EE230- Analog lab (Labwork-6)
Spring Semester: Year 2021-22

March 3, 2022

Instructions:

- Show the results of each question to the evaluating TA during the offline lab session on March 3 or March 4, 2022.
- No Additional time will be given. (Time slot: 2 PM to 5 PM)
- Non-ideal parameters are to be measured of op amp 741.

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

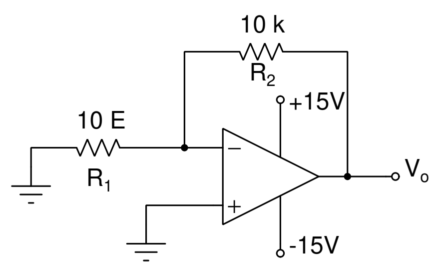

Figure 1: Circuit for measurement of V_{OS}

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

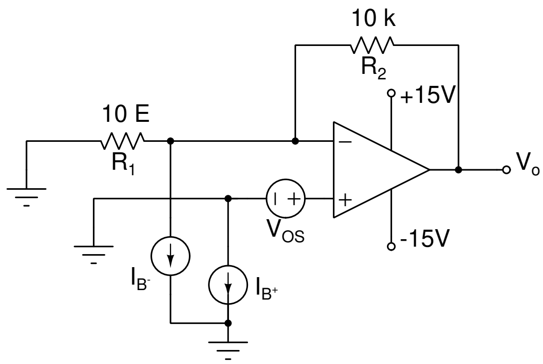

Figure 2: Equivalent circuit

iii. Build the circuit shown in Fig.[1] on a breadboard and measure the offset voltage V_{OS} using the above equation. Verify your measured value with the value given in op amp 741 datasheet.

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

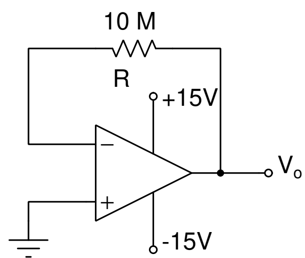

Figure 3: Circuit for measurement of I_B^-

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. Verify your measured value with the value given in op amp 741 datasheet.

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

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

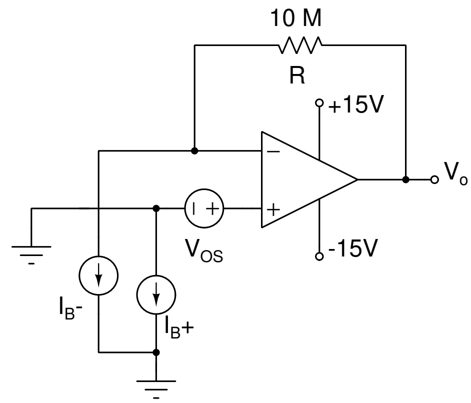

Figure 4: Equivalent circuit

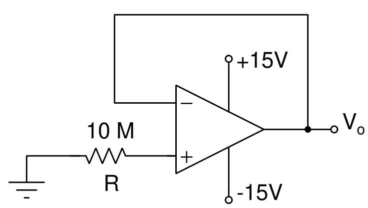

Figure 5: Circuit for measurement of I_B^+

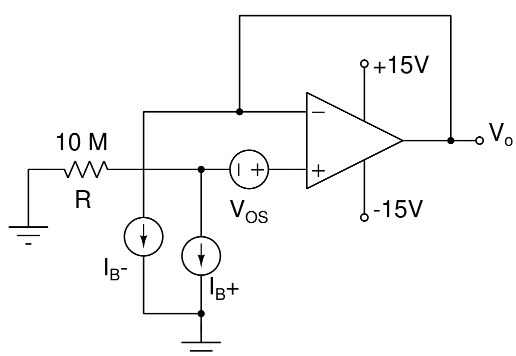

Figure 6: Equivalent circuit

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. **Measurement of DC 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. Measurement of A_{OL} with a simple scheme shown in Fig.[7] does not work for the following reasons:

