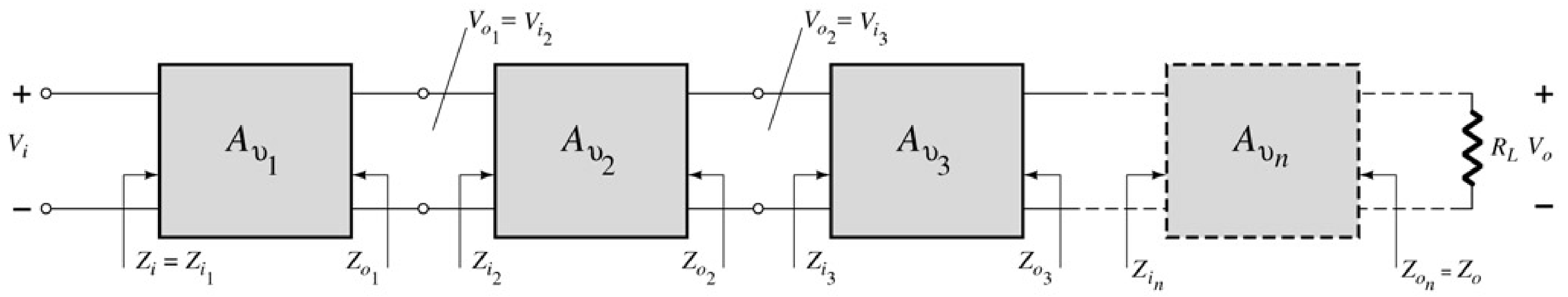
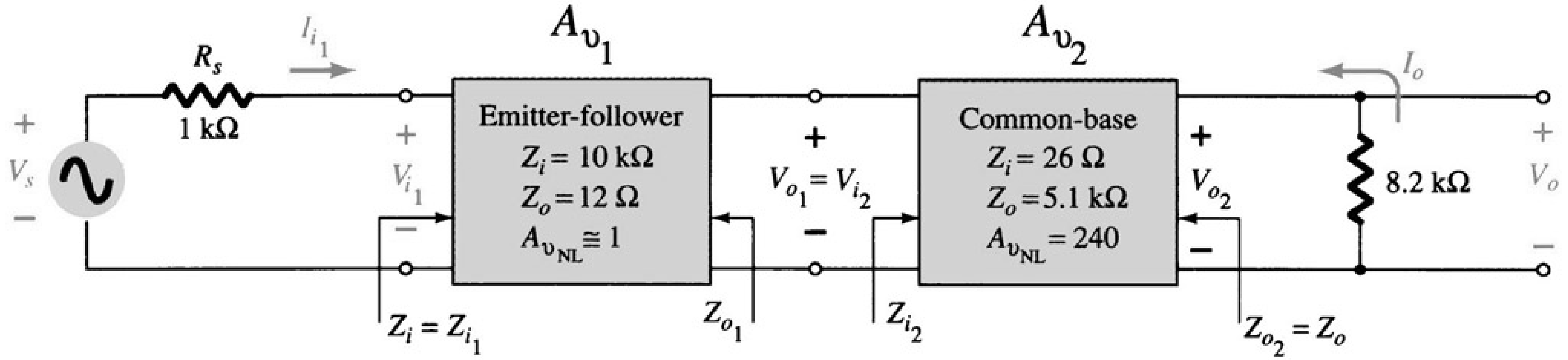
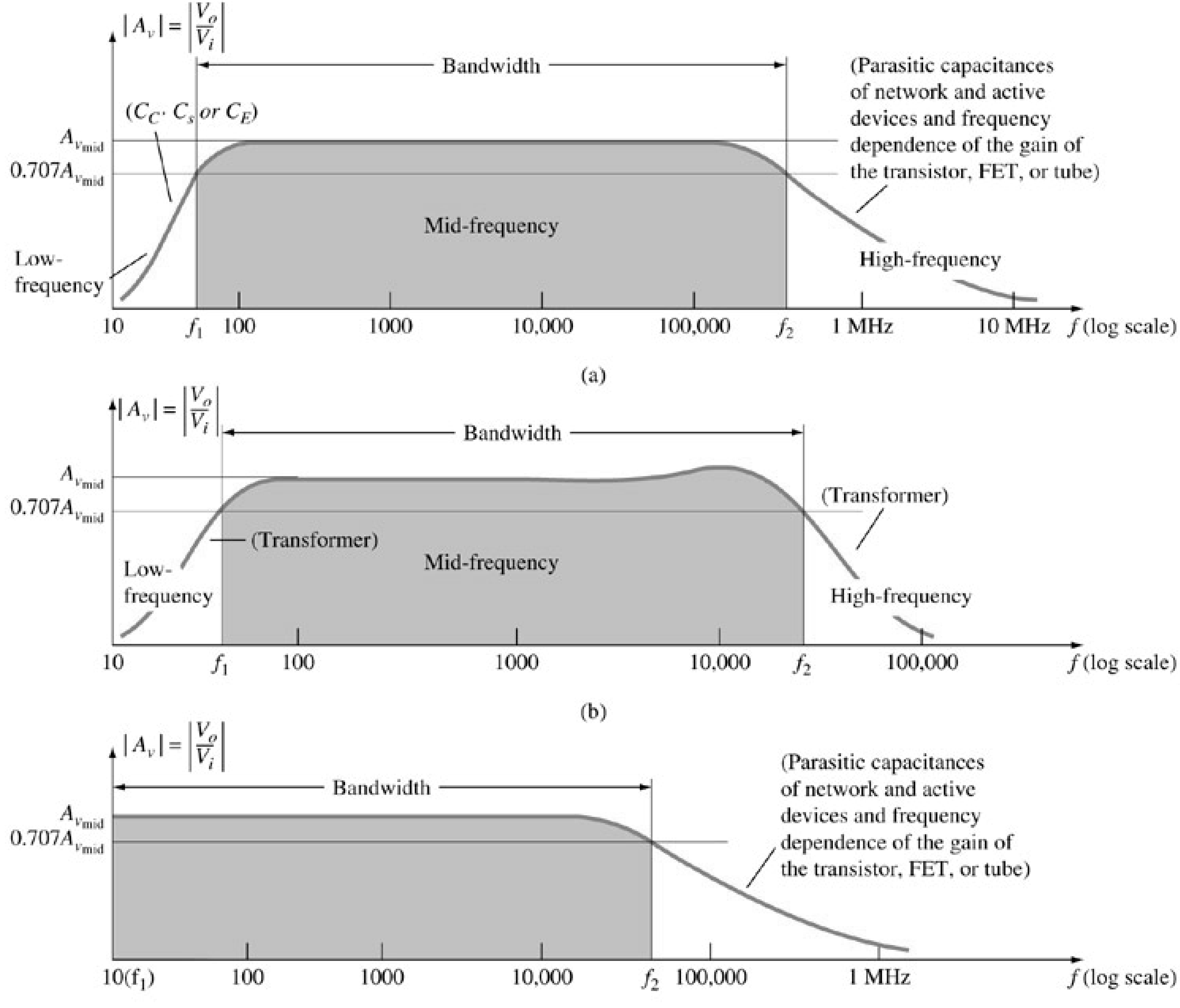
Multistage Amplifiers

