# Electronic circuits and systems
# ELEC271

## Part 14
## Feedback theory applied to generic amplifier types

**Look at feedback applied to the 4 amplifier types**

- Voltage
- Current
- Transresistance
- transconductance

# Application of feedback theory to amplifiers

**Summary so far:**

- Negative feedback converts a **high gain but poorly stabilised amp**. Into one which is nearly **ideal**
  - having practically constant gain independent of source and load impedances

- An ideal amplifier has $R_{in}$, $R_{out}$ values which are either
  - $\infty$ (open circuit)
  - 0 (short circuit)

  **THE FEEDBACK TOPOLOGY DETERMINES WHICH!**

If the loop gain, $A_{ol}\,\beta$ is sufficiently large, then the closed loop gain, $A_f$ is equal to $1/\beta$: TO A GOOD APPROXIMATION

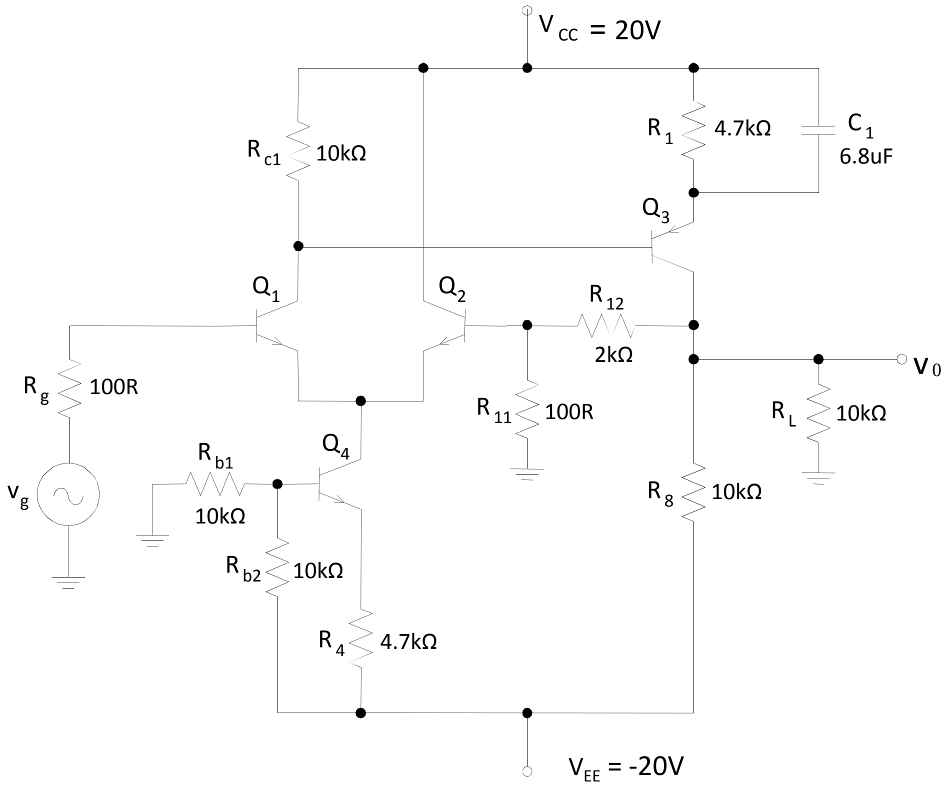
- **We will now apply these ideas to some real amplifier circuits and establish a simple method for finding the gain.**

# $1^{st}$ Circuit type

**Output sampling?**

**Input summing?**

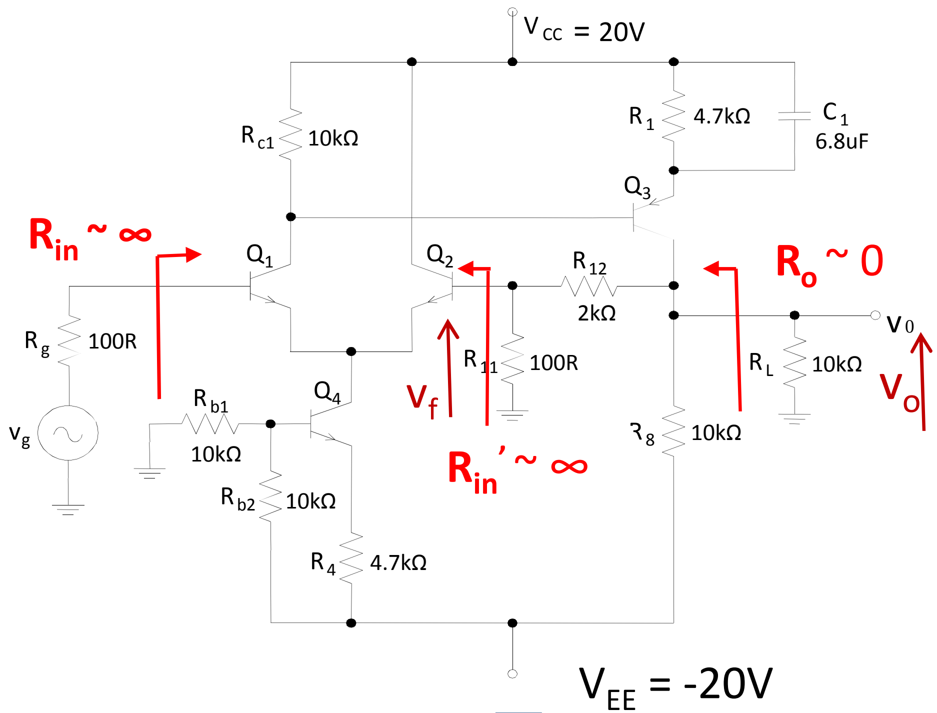
**So amplifier type is?**



# 1st Circuit type

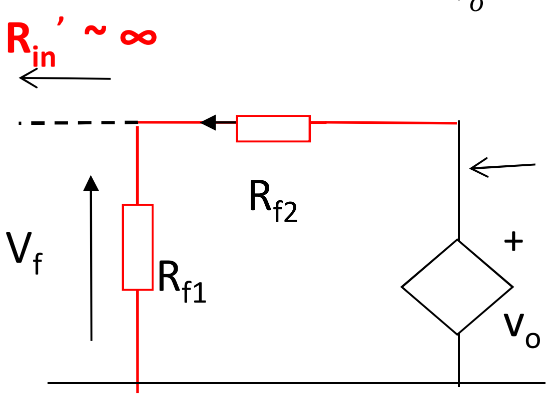
**Voltage sensing at output**

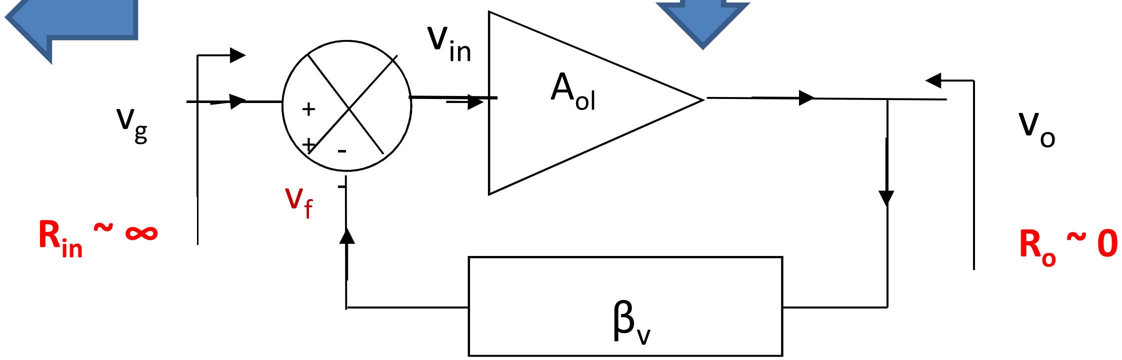
**Voltage summing at input**




**So voltage amplifier**

**Want to find** $\beta_v = \dfrac{v_f}{v_o}$




$$v_f = \frac{R_{f1}}{R_{f1}+R_{f2}} v_o$$

$$\beta_v = \frac{v_f}{v_o} = \frac{100}{100+2k} = \frac{1}{21}$$

$$\boxed{A_{fv} = \frac{v_o}{v_g} = \frac{1}{\beta_v} = 21}$$

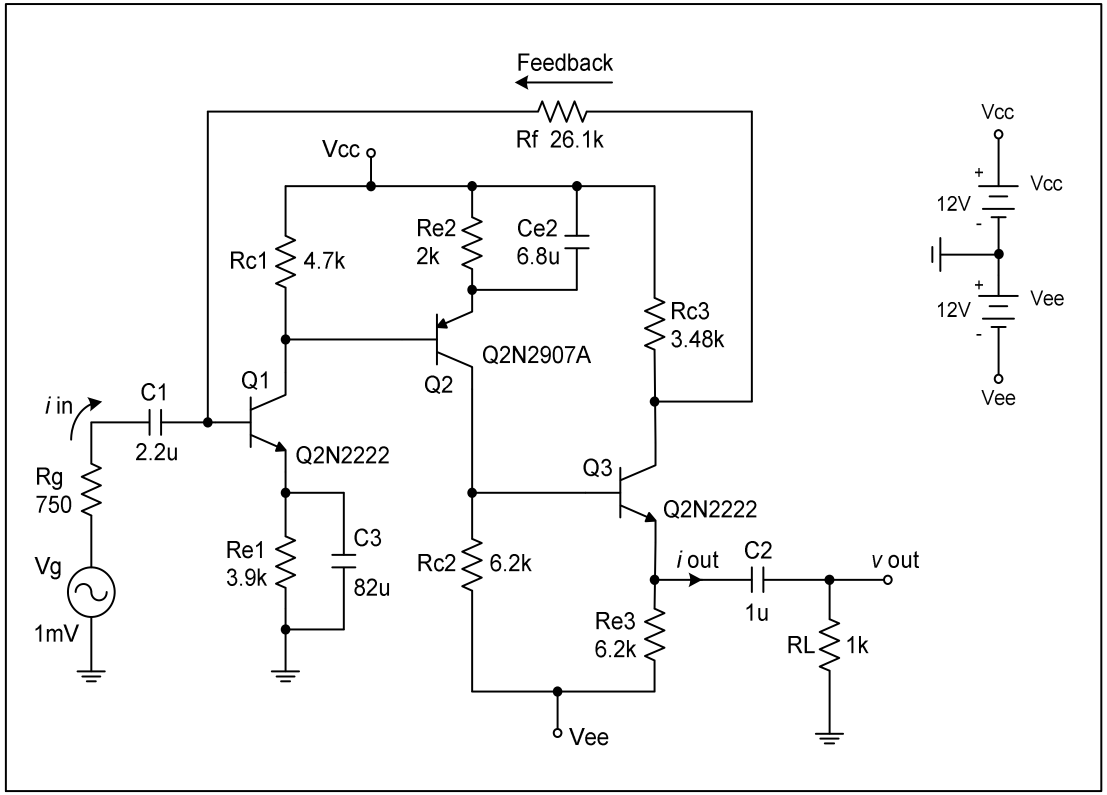
**Agrees very well with previous result using SPICE (see part 10)**

