CHAPTER 5

LARGE POWER AMPLIFIERS

Difference between voltage and power amplifier.

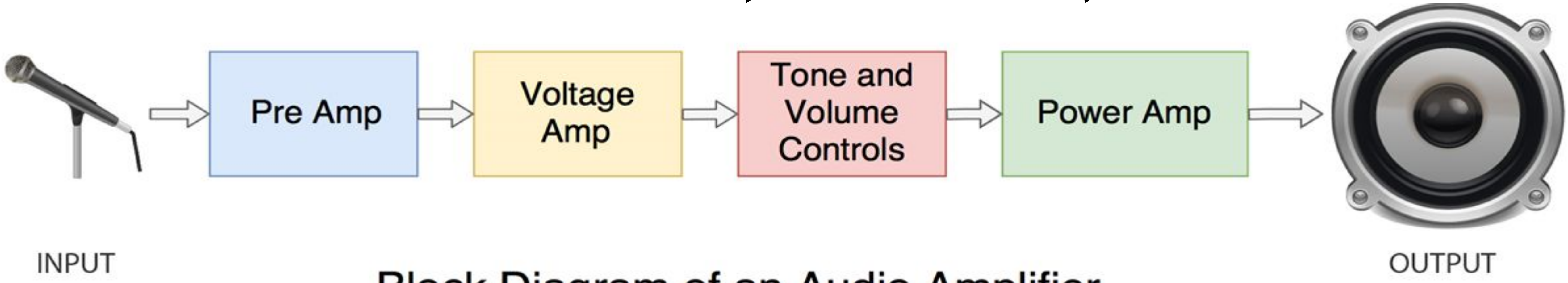
Voltage amplifier

- Voltage amplifier is used to raise voltage level of weak signal.
- No need of heat sink in voltage amplifier.
- Distortion in output will be minimum.
- Size of transistor used is small.
- RC coupling is widely used.
- Used as first stage of amplifier.
- Output impedance is high.

Power amplifier

- Power amplifier is used to raise power level of weak signal.
- Heat sink are used in power amplifier.
- Distortion in output will be minimum.
- Size of power transistor is large.
- Transformer coupling is widely used.
- Used as last stage of amplifier.
- Output impedance is low.

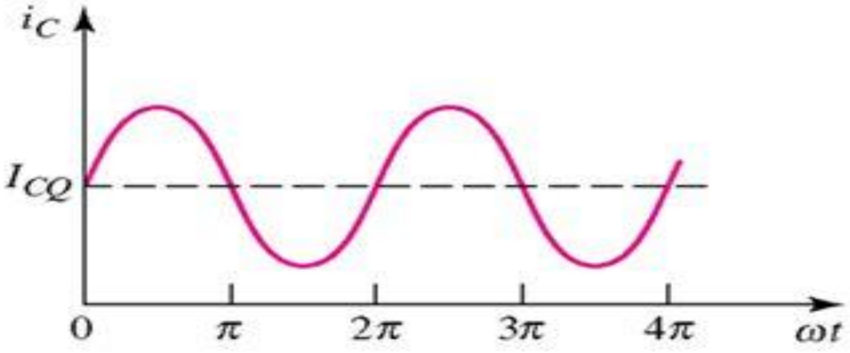
POWER AMPLIFIER



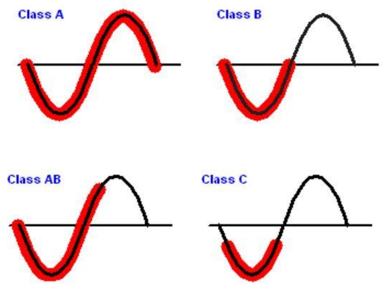
Block Diagram of an Audio Amplifier

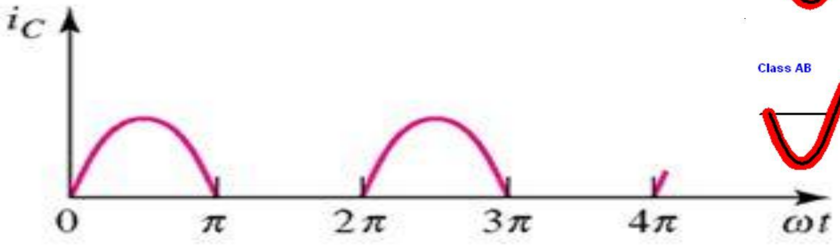
- ✔ A power amplifier is an electronic amplifier designed to increase the magnitude of power of a given input signal.
- ✔ The power of the input signal is increased to a level high enough to drive loads of output devices like speakers, headphones, RF transmitters etc.
- ✔ Unlike voltage/current amplifiers, a power amplifier is designed to drive loads directly and is used as a final block in an amplifier chain.
- ✔ The input signal to a power amplifier needs to be above a certain threshold. So instead of directly passing the raw audio/RF signal to the power amplifier, it is first pre-amplified using current/voltage amplifiers and is sent as input to the power amp after making necessary modifications.

Power Amplifiers Classification

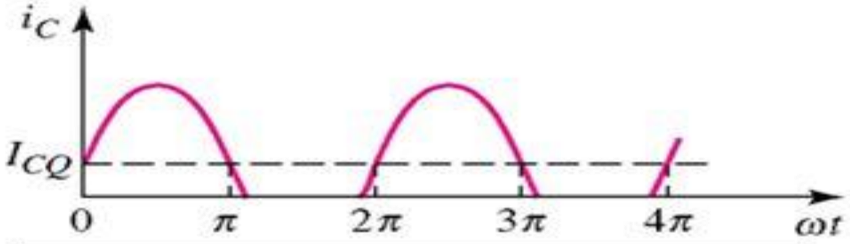


Class A - The transistor conducts during the whole cycle of sinusoidal input signal

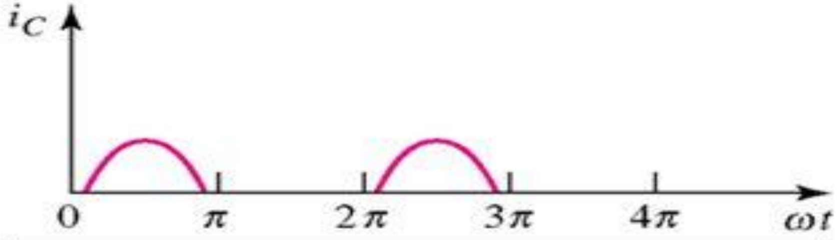




Class B - The transistor conducts during one-half cycle of input signal



Class AB - The transistor conducts for slightly more than half a cycle of input signal

