date: 2025-01-30

TFE4188 - Lecture 3

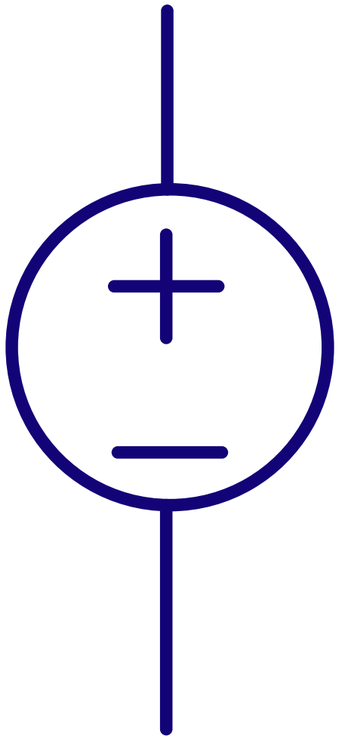
Reference and bias

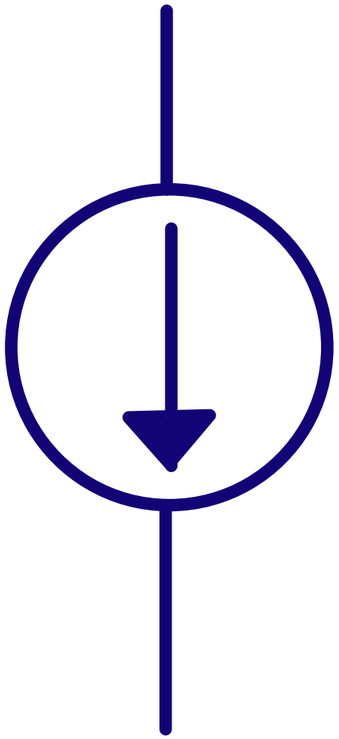
Goal for today

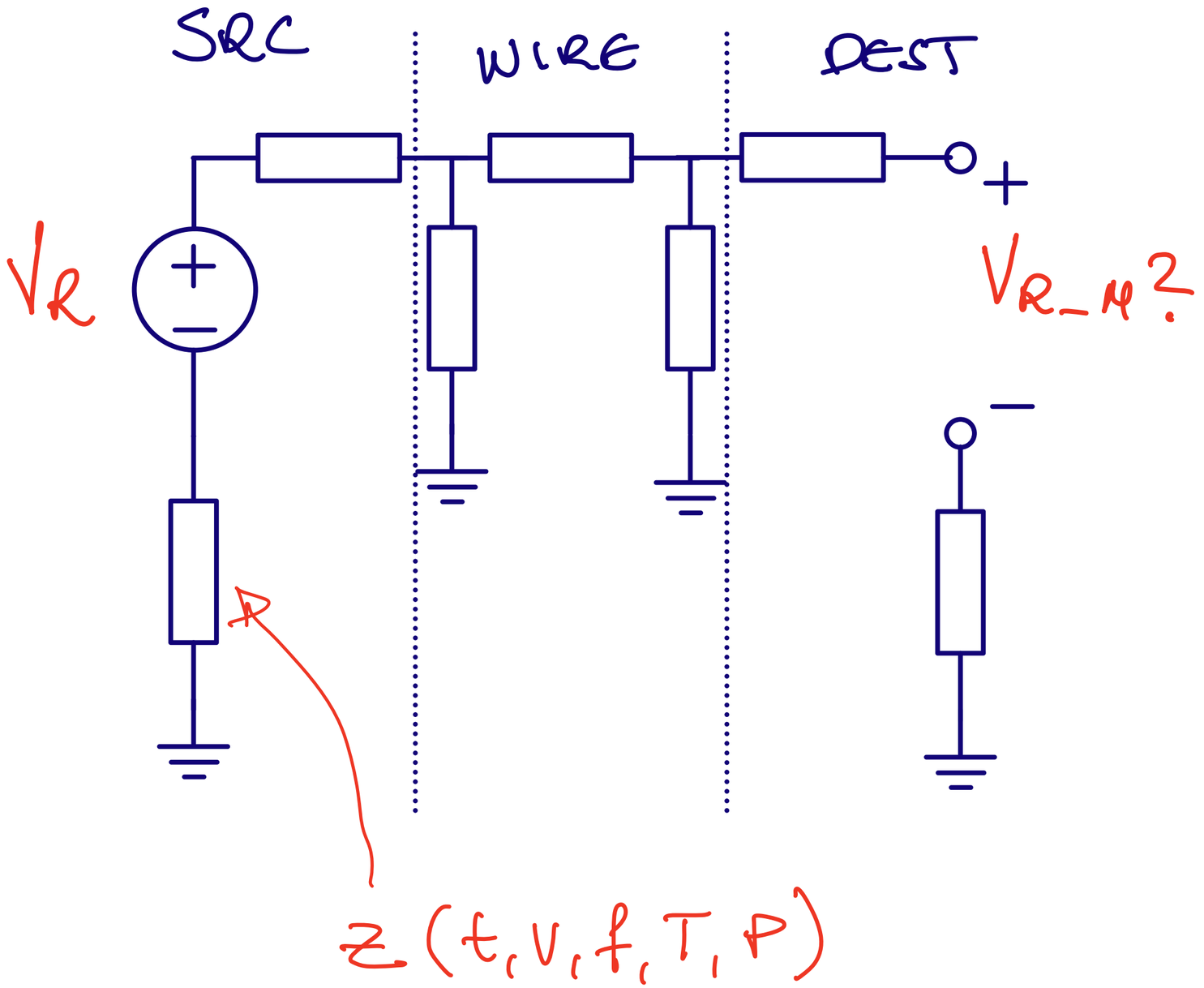
Understand **why** we need reference and bias circuits

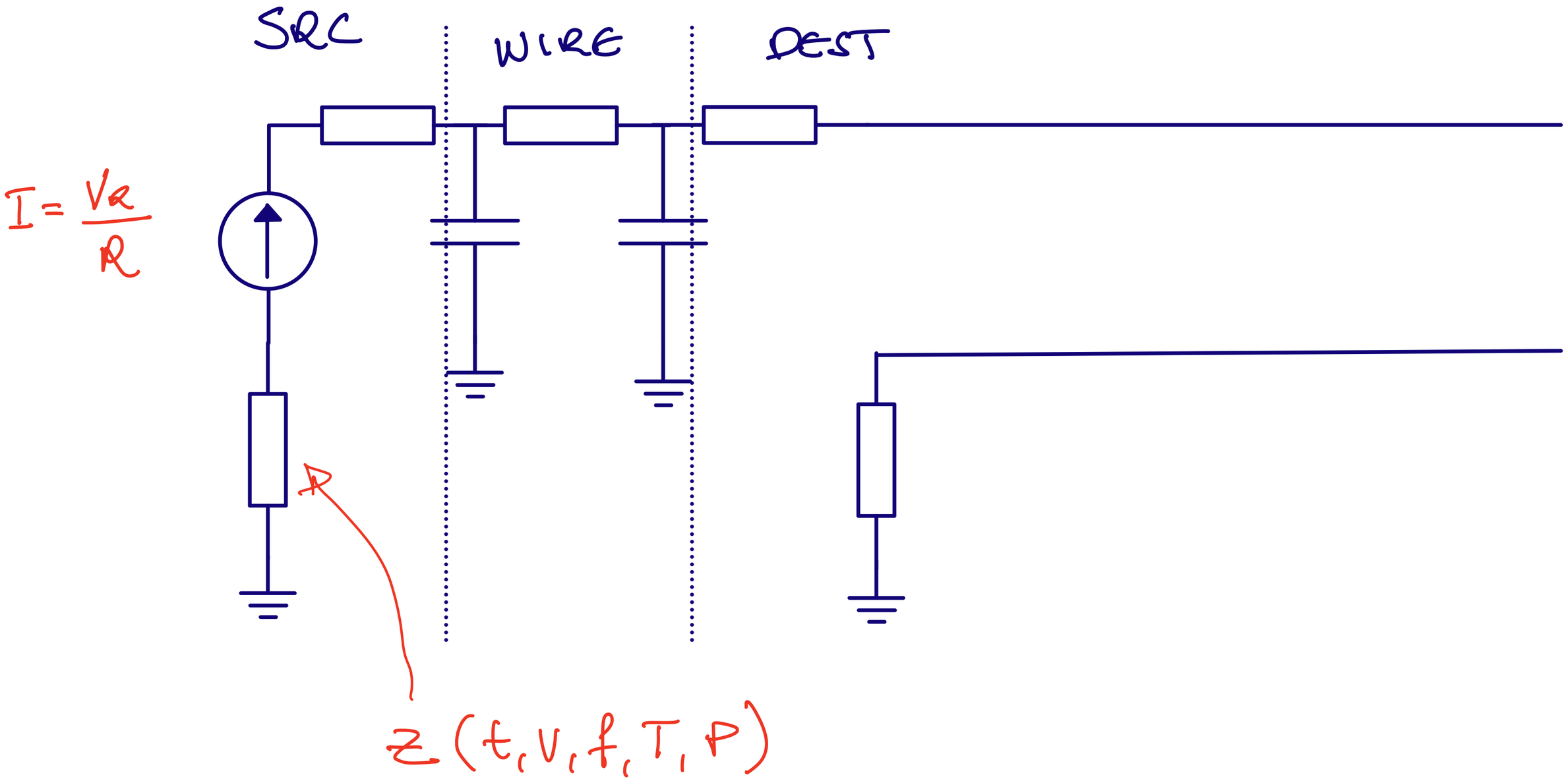
Introduction to **circuit architectures**