Cascade Connection







|A_v| = |V_o/V_i|
Bandwidth
(Parasitic capacitances of network and active devices and frequency dependence of the gain of the transistor, FET, or tube)
(C_C, C_s or C_E)
A_v_mid
0.707A_v_mid
Mid-frequency
Low-frequency
High-frequency
10
f_1
100
1000
10,000
100,000
f_2
1 MHz
10 MHz
f (log scale)

(a)

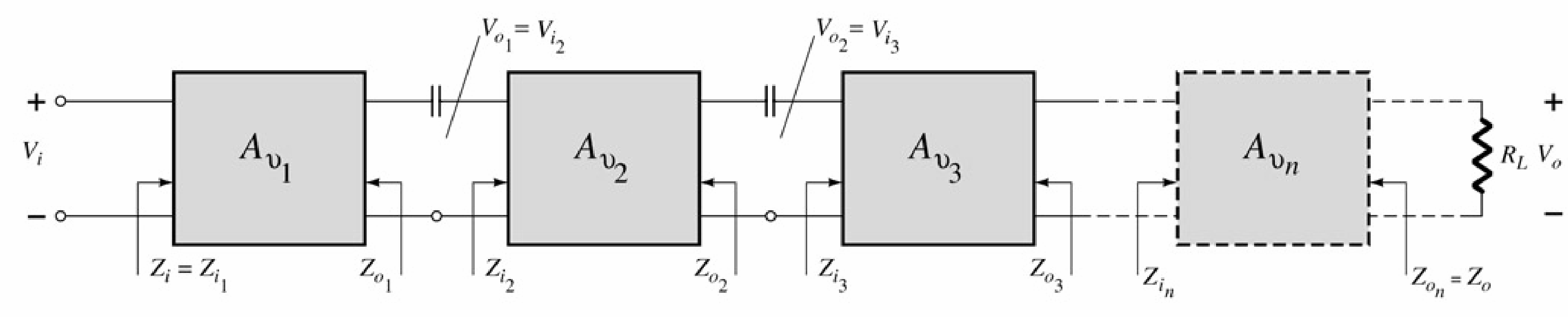
|A_v| = |V_o/V_i|
Bandwidth
A_v_mid
0.707A_v_mid
(Transformer)
(Transformer)
Mid-frequency
Low-frequency
High-frequency
10
f_1
100
1000
10,000
f_2
100,000
f (log scale)

(b)

|A_v| = |V_o/V_i|
Bandwidth
A_v_mid
0.707A_v_mid
(Parasitic capacitances of network and active devices and frequency dependence of the gain of the transistor, FET, or tube)
10(f_1)
100
1000
10,000
f_2
100,000
1 MHz
f (log scale)

(c)

AC Coupled Multistage Amplifiers



The output of one amplifier is the input to the next amplifier.

Note the DC bias circuits **are isolated** from each other by the coupling capacitors.

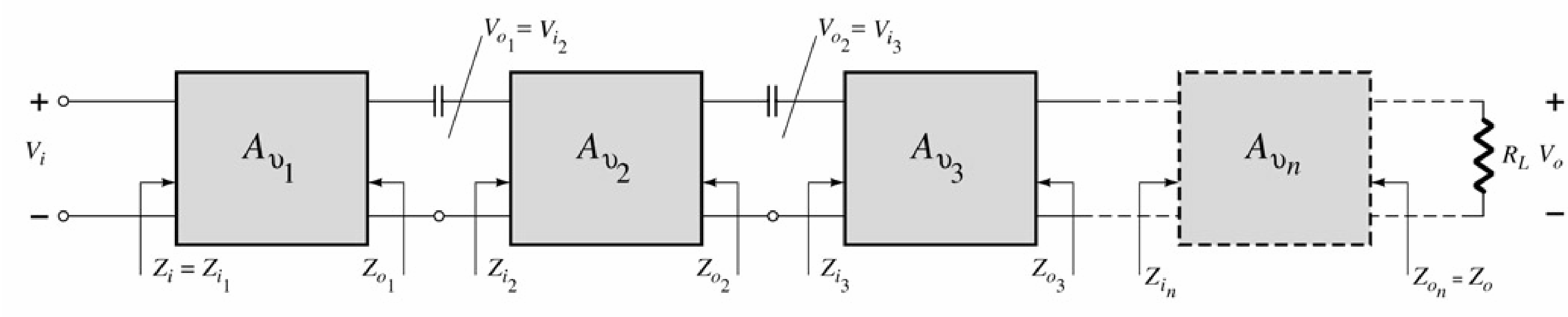
The DC calculations **are independent** of the cascading.
The AC calculations for gain and impedance are interdependent.

