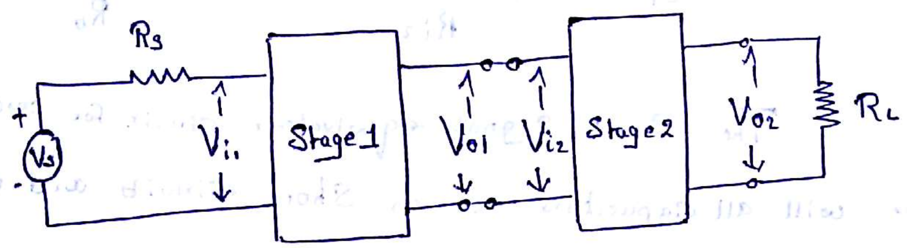
Multistage Amplifiers :

For faithful amplification amplifier should have desired Voltage gain, Current gain and it should match its input impedance with the source and output impedance with the load.

Limitation of Multistage Amplifiers:

1. The bandwidth of multistage amplifier is always less than that of the bandwidth of a single stage amplifier.
2. Non-linear distortion is more in multistage amplifiers than single stage amplifiers.

Two stage Cascaded Amplifier



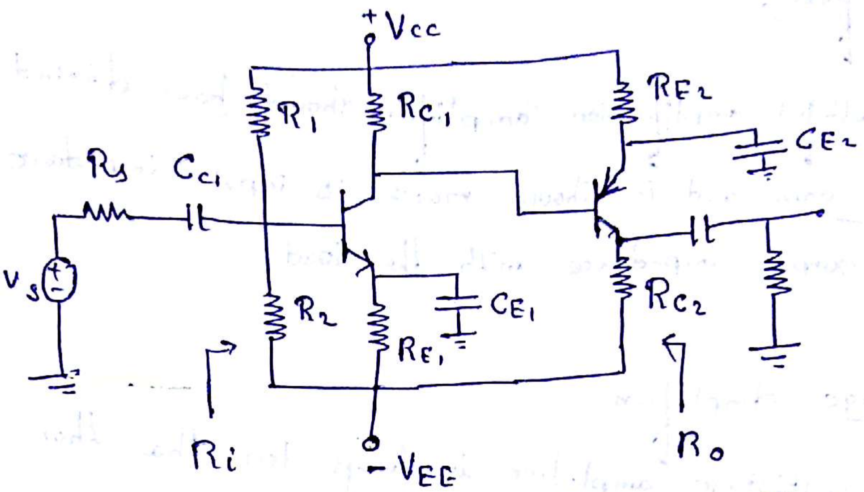
O/P of first stage is connected to the input of second stage.

Overall Voltage gain $A_V = \frac{V_{o2}}{V_{i1}} = \frac{V_{o2}}{V_{i2}} \cdot \frac{V_{i2}}{V_{i1}}$

we know — $V_{o1} = V_{i2}$

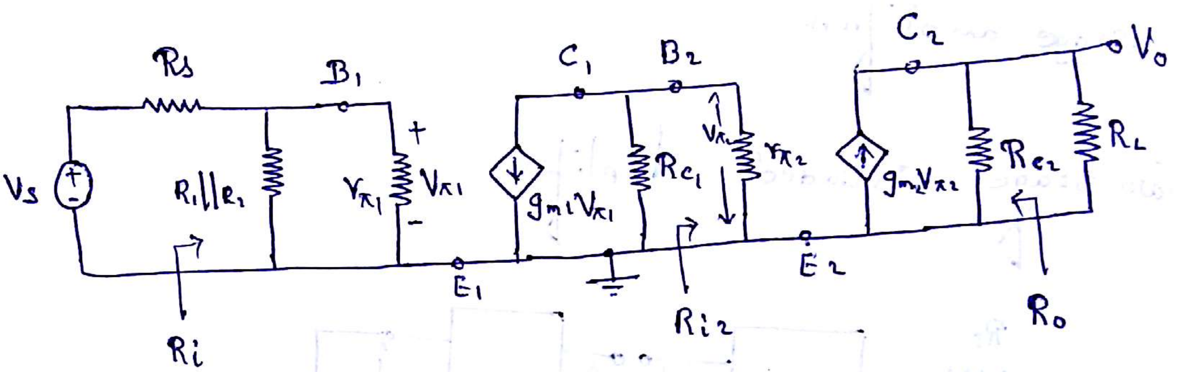
$$A_V = \frac{V_{o2}}{V_{i2}} \times \frac{V_{o1}}{V_{i1}} = A_{V_2} \cdot A_{V_1}$$

∴ Voltage gain of multistage amplifier is the product of individual stages.



Two-stage CE-amplifier.

