TFE4152 - Lecture 9

Current mirrors and Amplifiers

Source

Week	Book	Monday	Book	Friday
34		Introduction, what are we going to do in this course. Why do you need it?	WH 1 , WH 15	Manufacturing of integrated circuits
35	CJM 1.1	pn Junctions	CJM 1.2 WH 1.3, 2.1-2.4	Mosfet transistors
36	CJM 1.2 WH 1.3, 2.1-2.4	Mosfet transistors	CJM 1.3 - 1.6	Modeling and passive devices
37		Guest Lecture - Sony	CJM 3.1, 3.5, 3.6	Current mirrors
38	CJM 3.2, 3.3,3.4 3.7	**Amplifiers**	CJM, CJM 2 WH 1.5	SPICE simulation and layout
39		Verilog		Verilog
40	WH 1.4 WH 2.5	CMOS Logic	WH 3	Speed
41	WH 4	Power	WH 5	Wires
42	WH 6	Scaling Reliability and Variability	WH 8	Gates
43	WH 9	Sequencing	WH 10	Datapaths - Adders
44	WH 10	Datapaths - Multipliers, Counters	WH 11	Memories
45	WH 12	Packaging	WH 14	Test
46		Guest lecture - Nordic Semiconductor		
47	CJM	Recap of CJM	WH	Recap of WH

Goal for today

Current mirrors

Amplifiers

Errata

Process variations - Correction

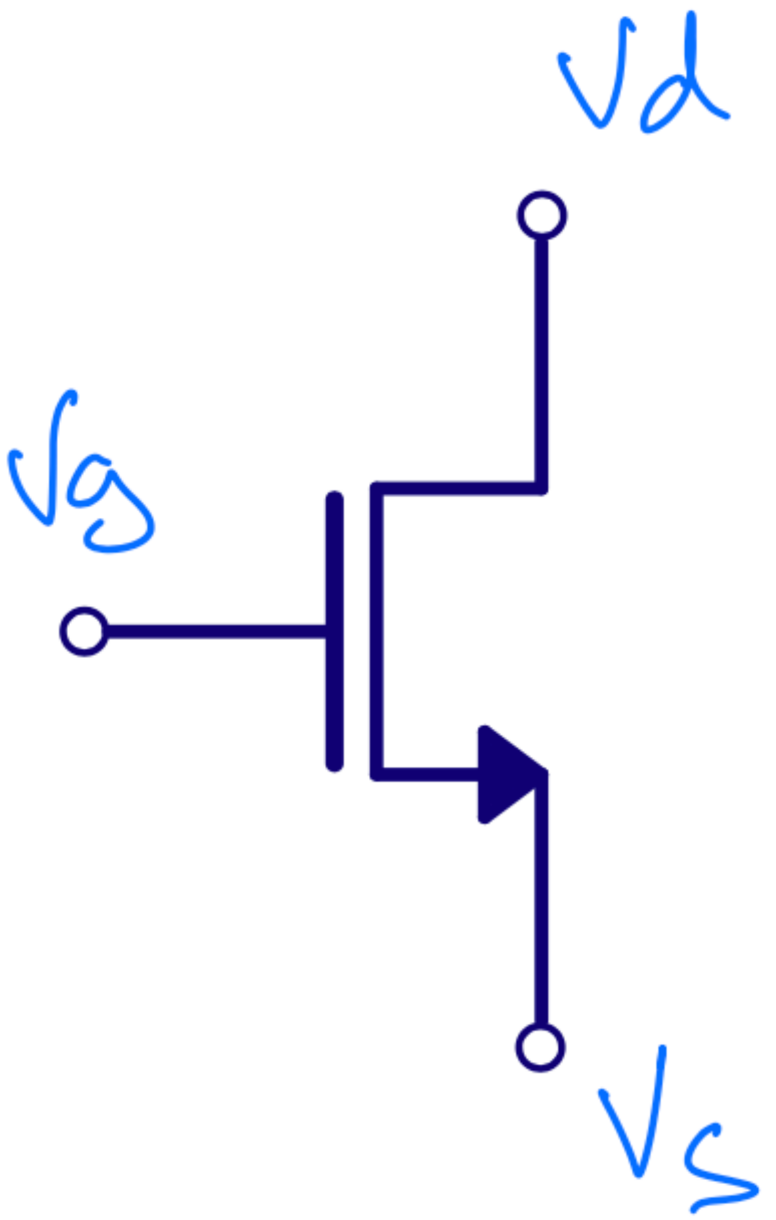
Wrong

Assume strong inversion and active $V_{eff} = \sqrt{2\mu_p C_{ox}\frac{W}{L} I_1}$

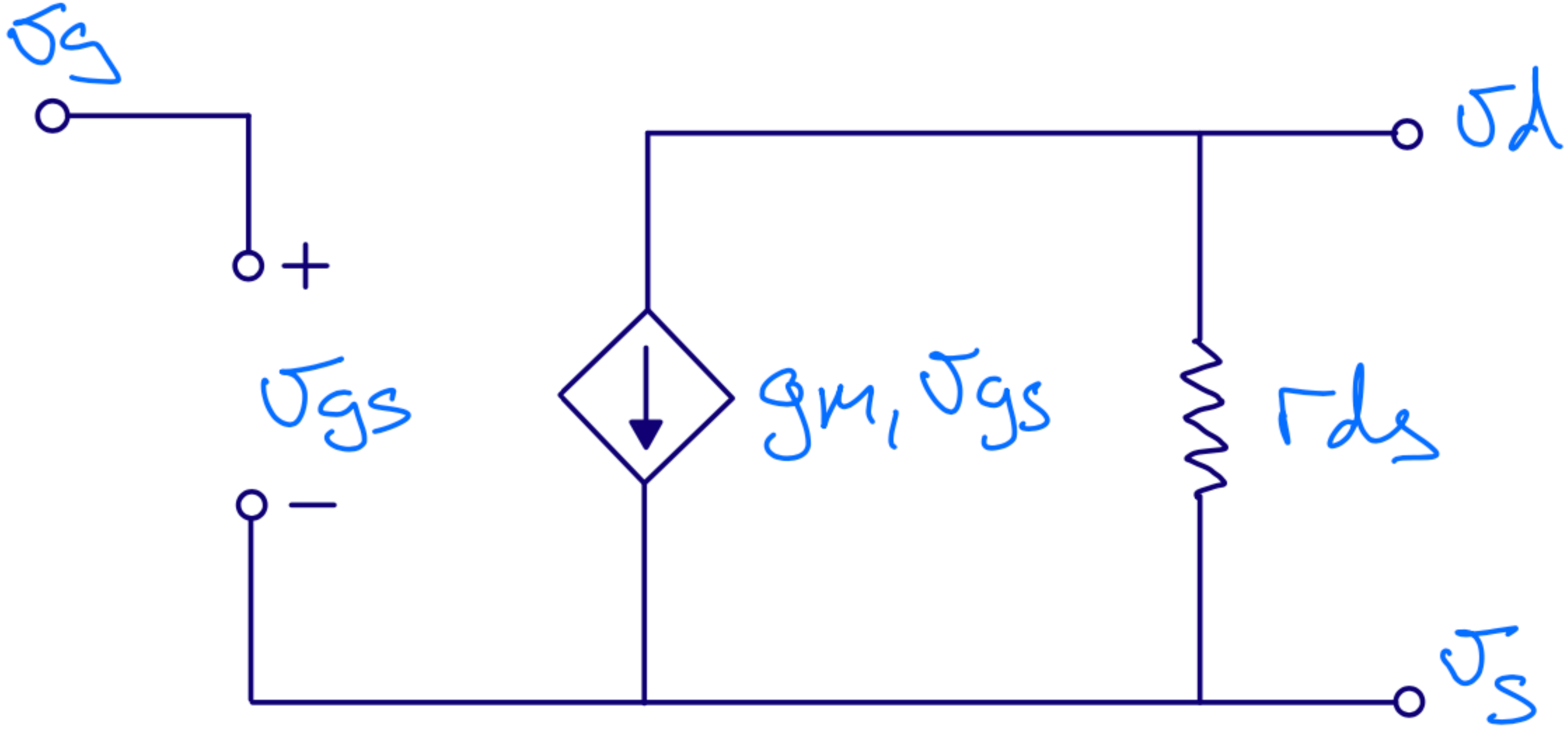
Correct

Assume strong inversion and active $V_{eff} = \sqrt{\frac{2}{\mu_p C_{ox}\frac{W}{L}} I_1}$

