EE 4350
OTA Laboratory Experiment

The Operational Transconductance Amplifier is widely used in integrated amplifier and filter applications. There are also some specific discrete applications where the device can be used. Irrespective whether used in integrated or discrete applications, issues surrounding design and performance are mostly common.

In the lecture we have focused on MOS-based OTAs but the same architectures can be used to build BJT-based OTAs. But the BJT-based OTAs have a much larger practical adjustment range. In this experiment we will work with BJT-based OTAs because discrete bipolar OTAs are easily accessible.

There are several discrete BJT OTAs on the market. The CA 3080 and 3092, introduced by RCA, were the first. More recent, the NE 5517 has become quite popular. It is a DUAL OTA with tail bias current control. Another useful OTA is the LM13700 manufactured by Texas Instruments. These devices are particularly useful in the design of voltage or current controlled applications. One of the particularly attractive applications of the OTA is in the design of voltage-controller or current-controlled amplifiers and filters whereby a dc voltage or a dc current can be used to control or adjust key characteristics of a filter such as the band edges, the mid-band gain, or the bandwidth.

The commercial OTAs typically use a differential amplifier at the input so when operating open-loop the signal swing at the input terminals is quite limited. In this experiment we will create an OTA that provides for large differential inputs to make measurements easier. The OTA we will create is shown in Fig. 1. The commercial OTA shown in teal color is a commercial OTA. We will use the LM 13700 in this experiment. There are three terminals (not including the biasing voltages V_{DD} and V_{SS} and the adjustment current I_{ABC}) for the Equivalent OTA, specifically the $\mathbf{V_1}$ and $\mathbf{V_2}$ input terminals and the output terminal which shows an output current $\mathbf{I_{OUT}}$ on this terminal. The output current of this equivalent OTA is given by the expression

$$I_{OUT} = g_m \left(V_3 - V_4 \right)$$

where V_3 and V_4 are internal voltages and where g_m is the transconductance gain of the commercial OTA. The two operational amplifiers and the four resistors form an attenuator to attenuate the actual input signals on the $\mathbf{V_1}$ and $\mathbf{V_2}$ pins by a factor of θ before the signal gets to the input terminals of the commercial OTA.

The transconductance gain of the Equivalent OTA is given by the expression $g_{mEQ} = \theta g_m$ and hence the output current of the equivalent OTA is given by the expression

$$I_{OUT} = \theta g_m \left(V_1 - V_2 \right) = g_{mEQ} \left(V_1 - V_2 \right)$$

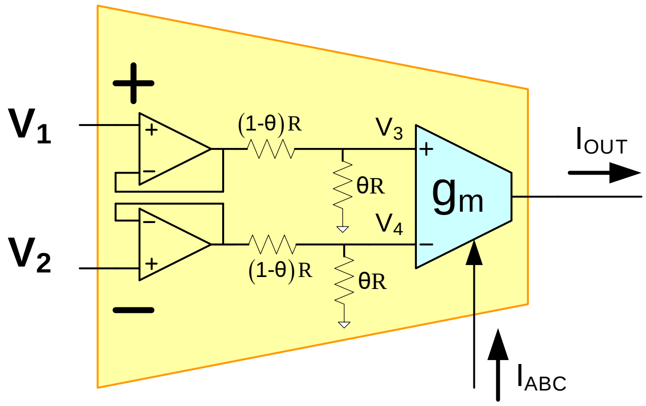

Fig. 1 Equivalent OTA

The bias current, designated as I_{ABC} (which stands for Amplifier Bias Current) is used to program the transconductance gain by adjusting the tail current of the differential input pair. For the LM 13700, the relationship between I_{ABC} and g_m is given by the expression

$$g_m = 19.2\text{v}^{-1} \bullet I_{ABC}$$

Hence, g_{mEQ} is given by the expression

$$g_{mEQ} = \theta g_m = \theta \bullet 19.2\text{v}^{-1} \bullet I_{ABC}$$

The bias current I_{ABC} is generated with a current mirror referenced to V_{SS} as shown in Fig. 2a. The bias current is mirrored with the Q_1:Q_2:Q_3 current mirror to generate an internal current I_{TAIL} that is used to bias the differential input pair for the OTA. One easy way to adjust the current I_{ABC} for the OTA is to use the voltage source V_{ADJ} and the resistor R_B as shown in Fig. 2b. Note the negative terminal of V_{ADJ} is connected to V_{SS} so a floating voltage source will be needed for this connection. The current I_{ABC} is approximately given by the expression

