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

March 2, 2022

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

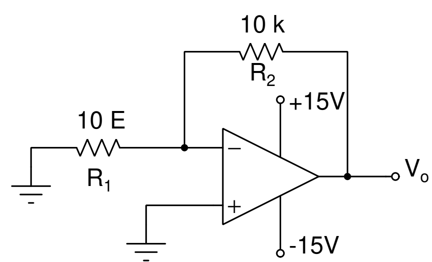


Figure 1: Circuit for measurement of $V_{OS}$

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

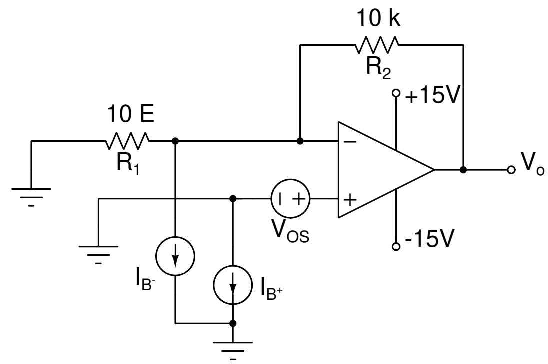


Figure 2: Equivalent circuit

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

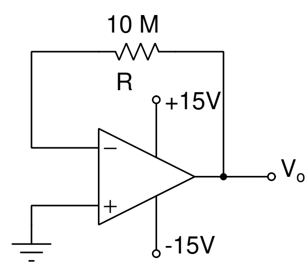


Figure 3: Circuit for measurement of $I_B^-$

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 $I_B^+ = \frac{V_o}{R}$

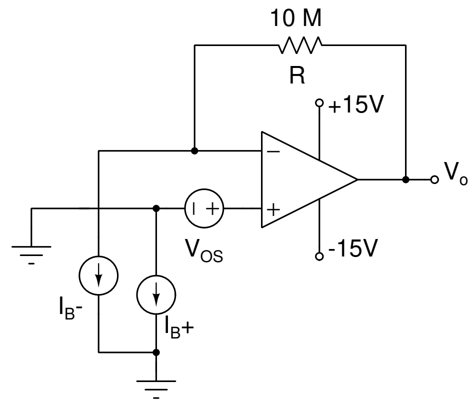


Figure 4: Equivalent circuit

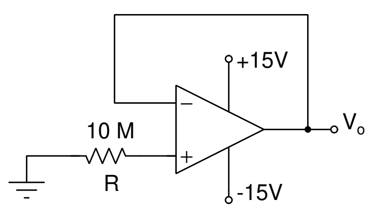


Figure 5: Circuit for measurement of $I_B^+$

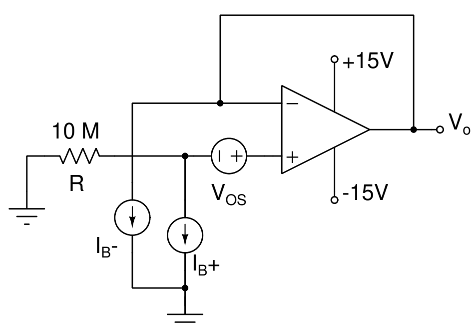


Figure 6: Equivalent circuit

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:

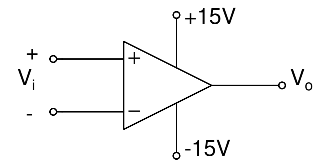


Figure 7: An op amp operated in the open-loop configuration

(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.

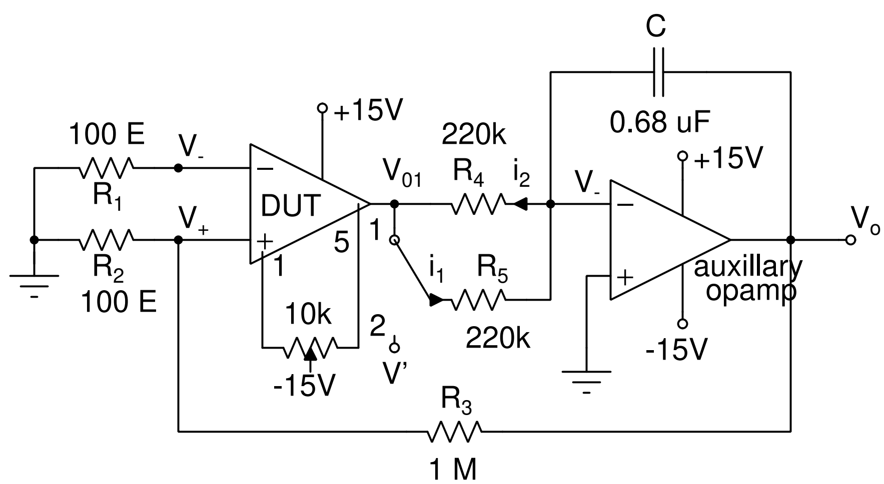


Figure 8: Measurement of DC open-loop gain $A_{OL}$