Department of Electrical and Electronic Engineering
Shahjalal University of Science and Technology

EEE 222: Electronic Circuit Simulation Laboratory

EXPERIMENT NO: 06

Name of the Simulation:

6a: DETERMINATION OF OPERATIONAL AMPLIFIER CHARACTERISTICS
6b: LINEAR APPLICATION OF OPERATIONAL AMPLIFIERS

OBJECTIVE OF *6a*

The objective of this module is to determine the following Op-Amp characteristics using spice simulation

1) *Measurement of Open-loop Gain, A_{OL}*
2) *Measurement of Open-loop Break-frequency, f_o*
3) *Input offset voltage, V_{io}*
4) *Bias currents (I_{B+},I_{B-}) & Input offset current I_{os}*
5) *Slew-Rate*

OBJECTIVE OF *6b*

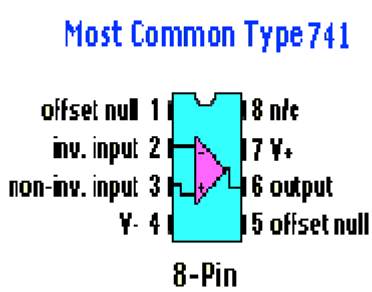
To investigate the different linear applications of the operational amplifier, for example

6) *inverting multiplier*
7) *inverting summer*
8) *differential amplifier*
9) *inverting integrator and*
10) *inverting differentiator*

THEORY

FAMILIARIZATION WITH OP-AMP

There are different types of Op-Amp ICs. Most common one is uA741. Its pin configuration is given below-



Definition of 741-pin functions:

Pin 1 (Offset Null): Since the op-amp is the differential type, input offset voltage must be controlled so as to minimize offset. Offset voltage is nulled by application of a voltage of opposite polarity to the offset. An offset null-adjustment potentiometer may be used to compensate for offset voltage. The null-offset potentiometer also compensates for irregularities in the operational amplifier manufacturing process which may cause an offset. Consequently, the null potentiometer is recommended for critical applications. See 'Offset Null Adjustment' for method.

Pin 2 (Inverted Input): All input signals at this pin will be inverted at output pin 6. Pins 2 and 3 are very important (obviously) to get the correct input signals or the op amp can not do its work.

Pin 3 (Non-Inverted Input): All input signals at this pin will be processed normally without inversion. The rest is the same as pin 2.

Pin 4 (-V): The V- pin (also referred to as Vss) is the negative supply voltage terminal. Supply-voltage operating range for the 741 is -4.5 volts (minimum) to -18 volts (max), and it is specified for operation between -5 and -15 Vdc. The device will operate essentially the same over this range of voltages without change in timing period. Sensitivity of time interval to supply voltage change is low, typically 0.1% per volt. (Note: Do not confuse the -V with ground).

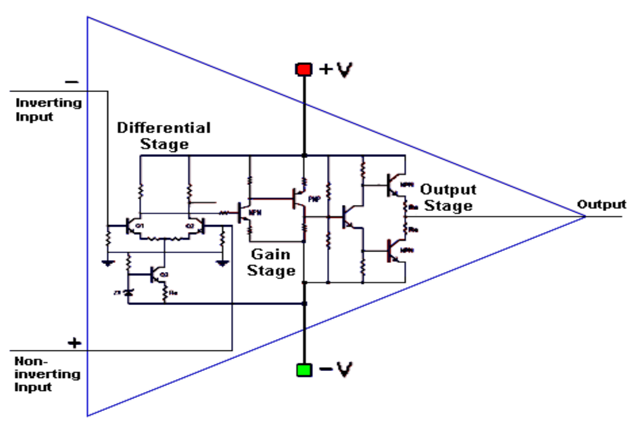
Pin 5 (Offset Null): See pin 1.

Pin 6 (Output): Output signal's polarity will be the opposite of the input's when this signal is applied to the op-amp's inverting input. For example, a sine-wave at the inverting input will output a square-wave in the case of an inverting comparator circuit.

