

# EE 435

## OTA Laboratory Experiment

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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  $V_1$  and  $V_2$  input terminals and the output terminal which shows an output current  $I_{OUT}$  on this terminal. The output current of this equivalent OTA is given by the expression

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

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  $V_1$  and  $V_2$  pins by a factor of  $\theta$  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

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

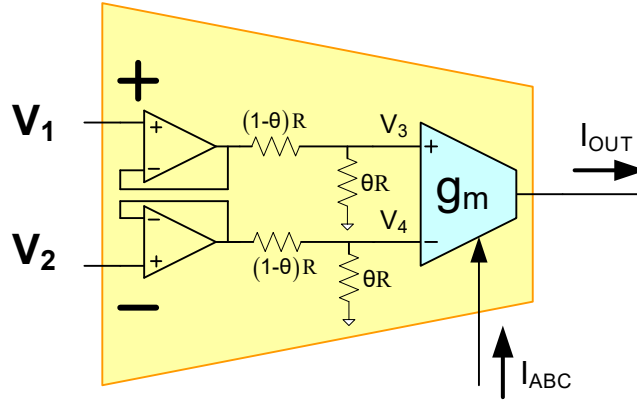


Fig. 1 Equivalent OTA

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

$$g_m = 19.2V^{-1} \cdot I_{ABC}$$

Hence,  $g_{mEQ}$  is given by the expression

$$g_{mEQ} = \theta g_m = \theta \cdot 19.2V^{-1} \cdot I_{ABC}$$

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

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

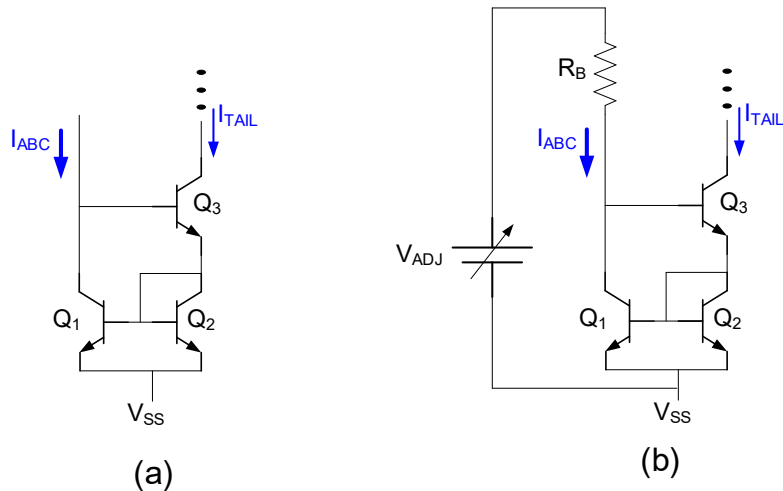


Fig. 2. Bias Current Control of LM 13700 OTA

**Part 1** Design and test a voltage controlled noninverting and inverting amplifiers.

- The gain of the noninverting amplifier should be adjustable from +1 to +10
- The gain of the inverting amplifier should be adjustable from -1 to -10
- 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 2** 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.

- Obtain the transfer function of the bandpass filter
- 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.
- Experimentally verify the operation of this programmable filter (Remember to use the Equivalent OTAs of Fig. 1.)

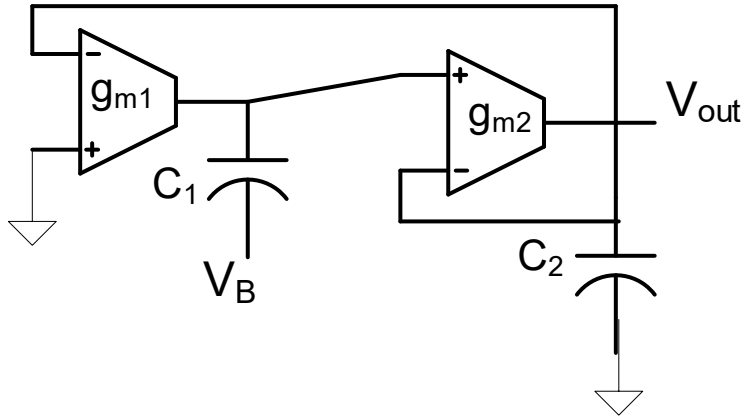


Fig. 3. Second-order OTA-based Bandpass Filter