EE 230 – Analog Lab - 2021-22/I (Autumn)

Experiment 4: Current Source, Current Mirror, and Differential Pair

(Ver 2.1, Aug 17,2021)

Part A – BJT Current Source

Learning Objectives

1. Understanding the design and performance of a practical BJT current source using a *pnp* transistor. Understanding its limitations as a current source.
2. Understanding the design and implementation of a practical current mirror using a general purpose *npn* arrays IC (CA3046).
3. Understanding the working and implementation of a differential pair and its VTC.

1.1 BJT Current Source

Circuit diagram of a BJT current source is shown below.

Circuit values: Vcc = 12 V, R_E = 4.7 kΩ, V_Z = 5.6 V, R_B = 2.2 kΩ, R_L – different values (100 Ω, 470 Ω, 1 kΩ, 2.2 kΩ, 3.3 kΩ, 4.7 kΩ, 5.6 kΩ, 6.8 kΩ, 8.2 kΩ, 10 kΩ).

BJT – BC 557. Assume β = 100, V_{BE} = - 0.7 V, V_{CEsat} = - 0.2 V.

Zener diode: V_Z = 5.6 V

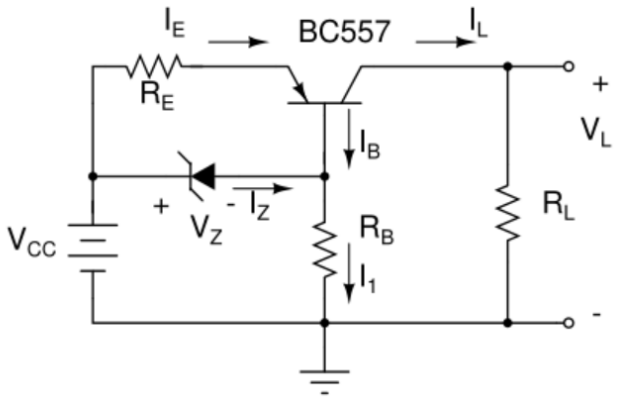

Fig 1 BJT current source

Analysis

Analyse the above BJT current source circuit. You may neglect the base current and assume $I_L = I_E$.

i) Evaluate the value of I_L in mA and V_L in volts for R_L = 100 Ω and 1 kΩ.

ii) Estimate the maximum value of R_L that can be used so as to obtain I_L as in (i) above.

iii) Calculate I_L value for different values of R_L (100 Ω, 470 Ω, 1 kΩ, 2.2 kΩ, 3.3 kΩ, 4.7 kΩ, 5.6 kΩ, 6.8 kΩ, 8.2 kΩ, 10 kΩ). Sketch the I_L vs V_L plot.

iv) Explain why I_L reduces for higher values of R_L.

1.1.1 NGSPICE Simulation (using BC557 model)

i) Using NGSPICE simulations determine the operating point for R_L = 1 kΩ. Use the model of BC557A given below.

ii) Vary R_L from 1 kΩ to 10 kΩ in steps of 1 kΩ. (Hint: Use **.dc RL 1k 10k 1k**). Observe the variation in I_L for higher R_L values.

iii) Plot I_L vs V_L for the above R_L values.