Pin 7 (posV): The V+ pin (also referred to as Vcc) is the positive supply voltage terminal of the 741 Op-Amp IC. Supply-voltage operating range for the 741 is +4.5 volts (minimum) to +18 volts (maximum), and it is specified for operation between +5 and +15 Vdc. The device will operate essentially the same over this range of voltages without change in timing period. Actually, the most significant operational difference is the output drive capability, which increases for both current and voltage range as the supply voltage is increased. Sensitivity of time interval to supply voltage change is low, typically 0.1% per volt.

Pin 8 (N/C): The 'N/C' stands for 'Not Connected'. There is no other explanation. There is nothing connected to this pin, it is just there to make it a standard 8-pin package.

Input Stage **Gain Stage** **Output Stage**



Op Amp Stages

It is well known that the characteristics of commercially available operational amplifiers are different from the ideal characteristics. Although it is possible to use some of these non-ideal characteristics to advantage; for example the finite bandwidth and finite gain characteristics can be used to construct capacitor less filters and oscillators, in general the non-ideal characteristics of the operational amplifiers may degrade the circuit performance. Therefore, manufacturers usually provide users with the most important parameters of the operational amplifiers.

Table1: Typical Performance of Op-Amps.

	uA741	LM118	AD507k
Open-Loop Gain (db)	106	100	100
Input offset voltage (mv)	≤5	≤4	≤5
Bias Current (nA)	≤500	≤250	≤15
Offset Current (nA)	≤200	≤50	≤15
Slew Rate (V/µs)	0.5	≥50	35
Full-power bandwidth (kHz)	10	1000	600
CMRR (db)	80	90	100
Input Res. (MΩ)	2	5	300
Unity-gain B.W. (MHz)	1	15	35

Table1 shows the typical performance of selected operational amplifiers. These data, however, give the average performance of a selected type. The actual performance of a particular operational amplifier may be different from its typical characteristics. It is, therefore, important to know how to measure the operational amplifier characteristics using simple equipments available in any laboratory.

1) Measurement of Open-loop Gain, A_{OL}

Direct measurement of the open-loop gain is not feasible because of the large values involved. Instead, measurement of open-loop gain can be carried out with the operational amplifier embedded in a negative-feedback circuit. Such an arrangement is shown in Fig.6a1.

You can obtain an expression for the output voltage V_o in terms of the input voltage V_{sin} and the voltage V_1. (Applying KCL at V_1, we get $\mathbf{V_o=2V_1-V_3+10V_{sin}}$)
If we select $10R_1=R_2=R_f=10k\Omega$, $R_3=10\Omega$

