Two or more amplifiers can be connected in a cascaded arrangement with the output of one amplifier driving the input of the next. Each amplifier in a cascaded arrangement is known as a stage. The basic purpose of a multistage arrangement is to increase the overall voltage gain.

Multistage voltage gain

The overall voltage gain, A_v of cascaded amplifiers as shown below, is the product of the individual voltage gains.

$$A'_v = A_{v_1}A_{v_2}A_{v_3} \dots A_{v_n} \qquad \textit{where } n \textit{ is the number of stages.}$$

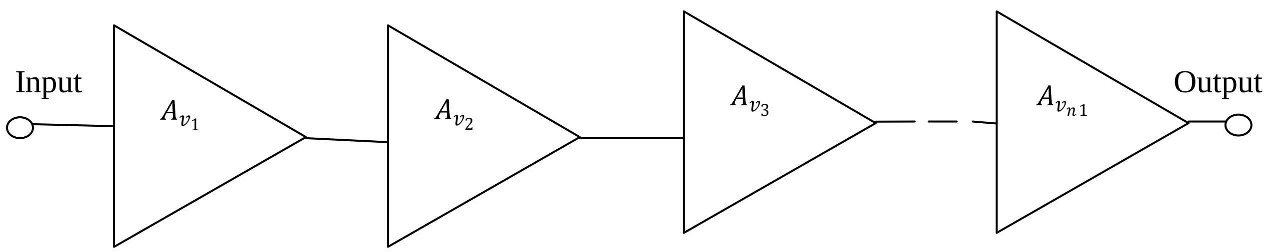


Fig.1 cascaded amplifiers where each triangular symbol represents a separate amplifier

Voltage gain expressed in Decibels

Amplifier voltage gain is often expressed in decibels (dB) as follows:

$$A_{v(dB)} = 20logA_v$$

This is particularly useful in multistage systems because the overall voltage gain in dB is the sum of the individual voltage gains in dB.

$$A'_{v(dB)} = A_{v_1(dB)} + A_{v_2(dB)} + \dots + A_{v_n(dB)}$$

Multistage Amplifier Analysis

For the purpose of illustration, we will use the two stage capacitive coupled amplifiers in fig 2. Notice both stages are identical common emitter amplifier with the output of the first stage capacitive coupled to the input of the second stage.

Capacitive coupling prevents the DC bias of one stage from affecting that of the other but allows the AC-signal to pass without attenuation because $X_C = 0\Omega$ at the frequency of operation.

