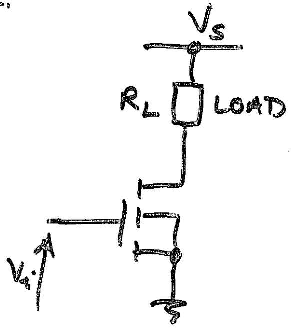
MOSFET SWITCHES

to switch device on apply >10V to gate with respect to source [absolute maximum $V_{GS} = 20$ V for most MOSFET switches]

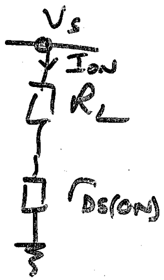


When "on" mosfet behaves like a resistor

— symbolically ... $r_{DS(on)}$

— specified by manufacturers.

On state equivalent cct



usually $R_L \gg r_{DS(on)}$

$I_{ON} \approx V_s / R_L$ ← perfectly acceptable

$$I_{ON} = \frac{V_s}{R_L + r_{DS(on)}}$$

Power lost in switch during on state $= I_{ON}^2 \, r_{DS(on)}$

Loads that contain inductance.

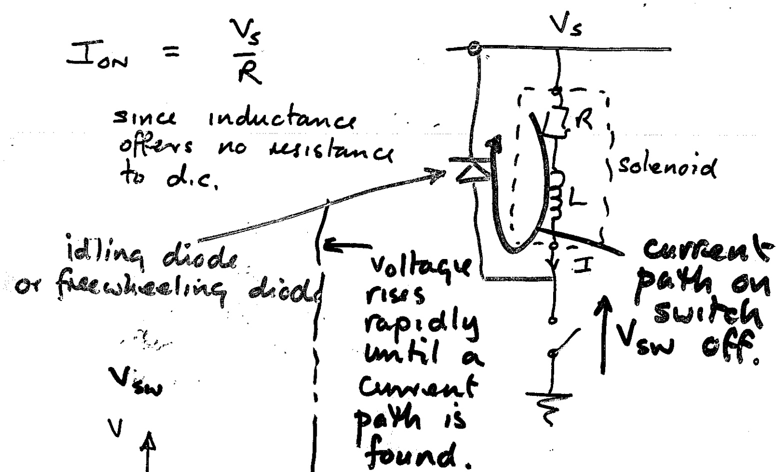
— any device that converts electrical to mechanical energy will contain inductance via magnetic fields.

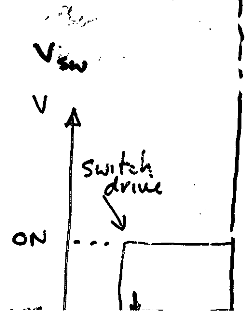
— The inductance stores energy

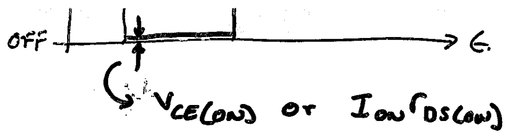
— This causes problems for switches.

$$I_{ON} = \frac{V_s}{R}$$

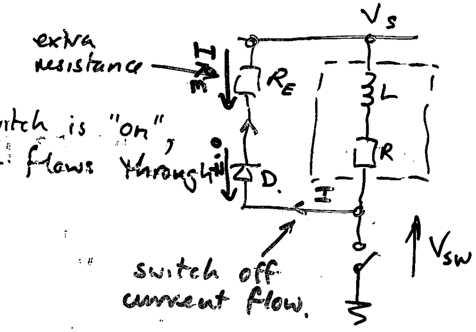
since inductance offers no resistance to d.c.







getting energy out more quickly ....



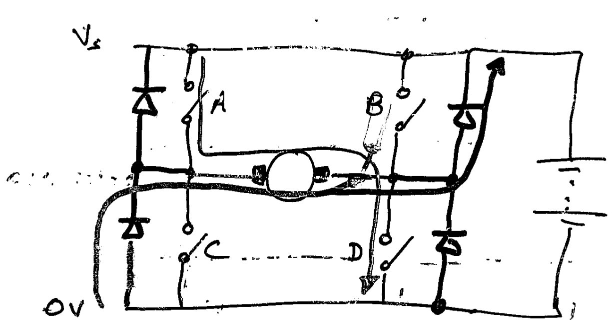
When switch is "on", no current flows through D + R_E

$I_{ON} = \frac{V_s}{R}$ immediately before switch off

so $I = \frac{V_s}{R}$ immediately after switching because L tries to keep the same current flowing.

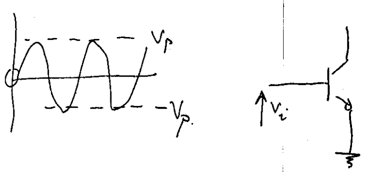
$V_{SW\ pk} = V_s + IR_E + 0.7$.

