Experiment
4
CMOS Operational Amplifier (2)

Small-signal Analysis

Objectives

1. To emphasize the importance of the *best DC bias-point* and *dynamic range* in high voltage-gain circuit.
2. To have the greatest performance in frequency response by employing *feedback network* and *compensation capacitor* to the circuit.

Overview

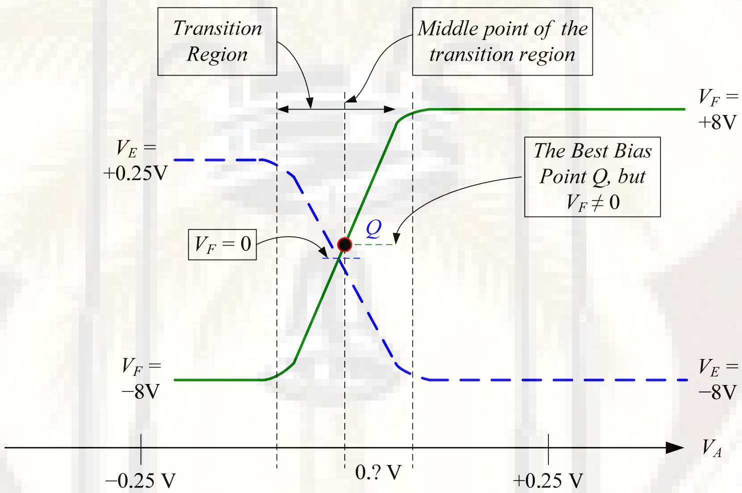


Fig. 1 DC-Sweep Diagram of (V_E,V_F) vs V_A

Refer to the diagram shown in Fig. 2,

1. The curve slope in the transition region is high, which means the voltage gain will be high as well.
2. The voltage gain at the two different DC-bias point is shown as follow:

$$\left.\frac{v_{o1}}{v_i}\right|_{Q_1} < \left.\frac{v_{o2}}{v_i}\right|_{Q_2},$$

where: $\left.V_A\right|_{Q_1} \le \left.V_A\right|_{Q_2}$

3. We can conclude that the slightly change with V_A will result the huge voltage gain variation. In the best DC-bias point, $V_F \neq 0$. Therefore, in order to have maximum voltage gain, we are not necessarily to insist on adjusting $V_F = 0$.

