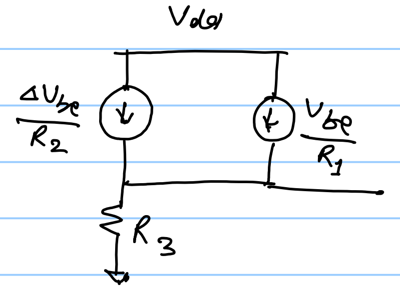
# Sub-1V Bandgap




$$V_{bg} = \left( \frac{V_{be}}{R_1} + \frac{\Delta V_{be}}{R_2} \right) R_3$$

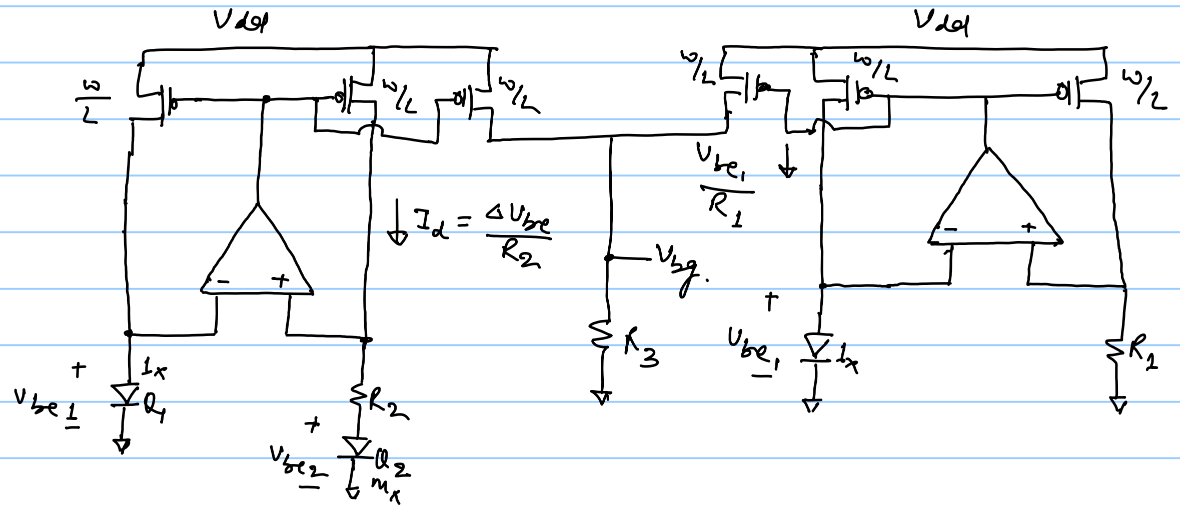
$$= \frac{R_3}{R_1} \left[ V_{be} + \frac{R_1}{R_2} V_T \ln(n) \right]$$

$\frac{R_3}{R_1}$ → Scaling factor.

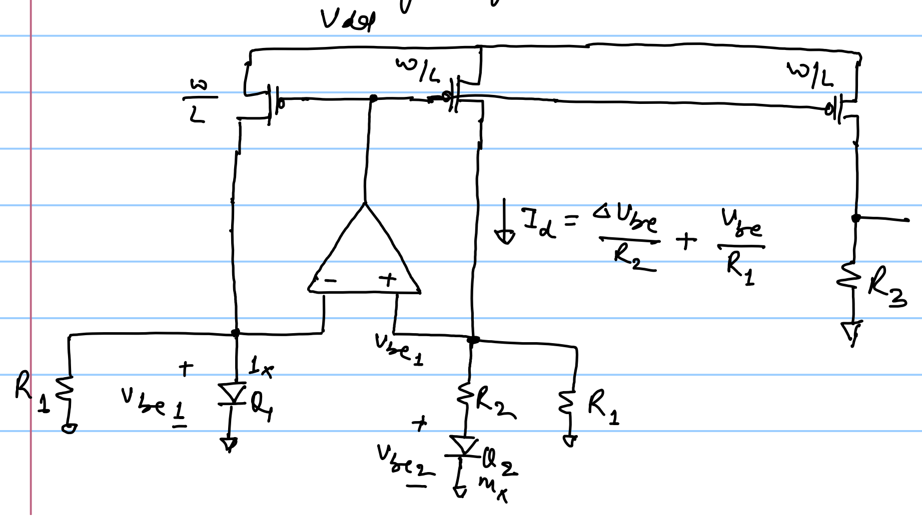
$\left[ V_{be} + \frac{R_1}{R_2} V_T \ln(n) \right]$ → Standard 1.2V BGR

$\frac{R_1}{R_2}$ → decides temperature coefficient

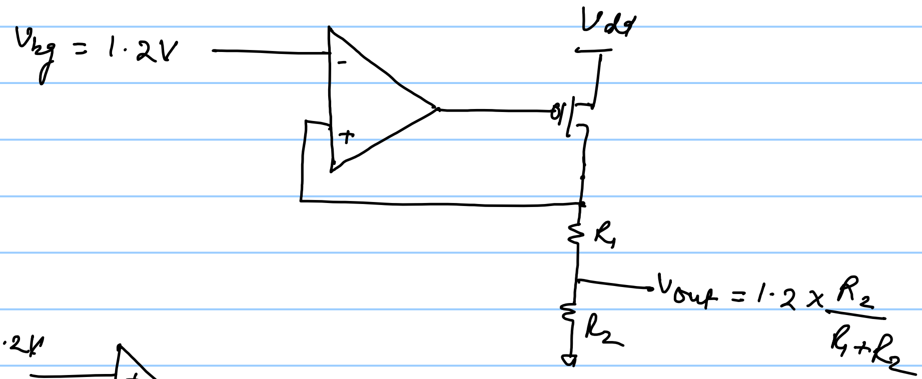
$\frac{R_3}{R_1}$ → decides output voltage

