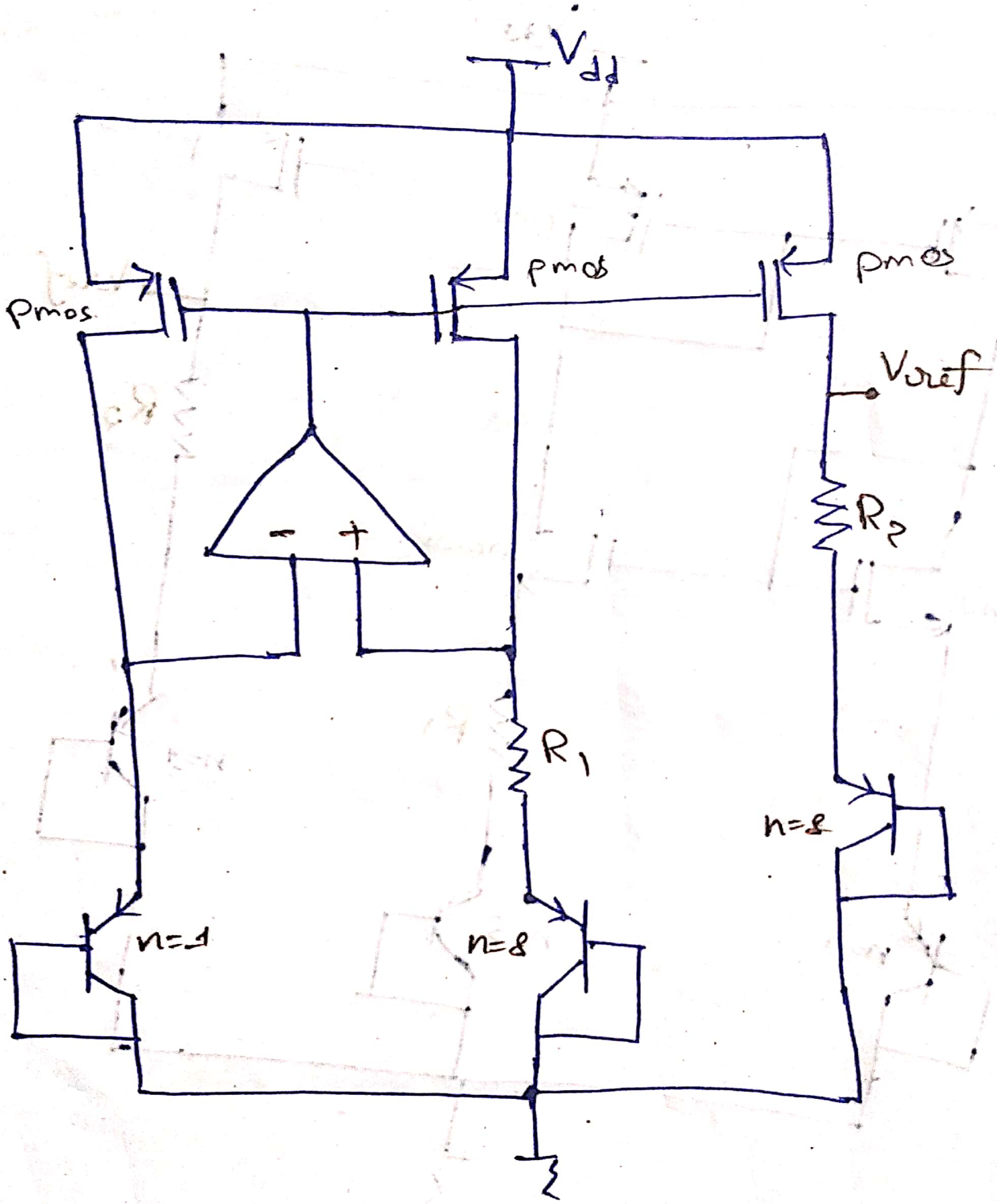
