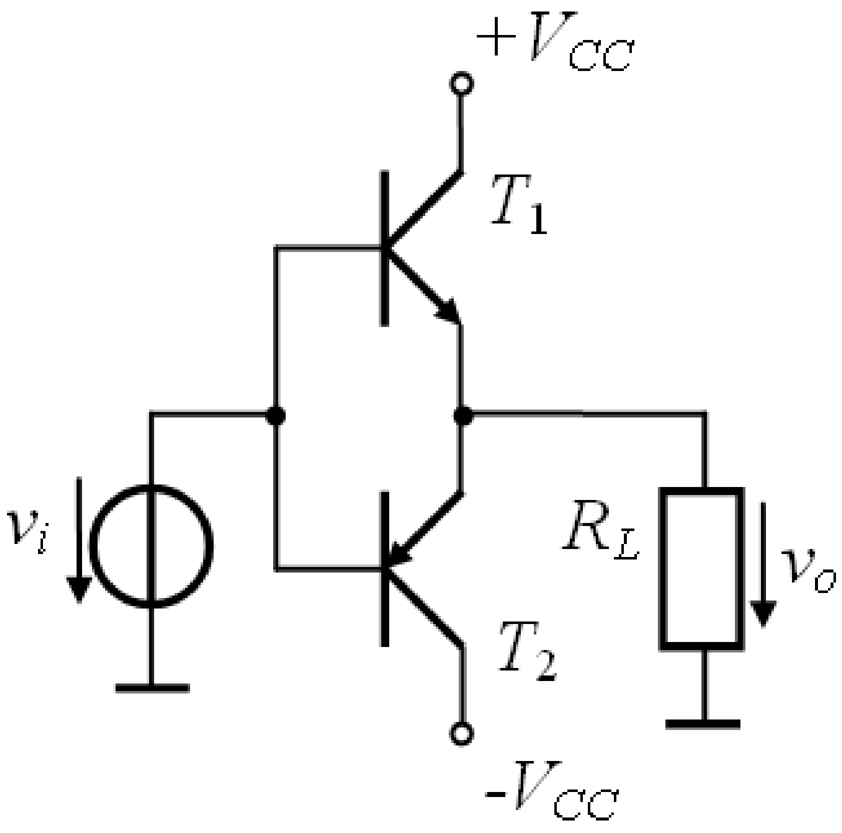
Power Amplifiers

Class B
Class AB

Class B

The circuit



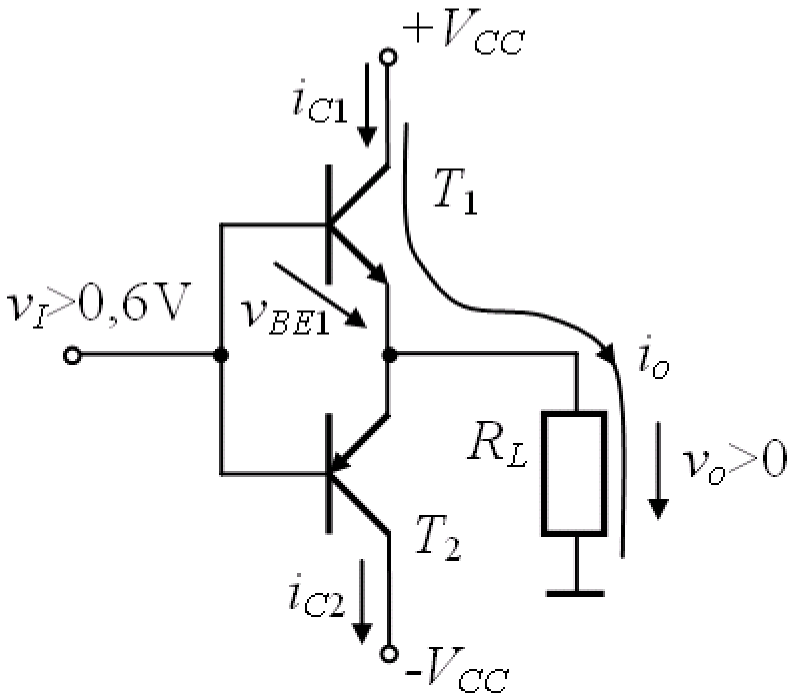
each transistor conducts for a half of every signal period

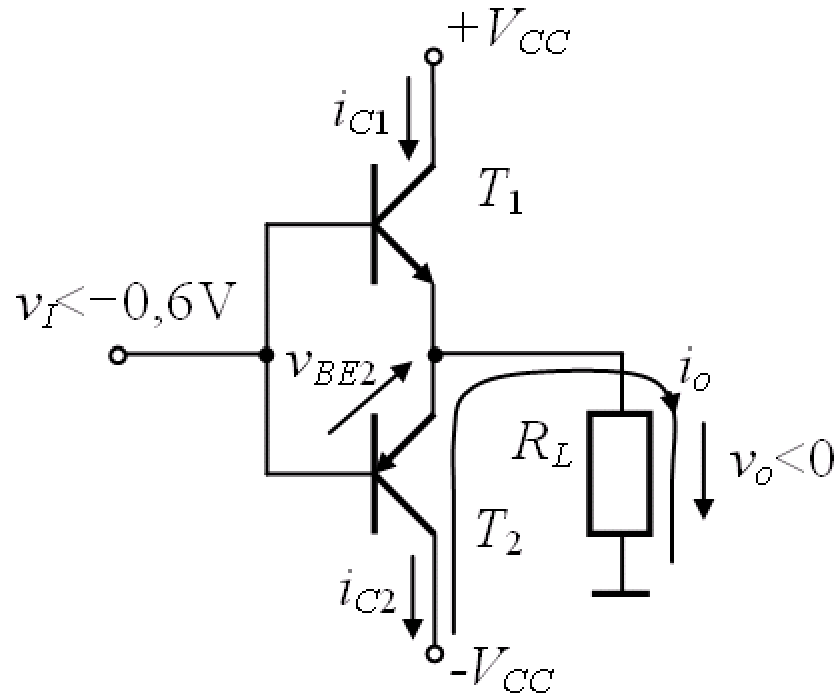
complementary pair

push-pull arrangement

Operation

$v_I \in (-0.7\text{V};\ +0.7\text{V})$ $T1-(off),\ T2-(off)$ $v_O = 0\text{V}$





$v_I \geq 0.7\text{V}$ $T1-(on),\ T2-(off)$

$$v_O = v_I - v_{BE1} = v_I - 0.7\text{V}$$

$i_O > 0$ $i_{C1} = i_O$ $i_{C2} = 0$

$$\boxed{v_{o\max} = V_{CC} - V_{CE\text{sat}} \approx V_{CC}}$$

$v_I \leq -0.7\text{V}$ $T1-(off),\ T2-(on)$

$$v_O = v_I - v_{BE2} = v_I + 0.7\text{V}$$

$i_O < 0$ $i_{C2} = -i_O$ $i_{C1} = 0$

$$\boxed{v_{o\min} = -V_{CC} + V_{CE1sat} \approx -V_{CC}}$$

Voltage transfer characteristic (VTC)

