Class AB Output Stage

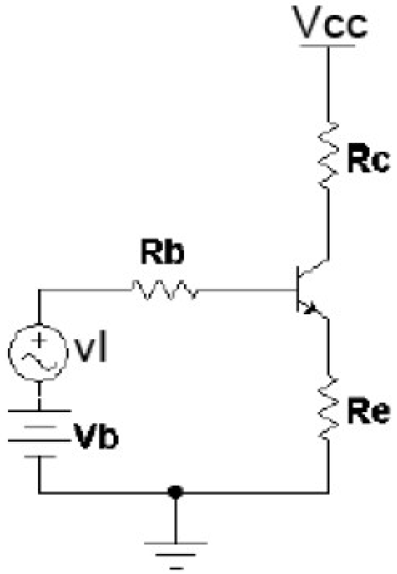
- Class AB amplifier Operation
- Multisim Simulation - VTC
- Class AB amplifier biasing
- Widlar current source
- Multisim Simulation - Biasing

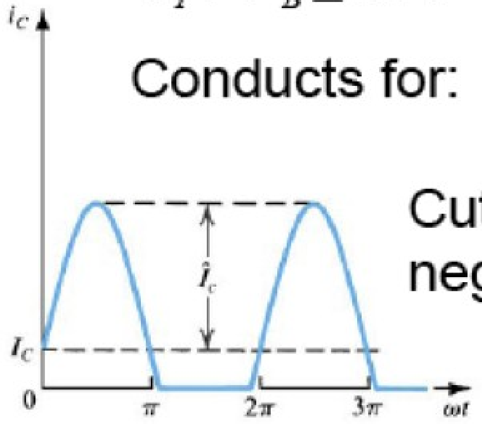
Class AB Operation

Class AB – Amplifier transistor conducts for positive v_I swing + part of negative v_I swing s.t.:

$$v_I + V_B \geq 0.7\,V \quad \text{where} \quad V_B < max(v_I)$$

Conducts for: $v_I \geq 0.7 - V_B$





Cut-off for rest of negative v_I swing:

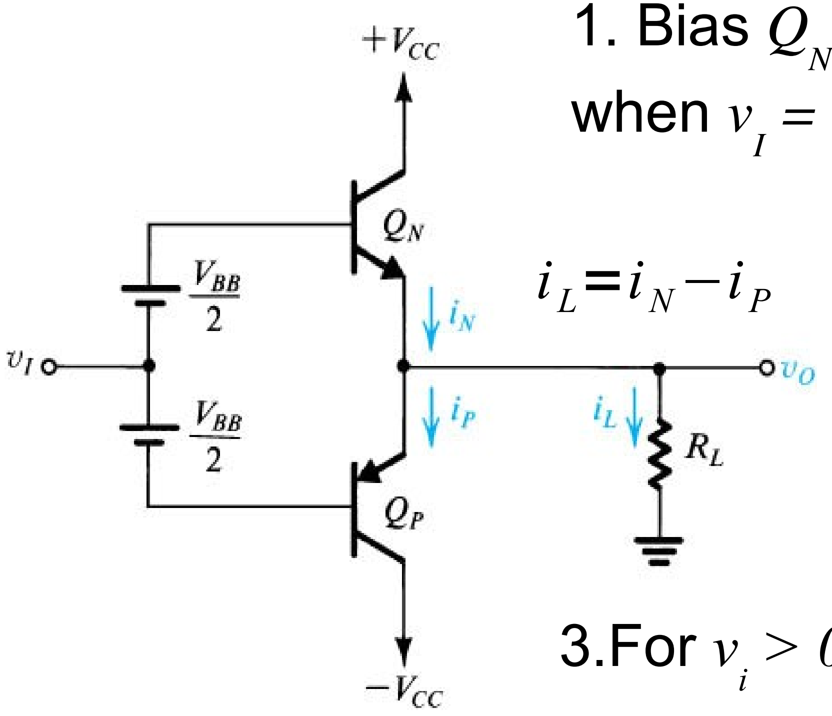
Transistor cut-off ($i_C = 0$) it:

$$v_I + V_B < 0.7\,V$$

NOTE: 1. when $v_I = 0$, $i_C = I_C$

2. a 2nd class AB BJT is needed to conduct for interval slightly larger than the negative v_I cycle.

Basic Class AB Amplifier Circuit



$i_L = i_N - i_P$

1. Bias Q_N and Q_P into slight conduction (fwd. act.) when $v_I = 0$: $i_N = i_P$.

2 Ideally Q_N and Q_P are:

   a. Matched (unlikely with discrete transistors and challenging in IC).

   b. Operate at same ambient temperature.

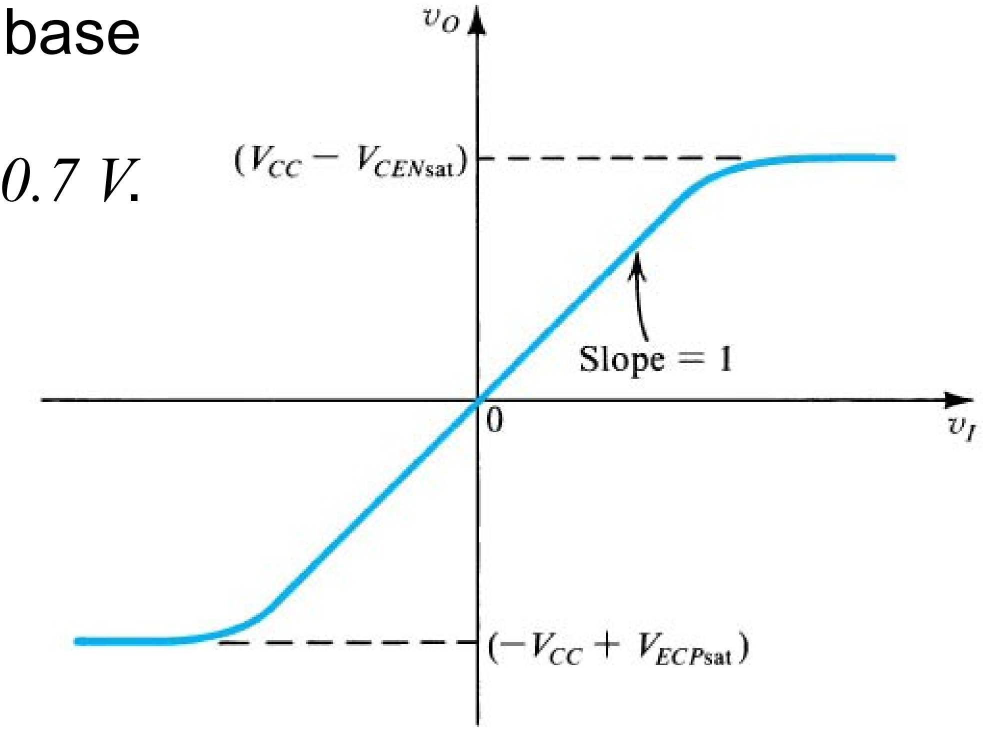
3.For $v_i > 0$: $i_N > i_P$ i.e. Q_N most cond. (like Class B).

