date: 2024-01-26

# TFE4188 - Lecture 3

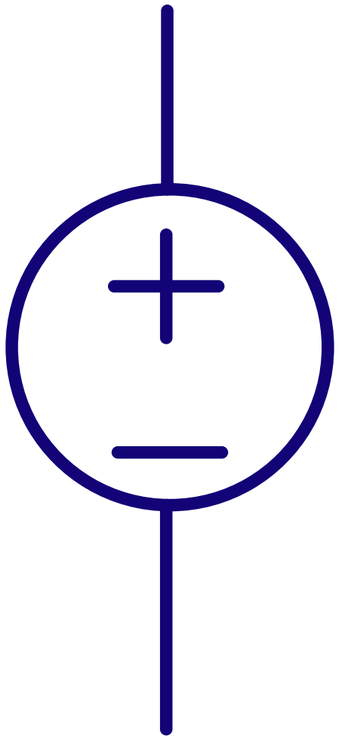
# Reference and bias

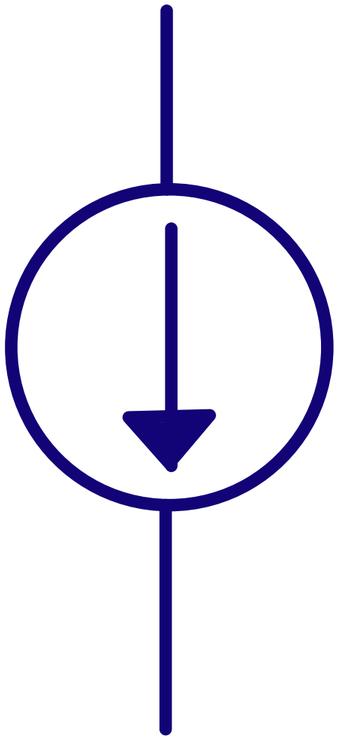
# Goal for today

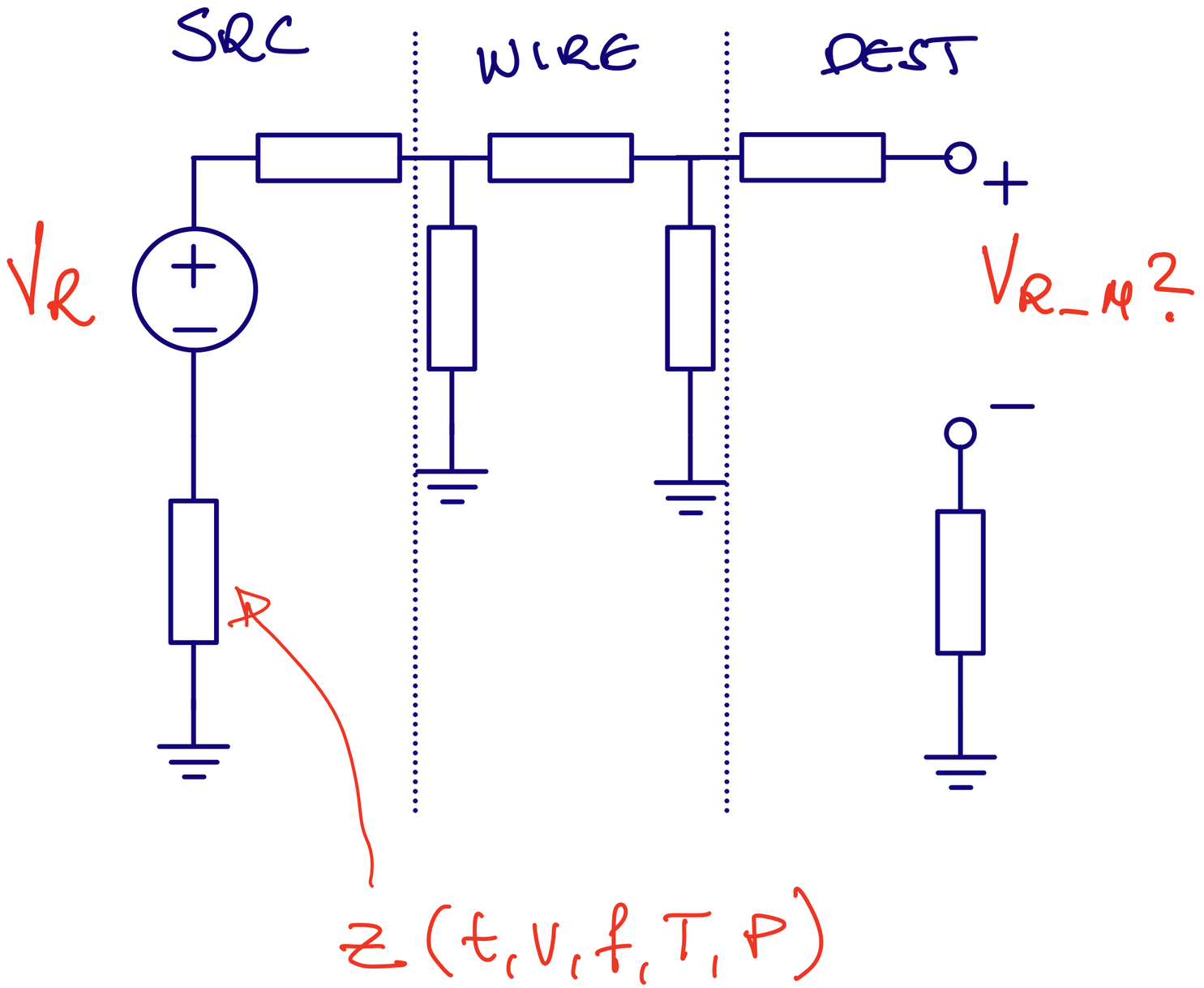
Understand **why** we need reference and bias circuits

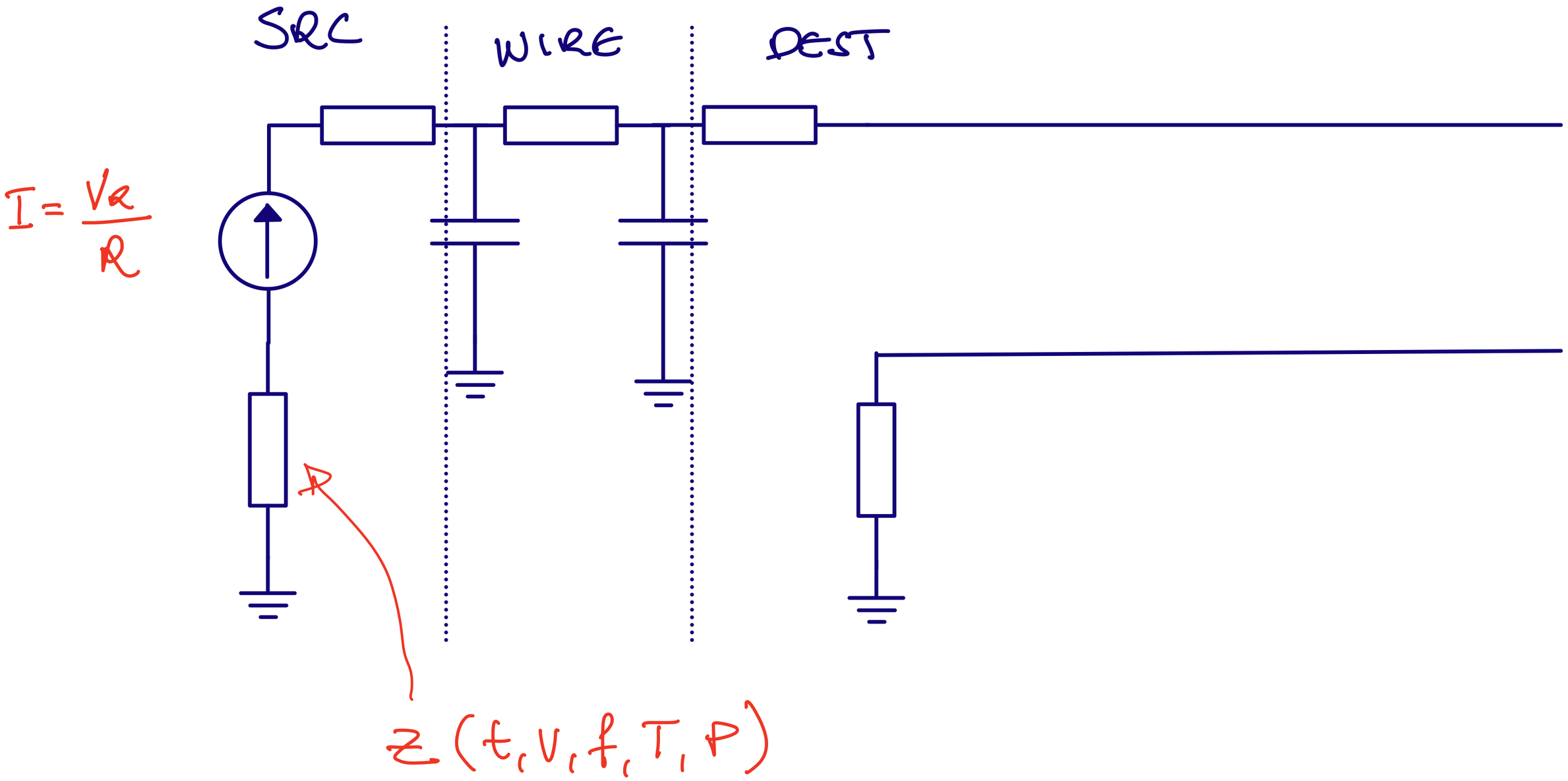
Introduction to **circuit architectures**

