KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS
DEPARTMENT OF ELECTRICAL ENGINEERING
Electronic Circuits II – EE303

Experiment # 4

Gain Frequency Characteristics of Multistage Transistor Amplifiers

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 nonideal characteristics to advantage; for example the finite bandwidth and the finite gain characteristic can be used to construct capacitorless filters and oscillators, in general the nonideal characteristics of the operational amplifiers may degrade the circuit performance. Therefore, manufacturers usually provide users with the most important parameters of the operational amplifiers. Table I 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 characteristic. 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

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 Figure 1. Obtain an expression for the output voltage in terms of the voltage V_{in}, an the voltage V_x. If we select

$$10R_1 = R_2 = R_F = 10k\Omega,\ R_3 = 10\Omega$$

then is is easy to show that for large values of operational amplifier gain, the overall gain: that is with the feedback loop closed will be ≈ -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_{in} can be used without driving V_{out} to saturation levels. What is important is the simple relation between V_{out} and V_x; obtain this relation. Clearly, it is a simple matter to measure V_x and V_{out} and hence to calculate the gain of the operational amplifier.

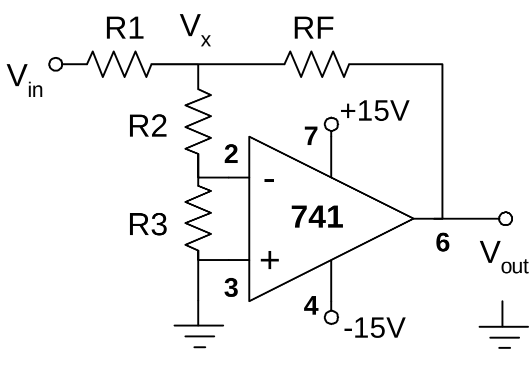


Figure 1

Some additional caution has to be exercised in measuring the operational amplifier gain using this method. This is because the open loop break frequency of the op-amp is as low as few Hz. Therefore, to measure the op-amp gain correctly we must choose a frequency that is lower than the break frequency of the op-amp. A good way to assure that we have selected the right frequency is to display both V_{out} and V_x on the oscilloscope in a Lissajou pattern. At frequencies above the break frequency we will obtain an ellipse. Why? Then by reducing the frequency until the ellipse is converted to a straight line then we can assume that we are using the right frequency and consequently the measured value of the op-amp gain can be considered correct. Explain this. You may face some difficulties in deciding whether you are seeing a straight line or not on the oscilloscope. Why? Anyway, try to avoid this.

2. <u>Measurement of open loop break frequency</u>

Consider the circuit shown in Figure 2. We know that at relatively high frequencies (w.r.t. the open loop break frequency), the gain of the op amp can be expressed by

$$A = \frac{A_o}{1 + jw / w_o}$$

At the frequency w_t corresponding to unity gain, it is easy to show that

$$A_o = w_t / w_o$$

The above equation can be easily proved since we know that $w_t >> w_o$. Therefore the gain of the op-amp can be expressed by

$$A = \frac{A_o}{1 + jA_o w / w_t}$$

It is easy to show that when $R_1 = R_2$ the gain V_{out}/V_{in} will be

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

Substituting the value of A and since A_o is very large it is easy to show that

$$A_{VF} = \frac{-1}{1 + 2w / w_t}$$

From the last equation it is obvious that the gain will drop to $1/\sqrt{2}$ when $w_m = w_t/2$. We can measure w_m. Since we know the open loop voltage gain A_o, then it is easy to calculate w_o.

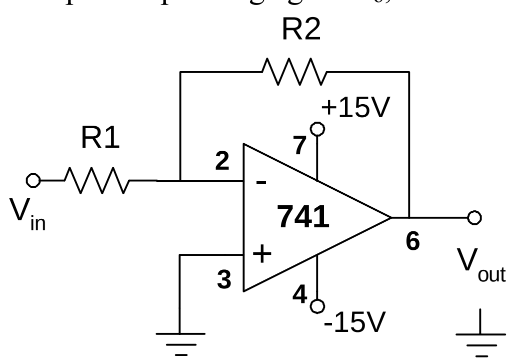
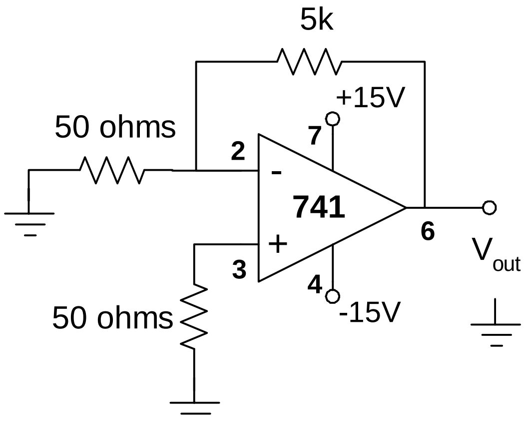


