EE 113 – Intro to Electrical Engg Practice: 2021-22/I

Tutorial – 3 (16/12/2021, Thu) – Time: 10:30-11:30

Problem Sheet – 3

Topics: BJT dc circuits, Opamp amplifiers (linear applications), Opamp circuits (non-linear applications)

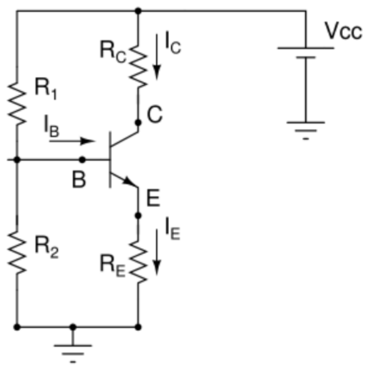
Part A– BJT DC Circuits

1. BJT CE amplifier bias circuit (application of Thevenin's theorem – checking for active mode)
   For the biasing circuit of CE amp shown below, the component values are:
   Vcc = 10 V; R_1=10 kΩ, R_2 = 2.5 kΩ, R_E = 1 kΩ, R_C = 1.2 kΩ. Analyse the circuit and determine the bias currents I_B, I_C and the node voltages V_B, V_C and V_E and the voltage V_{CE} (between the Collector and Emitter). Assume β = 40. Assume V_{BE} = 0.7 V, and VCE sat = 0.2 V.
   Comment on the mode of the BJT.

   Hint: Apply Thevenin's theorem at the base terminal (between B and ground). This will reduce the input side to just one loop. Apply KVL in the base-emitter or BE loop. Assume that the BJT is in the active mode. Hence, we can write: $I_C = \beta I_B$. We know that from KCL, $I_E = I_C + I_B$, hence we can write $I_E = (\beta+1) I_B$. In the KVL equation in the BE loop, we will now have only one unknown, which is I_B. Substitute and determine I_B. Now determine I_C and I_E. $V_C = Vcc – I_C . R_C$; $V_E = I_E R_E$ and $V_{CE} = V_C – V_E$.

   Verification of the active mode assumption of BJT: Check whether $V_{CE} > V_{CEsat}$. If so, your assumption is correct. If not, your assumption is wrong. We will see this case in the next problem.

   [Answers: I_B = 30.23 μA; I_C = 1.21 mA ; V_B = 1.94 V ; V_C = 8.55 V; V_E = 1.24 V ; V_{CE} = 7.31 V.
   BJT is active (or has the active mode of operation in the given circuit).]



2. Repeat the problem of question 1, but for the value of RC. For this question, consider RC = 10 kΩ. What is the mode of operation of the BJT? What is the maximum value of RC for which the circuit would remain in the active mode?
   Hint: Start with the analysis as done for question 1. Assume, active mode of operation. Evaluate V_{CE} and verify whether your assumption is correct. Find the R_{Cmax} value for the BJT to be in active mode. (If anyone is too keen to calculate the actual currents and node voltages when the BJT is in the saturation mode, then you need to write two equations – one for the input loop (the BE loop) and one for the output loop (the CE loop). $I_E = I_C + I_B$ is always valid as it is essentially from KCL. Since the BJT is saturated, $V_C = V_{CEsat}$ = 0.2 V. Solve for the two unknown currents, either I_C and I_B or I_C and I_E).

   (Answer: R_{Cmax} = 7.07 kΩ (= $[V_{CC} – V_{CEsat} - V_E]/I_C$; For the BJT to be in the active mode, $R_C < R_{Cmax}$.)

3. a) A BJT circuit is shown below in Fig.P3. Determine the currents I_C, I_B and I_E and the node voltages V_C and V_B. Circuit and BJT parameters are: Vcc = 12 V, R_C = 1 kΩ, R_B = 50 kΩ, β = 40, V_{BE} = 0.7 V, V_{CEsat} = 0.2 V. Comment on the mode of operation of the BJT.