$v_I \geq 0.7\text{V} \quad T1-(on), T2-(off)$

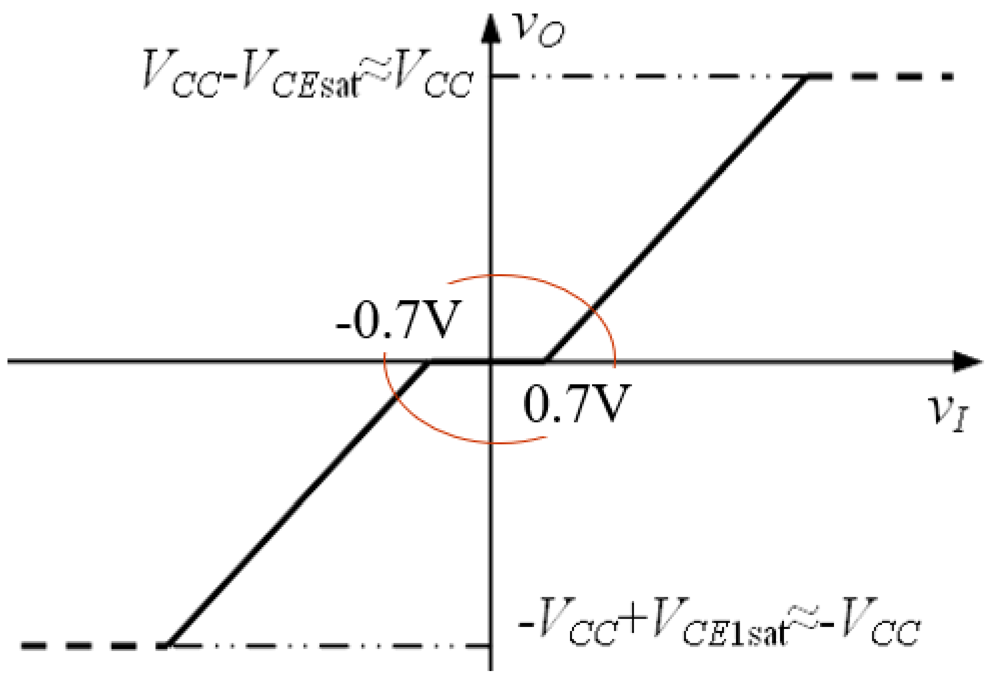
$v_O = v_I - 0.7\text{V}$

$$\boxed{v_{o\max} = V_{CC} - V_{CE\text{sat}} \approx V_{CC}}$$

$v_I \in (-0.7\text{V};\ 0.7\text{V})$

$T1-(off),\ T2-(off)$

$v_O = 0\text{V}$

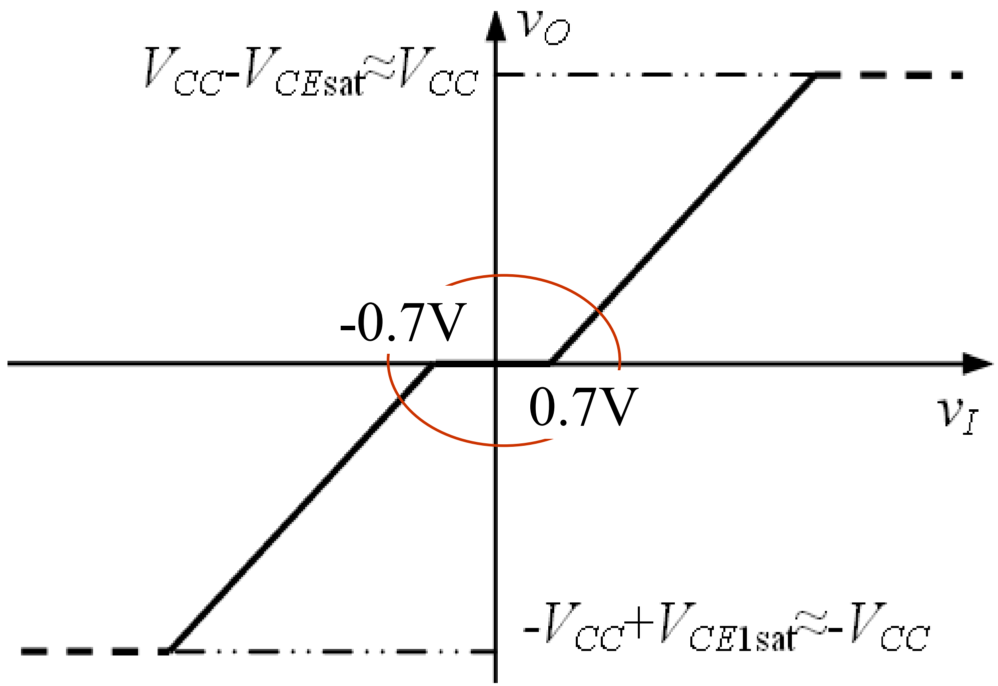


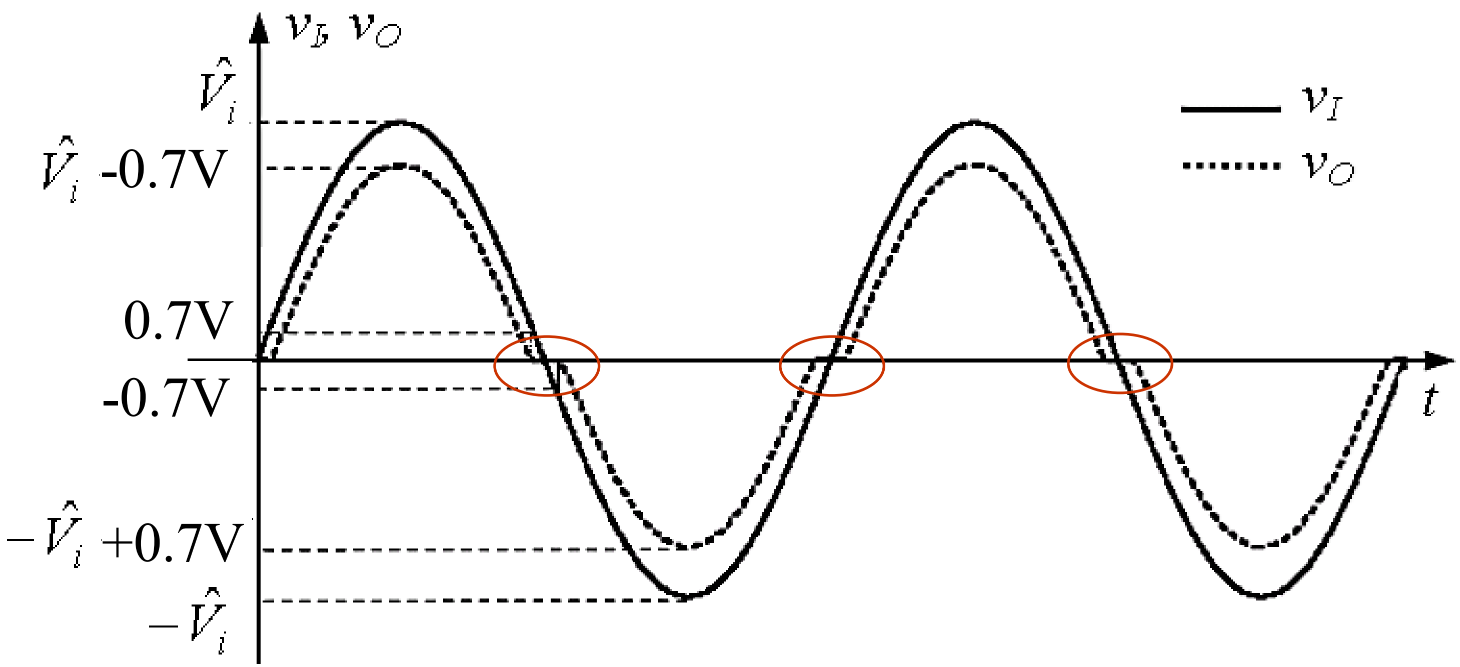
$v_I \leq -0.7\text{V} \quad T1-(off), T2-(on)$

