Summary Report Week 2

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1 Simulation Details

- **Environment**: LTspiceXVII
- **Important component(s)**: LM741 Opamp IC
- **References**:
  - OpAmps and Integrated Circuits by Ramakant Gayakwad
  - Introduction to LT-Spice Lecture by Ahmed Abu Hazar

2 Frequency Response Analysis of an OpAmp

In this week I analysed the frequency responses of the op amp circuits and its DC and AC amplification.

Open loop voltage gain is one of the most important things we need to keep in mind while designing an op amp based circuit. The gain parameter is directly linked to the operating frequency of the system. Typically the gain decreases as the frequency of a system increases. In the previous week we have assumed the gain to be constant but it is actually a function of frequency.The manner in which the gain of the op amp responds to changing frequencies is called the **frequency response** of the circuit and the graph between the magnitude of gain versus the frequency is called the **frequency response plot**.

3 Compensating Networks

Generally for any op amp there are two affects of increase in frequency-

- The gain of the amplifier decreases
- The phase shift between the input and output increases.

Thus both gain and phase shift is proved to be a function of frequency. An op amp is constructed with a number of semiconductor devices like FET and BJT, which leads to formation of some stray capacitance in the internal circuitry of the op amp.This capacitance cause the above mentioned changes in gain and phase shift.

Thus compensating networks consisting of resistors and capacitors are used to modify the performance of the op amp circuit over a desired frequency range. The first generation op amps like the 709 or 709C do not have internal compensating network, however the later generation op amps like 741 do have internal compensating networks, thus no extra circuitry is required for correction.

In this report I will mostly cover the internally compensated op amps.

4 Internally compensated Op amps

741 IC is an example of internally compensating op amps as shown in Figure 1. Let's visit some important terminology before the analysis:

- **Break-frequency,** f_o: It is the frequency where the open loop gain is down 3dB or 0.707 of its value at 0 Hz. In Figure 1 and Figure 2 we have f_o = 41.48kHz and 143.97kHz.
- **Unity gain-bandwidth(UGB)**:It is the frequency when the gain of the op amp is 0dB or 1. It is typically of the range 1MHz for compensated op amps.

4.1 Open Loop Frequency analysis of compensated op amp (LM741)

Note : All the calculations from the plots are the approximate values.

In the following open loop circuit, we use an internally compensated LM741 op amp. No other external adjustments are used.

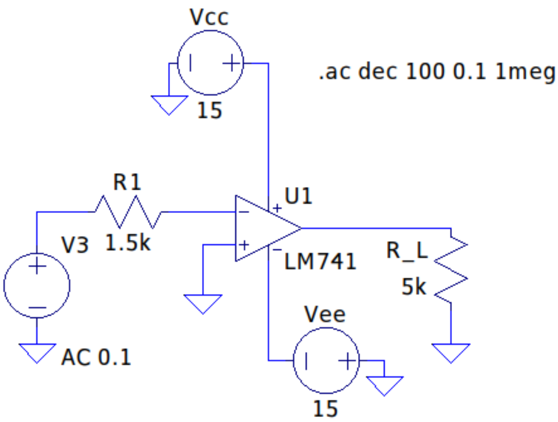


Figure 1: Voltage Compensated Open Loop OpAmp

Analysis :
From figure 2(a), we have the at 0Hz, gain = 27.54. Therefore, from the break frequency definition we have f_o = Frequency at a gain of$(27.54-3)dB = 24.3dB$. Tracing 24.3dB in the *frequency plot*, we have $f_o = 41.48kHz$ (Figure 2(b)).

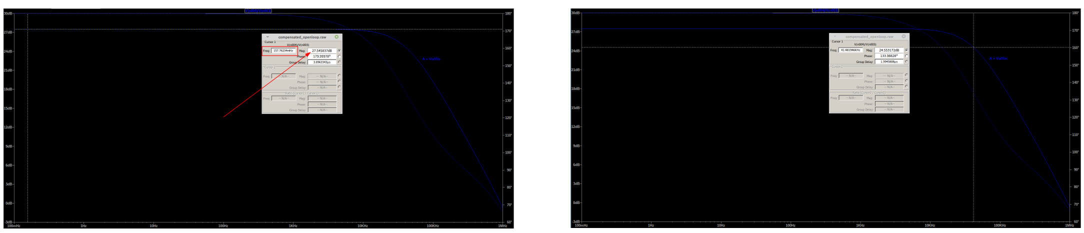
For UGB (Figure 3), tracing the frequency value at 0dB, we get the $UGB = 931.42kHz$.

4.2 Close Loop Frequency analysis of compensated op amp (LM741)

In the following close loop circuit (Figure 4), we use an internally compensated LM741 op amp. We use a simple resistive feedback in the feedback loop.No other external adjustments are used.

Analysis :
From figure 5(a), we have the at 0Hz, gain = 15.56. Therefore, from the break frequency definition we have f_o = Frequency at a gain of$(15.56-3)dB = 12.56dB$. Tracing 24.3dB in the *frequency plot*, we have $f_o = 143.9kHz$ (Figure 5(b)).

For UGB (Figure 6), tracing the frequency value at 0dB, we get the $UGB = 814.52kHz$.