# $2^{nd}$ Circuit type

**Output sampling?**

**Input summing?**

**So amplifier type is?**



# 2nd Circuit type

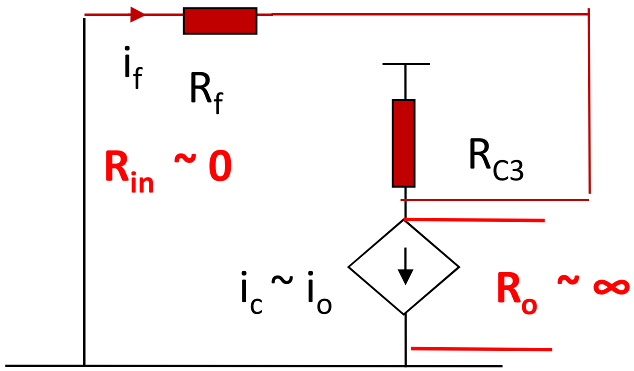
**Current sampling at o/p**

**Current summing at I/p**

**Current amplifier**

**Need to find** $\beta_i = \dfrac{i_f}{i_o}$

since $i_c \sim i_o$ we can draw feedback circuit as

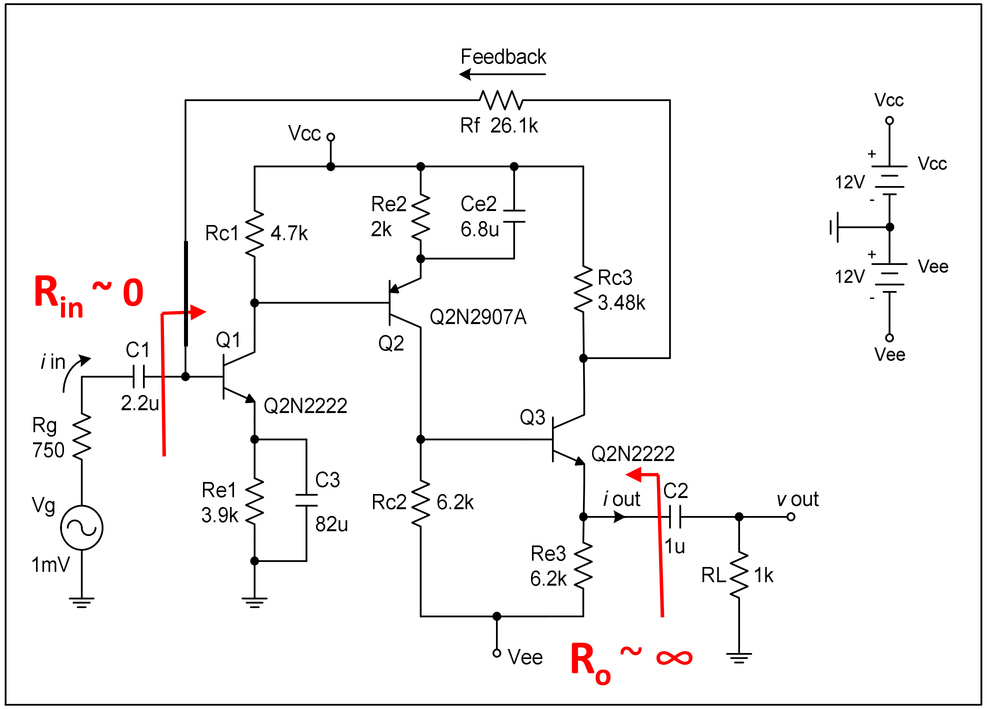


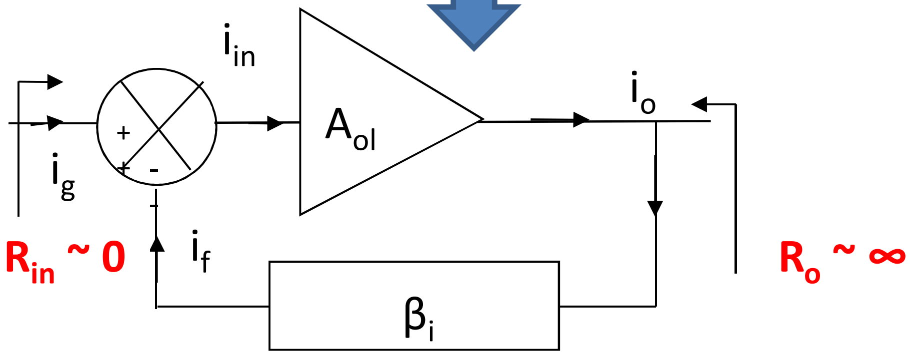

$$i_f = i_o \frac{R_{C3}}{R_{C3} + R_f}$$

Current division

$$\beta_i = \frac{i_f}{i_o} = \frac{R_{C3}}{R_{C3} + R_f} = \frac{3.48k}{3.48k + 26.1k} = \frac{1}{8.5}$$

$$\boxed{A_{fi} = \frac{i_o}{i_g} = \frac{1}{\beta_i} = 8.5}$$



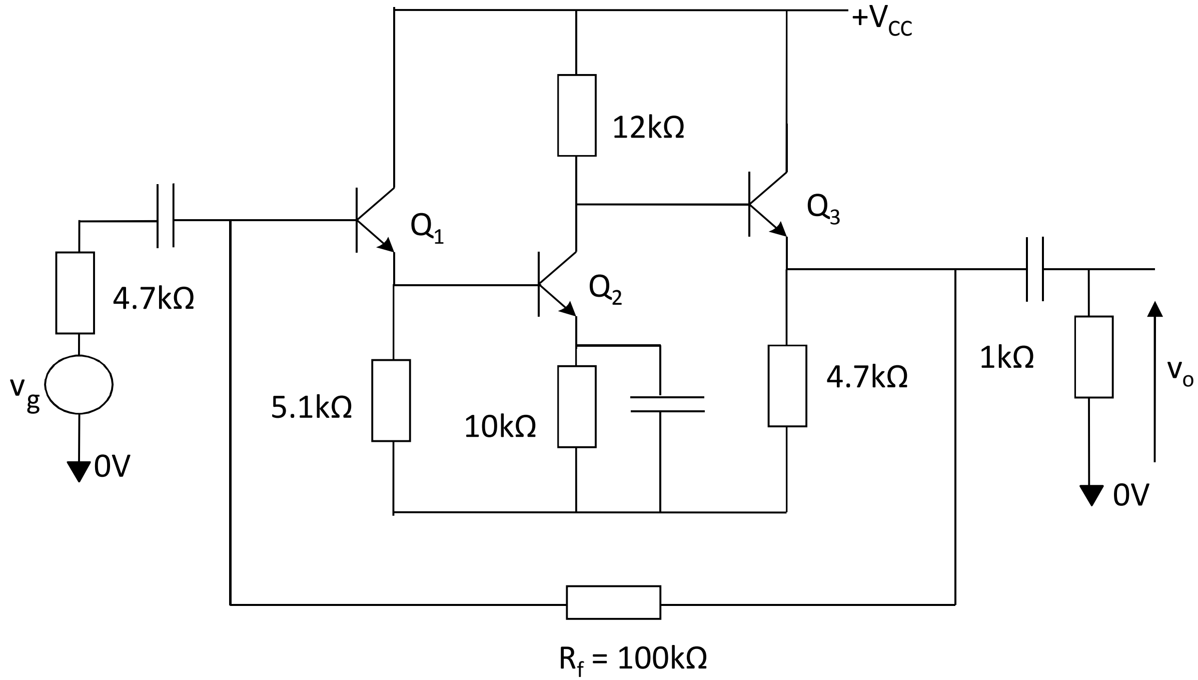

Agrees very well with previous result using SPICE (see part 11)

