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

Experiment 3: BJT Voltage Amplifiers (CE and CC)

(Ver 2, Aug 10,2021)

Part A – Common-Emitter Amplifier

Learning Objectives

1. Understanding the basic parameters that characterize a single-stage BJT voltage amplifier (midband gain, frequency response, input resistance and output resistance).
2. Understanding the benefits of negative feedback and the trade-offs involved.
3. Understanding the benefits of multistage amplifiers in improving voltage amplifier parameters.

1.1 Common-Emitter Amplifier: Biasing Circuit

Circuit diagram of the Common-Emitter amplifier is shown below.

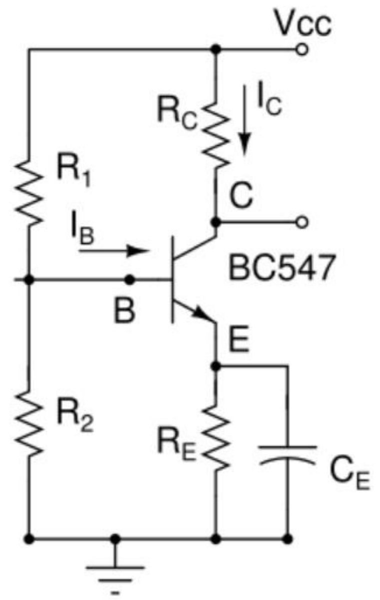

Fig 1 Common-Emitter Amplifier (Biasing circuit)

Analysis

For this part (biasing circuit) the component values are: Vcc = 12 V; R_1=10 kΩ, R_2 = 2.2 kΩ, R_E = 1 kΩ, R_C = 1.2 kΩ. Analyse the circuit and determine the currents I_B, I_C and the node voltages V_B, V_C and V_E. Assume $\beta = 200$. Comment on the mode of the BJT.

Hint: Apply Thevenin's theorem at the base terminal for the analysis.

1.1.1 NGSPICE Simulation (using BC547 model)

Using NGSPICE simulations determine the operating point of the given CE amplifier. Use the model of BC547A given below. Verify the results you obtained through analysis.

```
.model bc547a NPN IS=10f BF=200 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
```

1.2 Common-Emitter Amplifier (with bypass Capacitor C_E): Midband Voltage Gain

A) Case 1: R_S = 0, R_L = 100 kΩ

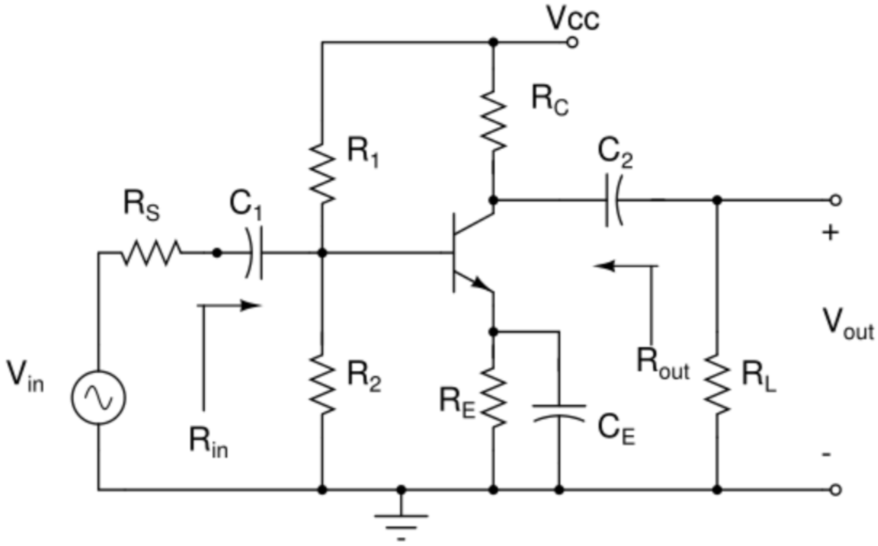

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Fig 2 Full Common-Emitter Amplifier (with V_{in} and R_L)

For this part the component values are: Vcc = 12 V; R_1=10 kΩ, R_2 = 2.2 kΩ, R_E = 1 kΩ, R_C = 1.2 kΩ. R_S = 0, R_L = 100 kΩ, C_1 = 10 μF, C_2 = 10 μF, C_E = 100 μF.
Assume $V_{in} = 10 \sin \omega t$ mV

<u>Analytical Results (for Voltage Gain)</u>
For the given circuit parameters, calculate the midband voltage gain (for $R_L = \infty$).

