# EE230: Analog Circuits Lab
# Lab - 6

Abhineet Agarwal, 22B1219

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## 1 Measurement of offset voltage and bias currents

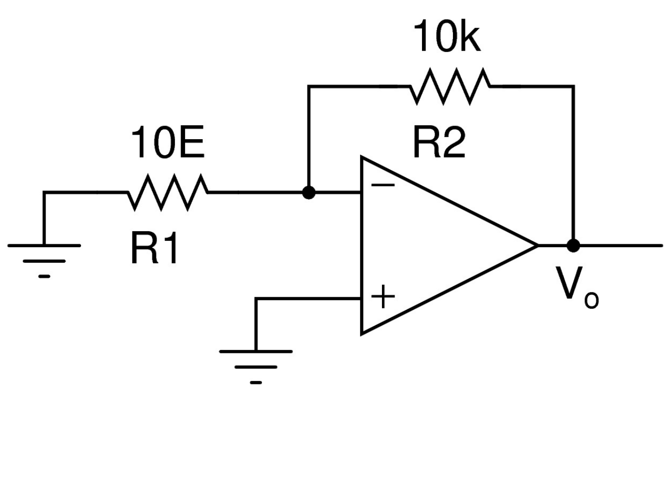
### 1.1 Measurement of $V_{os}$

#### 1.1.1 Aim of the experiment

The aim of this experiment was to measure the input offset voltage $V_{os}$ of the given OpAmp IC (LM741 IC).

#### 1.1.2 Design

The circuit to calculate the input offset voltage is shown in the figure below.

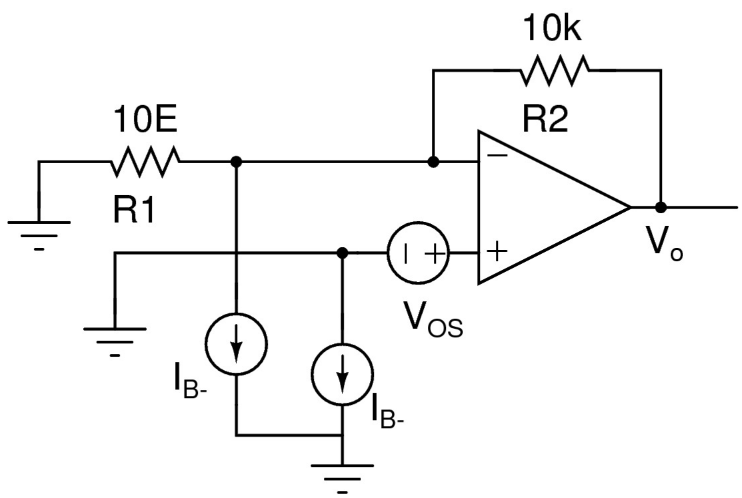



$R_1 = 10\Omega$

$R_2 = 10\text{k}\Omega$
Supply voltages of the Op-Amp $= \pm 15\text{V}$

### 1.1.3 Experimental results

(i) The equivalent circuit, considering the OpAmp non-idealities is shown below:




the output of this circuit is given by:

$$V_o = V_{OS}(1 + \frac{R_2}{R_1}) + R_2 I_B^-$$

(ii) For a dominating value of $V_{OS}$ with negligible $I_B^-$, we can write the above equation as

$$V_{OS} = \frac{V_o}{(1 + \frac{R_2}{R_1})} \approx \frac{V_o}{R_2/R_1}$$

(iii) The values of the resistors used are tabulated below:

| | $R_1$ | $R_2$ |
|---|---|---|
| theoretical | $10\Omega$ | $10k\Omega$ |
| measured | $10.2\Omega$ | $9.80k\Omega$ |

(iv) Measured output of the circuit $V_o = 1.66V$
Thus, using the above formula, offset voltage $V_{OS}$

$$V_{OS} = 1.66mV$$

thus, the measured and the typical datasheet values of the offset voltage are tabulated below:

| | $V_{OS}$ |
|---|---|
| datasheet | $1 - 6mV$ |
| measured | $1.66mV$ |

### 1.1.4 Conclusion and Inference

Thus, we measured successfully the offset voltage of the given OpAmp LM741 IC.

### 1.1.5 Experiment completion status

All parts of this experiment were successfully completed in the lab.