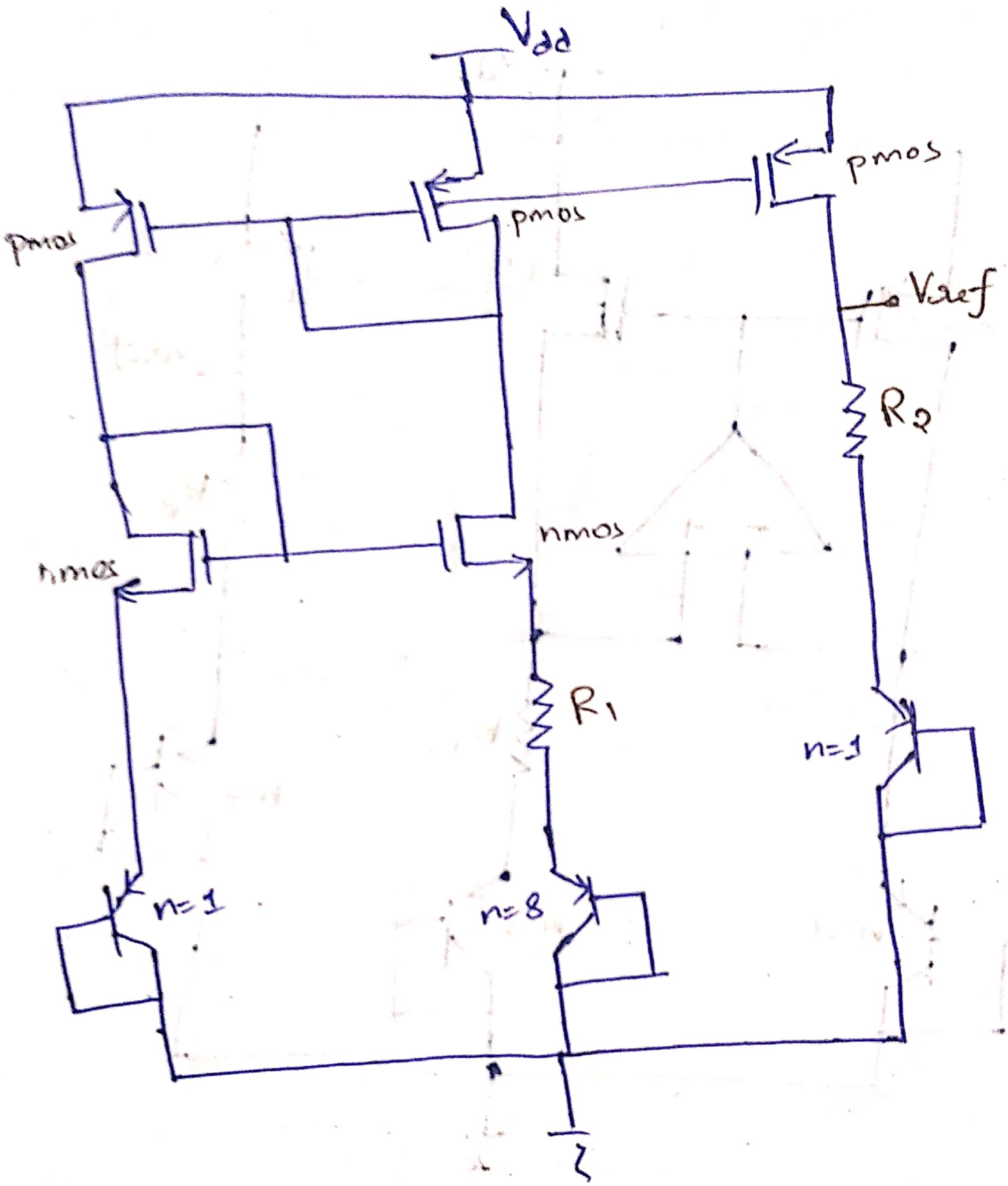