To drive electric motors ... H bridges are used --



- if A + D on. → green current
- if A + D now switch off → blue current.

Transistors as Amplifiers



— All amplifying devices work by treating the signal as a small perturbation to a set of d.c. operating conditions — ie, a bias circuit must be designed that defines I_C (for a bipolar) or I_D (for a FET)

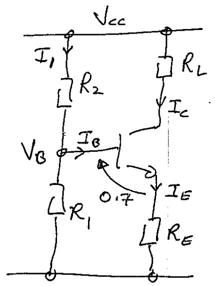
— I'll talk about BJT ccts

Bias problem is how to put a cct around the transistor that will control I_C

the objective of the bias cct is to control this.

Two sensible bias ccts...

(1)



R_1, R_2 + R_E are involved in control of I_C

Static Current gain $= \frac{I_C}{I_B}$

= large

$\approx$ 200 - 300

So $I_E = I_C + I_B$

$\approx I_C$ since $I_C \gg I_B$.

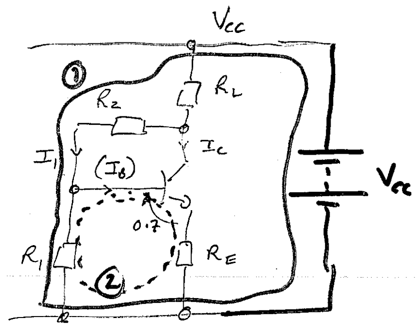
$$I_1 \approx \frac{V_{cc}}{R_1 + R_2}.$$

$$V_B = \frac{V_{cc} \cdot R_1}{R_1 + R_2} \quad \text{(assuming } I_B \text{ negligible)}$$

$$V_B = 0.7 + I_E R_E \approx 0.7 + I_C R_E \quad (\text{since } I_C \approx I_E)$$

(2)

Assume I_B negligible



loop (1)

$$I_1 R_1 + I_1 R_2 + (I_1 + I_C) R_L = V_{cc}$$

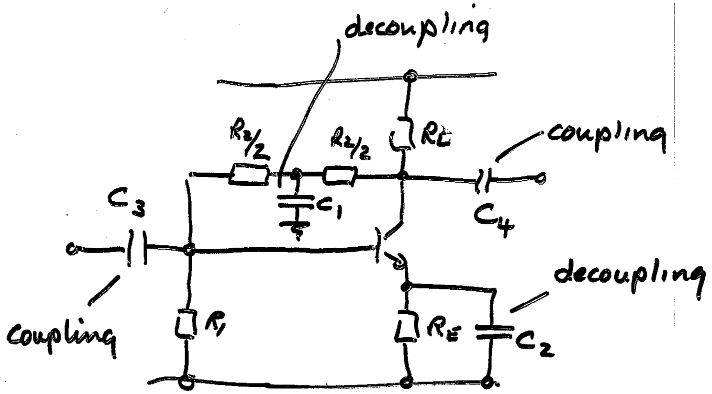
or $I_1 (R_1 + R_2 + R_L) + I_C R_L = V_{cc}$.

loop (2)

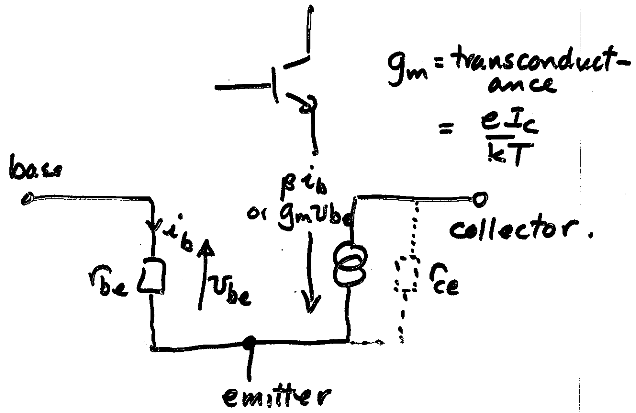
$$I_1 R_1 = 0.7 + I_C R_E \quad \left(\text{assumes } I_C \approx I_E\right)$$

Getting Signals in and Out

Getting Signals in + Out.