1.2.1 NGSPICE Simulation

Through NGSPICE simulation determine the midband gain of the CE amplifier. Compare your simulation results with your analytical results.

1.3 Common-Emitter Amplifier (with bypass Capacitor C_E): Frequency Response

<u>Optional - Analytical Results (for f_L and f_H)</u>
Use the analytical results for f_L (lower 3-dB frequency) and f_H (upper 3-dB frequency) and calculate estimates for f_L and f_H values.

1.3.1 NGSPICE Simulation

Use **.ac** command to do ac analysis to obtain the amplitude frequency response of the CE amplifier. Find out the two points which are 3 dB lower than the mid-band flat region. Directly measure from the amplitude response the coordinates of f_H and f_L (ampl and freq).

Obtain bandwidth (=($f_H - f_L$). Also evaluate the product of midband gain and bandwidth.

1.4 Common-Emitter Amplifier (with bypass Capacitor C_E): Effect of R_L on the Midband Gain

Optional - Analytical Results (for the R_{out} of the CEAmp)

Based on your analytical estimate of R_{out} of the CE amp, calculate the amplitude of V_{out} .

1.4.1 NGSPICE Simulation

For the CE amplifier of Fig.2, obtain the midband voltage gain for the following two values of R_L.

Case (i): $R_L = 12\ k\Omega$

Case (ii): $R_L = 1.2\ k\Omega$

1.5 Common-Emitter Amplifier (with bypass Capacitor C_E): Effect of R_S on the Midband Gain

Optional - Analytical Results (for the Rin of the CE Amp)

Based on your analytical estimate of R_{in} of the CE amp, calculate the amplitude of V_{out} .

1.5.1 NGSPICE Simulation

For the CE amplifier of Fig.2, obtain the midband voltage gain for the following two values of R_S.

Case (i): $R_S = 10\ k\Omega$

Case (ii): $R_S = 2.2\ k\Omega$

1.6 Common-Emitter Amplifier (without bypass Capacitor C_E): Midband Gain

For the subsequent parts of CE amp (i.e. with capacitor C_E open), assume $V_{in} = 1 \sin \omega t$ V

Analytical Results

For the case with the bypass capacitor C_E open, calculate the voltage gain (for $R_L = \infty$).

1.6.1 NGSPICE Simulation

Using NGSPICE simulations to determine the midband gain of the given CE amplifier assuming the bypass capacitor C_E is open. Compare your simulation results with your analytical results.

1.7 Common-Emitter Amplifier (without bypass Capacitor C_E): Frequency Response

Optional - Analytical Results (for f_L and f_H)

Use the analytical results for f_L (lower 3-dB frequency) and f_H (upper 3-dB frequency) and calculate estimates for f_L and f_H values.

1.6.1 NGSPICE Simulation

Using **.ac** command to do ac analysis and obtain the amplitude frequency response for the case of un-bypassed R_E. Find out the two points which are 3 dB lower than the mid-band flat region. Directly measure from the amplitude response the coordinates of f_H and f_L (ampl and freq).

Evaluate the bandwidth (=($f_H - f_L$) of this amplifier. Also, evaluate the product of midband gain and bandwidth.