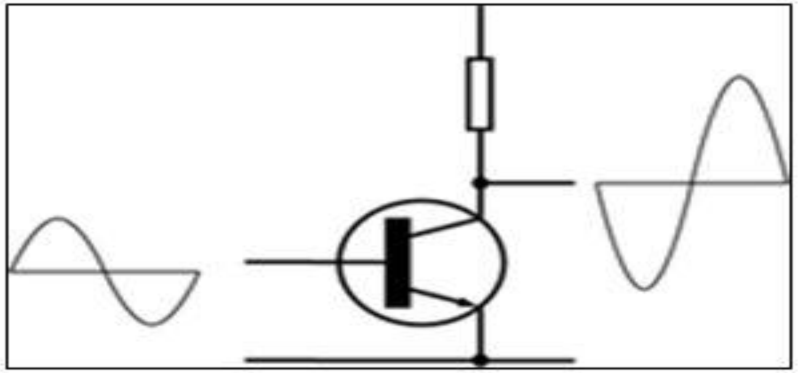


Class C - The transistor conducts for less than half a cycle of input signal

Amplifier classes

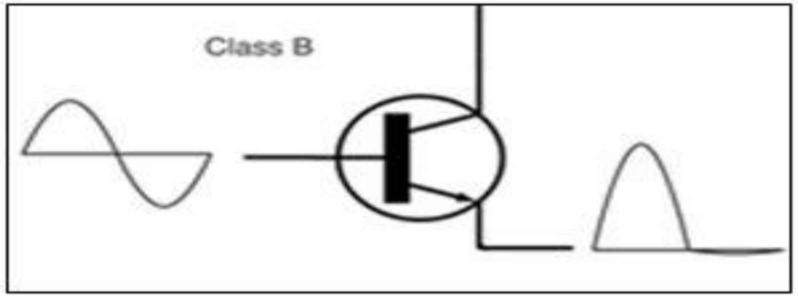
Class A

- *Linear*
- *Bias current*
- *Low efficiency*
- *360 degrees*



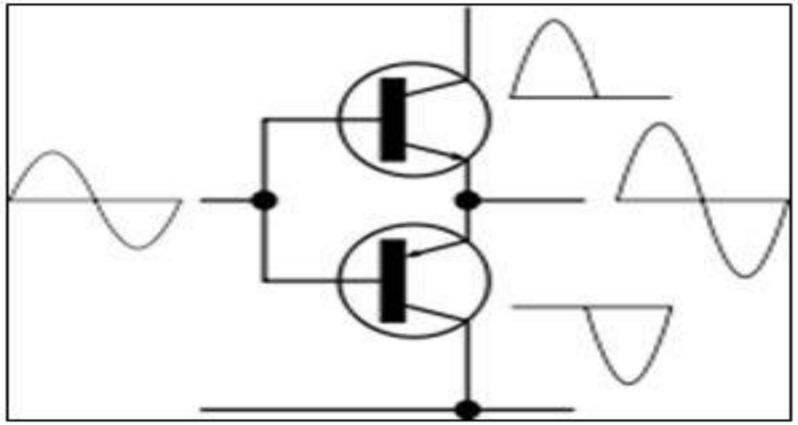
Class B

- *High distortion*
- *Better efficiency*
- *180-360 degrees*



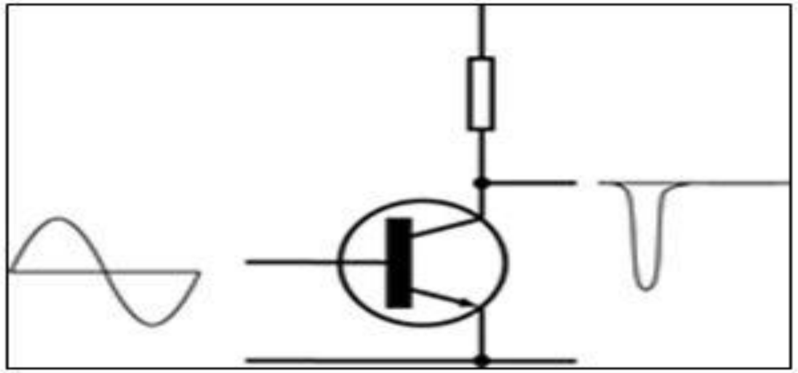
Class AB

- *Linear*
- *Better efficiency*
- *More complex*
- *360 Degrees*



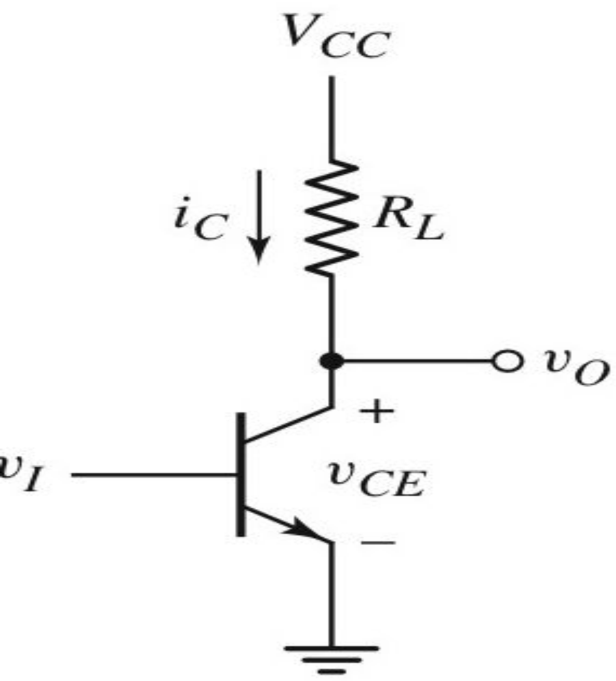
Class C

- *Non-Linear*
- *High efficiency*
- *0-180 degrees*

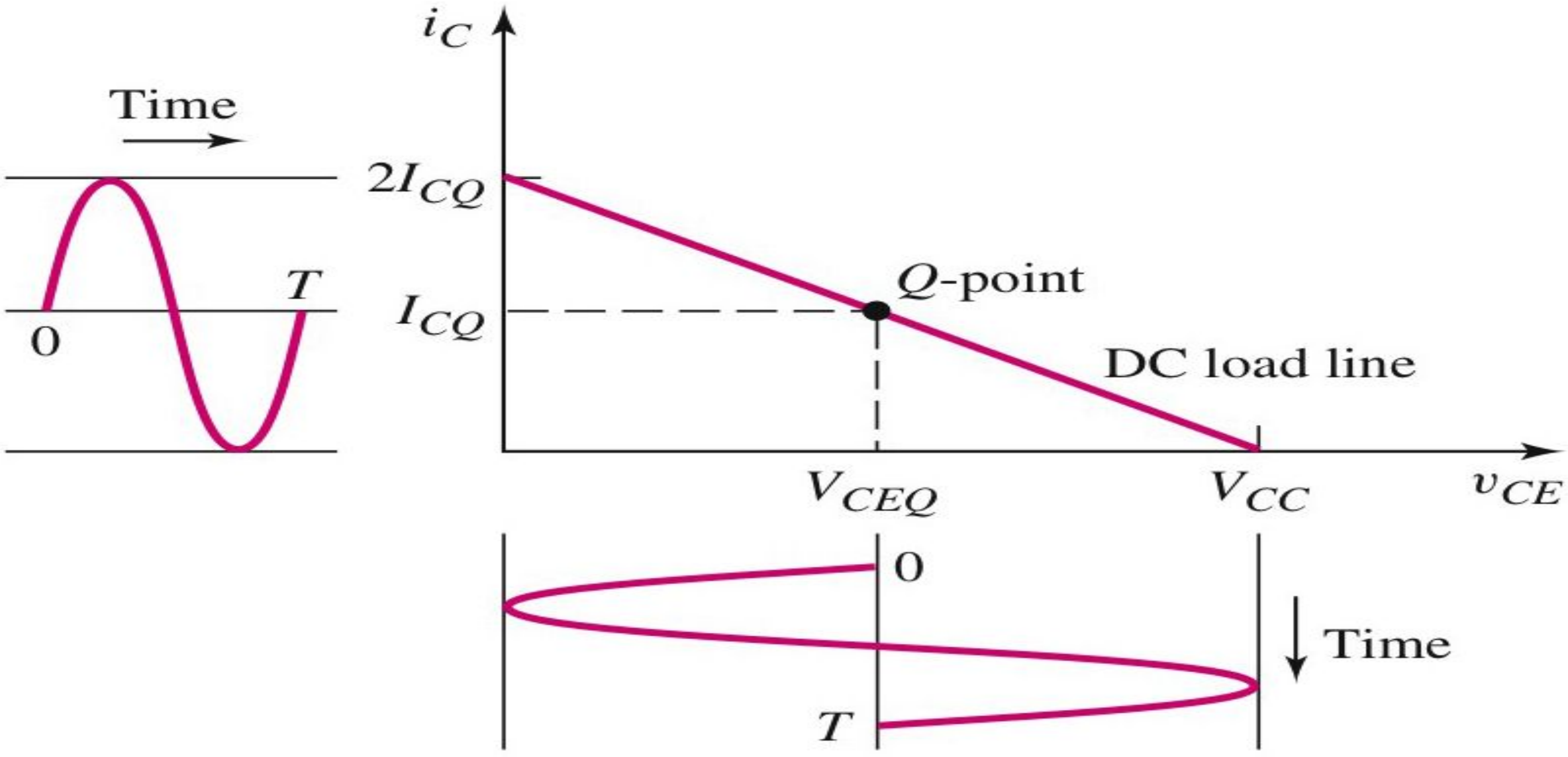


Class–A operation

For maximum swing (+ve and –ve), transistor is biased such that the Q point is at center of the load line.
The transistor conducts for a full cycle of the input signal

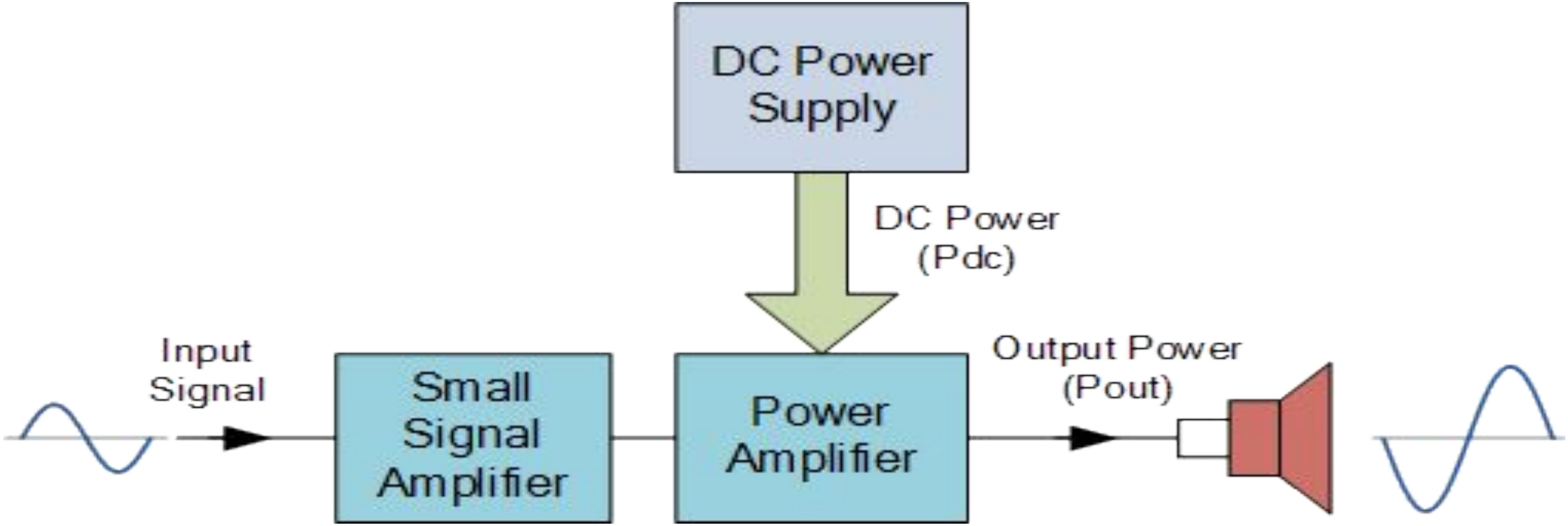


(a)



(b)

POWER AMPLIFIER EFFICIENCY

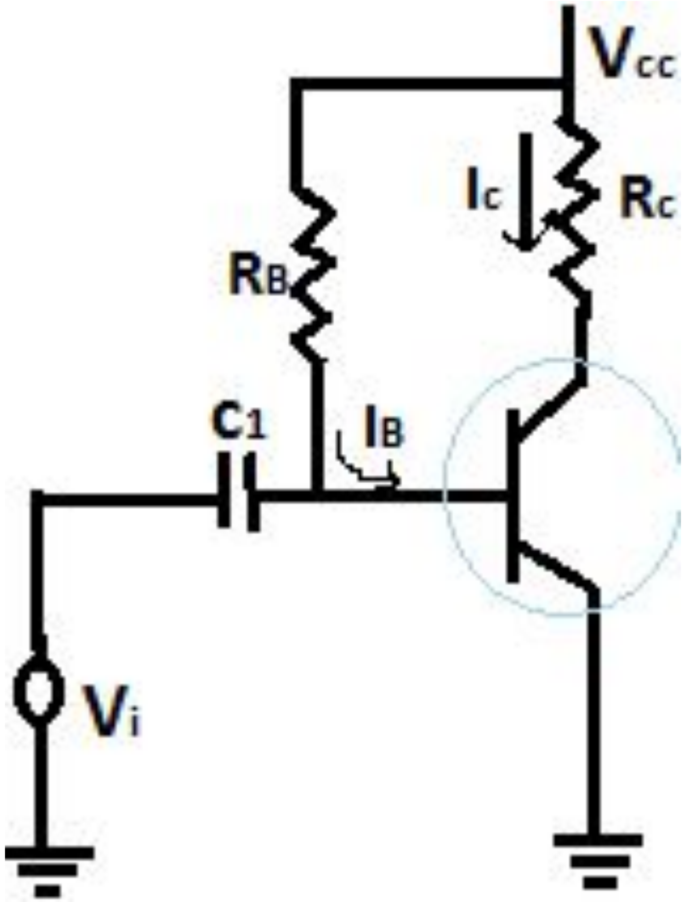


$$\eta\% = \frac{P_{OUT}}{P_{DC}} \times 100$$

Where:

- $\eta\%$ – is the efficiency of the amplifier.
- Pout – is the amplifiers output power delivered to the load.
- Pdc – is the DC power taken from the supply.

