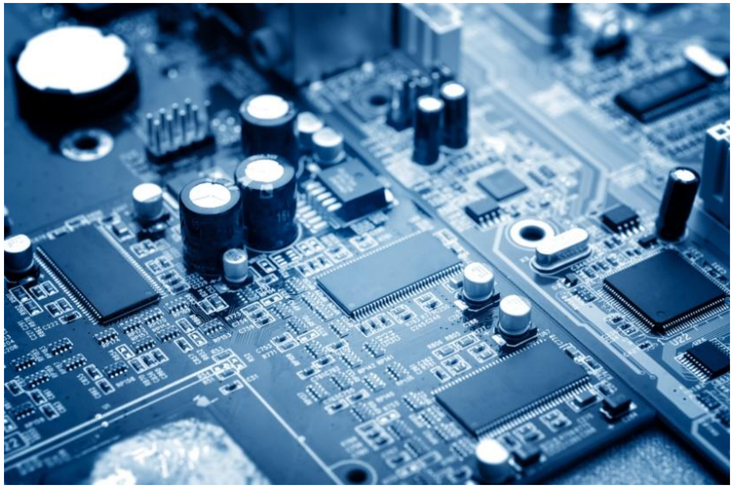
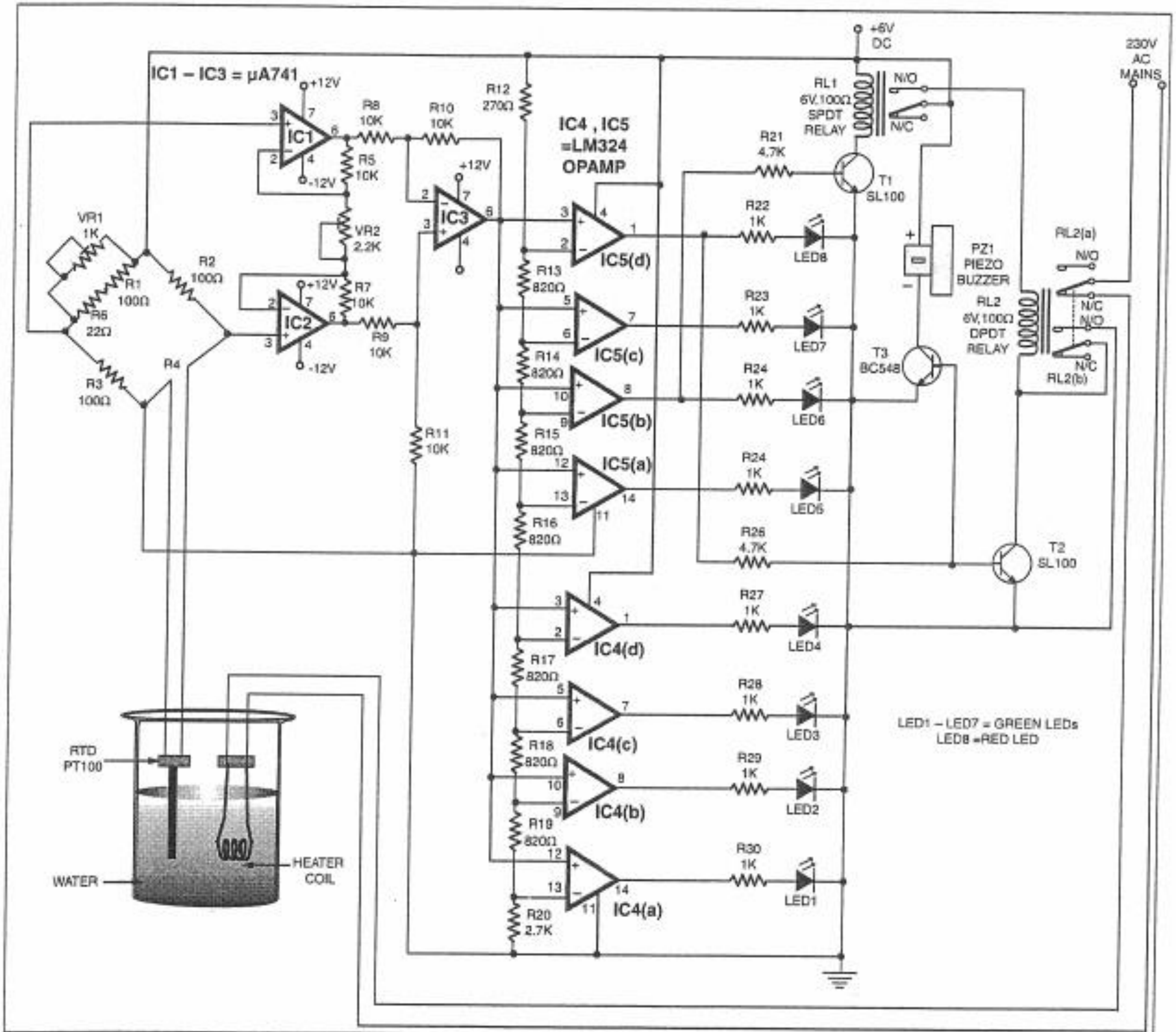
ENEE3304 ELECTRONICS2

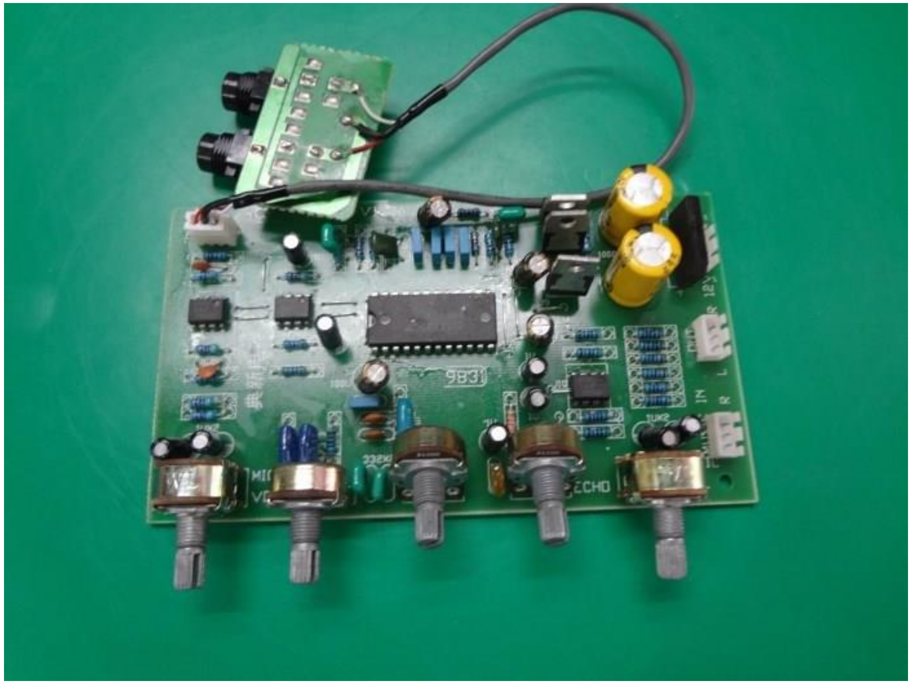


Instructor : Mr.Mohammad AL-Jubeh

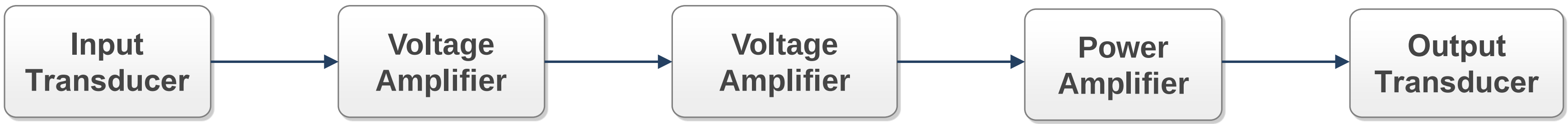
ENEE3304 Project1 : Water Temperature Controller

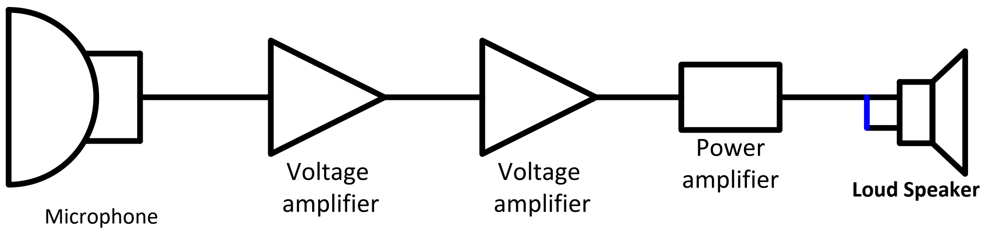


Power Amplifiers



General Audio Amplifier System





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.

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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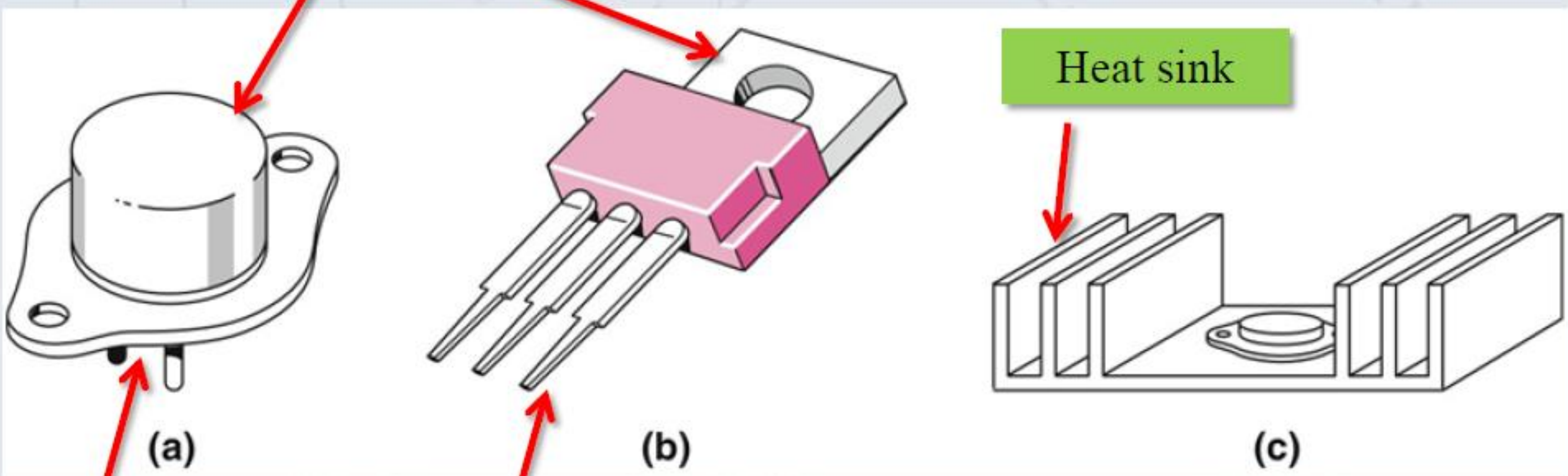
Packaging Schemes

Can/tab is normally the collector (BJT)



E & B (BJT)

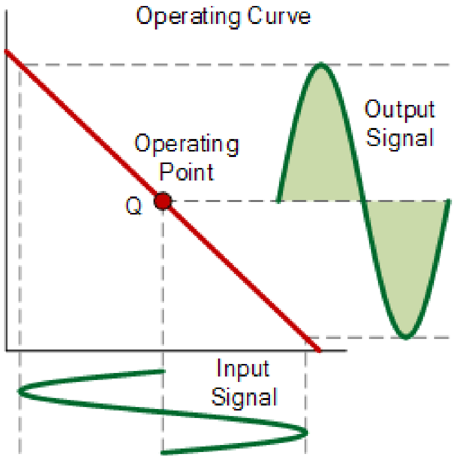
TO-3

One of these may also be collector (BJT)