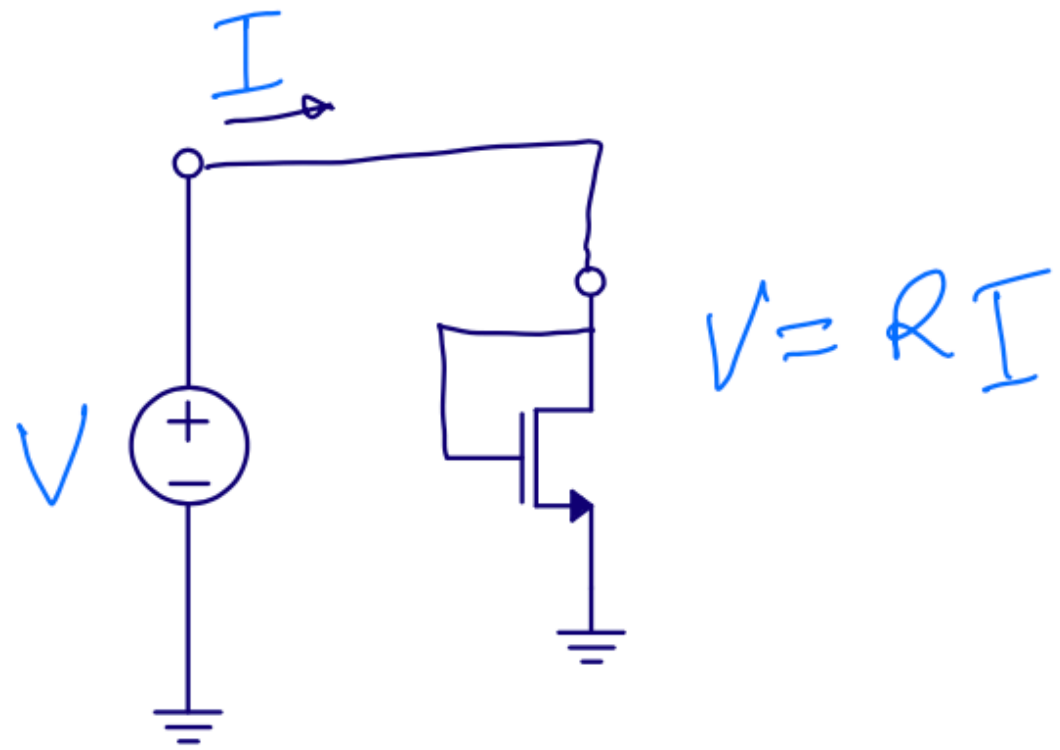
Large signal vs small signal

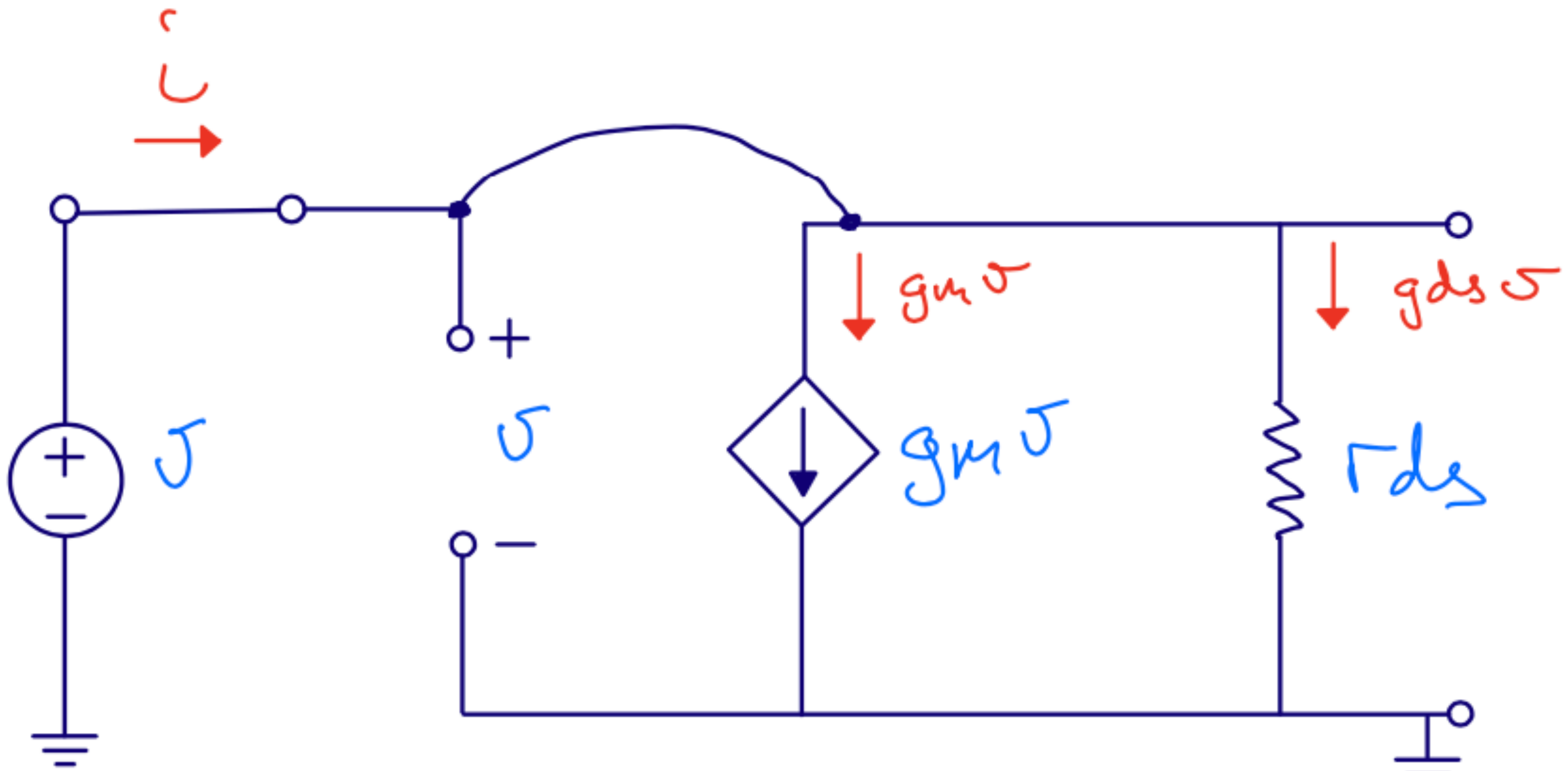


Large signal



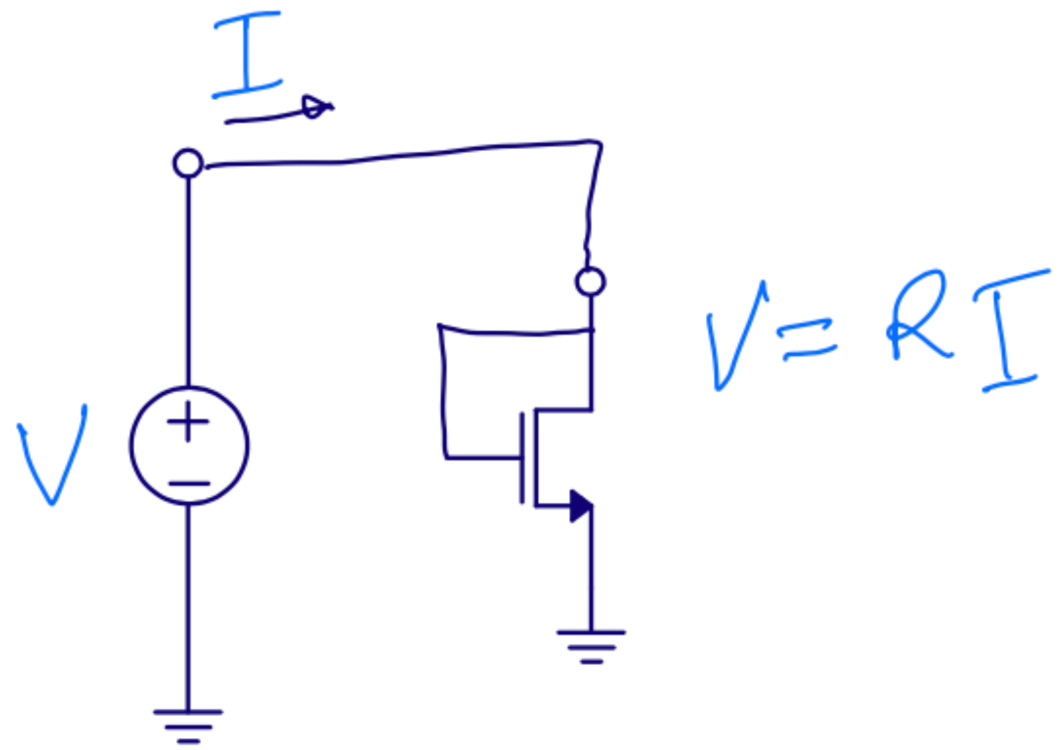
Small signal

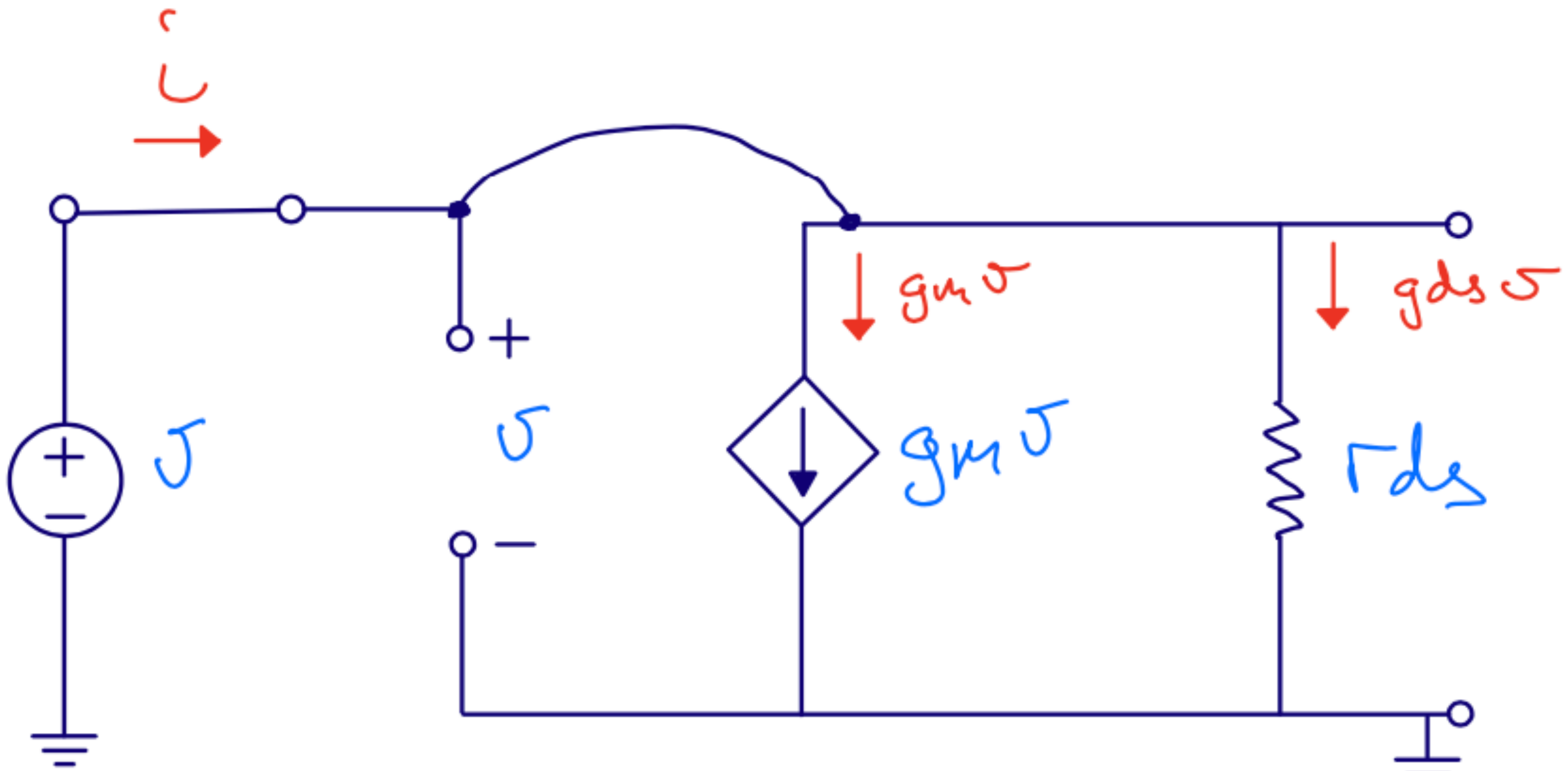




$$I \neq i$$

$$V \neq v$$

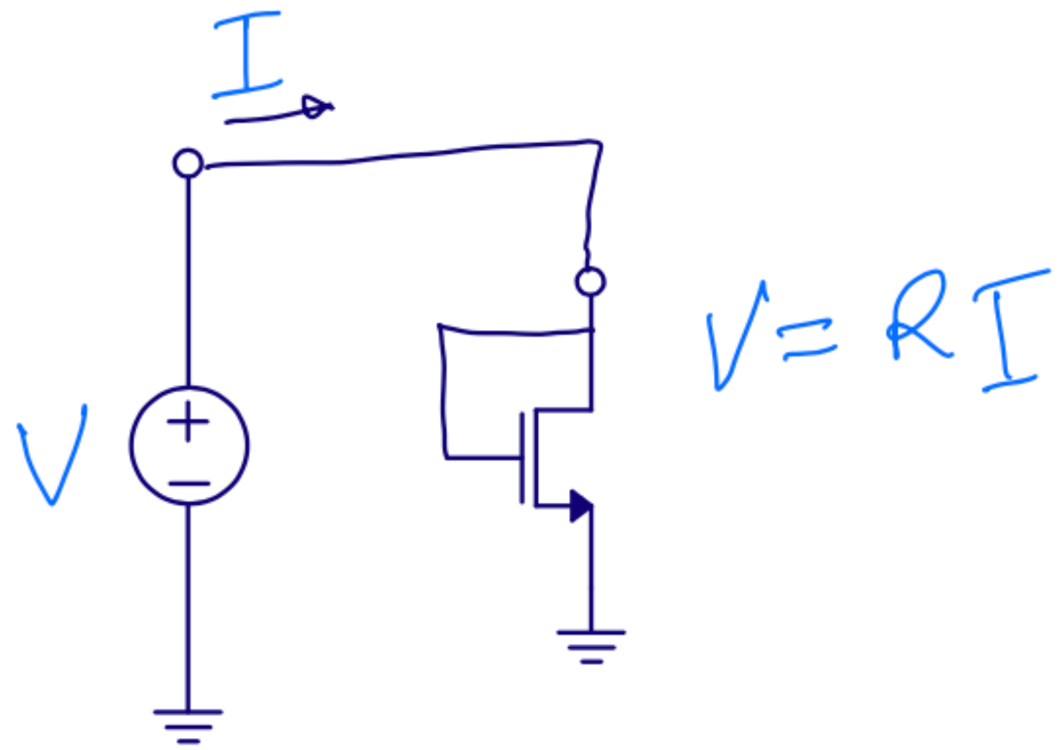


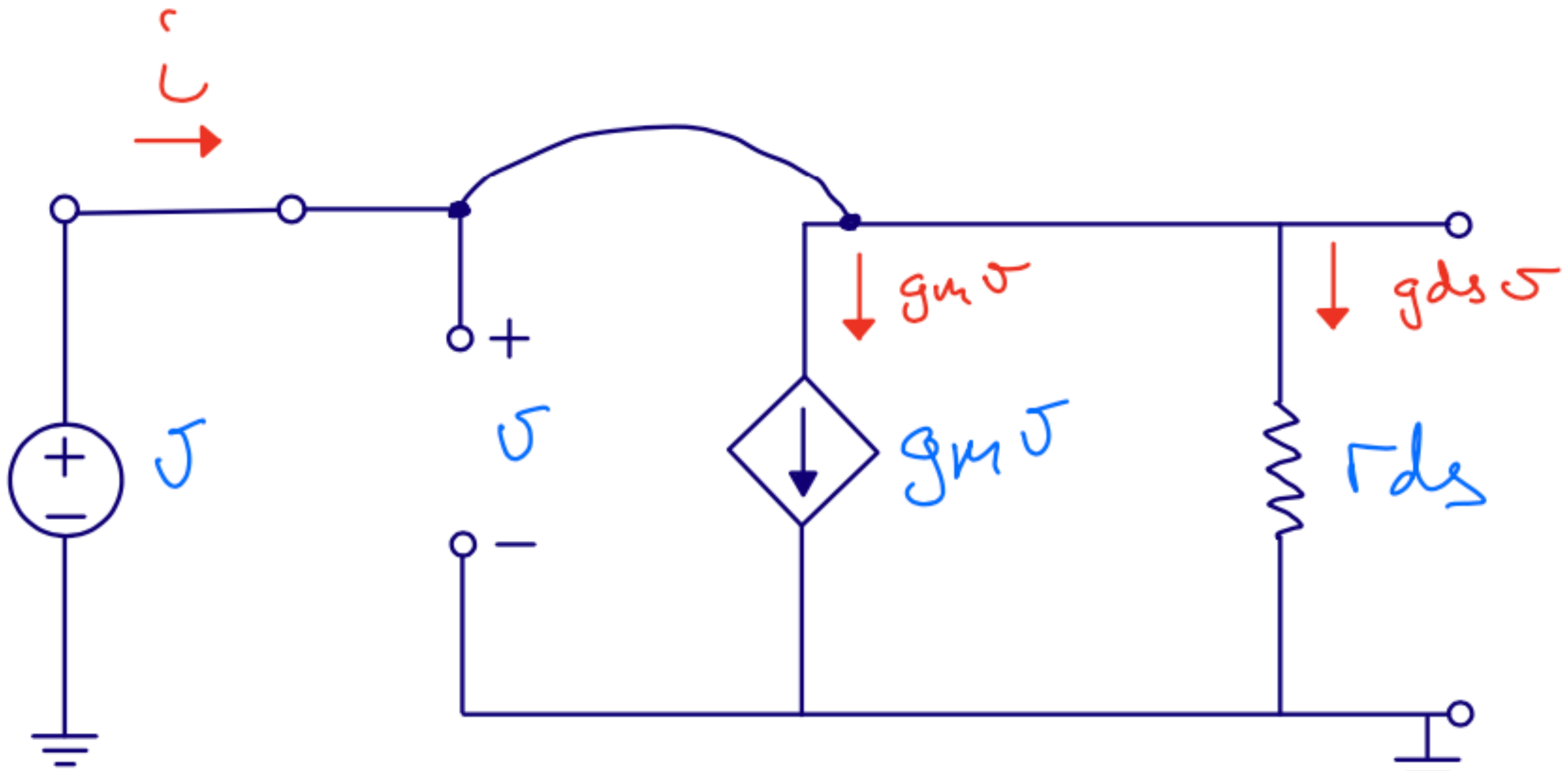


$$I = I_{bias} + i$$

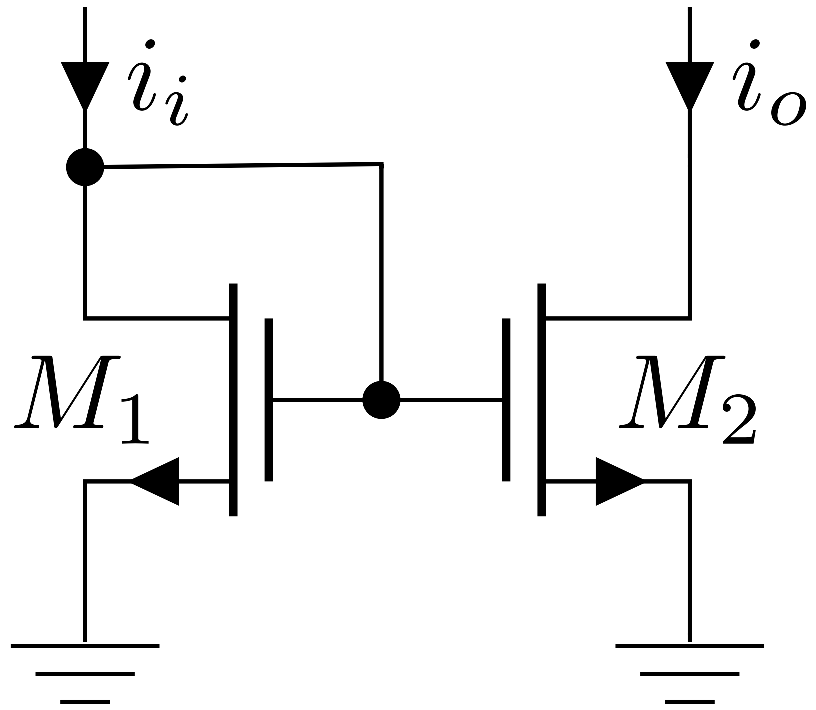
$$V = V_{bias} + v$$

Current Mirror

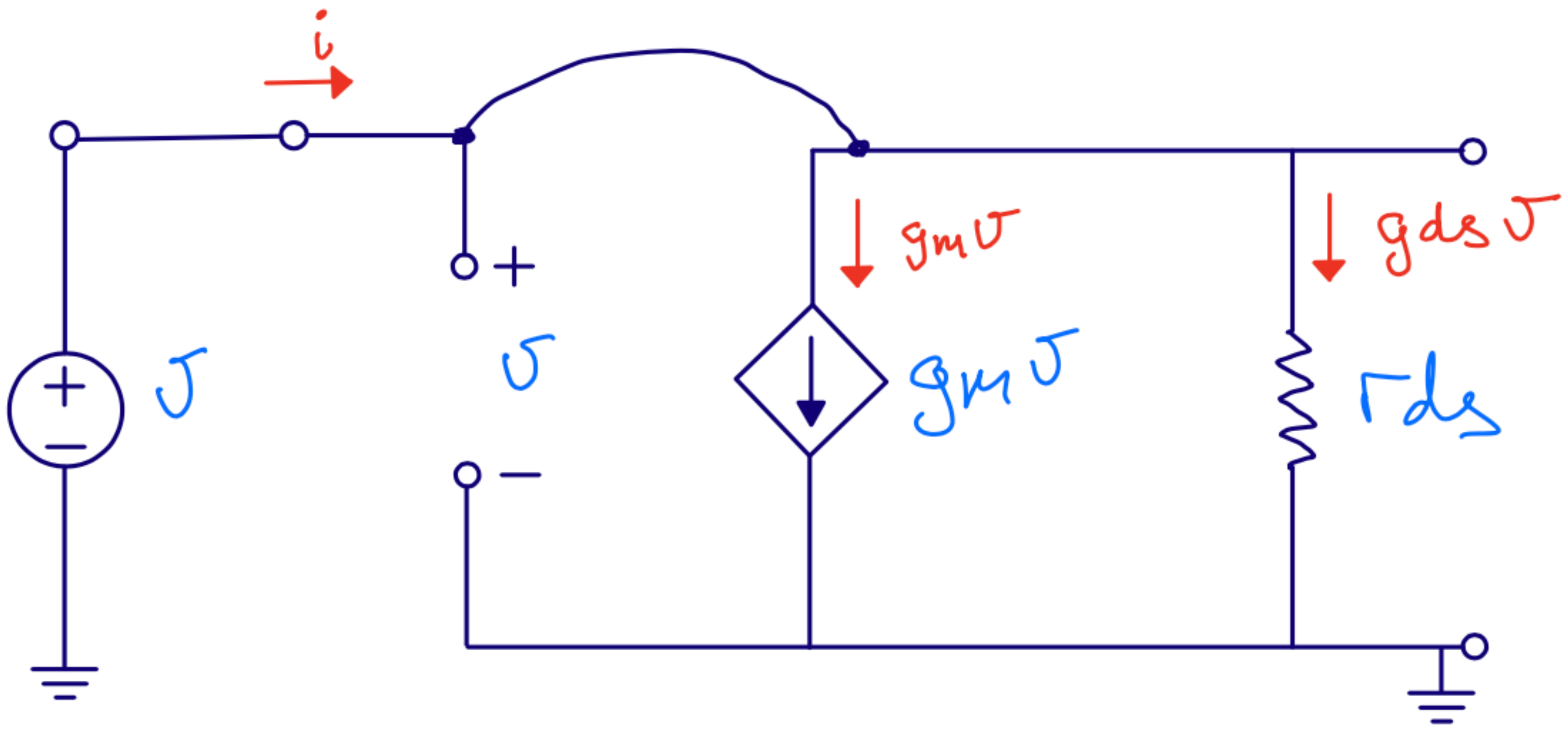




M_1 is diode connected ($V_G = V_D$)



Current mirror r_{in}



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

$$r_{in} = \frac{v}{i}$$

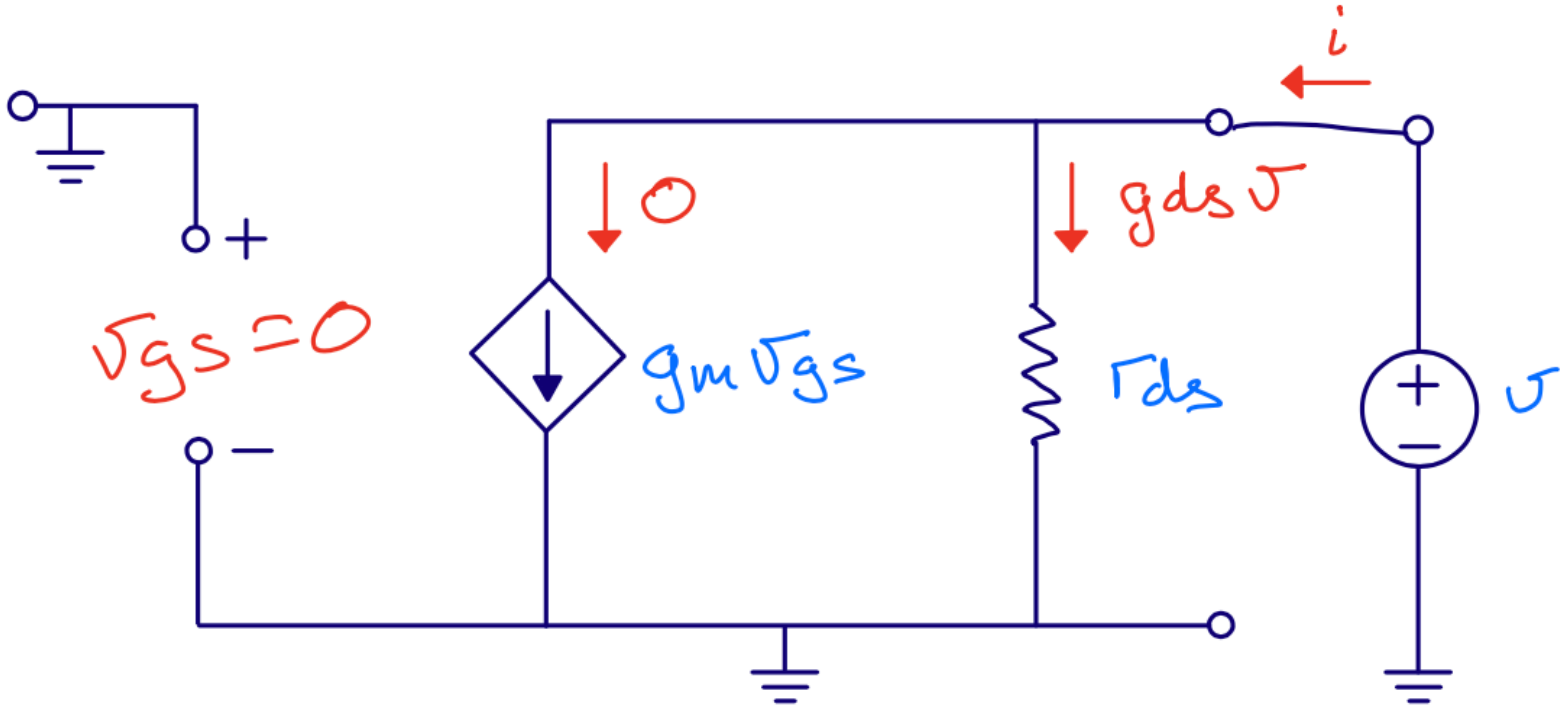
$$i = g_m v + g_{ds} v$$

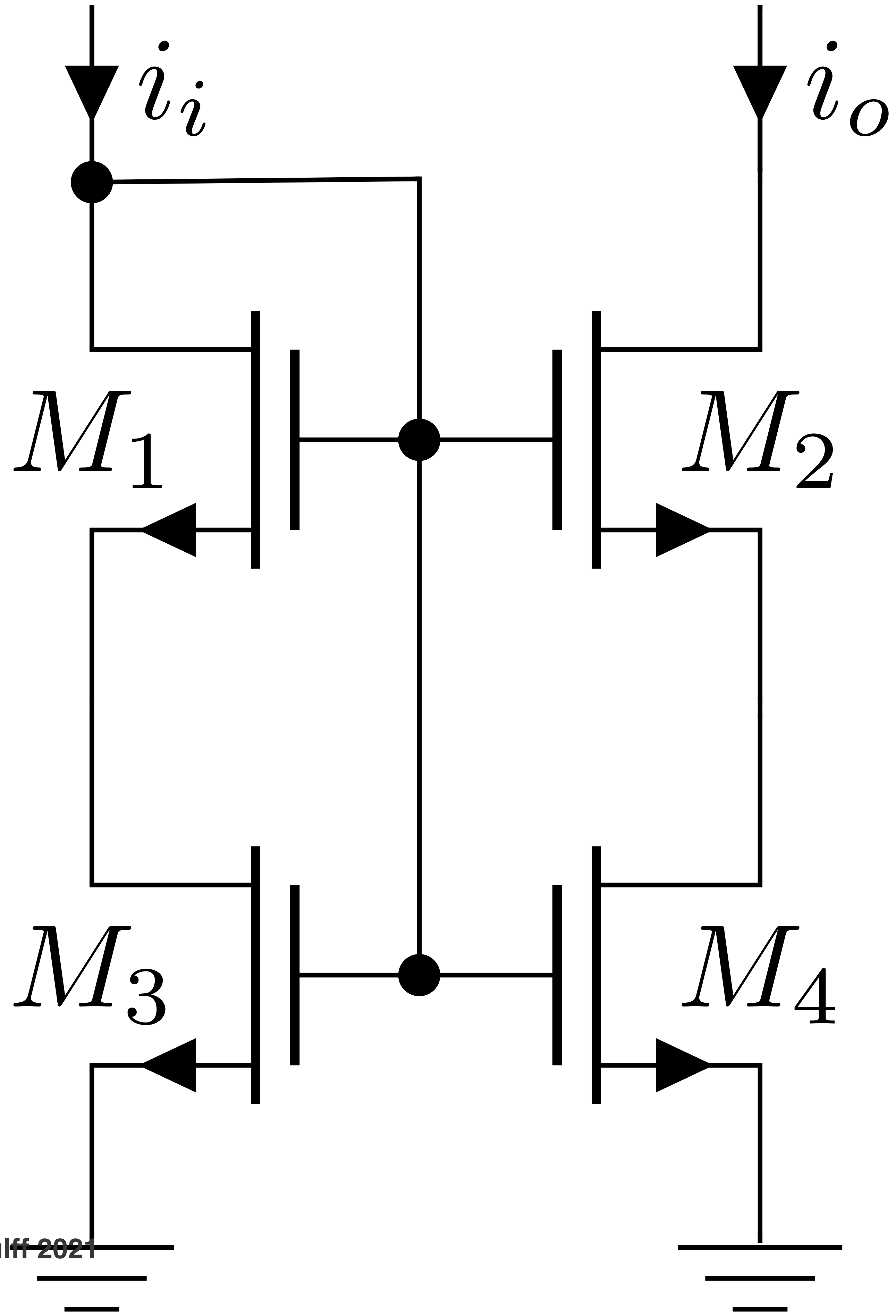
$$r_{in} = \frac{1}{gm + gds} \approx \frac{1}{gm}$$

Current mirror r_{out}

Output voltage does not affect v_{gs}

$r_{out} = r_{ds}$

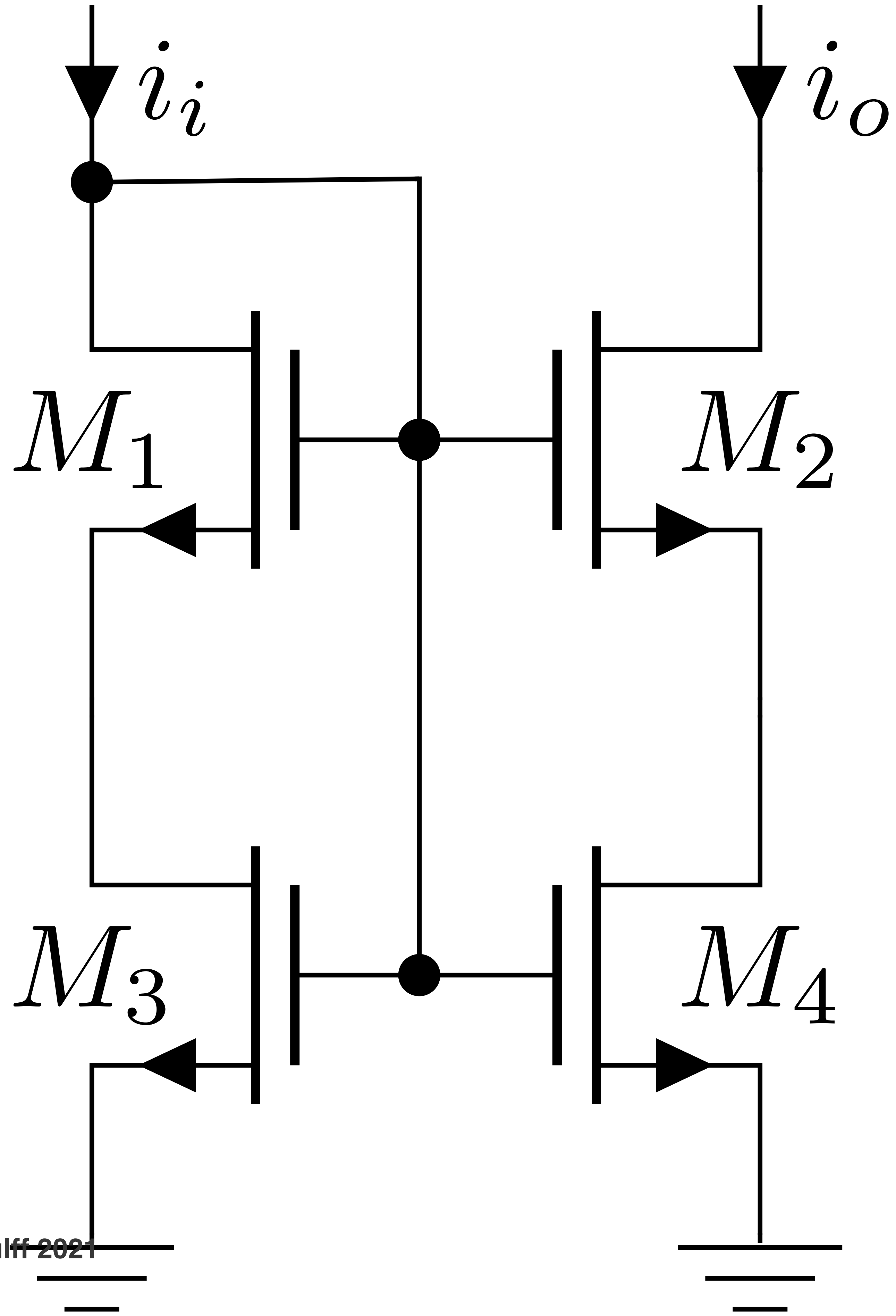


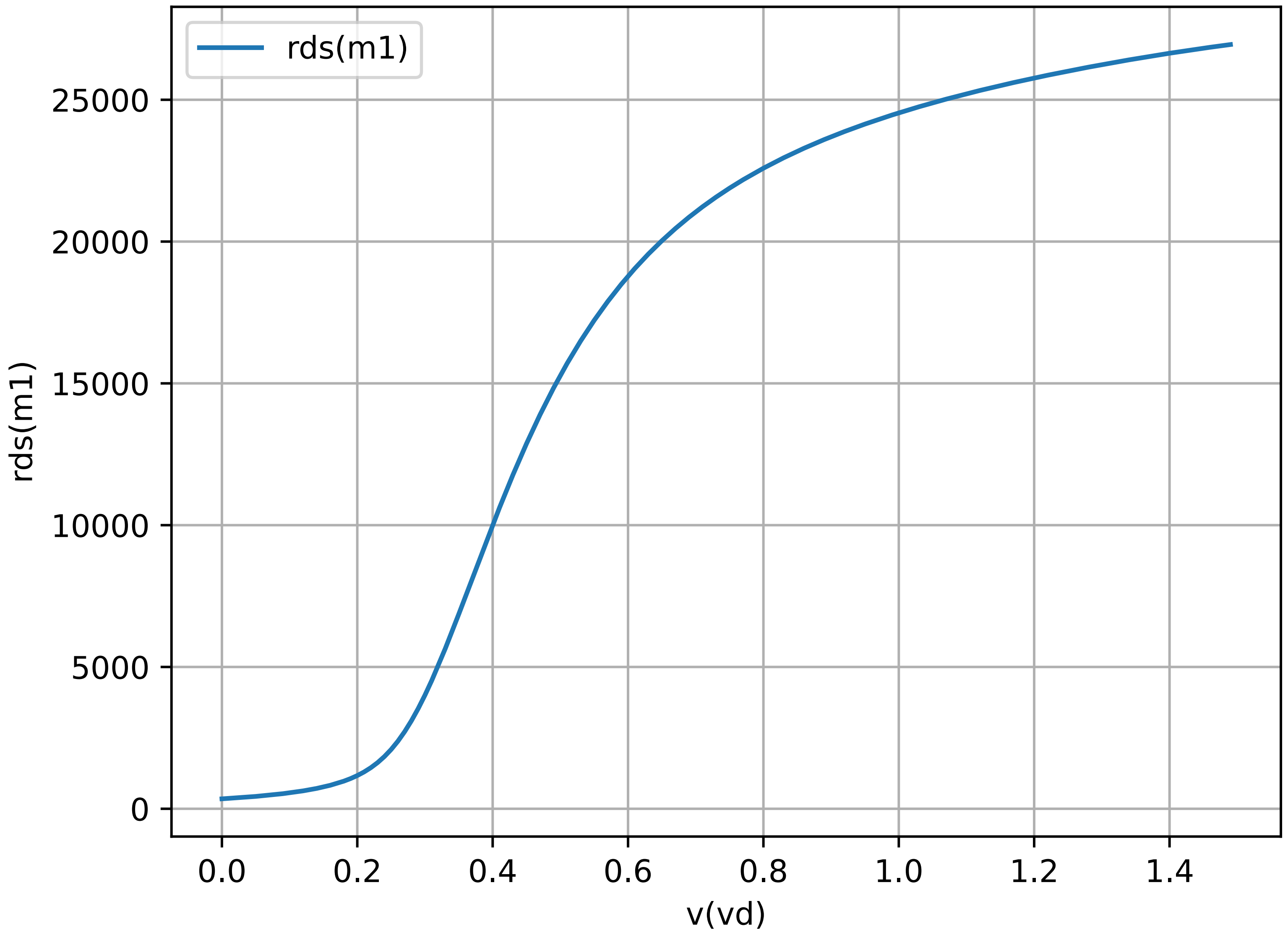


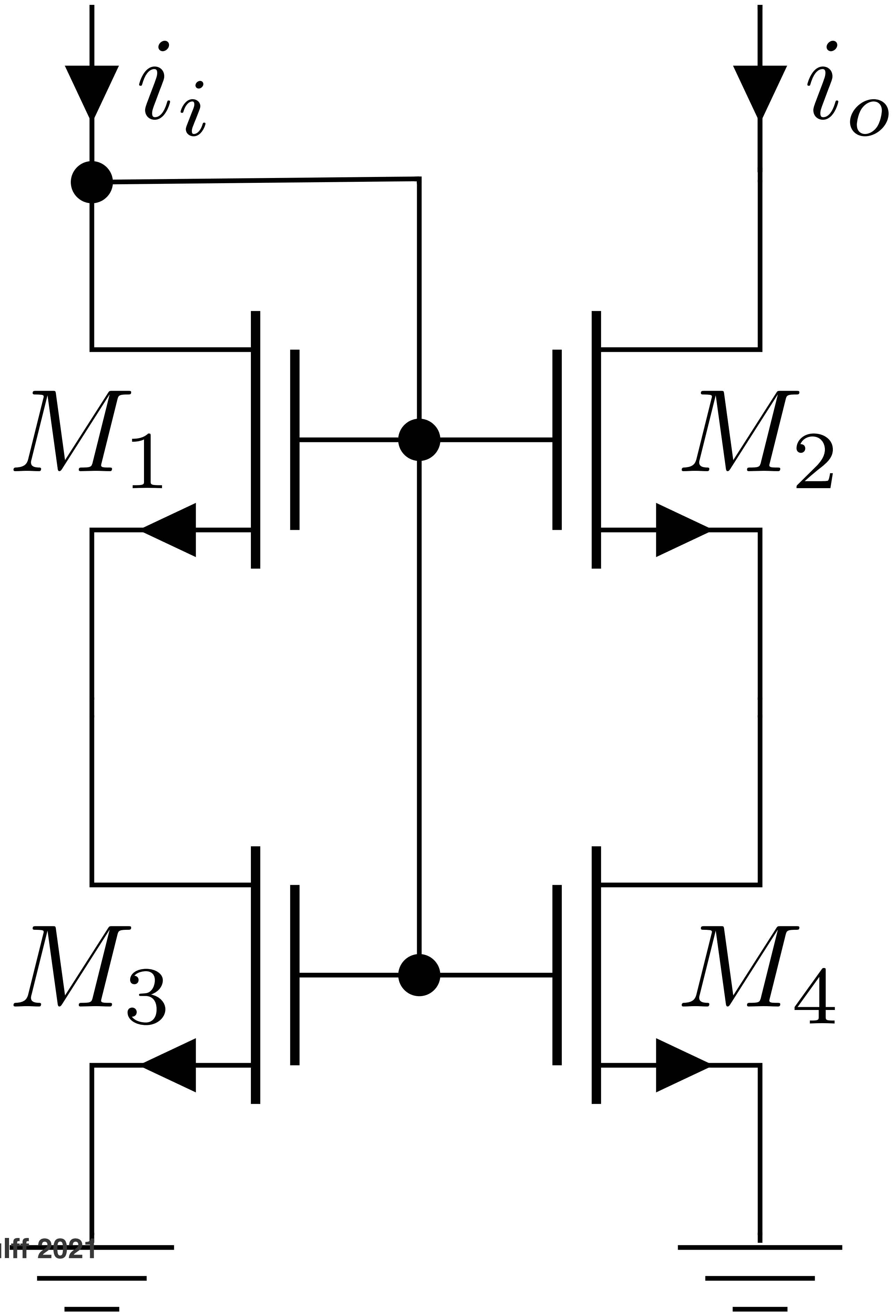
Source degeneration

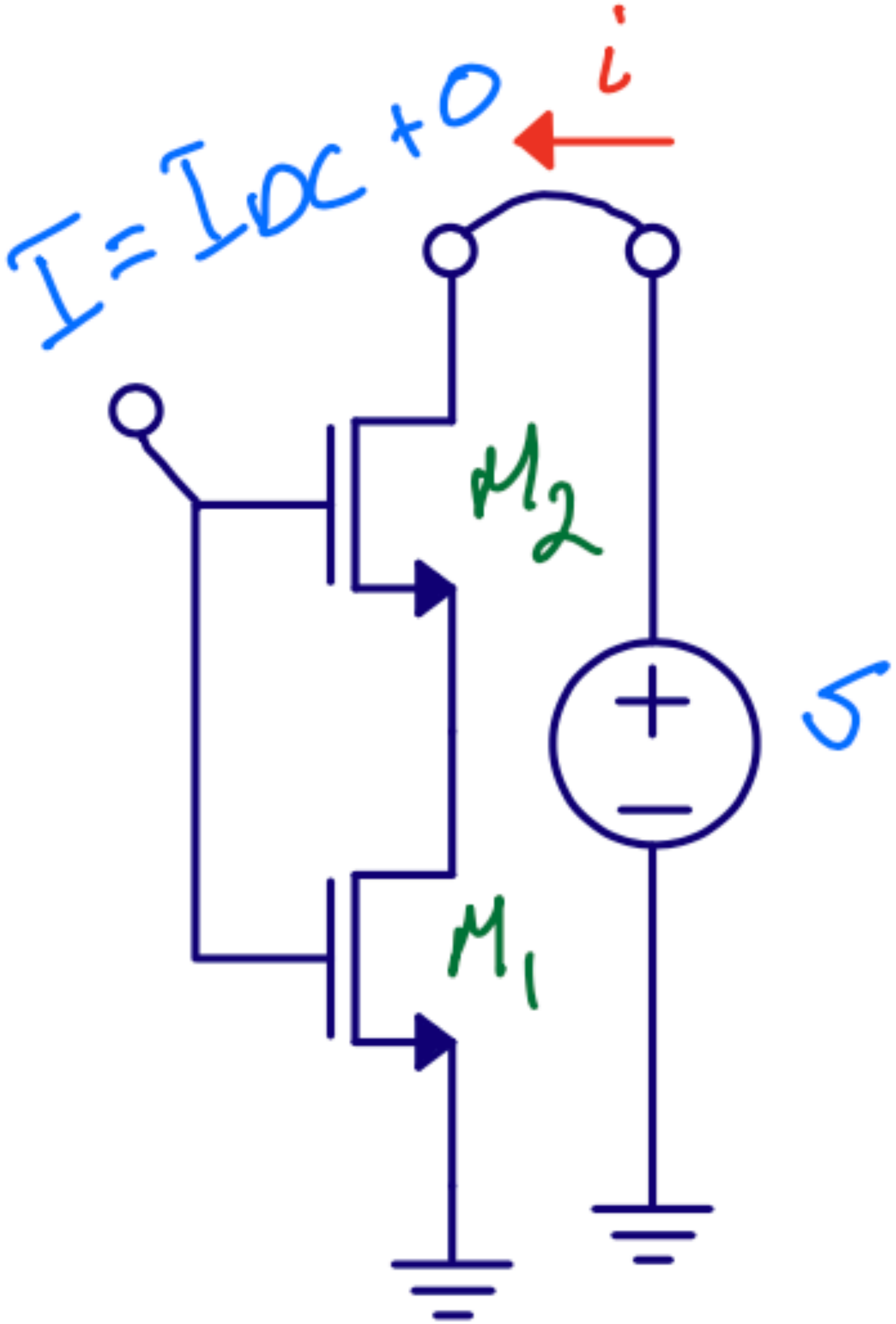
What is the operating region of M3 and M4?