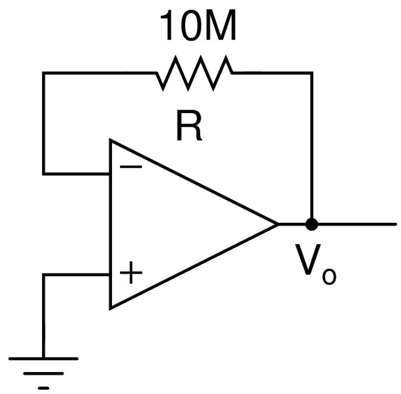
## 1.2 Measurement of bias current $I_B^-$

### 1.2.1 Aim of the experiment

The aim of this experiment was to measure the input bias current in the inverting input $I_B^-$ of the given OpAmp IC (LM741 IC).

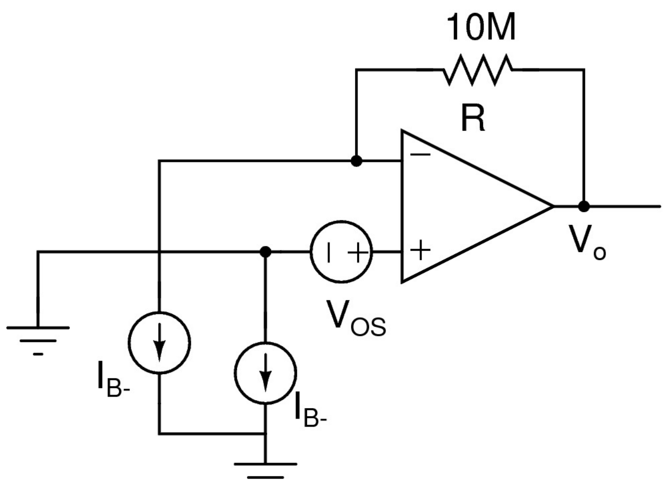
### 1.2.2 Design

The circuit to calculate the input bias current $I_B^-$ is shown in the figure below.
$R = 10\text{M}\Omega$
Supply voltages of the Op-Amp = $\pm 15\text{V}$




### 1.2.3 Experimental results

(i) The equivalent circuit, considering the OpAmp non-idealities is shown below:




the output of this circuit is given by:

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

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

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

(iii) The values of the resistor used tabulated below:

| | $R$ |
|---|---|
| theoretical | 10MΩ |
| measured | 10.1MΩ |

(iv) Measured output of the circuit $V_o = 2.34V$
Thus, using the above formula, offset voltage $I_B^-$

$$I_B^- = 234nA$$

thus, the measured and the typical datasheet values of the input bias current are tabulated below:

| | $I_B^-$ |
|---|---|
| datasheet | 80 – 500 nA |
| measured | 234 nA |

#### 1.2.4 Conclusion and Inference

Thus, we measured successfully the input bias current in the inverting terminal of the given OpAmp LM741 IC.

#### 1.2.5 Experiment completion status

All parts of this experiment were successfully completed in the lab.

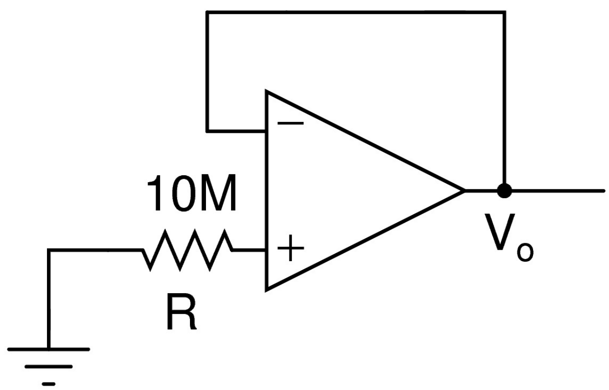
### 1.3 Measurement of bias current $I_B^+$

#### 1.3.1 Aim of the experiment

The aim of this experiment was to measure the input bias current in the non-inverting input $I_B^+$ of the given OpAmp IC (LM741 IC).

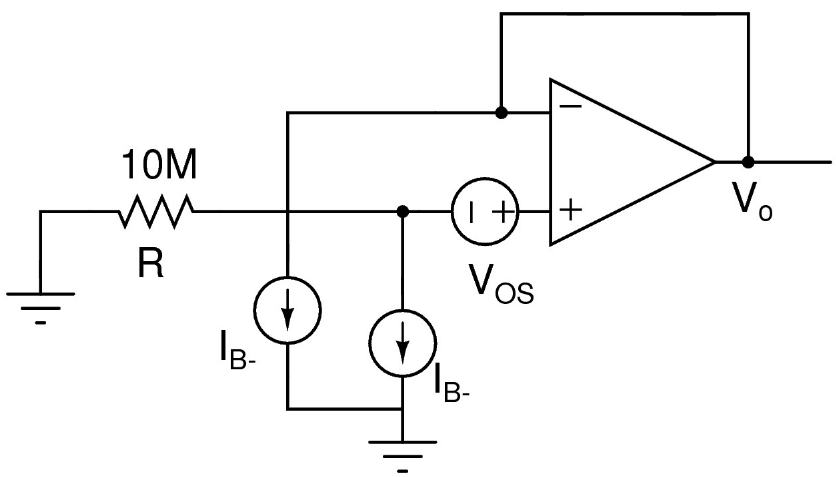
#### 1.3.2 Design

The circuit to calculate the input bias current $I_B^+$ is shown in the figure below.
$R$ = 10MΩ
Supply voltages of the Op-Amp = ±15V