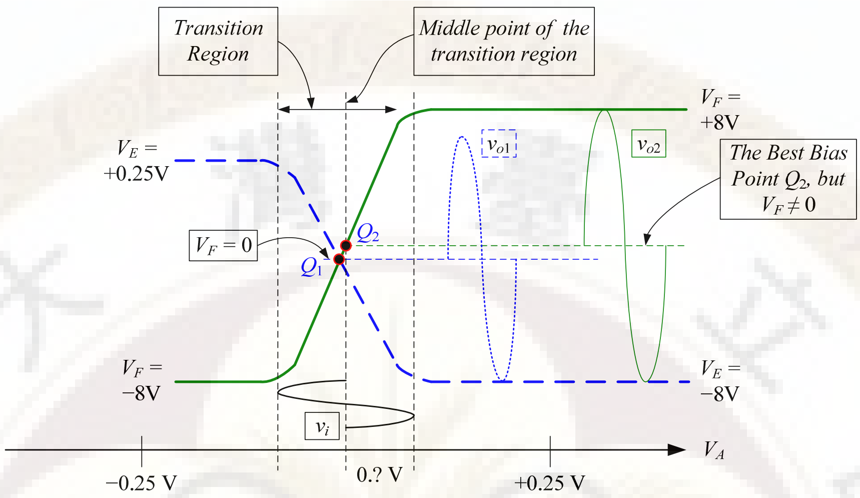


Fig. 2 Selection of the best DC-bias point

Components and Instrumentation

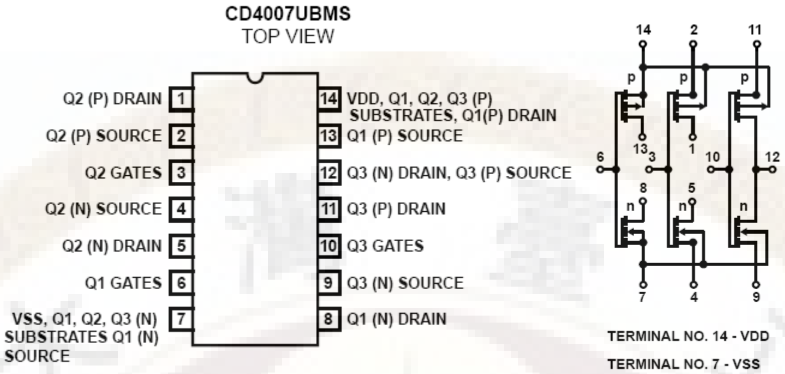
Instrument	Quantity	Components	Quantity
Oscilloscope	1	CD 4007	3
Multi-meter	1	VR (可變電阻) (1 kΩ)	1
Power supplier	1	10 kΩ	1
Function Gen.	1	1 kΩ	1
0.47 μF	1	18 kΩ	2

Instrument confirmation

Before you proceed to any part of the experiment, please remember to do the **Instrument Examinations** to the instruments before performing any experiment. The examining procedures are shown in experiment 1.

Lab Work

1. CD4007—PINOUT



Note: Always supply voltage $-V_{SS} = -8V$ in pin7 and $V_{DD} = +8V$ in pin 14 for every chip of CD4007. The experimental results will be unreasonable if the above notice has not been followed.

2. Tuning the best DC-bias point
   (1) Adjust VR (R_3) in Fig. 3 (shown in the next page) to have $V_F \doteqdot 0$.
3. Set up the dynamic range, and voltage gain
   (2) In Fig. 4, apply the input small signal V_i to the breadboard by using function generator to generate $v_i = v_{ac} \times \sin(2\pi ft)$, $2v_{ac} = 20\mathrm{mV}_{(p\text{-}p)}$, $f = 1$ kHz.

