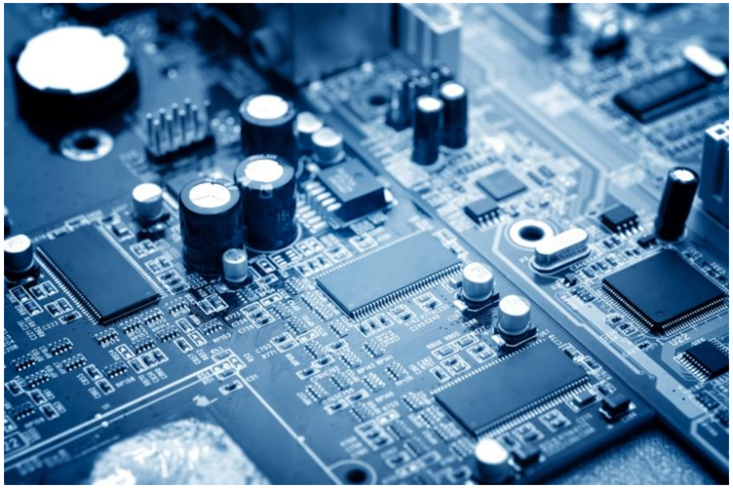
ENEE3304 ELECTRONICS2



Instructor : Mr.Mohammad AL-Jubeh

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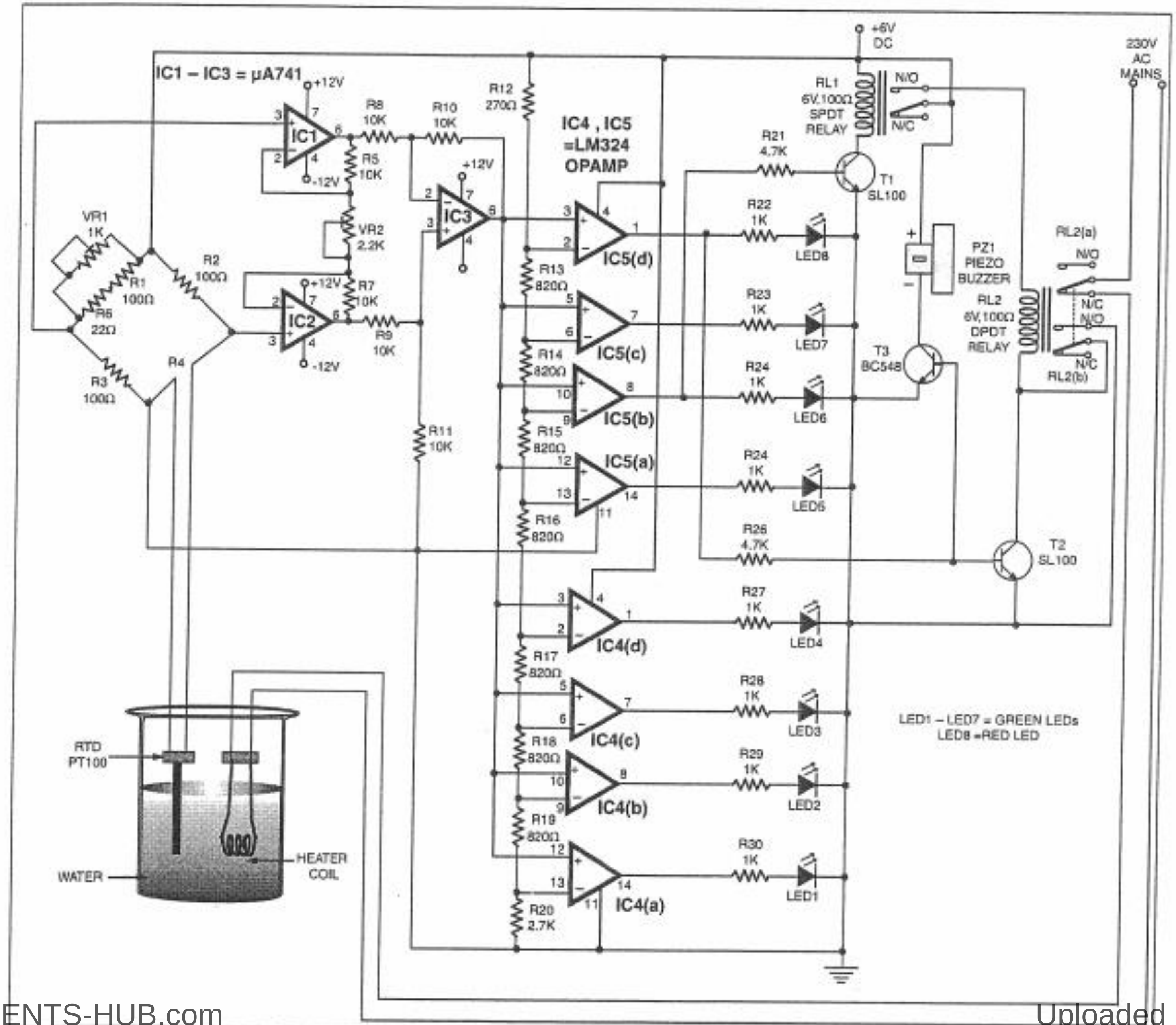
ENEE3304 Project1 : Water Temperature Controller



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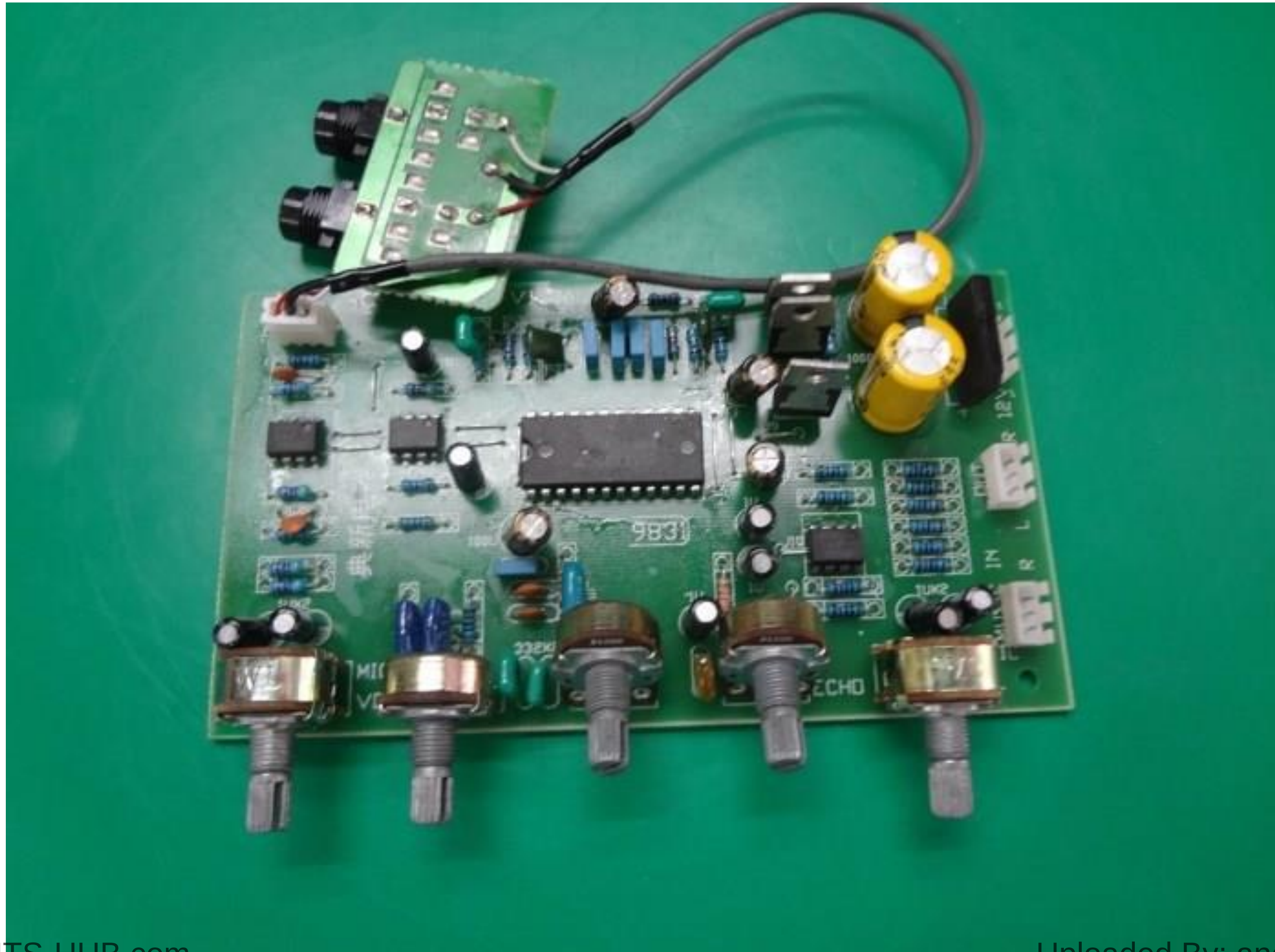
Power Amplifiers



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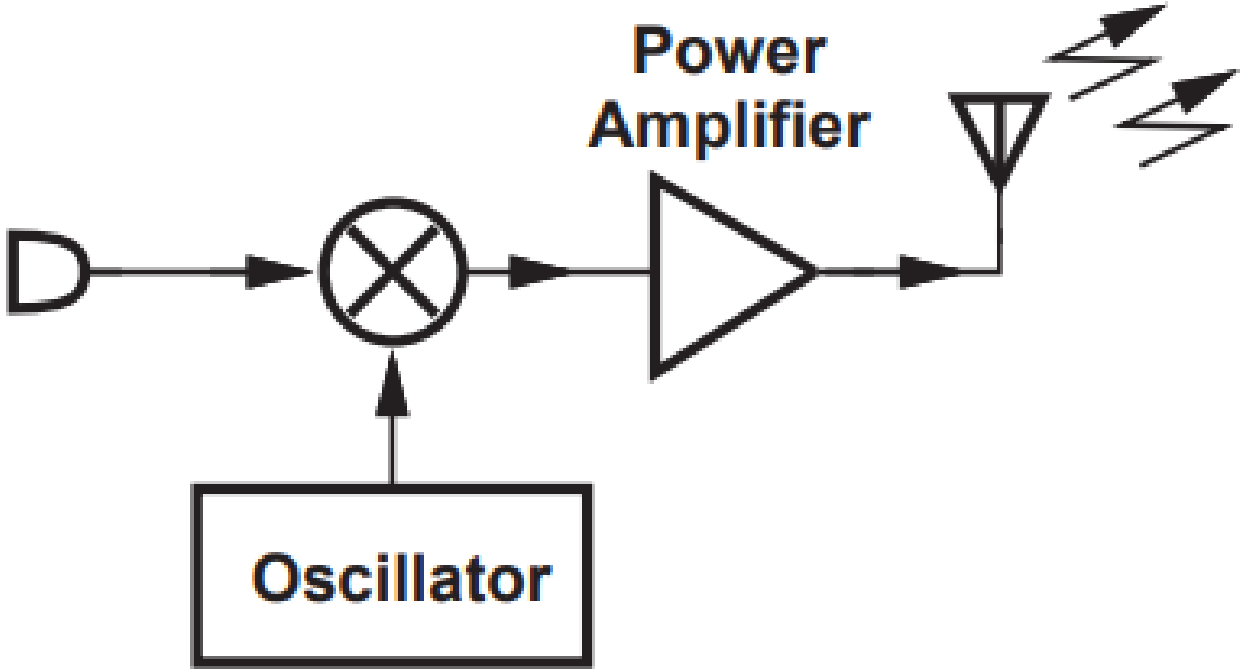
Transmitter



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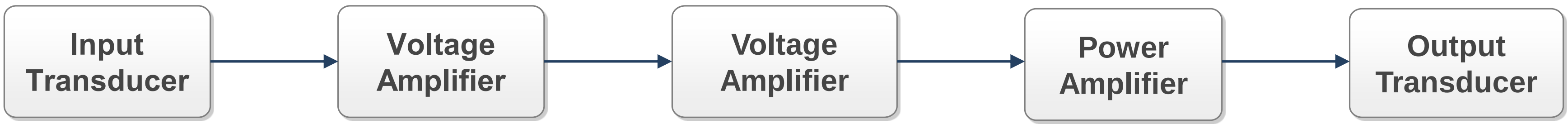
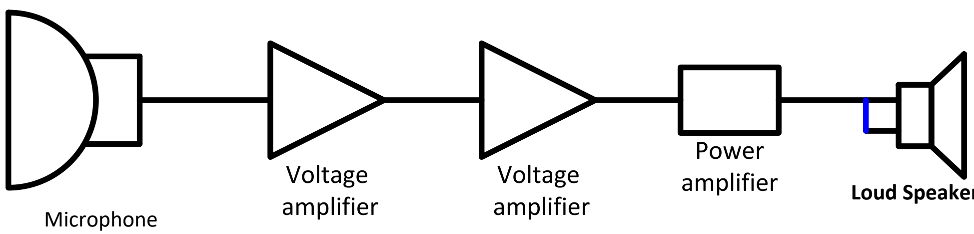
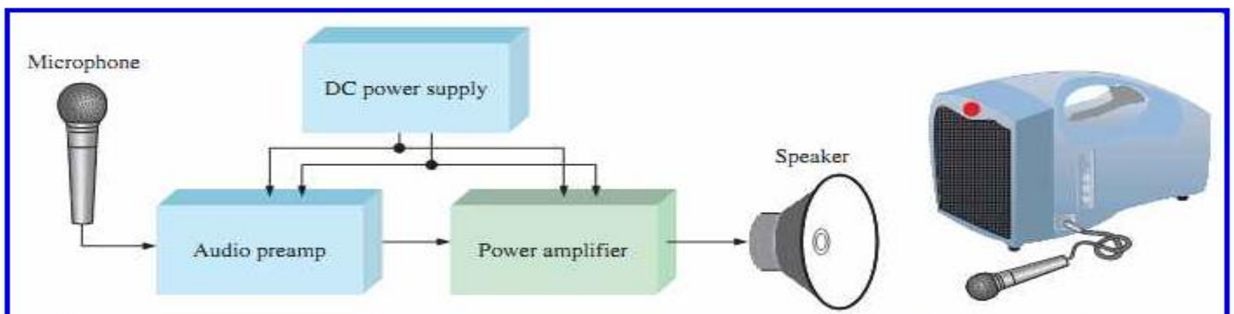
General Audio Amplifier System







(a) PA system block diagram
(b) Physical configuration

Input transducer : Microphone
Microphone : Used to convert acoustical energy to electrical energy .
Output Transducer : Loud speaker
Loud speaker: Used to convert electrical energy to acoustical energy.

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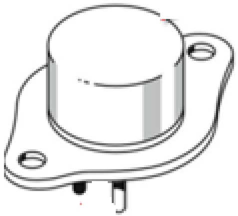
Power Amplifiers

* A Power amplifier is one that is used to deliver a large amount of power to a load with good efficiency.

* To do this function , it must be capable of dissipating a large amount of power .

* It contains a bulky component having large surface area to enhance heat transfer.



* It is often the last stage of amplifier system.

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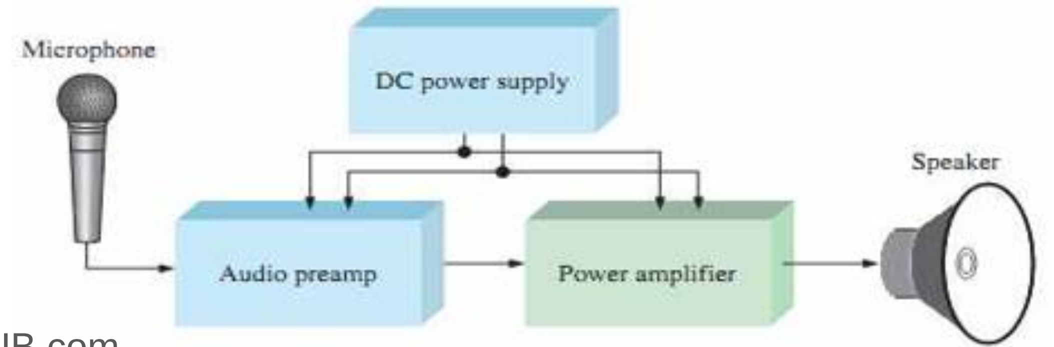

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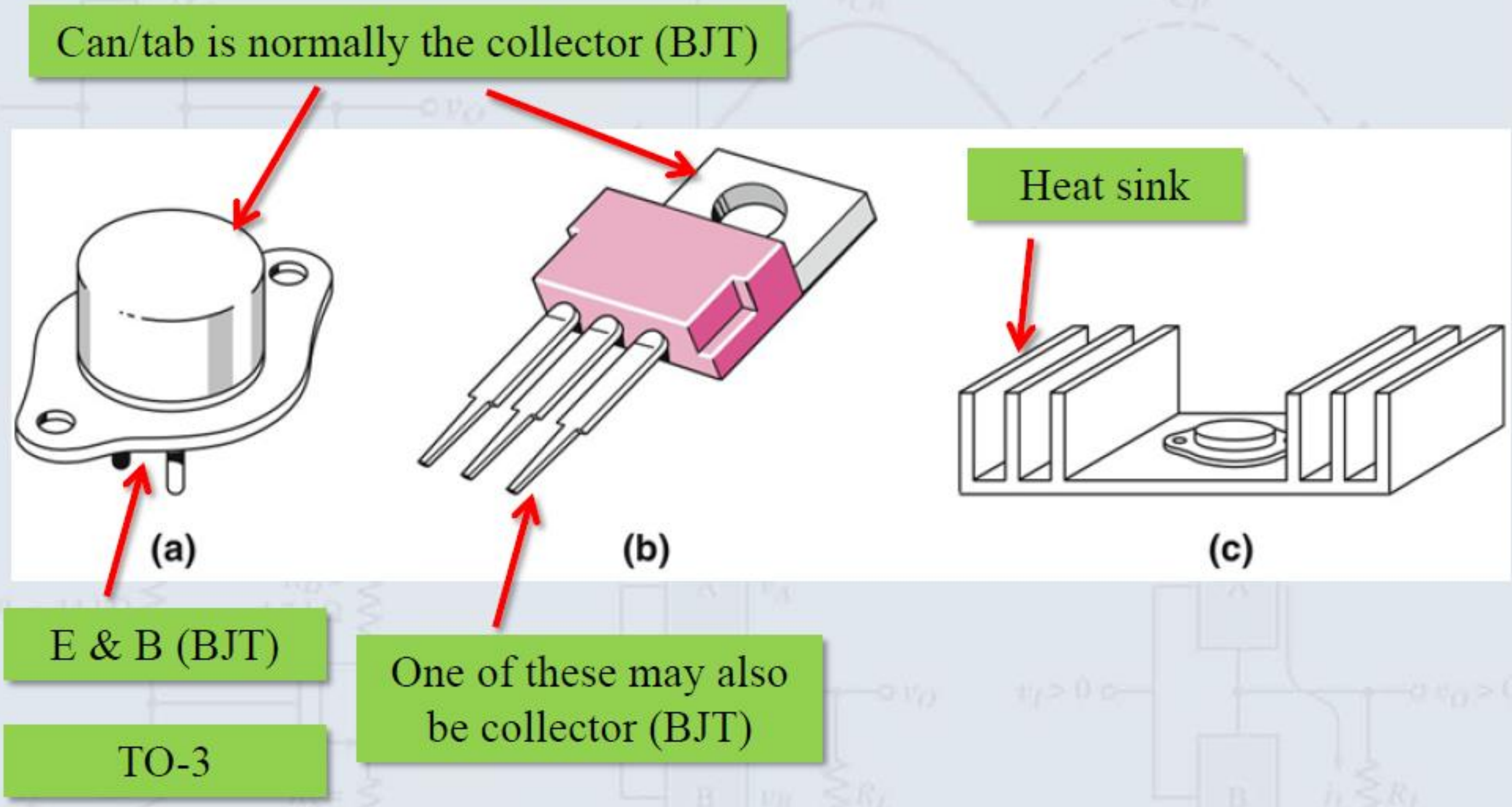
Packaging Schemes



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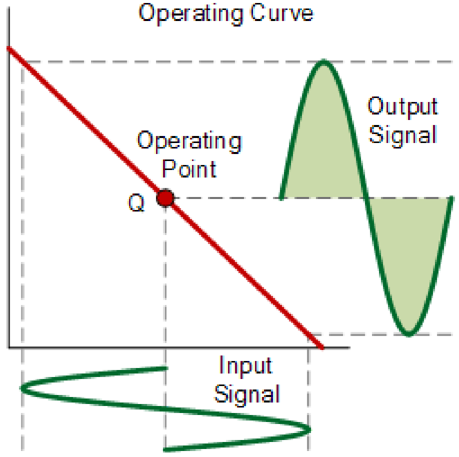
Power Amplifiers

* It's designed so that the power transistor can operate in the entire range of it's output from saturation to cut off.

* For a class A power Amplifier, the Q point is designed to meet maximum symmetrical swing



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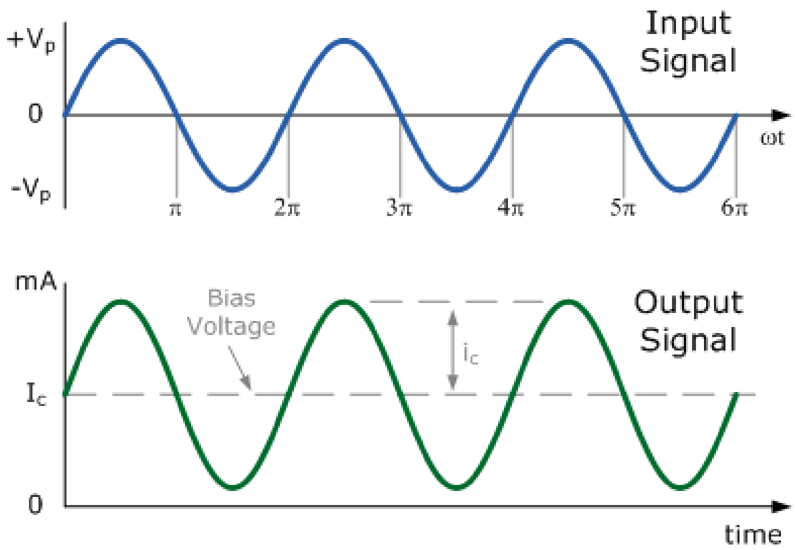
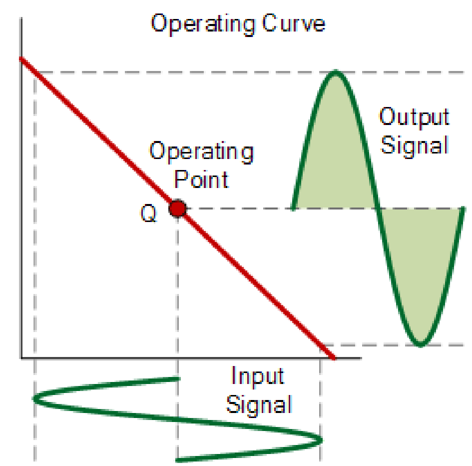
Classes of Power Amplifiers

Power amplifiers are classified according to the percent of time the output transistors are conducting.

1) Class A Power Amplifier: $\theta = 360°$





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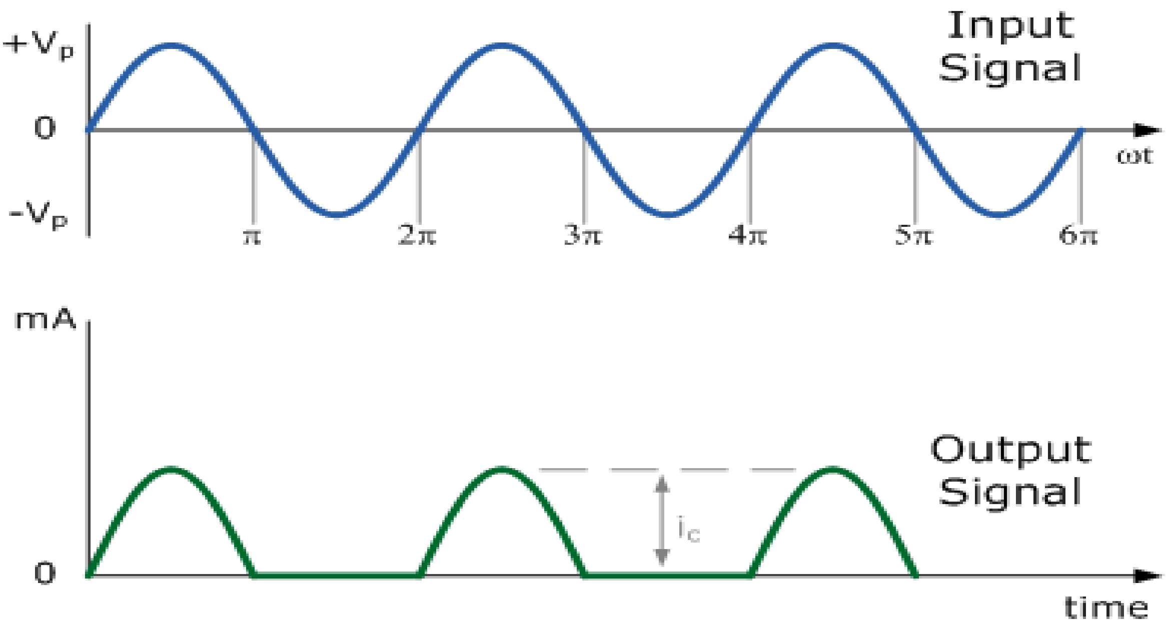
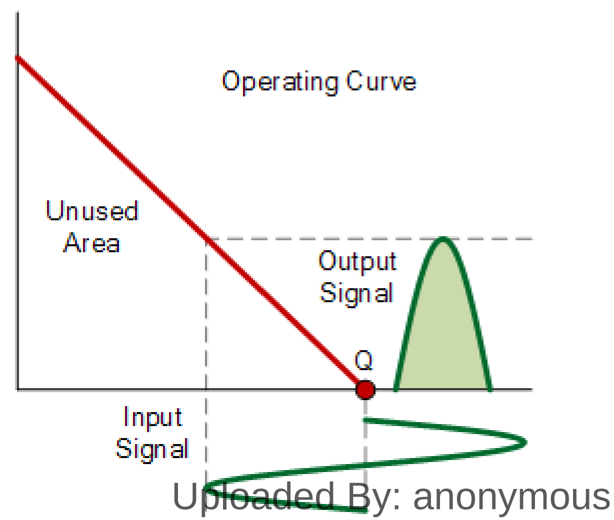
Classes of Power Amplifiers

2) Class B Power Amplifier : $\theta = 180°$





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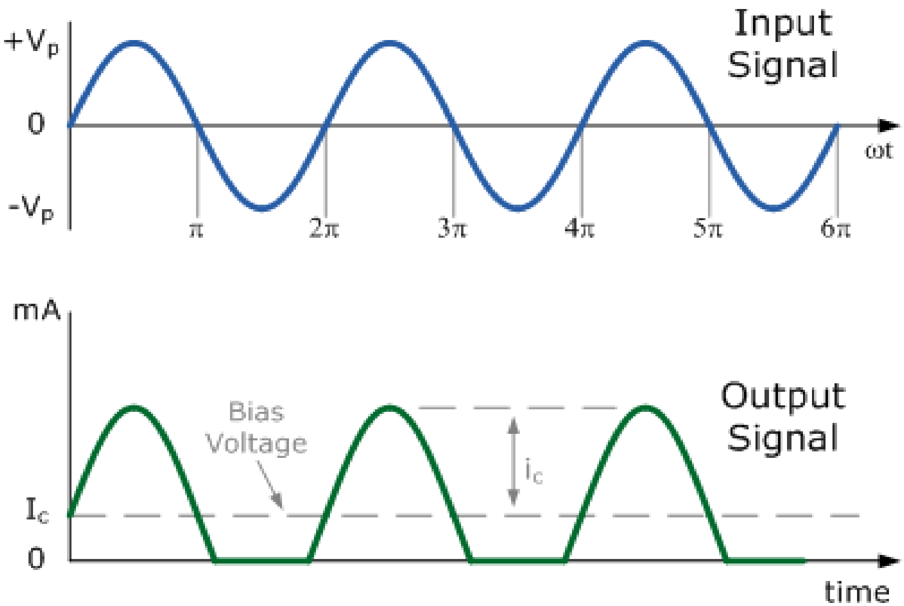
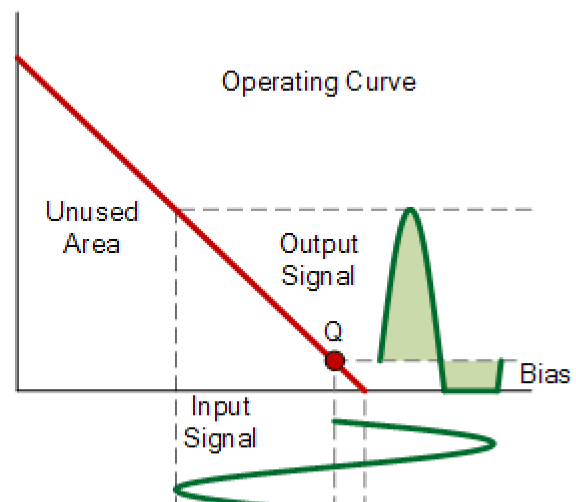
Classes of Power Amplifiers