Model of BC557A

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.model bc557a PNP IS=10f BF=100 ISE=10.3f IKF=50m NE=1.3
+ BR=9.5 VAF=80 IKR=12m ISC=47p NC=2 VAR=10 RB=280 RE=1 RC=40
+ tr=0.3u tf=0.5n cje=12p vje=0.48 mje=0.5 cjc=6p vjc=0.7 mjc=0.33 kf=2f
```

Part B – BJT Current Mirror based Current Source

2.1 Current Mirror

Circuit diagram of a simple BJT current source (based on the basic BJT current mirror) is shown in Fig.2. For our implementation of the current source and measurements in the WEL Lab, we will be using a general purpose *npn* transistor arrays IC (CA 3046).

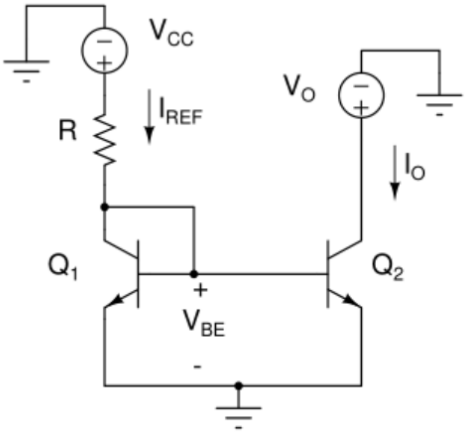

Fig. 2 BJT Current mirror based current source

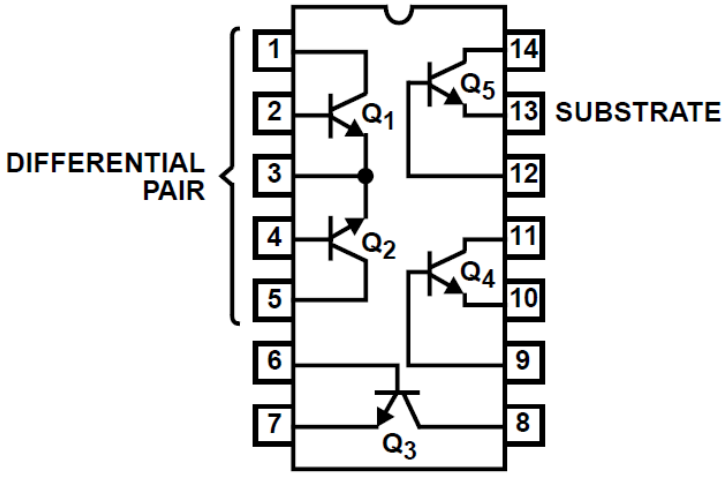

Fig. 3 Pin-out of CA3046

Analysis

Calculate I_{REF} in mA for Vcc = 12 V; R =10 kΩ, and V_{BE} = 0.7 V.

Case (i) : Evaluate the output current I_o, for V_o = 1 V and V_o = 5V, assuming β = 100 and Early voltage, V_A = 80.

Case (ii) : Evaluate the output current Io, for Vo = 1 V and Vo = 5V, assuming β = 100 and Early voltage, V_A = 200.

Note the following:

a) CA3046 consists of five general purpose silicon NPN transistors on a common monolithic substrate. Two of the transistors are internally connected to form a differentially connected pair.
b) The BJTs in the CA3046 IC provide the very significant inherent integrated circuit advantages of close electrical and thermal matching.
c) The collector of each transistor of the CA3046 is isolated from the substrate by an integral diode. The substrate (Terminal 13) must be connected to the most negative point in the external circuit to maintain isolation between transistors and to provide for normal transistor action.

2.1.1 NGSPICE Simulation

i) Use NGSPICE simulations to verify the analytical results of Sec 2.1 (i.e. I_o value in mA for V_o = 1 V). Assume β = 100, and V_A = 80 V

ii) Use **.dc** analysis to obtain the following I_o values:

(a) for V_o varying from 1 V to 5 V with a step-size of 0.5 V, assuming V_A = 80 V.

(b) for V_o varying from 1 V to 5 V with a step-size of 0.5 V, assuming V_A = 200 V.

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Part C – Differential Pair

3.1 Differential Pair

The circuit diagram of the differential pair implemented using CA406 *npn* transistor arrays is shown below. Circuit values: Vcc = + 12 V, - V_{EE} = - 12 V, $R_{C1} = R_{C2}$ = 6.8 kΩ, $R_{B1} = R_{B2}$ = 1 kΩ, R_E = 10 kΩ, R_E = 10 kΩ.

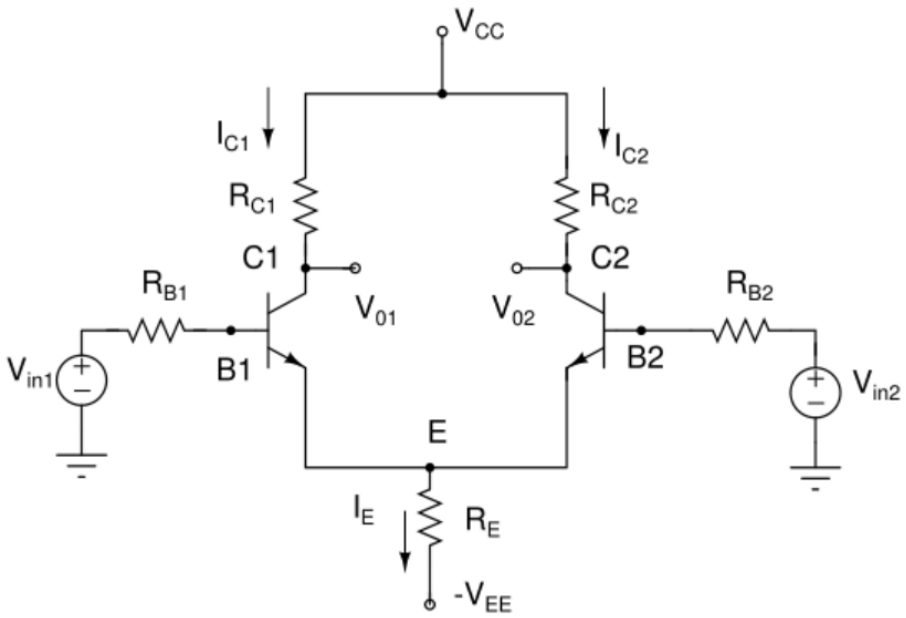

Fig. 4 Differential Pair using CA 3046