$v_O = v_I + 0.7\text{V}$

$$\boxed{v_{o\min} = -V_{CC} + V_{CE1sat} \approx -V_{CC}}$$

Crossover distortions



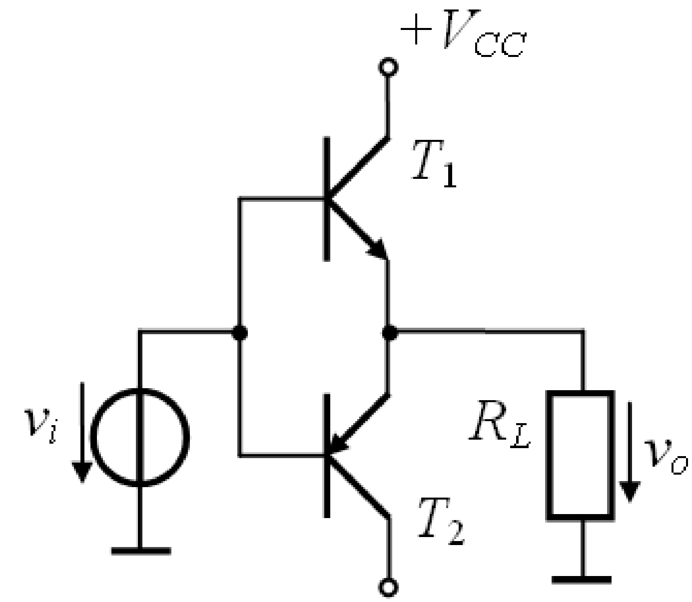


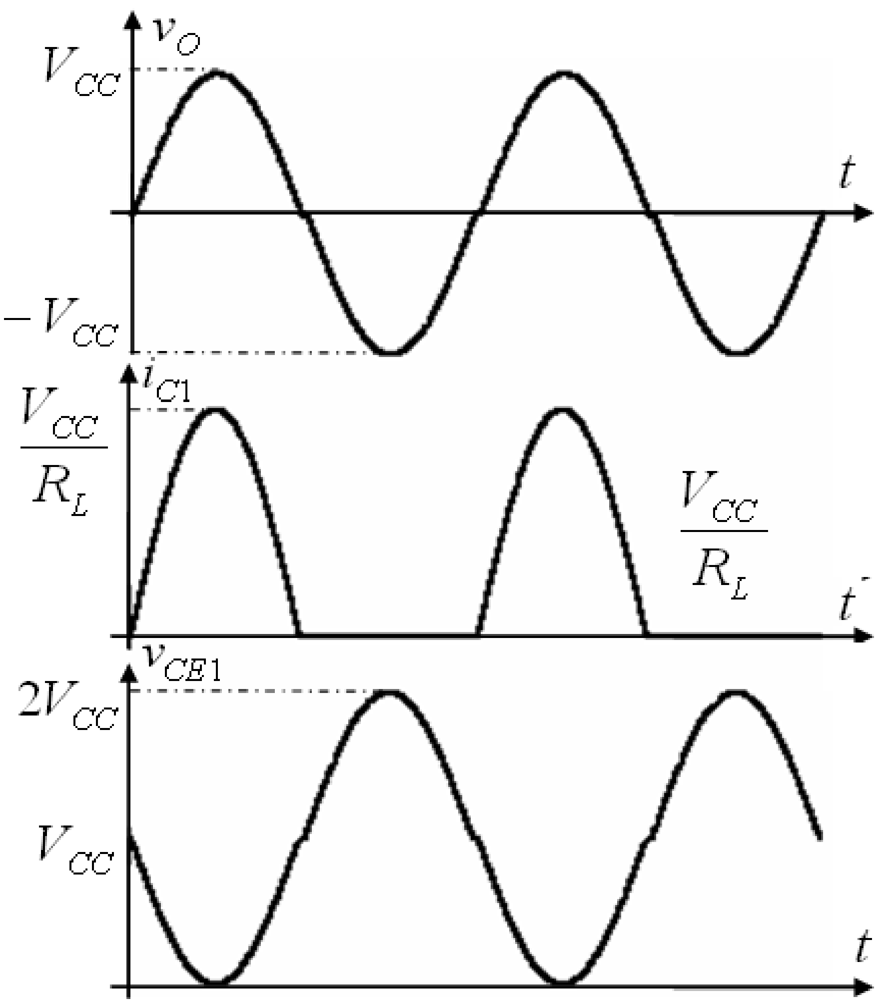
Waveforms

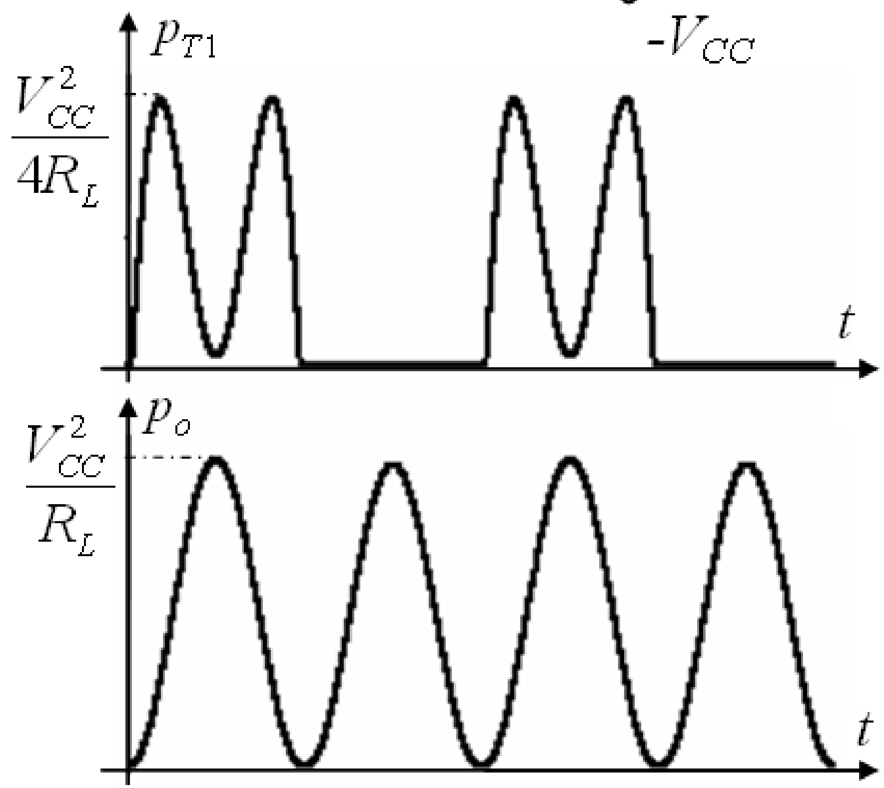
Assume the signal magnitude sufficiently high to neglect the crossover distortions.

$$\hat{V}_o = V_{CC}$$

$$v_o(t) = \hat{V}_o \sin \omega t$$







Powers. Efficiency

$$\eta = \frac{P_O}{P_{PS}}$$

$$P_{PS}^{+} = \frac{1}{T}\int_0^T V_{CC}\, i_{C1}(t)dt = \frac{1}{T}\int_0^{T/2} V_{CC}\frac{\hat{V}_o \sin\omega t}{R_L}dt$$

$$P_{PS}^{+} = \frac{1}{T}\frac{V_{CC}\hat{V}_o}{R_L}\int_0^{T/2}\sin\frac{2\pi}{T}tdt$$

$$P_{PS}^{+} = \frac{1}{\pi}\frac{V_{CC}\hat{V}_o}{R_L}$$

$$P_{PS} = P_{PS}^{+} + P_{PS}^{-} = \frac{2}{\pi}\frac{V_{CC}\hat{V}_o}{R_L}$$

For $\hat{V}_o = V_{CC}$ $\quad \boxed{P_{PS\max} = \frac{2}{\pi}\frac{V_{CC}^2}{R_L}}$

$$P_O = V_{Orms}I_{Orms} = \frac{\hat{V}_O^2}{2R_L}$$

For $\hat{V}_O = V_{CC}$ $\quad \boxed{P_{O\max} = \frac{V_{CC}^2}{2R_L}}$

Average efficiency: $\eta = \frac{P_O}{P_{PS}} = \frac{\hat{V}_O^2}{2R_L}\frac{\pi}{2}\frac{R_L}{V_{CC}\hat{V}_O} = \frac{\pi}{4}\frac{\hat{V}_O}{V_{CC}}$

Maximum average efficiency: for $\hat{V}_O = V_{CC}$ $\quad \boxed{\eta_{max} = \frac{\pi}{4} = 78.5\%}$

The amplifying transistor

$$P_T = \frac{1}{2}\left(P_{PS} - P_O\right) \qquad P_T = \frac{1}{2}\left(P_{PS} - P_O\right) = \frac{1}{\pi}\frac{V_{CC}\hat{V}_o}{R_L} - \frac{\hat{V}_o^2}{4R_L}$$

Maximum efficiency: $\hat{V}_O = V_{CC}$ $\quad P_T = \frac{1}{\pi}\frac{V_{CC}^2}{R_L} - \frac{\hat{V}_{CC}^2}{4R_L} = 0.068\frac{\hat{V}_{CC}^2}{R_L}$

What is the maximum average power dissipated by a transistor depending on the output voltage magnitude?