4.For $v_i < 0$: $i_P > i_N$ i.e. Q_P most cond. (like Class B).

NOTE. This is base-voltage biasing with all its stability problems!

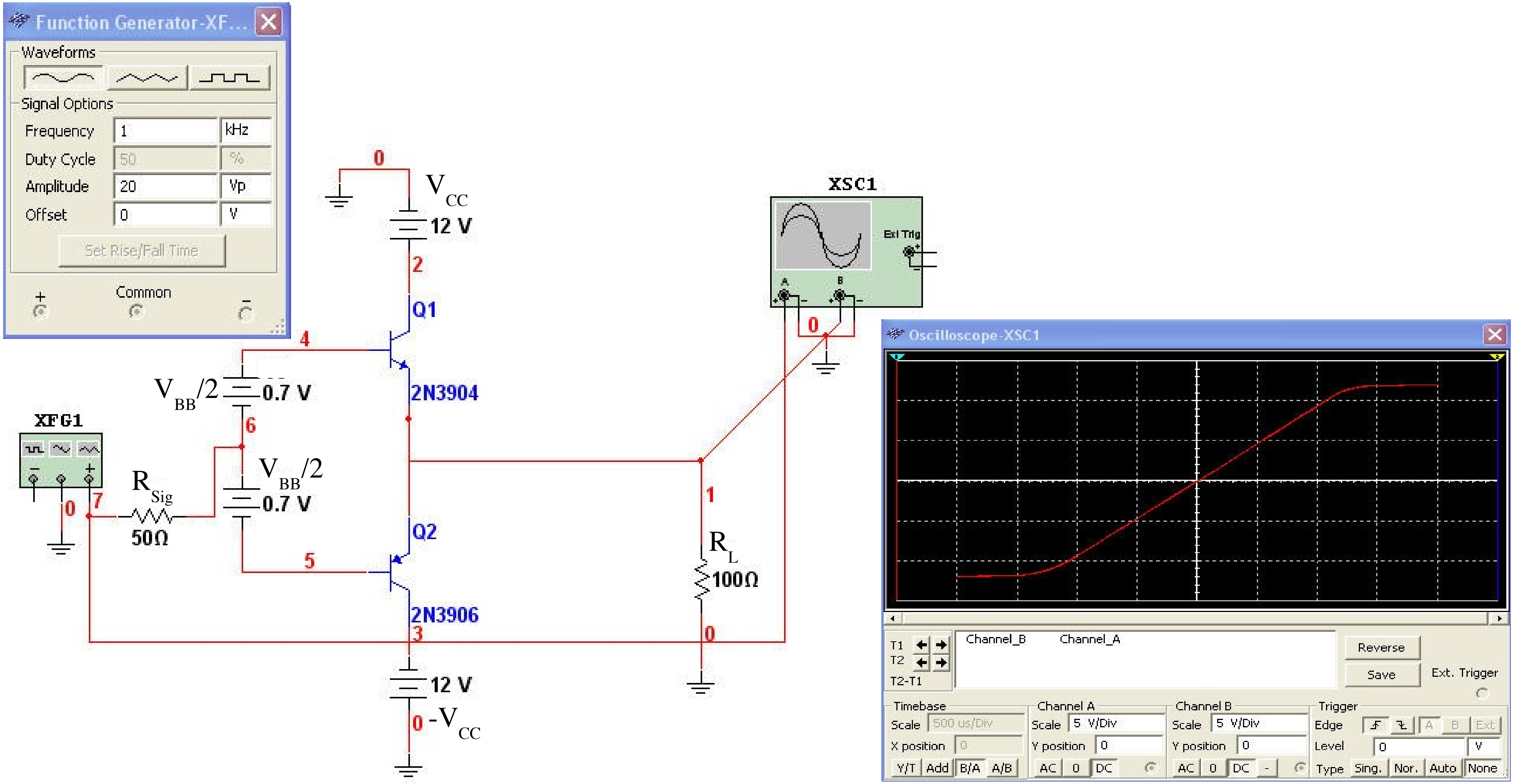
Class AB VTC Plot

Requires the two DC base voltage sources to be matched and $V_{BB}/2 = 0.7\ V$.



Amplitude: 20 V_p
Frequency: 1 kHz

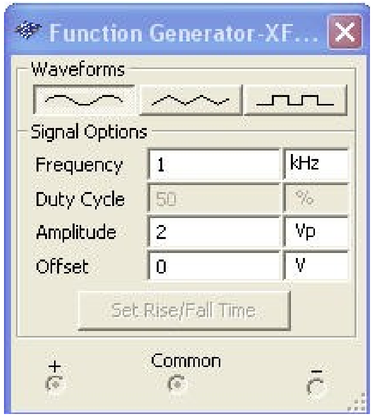
Class AB VTC Simulation



Function Generator-XF…
Frequency: 1 kHz
Duty Cycle: 50 %
Amplitude: 20 Vp
Offset: 0 V

Oscilloscope-XSC1
Timebase Scale: 500 us/Div
X position: 0
Channel A Scale: 5 V/Div
Channel A Y position: 0
Channel B Scale: 5 V/Div
Channel B Y position: 0
Trigger Level: 0 V

Class AB VTC Simulation - cont.

