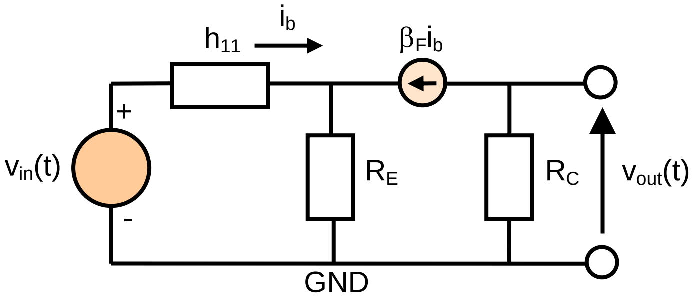
Tutorial 4 – Answers

Question 1

We are not required to perform the DC analysis of the circuit. We can simply assume that the BJT is in the forward active mode without having to demonstrate it.

As for the AC analysis, the small-signal model of our common-emitter amplifier with symmetrical power supplies is depicted below.



We can show that $v_{out}(t) = -R_C\,\beta_F\,i_b$.

In addition, we can write $v_{in}(t) = h_{11}\,i_b + R_E\,(1+\beta_F)\,i_b \approx (h_{11} + R_E\,\beta_F)\,i_b$.

The small-signal voltage gain of the amplifier is thus given by

$$A_V = \frac{v_{out}(t)}{v_{in}(t)} \approx -\frac{\beta_F\,R_C}{h_{11} + R_E\,\beta_F},$$

which is the usual result obtained for a common-emitter with negative feedback.

It is not possible to compute the value of this voltage gain as we do not know the value of the resistance h_{11}. However, if we assume that $h_{11} << R_E\,\beta_F$, which is always the case with a good biasing, we have

$$A_v \approx -\frac{R_C}{R_E} \approx \text{-4.1.}$$

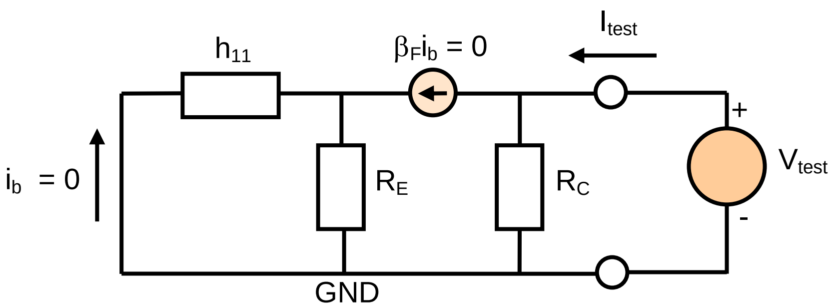
Therefore, these results show that using two symmetrical power supplies instead of a single one (like in the examples of Tutorial 3) does not result in any change in the voltage gain expression.

It is easy to show that the small-signal input resistance is given by

$$r_{in} = \frac{v_{in}(t)}{i_b} \approx h_{11} + R_E\beta_F \, .$$

Once again, if we assume that $h_{11} << R_E\,\beta_F$, we obtain $r_{in} \approx R_E\beta_F$ = 150 kΩ. This is a very high value (highly desirable for a voltage amplifier in order to minimise the loading effect for an eventual up-stream circuit). This input resistance is much larger than those of the common-emitter amplifiers with negative feedback studied in Tutorial 3. This higher input resistance is due to the absence of both biasing resistances R_1 and R_2.

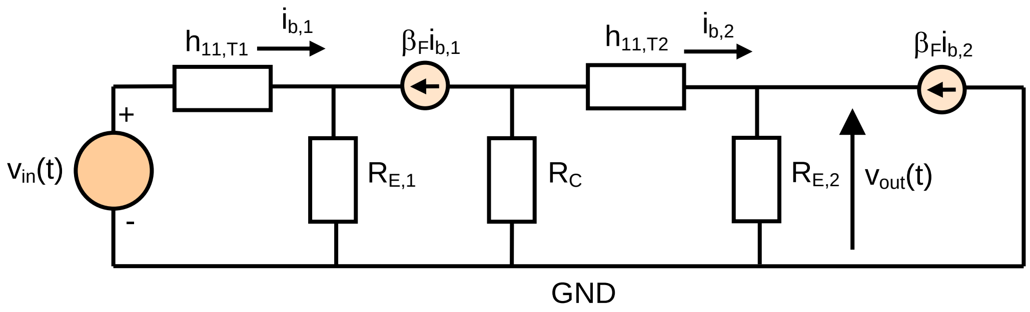
The small-signal output resistance is given by $r_{out} = R_C$ = 6.2 kΩ (usual result for a common-emitter amplifier).



