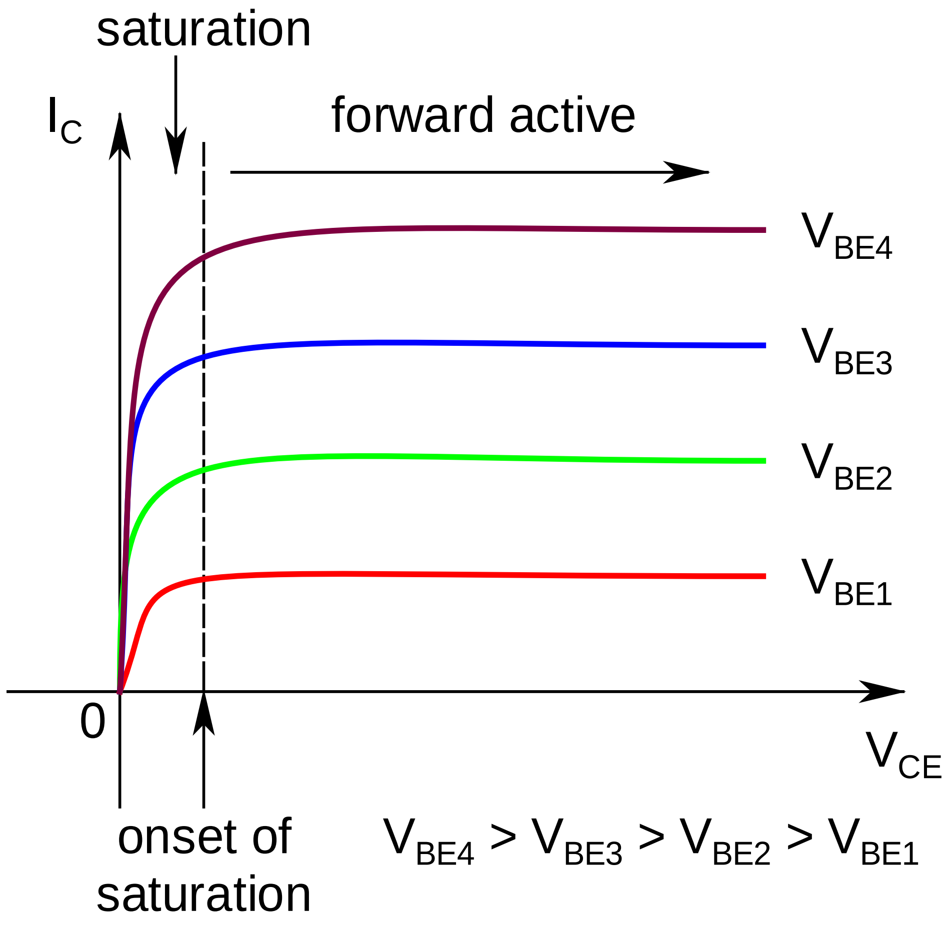
Current Gain

- ***Common-Emitter (CE) Current Gain***:
  - $\beta = I_C/I_B$ (***Higher the better***!)
- ***Common-Base (CB) Current Gain***:
  - $\alpha = I_C/I_E$ (≤ 1: ***closer to 1, better it is***!)
- Also, $I_E = I_C + I_B$
  - $\alpha = \beta/(\beta + 1)$ and $\beta = \alpha/(1 - \alpha)$
- ***Note***: As $\alpha \to 1$, $\beta \to \infty$
- ***Typical values***: $\beta \sim 100$-5000, $\alpha \sim 0.99$-0.9998

Current-Voltage Relation

- ***BE junction*** basically a ***diode***
  - $I_E = I_{ES}\exp(V_{BE}/V_T)$ $(V_{BE} > 4V_T)$
    - I_{ES}: ***Reverse Saturation Current of BE junction***
- A ***fraction*** α of I_E reaches ***collector***
  - $I_C = \alpha I_E = I_S\exp(V_{BE}/V_T)$
    - I_S $(= \alpha I_{ES})$: ***Saturation current of the BJT***
- The ***difference*** between I_E and I_C is I_B
  - $I_B = I_E – I_C$

Output Characteristic



- ***Quick Estimate***:
  - Under ***forward bias***, $V_{BE} \sim 0.7$ V
  - ***Justification***:
    - $V_\gamma \sim 0.6$ V
    - 0.7 V is 100 mV above $V_\gamma \Rightarrow$ ***junction sufficiently forward biased***
    - I_C-V_{BE} relation ***exponential*** $\Rightarrow$ A ***little change*** in V_{BE} can cause a ***large change*** in I_C
  - ***Heuristic estimate***: ***not accurate***, however, ***extremely useful*** for a ***quick hand-calculation***
- $V_{CE} = V_{BE} - V_{BC}$ (***applying chain rule***)

- Thus, for $V_{CE} > 0.7$ V, V_{BC} ***negative***
  - BC junction ***reverse biased*** and FA operation is ***maintained***
- As $V_{CE} \rightarrow 0.7$ V, $V_{BC} \rightarrow 0$
  - BC junction ***losing its reverse bias***
- At $V_{CE} = 0.7$ V, $V_{BC} = 0$
  - BC junction ***under zero bias***
- For $V_{CE} < 0.7$ V, V_{BC} turns ***positive***
  - Both BE and BC junctions become ***forward biased*** $\Rightarrow$ ***saturation***