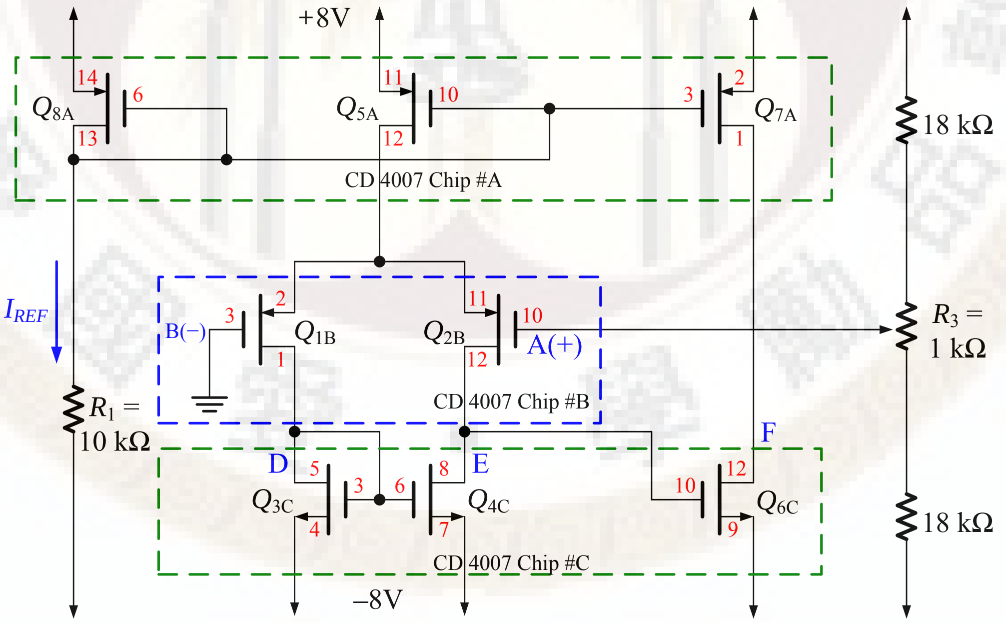


Fig. 3 Selection of DC-bias point in Two-stage OP-Amp circuit

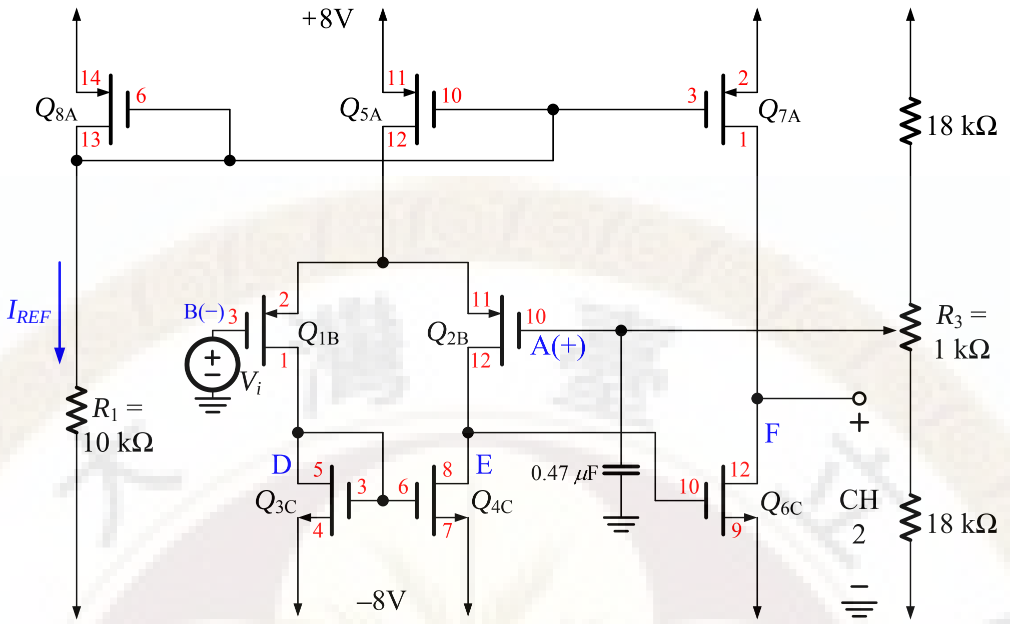


Fig. 4 Small signal applied in Two-stage OP-Amp circuit

(3) Make sure that the v_i is measured from the breadboard by using the probe from **CH1** in oscilloscope.

(4) Oscilloscope ► **YT mode.**

(5) Adjust VR (R_3) 1 $k\Omega$ in Fig. 2-2 to have maximum small-signal voltage gain V_F/V_i.

(6) Keep the previous adjustment of R_3 constantly.

(7) Record the voltage gain $A_{M.1}$ = ________V/V (Reference value $|A_{M.1}| \geq 200V/V$.) by observing the differentiation of input and output voltage value shown in the oscilloscope.

(8) Record the V_F (DC) = ________V, R_3 = ________$k\Omega$, ________$k\Omega$.

(9) Confirm whether the voltage gain is the same as the slope of the curve at transition region measured in step 6 at Exp 3. (Y/N) ________ .

(10) Increase/Decrease V_i until the waveform of V_F just distort.

(11) Record the peak-to-peak value of V_i = ______V. (Dynamic range).

(Hint: Dynamic range is the largest possible input value that doesn't make output waveform distort.)

4. Frequency response

(12) Set $v_i = v_{ac} \times \sin(2\pi ft)$, $2v_{ac}$ =20mV$_{(p\text{-}p)}$, f = 1 kHz.

(13) Function generator ► Adjust Frequency and observe the voltage gain A_V in oscilloscope until A_V=0.707×A_M.

(14) Record the frequency $f_{3dB.1}$ = ________Hz. (Reference: $f_{3dB.1} \geq 30kHz$.)

(15) Change the frequency of input voltage source, and record the input and output voltage shown in oscilloscope to the following table.

f (Hz)	$V_{i(p\text{-}p)}$	$V_{O(p\text{-}p)}$	A_V	f (Hz)	$V_{i(p\text{-}p)}$	$V_{O(p\text{-}p)}$	A_V
10				5K			
20				10K			
50				20K			
100				50K			
200				100K			
500				200K			
1K				500K			
2K				1M			

※ *Homework* #1: Apply the measured data from the above table to the editing software such as EXCEL and MATLAB, and illustrate the frequency-response diagram with marking f_{3dB} and the corresponding voltage.