SERIES FED CLASS A POWER AMPLIFIER



The dc bias set by Vcc and RB fixes the dc base-bias current at

IB = (Vcc-0.7V)/RB

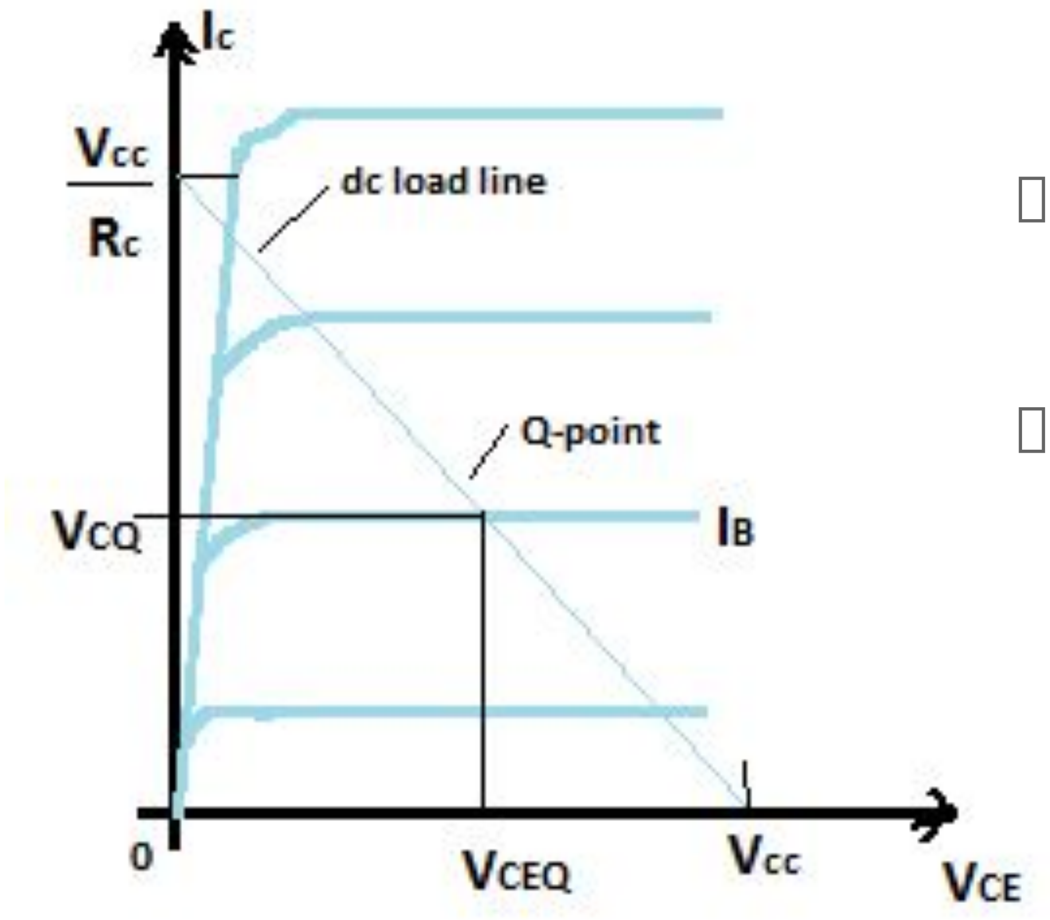
with the collector current then being

Ic =B(beta) IB

with the collector-emitter voltage then

VCE=Vcc -Ic Rc

SERIES FED CLASS A POWER AMPLIFIER



- If the dc bias collector current is set at one-half the possible signal swing (between 0 and Vcc/Rc), the largest collector current swing will be possible.
- Additionally, if the quiescent collector-emitter voltage is set at one-half the supply voltage, the largest voltage swing will be possible.
- With the Q-point set at this optimum bias point, the power considerations for the circuit of Fig. below are determined.

Series Fed Class A Power Amplifier

When an input ac signal is applied to the amplifier of Fig. 16.2, the output will vary from its dc bias operating voltage and current. A small input signal will cause the base current to vary above and below the dc bias point, which will then cause the collector current (output) to vary from the dc bias point set as well as the collector-emitter voltage to vary around its dc bias value.

As the input signal is made larger, the output will vary further around the established dc bias point until either the current or the voltage reaches a limiting condition. For the current, this limiting condition is either zero current at the low end or Vcc/Rc at the high end of its swing. For the collector-emitter voltage, the limit is either 0 V or the supply voltage, Vcc.

POWER EFFICIENCY OF SERIES FED CLASS A PA

The power into an amplifier is provided by the supply. With no input signal, the dc current drawn is the collector bias current, ICQ. The power then drawn from the supply is Pi(dc) = VCC ICQ

The output voltage and curent varying around the bias point provide ac power to the load. This ac power is delivered to the load, RC, in the circuit of Fig. 16.2. The ac signal, Vi, causes the base current to vary around the dc bias current and the collector current around its quiescent level, ICQ.

The ac input signal results in ac current and ac voltage signals. The larger the input signal, the larger the output swing, up to the maximum set by the circuit. The ac power delivered to the load (RC) can be expressed in a number of ways.

POWER EFFICIENCY OF SERIES FED CLASS A PA

Maximum Efficiency:

$$P_{DC} = V_{DC} \cdot I_{DC} = V_{CC} \cdot I_{CQ}$$

$$P_o = \frac{V_{CE}(p)}{\sqrt{2}} \cdot \frac{I_C(p)}{\sqrt{2}} = 0.5\, V_{CE}(p) \cdot I_C(p)$$

$$\eta_{maximum} = \frac{P_o}{P_{DC}} \times 100\%$$

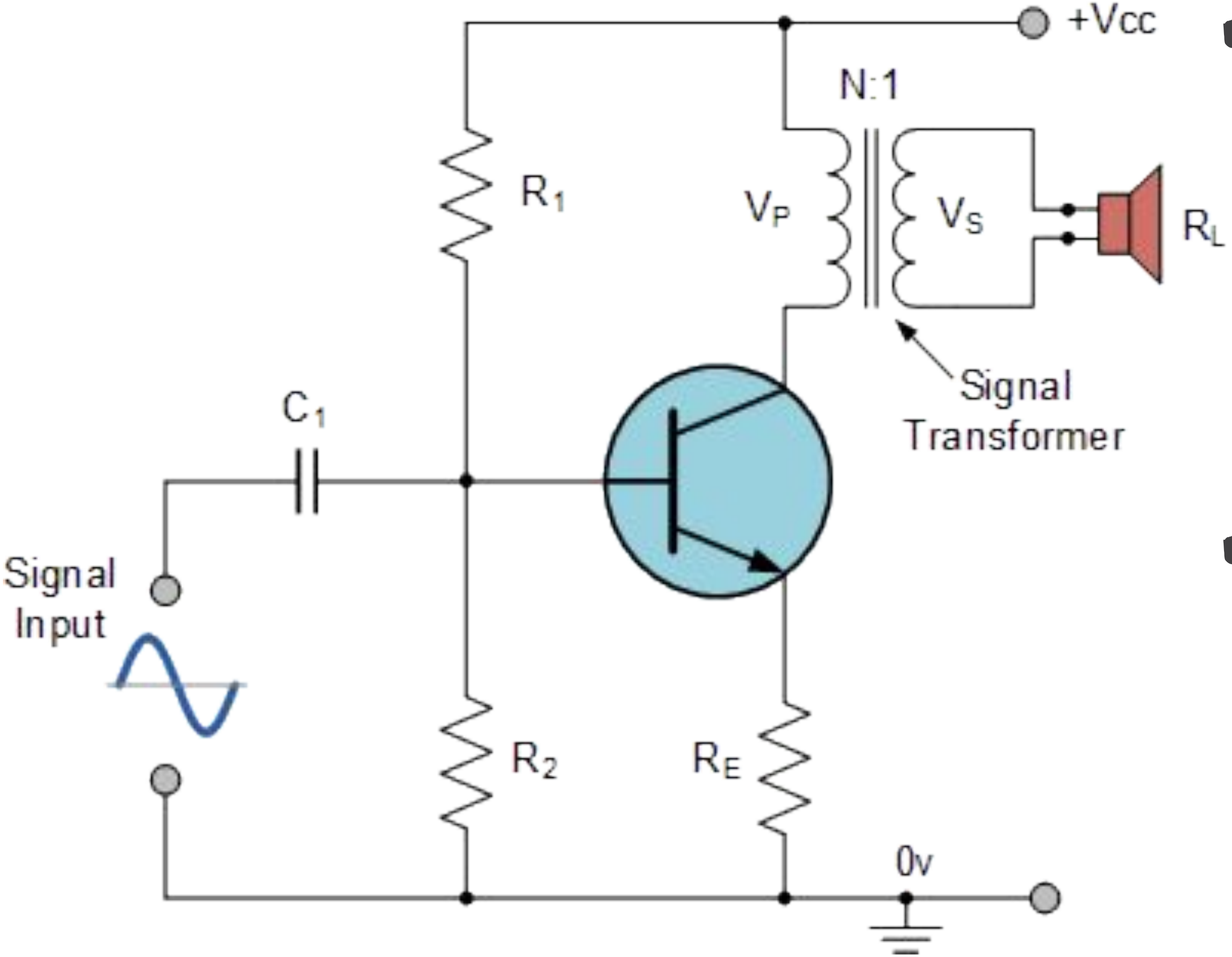
$$= 0.5\, V_{CE}(p) \cdot I_C(p) \times \frac{1}{V_{CC} \cdot I_{CQ}} \times 100\%$$

$$= 0.5\, \frac{V_{CC}}{2} \cdot I_{CQ} \times \frac{1}{V_{CC} \cdot I_{CQ}} \times 100\%$$

$$= 25\%$$

Maximum theoretical efficiency of Series Fed class A amplifier is therefore 25%

TRANSFORMER COUPLED CLASS A POWER AMPLIFIER



- ✔ As the Collector current, Ic is reduced to below the quiescent Q-point set up by the base bias voltage, due to variations in the base current, the magnetic flux in the transformer core collapses causing an induced emf in the transformer primary windings.
- ✔ This causes an instantaneous collector voltage to rise to a value of twice the supply voltage 2Vcc giving a maximum collector current of twice Ic when the Collector voltage is at its minimum.