Compare the above results (bandwidth and Gain-Bandwidth product) with that of the CE amp with R_E bypassed with C_E. Comment on the results

Part B – Common-Collector Amplifier

2.1 Common-Collector Amplifier: Biasing Circuit

Circuit diagram of a Common-Collector (CC) amplifier is shown in Fig.3. We shall study this amplifier first as a buffer and then use it in cascade with the earlier CE amplifier

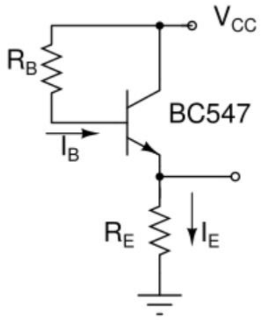

Fig. 3 Common-Collector (CC) amplifier – biasing

<u>Analysis</u>

For this part (biasing circuit) the component values are: Vcc = 12 V; R_B=1 MΩ, R_E = 10 kΩ. Analyse the circuit and determine the currents I_B, I_E and the node voltages V_B, and V_E. Assume β = 200, V_{BE} = 0.7 V. Comment on the mode of the BJT.

2.1.1 NGSPICE Simulation

Using NGSPICE simulations determine the operating point of the above CC amplifier. Use the model of BC547A. Verify the results you obtained through analysis.

2.2 Common-Collector Amplifier: Midband Gain

Complete circuit diagram (with V_{in}, and R_L) of the CC amplifier is shown in Fig.4.
Circuit parameters: Vcc = 12 V; R_B=1 MΩ, R_E = 10 kΩ, $C_1 = C_2$ = 10μF. Assume R_S = 0 and R_L to be infinite. Analyse the circuit and determine the currents I_B, I_E and the node voltages V_B, and V_E.
Assume β = 200. Take $V_{in} = 1 \sin \omega t$ V.

<u>Analytical Results (for midband Voltage Gain)</u>

For the given circuit parameters, calculate the midband voltage gain (for $R_L = \infty$).

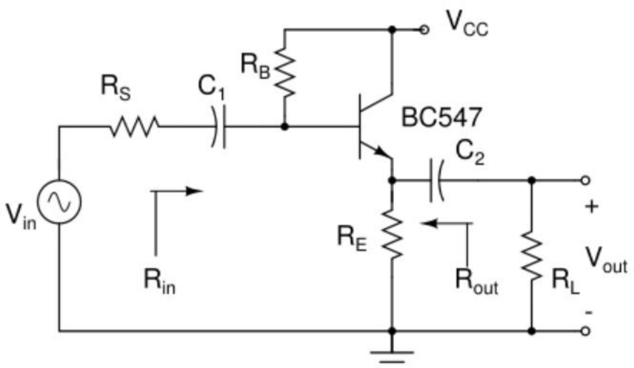

Fig. 4 Common-Collector (CC) amplifier

2.2.1 NGSPICE Simulation

Through NGSPICE simulation determine the midband gain of the CC amplifier. Compare your simulation results with your analytical results.

2.3 Common-Collector Amplifier: Freq Response

Optional - Analytical Results (for f_L and f_H)

Use the analytical results for f_L (lower 3-dB frequency) and f_H (upper 3-dB frequency) and calculate estimates for f_L and f_H values.

2.3.1 NGSPICE Simulation

Use **.ac** command to do ac analysis to obtain the amplitude frequency response of the CC amplifier. Find out the two points which are 3 dB lower than the mid-band flat region. Directly measure from the amplitude response the coordinates of f_H and f_L (ampl and freq).

Obtain bandwidth (=($f_H - f_L$). Also evaluate the product of midband gain and bandwidth.

2.4 Common-Collector Amplifier: Effect of R_L on Midband Gain

Optional - Analytical Results (for the R_{out} of the CC Amp)

Take $V_{in} = 1 \sin \omega t$ V.

Based on your analytical estimate of R_{out} of the CC amp, calculate the amplitude of V_{out} for different R_L values:

Case (i): $R_L = 10$ kΩ

Case (ii): $R_L = 1$ kΩ

Case (iii): $R_L = 100$ Ω

243.1 NGSPICE Simulation

For the CC amplifier of Fig.4, obtain the midband voltage gain for the following three values of R_L.

Case (i): $R_L = 10$ kΩ

Case (ii): $R_L = 1$ kΩ

Case (iii): $R_L = 100$ Ω

2.5 Common-Collector Amplifier: Effect of R_S on Midband Gain

Optional - Analytical Results (for the R_{in} of the CC Amp)

Take $V_{in} = 1 \sin \omega t$ V.