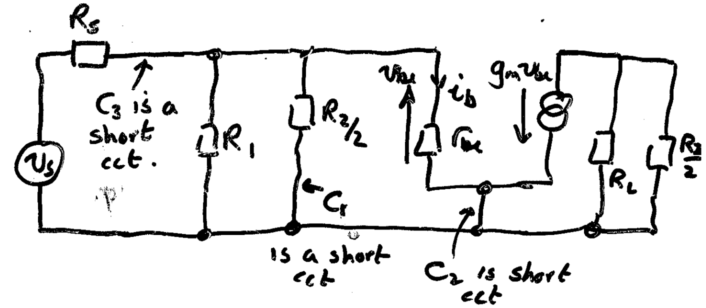


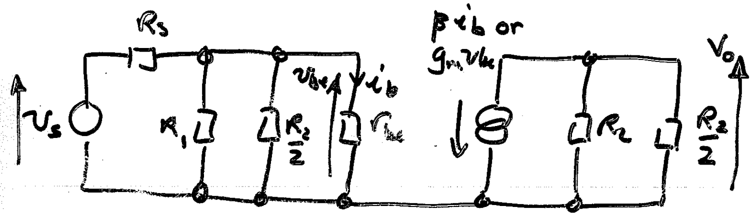
Small signal transistor model



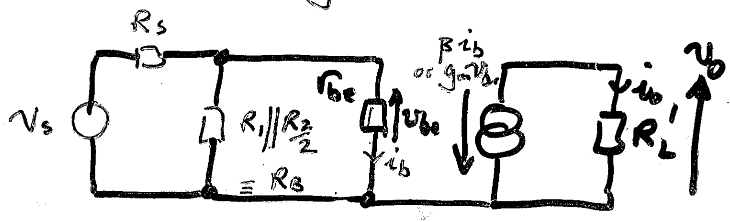
Small signal version of whole cct

— put yourself in the position of the signal ....





What is circuit gain ?



$$i_o R_L' = v_o \qquad R_L' = R_L \| \frac{R_2}{2}$$

and $i_o = -g_m v_{be}$

So $v_o = -g_m v_{be} R_L'$

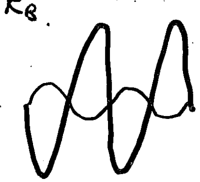
For input cct, $v_{be} = v_s \times \dfrac{r_{be} \| R_1 \| R_2/2}{R_s + r_{be} \| R_1 \| R_2/2}$

So $v_o = -g_m R_L' \cdot v_s \cdot \dfrac{r_{be} \| R_B}{R_s + r_{be} \| R_B}$

$$\frac{v_o}{v_s} = -g_m R_L' \cdot \frac{r_{be} \| R_B}{R_s + r_{be} \| R_B}.$$

means that if input is

output is

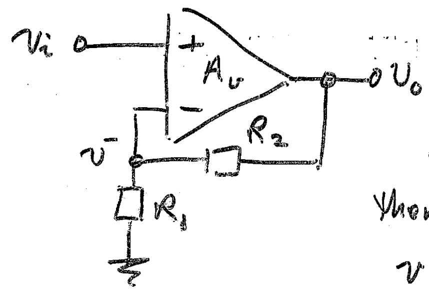


180° phase shift between input + output.

or signal shape is inverted.

Operational Amplifiers

Two basic circuits .....



Let $A_v \Rightarrow \infty$

Then since $v_o = A_v(v^+ - v^-)$

$$v^+ - v^- = \frac{v_o}{A_v} \approx 0$$

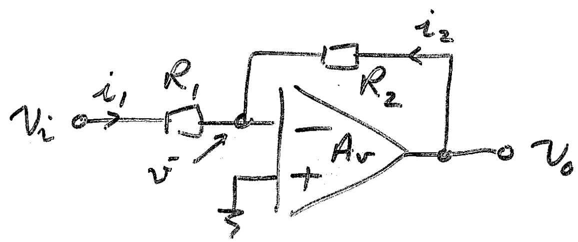
since $A_v \approx \infty$

$v^- = v_o \dfrac{R_1}{R_1 + R_2}$ (since negligible current flows into inverting input).

Since $v^+ \approx v^-$

$v_i \approx v_o \dfrac{R_1}{R_1 + R_2}$ or $\underline{\underline{\dfrac{v_o}{v_i} = \dfrac{R_1 + R_2}{R_1}}}$

Inverting Amplifier



if $A_v \Rightarrow \infty$, $v^+ \approx v^-$

but $v^+ = 0$ so $v^- \approx 0$

v^- often called a "virtual earth"

$i_1 + i_2 = 0$ since op-amp input current is negligible

$$\frac{v_i - v^-}{R_1} + \frac{v_o - v^-}{R_2} \quad \text{but } v^- \approx 0$$

$$\therefore \quad \frac{v_i}{R_1} \approx -\frac{v_o}{R_2} \quad \text{so} \quad \frac{v_o}{v_i} \approx -\frac{R_2}{R_1}$$

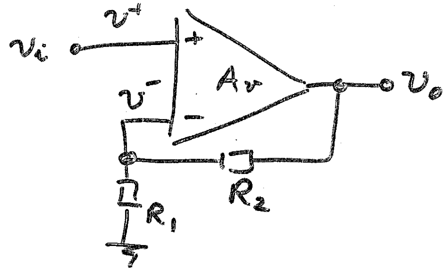
What about <u>circuit</u> input resistance?