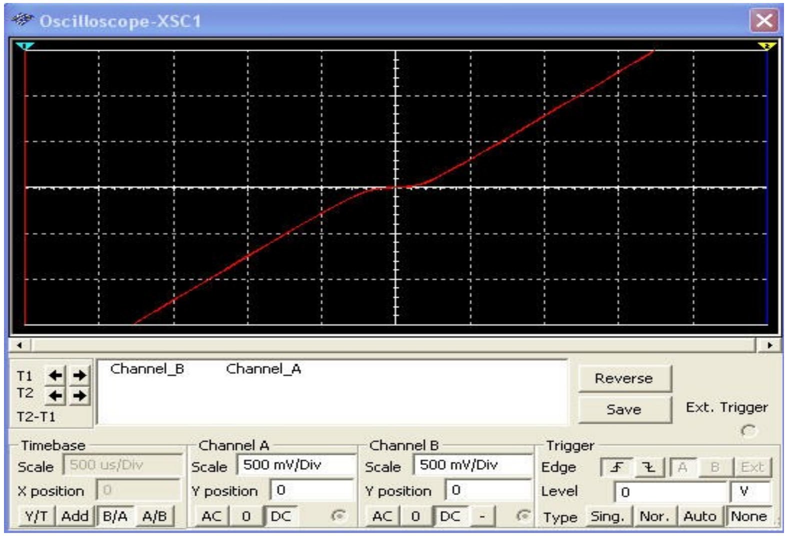


Frequency 1 kHz
Duty Cycle 50 %
Amplitude 2 Vp
Offset 0 V

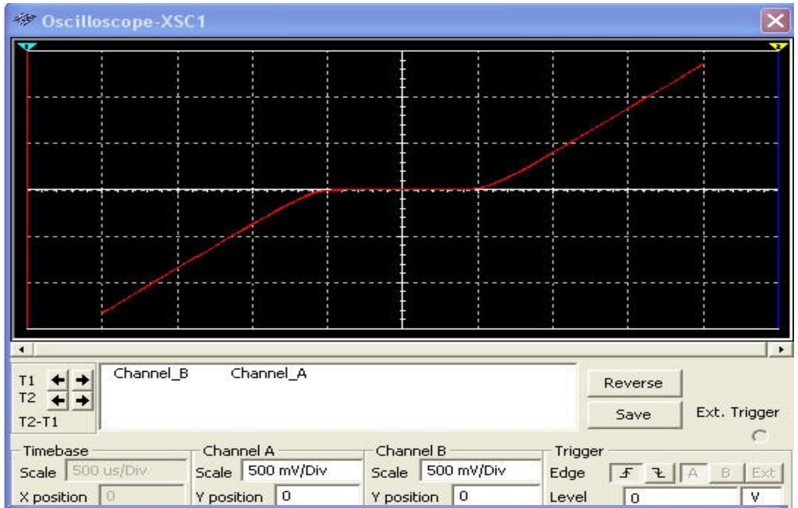
Amplitude: 2 V_p

Frequency: 1 kHz

$$\frac{V_{BB}}{2}=0.5\,V$$

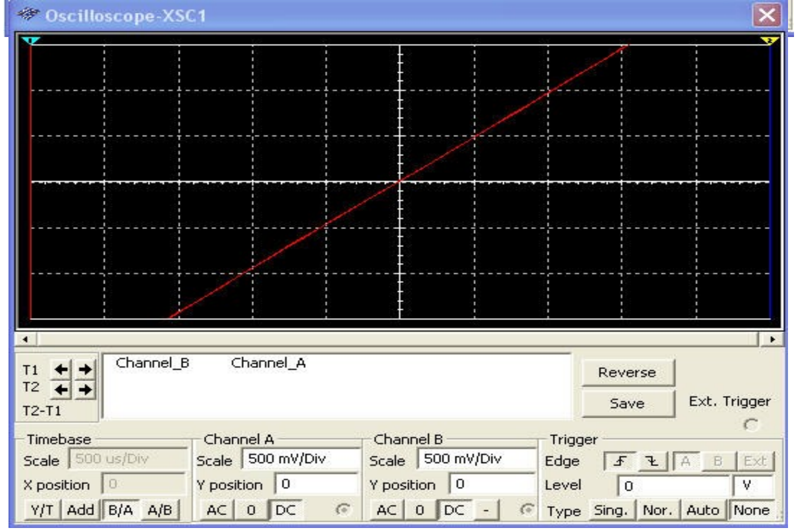


Timebase Scale 500 us/Div, X position 0
Channel A Scale 500 mV/Div, Y position 0
Channel B Scale 500 mV/Div, Y position 0
Trigger Edge, Level 0 V, Type



Timebase Scale 500 us/Div, X position 0
Channel A Scale 500 mV/Div, Y position 0
Channel B Scale 500 mV/Div, Y position 0
Trigger Edge, Level 0 V

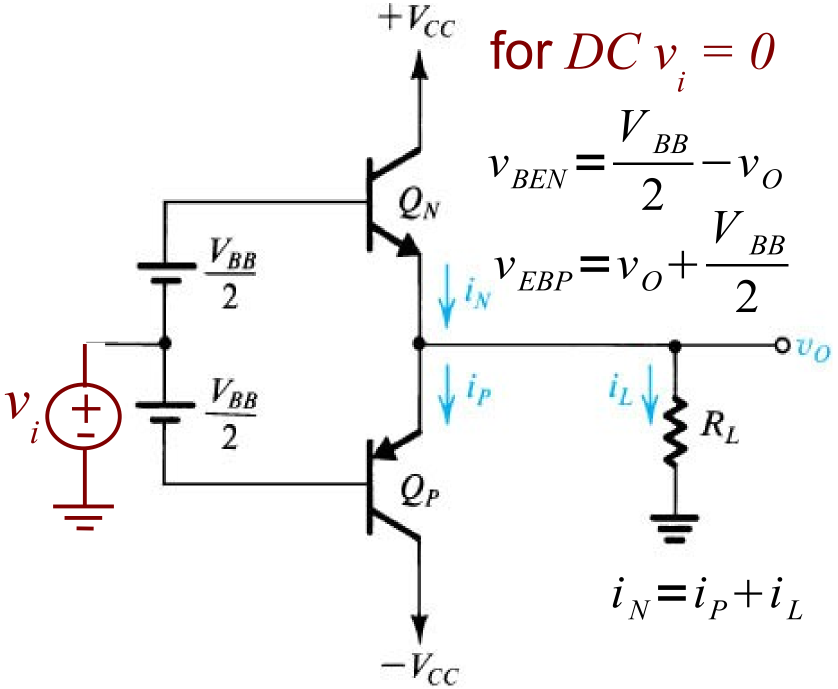
$$\frac{V_{BB}}{2}=0.1\,V$$



Timebase Scale 500 us/Div, X position 0
Channel A Scale 500 mV/Div, Y position 0
Channel B Scale 500 mV/Div, Y position 0
Trigger Edge, Level 0 V, Type

$$\frac{V_{BB}}{2}=0.7\,V$$

Class AB Circuit Operation - cont.



for DC $v_i = 0$

$$v_{BEN} = \frac{V_{BB}}{2} - v_O$$

$$v_{EBP} = v_O + \frac{V_{BB}}{2}$$

$$i_N = i_P + i_L$$

Bias (Q_N & Q_P matched):

$$I_N = I_P = I_Q = I_S e^{\frac{V_{BB}}{2V_T}}$$

Output voltage for $v_i \neq 0$:

$$\text{for } v_i > 0 \; v_o = v_i + \frac{V_{BB}}{2} - v_{BEN} \Rightarrow v_o \approx v_i$$

$$\text{for } v_i < 0 \; v_o = v_i - \frac{V_{BB}}{2} + v_{EBP} \Rightarrow v_o \approx v_i$$

Base-to base voltage is constant!