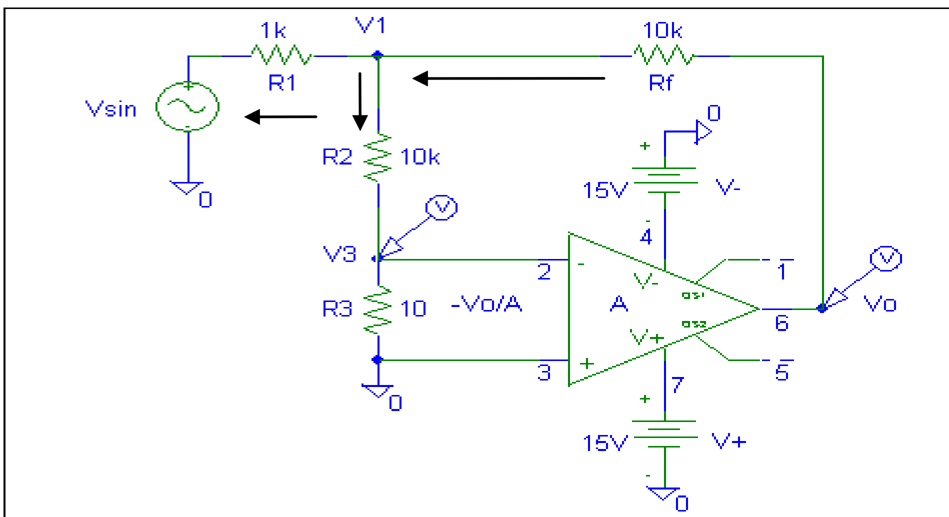


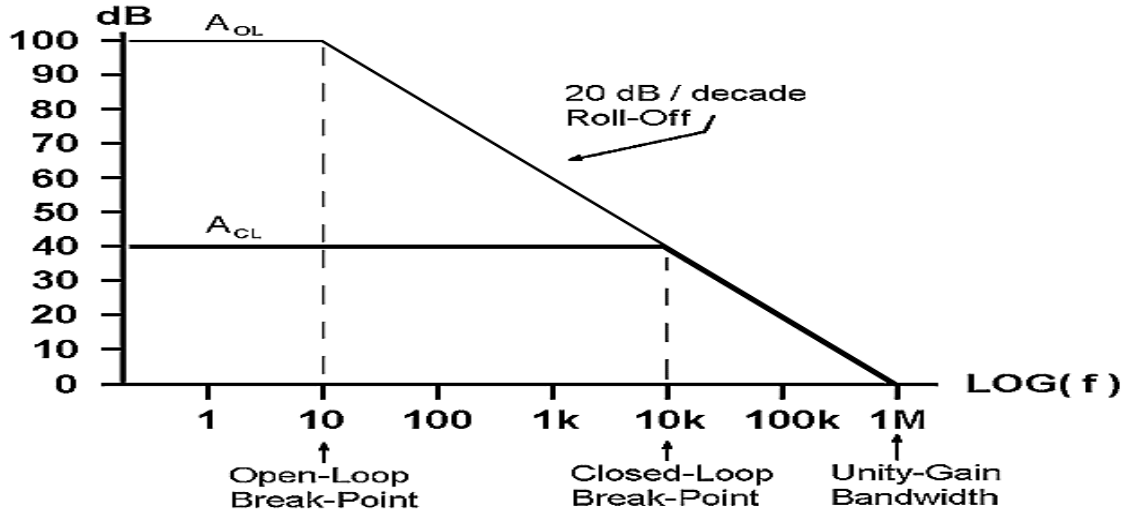
Fig 6a1: Assume input impedance = infinite

then it is easy to show that for large values of operational amplifier gain, the overall-gain; that is with the feedback loop closed will be $\cong -10$. This value is not important in itself; its significance is to assure us that there is sufficient negative feedback so that reasonable values of V_{sin} can be used without driving V_0 to saturation levels. What is important is the simple relation between V_0 and V_1; obtain this relation. Clearly, it is a simple matter to measure V_1 and V_0 and hence to calculate the gain of the operational amplifier. (See equation)

Open-loop Gain, A_{OL}= Output/Difference input= V_o/V_3
Closed-loop Gain, A_{CL}= Output/Input= V_o/V_{sin}

Note: Use very low frequency i.e. few hertz.

2) *Measurement of Open-loop Break-frequency* ('cut-off' or 'corner' frequency), f_o



Consider the above Fig. At relatively high frequencies (w.r.t. the open-loop break-frequency), the gain of the Op Amp can be expressed by