# Why

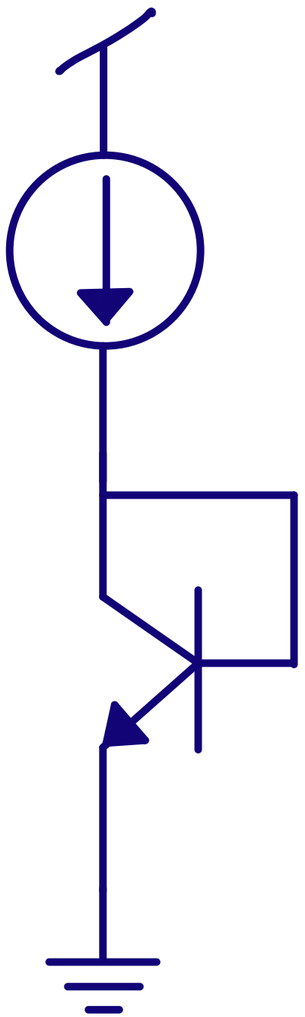





SRC
WIRE
DEST
+
$V_R$
$V_{R\_M}$?
−
R
$Z(t, V, f, T, P)$


SRC
WIRE
DEST
$I = \frac{V_R}{R}$
R
$z(t, V, f, T, P)$

# Bandgap voltage reference



# A voltage complementary to temperature (CTAT)

$$I_D = I_S \left( e^{\frac{V_{BE}}{V_T}} - 1 \right) + I_B \approx I_S e^{\frac{V_{BE}}{V_T}}$$

$$V_T = \frac{kT}{q}$$

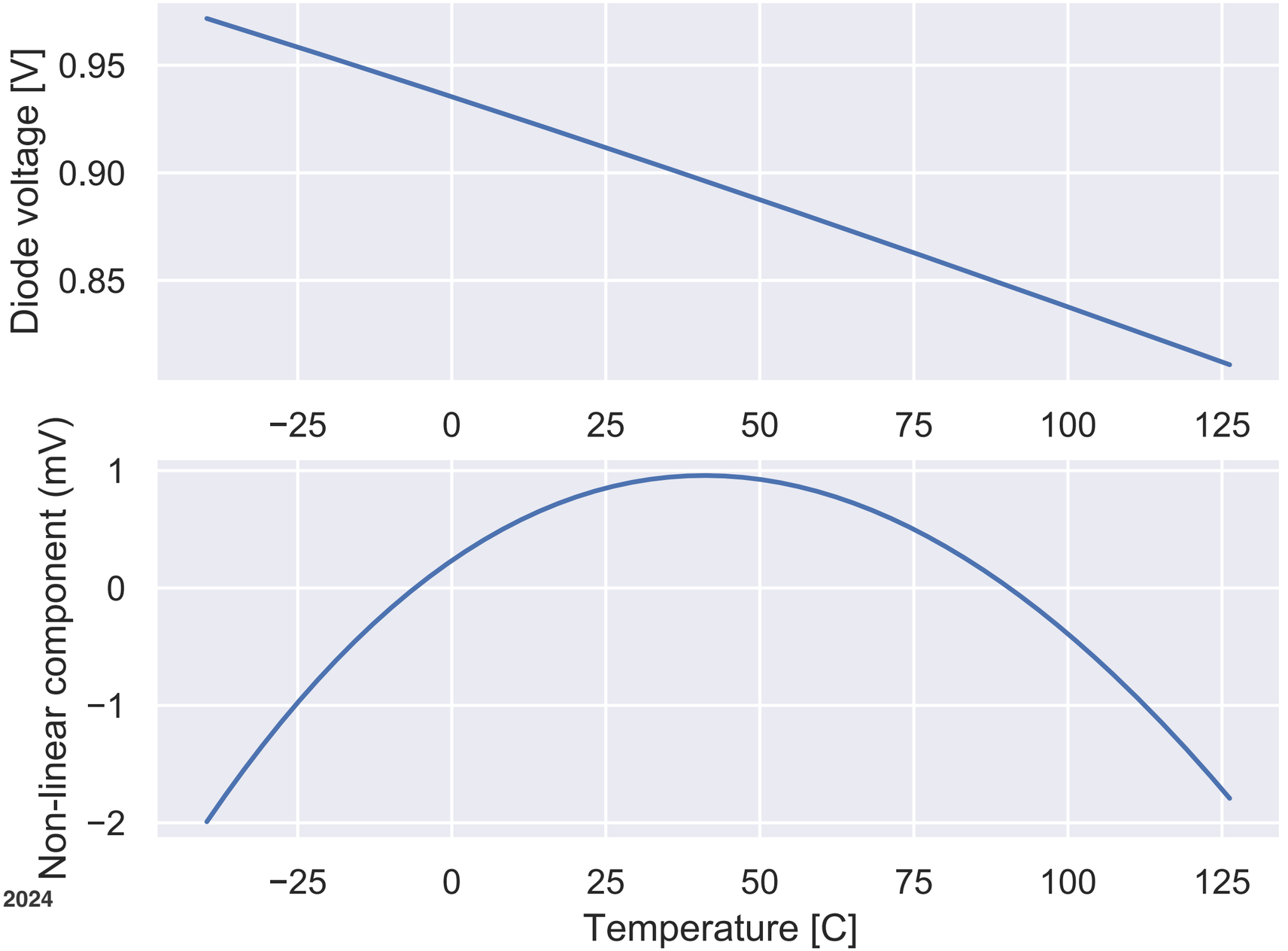
$$V_{BE} = \frac{kT}{q} \ln \frac{I_C}{I_S}$$

