Summary Report - Week 1

Manpa Barman

August 21 , 2021

1. Operational Amplifiers or Op-amps

A literature survey was done to analyse the operating conditions of an operational amplifier under open loop and closed loop conditions.

- Study of the Op amp basics
- Simulating the circuits in LTSpiceVIII

2. Simulation Details

- **Environment**: LTspiceXVII
- **Important component(s)**: LM741 op-amp IC
- **Reference Book**: Op-Amps and Integrated Circuits by Ramakant Gayakwad

2.1 Introduction

Op-Amp is a device used to amplify any type of ac or dc signals. It was primarily used for operations like addition, subtraction, multiplication, integration etc and thus its name but now it is mostly used for amplification purposes.

In market we can buy one as a linear IC with names like LM741 (primitive general purpose one) and LM380 used for audio power applications.

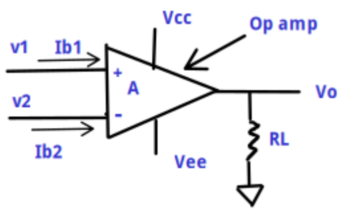
2.2 Open Loop Configuration of an Op-Amp

Any op-amp circuit where output is no way fed to the input directly or indirectly is called an open loop circuit.

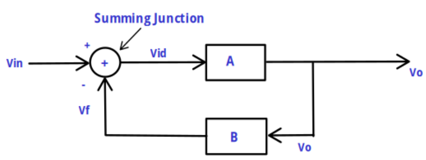
For the circuit shown in Figure 1 (a): $v_o = A(v_1 - v_2)$, where A= large signal voltage gain or differential voltage gain,v_1= voltage at the non inverting input terminal w.r.t. ground, v_2 = voltage at the inverting input terminal w.r.t. ground and v_o= output voltage.

Some must know typical component ranges for OPEN LOOP systems.

- A $\approx 10^5$ - Large Signal Voltage signal specified in the datasheet
- I_{B1} and $I_{B2} \approx 500nA$ - current from inverting or noninverting terminal to the ground

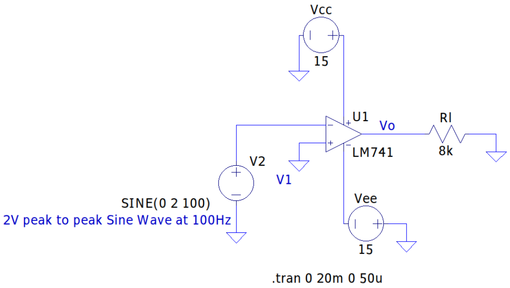


(a) Open Loop Configuration

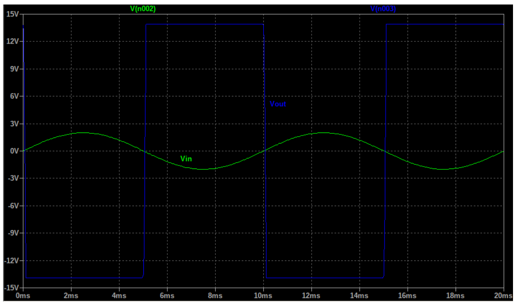


(b) Closed Loop Configuration

Figure 1: Basic Figures of Open and Closed Loop Configuration of Op amp

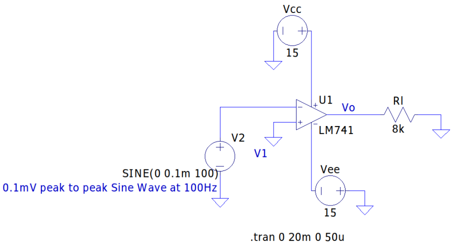


(a) Circuit

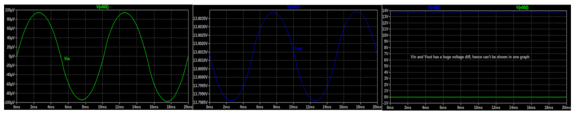


(b) Waveform

Figure 2: Open Loop Inverting Amplifier with saturated output



(a) Circuit



(b) Waveform

Figure 3: Open Loop Inverting Amplifier with unsaturated output

- R_i - $2M\Omega$ - Input resistance from any one terminal w.r.t. ground - Differenential Input Resistance
- $R_o \approx 75\Omega$ - Output resistance w.r.t. ground
- V_{CC} and V_{EE} - $+15V$ and $-15V$ (specified in the datasheet)
- Maximum Common Mode Voltage - $+13V$ and $-13V$ - When the same voltage is applied to both the terminals- Common Mode Configuration
- Common Mode Gain, $A_{CM} = \frac{V_{ocm}}{V_{cm}}$
- CMRR $= \frac{A}{A_{CM}} \approx 90 - 120dB$
- $R_L \geq 2k\Omega$
- Output Voltage Swing $\approx +13V$ and $-13V$ -Indicates the values of positive and negative saturation voltages of an op amp. The output voltage never exceeds the supply voltage V_{CC} and V_{EE}