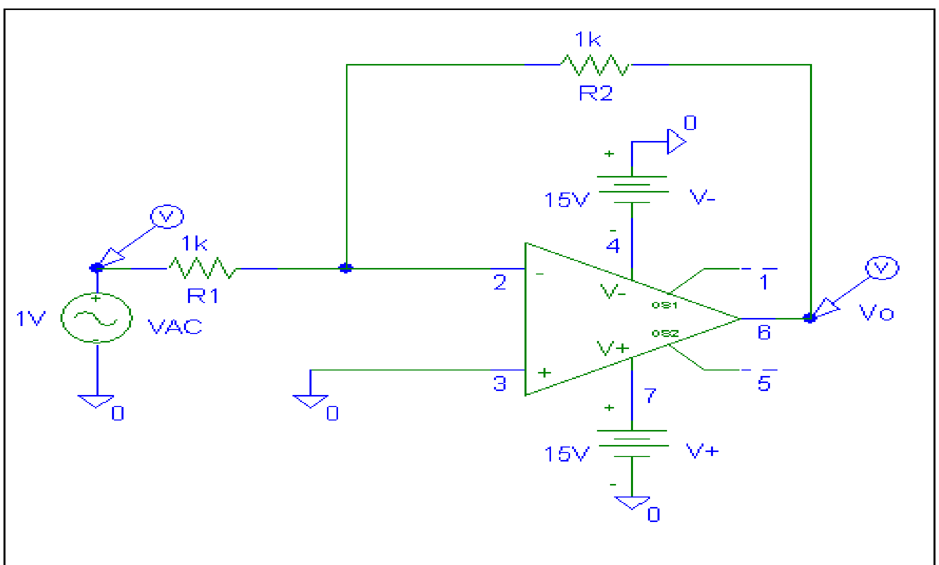


Fig 6a2: Assume input impedance = infinite

$$A = \frac{A_{OL}}{1 + jw/w_0}$$

At the frequency w_t corresponding to ***unity-gain***, A=1, $w = w_t$, *so*

$$A_{OL} = 1 + jw_t / w_0$$

Since we know that $w_t >> w_0$

$$A_{OL} \cong w_t / w_0$$

$$\Rightarrow w_0 \cong w_t / A_{OL}$$

Therefore the gain of the Op Amp can be expressed by

$$A = \frac{A_{OL}}{1 + jA_{OL} w / w_t}$$

It is easy to show that, in Fig.6a2 when $R_1 = R_2$ the gain V_0/V_i will be

$$A_{vF} = \frac{-1}{1+2/A}$$

Substituting the value of A and since A_{0L} is very large it is easy to show that

$$A_{vF} = \frac{-1}{1+j2w/w_t} = -\frac{1}{1+j2w/w_t}$$

From the last eqn. it is obvious that the gain will drop to $1/\sqrt{2}$ when $w_m = \frac{w_t}{2}$. We can measure w_m. And since we know the open-loop voltage gain A_{0L}, then it is easy to calculate w_0 (hence f_o).

3) *Input offset voltage, V_{io}*

With '0' input voltage, out put of Op-Amp is not zero, because of input offset voltage. It is *modeled* as a DC voltage connected to the +input. Measuring the output, V_{io} can be calculated.