Why

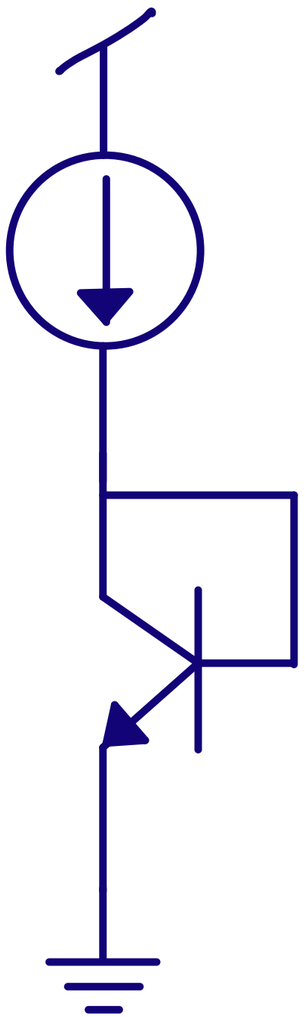





SRC
WIRE
DEST
+
V_R
V_{R_M}?
−
R
$Z(t, V, f, T, P)$


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

Bandgap voltage reference



A voltage complementary to temperature (CTAT)

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

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

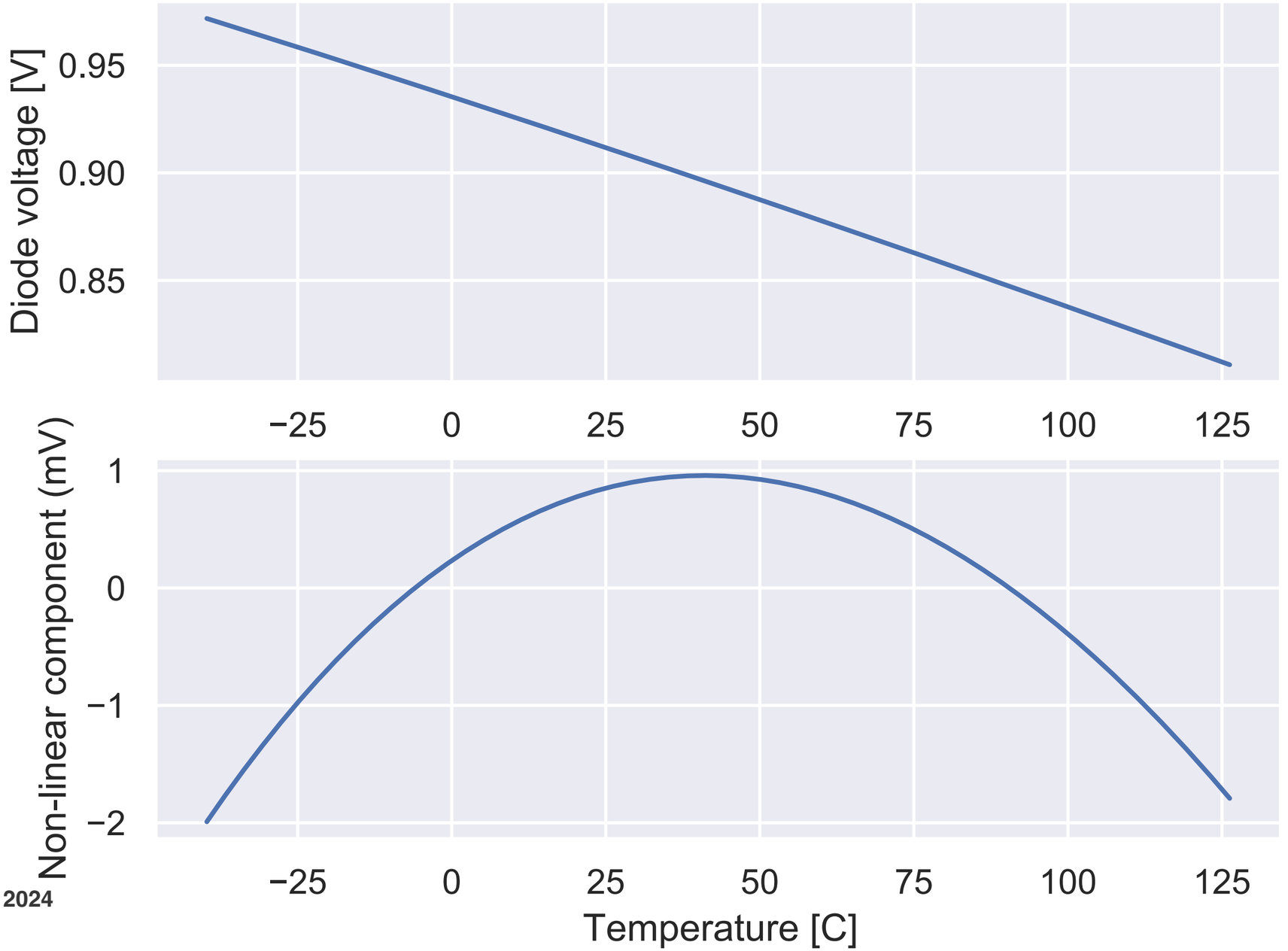
$$V_{BE} = \frac{kT}{q} \ln \frac{I_C}{I_S}$$

