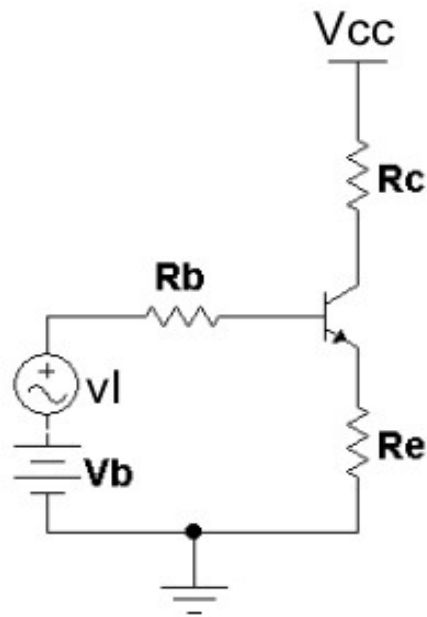




Class B Output Stage

- Class B Operation
- Multisim Simulations
- Class B Power Efficiency

Class B Amplifier Operation



Transistor cut off ($i_C = 0$) if:

$$v_I + V_B < 0.7 V$$

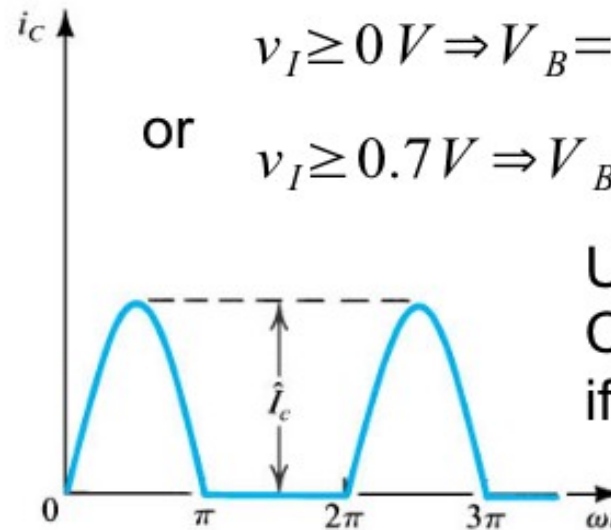
Class B – Amplifier BJT conducts for positive-half of v_I cycle.

Amp conducts for all v_I s.t.:

$$v_I \geq 0 V \Rightarrow V_B = 0.7 V$$

or

$$v_I \geq 0.7 V \Rightarrow V_B = 0 V$$



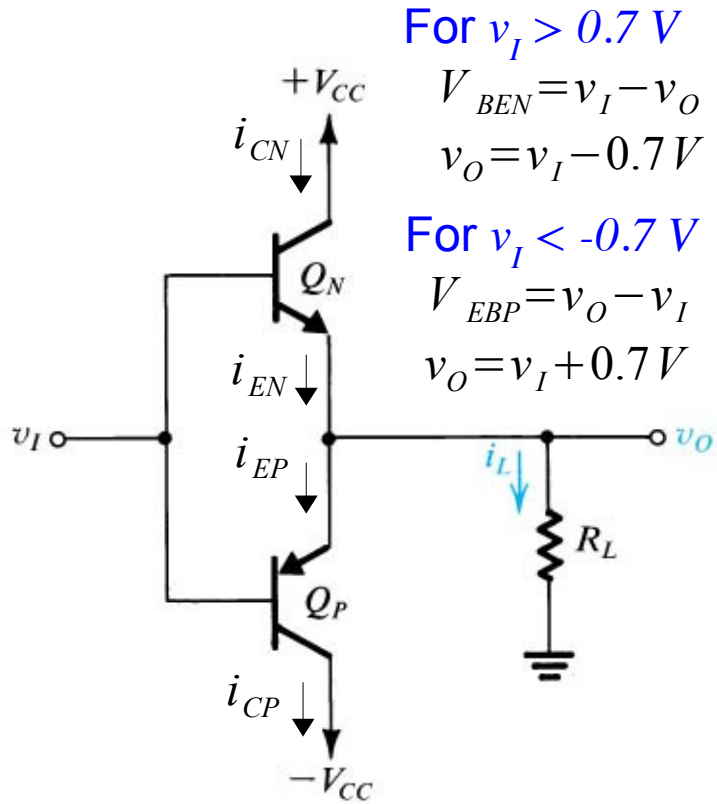
Usually assume Class B operation if $V_B = 0 V$.

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

2. a 2nd class B BJT is needed to conduct for the negative v_I cycle.



The Class B Output Stage



For $v_I > 0.7 V$

$$V_{BEN} = v_I - v_O$$

$$v_O = v_I - 0.7 V$$

For $v_I < -0.7 V$

$$V_{EBP} = v_O - v_I$$

$$v_O = v_I + 0.7 V$$

0. For $v_I = 0 V$, Q_N and Q_P cutoff.

$$v_O = 0 V$$

I. For $v_I > V_{BEN} = 0.7 V$, $Q_N = ON$, $Q_P = OFF$.

a. $i_L = i_{EN} \approx i_{CN}$

b. Q_N saturates if $v_O > V_{CC} - V_{CE-sat}$.

c. Q_P is cut off for $v_I > -0.7 V$.

The output voltage v_O follows the input v_I , less the $Q_N V_{BE}$ drop, up to Q_N saturation.