Power Amplifiers

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

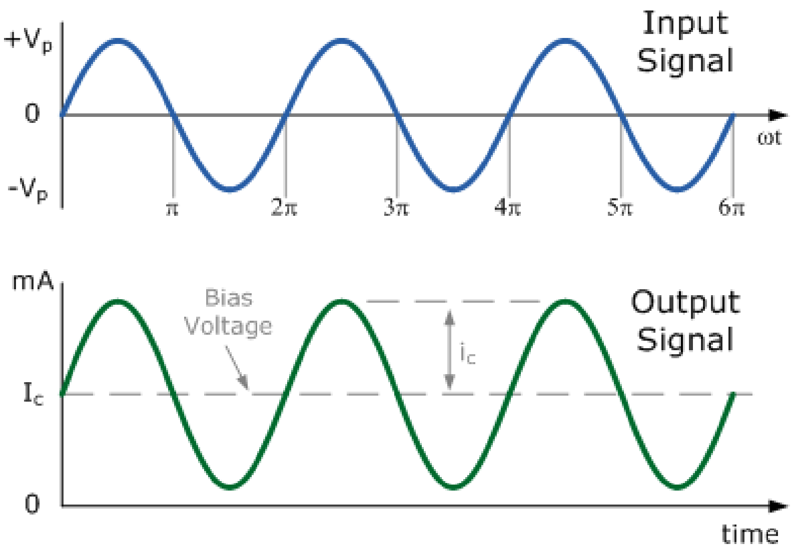
*** For a class A power Amplifier, the Q point is designed to meet maximum symmetrical swing**

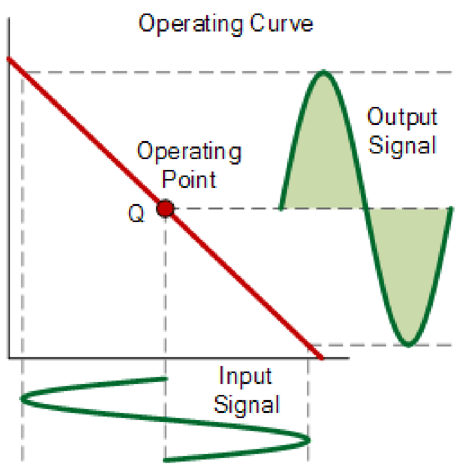


Classes of Power Amplifiers

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

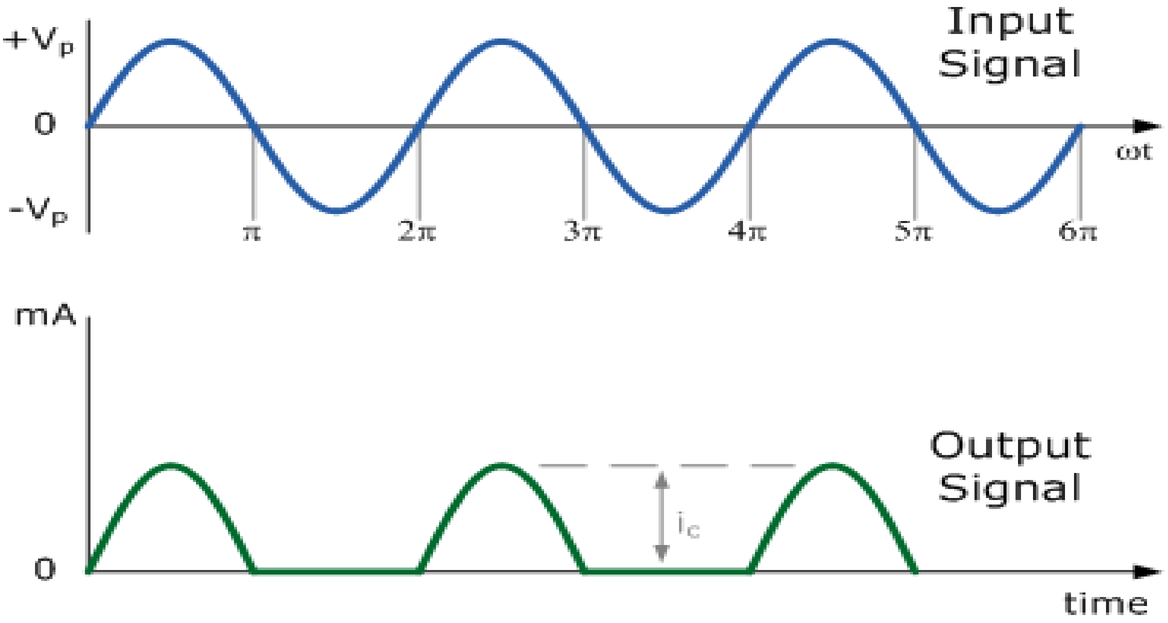
1) Class A Power Amplifier: $\theta = 360°$

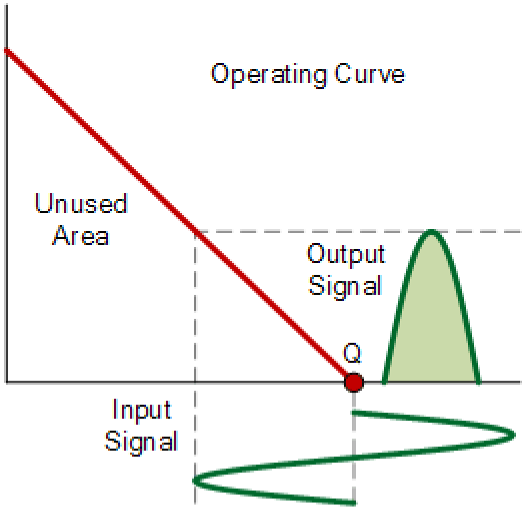




Classes of Power Amplifiers

2) Class B Power Amplifier : θ =180°

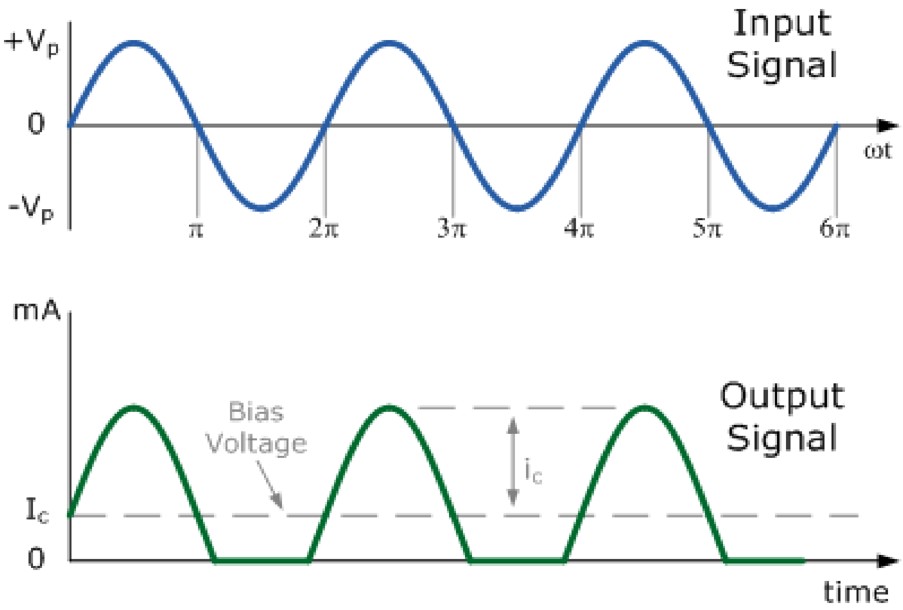


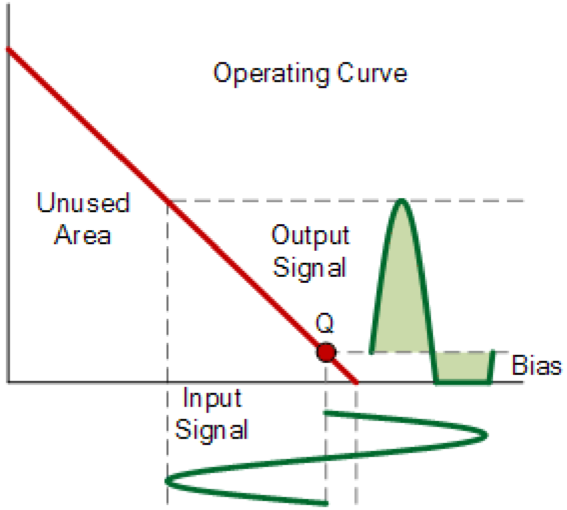


Classes of Power Amplifiers

3) Class AB Power Amplifier

$360° > \boldsymbol{\theta} > 180°$



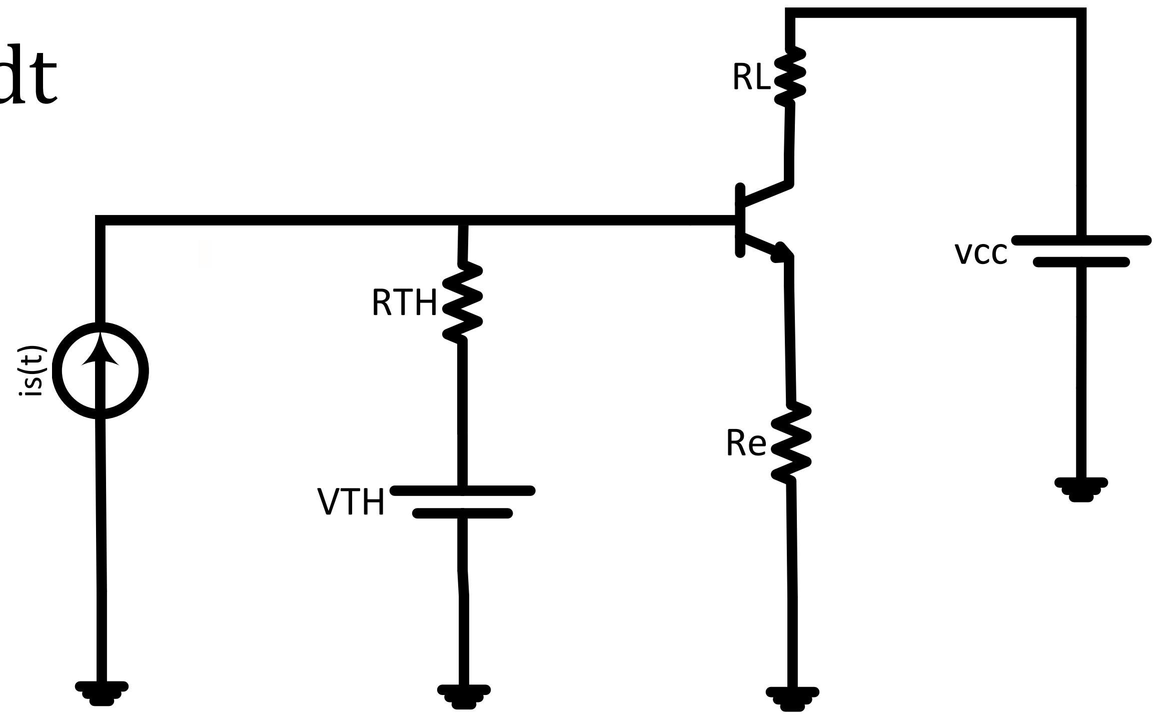


Class A Power Amplifier

Power Calculation :

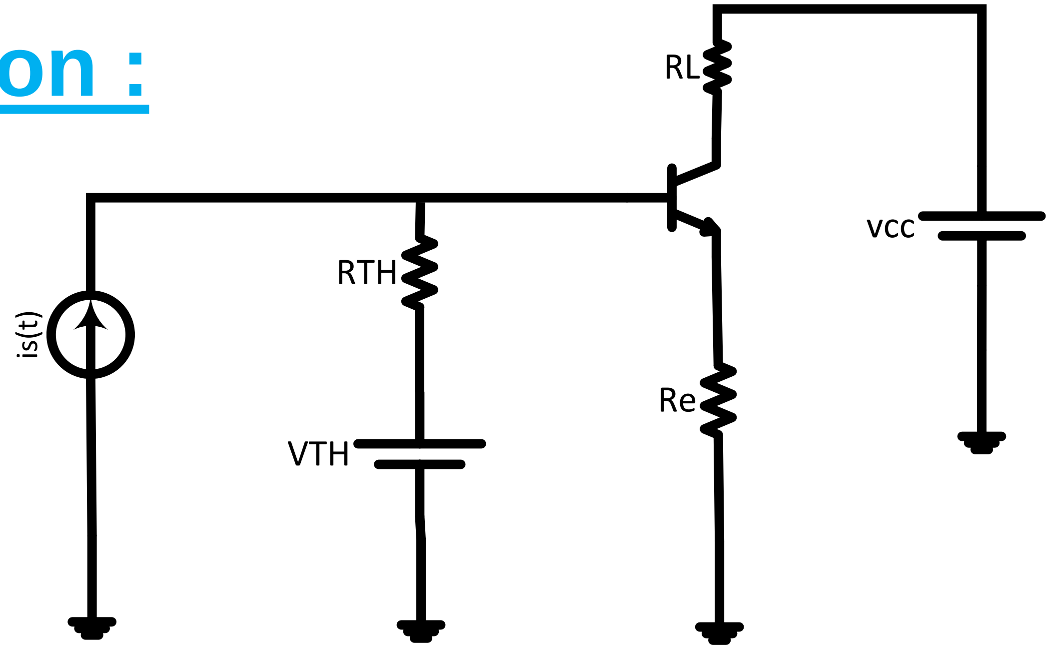
The average power supplied or dissipated by any linear or nonlinear device is :