The overall gain:

$$A_v = A_{v_1} \times \frac{Z_{i_2}}{Z_{o_1} + Z_{i_2}} \times A_{v_2} \times \cdots \frac{Z_{i_k}}{Z_{o_{k-1}} + Z_{i_k}} \times A_{v_k} \cdots \times \frac{Z_{i_n}}{Z_{o_{n-1}} + Z_{i_n}} \times A_{v_n}$$

with $Z_i = Z_{i_1}$ and $Z_o = Z_{o_n}$

AC Coupled Multistage Amplifiers



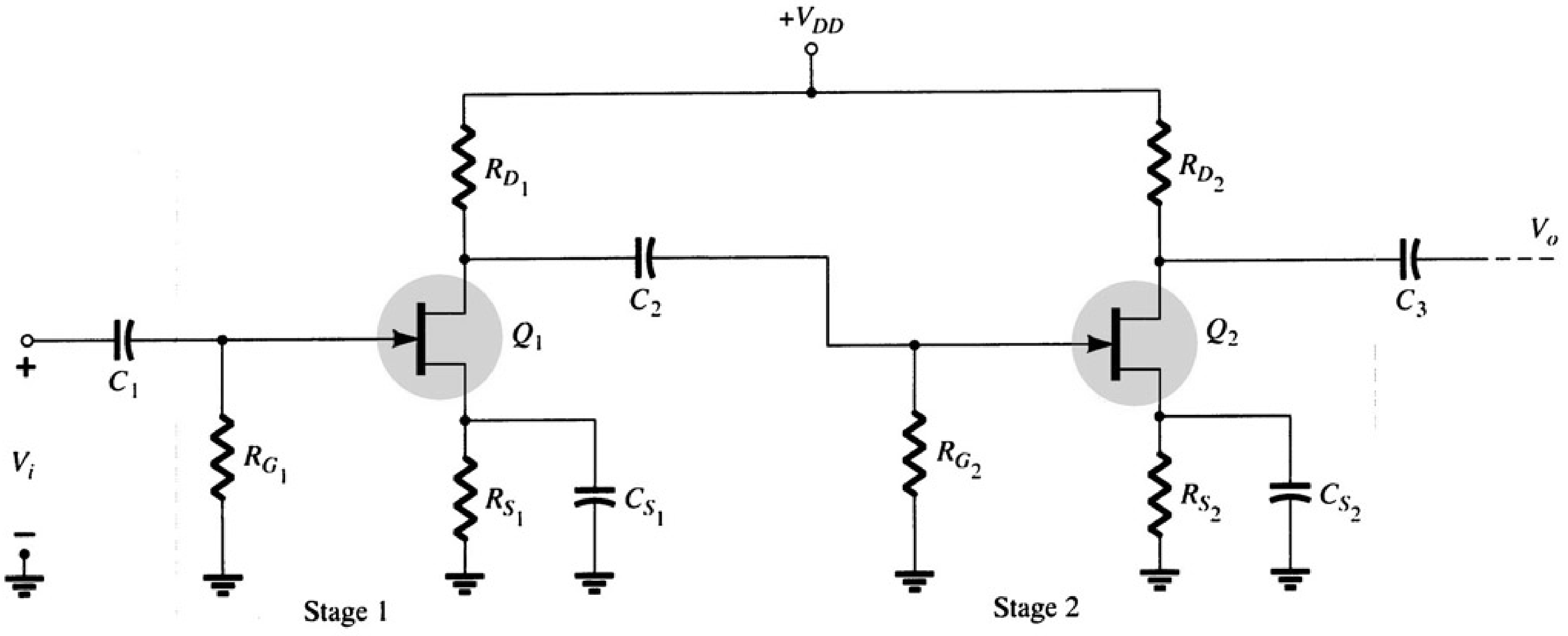
We can also express the overall gain as follows