# 3rd Circuit type

**sensing at output ?**

**summing at i/p ?**

**amplifier type is?**



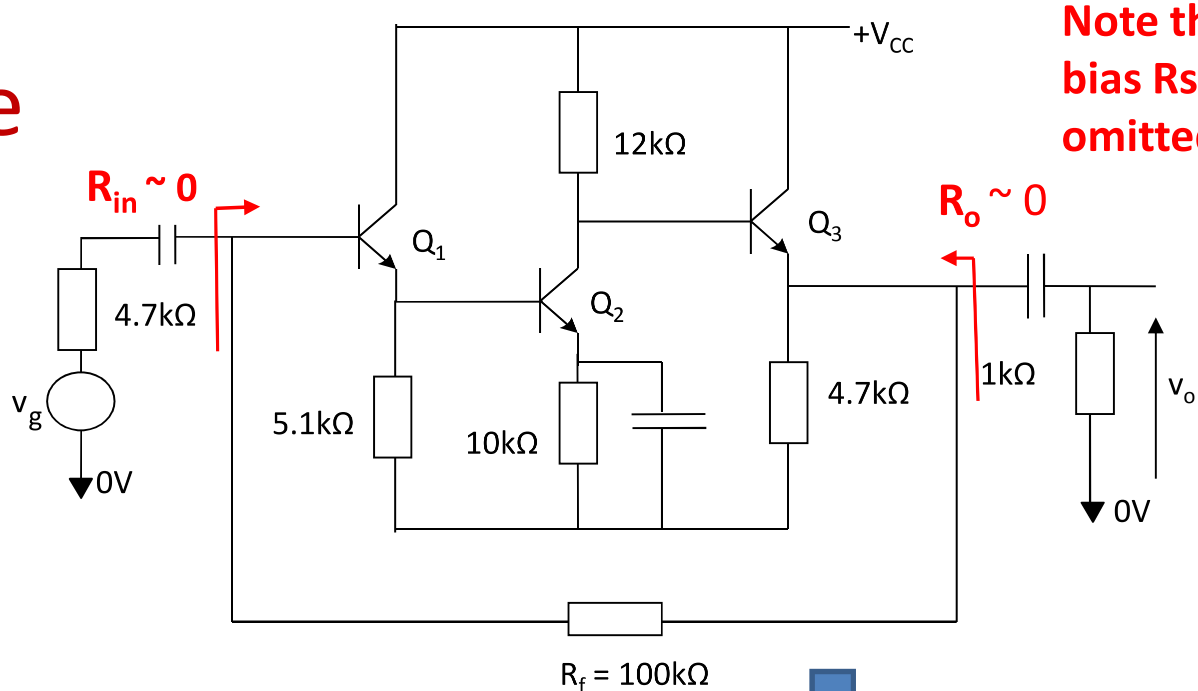
# $3^{rd}$ Circuit type

**Sampling voltage at o/p**

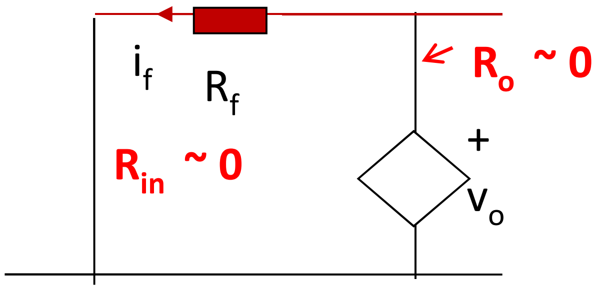
**Input current summing**

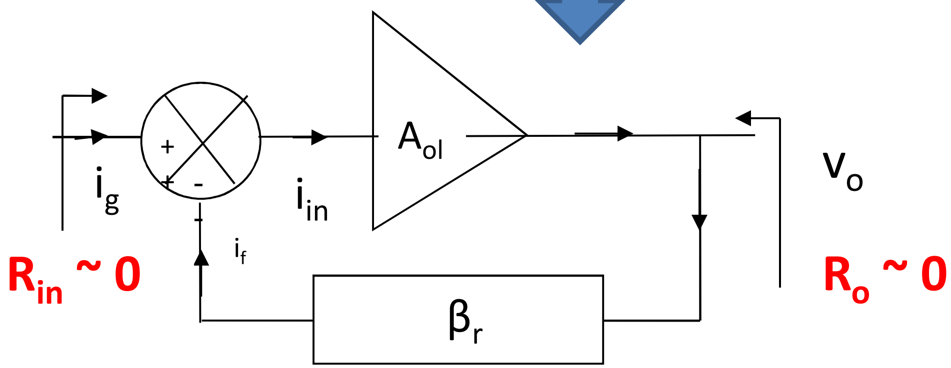
**Transresistance amplifier**

**Note that dc bias Rs are omitted**




We need to find $\beta_r = \dfrac{i_f}{v_o}$




So $i_f = \dfrac{v_o}{R_f}$

$$\beta_r = \frac{i_f}{v_o} = \frac{1}{R_f} = \frac{1}{100k\Omega} \quad \Rightarrow \quad A_{fr} \sim \frac{1}{\beta_r} = \frac{v_o}{i_g} = 100k\Omega$$

**trans-R gain**

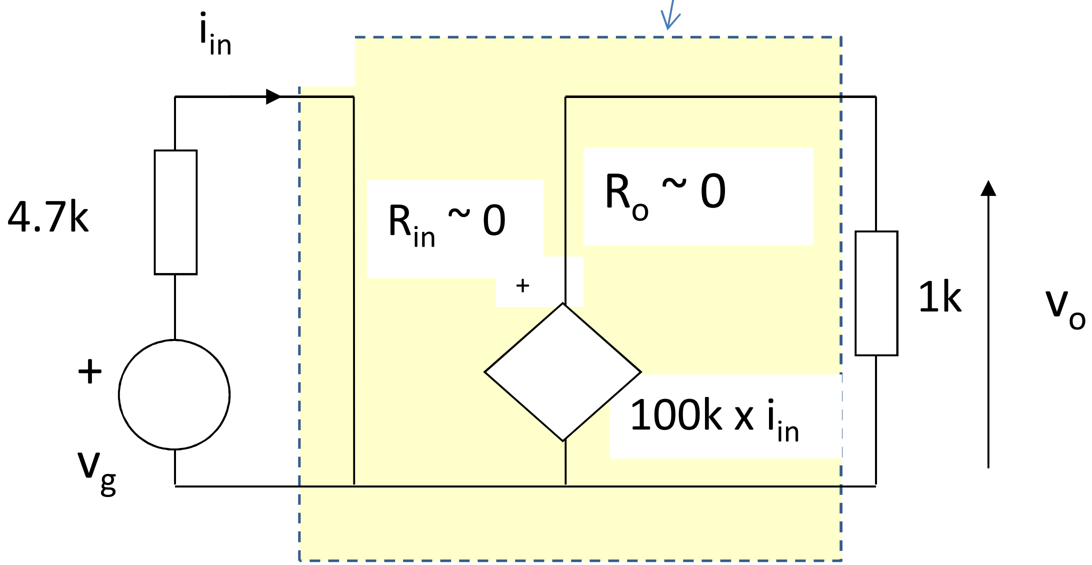
# What if we want to find the voltage gain of the trans-resistance amplifier?

- Replace amplifier schematic with ideal equivalent circuit of trans-R amplifier system
- Ideal current amp has **zero input resistance** and **zero output resistance** as shown

$$v_o = 100k \times i_{in}$$

$$i_{in} = \frac{v_g}{4.7k}$$

$$A_V = \frac{v_o}{v_g} = \frac{100k}{4.7k} = 21.3$$

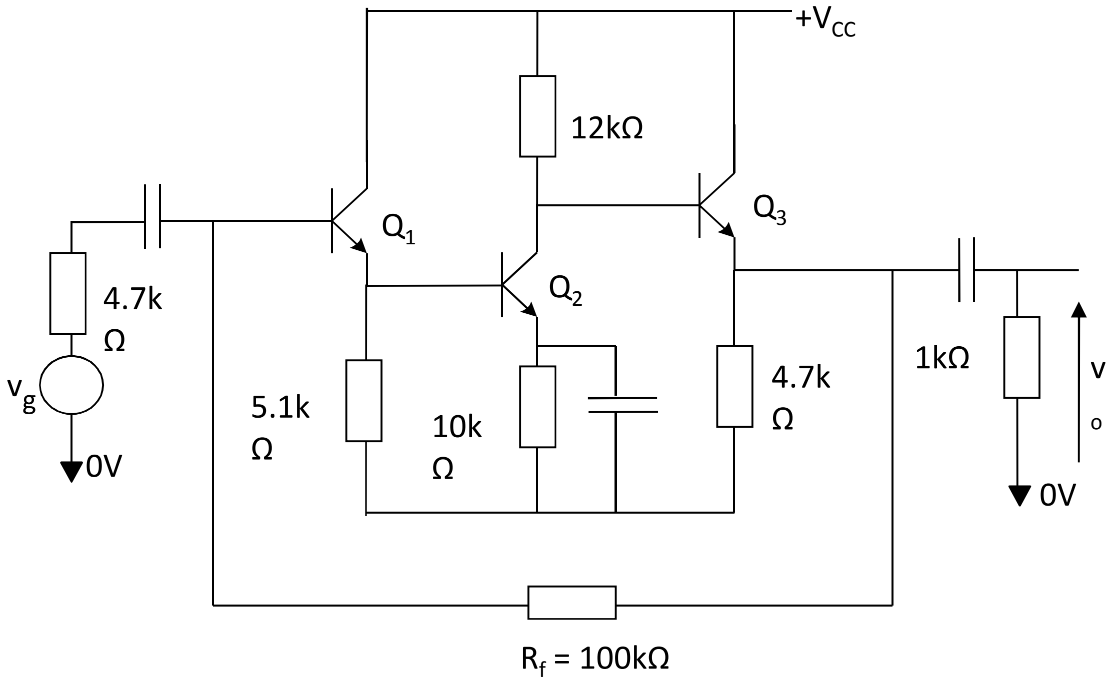



PSPICE gives a voltage gain of 18.6… Agreement not as good as before.. Why?

# Possible reasons

1. Forward path is EF, CE, EF; so $A_{ol}$ may not be very big
   So $A_{ol}\,\beta_r$ may not be big enough for good approx.

**Q: which $A_{ol}$ should be considered??**



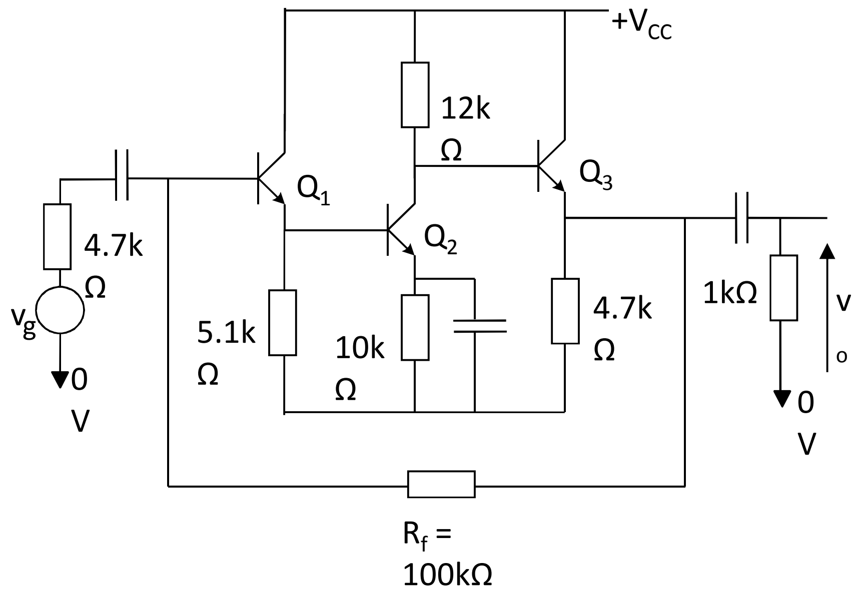

2. Negative feedback is trying to force $R_{in} \rightarrow 0$….

   … but input stage is EF which has a very high input resistance without feedback!

   **bad!** If we had started with a design having an input stage with a low input resistance then effect of NF would have been better…

# CHECK: $A_{ol}$ of trans-R amp??

$$A_{ol}(trans-R) = \frac{v_o}{i_g} = \frac{v_o}{v_{i3}}\frac{v_{o2}}{v_{i2}}\frac{v_{o1}}{i_g}$$




$$A_{ol}(trans-R) = A_{V3}A_{V2}R_{M1}$$

$A_{V3}$ (CC) ~ 1
Small!