Hint: Note in Fig.P3. $I \neq I_C$, but actually $I = I_E$
(Answers: I_B = 124.18 µA; I_C = 4.97 mA ; I_E = 5.09 mA; V_C = 6.91 V; V_B = 0.7 V).

b) In the above circuit if R_C is now changed to 10 kΩ, while keeping all other circuit values and BJT parameters as earlier, determine once again the currents I_C, I_B and I_E and the node voltage V_C. Comment on the mode of operation of the BJT. What is the special feature of this circuit (from the point of view of biasing and the BJT mode). Compare this feature with the circuit of problem 1.
(Note that the BJT mode of operation of the circuit in problem 1 changed from active to saturation when R_C was changed from 1.2 kΩ to 10 kΩ).
(Answers: I_B = 24.57 µA; I_C = 0.98 mA ; I_E = 1.01 mA; V_C = 1.93 V; V_B = 0.7 V).

4. A modified version of the circuit of Fig.P3 is shown in Fig.P4. Determine the currents I_C, I_B and I_E and the node voltage V_C and V_E. Circuit and BJT parameters are: Vcc = 12 V, R_C = 1 kΩ, R_B = 50 kΩ, R_E = 2 kΩ, β = 40, V_{BE} = 0.7 V, V_{CEsat} = 0.2 V. Comment on the mode of operation of the BJT.
(Answers: I_B = 65.32 µA; I_C = 2.61 mA ; I_E = 2.68 mA; V_C = 9.32 V; V_B = 6.06 V ; V_E = 5.36 V).

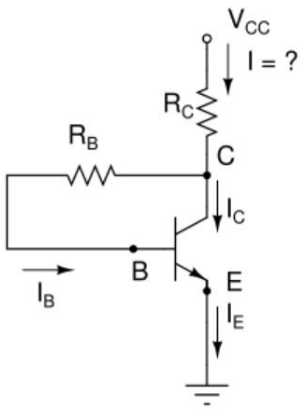


Fig. P3

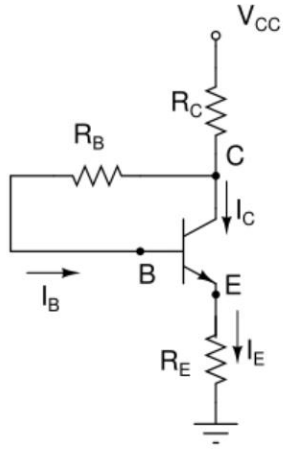


Fig. P4

Part B – Opamp Amplifier Circuits – Linear Applications

5. The circuit diagram of an Opamp inverting amplifier is shown below in Fig.P5. The circuit values are: +Vcc = +12 V, -Vcc = -12 V. R_1 = 5 kΩ, R_F = 50 kΩ. The input signal is V_{in} = 0.2 sin ωt V. Sketch the V_{in} and V_{out} waveforms. Assume that the maximum possible Opamp output levels possible are +/- Vcc.

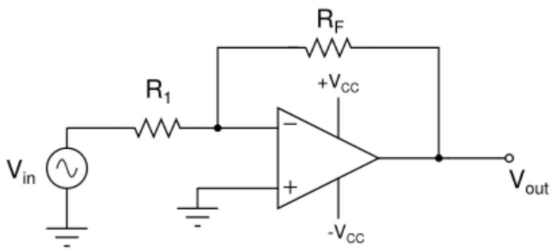


Fig. P5

6. For the circuit shown in Fig.P5, if R_F is now increased to 500 kΩ, while keeping R_1 = 5 kΩ and V_{in} the same as in problem 5, sketch V_{in} and V_{out} waveforms. Explain the V_{out} sketch (as to why it is abnormal). Once again assume that the maximum possible Opamp output levels are +/- Vcc.

7. Once again consider the inverting amplifier of problem 5, i.e. $R_1 = 5\ k\Omega$, $R_F = 50\ k\Omega$. Now the V_{in} signal is from a sensor, which has Thevenin equivalent Voltage, $V_{Th} = 0.1$ V, and the Thevenin equivalent resistance, $R_{Th} = 3\ k\Omega$. What would be the Opamp output V_{out} for this case?

8. The circuit diagram of simple resistive summer is shown in Fig.P8. Evaluate V_{out} and sketch it. What are its maximum and minimum values?
   Circuit values: $V_1 = 2 \sin \omega t$; $V_2 = -5$ V ; $R_1 = 2\ k\Omega$, $R_2 = 4\ k\Omega$, and $R_F = 4\ k\Omega$.

