PHYS3360/AEP3630

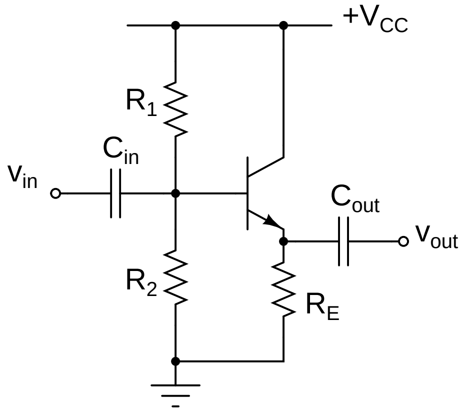
Four Basic Transistor Amplifier Configurations

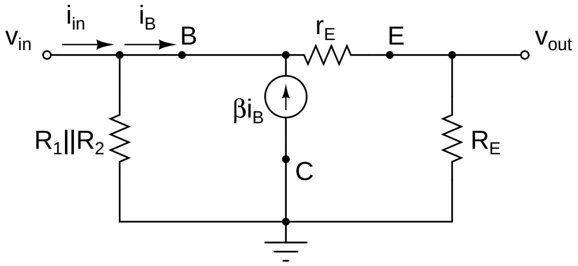
The four basic single transistor amplifier configurations are as following: common collector (CC), common base (CB), common emitter (CE), and unbypassed emitter resistor variant of CE amplifier (UBER). These provide basic building blocks that can be combined to obtain the needed input and output characteristics (gain, R_{in}, R_{out}). The following table summarizes the properties of the four basic configurations of the transistor amplifiers.

Configuration	G	R_{in}	R_{out}
CC	$\sim$1	large	small
CB	large, non-inverting	small	moderate
CE	large, inverting	moderate	moderate
UBER	moderate, inverting	large	moderate

Common Collector Amplifier (Emitter Follower)

The circuit is shown on the left, and its small-signal equivalent is on the right. Here, and in other circuits capacitors are chosen such that their impedances are sufficiently small for input frequencies of interest that they can be ignored in small-signal equivalent circuits.





From the small-signal equivalent circuit we find that $v_{out} = i_E R_E = i_B(\beta+1)R_E$, and $v_{in} = i_E(r_E+R_E) = i_B(\beta+1)(r_E+R_E)$. Thus, the voltage gain is

$$G = \frac{v_{out}}{v_{in}} = \frac{R_E}{R_E + r_E} \approx 1.$$

Input resistance is given by $R_{in} = (R_1||R_2)||R'_{in}$, where the parallel to $(R_1||R_2)$ resistance $R'_{in} = v_{in}/i_B = (\beta+1)(r_E+R_E)$. Thus,

$$R_{in} = R_1||R_2||(\beta+1)(r_E+R_E).$$

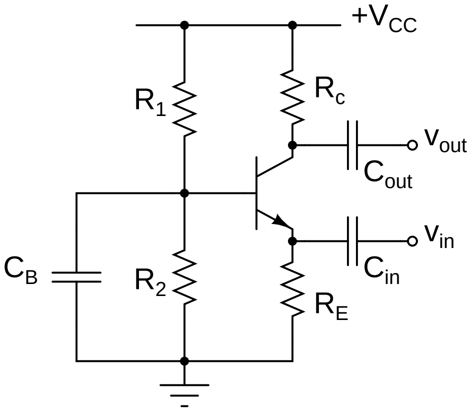
Output resistance is given by $R_{out} = v_{oc}/i_{sc}$, where v_{oc} is the open-circuit voltage across the output terminal and the ground $v_{oc} = v_{out} = v_{in}R_E/(r_E+R_E)$, and i_{sc} is a short-circuit current, which is simply $i_{sc} = v_{in}/r_E$. Thus,

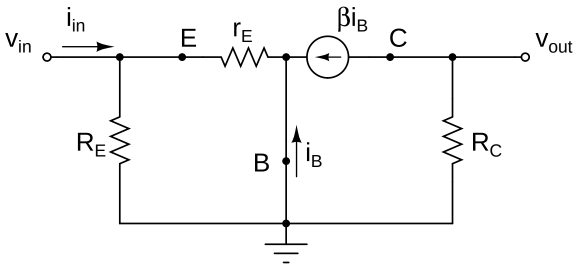
$$R_{out} = r_E||R_E.$$

We note that R_{in} can be made quite large, while R_{out} is small ($< r_E$).

Common Base Amplifier

The circuit is shown on the left, and its small-signal equivalent circuit is shown on the right.





