Outline

- Transistors/FET’s continued
  - Common Emitter Amp
  - Transistor switch (only digital info is controlled)
  - Analog switch
- Why $I_C = \beta I_B$? if time allows.

Common Emitter Amp (real amp!)

This amp does amplify the signal voltage, \(v_C/v_B > 1\).

What is the quiescent voltages and current: $V_B$, $V_E$, $V_C$, $I_B$, $I_E$, and $I_C$?

- $I_C + I_B = I_E$
- $V_{CC} - V_C = R_C*I_C$
- $V_E - V_{EE} = R_E*I_E$ (in class we assumed that $V_{EE} = 0$, but here it can take non-zero value like $-15$ V)
- $I_C = \beta I_B$
- $V_B - V_E = 0.6V$
- \((V_{CC} - V_B)/R_1 = (V_B - V_{EE})/R_2 + I_B\)
  - $I_E = (1+\beta)I_B$
  - $V_{CC} - V_C = R_C*\beta I_B$
  - $V_E - V_{EE} = R_E*(1+\beta)I_B$
    - $V_B - 0.6V - V_{EE} = R_E*(1+\beta)I_B$
    - $V_B = 0.6V + V_{EE} + R_E*(1+\beta)I_B$
    - \((V_{CC} - (0.6V + V_{EE} + R_E*(1+\beta)I_B))/R_1 = ((0.6V + V_{EE} + R_E*(1+\beta)I_B) - V_{EE})/R_2 + I_B\)
    - $(V_{CC} - (0.6V + V_{EE}))/R_1 - 0.6V/R_2$
      - $[R_E*(1+\beta)/R_1 + R_E*(1+\beta)/R_2 + 1]I_B$
\[ I_B = \frac{V_{CC} - 0.6 - V_{EE} - 0.6}{R_1 \frac{R_2}{R_E(1 + \beta) + R_E(1 + \beta)} + 1} = \frac{(V_{CC} - 0.6 - V_{EE})R_2 - 0.6R_1}{R_E(1 + \beta)(R_1 + R_2) + R_1R_2} \]

\[ R_E(1 + \beta)((R_1 + R_2) + \frac{R_1R_2}{R_E(1 + \beta)}) \]

\[ \approx \frac{(V_{CC} - V_{EE})R_2}{R_E(1 + \beta)(R_1 + R_2)} \left[ 1 - \frac{R_1R_2}{R_E(1 + \beta)(R_1 + R_2)} \right] - \frac{0.6}{R_E(1 + \beta)} \]

or alternatively,

\[ \frac{(V_{CC} - 0.6 - V_{EE})R_2 - 0.6R_1}{R_E(1 + \beta)(R_1 + R_2) + R_1R_2} \]

\[ \frac{(V_{CC} - V_{EE})R_2}{R_1 + R_2} - \frac{0.6}{R_E(1 + \beta) + \frac{R_1R_2}{(R_1 + R_2)}} \]

\[ \frac{V_0 - (0.6 + V_{EE})}{R_E' + R_1 // R_2} \]

where

\[ V_0 = \frac{(V_{CC}R_2 + V_{EE}R_1)}{R_1 + R_2} \] and \( R_E' \equiv R_E(1 + \beta) \)

\[ V_B = 0.6V + V_{EE} + R_E'(1 + \beta) \frac{V_0 - (0.6 + V_{EE})}{R_E' + R_1 // R_2} \]

\[ = 0.6 + V_{EE} + \frac{R_E'}{R_E + R_1 // R_2} \frac{V_0 - (0.6 + V_{EE})}{R_E' + R_1 // R_2} \]

\[ = \frac{R_E'V_0 - R_E'(0.6 + V_{EE}) + (0.6 + V_{EE})(R_E' + R_1 // R_2)}{R_E + R_1 // R_2} \]

\[ = \frac{R_E'V_0 + (0.6 + V_{EE})(R_1 // R_2)}{R_E' + R_1 // R_2} \]

\[ I_C = \beta*I_B = \beta \frac{V_0 - (0.6 + V_{EE})}{R_E' + R_1 // R_2} = \frac{V_0 - (0.6 + V_{EE})}{R_E \frac{1 + \beta}{\beta} + \frac{R_1 // R_2}{\beta}} \]

\[ V_C = V_{CC} - R_C*I_C = V_{CC} - R_C \frac{V_0 - (0.6 + V_{EE})}{R_E \frac{1 + \beta}{\beta} + \frac{R_1 // R_2}{\beta}} \]
• Or in a more intuitive fashion,
• From the base side, 1k connected to the emitter is the same as multiplied by β, so it is much larger than the 1k on the base, and negligible. So $V_B$ is 15 V divided by 10k and 1k ~ 1.36 V.
• Then $V_E$ is lower by 0.6 V → 0.76 V.
• $I_E$ must then be 0.76 V/1k = 0.76 mA.
• $I_C$ must then be also 0.76 mA (ignoring $1/β$ difference)
• $V_C$ must then be 0.76 mA*10k lower than 15 V → 15 – 7.6 = 7.4 V.
• $I_B$ must be 0.76 mA/β = 7.6 µA. Since the voltage divider on the base has current of 15/11k = 1.36 mA, this 7.6 µA is small enough to be neglected.

• When an AC voltage, $Δv$, is applied, at the input, what is the AC voltages and currents $v_B$, $v_E$, $v_C$, $i_B$, $i_E$, and $i_C$? What is the gain of this amp? (Assume that freq is “high enough”)
  • $(I_C+i_C)+(I_B+i_B) = (I_E+i_E)$ but since already $I_C + I_B = I_E$, $i_C + i_B = i_E$.
  • $V_{CC} – (V_C + v_C) = R_C*(I_C+i_C)$ but since already $V_{CC} – V_C = R_C*I_C$ so $-v_C = R_C*i_C$
  • Similarly,
    • $v_E = R_E*i_E$
    • $i_C = βi_B$
    • $v_B – v_E = 0$
    • $-v_B/R_1 = v_B/R_2 + i_B$ won’t hold since the change in $v_B$ is caused by changing current flowing into the base.
      ○ $v_B = v_E = R_E*i_E = R_E*(1+β)i_B$
      ○ $v_C = -R_C*i_C = -R_C*βi_B = -R_C*βv_B/R_E(1+β)$
        $\sim -(R_C/R_E)v_B$
  • Or in more intuitive fashion,
    • $v_B = v_E = Δv$, $i_E = i_C = Δv/1k$. Then $v_C = Δv/1k*10k = 10Δv$.
    • So the gain must be 10.
    • Note that since $V_E = 0.8V$, $v_E$ cannot go down more than 0.8V.
    • Similarly, $v_C$ cannot go up 8 V or go down by 7 V.
• What is the input and output impedance of this circuit (for AC)?
  • Input impedance is similar to the emitter follower: inherent input impedance is $(1+β)*1k$ (in emitter). But 10k and 1k connected from input (to ground and 15V) act as input impedance (in parallel), which actually dominate the net impedance. So it is about 1k (slightly less).
  • $Z_{in} = v_B/i_{in}$, where $i_{in}$ is $i_B + i_1 + i_2 = v_B/R_E*(1+β) + v_B/R_2 + v_B/R_1$. So
• $Z_{in} = v_B/i_{in} = (1/R_E*(1+\beta) + 1/R_1 + 1/R_2)^{-1} = R'_E//R_1//R_2$.

• Output impedance is $R_C$ [and $v_0 = v_{in}*(R_C/ R_E)$].