Here both the stages are biased in a forward-active region



The small signal equivalent circuit for two-stage CE-amplifier will all capacitors act as short circuit and each transistor output resistance r_o is infinite

Before starting the analysis of multistage amplifier we should note that, in multistage amplifiers the output impedance of one stage is shunted by the input impedance of the next stage. Here it is always advantageous to start analysis with the last stage.

Stage 2: Input resistance $R_{i2} = R_{i2} = r_{\pi_2}$

Voltage Gain : $\dfrac{V_o}{V_{\pi_2}}$

$$V_o = g_{m2} V_{\pi 2} (R_{C2} \| R_L)$$

$$\frac{V_o}{V_{\pi 2}} = g_{m2} (R_{C2} \| R_L)$$

Stage 1! Input Resistance (R_i)

$$R_{i1} = R_i = R_1 \| R_2 \| r_{\pi 1}$$

Voltage Gain: $\frac{V_{\pi 2}}{V_{\pi 1}}$

$$V_{\pi 2} = g_{m1} V_{\pi 1} (R'_{L1})$$

$$= g_{m1} V_{\pi 1} (R_{C1} \| R_{i2})$$

$$= g_{m1} V_{\pi 1} (R_{C1} \| r_{\pi 2})$$

$$\therefore \frac{V_{\pi 2}}{V_{\pi 1}} = g_{m1} (R_{C1} \| r_{\pi 2})$$

Applying Voltage divider rule we have,

$$V_{\pi 1} = \frac{R_i}{R_i + R_s} \cdot V_s$$

Overall Voltage gain (A_v)

$$A_v = \frac{V_o}{V_s} = \frac{V_o}{V_{\pi 2}} \times \frac{V_{\pi 2}}{V_{\pi 1}} \times \frac{V_{\pi 1}}{V_s}$$

$$= g_{m2} (R_{C2} \| R_L) g_{m1} (R_{C1} \| r_{\pi 2}) \left[\frac{R_i}{R_i + R_s} \right]$$

$$A_v = g_{m1} g_{m2} (R_{C2} \| R_L) (R_{C1} \| r_{\pi 2}) \left(\frac{R_i}{R_i + R_s} \right)$$

Output Resistance (R_o):

To determine the output resistance, the independent source V_s is set equal to zero.

As a result $V_{\pi 1} = 0$.

$g_{m1} V_{\pi 1} = 0$, which gives $V_{\pi 2} = 0$

and $g_{m2} V_{\pi 2} = 0$.

∴ The output resistance is therefore given by

$$\boxed{R_o = R_{C2}}$$

Cascode Amplifier:

The cascode amplifier consists of a CE amplifier in series with a common base amplifier stage. It is one approach to solve the low impedance problem of a common base circuit. Transistor Q_1 and its associated components operate as a common emitter stage, while Q_2 as CB.

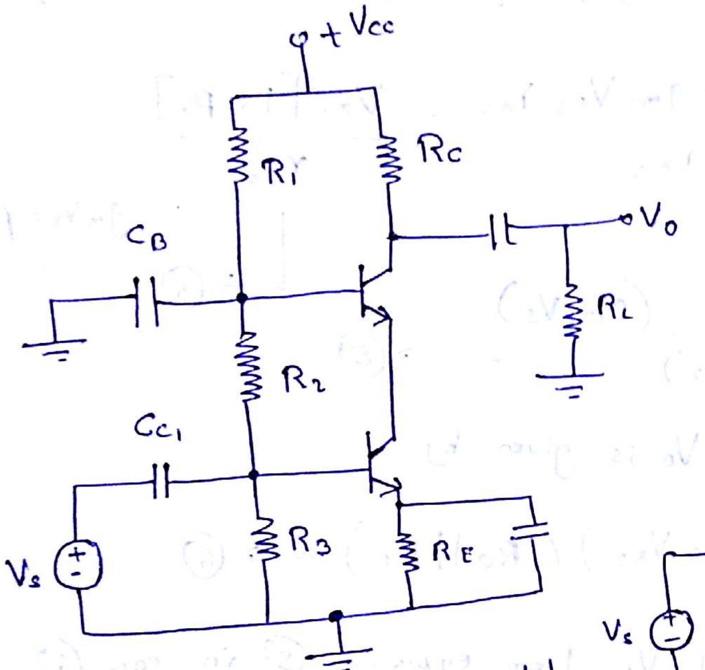
Features:

1) It provides high input impedance
2) It provides high voltage gain
3) It provides improved input-output isolation as there is no direct coupling from the output to input. This eliminates the Miller effect and thus provides a much bandwidth.