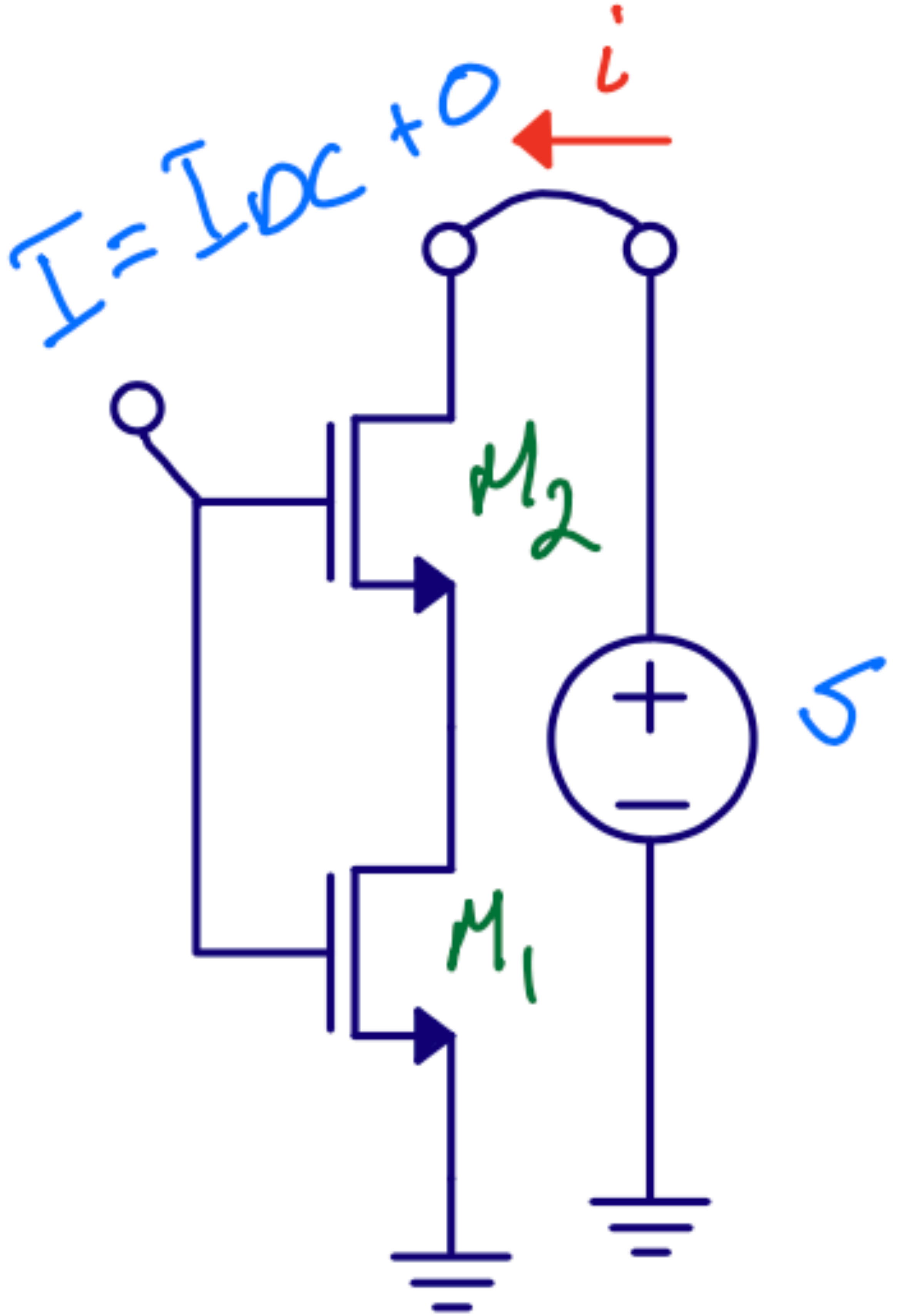
What is the operating region of M1 and M2?

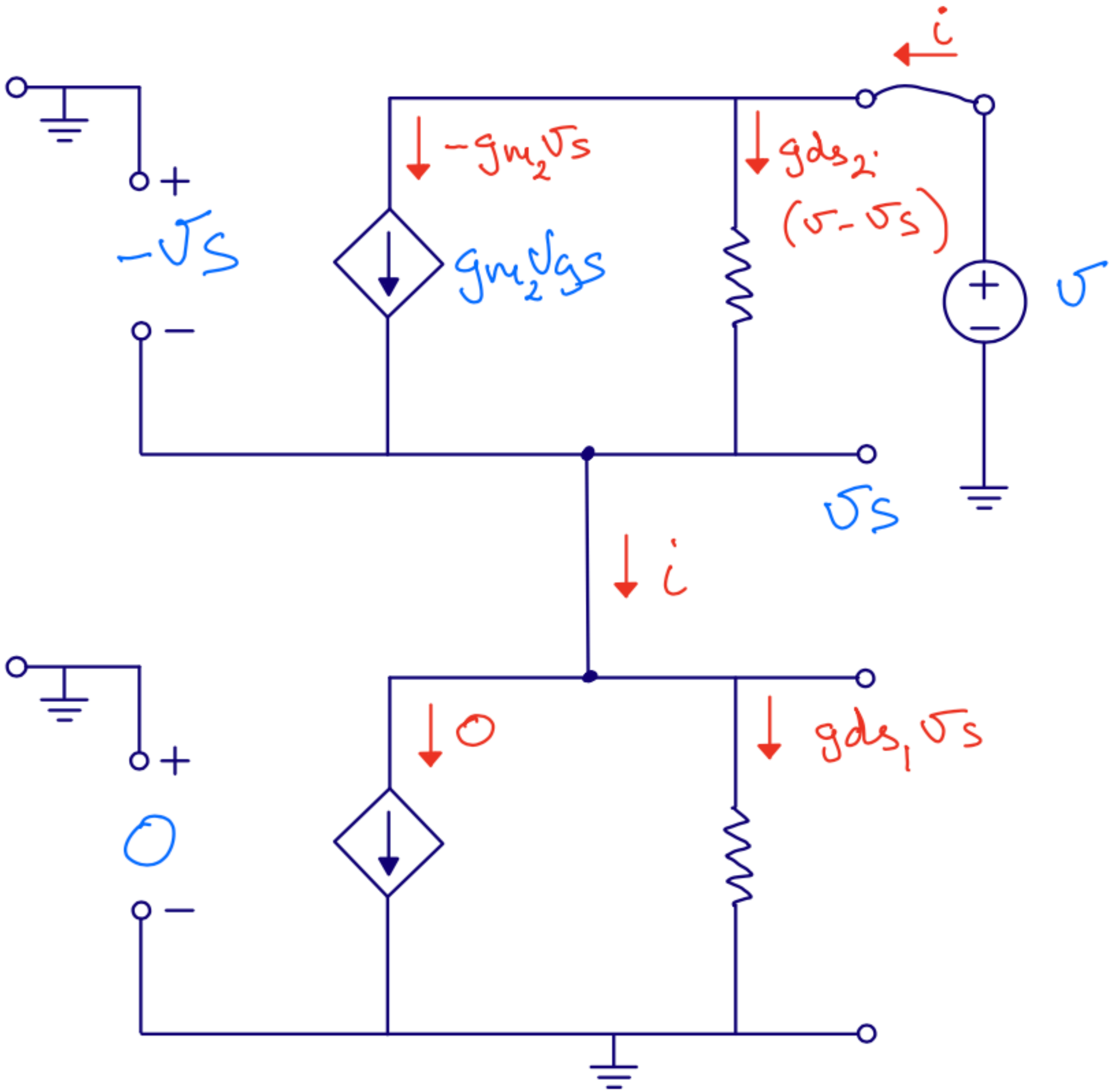

i_i
i_o
M_1
M_2
M_3
M_4


rds(m1)
rds(m1)
v(vd)
0
5000
10000
15000
20000
25000
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4


i_i
i_o
M_1
M_2
M_3
M_4


$I = I_{DC} + 0$
i
M_2
M_1
5


I = IDC + 0
i
M2
M1
v


i
-gm2 vs
gds2 (v - vs)
-vs
gm2 vgs
v
vs
i
0
gds1 vs
0

Source degeneration r_{out}

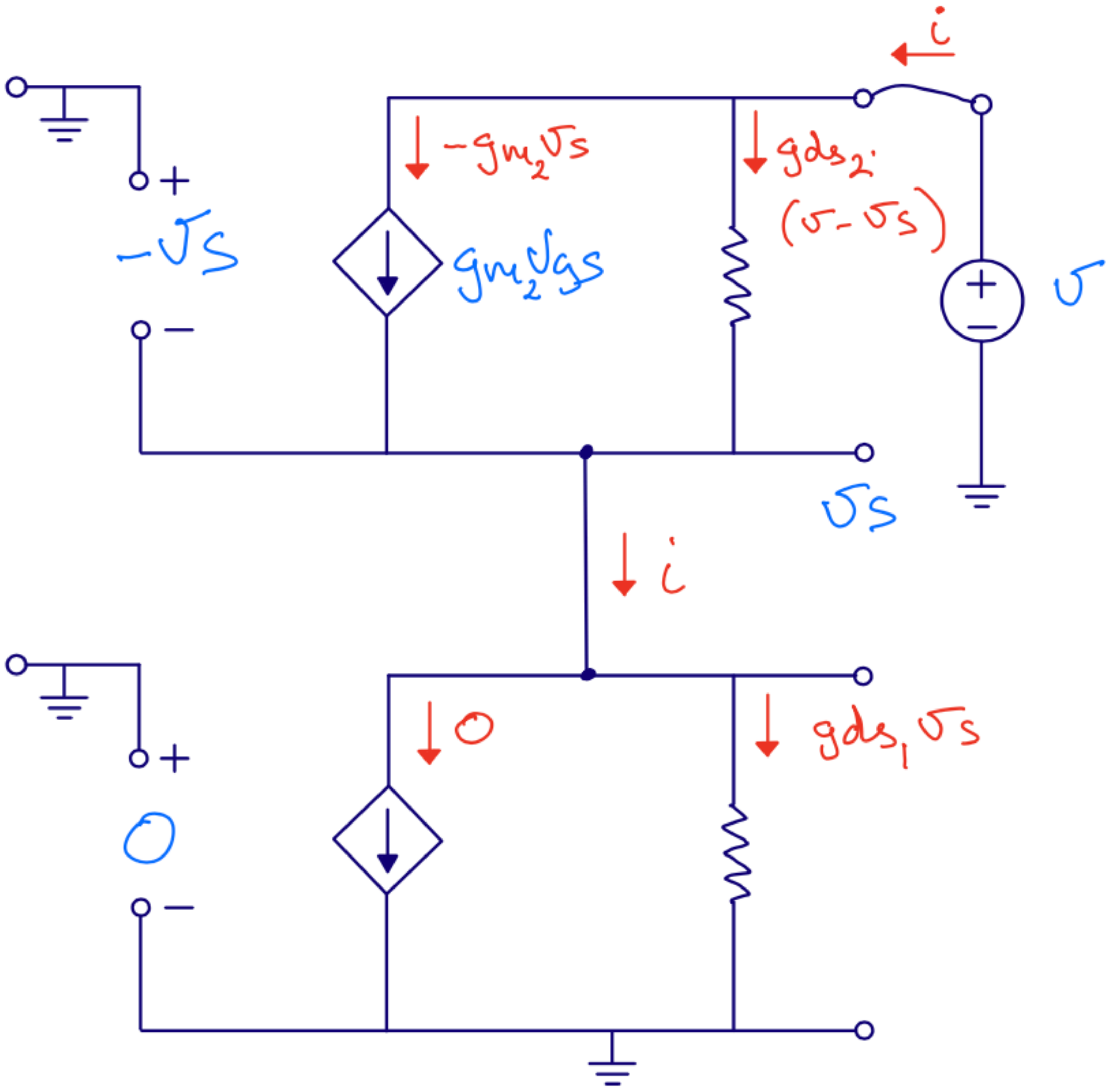
$$v_{gs1} = 0$$

$$v_{gs2} = -v_s$$

$$i = g_{ds1} v_s \Rightarrow v_s = i r_{ds1}$$

$$r_{out} = \frac{v}{i}$$

$$i = -g_{m2} v_s + \frac{v - v_s}{r_{ds2}}$$



$$i = -g_{m2}v_s + \frac{v - v_s}{r_{ds2}} \quad \text{insert } v_s = i r_{ds1}$$

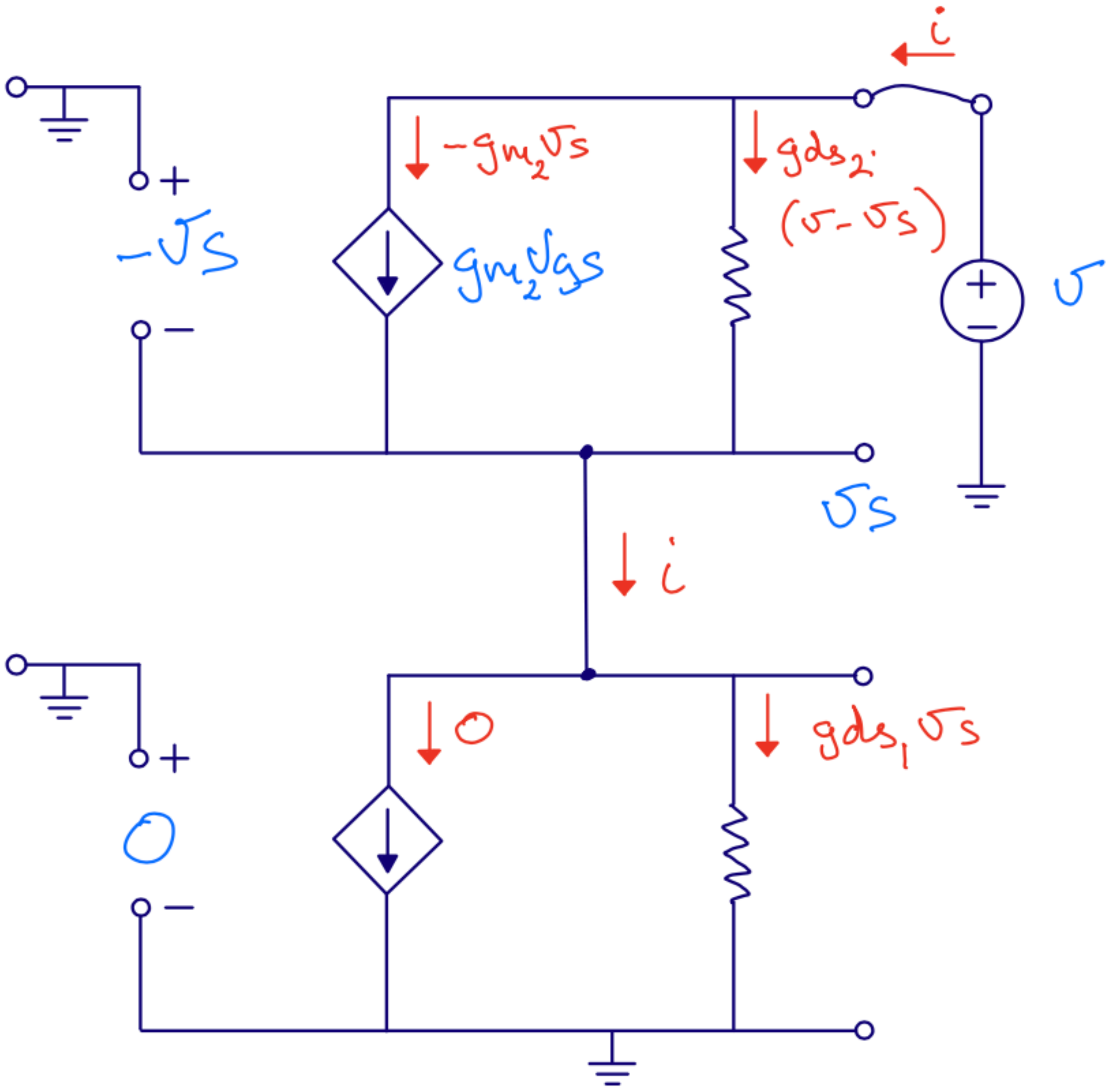
$$i = -i g_{m2} r_{ds1} + \frac{v - i r_{ds1}}{r_{ds2}}$$

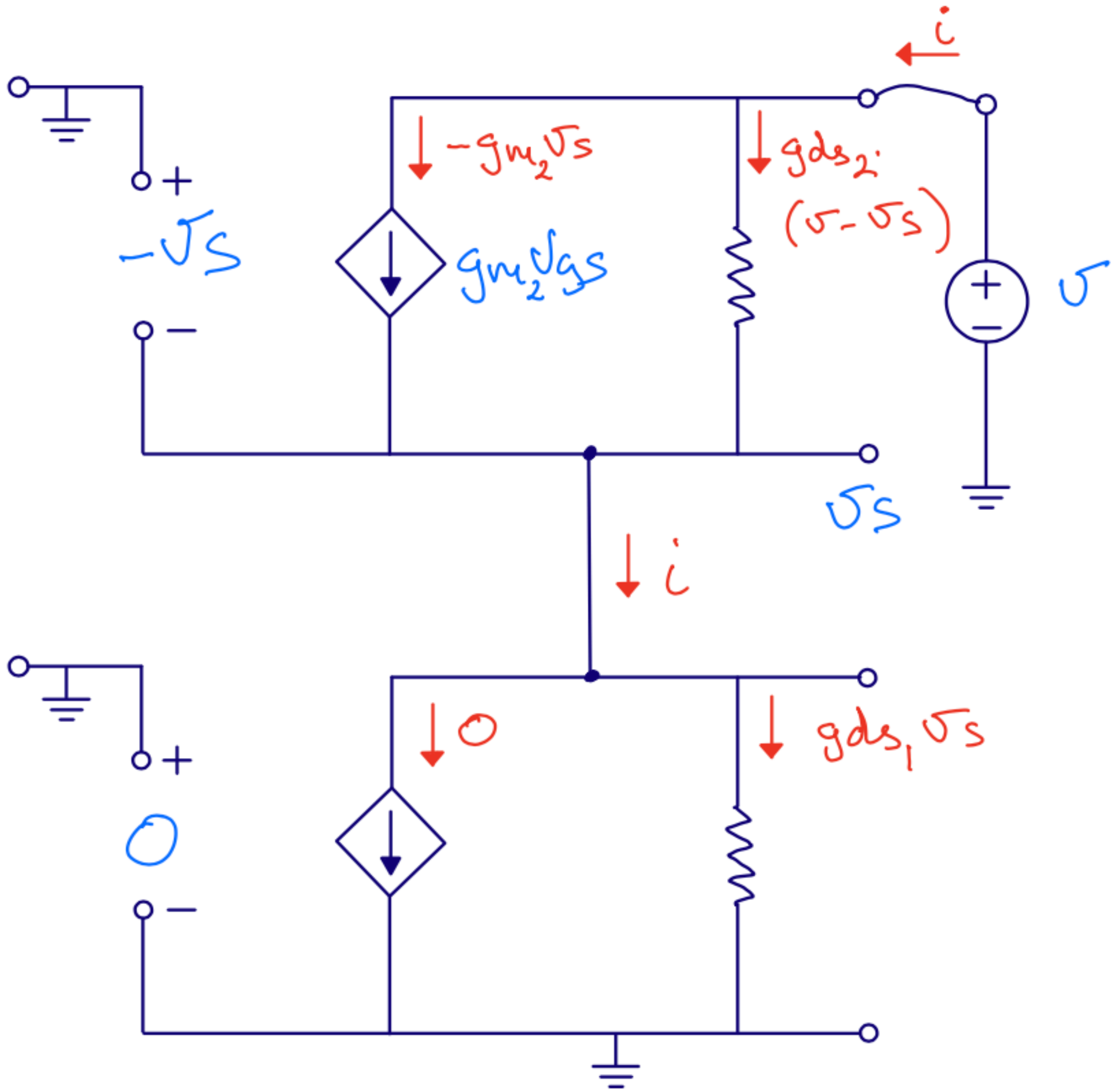
$$i r_{ds2} + i g_{m2} r_{ds1} r_{ds2} + i r_{ds1} = v$$

$$r_{ds2} + g_{m2} r_{ds1} r_{ds2} + r_{ds1} = \frac{v}{i}$$

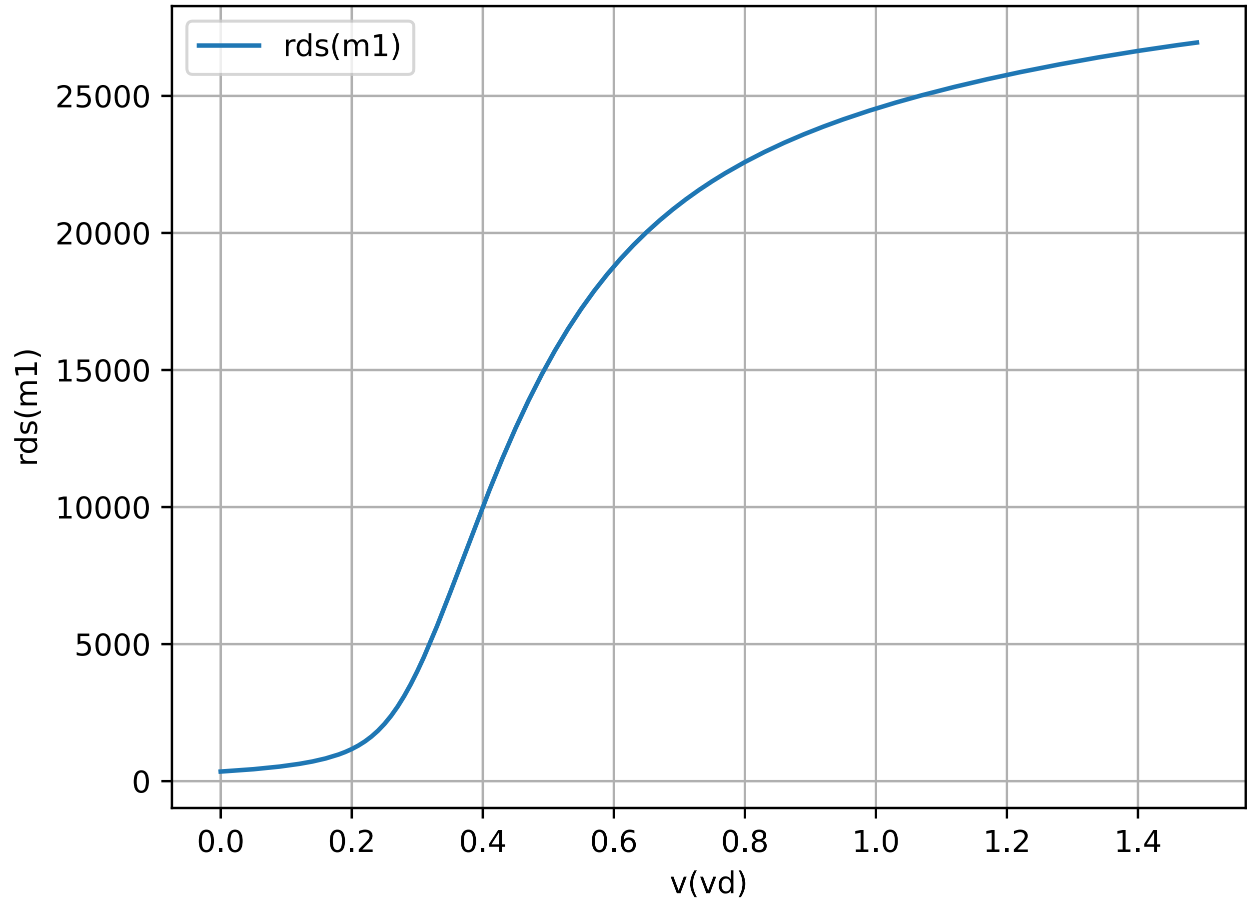
$$r_{out} = r_{ds2}\left[1 + r_{ds1}\left(\frac{1}{r_{ds2}} + g_{m2}\right)\right]$$