3) Class AB Power Amplifier

$360° > \theta > 180°$





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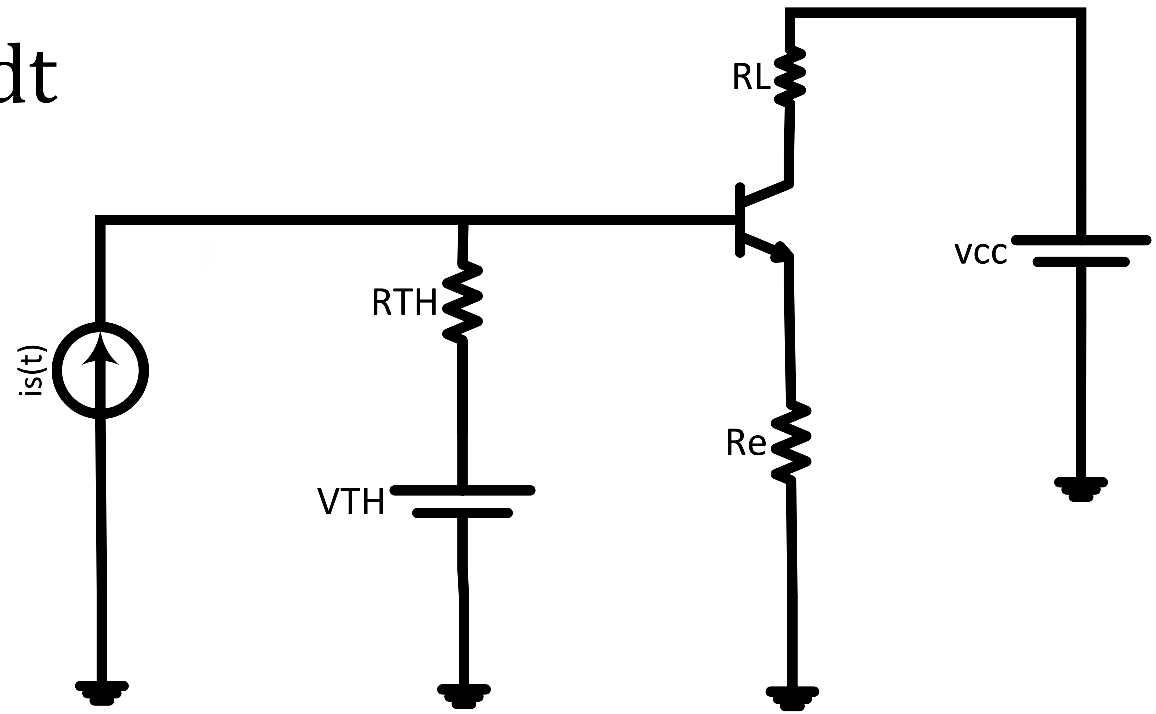
Class A Power Amplifier

Power Calculation :

The average power supplied or dissipated by any linear or nonlinear device is :

$$P_{av} = \frac{1}{T}\int_0^T V(t)i(t)\,dt$$



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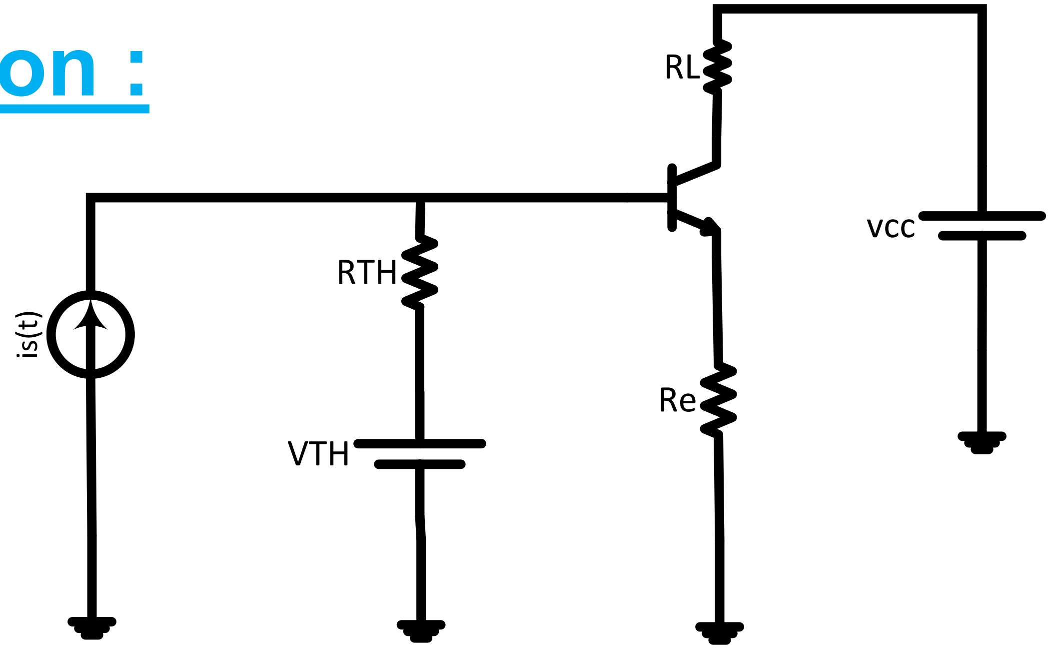
Power Calculation :

$$P_{av} = \frac{1}{T}\int_0^T V(t)\,i(t)\,\mathrm{dt}$$



$V(t)$ **:Total voltage across the device**

$i(t)$ **: Total current through the device**

$V(t) = V + v$

v **= Vm Cos(ωt)**

$i(t) = I + i$

i**= Im Cos(ωt)**

$$P_{av} = \frac{1}{T}\int_0^T (V + v)(I + i)\,\mathbf{dt}$$

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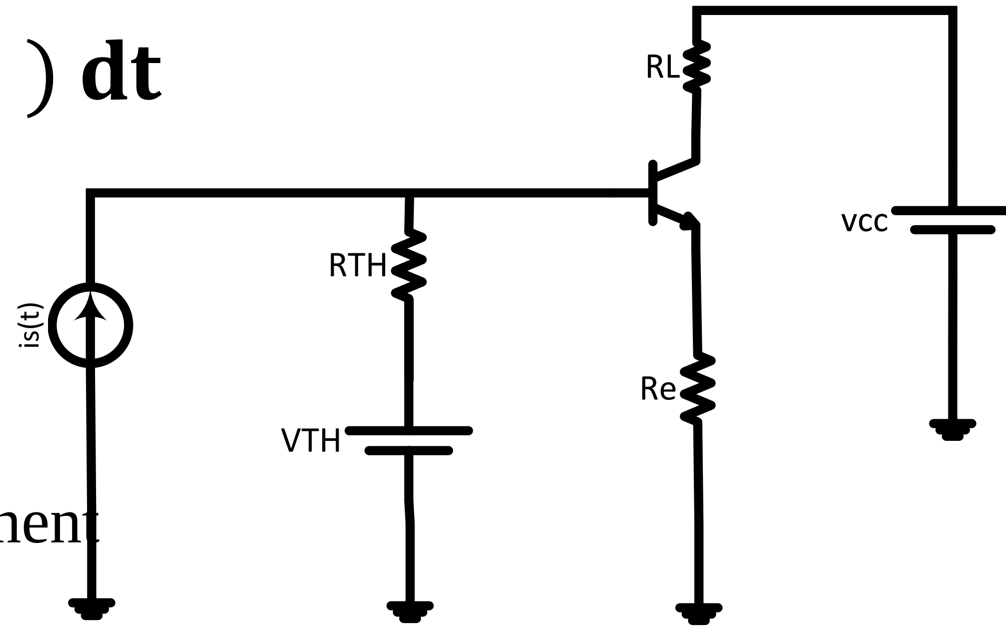
Power Calculation :

$$P_{av} = \frac{1}{T}\int_0^T (V + v)(I + i)\,dt$$



Since :

$$\frac{1}{T}\int_0^T v\,dt = \frac{1}{T}\int_0^T i\,dt = 0$$

ac component

$$P_{av} = \frac{1}{T}\int_0^T v\,i\,dt + VI$$

dc component

The average power dissipated or supplied by a device consists of the sum of the power in AC and DC terms .

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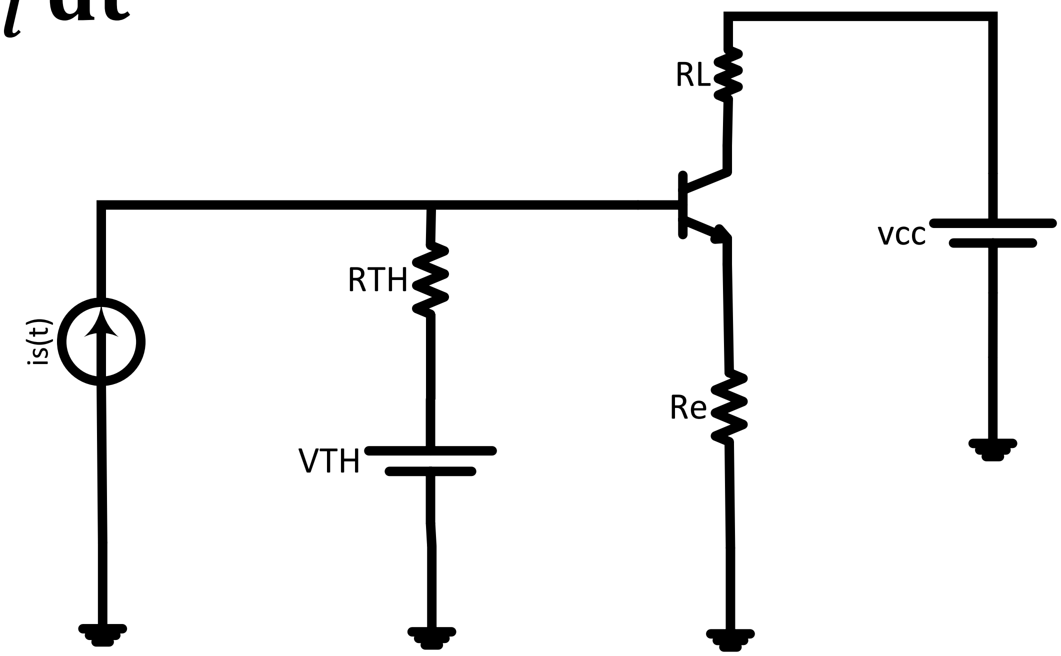
The Ac Average Power Dissipated in The Load : $P_{l,ac}$

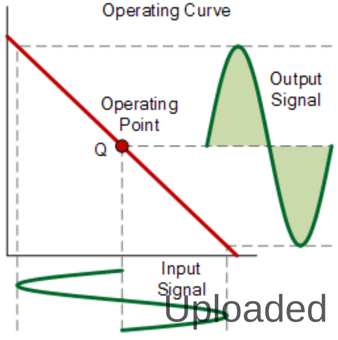
$$P_{l,ac} = \frac{1}{T}\int_0^T i_{c(t)}^2 \; R_l \; dt$$

$$i_{c(t)} = I_{cm} \; \text{Cos(wt)}$$

$$P_{l,ac} = \frac{1}{2} \; I_{cm}{}^2 \; R_L$$

$$(P_{l,ac}) \, , _{max} = \frac{1}{2} \; I_{cm,max}^2 R_L$$





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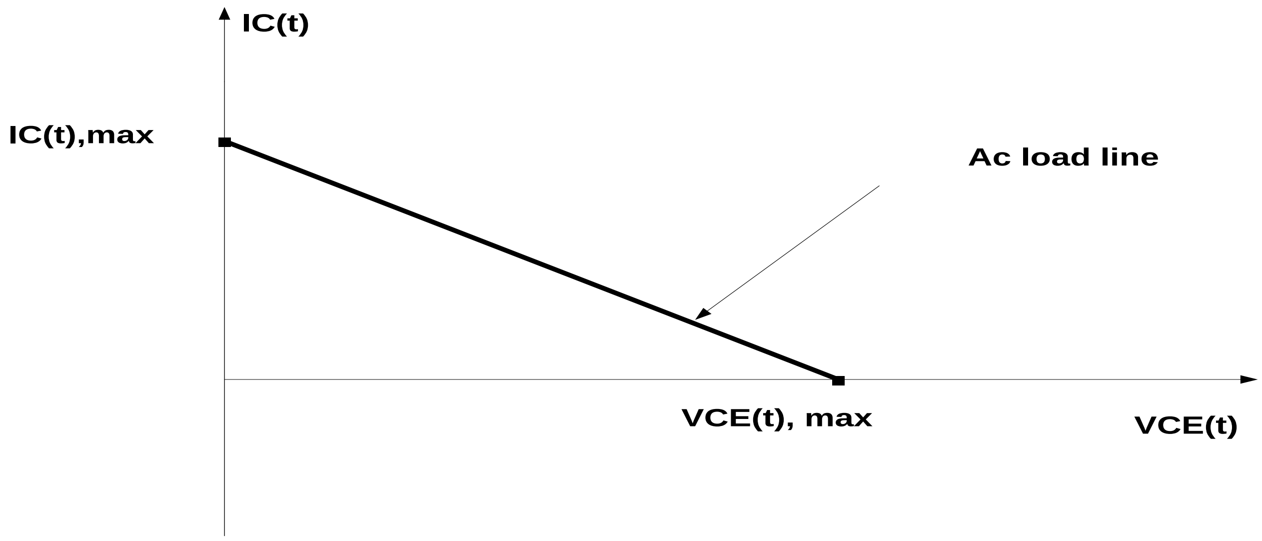

- $i_{C(t),max} = I_{CQ} + \frac{V_{CEQ}}{R_{ac}}$

- $V_{CE(t),max} = V_{CEQ} + R_{ac}\, I_{CQ}$

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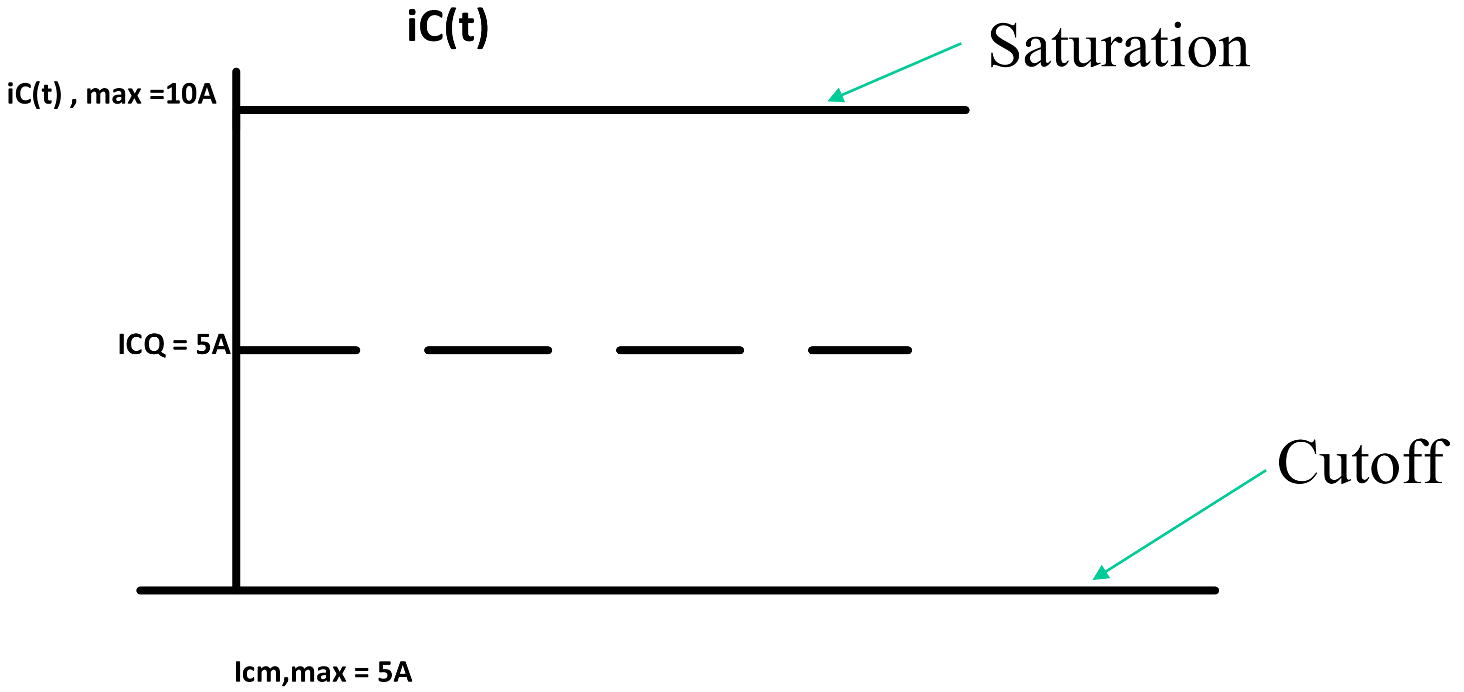

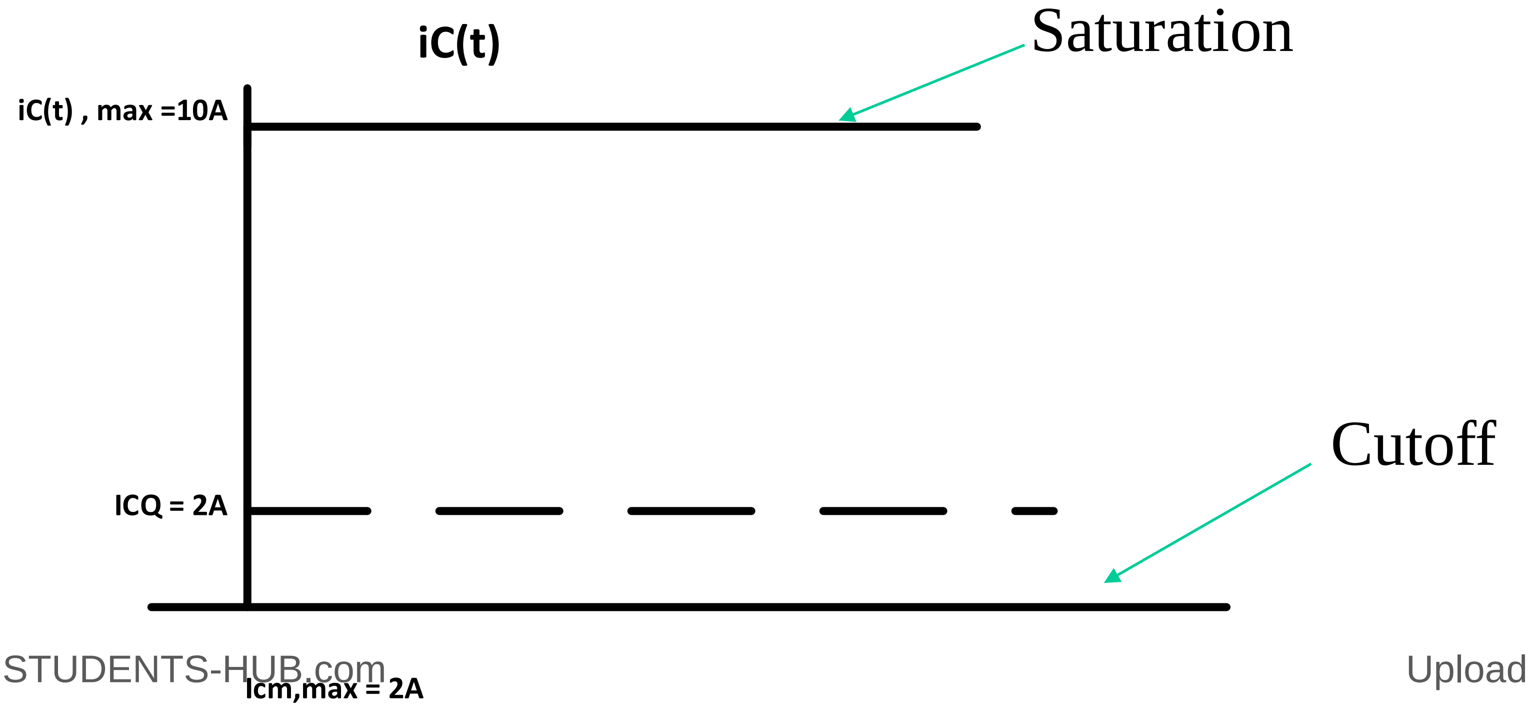

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If the Q point is designed to meet maximum symmetrical swing case.

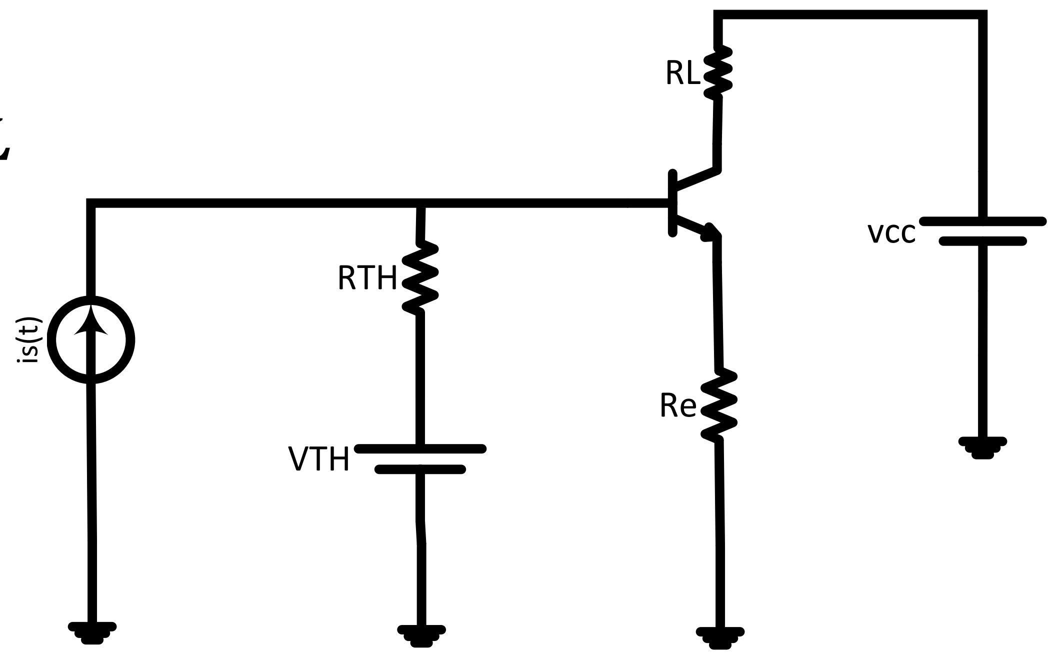
$$I_{cm\,,\,max} = I_{CQ}$$

$$(P_{l,ac})\,,\,max = \frac{1}{2} I_{CQ}{}^{2} R_L$$

$$I_{CQ} = \frac{V_{cc}}{R_{ac+}\ R_{dc}}$$

$$R_{dc} = R_l + R_e$$

$$R_{ac} = R_l + R_e$$



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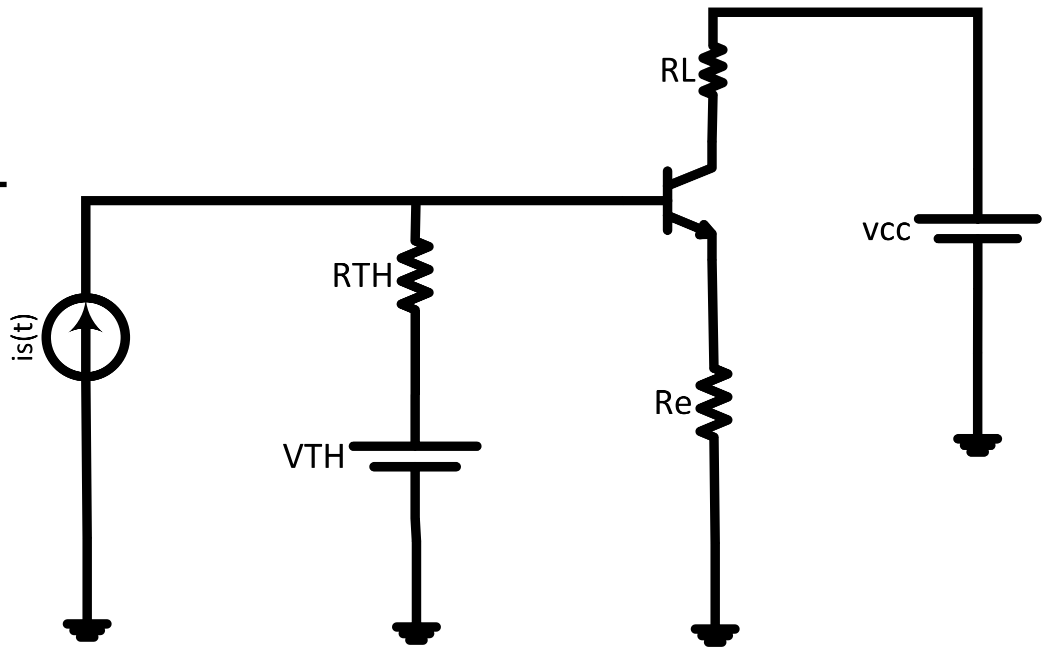
The Average Power Dissipated in The Load

$$I_{CQ} = \frac{V_{cc}}{2(R_{l+}R_e)}$$

$$(P_{l,ac})_{max} = \frac{{V_{cc}}^2 R_l}{8(R_{l+}R_e)^2}$$

$$If\ R_e << R_l$$

$$(P_{l,ac})_{,max} = \frac{{V_{cc}}^2}{8\ R_l}$$



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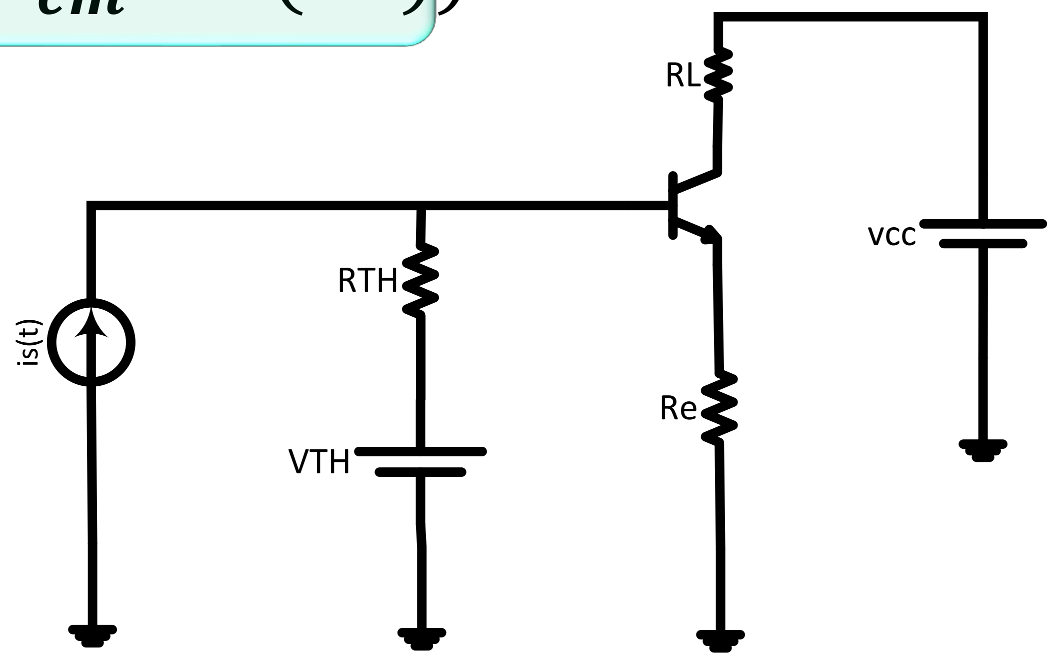
Average Power Delivered by the Supply : P_{cc}

$$P_{cc} = \frac{1}{T}\int_0^T V_{cc}\, i_C(t)\,dt$$

$i_C(t)$

$$P_{cc} = \frac{1}{T}\int_0^T V_{cc}\,(I_{CQ} + I_{cm}\cos(\omega t))\,dt$$



$$P_{cc} = V_{cc} I_{CQ}$$

But : $I_{CQ} = \dfrac{V_{cc}}{2(R_l + R_e)}$

$$P_{cc} = \frac{V_{cc}^2}{2(R_l + R_e)}$$

If $R_e << R_l$

$$P_{cc} = \frac{V_{cc}^2}{2R_l}$$

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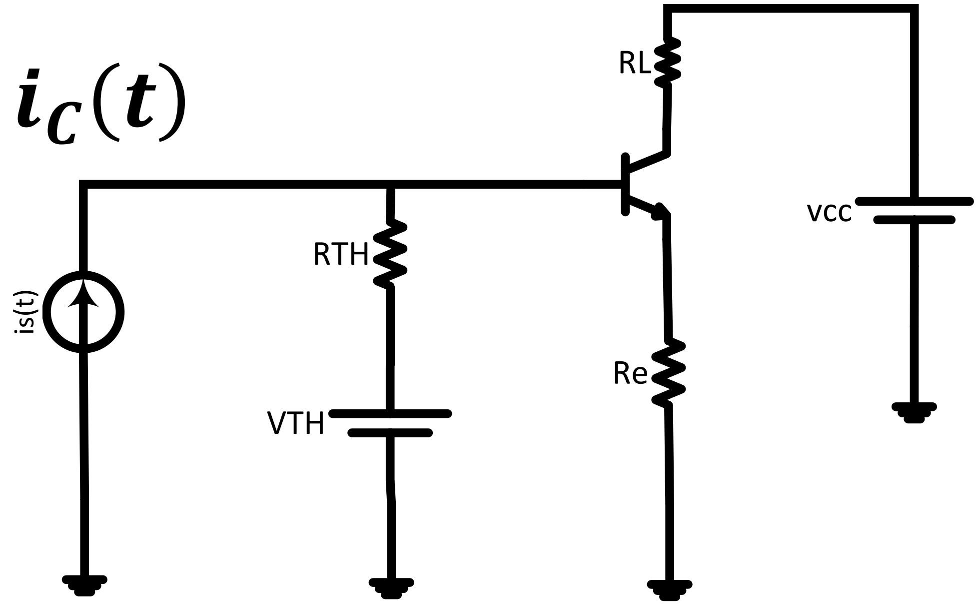
Average Power Dissipated in the Transistor :P_c

$$P_c = \frac{1}{T}\int_0^T V_{CE}(t)\ \ i_C(t)dt$$

$$V_{CE}(t) = V_{cc} - (R_{l+}R_e)\ \ i_C(t)$$



$$P_c = \frac{1}{T}\int_0^T [V_{cc} - (R_{l+}R_e)\ \ i_C(t)\ ]\ \ i_C(t)dt$$

$$P_c = \frac{1}{T}\int_0^T V_{cc}\ \ i_C(t)dt\ \ - \frac{1}{T}\int_0^T (R_{l+}R_e)\ \ i_C(t)^2\ dt$$