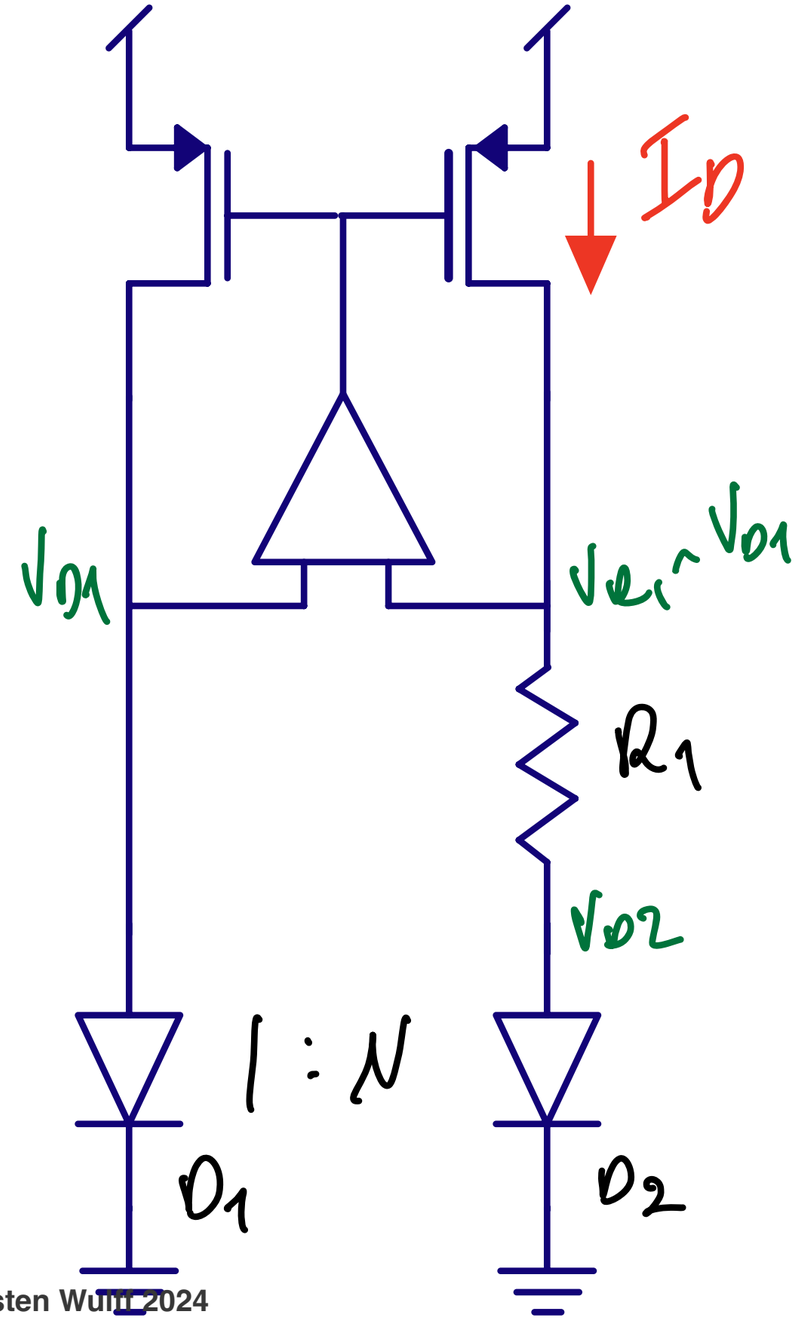
$$I_S = qAn_i^2 \left[ \frac{D_n}{L_n N_A} + \frac{D_p}{L_p N_D} \right]$$

# Some algebra (see Diodes)

$$V_{BE} = \frac{kT}{q}(\ell - 3\ln T) + V_G$$

$$\ell = \ln I_C - \ln qA - \ln\left[\frac{D_n}{L_n N_A} + \frac{D_p}{L_p N_D}\right] - 2\ln 2 - \frac{3}{2}\ln m_n^* - \frac{3}{2}\ln m_p^* - 3\ln\frac{2\pi k}{h^2}$$

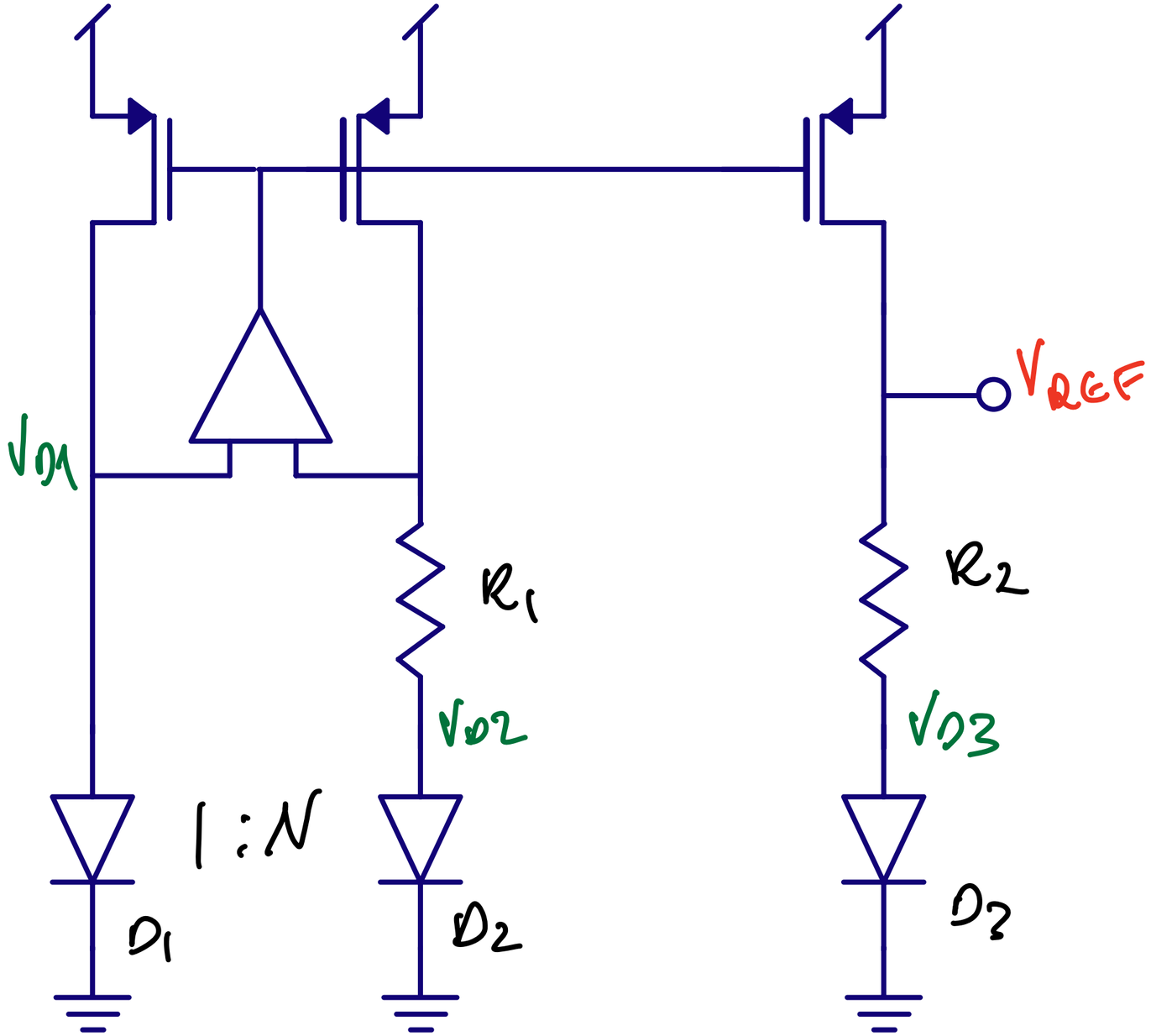

Diode voltage [V]
0.95
0.90
0.85
−25
0
25
50
75
100
125
Non-linear component (mV)
1
0
−1
−2
−25
0
25
50
75
100
125
Temperature [C]