$$A_v = A_{v1}^* \times A_{v2}^* \times \cdots A_{vk}^* \cdots \times A_{vn}$$

where

$$A_{vk}^* = A_{vk} \times \frac{Z_{i_{k+1}}}{Z_{o_k} + Z_{i_{k+1}}}$$

FET Cascade Amplifier

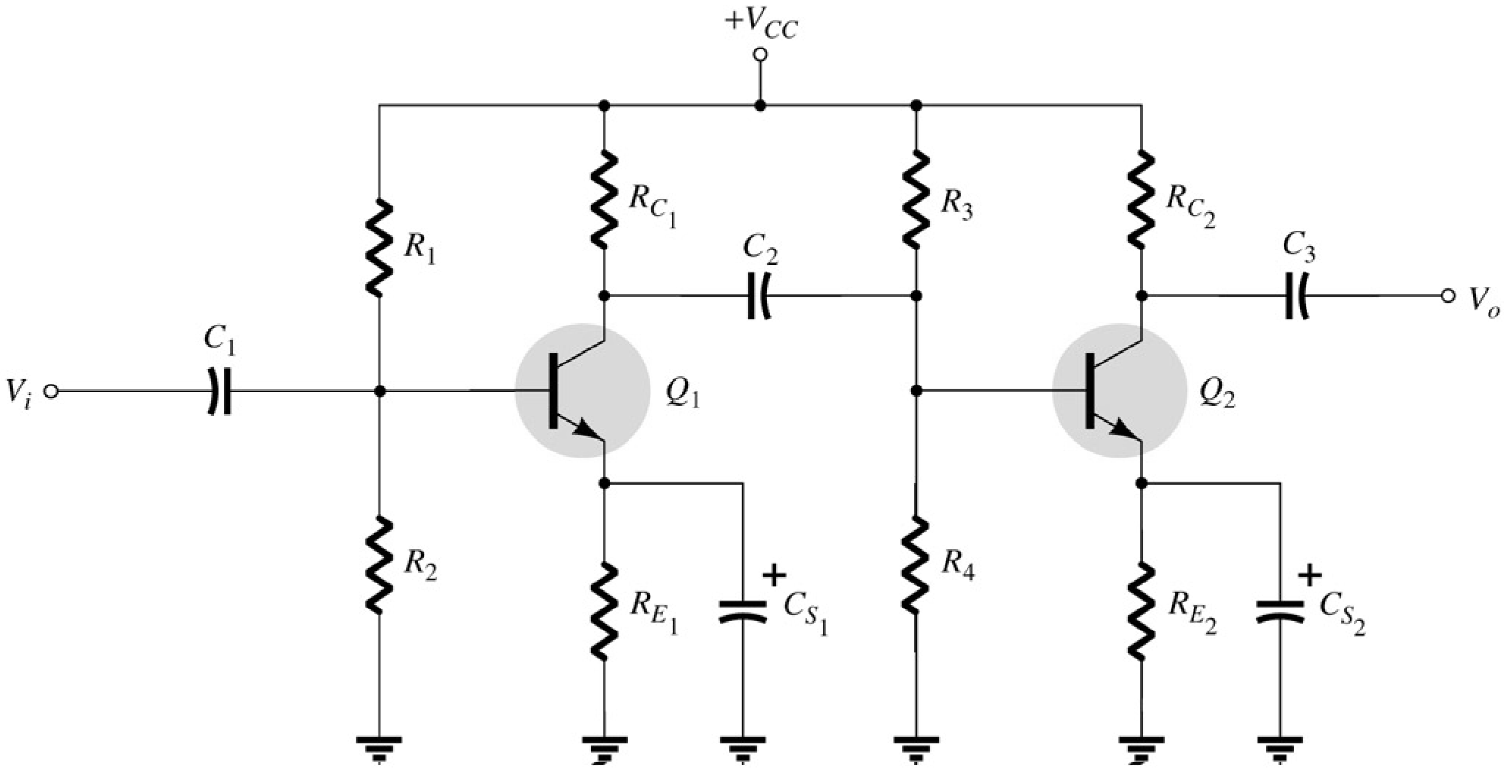


Voltage Gain: $$A_v = A_{v_2} A_{v_1}^* = \left(-g_{m_2} R_{D_2}\right)\left[-g_{m_1}\left(R_{D_1} \parallel R_{G_2}\right)\right]$$

Input Impedance: $$Z_i = R_{G_1}$$

Output Impedance: $$Z_o = R_{D_2}$$

BJT Cascade Amplifier



Voltage Gain: $$A_v = A_{v_2} A_{v_1}^* = \left(-\frac{h_{fe_2} R_{C_2}}{h_{ie_2}} \right) \left(-\frac{h_{fe_1} \left[R_{C_1} \parallel \left(R_3 \parallel R_4 \parallel h_{ie_2} \right) \right]}{h_{ie_1}} \right)$$

Input Impedance: $$Z_i = R_1 \parallel R_2 \parallel h_{ie_1}$$

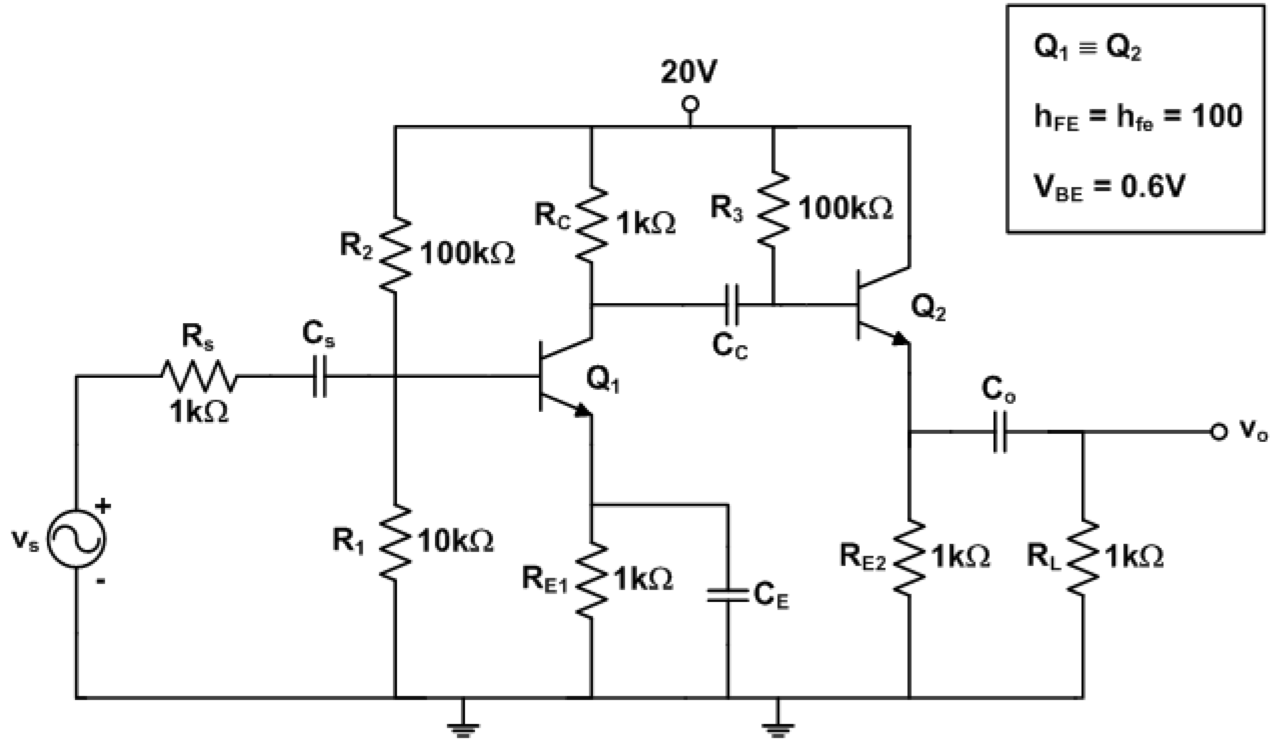
Output Impedance: $$Z_o = R_{C2} \parallel \frac{1}{h_{oe_2}}$$

Combination of FET and BJT Cascade

A FET-BJT cascade is calculated in a similar fashion as a FET-FET or a BJT-BJT cascade.