$v_{BEN} + v_{EBP} = V_{BB}$ for all v_i

Class AB Circuit Operation - cont.

$$for\ v_i>0\ v_o=v_i+\frac{V_{BB}}{2}-v_{BEN}\Rightarrow v_{BEN}=v_i-v_o+\frac{V_{BB}}{2}$$

$$for\ v_i<0\ v_o=v_i-\frac{V_{BB}}{2}+v_{EBP}\Rightarrow v_{EBP}=v_o-v_i+\frac{V_{BB}}{2}$$

ADD

$v_{BEN}+v_{EBP}=V_{BB}$ for all v_i Note for Class B $V_{BB}=0$

Using the currents

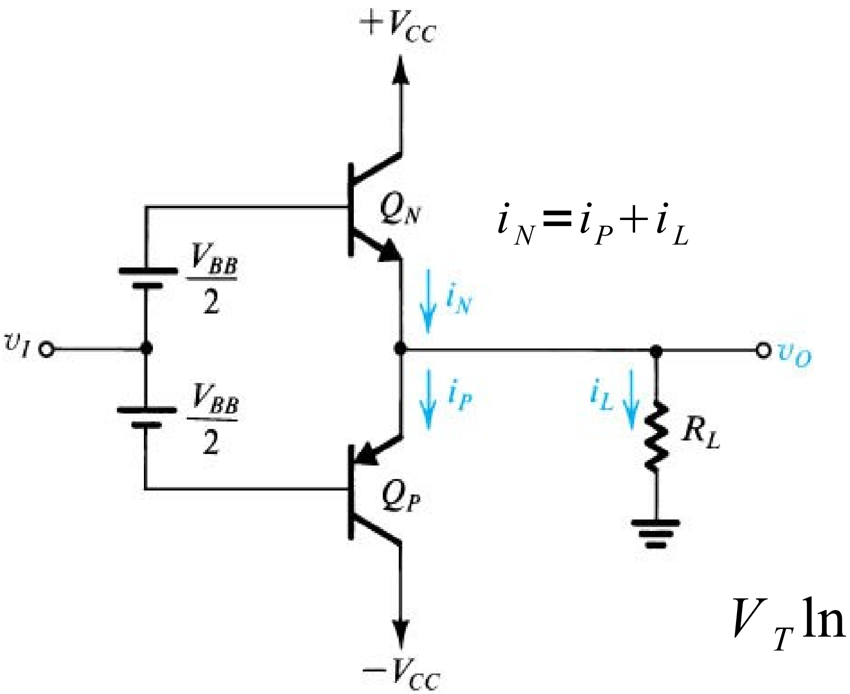
$$i_N=I_S e^{\frac{v_{BEN}}{v_T}}\Rightarrow v_{BEN}=V_T\ln\left(\frac{i_N}{I_S}\right)$$

$$i_P=I_S e^{\frac{v_{EBP}}{V_T}}\Rightarrow v_{EBP}=V_T\ln\left(\frac{i_P}{I_S}\right)$$

$$I_N=I_P=I_Q=I_S e^{\frac{V_{BB}}{2V_T}}\Rightarrow V_{BB}=2V_T\ln\left(\frac{I_Q}{I_S}\right)$$

$V_T\ln\left(\frac{i_N}{I_S}\right)+V_T\ln\left(\frac{i_P}{I_S}\right)=2V_T\ln\left(\frac{I_Q}{I_S}\right)$ for all v_i

Class AB Circuit Operation - cont.



$$i_N=i_P+i_L$$

from the previous slide

$$\boxed{V_T\ln\left(\frac{i_N}{I_S}\right)+V_T\ln\left(\frac{i_P}{I_S}\right)}=2V_T\ln\left(\frac{I_Q}{I_S}\right)$$

$$\boxed{V_T\ln\left(\frac{i_N i_P}{I_S^2}\right)}=2V_T\ln\left(\frac{I_Q}{I_S}\right)$$

$$V_T\ln(i_N i_P)-\cancel{V_T\ln(I_S^2)}=2V_T\ln(I_Q)-\cancel{2V_T\ln(I_S)}$$

$\ln(i_N i_P)=\ln(I_Q^2)$ or $i_N i_P=I_Q^2$

Constant base voltage condition: $\boxed{v_{BEN}+v_{EBP}=V_{BB} \quad => \quad i_N i_P=I_Q^2}$

Class AB Circuit Operation – VTC cont.

The constant base voltage condition $i_P i_N = I_Q^2$ where I_Q is typically small.

For example let $I_Q = 1\ mA$ and $i_N = 10\ mA$.

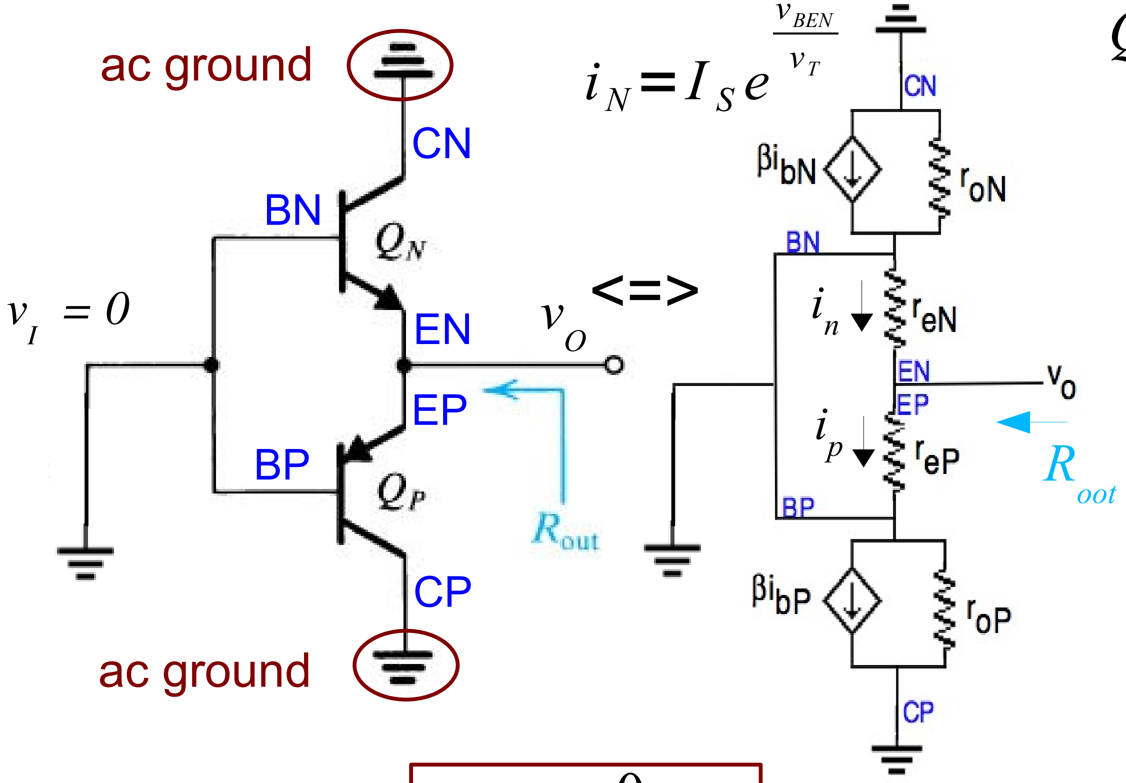
$$i_P = \frac{I_Q^2}{i_N} = \frac{1 \cdot 10^{-6}}{10 \cdot 10^{-3}} = 0.1\ mA = \frac{1}{100} i_N$$

