ELEN 458 Lab 2
OTA Characterization

I Objectives

The objective of this laboratory is to help the student become aware of the characteristics and limitations of the Operational Transconductance Amplifier (OTA).
The dependence of the OTA characteristics on g_m as well as proper bias techniques will be illustrated. The student should note that most of the OTA's characteristics vary as a function of the amplifier bias current, I_{ABC}.

II Component List

- LM 13600 OTA (x1)
- uA741 Opamp (x1)
- Resistors : 50k ohms potentiometer (x1), 30k ohms (x1), 1k ohms (x1), 10k ohms (x2)

III Introduction

In comparison to the operational amplifier, the transconductance amplifier (often termed as the Operational Transconductance Amplifier (OTA)) offers excellent frequency response, is readily programmable by a DC bias current and requires a small amount of silicon chip design area. Good performance is attainable with both bipolar and MOS implementations.

Although it can be used in feedback applications, the OTA finds many applications as an open-loop amplifier element. In those applications, linearity and accuracy of the transconductance gain are the major interest.

Throughout this experiment, the OTA chip, LM13600 would be used. The OTA is using bipolar technology and has linearizing diodes at the input to improve the linearity of the devices. Pick a reasonable value of resistor to bias the 'diode bias' pin (e.g. 15k ohms).

CAUTION :

Biasing the OTA

The OTA is an unique integrated circuit in that it requires the user to bias the IC before it can be used (refer to the schematic of LM13600 datasheet – http://www.national.com). Figure #1 shows a biasing circuit for use with the OTA. Note that the circuit is also designed to withstand maximum variation in the amplifier bias current, I_{ABC}. This biasing circuit will **NOT** be shown in future labs, but it or a similar biasing circuit must be used. **You should make sure the bias current I_{ABC} pin is properly connected before you turn on power supplies to the OTA.**

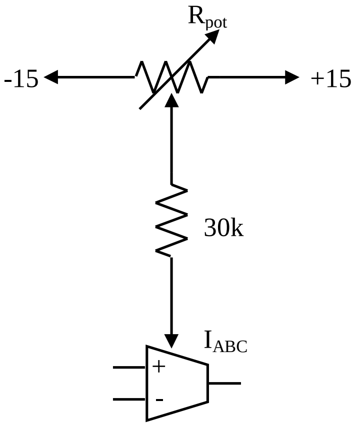

Figure #1

IV Lab Procedure

1. OTA Buffering

An ideal current source should have an infinite output impedance. The OTA, a non-ideal integrated circuit, has a finite output impedance. The I-to-V converter in Figure #1A allows the OTA to drive into a virtual ground, as well as converting the OTA output current to a voltage, such that $V_{OUT}=-R_L I_{OUT}$. Note that by measuring V_{OUT}, we can obtain the value of I_{OUT}

2. Measuring the constant h (SPICE & Expt)

The output of the OTA is linear over a small operating range (maximum input of $\approx 50mV$ peak to peak). Do not exceed 50mV for the input signal. In order to keep the OTA in the linear operating region, the input voltage V'_{in} must be reduced to an acceptable magnitude. This new voltage will be called $V_{in.}$ Using the circuit in Figure #2, measure the values of *h* for four I_{ABC} from 0.1mA to 1.0mA for the LM13600 in the experiment. In SPICE simulation, sweep I_{ABC} with resolution of 10uA.

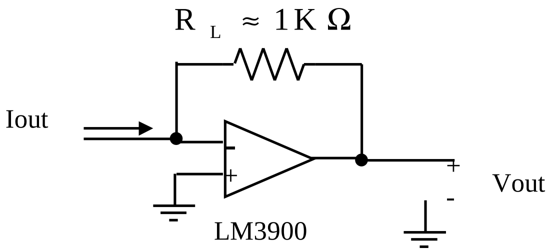

Fig. #1A

Note that the value of *h* is fairly constant over the range of I_{ABC}. Provide the average value of *h* and g_m for each I_{ABC}. The term *h* can be derived as follows :

Since $g_m = hI_{ABC}$ and $V_o = I_oR_L = g_mV_{in}R_L$. Then

$$h = \frac{g_m}{I_{ABC}} = \frac{V_o}{V_{in}I_{ABC}R_L}$$

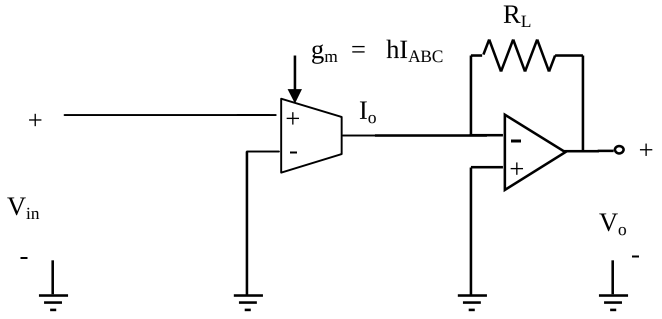

Fig. #2

HINT :

Put the channel 1 of the oscilloscope on V_{in} and channel 2 on V_{in}' and adjust to desired amplitude. Now place channel two on the output. With the voltage divider scheme, this will allow a larger signal at V_{in} (if too small - noise concern), without saturating/distorting the output signal.