This combination provides a high gain from the BJT with the high input impedance from the FET.

Ex1:

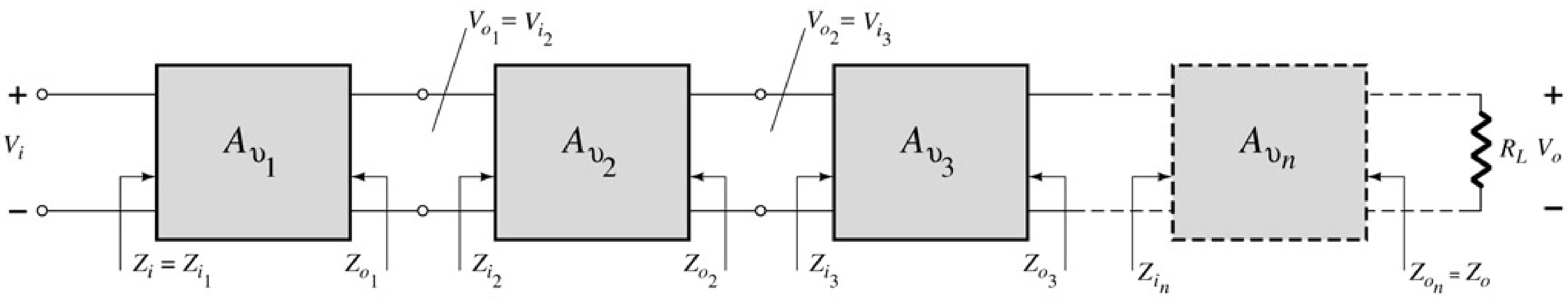


a) Draw AC and DC load lines for both transistors.

b) Calculate the overall voltage gain $\mathbf{A_V = v_o / v_s}$.

c) Find $\mathbf{v_{s\,(max)}}$ which produces maximum undistorted output voltage.

DC Coupled Multistage Amplifiers



The output of one amplifier is the input to the next amplifier.

Note the DC bias circuits **are not isolated** from each other
The DC calculations **are not independent** of the cascading.

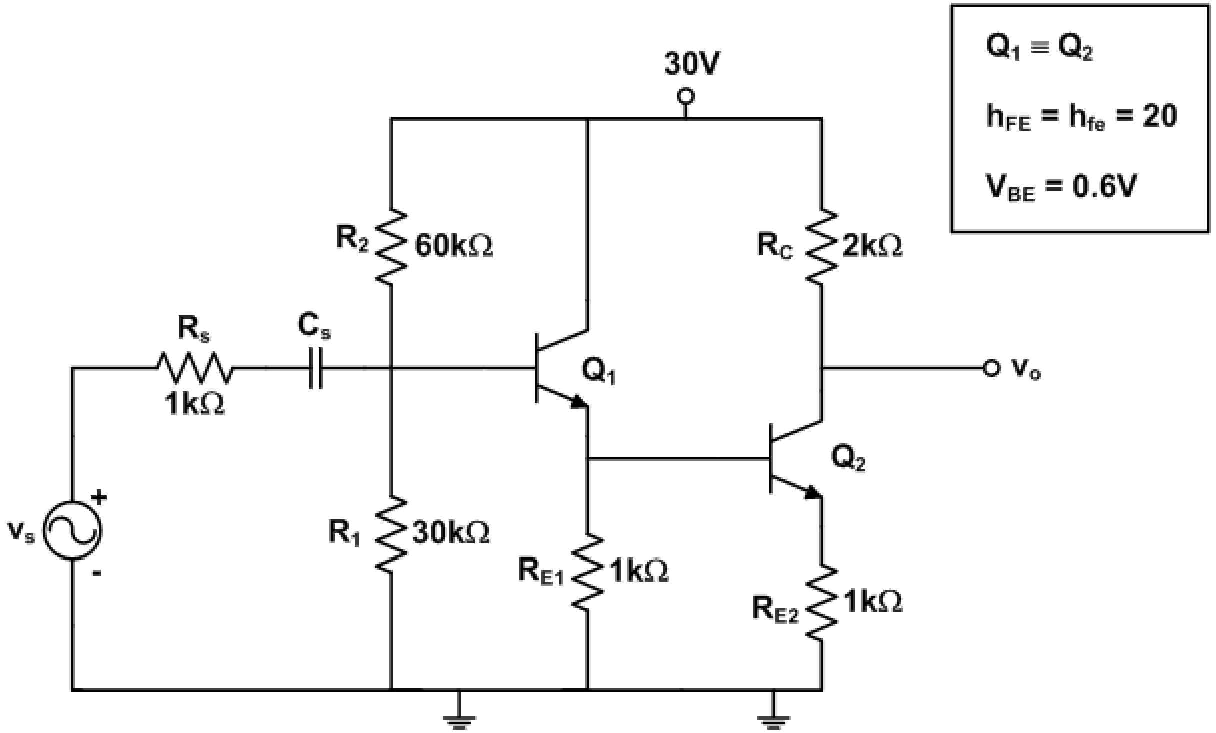
Used either to amplify very low frequency signals or to amplify DC signals

The overall gain:

$$A_v = A_{v1} \times \frac{Z_{i_2}}{Z_{o_1} + Z_{i_2}} \times A_{v2} \times \cdots \frac{Z_{i_k}}{Z_{o_{k-1}} + Z_{i_k}} \times A_{v_k} \cdots \times \frac{Z_{i_n}}{Z_{o_{n-1}} + Z_{i_n}} \times A_{v_n}$$

with $Z_i = Z_{i_1}$ and $Z_o = Z_{o_n}$

Ex2:

