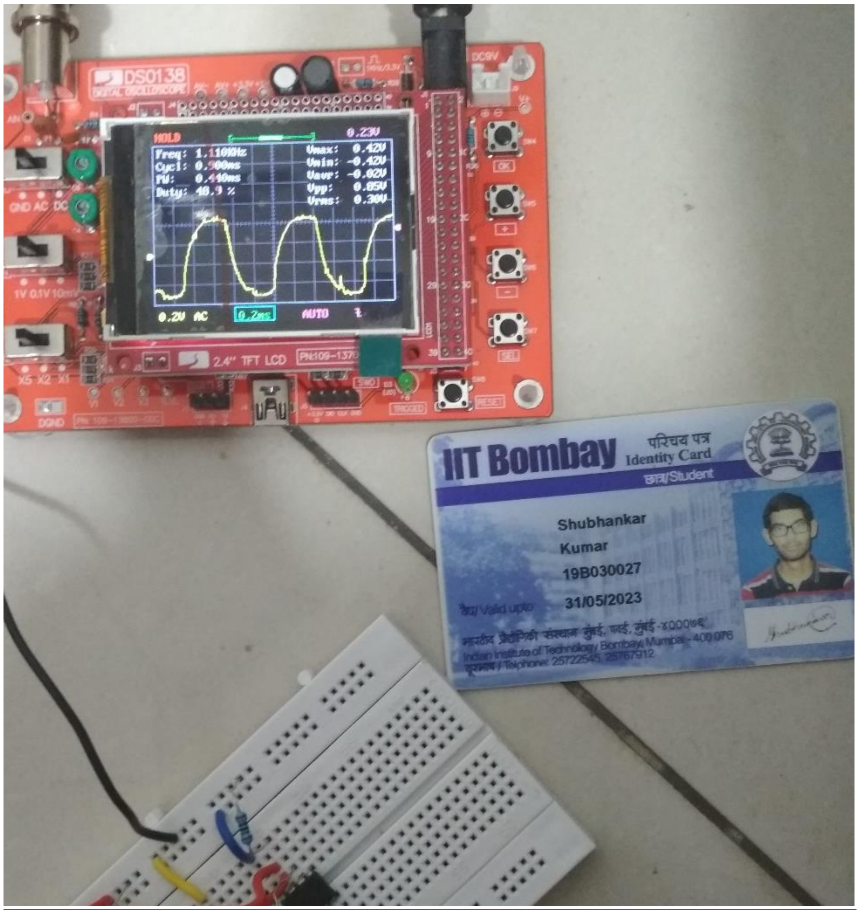




A.2) Circuit demo: Non-inverting amplifier with $V_{out} = +10V_{in}$ [6]

Build the opamp circuit as designed and simulated in the above steps on your breadboard. Drive the input V_{in} with the FG used in earlier labs. Set the FG output amplitude as chosen in the simulation.

Put a photo of your working setup here, clearly labelling V_{in} and V_{out}. With a single channel DSO measurement, it is not possible to measure the phase difference in experiment (at least at this stage, maybe later?!)