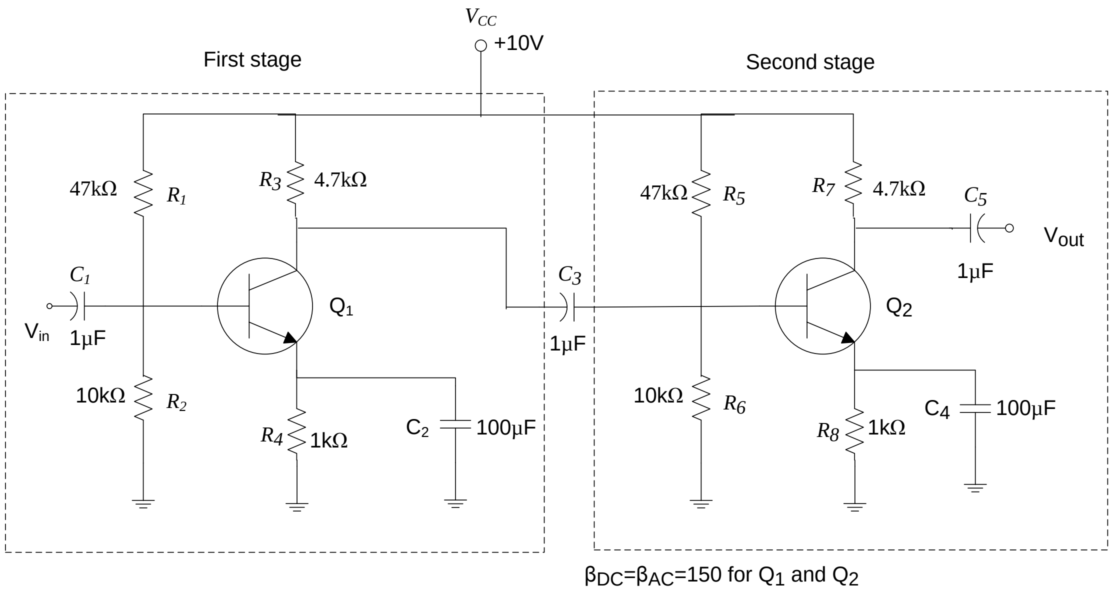
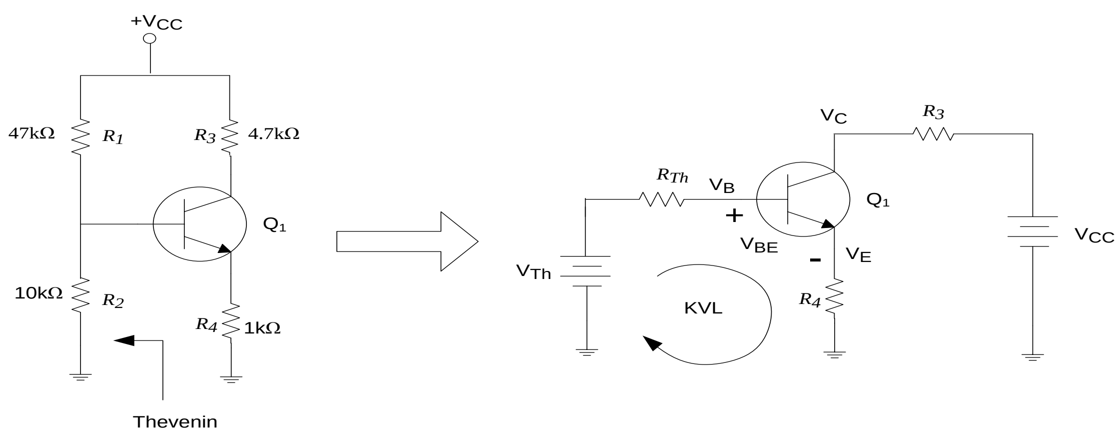


Figure 2 A two stage Common emitter amplifier

DC voltages in the capacitive coupled multi stage amplifier

Since both stages in fig 2 are identical, the voltages for Q1 and Q2 are the same.



R_{Th} = R_1//R_2 = *8.245kΩ*

V_{Th} = [R_2 /(R_1 + R_2)] VCC

KVL (BE loop)

$$-V_{Th} + I_B R_{Th} + V_{BE} + (1+\beta)R_4 = 0$$

$$-1.754 + 8.245 I_B + 0.7 + 151 I_B = 0$$

$$\therefore I_B = 6.62\mu A$$

The base voltage is calculated as

$$V_B = V_{Th} - I_B R_{Th} = 1.7\ V$$

The emitter voltage is:

$$V_E = V_B - V_{BE} V_E = 1\ V$$

The emitter current is

$$I_E = \frac{V_E}{R_4} = \frac{1\ V}{1\ K} = 1\ mA$$

The collector current is

$$I_E \cong I_C = 1\ mA$$

The collector voltage is

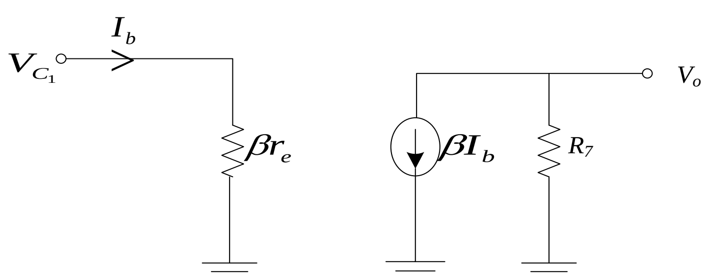
$$V_C = V_{CC} - I_C R_3 V_C = 5.3\ V$$

Loading effect

In determining the voltage gain of the first stage, you must consider the loading effect of the second stage. Because the coupling capacitor C_3 effectively appears as a short at the signal frequency, the total input resistance of the second stage presents an ac-load to the first stage.