- V_{CE} = 0.7 V is known as ***onset of saturation*** (OS)
- ***Saturation***:
  - For V_{CE} < 0.7 V
  - CB junction becomes ***forward biased***
  - Collector also starts to ***inject*** electrons to base
  - ***Two effects***:
    - ***Net electrons reaching collector***$\downarrow \Rightarrow I_C\downarrow$
    - ***Base gets flooded with electrons*** $\Rightarrow$ ***Recombination increases manyfold*** $\Rightarrow I_B\uparrow$
    - Thus, $\beta\downarrow \Rightarrow$ Defined as β_{sat} $(= I_{C,sat}/I_{B,sat})$

- Noting that $V_\gamma = 0.6$ V, for $V_{BC} \le 0.5$ V, ***injection*** of electrons from ***collector to base*** will be ***negligible***
  - It can be ***assumed*** that ***FA operation*** is ***maintained*** till this point, with β ***retaining*** its ***nominal value***
  - $V_{CE} = 0.2$ V at this point, and is known as the ***point of soft saturation*** (SS)
- Beyond this point, BJT enters the ***operating domain*** known as ***hard saturation*** (HS)

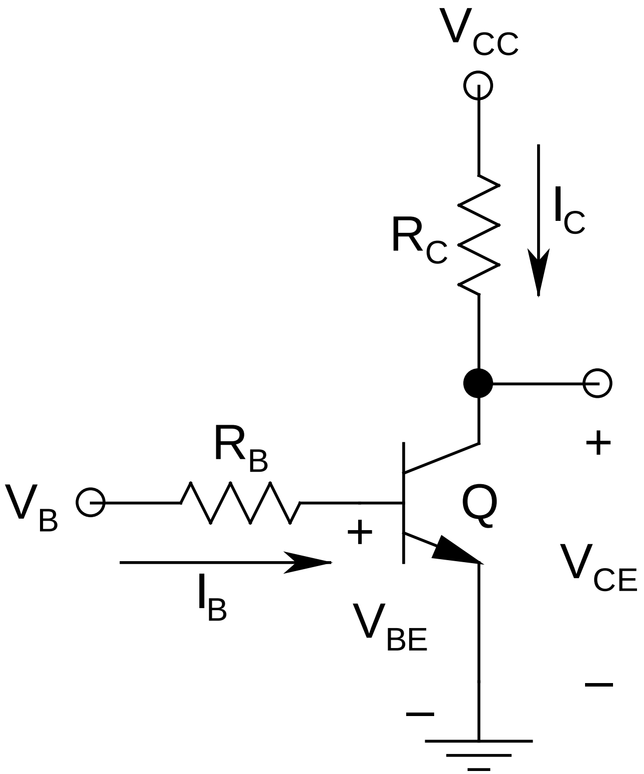
- In ***hard saturation***, $V_{BC} \approx 0.7$ V, and collector ***injects*** electrons ***vigorously*** into the base
- To ***counter*** this effect, V_{BE} automatically ***increases*** to about 0.8 V
- At this point, $V_{CE} = 0.1$ V, and is known as the ***point of hard saturation*** (HS)
- Note that all these numbers are for ***quick estimates***, and ***actual values*** can be a ***little different*** from these

- ***Degree of Saturation*** (DoS):
  - DoS = β/β_{sat} (≥ 1)
  - Portrays how ***deeply*** the BJT is driven into ***saturation***
- ***Commonly used values*** of ***parameters*** for ***quick estimate***:
  - $V_{BE}(FA) = V_{BE}(SS) = 0.7$ V
  - $V_{BE}(HS) = 0.8$ V, $V_{CE}(HS) = 0.1$ V
  - $V_{CE}(OS) = 0.7$ V, $V_{CE}(SS) = 0.2$ V
  - DoS(FA,OS,SS) = 1, DoS(HS) > 1

- BJTs in ***analog circuits*** are used as ***amplifiers***, and should ***never*** be pushed to ***hard saturation*** (β ***drops significantly***)
  - ***Lowest limit*** of $V_{CE} = 0.2$ V (***soft saturation***)
- On the other hand, BJTs used in ***digital circuits***, while ***on***, are always pushed to ***hard saturation***, since they act basically as ***switches***
  - $V_{CE} = 0.1$ V (***hard saturation***)

Finding the Operating Point: Load Line Analysis

- ***Quick estimate*** in ***FA mode***:
  - $I_B = (V_B - V_{BE})/R_B$
  - $V_{BE} = 0.7$ V
  - $I_C = \beta I_B$
  - ***Independent*** of R_C, so long as ***FA operation*** is ***maintained***



- For ***continuous variation*** of V_B, ***continuous variation*** of I_C and I_B
  - The ***output characteristics*** will ***fill up*** the ***entire quadrant***
- The ***operating point*** (***Q-point***) can ***lie anywhere*** in this ***quadrant***
- To find the ***unique*** Q-point, need to ***draw*** the ***load line***
- ***Load line equation***:
  - $I_C = (V_{CC} - V_{CE})/R_C$