II. For $v_I < V_{BEP} = -0.7 V$, $Q_P = ON$, $Q_N = OFF$.

a. $i_L = -i_{EP} \approx -i_{CP}$

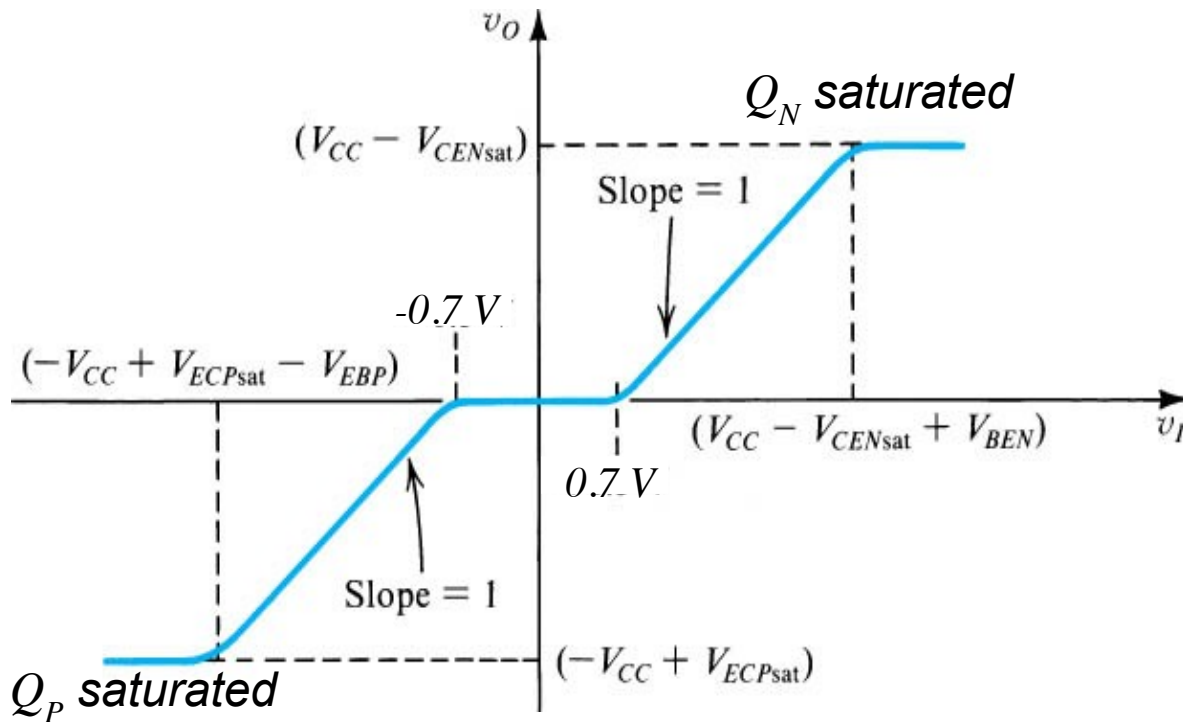
b. Q_P saturates if $v_O < -V_{CC} + V_{CE-sat}$

c. Q_N is cut off for $v_I < 0.7 V$.

The output voltage v_O follows the input v_I , plus the $Q_P V_{EB}$ drop, down to Q_P saturation.



Class B Amplifier VTC Plot



$$v_o = v_i - 0.7V$$

For:

$$0.7V < v_i < (V_{CC} - V_{CENsat}) + 0.7V$$

$$v_o = 0V$$

For:

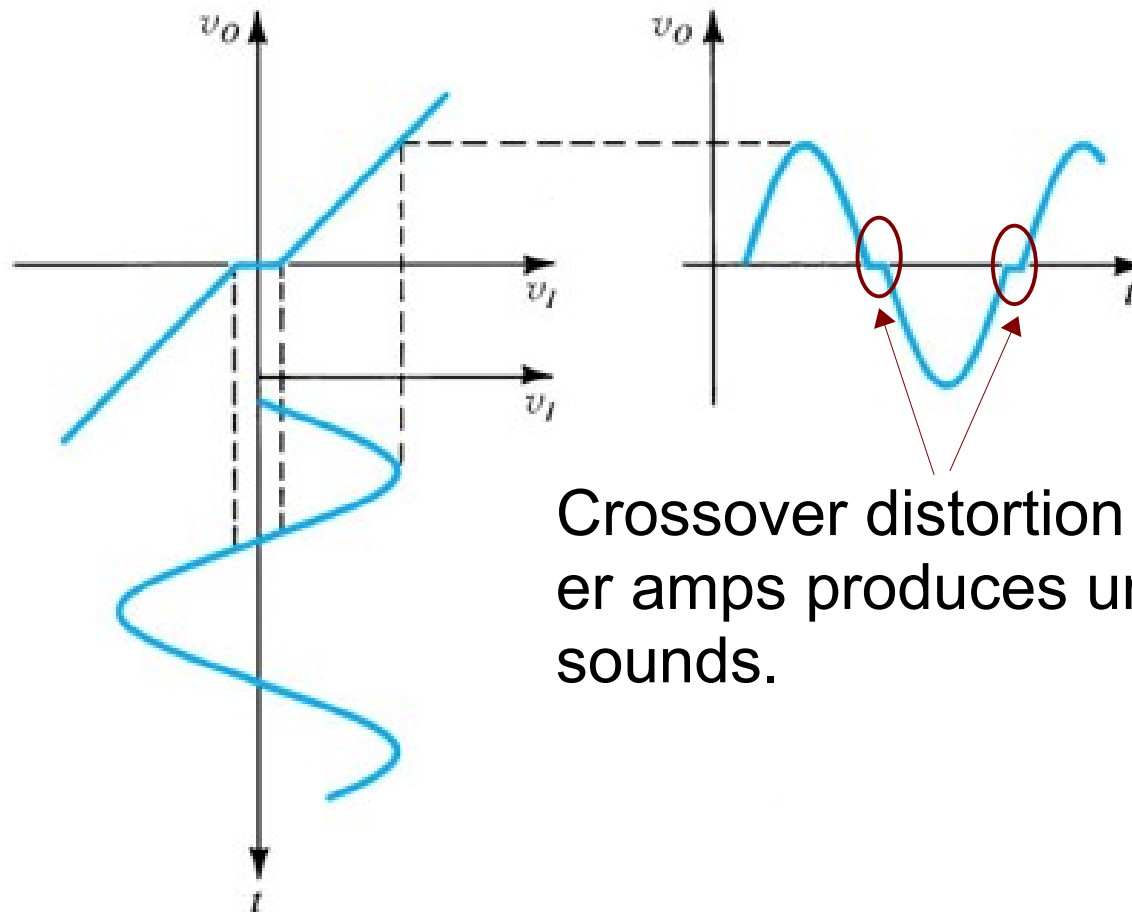
$$-0.7V < v_i < 0.7V$$

$$v_o = v_i + 0.7V$$

For:

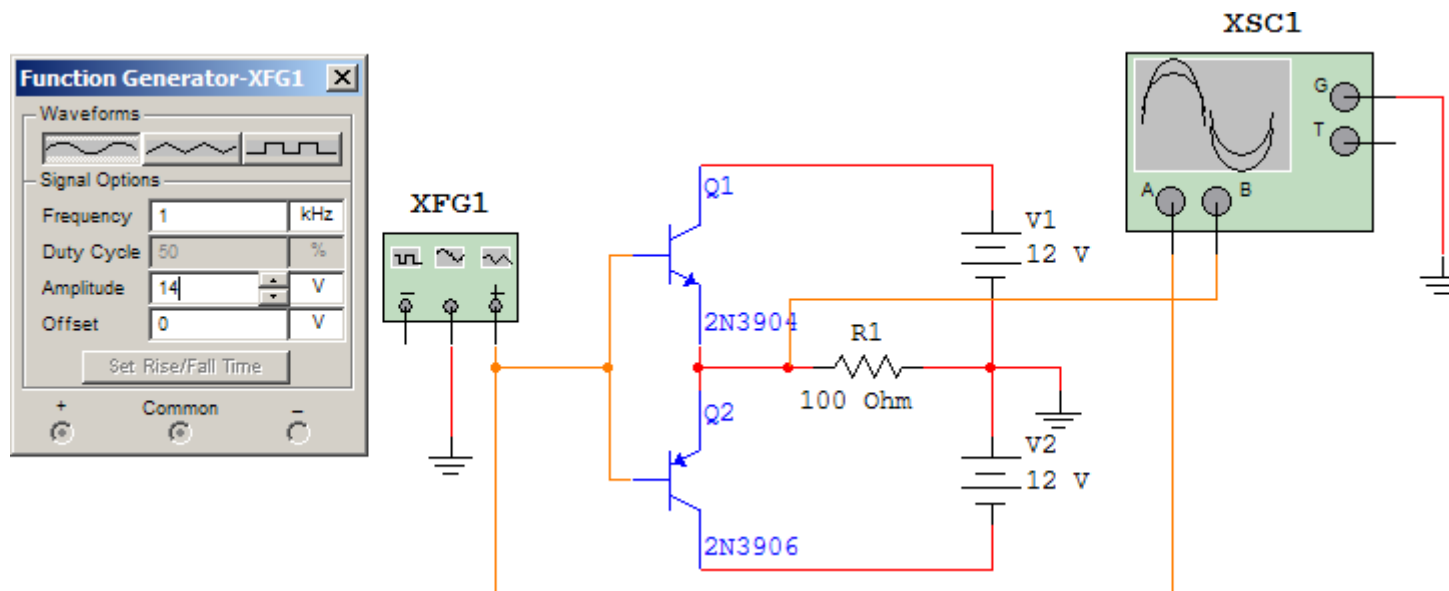
$$-(V_{CC} - V_{ECPsat}) - 0.7V < v_i < -0.7V$$

Class B Crossover Distortion

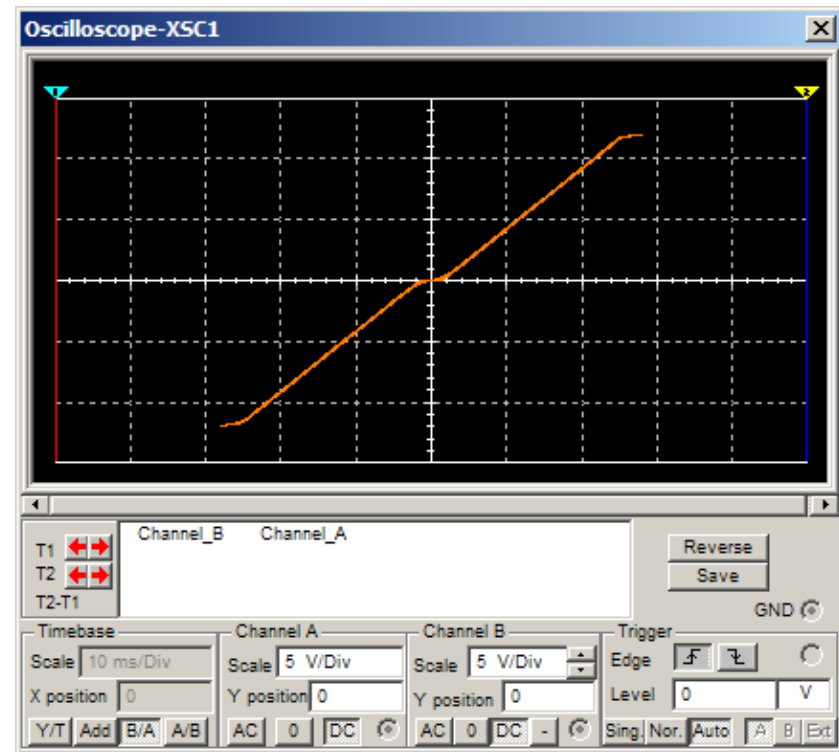
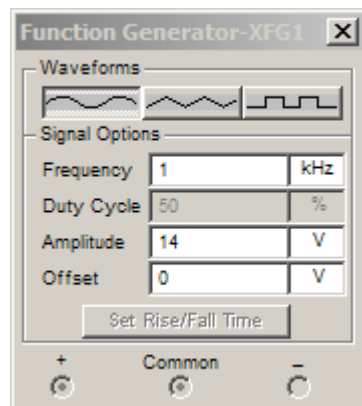


Crossover distortion in audio power amps produces unpleasant sounds.