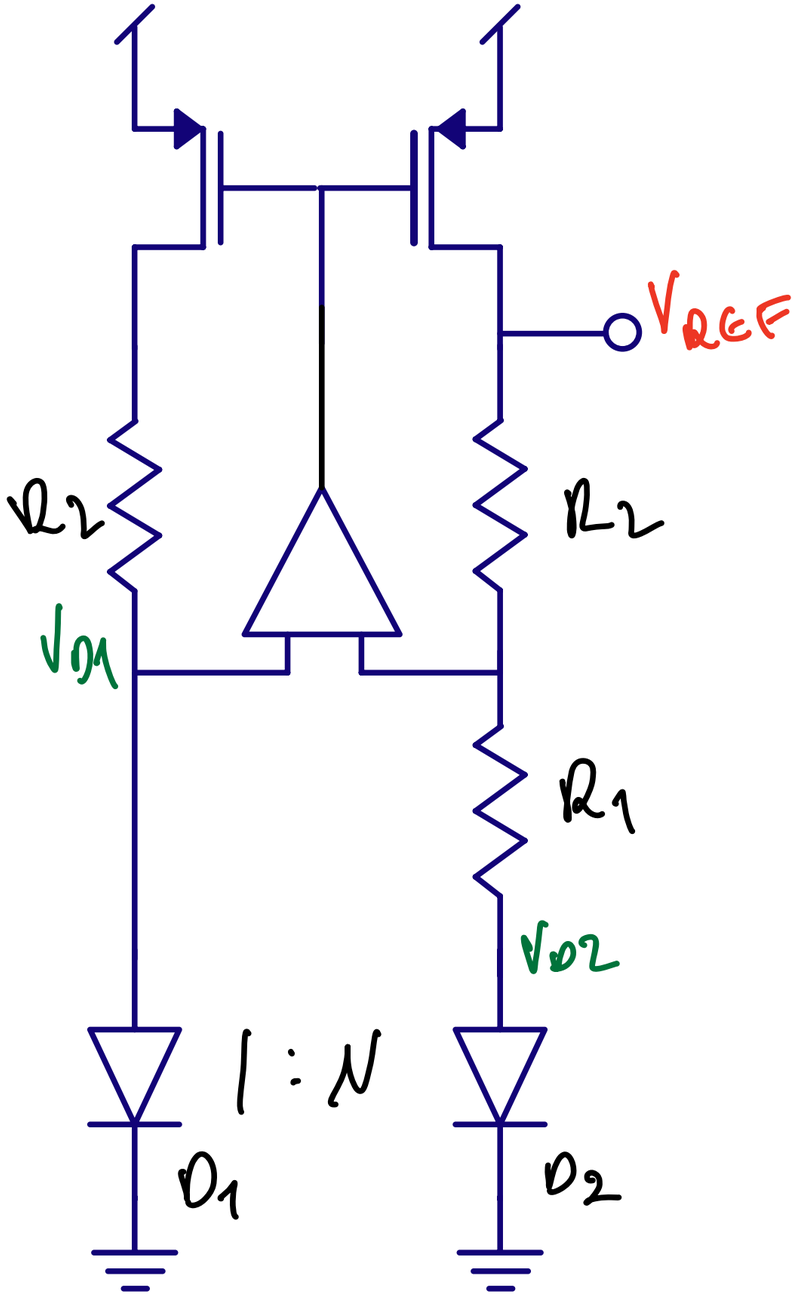


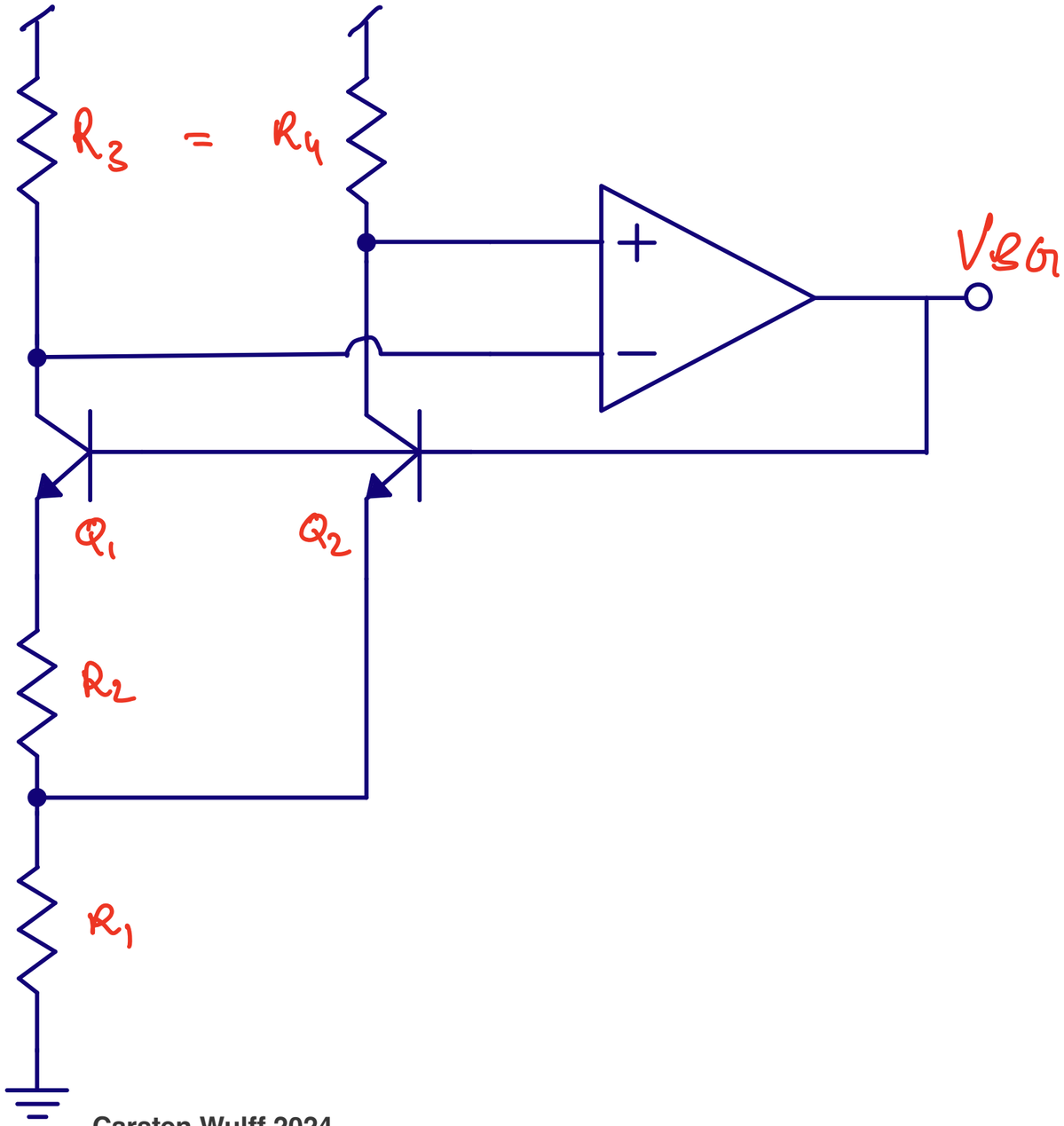

# A current proportional to temperature (PTAT)

$$V_{D1} - V_{D2} = V_T \ln \frac{I_D}{I_{S1}} - V_T \ln \frac{I_D}{I_{S2}} = V_T \ln \frac{I_{S2}}{I_{S1}} = V_T \ln N$$