$$r_{out} = r_{ds2}\left[1 + r_{ds1}(g_{m2} + g_{ds2})\right]$$





$$r_{out} = r_{ds2}\left[1 + r_{ds1}\left(g_{m2} + g_{ds1}\right)\right]$$

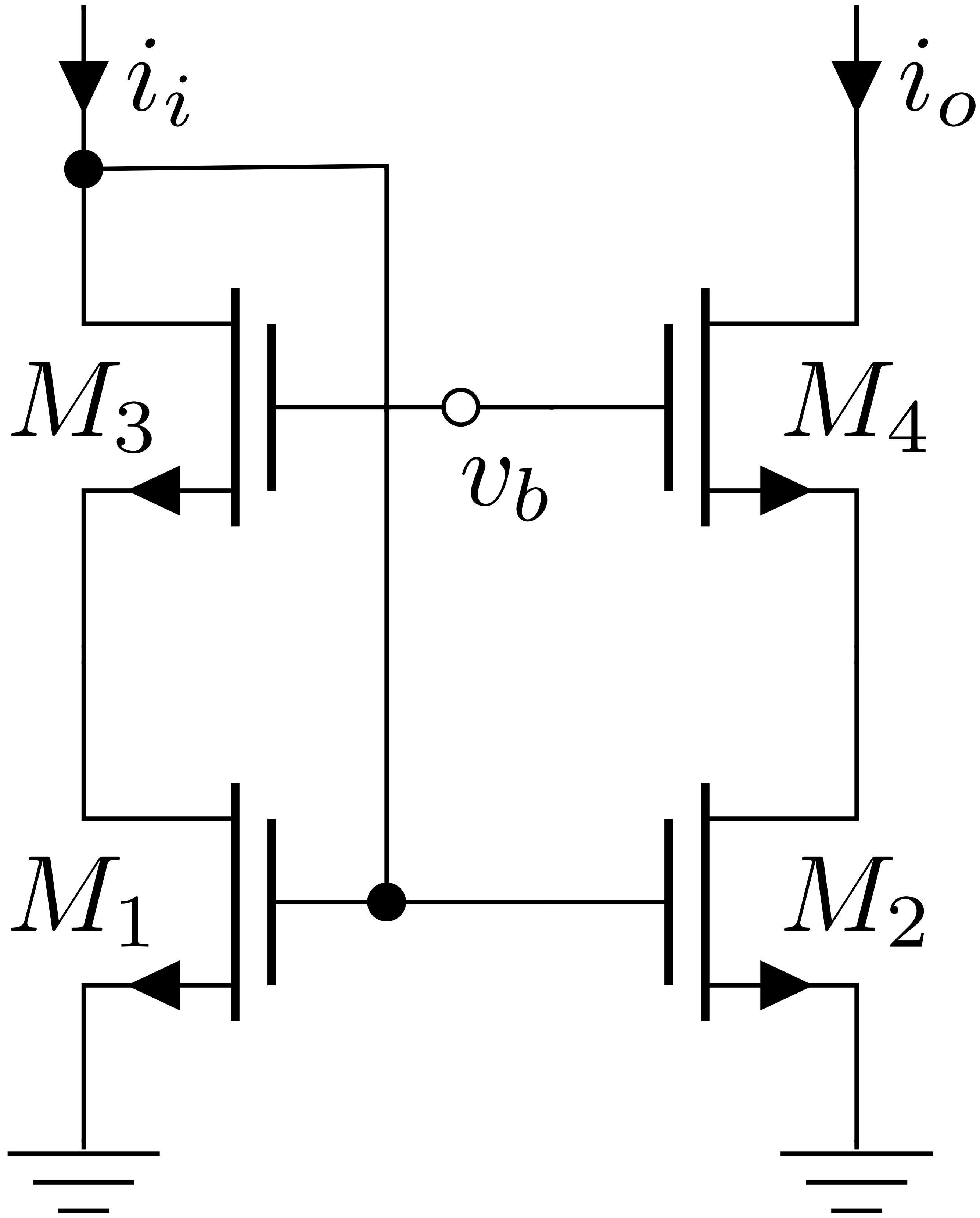


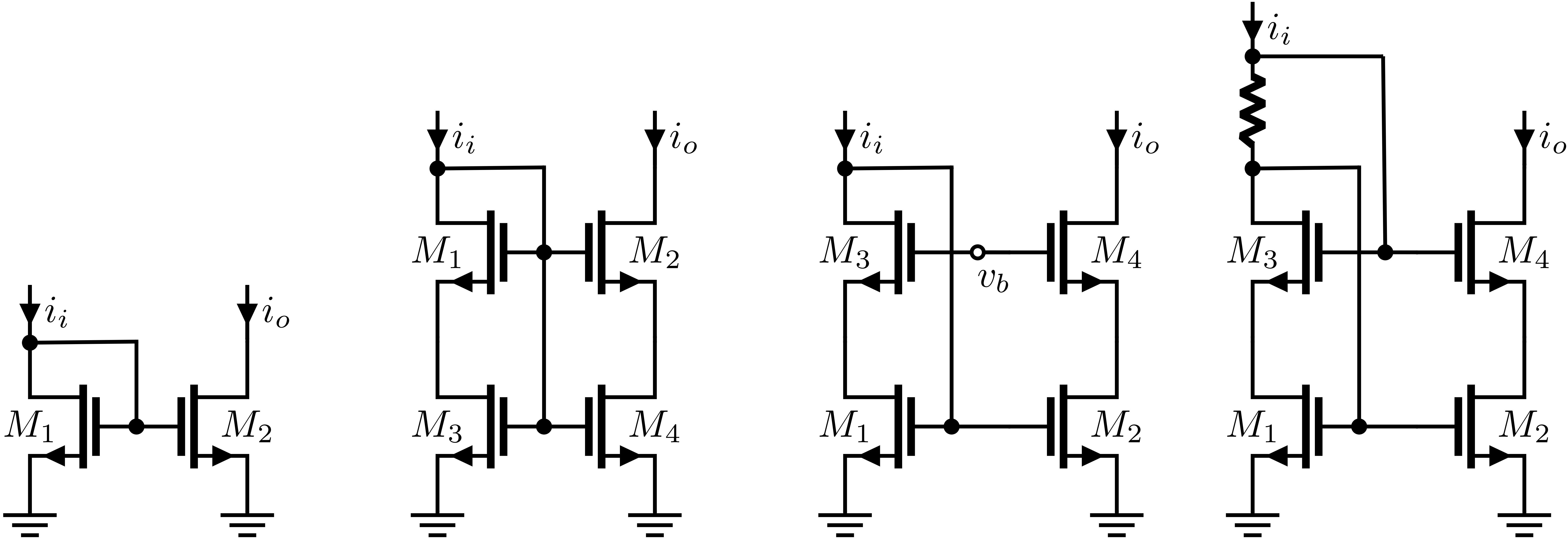
Cascode current mirror

Same equation as source degeneration, but M_2 is in saturation

$$r_{ds2(\text{saturation})} > r_{ds2(\text{linear})}$$

$$r_{out} = r_{ds4}\left[1 + r_{ds2}\left(g_{m4} + g_{ds2}\right)\right]$$





a) “normal” b) Self Cascode c) Cascode d) Lazy Cascode

One more current mirror ...

"High speed, high gain OTA in a digital 90nm CMOS technology" Berntsen, Wulff, Ytterdal

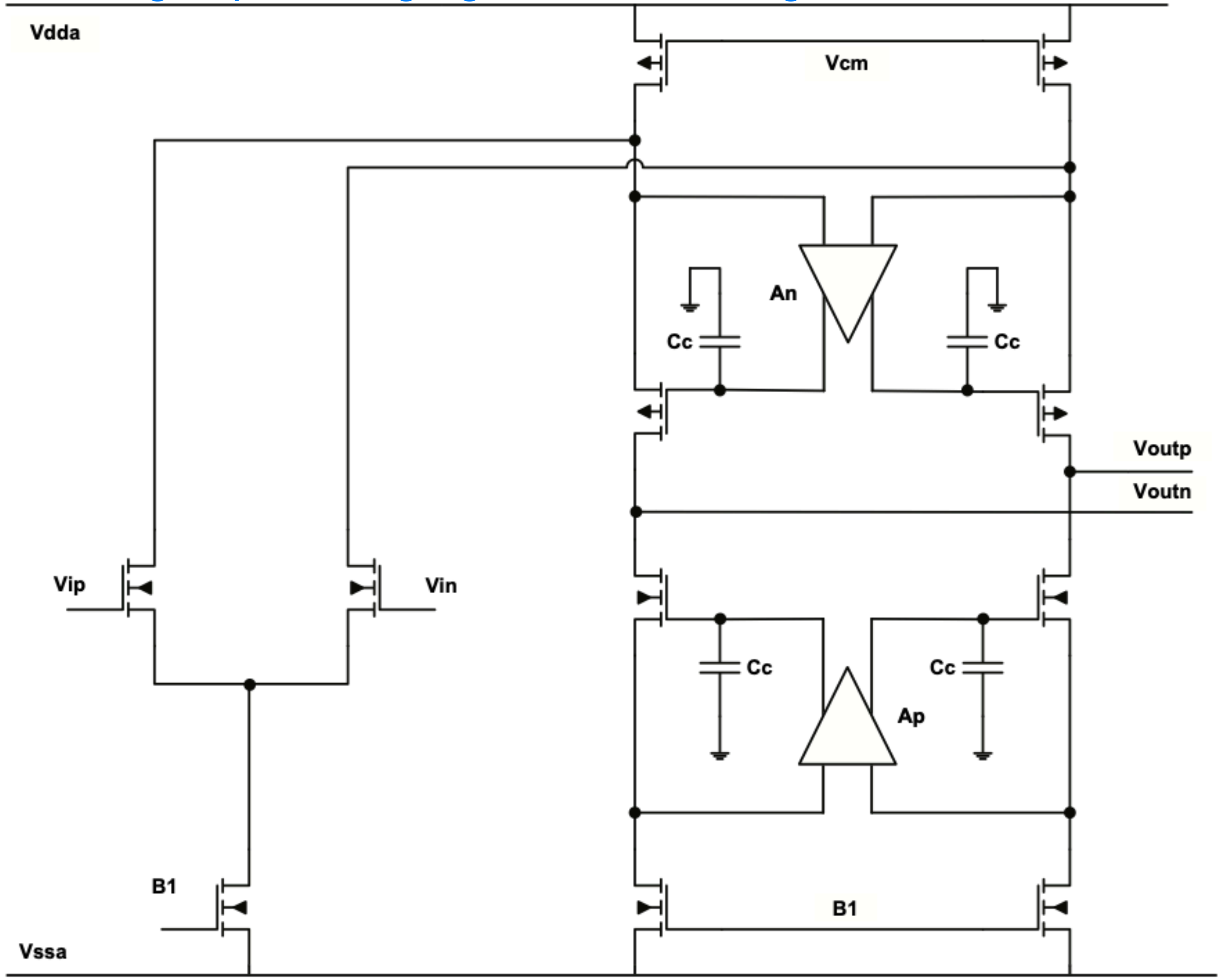


Fig. 2. OTA circuit with fully differential gain enhancement.

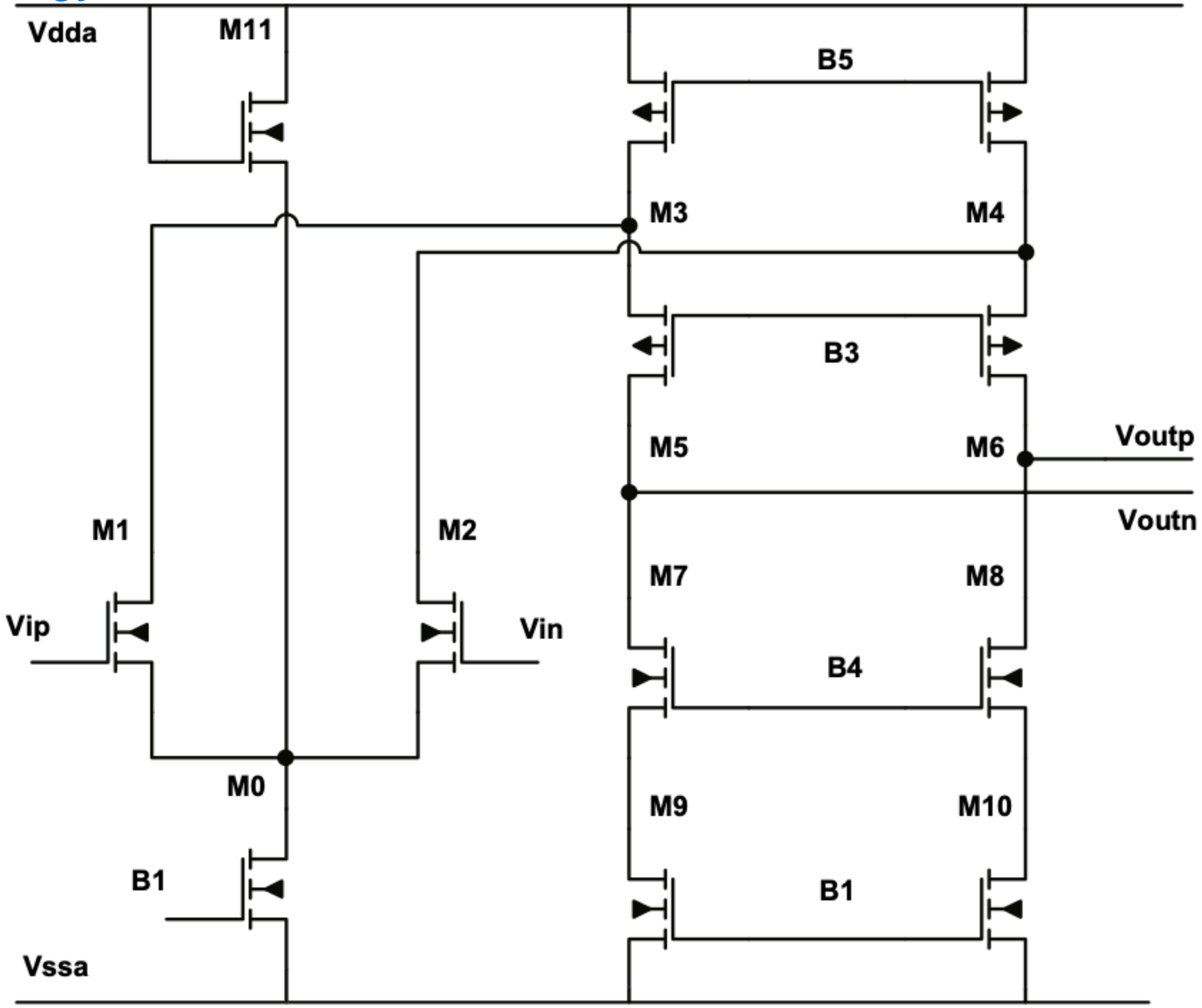
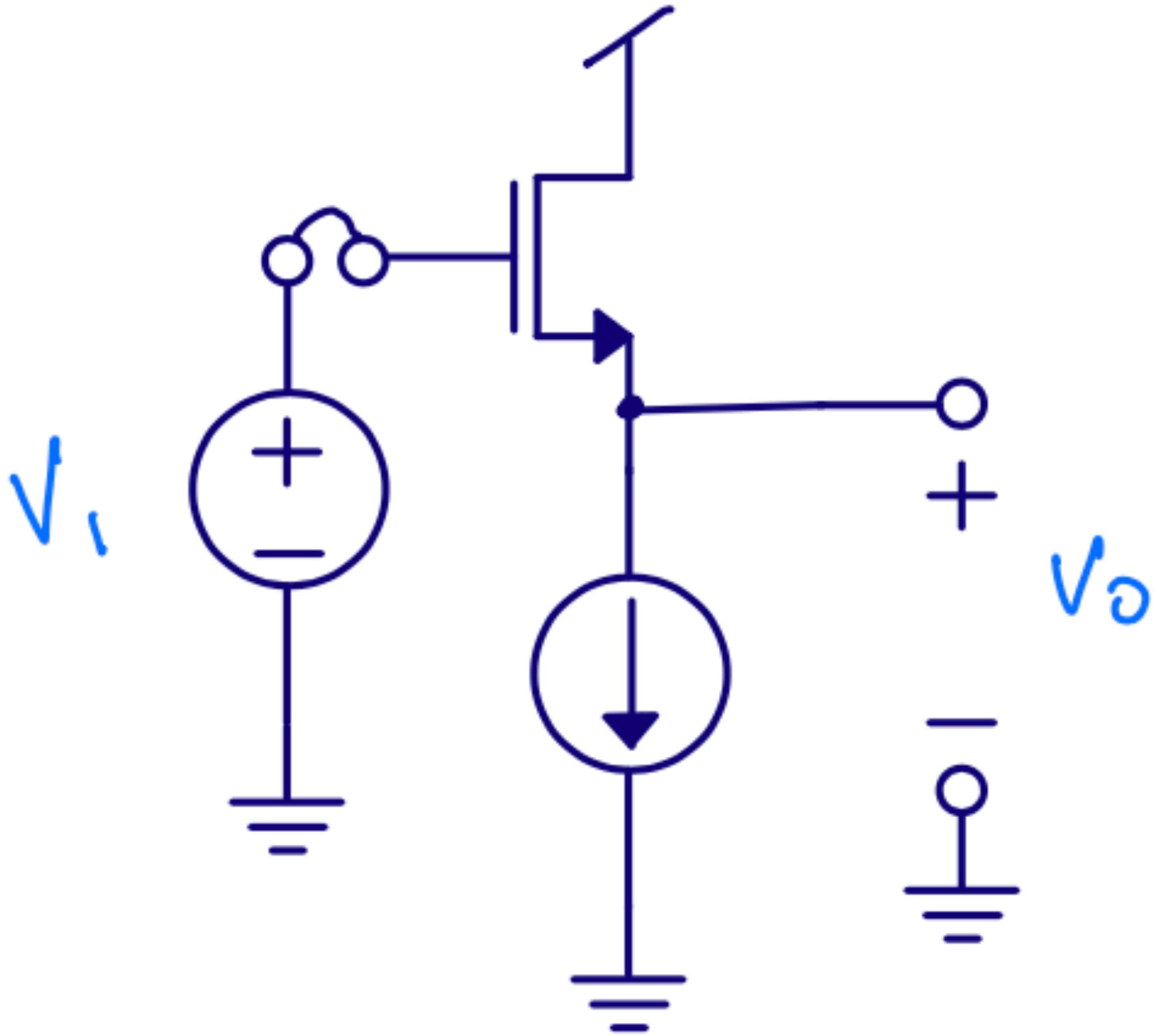


Fig. 3. Fully differential supplemental OTA .

Amplifiers

Source follower

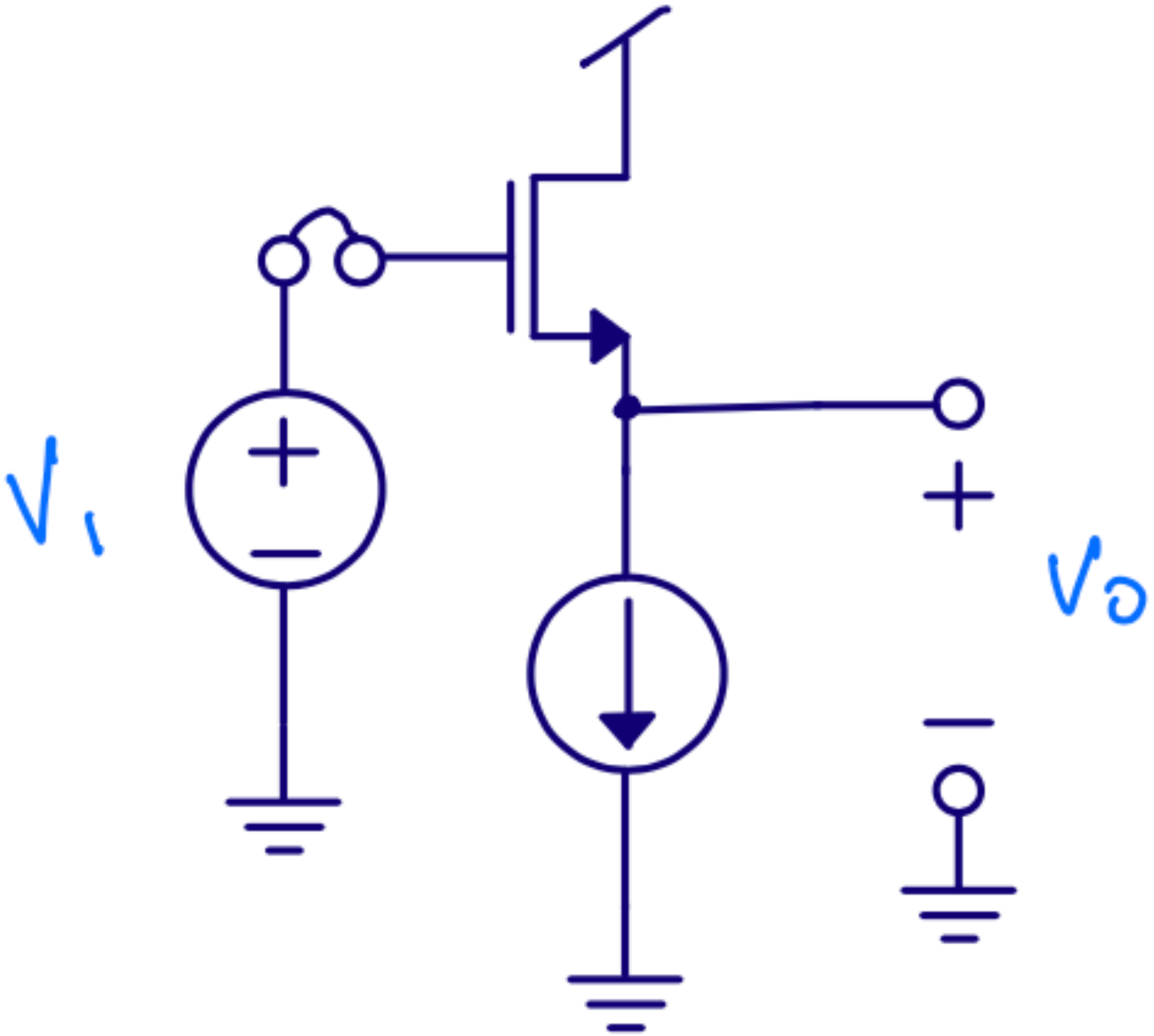


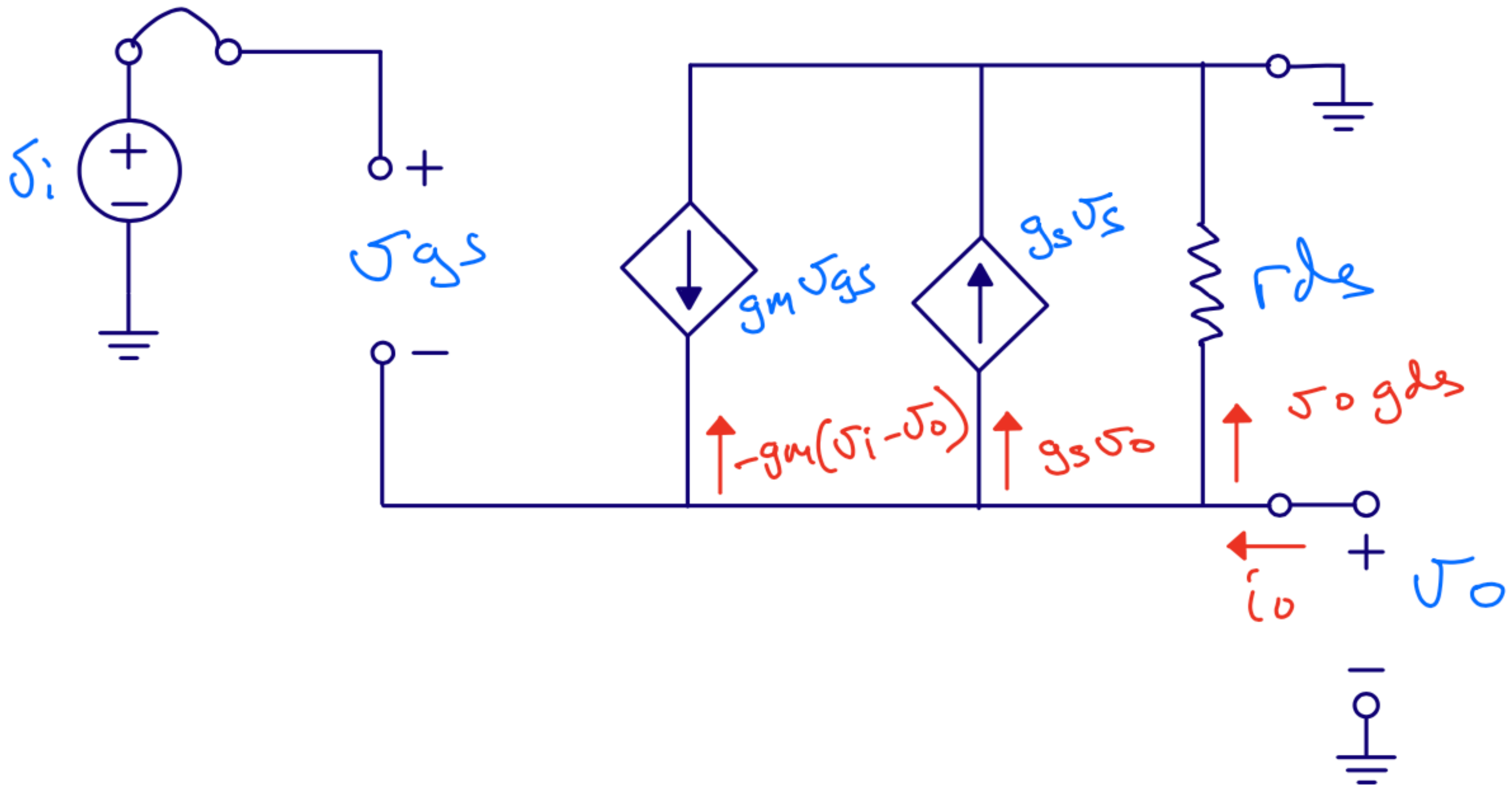
Source follower

Input resistance $\approx \infty$

Gain $A = \frac{v_o}{v_i}$?