Using the r_e model for the transistor, assuming$r_o \cong \infty$,

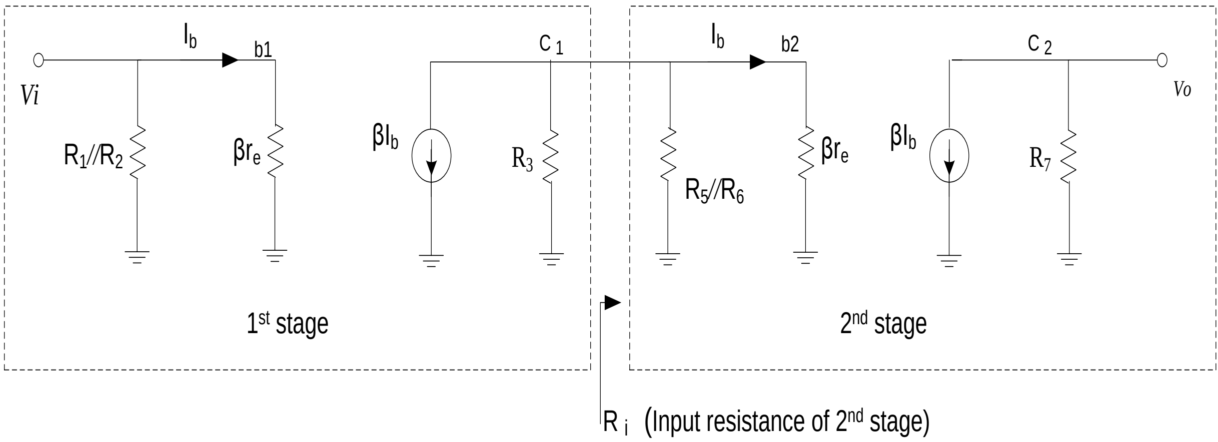
Voltage gain of the second stage



$$r_e = \frac{26mV}{I_E} = \frac{26mV}{1mA} = 26\Omega$$

$$A_{V_2} = \frac{V_o}{V_{C_1}} = \frac{-(\beta I_b)(R_7)}{(\beta r_e) I_b} = \frac{-R_7}{r_e} = \frac{-4.7k}{26}\Omega = 180.77$$

Voltage gain of the first stage

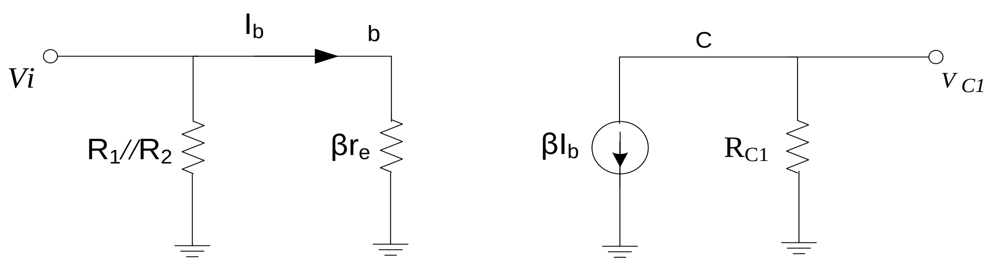


Input resistance from the second stage

$$R_i = R_5//R_6//\beta r_e$$

Thus, the total ac-collector resistance of the first stage is:

$$R_{c_1} = R_3//R_i = R_3//R_5//R_6//\beta r_e = 1.52k\Omega$$



$$A_v = \frac{V_{C_1}}{V_i} = \frac{(-\beta I_b)(R_{C_1})}{(\beta r_e)(I_b)} = \frac{-R_{C_1}}{r_e} = \frac{-1.52k\Omega}{26\Omega} = 58.57$$

Overall voltage gain

$$A_v^{'} = A_{v_1}A_{v_2} = (58.57)(180.77) = 10{,}588$$

The overall voltage gain can be expressed in dB.

$$A_v^{'}(dB) = 20\log 10{,}588 = 4.025$$

Direct coupled Multistage Amplifiers:

A basic two-stage, direct coupled amplifier is shown in fig.3. Notice that there are no coupling or bypass capacitors in this circuit.