→ very high for non-inverting; governed by input resistance of op-amp itself. (and made even larger by the effects of the feedback.

→ quite low for inverting where r_{in} for the cct $= R_1$.

If one wants to explore the effects of a finite A_v, a slightly more involved approach is needed...

v^+



$$v^+ = v_i$$

$$v^- = v_o \frac{R_1}{R_1 + R_2}$$

now use op-amp equation

$$v_o = A_v(v^+ - v^-)$$

$$= A_v\left(v_i - \frac{v_o R_1}{R_1 + R_2}\right)$$

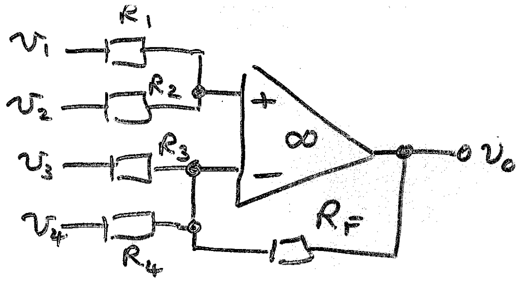
$$\frac{v_o}{A_v} + \frac{v_o R_1}{R_1 + R_2} = v_i$$

$$\frac{v_o}{v_i} = \frac{1}{\frac{1}{A_v} + \frac{R_1}{R_1 + R_2}}$$

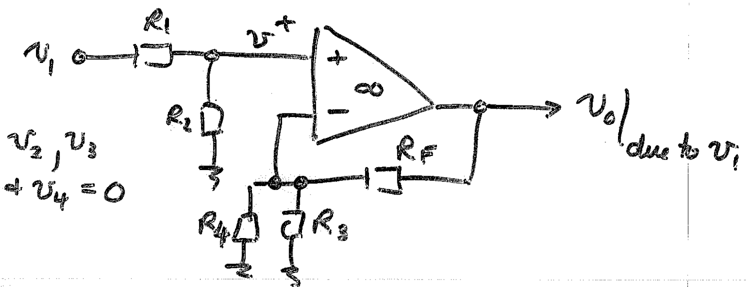
— Always use ideal approximation for initial design

Op-amps with multiple inputs....

v_i R_1



(1) using superposition



v_2, v_3
$+ v_4 = 0$

$$v_o\Big|_{v_1} = v^+ \cdot \frac{R_F + R_3 \| R_4}{R_3 \| R_4}$$

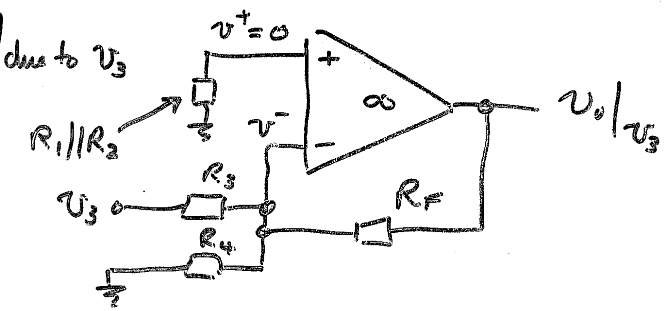
and $v^+ = \dfrac{v_1 R_2}{R_1 + R_2}$

$$v_o\Big|_{v_1} = v_1 \frac{R_2}{R_1 + R_2} \cdot \frac{R_F + R_3 \| R_4}{R_3 \| R_4}$$

$v_o\Big|_{\text{due to } v_2}$ is very similar to $v_o\Big|_{v_1}$ since only R_1 + R_2 are changed

$$v_o\Big|_{v_2} = v_2 \frac{R_1}{R_1 + R_2} \cdot \frac{R_F + R_3 \| R_4}{R_3 \| R_4}$$

$v_o\Big|_{\text{due to } v_3}$



$$v_o\Big|_{\text{due to } v_3} = v_3\left(-\frac{R_F}{R_3}\right)$$

(R_4 plays no part because $v^+ = 0$ so $v^- = 0$ so 0V across R_4 at all times)

$$v_o\Big|_{\text{due to } v_4} = v_4\left(-\frac{R_F}{R_4}\right)$$ using a similar argument.

$$v_{oT} = v_o\Big|_{v_1} + v_o\Big|_{v_2} + v_o\Big|_{v_3} + v_o\Big|_{v_4}.$$