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BJT amplifier -basics

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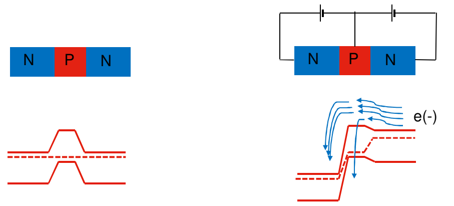
BJT model



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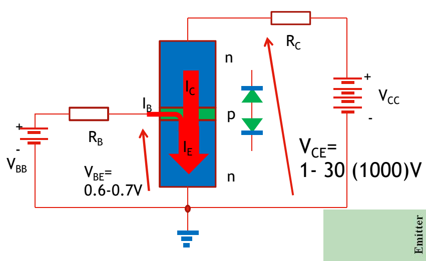
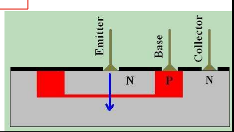
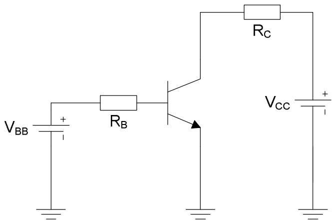
Currents in BJT





CE conection - Base bias



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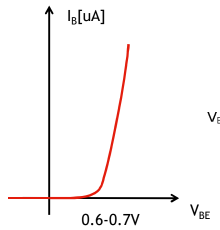
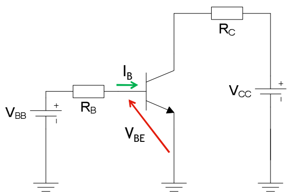
Input characteristic





$$I_B = I_s\left(e^{\frac{U_{BE}}{\varphi_T}} - 1\right)$$

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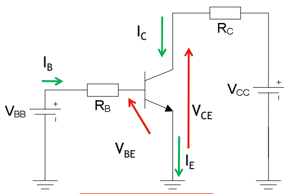
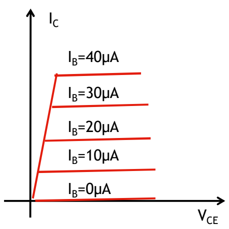
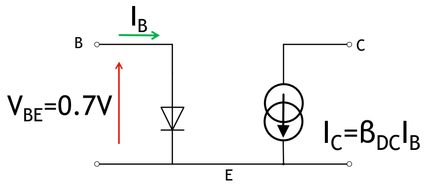
Output characteristic



$$I_E = I_C + I_B$$
$$I_E \approx I_C$$
$$I_B << I_C$$



BJT - the simplest model (Ebers - Molle)



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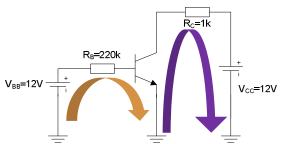
Bias calculation - simle example



$$V_{BB} = I_B R_B + V_{BE}$$

$$V_{CC} = V_{CE} + R_C I_C$$

$$V_{BE} = 0.65V$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{12 - 0.65}{220k} = 51.6\mu A$$

$$I_C = I_B \cdot \beta_{DC} = 51.6\mu A \cdot 150 = 7.74mA$$

$$V_{CE} = V_{CC} - R_C I_C = 12 - 1k \cdot 7.74mA = 4.26V$$

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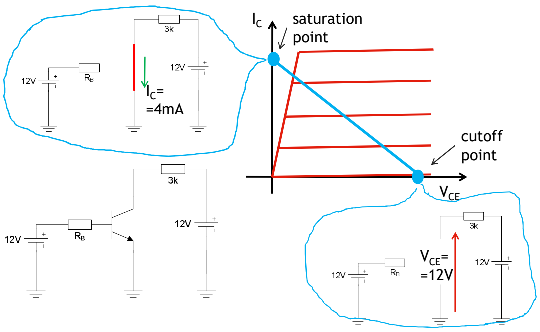
DC load line



