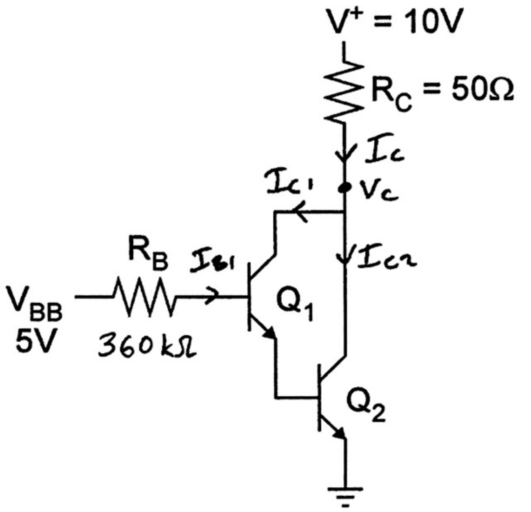
A Darlington pair is used to generate a large current to drive a small resistive load. Determine the current through the load resistance, RC. Also, verify that both transistors operate in forward active mode. Use only the following parameters for this problem.

$\beta=99$, $V_{BE,ON}=0.7V$, $V_{CE,SAT}=0.2V$




Initially assume both transistors operate in forward active

KVL

$$V_{BB} = I_{B1} R_B + \underbrace{V_{BE,ON}}_{Q_1} + \underbrace{V_{BE,ON}}_{Q_2}$$

$$I_{B1} = \frac{V_{BB} + 2V_{BE,ON}}{R_B} = \frac{5V - 1.4V}{36k\Omega} = 10\mu A$$

$$I_{E1} = I_{B2} = (1+\beta) I_{B1}$$

$$I_C = I_{C1} + I_{C2}$$
$$= \beta I_{B1} + \beta I_{B2}$$
$$= \beta I_{B1} + \beta(1+\beta) I_{B1}$$

$$V_C = V^+ - I_C R_C$$

If $V_C > V_{CE,sat}$ $\rightarrow$ $Q_2$ is in forward active

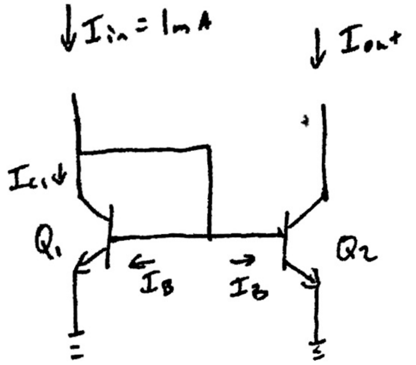
If $V_C - V_{E1} > V_{CE,sat}$ $\rightarrow$ $Q_1$ is in forward active

$$V_C > V_{CE,sat} + V_{E1}$$
$$V_C > V_{CE,sat} + V_{BE,ON}$$

$$I_{E1} = I_{B2} = (1+\beta) I_{B1}$$

$I_C = \beta I_{B1} + \beta(1+\beta) I_{B1} = 99.99mA$ $\rightarrow$ Flows through $R_C$

$V_C = V^+ - I_C R_C = 5.0005V$ $> V_{CE,sat}$ $> V_{CE,sat} + V_{BE,ON}$ $\therefore$ Forward Active




Let $V_A \to \infty$ All transistors in Forward Active

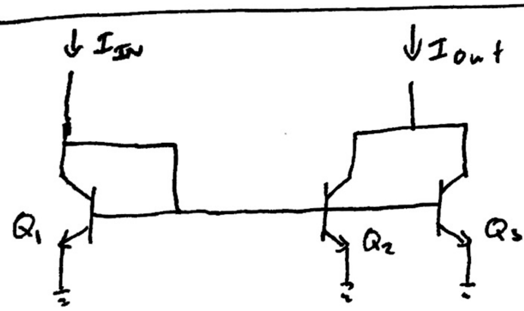
$\beta = 20$

$$I_{in} = I_{C1} + 2I_B = \beta I_B + 2 I_B$$

$$I_{in} = (\beta + 2) I_B$$

$$I_{out} = I_{C2} = I_{C1} = \beta I_B$$

$$\therefore I_{out} = \frac{\beta}{\beta + 2} I_{in} = 0.9091 \text{ mA}$$




This is just two transistors in parallel at the output → Both have the same $V_{BE}$

$$I_{in} = I_{C1} + 3 I_B$$

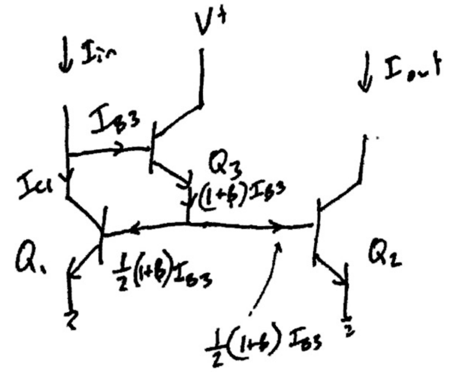
↑ Extra transistor

$$I_{in} = (\beta + 3) I_B$$

$$I_{out} = I_{C2} + I_{C3} = 2\beta I_B$$

$$\therefore I_{out} = \frac{2\beta}{\beta + 3} I_{in} = 1.7391 \text{ mA}$$

Almost twice the previous case




$$I_{C1} = \beta I_{B1} = \frac{1}{2}(\beta)(1+\beta) I_{B3}$$

$$I_{in} = I_{C1} + I_{B3}$$

$$= \frac{1}{2}(\beta)(1+\beta) I_{B3} + I_{B3}$$

$$= \left[1 + \frac{1}{2}(\beta)(1+\beta)\right] I_{B3}$$

$$I_{out} = I_{C2} = \beta I_{B2}$$

$$I_{out} = (\beta)\left[\frac{1}{2}(1+\beta) I_{B3}\right]$$

$$I_{out} = \frac{\frac{1}{2}(\beta)(1+\beta)}{1 + \frac{1}{2}(\beta)(1+\beta)} I_{in} = 0.9953 \text{ mA}$$

(Much closer to $I_{in}$ than the first case)