Output resistance r_{out}?


V_I
+
−
+
V_O
−


v_i
+
−
+
v_gs
−
g_m v_gs
g_s v_s
r_ds
-g_m(v_i - v_o)
g_s v_o
v_o g_ds
i_o
+
v_o
−

Source follower - Gain

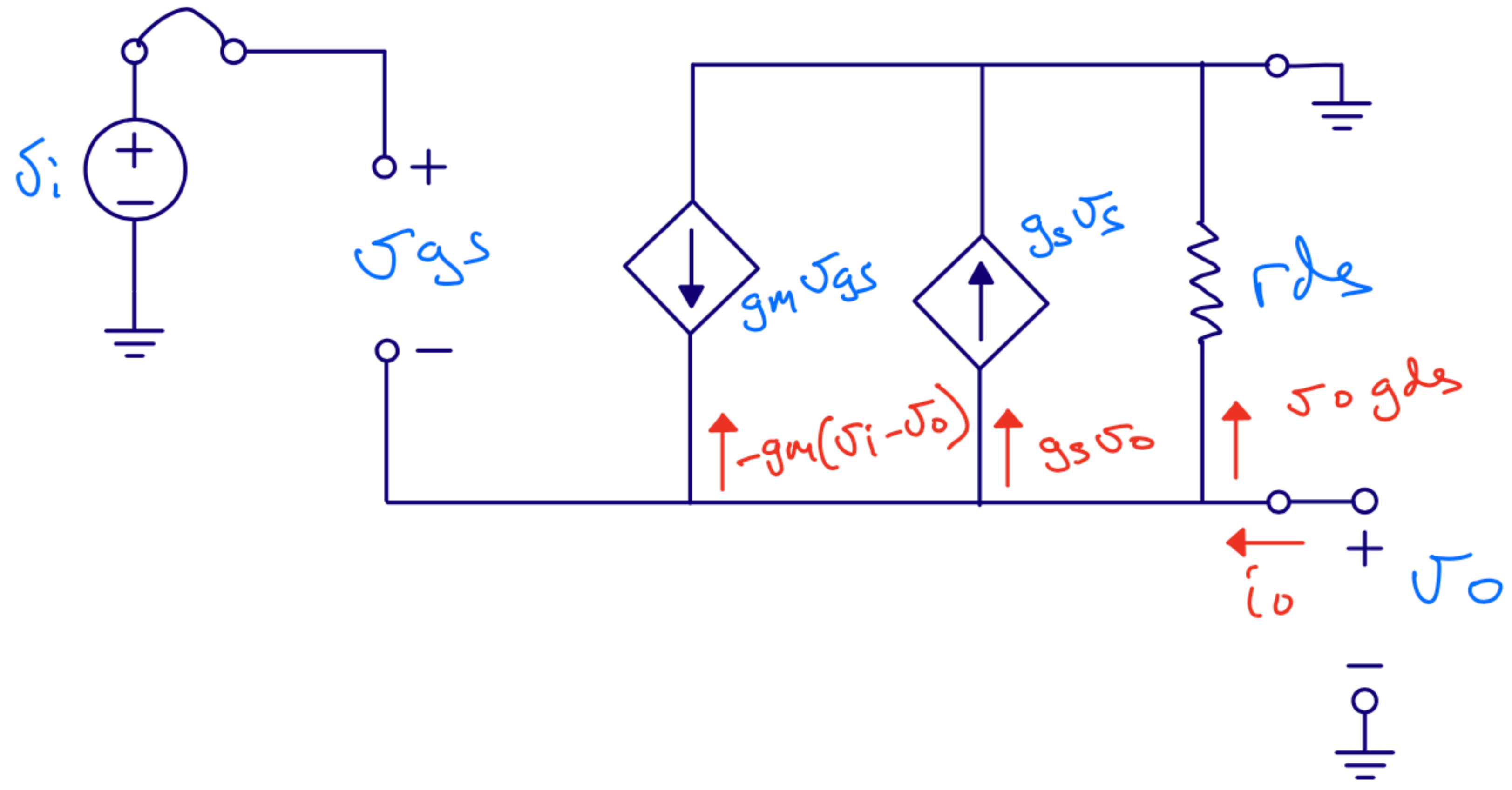
$$i_o = v_o(g_{ds} + g_s) - g_m v_i + v_o g_m$$

$$i_o = 0$$

$$g_m v_i = v_o(g_m + g_s + g_{ds})$$

$$A = \frac{v_o}{v_i} = \frac{g_m}{g_m + g_{ds} + g_s}$$

Gain is less than 1



Source follower - r_{out}

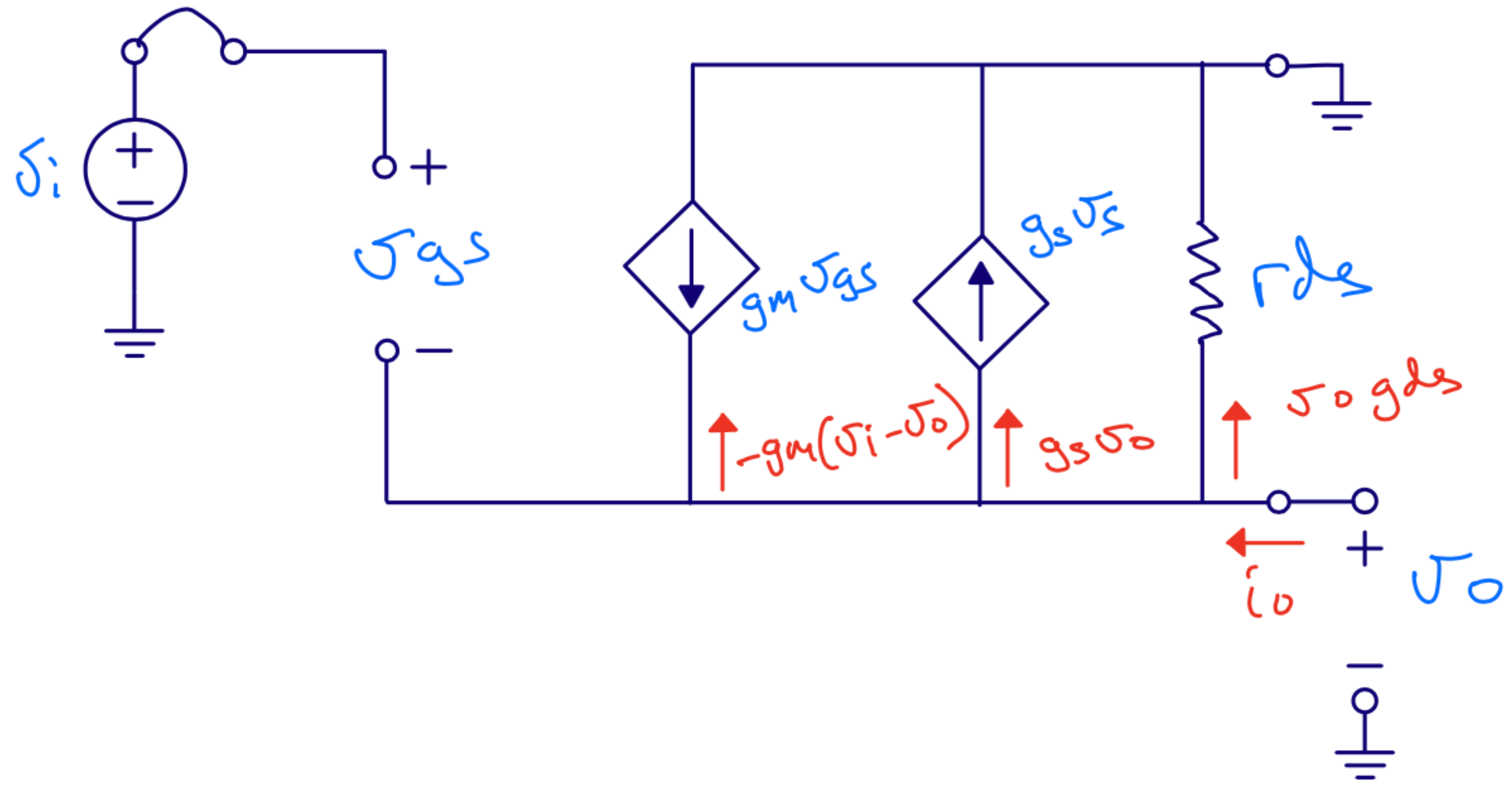
$$i_o = v_o(g_{ds} + g_s) - g_m v_i + v_o g_m$$

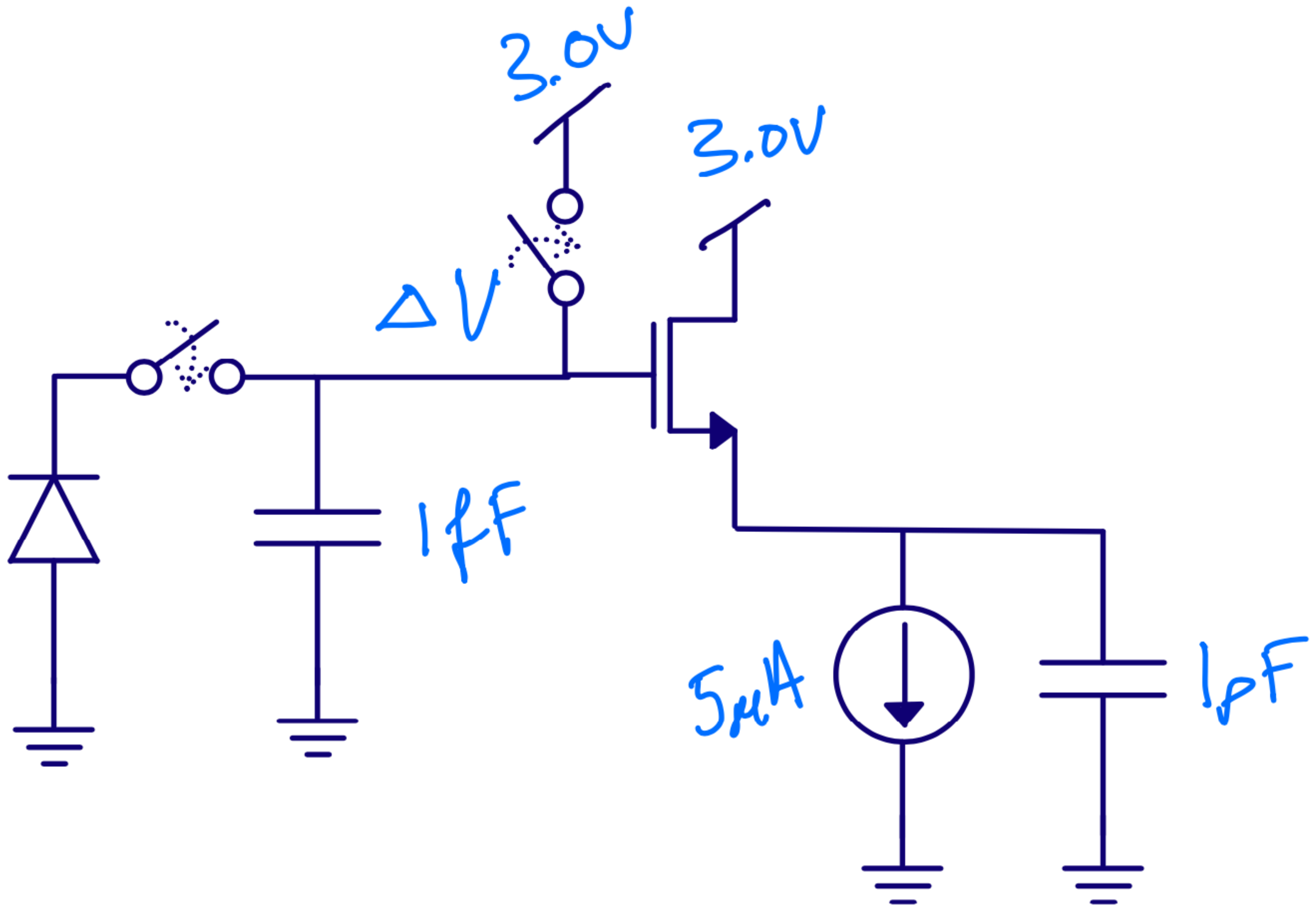
$$v_i = 0$$

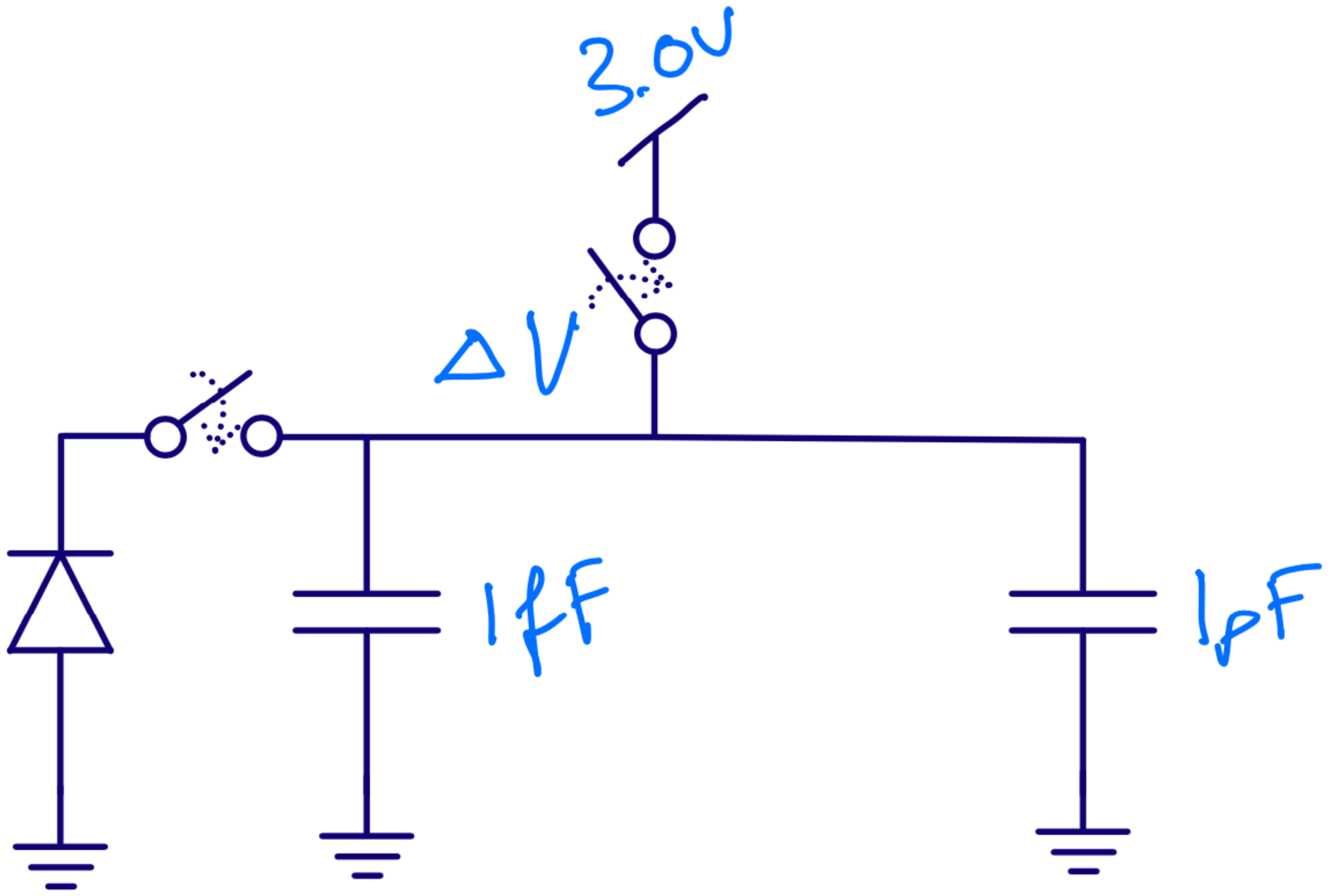
$$i_o = v_o(g_{ds} + g_s + g_m)$$

$$r_{out} = \frac{v_o}{i_o} = \frac{1}{g_m + g_{ds} + g_s}$$

$$r_{out} \approx \frac{1}{g_m}$$

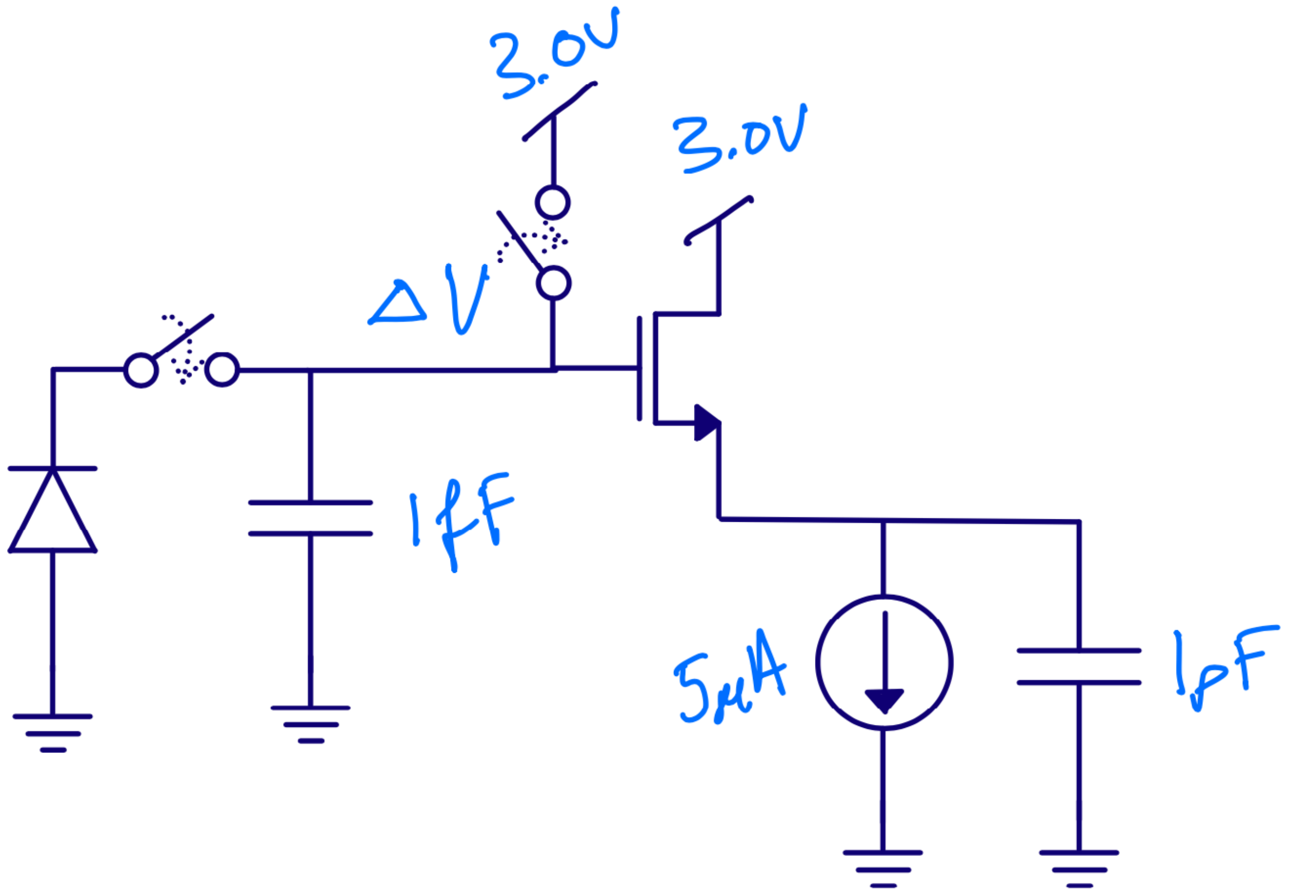



3.0V
3.0V
ΔV
1fF
5μA
1pF

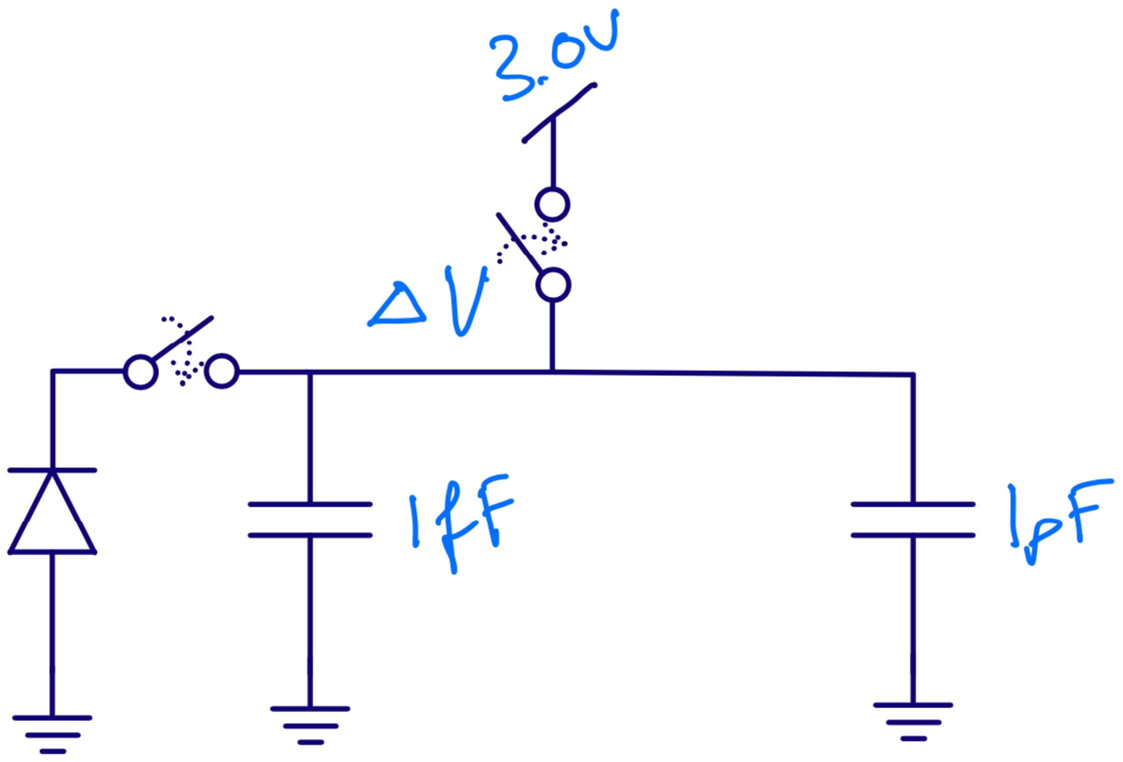

3.0V
ΔV
1fF
1pF

Assume 100 electrons

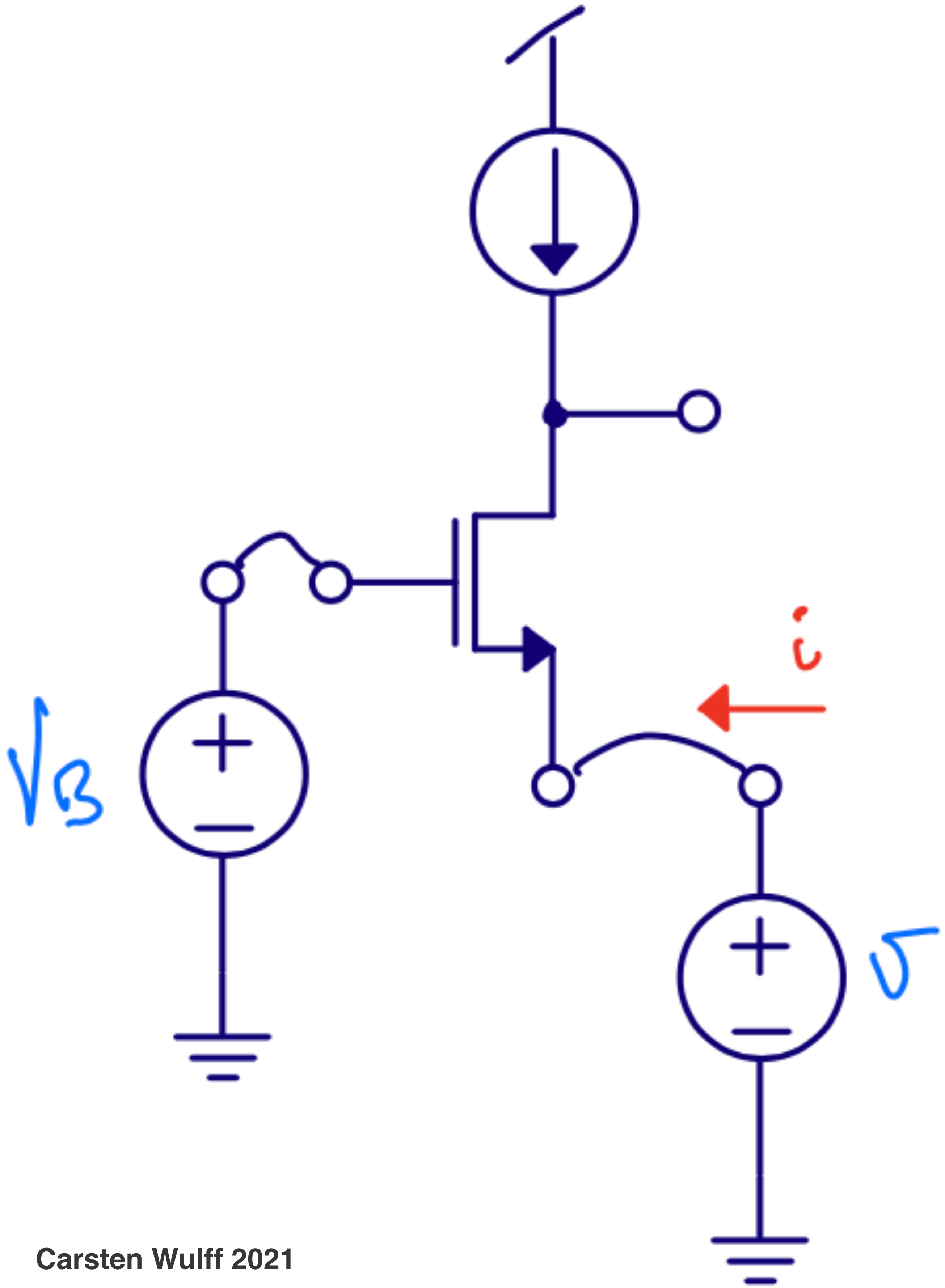
$\Delta V = Q/C = -1.6 \times 10^{-19} \times 100/(1 \times 10^{-15}) = -16\,\mathrm{mV}$