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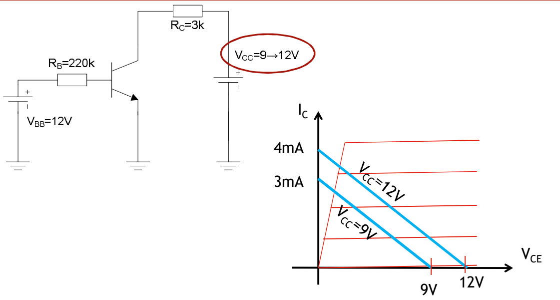
Load line vs. V_{CC}



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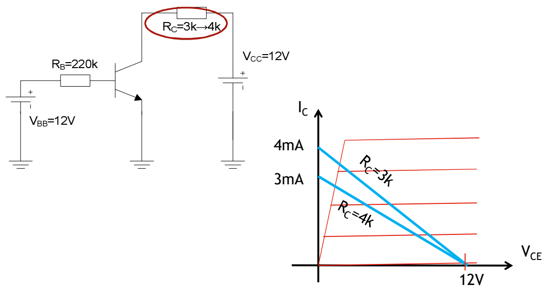
Load line vs. R_C



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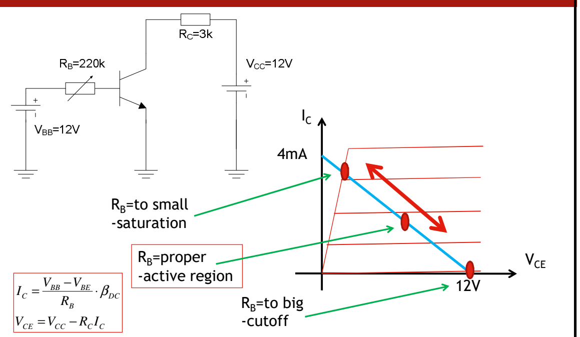
Quiescent point line vs. V_{BB} or R_B



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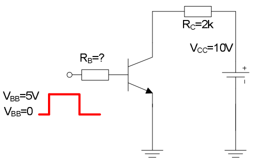
cutoff - saturation (hard and soft) BJT as a switch

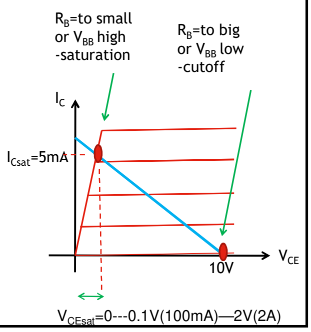


soft saturation

$$\beta_{DC(sat)} = \frac{I_C}{I_B} > 10 \Rightarrow R_B > 8.7k$$

hard saturation

$$\beta_{DC(sat)} = \frac{I_C}{I_B} < 10 \Rightarrow R_B < 8.7k$$



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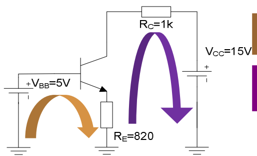
CB connaction - Emitter bias



$$V_{BB} = I_E R_E + V_{BE}$$

$$V_{CC} = V_{CE} + R_C I_C + R_E I_E$$

$$V_{BE} = 0.65V; \quad I_C \approx I_E$$

$$I_E = \frac{V_{BB} - V_{BE}}{R_E} = \frac{5 - 0.65}{820} = 5.3mA \approx I_C$$

$$V_{CE} = V_{CC} - R_C I_C - R_E I_E \approx V_{CC} - (R_C + R_E) I_C =$$

$$= 15 - (1k + 820) \cdot 5.3mA = 5.35V$$

HINT: Q-poit is immune to current gain β

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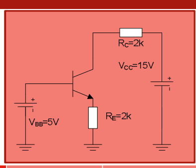
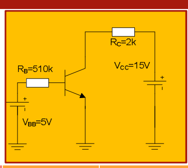
Emitter bias vs. Base bias

