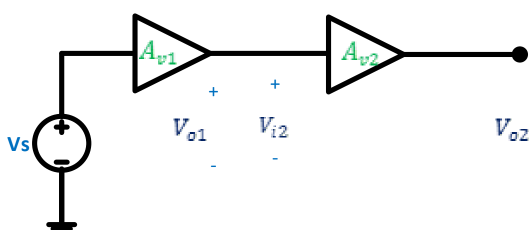
Multistage Amplifiers

1) Additional Amplification can be required .

2) Improving the performance of the amplifier (high input impedance ,high gain , small output impedance) .

3) Increasing the Bandwidth .

Multistage Amplifiers



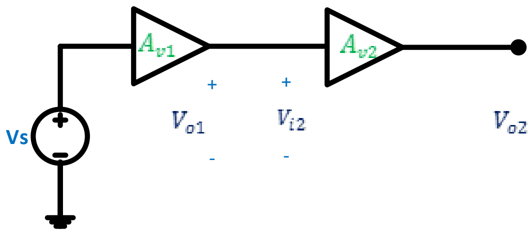
$$V_{O2} = Av_2 V_{i2}$$

$$V_{i2} = V_{O1}$$

$$V_{O1} = Av_1 V_S$$

$$\frac{V_{O2}}{V_S} = Av_1 . Av_2$$

Multistage Amplifiers



❖ **When the output of one amplifier stage is connected to the input of another , the amplifier stages are said to be in cascade .**

❖ $\mathbf{Av_T = Av_1 . Av_2 \ . Av_3 .... Av_n}$
Av_1 , Av_2, and Av_n are the in – circuit gains .

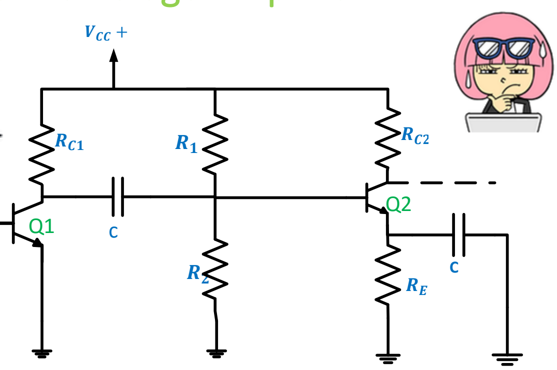
Multistage Amplifiers

Methods of Coupling:

- **Capacitor Coupling.**
- **Direct Coupling.**
- **Transformer Coupling.**

Capacitor Coupled Multistage Amplifier

Advantages:

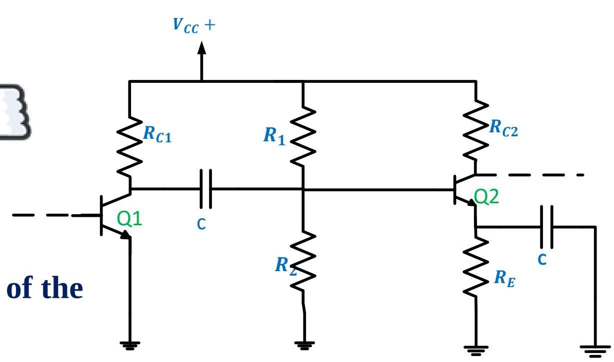


- **the coupling capacitor blocks the flow of DC current while it permits the flow of Ac signal between stages .**

- **It makes it possible to have a dc bias voltage at the output of one stage that is different from the dc bias voltage at the input to the next stage**
- **(stage isolation) .**

Capacitor Coupled Multistage Amplifier

Disadvantages:

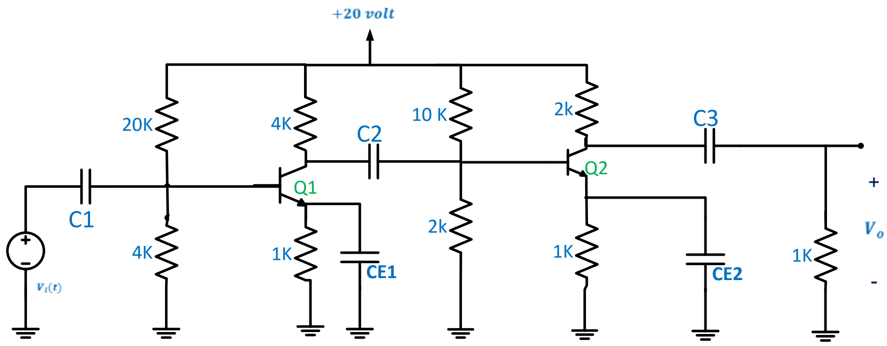


- **It effects the low – frequency response of the amplifier .**

- **It not used in integrated circuit , because it is difficult and uneconomical to fabricate capacitors on a chip .**

Capacitor Coupled Multistage Amplifier

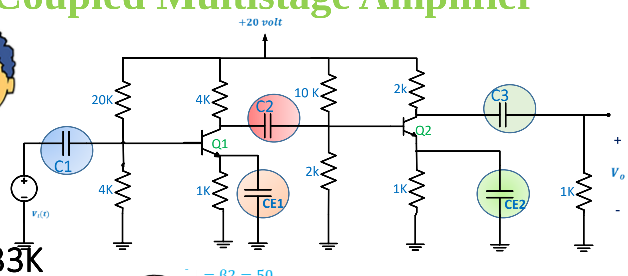
Example: **find the gain of the multistage amplifier**



$\beta1 = \beta2 = 50$

Capacitor Coupled Multistage Amplifier

Solution:



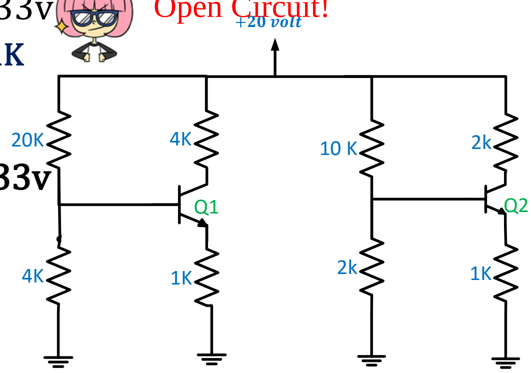
DC Analysis:

R_{TH1}= 4K \\ 20K = 3.33K

$V_{TH1} = \frac{4K}{4K+20K}(20) = 3.33$v

Open Circuit!