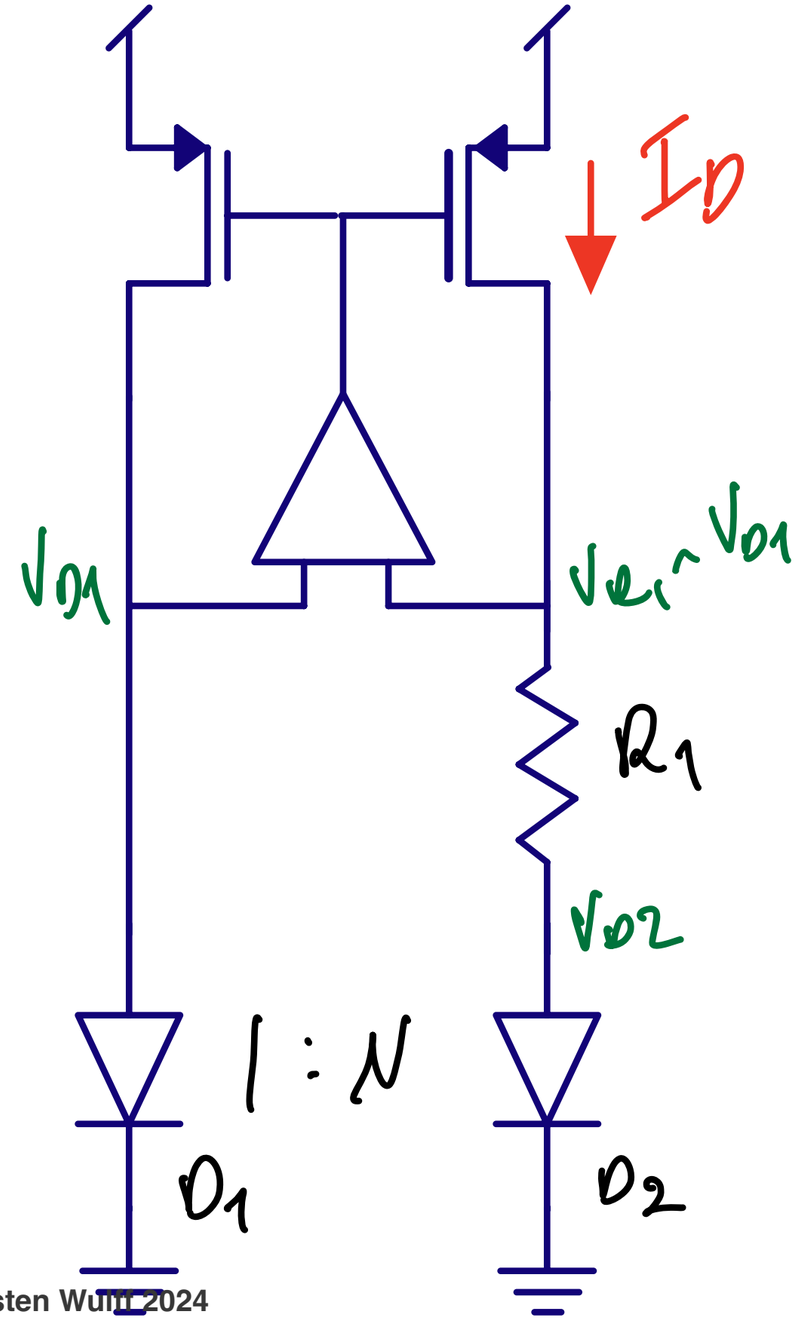
$$I_S = qAn_i^2 \left[\frac{D_n}{L_n N_A} + \frac{D_p}{L_p N_D} \right]$$

Some algebra (see Diodes)

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

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

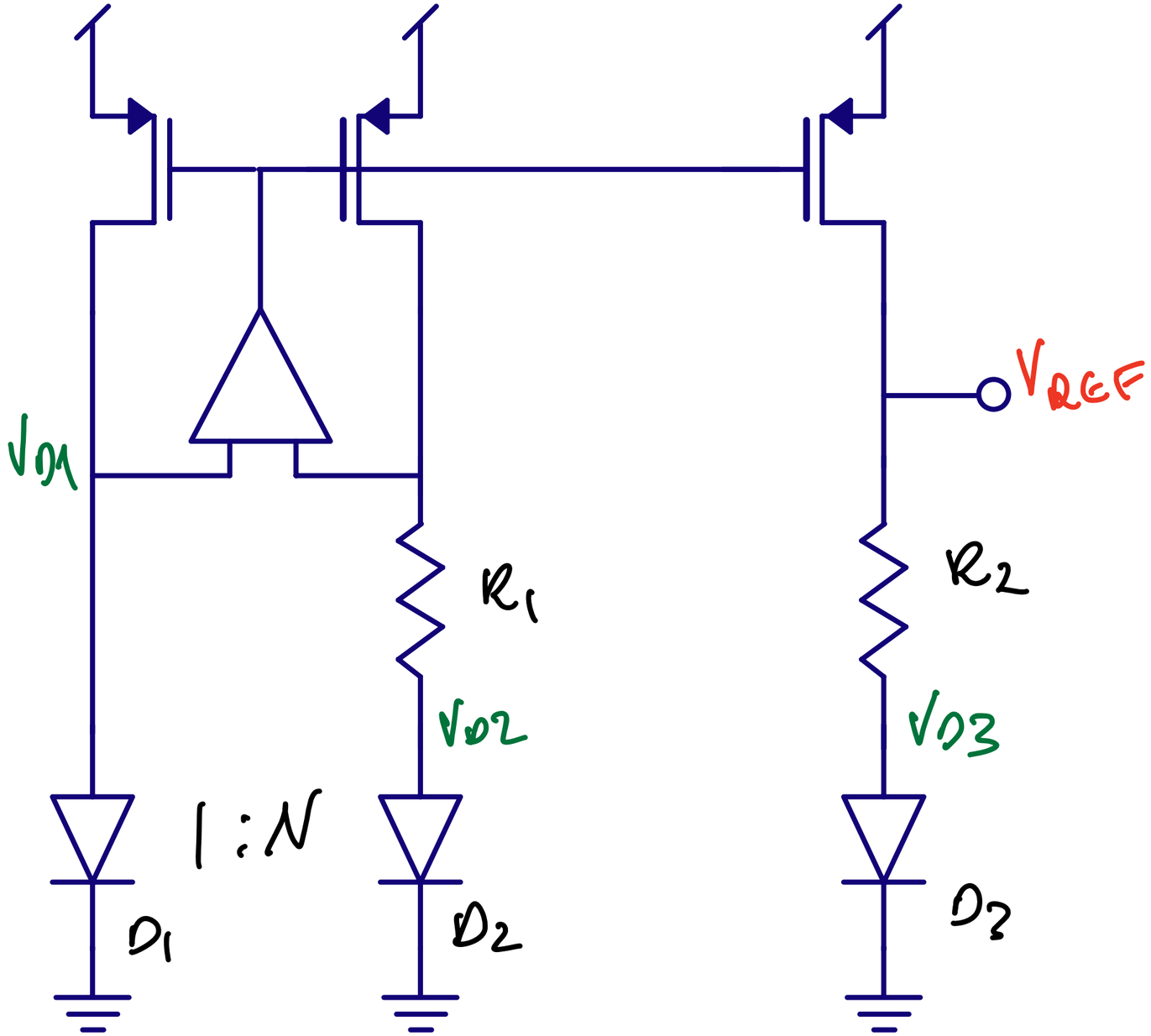

Diode voltage [V]
0.95
0.90
0.85
−25
0
25
50
75
100
125
Non-linear component (mV)
1
0
−1
−2
−25
0
25
50
75
100
125
Temperature [C]