Cutoff/saturation
Switching/ digital





β_{DC}	100	250	100	250
I_B	22μA	8.7μA	8.5μA	8.5μA
I_C	2.17mA	2.17mA	0.85mA	2.13mA
V_{CE}	6.3V	6.3V	13.3	10.7
mode	**Active/linear**		**Cutoff/saturation**	
application	Controlled IC drivers/amp		**Switching/digital**	

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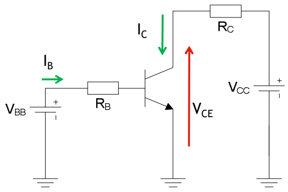
Small changes effect



←↑→↓

	I_B	I_C	V_{CE}
↑V_{BB}	↑	↑	↓
↑V_{CC}	-	-	↑
↑R_C	-	-	↓
↑R_B	↓	↓	↑
↑T(↓V_{BE})	↑	↑	↓
↑β	-	↑	↓

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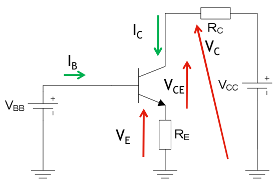
Small changes effect



←↑→↓

	I_B	I_C	V_E	V_C	V_{CE}
↑V_{BB}	↑	↑	↑	↓	↓
↑V_{CC}	-	-	-	↑	↑
↑R_C	-	-	-	↓	↓
↑R_E	↓	↓	-	↑	↑
↑T(↓V_{BE})	↑	↑	↑	↓	↓
↑β	-	-	-	-	-

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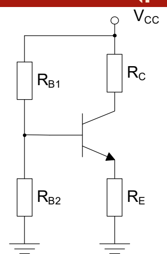
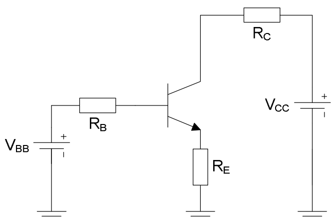
VDB – Voltage Divider Bias mixed (potentiometric) biasing





Thevenin theorem >>>>>>>>>

$$V_{BB} = V_{CC}\frac{R_{B2}}{R_{B1}+R_{B2}}$$

$$R_B = R_{B1} \parallel R_{B2}$$

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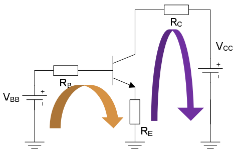
Potentiometric biasing



$$V_{BB} = I_B R_B + I_E R_E + V_{BE}$$

$$V_{CC} = V_{CE} + R_C I_C + R_E I_E$$

$$V_{BE} = 0.65V; \quad I_C \approx I_E; \quad I_C = \beta_{DC} I_B$$

$$I_E = \frac{V_{BB} - V_{BE}}{R_E + R_B/\beta_{DC}} \approx I_C$$

$$V_{CE} = V_{CC} - R_C I_C - R_E I_E \approx V_{CC} - (R_C + R_E) I_C$$

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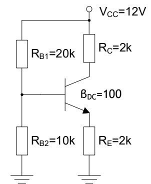
Potentiometric biasing - an example



$$V_{BB} = V_{CC} \frac{R_{B2}}{R_{B1} + R_{B2}} = 4V$$

$$R_B = R_{B1} \parallel R_{B2} = 6.66k$$

$$V_{BE} = 0.65V; \quad I_C \approx I_E; \quad I_C = \beta_{DC} I_B$$

$$I_E \approx I_C = \frac{V_{BB} - V_{BE}}{R_E + R_B/\beta_{DC}} = 1.62mA$$

$$V_{CE} = V_{CC} - R_C I_C - R_E I_E \approx V_{CC} - (R_C + R_E) I_C = 5.5V$$

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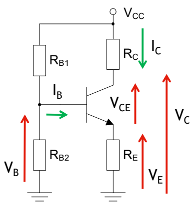
Small changes effect