The dc collector voltage of the first stage provides the base bias voltage for the second stage. Because of direct coupling, this type of amplifier has a better low frequency response than the capacitive coupled type in which the reactance of coupling and bypass capacitors at very low frequency may become excessive.

The increased reactance of capacitors at lower frequencies produces gain reduction in capacitive coupled amplifiers.

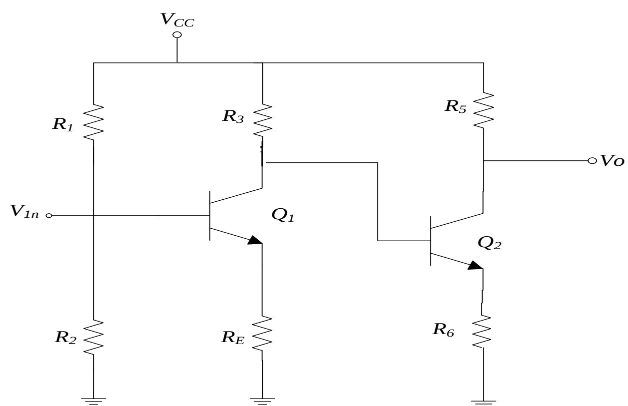
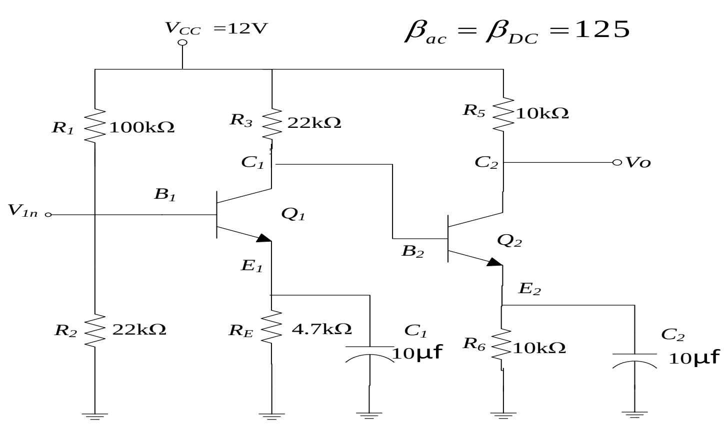


Fig.3.A basic two-stage direct coupled amplifier.

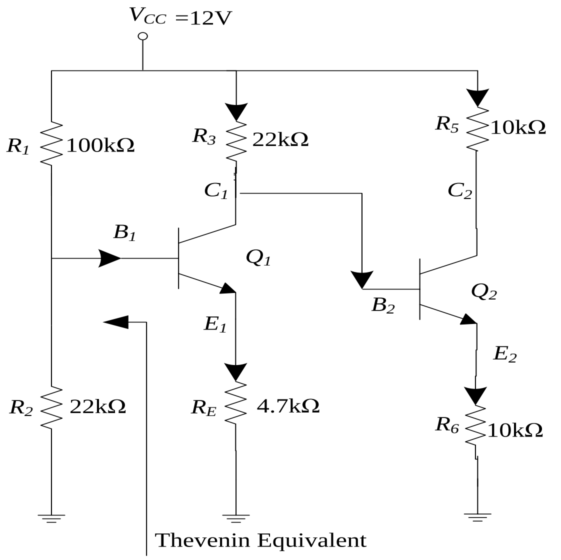
The advantage of direct coupled amplifiers is that small changes in the dc bias voltages from temperature effects or power supply variation are amplified by the succeeding stages, which can result in a significant drift in the dc levels throughout the circuit.