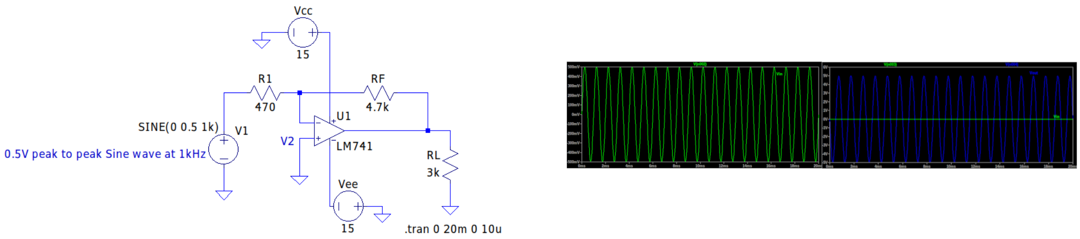
The above given numbers should be there in our mind before designing a circuit. Output Voltage swing is one most import parameter which limits the use of open loop systems except for a few use cases like square wave generator etc as if the outputs exceeds the swing limits the system clips the outputs to the max and min swings. Also since open loop systems have a huge voltage gain ($\approx 10^5$) so we have to use very very small differential inputs to not get our output in the saturated region and smaller the voltage more noisy signals we get.

Another drawback of open loop systems is its very low bandwidth of approximately 5Hz which is impractical. (Bandwidth is the band of frequencies for which gain remains constant)

A. Open Loop Schematics

The inverting configuration comparison is shown in Figure 2 and Figure 3. The non-inverting and differential configuration can be generated in a similar fashion.

Figure 2 shows an example when the output voltage gets saturated and clipped and Figure 3 shows an example when we give sufficiently low input such that the output is not clipped.



(a) Circuit

(b) Waveform

Figure 4: Closed Loop Configuration of Op amps

2.3 Close Loop Configuration of an Op amp

Any Op amp should exhibit a few characteristics like infinite voltage gain,A ; infinite input resistance,R_i; Zero output resistance, R_o; zero output voltage when input is zero; infinite bandwidth; infinite CMRR etc.

However the open loop systems do not even near to this characteristics except for high voltage gain also its saturating characteristic makes it difficult to use in all applications.

So we use a feedback loop or a closed loop configuration where the output is indirectly or directly fed to the input as shown in Figure 4 (b)

- A = gain without feedback/open loop voltage gain = $A = \frac{v_o}{v_{id}}$
- A_F = gain with feedback loop/closed loop voltage gain = $A_F = \frac{v_o}{v_{in}}$
- B = gain of feedback circuit = $B = \frac{v_f}{v_o}$

For a closed loop circuit (non-inverting configuration), $A_F = 1 + \frac{R_F}{R_i}$ (for inverting configuration $A_F = -\frac{R_F}{R_i}$). Hence the gain is only dependent on the ratio of the two resistor and not the input voltage as in open loop configuration. So we can choose any values of the resistors maintaining the ratio of the gain according to our needs. The only restriction is that all the component values should be less than $1M\Omega$ so that it do not effect the internal circuitry of the op amp.

Also all the other characteristics like mentioned above is satisfied more than its open loop counterpart except for the lower large signal voltage gain trade off.The formulas given below justifies the statement.

- $A_F = \frac{1}{B}$
- $A_F = \frac{A}{1+AB}$
- $R_{if} = R_f(1 + AB)$ - increased input resistance
- $R_o = \frac{R_o}{1+AB}$ - decreased output resistance
- $f_F = f_o(1 + AB)$ - increased bandwidth
- $V_{ooF} = \frac{+-V_{sat}}{1+AB}$ - *Only trade off is the output voltage*

A. Close loop schematics

The non inverting amplifier schematic is shown in shown in Figure 4. We can do similar for inverting and differential configuration. Here we can see that the gain is controlled by the resistors in the circuit and no saturation occurs even at higher input voltages unlike open loop systems.