P_{cc}

$$\frac{1}{T}\int_0^T\ \ i_C(t)^2\ dt\ \ = I_{CQ}{}^2 + \frac{I_{cm}{}^2}{2}$$

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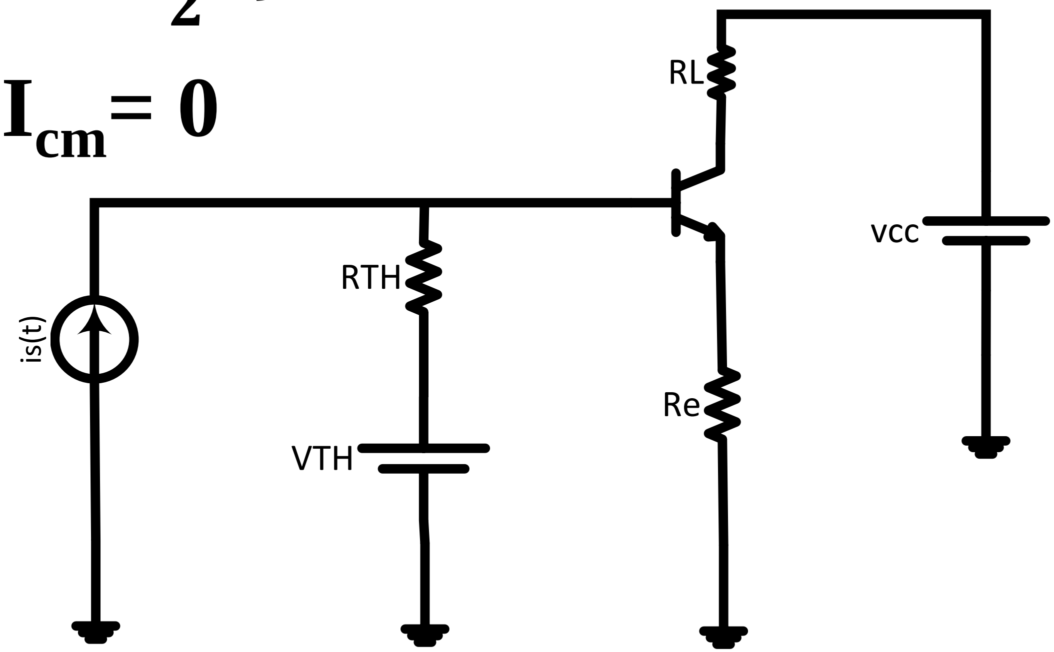
Average Power Dissipated in the Transistor

$$P_c = P_{cc} - (R_{l+}R_e)(I_{CQ}^2 + \frac{I_{cm}^2}{2})$$

∴ Pc is maximum when $I_{cm} = 0$



$$\therefore P_{c,max} = P_{cc} - (R_{l+}R_e)(I_{CQ}^2)$$

$$P_{c,\,max} = \frac{V_{cc}^2}{4(R_{l+}R_e)}$$

$$If\ R_e << R_l$$

$$P_{c,max} = \frac{V_{cc}^2}{4R_l}$$

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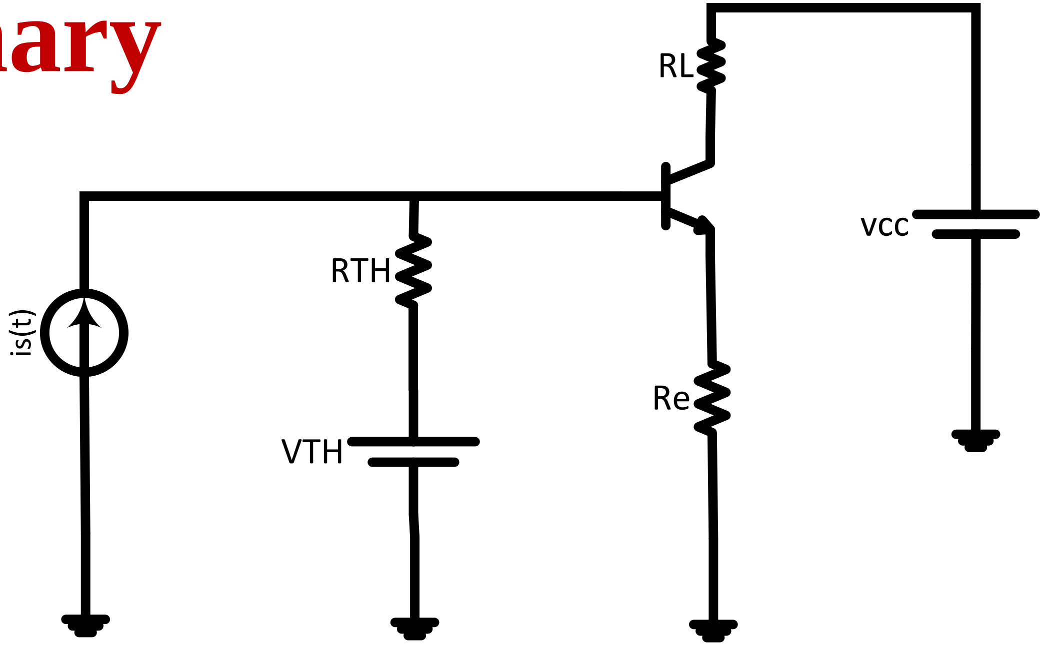
Summary



$$P_{l,ac} = \frac{1}{2} \, I_{cm}{}^{2} \, R_L$$

If $R_e << R_l$

$$(P_{l,ac})\,,_{max} = \frac{V_{cc}{}^{2}}{8R_l}$$

$$P_{c,max} = \frac{V_{cc}{}^{2}}{4R_l}$$

$$P_{cc} = \frac{V_{cc}{}^{2}}{2R_l}$$

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Efficiency: η

$$\eta = \frac{P_{l,ac}}{P_{cc}} \; *100\%$$

$$\eta = \frac{\frac{I_{cm}{}^2 R_l}{2}}{\frac{V_{cc}{}^2}{2R_l}} \; *100\%$$

$$\eta\, max = \frac{\frac{V_{cc}{}^2}{8R_l}}{\frac{V_{cc}{}^2}{2R_l}} *100\%$$

$$\eta\, max = 25\%$$

$$\eta \;\; is \;\; max\, when\, I_{cm} = I_{cm}, max$$

If the Q point is designed to meet maximum symmetrical swing case.

and $I_{cm\,,\,max} = \; I_{CQ}$

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γ : Figure of merit

$$\gamma = \frac{P_{C\,,\,max}}{(P_{l,ac})\,,\,max}$$

$$\gamma = 2$$

$$P_{C\,,\,max} = \frac{{V_{cc}}^2}{4R_l}$$

$$(P_{l,ac})\,,\,max = \frac{{V_{cc}}^2}{8R_l}$$

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The Class A Common Emitter Power Amplifier with Choke

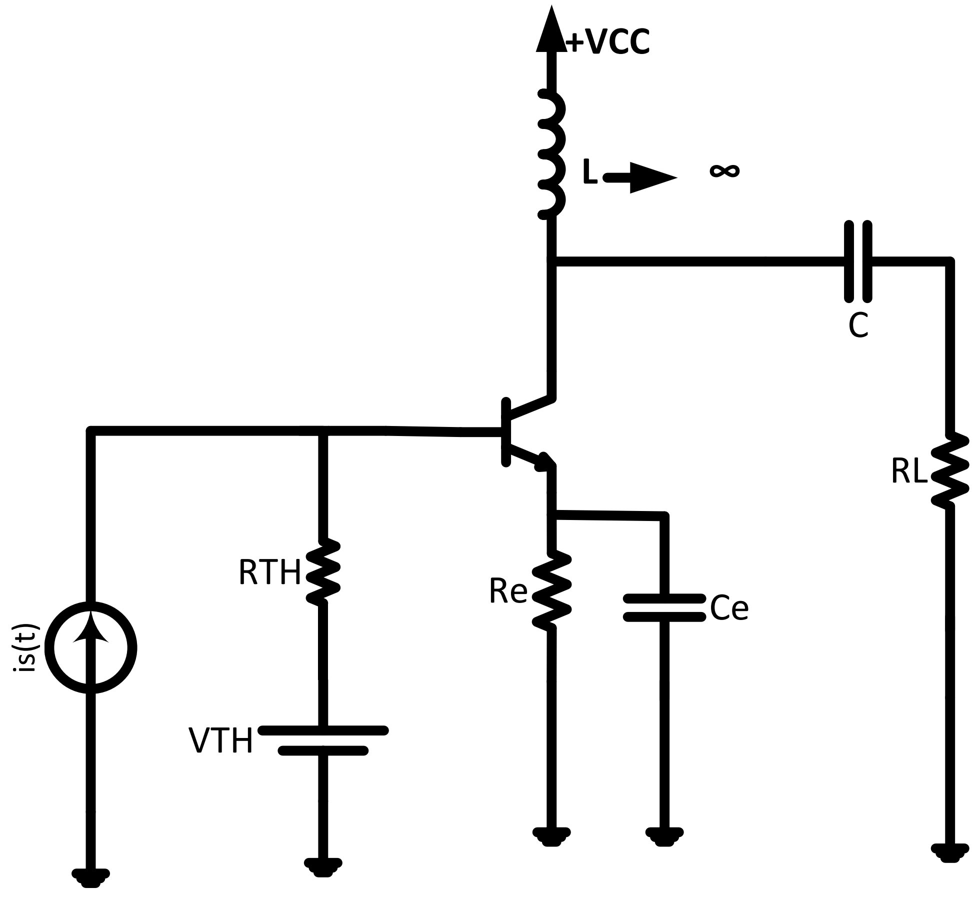
For Maximum Symmetrical swing:

$$I_{CQ} = \frac{V_{cc}}{(R_{ac+}R_{dc})}$$

$$R_{ac} = Rl$$

$$R_{dc} = R_e$$

$$I_{CQ} = \frac{V_{cc}}{(R_{l+}R_e)}$$



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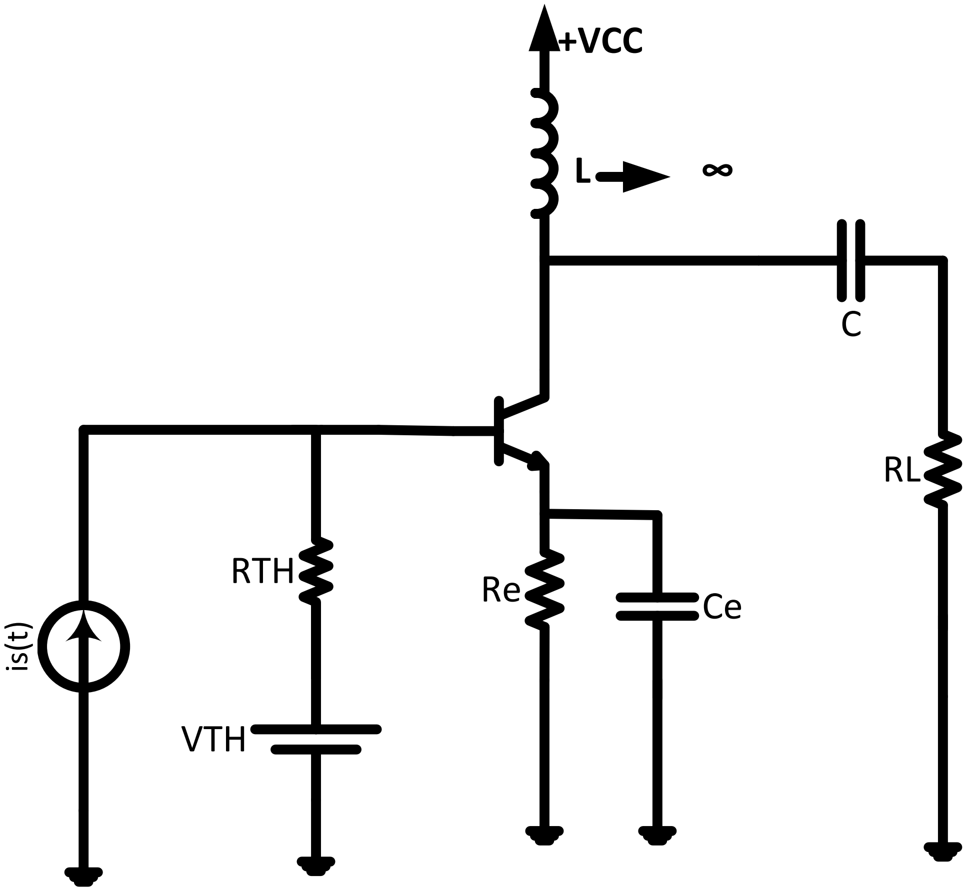

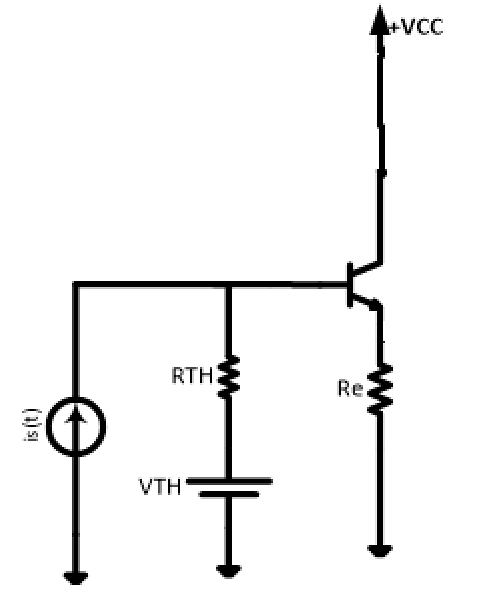

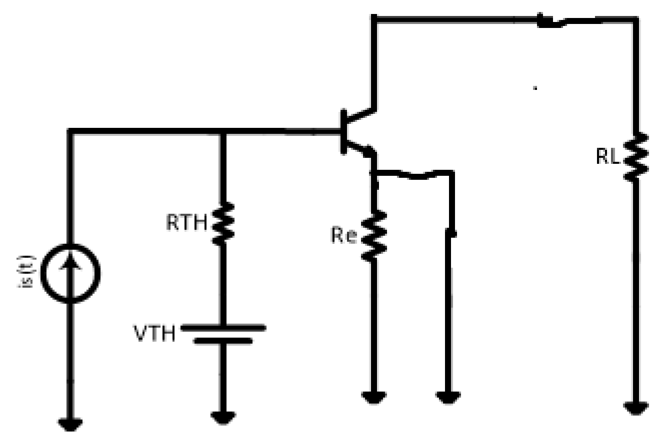

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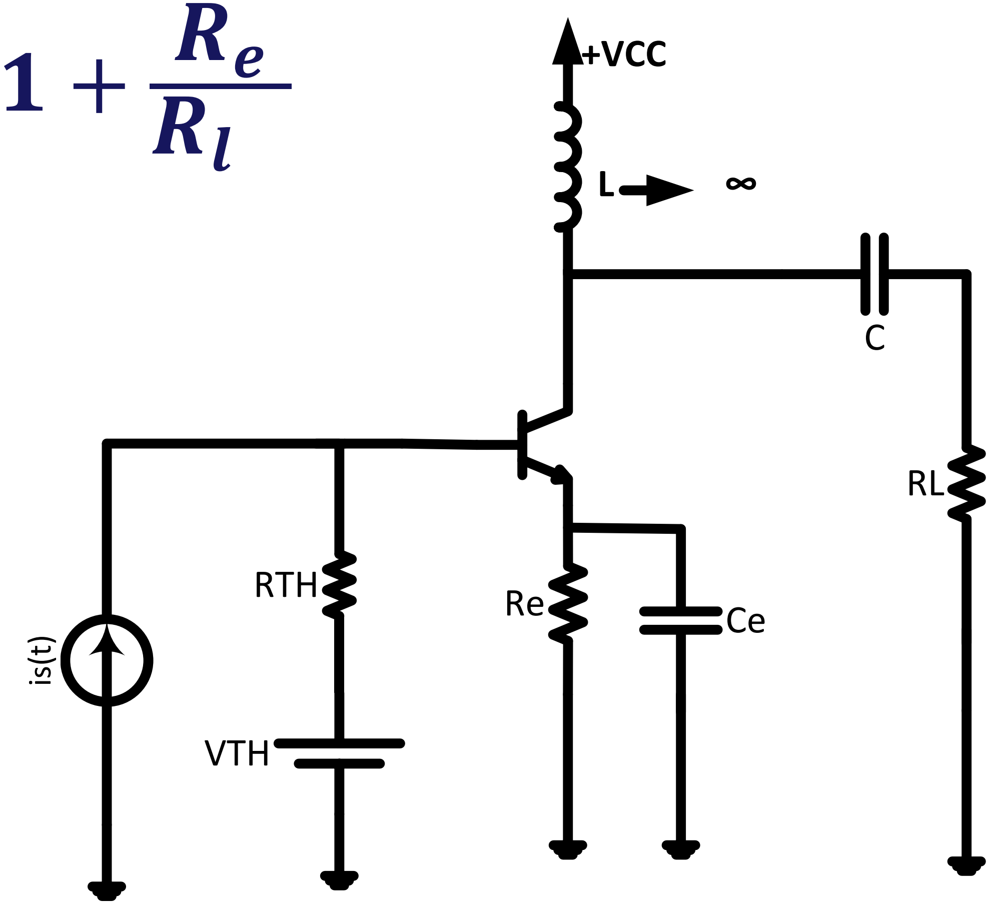
The Class A Common Emitter Power Amplifier with Choke

$$V_{CEQ} = R_{ac} * I_{CQ} = \frac{V_{cc}}{1 + \frac{R_e}{R_l}}$$



If $R_e << R_l$

$$I_{CQ} = \frac{V_{cc}}{R_l}$$

$$V_{CEQ} = V_{cc}$$

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Power Calculation:

$$I_{CQ} = \frac{V_{cc}}{R_l}$$

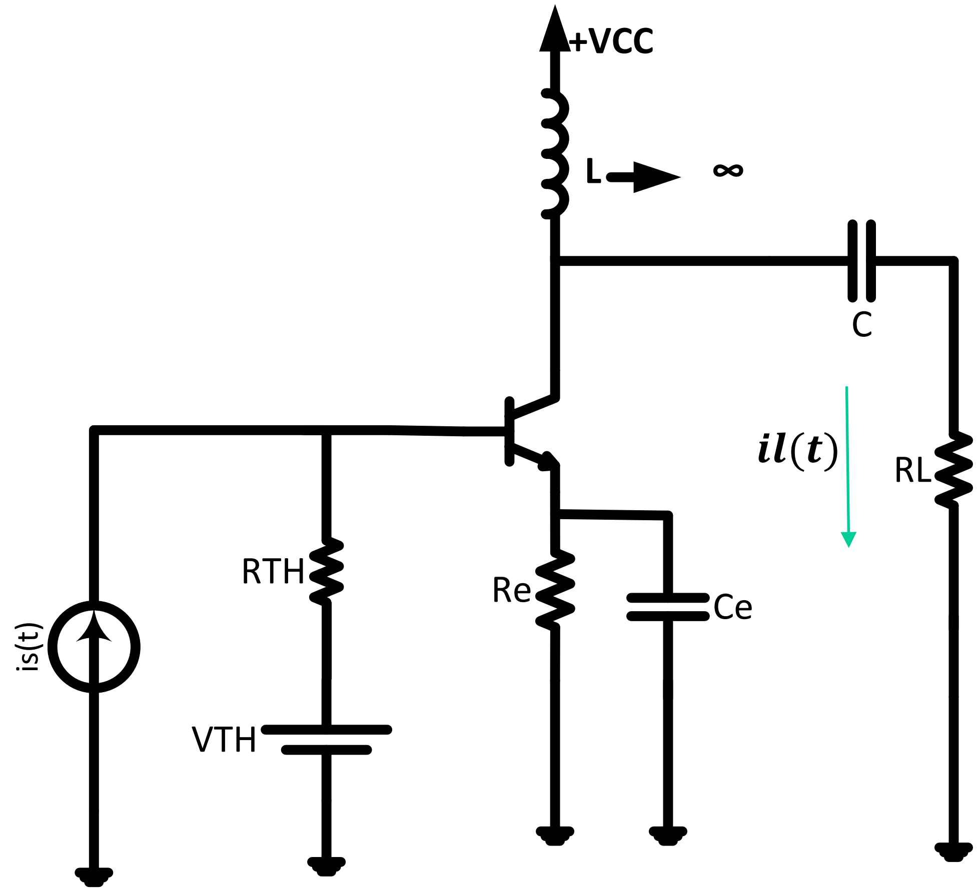
$$V_{CEQ} = V_{cc}$$

$$P_{l,ac} = \frac{1}{2} {I_{lm}}^2 R_l$$

$$= \frac{1}{2} {I_{cm}}^2 R_l$$

$$(P_{l,ac})_{,max} = \frac{1}{2} {I_{CQ}}^2 R_l$$

$$(P_{l,ac})_{,max} = \frac{{V_{cc}}^2}{2R_l}$$



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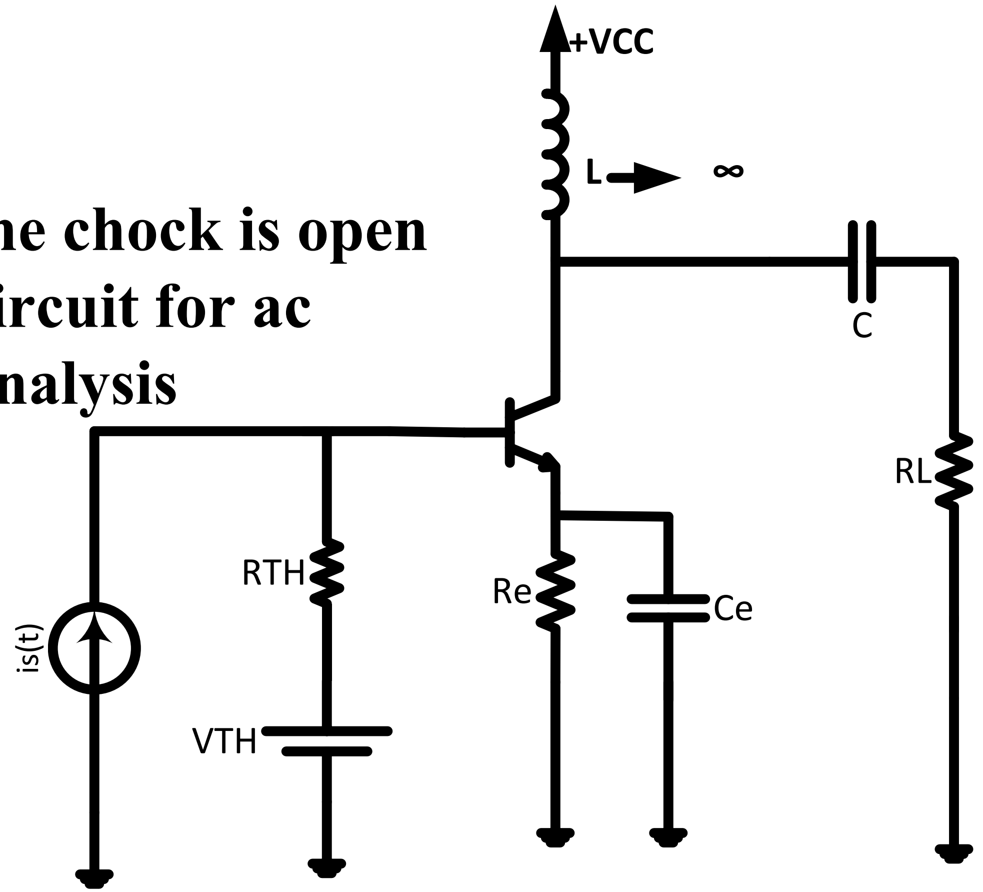
Power Calculation:

$$P_{cc} = \frac{1}{T}\int_0^T V_{cc}\, i_{CC}(\text{t})\text{dt}$$

$$i_{CC}(\text{t}) = I_{CQ}$$

the chock is open circuit for ac analysis



$$P_{cc} = V_{cc}I_{CQ} = \frac{{V_{cc}}^2}{R_l}$$

$$P_c = P_{cc} - P_l$$

$$P_c = \frac{{V_{cc}}^2}{R_l} - \frac{1}{2}{I_{cm}}^2 R_l$$

$$P_{c\,,max} = \frac{{V_{cc}}^2}{R_l} = P_{cc}$$

$$P_{cc} = P_{c\,max} = V_{CEQ}I_{CQ}$$

Prove ??

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Efficiency:

$$\eta = \frac{P_{l,ac}}{P_{cc}} \ *100\%$$

$$I_{cm}\ , max = I_{CQ}$$

$$\eta = \frac{\frac{{I_{cm}}^2 R_l}{2}}{V_{cc} I_{CQ}} \ *100\%$$

$$\eta\ max = 50\%$$

$$\gamma = \frac{P_{c\ max}}{(P_{l,ac})\ , max}$$

$$\eta = \frac{\frac{{I_{cm}}^2 R_l}{2}}{{I_{CQ}}^2 * R_l} \ *100\%$$

$$\boxed{\gamma = 2}$$

$$\eta = \frac{1}{2} \left(\frac{I_{cm}}{I_{CQ}}\right)^2 *100\%$$

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Transistor Ratings:

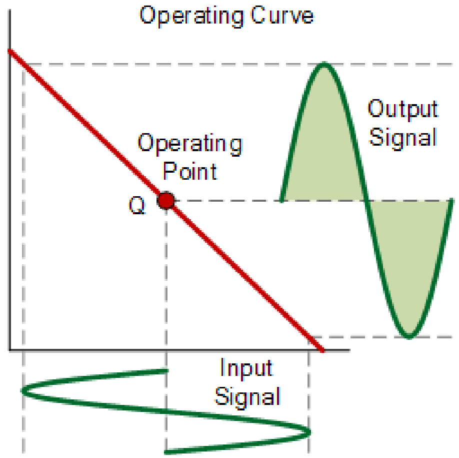
$$i_C(\mathrm{t})\,,\mathbf{max}$$

$$V_{CE}\,(t), max = \beta V_{CEO}$$

$$P_{C,max} = V_{CEQ}\,.\,I_{CQ}$$

$$2I_{CQ} < i_C(t),\ \mathbf{max}$$

$$2V_{CEQ} < \ \beta V_{CEO}$$



Maximum Symmetrical swing

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Transistor Ratings:

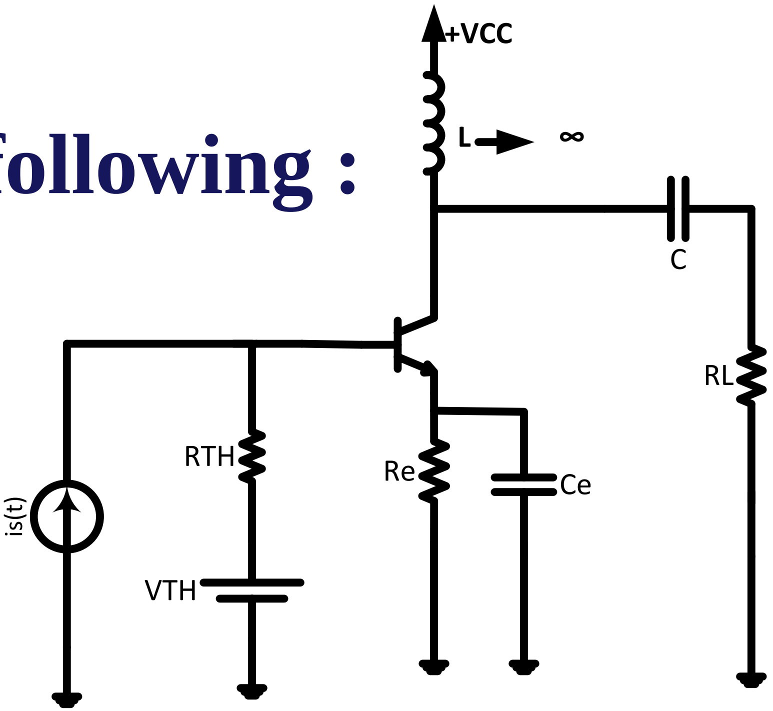
EXAMPLE:

A Power Transistor has the following :

BVCEO = 40V

$i_C(t)\,, max = 2\text{A}$

Pc , max = 4W



Determine the Q point so that the maximum power dissipated by a 10 Ω load

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Solution :

$$\text{Pc , max} = V_{CEQ} \, . \, I_{CQ} \qquad (P_{l,ac})\,,\,max = \frac{1}{2} {I_{CQ}}^2 R_l = 2\text{W}$$

$$V_{CEQ} = \text{Rac} \, . \, I_{CQ} = R_l . \, I_{CQ} \qquad P_{cc} = V_{cc} I_{CQ} = 4\text{W}$$

$$I_{CQ} = \sqrt{\frac{P_{c\,max}}{R_l}} = 0.63\ A \qquad \eta_{,max} = 50\%$$

$$V_{CEQ} = \sqrt{Pc, \text{max}. R_l} = 6.3\text{V}$$

$Is \qquad 2V_{CEQ} < \beta V_{CEO} = 40\text{V}$ Yes

Is $\qquad 2I_{CQ} < i_c(t)\ \text{max} = 2\text{A}$ Yes

$$\text{Vcc} = V_{CEQ} = 6.3\ \text{V}$$

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Transistor Ratings:

Let us consider the same Problem , But with ic(t),max = 1A

Solution:

$$I_{CQ} = \sqrt{\frac{P_{c\,max}}{R_l}} = 0.63\ A$$

$$V_{CEQ} = \sqrt{Pc, max. RL} = 6.3\ \text{V}$$

Is $2I_{CQ} < i_c(t)$ **max = 1A** **N0**

There is A problem !