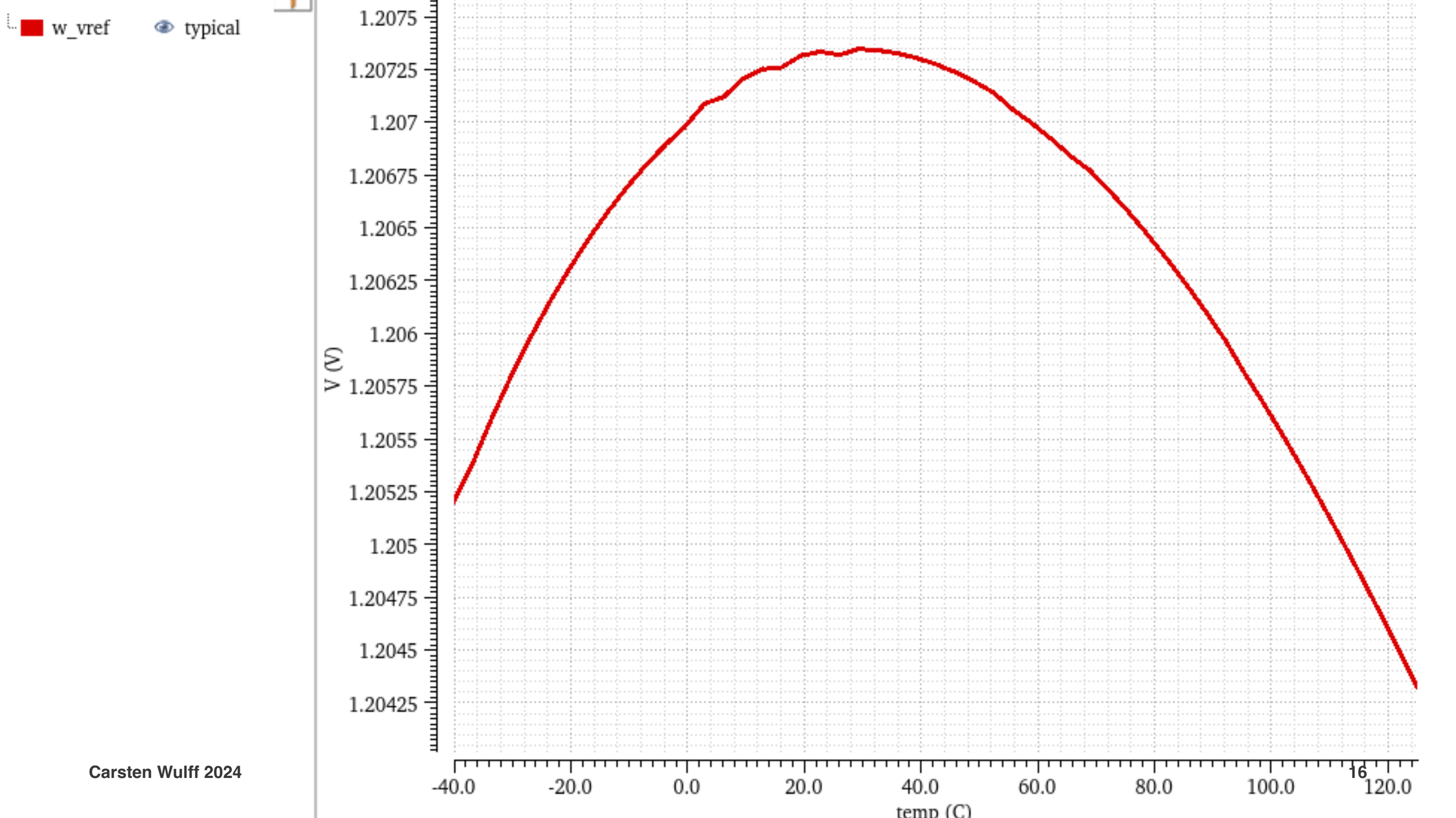
# How to combine a CTAT with a PTAT ?