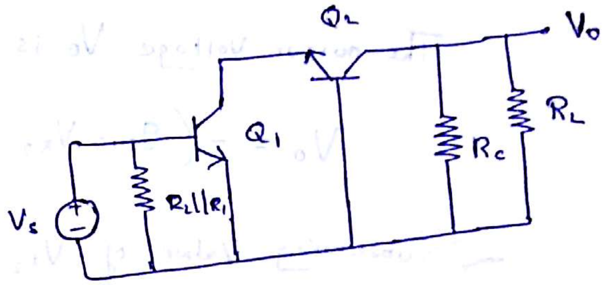
4) It provides very high output resistance

5) It also provides high slew rate and high stability.

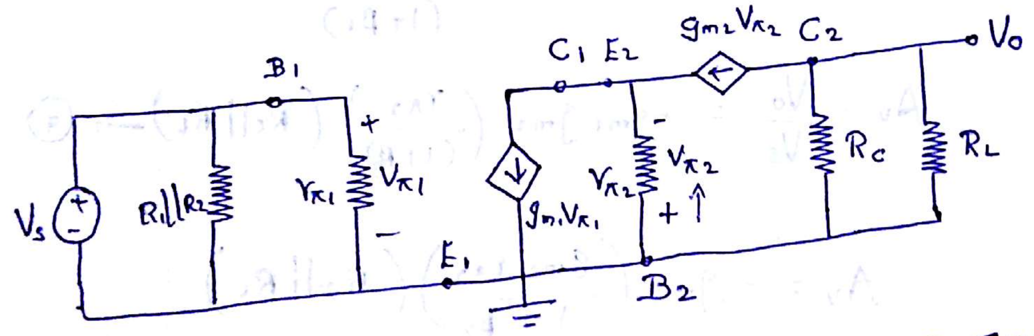
6) ~~I~~ The only disadvantage of cascode circuit is that it requires two transistors and requires a relatively high supply voltage.



CE - CB - Cascode amplifier



Ac equivalent.



Small signal equivalent circuit of CE - CB Cascode amplifier.

From the small signal model, we have

$$V_s = V_{\pi 1} \rightarrow (1)$$

Applying KCL equation at E_2, we have

$$g_{m1} V_{\pi 1} = \frac{V_{\pi 2}}{r_{\pi 2}} + g_{m2} V_{\pi 2} \rightarrow (2)$$

$$\therefore g_{m1} V_s = \frac{V_{\pi 2}}{r_{\pi 2}} + g_{m2} V_{\pi 2} \rightarrow (3) \quad [\because V_s = V_{\pi 1}]$$

$$g_{m1} V_s = \frac{V_{\pi 2} + g_{m2} V_{\pi 2} \cdot r_{\pi 2}}{r_{\pi 2}} = \frac{V_{\pi 2}[1 + \beta_2]}{r_{\pi 2}} \rightarrow (4) \quad \because g_m r_\pi = \beta$$

$$\therefore V_{\pi 2} = \frac{r_{\pi 2}}{(1+\beta_2)} (g_{m1} V_s) \rightarrow (5)$$

The output voltage V_o is given by

$$V_o = -(g_{m2} V_{\pi 2})(R_C \| R_L) \rightarrow (6)$$

Substituting value of $V_{\pi 2}$ from equation (5) in eqn (6)

$$V_o = -g_{m2} (g_{m1} V_s) \frac{r_{\pi 2}}{(1+\beta_2)} (R_C \| R_L)$$

$$A_v = \frac{V_o}{V_s} = -g_{m1} g_{m2} \left(\frac{r_{\pi 2}}{(1+\beta_2)}\right) (R_C \| R_L) \rightarrow (7)$$

$$A_v = -g_{m1} \left(\frac{g_{m2} \cdot r_{\pi 2}}{1+\beta_2}\right)(R_C \| R_L)$$