I_{E1}=2.47 mA $\therefore$ h_{ie1}= 0.51K



R_{TH2}= 2K \\ 10K = 1.67 K

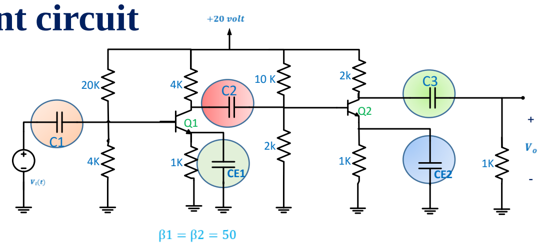
$V_{TH2} = \frac{2K}{2K+10K}(20) = 3.33$v

I_{E2}=2.55 mA

$\therefore$ $h_{ie2} \approx$ 0.51K

Capacitor Coupled Multistage Amplifier

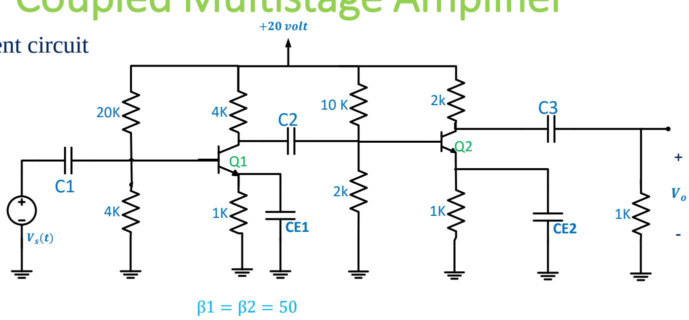
Ac small signal equivalent circuit

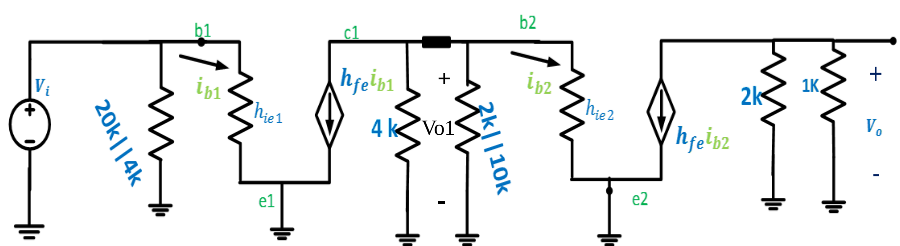


Short Circuit

Capacitor Coupled Multistage Amplifier

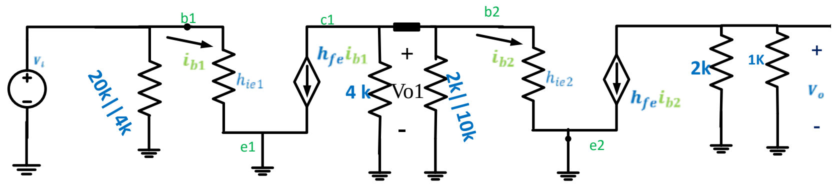
Ac small signal equivalent circuit





Capacitor Coupled Multistage Amplifier

$Av_T = Av_1 . Av_2$



- $Av_1 = \frac{V_{O1}}{V_i}$

$V_{O1} = -h_{fe1} ib_1 (4k||2k||10k||h_{ie2})$

$ib_1 = \frac{V_i}{h_{ie1}}$

- $Av_1 = -34.14$
- $Av_2 = \frac{V_{O2}}{V_{i2}} = \frac{V_{O2}}{V_{O1}} = \frac{V_O}{V_{O1}}$