OPTIONAL

$$\frac{dP_T}{d\hat{V}_O} = 0 \quad \Rightarrow \quad \hat{V}_o = \frac{2}{\pi}V_{CC} = 0.64V_{CC}$$

Maximum average power: $\hat{V}_o = 0.64V_{CC}$ $\quad P_{T\,max} = \frac{1}{\pi^2}\frac{V_{CC}^2}{R_L} \approx 0.1\frac{V_{CC}^2}{R_L}$

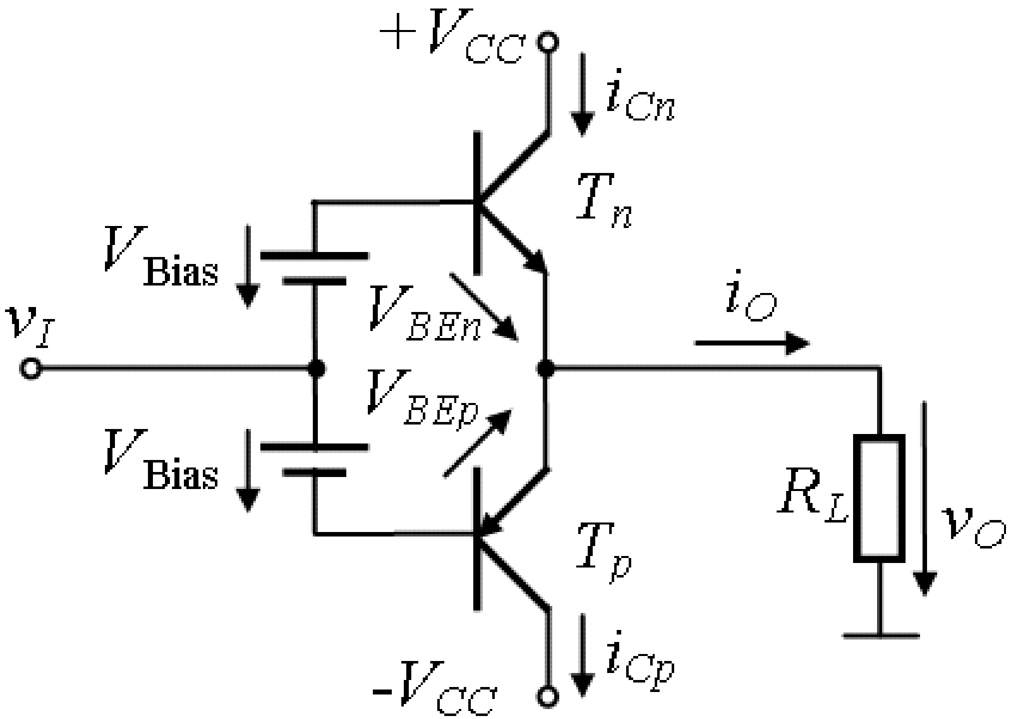
Maximum instantaneous power: $\hat{V}_o = V_{CC}$ $\quad p_{T\,max} = \frac{1}{4}\frac{V_{CC}^2}{R_L} = 0.25\frac{V_{CC}^2}{R_L}$

$$i_{C\max} = \frac{V_{CC}}{R_L} \qquad v_{CE\max} = 2V_{CC}$$

Class AB

- Crossover distortion, specific to class B amplifier can be virtually eliminated

Class AB Amplifier. Basic Circuit



• biasing the complementary output transistors at a small output current

$$V_{Bias} \approx 0.7\text{V}$$

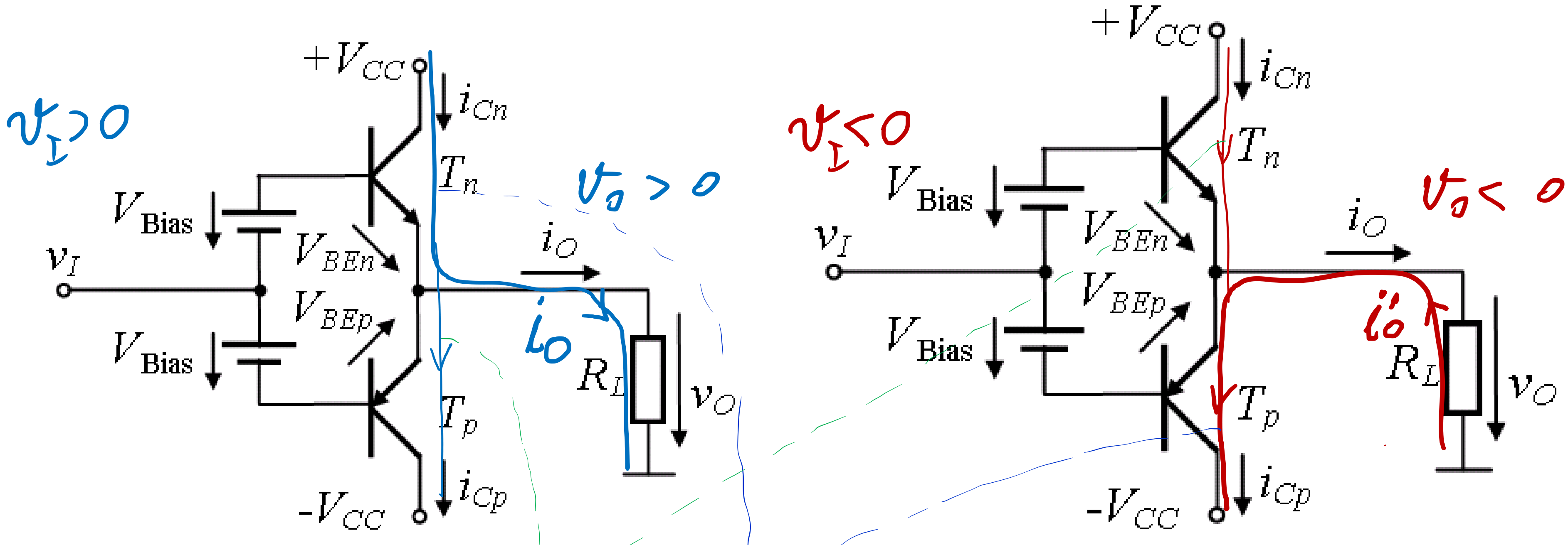
$$I = I_S e^{\frac{V_{Bias}}{V_T}}$$

v_I - positive

$$v_O(t) = v_I(t) + V_{Bias} - V_{BEn} \approx v_I(t)$$

v_I - negative

$$v_O(t) = v_I(t) - V_{Bias} - V_{BEp} \approx v_I(t)$$



class A   class B

AB

$v_I > 0, \; v_o > 0$

$i_{En} = i_o + i_{Cp}$

T_n provides the output current

T_n -(c) ; T_p -(C)