The Class AB circuit, over most of its input signal range, operates as if either the Q_N or Q_P transistor is conducting and the Q_P or Q_N transistor is cut off.

For small values of v_I both Q_N and Q_P conduct, and as v_I is increased or decreased, the conduction of Q_N or Q_P dominates, respectively.

Using this approximation we see that a class AB amplifier acts much like a class B amplifier; but without the dead zone.

Class AB Small-Signal Output Resistance



$$i_N = I_S e^{\frac{v_{BEN}}{v_T}}$$

Instantaneous resistance for the Q_N transistor - assume $\alpha = 1$:

$$\frac{di_N}{dv_{BEN}} = \frac{I_S e^{\frac{v_{BEN}}{V_T}}}{V_T} = \frac{i_N}{V_T}$$

For the Q_P transistor:

$$\frac{di_P}{dv_{EBP}} = \frac{i_P}{V_T}$$

Hence:

$$r_{eN} = \frac{V_T}{i_N} \quad \text{and} \quad r_{eP} = \frac{V_T}{i_P}$$

$$\boxed{\begin{gathered} v_I = 0 \\ R_{out} = r_{eN} \| r_{eP} \end{gathered}}$$

$v_I > 0$ V: $i_N > i_P \Rightarrow R_{out} \approx r_{eN}$

$v_I < 0$ V: $i_P > i_N \Rightarrow R_{out} \approx r_{eP}$

Small-Signal Output Resistance - cont.

The two emitter resistors are in parallel:

$$R_{out}=r_{eN}||r_{eP}=\frac{\frac{V_T^2}{i_N i_P}}{\frac{V_T}{i_N}+\frac{V_T}{i_P}}=\frac{V_T}{i_N i_P\left(\frac{1}{i_N}+\frac{1}{i_P}\right)}=\frac{V_T}{i_N+i_P}$$ and $$i_L=\frac{v_O}{R_L}=i_N-i_P$$

At $i_N = i_P$ (the no-signal condition i.e. $v_O = 0$ => $i_L = 0$): $i_N=i_P=I_Q$

$$R_{out}=\frac{V_T}{2I_Q}$$

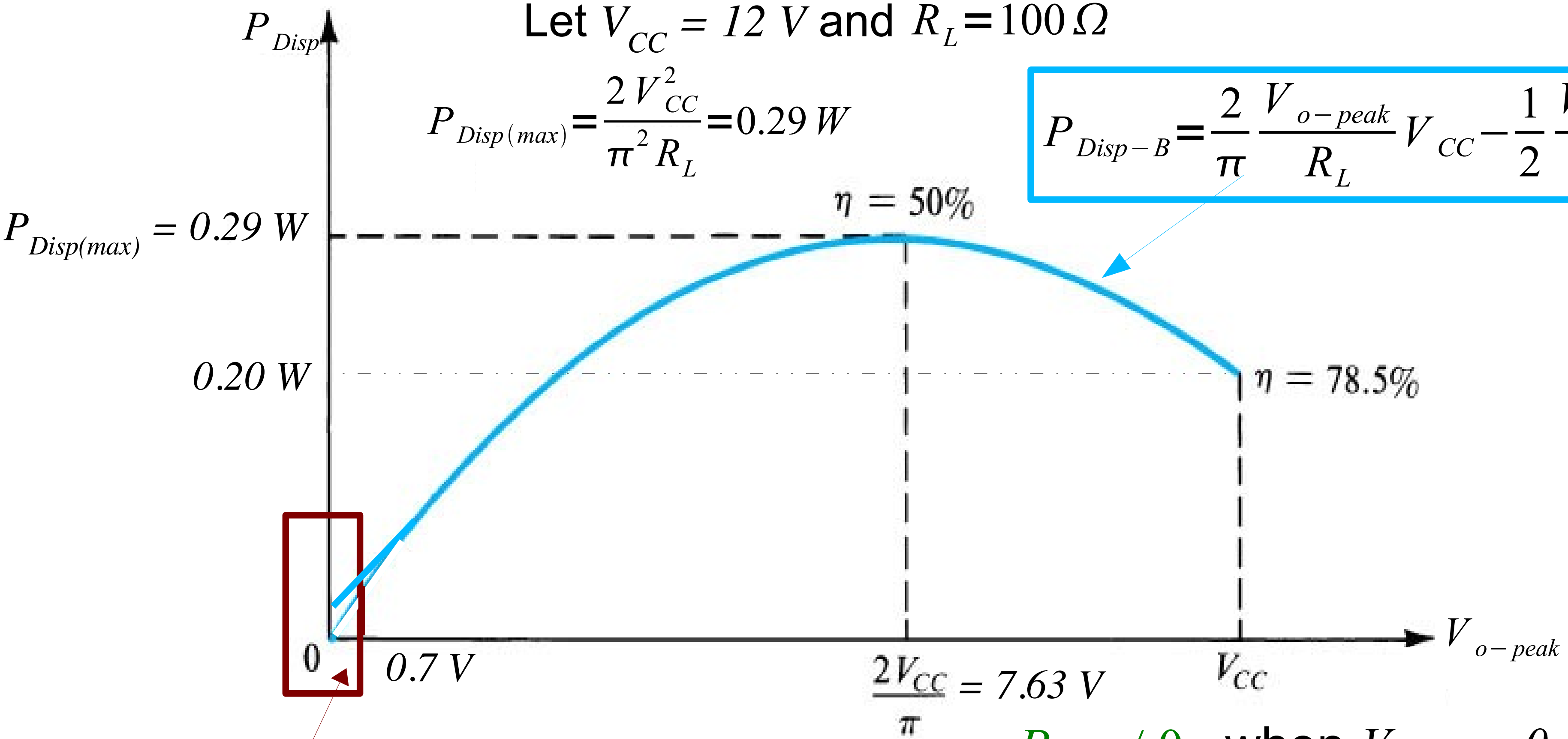
So, for small signals, a small load current I_Q flows => no dead-zone!