BGR with op-amp :-



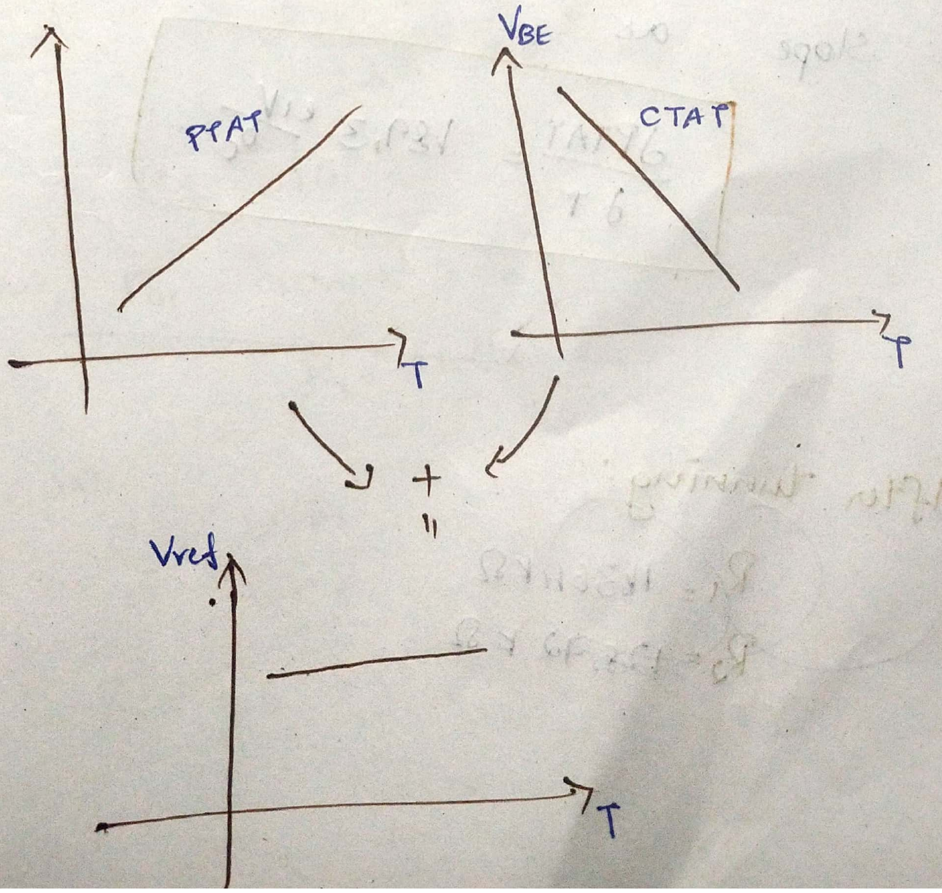
BGR with current mirror

Design:-

→ To achieve temperature independence, BGR circuit rely on two temperature-dependent voltage components.

1) PTAT:- This component increases linearly with temperature and is typically derived from the thermal voltage

2) CTAT:- This component decreases linearly with temperature and is generated using the base-emitter voltage of BJT.



For CTAT slope :-

→ The slope of CTAT is derived from simulating test circuit 1

→ we are using umc180 nm technology

$$\therefore \boxed{\frac{\partial V_{BE}}{\partial T} = -1.938 \ mV/^{\circ}C}$$

For PTAT slope :-

→ we have taken multiplier, n=8

→ For this we have plotted $V_{BE} - V_{BEn}$ with varying temperature;

→ From this we have found out the slope as

$$\boxed{\frac{\partial PTAT}{\partial T} = 189.3 \ uV/^{\circ}C}$$

→ Now we need to adjust PTAT such that it gets cancelled with CTAT using R_1, R_2.

here

$$V_{ref} = \underbrace{\frac{R_2}{R_1} \ln n \, V_T}_{PTAT} + \underbrace{V_{BE}}_{CTAT}$$

diff w.r.t Temperature.

$$\frac{\partial V_{out}}{\partial T} \Rightarrow$$

$$0 = \alpha_1 \frac{\partial PTAT}{\partial T} + \frac{\partial V_{BE}}{\partial T}$$

$$\alpha_1 = \frac{-\frac{\partial V_{BE}}{\partial T}}{\frac{\partial PTAT}{\partial T}}$$