$\Delta V = Q/C = -1.6 \times 10^{-19} \times 100/(1 \times 10^{-12}) = -16\,\mathrm{uV}$



Common gate

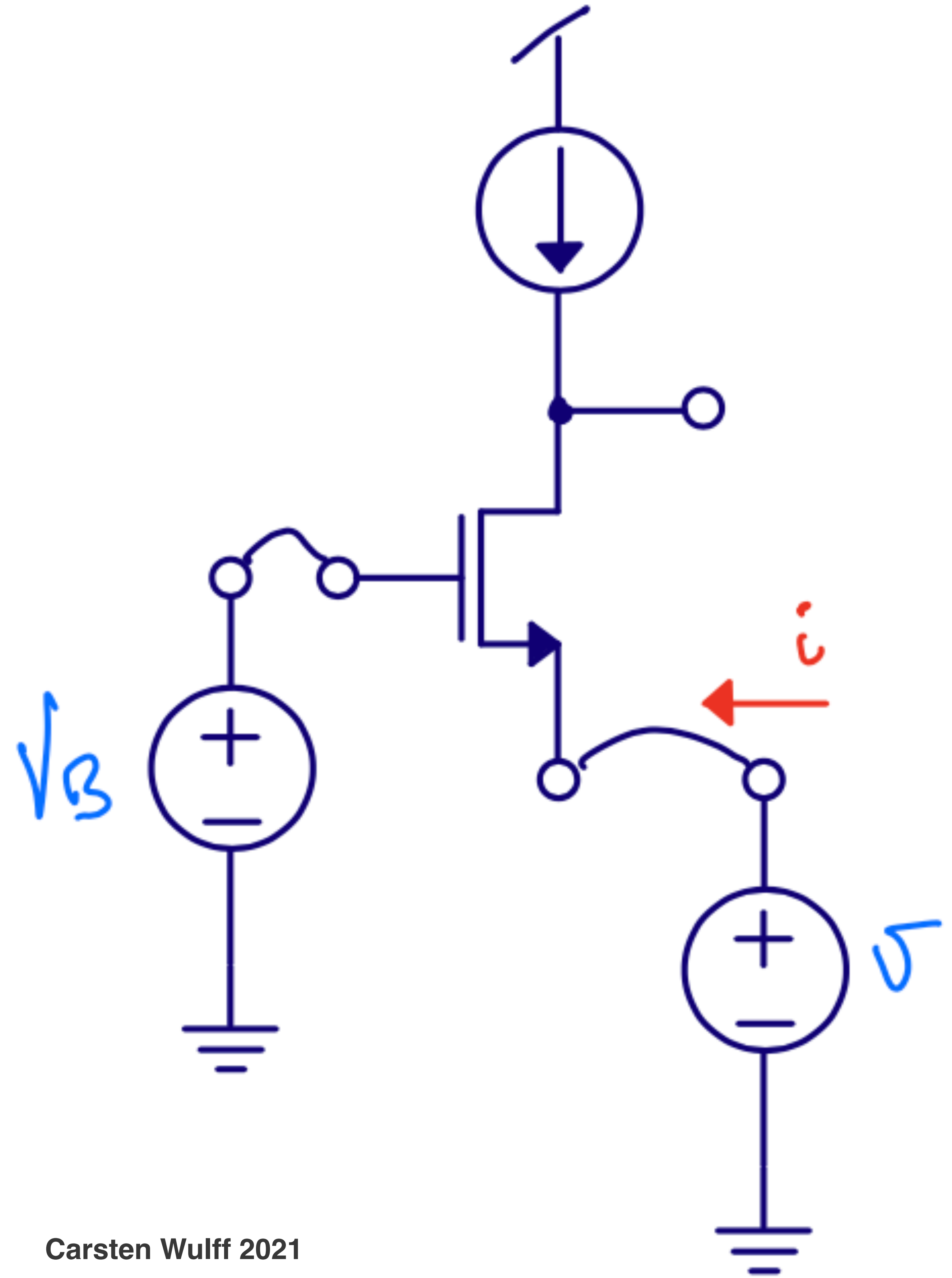


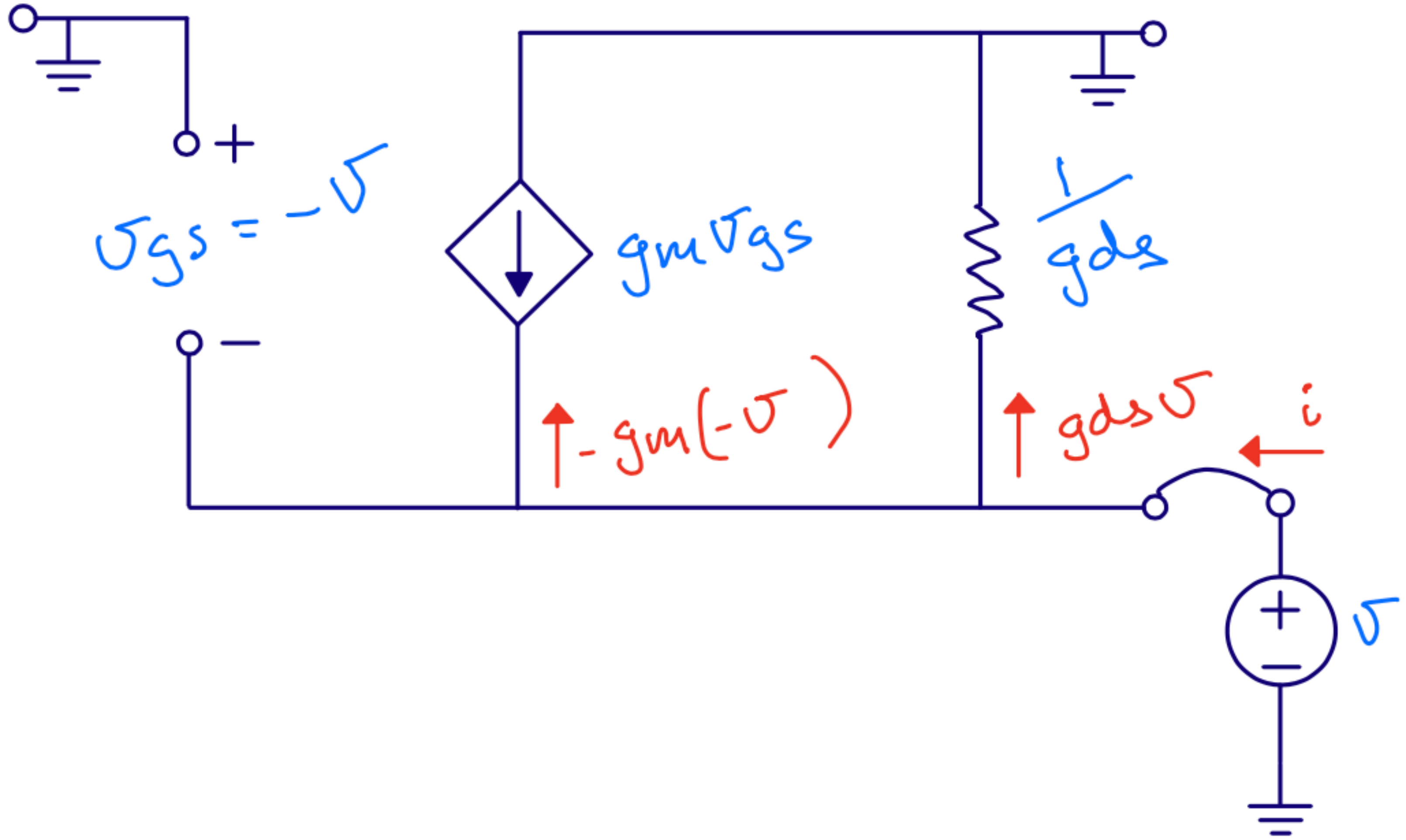
Common gate

Input resistance ?

Gain ?

Output resistance ?


i
VB
v


+
vgs = -v
−
gmvgs
1/gds
-gm(-v)
gdsv
i
v

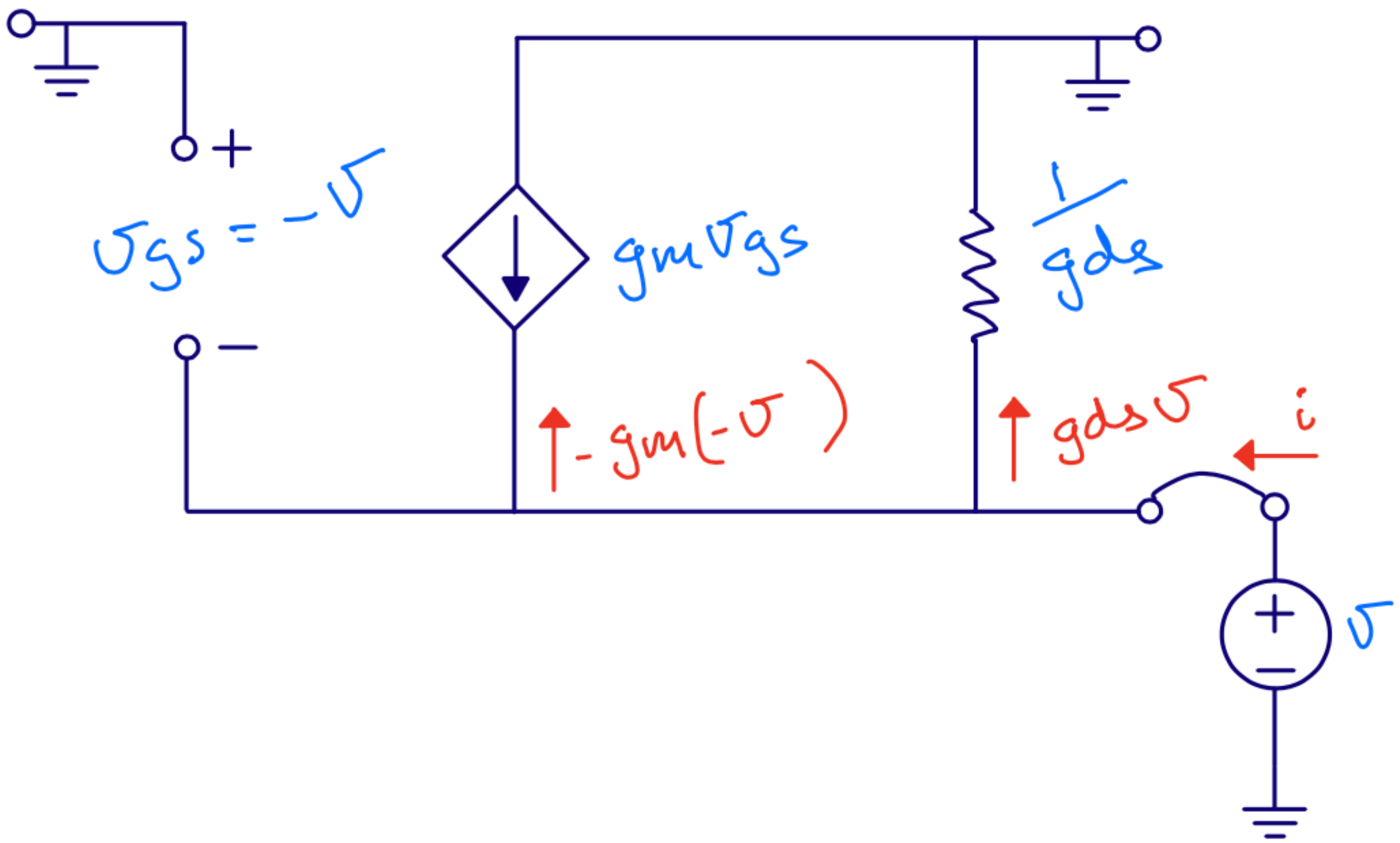
Common gate - r_{in}

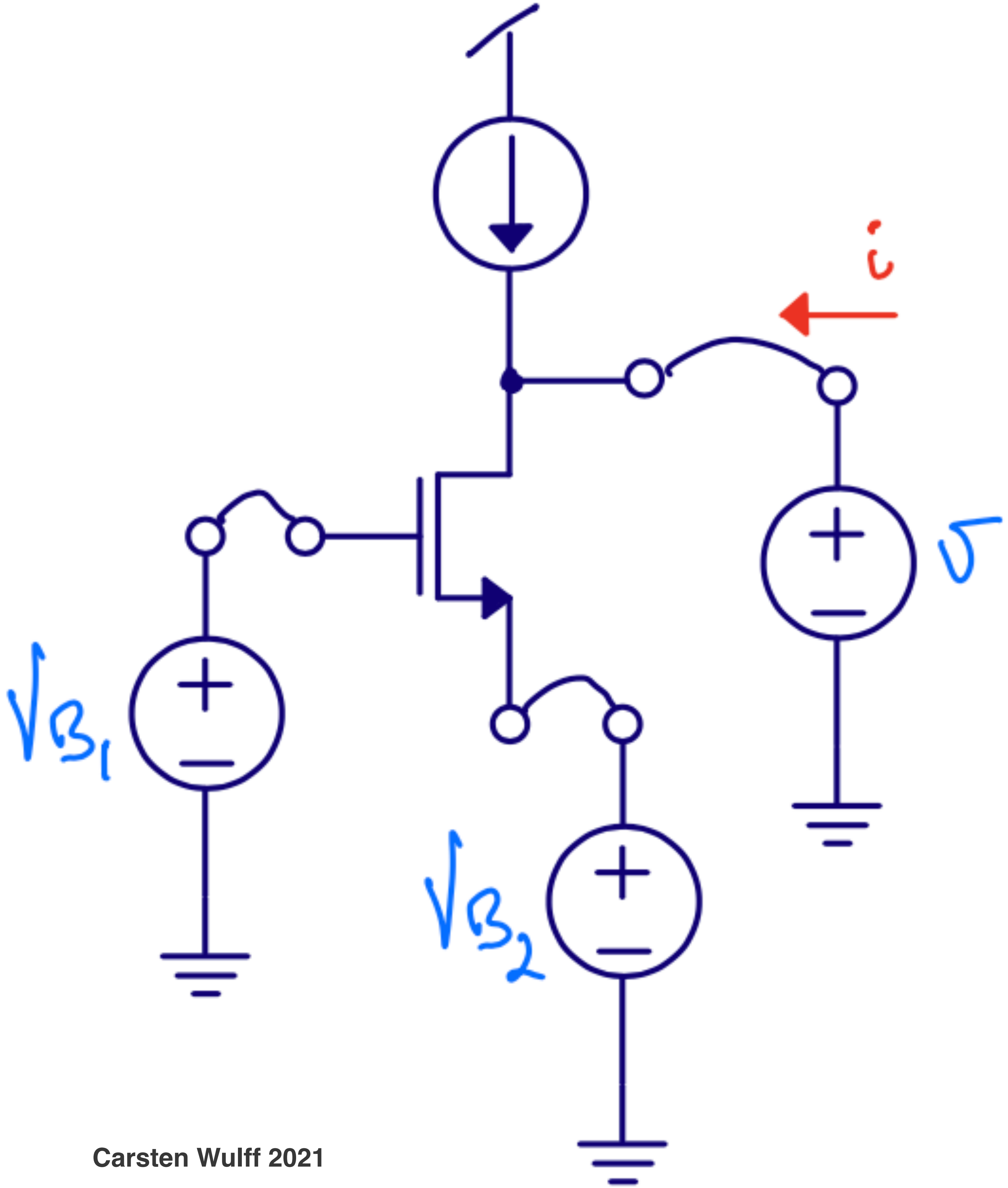
$$i = g_m v + g_{ds} v$$

$$r_{in} = \frac{1}{g_m + g_{ds}} \approx \frac{1}{g_m}$$

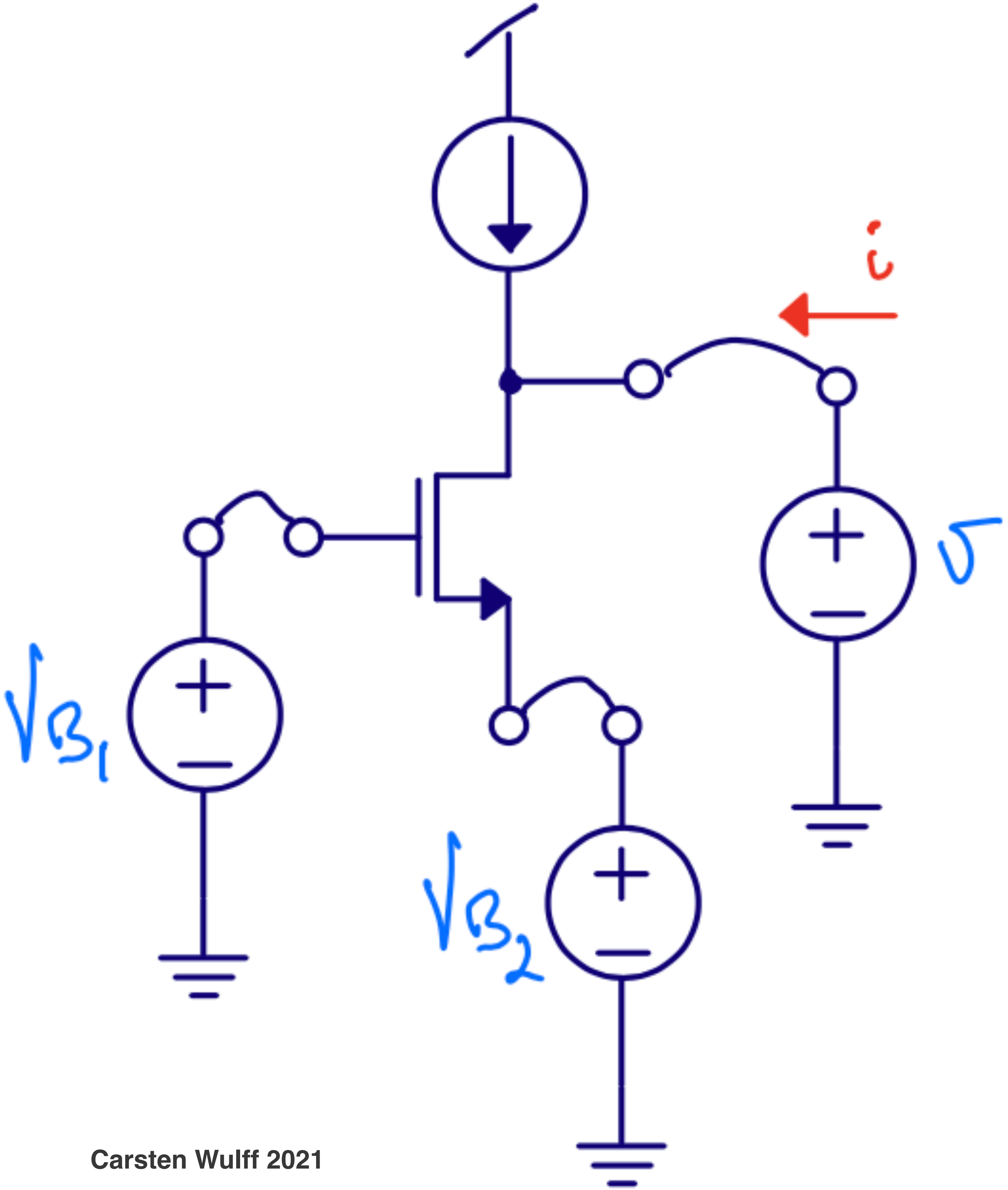
However, we've ignored load resistance.