DSO138
DIGITAL OSCILLOSCOPE
HOLD
0.23V
Freq: 1.110KHz
Cycl: 0.900ms
PW: 0.440ms
Duty: 48.9 %
Vmax: 0.42V
Vmin: -0.42V
Vavr: -0.02V
Vpp: 0.85V
Vrms: 0.30V
0.2V AC
0.2ms
AUTO
2.4" TFT LCD
IIT Bombay
परिचय पत्र
Identity Card
छात्र/Student
Shubhankar
Kumar
19B030027
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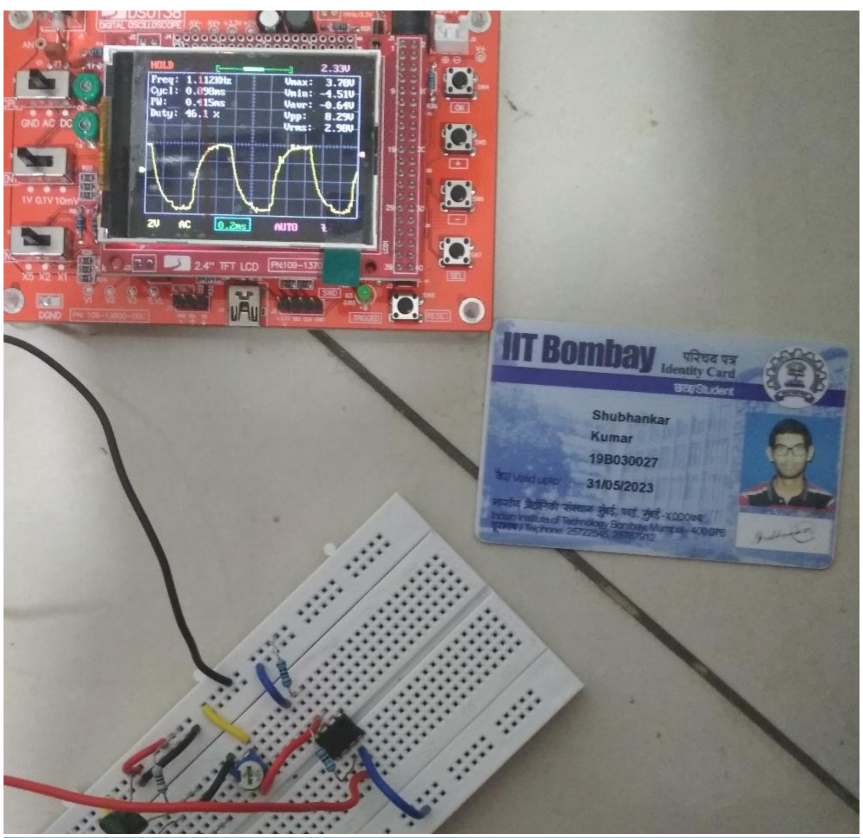
V_{in}


DIGITAL OSCILLOSCOPE
HOLD
2.33V
Freq: 1.112KHz
Cycl: 0.898ms
PW: 0.415ms
Duty: 46.1 %
Vmax: 3.78V
Vmin: -4.51V
Vavr: -0.64V
Vpp: 8.29V
Vrms: 2.98V
2V AC
0.2ms
AUTO
2.4" TFT LCD
IIT Bombay
परिचय पत्र
Identity Card
छात्र/Student
Shubhankar
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V_{out}

A.3) Negative feedback, inverting the sign of V_{in}

By a rearrangement of node connections in Fig 1 it is possible to apply a negative sign to the gain: $V_{out} = -G_f V_{in}$.
This is called an 'inverting' configuration since V_{out} is out of phase with respect to V_{in} by 180°
Keep in mind that for negative feedback, by definition a fraction of V_{out} must be applied to the V_- terminal of the opamp. However, you are free to cleverly connect V_{in} to either V_+ or V_-

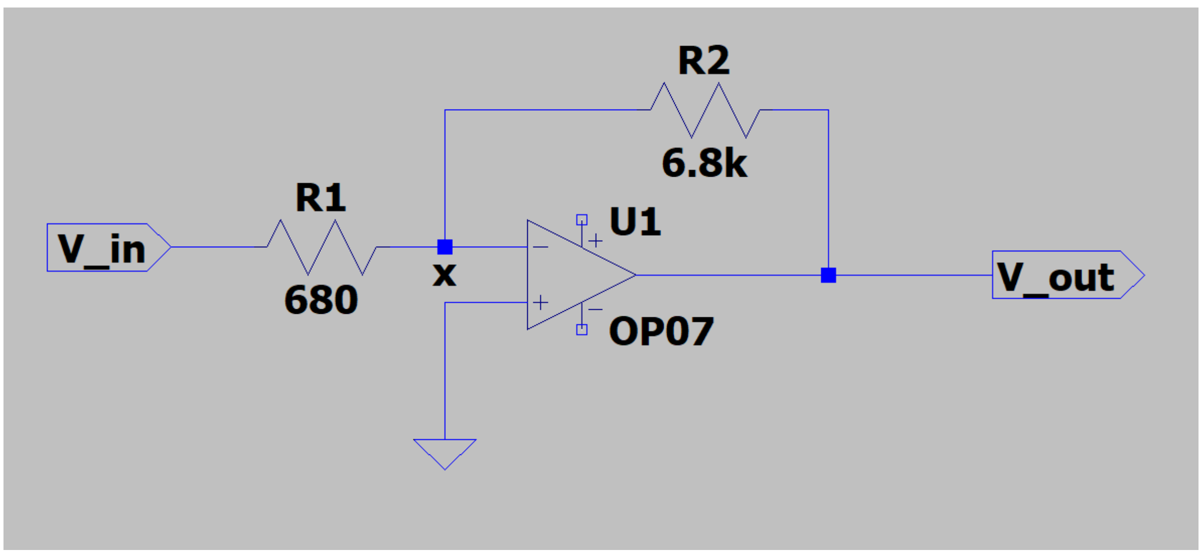
Work out your circuit design and component values for implementing the experimental relation $\boldsymbol{V_{out} = -10 \times V_{in}}$: the absolute value of the G_f is the same, but now there is a negative sign!