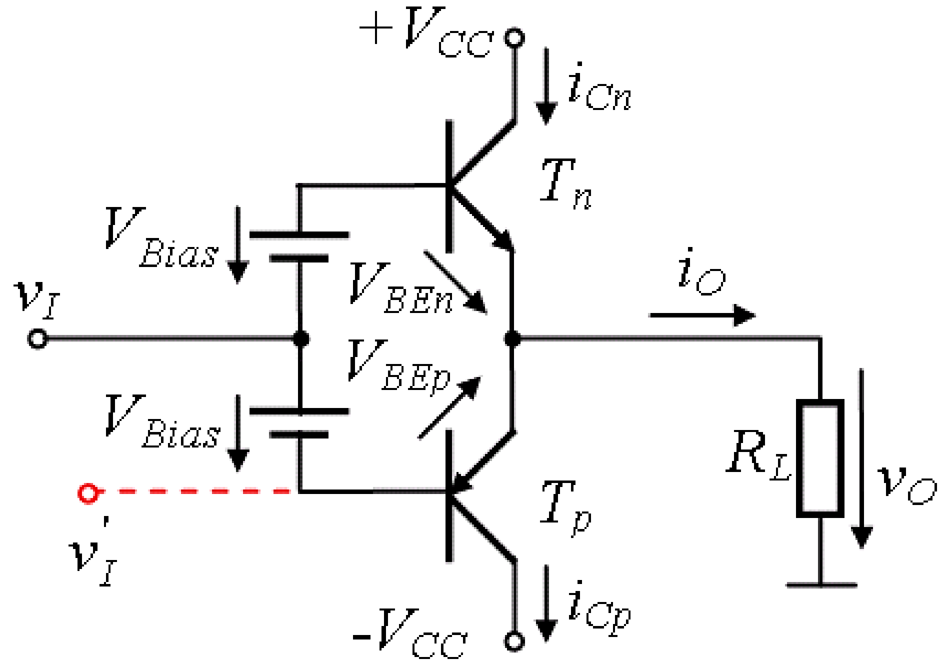
$v_I < 0, \; v_o < 0$

$i_{Cp} = i_o' + i_{Cn}$

T_p provides the output current

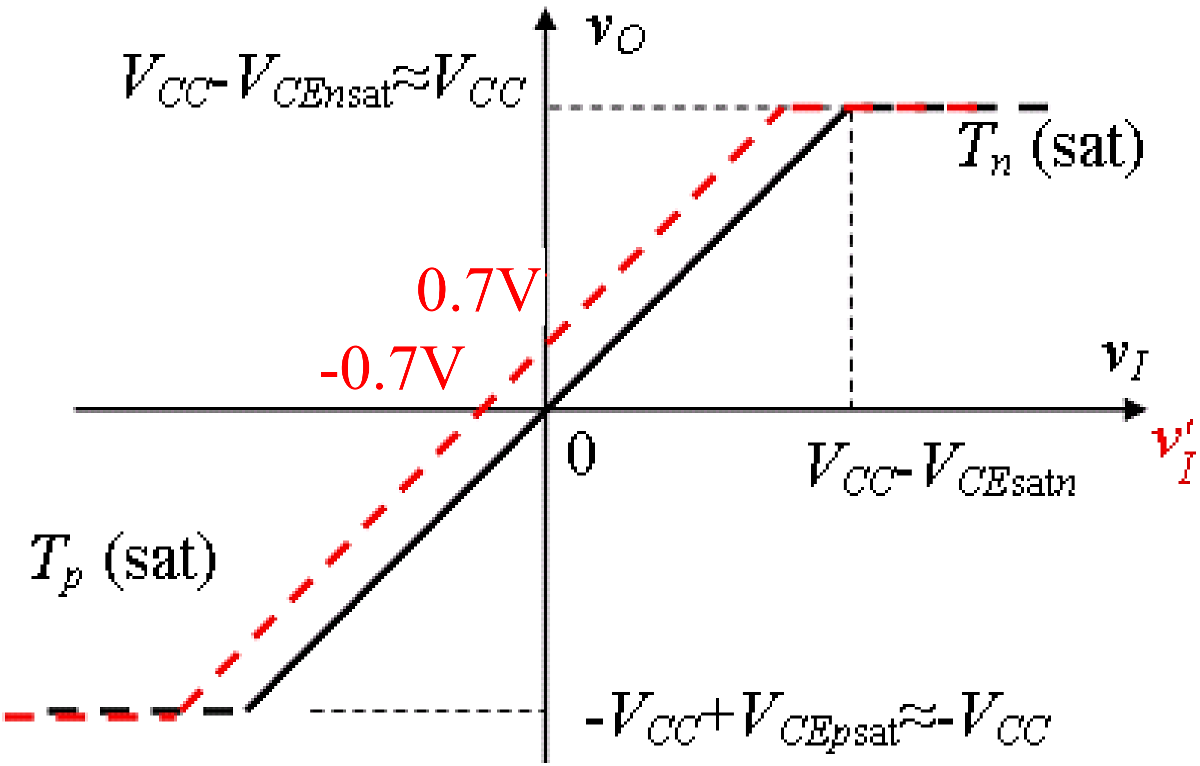
T_p -(C) T_n -(C)

Voltage Transfer Characteristic (VTC)



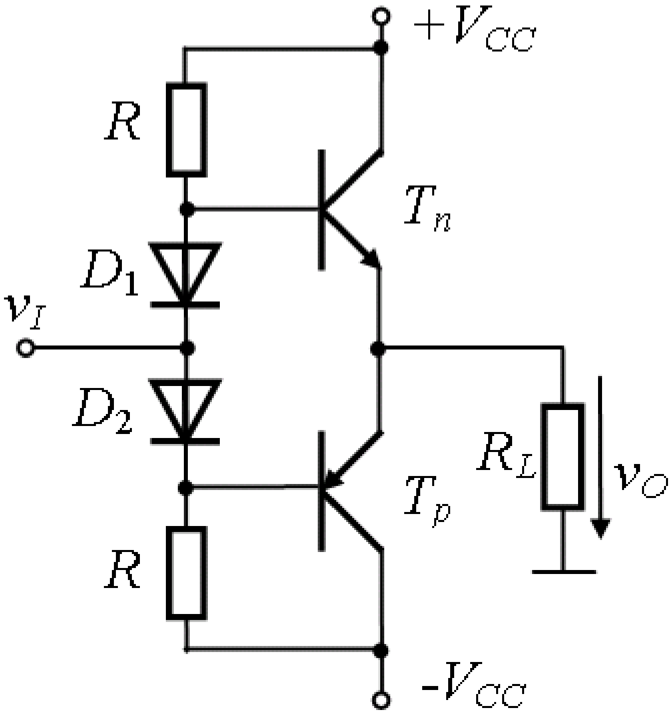
$$v_O(t) = v_I(t)$$

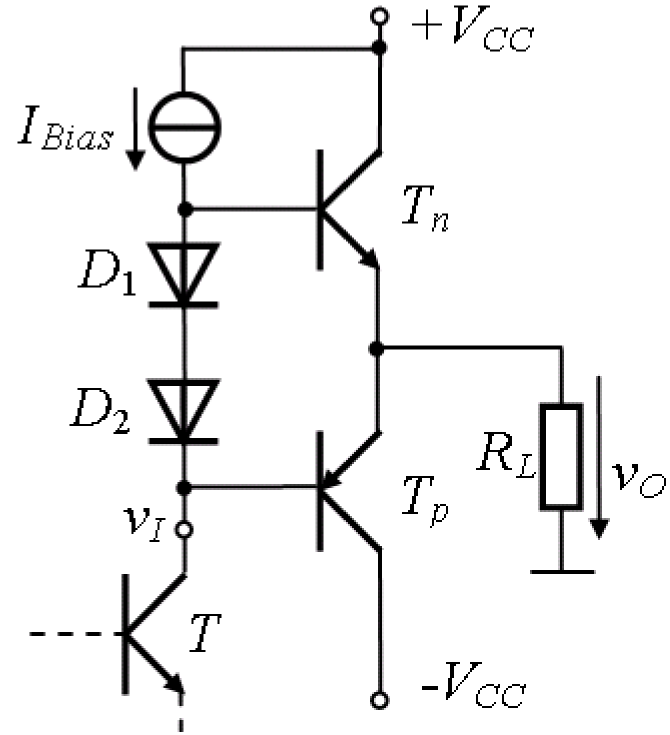
$$v_O(t) = v_I'(t) + 0.7\text{V}$$



Solutions to generate V_{bias}?

Biasing using Diodes





R should allow the currents in the diodes and in the bases of the transistors, even for maximum output current

T is the driver transistor from previous amplifier stage

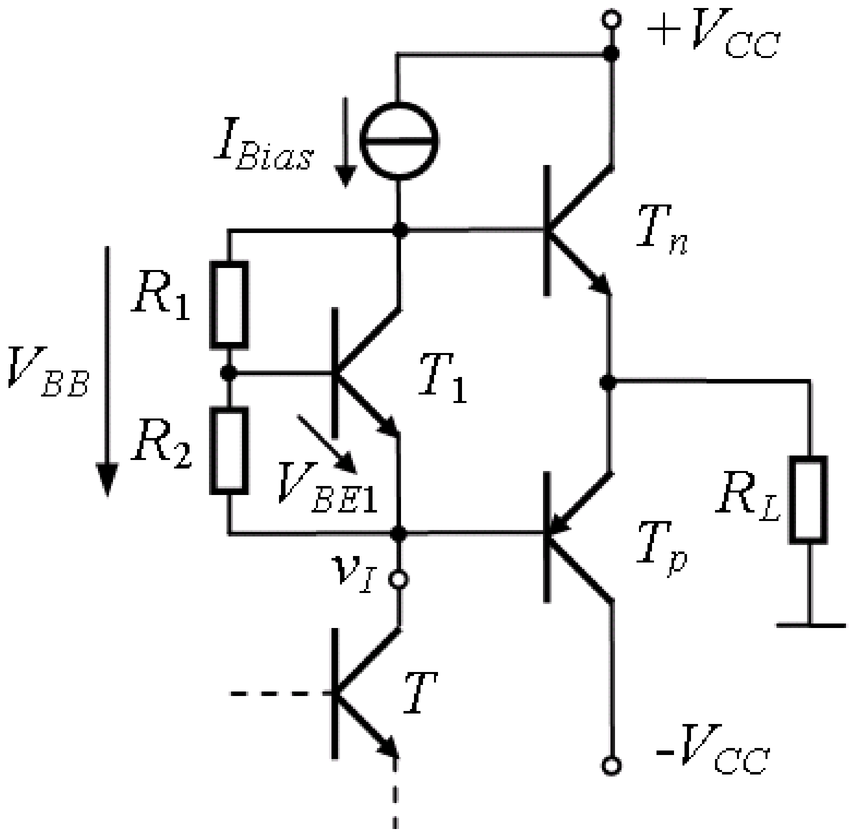
V_{CC}= +15V $\quad \hat{V}_O = 8\text{V} \quad \beta$=50