$A_{V2}$ (CE) ~ - $g_{m2}$ 12k//$R_{i3}$

Large!

$$R_M = (1+\beta_o)R_E \,//\, R_{i2}$$

Large!

**So $A_{ol}$ (Trans-R) likely to be quite big**
**Look at 2nd reason**

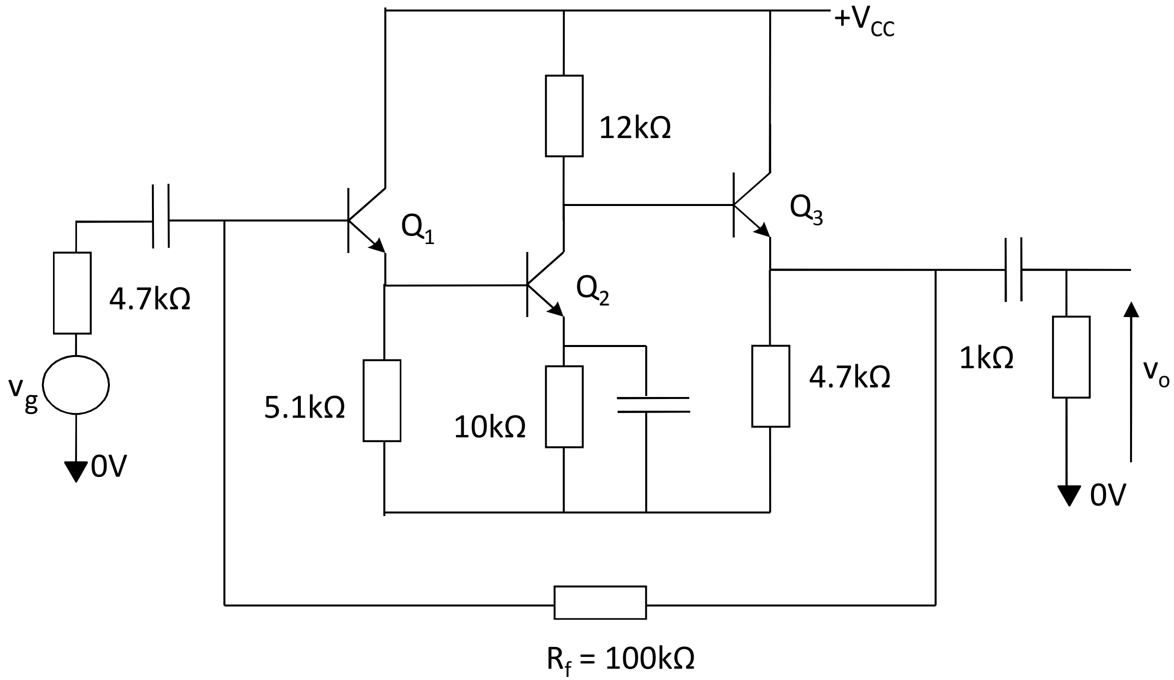
# Possible reasons

1. ~~**Forward path is EF, CE, EF;** so $A_{ol}$ may not be very big. So $A_{ol}\,\beta_r$ may not be big enough for good approx.~~

2. **Negative feedback is trying to force $R_{in}$ → 0….**

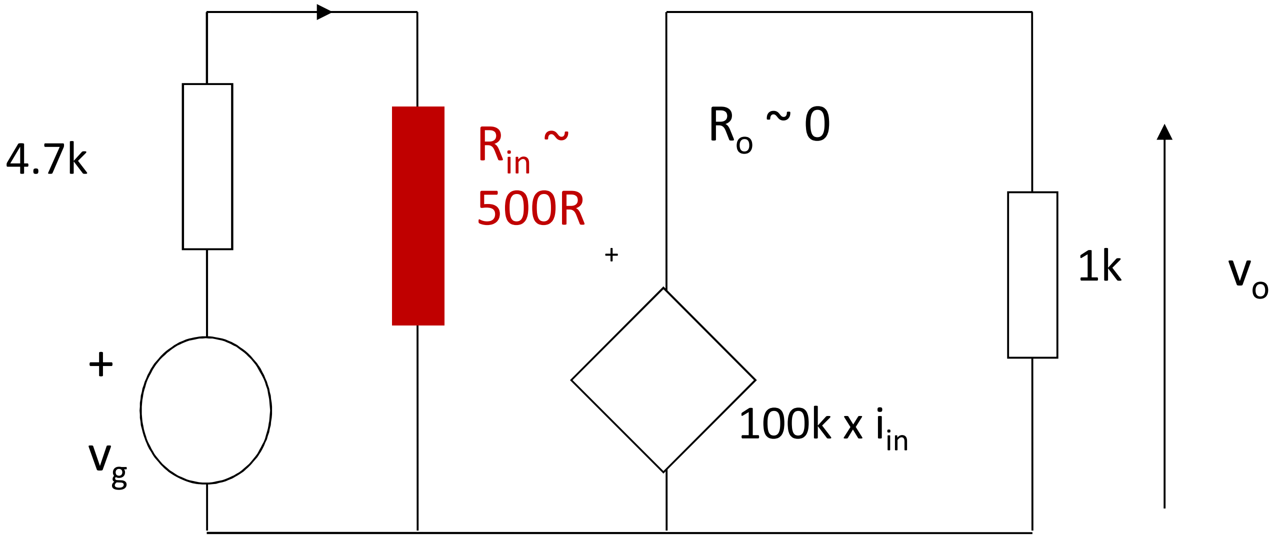
   **… but input stage is EF which has a very high input resistance without feedback!**

   **bad!** If we had started with a design having an input stage with a low input resistance then effect of NF would have been better…




NB PSPICE gives $R_{in}$ ~ 500R → **add to equivalent circuit**

# Check




$$v_o = 100k \times i_{in}$$

$$i_{in} = \frac{v_g}{4.7k + 500}$$

$$A_V = \frac{v_o}{v_g} = \frac{100k}{5.2k} = 19.2$$

**PSPICE value of 18.6 !**

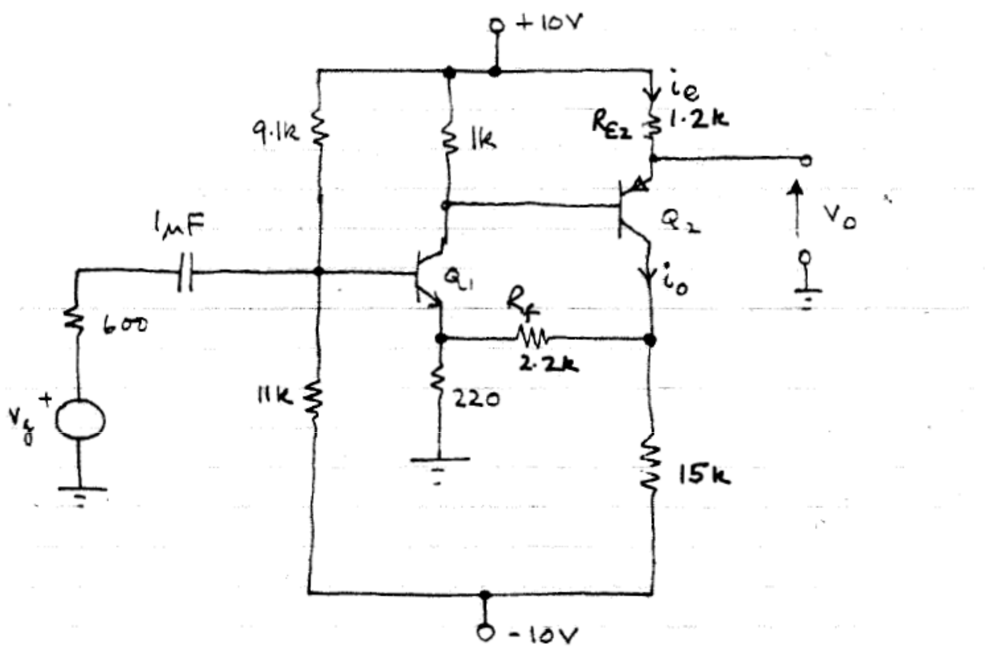
**Message:** Start with a design having a low input resistance if you want to make a good trans-R !! amp!