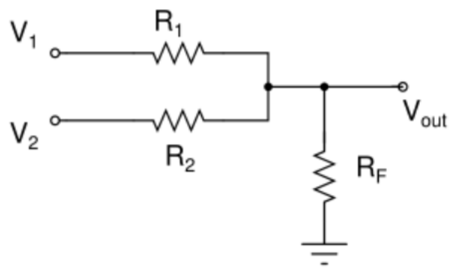


Fig. P8 Simple resistive summer

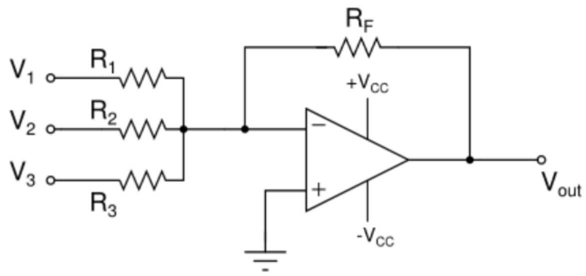


Fig. P9 Opamp Summer

9. a) The circuit diagram of an Opamp based summer is shown in Fig.P9. Derive the expression for V_{out}.
   b) Given $R_1 = 2\ k\Omega$, $R_2 = 4\ k\Omega$, $R_3 = 4\ k\Omega$, $R_F = 4\ k\Omega$ and $V_1 = 2 \sin \omega t$; $V_2 = -7$ V ; $V_3 = +2$ V. Sketch V_{out}.
   c) What are the advantages the Opamp based summer compared to the simple resistive summer of Fig. P8?

10. The circuit diagram of a non-inverting amplifier is shown in Fig.P10.
    The circuit values are: +Vcc = +12 V, -Vcc = -12 V. $R_1 = 5\ k\Omega$, $R_F = 50\ k\Omega$.
    The input signal is $V_{in} = 0.2 \sin \omega t$ V. Sketch the V_{in} and V_{out} waveforms. Assume that the maximum possible Opamp output levels possible are +/- Vcc.

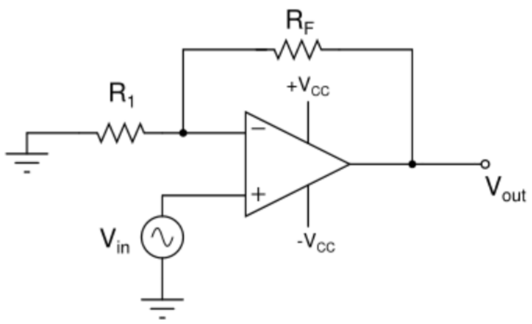


Fig.P10 Non-inverting amplifier

11. a) Assume that now you are applying the sensor output mentioned in problem 7 as the V_{in} of the non-inverting amplifier of Fig.P10. What would be the Opamp output V_{out} for this case?
    b) Based on the answer 11 (a), give one of the major advantages of the non-inverting amplifier when compared to an inverting amplifier.

12. The circuit diagram of an Opamp difference amplifier is shown in Fig. P12. The circuit values given are: $+V_{cc} = +12$ V, $-V_{cc} = -12$ V. $R_4 = R_2 = 30$ kΩ, $R_1 = R_3 = 10$ kΩ.
    a) If $V_A = 4$ V and $V_B = 2$ V, what will be V_{out}?
    b) If $V_A = 1.5 \sin \omega t$ V and $V_B = -1.5$ V, what will be V_{out}? What will be the maximum and minimum values of V_{out}?