$$r_{in} \approx \frac{1}{g_m}\left(1 + \frac{R_L}{r_{ds}}\right)$$

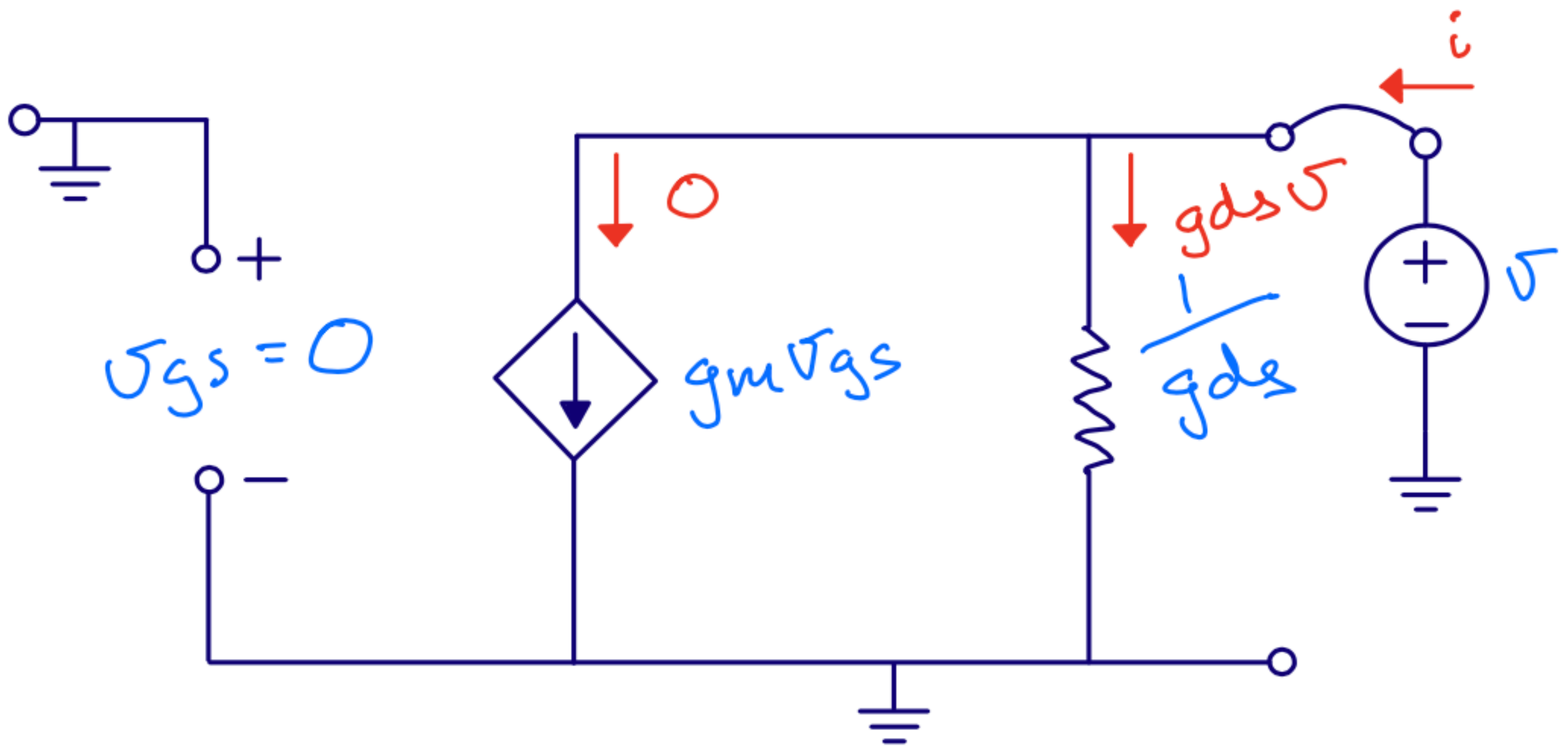




Common gate - r_{out}



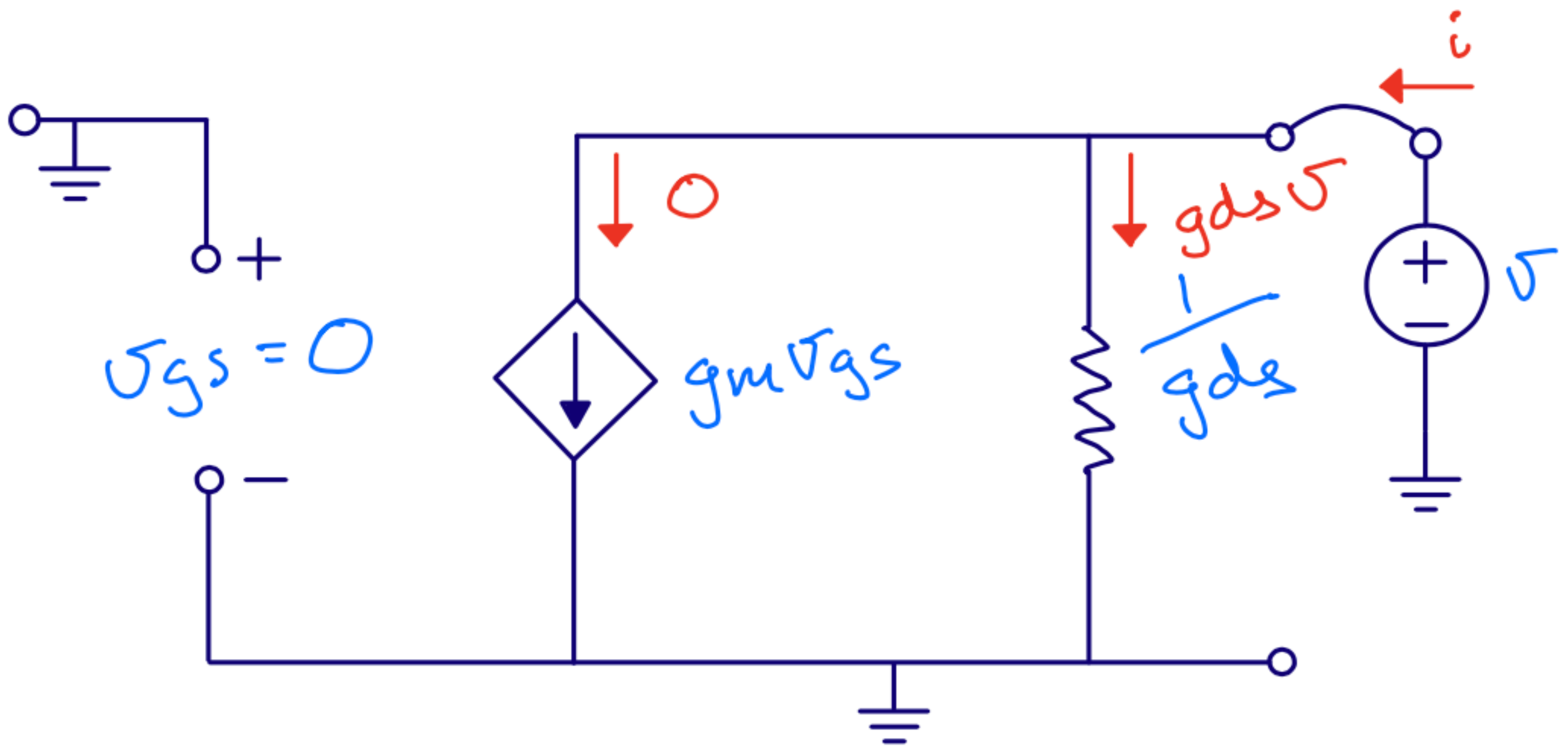
i
v
VB1
VB2

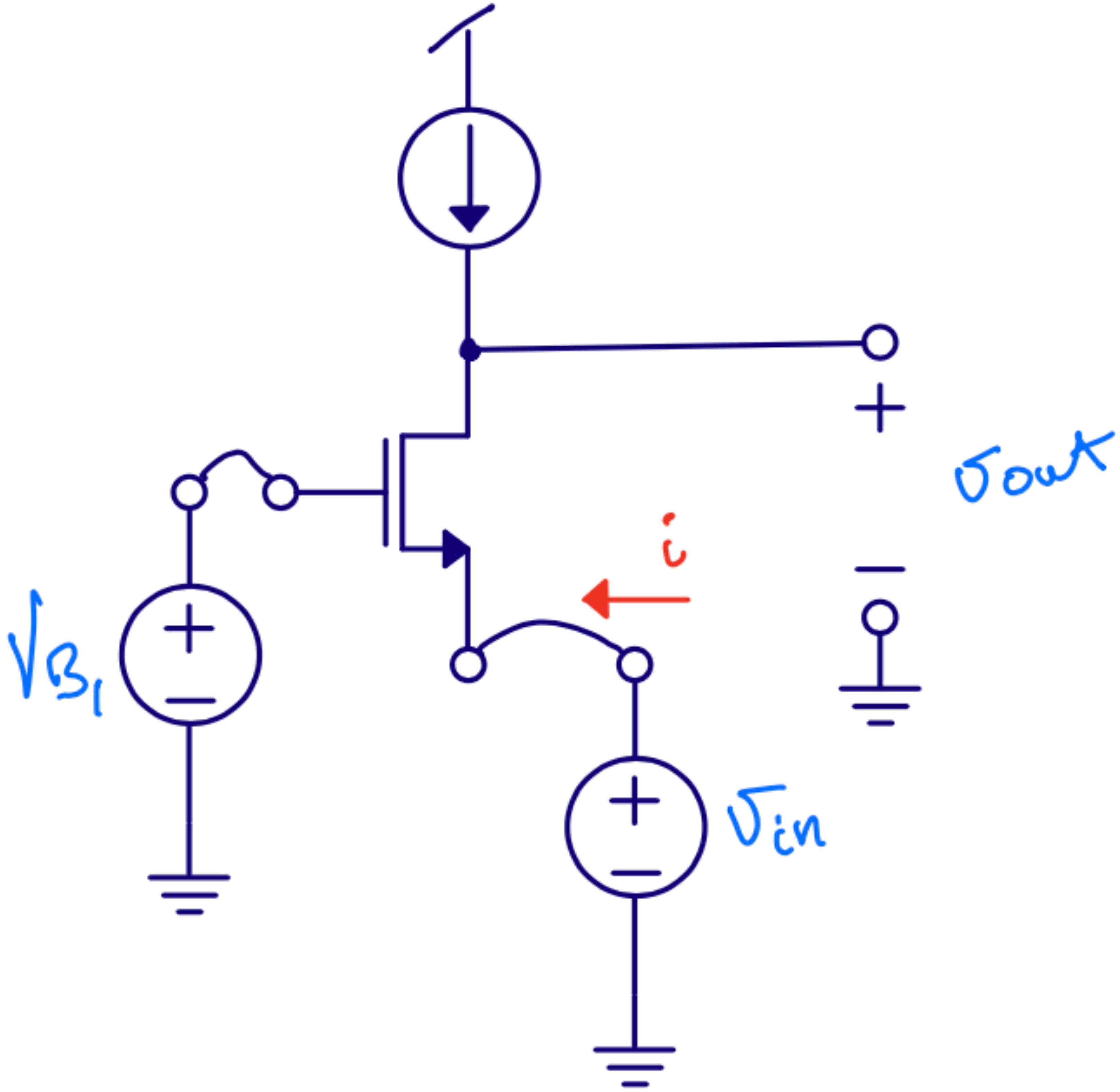


i
+
vgs = 0
−
0
gm vgs
gds v
1/gds
v

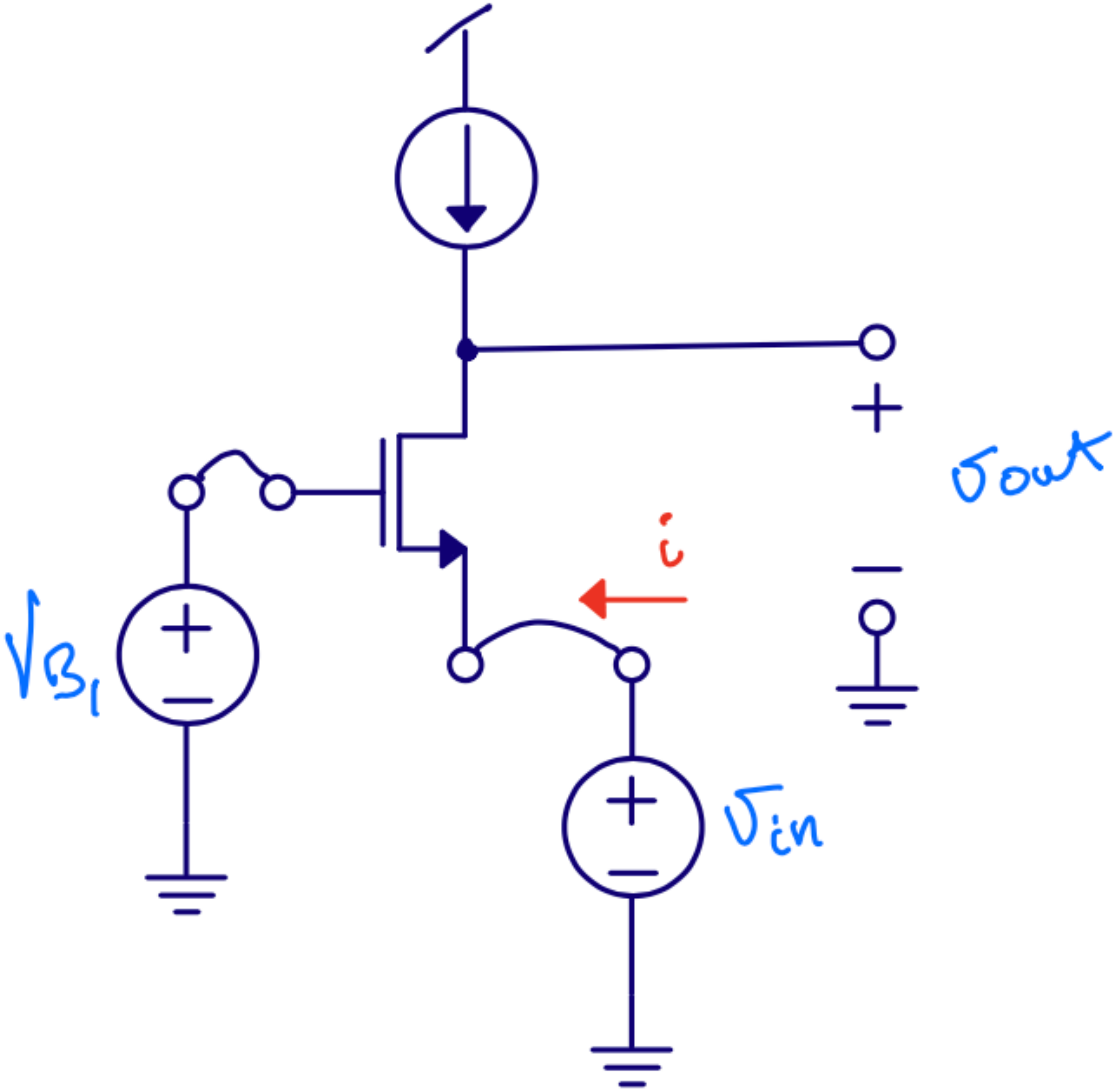
Common gate - r_{out}

$$r_{out} = r_{ds}$$

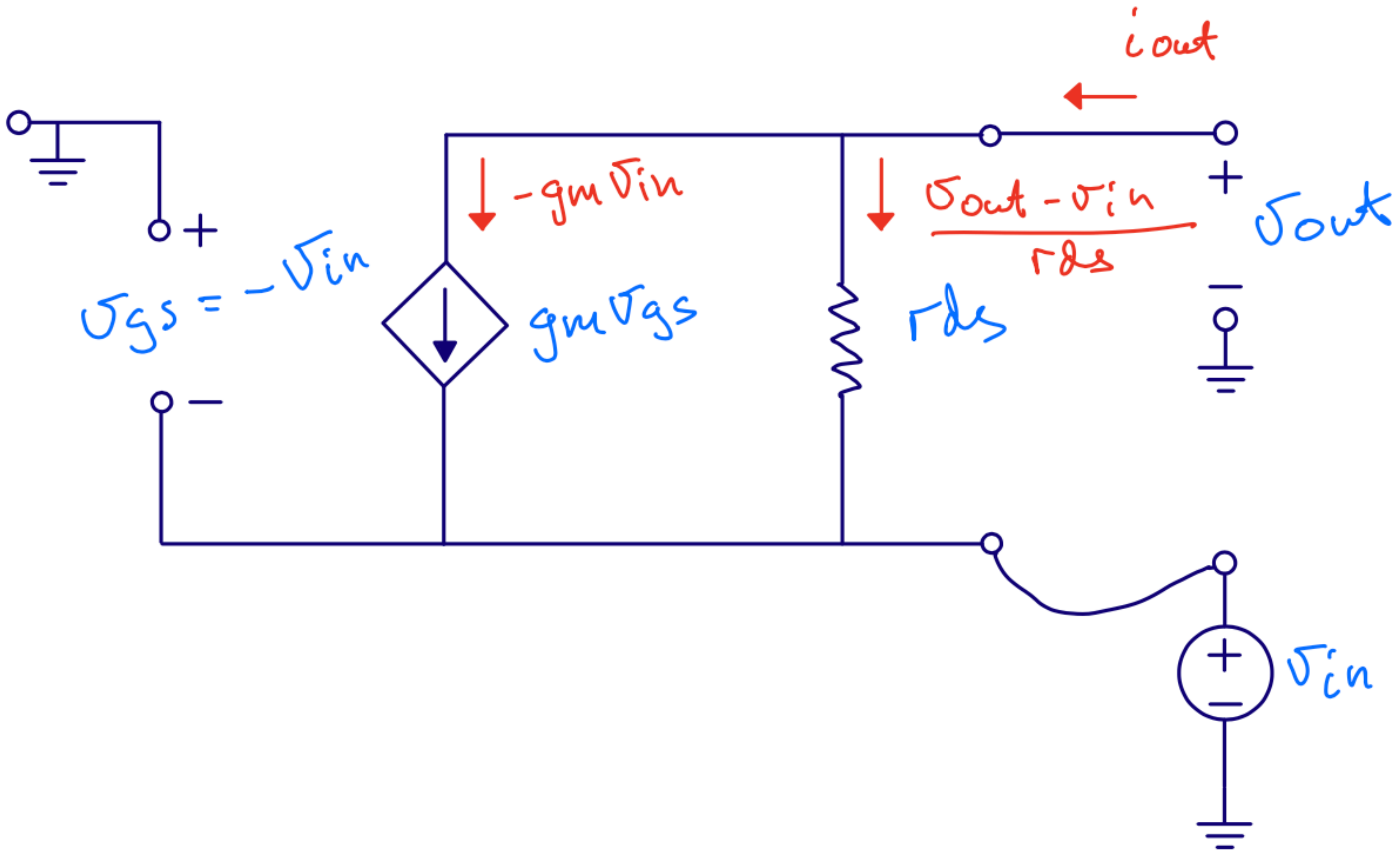




Common gate - Gain



V_{B1}
v_{in}
i
v_{out}



i_{out}
$v_{gs} = -v_{in}$
$-g_m v_{in}$
$g_m v_{gs}$
$\frac{v_{out} - v_{in}}{r_{ds}}$
r_{ds}
v_{out}
v_{in}

Common gate - Gain

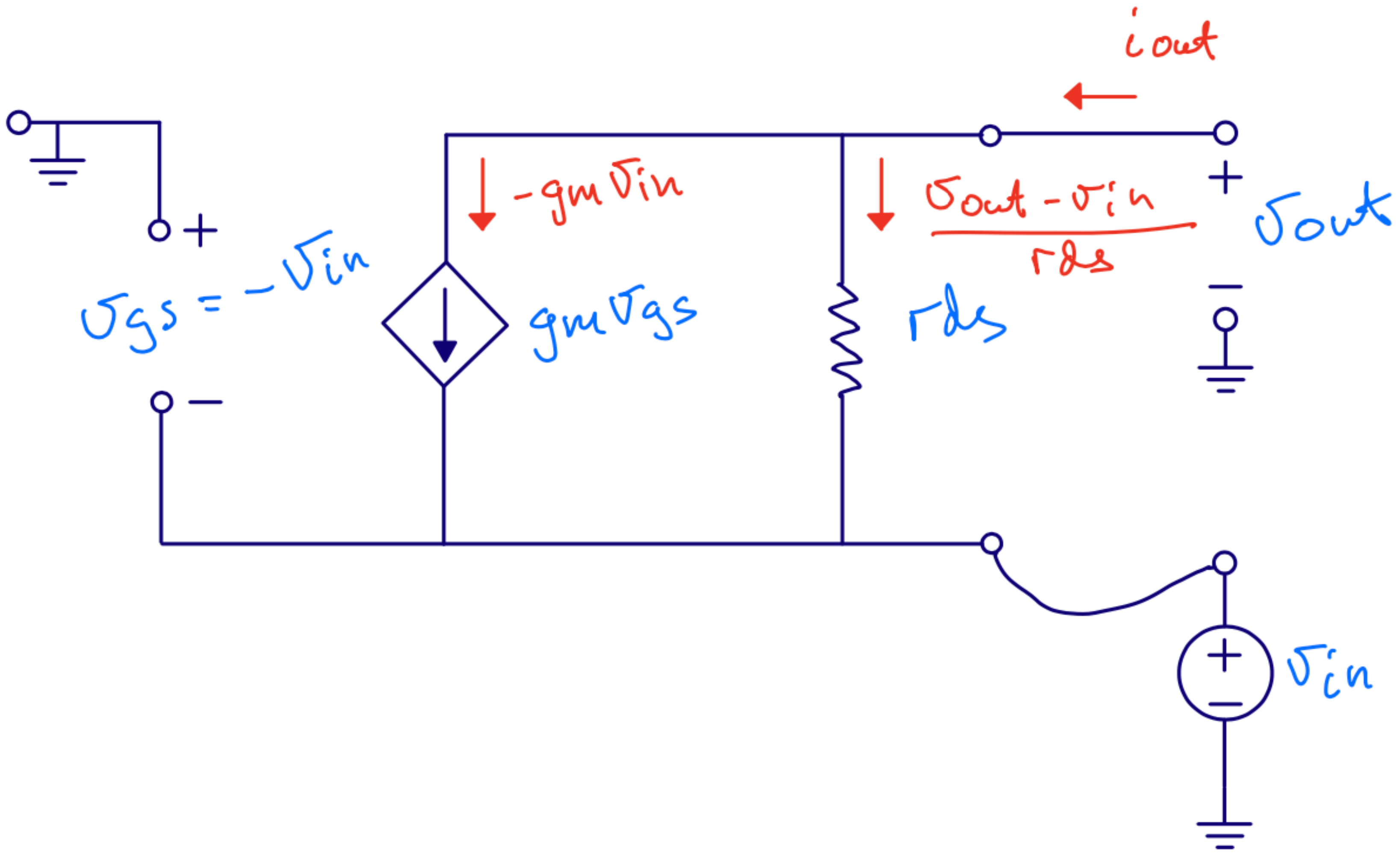
$$i_o = -g_m v_i + \frac{v_o - v_i}{r_{ds}}$$

$$i_o = 0$$

$$0 = -g_m v_i r_{ds} + v_o - v_i$$

$$v_i(1 + g_m r_{ds}) = v_o$$

$$\frac{v_o}{v_i} = 1 + g_m r_{ds}$$



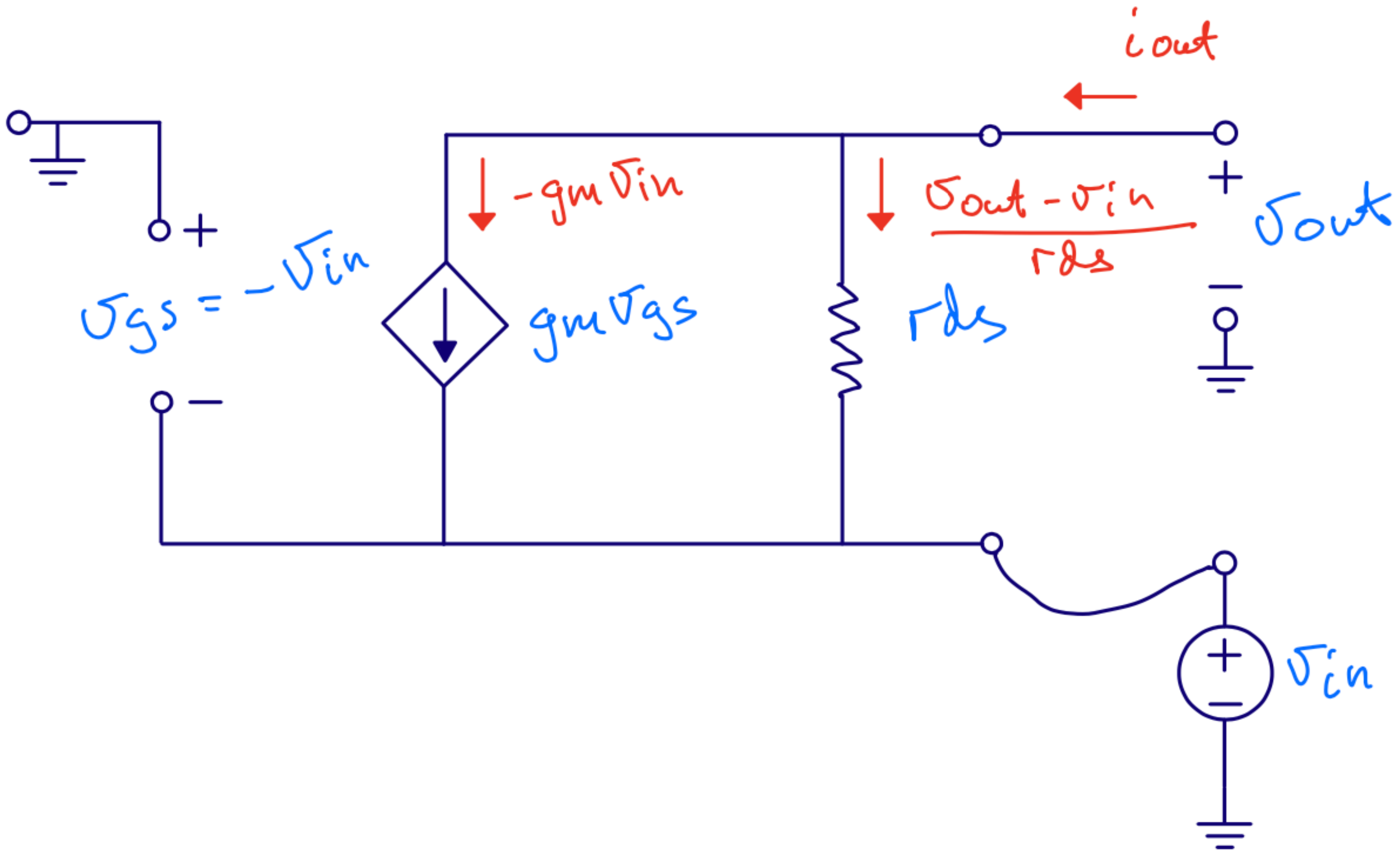
Common gate - Gain

We've ignored bulk effect (g_s), source resistance (R_S) and load resistance (R_L)

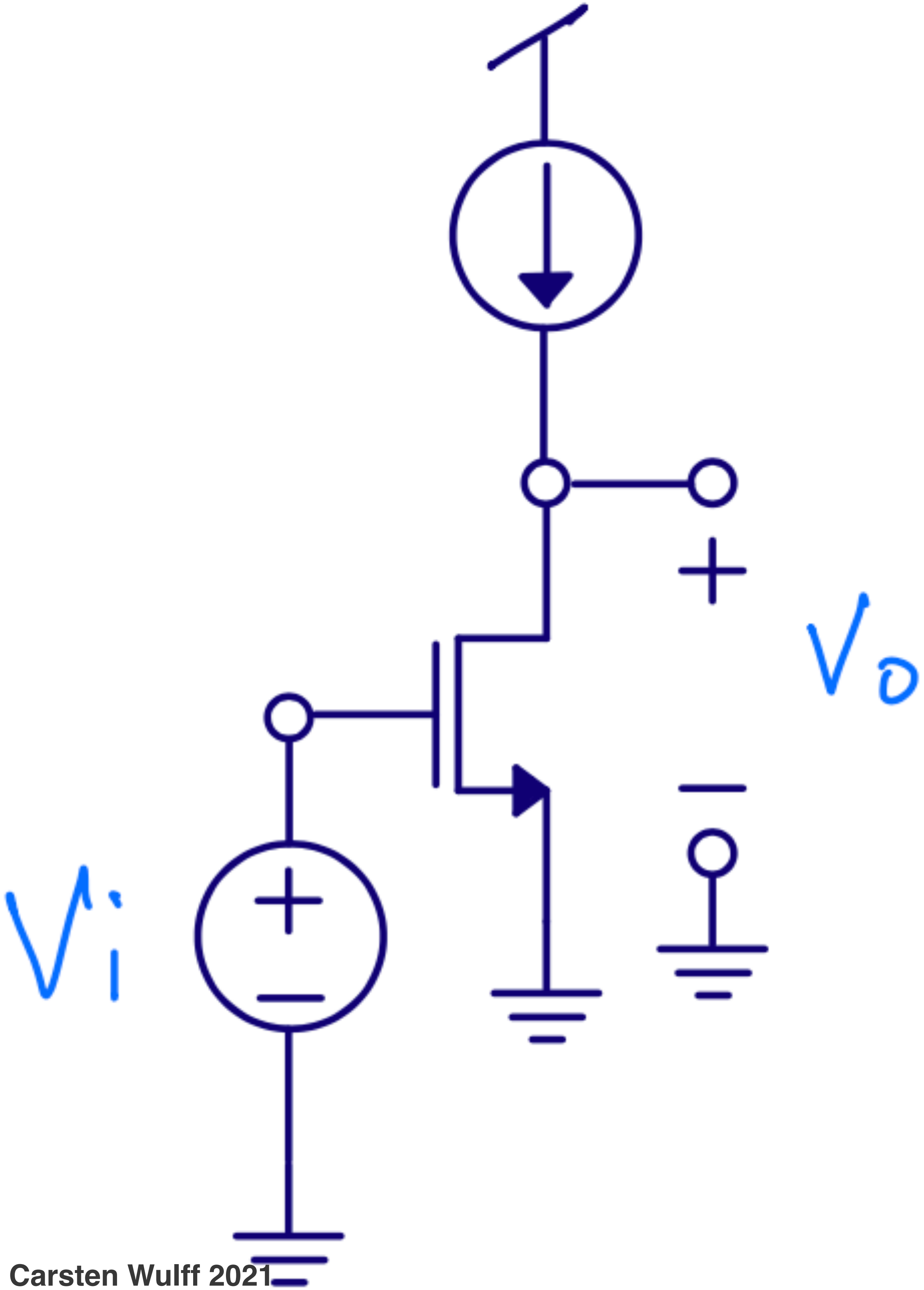
$$A = \frac{(g_m + g_s + g_{ds})(R_L || r_{ds})}{1 + R_S\left(\frac{g_m + g_s + g_{ds}}{1 + R_L/r_{ds}}\right)}$$