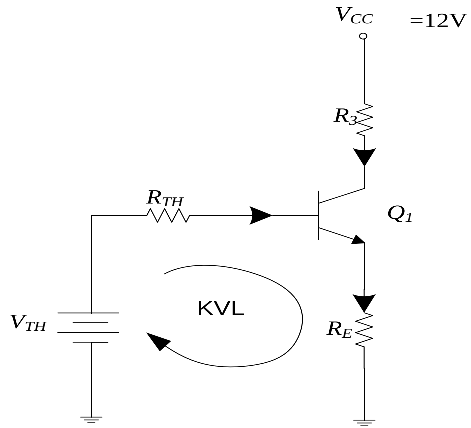
Example: - for the direct coupled amplifier shown, determine all dc voltages for both stages and over all ac voltage gain.



1

DC analysis





$$V_{TH} = \left[\frac{R_2}{R_1 + R_2}\right](12) = 2.164V \qquad and \qquad R_{TH} = R_1||R_2 = 18.032K\Omega$$

KVL around BE loop of Q_{1},

$$-V_{TH}+I_{B1}R_{TH} + V_{BE} + I_{E1}R_4 = 0$$

$$I_{B1} = \frac{V_{TH-}V_{BE}}{R_{TH} + (1+\beta)R_4} = \frac{12 - 0.7}{18.032K + 126 * 4.7K} = 2.465\mu A$$

$$\therefore \ I_{E1} = (1+\beta)I_{B1} = 0.31mA \qquad and \quad I_{C1} = (\beta)I_{B1} = 0.308mA$$

$$V_{E1} = R_4 \, I_{E1} = 1.46V$$

$$V_{B1} = V_{E1} + \ I_{BE} = 2.16V$$

KVL around CE loop of Q1,

$$V_{C1} = V_{CC} - R_3 \, I_{C1} = 5.224V$$

KVL around BE loop of Q2,

$V_{E2} = V_{B2} - V_{BE} = 4.46V$ But $V_{B2} = \ V_{C1} = 5.224V$

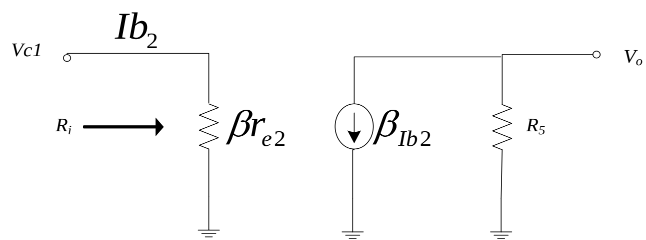
$$I_{B1} = \frac{I_{E1}}{(1+\beta)} = 3.54\mu A$$

$$I_{C2} \ = (\beta)I_{B2} = 0.442mA$$

KVL around CE loop of Q2,

$$V_{C2} = V_{CC} - R_5\, I_{C2} = 7.57$$

Voltage gain of the 2nd stage.

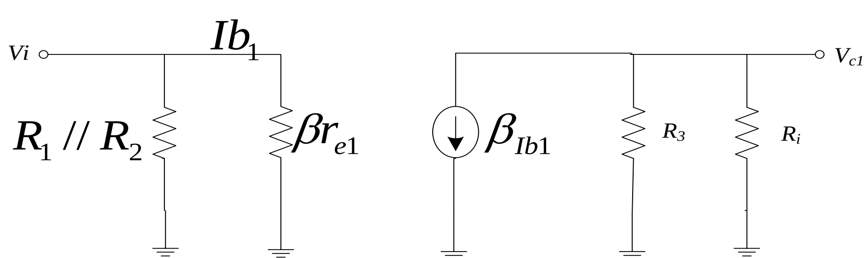


$$R_i = \frac{V_{C1}}{I_{b2}} = \beta r_{e2}, r_{e2} = \frac{0.026V}{I_{E2}} = 0.056K\Omega$$

$$R_i = 125 \times 0.056K\Omega = 7K$$

$$A_{V2} = \frac{V_o}{V_{C1}} = \frac{(-\beta I_{b2})(R_S)}{(I_{b2})(\beta r_{e2})} = \frac{-R_S}{r_{e2}} \cong 179$$