$V_{O2} = -h_{fe2} ib_2 (1k||2k)$

$ib_2 = \frac{V_{O1}}{h_{ie2}}$

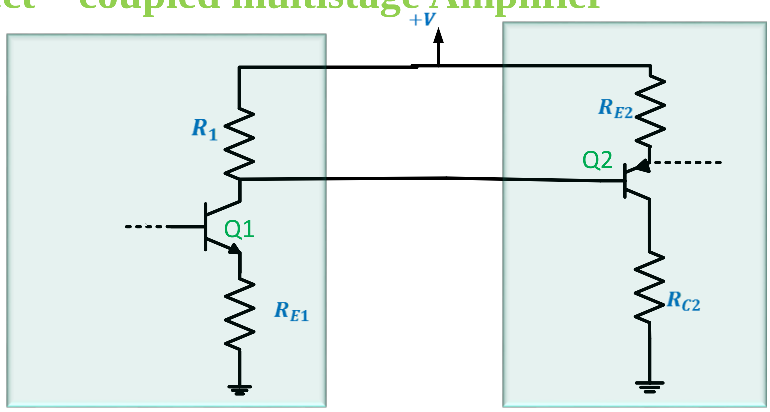
- $Av_2 = -66.66$

$Av_T = Av_1 . Av_2$

- $Av_T = 2342$

2) Direct – coupled multistage Amplifier

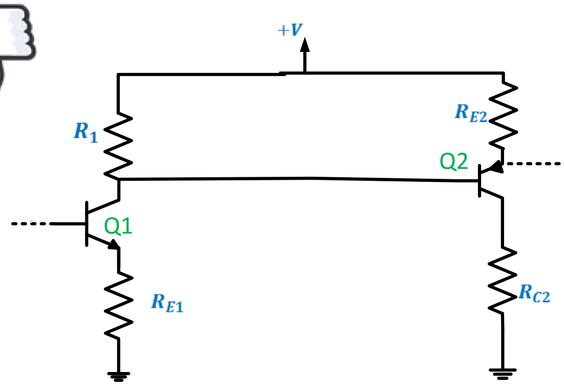
Advantages



- ❖Used in differential and operational amplifier .
- ❖Used in low and high frequency applications .

2) Direct – coupled multistage Amplifier

Disadvantages



- ❖ Any change in the dc voltage at the output of one stage produce an identical change in dc voltage at the input to the next stage
  - ➢We must use R_E .
  - ➢We must use alternating transistor types (npn, pnp) .

2) Direct – coupled multistage Amplifier

Darlington compound configuration

DC Analysis :

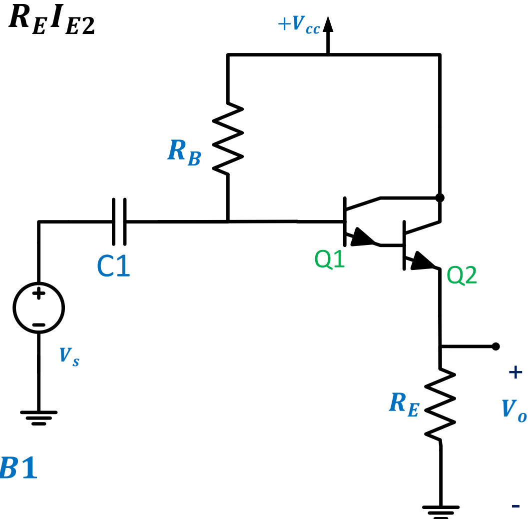
$$V_{cc} = R_B I_{B1} + V_{BE1} + V_{BE2} + R_E I_{E2}$$

$$I_{E2} = (\beta_2+1)\, I_{B2}$$

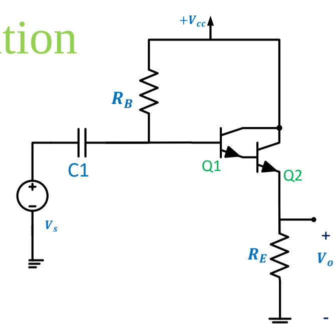
$$I_{B2} = I_{E1}$$

$$I_{E1} = (\beta_1+1)\, I_{B1}$$

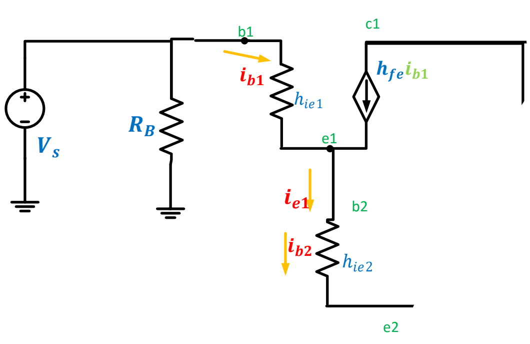
$$\therefore I_{E2} = (\beta_2+1)(\beta_1+1)\, I_{B1}$$



Darlington compound configuration



Ac small signal equivalent circuit



Darlington compound configuration

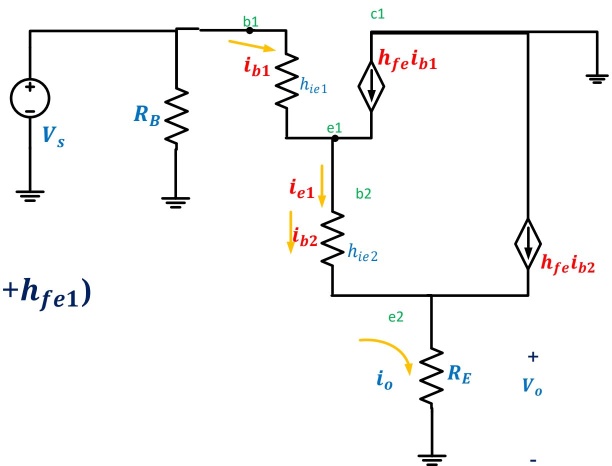
$$A_i = \frac{i_O}{ib_1} = \frac{ie_2}{ib_1}$$