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



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)**

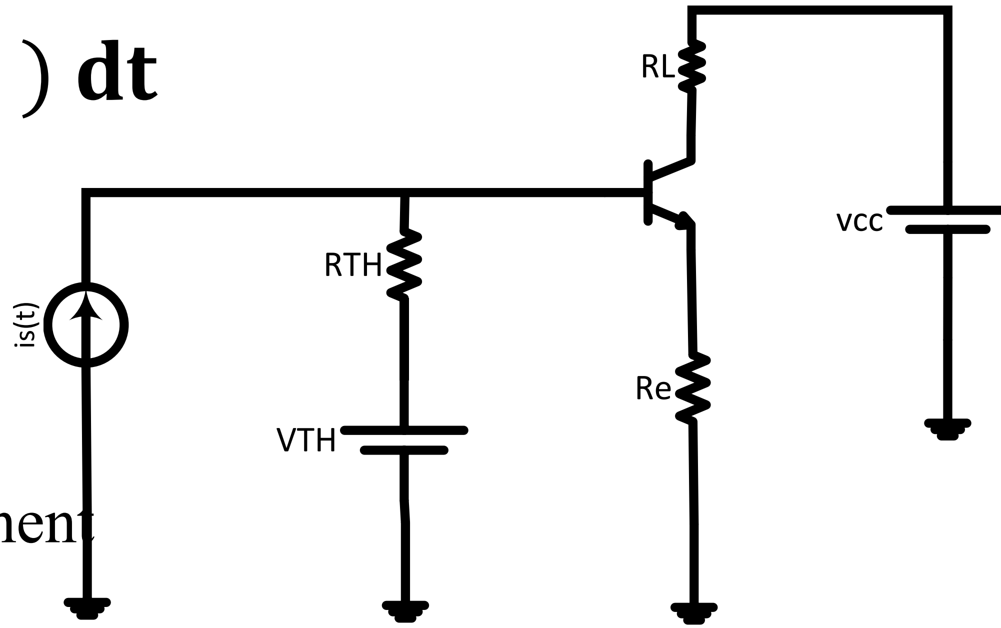
$i(t) = I + i$

i= **Im Cos(ωt)**

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

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

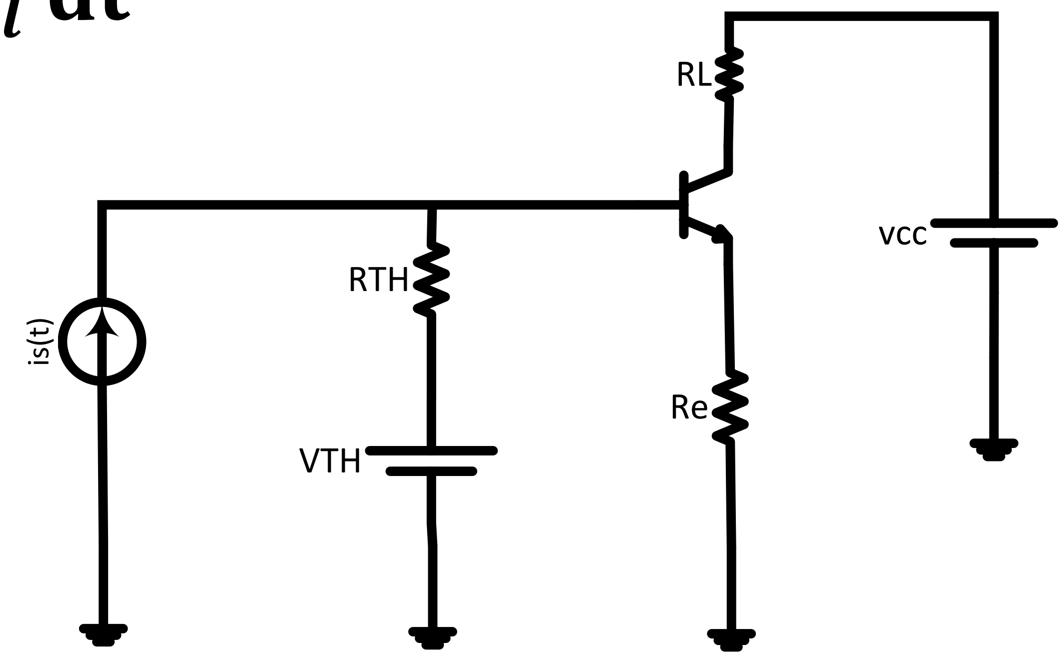
The average power dissipated or supplied by a device consists of the sum of the power in AC and DC terms .

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

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

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

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



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

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

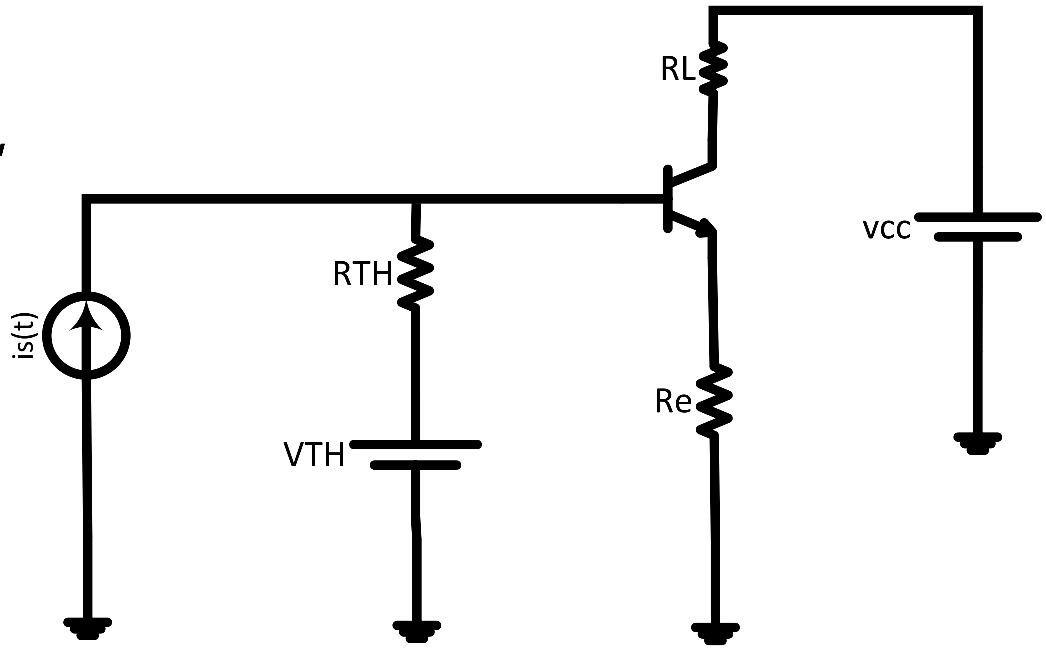
$$I_{cm\,,\,max} = I_{CQ}$$

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

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

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

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



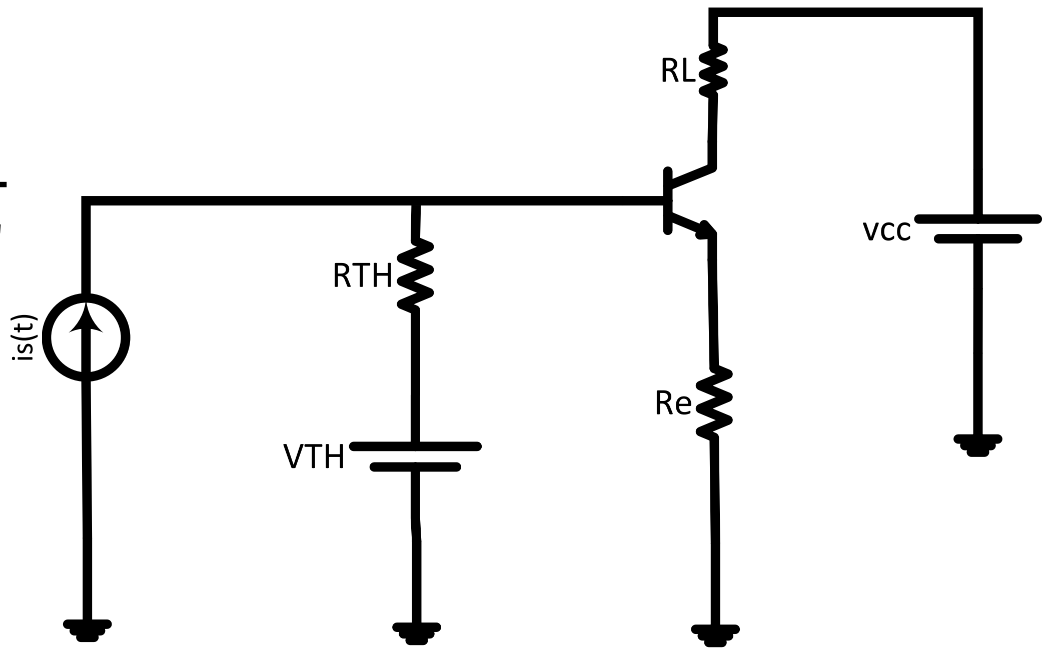
The Average Power Dissipated in The Load

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

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

$$If\ R_e << R_l$$

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



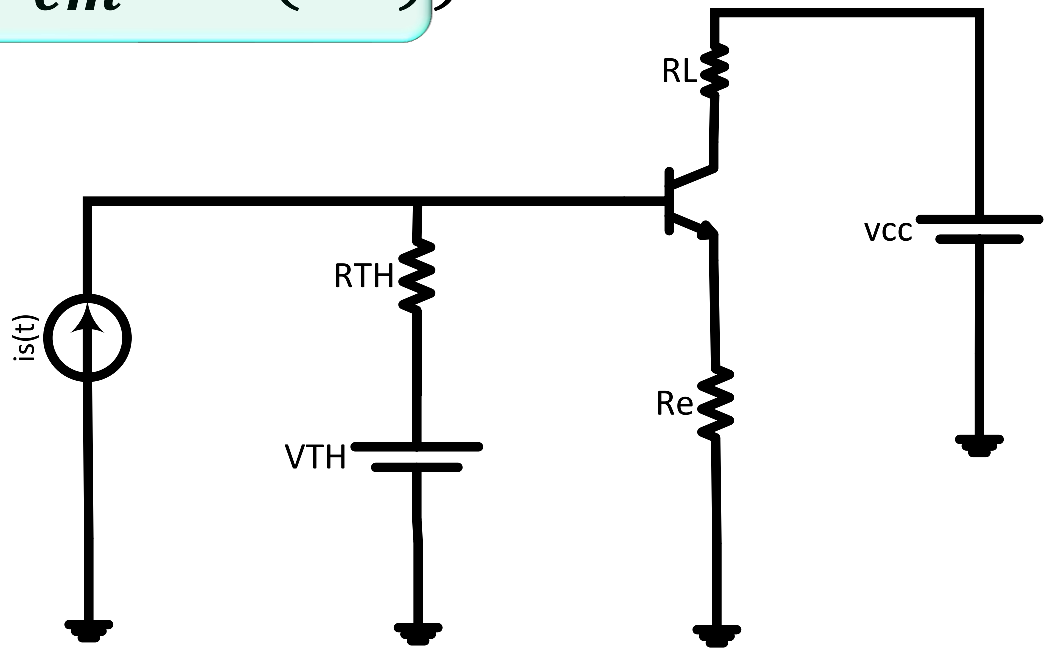
Average Power Delivered by the Supply : P_{cc}

