**EE 230 - Analog Lab**
Wadhwani Electronics Laboratory
Electrical Engineering IIT Bombay

Lab: 6

## Instructions:

- Write down all your observations in notebook.
- Verify your calculations with your respective TA.

## Objectives:

- To understand the effects of Opamp offsets and able to measure and compensate them.
- To measure open-loop gain

1. **Measurement of offset voltage and bias currents**

   When an op amp is used in a circuit, the bias currents $I_B^+$ and $I_B^-$ as well as the input offset voltage $V_{OS}$ would generally affect the output voltage. In order to measure these quantities, we require circuits which enhance the contributions of one of these parameters while keeping the other two contributions small.

   (a) **Measurement of $V_{os}$**

   i. Fig.[ 1] shows a circuit which can be used for measurement of $V_{OS}$. Fig. [ 2] shows the same circuit re-drawn using the op amp equivalent circuit which accounts for the op-amp non-idealities, viz., $V_{OS}$, $I_B^+$ and $I_B^-$. Using superposition, we can show that $V_o = V_{OS}(1 + \frac{R2}{R1}) + R_2 I_B^-$.

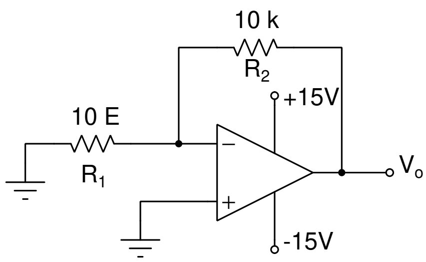


Figure 1: Circuit for measurement of $V_{OS}$

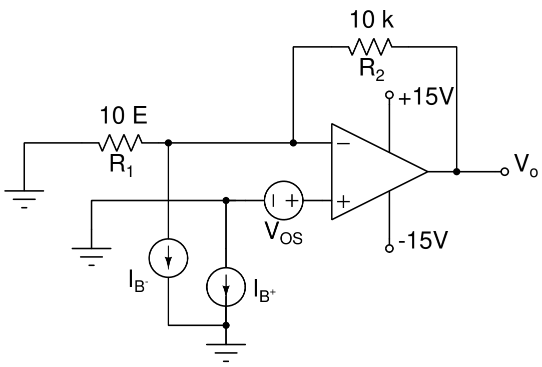


Figure 2: Equivalent circuit

   ii. For dominating value of $V_{OS}$ with negligible $I_B^-$, we can write the above equation as $V_{OS} = \frac{V_o}{1+R2/R1} \approx \frac{V_o}{R2/R1}$

iii. Since resistors can have variations we want to know exact values to determine $V_{os}$ accurately. Measure all the resistance values and tabulate them **[1 Marks]**

iv. Build the circuit shown in Fig.[ 1] on a breadboard and measure the offset voltage $V_{OS}$ using the above equation. Tabulate and verify your measured value with the value given in op amp 741 datasheet. **[2 Marks]**

(b) **Measurement of bias current $I_B^-$**

i. A circuit for measurement of the bias current $I_B^-$ is shown in Fig.[ 3], and the corresponding equivalent circuit is shown in Fig.[ 4] . Since the op amp in Fig.[ 4] is ideal, we have $V_- = V_+ = V_{OS}$, and the output voltage is
$V_o = V_- + I_B^- R = V_{OS} + I_B^- R$

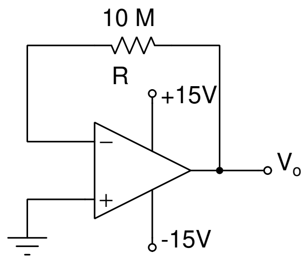


Figure 3: Circuit for measurement of $I_B^-$

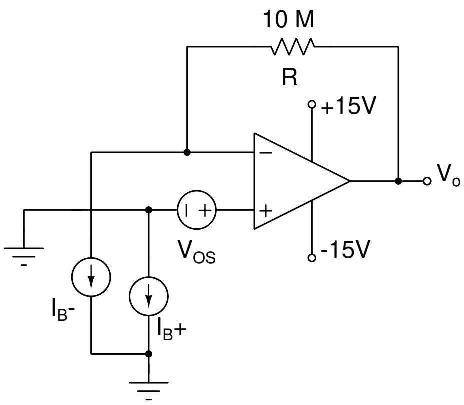


Figure 4: Equivalent circuit

ii. As the $V_{OS}$ term is very small compared to the value of $I_B^- R$, where $R = 10M\Omega$, and therefore we get $I_B^- = \frac{V_o}{R}$

iii. Build the circuit shown in Fig.[ 3] on a breadboard and measure the bias current $I_B^-$ using the above equation. Tabulate and verify your measured value with the value given in op amp 741 datasheet. **[2 Marks]**