If $R_L >> r_{ds}$, $R_S = 0$ and $g_s = 0$

$$A = \frac{(g_m + g_{ds})r_{ds}}{1} = 1 + g_m r_{ds}$$



Common source

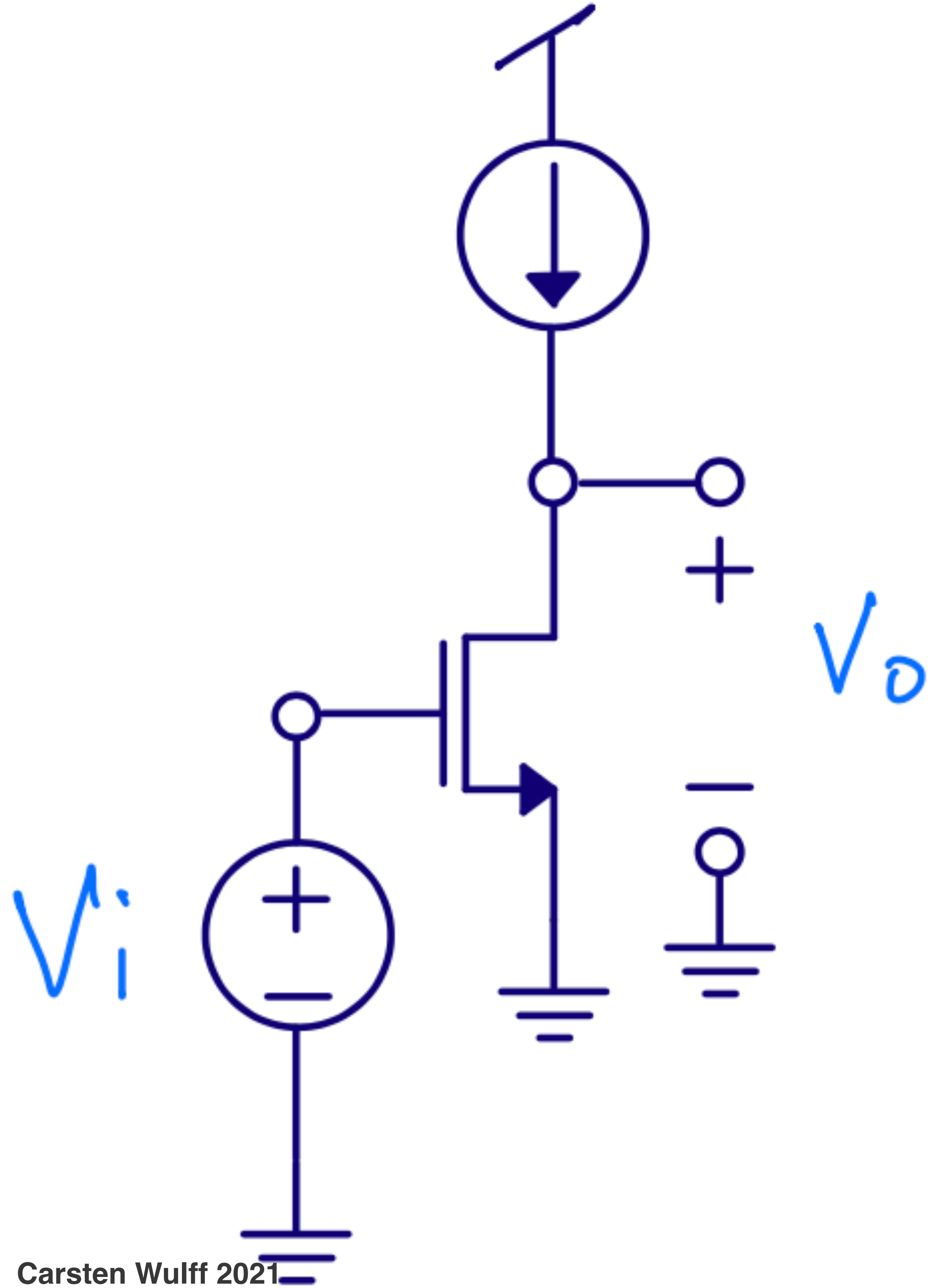


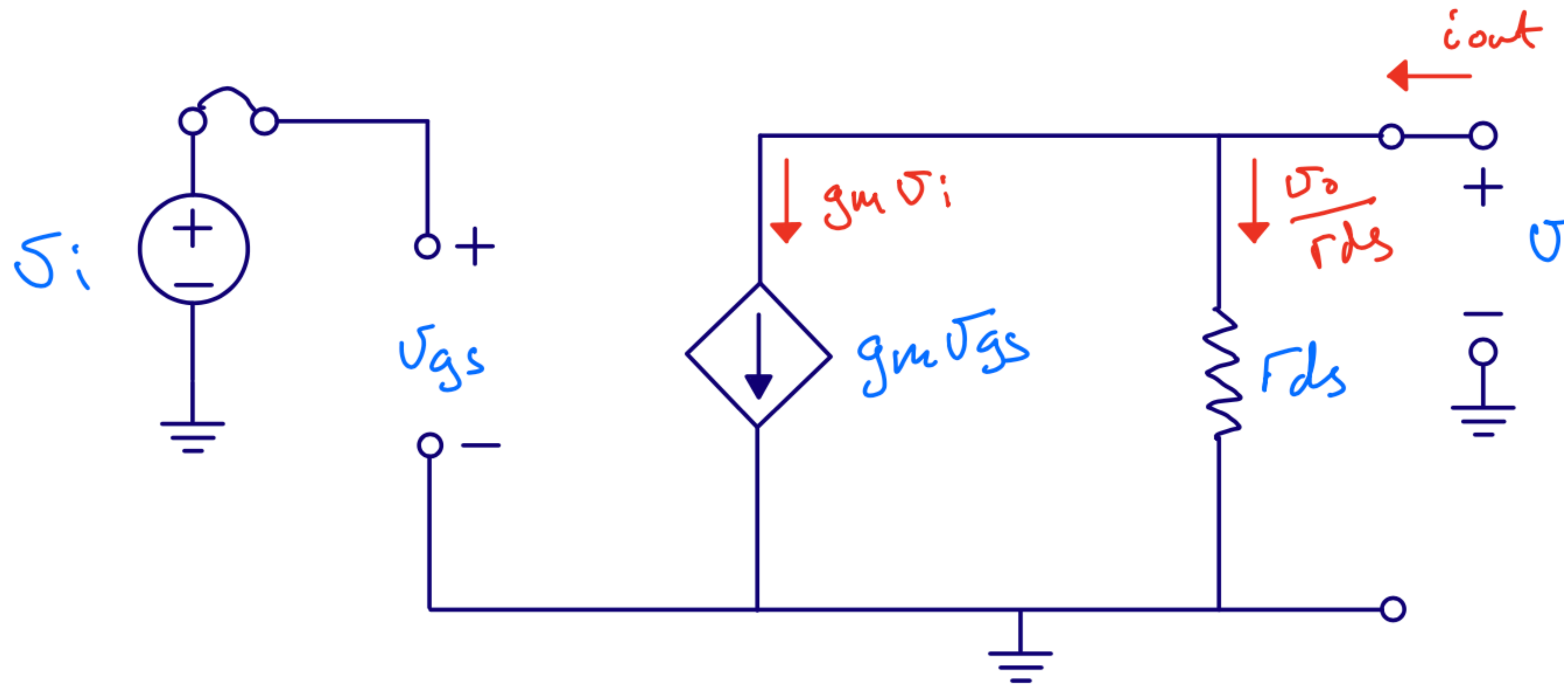
Common source

Input resistance $r_{in} \approx \infty$

Output resistance $r_{out} = r_{ds}$, it's same circuit as the output of a current mirror

Gain ?


V_i
+
−
V_o
+
−


v_i
v_gs
gm v_i
gm v_gs
v_o / rds
rds
i_out
v_o
+
−

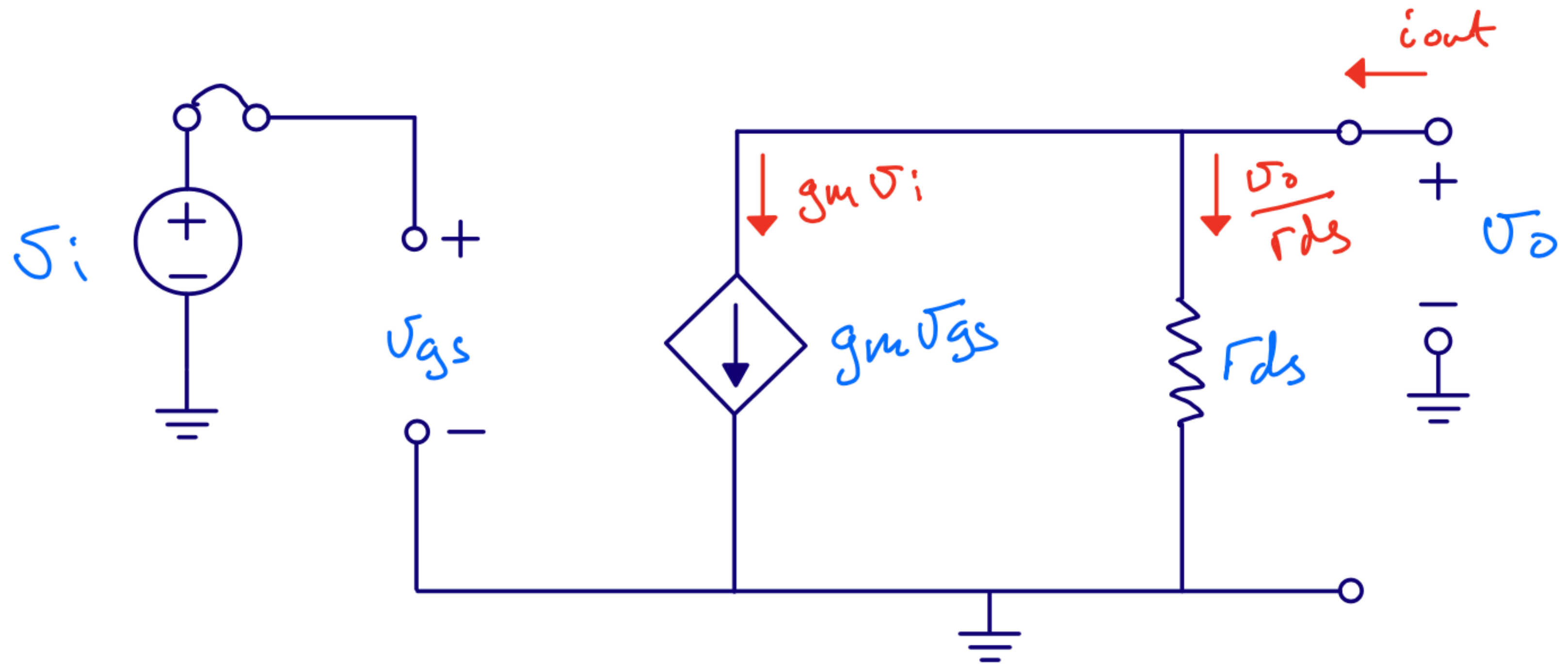
Common source - Gain

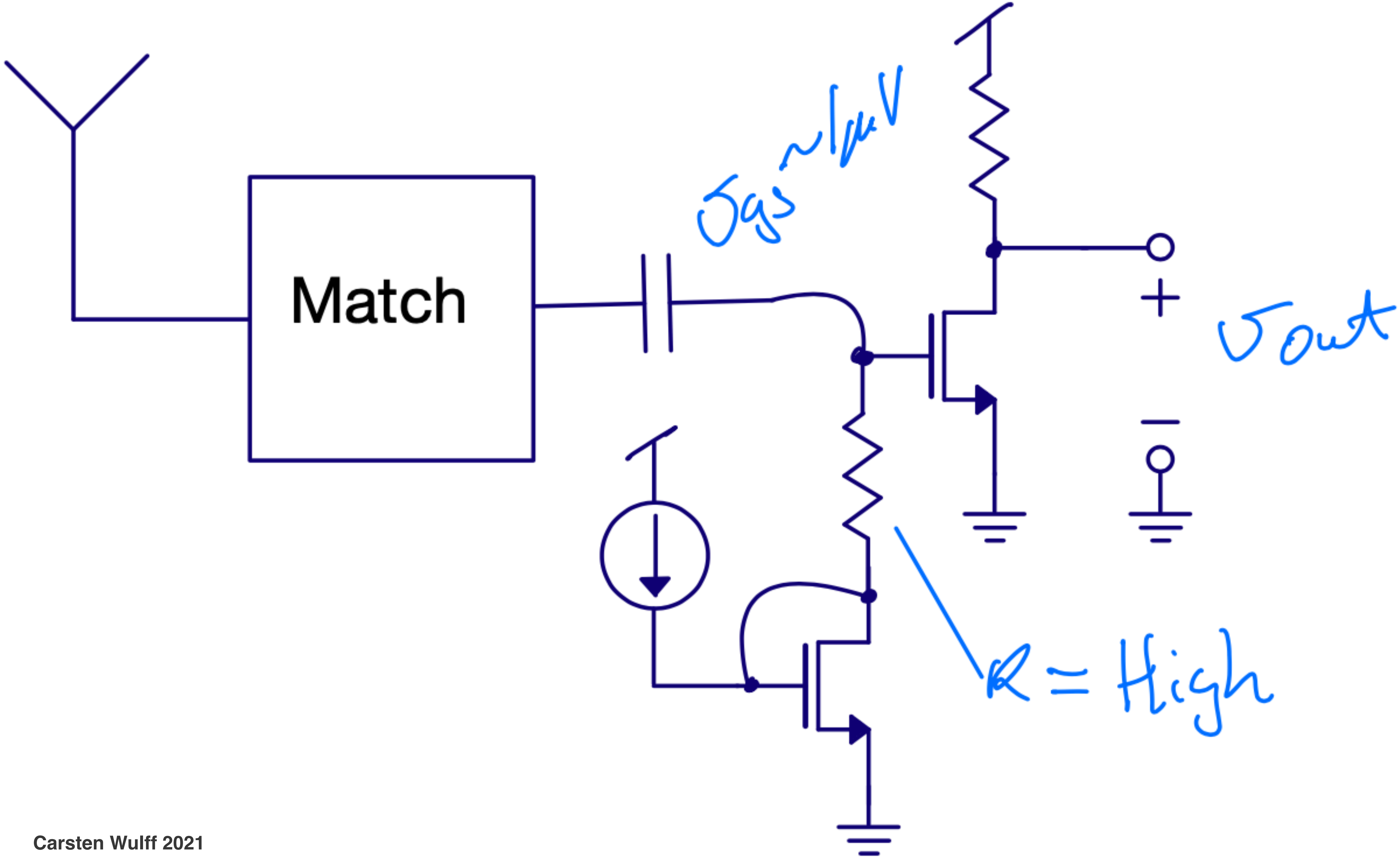
$$i_o = g_m v_i + \frac{v_o}{r_{ds}}$$

$$i_o = 0$$

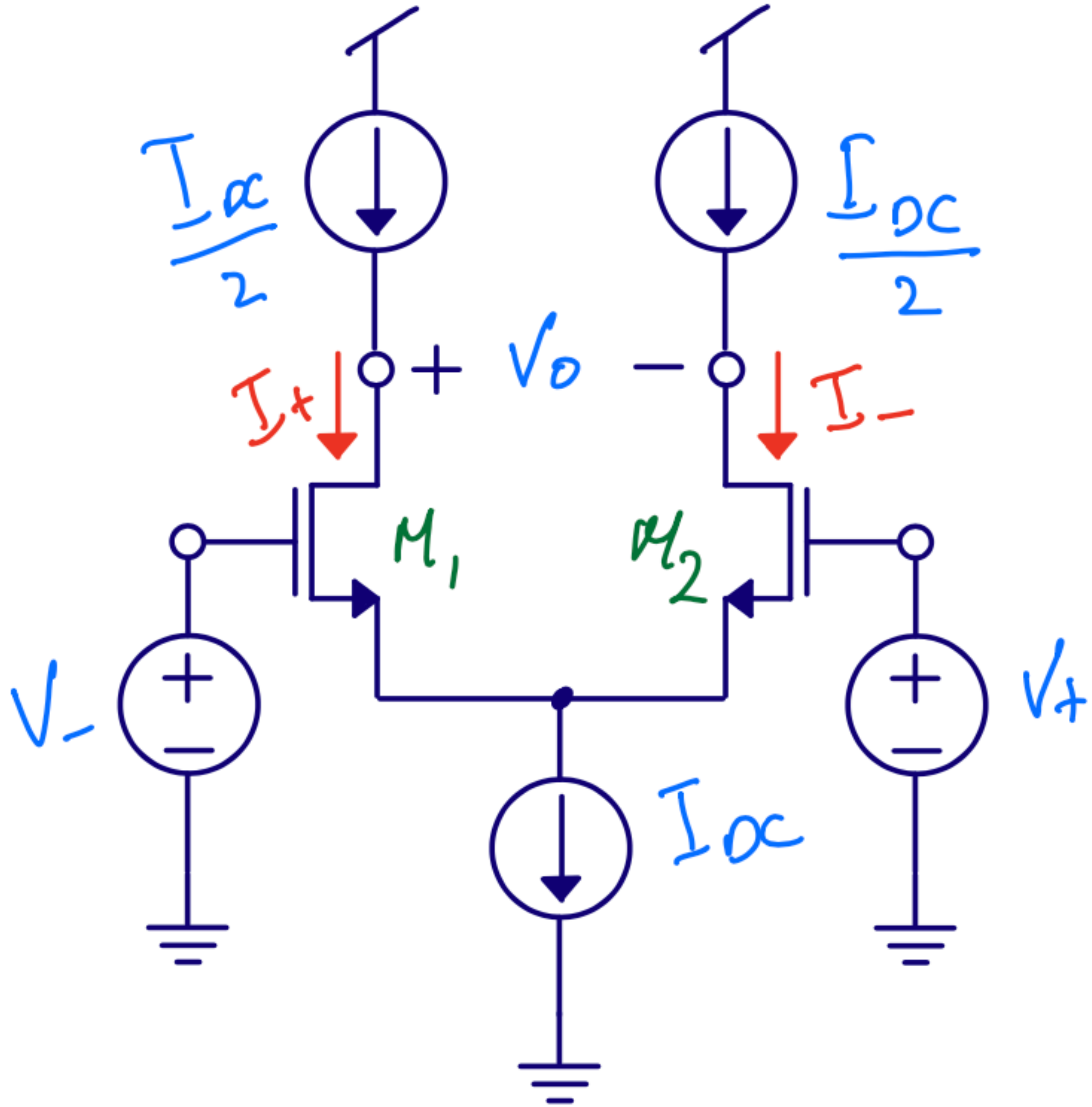
$$-g_m v_i = \frac{v_o}{r_{ds}}$$

$$\frac{v_o}{v_i} = -g_m r_{ds}$$





Match
$v_{gs} \sim 1\mu V$
+
v_{out}
−
R = High



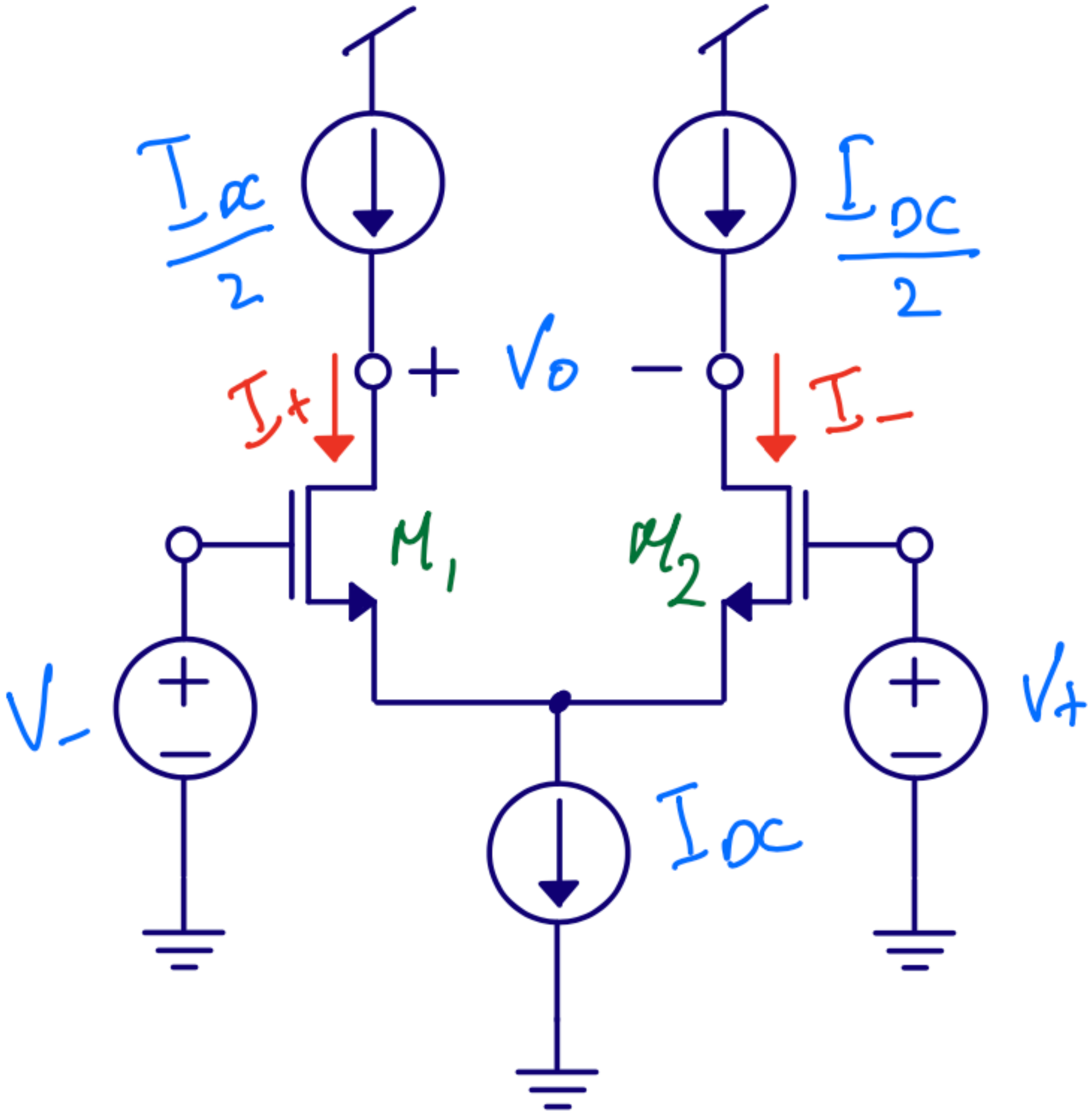
Differential pair

Input resistance $r_{in} \approx \infty$

Gain $A = g_m r_{ds}$

Output resistance $r_{out} = r_{ds}$

Best analyzed with T model of transistor (see CJM page 31)



Diff pairs are cool

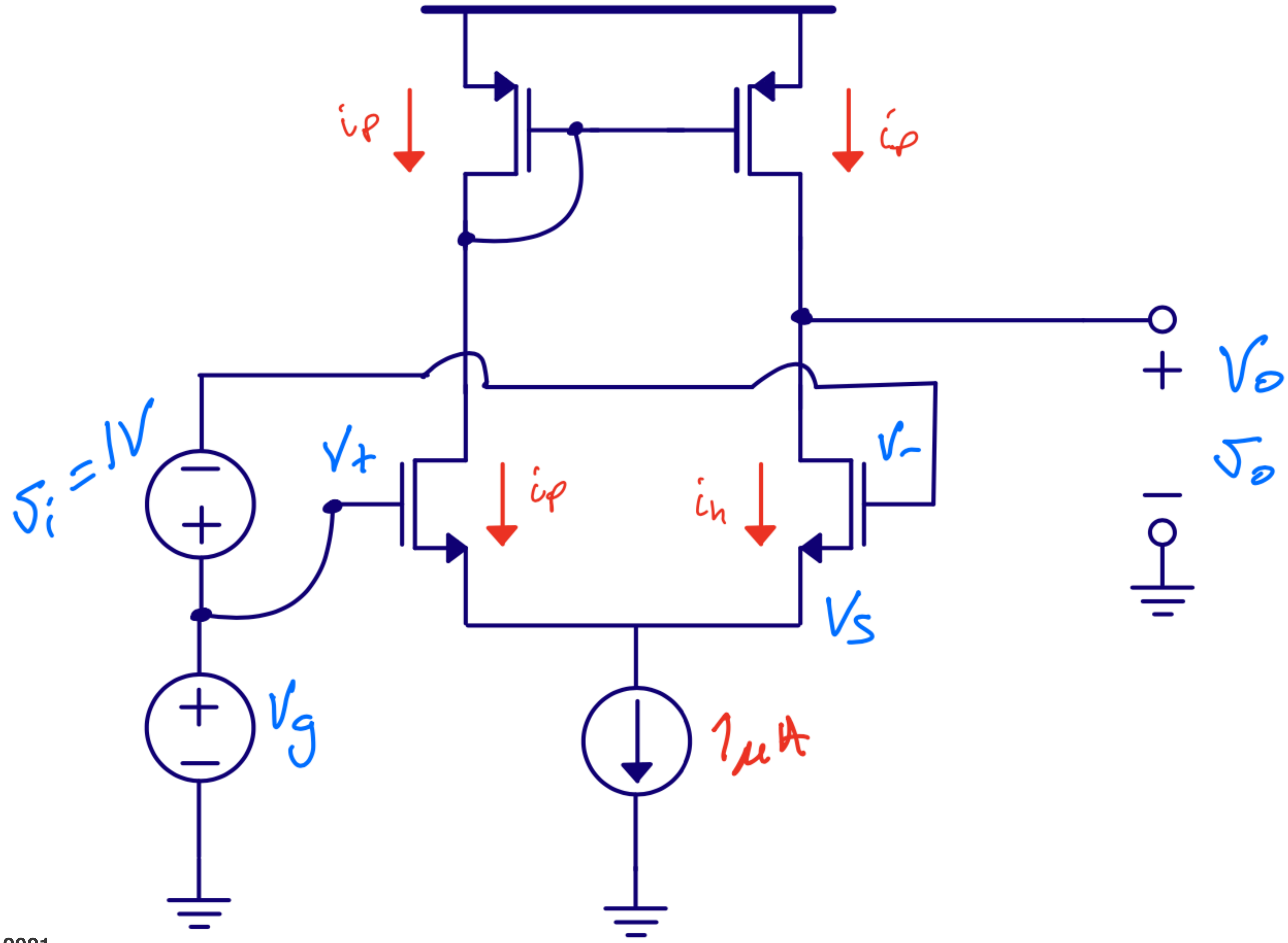
Can choose between

$v_o = g_m r_{ds} v_i$

and

$v_o = -g_m r_{ds} v_i$

by flipping input (or output) connections



i_p
i_p
$v_i = 1V$
V_+
i_p
i_n
V_-
V_o
v_o
+
−
V_S
V_g
$1\mu A$

Thanks!