Voltage gain of the 1nd stage



$$r_{e1} = \frac{0.026V}{I_{E1}} = 0.08K\Omega$$

$$A_{V1} = \frac{V_{C1}}{V_i} = \frac{(-\beta I_{b1})(R_3 \,//\, R_i)}{(I_{b1})(\beta r_{e1})} = \frac{-(R_3 \,//\, R_i)}{r_{e1}}$$

$$A_{V1} \cong 66$$

Overall voltage gain

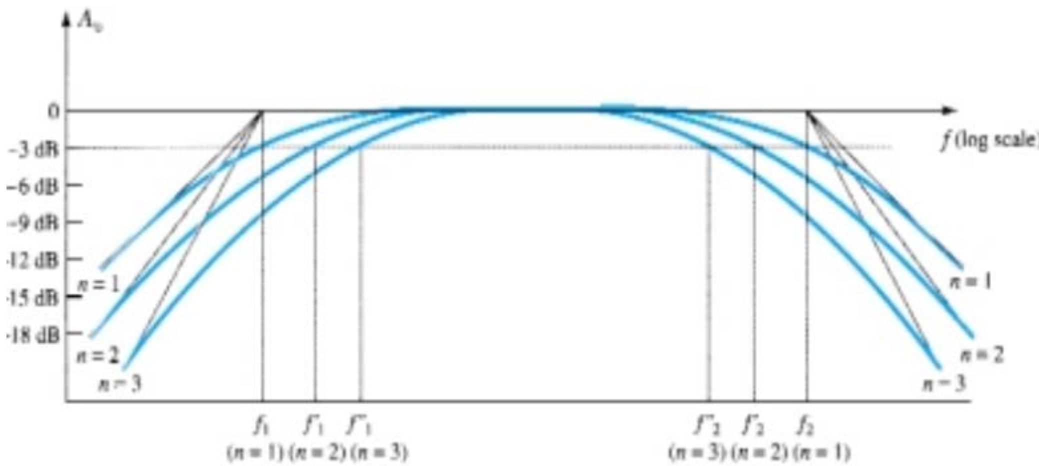
$$A'_V = A_{V1} A_{V2} = 66 \times 179$$

$$A'_V = 11{,}814$$

MULTISTAGE FREQUENCY EFFECTS

For a second transistor stage connected directly to the output of a first stage, there will be a significant change in the overall frequency response. For each additional stage the upper cutoff frequency will be determined primarily by that stage having the lowest- cutoff frequency. The low-frequency cutoff is primarily determined by that stag having the highest low-frequency cutoff frequency. Obviously, therefore, one poorly designed stage can offset an otherwise well-designed cascaded system.

The effect of increasing the number of stages can be clearly demonstrated by considering the situations indicated in Figure below. In each case, the upper and lower cutoff frequencies of each of the cascaded stages are identical. For a single stage, the cutoff frequencies are f1 and f2 as indicated. For two identical stages in cascade, the drop-off rate in the high- and low-frequency regions has increased to 40dB/decade, 60dB/decade for three stages and so forth.



For the low-frequency region,

$$A_{v(overall)} = A_{1(low)} A_{2(low)} \cdots A_{n(low)}$$

But, for identical stages, $A_{1(low)} = A_{2(low)} = \cdots = A_{n(low)}$

Hence, $A_{v(overall)} = [A_{1(low)}]^n$ or $\frac{A_{v(overall)}}{A_{v(mid)}} = \frac{[A_{1(low)}]^n}{A_{v(mid)}} = \frac{1}{(1 - jf/f1)^n}$

At the cut-off frequency, $\left|\frac{A_{v(overall)}}{A_{v(mid)}}\right| = \frac{1}{\sqrt{\left[1 + [(f'/f1^2)]\right]^n}} = 1/\sqrt{2}$

$$\therefore\ f_{low(overall)} = f_1{}' = \frac{f_1}{\sqrt{2^{1/n} - 1}}$$

Similarly, the higher cut-off frequency is calculated as

$$\therefore\ f_{hing(overall)} = \sqrt{2^{1/n} - 1}\, f_2$$