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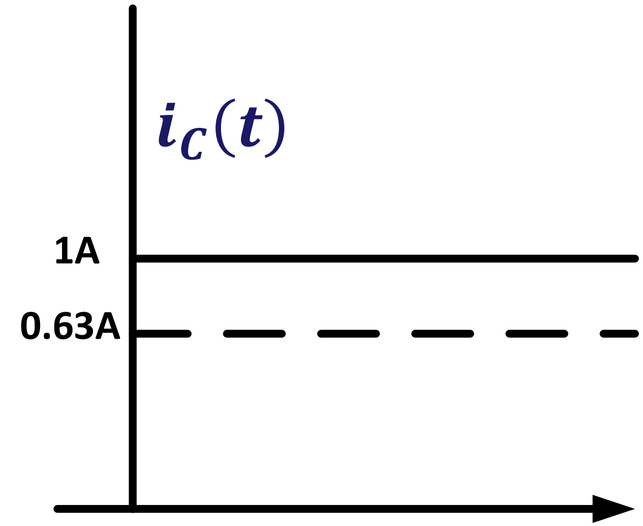
a) If the Q point left unchanged



V_{CEQ} = 6.3V Vcc = 6.3V

ICQ = 0.63 A

$I_{cm\,,\,max} = \ 0.37\ A$

(PL,ac),max = $\frac{1}{2} I_{cm,max}{}^2 R_l$ = 0.69 W

Pcc = Vcc*ICQ = 4W

$\eta_{,max} = 17.25\%$

Pc,max = V_{CEQ} . ICQ = 4W

$\gamma = 5.8$

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Second solution

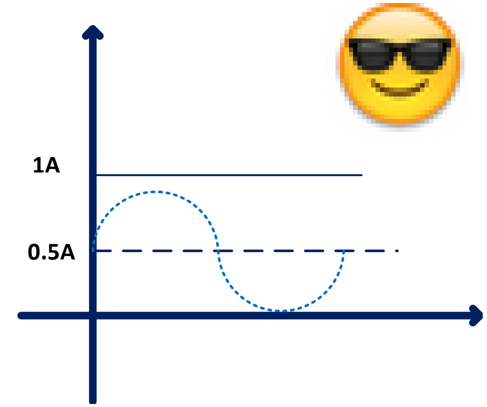
Let us consider the same Problem , But with ic(t),max = 1A

b) If we let ICQ = 0.5 $i_C(t)$,max ⟹ ICQ = 0.5 A

∴ Icm,max = 0.5 A

$(P_{l,ac})\ ,\ _{max} = \frac{1}{2} {I_{CQ}}^2 R_l$ = 1.25 W

$\eta_{,max} = 50\%$



V_{CEQ} = Rac . ICQ = 5V

Vcc = V_{CEQ} = 5V

Pc,max = VCEQ*ICQ = 2.5W

$\gamma = 2$

PCC = VCC ICQ = 2.5W

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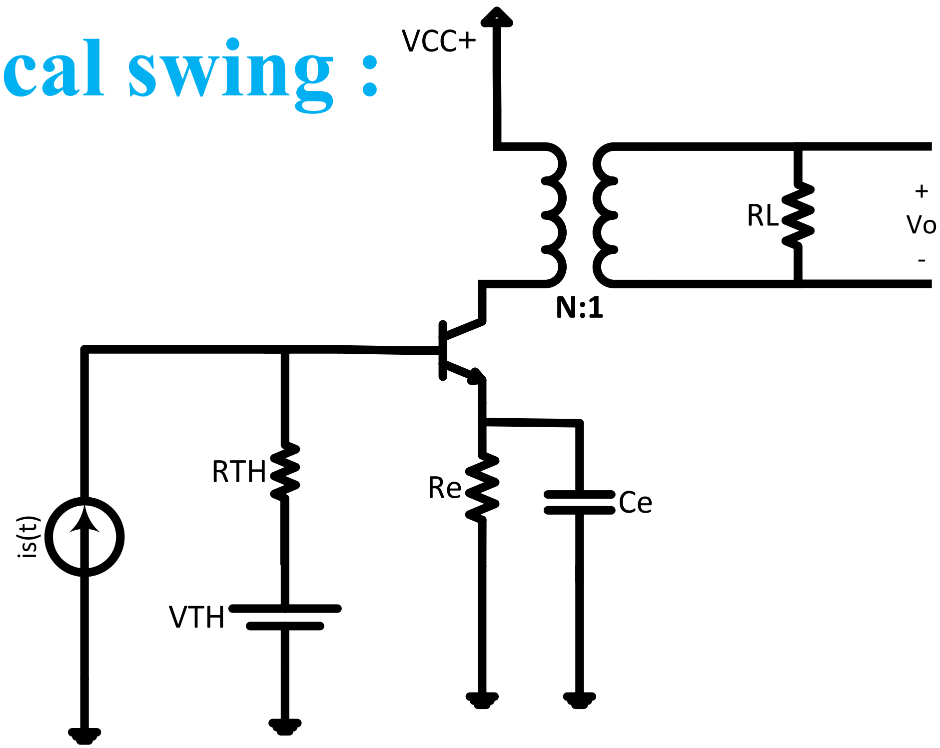
Transformer coupled class A Power Amplifier:

For Maximum symmetrical swing :

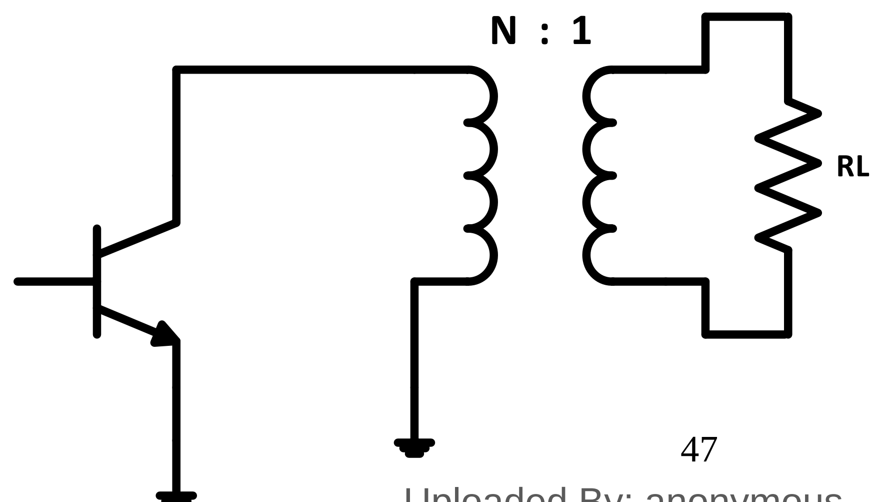


$$I_{CQ} = \frac{V_{cc}}{R_{ac+}\ R_{dc}}$$

$$R_{ac} = N^2 R_l = \text{RL}'$$

$$R_{dc} = R_e$$

$$I_{CQ} = \frac{V_{cc}}{\text{RL}' + R_e}$$



$$If \quad R_e << R_l'$$

$$I_{CQ} = \frac{V_{cc}}{R_{l'}}$$

$$V_{CEQ} = Rac\ * ICQ = V_{cc}$$

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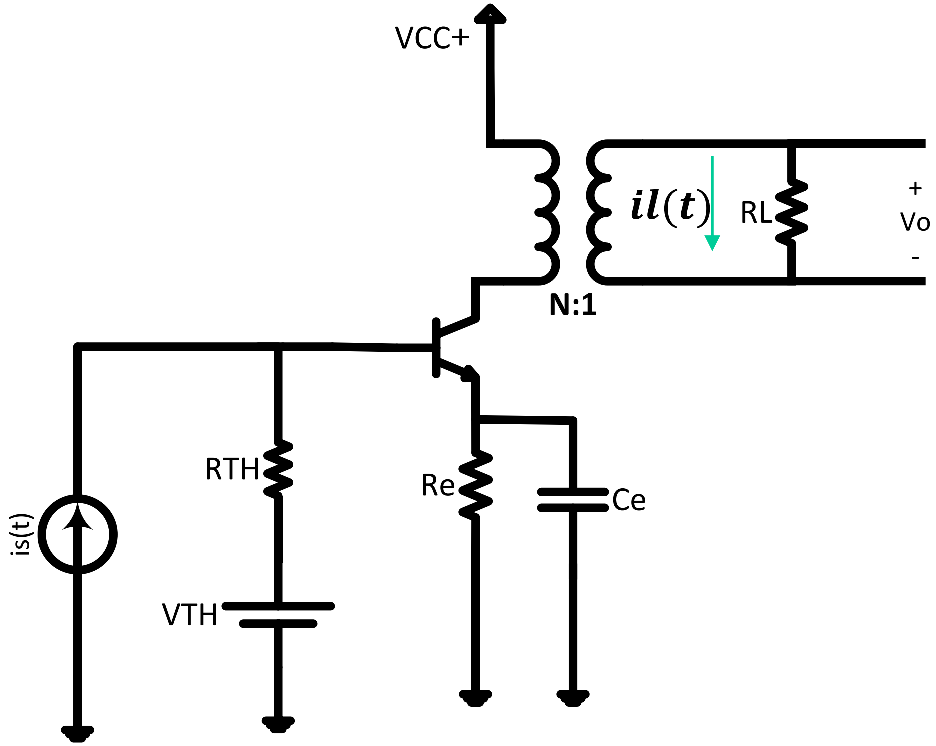
Power Calculation:



$$P_{(l,ac)} = \frac{1}{2} I_{lm}{}^{2} R_l$$

$$I_{lm} = N \cdot Icm$$

$$\therefore PL.ac = \frac{1}{2} I_{cm}{}^{2} R_l'$$

$$(PL.ac),max = \frac{1}{2} I_{cm,max}{}^{2} R_l'$$

$$(PL.ac),max = \frac{1}{2} I_{CQ}{}^{2} R_l'$$

$$P_{(l,ac),max} = \frac{V_{cc}{}^{2}}{2R_l{}'}$$

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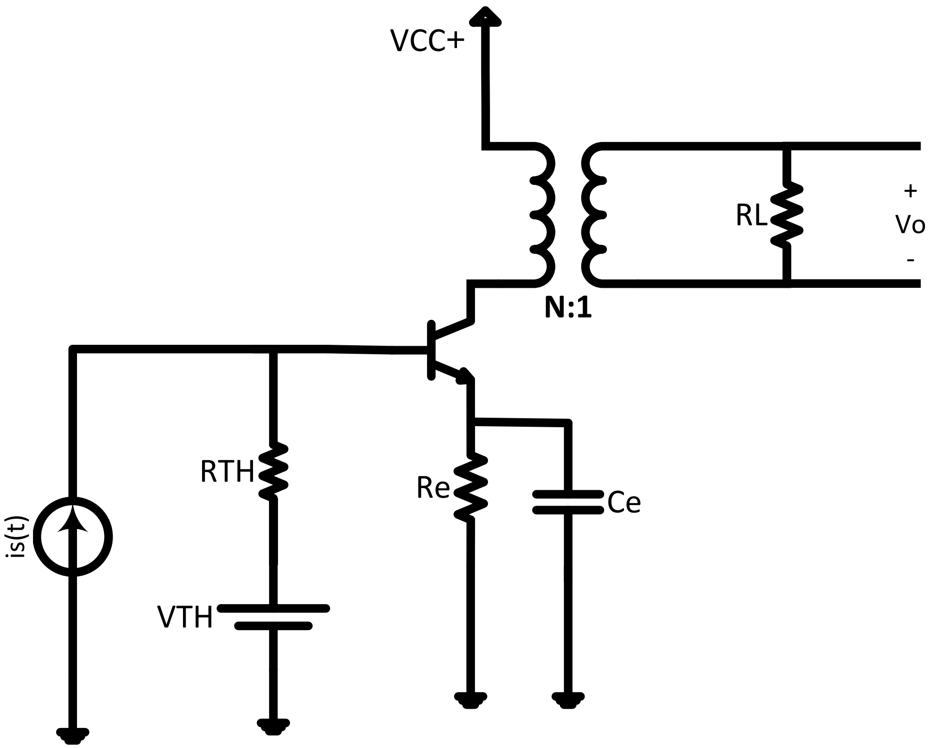
Power Calculation:

$$P_{cc} = \frac{1}{T}\int_0^T V_{cc} i_{cc}(\mathrm{t})\mathrm{dt}$$

$$i_{cc}(\mathrm{t}) = ic(t) = I_{CQ} + I_{cm}\cos\omega t$$

$$P_{cc} = V_{cc}I_{CQ} = \frac{{V_{cc}}^2}{{R_l}'} = {I_{CQ}}^2 R_l'$$



$$P_c = P_{cc} - P_{l,ac}$$

$$P_c = P_{cc} - \frac{1}{2}{I_{cm}}^2 R_l'$$

$$P_{c,max} = \frac{{V_{cc}}^2}{R_l'} = P_{cc}$$

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Power Calculation:

$$\eta = \frac{P_{l,ac}}{P_{cc}} *100\%$$

$$I_{cm,}max = I_{CQ}$$

$$\boxed{\eta_{,max} = 50\%}$$

$$\eta = \frac{\frac{I_{cm}{}^2 R_l'}{2}}{I_{CQ}{}^2 * R_l'} *100\%$$

$$\gamma = \frac{P_{C,max}}{(PL, ac), max}$$

$$\eta = \frac{1}{2} \left(\frac{I_{cm}}{I_{CQ}}\right)^2 *100\%$$

$$\boxed{\gamma = 2}$$

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Ratings:

EXAMPLE:

A Power Transistor has the following :

BVCEO = 40V

Pc , max = 4W

ic(t),max = 1A

Determine the Q point so that the maximum power dissipated by a 10 Ω load.

Solution :

Pc , max = $V_{CEQ} \cdot \boldsymbol{I_{CQ}}$.

V_{CEQ} = Rac . $\boldsymbol{I_{CQ}}$

V_{CEQ} = $R_l' \cdot \boldsymbol{I_{CQ}}$

$$\boldsymbol{I_{CQ}} = \sqrt{\frac{P_{c\,max}}{R_{l'}}} = (0.63/N)\ A$$

$$V_{CEQ} = \sqrt{Pc, \max . R_l'} = (6.3\text{N})\ \text{V}$$

How to choose N ?

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The Q point must satisfy :

$2V_{CEQ} < \beta V_{CEO} = 40\text{V}$

$2V_{CEQ} = 12.6\text{N} < 40\text{ V}$ ⟹ $\mathbf{3.17 > \boldsymbol{N}}$

$2I_{CQ} < \text{ic(t) , max} = 1\text{A}$

$2I_{CQ} = (1.26/N) < 1\text{A}$ ⟹ $\boldsymbol{N > 1.26}$

$\boldsymbol{3.17 > N > 1.26}$

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a) Let N = 2

$$I_{CQ} = \frac{0.63}{2} = 0.315A$$

V_{CEQ}= 12.6 V

$$(P_{l,ac})_{max} = \frac{1}{2} I_{CQ}{}^{2} R_l{}' = 2W$$

$$P_{cc} = V_{cc} I_{CQ} = 4W$$

$$\eta_{,max} = 50\%$$

b) Let N=3

$$I_{CQ} = 0.21A$$

V_{CEQ}= 18.9 V

Vcc= 18.9 V

$$(P_{l,ac})_{max} = \frac{1}{2} I_{CQ}{}^{2} R_l{}' = 2W$$

$$P_{c,max} = V_{CEQ} I_{CQ} = 4W$$

$$\eta_{,max} = 50\%$$

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Class A Output stage Power Amplifier:

Q1 is common collector amplifier

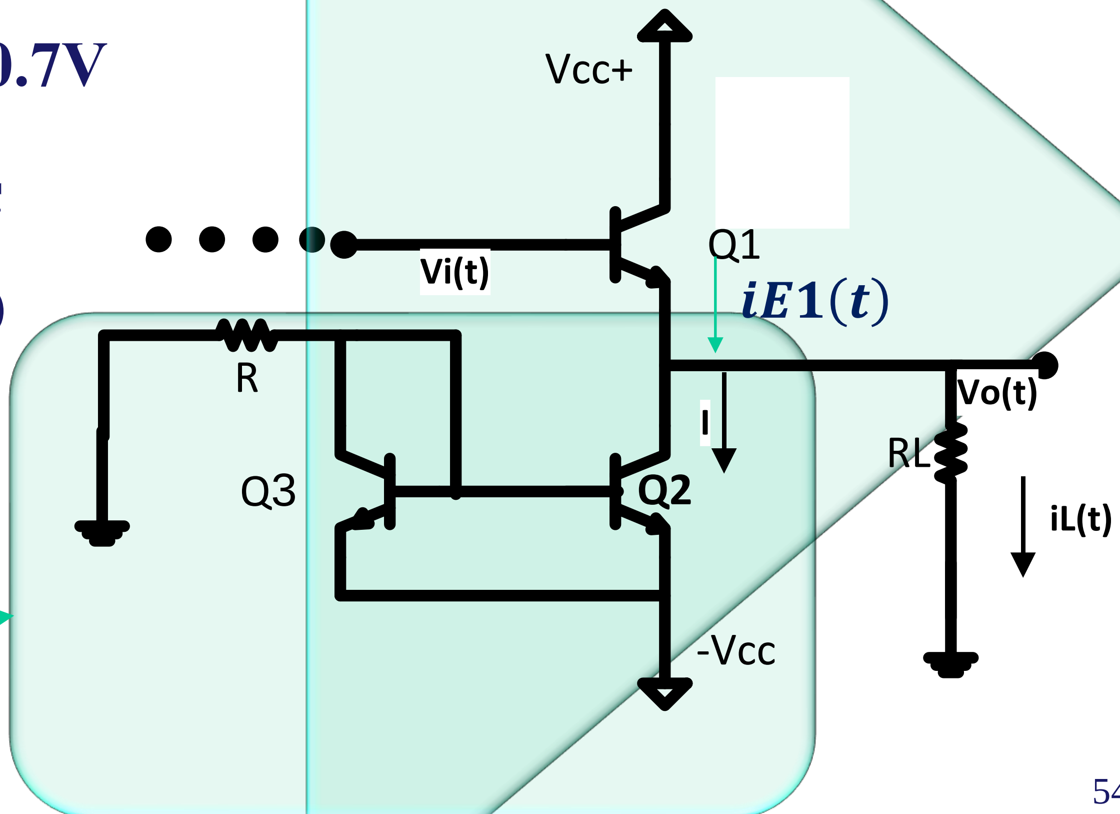
The output stage is designed so that :

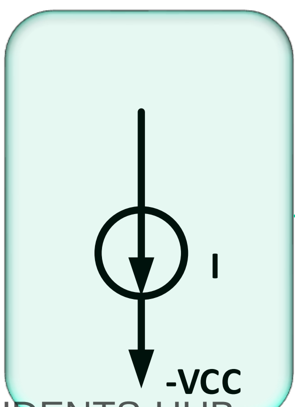
$V_o = 0$, $I_L = 0$, $V_i = 0.7V$

$I_{E1} = I$, $V_{CEQ1} = V_{CC}$

$V_o(t) = V_i(t) – V_{BE}(t)$

$V_o(t) \approx V_i(t) - V_{BE}$





Current source

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Transfer Curve:

$$Vo(t) = Vi(t) - VBE$$

$$Vo(t) = Vcc - VCE1(t)$$

$$Vo(t), max = Vcc - VCE1, sat$$

(When T1 enters Saturation)

$$Vo(t) = VCE2(t) - Vcc$$

$$Vo(t), min = VCE2, sat - Vcc$$

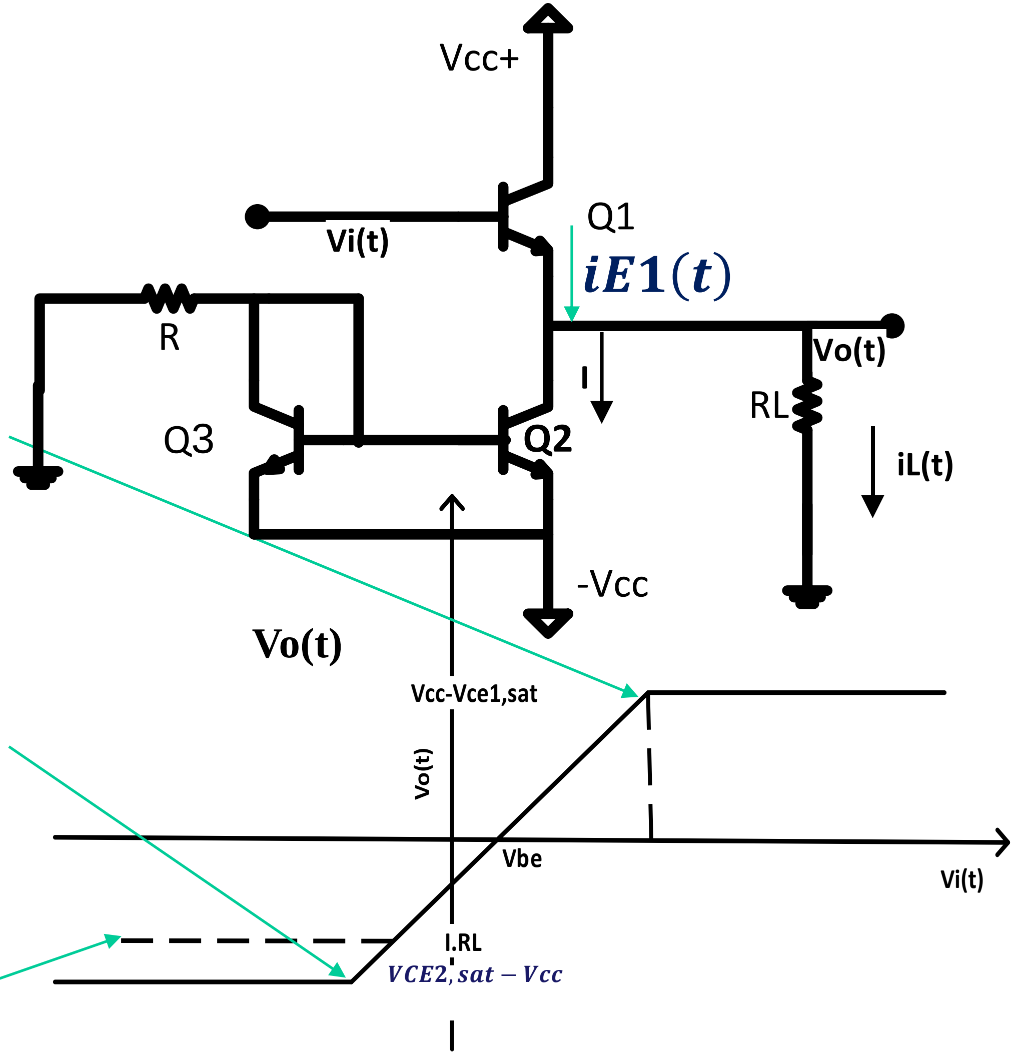
(When T2 enters Saturation)

Or:

$$Vo(t), min = -IRL$$

(When T1 enters Cuttoff)

$$iE1(t) = 0$$



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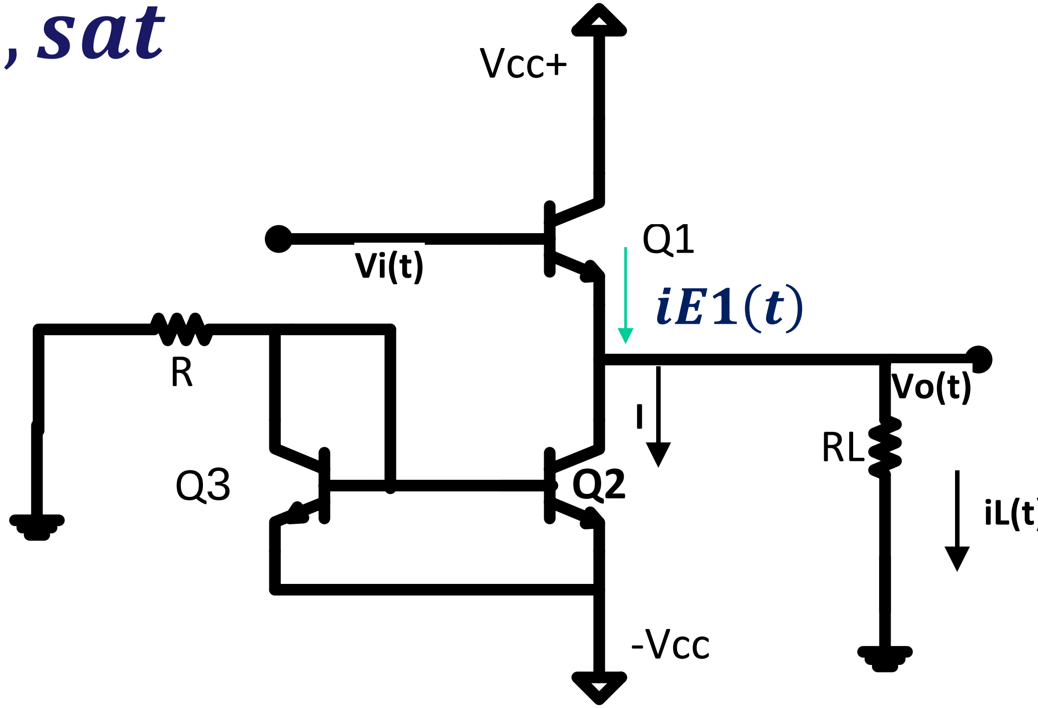
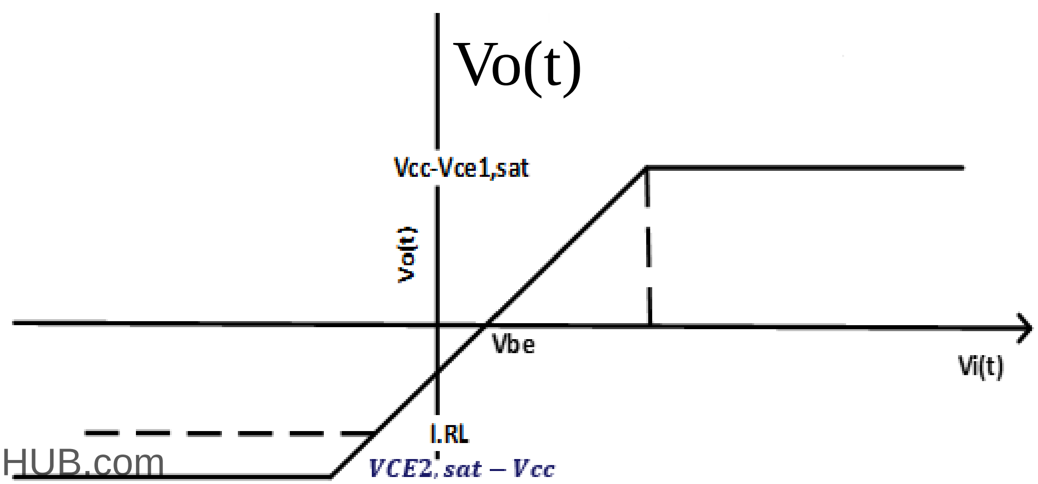
To allow Maximum symmetrical swing :

$$-IRL = -Vcc + VCE2, sat$$

$$-IRL \cong -Vcc$$

$$\therefore I = \frac{Vcc}{RL}$$





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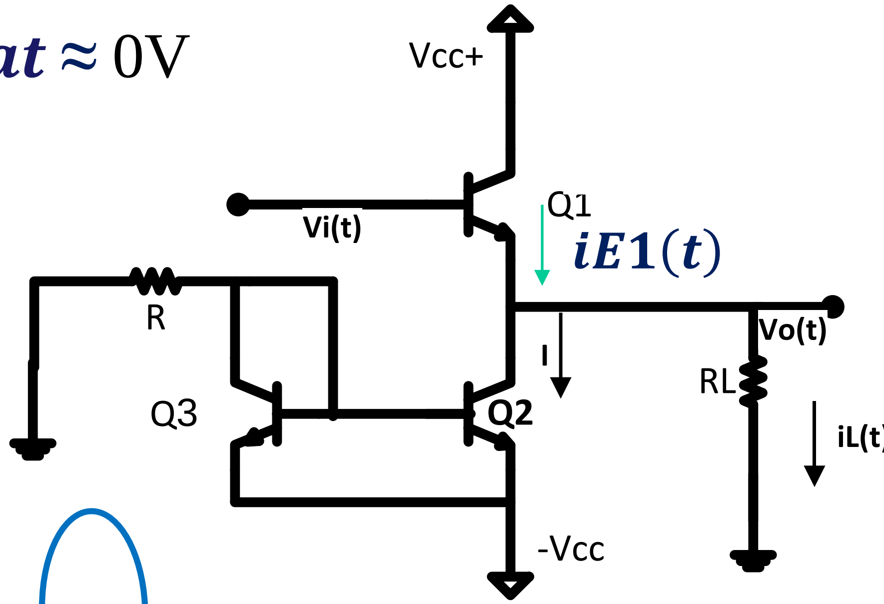
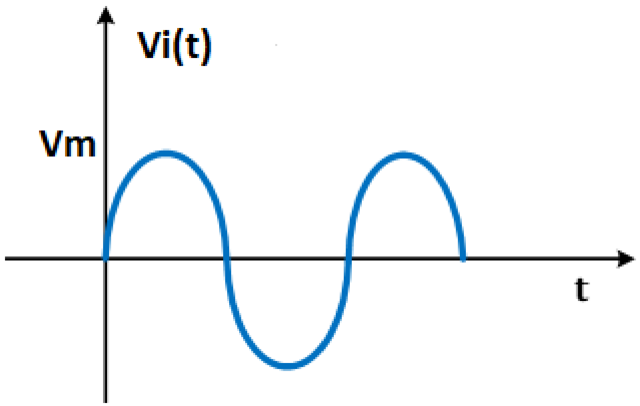
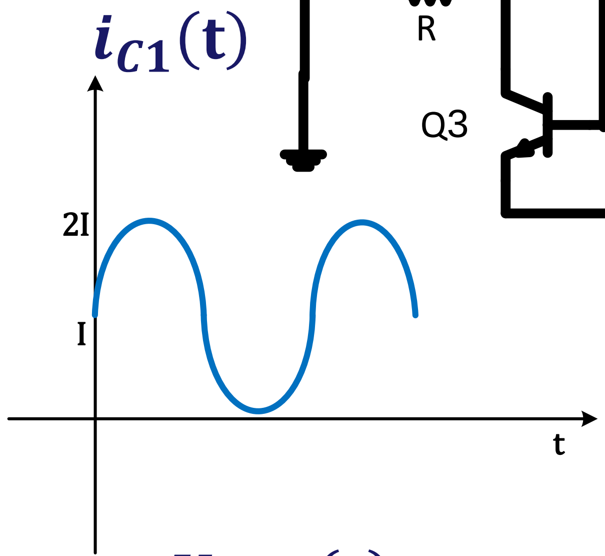
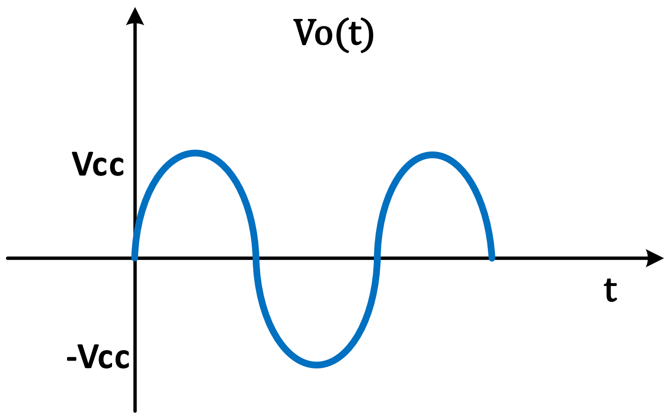
Signal Wave forms: $VCE,sat \approx 0V$