Class AB Power Conversion Efficiency & Power Dissipation Similar to Class B

Let $V_{CC} = 12\ V$ and $R_L = 100\ \Omega$

$$P_{Disp(max)} = \frac{2 V_{CC}^2}{\pi^2 R_L} = 0.29\ W$$

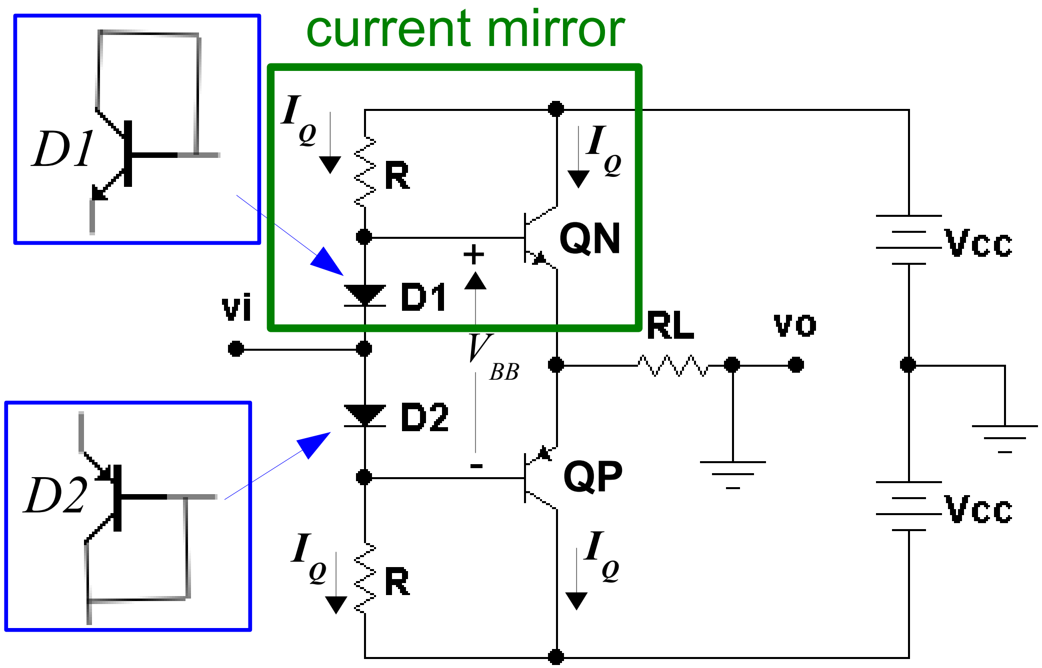
$$P_{Disp-B} = \frac{2}{\pi} \frac{V_{o-peak}}{R_L} V_{CC} - \frac{1}{2} \frac{V_{o-peak}^2}{R_L}$$



Accurate for small $V_{o\text{-}peak}$.

$P_{Disp} \neq 0$ when $V_{o\text{-}peak} = 0$

Class AB Amplifier Biasing



A straightforward biasing approach: *D1* and *D2* are diode-connected transistors identical to *QN* and *QP*, respectively.

They form mirrors with the quiescent currents I_Q set by matched R's:

$$I_Q = \frac{2V_{CC} - 1.4}{2R} = \frac{V_{CC} - 0.7}{R}$$

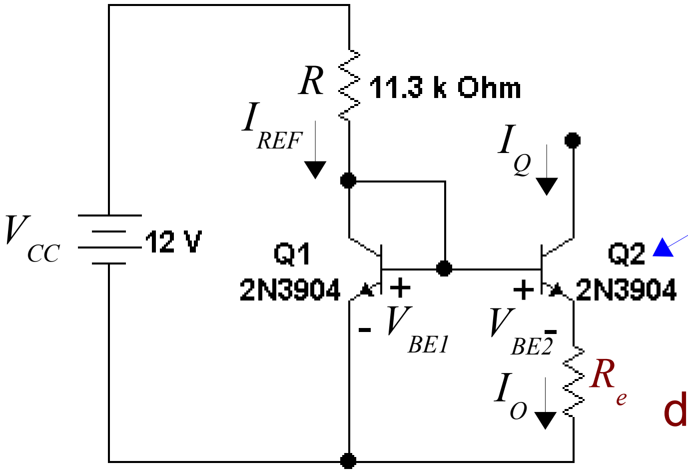
or:

$$R = \frac{V_{CC} - 0.7}{I_Q}$$

Recall: With mirrors, the ambient temperature for all transistors needs to be matched!

Widlar Current Source

I_N = bias current for Class AB amplifier NPN



$I_Q = I_N$

Q2 = QN

emitter degeneration

$$V_{BE1} = V_T \, ln\left(\frac{I_{REF}}{I_S}\right)$$

$$V_{BE2} = V_T \, ln\left(\frac{I_Q}{I_S}\right)$$

$$V_{BE1} - V_{BE2} = V_T \ln\left(\frac{I_{REF}}{\cancel{I_S}} \frac{\cancel{I_S}}{I_Q}\right) = V_T \ln\left(\frac{I_{REF}}{I_Q}\right)$$

$$I_{REF} = \frac{V_{CC} - V_{BE1}}{R} = \frac{12\,V - 0.7\,V}{11.3\,k\,\Omega} = 1\,mA$$

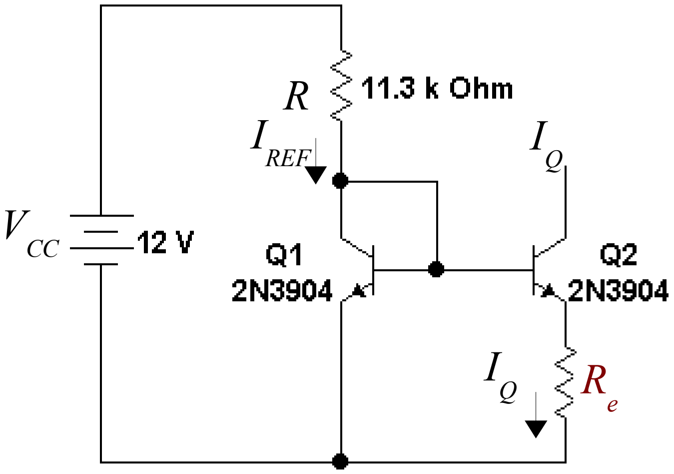
$$V_{BE1} = V_{BE2} + I_Q R_e$$

$$\boxed{I_Q R_e = V_T \, ln\left(\frac{I_{REF}}{I_Q}\right)}$$

Note: Pages 543-546 in Sedra & Smith Text.