3. Maximum output current, $I_{o\ MAX}$ (SPICE and Expt)

Using the circuit in Figure #2, measure the maximum output current for four values of $I_{ABC.}$ $I_{o\ MAX}$ is found by increasing V_{in} until I_o saturates. Note the relationship between the value of I_{ABC} and $I_{o\ MAX}$.

4. Maximum Differential Input Voltage (SPICE only)

The maximum differential input voltage (set to low frequency e.g. 1kHz) is found using the circuit of Figure #2, with the output monitored with a distortion analyzer. Increase V_{in} until the output voltage of the circuit has reached a 5% distortion. Measure and record the voltage at V_{in}. This is the maximum differential input voltage, $V_{d\ MAX}$. Measure $V_{d\ MAX}$ for four values of I_{ABC}.

5. Measurement of V_{os} (SPICE and Expt)

The differential input of the OTA is made up of a pair of BJTs. Because these transistors are not perfectly matched, there will be a definite offset voltage between the two input terminals. Using Figure #4 (switches shorting inputs to ground), measure the value of V_{os} for four values of I_{ABC}. The offset voltage can be computed using the equation

$$V_{os} = \pm \frac{V_o}{g_m R_L}$$

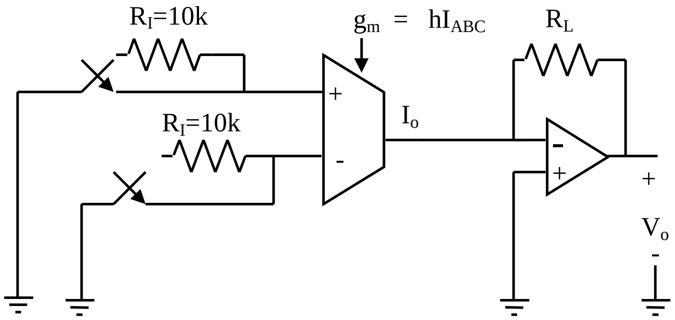

Fig. #4

6. Input offset current, I_{os} (SPICE and Expt)

The BJT in the differential input stage of the OTA will cause a small current to flow into the input of the OTA. The currents into the two inputs are slightly different. This difference is the offset current. Using the circuit in Figure #4 (switches connecting the $10k\Omega$ resistors between the inputs and ground), measure the offset. The equation for the current is

$$I_{os} = \pm\left(\frac{V_o}{g_m R_I R_L} - \frac{V_{os}}{R_I}\right)$$

Measure I_{os} for four values of $I_{ABC.}$

7. Measuring the input impedance of the OTA (SPICE and Expt)

The input impedance of the OTA is ideally infinite, but due to the fact that a non-ideal device is being used, the OTA has a finite input impedance. Use the circuit of Figure #3 to measure the value of the input impedance for the OTA. Adjust the potentiometer until V_{in}' is approximately ½ V_{in}. The input impedance, R_{in}, is then equal to the value of the potentiometer. Measure the value of R_{in} at four values of $I_{ABC.}$.

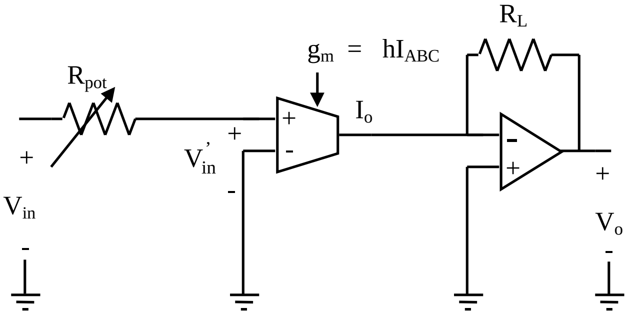

Fig. #3

Note : Before you perform the measurement, Disable the 'diode bias' pin. Make sure you cancel first the offset of the Op Amp using the method in lab1.