$$I_{ABC} = \frac{V_{ADJ} - 1.2V}{R_B}$$

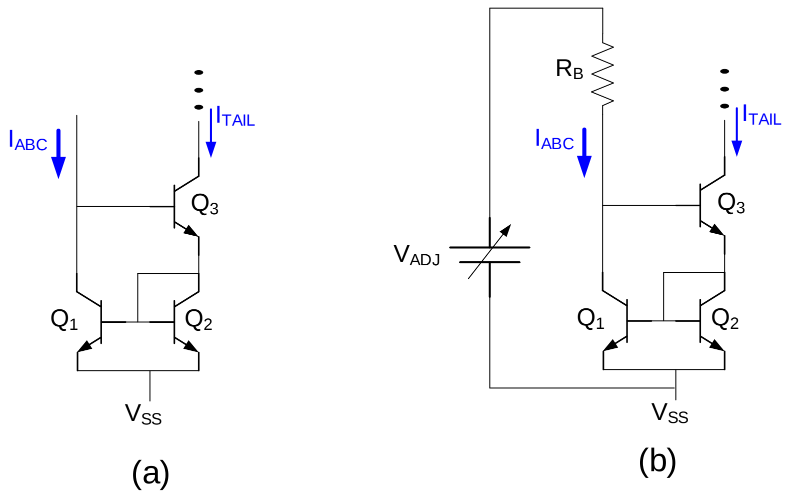

Fig. 2. Bias Current Control of LM 13700 OTA

Part 1

Open the LM 13700 OTA datasheet. Find information in it to answer the following questions. **Show your TA your answers before continuing with the lab.**

a) Find the pinout of the part, take a screenshot, and paste it in a separate document. What pins do you think you'll need for this lab and which ones are not needed?
b) What is the maximum rated supply voltage for the OTA?
c) What is the maximum rated bias (I_{ABC}) current?
d) What are the recommended supply voltages?
e) Find a plot of the transconductance vs bias (I_{ABC}) current. What information is useful from this plot?
f) Find a plot of the linearity (distortion = non-linearity) vs differential input voltage. What can you conclude from this plot? How does the plot explain the need for the attenuators at the OTA inputs?
g) Find the functional block diagram of the OTA. Do you notice any similarities to the current mirror op amp designed in the previous lab?
h) What does TI recommend regarding powering the OTA (Hint: bypass capacitors). The following sources have some more info on bypass capacitors (and there is much more out there)
    a. https://e2e.ti.com/blogs_/archives/b/thesignal/posts/bypass-capacitors-yes-but-why
    b. https://www.youtube.com/watch?v=bqoXtpcHtgc
    c. https://www.youtube.com/watch?v=BcJ6UdDx1vg
    d. https://www.youtube.com/watch?v=1xicZF9glH0

Please use at least a 0.1uF ceramic bypass capacitor on each supply pin for this lab. Adding an additional 1uF (or close) electrolytic capacitor would be good as well.

Part 2 Design and test a voltage controlled noninverting and inverting amplifiers.

a) The gain of the noninverting amplifier should be adjustable from +1 to +10
b) The gain of the inverting amplifier should be adjustable from -1 to -10
c) Extra Credit – Design a noninverting amplifier where the gain is adjustable from +1 to +10 as a control voltage is changed between 1V and 2V.

Part 3 A second-order OTA-Based Bandpass Filter is shown in Fig. 3. By adjusting the transconductance gains appropriately, the center frequency of the filter can be continuously programmed.

a) Obtain the transfer function of the bandpass filter
b) Design this filter with a pole Q of 2 so that the resonant frequency is programmable and can be varied by a factor of 4 by adjusting the bias current of an OTA. Target the adjustment range from 5KHz to 20KHz but you may change the range a bit based upon available capacitor values.
c) Experimentally verify the operation of this programmable filter (Remember to use the Equivalent OTAs of Fig. 1.)

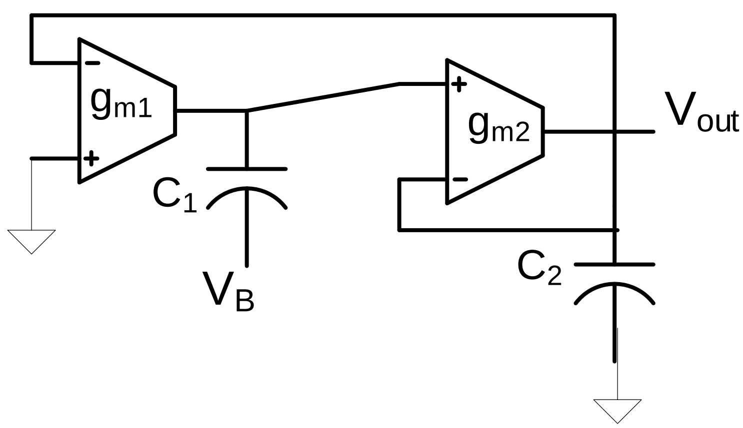

Fig. 3. Second-order OTA-based Bandpass Filter