A.3.1) [4]

Circuit design: **2 marks**

Equations: **1 marks**

LTSpice simulation: **1 marks**

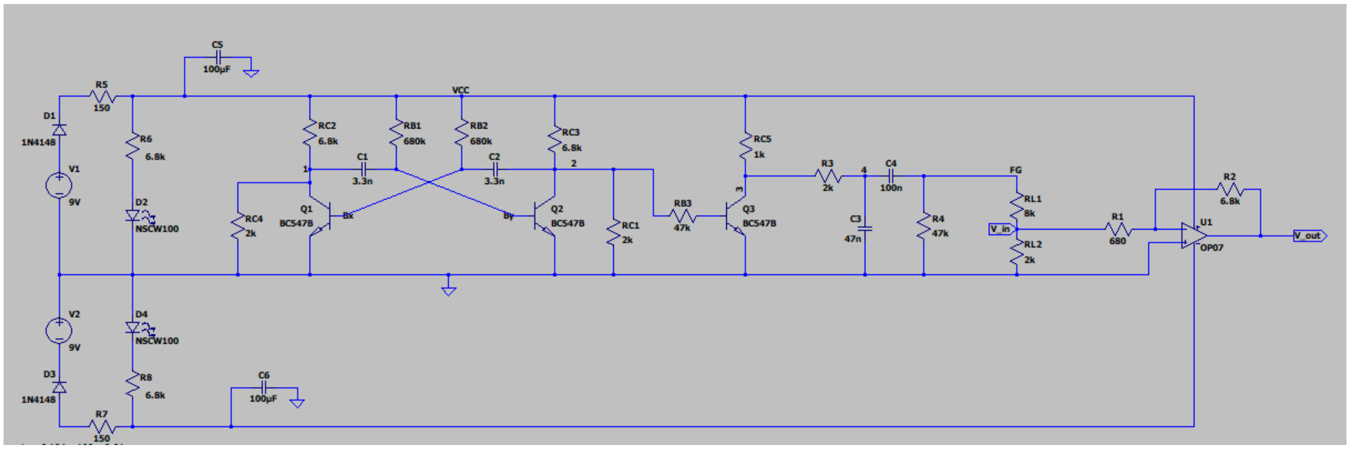


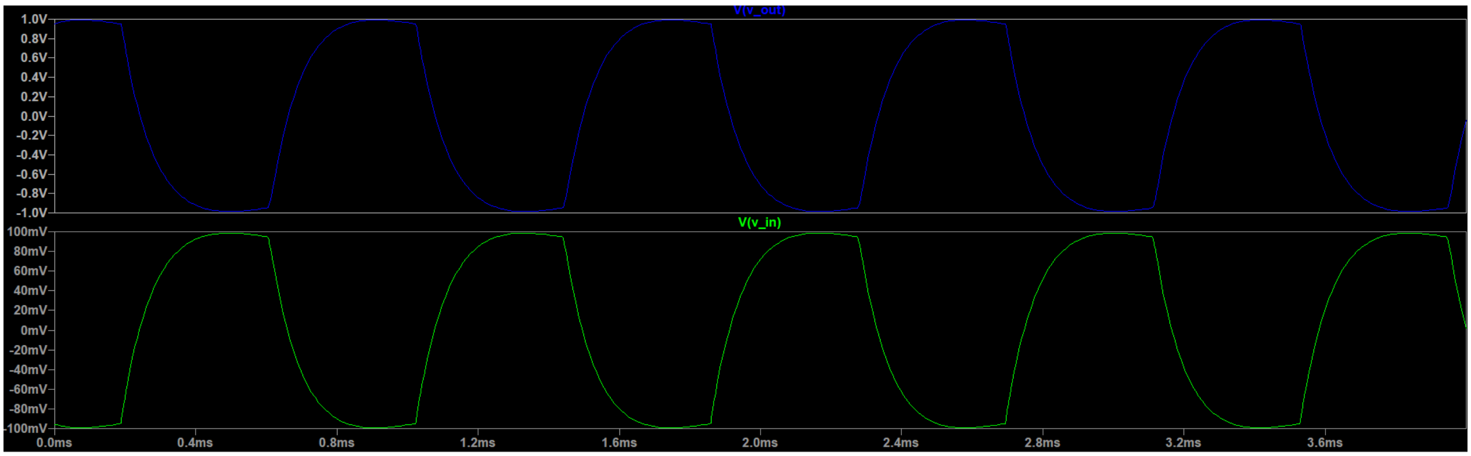
Applying KCL at node x,

$$\frac{Vin - 0}{R1} = \frac{0 - Vout}{R2}$$

$$\text{Therefore, } \frac{Vout}{Vin} = -\frac{R2}{R1}$$