(c) **Measurement of bias current $I_B^+$**

i. The circuit shown in Fig.[ 5] with the corresponding equivalent circuit shown in Fig.[ 6] , can be used for measurement of $I_B^+$. Since the input current for the ideal op amp of Fig.[ 6] is zero, the current $I_B^+$ must go through R, causing $V_+ = I_B^+ R + V_{OS}$, and $V_o = V_- = V_+ = I_B^+ R + V_{OS}$

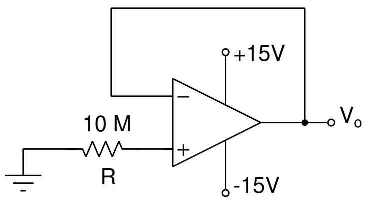


Figure 5: Circuit for measurement of $I_B^+$

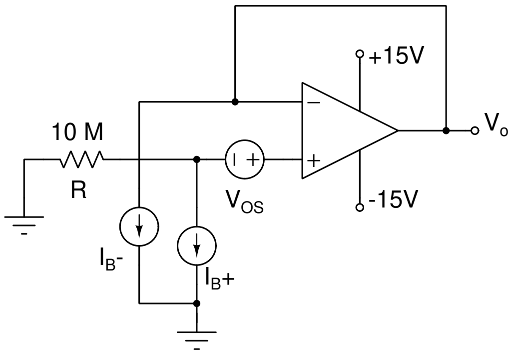


Figure 6: Equivalent circuit

ii. For typical values of $I_B^+$ and $V_{OS}$, with $R = 10M\Omega$, the first term dominates, giving $I_B^+ = \frac{V_o}{R}$

iii. Build the circuit shown in Fig.[ 5] on a breadboard and measure the bias current $I_B^+$ using the above equation. Verify your measured value with the value given in op amp 741 datasheet.

\- **[2 Marks]**

**Input offset voltage compensation using offset null pin**:
Operational amplifier IC's have the internal compensation circuit which facilitates offset-voltage compensation. Compensation has to be done externally by using offset null pins. 10K pot has to be connected between offset null pins (Check pin-out diagram in datasheet to identify offset null pins). You will require this in next experiment.

2. **Measurement of Open-loop gain** One of the most important features of an op amp is a high open-loop gain $A_{OL}$ which is typically in the range $10^5$ to $10^6$ (DC gain). Measurement of $A_{OL}$ with a simple scheme shown in Fig.[ 7] does not work for the following reasons:

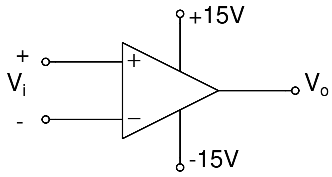


Figure 7: An op amp operated in the open-loop configuration

(a) With a large gain of $10^5$ or more, the op amp is likely to be driven to saturation on account of the input offset voltage $V_{OS}$ which is typically in the range $-5mV$ to $+5mV$ for Op Amp 741.

(b) Even if we had a magical op amp with $V_{OS} = 0V$ (or we compensated for the effect of $V_{OS}$ by some means), measurement of $A_{OL}$ is still a challenge. Suppose $A_{OL} = 2\text{x}10^5$, and we want an output voltage of $1V$, for example. This would require $V_i = \frac{1V}{2\text{X}10^5} = 5\mu V$, a very small voltage to apply or measure in the lab.