### 1.3.3 Experimental results

(i) The equivalent circuit, considering the OpAmp non-idealities is shown below:




the output of this circuit is given by:

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

(ii) As the $V_{OS}$ term is very small compared to the value of $I_B^+ R$, where $R = 10\text{M}\Omega$, therefore we get

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

(iii) The values of the resistor used tabulated below:

| | $R$ |
|---|---|
| theoretical | $10\text{M}\Omega$ |
| measured | $10.1\text{M}\Omega$ |

Measured output of the circuit $V_o = 0.99V$
Thus, using the above formula, offset voltage $I_B^+$

$$I_B^+ = 99nA$$

Thus, the measured and the typical datasheet values of the input bias current are tabulated below:

| | $I_B^+$ |
|---|---|
| datasheet | $20 - 200$ nA |
| measured | 99 nA |

### 1.3.4 Conclusion and Inference

Thus, we measured successfully the input bias current in the non-inverting terminal of the given OpAmp LM741 IC.

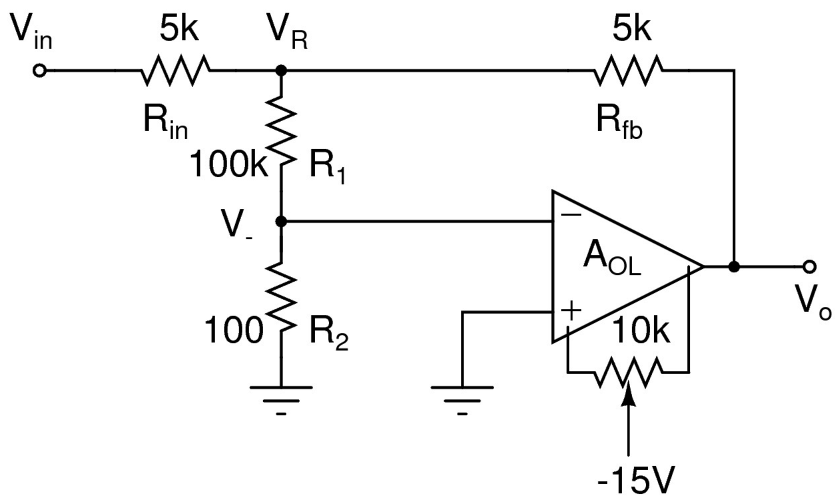
### 1.3.5 Experiment completion status

All parts of this experiment were successfully completed in the lab.

# 2 Measurement of Open-loop gain

## 2.1 Aim of the experiment

The aim of this experiment was to measure the open-loop gain of the given OpAmp LM741 IC, and to analyse it's frequency response.




## 2.2 Design

The OpAmp configuration used to measure the open-loop gain is shown below.

$R_{in} = R_{fb} = 5k\Omega$
$R_1 = 100k\Omega$
$R_2 = 100\Omega$
$10k\Omega$ pot. was used for offset voltage nullification
Supply voltages of the Op-Amp = ±15V

## 2.3 Experimental results

(i) The values of the resistors used in the given circuit are tabulated below:

| | theoretical | measured |
|---|---|---|
| $R_{in}$ | $5k\Omega$ | $5k\Omega$ |
| $R_{fb}$ | $5k\Omega$ | $5k\Omega$ |
| $R_1$ | $100k\Omega$ | $99.7k\Omega$ |
| $R_2$ | $100\Omega$ | $99.8\Omega$ |

(ii) Connecting the 10k pot. across the offset null pins, and connecting the variable leg of the pot. to $V_{EE}$, we adjust the pot. appropriately so that output $V_o = 0V$ for $V_{in} = 0V$.
The value of $V_o$ after nullifying the offset $= 0.01V$

(iii) For $V_{in} = 1V$, the observed $V_o = -1.010V$.
As the measured value is almost same as the expected output $V_o = -1V$, thus this verifies that the offset has been nullified and that the circuit is connected properly.