$$\boxed{A_v \simeq -g_m (R_C \| R_L)}$$

$\because g_{m2} \cdot r_{\pi 2} = \beta_2$

and

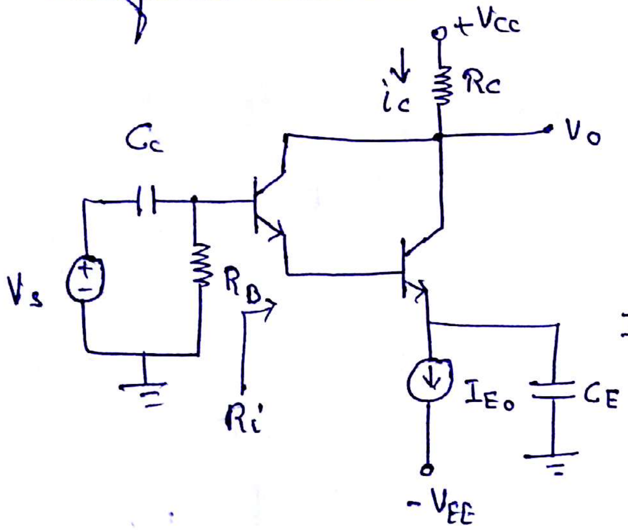
$$\frac{\beta_2}{1+\beta_2} \simeq 1$$

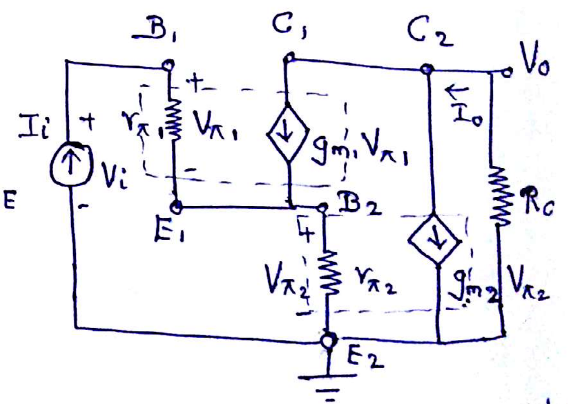
Darlington Amplifier:

A Single Stage emitter follower Circuit can give input impedance up to 500 KΩ. However the input impadance considering biasing resistors is significantly less. Because $R_i' = R_1 \| R_2 \| R_i$. The input impedance of the circuit can be improved by direct coupling of two stages of emitter follower amplifier. The input impedance can be improved by two techniques:

* Using Direct Coupling (Darlington Connection)
* Using Bootstrap technique.

Darlington Transistors:





Small-signal equivalent circuit

Cascaded connection of two emitter followers is called the Darlington connection - It improves current gain.

Small Signal Current gain (A_i)

Looking at node B_1 and E_1 we have

$$V_{\pi_1} = I_i \cdot r_{\pi 1} \longrightarrow ①$$

$$\therefore g_{m_1} V_{\pi 1} = g_{m_1} I_i r_{\pi_1} = \beta_1 I_i \quad (\because \beta = g_m r_\pi) \longrightarrow ②$$

we have

$$V_{\pi_2} = (I_i + g_m V_{\pi 1}) \cdot r_{\pi 2} \longrightarrow ③$$

Substituting Value of $g_{m1} \cdot V_{\pi 1}$ from ② we have

$$V_{\pi_2} = (I_i + \beta_1 I_i) r_{\pi 2} \longrightarrow ④$$

The output Current I_o is given by

$$I_o = g_{m_1} V_{\pi 1} + g_{m_2} V_{\pi 2} = \beta_1 I_i + g_{m2} r_{\pi 2} [I_i + \beta_1 I_i$$

$$I_o = \beta I_i + \beta_2 [I_i + \beta_1 I_i] \quad [\because g_{m2} r_{\pi 2} = \beta_2]$$

$$I_o = \beta I_i + \beta_2 I_i [1 + \beta_1] \longrightarrow ⑤$$

$\therefore$ The over all Current gain

$$A_I = \frac{I_o}{I_i} = \beta_1 + \beta_2 (1 + \beta_1) \simeq \beta_1 \beta_2 \longrightarrow ⑥$$

The equation ⑥ States that the overall Current gain of a Darlington pair is the product of the individual Current gain.

Input Resistance (R_i)

$$R_i = \frac{V_i}{I_i} \longrightarrow (7)$$

we have $V_i = V_{\pi 1} + V_{\pi 2} = I_i r_{\pi 1} + (I_i + \beta_1 I_i) r_{\pi 2}$

$$= I_i [r_{\pi 1} + (1+\beta_1) r_{\pi 2}] \longrightarrow (8)$$

$I_C = \beta I_B$

$$r_{\pi 1} = \frac{\beta_1}{g_{m1}} = \frac{\beta_1 V_T}{I_{CQ1}} \qquad \because g_m r_\pi = \beta$$

and $g_m = \frac{I_{CQ}}{V_T}$

$I_{CQ1} = \frac{I_{CQ2}}{\beta_2}$

$$r_{\pi 1} = \frac{\beta_1 V_T \beta_2}{I_{CQ2}} \qquad \left[\because I_{CQ1} = \frac{I_{CQ2}}{\beta_2} \right.$$

Therefore,

$$r_{\pi 1} = \beta_1 \left(\frac{\beta_2 V_T}{I_{CQ2}} \right) = \beta_1 r_{\pi 2}$$

$$\because r_{\pi 2} = \frac{\beta_2}{g_{m2}} = \frac{\beta_2 V_T}{I_{CQ2}}$$

$$\therefore R_i = r_{\pi 1} + (1+\beta_1) r_{\pi 2}$$

$$\boxed{R_i = \beta_1 r_{\pi 2} + (1+\beta_1) r_{\pi 2}} \longrightarrow (9)$$

$$\boxed{R_i \simeq 2 \beta_1 r_{\pi 2}} \longrightarrow (10)$$

Equation (10) Shows that the input resistance of a Darlington pair is large, because of the β multiplication.