# 4th Circuit type

**Output sampling?**

**Input summing?**

**So amplifier type is?**



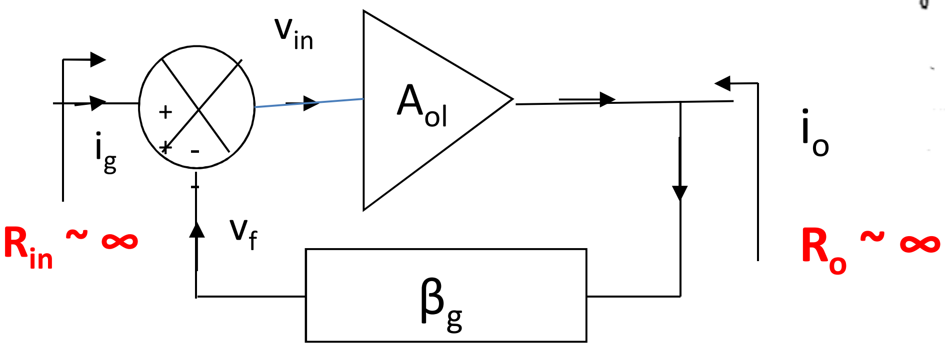
# 4th Circuit type

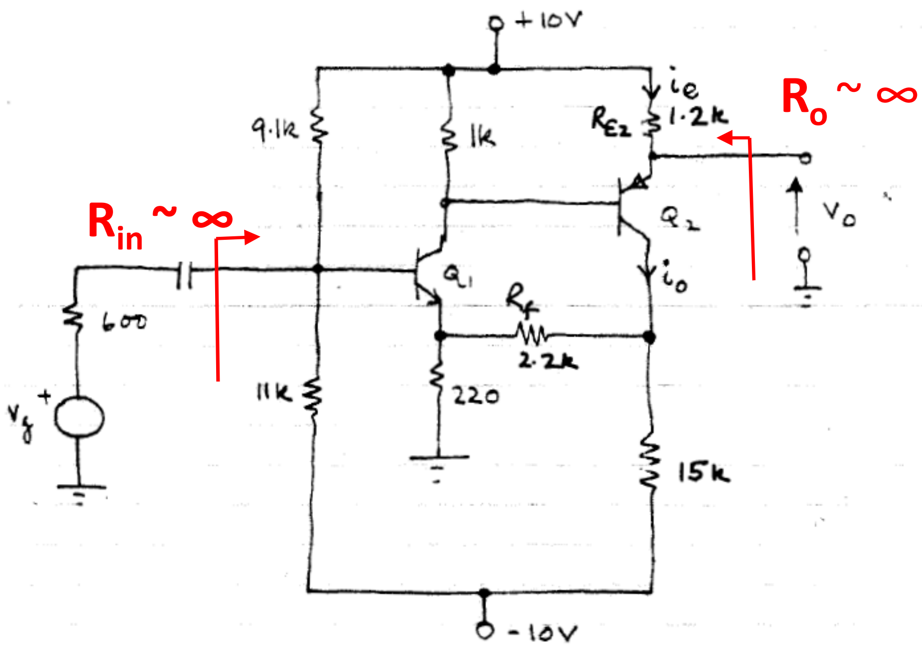
Output sampling is **current sensing**

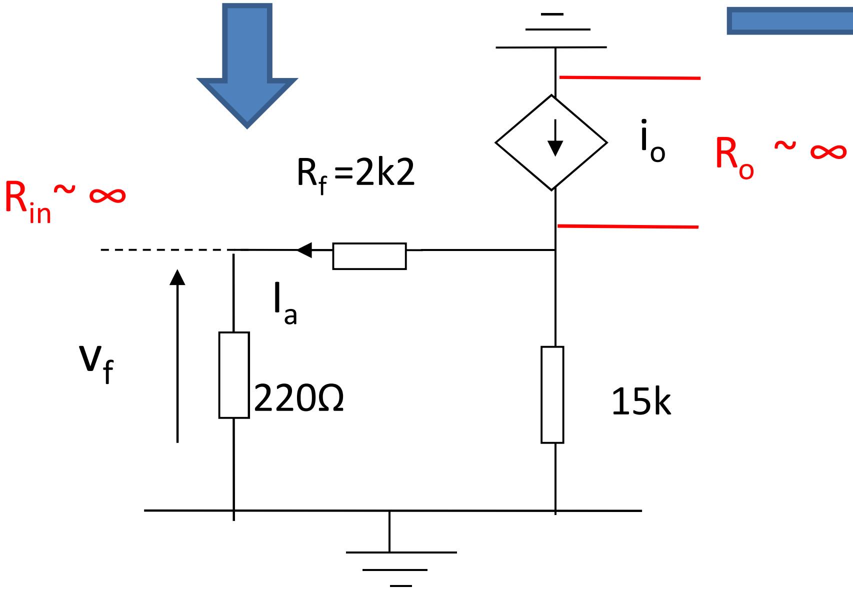
Input summing is **voltage summing**

Amplifier type is **transconductance**

**Compare with**




Need to find $\beta_g = \dfrac{v_f}{i_o}$

$$i_a = \frac{15k}{15k + 2.2k + 220} i_o = 0.861 i_o$$

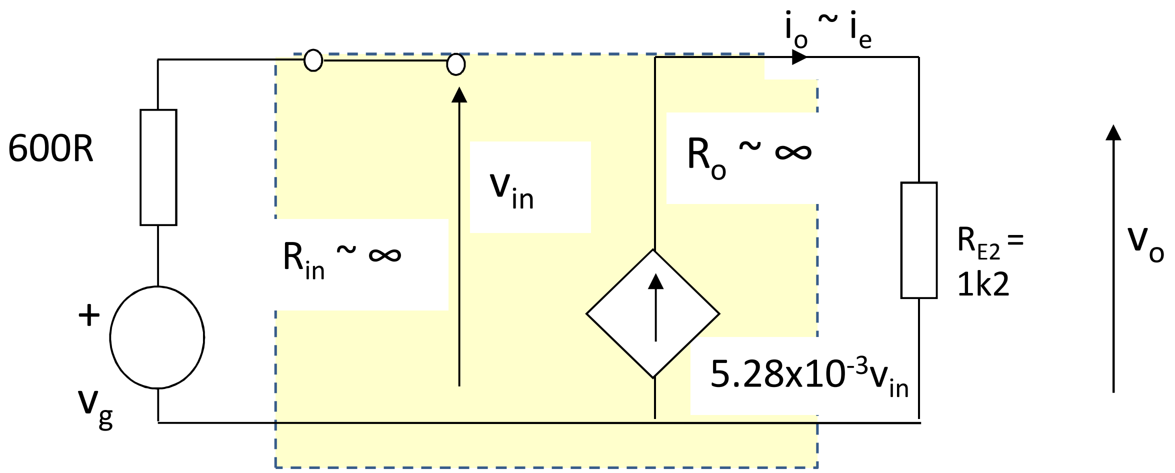
$$v_f = 220\ \Omega \times 0.861 \times i_o$$

$$\beta_g = \frac{v_f}{i_o} = 189.4\Omega$$

$$\boxed{A_{fg} = \frac{1}{\beta_g} = \frac{1}{189.4\Omega} = 5.28mA/V}$$

# What if we want to find the voltage gain of the transconductance amplifier?

- Ideal trans-G amp has infinite input resistance and infinite output resistance as shown




$$v_o = 1.2k \times 5.28.10^{-3} v_{in} \qquad v_{in} = v_g$$

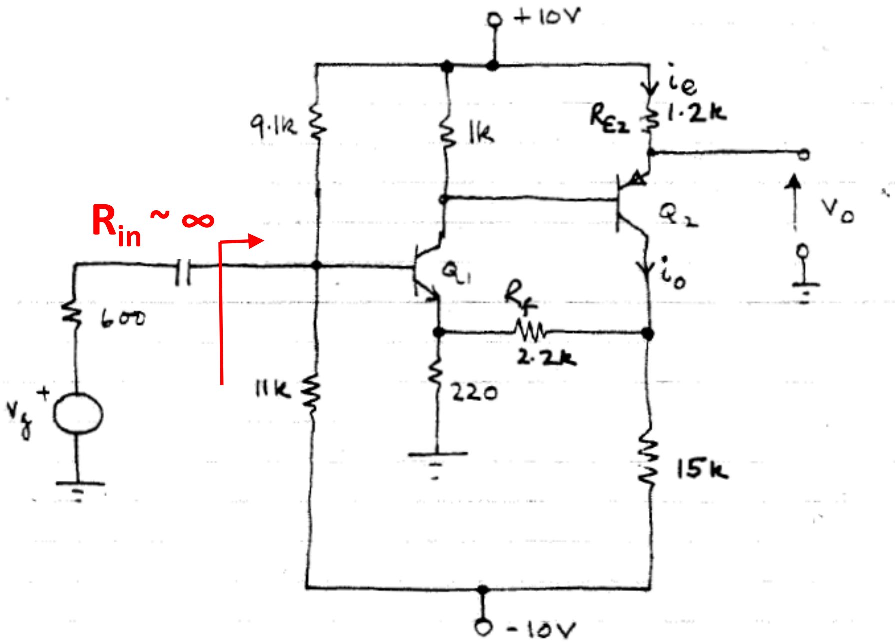
$$\boxed{A_V = \frac{v_o}{v_g} = 6.34}$$

PSPICE gives a voltage gain of 2.15 – factor of 3 out!

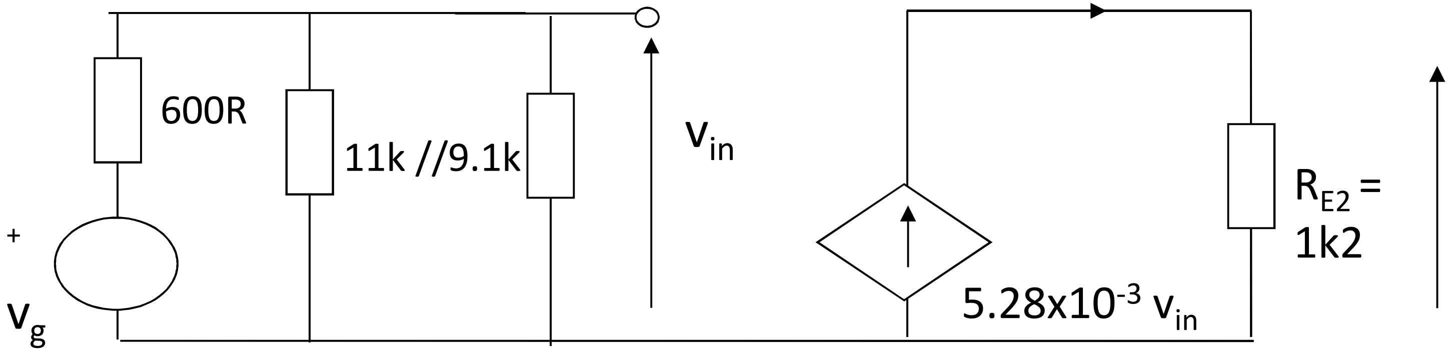
**Why??**

# Possible reasons -1

- **$R_{in}$ is actually at base of $Q_1$** where voltage summing occurs – so $v_g$ is attenuated by base biasing resistors which are 'outside the feedback loop.'




- ∴ improved equivalent circuit is:




So that

$$v_{in} = \frac{11k // 9.1k}{11k // 9.1k + 600} v_g = 0.89 v_g$$

And

$$\frac{v_o}{v_g} = 0.89 \times 6.34 = 5.64$$

**-still too big!**

# Possible reasons -2

$T = \beta_g A_{olg}$

- **LOOP GAIN is too small.** I calculated loop gain to be only **0.634 –** certainly small!! – should be much bigger than 1 for approximate formula to be accurate. $A_f \sim \frac{1}{\beta}$

- **Bad design!!**
- **But can we use this value of loop gain (0.634) to get a better estimate of gain?**

$$A_f = A_\infty \frac{T}{1+T}$$

T = loop gain ($A_{ol}\beta$) and $A_\infty$ is the gain assuming T is large (ie infinite)

$$A_{fg} = 5.28\times10^{-3} \times \frac{0.634}{1+0.634}$$

= 2.05 mA/V

(cf 1.9mA/V from SPICE)

$$\frac{v_o}{v_g} = 0.89 \times 1.2k \times 2.05.10^{-3} = 2.19$$

**Compared with $A_V$ = 2.15 from PSPICE**

- NB PSPICE has to invert a 6x6 matrix with complex coefficients to solve this problem.
- Our 'back of the envelope' method is **much simpler**!