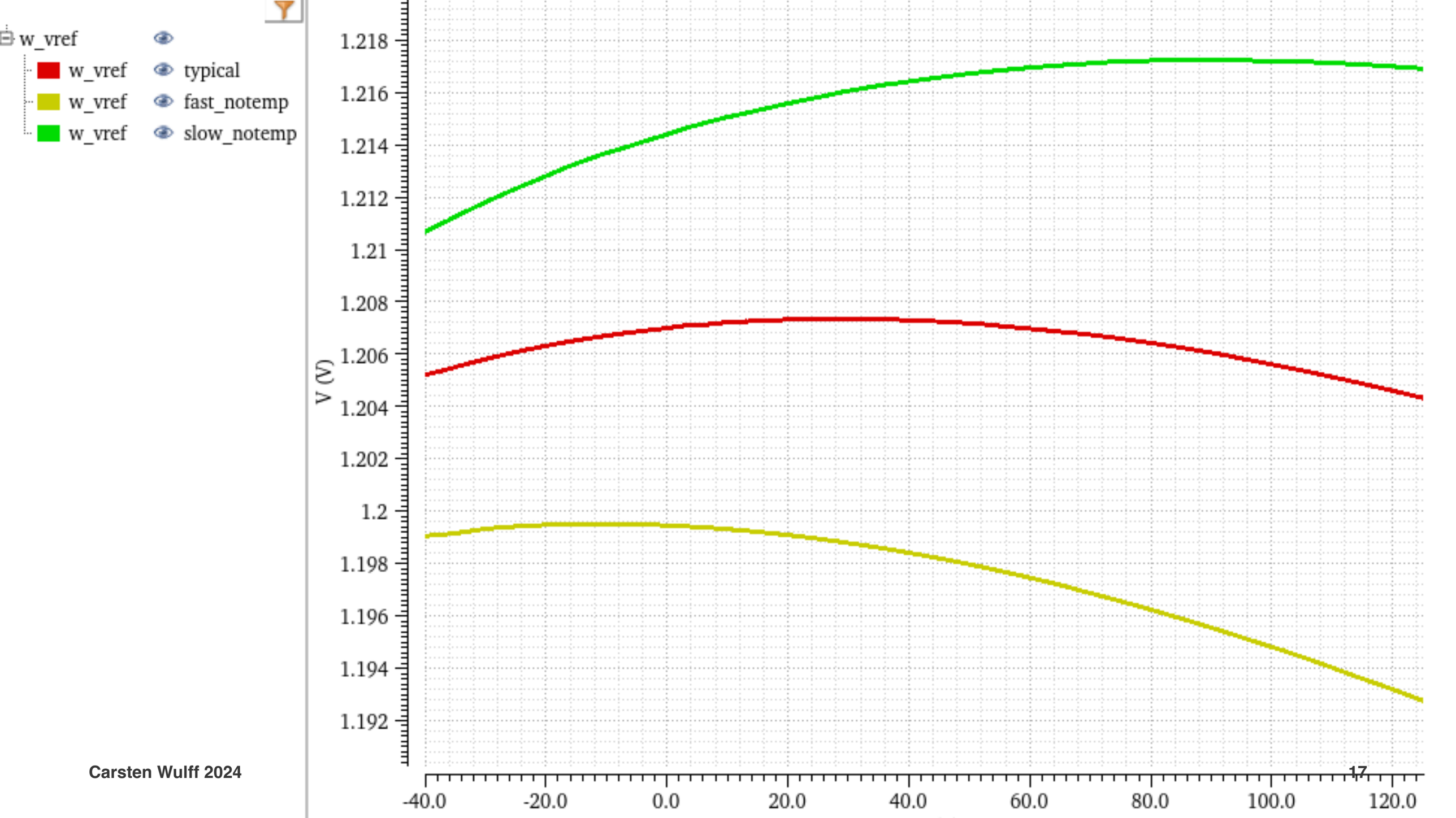

$V_{REF}$
$V_{D1}$
$R_1$
$R_2$
$V_{D2}$
$V_{D3}$
1 : N
$D_1$
$D_2$
$D_3$


$V_{REF}$
$R_2$
$R_2$
$V_{D1}$
$R_1$
$V_{D2}$
1 : N
$D_1$
$D_2$

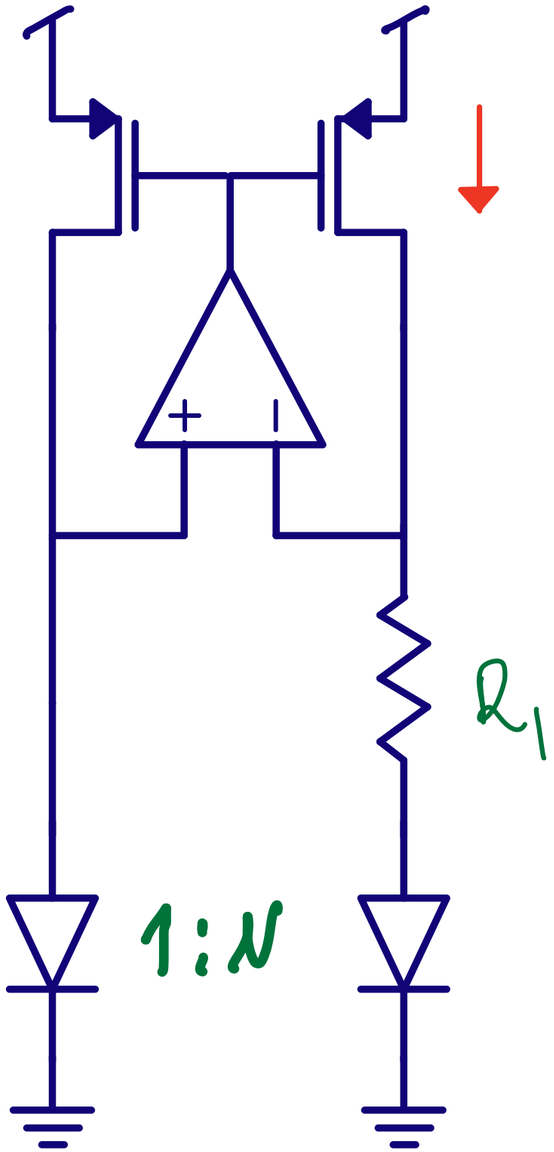


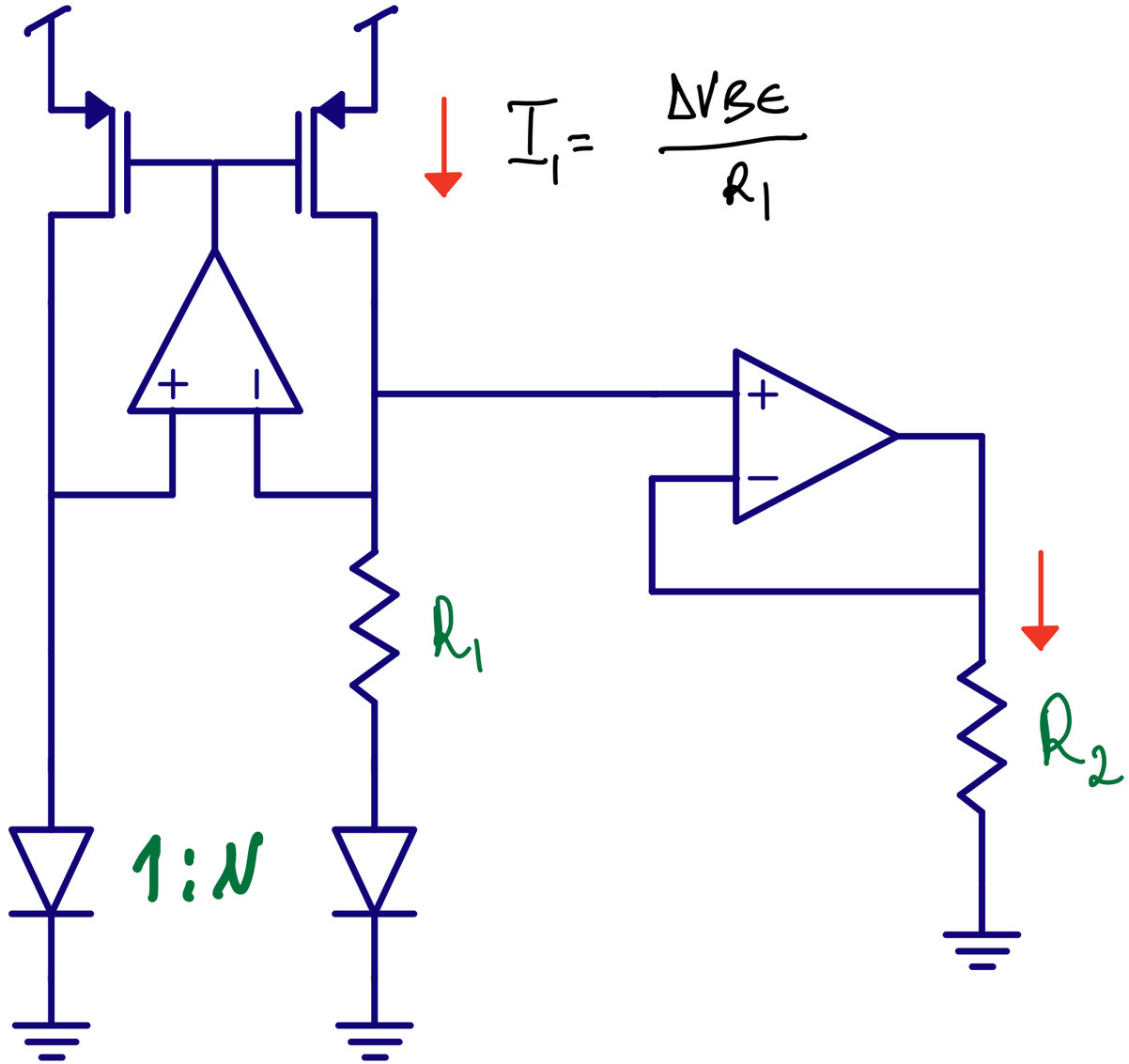

$$V_{BG} = V_{G0} + (m-1)\frac{kT}{q}\ln\frac{T_0}{T} + T\left[\frac{k}{q}\ln\frac{J_2}{J_1}\frac{2R2}{R1} - \frac{V_{G0}-V_{be0}}{T_0}\right]$$


w_vref
typical
1.2075
1.20725
1.207
1.20675
1.2065
1.20625
1.206
1.20575
1.2055
1.20525
1.205
1.20475
1.2045
1.20425
V (V)
-40.0
-20.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
temp (C)