Efficiency of Transformer Coupled Class A PA

The r.m.s. Collector voltage is given as:

$$V_{CE} = \frac{V_{C(max)} - V_{C(min)}}{2\sqrt{2}} = \frac{2V_{CC} - 0}{2\sqrt{2}}$$

The r.m.s. Collector current is given as:

$$I_{CE} = \frac{I_{C(max)} - I_{C(min)}}{2\sqrt{2}} = \frac{2I_C - 0}{2\sqrt{2}}$$

The r.m.s. Power delivered to the load (Pac) is therefore given as:

$$P_{ac} = V_{CE} \times I_{CE} = \frac{2V_{CC}}{2\sqrt{2}} \times \frac{2I_C}{2\sqrt{2}} = \frac{2V_{CC}\,2I_C}{8}$$

Efficiency of Transformer Coupled Class A PA

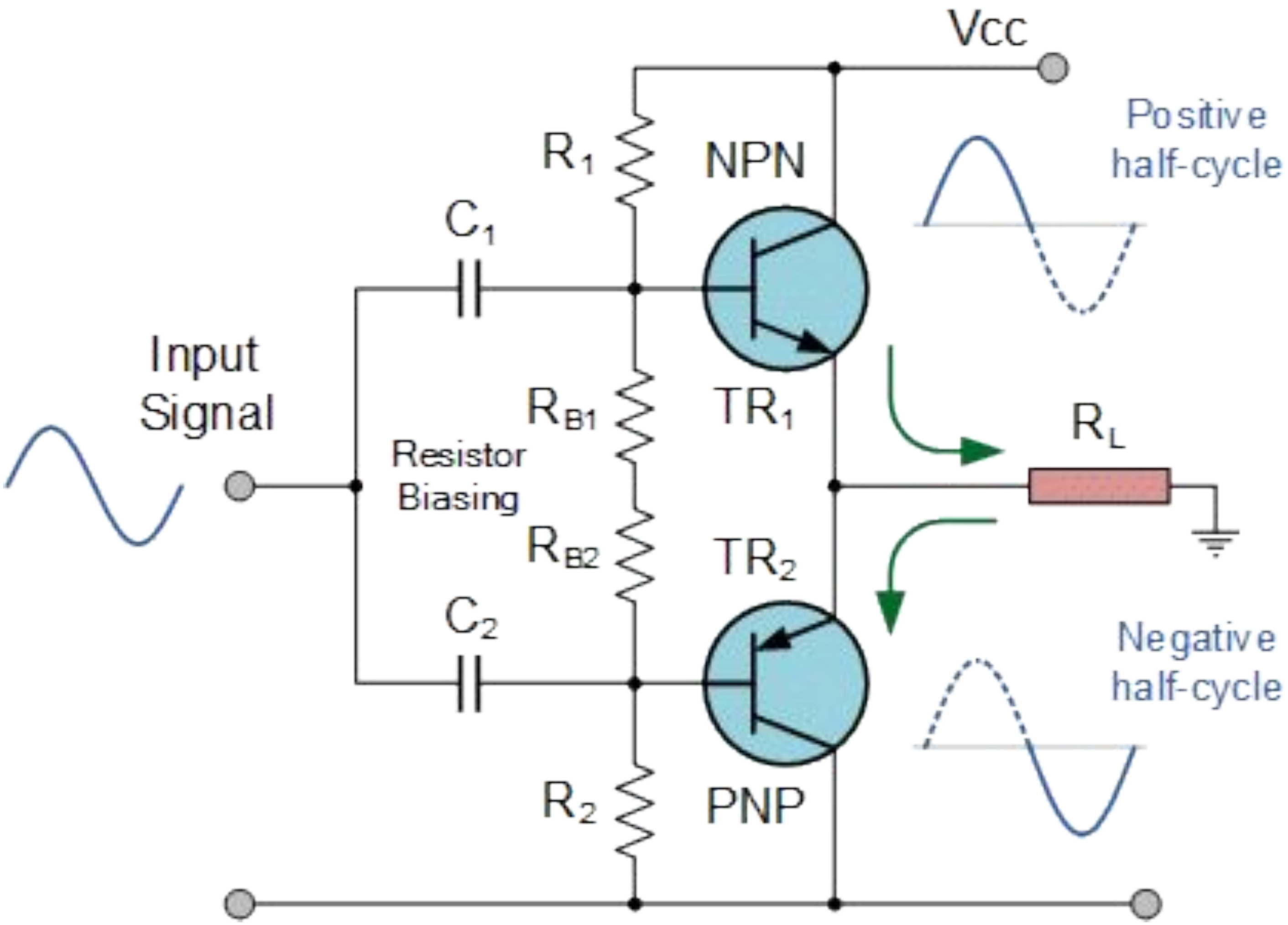
The average power drawn from the supply (Pdc) is given by:

$$P_{dc} = V_{CC} \times I_C$$

and therefore the efficiency of a Transformer-coupled Class A amplifier is given as:

$$\eta_{(max)} = \frac{P_{ac}}{P_{dc}} = \frac{2V_{CC}\,2I_C}{8V_{CC}I_C} \times 100\%$$

Maximum theoretical efficiency of Transformer coupled class A amplifier is therefore 50%


Vcc
Positive half-cycle
R1
NPN
C1
Input Signal
RB1
TR1
RL
Resistor Biasing
RB2
TR2
C2
Negative half-cycle
R2
PNP

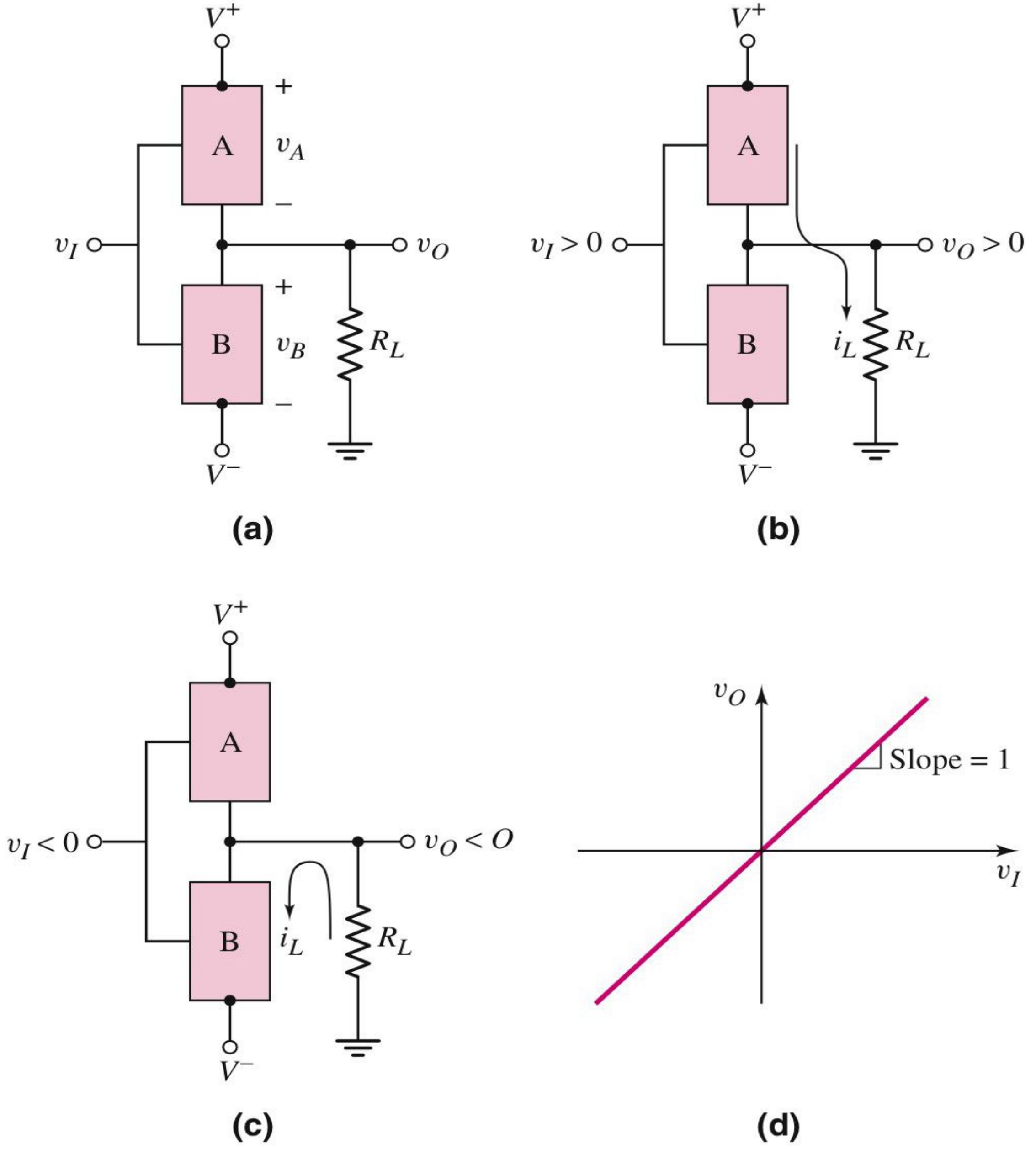
Cass–B operation

Consists of complementary pair electronic devices

One conducts for one half cycle of the input signal and the other conducts for another half of the input signal

Both devices are off when the input is zero

(See Figure)



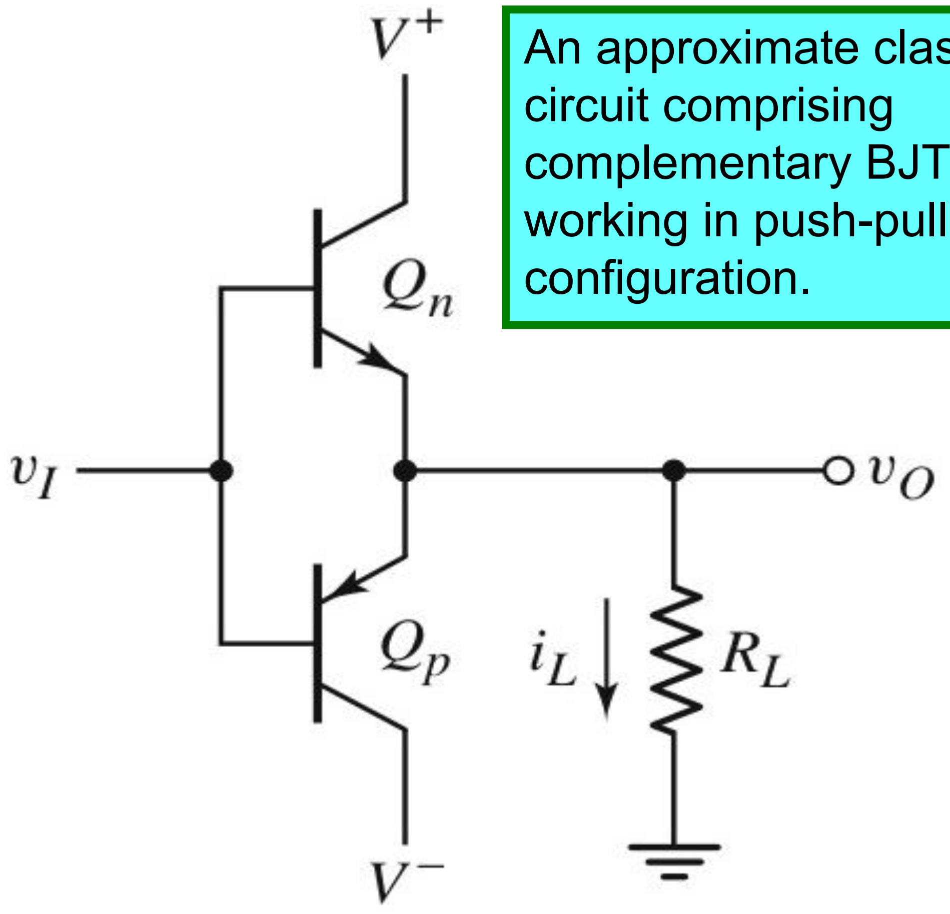
V+
V−
A
B
vA
vB
vI
vO
RL
(a)
vI > 0
vO > 0
iL
(b)
vI < 0
vO < O
(c)
Slope = 1
(d)