# Conclusions of part 14

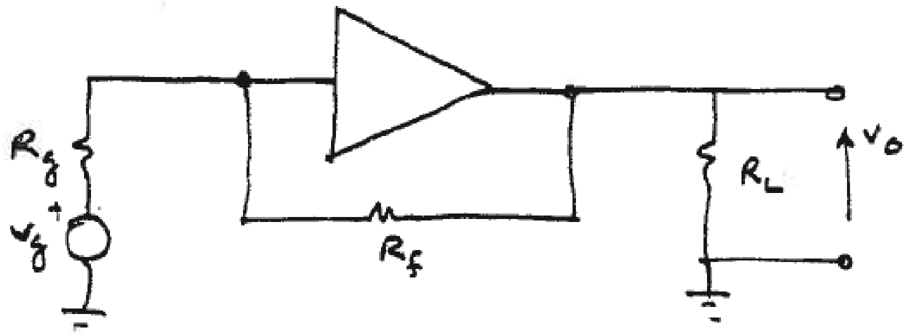
**To calculate the approximate gain of an amplifier with feedback:**

- Determine the **topology** of the feedback network
- Identify WHICH **ideal** amplifier is approximated: what are the ideal values for $R_{in}$, $R_{out}$
- What form does $\beta = \frac{x_f}{x_o}$ take?
- Calculate $\beta$ (use $R_{in}$ and $R_{out}$ ideal values to help!)
- Calculate $A_f$ from $A_f \sim \frac{1}{\beta}$
- Calculate the gain you require if it is not the gain stabilised by feedback by using the Ideal model (this assumes LOOP GAIN, T >> 1)

$T = \beta A_{ol}$

# Worked Example ('Problems II')

**Calculate the voltage gain, $v_o/v_g$ assuming that the loop gain is infinite.**
**Obtain a better estimate of the gain given that the loop gain is 15.**
**$R_g$ = 1k, $R_f$ = 10k, $R_L$ =500R**




1. Feedback topology at output?
   Feedback topology at input?

2. 'Ideal' (stabilised) amplifier?
   $R_{in}$ = , $R_o$ =

3. What from does β take?

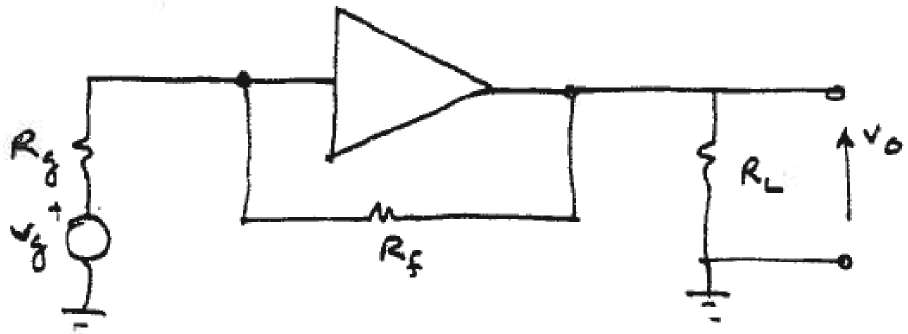
4. Calculate β

5. $A_f$ =

6. $V_o / V_g$

# Worked Example

Calculate the voltage gain, $v_o/v_g$ assuming that the loop gain is infinite.
Obtain a better estimate of the gain given that the loop gain is 15.
$R_g$ = 1k, $R_f$ = 10k, $R_L$ =500R




1. output: **Voltage sampling**
   Input: **Current summing**

2. 'Ideal' (stabilised) amplifier?
   $R_{in}$ = , $R_o$ =

3. What from does β take?

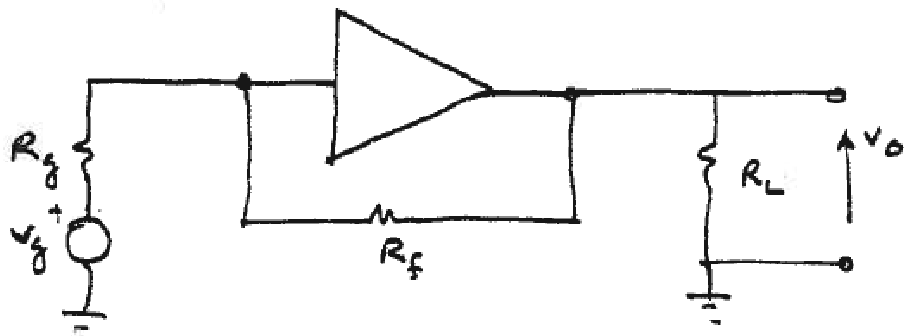
4. Calculate β

5. $A_f$ =

6. $V_o / V_g$

# Worked Example

Calculate the voltage gain, $v_o/v_g$ assuming that the loop gain is infinite.
Obtain a better estimate of the gain given that the loop gain is 15.
$R_g$ = 1k, $R_f$ = 10k, $R_L$ =500R




1. output: Voltage sampling
   Input: Current summing

2. **Transresistance amplifier**
   **$R_{in}$ ~ 0, $R_o$ ~ 0**

3. **What form does β take?**

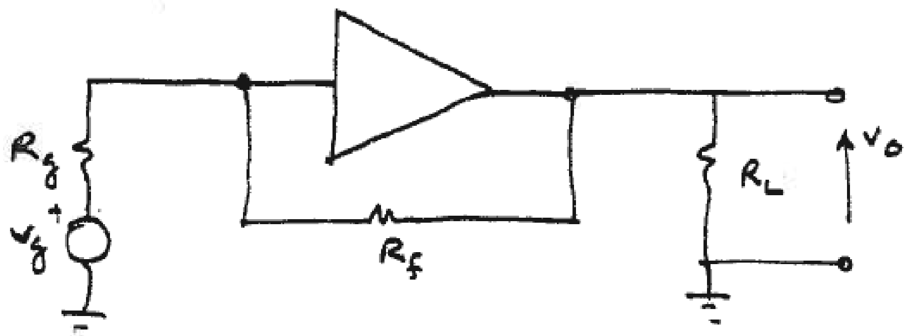
4. **Calculate β**

5. $A_f$ =

6. $V_o$ /$V_g$

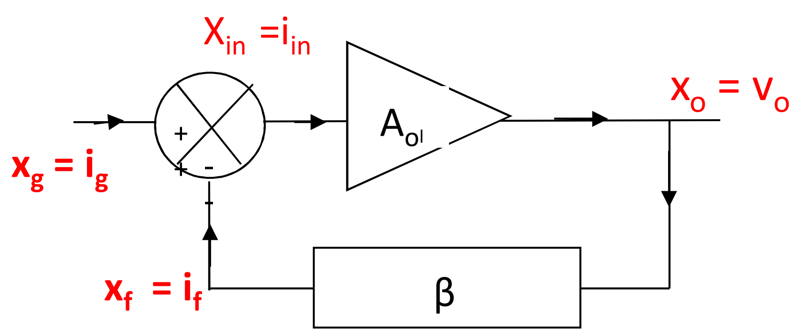
# Worked Example

Calculate the voltage gain, $v_o/v_g$ assuming that the loop gain is infinite.
Obtain a better estimate of the gain given that the loop gain is 15.
$R_g$ = 1k, $R_f$ = 10k, $R_L$ =500R



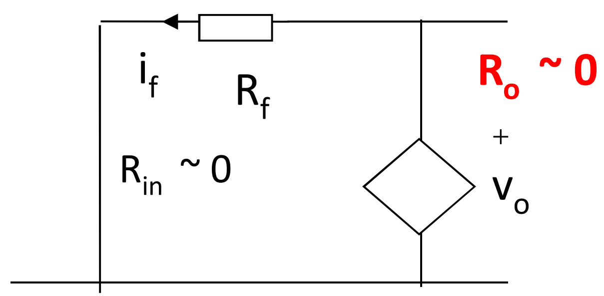

1. output: Voltage sampling
   Input: Current summing

2. Transresistance amplifier
   $R_{in} \sim 0$, $R_o \sim 0$




3. **$\beta = x_f / x_o$**

4. $I_f = v_o/R_f$ so $\boxed{\beta_r = \frac{i_f}{v_o} = \frac{1}{R_f} = \frac{1}{10k\Omega}}$




5. $A_f$ =

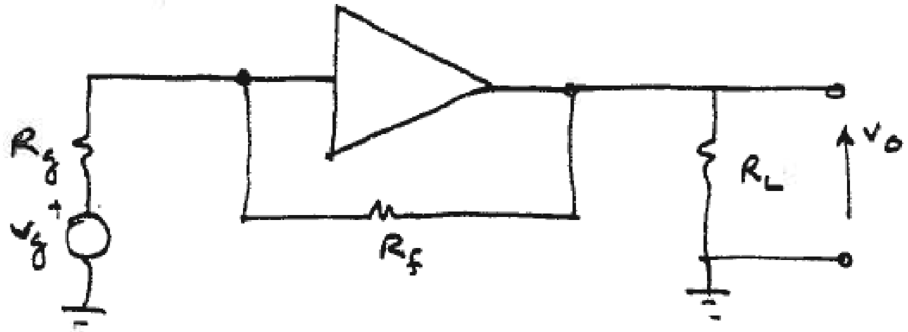
6. $V_o / V_g$

# Worked Example

**Calculate the voltage gain, $v_o/v_g$ assuming that the loop gain is infinite.**

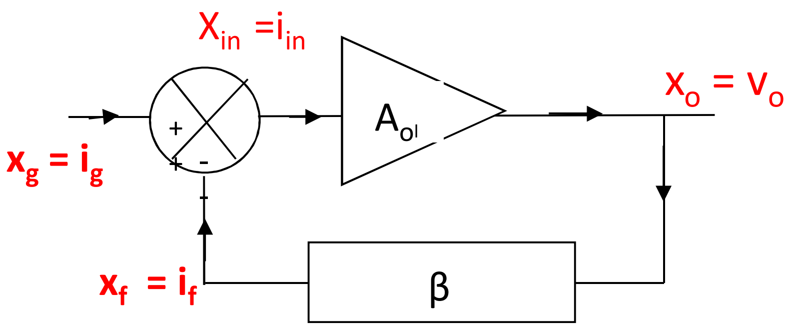
**Obtain a better estimate of the gain given that the loop gain is 15.**