$$= \frac{1.938 \times 10^{-3}}{189.3 \times 10^{-6}}$$

$$\alpha_1 = 10.23$$

now, For current, $I_o = 5\mu A$

$$R_1 = 11.364 \, k\Omega$$

now,

$$R_2 = \frac{\alpha_1 R_1}{\ln 8} = \frac{11.364 \times 10.23}{\ln 8}$$

$$R_2 = 128.72 \, k\Omega$$

After tunning:-

For current mirror based BGR:-

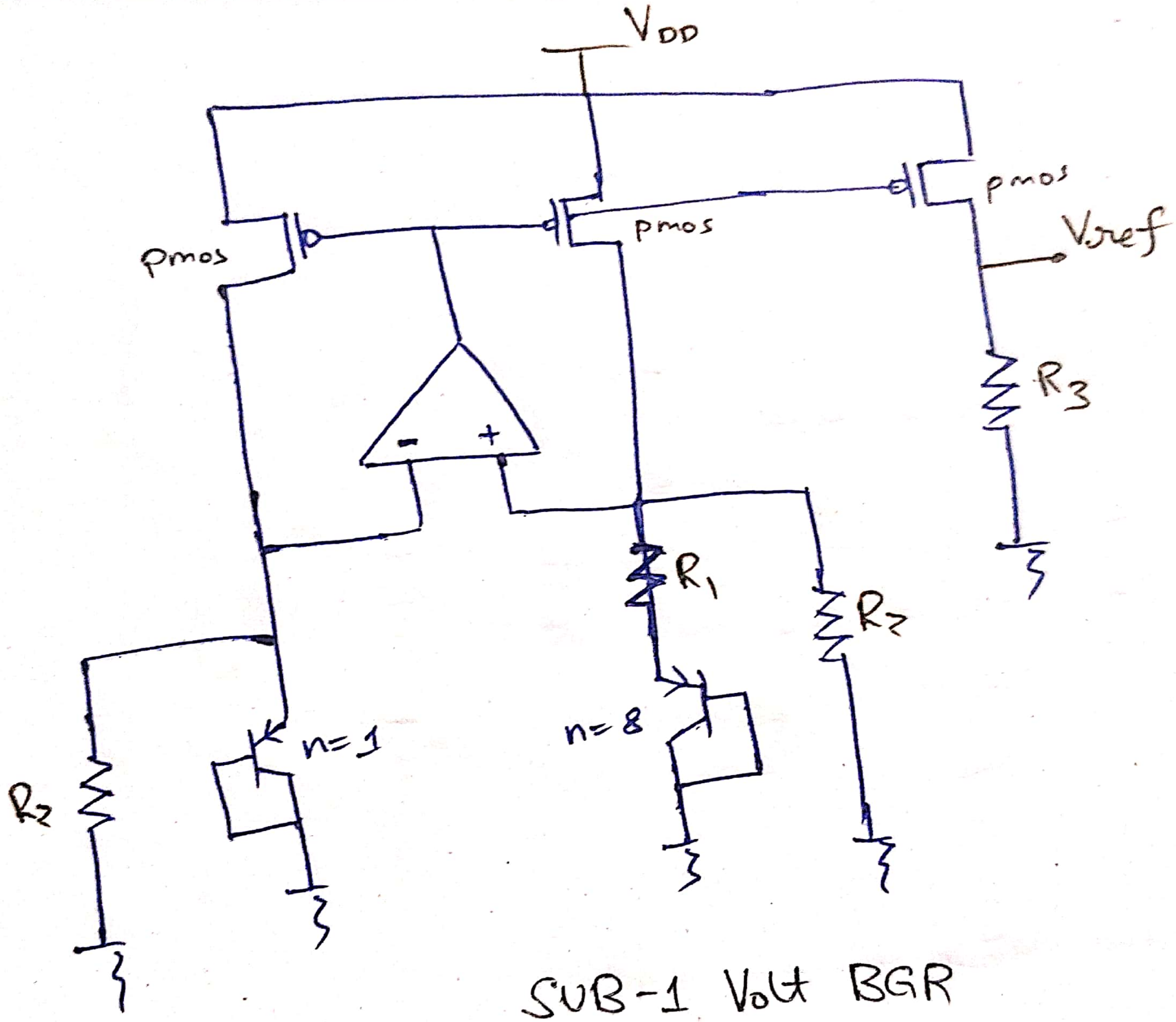
$R_1 = 13.224K\Omega$

$R_2 = 118.87k\Omega$

For op-amp based BGR:-

$R_1 = 11.364K\Omega$

$R_2 = 110.9k\Omega$.



SUB-1 Volt BGR

Design of Sub 1 Volt BGR using op-amp based BGR:-

For normal opamp based BGR

$$V_{ref}\Big|_{opamp} = V_{BE} + \frac{R_2}{R_1} V_T \ln(n).$$

For Sub 1 Volt BGR,

$$V_{ref} = \frac{R_3}{R_2}\left(V_{BE} + \frac{R_2}{R_1} V_T \ln(n)\right).$$

$$= \frac{R_3}{R_2} V_{ref}\Big|_{op\text{-}amp}$$

For $V_{ref} = 0.75V$

$$0.75 = \frac{R_3}{R_2}(1.25)$$

$$R_3 = \frac{0.75}{1.25} \times 110.9\,k\Omega$$

$$\boxed{R_3 = 66.54\,k\Omega}$$

After tunning:-

$R_1 = 12k\Omega$

$R_2 = 111.2k\Omega$

$R_3 = 68\,k\Omega$

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