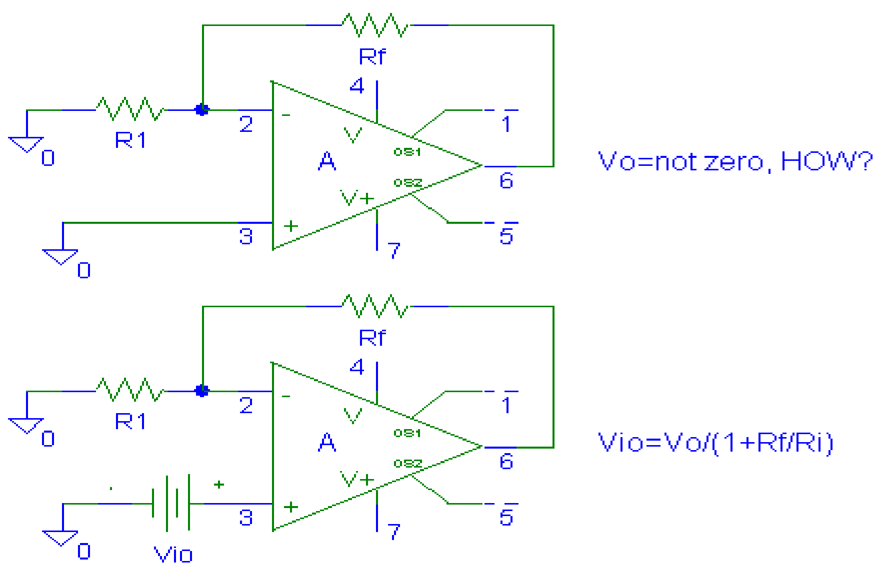


Fig 6a3T: DC source model to indicate Vio

4) *Bias currents (I_{B+},I_{B-}) & Input offset current I_{os}*

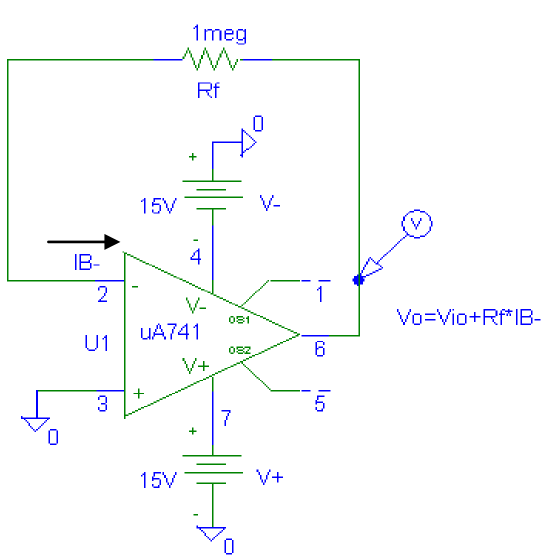


Fig6a41: Negative Bias Current

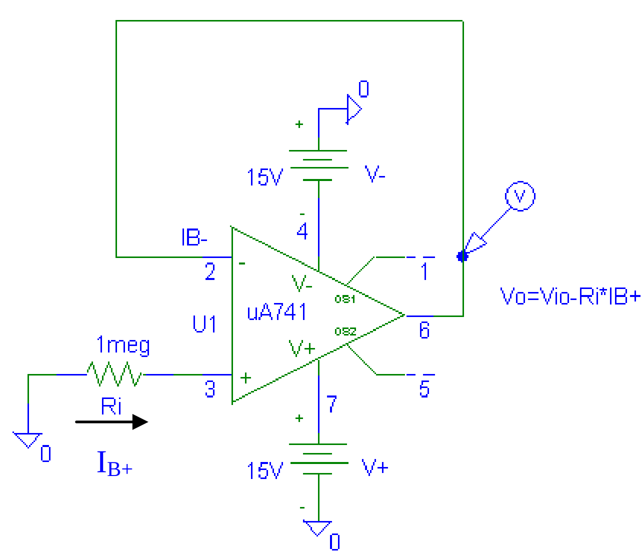


Fig6a42: Positive Bias Current

From Fig6a41 & Fig6a42, using the output voltage, bias currents can be calculated. Then input offset current $I_{os}=|I_{B+}|-|I_{B-}|$

5) Slew-Rate

From the discussion of section (2) we found that $w_t=w_0A_0$. Therefore, if we consider the circuit of Fig. 6a2, its gain can be expressed as

its gain can be expressed as

$$\frac{v_0}{v_i}=\frac{-R_2/R_1}{1+(1+R_2/R_1)/A}$$

Therefore, substituting for $A=\frac{w_t}{s}$ the gain can be expressed as

$$\frac{v_0}{v_i}=\frac{-R_2/R_1}{1+(1+R_2/R_1)s/w_t}$$

Which corresponds to an amplifier with dc gain of $-R_2/R_1$ and a 3.dB corner frequency of

$$w_t/(1+\frac{R_2}{R_1})$$

Therefore, if we measure the frequency response of a closed-loop amplifier with a gain of, say, 10, the 3-dB frequency of $w_t/11$ would be achieved. This is true only if the output voltage is quite small (less than a volt). On the other hand, Op Amps are capable of providing output signal swings that approach the voltages of the power supplies used. (Typical values are ±10V for ±15 volt power supplies). The *large-signal frequency response of Op Amps is limited by the slew-rate*. Specifically, there is an upper limit for the rate of change of the output voltage with time. This upper limit is called slew-rate. This slew-rate limiting cause's distortion in large-signal output sine waves. Specifically, as the frequency of the sine wave is increased, its slope, which is highest at the zero crossings, increases until that slope equals the Op Amp slew-rate. Increasing the frequency further will obviously result in a distorted output.

To measure the slew-rate, consider the circuit shown in Fig 6a5. If the input voltage is a square wave of 20 V peak-to-peak (here we assume that the dc supply voltage of the Op amp is ±15V i. e. the 20V p-to-p represents the maximum output voltage of the op amp) and if we keep the frequency at, say 1 KHz, then the output will be as shown in Fig.6a5; notice the effect of slew-rate. The slew-rate can be easily measured from the output. It is given by $\frac{V_0}{T_{SR}}$