We write for the output $v_{out} = -i_C R_C = -\beta i_B R_C$. The input $v_{in} = -i_E r_E = -(\beta+1) i_B r_E$. The resultant gain

$$G = \frac{\beta}{\beta+1}\frac{R_C}{r_E} \approx \frac{R_C}{r_E}.$$

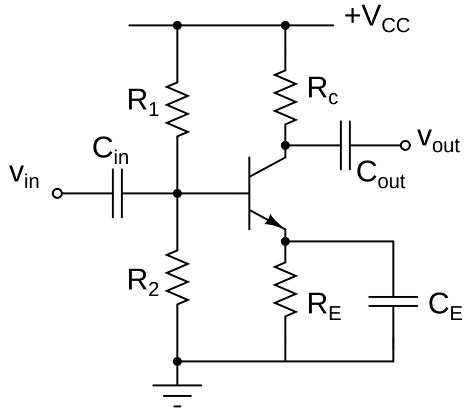
We can write immediately for input and output resistances:

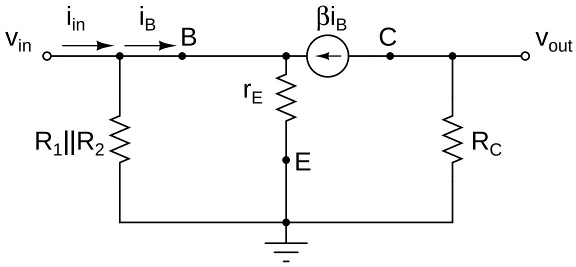
$$R_{in} = r_E || R_E, \text{ and } R_{out} = R_C.$$

We see that R_{in} is necessarily small ($< r_E$), and that the gain can be made large.

Common Emitter Amplifier

The circuit is shown on the left, and its small-signal equivalent circuit is shown on the right.





$v_{out} = -i_C R_C = -\beta i_B R_C$ and $v_{in} = i_E r_E = (\beta+1) i_B r_E$. The resultant gain

$$G = -\frac{\beta}{\beta+1}\frac{R_C}{r_E} \approx -\frac{R_C}{r_E}.$$

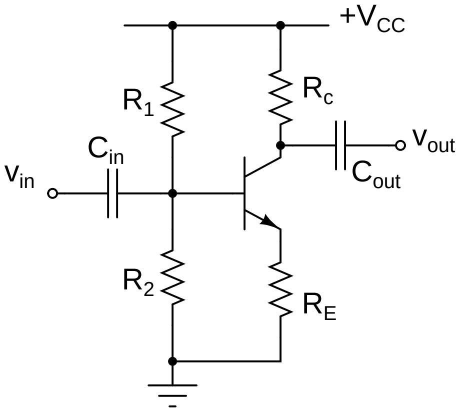
The input and output resistances are given by:

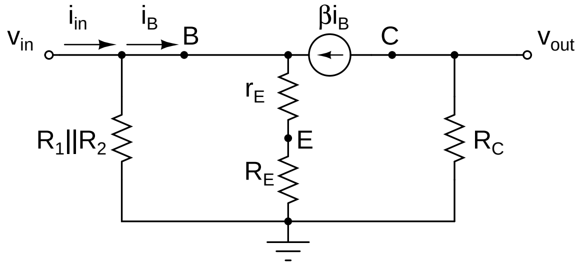
$$R_{in} = R_1 || R_2 || (\beta+1) r_E, \text{ and } R_{out} = R_C.$$

Note: the gain is similar to the CB amplifier except CE amplifier is inverting.

Upbypassed Emitter Resistor Amplifier

The circuit is shown on the left, and its small-signal equivalent circuit is shown on the right. Note: this is equivalent to CE amplifier except for R_E present in small-signal equivalent circuit.





$v_{out} = -i_C R_C = -\beta i_B R_C$ and $v_{in} = i_E(r_E + R_E) = (\beta + 1)i_B(r_E + R_E)$. The resultant gain

$$G = -\frac{\beta}{\beta+1}\frac{R_C}{r_E + R_E} \approx -\frac{R_C}{R_E}.$$

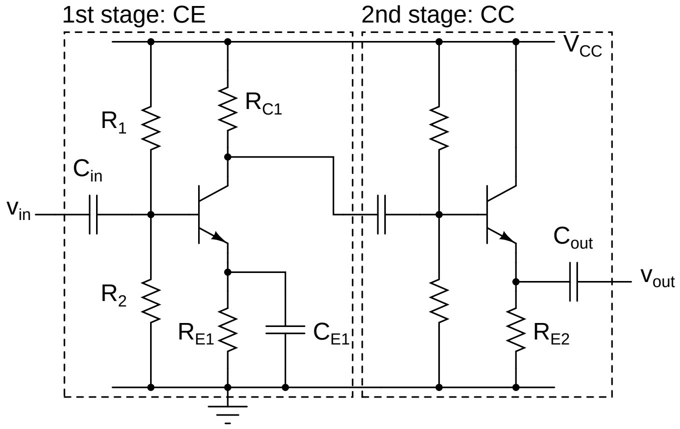
The input and output resistances are given by:

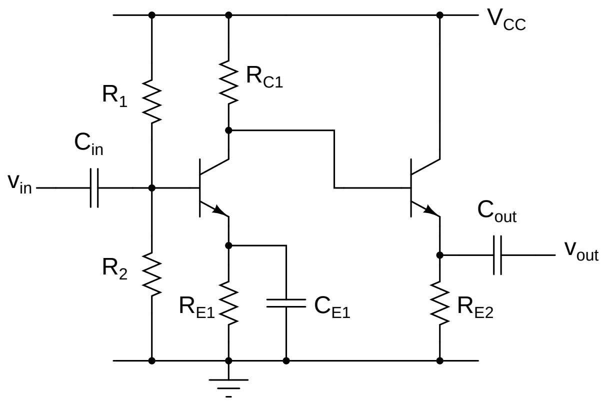
$$R_{in} = R_1||R_2||(\beta+1)(r_E + R_E), \text{ and } R_{out} = R_C.$$

Combining Multiple Stages

Oftentimes, no single configuration of the four basic types is sufficient to meet a particular application's requirement in terms of the desired gain, input, and output impedances.