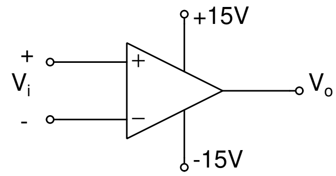

Figure 7: An op amp operated in the open-loop configuration

(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 V_{OL}? The trick is to use the op amp in a "servo loop" which ensures that its input voltage remains small enough to keep it in the linear region. Fig.[8] shows the circuit diagram. The op amp for which we want to measure A_{OL} is marked in the figure as the Device Under Test (DUT). The circuit has a high overall gain, but because of the negative feedback provided by R_3, it is stable. The capacitor C prevents the circuit from oscillating. We can measure the open-loop gain A_{OL} of the DUT using the circuit shown in Fig. [8] and the equation solved in the following steps.

i. 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 DUT to the extent possible, i.e., we adjust the pot, with the switch in position 1 (or simply open), to make V_o as small as possible. Because of the large gain of the auxiliary op amp, we can say that $V_{o1A} = 0V$. Let the output voltage V_o be denoted by V_{oA}.

ii. We now change the switch to position 2. With $V_- = V_+ = 0V$ and with the capacitor behaving like an open circuit in the DC condition, we have $i1 = i2$, and
$V_{o1B}= V_- - i_2 R_4 = 0 - \frac{V^{'}}{R_5} R_4 = -V^{'}$

We can attribute the difference $(V_{o1B} - V_{o1A})$ to the change in V_{o1}, i.e., $\Delta V_{o1} = V_{o1B} - V_{o1A} = -V^{'} - 0 = -V^{'}$. Let V_o be denoted by V_{oB}.

iii. For the DUT, its output V_{o1} has undergone a change of $-V^{'}$, and it is a result of a change in $(V_+ - V_-)$ which is equal to $\frac{R_2}{R_2+R_3}(V_{oB} - V_{oA})$. In other words, $\frac{R_2}{R_2+R_3}(V_{oB} - V_{oA})\text{x}A_{OL} = -V^{'}$, which can be used to obtain A_{OL} for the DUT. **Take the measurement of A_{OL} for $V^{'} = 1V, 2V, 3V$.** Verify your measured value with the value given in op amp 741 datasheet.

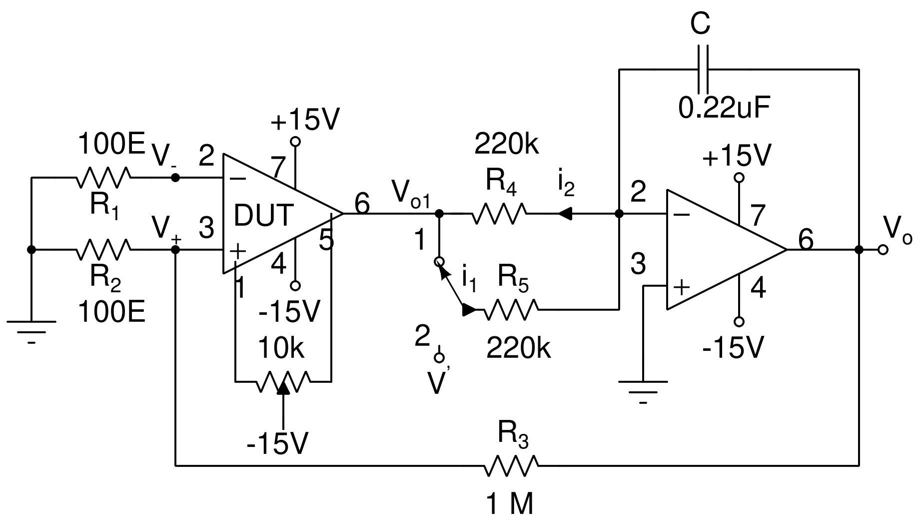

Figure 8: Measurement of DC open-loop gain A_{OL}