(iv) For $V_{in} = 15V_{pp}$, the measured peak-to-peak $V_R$ and $V_o$, and the calculated gain $A_{OL}$ is given by:

$$|A_{OL}| = \frac{|V_o|}{|V_R|} \frac{R_1 + R_2}{R_2}$$

Tabulated measurements of the same are given below:

| $f$ | $V_{o(pp)}$ | $V_{R(pp)}$ | $A_{OL}$ |
|---|---|---|---|
| 10 kHz | 880 mV | 7.28 V | 120.9 |
| 1 kHz | 6.48 V | 6.72 V | 964.2 |
| 500 Hz | 10.4 V | 5.52 V | 1884.1 |
| 100 Hz | 14.8 V | 1.64 V | 9024.3 |
| 20 Hz | 15.0 V | 336 mV | 44642.8 |
| 10 Hz | 15.2 V | 180 mV | 84444.4 |
| 9 Hz | 15.2 V | 172 mV | 88372.09 |
| 8 Hz | 15.2 V | 140 mV | 108571.4 |
| 7 Hz | 15.2 V | 124 mV | 122580.6 |
| 6 Hz | 15.2 V | 164 mV | 92682.9 |
| 5 Hz | 15.2 V | 88 mV | 172727 |
| 4 Hz | 15.2 V | 72 mV | 211111 |
| 3 Hz | 15.2 V | 60 mV | 253333 |
| 2 Hz | 15.2 V | 44 mV | 345454 |
| 1 Hz | 15.2 V | 36 mV | 506666 |

**Table**. Open-Loop Gain

(v) Now,
From the tabulated values, the maximum gain $A_{OL(max)} = 506666$
Now,
$\frac{1}{\sqrt{2}}$ (approximately 70.7%) of this maximum gain $A_{OL(max)} \approx 358266.96$

This value of gain occurs around 2 Hz
Thus, the 3-dB frequency (Bandwidth of the OpAmp) $\approx$ 2 Hz

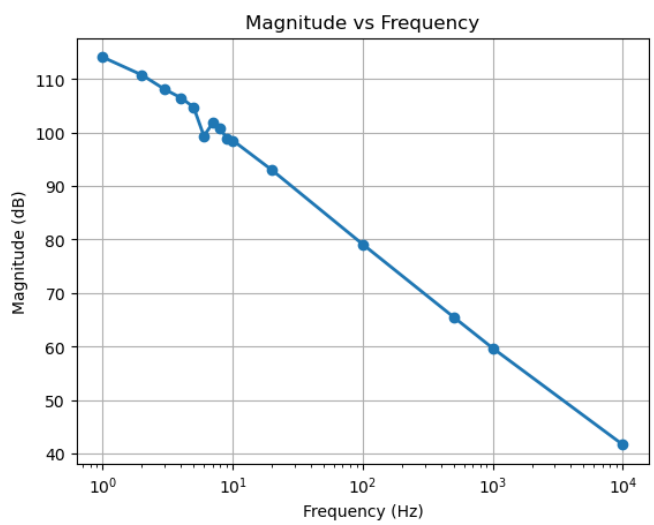
(vi) Roll-off slope = gain at 10kHz - gain at 1kHz (in dB)
Hence,
Roll-off slope = -29.3 dB/decade

Observed from the table, the given system has 1 pole, with a pole frequency $\approx$ 4Hz.

(vii) Thus, the measured and the typical datasheet values of the open-loop gain $A_{OL}$ and 3-db frequency are tabulated below:

| | $A_{OL}$ | 3-db freq. |
|---|---|---|
| datasheet | $2 \times 10^5$ | 7.5Hz |
| measured | $\approx 5 \times 10^5$ | $\approx$ 2Hz |

(viii) Magnitude frequency response of $A_{OL}$ (Bode Plot) is given below:



### 2.4 Conclusion and Inference

Thus, we measured the open-loop gain of the given OpAmp IC successfully and analysed it's frequency response.

### 2.5 Experiment completion status

All parts of this experiment were successfully completed in the lab.

# Parameters of the LM741 IC

The comparison between the measured and typical datasheet values of the parameters of the LM741 IC is tabulated below:

| | datasheet | measured |
|---|---|---|
| $V_{OS}$ | 1-6 mV | 1.66 mV |
| $I_B^-$ | 80-500 nA | 234 nA |
| $I_B^+$ | 20-200 nA | 99 nA |
| $A_{OL}$ | $2 \times 10^5$ | $\approx 5 \times 10^5$ |
| $f_{3dB}$ | 7.5 Hz | $\approx 2$ Hz |