Prelab report :

Perform simulations using HSPICE or PSPICE with the LM13600 (http://www.national.com/models/spice/analog/errata.html) and uA741(http://www.ti.com/sc/docs/msp/tools/macromod.html) macromodels. The objective of this exercise is to obtain the following parameters :

- h -a constant factor relating I_{ABC} and g_m
- $I_{o\,MAX}$ -the maximum output current for the OTA
- $V_{d\,MAX}$ -the maximum differential input voltage
- V_{os} -the input offset voltage
- I_{os} -the input offset current
- R_{in} -the input impedance of the OTA

In your pre-lab report, include :

1. A graph of h versus I_{ABC}.

2. Average value of h.

3. Values of g_m. Plot I_{ABC} vs. g_m.

4. A graph of $I_{O\,MAX}$ versus I_{ABC}.

5. A graph of $V_{d\,MAX}$ versus I_{ABC}.

6. A graph of R_{in} versus I_{ABC}.

7. A graph of V_{os} versus $I_{ABC.}$

8. A graph of I_{os} versus $I_{ABC.}$

*For Pre-lab SPICE simulation, use more points i.e. sweep I_{ABC} with fine resolution rather than only 4 points (which is for experimental part).

Final Lab Report Requirements(Min.) :

1. Gather simulation and experimental results corresponding to four points of I_{ABC} and plot on the same scale, the above eight graphs. (you may use excel or any graphic software to plot them).
2. Answers the following Questions :

a. Is the value of h constant for different values of I_{ABC}? If so, what is the value?

b. Does the maximum output current vary with g_m? Why or why not?

c. Does the maximum differential input voltage vary with g_m? Why or why not?

d. How does g_m affect the input resistance of the OTA?

e. How do the offset voltage and offset current vary with g_m? (state your observation)

f. What OTA parameters are dependant on g_m? What characteristics are not dependent on g_m?

g. List some design advantages of the OTA.

h. List some design disadvantages of the OTA.

i. Why must the input amplifier bias current pins of the OTA never be grounded?

j. Discuss the use of the OTA as a basic building block, i.e., summer, multiplier and as an integrator.

OTA Model File :

LM13600

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*//////////////////////////////////////////////////////////////////////
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* \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
* LM13600 Dual Operational Transconductance Amplifier
* \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
*
*                Amplifier Bias Input
*                 | Diode Bias
*                 | | Positive Input
*                 | | | Negative Input
*                 | | | | Output
*                 | | | | | Negative power supply
*                 | | | | | | Buffer Input
*                 | | | | | | | Buffer Output
*                 | | | | | | | | Positive power supply
*                 | | | | | | | | |
.SUBCKT LM13600/NS  1 2 3 4 5 6 7 8 11
*
* Features:
* gm adjustable over 6 decades.
* Excellent gm linearity.
* Linearizing diodes.
* Controlled impedance buffers.
* Wide supply range of +/-2V to +/-22V.
*
* Note:  This model is single-pole in nature and over-estimates
*      AC bandwidth and phase margin (stability) by over 2X.
*      Although refinement may be possible in the future, please
*      use benchtesting to finalize AC circuit design.
*
* Note: Model is for single device only and simulated
*      supply current is 1/2 of total device current.
*
*****************************************************
*
C1  6  4  4.8P
C2  3  6  4.8P
```

```
* Output capacitor
C3  5  6  6.26P
D1  2  4  DX
D2  2  3  DX
D3  11 21 DX
D4  21 22 DX
D5  1  26 DX
D6  26 27 DX
D7  5  29 DX
D8  28 5  DX
D10 31 25 DX
*  Clamp for -CMR
D11 28 25 DX
* Ios source
F1  4  3  POLY(1)   V6 1E-10 5.129E-2 -1.189E4 1.123E9
F2  11 5  V2        1.022
F3  25 6  V3        1.0
F4  5  6  V1        1.022
F5  30 6  V3        1.0
* Output impedance
F6  5  0  POLY(2)   V3 V7 0 0 0 0 1
G1  0  33 5         0 .55E-3
I1  11 6  300U
Q1  24 32 31        QX1
Q2  23 3  31        QX2
Q3  11 7  30        QX1
Q4  11 30 8         QY
V1  22 24 0V
V2  22 23 0V
V3  27 6  0V
V4  11 29 1.4
V5  28 6  1.2
V6  4  32 0V
V7  33 0  0V
.MODEL QX1 NPN (IS=5E-16     BF=200 NE=1.15 ISE=.63E-16 IKF=1E-2)
.MODEL QX2 NPN (IS=5.125E-16 BF=200 NE=1.15 ISE=.63E-16 IKF=1E-2)
.MODEL QY  NPN (IS=6E-15     BF=140)
.MODEL DX  D   (IS=5E-16)
.ENDS
*$
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