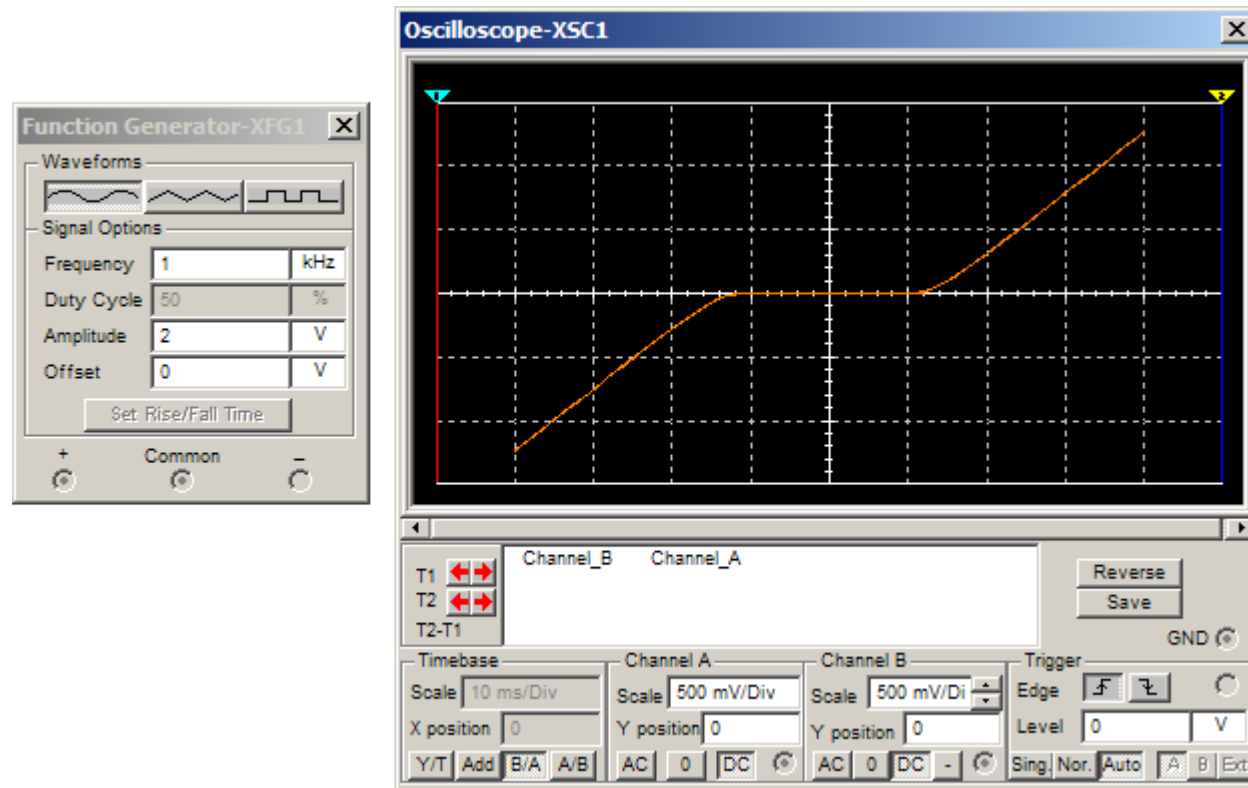
Multisim Simulation Class B VTC



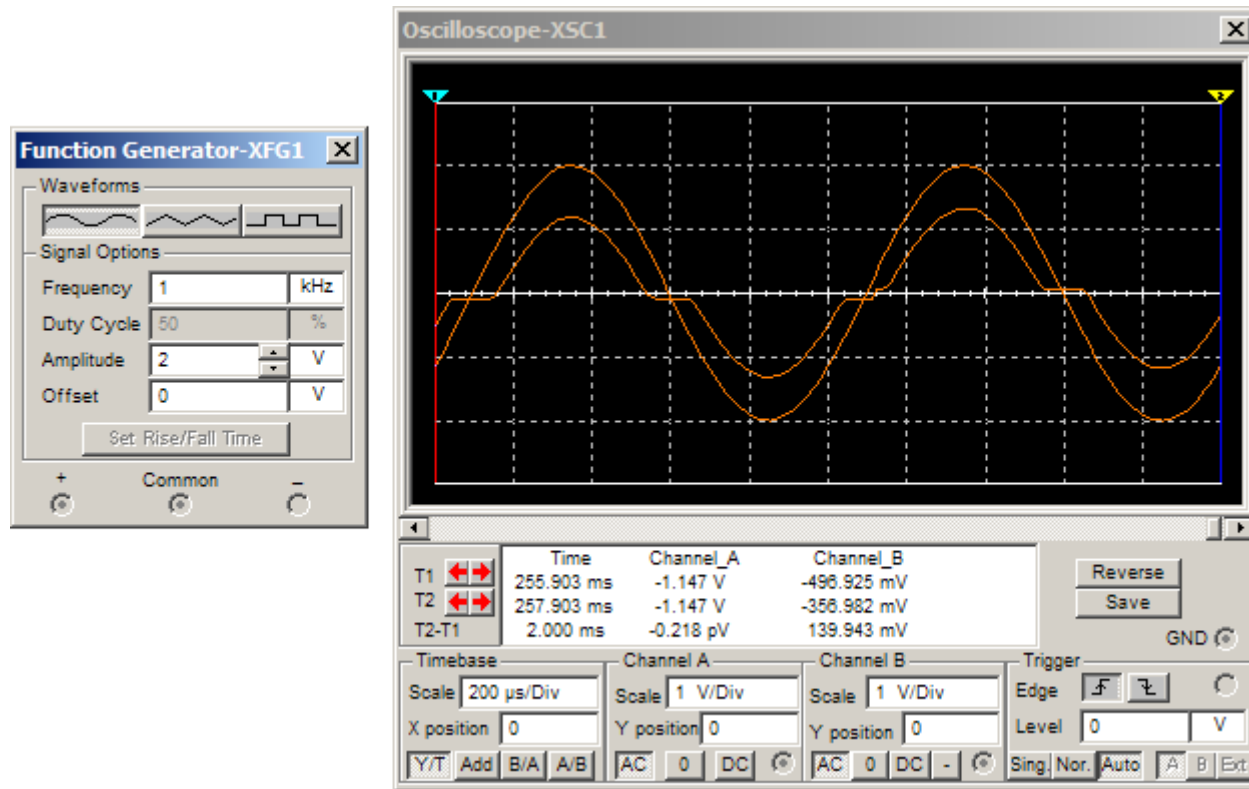
Multisim Simulation Class B VTC - cont.



Multisim Simulation Class B VTC - cont.



Multisim Simulation Class B Crossover Distortion



The “dead band” from $V_{BEP} = 0.7\text{ V} < v_i < V_{BEN} = 0.7\text{ V}$ causes **crossover distortion**. This distortion is severe, particularly for low voltage signals.

Class B Power Analysis

Simplifying Assumptions:

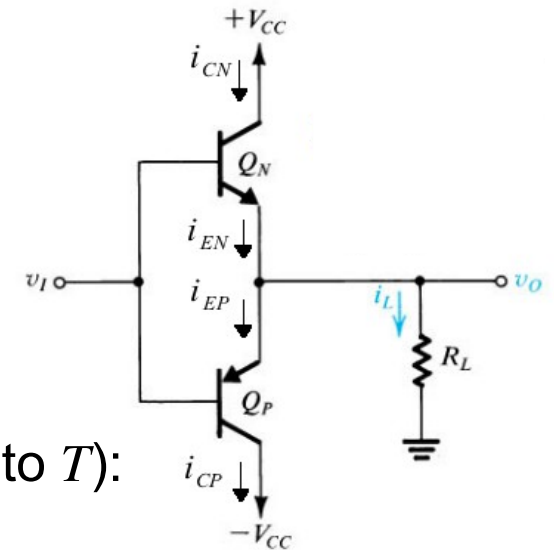
1. Ignore the dead-zone in v_o .
2. Let $v_{CEN-sat} = v_{ECP-sat} = 0\text{ V} \Rightarrow$ maximum v_o swing is $-V_{CC} \leq v_o \leq V_{CC}$

The average power to the load resistor:

$$P_{L-av} = V_{o-rms} I_{o-rms} = \frac{V_{o-rms}^2}{R_L} = \frac{1}{2} \frac{V_{o-peak}^2}{R_L}$$

The average power delivered by the positive $+V_{CC}$ power supply over the positive half-cycle (current is zero from $T/2$ to T):

$$P_{DP-av} = \frac{1}{T} \int_0^{\frac{T}{2}} V_{CC} i_{CN} dt = \frac{1}{T} \int_0^{\frac{T}{2}} V_{CC} i_L dt = \frac{1}{T} \int_0^{\frac{T}{2}} V_{CC} \frac{V_{o-peak}}{R_L} \sin\left(\frac{2\pi}{T}t\right) dt$$



Class B Power Analysis - cont.

$$P_{DP-av} = \frac{1}{T} V_{CC} \frac{V_{o-peak}}{R_L} \int_0^{\frac{T}{2}} \sin\left(\frac{2\pi}{T}t\right) dt$$

Recalling from calculus $\int \sin(ax) dx = \frac{-1}{a} \cos(ax)$

$$P_{DP-av} = \frac{1}{T} V_{CC} \frac{V_{o-peak}}{R_L} \left(\frac{-T}{2\pi} \cos\left(\frac{2\pi}{T}t\right) \right) \Big|_{t=0}^{t=T/2}$$

$$P_{DP-av} = -\frac{1}{2\pi} \frac{V_{o-peak}}{R_L} V_{CC} \left\{ \cos\left(\frac{2}{T}\pi \frac{T}{2}\right) - \cos\left(\frac{2}{T}\pi 0\right) \right\}$$

$$P_{DP-av} = -\frac{1}{2\pi} \frac{V_{o-peak}}{R_L} V_{CC} \left\{ \overset{-1}{\cos(\pi)} - \overset{1}{\cos(0)} \right\}$$

$$P_{DP-av} = \frac{1}{\pi} \frac{V_{o-peak}}{R_L} V_{CC}$$

Class B Power Analysis - cont.

