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

Lab: 6 Date: Feb 8, 2024

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

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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 $V_o = V_{OS}(1 + \frac{R2}{R1}) + R_2 I_B^-$.

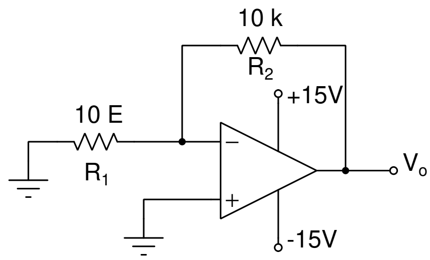

Figure 1: Circuit for measurement of V_{OS}

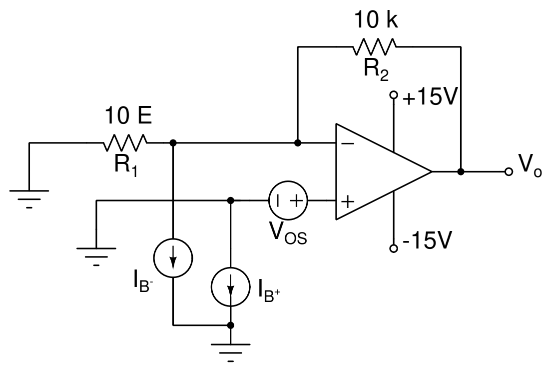

Figure 2: Equivalent circuit

   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
$V_o = V_- + I_B^- R = V_{OS} + I_B^- R$

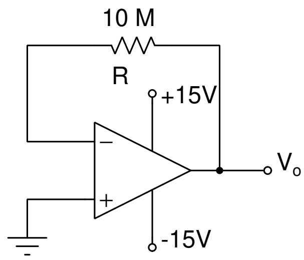

Figure 3: Circuit for measurement of I_B^-

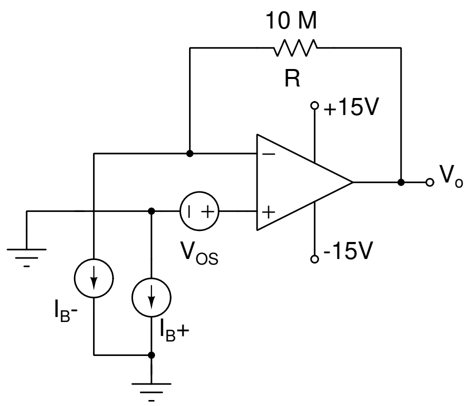

Figure 4: Equivalent circuit

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 $V_o = V_- = V_+ = I_B^+ R + V_{OS}$

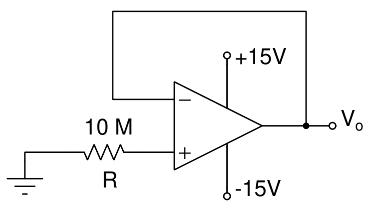

Figure 5: Circuit for measurement of I_B^+

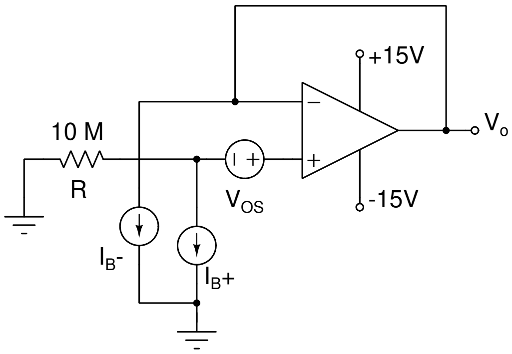

Figure 6: Equivalent circuit

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.
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[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:

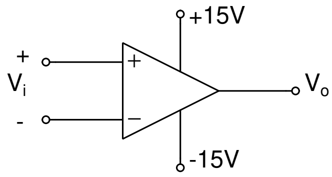

Figure 7: An op amp operated in the open-loop configuration

(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.

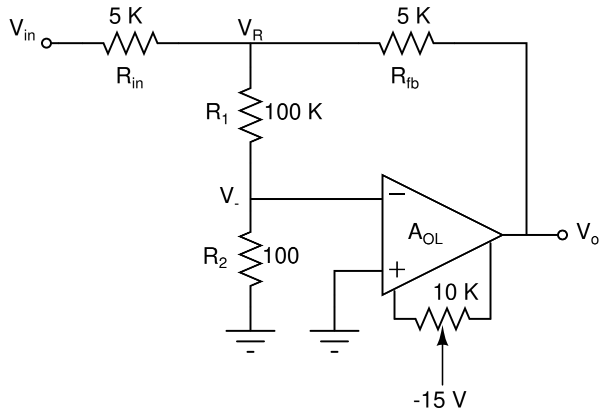

Figure 8: Measurement of open-loop gain A_{OL}

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).
\- **[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]**