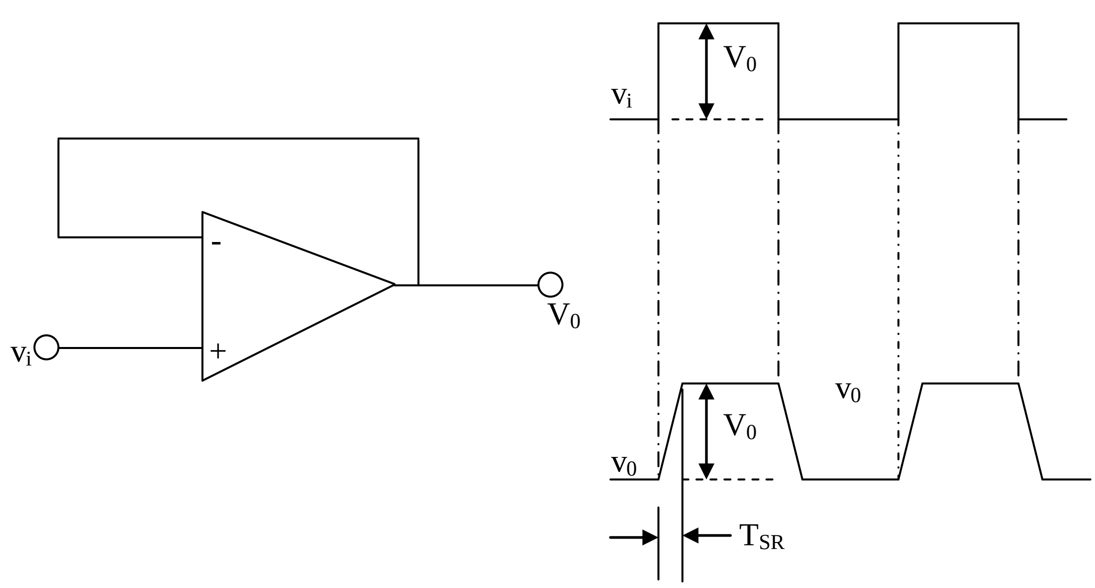


Fig. 6a5

6) Op-Amp Linear Operation

CIRCUIT SETUP FOR LINEAR OPERATION

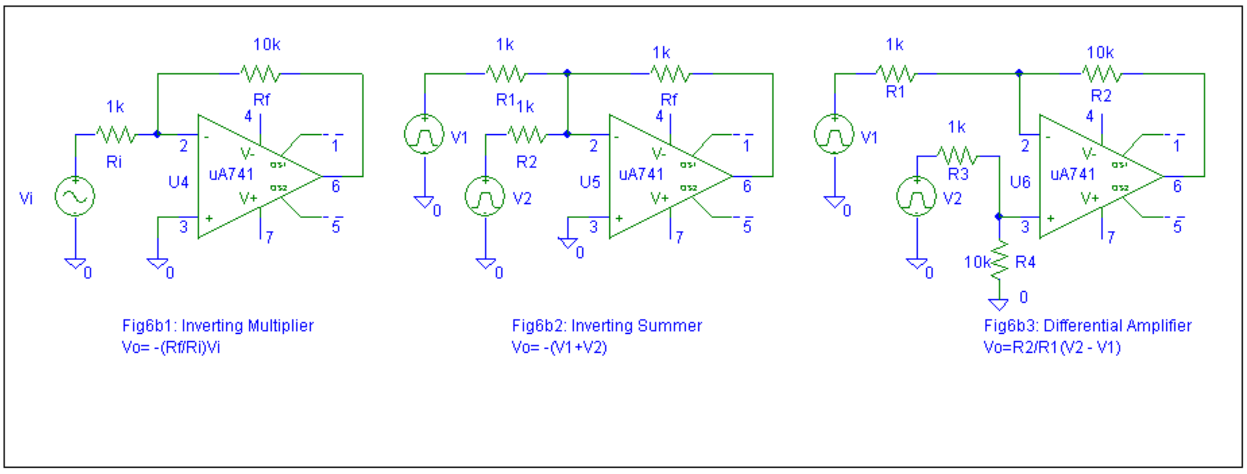


Fig6b1: Inverting Multiplier
Vo= -(Rf/Ri)Vi

Fig6b2: Inverting Summer
Vo= -(V1+V2)

Fig6b3: Differential Amplifier
Vo=R2/R1(V2 - V1)