	I_B	I_C	V_B	V_E	V_C	V_{CE}
↑V_{CC}	↑	↑	↑	↑	↑↓	↑↓
↑R_C	-	-	-	-	↓	↓
↑R_E	↓	↓	-	-	↑	↑
↑R_{B1}	↓	↓	↓	↓	↑	↑
↑R_{B2}	↑	↑	↑	↑	↓	↓
↑T(↓V_{BE})	↑	↑	↓	↑	↓	↓
↑β	-↓	↑	↑	↑	↓	↓

$$I_E = \frac{V_{BB} - V_{BE}}{R_E + R_B/\beta_{DC}} \approx I_C$$

$$V_{CE} = V_{CC} - R_C I_C - R_E I_E \approx V_{CC} - (R_C + R_E) I_C$$

←↑→↓

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Stiff/Firm voltage divider

$$I_E \approx I_C = \frac{V_{BB} - V_{BE}}{R_E + R_B/\beta_{DC}}$$

Emitter bias:
β_{DC} independent

$$I_E \approx I_C = \frac{V_{BB} - V_{BE}}{R_E}$$

Base bias:

$$I_E \approx I_C = \frac{V_{BB} - V_{BE}}{R_B/\beta_{DC}}$$

Stiff devider:

$$R_E > 100 \, R_B/\beta_{DC}$$

Firm devider:

$$R_E > 10 \, R_B/\beta_{DC}$$

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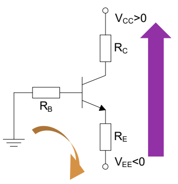
Two supply emitter bias



$$V_{EE} = I_B R_B + I_E R_E + V_{BE}$$

$$V_{CC} - V_{EE} = V_{CE} + R_C I_C + R_E I_E$$

$$V_{BE} = 0.65V; \quad I_C \approx I_E; \quad I_C = \beta_{DC} I_B$$

$$I_E \approx I_C = \frac{-V_{EE} - V_{BE}}{R_E + R_B/\beta_{DC}}$$

$$V_{CE} \approx (V_{CC} - V_{EE}) - (R_C + R_E) I_C$$

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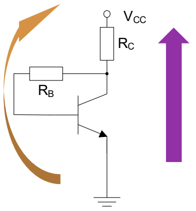
Collector feedback bias



$$V_{CC} = V_{BE} + I_B R_B + I_C R_C$$

$$V_{CC} \approx V_{CE} + R_C I_C$$

$$V_{BE} = 0.65V; \quad I_C \approx I_E; \quad I_C = \beta_{DC} I_B$$

$$I_E \approx I_C = \frac{V_{CC} - V_{BE}}{R_C + R_B/\beta_{DC}}$$

$$V_{CE} \approx V_{CC} - R_C I_C$$

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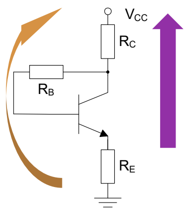
Collector- Emitter feedback bias



$$V_{CC} = I_B R_B + I_C R_C + I_E R_E + V_{BE}$$

$$V_{CC} \approx V_{CE} + R_C I_C + R_E I_E$$

$$V_{BE} = 0.65V; \quad I_C \approx I_E; \quad I_C = \beta_{DC} I_B$$

$$I_E \approx I_C = \frac{V_{CC} - V_{BE}}{R_E + R_C + R_B / \beta_{DC}}$$

$$V_{CE} \approx V_{CC} - (R_C + R_E) I_C$$

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Q - point stabilization

Higher – better temp stabillization

$$I_E \approx I_C = \frac{(V) - V_{BE}}{R + \left(R_B / \beta_{DC} \right)}$$

Smaller (in comp. with R) – better β stabillization

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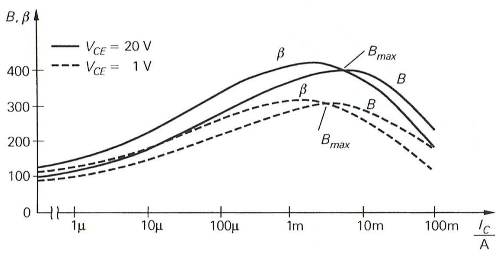
$B_{AC(B)}$, B_{DC} vs. Q-point