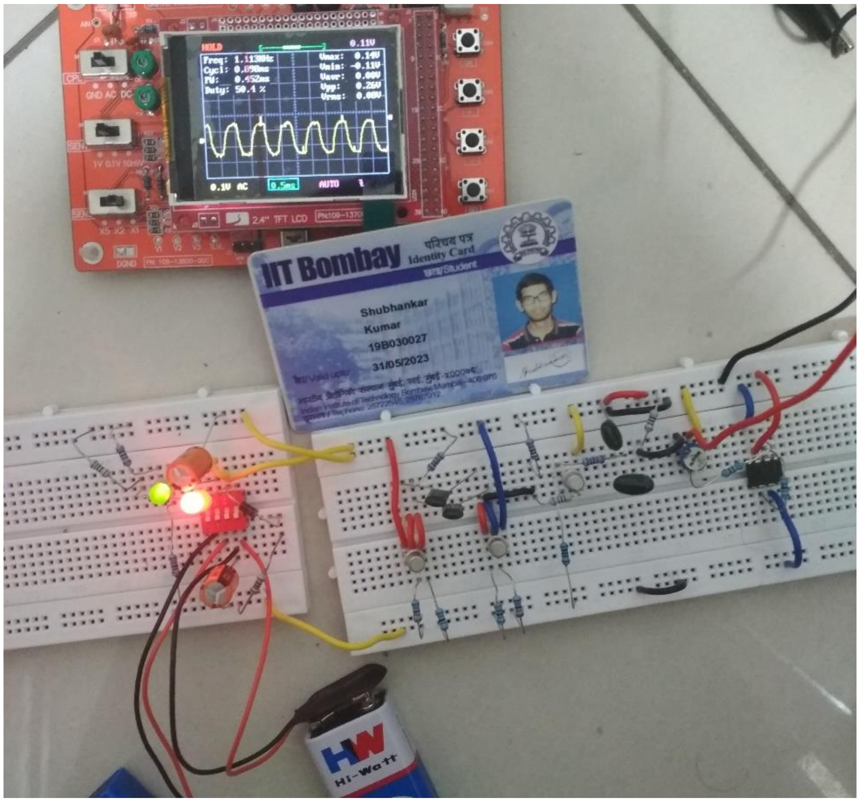
If we want the gain to be -10, then R1 and R2 can be taken as 680Ω and 6.8kΩ respectively.





A.3.2) Circuit demo of inverting amplification: $V_{out} = -10 \times V_{in}$ [3]

Build the circuit for inverting amplifier as per A.3.1 and put photos of your working setup.