Power delivered by the negative $-V_{CC}$ power source is equal to that for $+V_{CC}$:

$$P_{DN-av} = P_{DP-av} = \frac{1}{\pi} \frac{V_{o-peak}}{R_L} V_{CC}$$

Hence:

$$P_{D-av} = P_{DP-av} + P_{DN-av} = \frac{2}{\pi} \frac{V_{o-peak}}{R_L} V_{CC}$$

The power conversion efficiency of the class B amplifier (accurate for $|V_{o-peak}| > 0.7 V$) is:

$$\eta = \frac{P_{L-av}}{P_{D-av}} = \frac{\frac{1}{2} \frac{V_{o-peak}^2}{R_L}}{\frac{2}{\pi} \frac{V_{o-peak}}{R_L} V_{CC}} = \frac{\pi}{4} \frac{V_{o-peak}}{V_{CC}}$$

Class B Power Analysis - cont.

Maximum Class B power conversion efficiency:

Since we assume $-V_{CC} \leq v_o \leq V_{CC}$

$$\eta = \frac{\pi}{4} \frac{V_{o-peak}}{V_{CC}} \Rightarrow \eta_{max} = \frac{\pi}{4} = 0.785 \text{ or } 78.5 \%$$

Recall for Class A: $\eta_{max} = 0.25$ or 25 %

Power Dissipation:

Class B power dissipated in the transistors:

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

Class B Power Analysis - cont.

Note that the power dissipation goes to zero as V_{o-peak} approaches zero (More precisely, it's zero if V_{o-peak} is less than $0.7 V$):

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

To estimate maximum P_{Disp} : set derivative of P_{Disp} w.r.t. V_{o-peak} to zero, i.e.

$$\frac{dP_{Disp}}{dV_{o-peak}} = \frac{2}{\pi} \frac{V_{CC}}{R_L} - \frac{V_{o-peak}}{R_L} = 0 \quad \Rightarrow \quad V_{o-peak} = \frac{2}{\pi} V_{CC} < V_{CC}$$

$$P_{Disp(max)} = \frac{4}{\pi^2} \frac{V_{CC}^2}{R_L} - \frac{1}{2} \frac{4}{\pi^2} \frac{V_{CC}^2}{R_L} = \frac{2}{\pi^2} \frac{V_{CC}^2}{R_L}$$

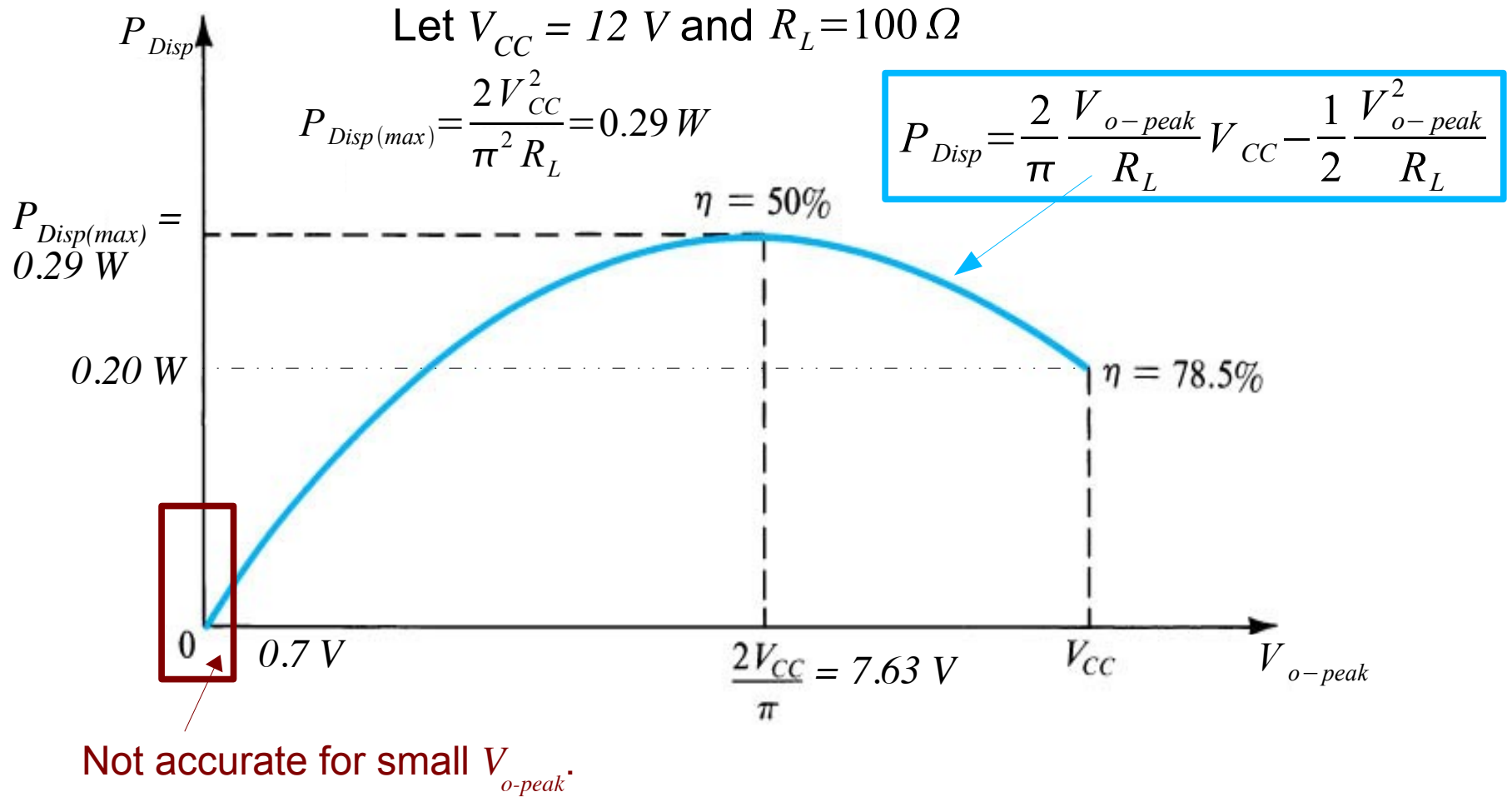
$\frac{1}{2} P_{Disp(max)}$ is dissipated in Q_N and $\frac{1}{2} P_{Disp(max)}$ is dissipated in Q_P .