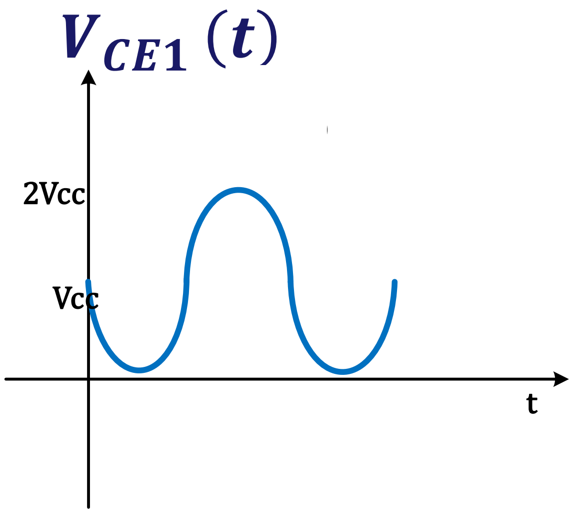
Maximum possible swing











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Signal Wave forms:

$iC1(t) \approx iE1(t)$ $VCE,sat \approx 0V$

$$iE1(t) = I + iL(t)$$

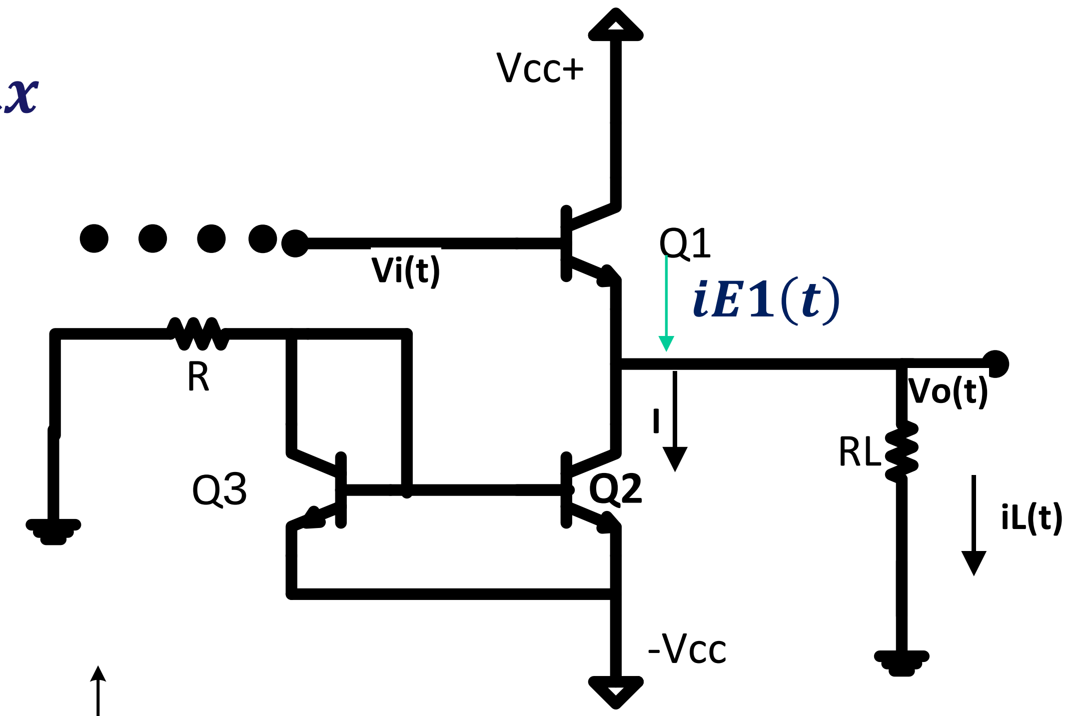
$$iE1(t),max = I + iL(t),max$$

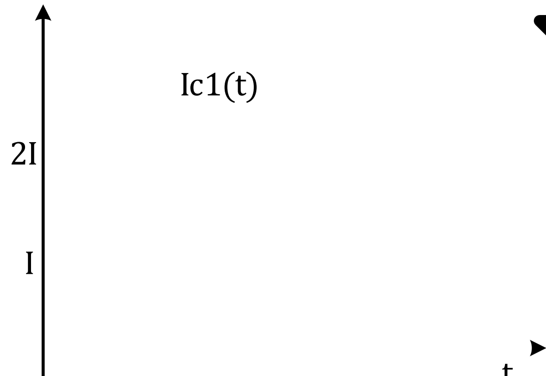
$$iE1(t),max = I + \frac{Vo(t),max}{RL}$$

$$iE1(t),max = I + \frac{Vcc}{RL}$$

$$iE1(t),max = I + I$$

$$iE1(t),max = 2I$$





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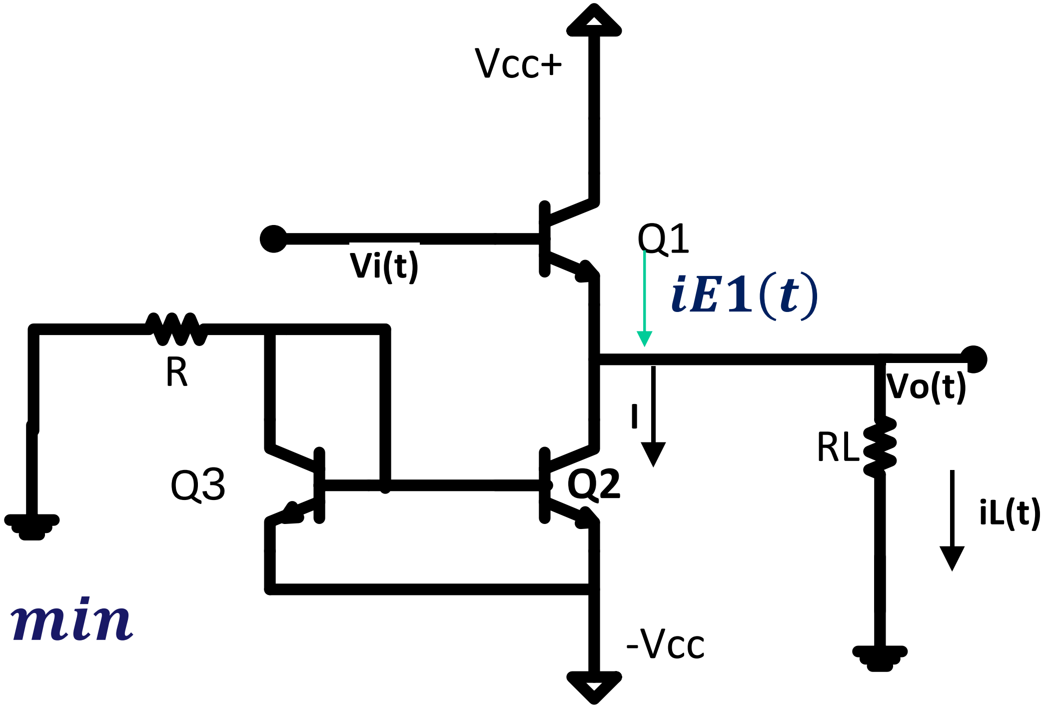
$$VCE, sat \approx 0\text{V}$$

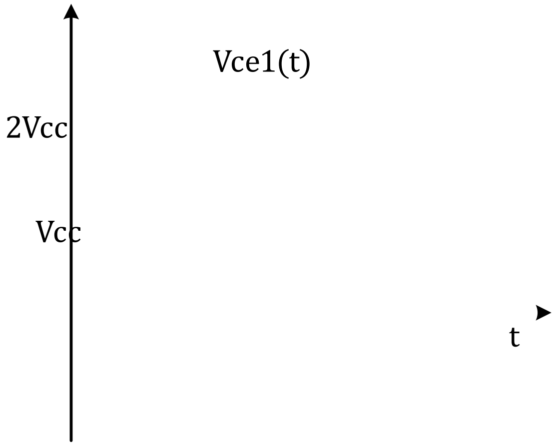


$$VCE1(t) = Vcc - Vo(t)$$

$$VCE1(t), max = Vcc - Vo(t), min$$

$$VCE1(t), max = Vcc - (-Vcc)$$

$$VCE1(t), max = 2Vcc$$



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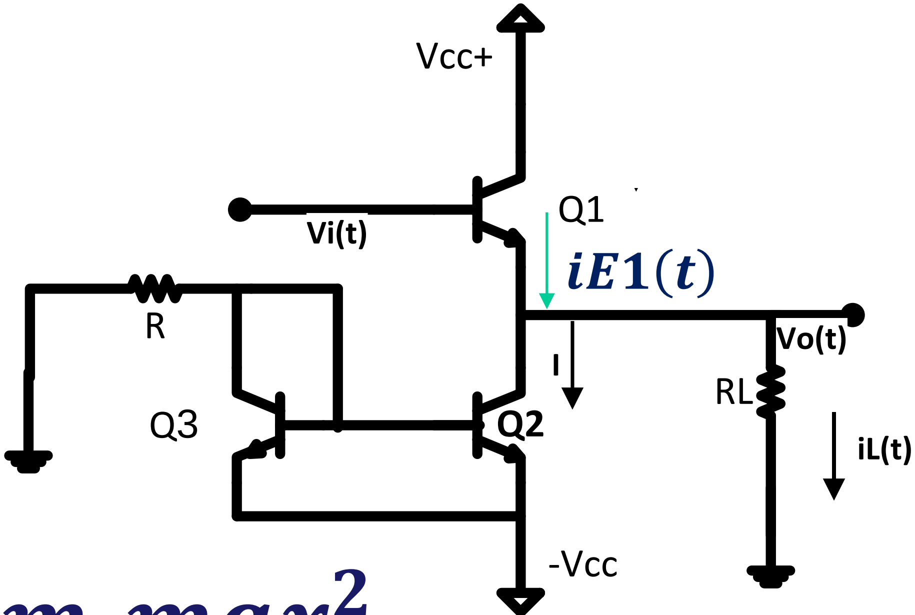
Power Calculation:



$$(PL, ac) = \frac{Vom^2}{2RL}$$

$$(PL, ac), max = \frac{Vom, max^2}{2RL} = \frac{Vcc^2}{2RL}$$

$$Pcc = Pcc1 + Pcc2$$

$$Pcc = 2Vcc * I$$

$$\eta, max = \frac{(PL, ac), max}{Pcc} * 100\%$$

$$\eta = \frac{PL, ac}{Pcc} * 100\%$$

$$\eta, max = 25\%$$

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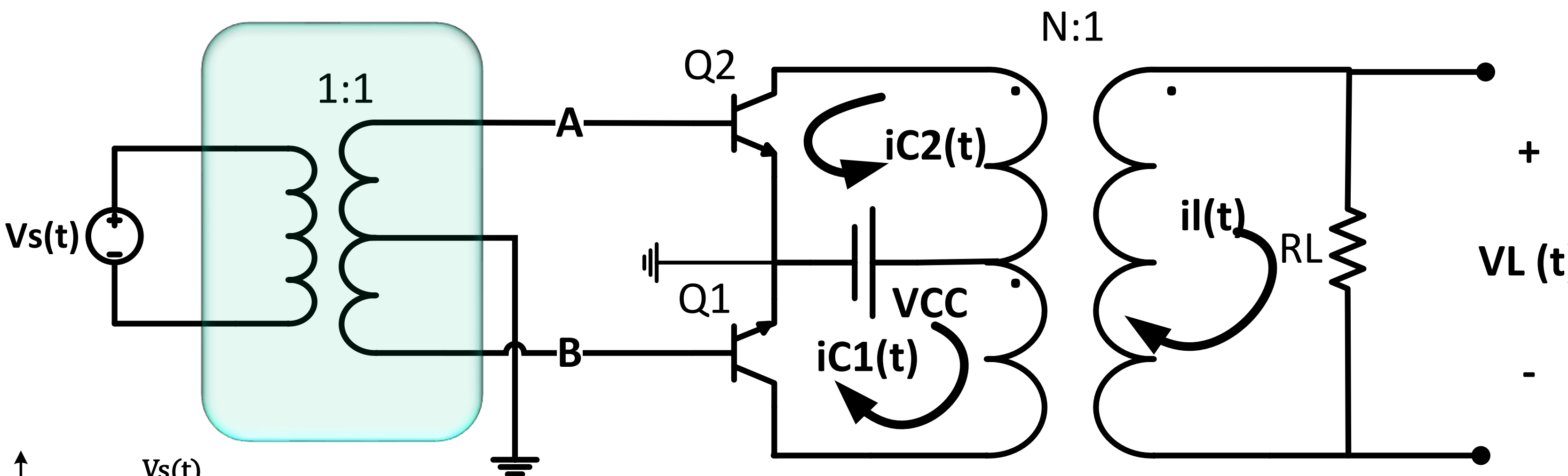
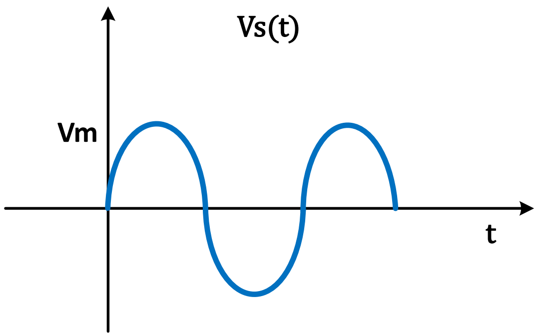
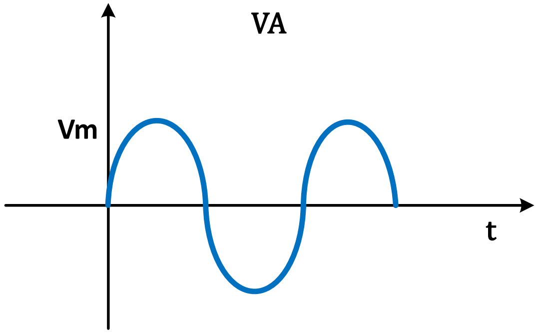
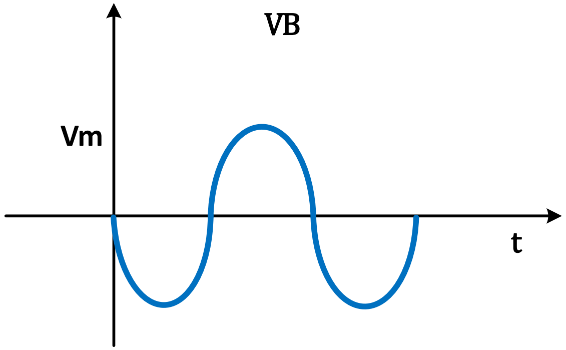
Class B Push-Pull Power Amplifier:









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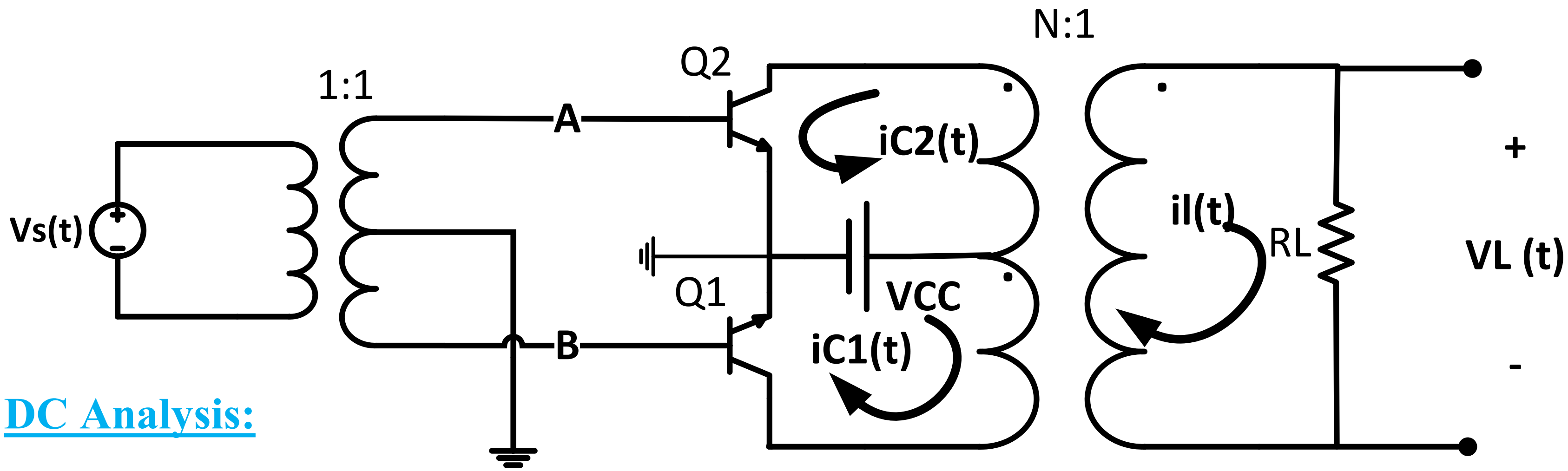
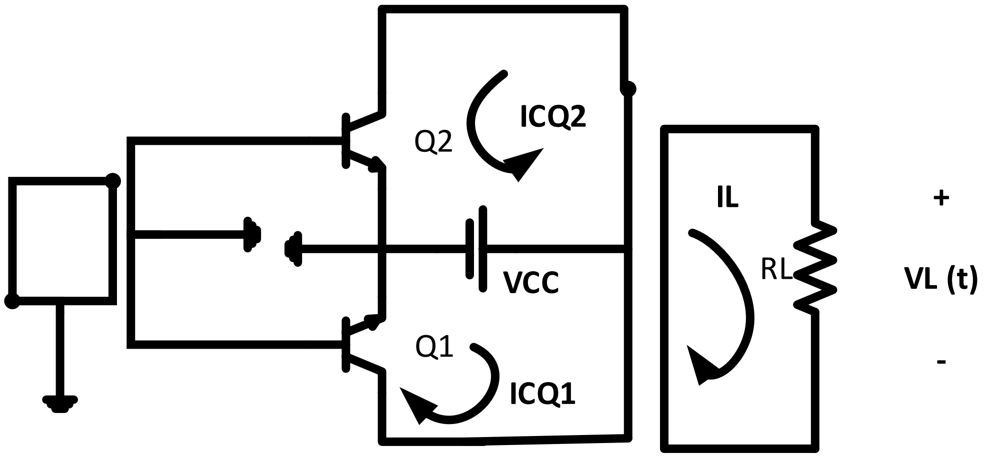
Class B Push-Pull Power Amplifier:



DC Analysis:



$$V_{BE1} = V_{BE2} = 0$$

$$Q_1 \ and \ Q_2 \ \ are \ cut \ off$$

$$I_{CQ1} = I_{CQ2} = 0$$

$$V_{CEQ1} = V_{CEQ2} = V_{cc}$$

$V_L = 0 \quad I_L = 0$

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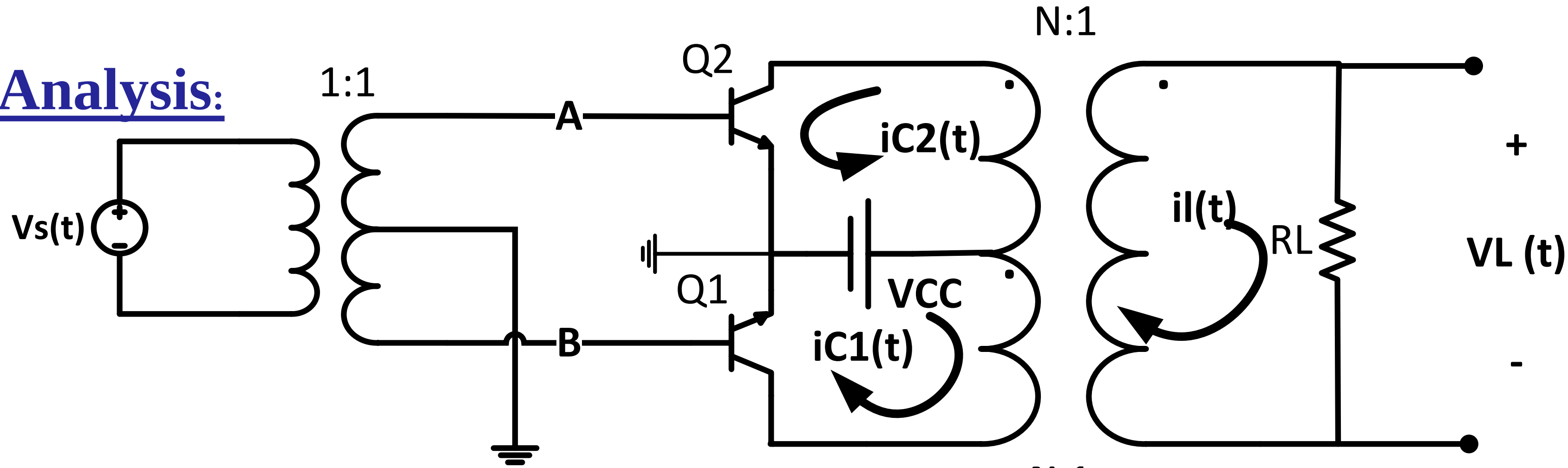
Class B Push-Pull Power Amplifier:

AC Analysis:



$$a)\ when\ v_s(t) > 0$$

$$v_A(t) > 0\ ; \quad Q_2\ is\ on$$

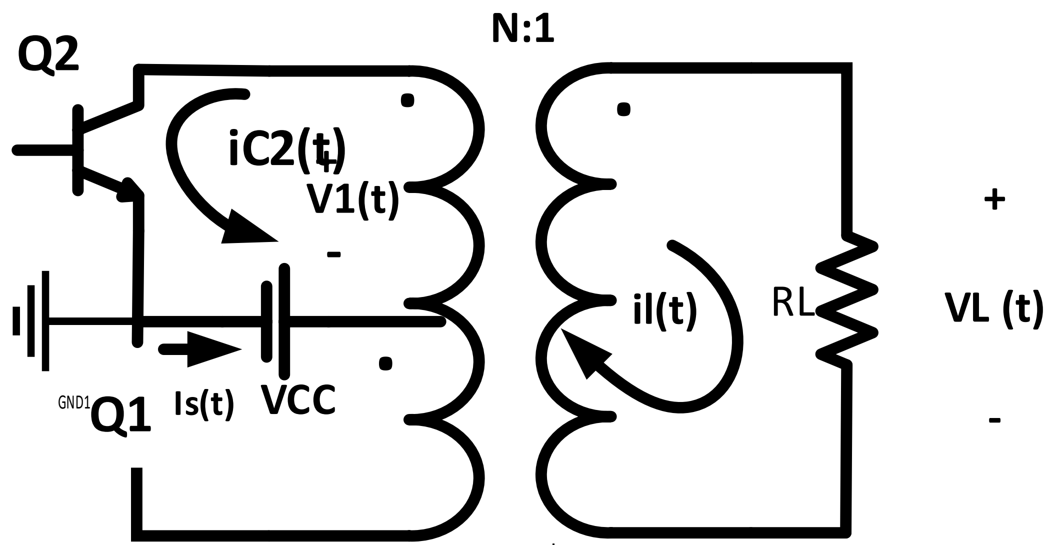
$$v_B(t) < 0\ ; \quad Q_1\ is\ off$$

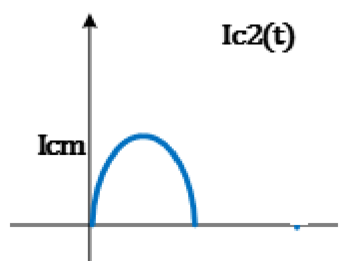
$$\therefore\ i_L(t) = \ -N i_{C2}(t)$$

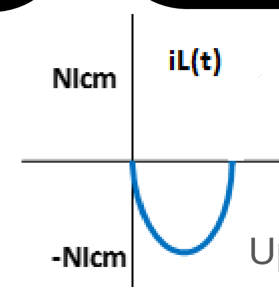
$$and$$

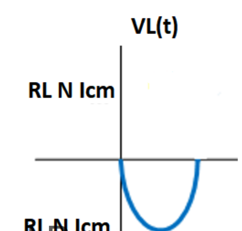
$$i_s(t) = i_{C2}(t)$$

$$v_L(t) = R_L\ i_L(t)$$









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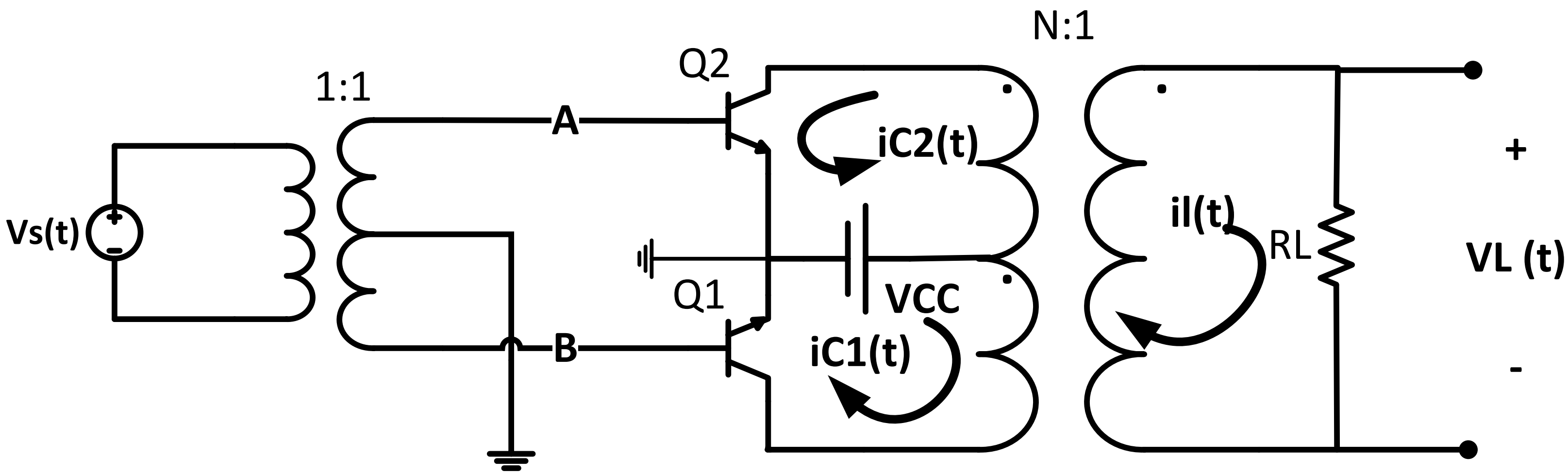


$$b)\ when\ v_s(t) < 0$$

$$v_A(t) < 0\ ;\quad Q_2\ is\ off$$

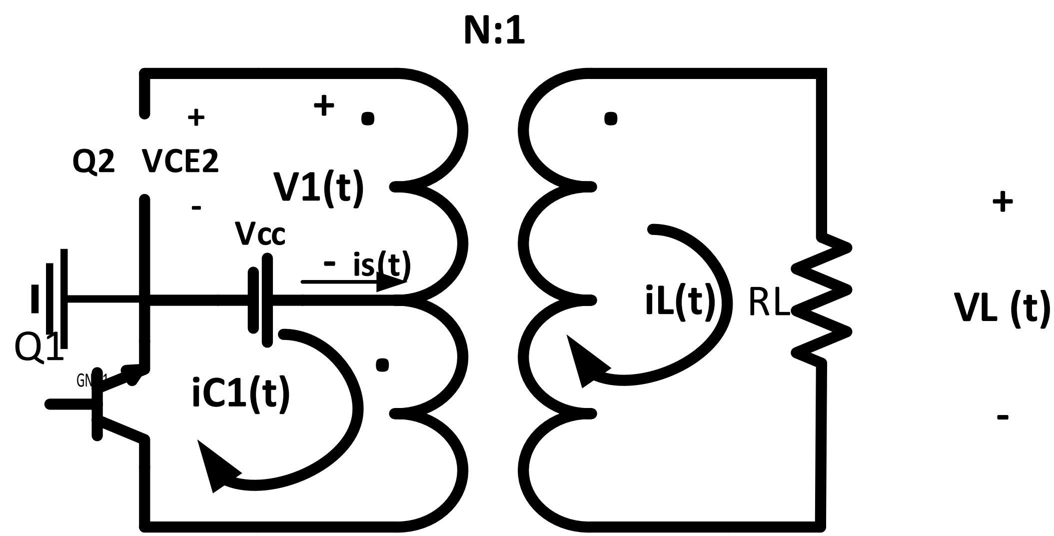
$$v_B(t) > 0\ ;\quad Q_1\ is\ on$$

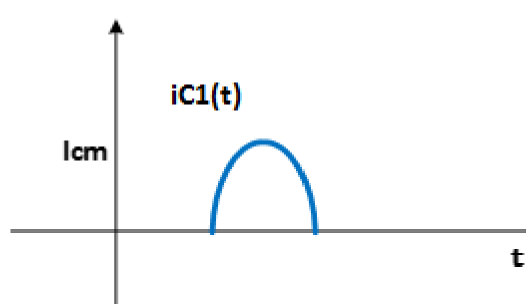
$$\therefore\ i_L(t) = \ +N\ i_{C1}(t)$$

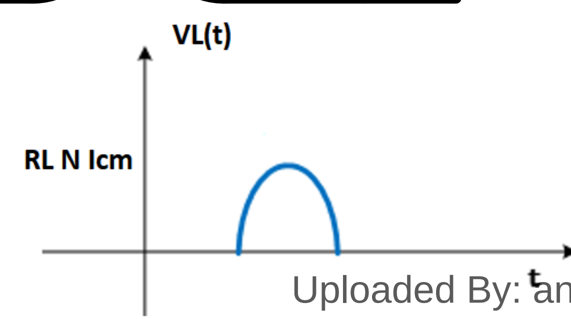
$$and$$

$$i_s(t) = \ i_{C1}(t)$$

$$v_L(t) = R_L\ i_L(t)$$







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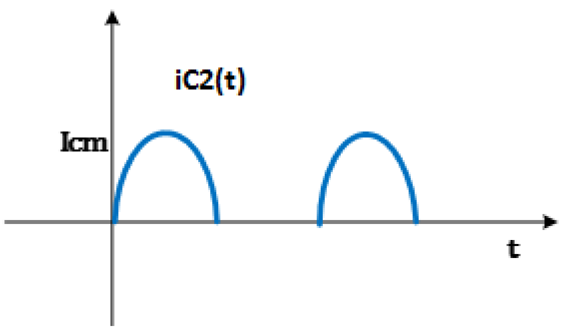
Class B Push-Pull Power Amplifier:

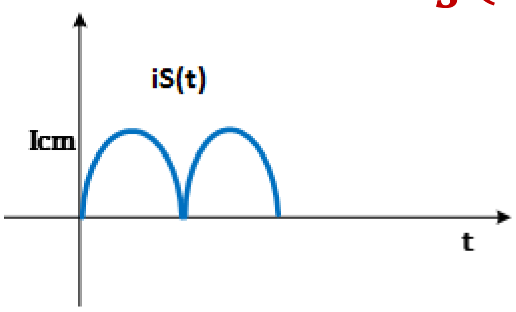
AC Analysis:

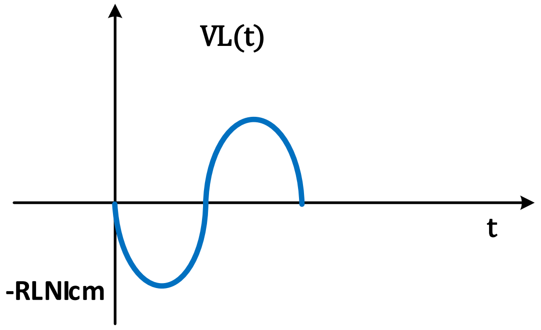
$c)\ for\ the\ complete\ cycle$

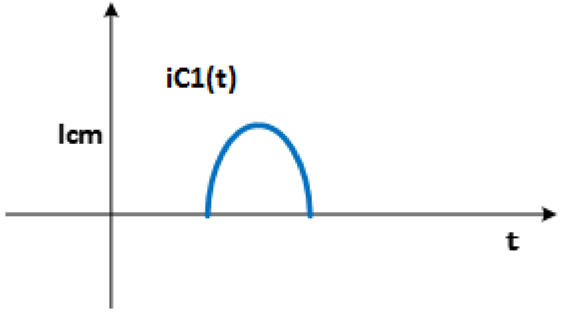
$$i_L(t) = N\left(i_{C1}(t) - i_{C2}(t)\right)$$

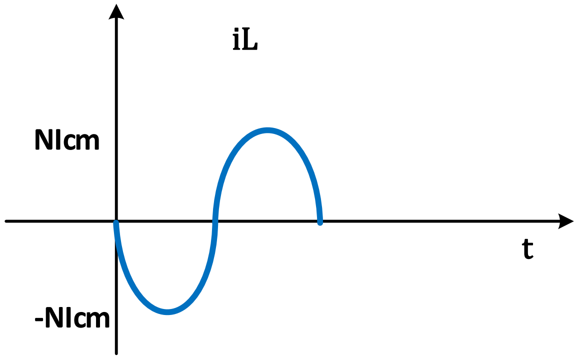
$$i_s(t) = i_{C2}(t) + i_{C1}(t)$$











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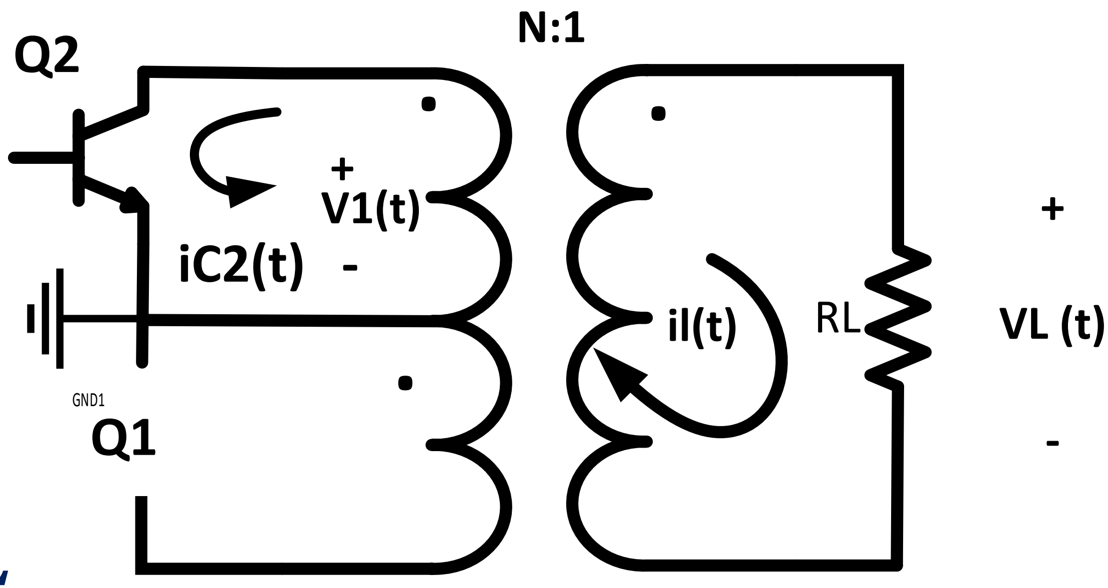
Class B Push-Pull Power Amplifier:

AC Load Line for Q2:



$$1)\ when\ v_s(t) > 0$$

$$v_A(t) > 0\ ;\quad Q_2\ is\ on$$

$$v_B(t) < 0\ ;\quad Q_1\ is\ off$$

$$R_l' = N^2 RL$$

$$v_{ce2} = -R_l' i_{c2} = -\left(N^2 R_L\right) i_{c2}$$

$$v_{CE2}(t) - V_{CEQ2} = -R_l'(i_{C2}(t) - I_{CQ2})$$

$$v_{CE2}(t) - V_{CEQ2} = -R_l' i_{C2}(t)$$

$$v_{CE2}(t) - V_{CC} = -R_l' i_{C2}(t)$$

$$V_{CC} - v_{CE2}(t) = R_l' i_{C2}(t)$$

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Class B Push-Pull Power Amplifier:

To find $i_{C2}(t)_{,max}$

$\rightarrow v_{CE2}(t) = v_{CE2,sat} = 0$

$$V_{CC} - 0 = R_l' i_{C2}(t)_{,max}$$

$$i_{c2}(t)_{,max} = \frac{V_{cc}}{R_l'}$$

$$I_{cm2,max} = \frac{V_{cc}}{R_l'}$$

To find $v_{CE}(t)_{,max}$

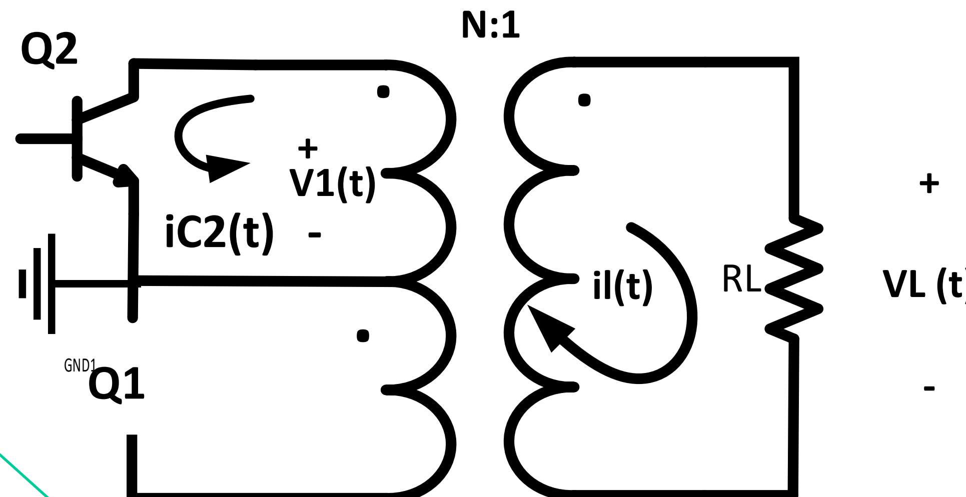
$\rightarrow i_{C2}(t) = 0$

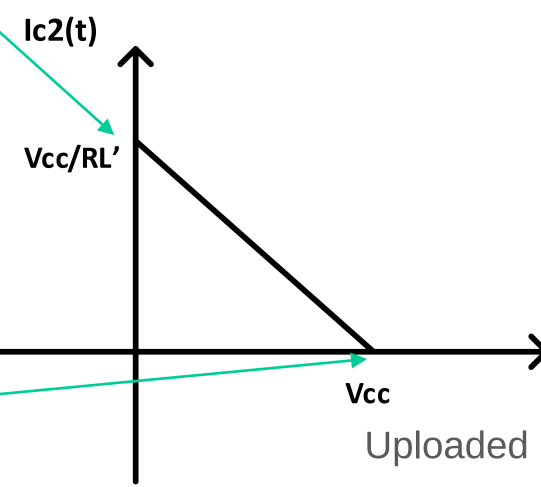
$$v_{CE2}(t)_{,max} - V_{cc} = 0$$

$$v_{CE2}(t)_{,max} = V_{cc}$$

AC Load Line for Q2:

$$V_{CC} - v_{CE2}(t) = R_l' i_{C2}(t)$$





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$$i_{c2}(t)_{,max} = \frac{V_{cc}}{R_l'}$$

$$I_{cm2,max} = \frac{V_{cc}}{R_l'}$$

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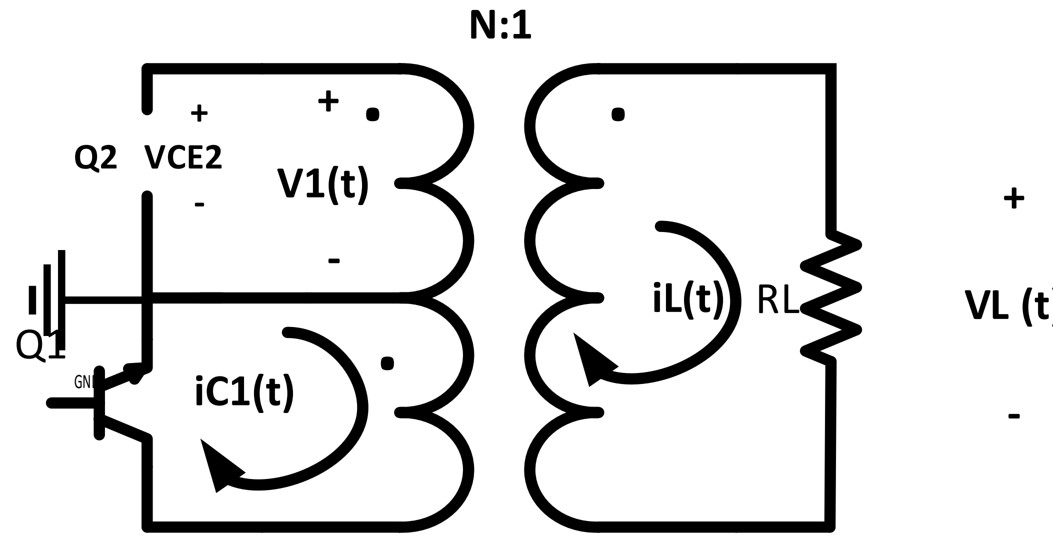
Class B Push-Pull Power Amplifier:

AC Load Line for Q2:

$$when\ v_s(t) < 0$$

$$v_A(t) < 0\ ; \quad Q_2\ is\ off$$

$$v_B(t) > 0\ ; \quad Q_1\ is\ on$$



$$v_{ce2} = v_1(t)$$

$$v_{CE2}(t) - V_{cc} = v_1(t)$$

$$v_{CE2}(t) - V_{cc} = N\, v_L(t)$$

$$v_{CE2}(t) = V_{cc} + N\, v_L(t)$$

$$v_{CE2}(t) = V_{cc} + N\, R_L\, N\, i_{C1}(t)$$

$$v_{CE2}(t) = V_{cc} + N^2\, R_L\, i_{C1}(t)$$

$$v_{CE2}(t) = V_{cc} + R_l' i_{C1}(t)$$

$$\therefore v_{CE2}(t)_{,max} = V_{cc} + R_l' i_{C1}(t)_{,max}$$

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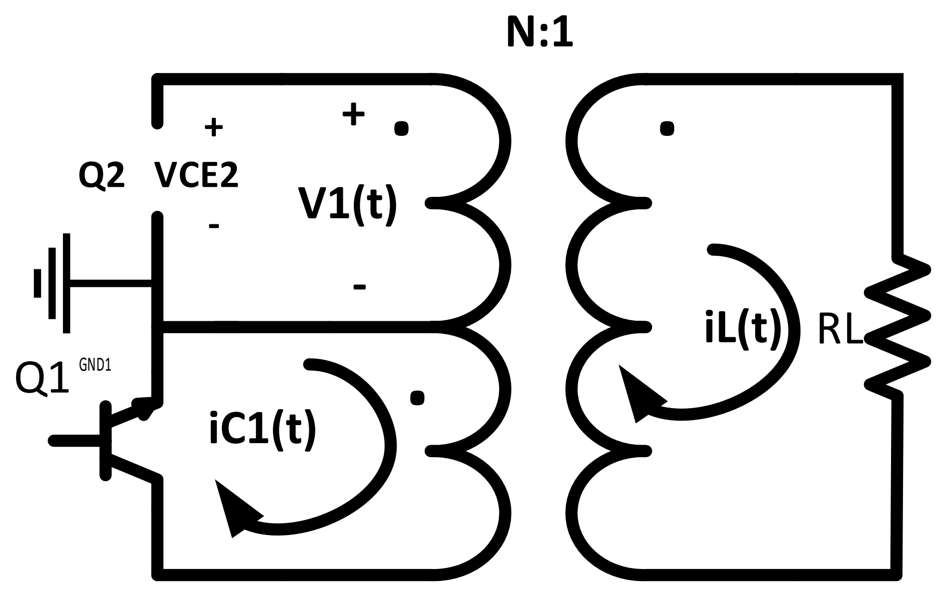
Class B Push-Pull Power Amplifier:

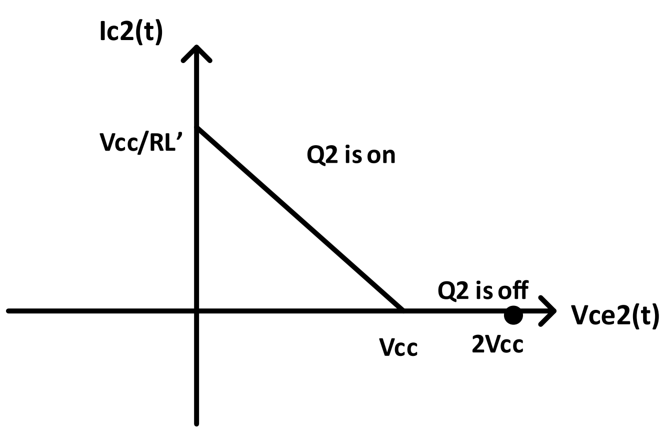
AC Load Line for Q2:



$$v_{CE2}(t)_{,max} = V_{cc} + R_l' \frac{V_{cc}}{R_l'}$$

$$v_{CE2}(t)_{,max} = V_{cc} + V_{cc}$$

$$v_{CE2}(t)_{,max} = 2V_{cc}$$



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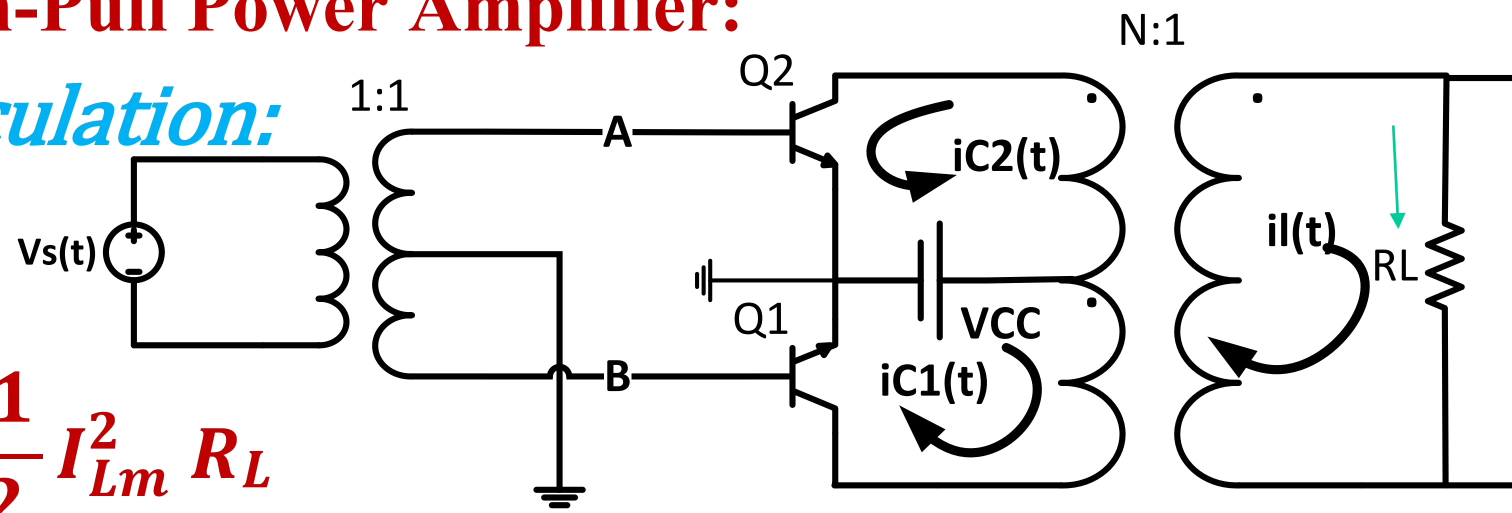
Class B Push-Pull Power Amplifier:

Power calculation:



$$P_{L,ac} = \frac{1}{2} I_{Lm}^2 R_L$$

$$I_{Lm} = N\, I_{cm}$$

$$\therefore \quad P_{L,ac} = \frac{1}{2} I_{cm}^2 R_L{}'$$

$$P_{L,ac}{}_{,max} = \frac{1}{2} (I_{cm,max}^2) R_L{}'$$

$$P_{L,ac}{}_{,max} = \frac{V_{cc}^2}{2R_L{}'}$$

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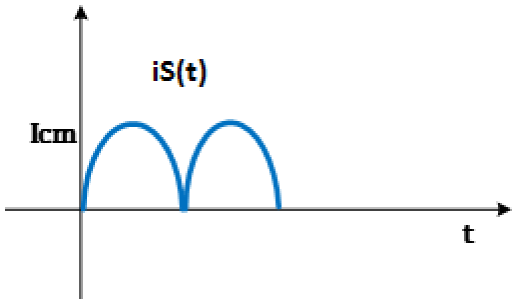
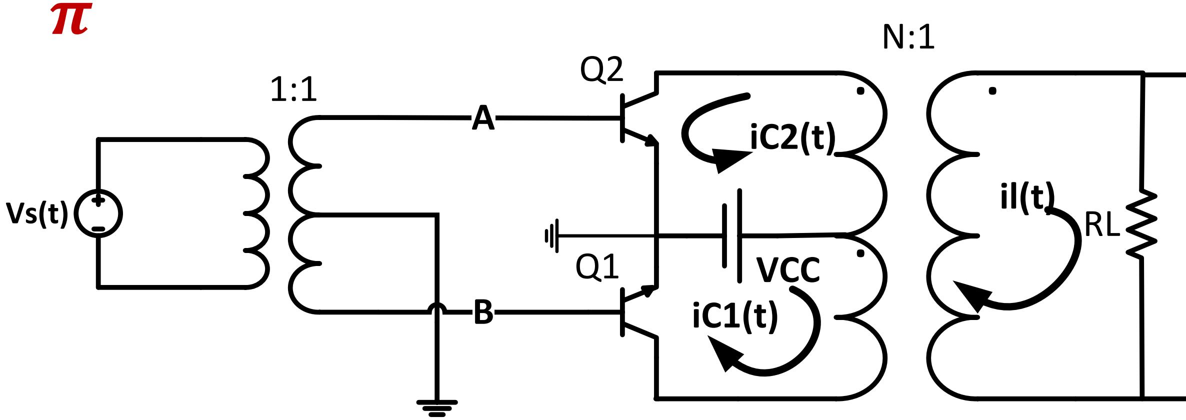
Class B Push-Pull Power Amplifier:

Power calculation:



$$P_{cc} = \frac{1}{T}\int_{0}^{T} V_{cc}\, i_s(t)dt = \frac{2V_{cc}\, I_{cm}}{\pi}$$

$$2Pc = Pcc - PL, ac$$



$$Pc = \frac{Pcc - PL, ac}{2}$$

$$Pc = \frac{Vcc * Icm}{\pi} - \frac{1}{4}\, Icm^2 RL'$$

$$\frac{dPc}{dIcm} = 0$$

$$Icm = \frac{2}{\pi}\frac{Vcc}{RL'}$$

$$\therefore Pc, max = \frac{Vcc^2}{\pi^2 RL'}$$

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$$\eta = \frac{P_{L,ac}}{P_{cc}} * 100\%$$

$$\eta = \frac{\pi}{4}\left(\frac{I_{cm}}{\frac{V_{cc}}{R_L{}'}}\right) * 100\%$$

$$\eta_{,max} = \frac{\pi}{4} * 100\% = 78.5\%$$

$$\gamma = \frac{Pc,max}{(PL,ac),max}$$

$$\gamma = \frac{2}{\pi^2} \cong 0.2$$

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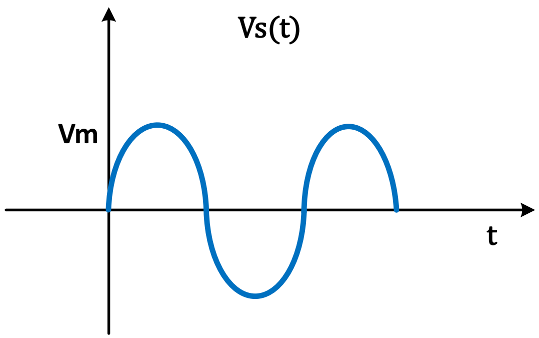
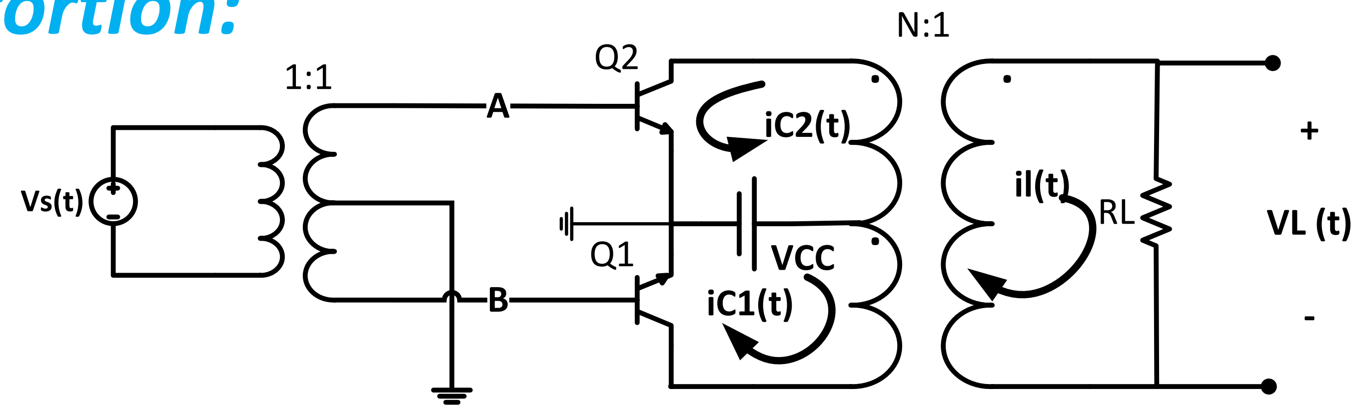
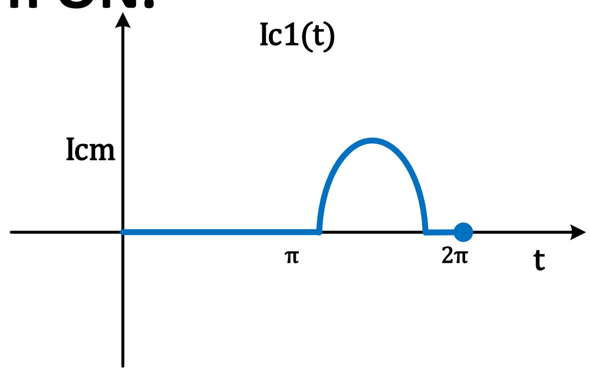
Class B Push-Pull Power Amplifier:

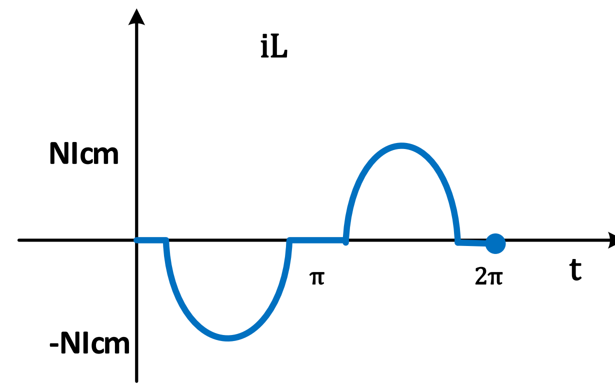
Cross Over Distortion:

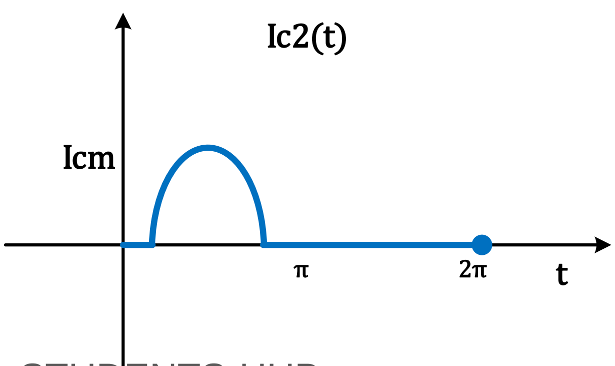




VA(t) has to increase above 0.7V for Q2 to turn on, and VB(t) has to go below -0.7V for Q1 to turn ON.







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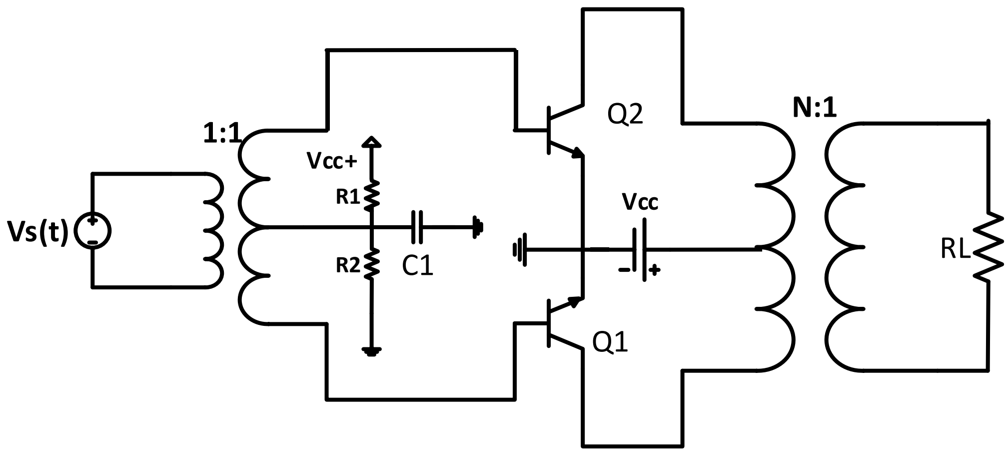
Class AB Push-Pull Power Amplifier:

Cross Over Distortion:

1)Cross over distortion can be reduced or eliminated by biasing each transistor slightly into conduction.



2)Typically the base-emitter junction are biased above 0.5V , 0.6V.

We Choose R1 & R2 So that:

$$\frac{R_2 \quad V_{cc}}{R_1 + R_2} = 0.5, 0.6, \dots \dots \dots .$$

3)When a transistor is biased slightly into conduction , the output current will flow during more than one-half cycle of a sinwave input signal.

4) Efficiency is reduced depending on how heavily the transistors are biased .