R_L=100Ω, I_{D1}=1.5mA

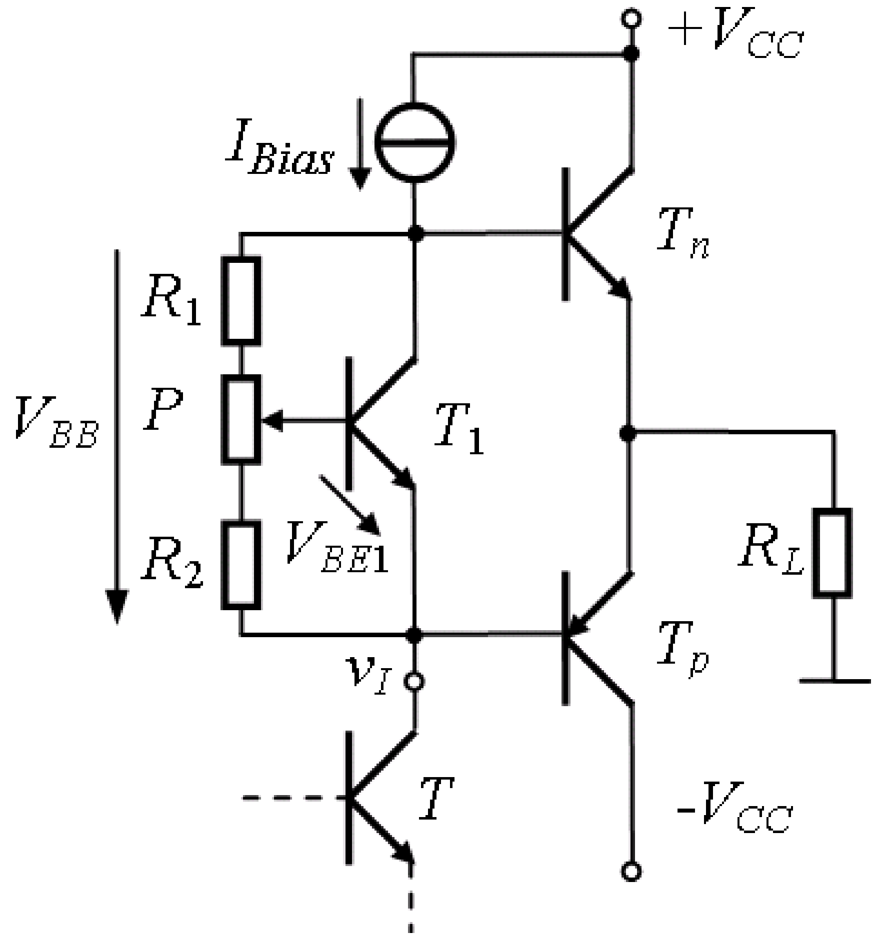
R=?, I_R=? (each R)

Biasing using V_{BE} Multiplier

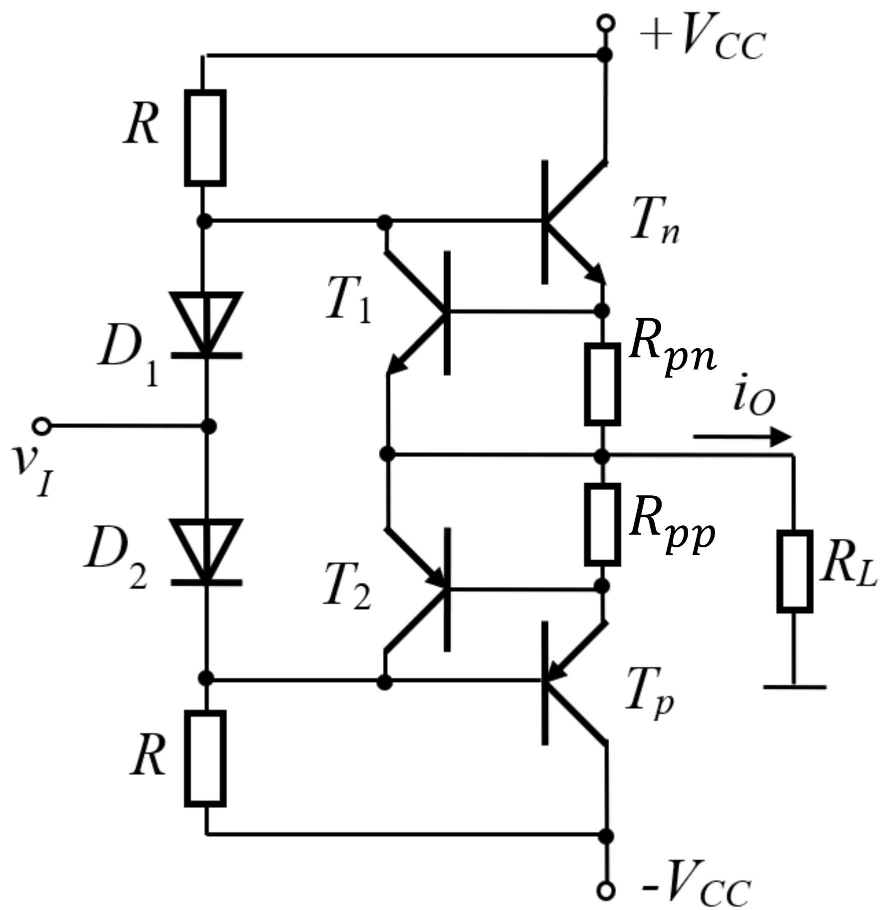
Optional



$$V_{BB} = \left(1 + \frac{R_1}{R_2}\right) V_{BE1}$$



Short-Circuit Protection



Protection against the effect of short-circuiting the output

Elements for short-circuit protection:

- T_1, R_{pn} – for $v_o > 0$V
- T_2, R_{pp} – for $v_o < 0$V

When $v_O > 0$V

- If $R_{pn} i_O < 0.6\text{V}$

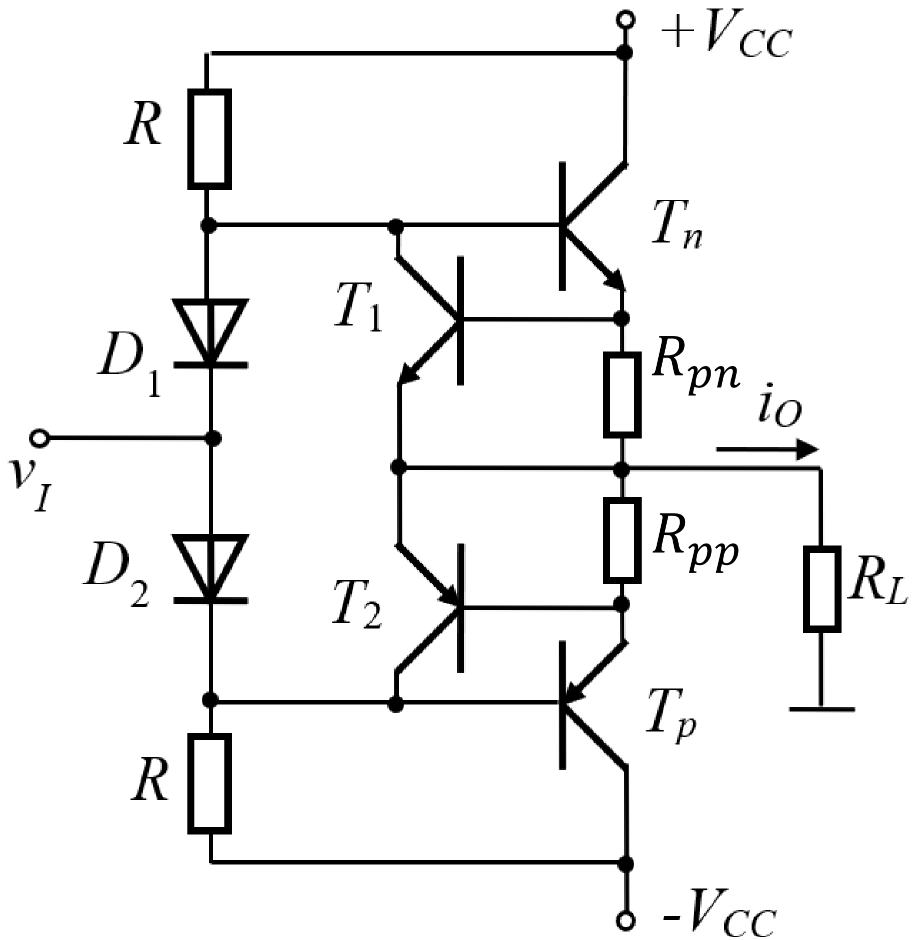
$$T_1 - (off); \quad i_O = \frac{v_O}{R_L}$$