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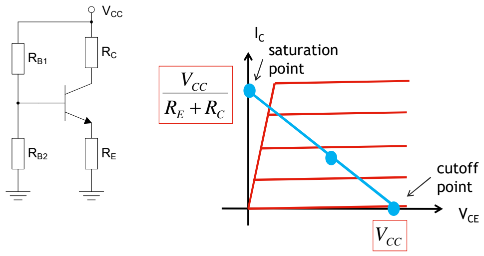
Load line



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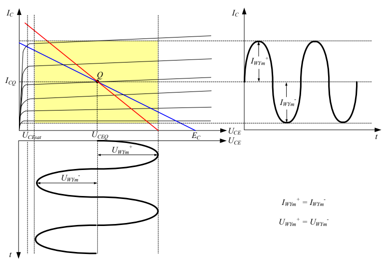
Correct Q-point



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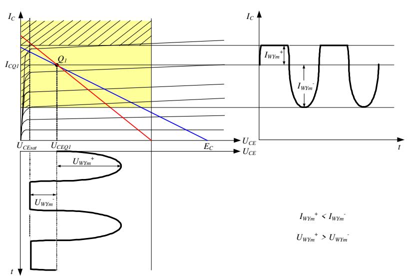
INCorrect Q-point
I_{cQ} to high



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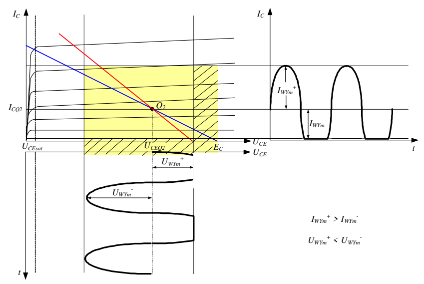
INCorrect Q-point I_{CQ} to low



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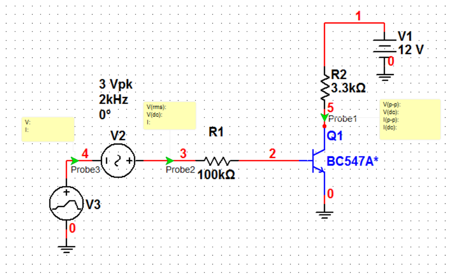
Q - point analysis (Spice)



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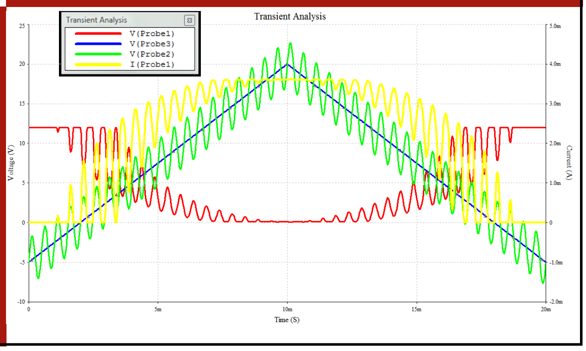
Q - point analysis results



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Q - point vs. application

Application	$I_C(Q)$	$V_{CE}(Q)$ [V]
Low noise l.f. amps	20-200 [uA]	1-5
Small to medium signal l.f. & h.f. amps	0.2-2 [mA]	3-10
High input impedance amps (op amps)	0.1-10 [uA]	0.7-5
Broadband h.f. amps; low noise h.f	5-50 [mA]	5-10
Midium power l.f. amps	0.1 -10 [A]	5-15
High power l.f. amps (clas A is not popular)	2-10 [A]	20-200
high power h.f. & special amps (not common - clas C is most popular)	2-10 [A]	20-1200

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Summary

- Ebers- Moll simplified model
- Bias calculation
  - base current
  - emiter current
  - voltage divider
  - collectore feedback
- Load line calculation
- Q-point vs. application

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Problems

- Draw and describe simplfied BJT model.
- What is the DC load line ?
- Estimate saturation point and cut-off for given circuit (known parameters: RC, RE, VCC).
- Estimate Q-point for given schematic diagram (known parameters: RB1,RB2, RC, RE, UBEQ, VCC, β).