Solutions to Part 7 Exercises

1. Derive equations for the transconductance and output resistance of a MOSFET in the linear region of operation.

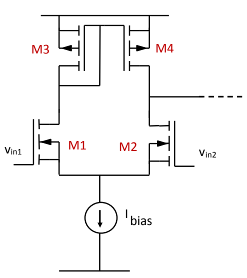
$$I_D = \beta\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$g_m = \left.\frac{\Delta I_D}{\Delta V_{GS}}\right|_{V_{DS}=const.} = \beta \times V_{DS}$$

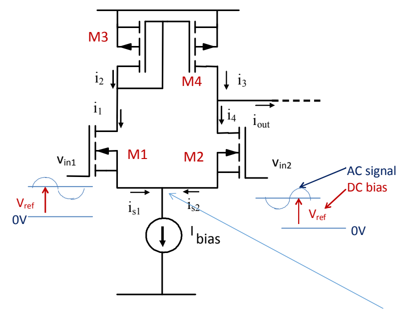
$$g_{ds} = \left.\frac{\Delta I_D}{\Delta V_{DS}}\right|_{V_{GS}=const.} = \beta \times (V_{GS}-V_T-V_{DS})$$

$$r_{ds} = \frac{1}{g_{ds}}$$

2. The figure shows a differential amplifier. Assuming that the amplifier feeds into a very large load resistance, show that the differential gain is given by $g_m \times r_{ds2} // r_{ds4}$ and the common mode is (ideally) zero. The technique is shown in part 5 – this derivation is much easier!



MOSFET Differential Amplifier



$$I_D \sim V_{GS}^2$$

$$i_1 = i_2$$

$$i_2 = i_3$$

Over 1st half of sine wave, i_1 increases, hence so does i_3

i_4 reduces, hence

$$i_{out} = i_4 - i_3$$

$$i_{s1} = -i_{s2}$$

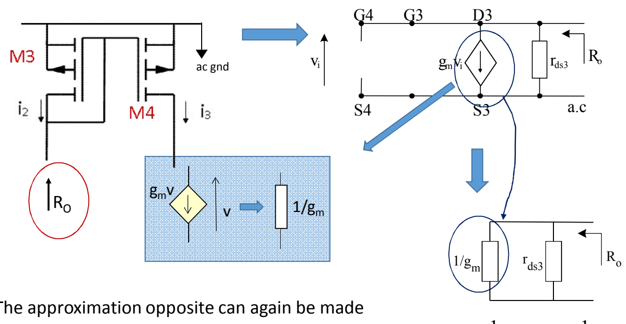
So forms an ac ground

voltage gain?

a.c. analysis: simpler than for BJTs!

Need an equivalent circuit for the current mirror load:

what 'resistance' is seen looking up into the current mirror?



The approximation opposite can again be made

(see Widlar CM notes)

$$R_o = \frac{1}{g_m} // r_{ds3} \approx \frac{1}{g_m}$$

Ac equivalent circuit for A_{Vd} (ignore r_{ds})

Note that the voltage drop across the $1/g_m$ load is

$v_4 = (g_m v_1) \times 1/g_m = v_1$

So $v_4 = v_1$

Then write:

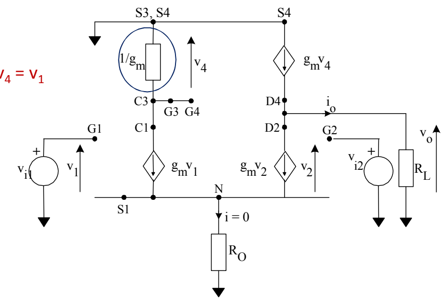
$i_o = g_m (v_4 - v_2)$ (KCL)

$= g_m (v_1 - v_2)$

$= g_m v_{id}$;

That is, $i_o = g_m v_{id}$

So $v_o = g_m v_{id} R_L$

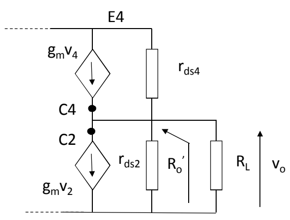


$\therefore A_{vd} = g_m R_L$ (single ended voltage gain)

Include the effect of r_{ds}'s

v_2 and v_4 are set to zero (by convention) for finding output resistance, the a.c. load is by inspection,

$R_o' = r_{ds4} // r_{ds2}$ and $R_o = r_{ds4} // r_{ds2} // R_L$



So **without** R_L $A_{Vd} = g_m (r_{ds4} // r_{ds2})$ - VERY HIGH
But **with** R_L, $A_{Vd} = g_m (r_{ds4} // r_{ds2} // R_L)$

if $R_L \ll r_{ds4} // r_{ds2}$, then $A_{Vd} \sim g_m R_L$ - VOLTAGE GAIN MUCH REDUCED if R_L small!

→ ensure that the diff. amp. is not fed into a low impedance stage!

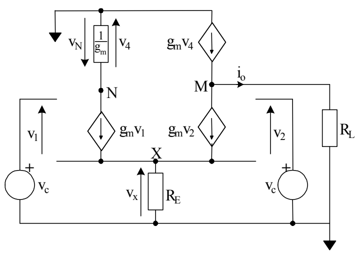
Common Mode Gain

Currents in left and right-hand sides of the circuit are the same (by CM action), so

$i_o = 0$

$v_o = 0$

$A_{vc} = 0$



Ideally, the common-mode gain is zero! (In reality, very small)