- If i_O increases,

when $R_{pn} i_O = 0.7\text{V}$

$$T_1 - (on); \quad i_{Omax} = \frac{V_{BE1,on}}{R_{pn}} = \frac{0.7\text{V}}{R_{pn}}$$

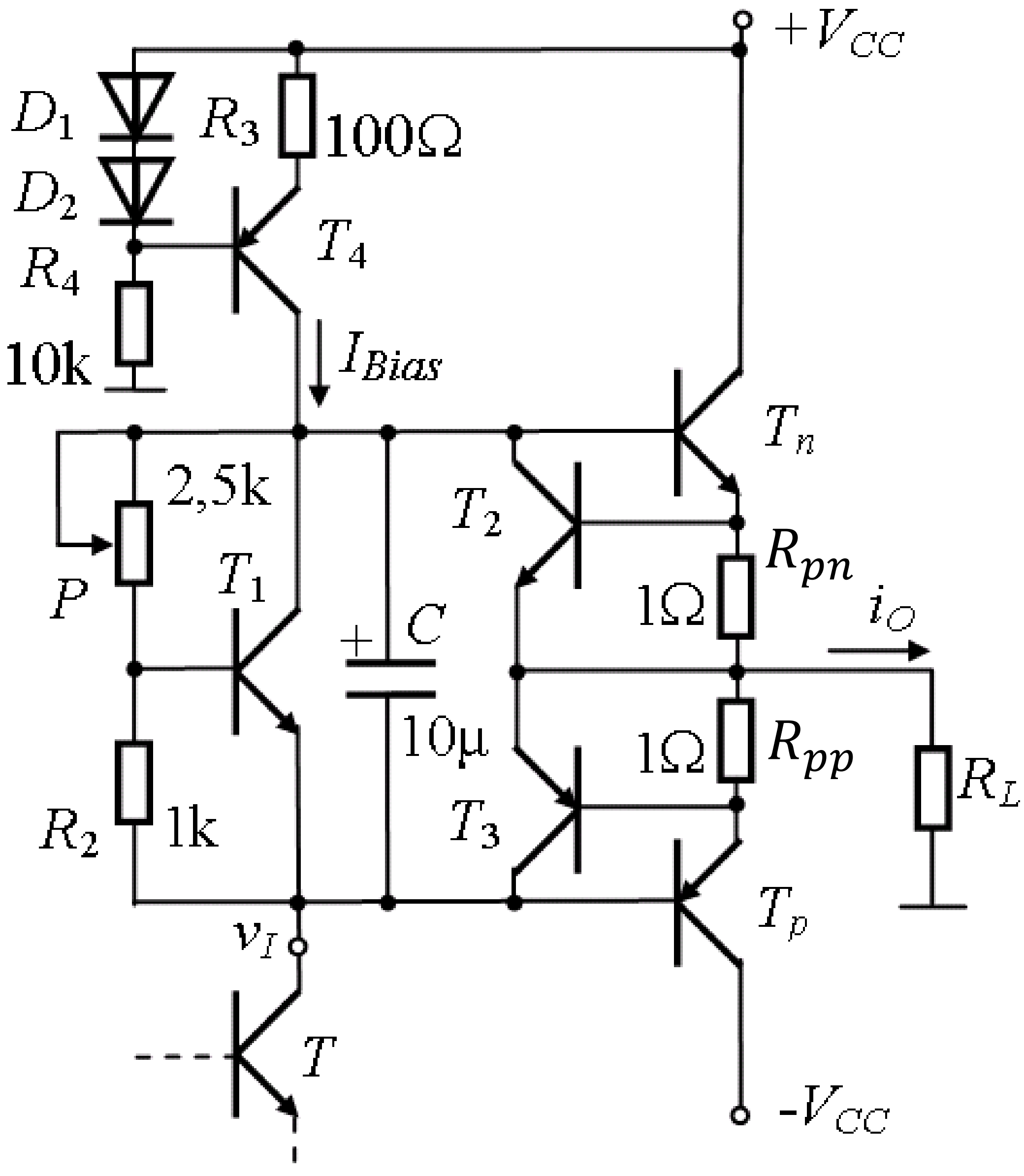
Short-Circuit Protection



- Effective in ensuring device safety
- Disadvantage: under normal operation up to 0.7V appears across each protection resistor. The voltage swing will be reduced by that much, in each direction
- Negative feedback, protection of the output transistor against thermal runaway

Optional

Illustration



$$_{Bias} = \frac{0.7 + 0.7 - 0.7}{0.1} = 7\text{mA}$$

P - adjusts the biasing voltage between V_{BE} and $3.5V_{BE}$

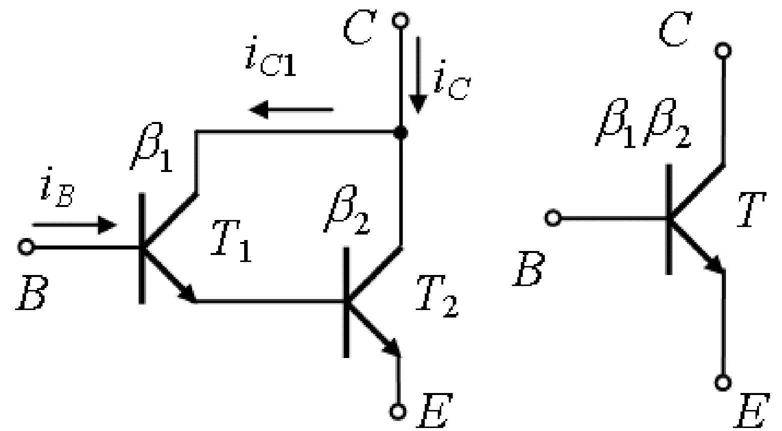
C - in the bases of T_n and T_p :