5) $78.5\% > \eta_{,max} > 50\%$

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Complementary symmetry Class B push pull Power Amplifier

$VBE1 + VEB2 = 0$

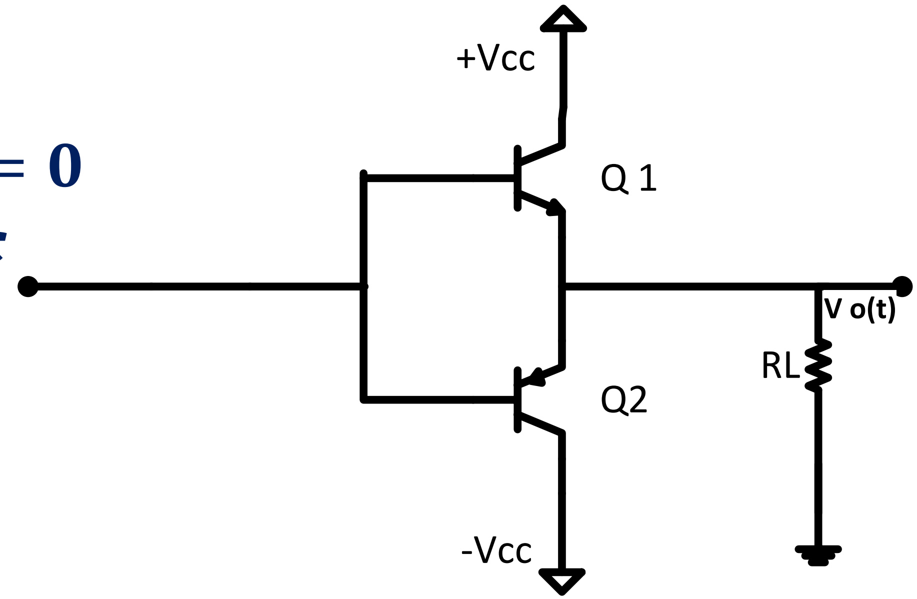
$\therefore Q1 \ and \ Q2$ are in cutoff

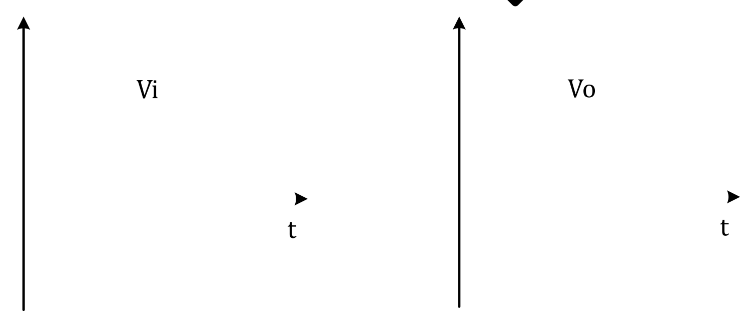
$ICQ1 = ICQ2 = 0 \, , IL = 0 \ \ , Vo = 0$

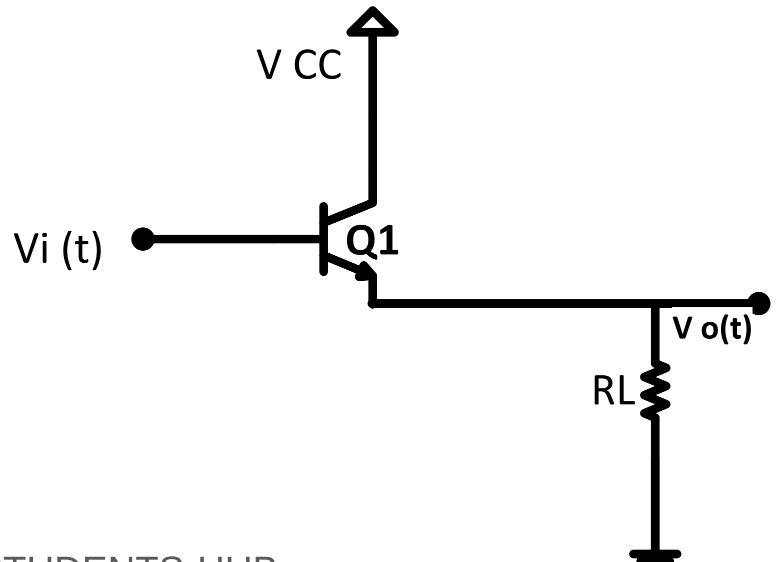
$VCEQ1 = Vcc \, , VECQ2 = Vcc$

When Vi(t) $>$ 0

$, Q1 \ is \ on \ \ , Q2 \ is \ off$







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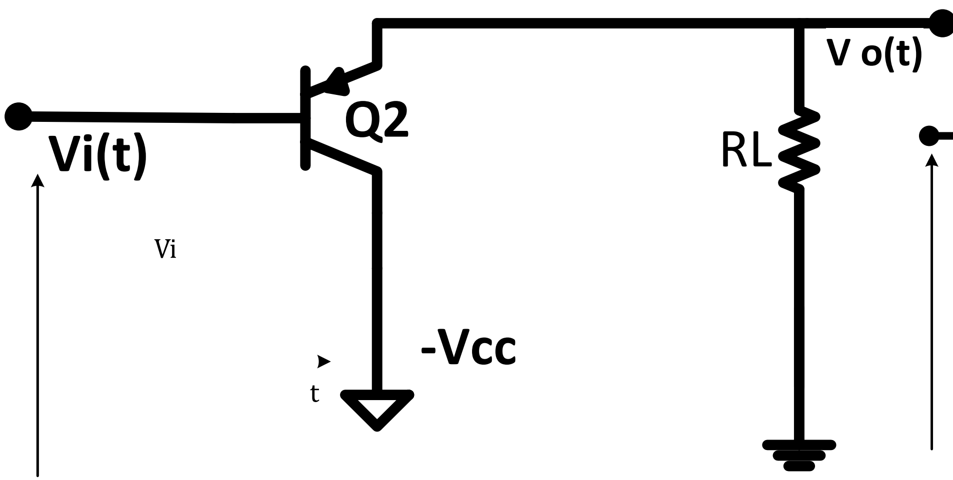
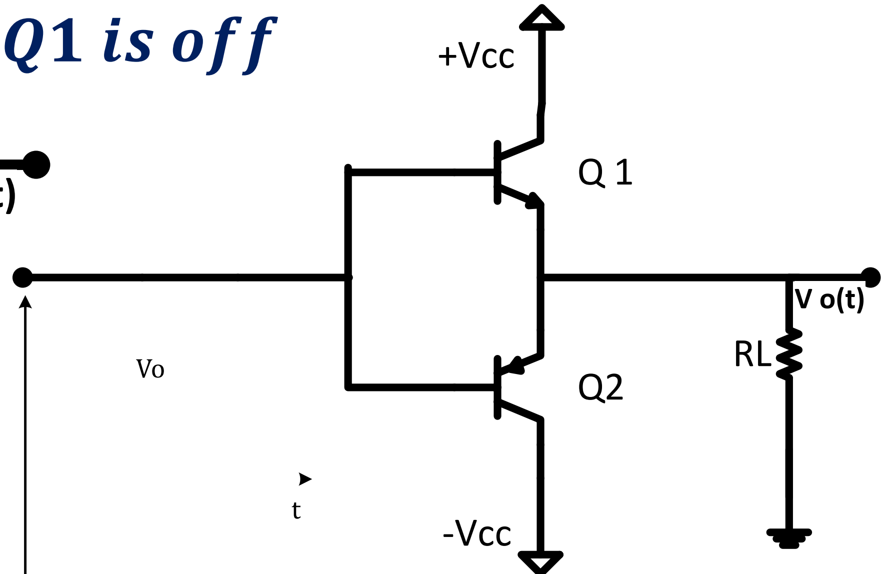
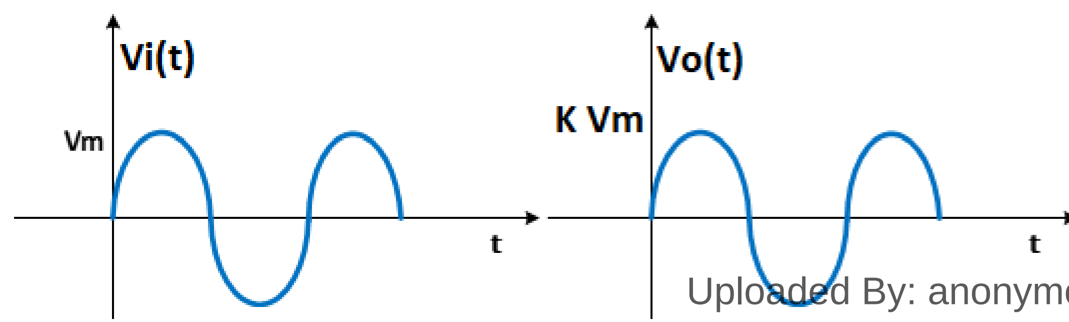
Complementary symmetry Class B push pull Power Amplifier

2) When Vi(t) $< \; 0, Q2 \; is \; on \;\; , Q1 \; is \; off$





For the complete cycle



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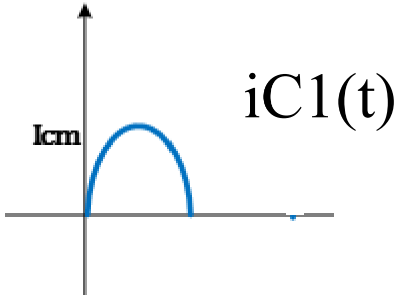
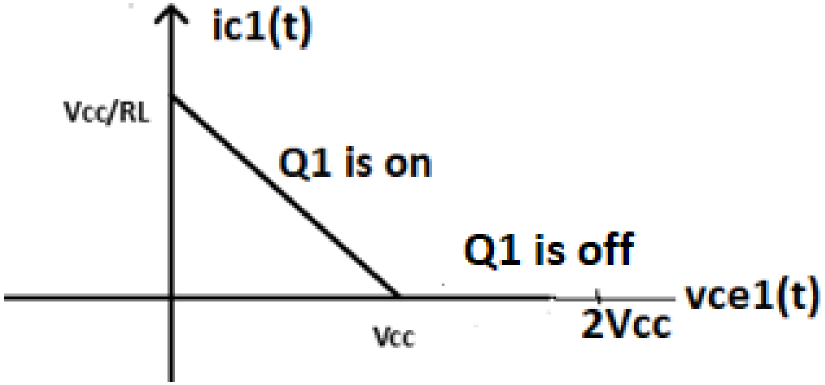


Ac load line



$$I_{cm1,max} = \frac{V_{cc}}{R_l}$$

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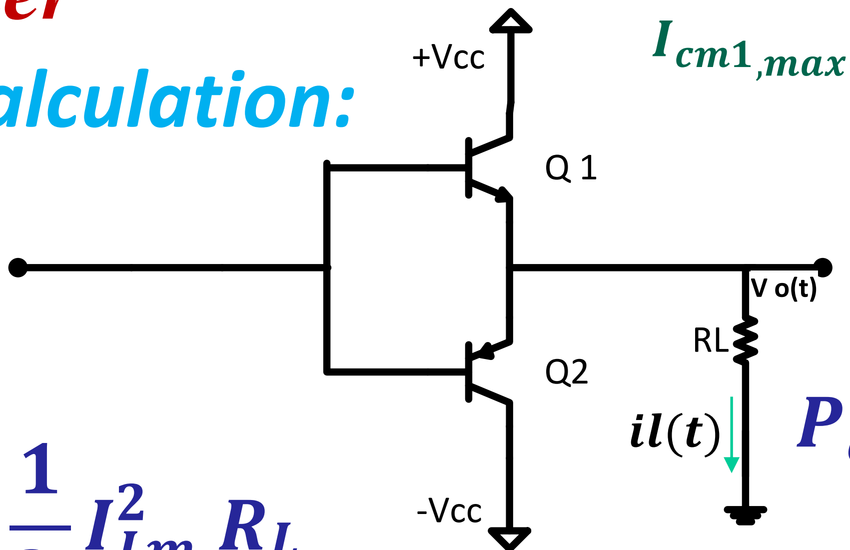
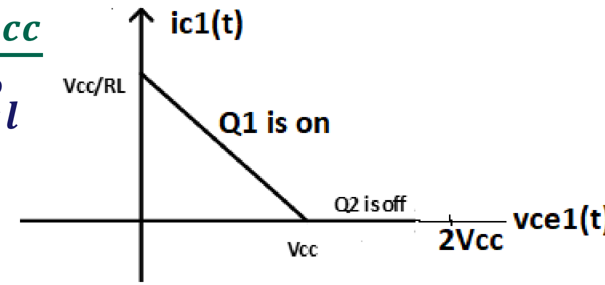
Complementary symmetry Class B push pull Power Amplifier

Power calculation:



$$I_{cm1,max} = \frac{V_{cc}}{R_l}$$



$$P_{cc} = \frac{1}{T}\int_0^T V_{cc}\, i_s(t)dt$$

$$= \frac{2V_{cc}\, I_{cm}}{\pi}$$

$$P_{L,ac} = \frac{1}{2} I_{Lm}^2 R_L$$

$$\therefore \quad P_{L,ac} = \frac{1}{2} I_{cm}^2 R_L$$

$$P_{L,ac,max} = \frac{1}{2}(I_{cm,max}^2) R_L$$

$$P_{L,ac,max} = \frac{V_{cc}^2}{2R_L}$$

$$\eta = \frac{P_{L,ac}}{P_{cc}} * 100\%$$

$$\eta_{,max} = \frac{\pi}{4} * 100\%$$

$$= 78.5\%$$

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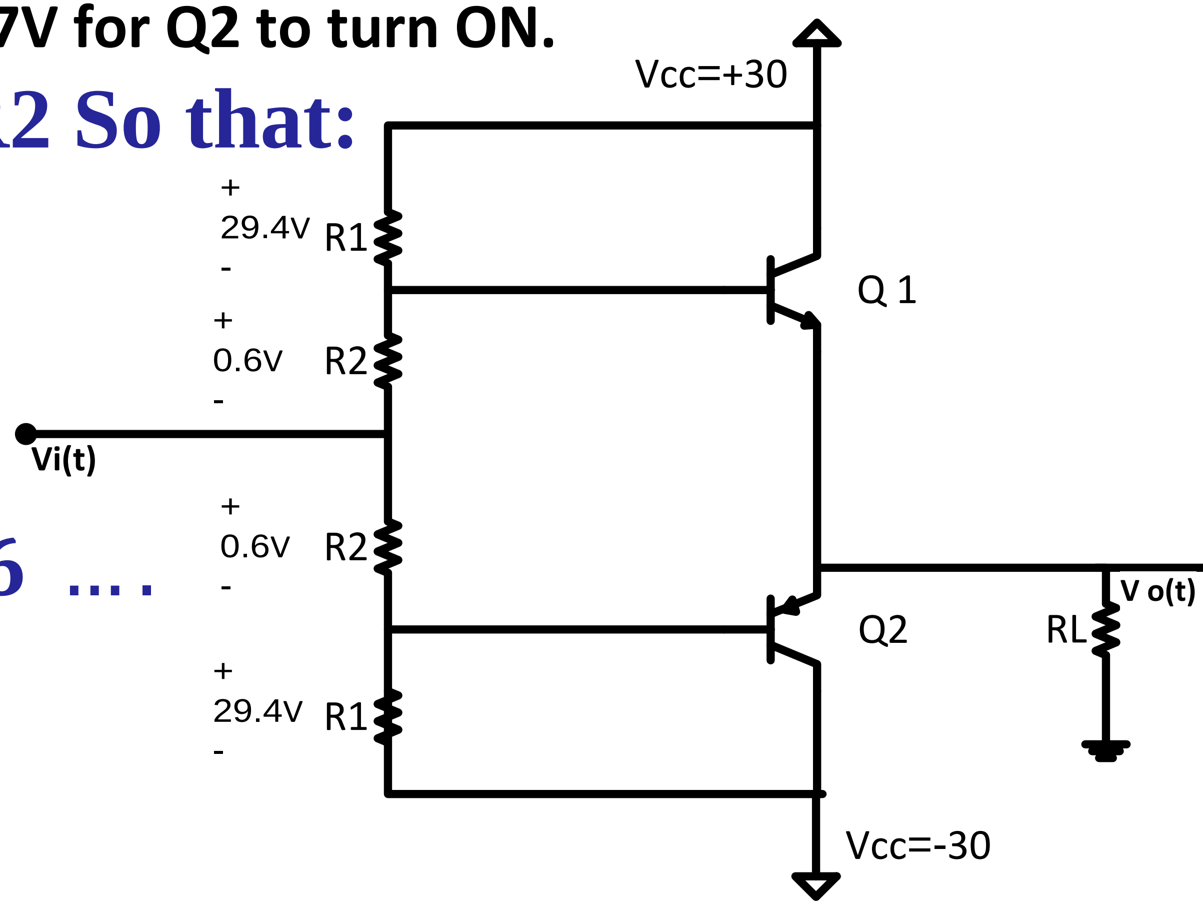
Complementary symmetry Class AB push pull Power Amplifier

Vin(t) has to increase above 0.7V for Q1 to turn on, or go below -0.7V for Q2 to turn ON.

We Choose R1 & R2 So that:



$$\frac{R_2 \quad V_{cc}}{R_1 + R_2} = 0.5, 0.6 \ \ldots .$$

VBE1 = VEB2 = 0.5 , 0.6 , …

So that ICQ1 ≈ ICQ2 =0 and Vo = 0

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Complementary symmetry Class AB push pull Power Amplifier

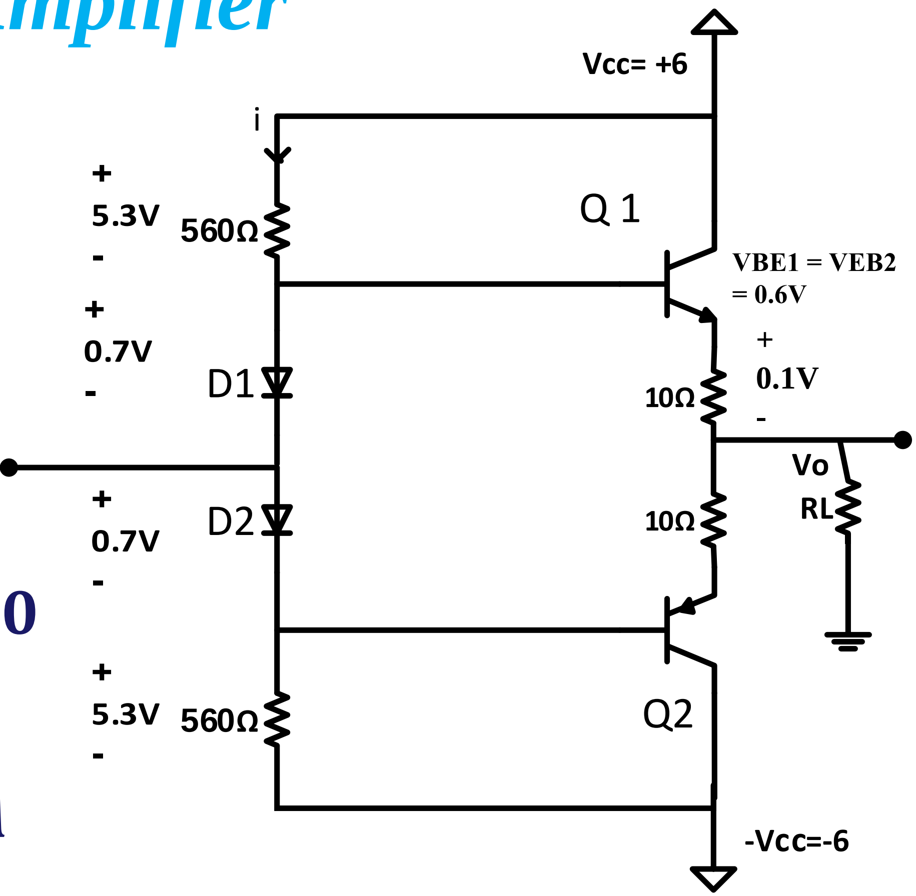
Practical Class AB Power Amplifier

To Provide Bias Stability

1)Small Re for bias Stability .

2)Diodes D1 and D2 for
Temperature Compensation.

Assume that I_B very small → 0



$$\therefore I = I_{D1} = I_{D2} = \frac{5.3}{560} = 9.46mA$$

$$\therefore I_{C1} = I_{C2} = \frac{0.1V}{10\ \Omega} = 10mA$$

V_D = O.7V @ room temp

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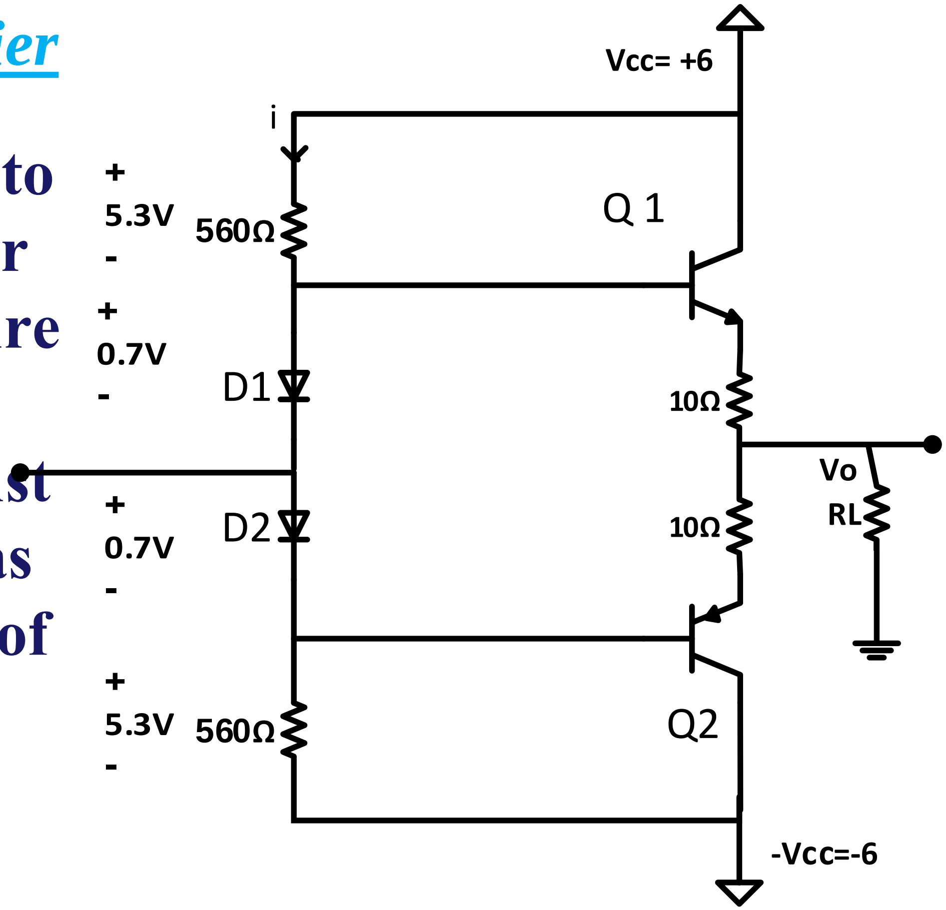
Complementary symmetry Class AB push pull Power Amplifier

Practical Class AB Power Amplifier

- **The forward bias required to turn on the output transistor Decreases as it's temperature Increase**
  The Diodes are used to adjust the bas emitter forward bias automatically as a function of temperature

- D_1, D_2 ***are always on***



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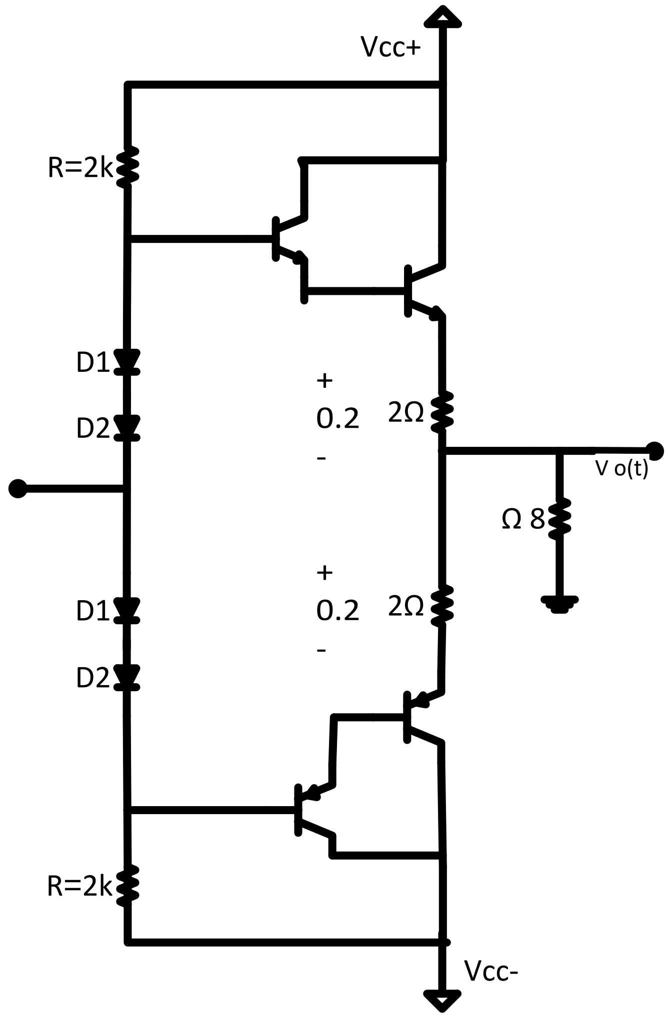
Complementary Class AB Power Amplifier using Darlington:

- **To Reduce The loading on the preceeding Stage.**



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Complementary Class AB Power Amplifier using VBE Mutiplier

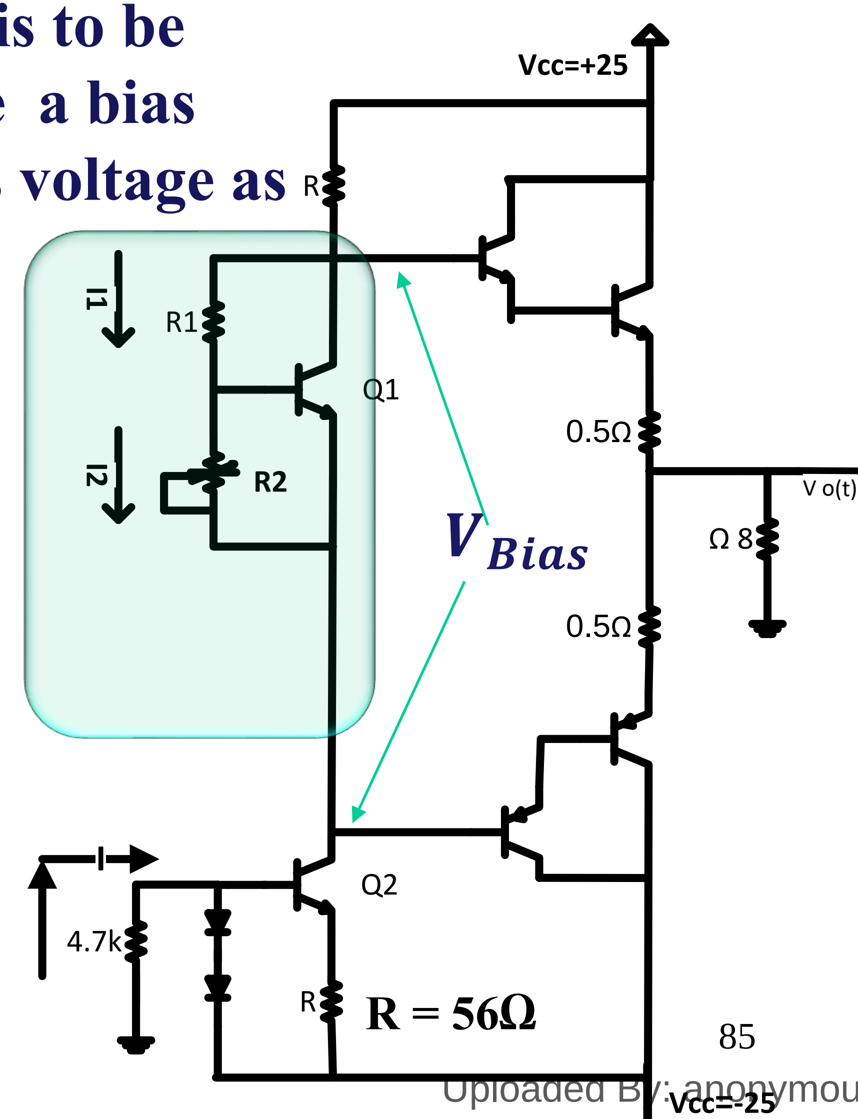
- **If a stable quiescent current is to be maintained , we must provide a bias circuit that decreases the bias voltage as the temperature increase .**

$$I = \frac{25 - 1.4}{4.7k} = 5.02mA$$

$$I_{E2} = \frac{0.7}{56\Omega} = 12.5mA$$

$$I_2 \approx I_1 \,;\, I_B \; very \; small$$

$$\therefore \; I_1 = I_2 = \frac{V_{BE}}{R_2}$$



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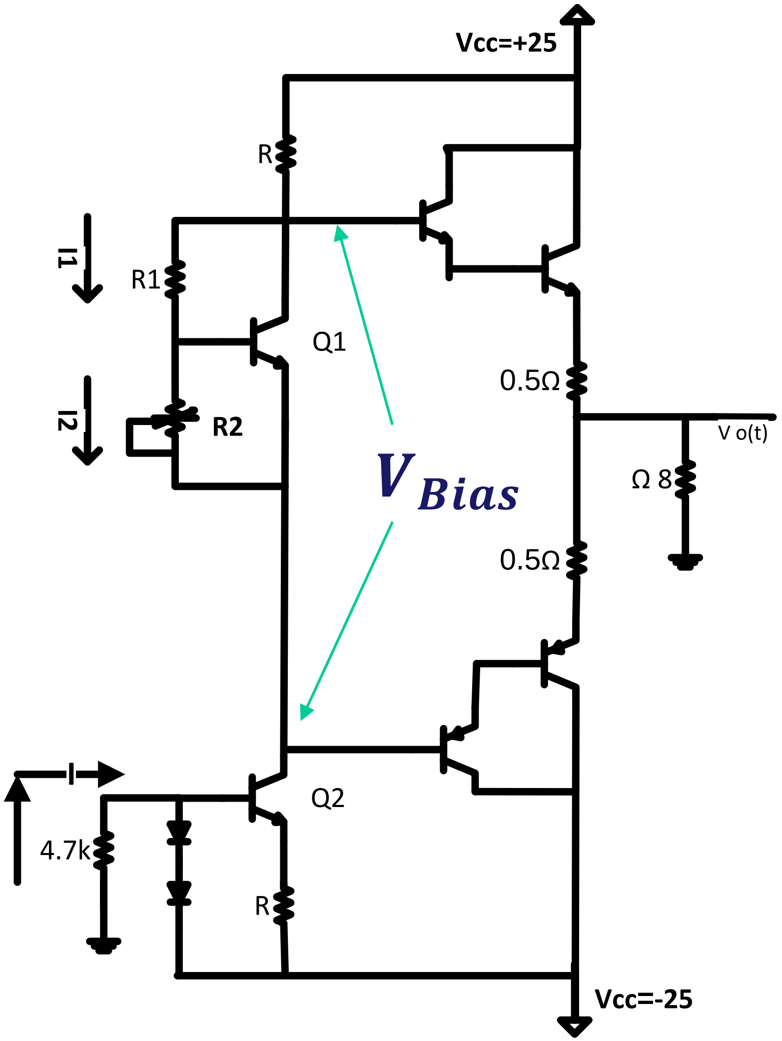
$$V_{Bias} = (R_1 I_1 + R_2 I_2)$$

$$I_2 \approx I_1$$

$$V_{Bias} = (R_1 + R_2) I_2$$

$$V_{Bias} = \left(1 + \frac{R_1}{R_2}\right) V_{BE}$$

V_{Bias} ***may be adjusted***



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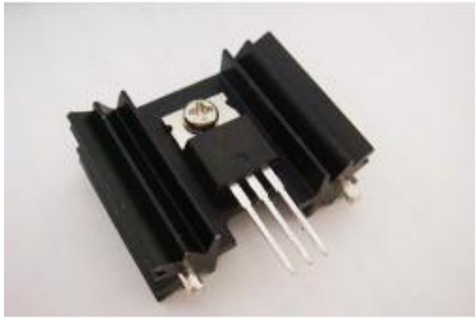
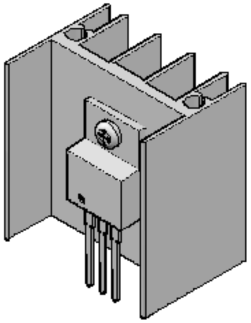
Transistor and Heat sink