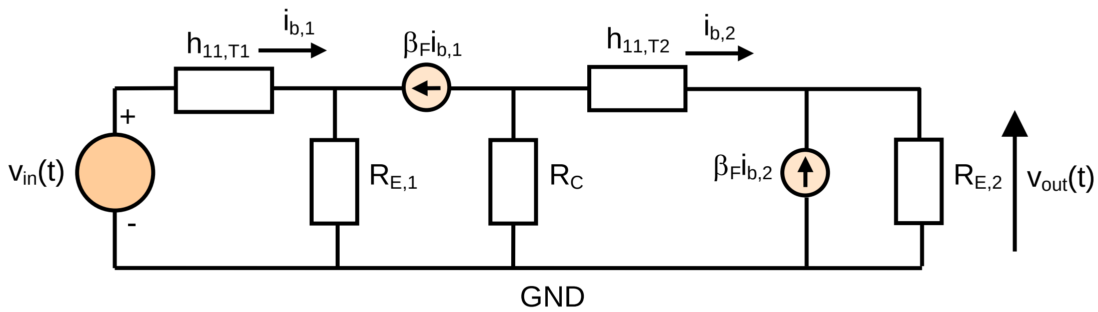
Question 2

We are not required to perform the DC analysis of the circuit. We can simply assume that the BJT is in the forward active mode without having to demonstrate it.

As for the AC analysis, the small-signal model of our common-emitter amplifier with an output stage is depicted below.



An equivalent, and slightly clearer, version is shown below.



We can show that $v_{out}(t) = R_{E,2}\,(1+\beta_F)\,i_{b,2} \approx R_{E,2}\,\beta_F\,i_{b,2}$.

In addition, we can write: $v_{in}(t) = h_{11,T1}\,i_{b,1} + R_{E,1}\,(1+\beta_F)\,i_{b,1} \approx (h_{11,,T1} + R_{E,1}\,\beta_F)\,i_{b,1}$.

We need a third equation to link both currents $i_{b,1}$ and $i_{b,2}$:

$R_C(\beta_F i_{b,1} + i_{b,2}) + h_{11,T2} i_{b,2} + R_{E,2}(\beta_F + 1) i_{b,2} = 0$ => $R_C\beta_F i_{b,1} + (R_C + h_{11,T2} + R_{E,2}\beta_F)\,i_{b,2} \approx 0$ =>

$$\frac{i_{b,2}}{i_{b,1}} \approx -\frac{R_C\beta_F}{R_C + h_{11,T2} + R_{E,2}\beta_F}.$$

Finally, the small-signal voltage gain of the amplifier is thus given by

$$A_v = \frac{v_{out}(t)}{v_{in}(t)} = \frac{v_{out}(t)}{i_{b,2}}\frac{i_{b,2}}{i_{b,1}}\frac{i_{b,1}}{v_{in}(t)} \approx -\frac{R_{E,2}R_C(\beta_F)^2}{(R_C + h_{11,T2} + R_{E,2}\beta_F)(h_{11,T1} + R_{E,1}\,\beta_F)}.$$