5. Internal frequency compensation (內部補償)

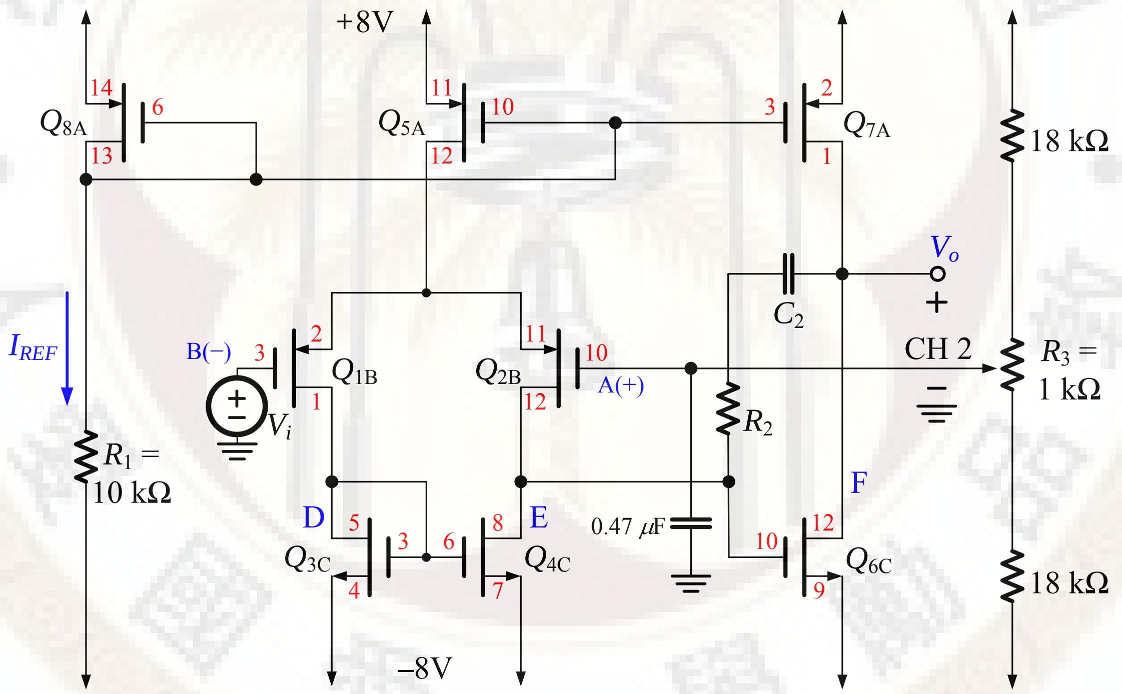


Fig. 5 Internal frequency compensation

(1) Use R_2 = 100 kΩ, C_2 = 10 pF in to implement the compensation circuit in Fig. 5.

(2) Repeat step (8) ~ (11) shown in step 3.

(3) Record the voltage gain $A_{M.2}$ = ________V/V. (Reference vlaue, $|A_{M.2}| \approx |A_{M.1}|$.)

(4) Record the dynamic range V_i = _______V.

(5) Record the frequency $f_{3dB.2}$ = ________Hz. (Reference, $f_{3dB.2} \approx f_{3dB.1}/2$)

(6) Change the frequency of input voltage source, and record the input and output voltage shown in oscilloscope to the following table.

f (Hz)	$V_{i(\text{p-p})}$	$V_{O(\text{p-p})}$	A_V	f (Hz)	$V_{i(\text{p-p})}$	$V_{O(\text{p-p})}$	A_V
10				5K			
20				10K			
50				20K			
100				50K			
200				100K			
500				200K			
1K				500K			
2K				1M			

※ *Homework* #2: Apply the measured data from the above table to the editing software such as EXCEL and MATLAB, and illustrate the frequency-response diagram with marking f_{3dB} and the corresponding voltage.