HOLD
0.11V
Freq: 1.113KHz
Cycl: 0.898ms
PW: 0.452ms
Duty: 50.4 %
Vmax: 0.14V
Vmin: -0.11V
Vaver: 0.00V
Vpp: 0.26V
Vrms: 0.08V
0.1V AC
0.5ms
AUTO
2.4" TFT LCD
IIT Bombay
परिचय पत्र
Identity Card
Shubhankar
Kumar
19B030027
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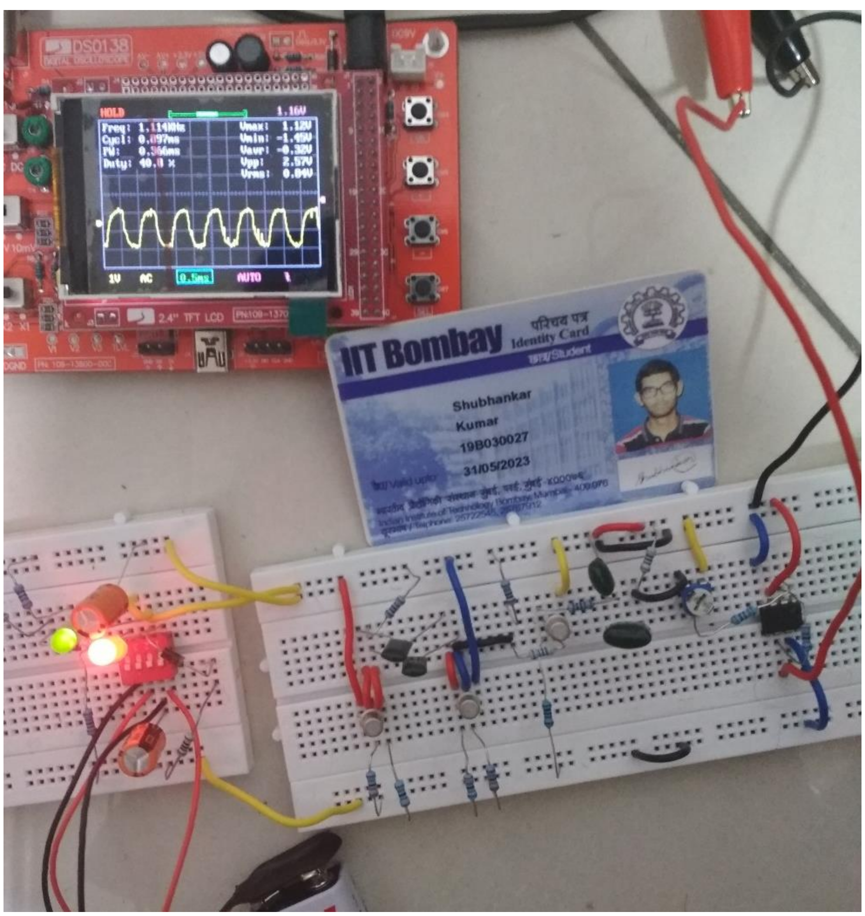
Hi-Watt

V_{in}


DSO138
HOLD
1.16V
Freq: 1.114KHz
Cycl: 0.897ms
PW: 0.366ms
Vmax: 1.12V
Vmin: -1.45V
Vavr: -0.32V
Vpp: 2.57V
Vrms: 0.84V
1V AC
0.5ms
AUTO
2.4" TFT LCD
IIT Bombay
परिचय पत्र
Identity Card
Shubhankar
Kumar
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V_{out}

A.3.3) With only a single channel measurement on the DSO, how can you tell that the amplifier is inverting the sign of V_{in}? It IS possible! **[3]**

(Check the input amplitude V_{in} being sent from your FG to opamp, and look ahead to question A.4 for a hint)

One way to identify this is the fact that V_+ will almost be equal to V_- in this case. Hence if we connect the black probe to V_+ (ground), the reading should be ~0V when the red probe is connected to V_-. Also, since V_- is approx. 0V and that the feedback is negative, the output voltage will be negative wrt V_-, therefore inverted wrt to V_{in}.

Another way is to use an "asymmetric" input such as a square wave, say between 0 and 9V. Then the output voltage will range between 0 and a negative number. This will confirm that the output is inverted wrt the input.

A.4) Input impedances?

1) What is the input impedance of the straightforward "non-inverting" configuration of A.1.1, when $V_{out} = +G_f V_{in}$? **[2]**

Explain your answer with calculation steps & logical reasoning of the flow of current into/out of various nodes (you can check this in your LTSpice simulation)

The input impedance in this case is generally very high

We have the relation, $Z_{in} = \left(1 + \frac{G_0}{G_f}\right) Z_0$, where G_f is the closed loop gain, G_0 is the open loop gain and Z_0 is the input impedance without any feedback.

In this case, $Z_{in} = V_{in}/I$. Now since I is extremely small, Z_{in} will be very large. Almost all the current passing through R_1 will go to R_2.

2) What is the input impedance of the "inverting" configuration of A.1.2, when $V_{out} = -G_f V_{in}$? **[2]**

Explain your answer with calculation steps & logical reasoning of the flow of current into/out of various nodes (you can check this in your LTSpice simulation)

In order that the circuit can operate correctly, the difference between the inverting and non-inverting inputs must be very small - the gain of the op amp is very high and therefore for a small output voltage, the difference between the two inputs is small.

This means that inverting input must be at virtually the same potential as the non-inverting one, i.e. at ground. As a result the input impedance of this op amp circuit is equal to the resistor R_2 (the input resistance).