$ie_2 = (1+h_{fe2})\, ib_2$

$ib_2 = ie_1$

$ie_1 = (1+h_{fe1})\, ib_1$

$$A_i = \frac{i_O}{ib_1} = (1+h_{fe2})\,(1+h_{fe1})$$



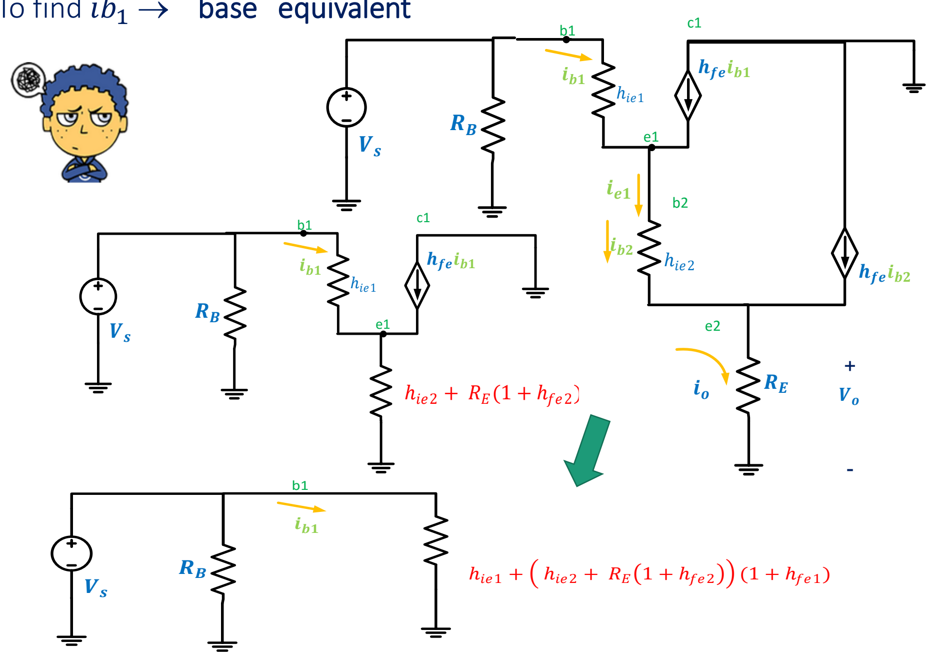
$$A_v = \frac{V_O}{V_S}$$

$V_O = R_E i_O$

$i_O = (1 + h_{fe2})\,(1 + h_{fe1}) ib_1$

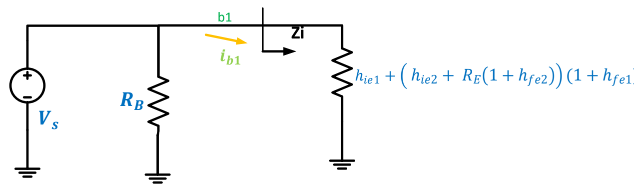
Darlington compound configuration

To find $ib_1 \rightarrow$ base equivalent

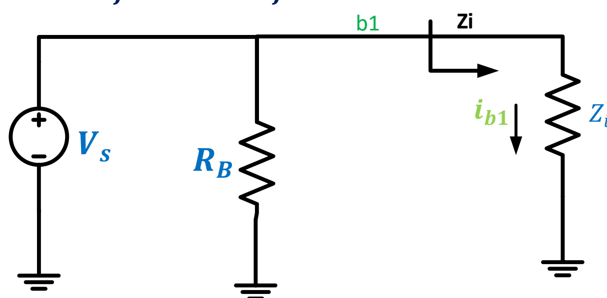


Darlington compound configuration

$$ib_1 = \frac{V_S}{Z_i}$$



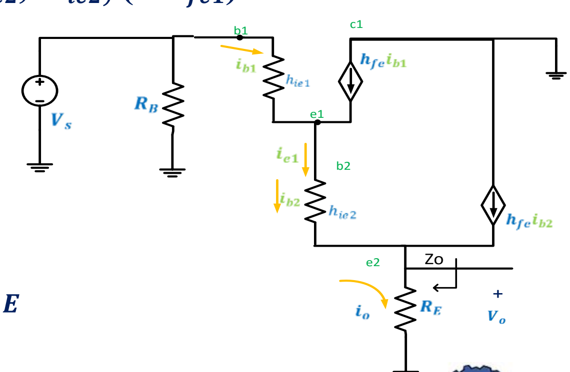
$$Z_i = h_{ie1} + (h_{ie2} + R_E\,(1+h_{fe2})\,)(1+h_{fe1})$$



Darlington compound configuration

$$A_v = \frac{R_E(1+h_{fe2})\,(1+h_{fe1})}{h_{ie1}+(R_E\,(1+h_{fe2})+h_{ie2})\,(1+h_{fe1})} < 1$$

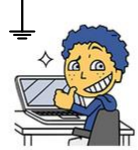
To find Z_O , set $V_S = 0$



$$Z_O = \left(\frac{\frac{h_{ie1}}{1+h_{fe1}} + h_{ie2}}{1+h_{fe2}}\right) || R_E$$

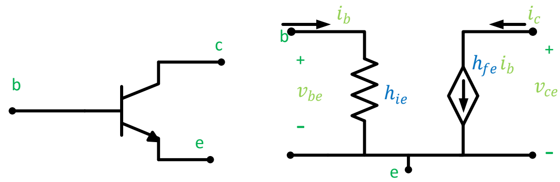
$\therefore A_i > 1$
$A_v < 1$

Z_i very very large
Z_O very very small
modified buffer

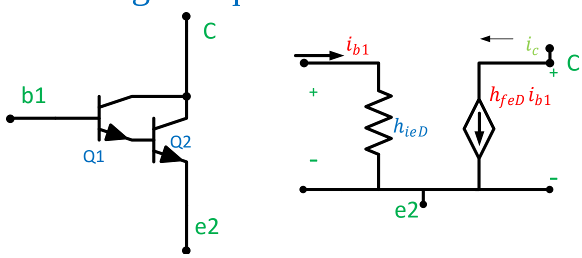


Darlington compound configuration

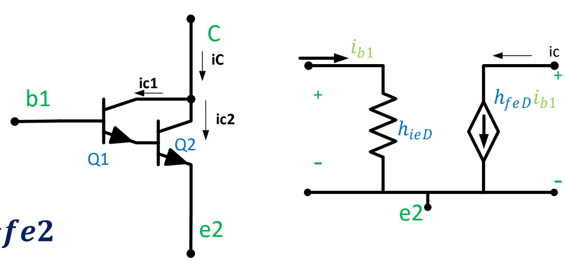
Ac small signal equivalent circuit of the BJT