Based on your analytical estimate of R_{in} of the CC amp, calculate the amplitude of V_{out} for different R_L values:

Case (i): $R_S = 1$ MΩ

Case (ii): $R_S = 560$ kΩ

Case (iii): $R_S = 100$ kΩ

2.5.1 NGSPICE Simulation

For the CC amplifier of Fig.4, obtain the midband voltage gain for the following three values of R_S.

Case (i): $R_S = 1$ MΩ

Case (ii): $R_S = 560$ kΩ

Case (iii): $R_S = 100$ kΩ

Part C – Two-stage Amplifier (CE and CC)

3.1 Two-stage Amplifier (CE and CC): Biasing Circuit

The circuit diagram of the two-stage amplifier (obtained by cascading the CE amplifier of Part A cascaded with a modified version of the CC amplifier of Part B) is shown in Fig.5.

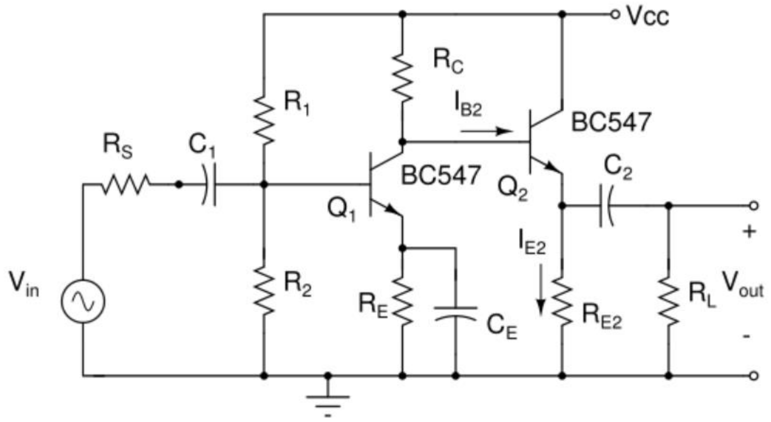

Fig. 5 Two-stage amplifier (CE and CC)

<u>Component values of the CE amp</u>

Vcc = 12 V; R_1=10 kΩ, R_2 = 2.2 kΩ, R_E = 1 kΩ, R_C = 1.2 kΩ.
R_S = 0, C_1 = 10 μF, C_E = 100 μF.

<u>Component values of the CC amp</u>

Vcc = 12 V, R_{E2} = 10 kΩ, R_L = 10 kΩ, C_2 = 10 μF.

Estimate the dc currents (I_{B2} and I_{E2}) and the voltage at the emitter terminal of Q_2 (CC amp).

3.1.1 NGSPICE Simulation

Verify the dc currents (I_{B2} and I_{E2}) and voltage at the emitter terminal of Q_2.

3.2 Two-stage Amplifier (CE and CC): Midband Gain

<u>Theoretical Results for the midband gain</u>

Assuming that there is no loading by the CC amp, the overall gain of the two-stage amplifier will be (A_{vCE}). (A_{vCC}), for reasonable R_L values (say > 1 kΩ).

3.2.1 NGSPICE Simulation

Verify the theoretical results obtained in Sec 3.2 through NGSPICE simulations.

3.3 Two-stage Amplifier (CE and CC): Frequency Response

Analysis of the frequency response of the two-stage amplifier is generally quite complex.

3.3.1 NGSPICE Simulation

Using NGSPICE simulations determine the f_L and f_H of the two-stage amplifier.

3.4 Two-stage Amplifier (CE and CC): Effect of R_L on Midband Gain

We can argue that the midband gain of the two-stage amplifier will not be affected for reasonable values of R_L (say > 1 kΩ).

3.4.1 NGSPICE Simulation

Obtain the effect of midband gain of the two-stage amplifier on a few R_L values and check whether the gain is affected for R_L > 1 kΩ.

Lab Report

1. For Experiment 3, please limit your Lab report to just 4 pages – one page for the biasing circuit of Sec 1.1, one page for the midband gain of CE amplifier (with the bypass capacitor C_E), one page for the effect of R_L and R_S on the midband gain, and the last page for the two-stage CE-CC amplifier (biasing and midband gain).
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. Analysis required only for Sec 1.1. 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.