Class B Power Analysis Summary

Power from sources:	$P_{D-av} = \frac{2}{\pi} \frac{V_{o-peak}}{R_L} V_{CC}$	$P_{D-av(max)} = \frac{2}{\pi} \frac{V_{CC}^2}{R_L}$
Power output to load:	$P_{L-av} = \frac{1}{2} \frac{V_{o-peak}^2}{R_L}$	$P_{L-av(max)} = \frac{1}{2} \frac{V_{CC}^2}{R_L}$
Power Conversion Efficiency:	$\eta = \frac{\pi}{4} \frac{V_{o-peak}}{V_{CC}}$	$\eta_{max} = \frac{\pi}{4} \approx 0.785$
Transistor dissipation $Q_N + Q_P$:	$P_{Disp} = \frac{2}{\pi} \frac{V_{o-peak}}{R_L} V_{CC} - \frac{1}{2} \frac{V_{o-peak}^2}{R_L}$	$P_{Disp(max)} = \frac{2}{\pi^2} \frac{V_{CC}^2}{R_L}$
Max dissipation at:	$V_{o-peak} = \frac{2}{\pi} V_{CC}$	$\eta_{max-Disp} = 0.5$



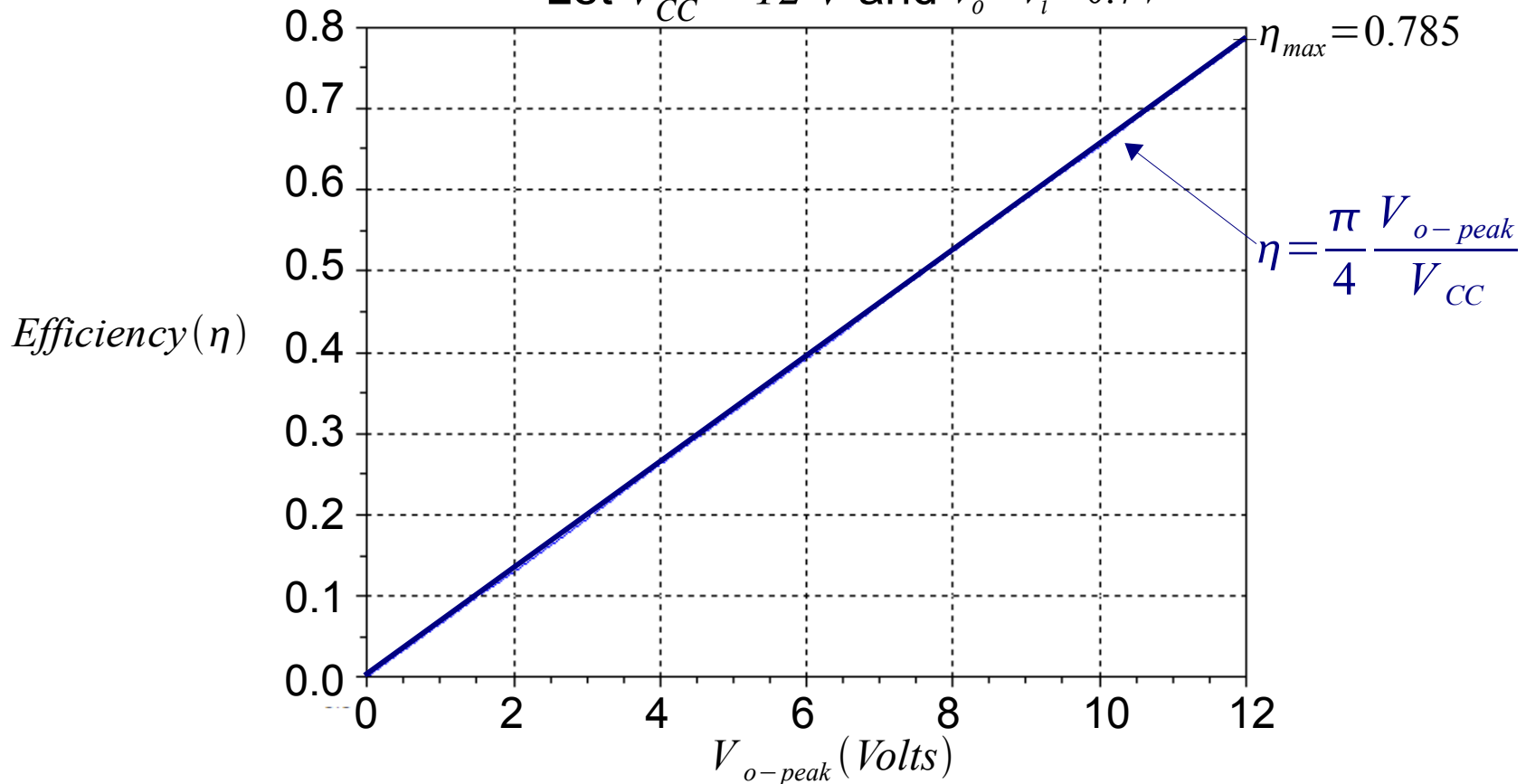
Power Dissipation Function Plot





Power Conversion Efficiency vs. Output Voltage Amplitude

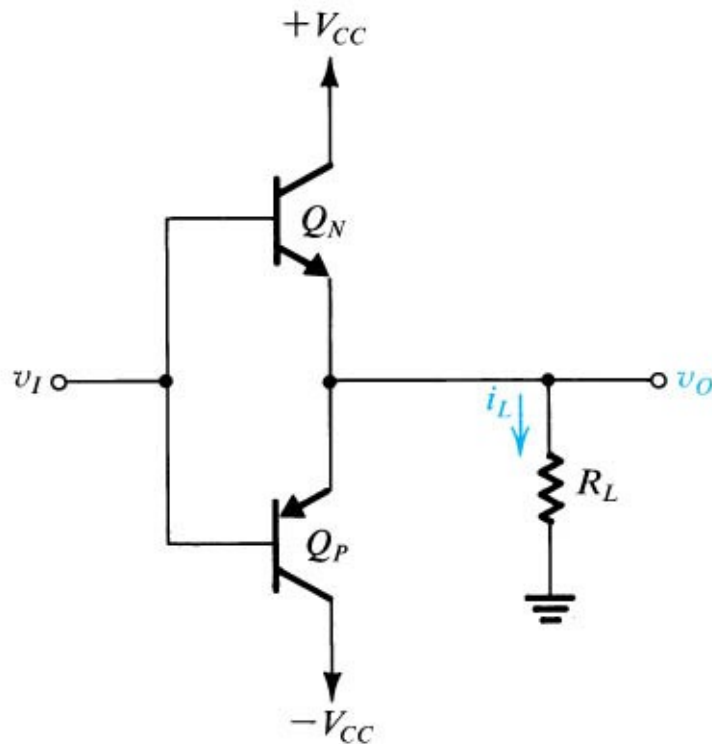
Let $V_{CC} = 12\text{ V}$ and $v_o = v_i - 0.7\text{ V}$



Class B Audio Amplifier Example

It is required to design a Class B output stage to deliver an average power of 20 W to an $8\ \Omega$ speaker load.