Ac small signal equivalent circuit of the Darlington



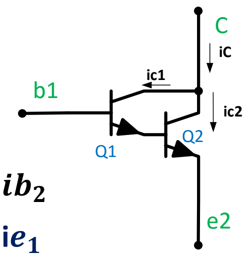
Darlington compound configuration

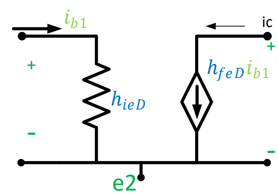


$$h_{ieD} = 2\,h_{ie1}$$
$$h_{feD} = h_{fe1} \cdot h_{fe2}$$
$$h_{feD} = \frac{i_c}{ib_1}$$
$$h_{ieD} = Z_i \text{ with } R_E = 0$$

Darlington compound configuration

$$h_{feD} = \frac{i_c}{ib_1}$$





$i_c = i_{c1} + i_{c2}$

$i_c = h_{fe1}\, ib_1 + h_{fe2} ib_2$

$i_c = h_{fe1} ib_1 + h_{fe2}\, ie_1$

$i_c = h_{fe1} ib_1 + h_{fe2}(1+h_{fe1}) ib_1$

$i_c = (h_{fe1} + h_{fe2} + h_{fe2} h_{fe1}) ib_1$

$h_{feD} = h_{fe1} + h_{fe2} + h_{fe2} h_{fe1}$

$h_{feD} \approx h_{fe2} h_{fe1}$

Darlington compound configuration

$$h_{ieD} = Z_i \,\Big|_{R_E=0}$$

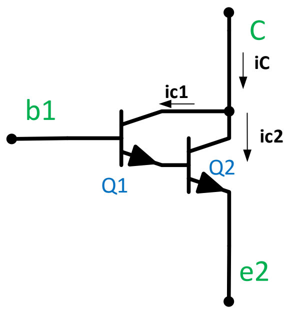
$$Z_i = h_{ie1} + (R_E(1+h_{fe2}) + h_{ie2})(1+h_{fe1})$$

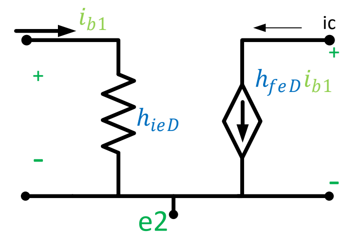
$$\therefore\ h_{ieD} = h_{ie1} + (1+h_{fe1})\, h_{ie2}$$

$$= h_{ie1} + (1+h_{fe1}) \frac{(1+h_{fe2})V_T}{I_{E2}}$$

$$= h_{ie1} + (1+h_{fe1}) \frac{(1+h_{fe2})V_T}{(1+h_{fe2})I_{E1}}$$

Darlington compound configuration





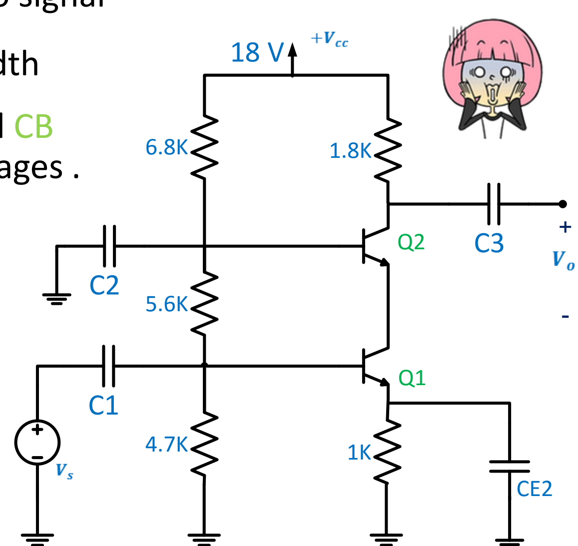
$$\therefore\ h_{ieD} = \ = h_{ie1} + \frac{(1+h_{fe1})V_T}{I_{E1}}$$

$$h_{ieD} = h_{ie1} + h_{ie1}$$

$$= 2h_{ie1}$$

Cascode Amplifier

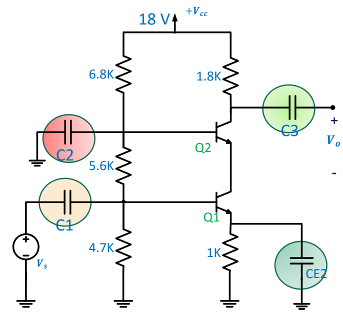
- Used to amplify video signal
- It has a wide bandwidth
- It consists of a CE and CB stages or CS and CG stages .



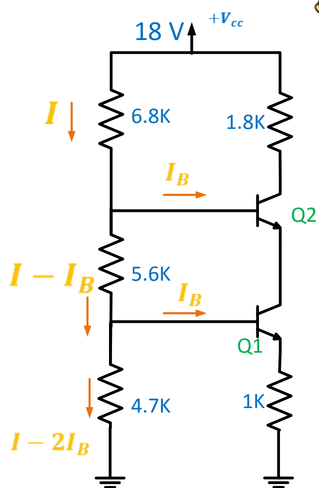
$\beta1 = \beta2 = 100$

2) Direct – coupled multistage Amplifier

Cascode Amplifier



DC Analysis :



Open Circuit!