Note $R_e > 0$ iff $I_Q < I_{REF}$

Widlar Current Source - cont.



$$I_Q R_e = V_T \, ln\left(\frac{I_{REF}}{I_Q}\right)$$

If R_e specified and I_{REF} chosen by the designer:

$$I_Q = \frac{V_T}{R_e}\left(ln\left(I_{REF}\right) - ln\left(I_Q\right)\right)$$

Solve for I_Q graphically.

If I_Q specified and I_{REF} chosen by designer:

$$R_e = \frac{V_T}{I_Q} ln\left(\frac{I_{REF}}{I_Q}\right)$$

Example Let $I_Q = 10\ \mu A$ & choose $I_{REF} = 10\ mA$, determine R and R_e:

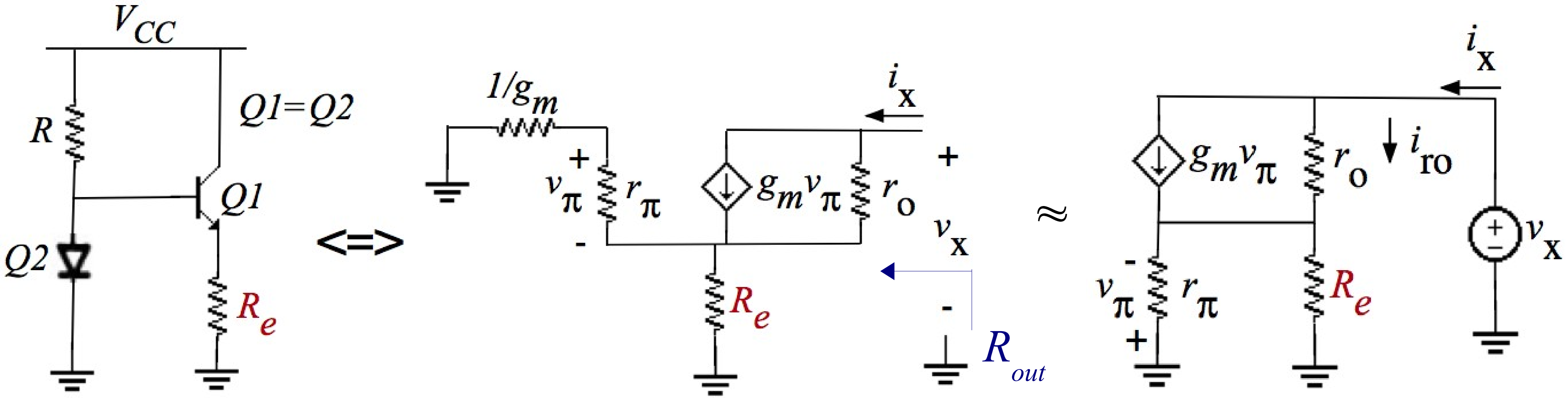
$$R = \frac{V_{CC} - V_{BE1}}{I_{REF}} = \frac{12\,V - 0.7\,V}{10\,mA} = 1.13\,k\,\Omega$$

$$R_e = \frac{V_T}{I_Q} ln\left(\frac{I_{REF}}{I_Q}\right) = \frac{0.025\,V}{10\,\mu\,A} ln\left(\frac{10\,m\,A}{10\,\mu\,A}\right)$$

$$= 2500 \ln(1000) = 17.27\,k\,\Omega$$

$$\boxed{R = 1.13\,k\,\Omega \quad R_e = 17.27\,k\,\Omega}$$

Widlar Current Mirror Small-Signal Analysis



$$r_\pi \gg 1/g_m$$

$$i_x = g_m v_\pi + i_{ro} = g_m v_\pi + \frac{v_x - (-v_\pi)}{r_o}$$

$$v_\pi = -r_\pi \| R_e i_x$$

$$i_x = -g_m r_\pi \| R_e i_x + \frac{v_x}{r_o} - \frac{r_\pi \| R_e i_x}{r_o}$$

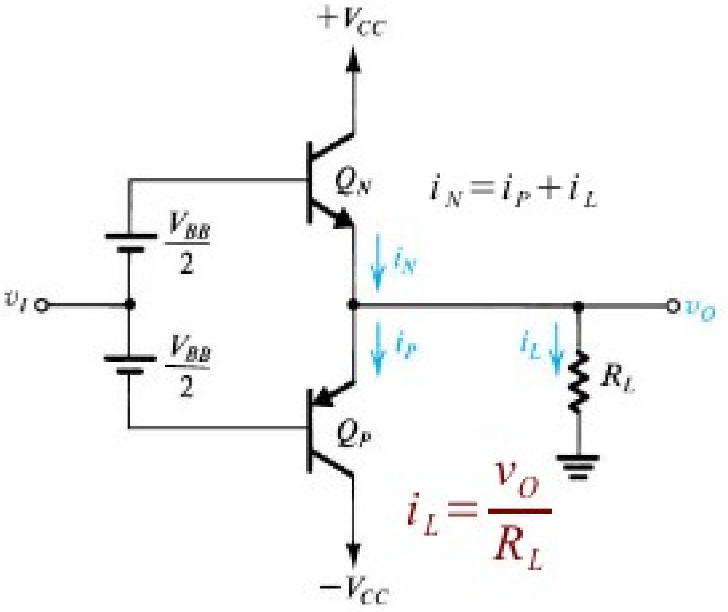
$$\approx -g_m r_\pi \| R_e i_x + \frac{v_x}{r_o}$$

R_{out} is greatly enhanced by adding emitter degeneration.

$$\boxed{\Rightarrow R_{out} = \frac{v_x}{i_x} = r_o\left(1 + g_m\left(R_e \| r_\pi\right)\right)}$$