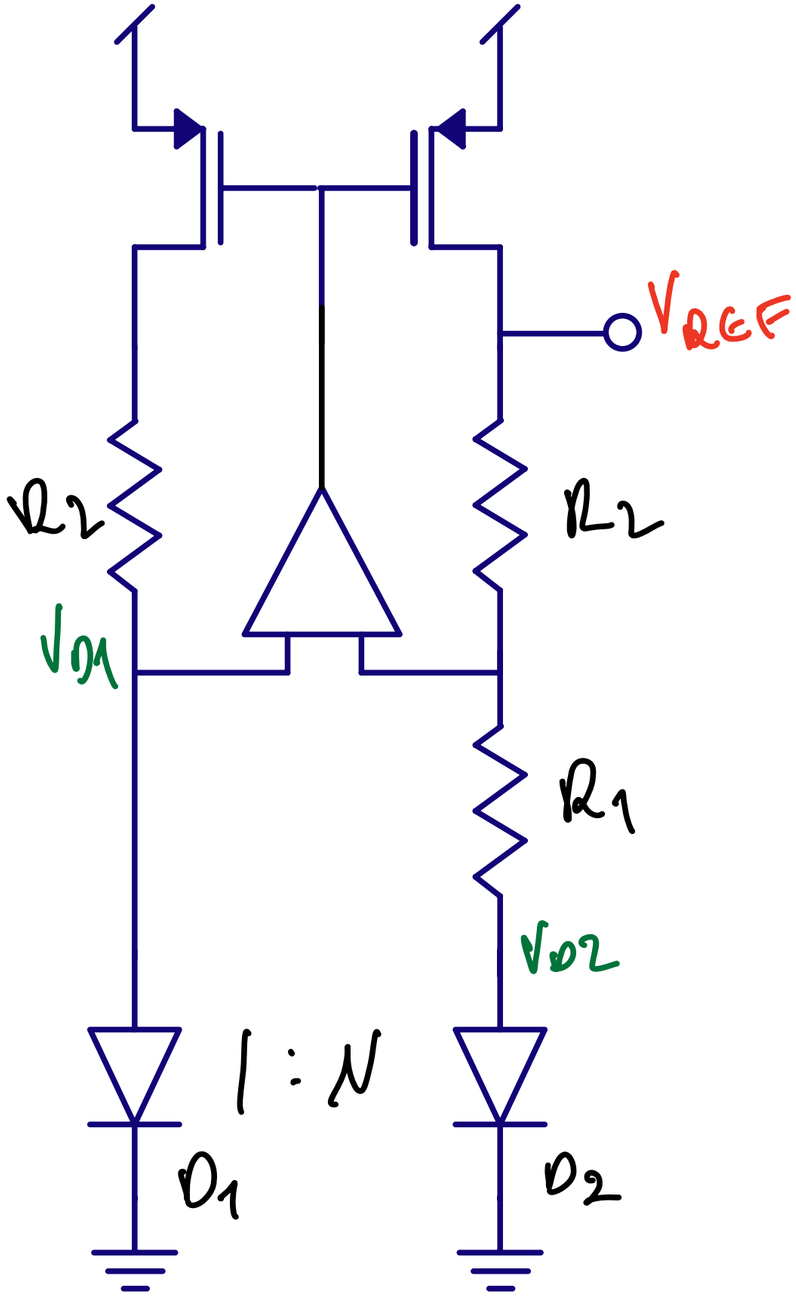


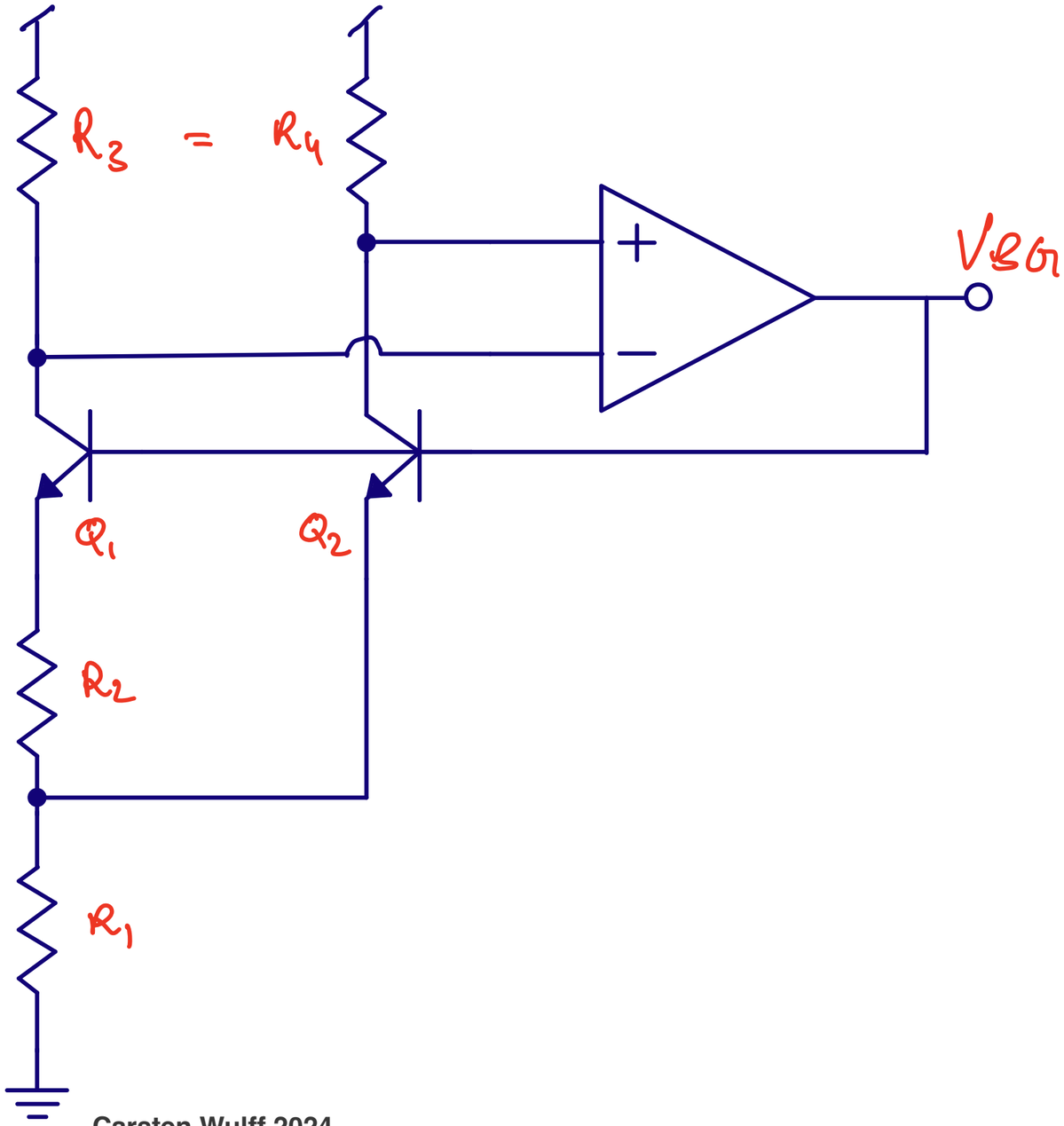
A current proportional to temperature (PTAT)