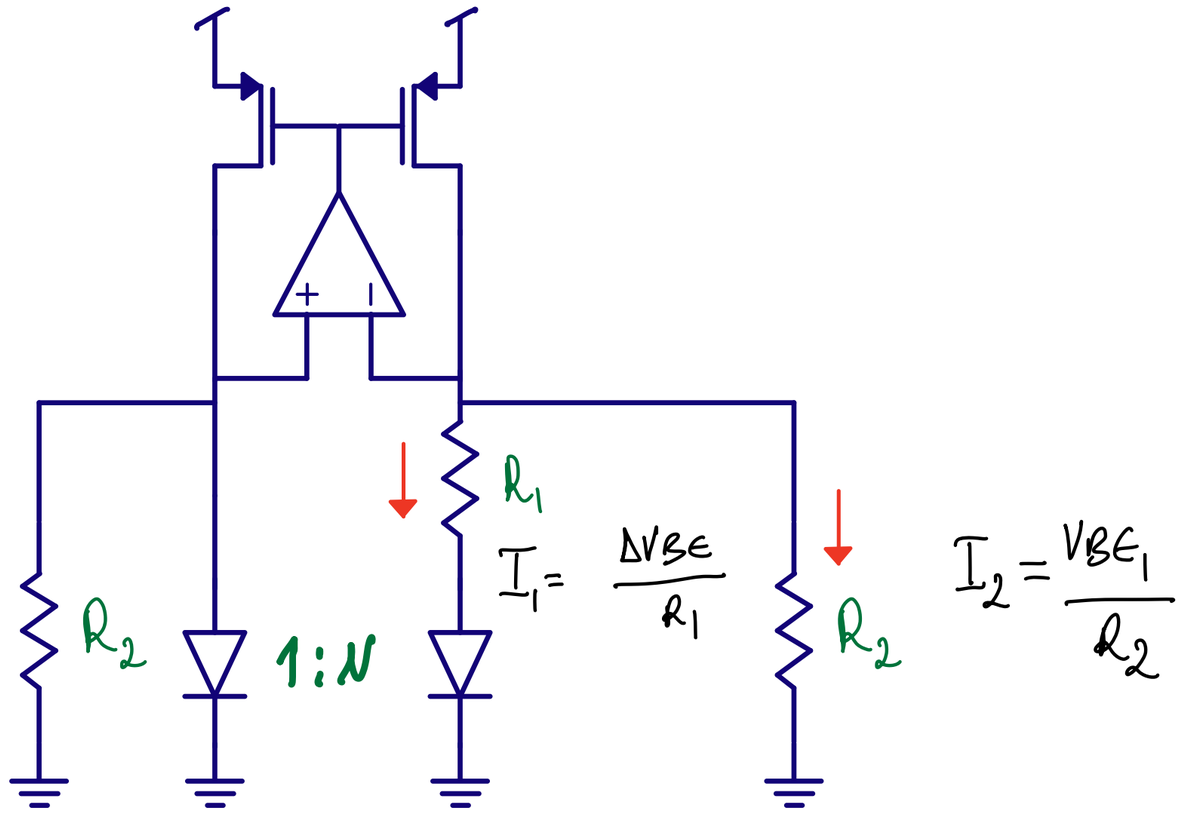

w_vref
w_vref typical
w_vref fast_notemp
w_vref slow_notemp
V (V)
1.218
1.216
1.214
1.212
1.21
1.208
1.206
1.204
1.202
1.2
1.198
1.196
1.194
1.192
-40.0
-20.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0