Complementary push-pull circuit

Assuming ideal transistor;
when $v_I = 0$;
both Q_n & Q_p are off;

when $v_I > 0$;
Q_n conducts & Q_p is off;

when $v_I < 0$;
Q_p conducts & Q_n is off



An approximate class-B circuit comprising complementary BJT pair working in push-pull configuration.

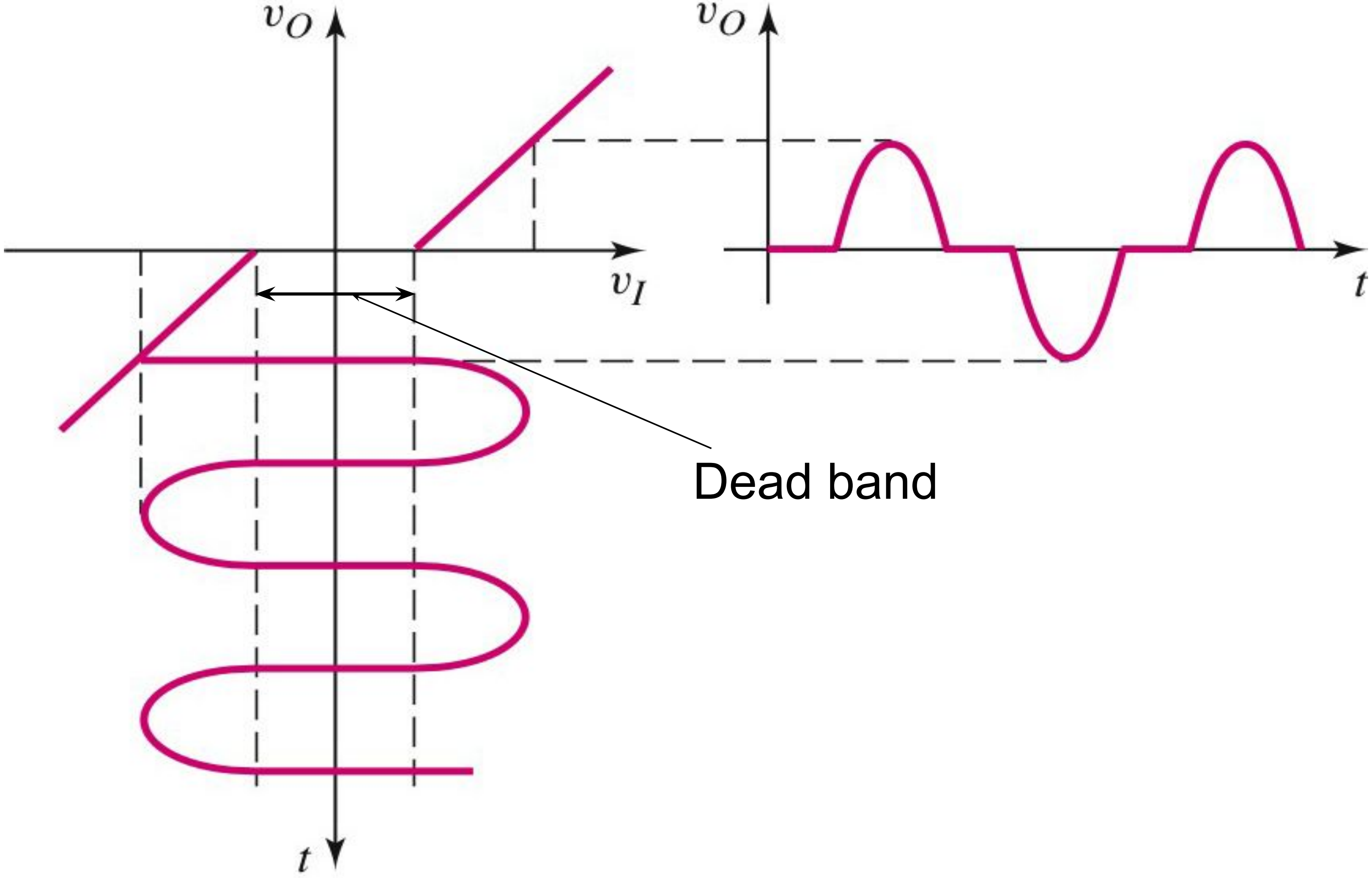
Assuming cut-in voltage of transistor is 0.6 V, v_O = 0 for a range 0.6 V < v_I < 0.6 V.

The transfer characteristic becomes non-linear (See Figure)

The range where both transistors are simultaneously off known as the *dead band*

The output will be distorted – **crossover distortion** (See Figure)

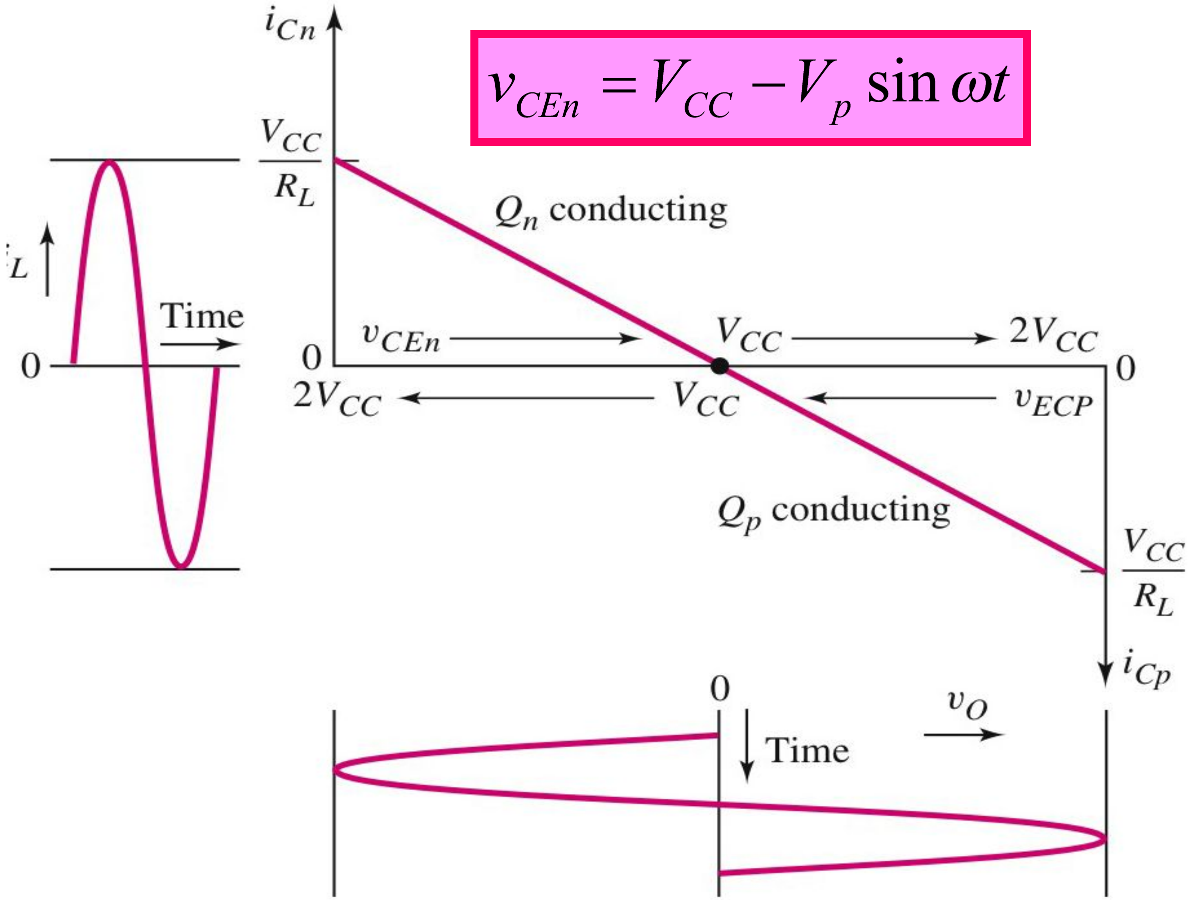
Crossover distortion can be eliminated by biasing the transistor with small quiescent current – class-AB



