5.3 BJT biasing

Name: _____ Class: _____ Date: _____ **Total: 24 marks**

KEY WORDS bipolar junction transistor • active region • voltage divider bias

Objective

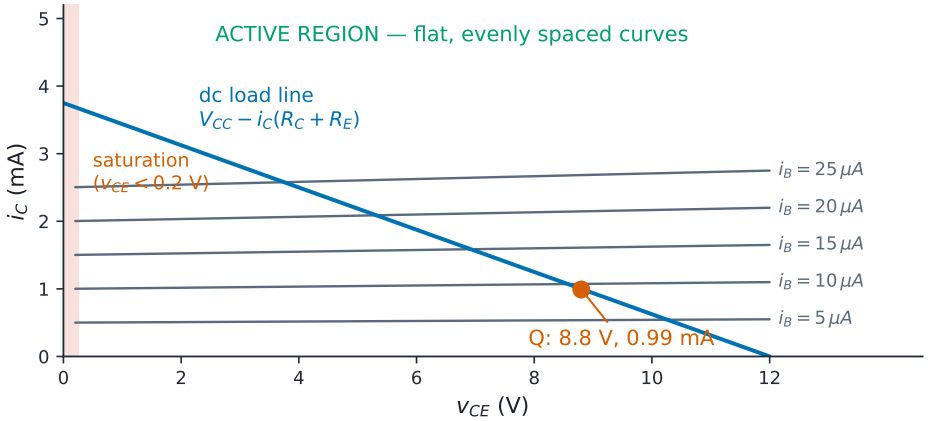
Design voltage-divider BJT bias points, verify the active region, and quantify bias stability against β spread – every bias checked against the region test.

1 Key knowledge and worked examples

■ **The BJT's one rule of amplification**

In the **active region** , $I_C = \beta \cdot I_B$ with $V_{BE} \approx 0.7V$; cut-off is $I_B = 0$; saturation is $V_{CE} \approx 0.2V$. The design task: put the bias point in the active region, centred so signal swings do not clip.

Divider bias on the output plane: the Q-point and its check



The 12 V dc load line (RC + RE = 3.2 kΩ) with the divider-bias Q-point at 0.99 mA, 8.8 V.

■ **Worked example: the divider bias, checked twice**

$V_{CC} = 12V$, $R_1 = 68k\Omega$, $R_2 = 12k\Omega$, $R_C = 2.2k\Omega$, $R_E = 1k\Omega$, $\beta = 100$. Thevenin: $V_B = 12 \times 12/80 = 1.8V$, $R_B = 68k \parallel 12k = 10.2k\Omega$. Then $V_E = 1.1V$, $I_C \approx 1.1mA$, $V_C = 9.58V$, $V_{CE} = 8.48V$.

Check 1 (region): $V_{CE} = 8.48 > 0.2$ – active ✓. Check 2 (stability): the exact $I_E = (V_B - 0.7)/(R_E + R_B/(\beta + 1))$ gives 1.00 mA at $\beta = 100$ and 1.05 mA at $\beta = 200$ – a 5% shift for a β doubling, because R_E dominates the denominator. That is the divider bias's whole purpose.

■ **Design rules of thumb**

- Make the divider stiff: $R_1 \parallel R_2 \leq \beta_{min} \cdot R_E/10$ – the base draws little.
- Put V_E near 0.1–0.2V_{CC} (thermal stability via R_E).
- Aim $V_{CE} \approx V_{CC}/2$ at the bias point for maximum symmetric swing.

2 Practice

2.1 $V_{CC} = 10V$, $R_1 = R_2 = 20k\Omega$, $R_E = 1k\Omega$, $R_C = 2k\Omega$, $\beta = 100$: find V_B, I_C, V_{CE} and name the region. [4]

2.2 Recompute 2.1's I_C with $\beta = 50$ using the exact formula $I_E = (V_B - 0.7)/(R_E + R_B/(\beta + 1))$; give the percentage shift. [3]

2.3 A fixed-bias circuit (R_B from V_CC to base, no R_E): state why its I_C tracks β directly and so is unstable. [2]

3 Exam-style questions

3.1 Design a divider bias for $V_{CC} = 12V$, $\beta \approx 150 (range 100–300)$, targeting $I_C = 2mA$ and $V_{CE} \approx 6V$, with R_E chosen for stability and the divider ten times stiffer than the base load.