IC1 = IE2 ≈ IC2

Since ß = ß2

IB1 = IB2 = IB

Cascode Amplifier

DC Analysis :

$I_{C1} = I_{E2} = I_{C2}$

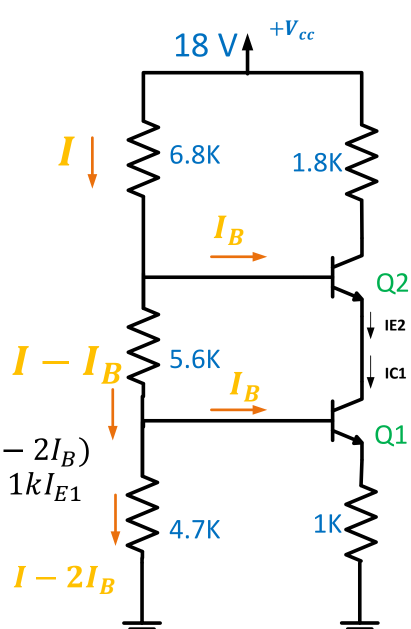
And since β1=β2

$I_{B1} = I_{B2} = I_B$

$18 = 6.8\text{k}\, I + 5.6k(I - I_B) + 4.7k(I - 2I_B)$

$18 = 6.8\text{k}\, I + 5.6k(I - I_B) + V_{BE1} + 1kI_{E1}$

Solving for $I_E = 4mA$



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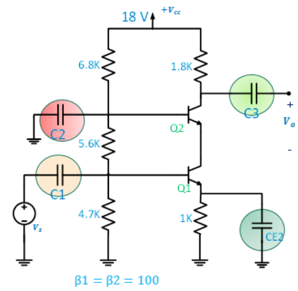
BZU

2) Direct – coupled multistage Amplifier

Cascode Amplifier



Ac small signal analysis

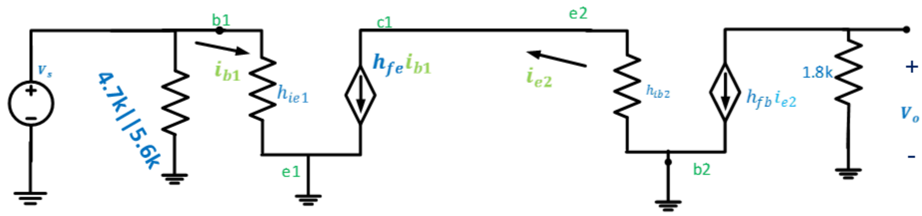
$V_O = -h_{fb} ie_2$ (1.8K)

$ie_2 = h_{fe1} ib_1$

$ib_1 = \frac{V_S}{h_{ie1}}$

$\therefore \; A_v = -294$

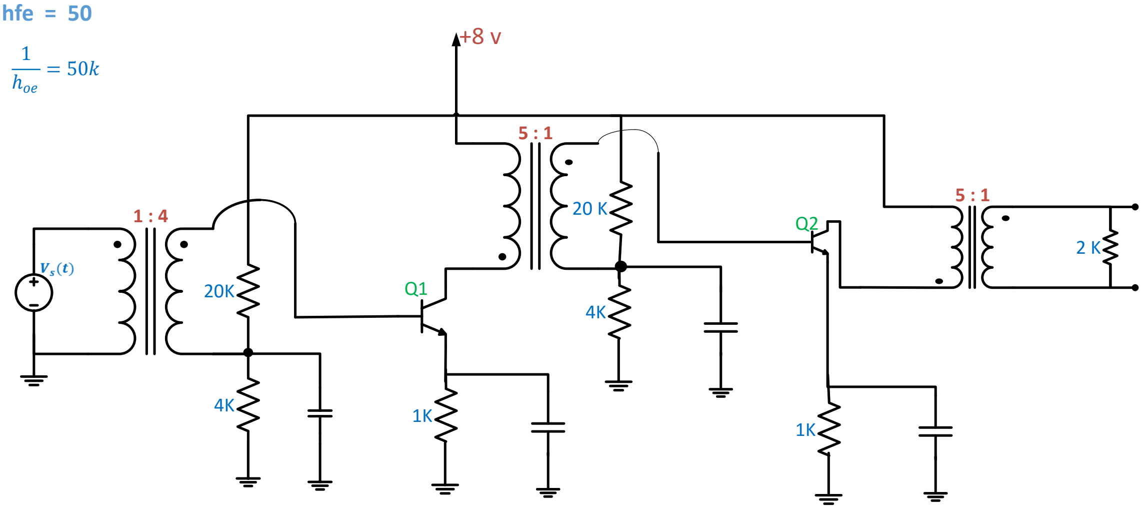
Short Circuit!



3) Transformer coupled multistage amplifier

hfe = 50

$\frac{1}{h_{oe}} = 50k$



3) Transformer coupled multistage amplifier

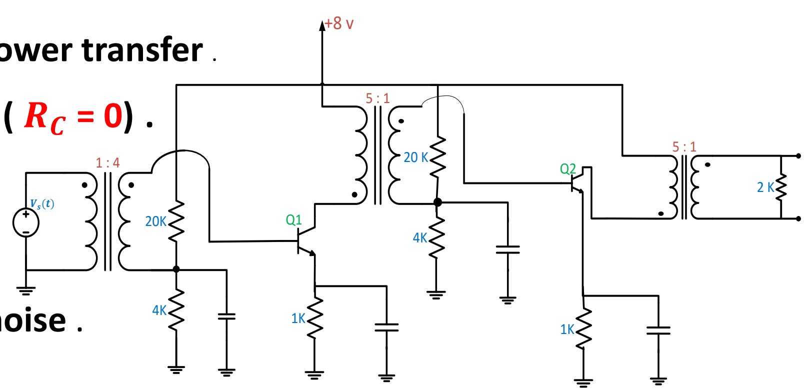
Advantages:

1) The coupling transformer is used to pass the ac signal from one stage to the next , while blocking the DC voltages .