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

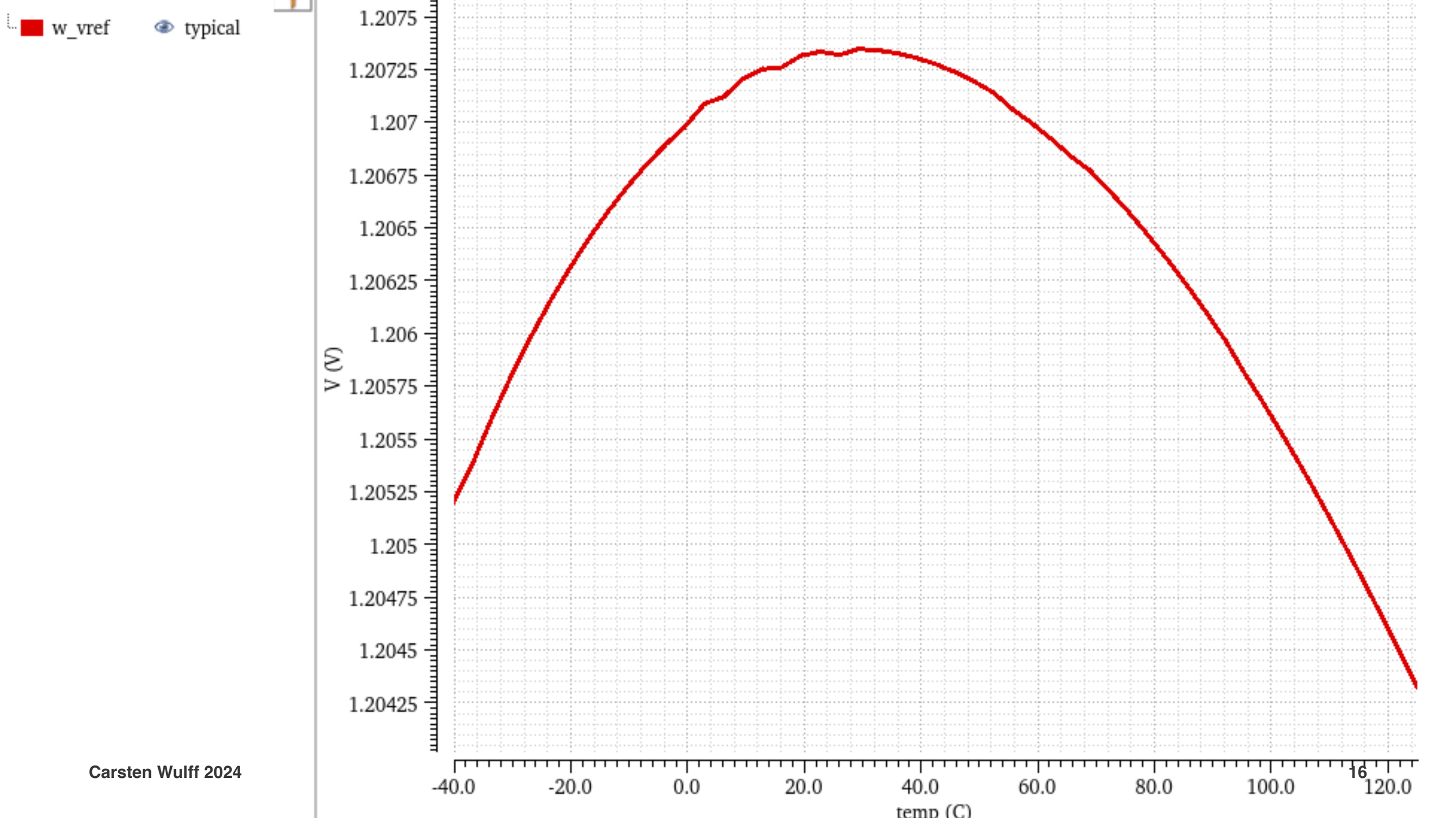
How to combine a CTAT with a PTAT ?