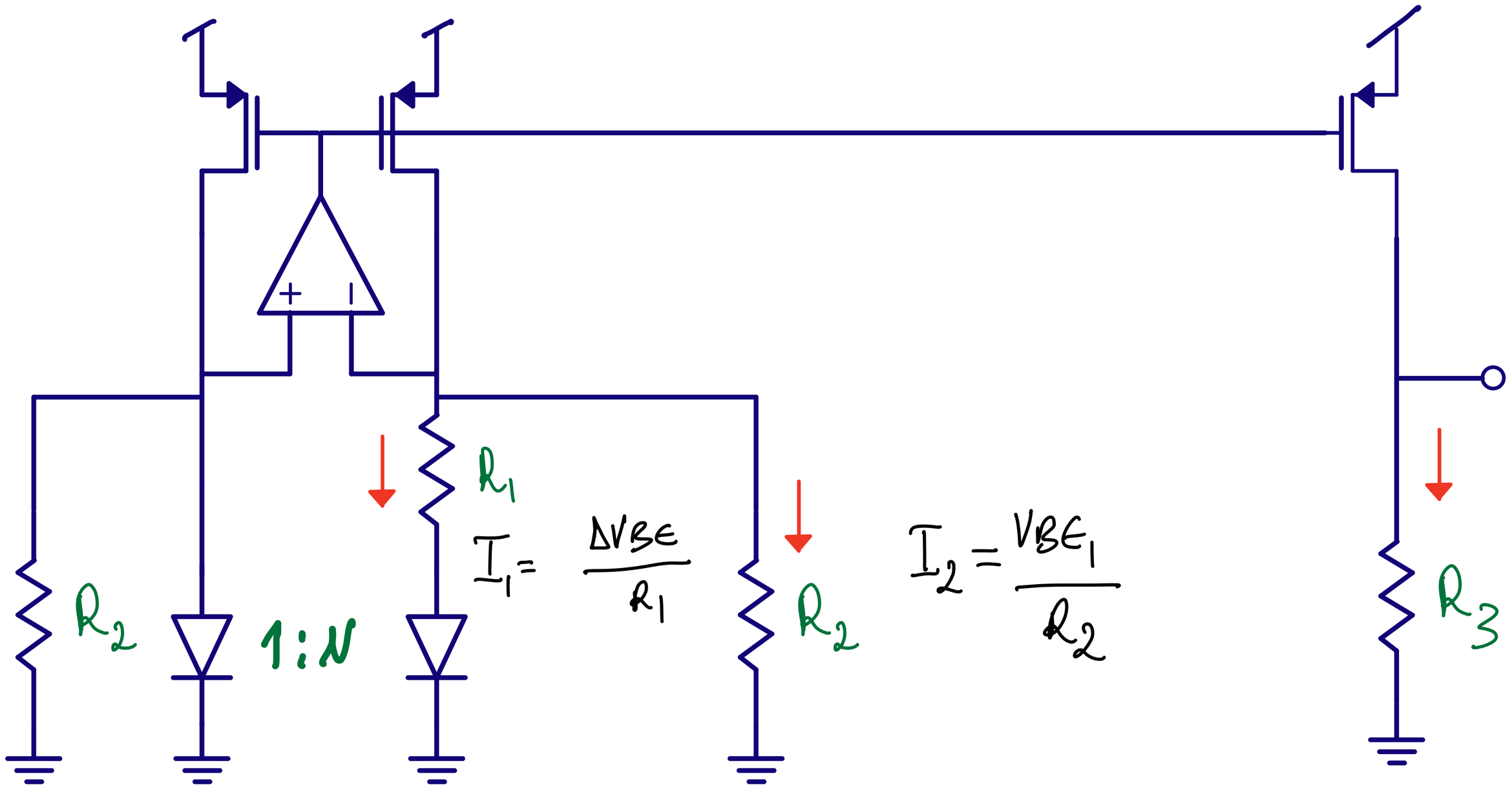
# Low voltage bandgap


+
-
$R_1$
1:N


$I_1 = \frac{\Delta V_{BE}}{R_1}$
+
−
$R_1$
1 : N
+
−
$R_2$

$$I_{PMOS} = \frac{V_D}{R_2} + \frac{\Delta V_D}{R_1}$$

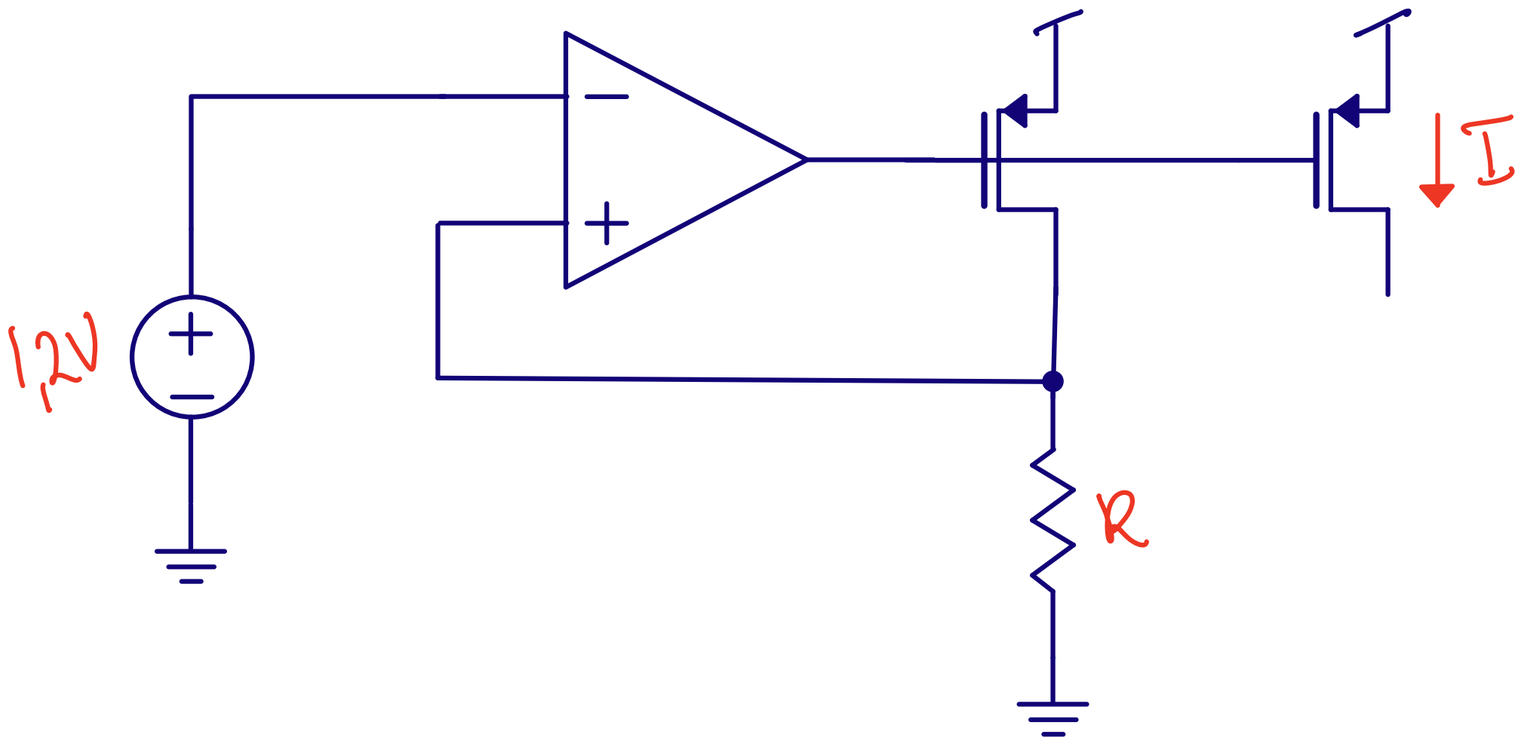


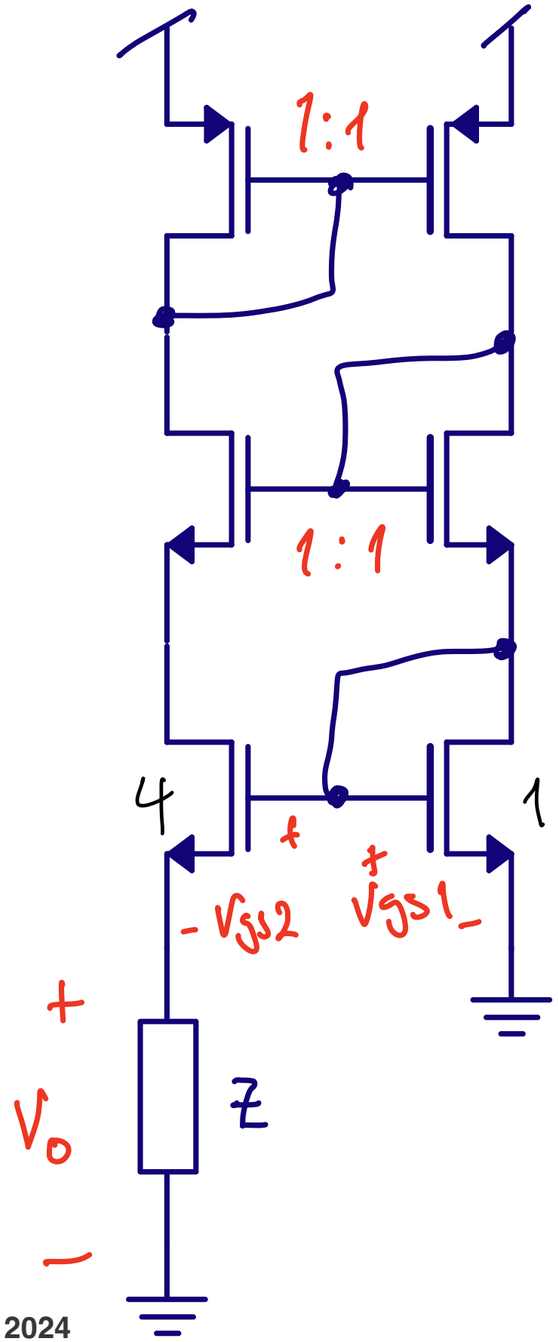

+
-
R1
R2
1:N
R2
R3
I1 = ΔVBE / R1
I2 = VBE1 / R2

# Bias

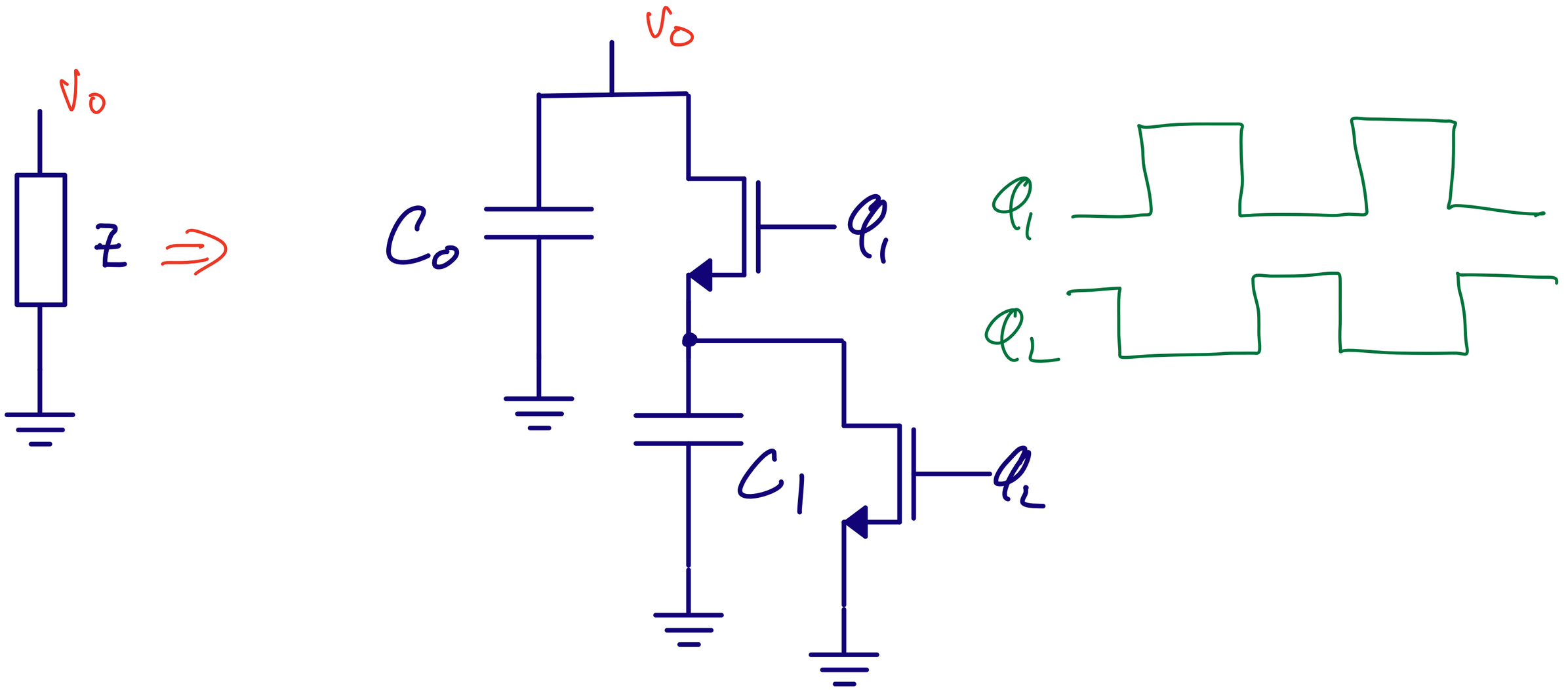
Sometimes we just need a current

# How does a VI converter circuit work?






# GmCell: Why is 1/Z proportional to transistor transconductance?


$V_0$
Z
$V_0$
$C_0$
$q_1$
$C_1$
$q_2$
$q_1$
$q_2$

# Thanks!