2) DC isolation .

3) matching for maximum power transfer .

4) low dc power dissipation (R_C = 0) .



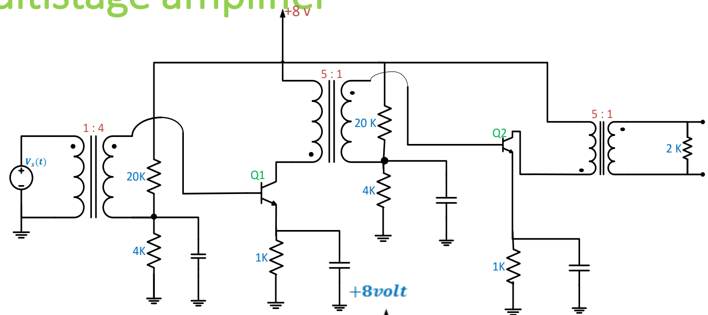
Disadvantages

1) cost , weight , size , and noise .

2) poor frequency response .

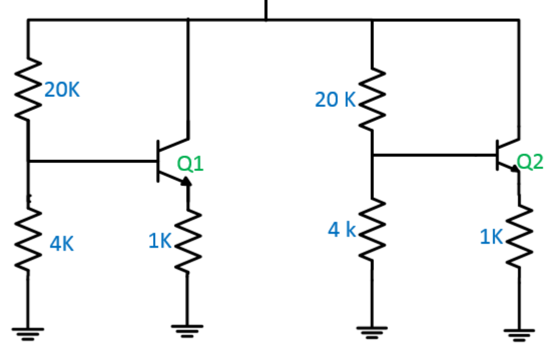
3) Transformer coupled multistage amplifier

DC Analysis:



$$R_{TH1} = R_{TH2} = 4K \backslash\backslash 20K = 3.33K$$

$$V_{TH1} = V_{TH2} = \frac{4K}{4K+20K}(+8) = 1.33\,V$$

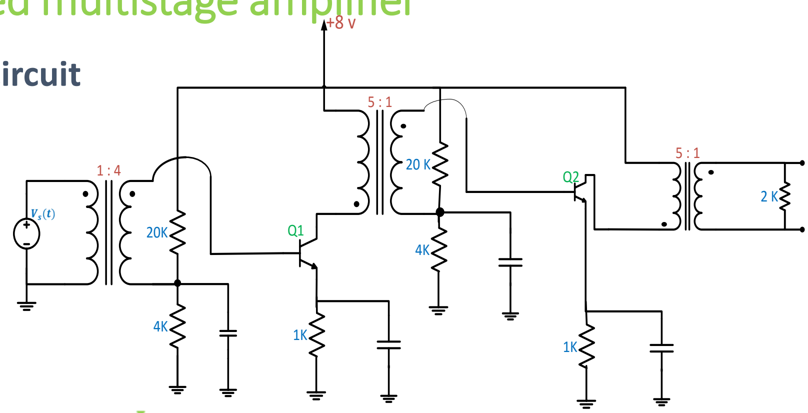


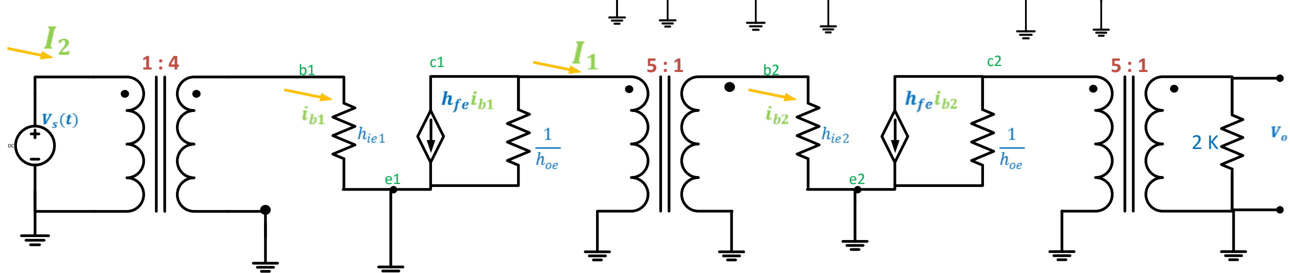
$$I_{E1} = I_{E2} = \frac{4K}{\frac{R_{TH}}{\beta+1} + 1K} = 0.595\,mA$$

$$\therefore \quad h_{ie1} = h_{ie2} = 2K$$

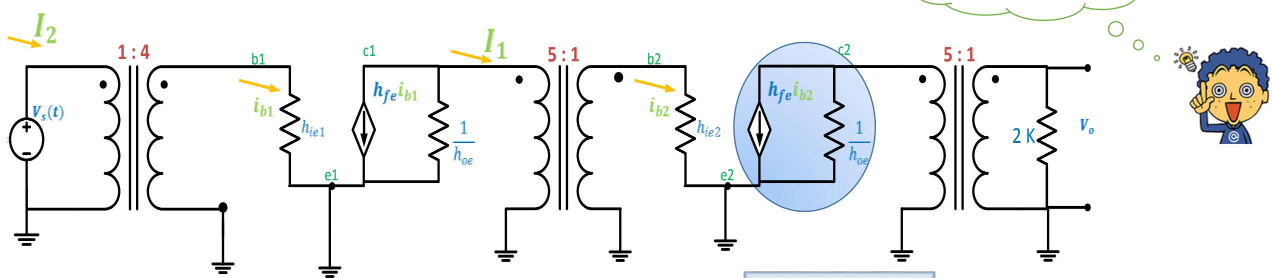
3) Transformer coupled multistage amplifier