DC Operating Values

Analysis:

For the given circuit values and assuming $V_{in1} = V_{in2}$ = 0 V, evaluate the currents I_E, I_{C1}, and I_{C2} as well as the node voltages V_E, V_{C1} and V_{C2}. You may neglect the base currents of Q_1 and Q_2.

We shall share Experimental results in the Lab Lecture. We made use of the differential pair of CA3046 (indicated in Fig. 3).

3.1.2 NGSPICE Simulation

For NGSPICE simulations use $V_{in1} = V_{in2}$ = 0 V. Evaluate the currents I_E, I_{C1}, and I_{C2} and the node voltages V_E, V_{C1} and V_{C2} . Compare these results with your analysis.

3.2 Differential Amplifier

The differential pair will be used a single-stage differential amplifier. For this purpose, signal was fed to one of the differential pair inputs, by making V_{in1} = 10 sin ωt mV (f = 1 kHz) and V_{in2} = 0 V.

Analysis

Evaluate the small-signal parameters of the diff amp and calculate the theoretical value of the single-ended voltage gain obtained at each of the outputs, V_{01} and V_{02} in response to V_{in1} = 10 sin ωt mV and V_{in2} = 0 V.

3.2.1 NGSPICE Simulation

Plot the V_{in1}, V_{01} and V_{02} waveforms. Measure the voltage gain (single-ended gain, i.e., V_{01pp}/V_{in1}pp), where pp stand for peak-to-peak. Verify the theoretical results obtained in Sec 3.2 through NGSPICE simulations.

3.3 Large-Signal Characteristics (Voltage-Transfer Characteristics - VTC)

Large-signal characteristics or VTC of the differential pair will be studied by keeping $V_{in\,2}$ = 0 and applying dc voltages to V_{in1} from -1 V to +1 V in steps of 0.01 V.

3.3.1 NGSPICE Simulation

Using NGSPICE simulations (**.dc** analysis) obtain the VTC (V_{in2} = 0 and V_{in1} varied from -1 V to +1 V in steps of 0.01 V). Plot the VTC by plotting V_{C1} vs V_{in1} and V_{C2} vs V_{in1}.

Lab Report

1. For Experiment 4, please limit your Lab report to just 4 pages – one page for the BJT Current source (using BC557), one page for the BJT current mirror based current source, and the third and the fourth pages for the differential pair results..
2. In each page, please include one of your NGSPICE programs, and one or two plots or the printed values, as the case may be. Please also add one line of what you learned.
3. The purpose of asking you to make shorter Lab reports is to make sure that you save some time. However, we assume that you have done all that was asked in the Lab handout (analysis and simulations). These and related topics may be asked in the Quizzes, as well as in the Midsem and Endsem examinations.