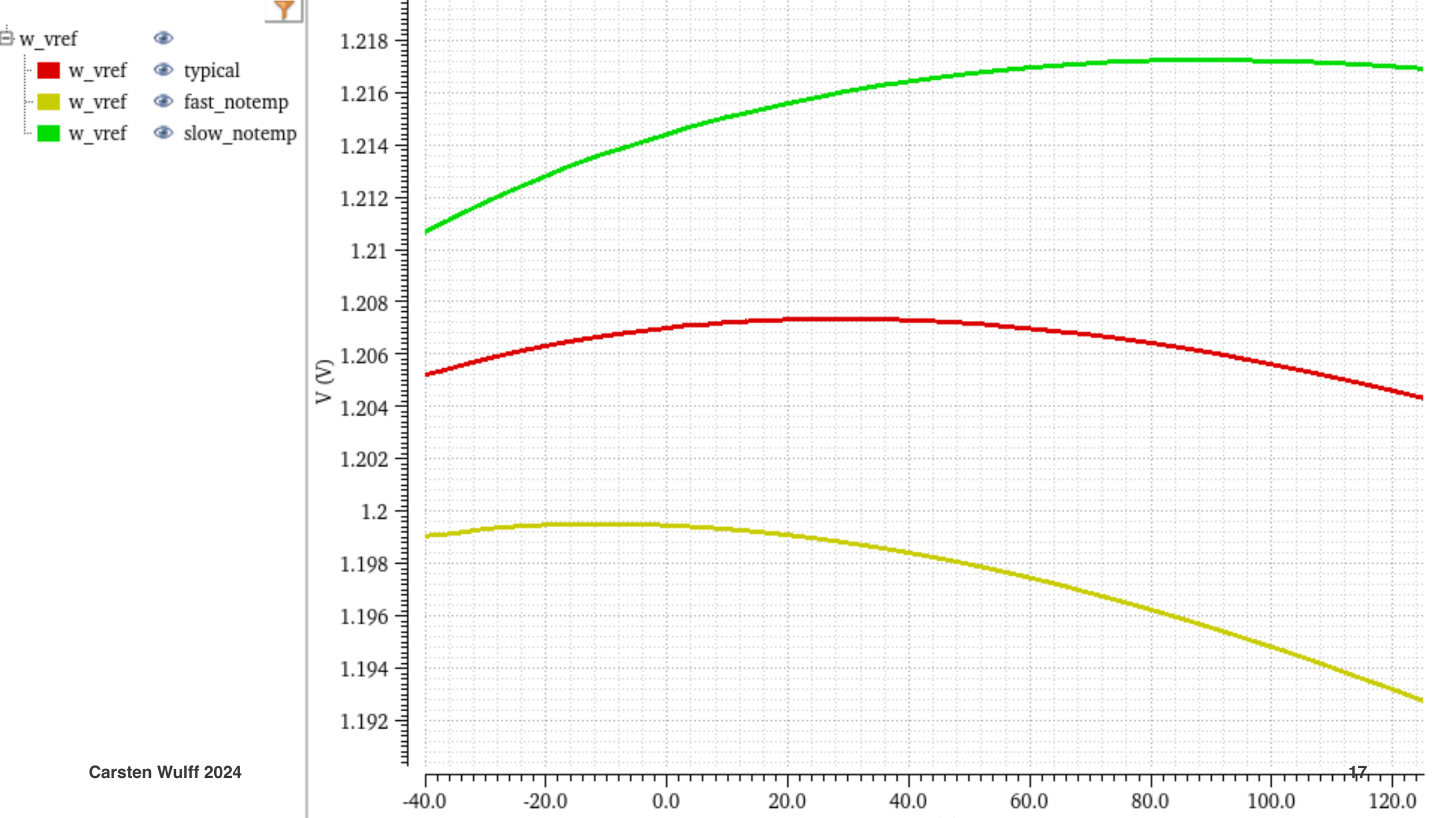

V_{REF}
V_{D1}
R_1
R_2
V_{D2}
V_{D3}
1 : N
D_1
D_2
D_3


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

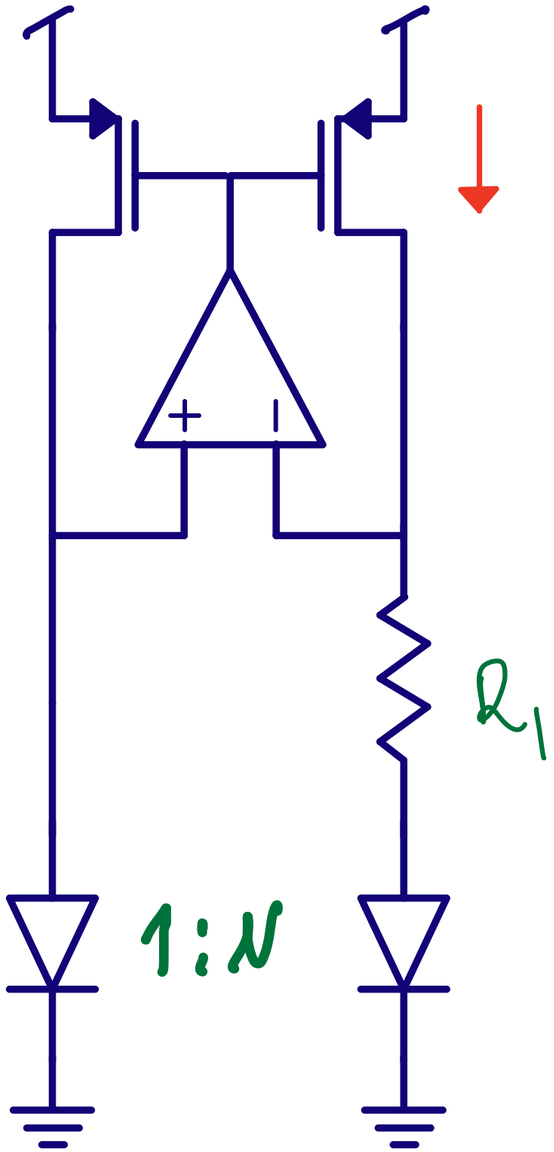


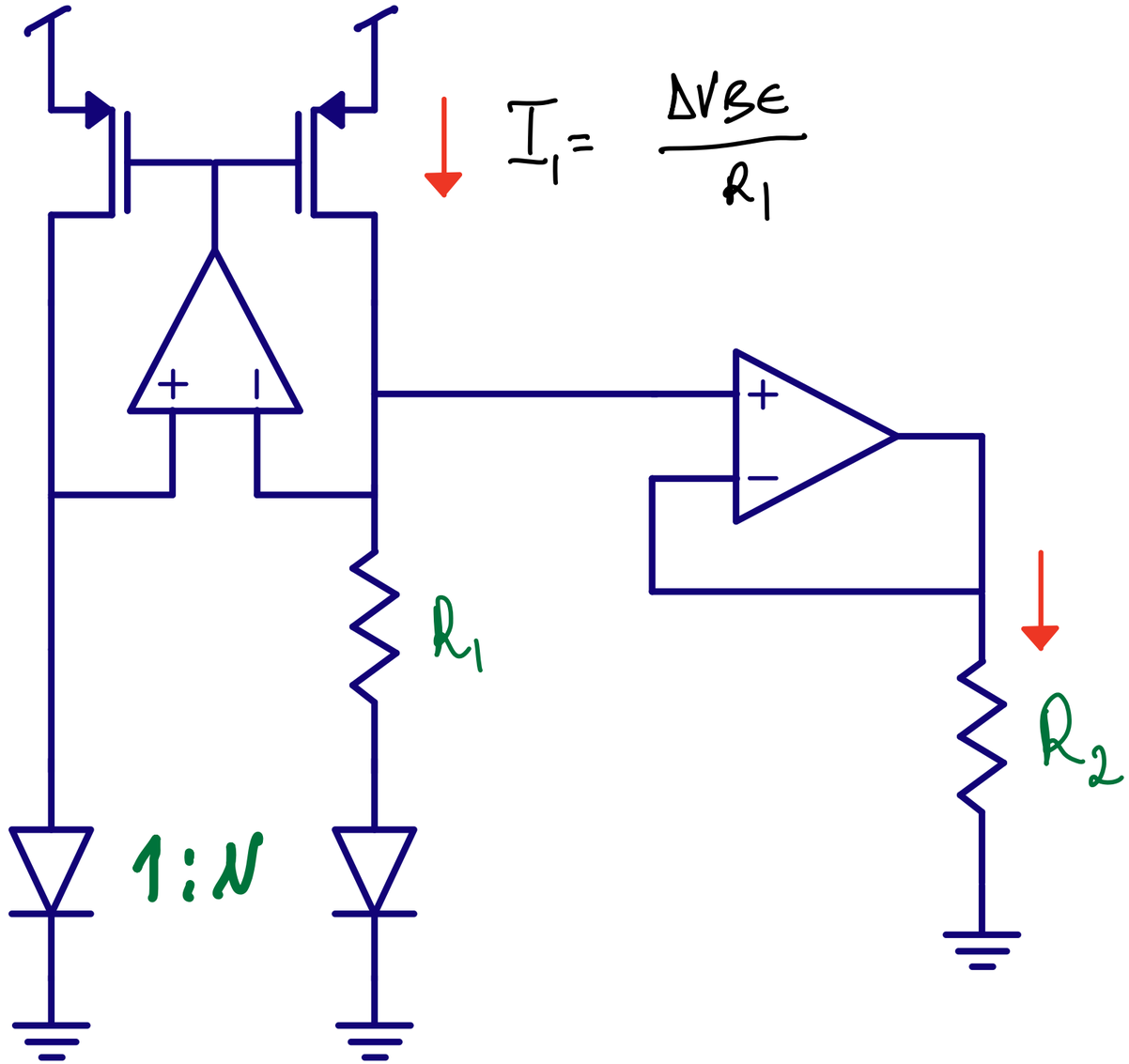
$$V_{BG} = V_{G0} + (m-1)\frac{kT}{q}\ln\frac{T_0}{T} + T\left[\frac{k}{q}\ln\frac{J_2}{J_1}\frac{2R2}{R1} - \frac{V_{G0}-V_{be0}}{T_0}\right]$$


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)

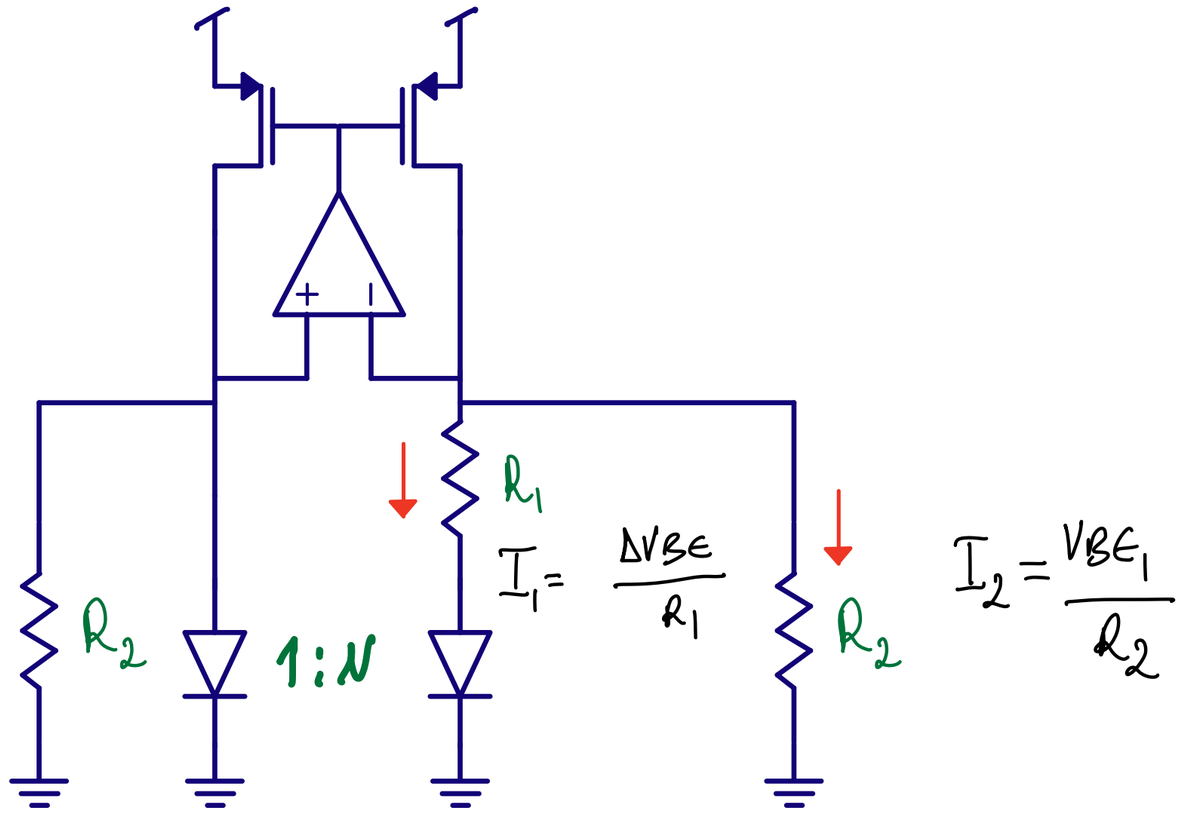

w_vref
w_vref typical
w_vref fast_notemp
w_vref slow_notemp
V (V)
1.218
1.216
1.214
1.212
1.21
1.208
1.206
1.204
1.202
1.2
1.198
1.196
1.194
1.192
-40.0
-20.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0