To avoid saturation of the transistors and non-linear distortion, the power supply V_{CC} is to be 5 V greater than peak output voltage.



1. Determine the V_{CC} required.
2. Determine peak current drawn from each power supply.
3. Determine the total power drawn from the power supplies.
4. Determine the power conversion efficiency.
5. Determine the max power each transistor must be able to dissipate safely.

Class B Audio Amplifier Example - cont.

SOLUTION:

1. Determine the V_{CC} required.

$$P_{L-av} = 20 W \text{ and } R_L = 8 \Omega$$

$$P_{L-av} = \frac{1}{2} \frac{V_{o-peak}^2}{R_L} = 20 W \Rightarrow V_{o-peak} = \sqrt{2 P_{L-av} R_L} = \sqrt{2 * 20 * 8} = 17.9 V$$

$$V_{CC} = V_{o-peak} + 5 V = 17.9 V + 5 V = \boxed{23 V}$$

2. Determine peak current drawn from each power supply.

$$I_{o-peak} = \frac{V_{o-peak}}{R_L} = \frac{17.9 V}{8 \Omega} = \boxed{2.24 A}$$

Class B Audio Amplifier Example - cont.

SOLUTION cont.:

3. Determine the total power drawn from the power supplies.

$$P_{D-av} = \frac{2}{\pi} \frac{V_{o-peak}}{R_L} V_{CC} = \frac{2}{\pi} \frac{17.9 V}{8 \Omega} 23 V = \boxed{32.8 W}$$

4. Determine the power conversion efficiency.

$$\eta = \frac{\pi}{4} \frac{V_{o-peak}}{V_{CC}} = \frac{\pi}{4} \frac{17.9 V}{23 V} = \boxed{0.61 \text{ or } 61 \%}$$

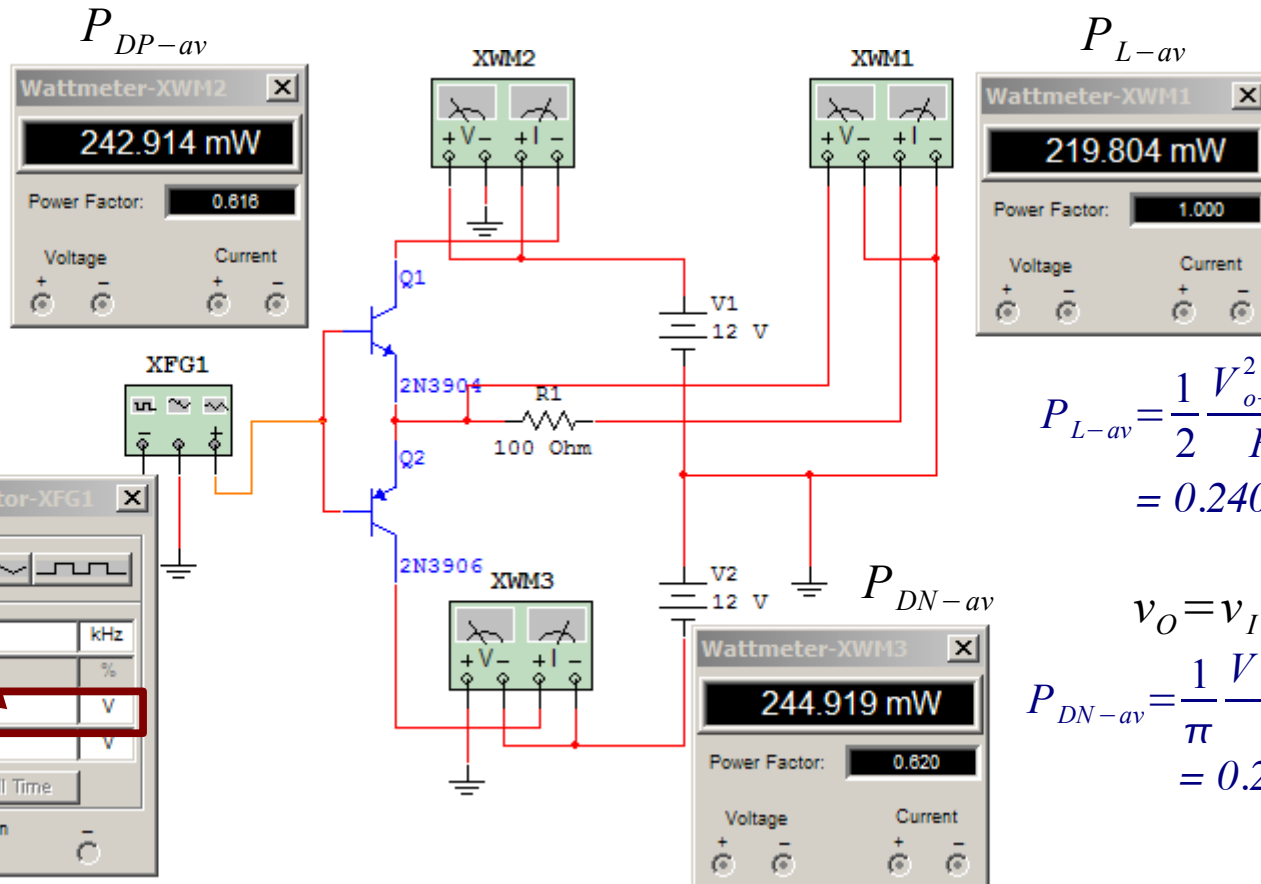
5. Determine the max power each transistor must dissipate safely.

$$P_{DispN(max)} = P_{DispP(max)} = \frac{1}{2} P_{Disp(max)} = \frac{1}{\pi^2} \frac{V_{CC}^2}{R_L} = \frac{1}{\pi^2} \frac{(23 V)^2}{8 \Omega} = \boxed{6.7 W}$$