6. Feedback network compensation (內部補償+回授電路)

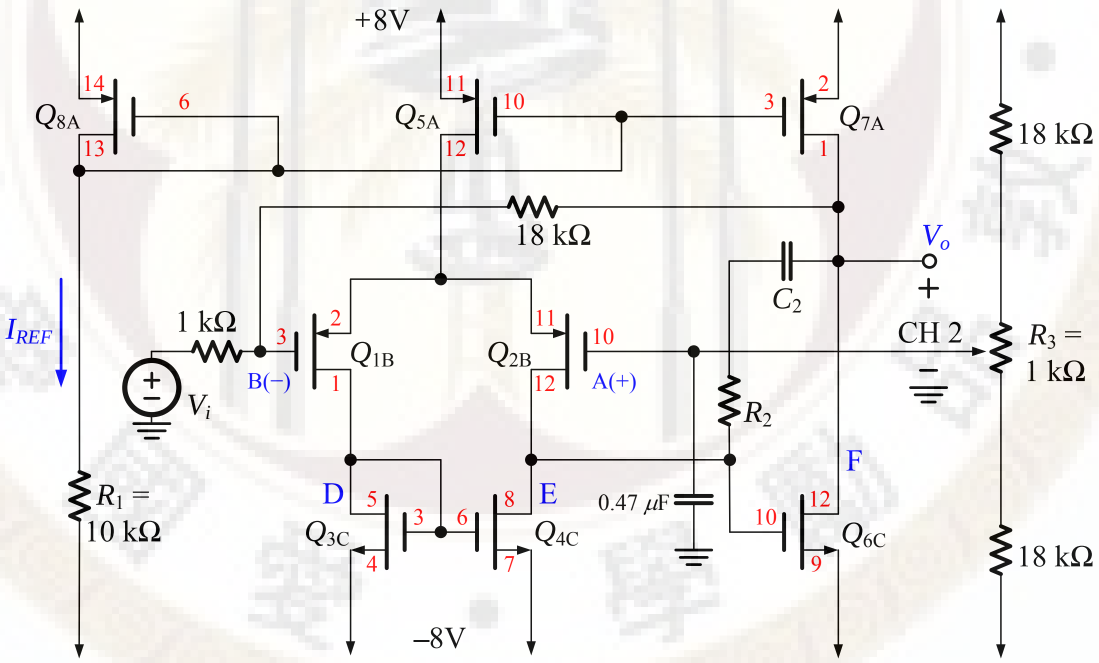


Fig. 6 Feedback network compensation

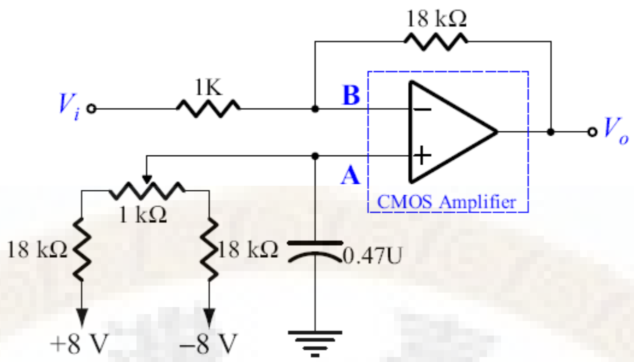


Fig. 7 Schematic circuit of Fig. 6

(1) Use R_2 = 100 $k\Omega$, C_2 = 10 pF in to implement the compensation circuit in Fig. 3.

(2) In Fig. 6, apply the input small signal V_i to the breadboard by using function generator to generate $v_i = v_{ac} \times \sin(2\pi ft)$, $2v_{ac}$ =100mV$_{(p\text{-}p)}$, f = 1 kHz.

(3) Repeat step (8) ~ (11) shown in step 3.

(4) Record the voltage gain $A_{M.3}$ = ________V/V.

(5) Record the dynamic range V_i = ______V.

(6) Record the frequency $f_{3dB.3}$ = __________Hz.

(7) Change the frequency of input voltage source, and record the input and output voltage shown in oscilloscope to the following table.

f (Hz)	$V_{i(p\text{-}p)}$	$V_{O(p\text{-}p)}$	A_V	f (Hz)	$V_{i(p\text{-}p)}$	$V_{O(p\text{-}p)}$	A_V
10				100K			
20				300K			
50				500K			
100				600K			
200				700K			
500				800K			
1K				900K			
2K				1M			
500				1.1 M			
5K				1.2 M			
10K				1.3 M			
20K				1.4 M			
50K				1.5 M			

※ *Homework* #3: Apply the measured data from the above table to the editing software such as EXCEL and MATLAB, and illustrate the frequency-response diagram with marking f_{3dB} and the corresponding voltage.

Reference

1. A.S. Sedra and K.C. Smith, *Microelectronic Circuits*, 6th ed., Oxford University Press publishing, New York, 2011.
2. A.S. Sedra and K.C. Smith, *Laboratory Manual for Microelectronic Circuits*, 3rd ed., Oxford University Press publishing, New York, 1997.