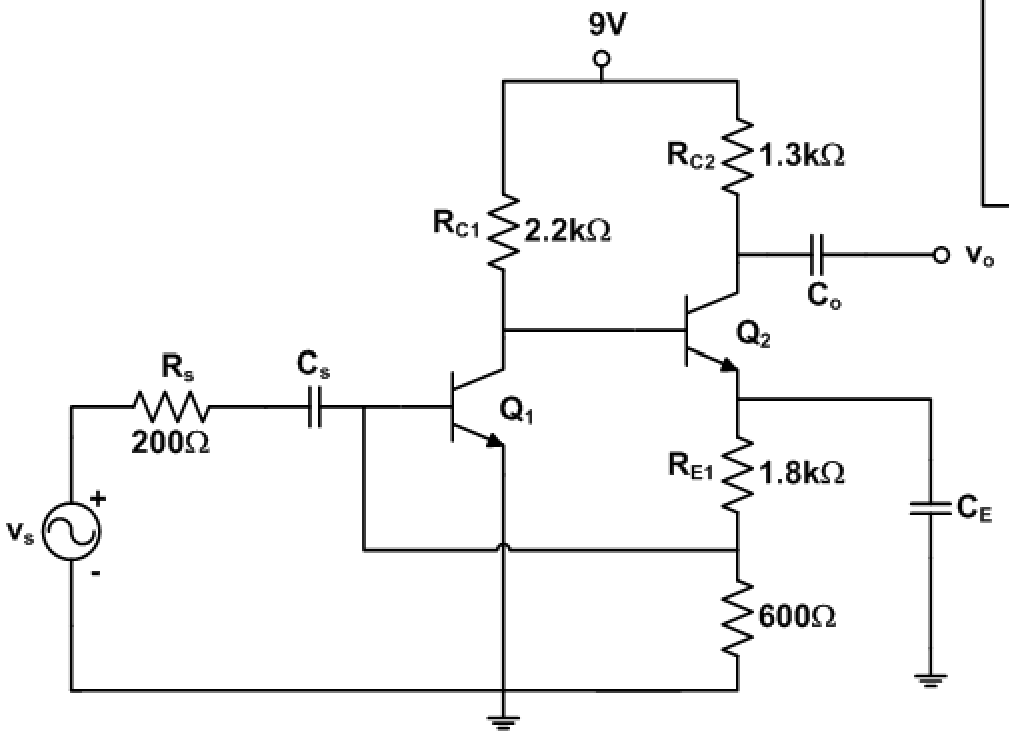


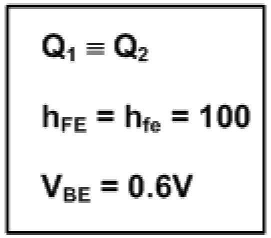
a) Draw AC and DC load lines for both transistors.

b) Calculate the overall voltage gain $\mathbf{A_V = v_o / v_s}$.

c) Find $\mathbf{v_{s\,(max)}}$ which produces maximum undistorted output voltage.

Ex3:





a) Draw AC and DC load lines for both transistors.

b) Calculate the overall voltage gain $\mathbf{A_V = v_o / v_s}$.

c) Find $\mathbf{v_{s\,(max)}}$ which produces maximum undistorted output voltage.

Ex4:

$h_{fe} = 50$ $h_{fb} = -0.98$

$h_{ie} = 1.1k\Omega$ $h_{ib} = 21.6\Omega$

$h_{oe} = 24\mu\ A/V$ $h_{ob} = 0.49\mu\ A/V$

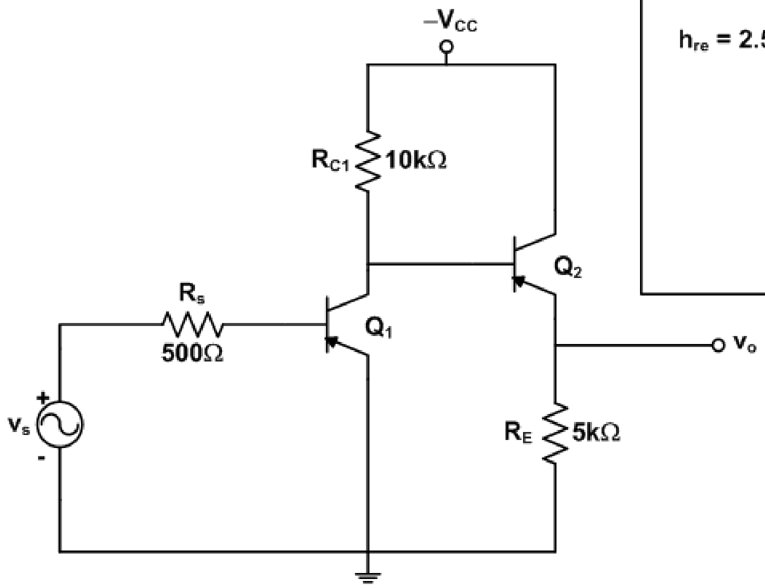
$h_{re} = 2.5\ 10^{-4}$ $h_{rb} = 2.59\ 10^{-4}$