Multisim Simulation – Max Power Dissipation

$$v_O = v_I - 0.7V$$

$$P_{DP-av} = \frac{1}{\pi} \frac{V_{o-peak}}{R_L} V_{CC} = 0.265 W$$



$$P_{L-av} = \frac{1}{2} \frac{V_{o-peak}^2}{R_L} = 0.240 W$$

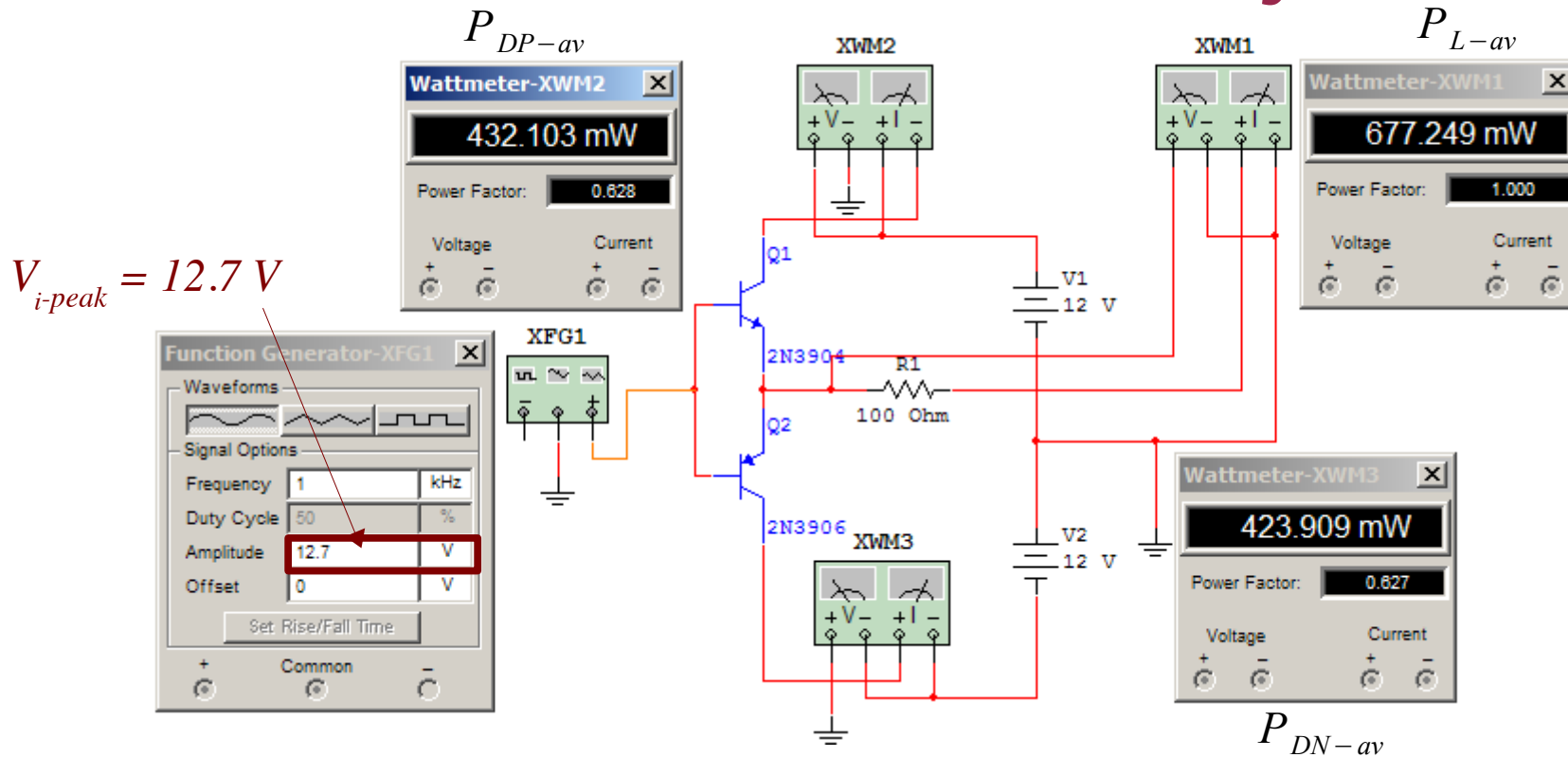
$$v_O = v_I + 0.7V$$

$$P_{DN-av} = \frac{1}{\pi} \frac{V_{o-peak}}{R_L} V_{CC} = 0.265 W$$

$$\eta_{sim} = \frac{P_{L-av}}{P_{DP-av} + P_{DN-av}} = \frac{0.2198}{0.2429 + 0.2449} = 0.45$$

$$\eta_{theory} = \frac{P_{L-av}}{P_{DP-av} + P_{DN-av}} = \frac{0.240}{0.265 + 0.265} = 0.45$$

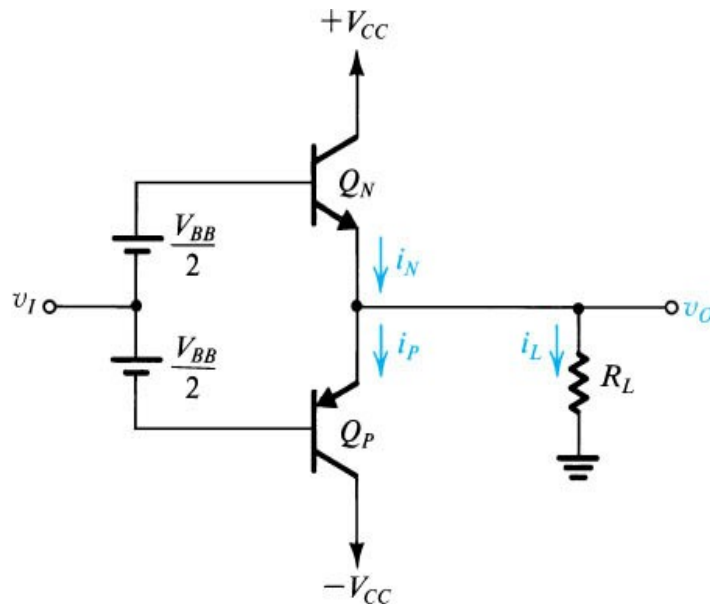
Multisim Simulation – Max Power Conversion Efficiency



$$\eta_{sim} = \frac{P_{L-av}}{P_{DP-av} + P_{DN-av}} = \frac{0.6772}{0.4231 + 0.4239} = 0.79$$

Anticipating Class AB – Eliminating Crossover Distortion

If we bias the bases of the emitter follower pair, we can set both transistors on the verge of conduction – or have them conduct a small bias current with zero signal input:



$$\frac{V_{BB}}{2} \approx 0.7 \text{ V.}$$

Class AB is a compromise between Class A and Class B

Summary

Class B advantages:

1. Much higher power conversion efficiency than class A for large signal amplitudes.
2. Zero power dissipation with zero input.

Class B disadvantage:

Higher distortion than class A, especially at low input amplitudes.

Class AB operation is a compromise mode:

1. Delivering better linearity than class B, with reduced efficiency.
2. Delivering better efficiency than class A, with reduced linearity.