(a) Frequency at $\approx 0Hz$ (b) Break Frequency

Figure 2: Open Loop Inverting Amplifier with saturated output

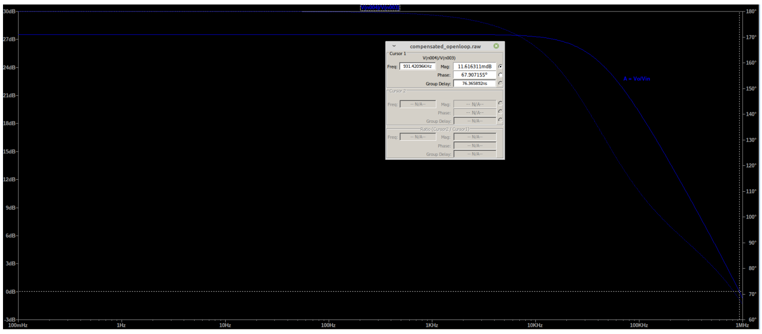


Figure 3: Unity Gain Bandwidth Determination

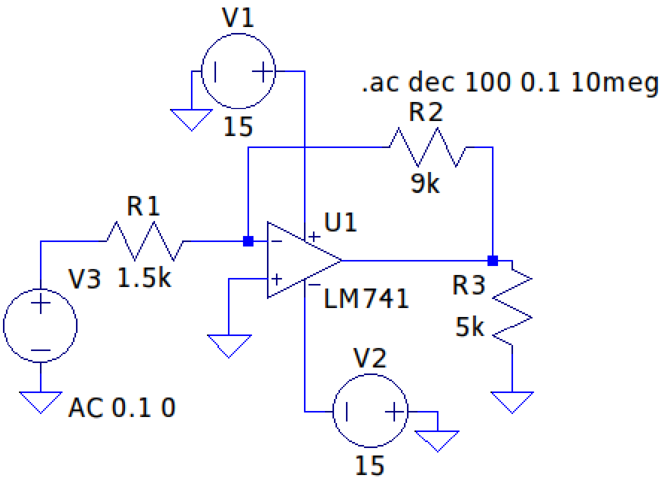
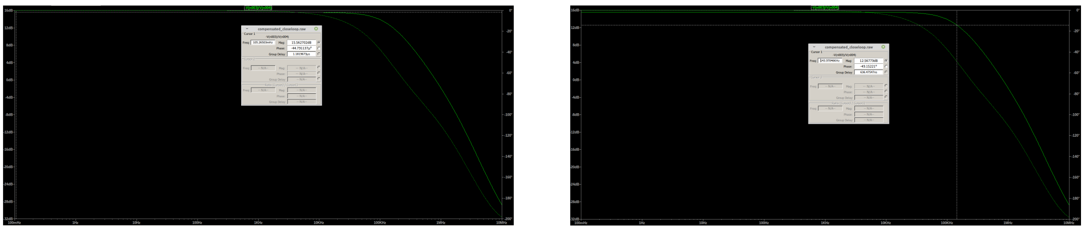


Figure 4: Voltage Compensated Close Loop OpAmp



(a) Frequency at $\approx 0Hz$

(b) Break Frequency

Figure 5: Close Loop Inverting Amplifier with saturated output

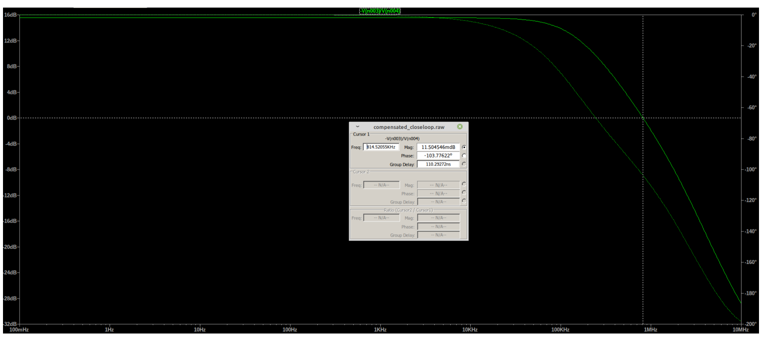


Figure 6: Unity Gain Bandwidth Determination

5 Modification in the High Frequency Model of an OpAmp

From the above discussion we see that after a certain frequency the gain starts *decreasing*. Therefore, there must be some capacitive component in the model along with the input (R_i) and output (R_o) resistances which *decreases* the resistance(reactance) due to which the gain also starts decreasing. These cumulative capacitances formed is due to the internal construction of the op-amp. For an op-amp with one break frequency , will represent all the capacitive effects by a single capacitor (Figure 7) and similarly for op-amps with more than one break frequency may be represented by using as many capacitors as the number of break frequencies.

The open loop gain as a function of frequency , A_{OL} is given by,

$$A_{OL}(f) = \frac{A}{1 + j(f/f_o)}$$

In polar form, the open loop magnitude is given by:

$$|A_{OL}(f)| = \frac{A}{\sqrt{1 + (f/f_o)^2}}$$

and the phase angle,

$$\Phi(f) = -tan_{-}1(\frac{f}{f_o})$$

If we want the gain in decibels we want will have to multiply the magnitude by $20log$ *in both sides of the open loop magnitude expression.*

For a typical op-amp, the UGB is usually given in the datasheet, along with the large signal voltage gain. Thus we can easily find the break frequency by- $f_o = \frac{UGB}{A}$

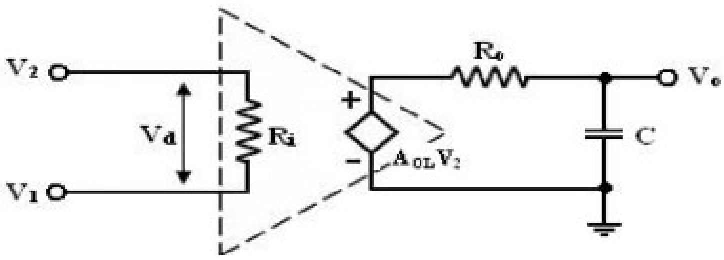


Figure 7: Equivalent Circuit of an op-amp (*Courtesy: BrainKart.com*)