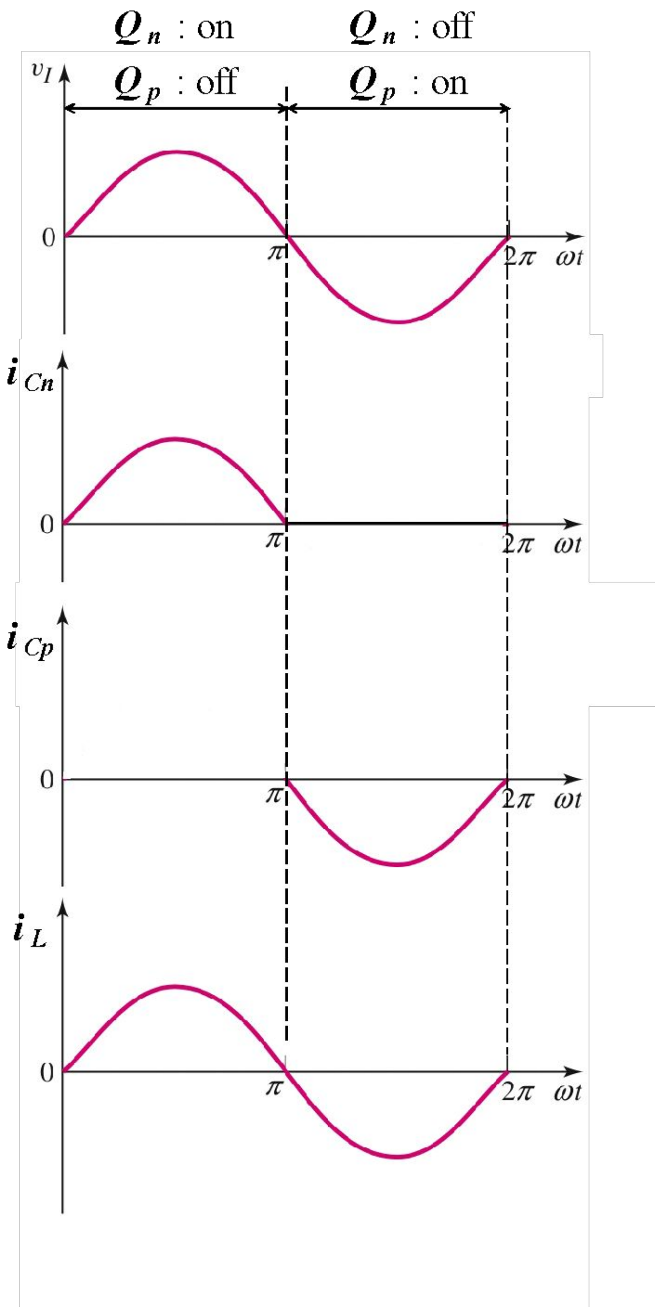
v_O
v_I
t
v_O
t
Dead band

Theoretical maximum efficiency of class-B amplifiers

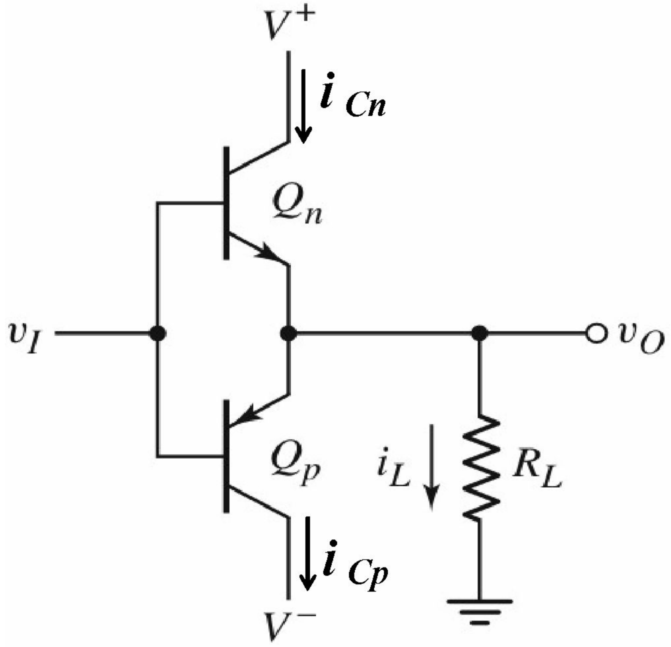
$$v_{CEn} = V_{CC} - V_p \sin \omega t$$



$$v_O = V_p \sin \omega t$$



Qn : on
Qn : off
Qp : off
Qp : on
vI
0
π
2π
ωt
i Cn
i Cp
i L



V+
i Cn
Qn
vI
vO
Qp
iL
RL
i Cp
V−

$$v_O = V_p \sin \omega t$$

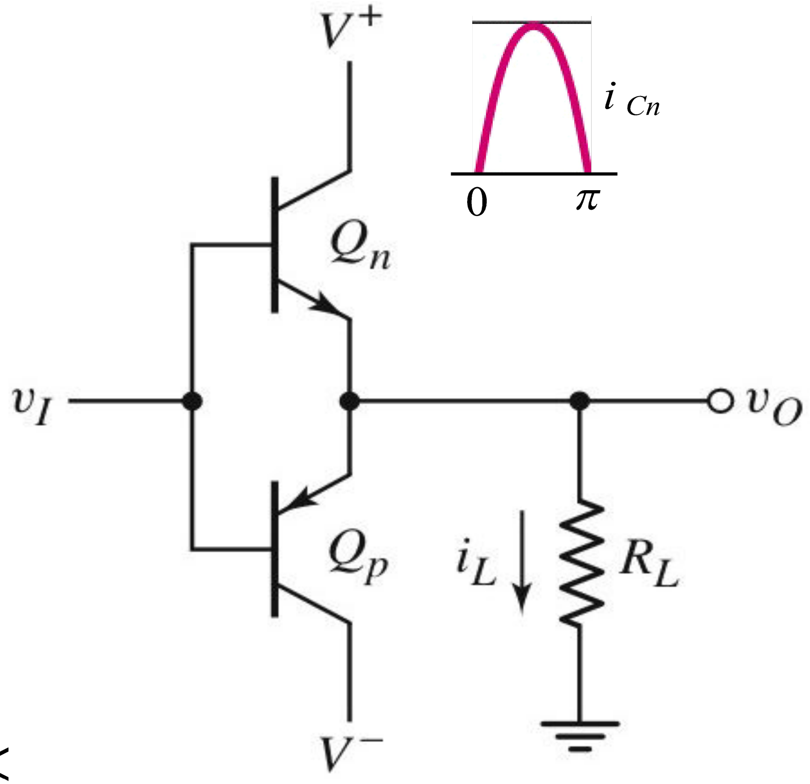
Maximum possible value of V_p is V_{CC}.

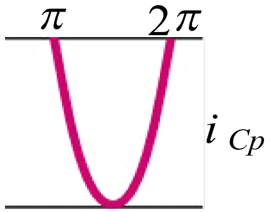
$$v_{CEn} = V_{CC} - V_p \sin \omega t$$

$$i_{Cn} = \frac{V_p}{R_L} \sin \omega t \quad \text{for} \quad 0 < \omega t <$$

and

$$i_{Cn} = 0 \quad \text{for} \quad \pi < \omega t < 2\pi$$





The instantaneous power in Q_n is;

$$p_{Qn} = v_{CEn} i_{Cn}$$

$$= \left(V_{CC} - V_p \sin\omega t\right)\left(\frac{V_p}{R_L}\sin\omega t\right) \qquad \text{for } 0 < \omega t < \pi$$

and

$$p_{Qn} = 0 \qquad \text{for } \pi < \omega t < 2\pi$$

The average power in Q_n is;

$$P_{Qn} = \frac{V_{CC}V_p}{\pi R_L} - \frac{V_p{}^2}{4R_L}$$

$$P_{Qn} = P_{Qn} \qquad \text{(symmetry)}$$

Differentiating for maximum P_{Qn} with respect to V_p gives us;

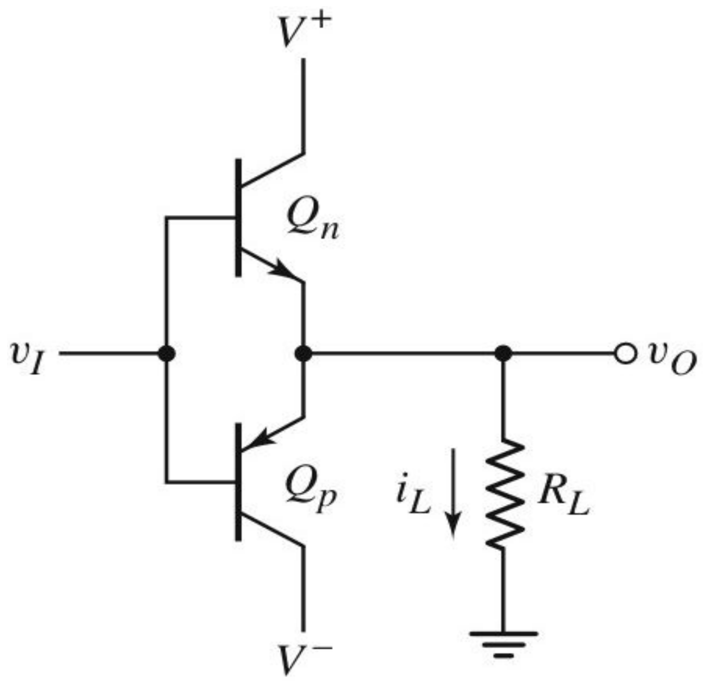
$$P_{Qn}(\max) = \frac{V_{CC}^2}{\pi^2 R_L} \qquad \left(\text{when } V_p = \frac{2V_{CC}}{\pi}\right)$$

Since each power source supplies half sinewave of current, the average value is;

$$I_S = \frac{V_p}{\pi R_L}$$

The total power supplied by the two sources is;

$$P_S = 2V_{CC} I_S = 2V_{CC}\left(\frac{V_p}{\pi R_L}\right)$$



The power delivered to the load is;

$$P_L = \frac{V_{O(\mathrm{rms})}^2}{R_L} = \frac{\left(V_p/\sqrt{2}\right)^2}{R_L} = \frac{V_p^2}{2R_L}$$

The efficiency is; $$\eta = \frac{P_L}{P_S} = \frac{\pi V_p}{4V_{CC}}$$

Maximum efficiency occures when $V_p = V_{CC}$

Under this condition;