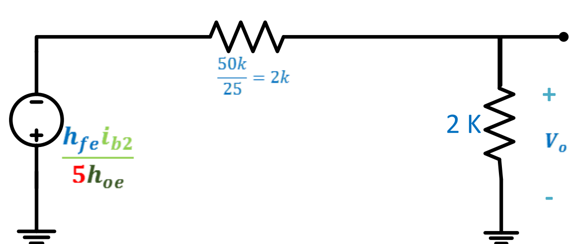
Ac small signal equivalent circuit

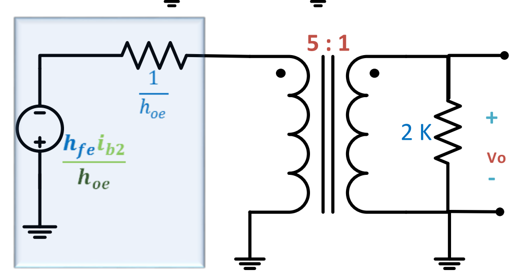




3) Transformer coupled multistage amplifier



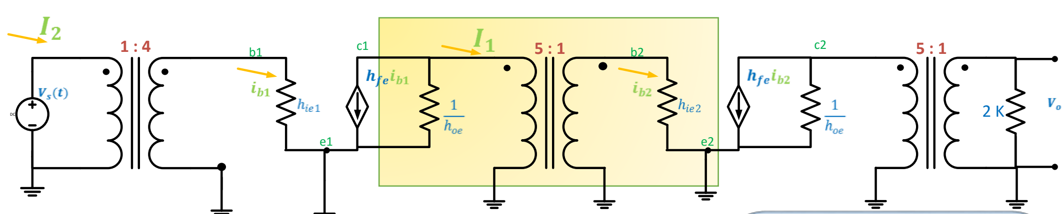




$$V_O = -\frac{2K}{2K+2K}\,\frac{hfe\ ib_2}{5hoe}$$

3) Transformer coupled multistage amplifier

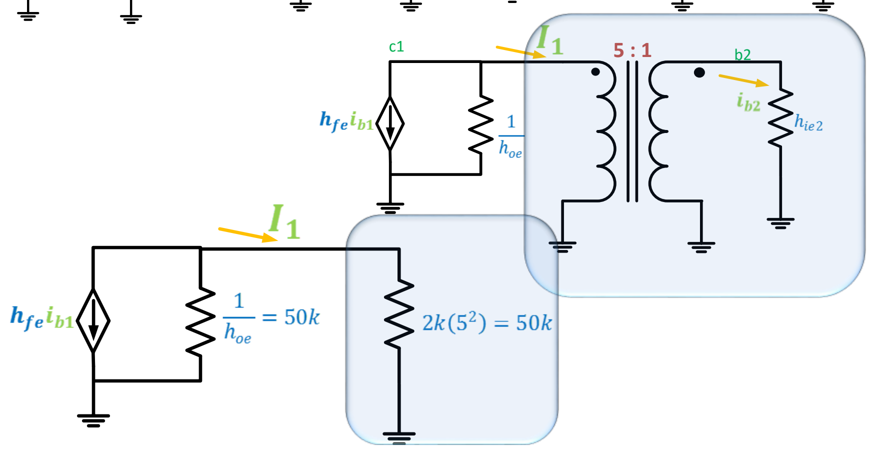
To find ib_2



$$ib_2 = 5I_1$$

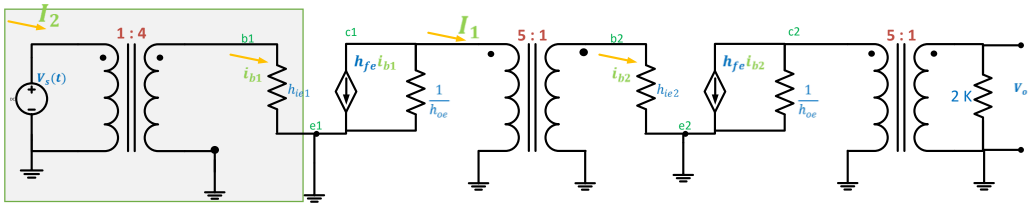
To find I_1

$$I_1 = -hfe\ ib_1\,\frac{50K}{50K+50K}$$



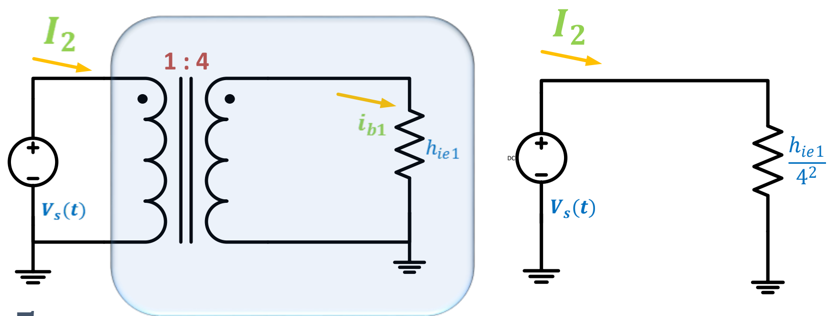
3) Transformer coupled multistage amplifier

To find ib_1



$$ib_1 = +\frac{1}{4}I_2$$

To find I_2



$$I_2 = \frac{V_S}{\frac{h_{ie1}}{16}}$$

$$\therefore A_v = \frac{V_O}{V_S} = +62.5$$