$h_{fc} = 51$

$h_{ic} = 1.1k\Omega$

$h_{oc} = 25\mu\ A/V$

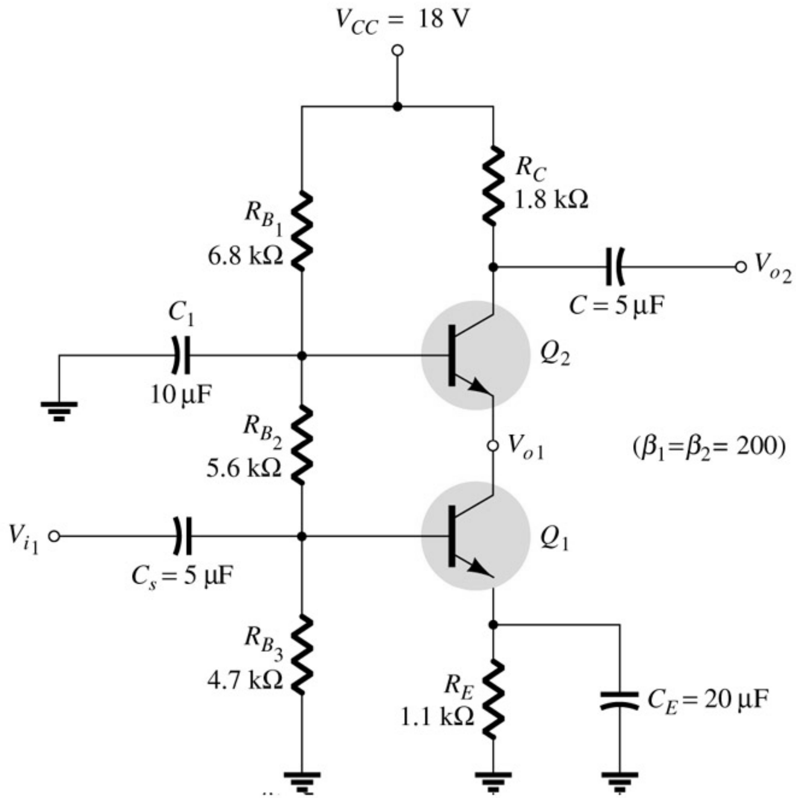
$h_{rc} = 1$



b) Calculate the overall voltage gain $\mathbf{A_V = v_o / v_s}$.

c) Find $\mathbf{R_o}$.

Cascode Connection

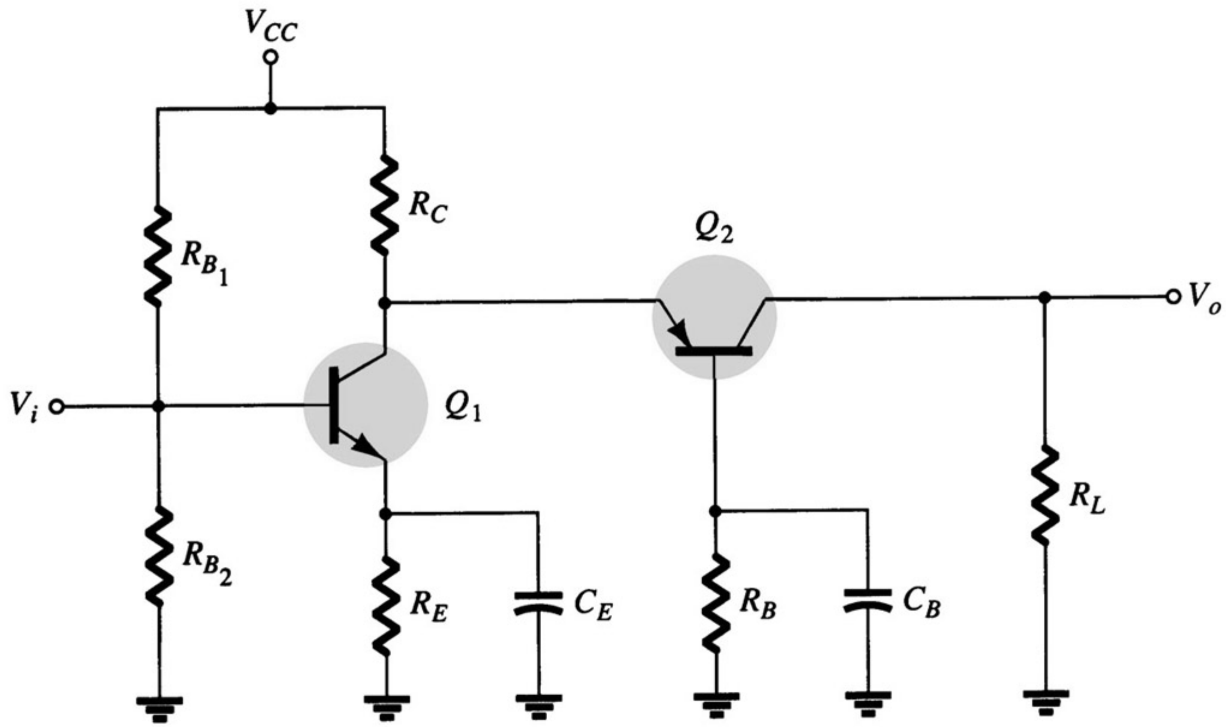


This is a CE – CB combination.