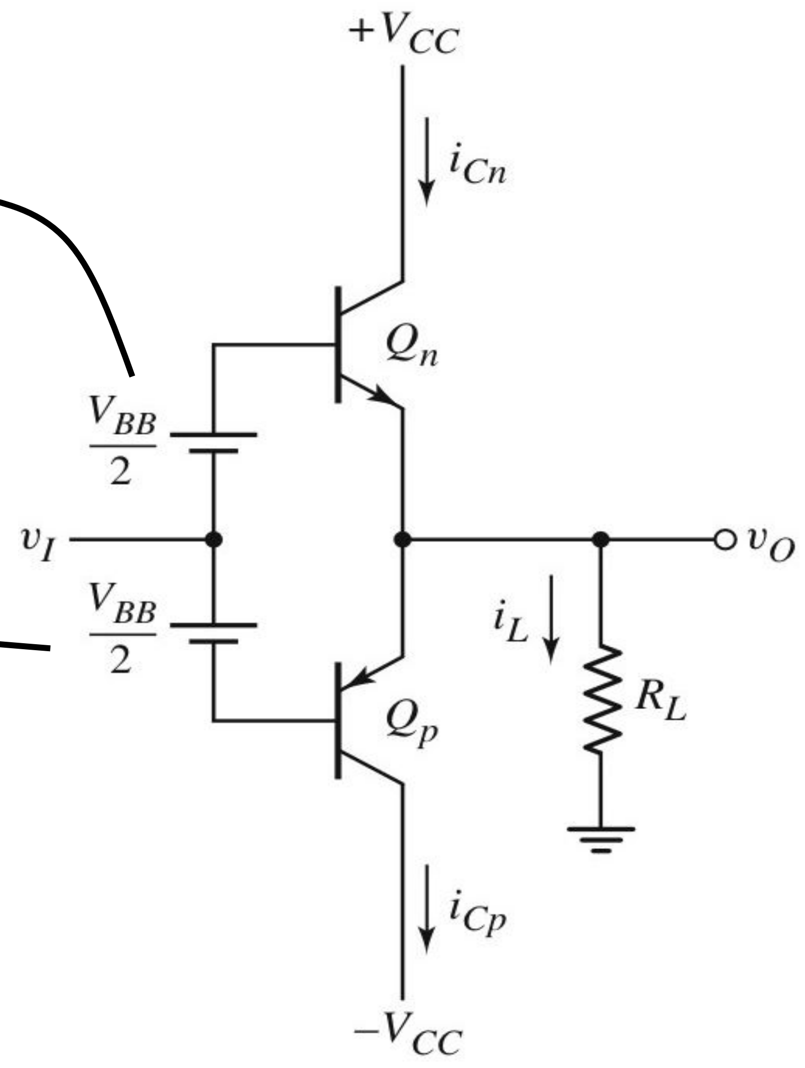
$$\eta = \frac{\pi}{4} = 0.785$$

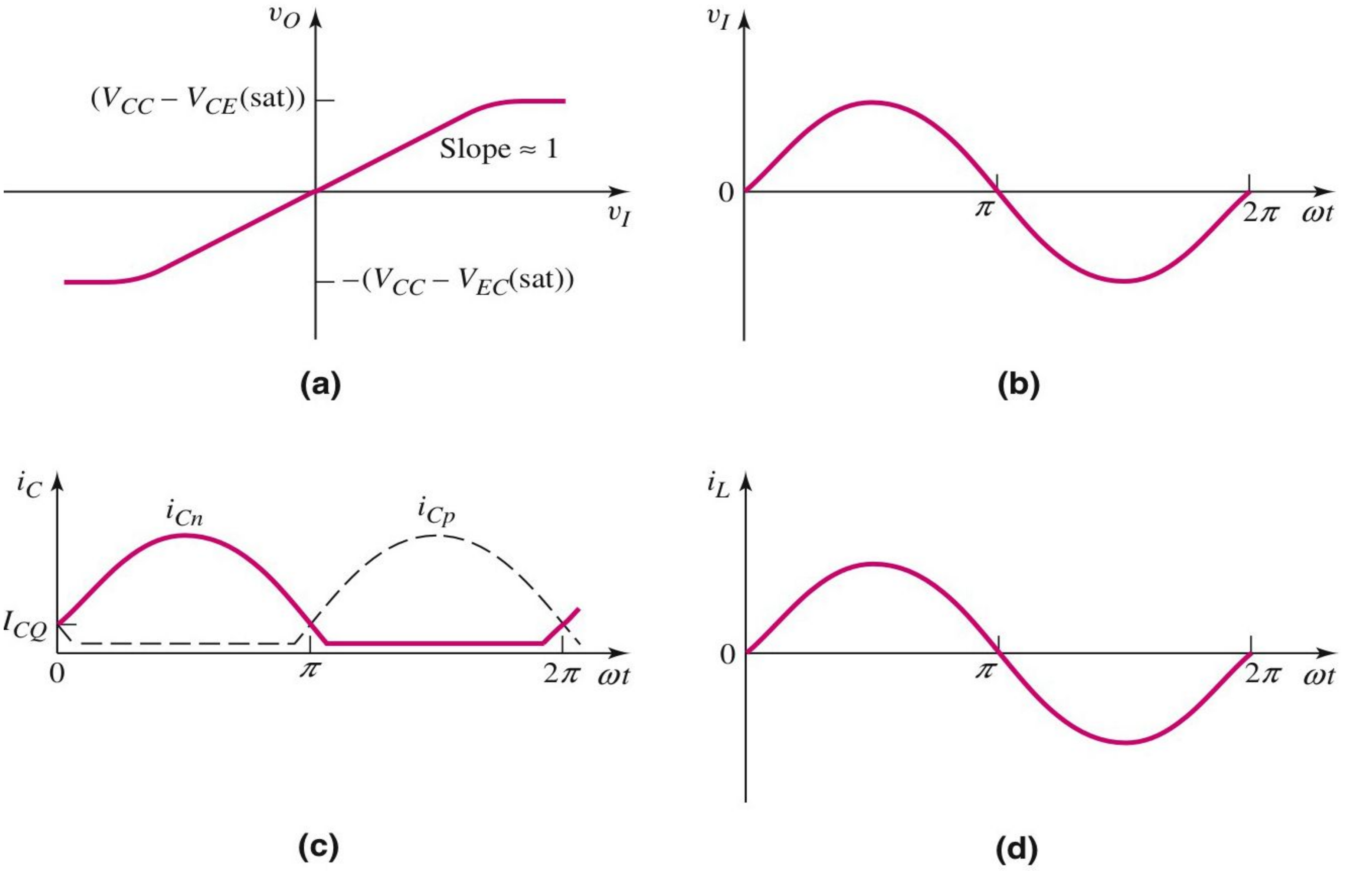
Maximum theoretical efficiency of class B amplifier is therefore 78.5%

Cass–AB operation

Small quiescent bias on each output transistor to eliminate crossover distortion

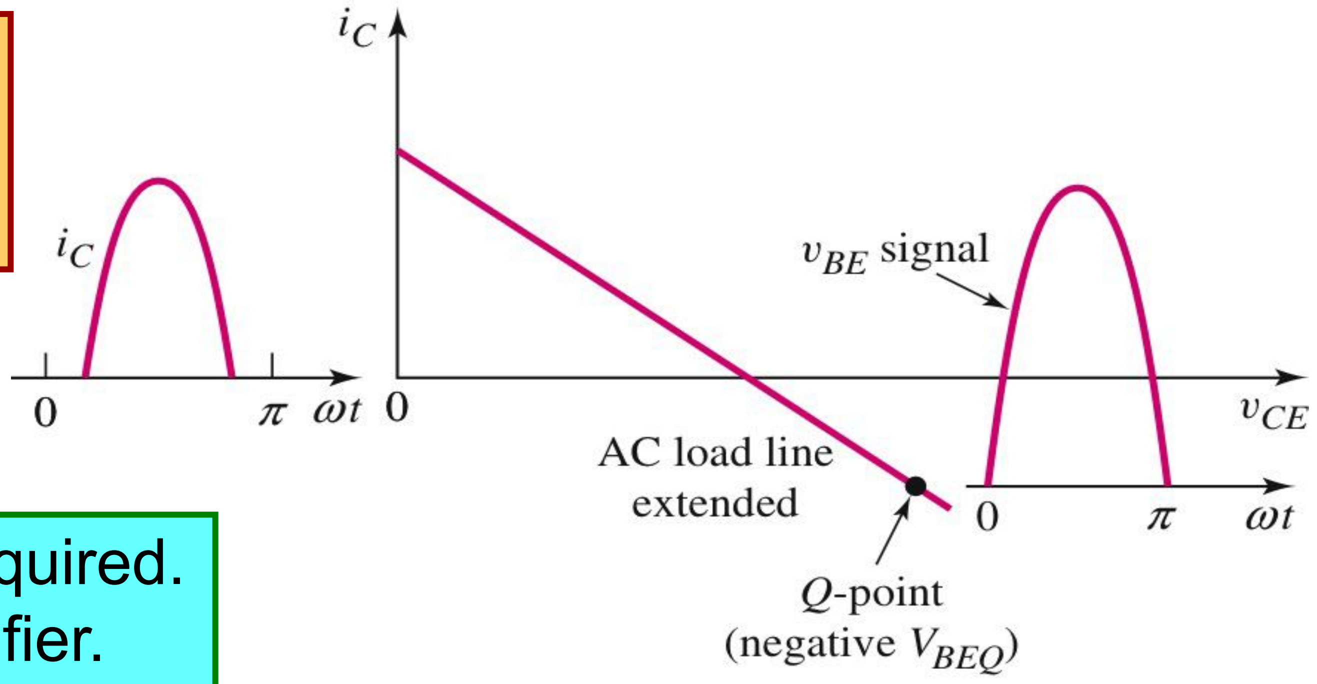
Small I_{CQ} flows through each transistor in the absent of input signal




v_O
$(V_{CC} - V_{CE}(\text{sat}))$
Slope ≈ 1
v_I
$-(V_{CC} - V_{EC}(\text{sat}))$
(a)
v_I
0
π
2π
ωt
(b)
i_C
i_{Cn}
i_{Cp}
I_{CQ}
0
π
2π
ωt
(c)
i_L
0
π
2π
ωt
(d)