**$R_g$ = 1k, $R_f$ = 10k, $R_L$ =500R**



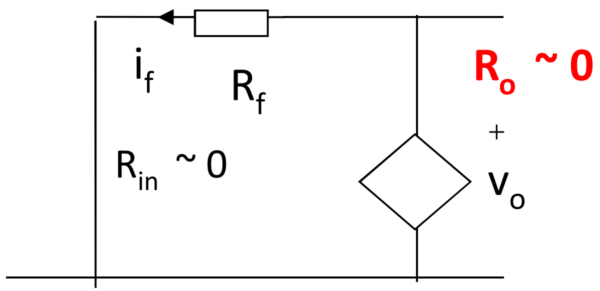

1. output: Voltage sampling
   Input: Current summing

2. Transresistance amplifier
   $R_{in} \sim 0$, $R_o \sim 0$




3. $\beta = x_f / x_o$

4. $I_f = v_o/R_f$ so $\beta_r = \frac{i_f}{v_o} = \frac{1}{R_f} = \frac{1}{10k\Omega}$




5. $A_f = 1/\beta_r = 10k\Omega$

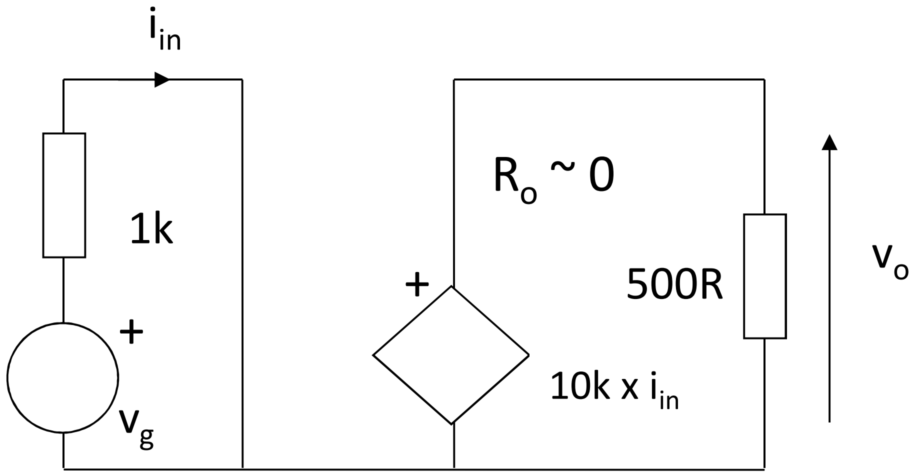
6. $V_o / V_g$ ?

# Work out $v_o$ / $v_g$

$$v_o = 10k \times i_{in}$$

$$i_{in} = \frac{v_g}{1k}$$

$$A_V = \frac{v_o}{v_g} = \frac{10k}{1k} = 10$$



# Worked Example

**Obtain a better estimate of the gain given that the loop gain is 15.**

New trans-resistance gain

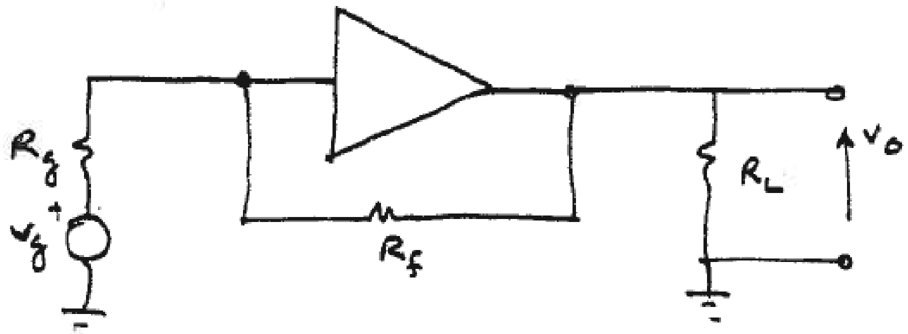
$$A_{fr} = A_{\infty}\frac{T}{1+T}$$

$$= 10k\frac{15}{1+15} = 9.375k\Omega$$

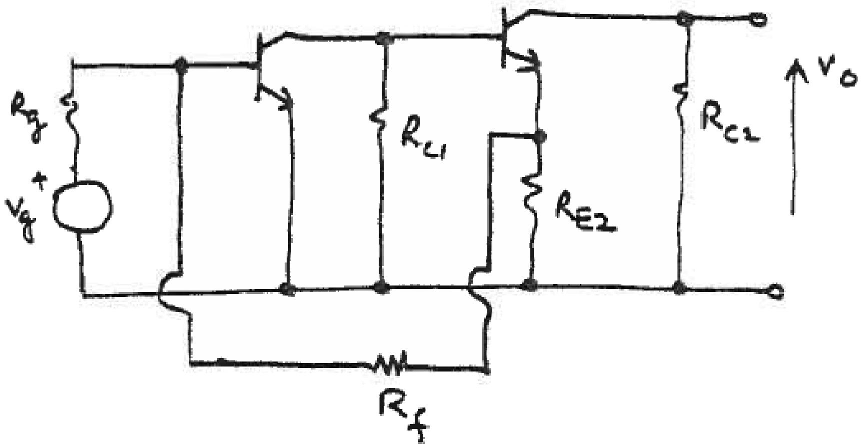
So better estimate of **voltage** gain

$$A_v = \frac{v_o}{v_g} = \frac{9.375k}{1k}$$

**= 9.375**

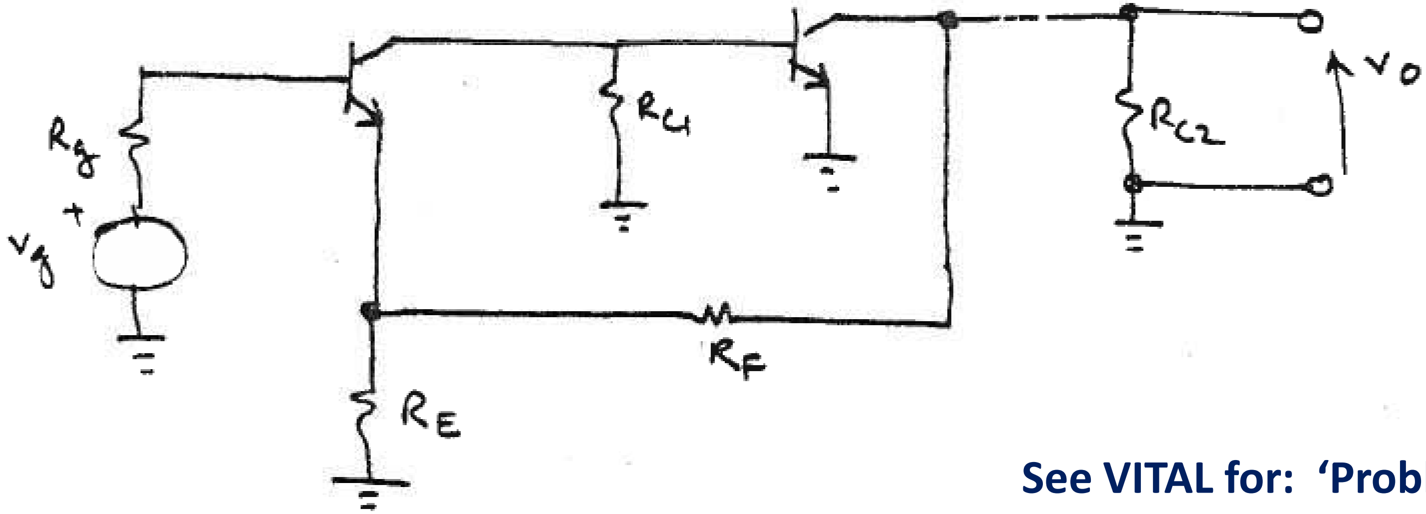


# Problem Sheet 2 (VITAL)




Assuming the loop gain is very large, show that

$$\frac{v_o}{v_g} = R_{C2} \cdot \frac{R_f + R_{E2}}{R_{E2}} \cdot \frac{1}{R_g}.$$

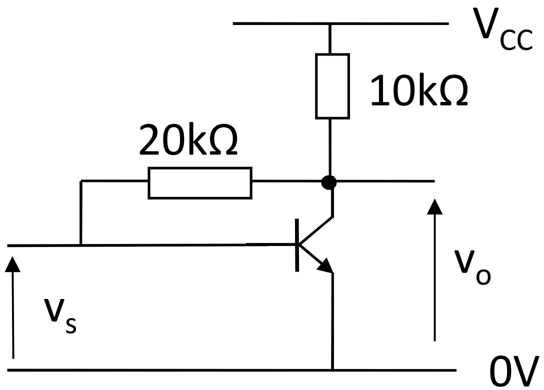



**(Bias resistors and coupling capacitors omitted for simplicity!)**

**See VITAL for: 'Problems Sheet 2'**

Solutions also! - but try the problems yourself first!!

# You try this one..

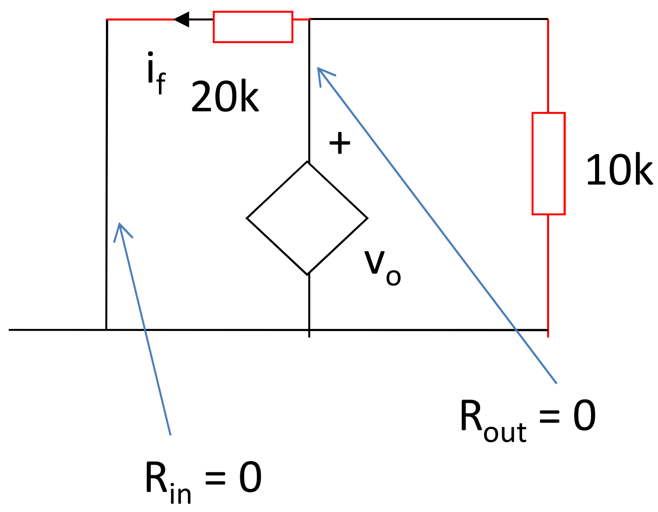



dc bias components are omitted for clarity.
Identify the feedback topology and hence the amplifier type.

output voltage sampling, input current summing;
Trans-resistance amplification is therefore stabilised.

Assuming that the amplifier has high loop gain, estimate a value for the gain that is stabilised by the feedback.