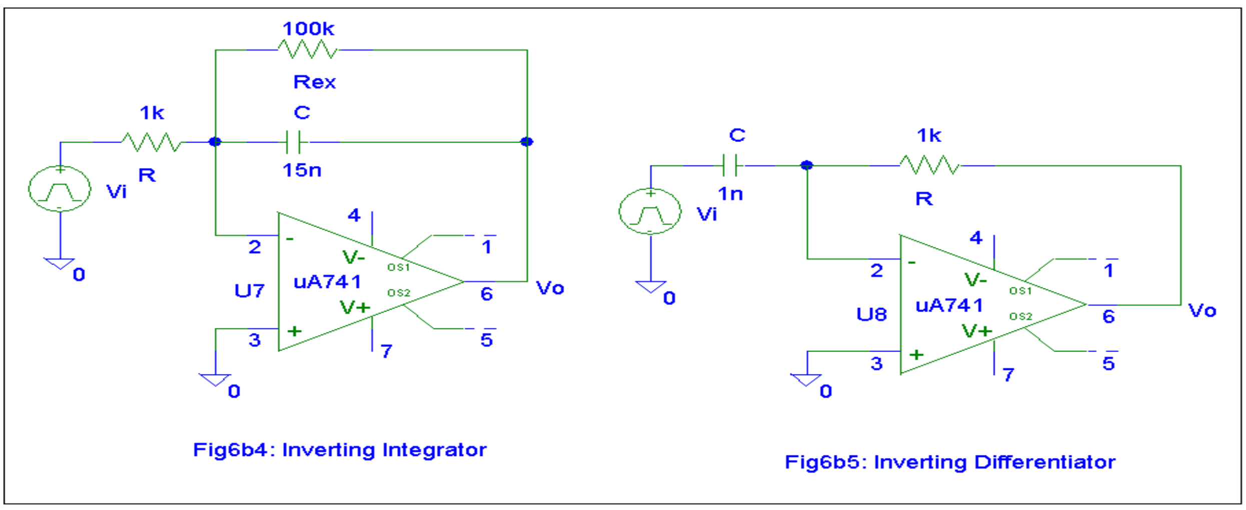


Fig6b4: Inverting Integrator

Fig6b5: Inverting Differentiator

PROCEDURES

1) *Measurement of Open-loop Gain, A_{OL}*

- Draw the circuit shown in Fig.6a1 in PSpice schematics. Use uA741 as Op-amp module.
- Set the input voltage V_{sin} at 5Hz, 1V peak. Set the transient and run simulation.
- From the probe output determine the rms values of V_o and V_3. $A_3 = V_{orms} / V_{3rms}$
- Now $A_{OL}=20*LOG_{10}(A_3)$ dB. Compare this value with **Table1**.

2) *Measurement of Open-loop Break-frequency* ('cut-off' or 'corner' frequency), *f_o*

- Draw the circuit shown in Fig.6a2 in PSpice schematics.
- Set the input voltage V_{AC} at 1V. Select AC Sweep from **Setup Analysis**. Select sweep from 1 Hz to 1 GHz in Decade mode, with 20 Pts/decade
- Mark the frequency where output is $1/\sqrt{2}$. This is f_m. Now $f_t=2f_m$
- Use value of A_{OL} to calculate $f_0 \cong f_t / A_{OL}$