$$g_m\left(R_e \| r_\pi\right) \gg 1$$

Quick Review

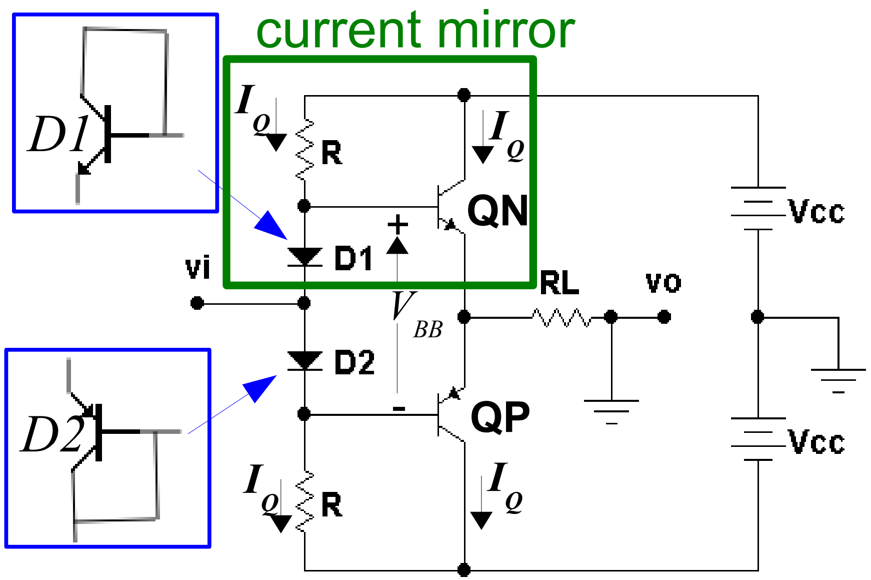


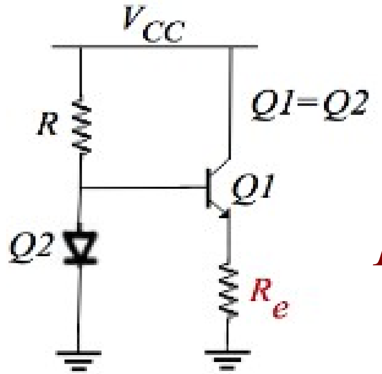
$$i_N = i_P + i_L$$

$$i_L = \frac{v_O}{R_L}$$

$$i_L = i_N - i_P$$

$$\boxed{v_{BEN} + v_{EBP} = V_{BB} \quad \Rightarrow \quad i_N i_P = I_Q^2}$$





Widlar Current Mirror

$$R_e = \frac{V_T}{I_Q} \ln\left(\frac{I_{REF}}{I_Q}\right)$$

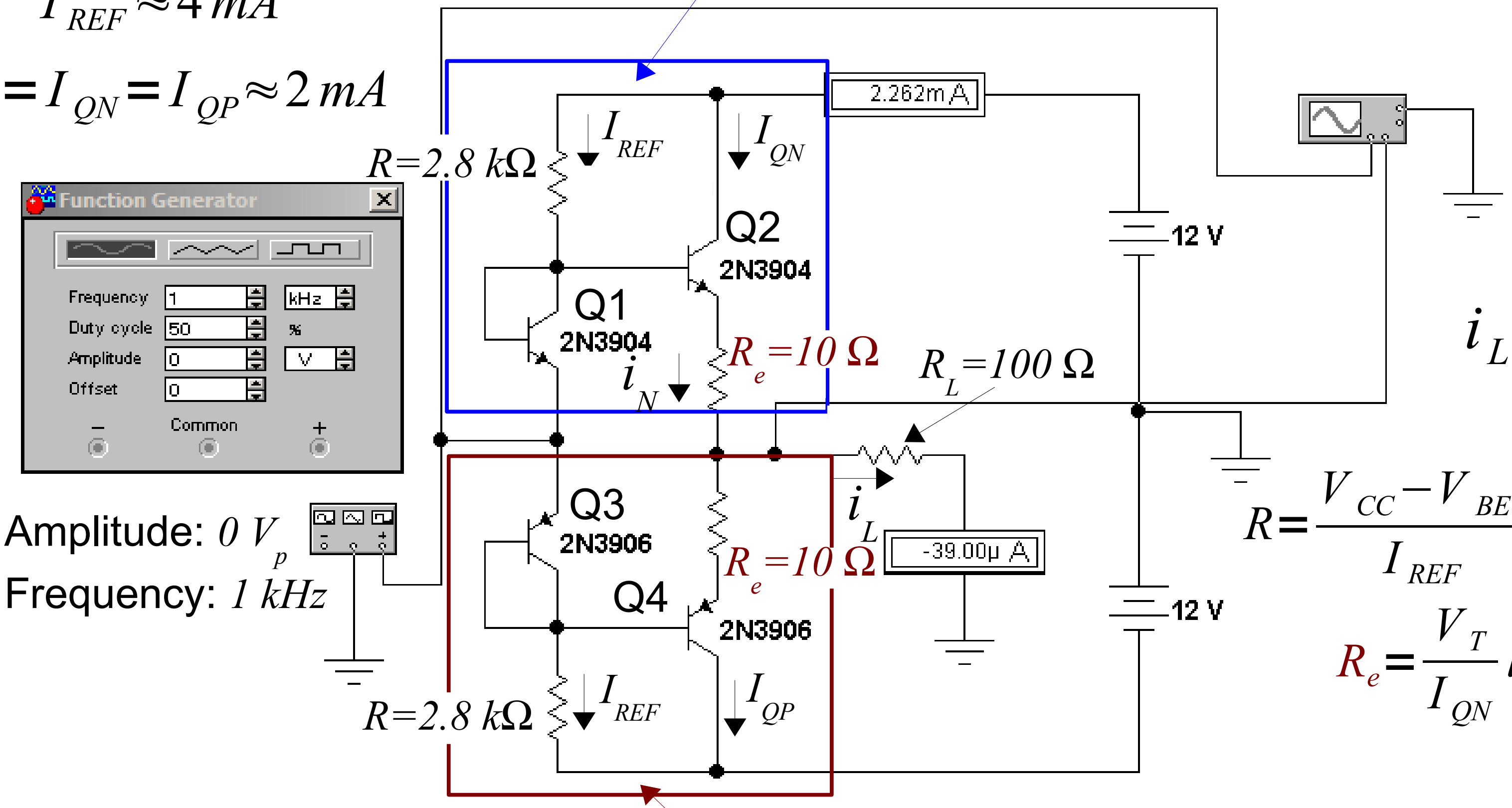
Class AB Current Biasing Simulation

Bias currents set at I_{REF} and I_Q by R and emitter resistor(s) R_e.

$$I_{REF} \approx 4\,mA$$

$$I_Q = I_{QN} = I_{QP} \approx 2\,mA$$

NPN Widlar current mirror



Frequency: 1 kHz
Duty cycle: 50 %
Amplitude: 0 V
Offset: 0

PNP Widlar current mirror

Amplitude: $0\ V_p$

Frequency: $1\ kHz$

$$i_L = i_N - i_P$$

$$R = \frac{V_{CC} - V_{BE1}}{I_{REF}} = \frac{V_{CC} - V_{EB3}}{I_{REF}} \approx 2.8\,k\,\Omega$$

$$R_e = \frac{V_T}{I_{QN}} ln\left(\frac{I_{REF}}{I_{QN}}\right) \approx 10\,\Omega$$

Conclusions

ADVANTAGE:

Class AB operation improves on Class B linearity.
Power conversion efficiency similar to Class B

DISADVANTAGES:

1. Emitter resistors absorb output power.
2. Power dissipation for low signal levels higher than Class B.
3. Temperature matching will be needed – more so. if emitter degeneration resistors are not used.