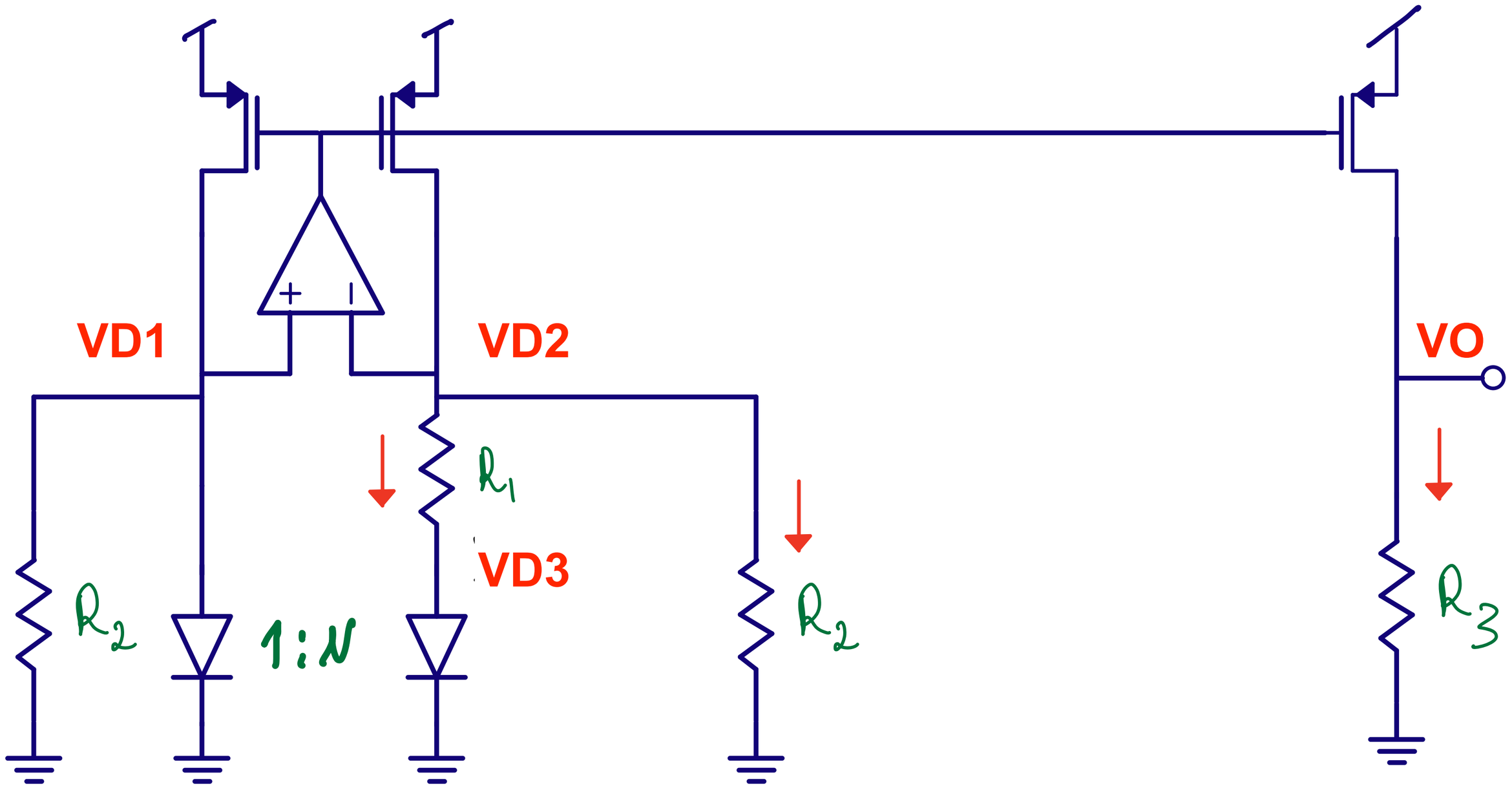
Low voltage bandgap


+
-
R_1
1:N


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

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

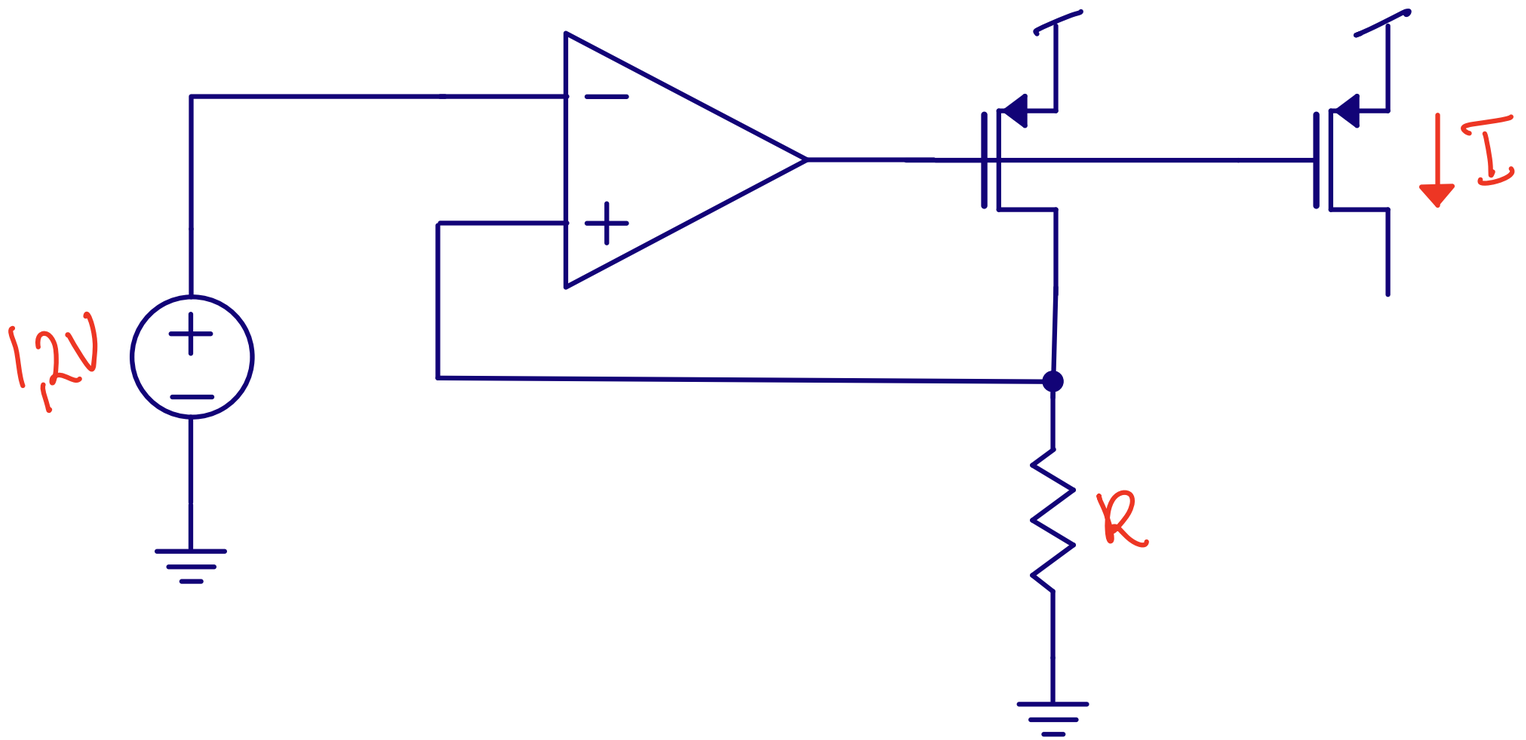


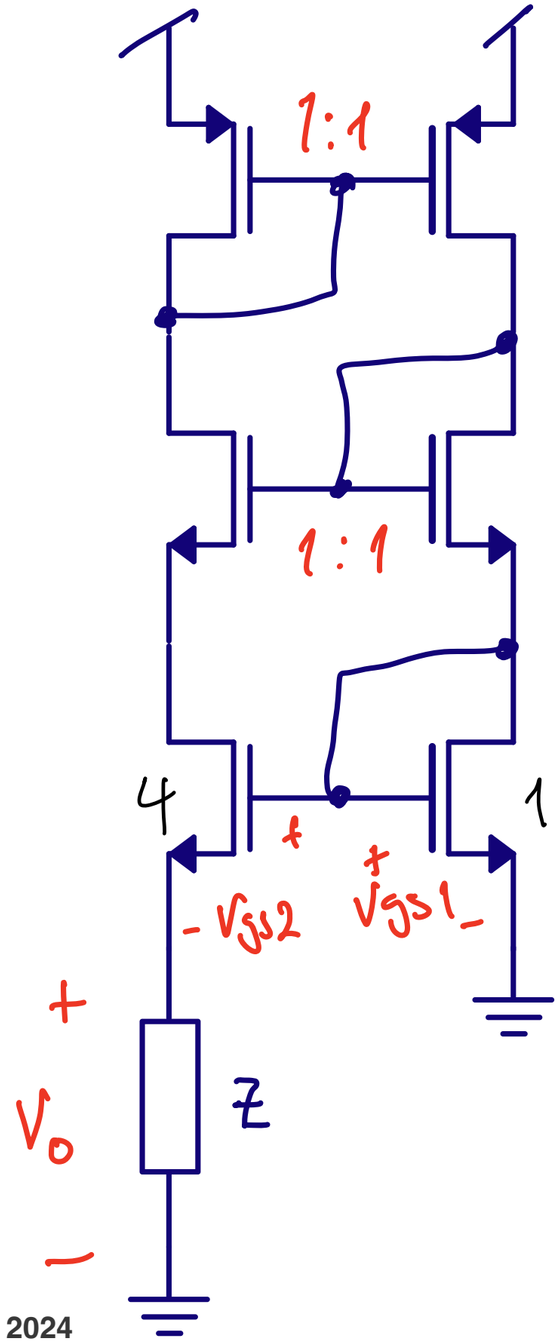

VD1
VD2
VO
R1
VD3
R2
1:N
R2
R3

Bias

Sometimes we just need a current

Voltage to current conversion





GM Cell

$$V_o = V_{GS1} - V_{GS2} = V_{eff1} + V_{tn} - V_{eff2} - V_{tn} = V_{eff1} - V_{eff2}$$

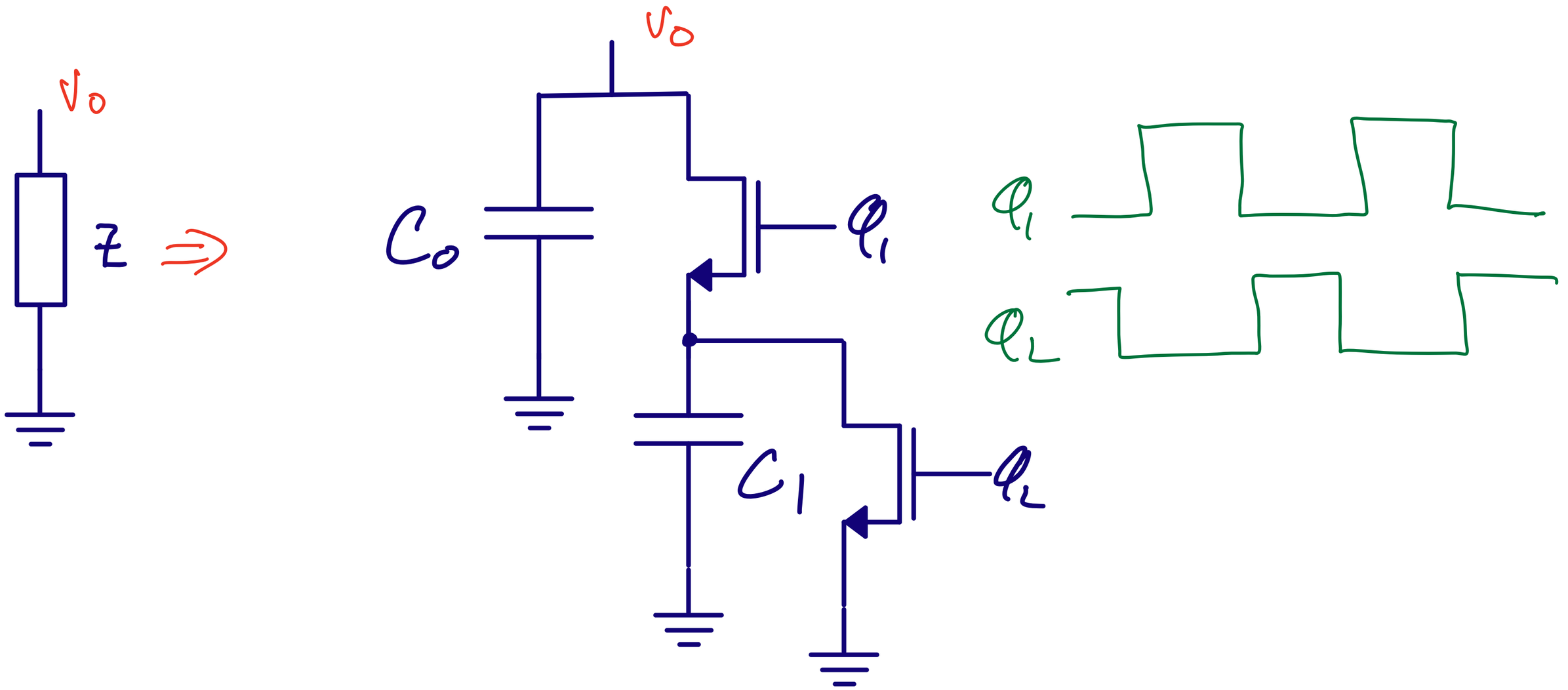
$$\frac{1}{2}\mu_n C_{ox}\frac{W_1}{L_1}V_{eff1}^2 = \frac{1}{2}\mu_n C_{ox} 4\frac{W_1}{L_1}V_{eff2}^2$$

$$V_{eff1} = 2V_{eff2}$$

$$g_m = \frac{2I_d}{V_{eff}}$$

$$I = \frac{V_{eff1}}{2Z}$$

$$Z \Rightarrow \frac{1}{g_m}$$


V_0
Z
V_0
C_0
q_1
C_1
q_2
q_1
q_2

Want to learn more?

A simple three-terminal IC bandgap reference

A CMOS bandgap reference circuit with sub-1-V operation

A sub-1-V 15-ppm//spl deg/C CMOS bandgap voltage reference without requiring low threshold voltage device

The Bandgap Reference

The Design of a Low-Voltage Bandgap Reference

Thanks!