The fundamental problem is to remove heat from the Semi-Conductor in order to keep Tj as low as possible





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Different types of heat sink

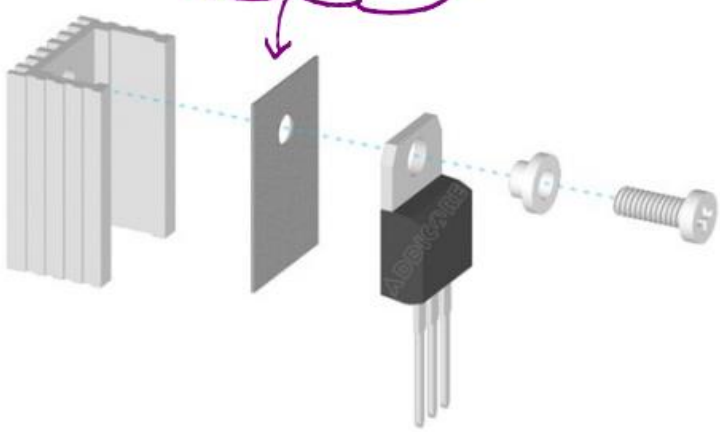
Thermal paste

OR

Thermal pad

Clip Mount

Screw mount



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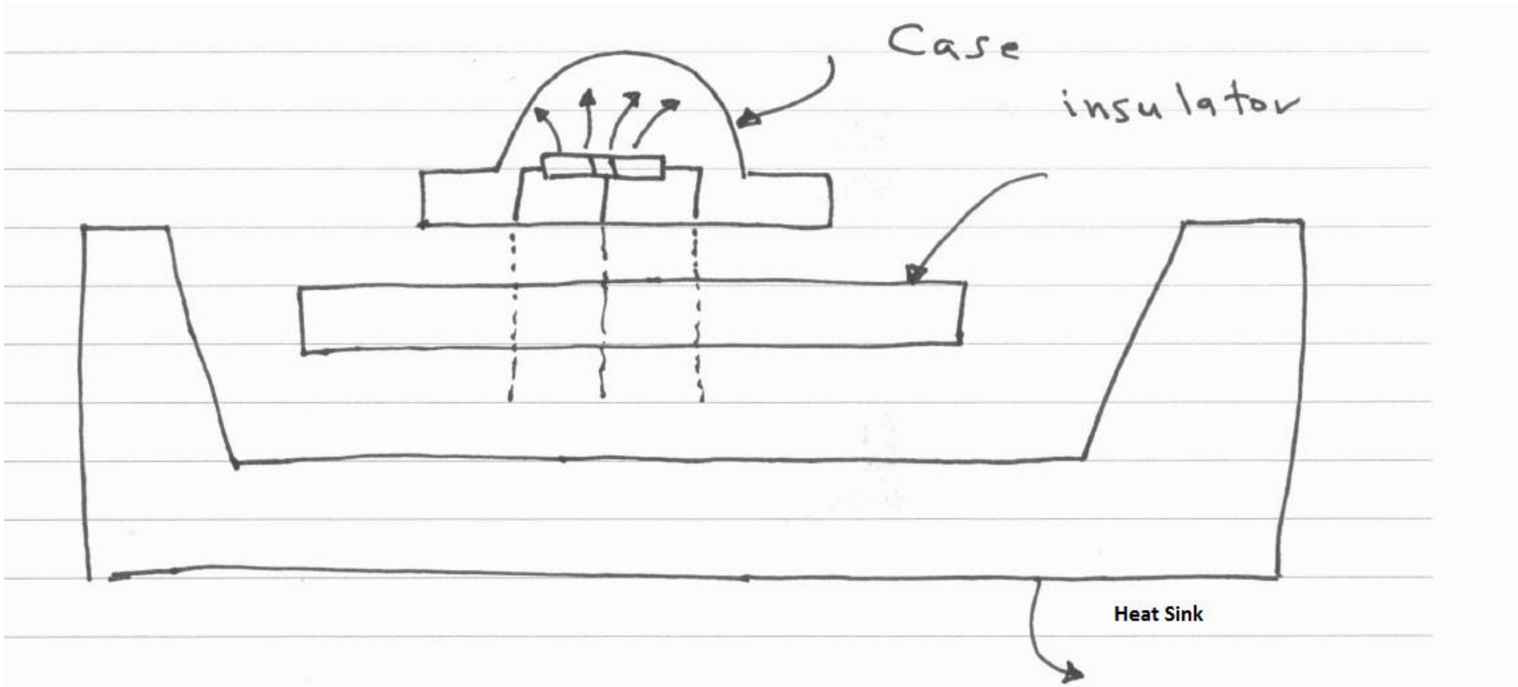
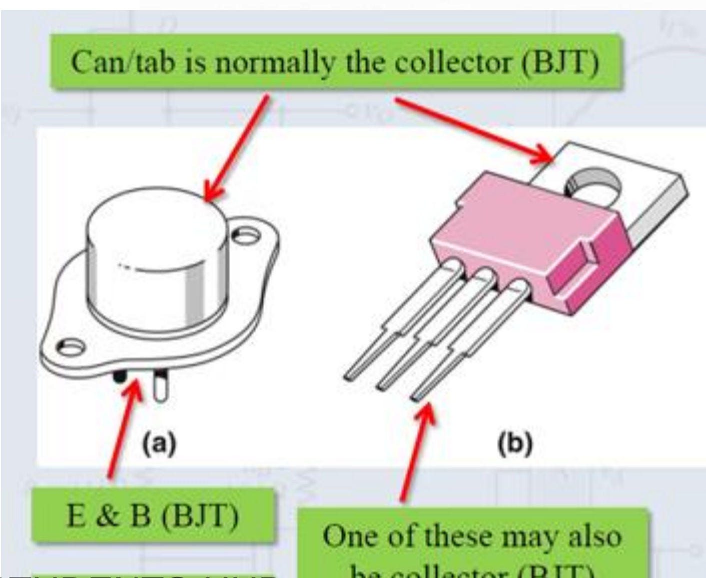
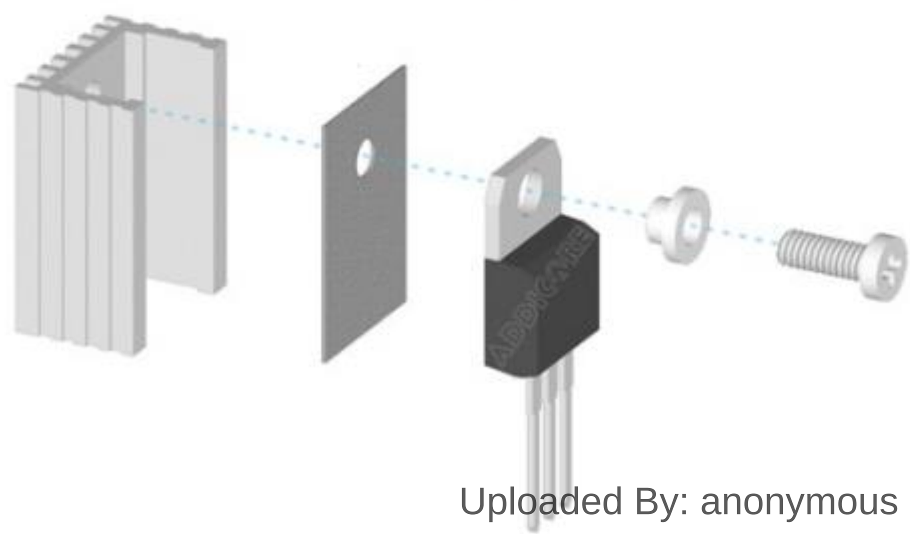
Transistor and Heat Sink







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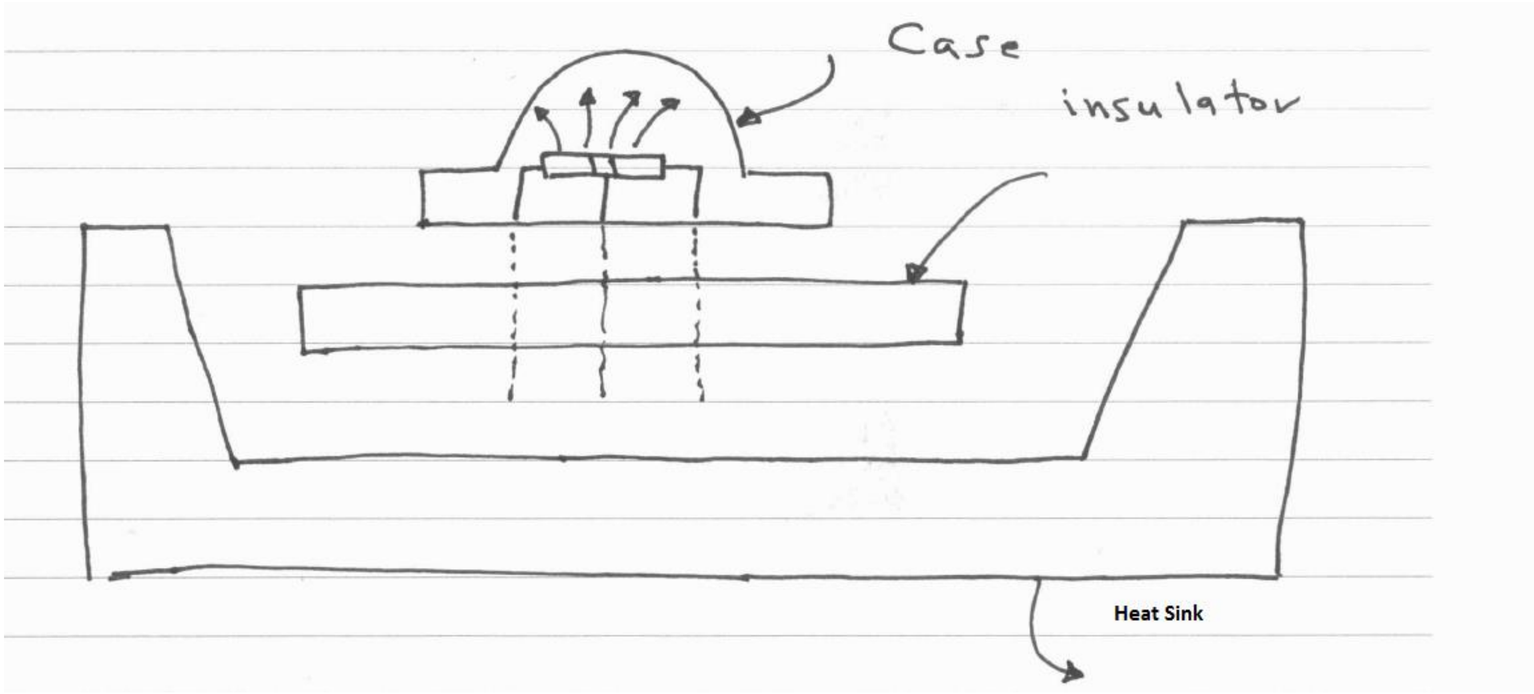
Transistor and Heat Sink



The fundamental Problem is to remove heat from the Semiconductors in order to keep Tj as low as possible

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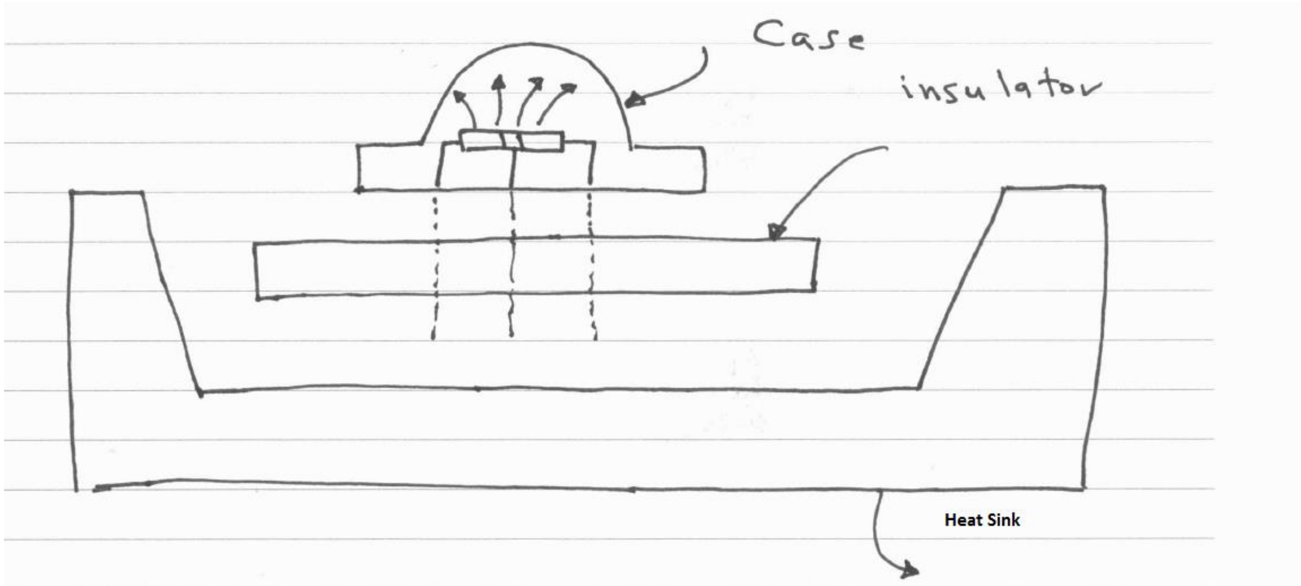
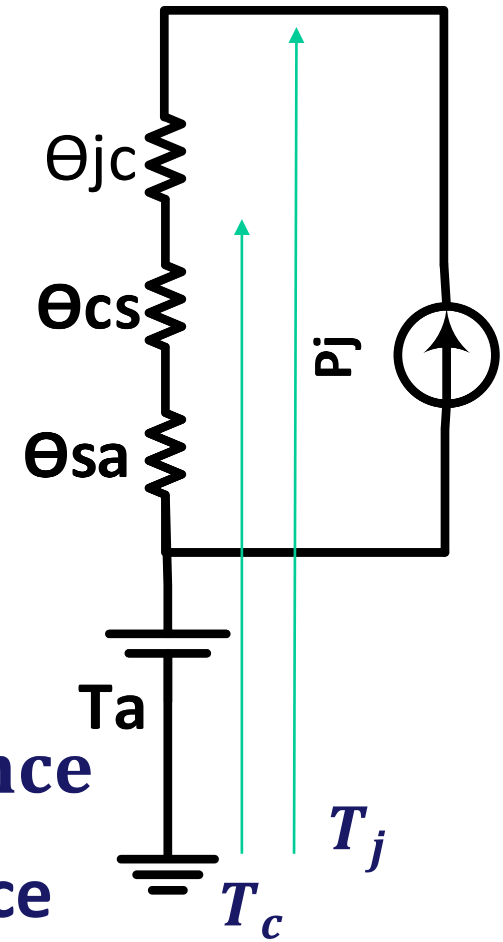
Transistor and Heat sink : Thermal to electrical analogy





$\theta_{jc} \equiv$ **Junction to case thermal resistance**

$\theta_{cs} \equiv$ **Case to heat sink thermal resistance**

$\theta_{sa} \equiv$ **Heat sink to ambient thermal resistance**

$T_j - T_a = \theta_{ja}\, P_j$ **"Thermal Ohm's Law"**

$\theta_{ja} = \theta_{jc} + \theta_{cs} + \theta_{sa}$

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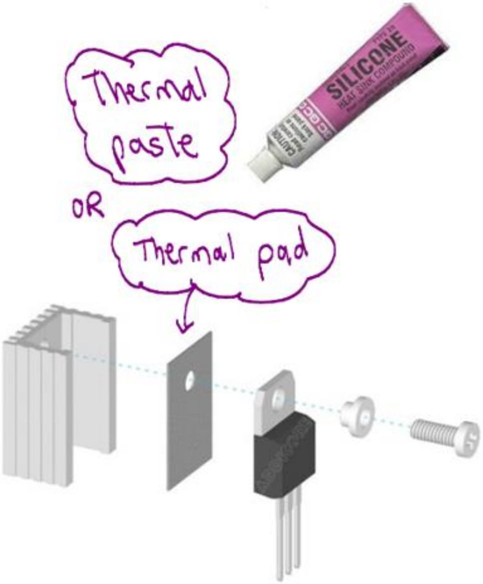
Transistor and Heat sink

θ_{jc}: **Depends on the construction of the power transistor.**

$\theta_{jc} = 1.92\ {}^{\circ}C/_{\omega}$

$\theta_{jc} = 0.875\ {}^{\circ}C/_{\omega}$

θ_{cs}: **Depends on the interface between case and sink , silicon grease or without.**



θ_{sa}: **Depends on the size of the heat sink .**

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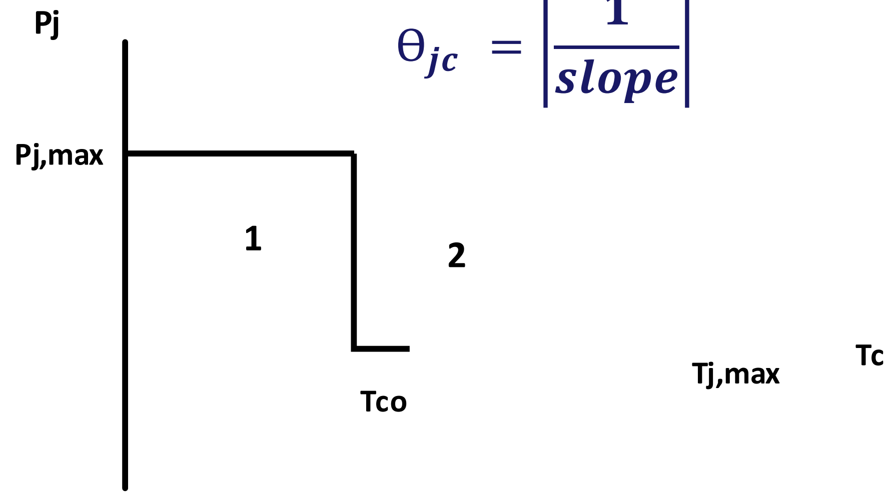
Power Derating Curve



$$\Theta_{jc} = \left|\frac{1}{slope}\right|$$

In Region 1:

$$P_j = P_{j,max}$$

$$\therefore if\ T_c < T_{co}\ ;\ P_j = P_{j,max}$$

In Region 2:

$$\therefore if\ T_c > T_{co}\ ;\ T_j = T_{j,max}$$

$$and\ \ P_j < P_{j,max}$$

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Transistor and Heat sink

Power Derating Curve

$$T_j - T_c = \Theta_{jc}\ P_j$$

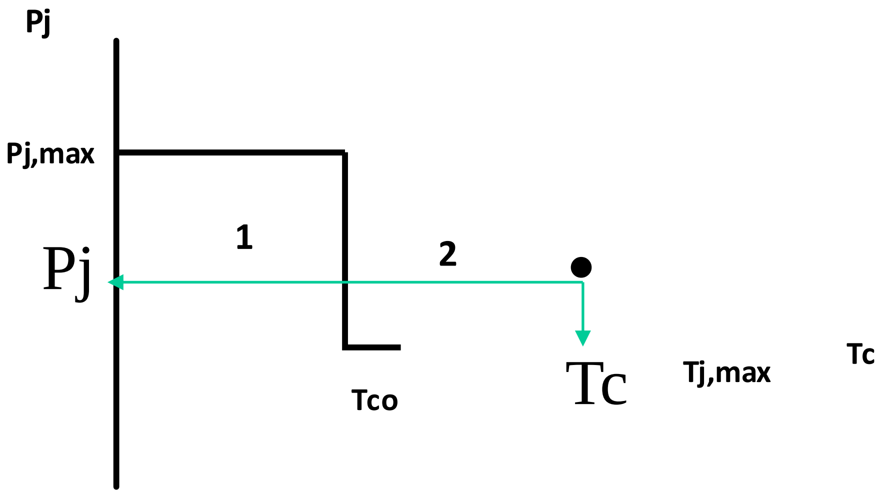
$$region\ \ 2 \rightarrow\ \ T_j = T_{j,max}$$

$$\Theta_{jc} = \left|\frac{1}{slope}\right|$$

$$T_{j,max} - T_c = \Theta_{jc}\ P_j$$

$$\Theta_{jc} = \frac{T_{j,max} - T_c}{P_j}$$

$$\Theta_{jc} = \frac{T_{j,max} - T_{co}}{P_{j,max}}$$



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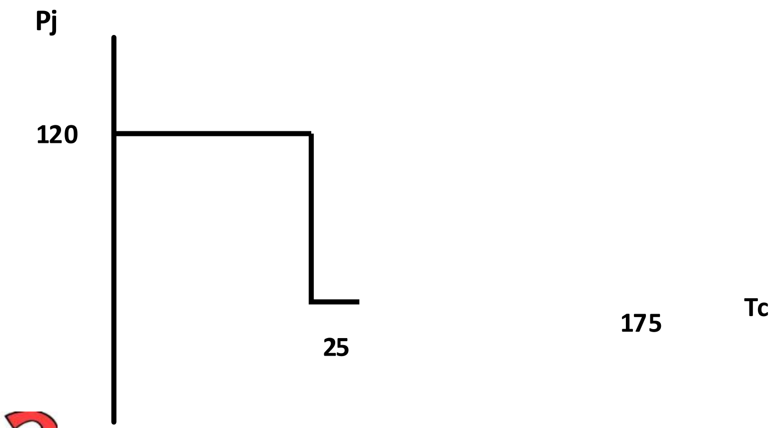
Transistor and Heat sink

A Silicon Power Transistor has a heat sink with $\Theta_{sa} = 1.5\ ^{\circ}C/\omega$
and using Insulator which has $\Theta_{cs} = 0.4\ ^{\circ}C/\omega$
, and has the given derating curve .



What is the power that the transistor can dissipate if $T_a = 40^{\circ}C$?

$T_{j,max} = 175\ ^{\circ}C$

$T_{co} = 25\ ^{\circ}C$

$P_{j,max} = 120W$

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Transistor and Heat sink

$$\theta_{jc} = \frac{T_{j,max} - T_{co}}{P_{j,max}}$$

$$= \frac{175 - 25}{120}$$

$$\theta_{jc} = 1.25\ {}^{\circ}C/\omega$$

$$since \quad T_{co} = 25^{\circ}C$$

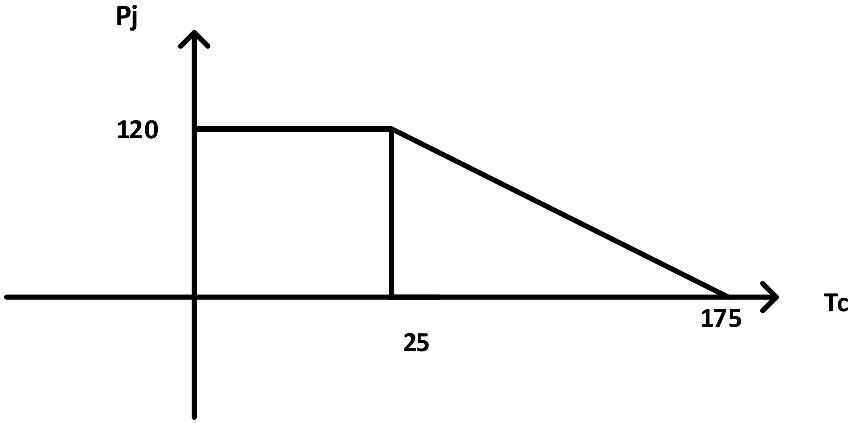
$$, \quad and \quad T_a = 40^{\circ}$$

$$\therefore \ T_c > T_{co}$$

$$\therefore region \ 2 \rightarrow \ T_j = T_{j,max}$$

$$T_j - T_a = \theta_{ja} P_j$$

$$\theta_{ja} = \theta_{jc} + \theta_{cs} + \theta_{sa}$$



$$\theta_{ja} = 3.15\ {}^{\circ}C/\omega$$

$$\therefore P_j = 42.8\ \omega$$

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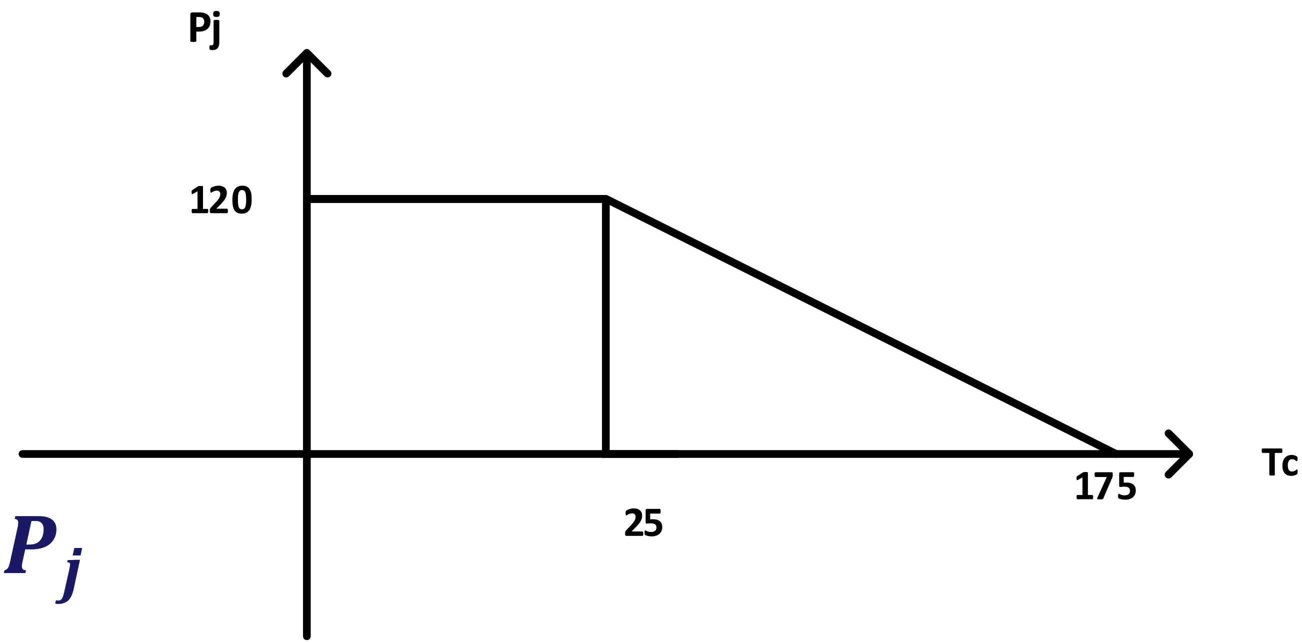
$$To\ find\ Tc:$$



$$T_j - T_c = \theta_{jc}\ P_j$$

$$T_{j,max} - T_c = \theta_{jc}\ P_j$$

$$T_c = 121.5℃$$

$$T_c > T_{co}$$

Region 2 as assumed

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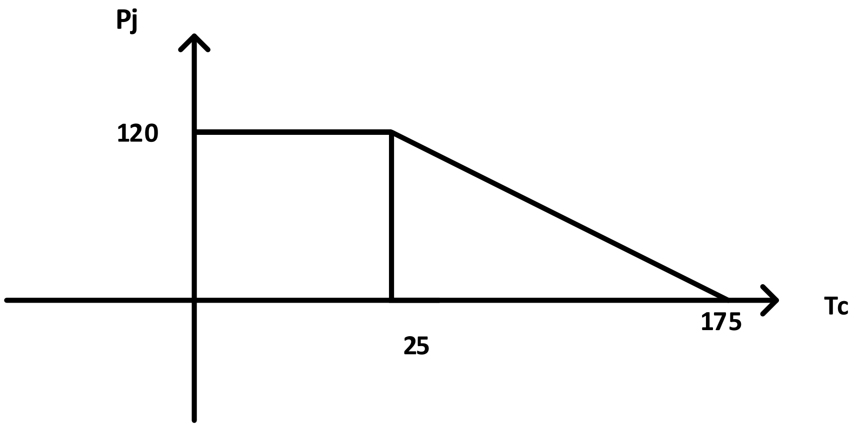
Transistor and Heat sink

If we are using infinite heat sink



$$\therefore \; T_c = T_a$$

$$\therefore \Theta_{ca} = 0$$

$$T_c > T_{co} \quad \therefore \quad \text{Region 2}$$

$$\Theta_{ja} = \Theta_{jc} + \Theta_{ca} = 1.25\ {}^{\circ}\mathrm{C}/\omega$$

$$T_j - T_a = \Theta_{ja} P_j$$

$$\therefore P_j = 108\ \omega$$

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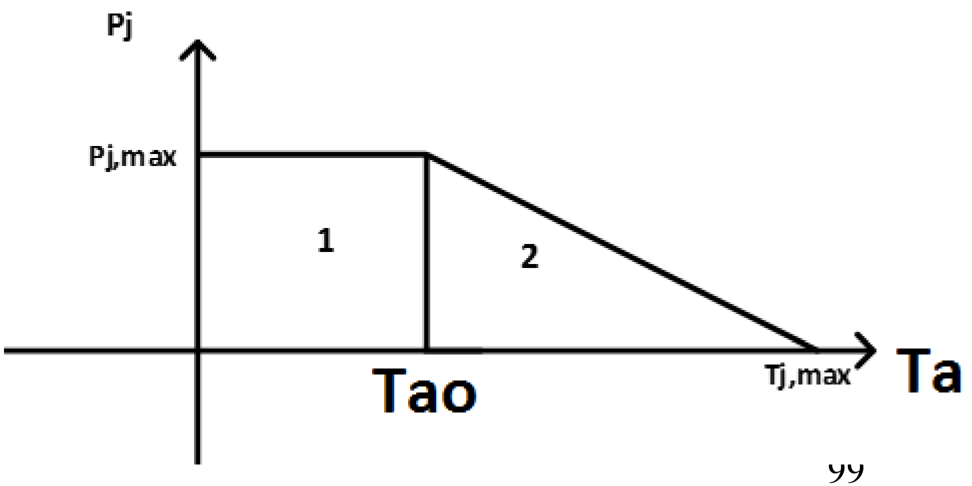
Transistor and Heat sink

$$For\ Operation\ in\ free\ air$$
$$(No\ special\ arrangment\ for\ cooling\ )$$

θ_{ja} *depends on the type of the case in which the transistor is packed*

$$\theta_{ja} = \left|\frac{1}{slope}\right|$$

$$\theta_{ja} = \frac{T_{j,max} - T_{ao}}{P_{j,max}}$$



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