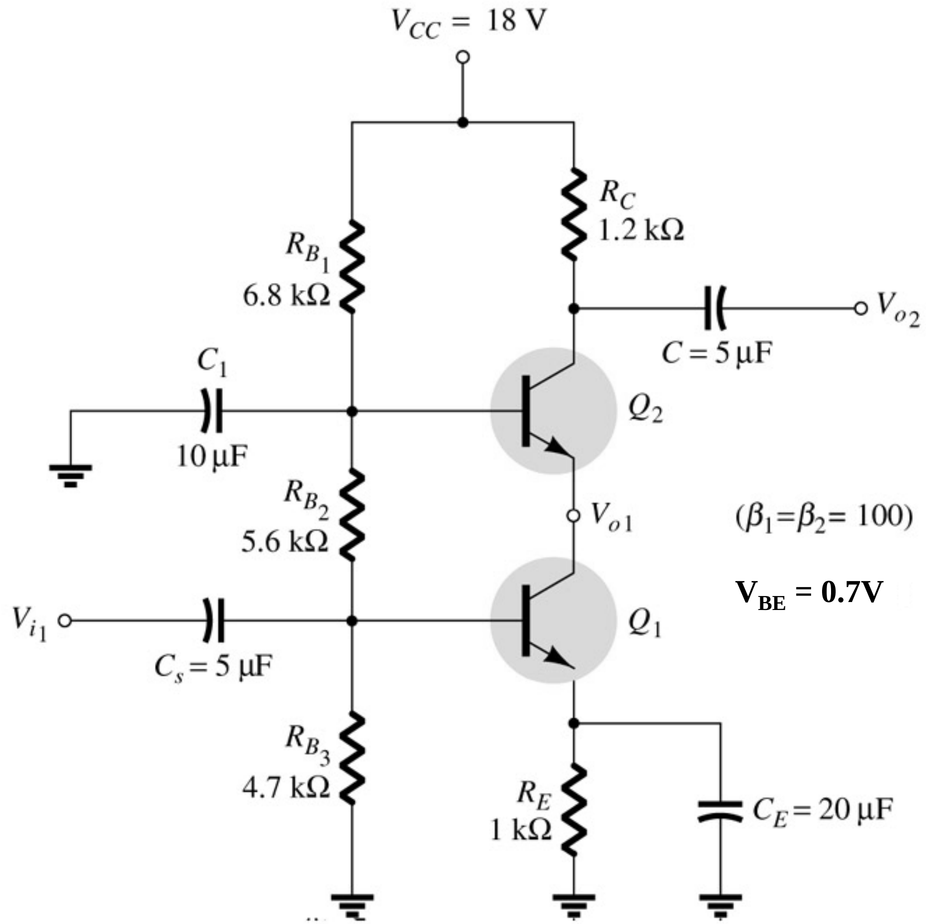
This arrangement provides high input impedance but a low voltage gain.

The low voltage gain reduces the Miller Input Capacitance therefore this combination works well in high frequency applications.

A more elaborate version of cascode amplifier



Ex5:



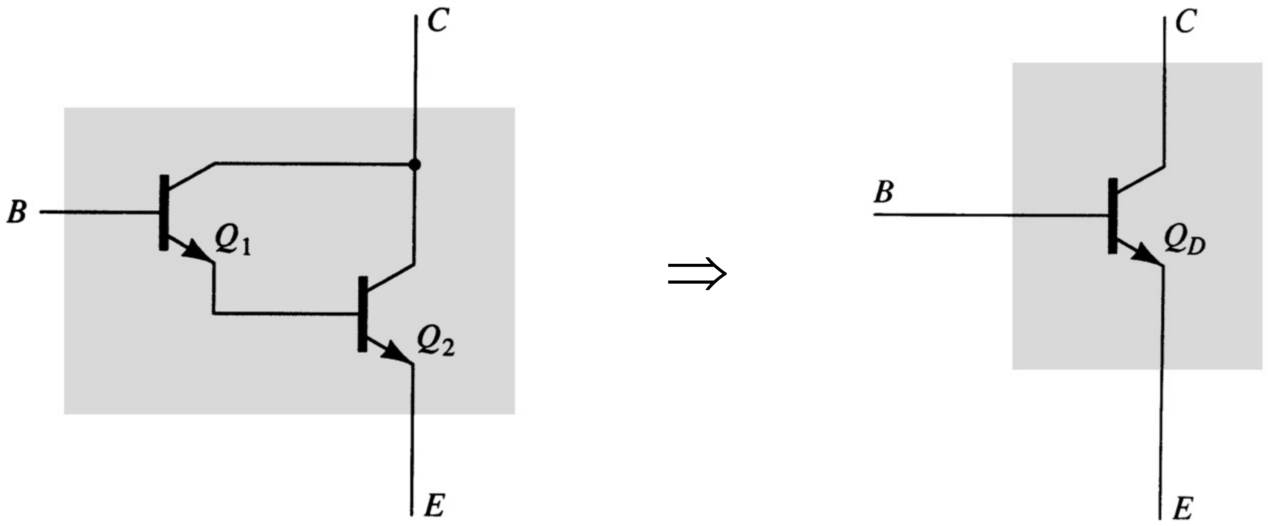
Consider the cascode amplifier above

a) Find the voltage gain $\mathbf{A_v = v_o/v_i}$

b) Find the input resistance $\mathbf{R_i}$

c) Find the output resistance $\mathbf{R_o}$

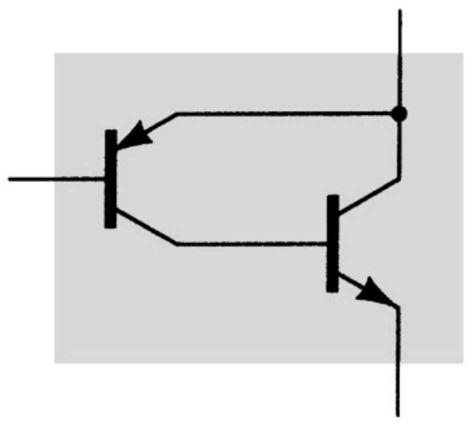
Darlington Connection



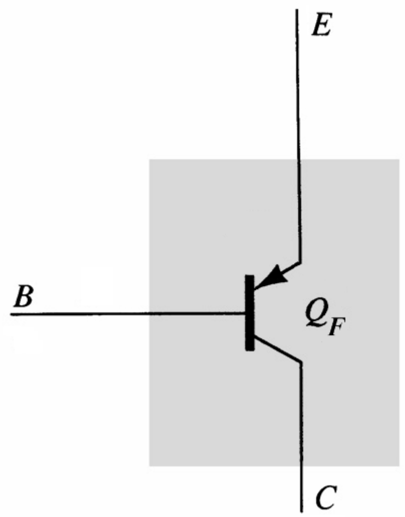
This combination provides large current gain, typically a few thousand.

It has a voltage gain of near 1, a low output impedance and a high input impedance.

Feedback Pair



$\Rightarrow$



This is a two-transistor circuit that operates like a Darlington pair.
It has similar characteristics: high current gain, voltage gain of near 1, low output impedance and high input impedance.
Note: it is ***not the Darlington*** configuration:

Darlington: 2 npn BJTs
Feedback Pair: pnp driving an npn BJT