(c) Given the above difficulties, how to we reliably measure $A_{OL}$? The trick is to use the op amp in a configuration shown in Fig.[ 8]. This configuration is generally called as "False summing junction method". The Op-amp has a high overall gain, but because of the negative feedback, closed loop gain is low and Op-amp is maintained in linear region. The principle idea behind this method is that owing to the very high gain of Op-amp, $V_-$ node voltage will be in $uV$ which can't be measured accurately in lab. But because of high gain from $V_-$ to $V_R$, we can easily measure $V_R$ as it will be in orders of $mV$. To calculate open loop gain we can easily show that $V_- = -\frac{V_o}{A_{OL}}$. We know $V_R = V_- \frac{R_1+R_2}{R_2}$. Therefore by solving above both the equations and calculating for open loop gain, we get $|A_{OL}| = \frac{|V_o|}{|V_R|} \frac{R_1+R_2}{R_2}$. Open loop gain is also dependent on frequency. We can measure $A_{OL}$ at different frequencies by applying input at desired frequency. This will give us $A_{OL}(jw)$. All the parameters can be easily measured in lab and open loop gain ($A_{OL}$) as a function of frequency can be determined easily.

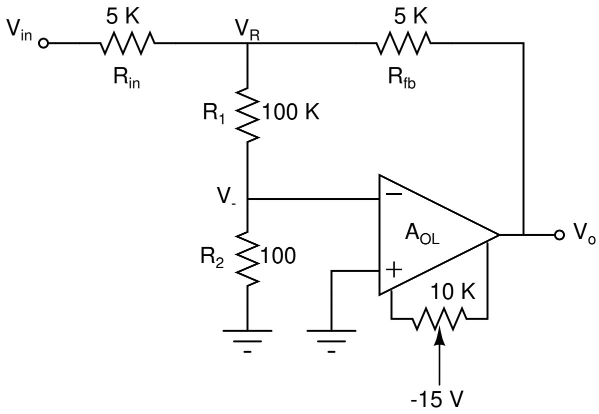


Figure 8: Measurement of open-loop gain $A_{OL}$

i. Since resistors can have variations we want to know exact values to determine $A_{OL}$ accurately. Measure all the resistance values and tabulate them **[1 Marks]**

ii. Build the circuit shown in Fig.[ 8] on a breadboard. Using the 10 k pot, we first nullify the effect of the offset voltage of the Op-amp to the extent possible, i.e., we adjust the pot, with $V_{in} = 0V$ and make $V_o$ approximately 0 V.
Note down the value of $V_o$ after nullifying offset **[1 Marks]**

iii. As a sanity check to verify whether offset is nullified and circuit is connected properly, apply $V_{in} = 1V(dc)$ and measure $V_o$, value of $V_o$ should be close to -1 V (Since $R_{in} = R_{fb}$)

iv. We now apply the input $V_{in}$ as 15 $V_{pp}$, sine wave with different frequencies. Measure the peak to peak voltage of $V_o$ and $V_R$ for the given frequencies:
1,2,3,4,5,6,7,8,9,10,20,100,500,1K,10K (in Hz). Calculate the $A_{OL}$ from the derived equation. Tabulate all the readings and corresponding $A_{OL}$ **[3 Marks]**
**Note:**
1. Start taking measurements from higher frequencies to lower frequencies
2. Setup DSO probes at 10x attenuation mode to avoid loading $V_R$ and $V_o$ nodes. Use measurement utility to measure peak to peak voltage at higher frequencies. For lower frequencies, there may be ripples/noise in $V_R$, in such case measurement utility might not be reliable so use cursor to measure.
3. Since circuit loop is slow, output will take time to settle specifically at lower frequencies. Thus wait until the output settles and then take measurements.
To know whether circuit is settled or not, observe the frequency (from measure utility) of $V_o$, if it matches with the input frequency then the circuit is settled.

v. Draw magnitude frequency response of $A_{OL}$ roughly in your notebook with proper annotations. Also mark the estimated 3-dB frequency (Bandwidth of Op-amp).
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**[2 Marks]**

vi. Determine the roll-off slope of $A_{OL}$ w.r.t. frequency in dB/dec. How many pole/poles does $A_{OL}$ have in given frequency range and what is the pole frequency. **[1 Marks]**

vii. Tabulate the $A_{OL}$ (DC) and 3-dB frequency measurements from your experiment and the datasheet (typical values) **[1 Marks]**

viii. (To be included in report): Plot Magnitude frequency response of $A_{OL}$ (Bode Plot). frequency axis should be in logarithmic scale and magnitude in dB.

**Tabulate all the parameters measured till now and corresponding datasheet typical values (Also add this table in report)** **[1 Marks]**