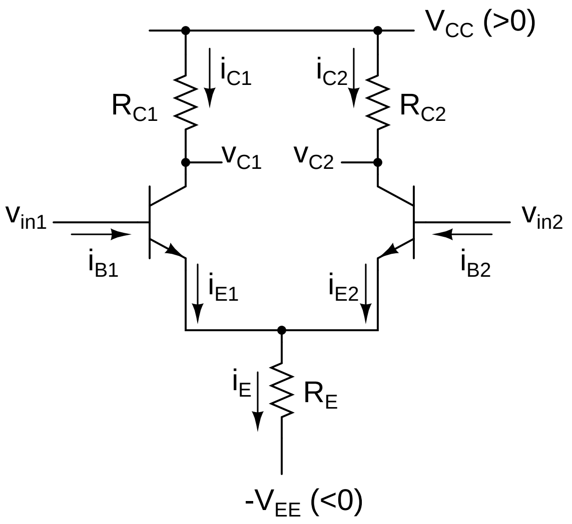
Suppose you would like to have a high G low R_{out} amplifier. One can achieve so by combining common emitter and common collector configurations. To connect the two stages, each biased using H-configuration, one can insert a capacitor between them so that the output of the first stage is transferred to the second stage without affecting biasing in each stage (see the circuit on the left). Generally, such an approach is less than ideal because the addition of intermediate capacitors degrades amplifier frequency response and requires more components. Instead, one can directly couple the stages as shown in the schematic below to the right. In this case the collector of the first stage is connected directly to the base of the second stage. Provided $I_{B2} \ll I_{C1}$, biasing of the first stage will be unaffected by the second stage.

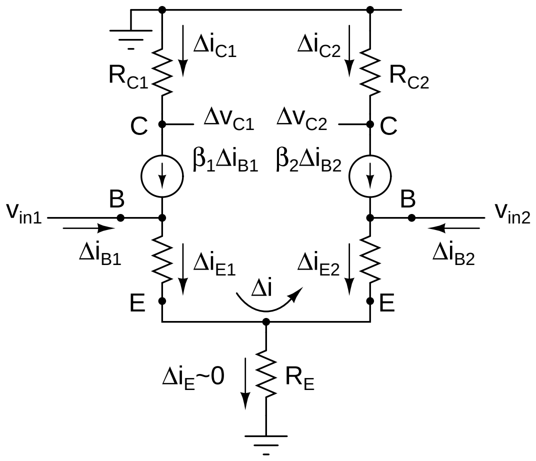




Difference Amplifier

This circuit is also known as an emitter-coupled pair. See the circuit and its small-signal equivalent below. Two small voltage inputs are supplied to bases of the two transistors. The circuit has two outputs, v_{C1} and v_{C2}.





The power supply voltage V_{EE} is chosen to be large enough so that the emitter voltages fluctuations due to v_{in1} and v_{in2} do not change the current flowing through R_E resistor. That current, which is roughly $(V_{EE} - 0.6\text{V})/R_E$ assuming v_{in1} and v_{in2} are small signals, is to a very high degree independent of the input voltages.

Next, we proceed to the small-signal circuit analysis. $R_E \gg r_{E1,E2}$, so little of the small signal current that flows between the two inputs through r_E's gets diverted to R_E. We can imagine replacing R_E by an open circuit (the small-signal part of i_E, Δi_E, is much less than Δi_{E1}, Δi_{E2}, etc.) and then writing the *small-signal current* circulating in the loop formed by the transistors

$$\Delta i = \Delta i_{E1} = -\Delta i_{E2} \approx \Delta i_{C1} = -\Delta i_{C2} = \frac{v_{in1} - v_{in2}}{r_{E1} + r_{E2}} = \frac{v_{diff}}{r_{E1} + r_{E2}}$$

The output voltage could be taken from either transistor's collector, providing both inverting and non-inverting outputs.

$$\Delta v_{C1} = -\Delta i R_{C1} = -\frac{R_{C1}}{r_{E1} + r_{E2}} v_{diff}$$

$$\Delta v_{C2} = \Delta i R_{C2} = \frac{R_{C2}}{r_{E1} + r_{E2}} v_{diff}$$

The ratio in front of v_{diff} defines differential gain, which can be made very large. The actual value is determined by specific r_E's, which are in turn determined by the Q points of each of the transistors. It is possible to include additional external emitter resistors to make the gains independent from $r_{E1,E2}$. A circuit similar to this one is used as an input stage for op-amps such as 741.