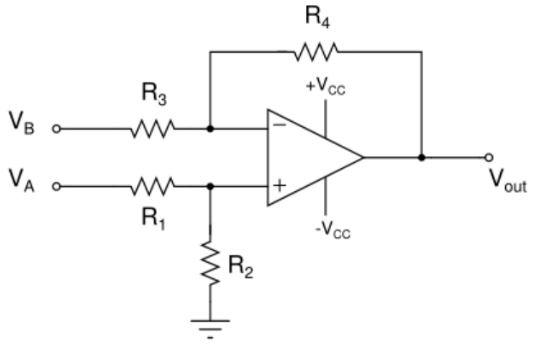


Fig. P12 Opamp difference amplifier

Part C – Opamp Amplifier Circuits – Non-linear applications (Comparator, Schmitt Trigger and Astable Multivibrator)

13. The circuit diagram of an Opamp comparator circuit is shown in Fig. P13. Sketch the Vout waveform for the following cases of V_{in} and V_{REF}.
    a) $V_{in} = 5 \sin \omega t$ V , $V_{REF} = 2$ V
    b) $V_{in} = 5 \sin \omega t$ V , $V_{REF} = -2$ V
    c) $V_{in} = 2$ V, $V_{REF} = 5$ V

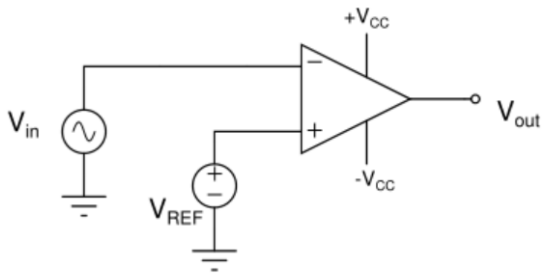


Fig. P13 Opamp comparator circuit

14. For the Opamp circuit shown in Fig. P14, sketch V_O and V_I waveforms for two cycles of the V_I waveform, indicating clearly the levels of V_I at which V_O transitions occur. Show your level calculations. (Opamp Power supply voltages are +12 V and -12 V. You may assume that the maximum and minimum levels of V_O correspond to the Power supply voltage levels.)

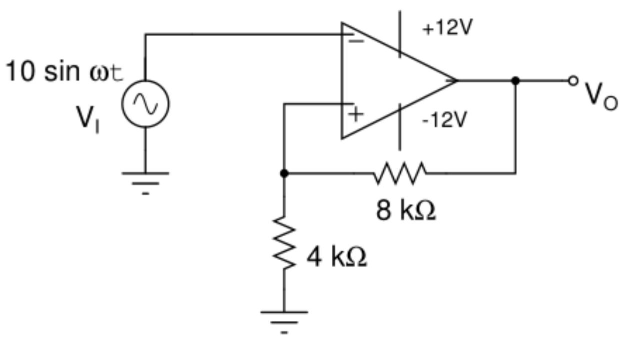


Fig. P14 Opamp circuit

15. The circuit diagram of an astable multivibrator (with +Vcc = +12 V, and -Vcc = -12 V) is shown in Fig. P15. Assume that the V_{out} saturation values are +/- Vcc. Assume $R_1 = 2 R_2$.
   a) Derive expressions for the time periods T_H and T_L of the V_{out} waveform (T_H is the Vout HIGH-level time period and T_L is the Vout LOW-level time period).
      Given: Capacitor equation: Vc = Vf + (Vi-Vf) exp(-t/RC)
   b) For R = 5 kΩ, C = 0.1 μF, R_1 = 12 kΩ and R_2 = 6 kΩ, evaluate T_H and T_L and the frequency of the V_{out} waveform.
   c) Sketch the V_{out} and V_c waveforms and mark the salient voltage and time periods.

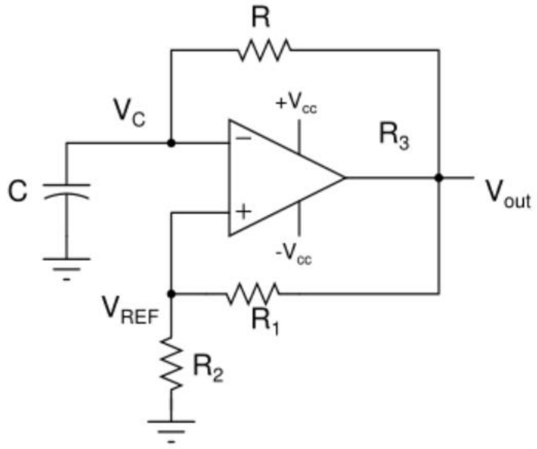


Fig. P 15 Astable multivibrator