Choose R_E (from a $V_E \approx 1.5V$ target), R_C (from the V_{CE} target), and R_1, R_2 (from V_B and the stiffness rule); compute the bias point at $\beta = 100$ and $\beta = 300$ and verify active-region operation and the I_C shift. [8]

3.2 An emitter-bias circuit has $V_{CC} = 15V$, $R_C = 3k\Omega$, $R_E = 2k\Omega$, and a base held at $V_B = 4V$ (a stiff divider; ignore its loading).

Compute I_C, V_{CE}, and the power in R_C and the transistor. Then state the maximum R_C before saturation with everything else fixed, and verify by computing V_{CE} at that R_C. [7]

Solutions

2.1

- $V_B = 10 \times 20/40 = 5V$; $R_B = 10k\Omega$.
- $I_C \approx (5 - 0.7)/1k = 4.3mA$.
- $V_{CE} = 10 - 4.3m \times 3k = 10 - 12.9 = -2.9V$ – impossible: the transistor is SATURATED, not active.

2.2

- At $\beta = 50$: $I_E = 4.3/(1k + 10k/51) = 4.3/1196 = 3.59mA$ (vs 3.91 mA at $\beta = 100$ via the same formula) – an 8% shift, large because the divider is only marginally stiff AND the point sits in saturation anyway.

2.3

- With no R_E, $I_B = (V_{CC} - 0.7)/R_B$ is fixed and $I_C = \beta \cdot I_B$ – any β change passes straight through, 1:1.

3.1

- $R_E = V_E/I_C = 1.5/2m = 750\Omega$; $V_B = 1.5 + 0.7 = 2.2V$.
- $V_{CE} = 6$ target: $V_{RC} = 12 - 6 - 1.5 = 4.5V \rightarrow R_C = 4.5/2m = 2.25k\Omega$ (2.2 k standard).
- Divider current $\approx 10 \times I_B(max) = 10 \times 2m/100 = 20mA$ – too greedy; the standard rule $R_1 \parallel R_2 \leq \beta_{min} \cdot R_E/10 = 100 \times 750/10 = 7.5k\Omega$.
- Solve: $V_B = 2.2 = 12 \cdot R_2/(R_1+R_2)$ with $R_1R_2/(R_1+R_2) = 7.5k$: $R_1 = 7.5k \times 12/2.2 = 40.9$ kΩ (top, to V_{CC}); $R_2 = 7.5k \times 12/(12 - 2.2) = 9.18$ kΩ (bottom). Check: $12 \times 9.18/50.08 = 2.2$ V ✓.
- $\beta = 100$: $I_C = 1.5/(750 + 7.5k/101) = 1.5/824 = 1.82$ mA; $\beta = 300$: $I_C = 1.5/(750 + 7.5k/301) = 1.5/775 = 1.94$ mA.
- Shift: 6.6% for a 3× β range ✓; V_{CE} at $\beta = 300$: $12 - 1.94m \times (2.2k + 0.75k) = 12 - 5.72 = 6.28V > 0.2$ – active ✓.

3.2

- $V_E = 4 - 0.7 = 3.3V$; $I_C \approx I_E = 3.3/2k = 1.65mA$.
- $V_{CE} = 15 - 1.65m \times 5k = 15 - 8.25 = 6.75V$ – active ✓.
- $P_{RC} = I^2R = (1.65m)^2 \times 3k = 8.17$ mW; $P_Q = V_{CE}I_C = 6.75 \times 1.65m = 11.1$ mW.
- Saturation when $V_{CE} = 0.2$: $R_C(max) = (15 - 3.3 - 0.2)/1.65m = 6.97k\Omega$.
- Check at 6.97 kΩ: $V_{CE} = 15 - 1.65m \times 8.97k = 15 - 14.8 = 0.2V$ ✓.