Need to find $\beta_r$ from equivalent circuit




$$v_o = i_f \times 20k$$

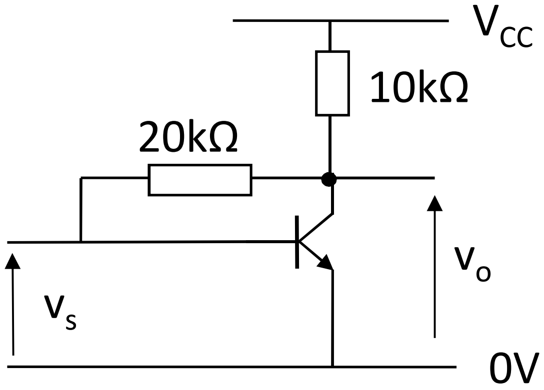
$$\beta = \frac{i_f}{v_o} = \frac{1}{20k}$$

$$\boxed{A_r \sim \frac{1}{\beta_r} = 20k}$$

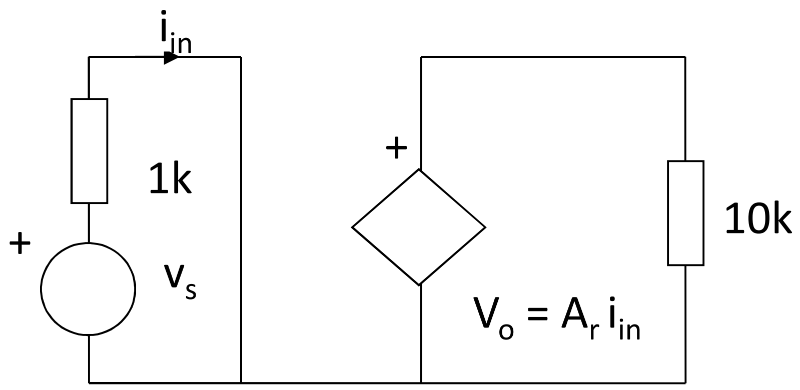
# You try this one (2)..

A signal source, $v_s$ with internal resistance, $R_S$ =1kΩ is connected to the amplifier.

Estimate the voltage gain of the amplifier




Need to draw ANOTHER equivalent circuit: for ideal Trans-R amp
Connect source and load



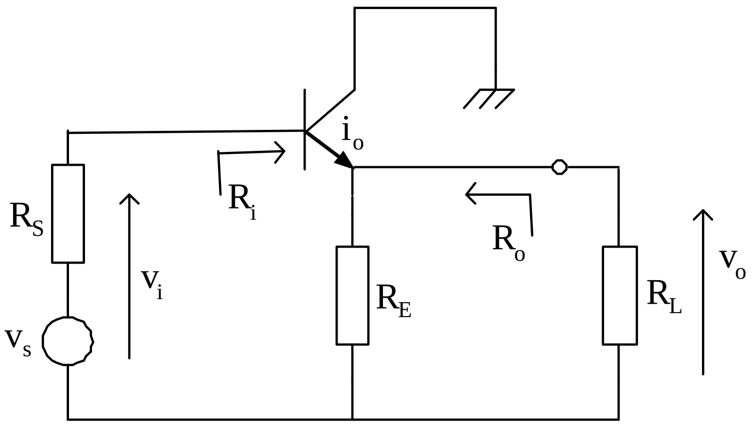

$$v_o = A_r i_{in} = A_r \frac{v_s}{1k}$$

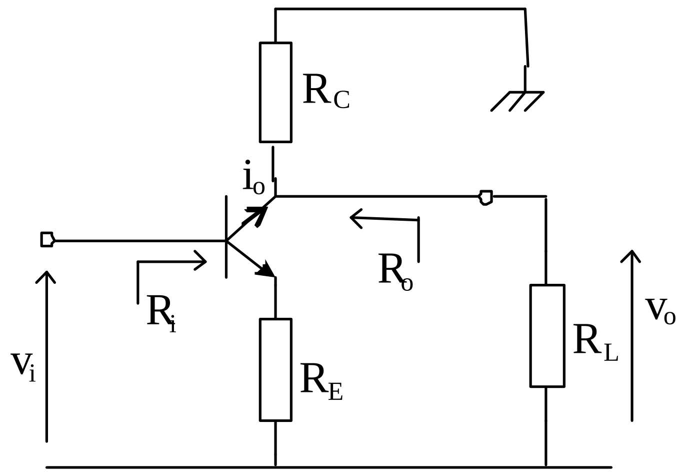
$$\frac{v_o}{v_s} = \frac{10k}{1k}$$

And voltage gain is **10**

# Exercises

These two familiar circuits have feedback!

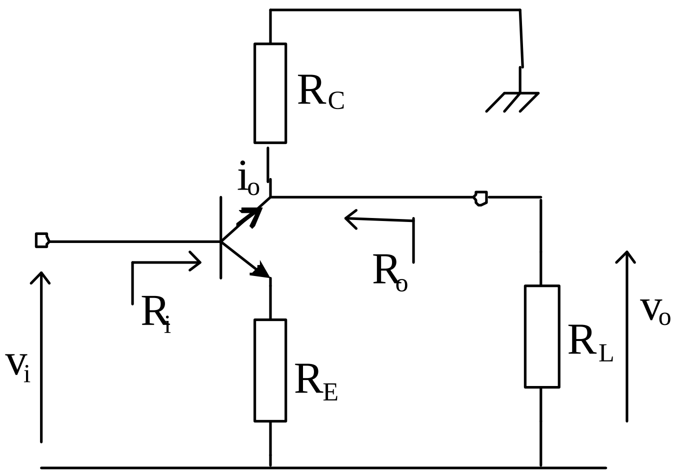



**See VITAL for: 'Problems Sheet 2'**

Solutions also! - but try the problems yourself first!!

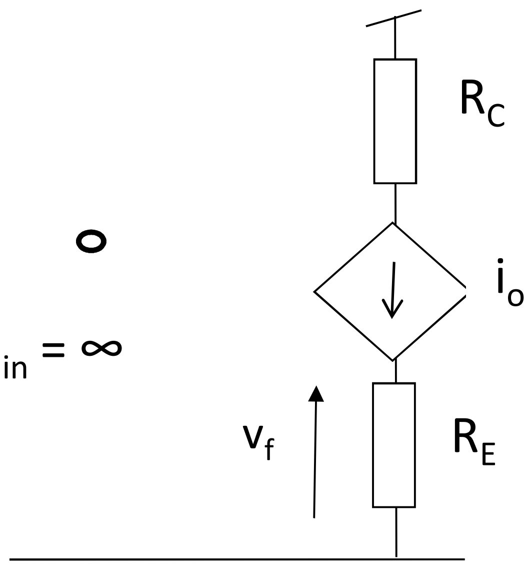
# Apply the method to CE-ED




$R_E$ - samples the output current!

Input voltage summing

So the amplifier is a stabilised transconductance amplifier!



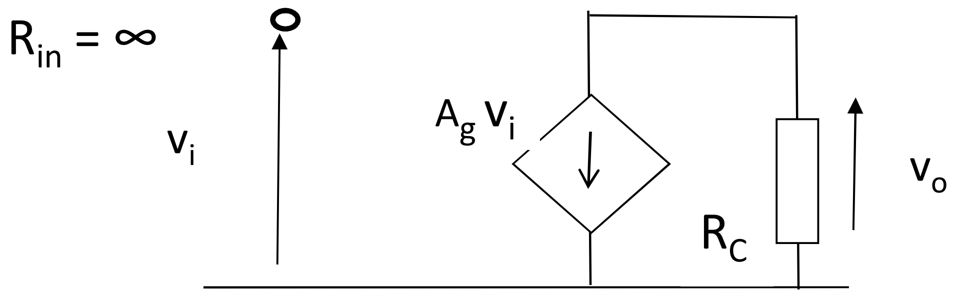

$R_{in} = \infty$

$$\beta_g = \frac{v_f}{i_o} = R_E$$

$$A_g = \frac{1}{\beta_g} = \frac{1}{R_E}$$

**Exercise:** show that the voltage gain can be estimated as $-R_C / R_E$

# Estimate the voltage gain of CE-ED



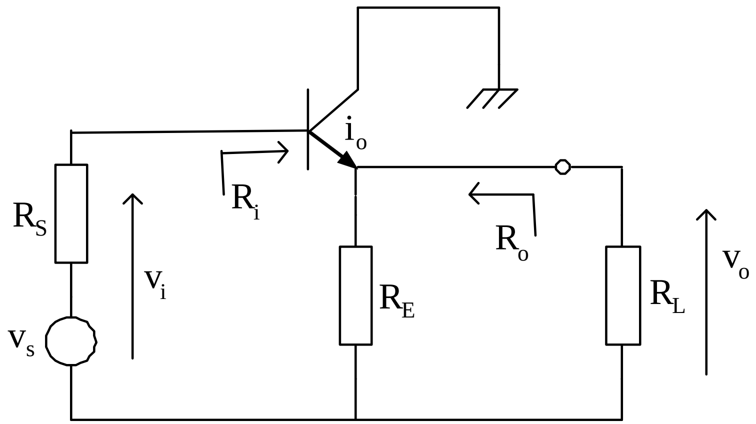

$$A_g = \frac{1}{R_E}$$

$$v_o = -A_g v_i R_C$$

$$v_o = -\frac{1}{R_E} v_i R_C$$

$$\frac{v_o}{v_i} \approx -\frac{R_C}{R_E}$$

# Apply the method to CC

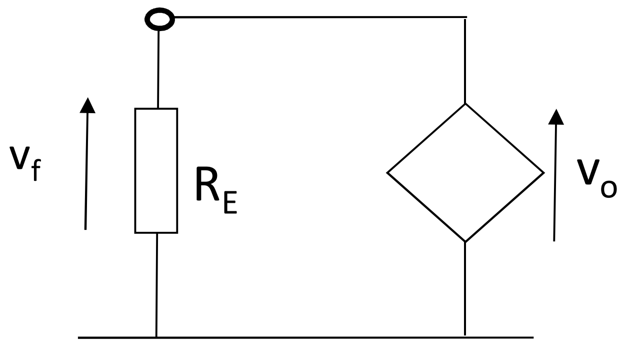



$R_E$ - samples the output voltage!

Input voltage summing

So the amplifier is a stabilised voltage amplifier!

$R_{in} = \infty$




$$\beta_v = \frac{v_f}{v_o} = 1$$

- Next we will look at operational amplifiers