3) *Input offset voltage, V_{io}*

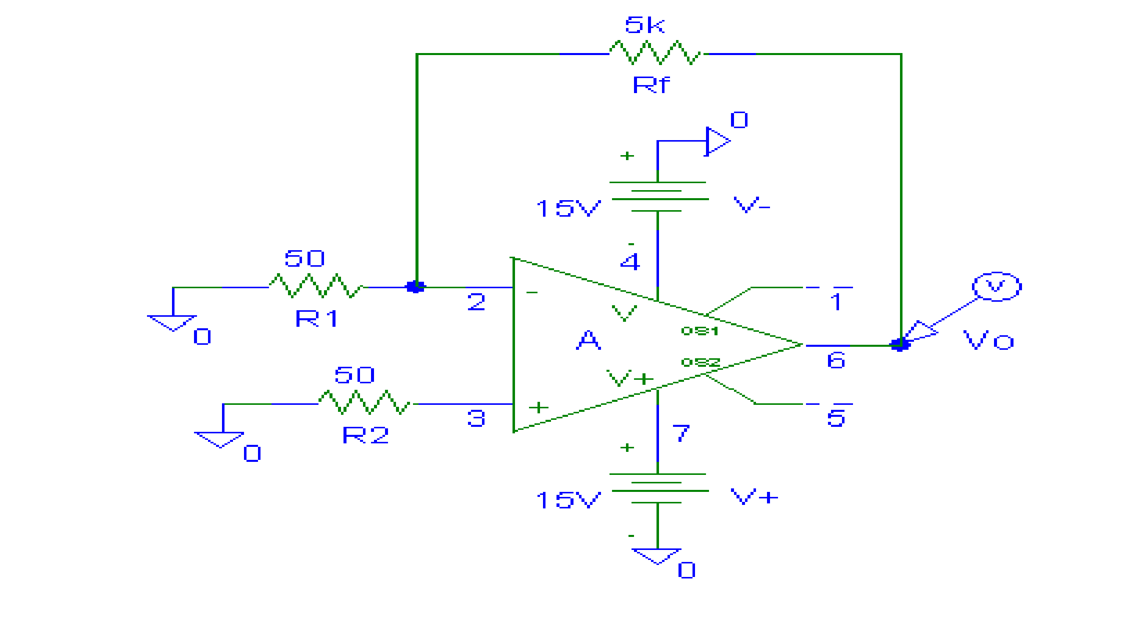


Fig 6a3: Circuit to measure Vio; effect of Ios is minimized.

- Draw the circuit shown in Fig.6a3 in PSpice schematics. (R_2 is used to minimize the effect if I_{os})
- Run simulation and mark V_o
- Now $V_{io} = \dfrac{V_o}{1 + R_f / R_1}$

4) *Bias currents (I_{B+},I_{B-}) & Input offset current I_{os}*

- Draw the circuit shown in Fig.6a41 in PSpice schematics. Run simulation and mark V_{o1}
- $I_{B-} = \dfrac{V_{o1} - V_{io}}{R_f}$
- Draw the circuit shown in Fig.6a42 in PSpice schematics. Run simulation and mark V_{o2}
- $I_{B+} = \dfrac{V_{io} - V_{o2}}{R_i}$
- Input offset current $I_{os} = |I_{B+}| - |I_{B-}|$

5) *Slew-Rate*

- Draw the circuit shown in Fig.6a5 in PSpice schematics.
- Set the input voltage to a square wave of 20 V peak-to-peak, 1kHz
- Select transient from **Setup Analysis**. Run simulation and mark V_o , T_{SR}
- $Slewrate = \dfrac{V_o}{T_{SR}}$

6) *Linear Applications*

- Draw the circuits shown in Fig.6b1~5 in PSpice schematics.
- Set the input voltages as suggested in **Table2**
- Select transient from **Setup Analysis**. Run simulation and mark outputs
- Roughly fill up **Table 2**

Table2: Linear Application Outputs.

CIRCUIT	Draw Output		
1. Inverting Multiplier R_i =1k, R_f =1k,10k,100k Vi=2v p-p Sin, 1kHz	R_f =1k	R_f =10k	R_f =100k
2. Inverting Summer R_f =1k,10k,100k V_1=2v pp, 1kHz(rec) V_2=2v pp, 1kHz(tri)	R_f =1k	R_f =10k	R_f =100k
3. Differential Amplifier (as Subtractor) If $R_2/R_1= R_4/R_3$ then $V_o= R_2/R_1(V_2 - V_1)$ V_1 =2v pp, 1kHz (rec) V_2 =2v pp, 1kHz (tri)	Select R’s for unsaturated V_o	Select R’s for saturated V_o	Select R’s for Subtracted V_o
4. Inverting Integrator Vi= 2v pp, 1kHz	Out put For V_i=Vsin	Out put For V_i=Vrec	Out put For V_i=Vtri
5. Inverting Differentiator Vi= 2v pp, 1kHz	Out put For V_i=Vsin	Out put For V_i=Vrec	Out put For V_i=Vtri