- same variable input voltage

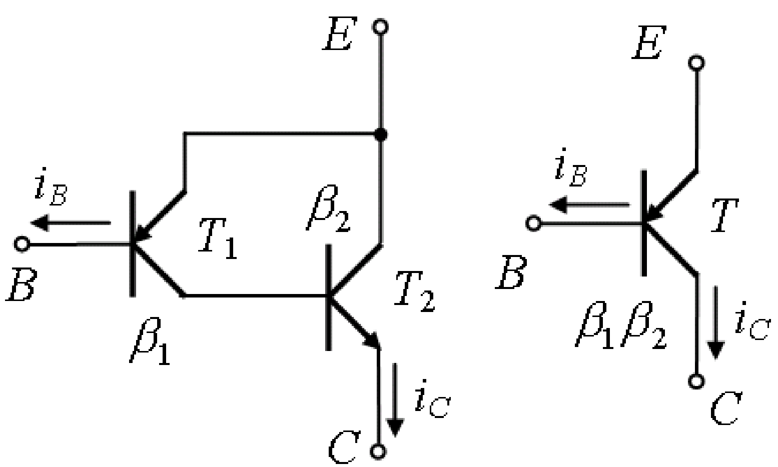
$i_{O\max}$=0.7A

Use of Compound Transistors with Higher Current Gain

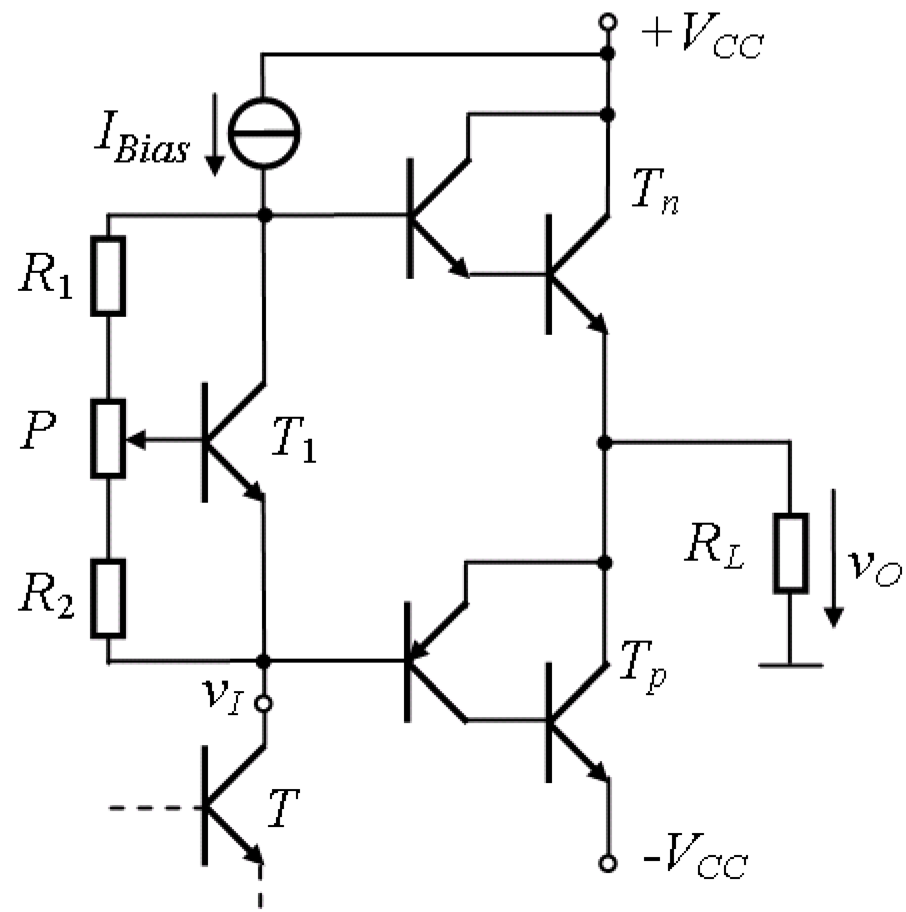
- Necessary for high output currents

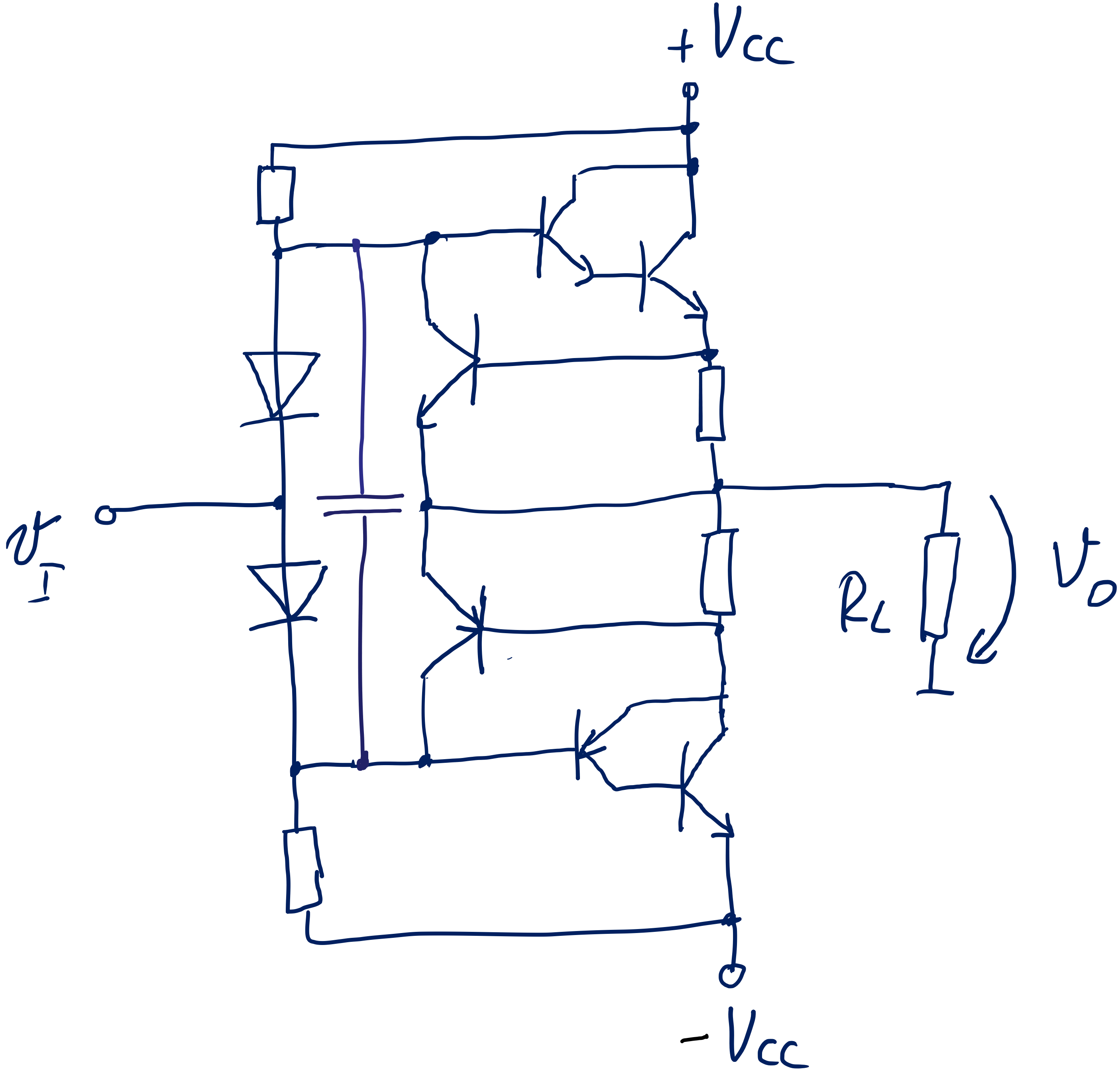


The Darlington *npn* configuration

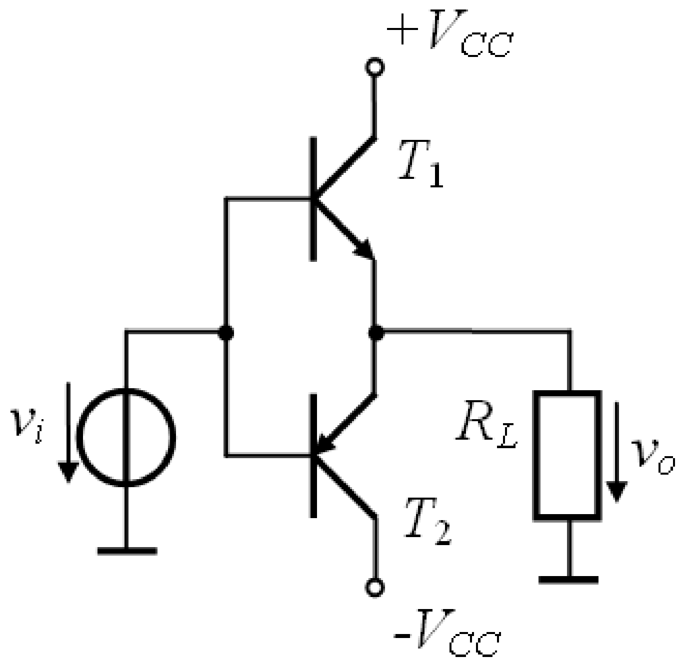


The compound *pnp* configuration preferred in IC





+Vcc
v_I
R_L
v_o
-Vcc



Problem

$\pm V_{CC} = \pm 15\text{V}$

$R_{L1} = 500\Omega$

$R_{L2} = 50\Omega$

a) What is the expression $v_O(v_i)$ for $v_i \in [-10\text{V};10\text{V}]$? Plot the $v_O(v_i)$ VTC. What is the operating class of this amplifier? What is the maximum theoretical average efficiency?

b) Plot $v_O(t)$ for: (1) $v_i(t) = 0.2\sin\omega t$ [V]; (2) $v_i(t) = 10\sin\omega t$ [V].

c) For $v_i(t) = 10\sin\omega t$ [V], $v_O(t)$ can be well approximated by a sinewave (neglecting crossover distortions). Compute: the average output power, the average power consumption, and the average efficiency of the stage. Plot the collector-emitter voltage and collector current for T_1 and T_2.

d) Propose a solution to eliminate crossover distortion.