It is not possible to compute the value of this voltage gain as we do not know the value of both resistances $h_{11,T1}$ and $h_{11,T2}$ (since no DC analysis has been performed). However, if we assume that $R_C + h_{11,T2} << R_{E,2}\,\beta_F$ and $h_{11,T1} << R_{E,1}\,\beta_F$, we can write:

$$A_v \approx -\frac{R_C}{R_{E,1}} \approx \text{-3.4}.$$

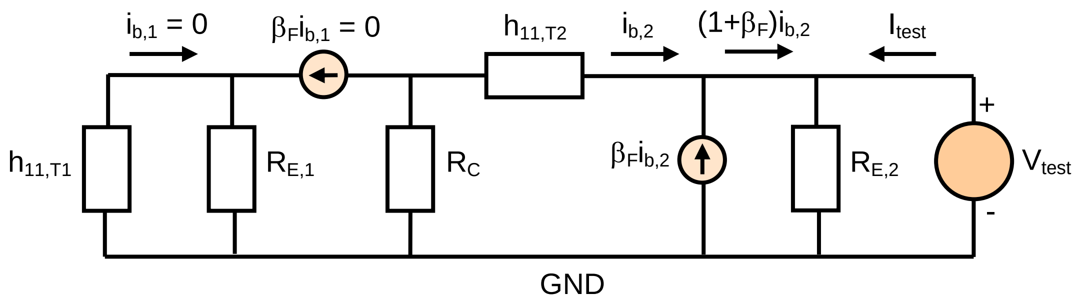
This expression is identical to that obtained with a simple common-emitter amplifier with negative feedback. Therefore, we conclude that the use of a common-collector amplifier at the output of a common-emitter amplifier has no significant effect on the voltage gain of the latter.

It is easy to show that the small-signal input resistance is given by

$$r_{in} = \frac{v_{in}(t)}{i_{b,1}} \approx h_{11,T1} + R_{E,1}\beta_F .$$

Once again, if we assume that $h_{11,T1} << R_{E,1}\,\beta_F$, we obtain $r_{in} \approx R_{E,1}\beta_F$ = 140 kΩ, which is a very high value. The expression of the input resistance is identical to that obtained for a classical common-emitter amplifier with negative feedback and symmetrical power supplies. This implies that the presence of the common-collector amplifier does not have any effect on the input resistance of the overall circuit.

The small-signal output resistance is given by $r_{out} = \left.\frac{V_{test}}{I_{test}}\right|_{v_{in}(t)=0}$.



We can write: $h_{11,T1}\,i_{b,1} + R_{E,1}\,(1+\beta_F)\,i_{b,1} = 0$, which leads to $i_{b,1} = 0$.

In addition, we have: $V_{test} = R_{E,2}\,(1+\beta_F)\,i_{b,2} + R_{E,2}\,I_{test} \approx R_{E,2}\,\beta_F\,i_{b,2} + R_{E,2}\,I_{test}$.

We need a third equation: $V_{test} = -(R_C + h_{11,T2})\,i_{b,2}$ => $i_{b,2} = -\dfrac{V_{test}}{R_C + h_{11,T2}}$.

By combining both equations, we obtain $V_{test} \approx -\dfrac{R_{E,2}\,\beta_F}{R_C + h_{11,T2}} V_{test} + R_{E,2}\,I_{test}$, which yields $\left(\dfrac{R_C + h_{11,T2} + R_{E,2}\,\beta_F}{R_C + h_{11,T2}}\right) V_{test} \approx R_{E,2}\,I_{test}$.

Finally, the small-signal output resistance is given by $r_{out} = \dfrac{V_{test}}{I_{test}} \approx \dfrac{R_{E,2}(R_C + h_{11,T2})}{R_C + h_{11,T2} + R_{E,2}\,\beta_F}$.

If we assume that $R_C + h_{11,T2} << R_{E,2}\,\beta_F$, we can write: $r_{out} \approx \dfrac{R_C + h_{11,T2}}{\beta_F}$.

Although we do not know here the value of the resistance $h_{11,T2}$, this expression clearly indicates that the output resistance is low (thanks to the presence of the common-collector amplifier). This is not the case with classical common-emitter amplifiers for which $r_{out} = R_C$. Therefore, due to their low output resistance (which is a very attractive feature for voltage amplifiers), common-collector amplifiers are often used at the output stage of more complex circuits, especially when the load resistance is very low in order to prevent an eventual collapse in the voltage gain (loading effect).

Question 3

The answers are in the hand-written document.