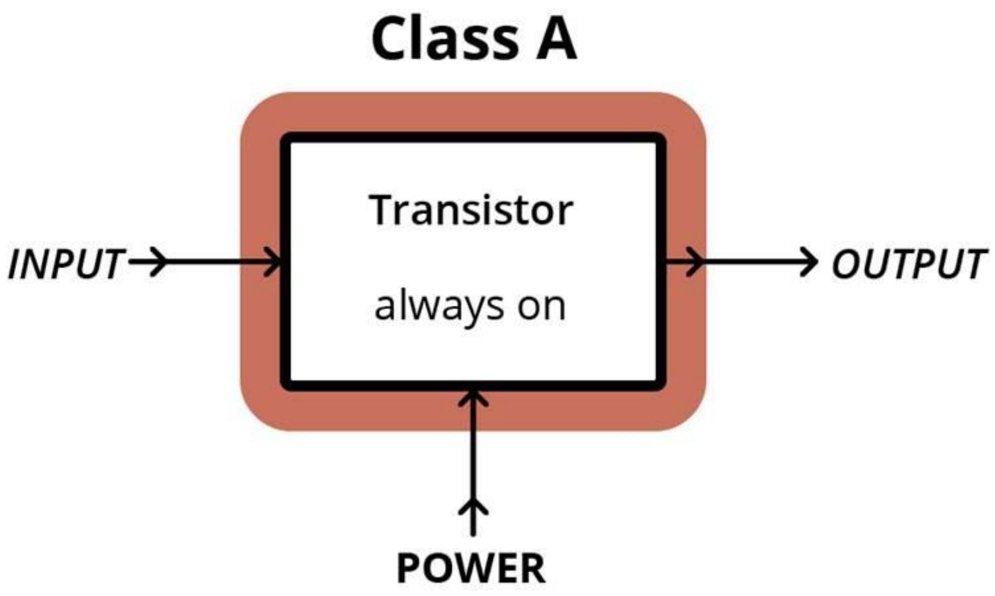
Cass–C operation

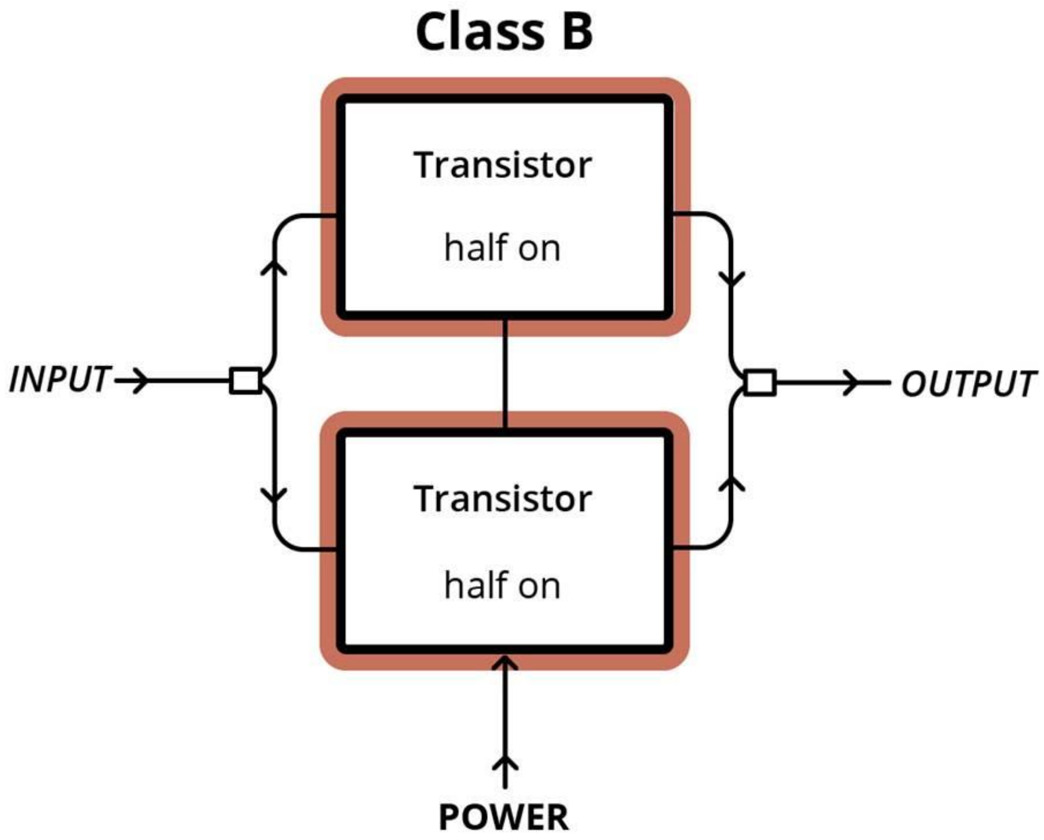
Transistor conducts for less than half a cycle of input signal

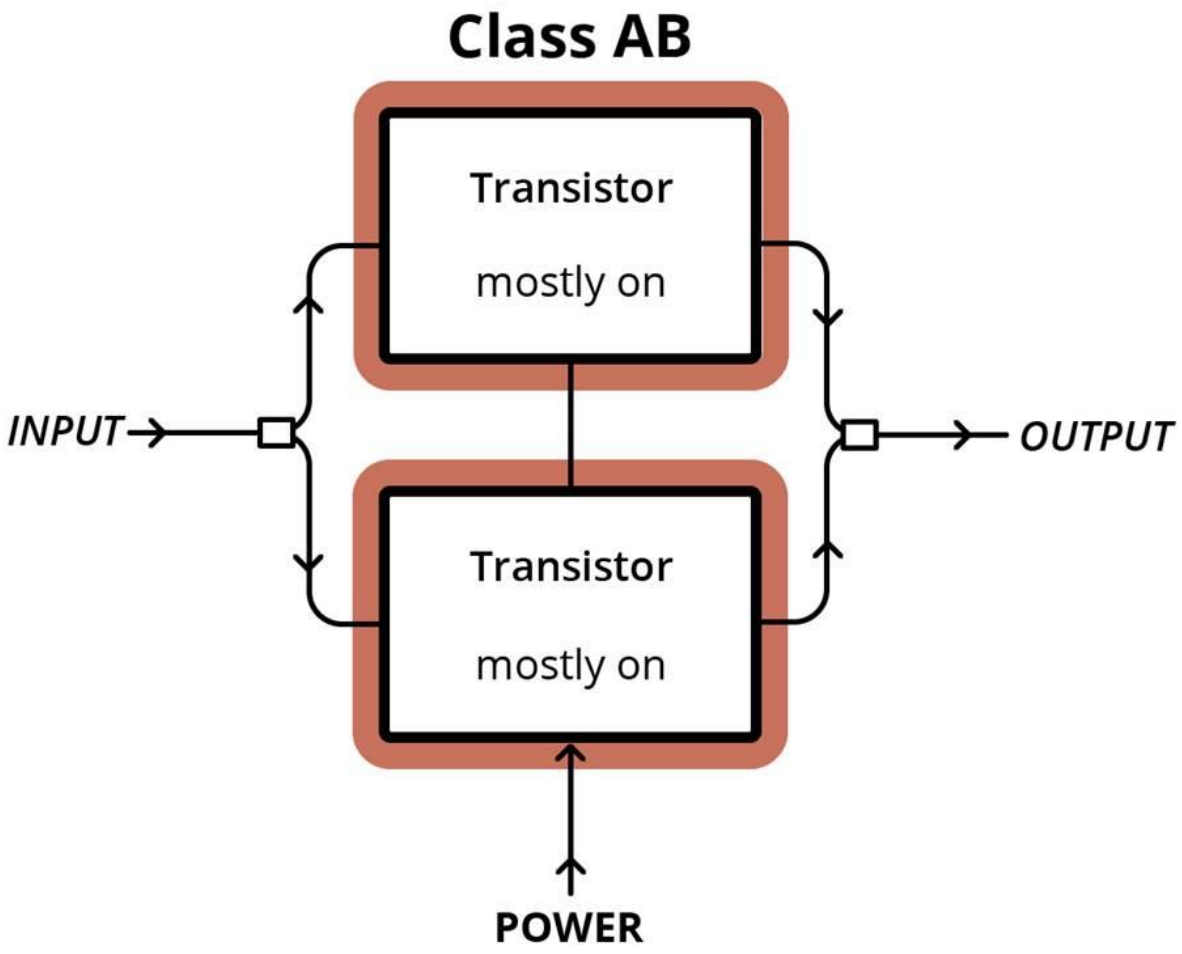


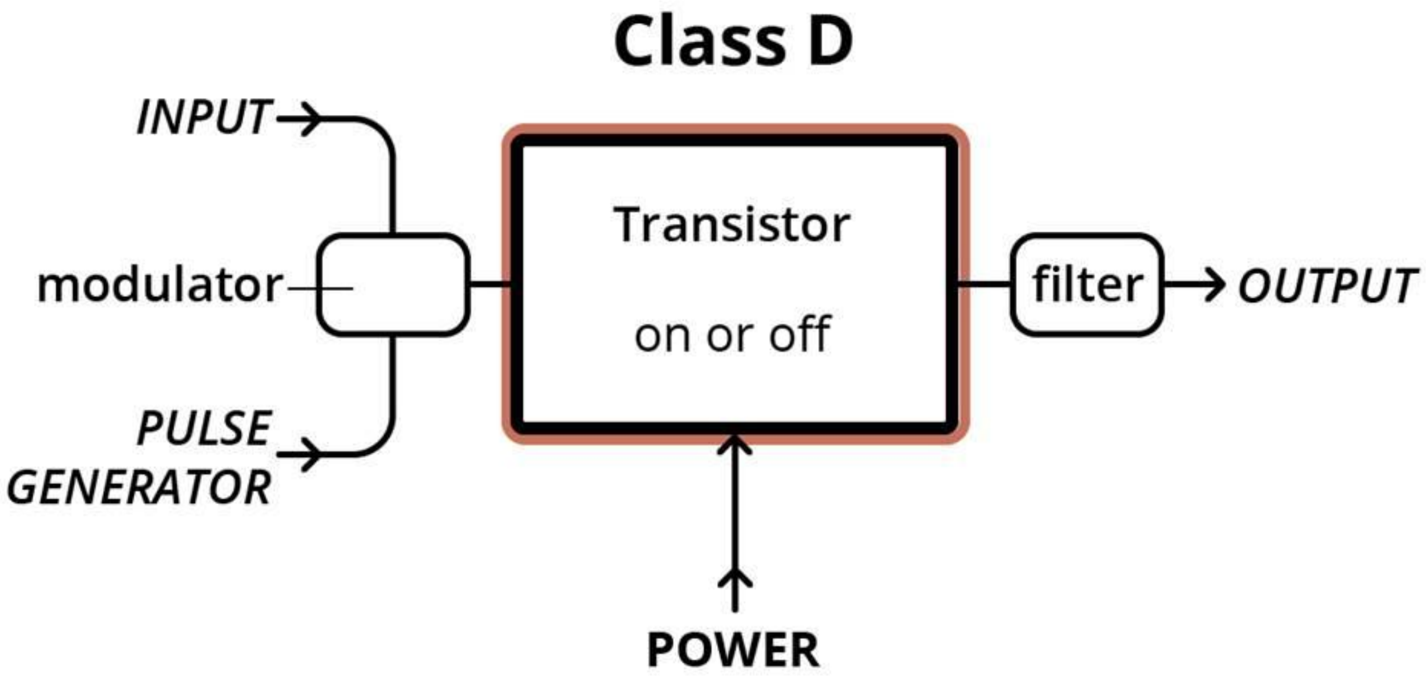
- Tuned circuit is required.
- Used for RF amplifier.
- Efficiency > 78.5%

B – E junction is reverse-biased to obtain Q-point beyond cut-off.


Class A
Transistor
always on
INPUT
OUTPUT
POWER


Class B
Transistor
half on
Transistor
half on
INPUT
OUTPUT
POWER


Class AB
Transistor
mostly on
Transistor
mostly on
INPUT
OUTPUT
POWER


Class D
INPUT
modulator
PULSE
GENERATOR
Transistor
on or off
filter
OUTPUT
POWER