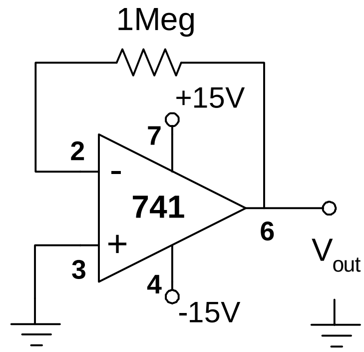
Figure 2

3. Input offset voltage, Bias current, Offset current

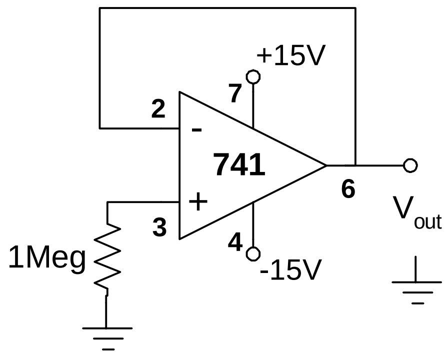
In order to measure offset voltage (Vos), I_1 and I_2 of general purpose op-amps using inexpensive methods, the circuits shown in Figure 3 are proposed. Verify the usefulness of these circuits by obtaining expressions for the output voltage for each circuit. Show how the offset parameters can be deduced from the measurement of the output voltages.



(a) Circuit to measure offset voltage; effect of I_{OS} is minimised



(b) Circuit to measure bias current in inverting terminal. Donot neglect V_{OS}



(c) Circuit to measure bias current in non-inverting terminal. Donot neglet V_{OS}.

Figure 3

4. Slew rate and full power bandwidth

From the discussion of section 2, we found that $w_t=w_oA_o$. Therefore, if we consider the circuit of Figure 2, its gain can be expressed as

$$\frac{V_{out}}{V_{in}} = \frac{-R_2/R_1}{1+(1+R_2/R_1)/A}$$

Therefore, substituting for $A=w_t/s$ the gain can be expressed as

$$\frac{V_{out}}{V_{in}} = \frac{-R_2/R_1}{1+(1+R_2/R_1)s/w_t}$$

which corresponds to an amplifier with dc gain of $-R_2/R_1$ and a 3dB corner frequency of $w_t/(1+R_2/R_1)$. Therefore, if we measure the frequency response of a closed loop amplifier with a gain of, say, 10, the 3dB 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 ±15V 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 causes 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. The op-amp data sheets usually specify the frequency at which a sine wave output, whose peak amplitude is equal to the maximum rated voltage, starts to show distortion. This frequency is called the full power bandwidth and is denoted by f_M. It is easy to show that

$$f_M = \frac{slew\,rate}{2\pi V_{\max}}$$

where V_{max} is the maximum specified output voltage of the op-amp.

To measure the slew rate and full power bandwidth, consider the circuit shown in Figure 4. If the input voltage is a square wave of 20V p-p (here we assume that the dc supply voltage of the op-amp is ±15V i.e. the 20V p-p represents the maximum output voltage of the op-amp) and if we keep the frequency at, say 1kHz, then the output will be as shown in Figure 4. Notice the effect of slew rate. The slew rate can be easily measured from the output. It is

$$\text{Slew Rate} = V_{out}/T_{SR}$$

Now apply a sine wave input of 20V p-p. Keep increasing the frequency of the input sine wave while monitoring the output until it starts to show distortion. Determine this frequency. This is f_M. Verify the relationship between f_M and the slew rate.

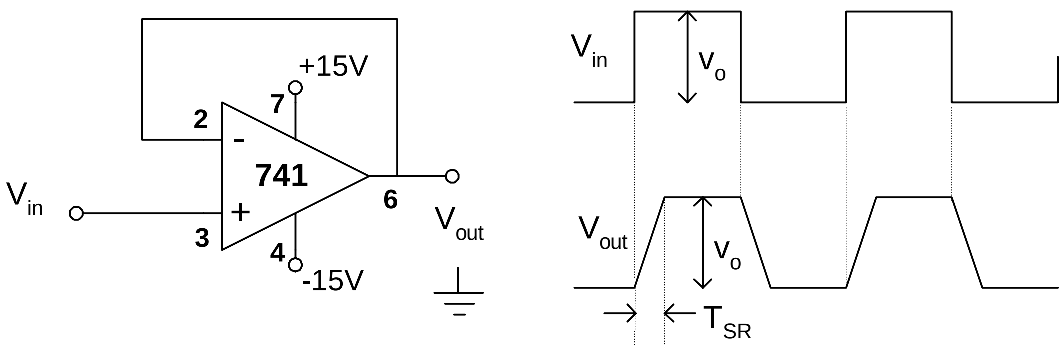


Figure 4

Table I : Typical Performance of Operational Amplifiers

	741	**LM118**	**AD507**
Input offset voltage (mV)	≤ 5	≤ 4	≤ 5
Bias current (nA)	≤ 500	≤ 250	≤ 15
Offset current (nA)	≤ 200	≤ 50	≤ 15
Open loop gain (dB)	106	100	100
CMRR (dB)	80	90	100
Input resistance (MΩ)	2	5	300
Slew rate (V/µs)	0.5	≥ 50	35
Unity gain bandwidth (MHz)	1	15	35
Full power bandwidth (kHz)	10	1000	600