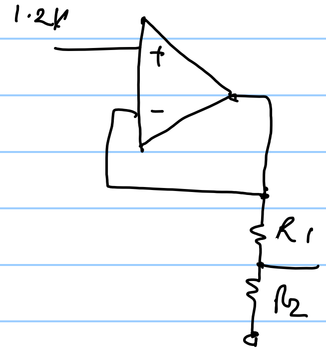



Re-design using single op-amp




$$V_{bg} = \frac{R_3}{R_1}\left(V_{be} + \frac{R_1}{R_2} V_T \ln(m)\right)$$


$V_{ref} = 1.2V$
-
+
Vdd
$R_1$
$R_2$
$V_{out} = 1.2 \times \frac{R_2}{R_1+R_2}$

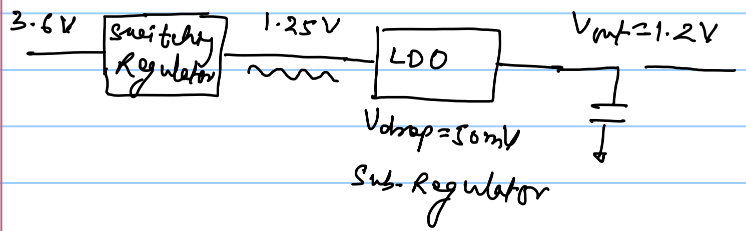

1.2V
+
-
$R_1$
$R_2$

## Linear Regulator

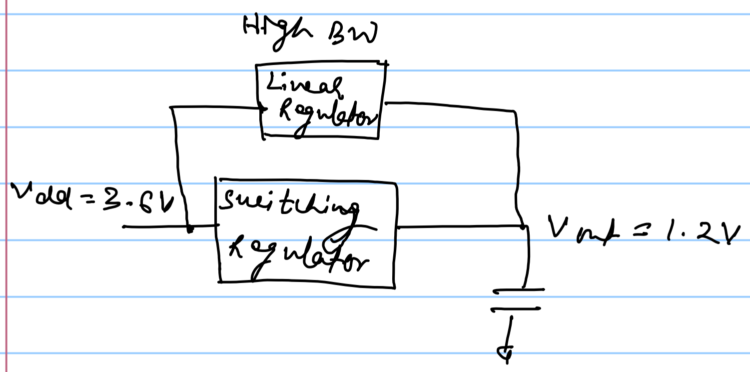
Also called LDO (Low drop-out Regulator)
when operated at low $(V_{dd} - V_{out}) = V_{drop}$

## Applications of LDO

① sub-regulators




② Parallel or Auxiliary current source.



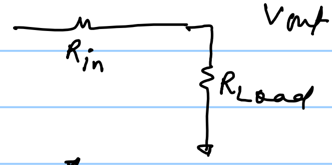

# Linear Regulator supplies current during transient
# Switching Regulator supplies average current
# Achieves faster transient response

③ <u>Regular Power supply</u>

# higher load current if Vdrop is low (< 10%)
# lighter load currents if Vdrop is high (< 50mA)

## Designing Linear Regulator

$V_{in} = 3.6\,V$ $\quad$ $V_{out} = 1.2V$

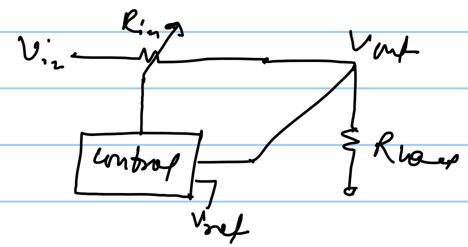


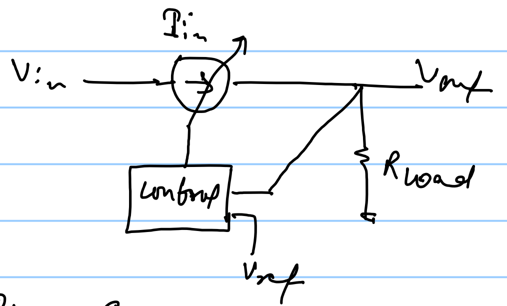

$$V_{out} = \frac{R_{load}}{R_{in} + R_{load}} \times V_{in}$$

# Varies with load current & $V_{in}$

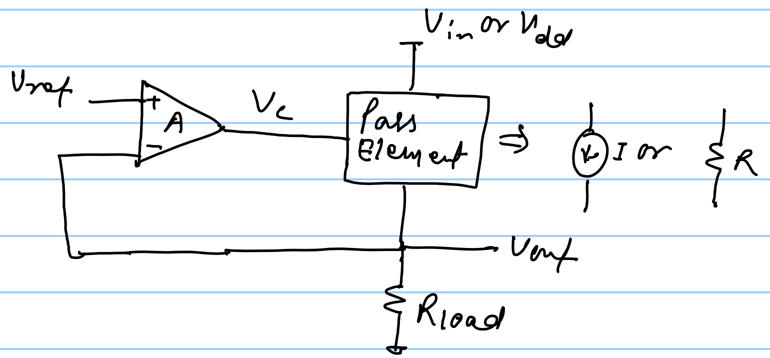
⇒ We need to vary $R_{in}$ if $V_{in}$ or $R_{load}$ is changed

$$V_{out} = \frac{R_{load}}{R_{in} + R_{load}} \times V_{in}$$






$I_{in} = I_{load}$




$I = G_m V_c \Rightarrow VCCS$

$R \propto V_c \Rightarrow VCR$