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

$$i_C(t)$$

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

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



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

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

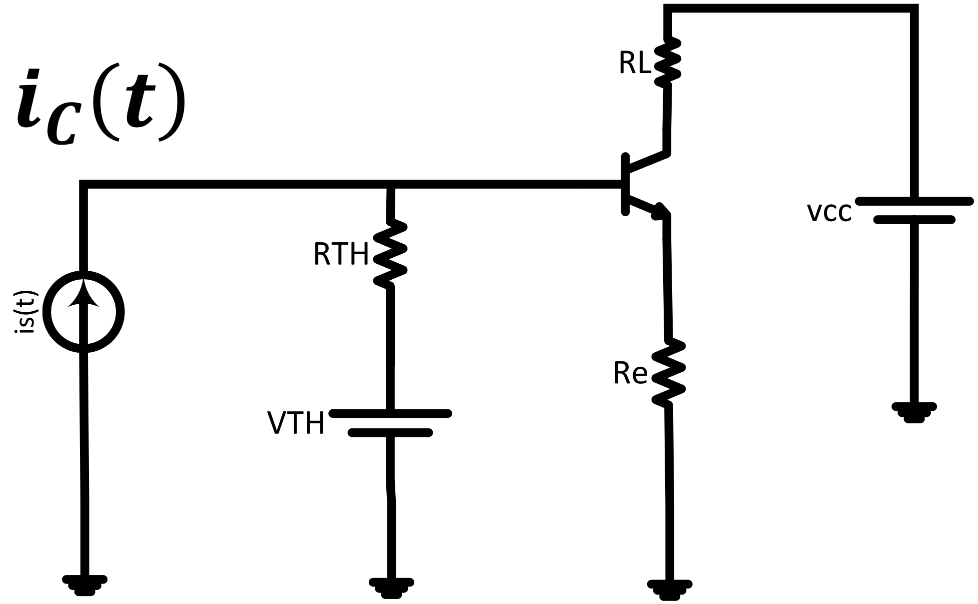
$$If\ R_e << R_l$$

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

Average Power Dissipated in the Transistor : P_c

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

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



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

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

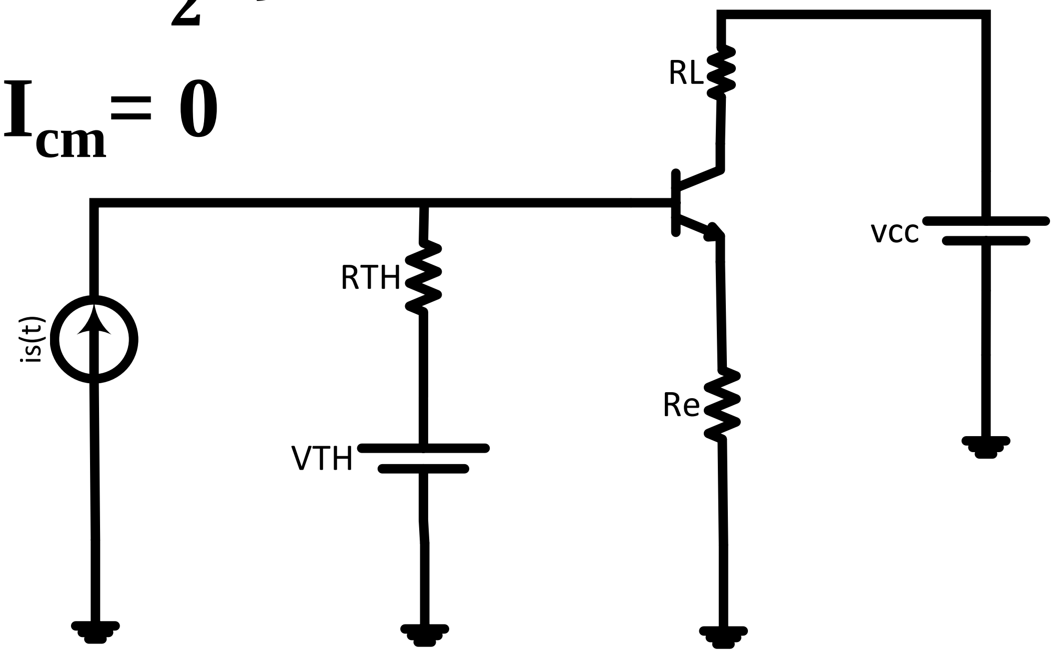
P_{cc}

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

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 $I_{cm} = 0$



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

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

$$If\ R_e << R_l$$

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

Summary

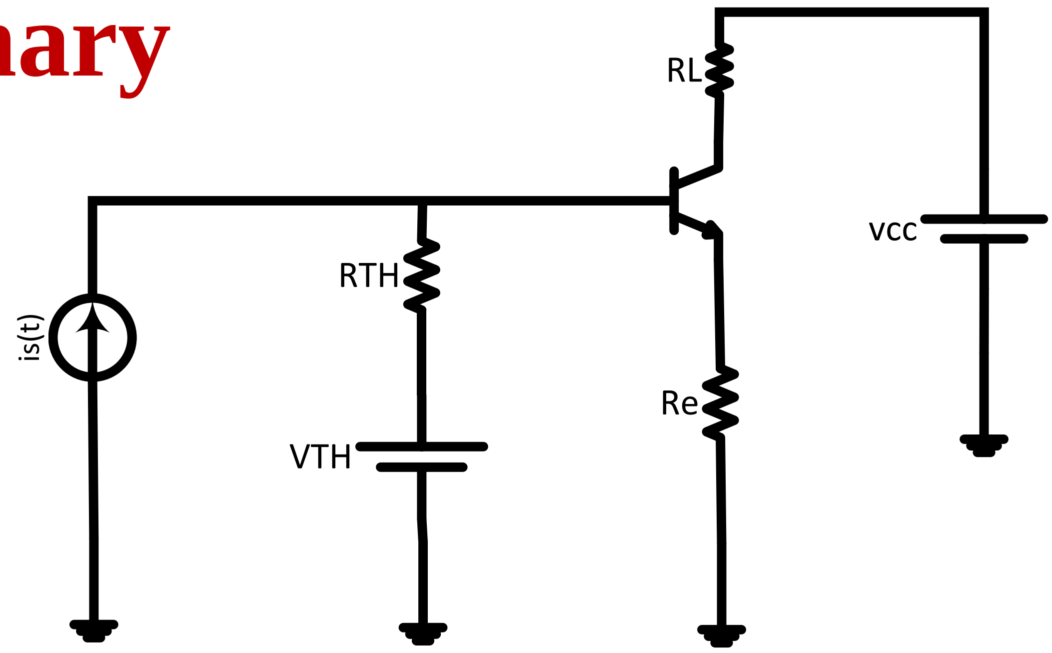
$$P_{l,ac} = \frac{1}{2} I_{cm}{}^{2} R_L$$

If $R_e << R_l$

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

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

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



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

γ : *Figure of merit*

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

$$\gamma = 2$$

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

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

The Class A Common Emitter Power Amplifier with Choke

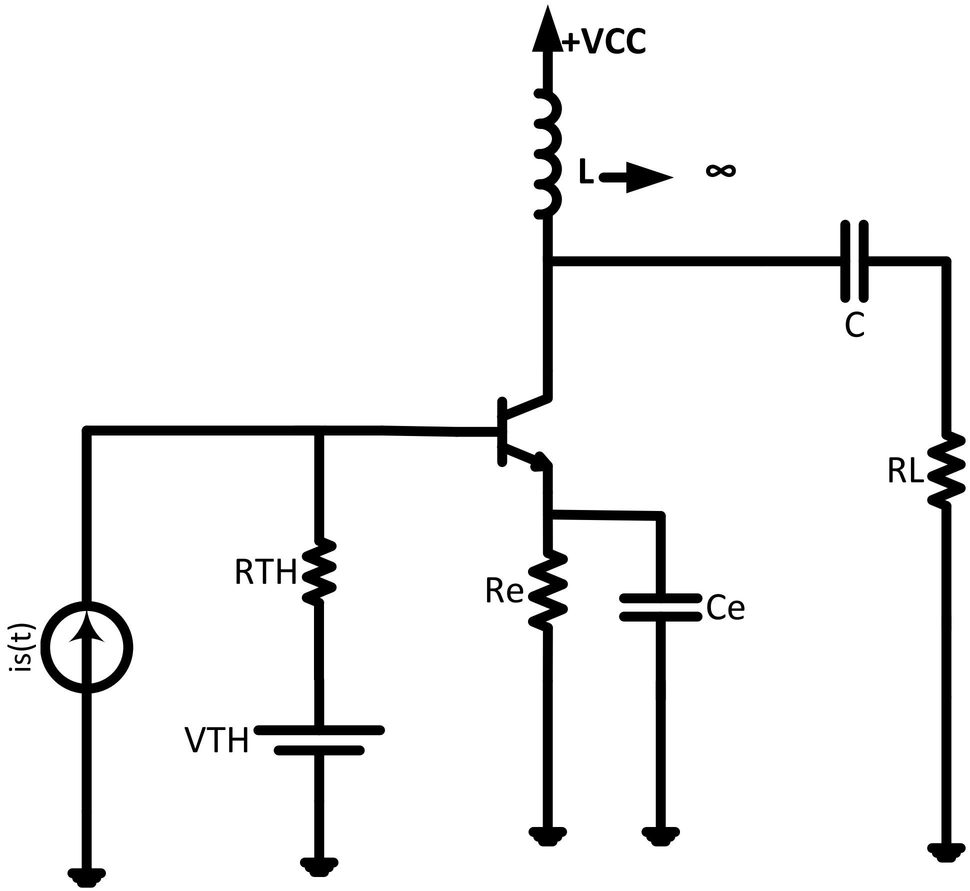
For Maximum Symmetrical swing:

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

$$R_{ac} = Rl$$

$$R_{dc} = R_e$$

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



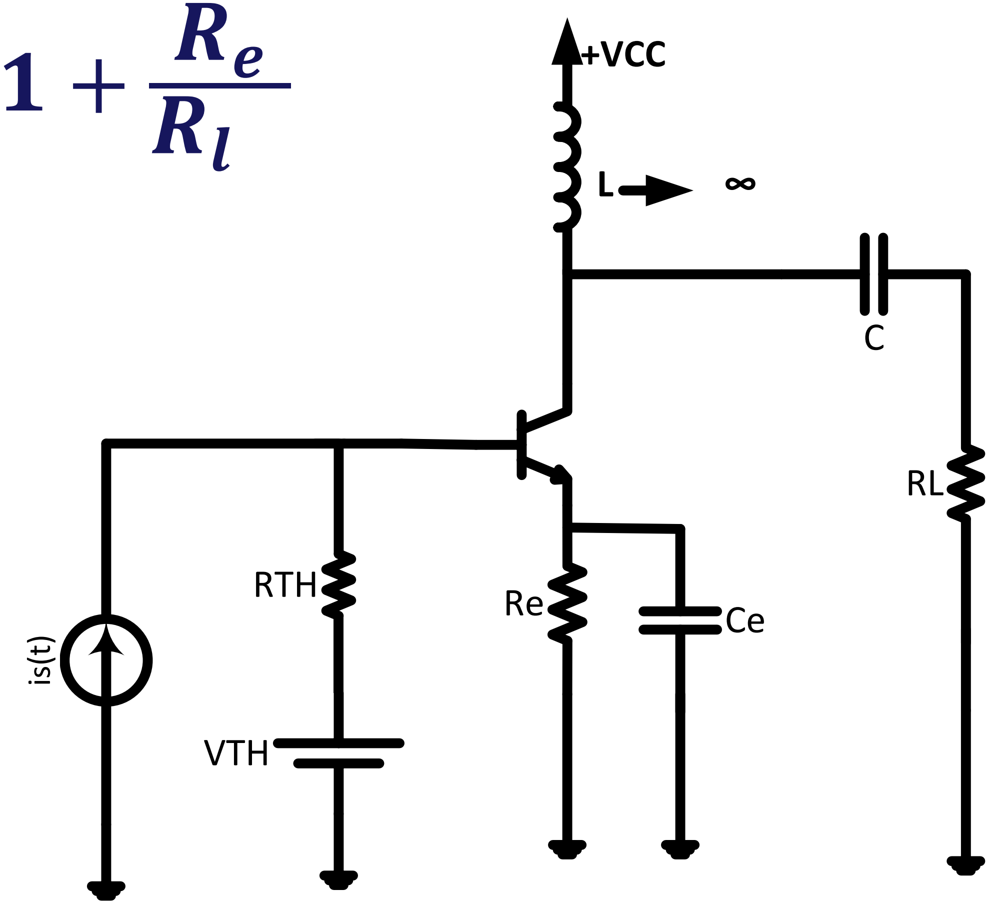
The Class A Common Emitter Power Amplifier with Choke

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

If $R_e << R_l$

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

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



Power Calculation:

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

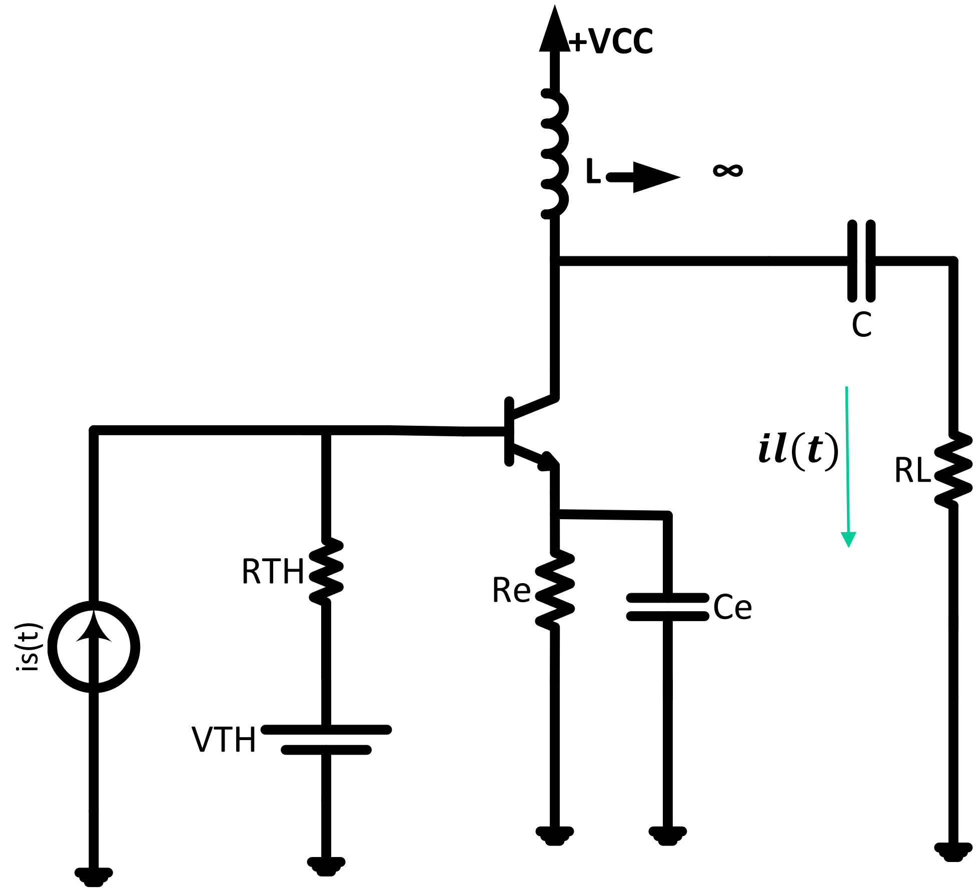
$$V_{CEQ} = V_{cc}$$

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

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

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

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

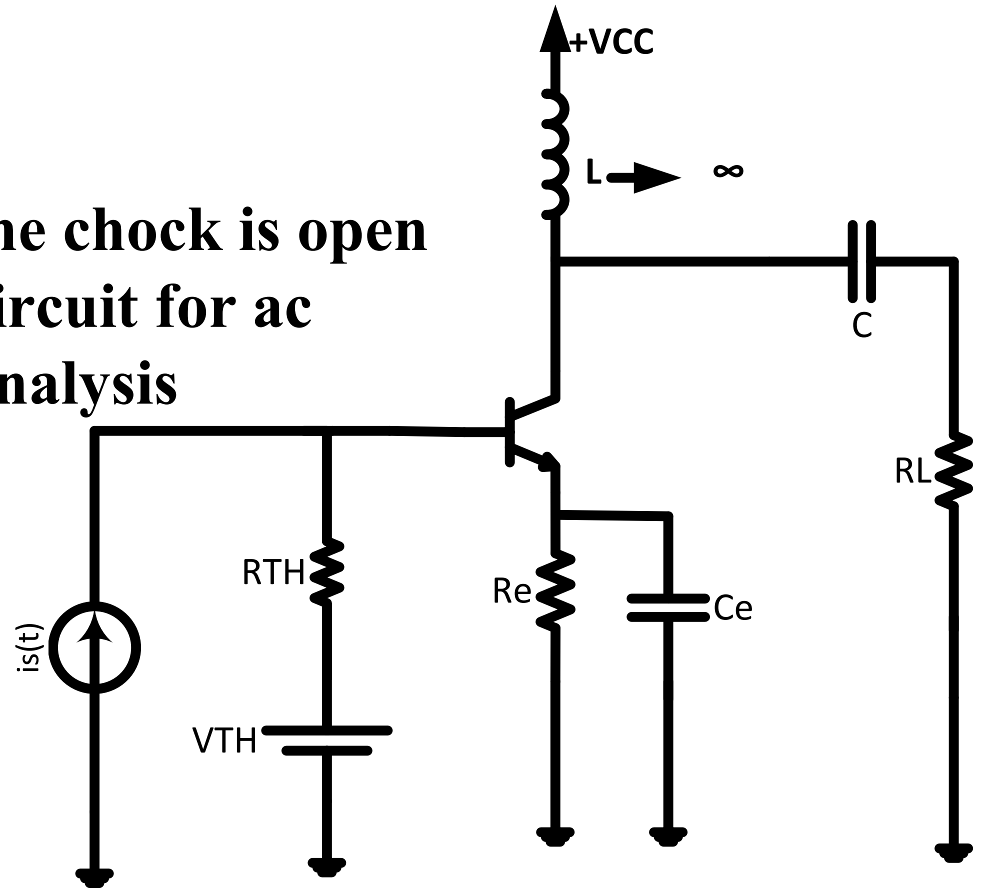


Power Calculation:

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

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

the chock is open circuit for ac analysis



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

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

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

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

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

Efficiency:

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

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

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

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

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

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

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

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

Transistor Ratings:

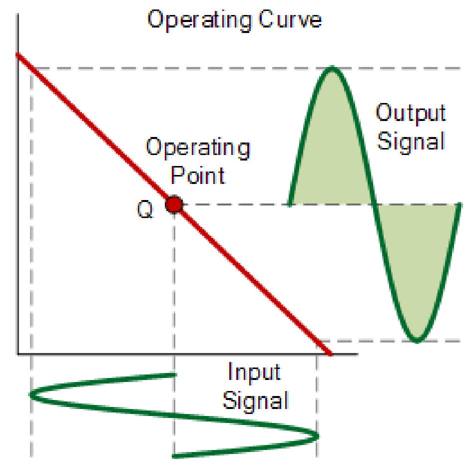
$i_C(t)$, max

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

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

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

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



Maximum Symmetrical swing

Transistor Ratings:

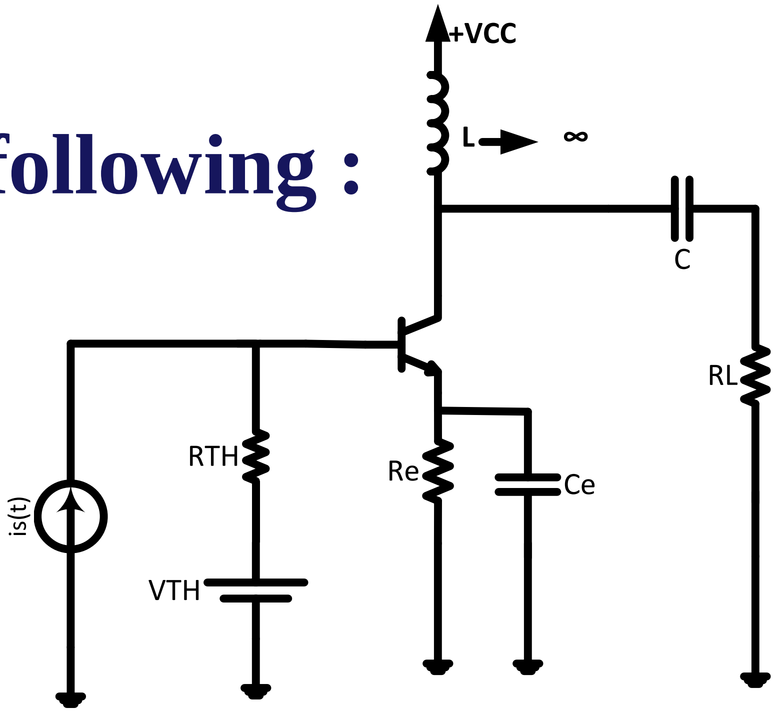
EXAMPLE:

A Power Transistor has the following :

BVCEO = 40V

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

Pc , max = 4W



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

Solution :

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

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

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

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

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

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

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

Transistor Ratings:

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

Solution:

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

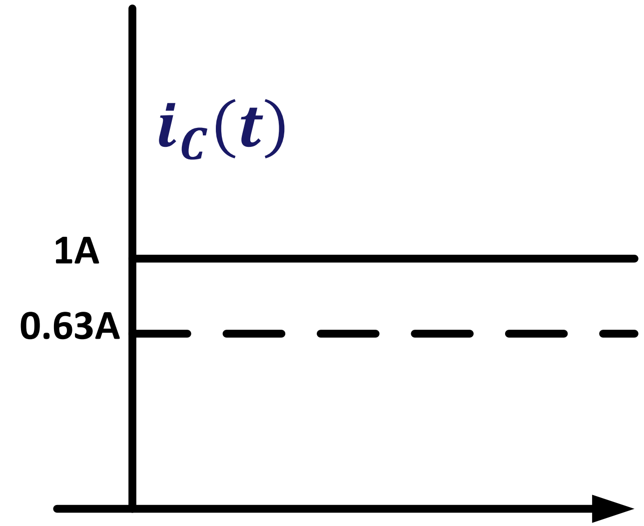
$$V_{CEQ} = \sqrt{Pc,max.RL} = 6.3\ \text{V}$$

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

There is A problem !

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

$\gamma = 5.8$

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

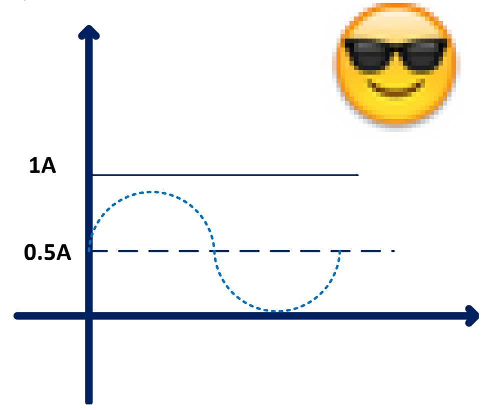
∴ Icm,max = 0.5 A

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

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

V_{CEQ} = Rac . ICQ = 5V

Vcc = V_{CEQ} = 5V



Pc,max = VCEQ*ICQ = 2.5W

Pcc = Vcc ICQ = 2.5W

$\gamma = 2$

Transformer coupled class A Power Amplifier:

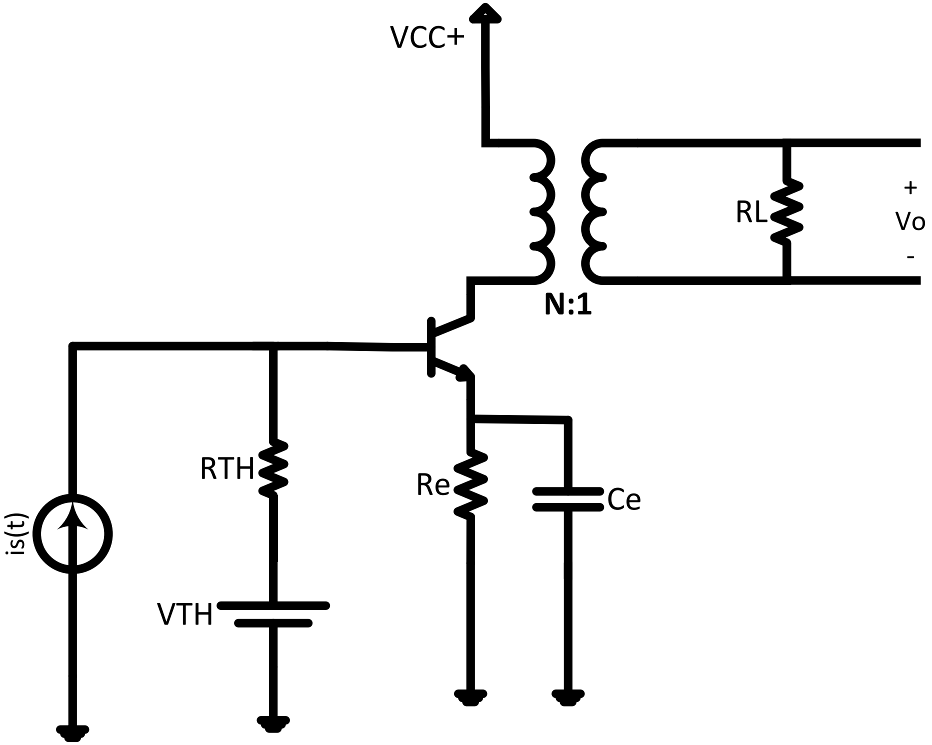
For Maximum symmetrical swing :

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

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

$$R_{dc} = R_e$$

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



$If \quad R_e << R_l'$

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

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

Power Calculation:

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

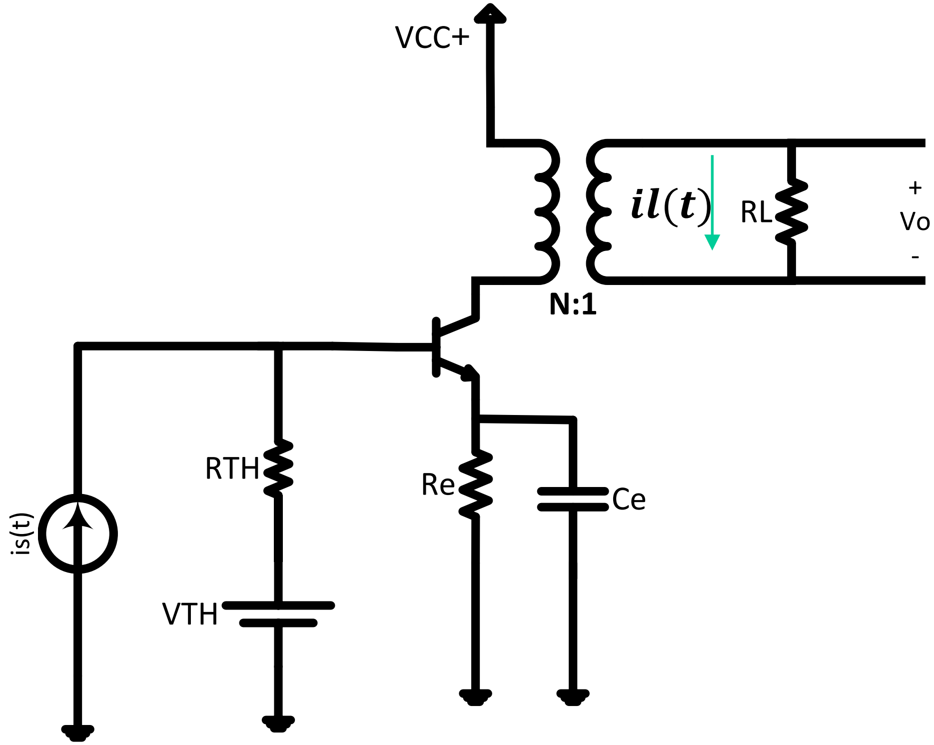
$$I_{lm} = N \,.\, Icm$$

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

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

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

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

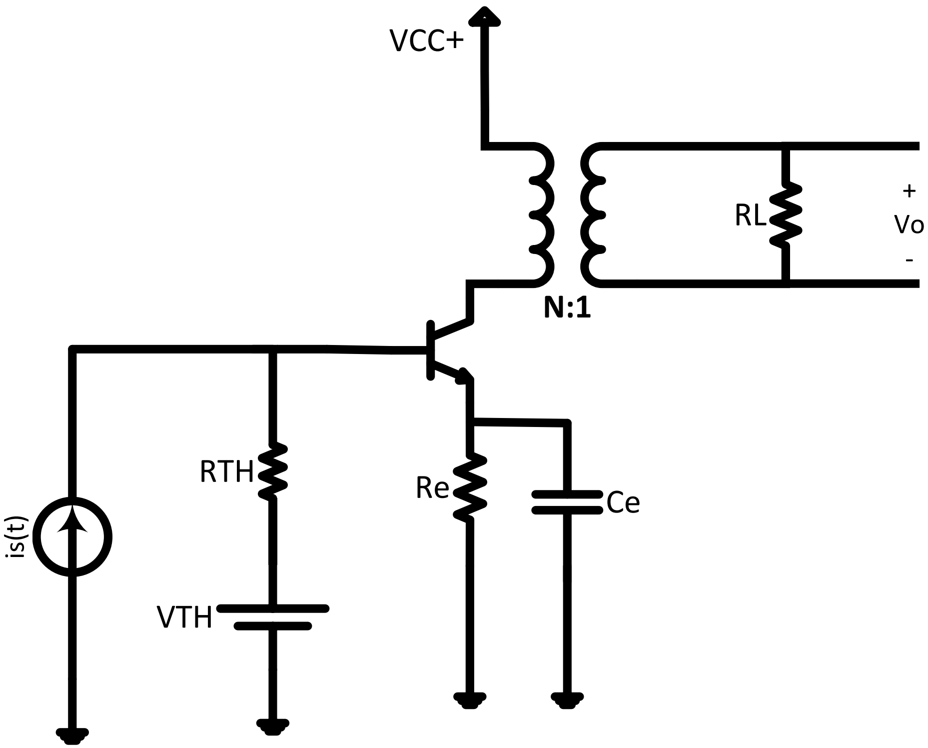


Power Calculation:

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

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

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



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

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

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

Power Calculation:

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

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

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

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

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

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

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

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 = $V_{CEQ} \cdot I_{CQ}$.

V_{CEQ} = Rac . I_{CQ}

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

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

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

How to choose N ?

The Q point must satisfy :

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

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

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

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

$\mathbf{3.17} \ > \boldsymbol{N} > \mathbf{1.26}$

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

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

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

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

Class A Output stage Power Amplifier:

Q1 is common collector amplifier
DILIVER A LARGE AMOUNT OF POWER

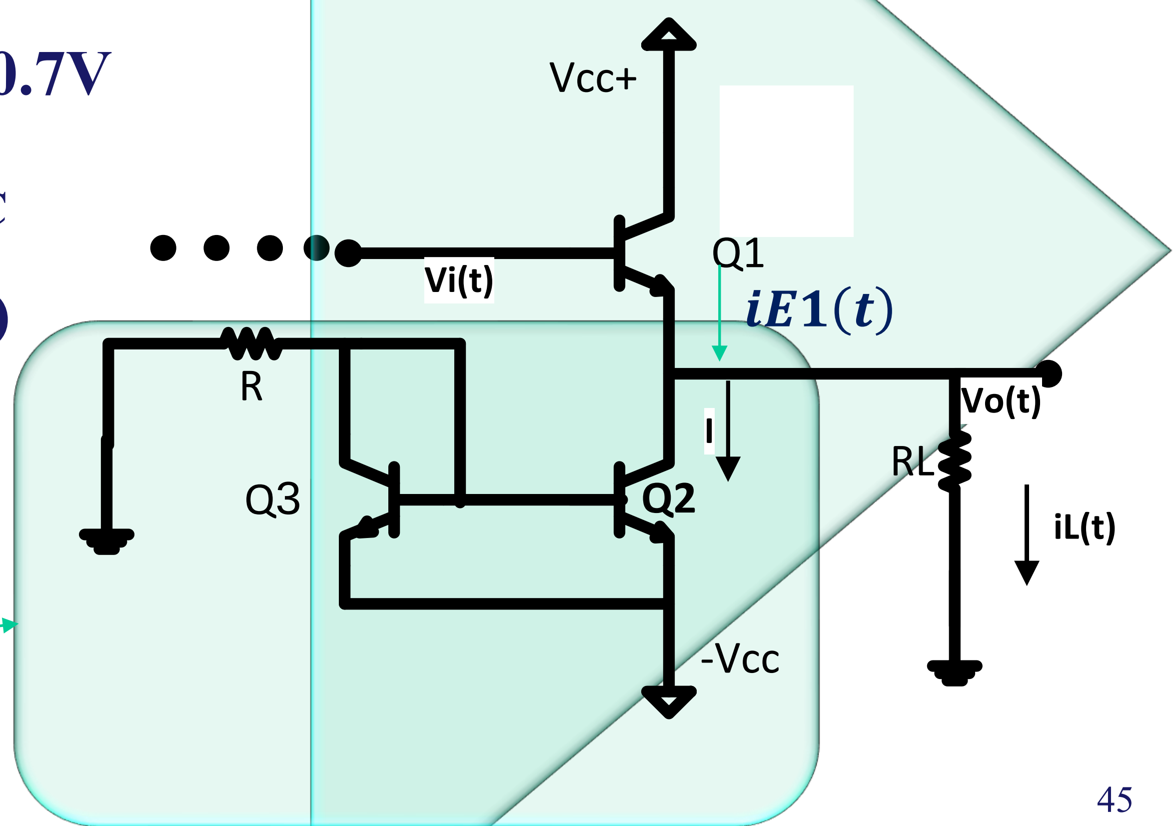
The output stage is designed so that :

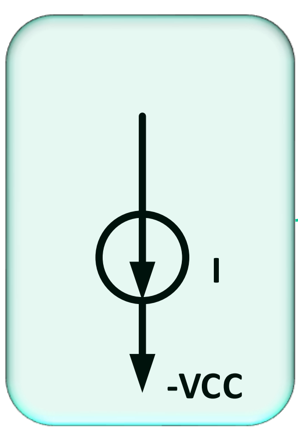
$V_o = 0$, $I_L = 0$, $V_i = 0.7V$

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

$V_o(t) = V_i(t) - V_{BE}(t)$

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





Current source

Transfer Curve:

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

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

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

(When T1 enters Saturation)

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

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

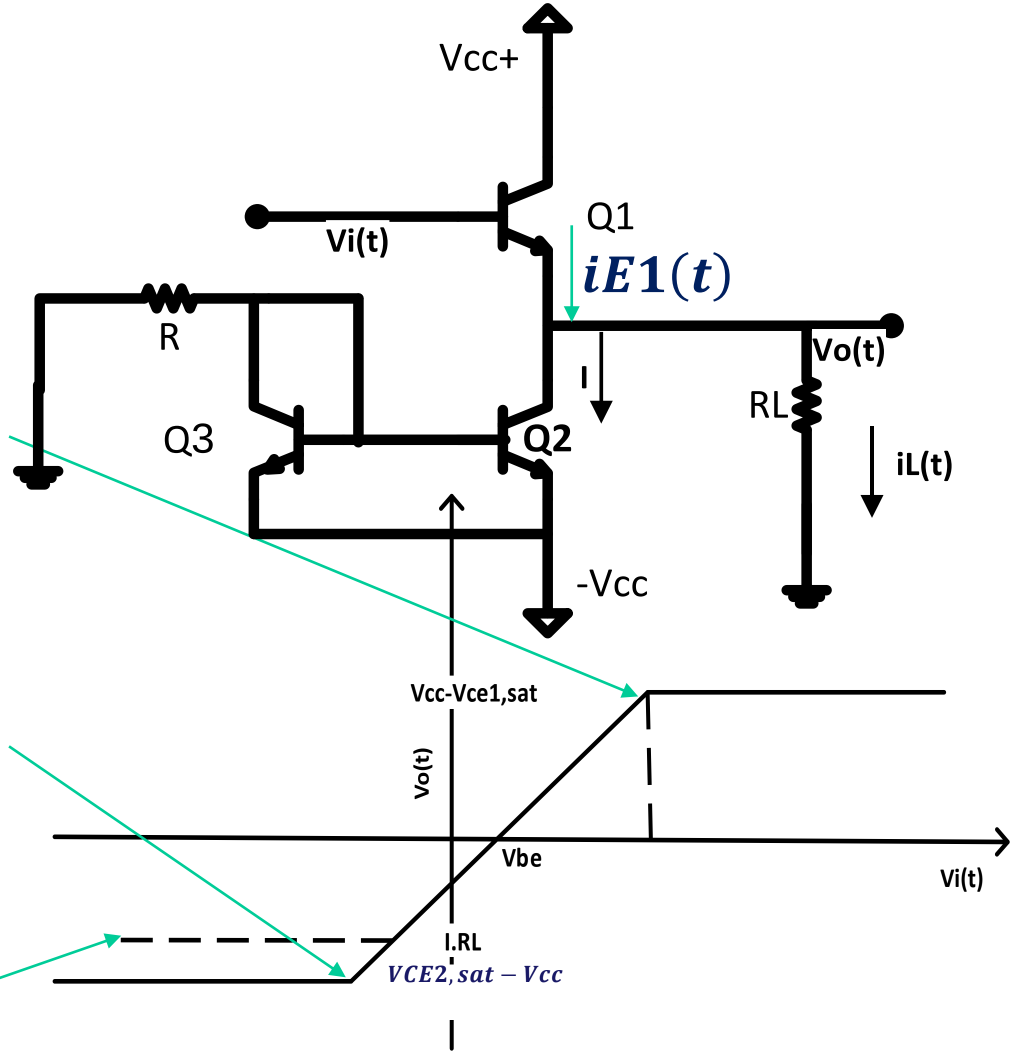
(When T enters Saturation)

Or:

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

(When T1 enters Cuttoff)

$$iE1(t) = 0$$



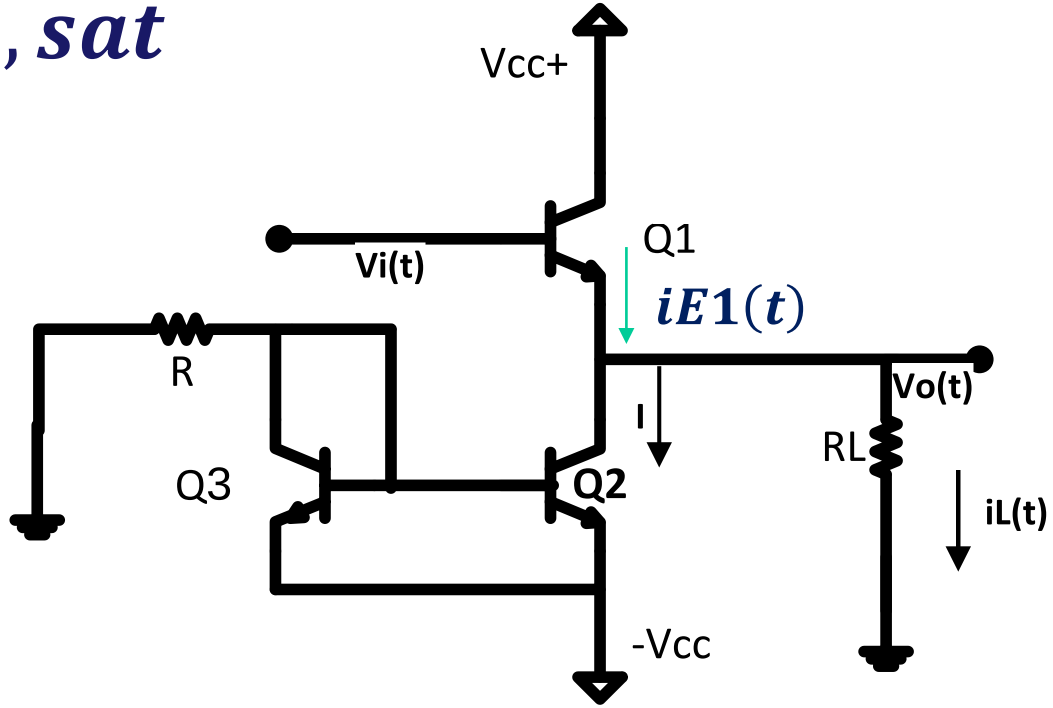
When Q2 gets into saturation:
Vo,min = -Vcc + Vce,sat
OR
When Q1 gets into cut-off:
iL = iE1 - I ---> iE1 = 0 ---> iL = -I
Vo,min = iL*RL = -I*R

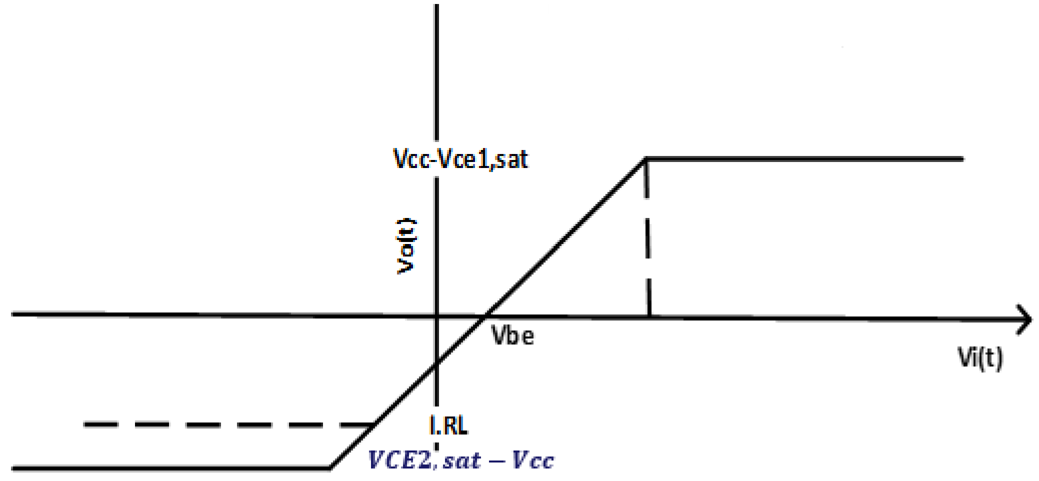
To allow Maximum symmetrical swing :

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

$$-IRL \cong -Vcc$$

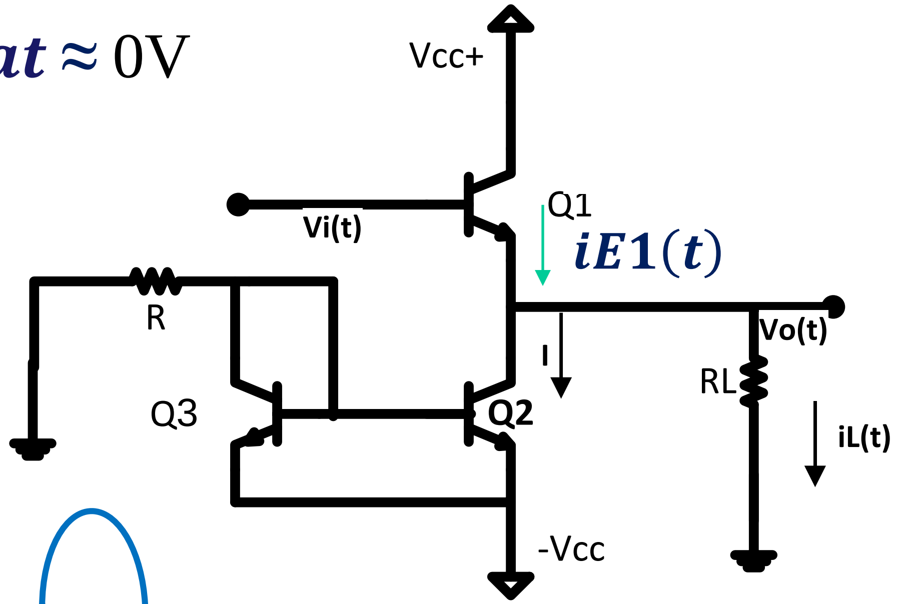
$$\therefore I = \frac{Vcc}{RL}$$

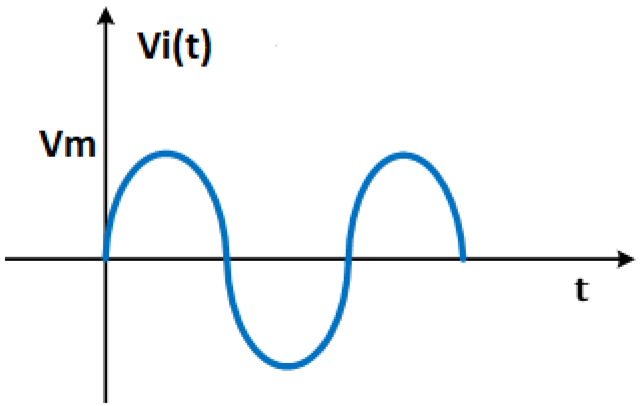


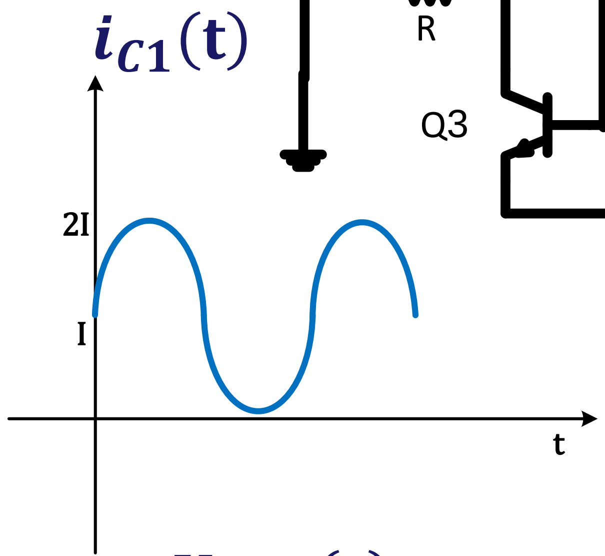


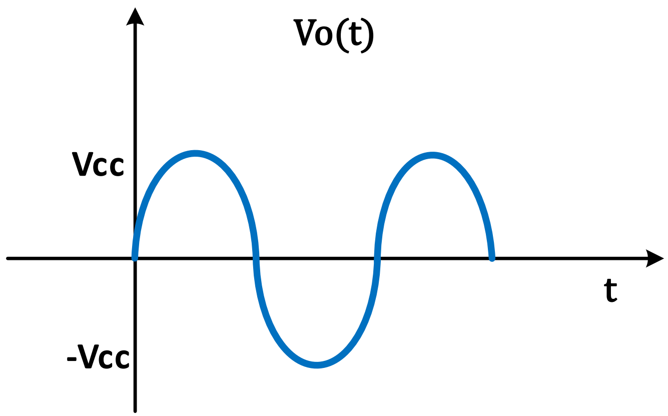
Signal Wave forms: $VCE,sat \approx 0\text{V}$

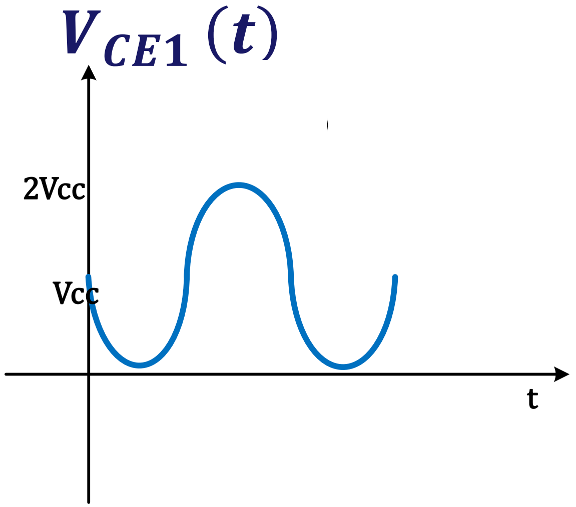
Maximum possible swing











Signal Wave forms:

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

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

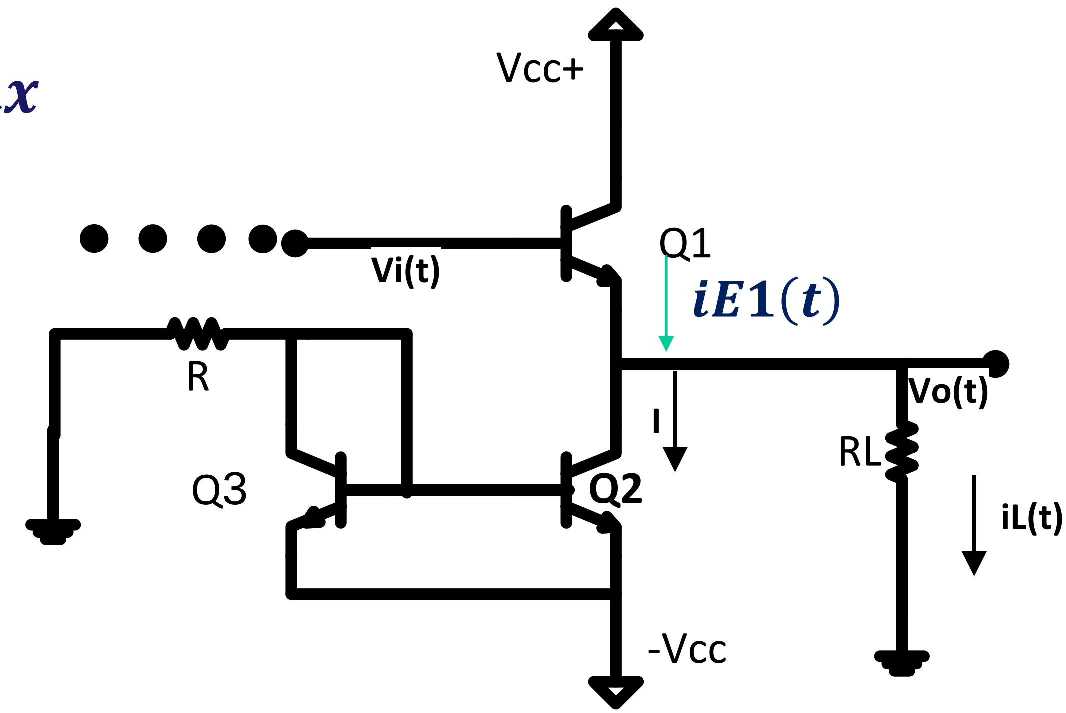
$$iE1(t),max = I + iL(t),max$$

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

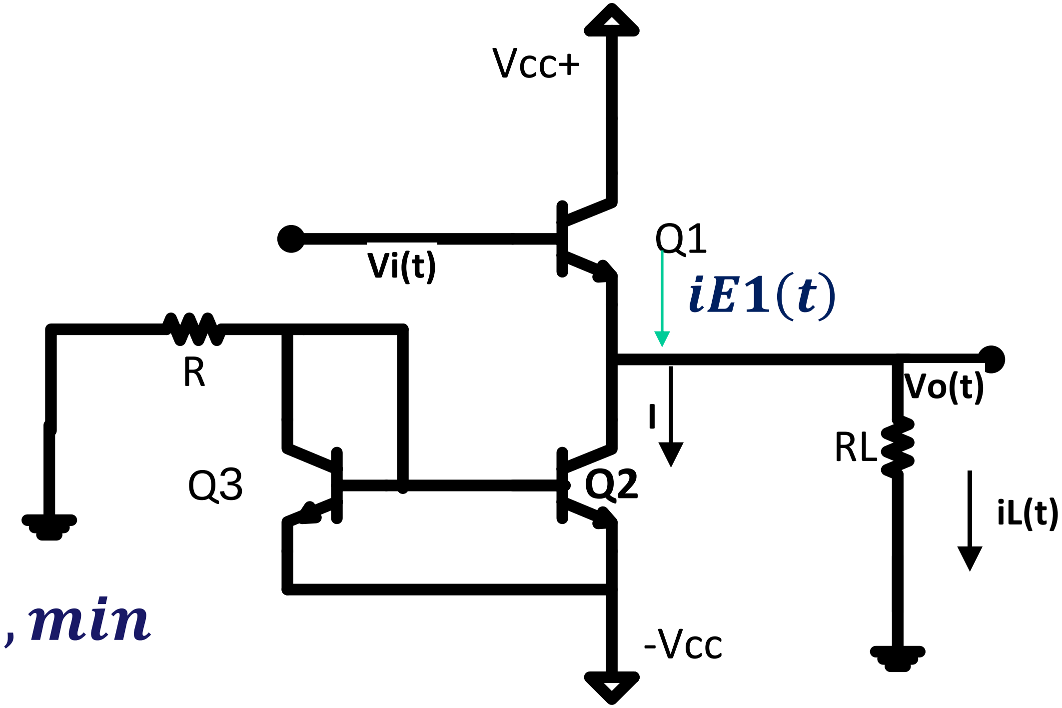
$$iE1(t),max = I + \frac{Vcc}{RL}$$

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

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



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



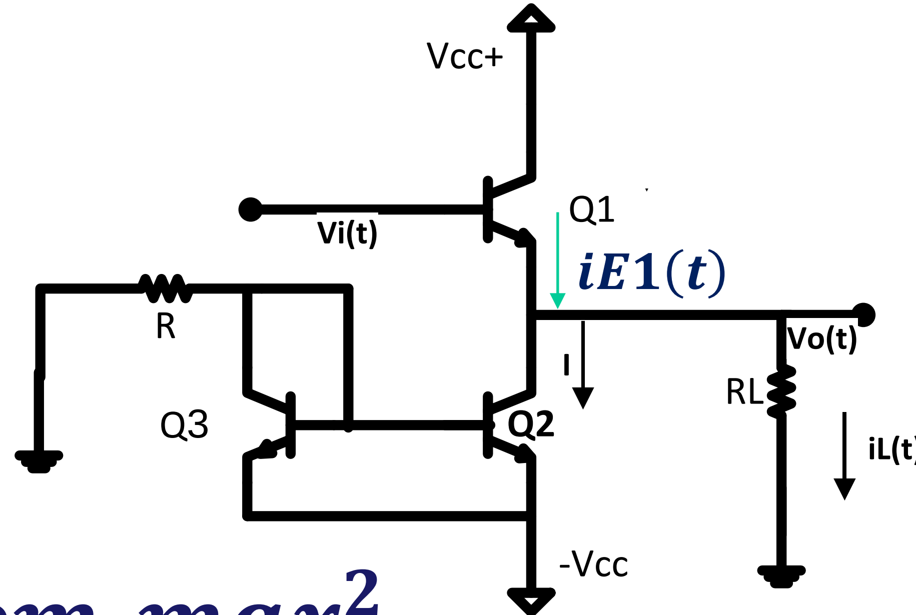
$$VCE1(t) \;= Vcc - Vo(t)$$

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

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

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

Power Calculation:



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

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

$$Pcc = Pcc1 + Pcc2$$

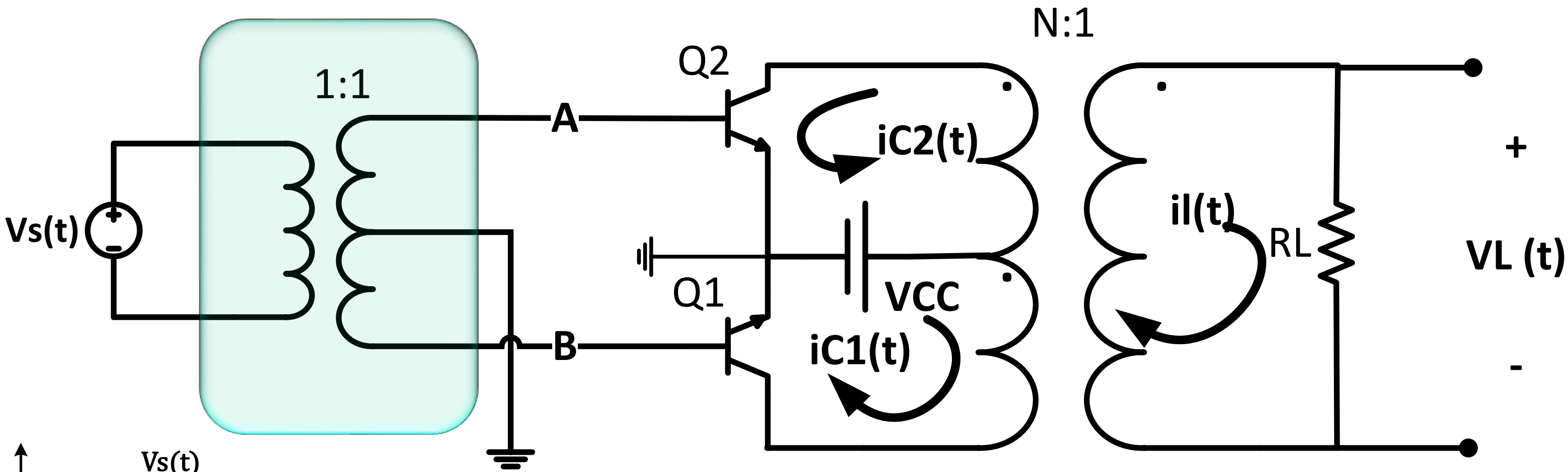
$$Pcc = 2Vcc * I$$

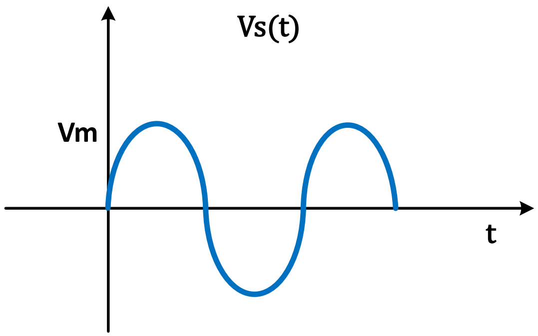
$$\eta, max = \frac{(PL, ac), max}{Pcc} * 100\%$$

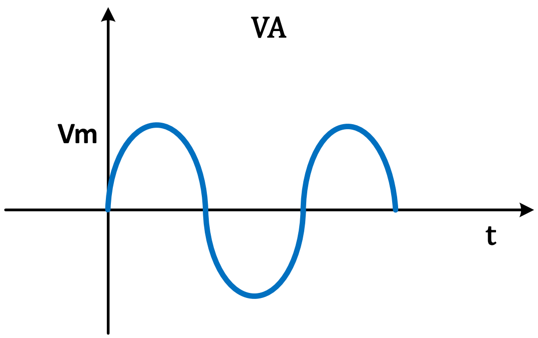
$$\eta = \frac{PL, ac}{Pcc} * 100\%$$

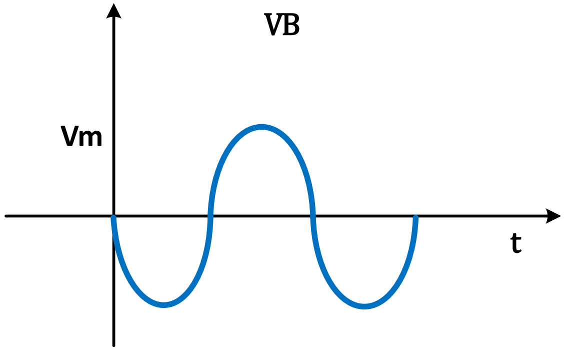
$$\eta, max = 25\%$$

Class B Push-Pull Power Amplifier:

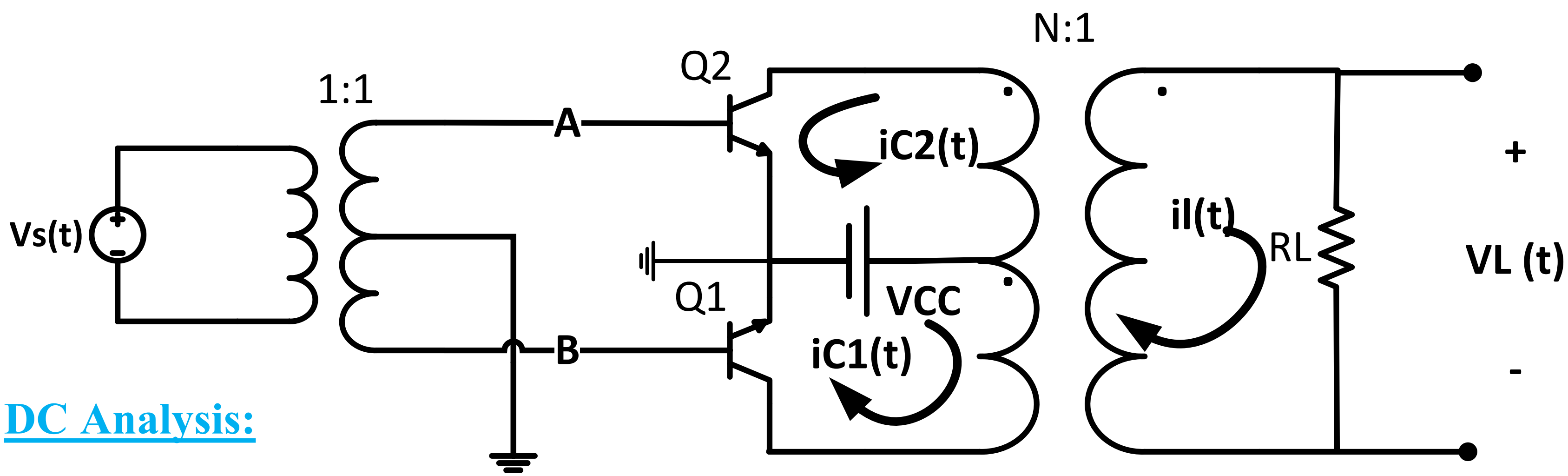




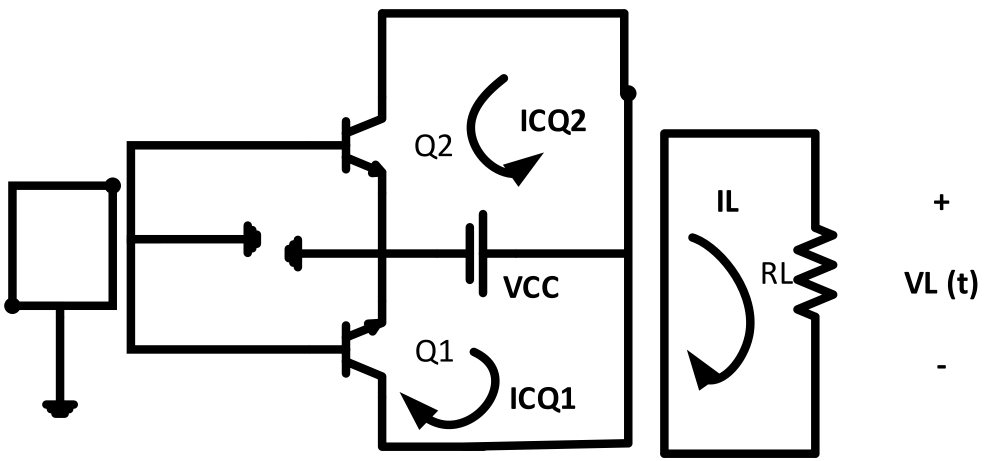




Class B Push-Pull Power Amplifier:



DC Analysis:



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

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

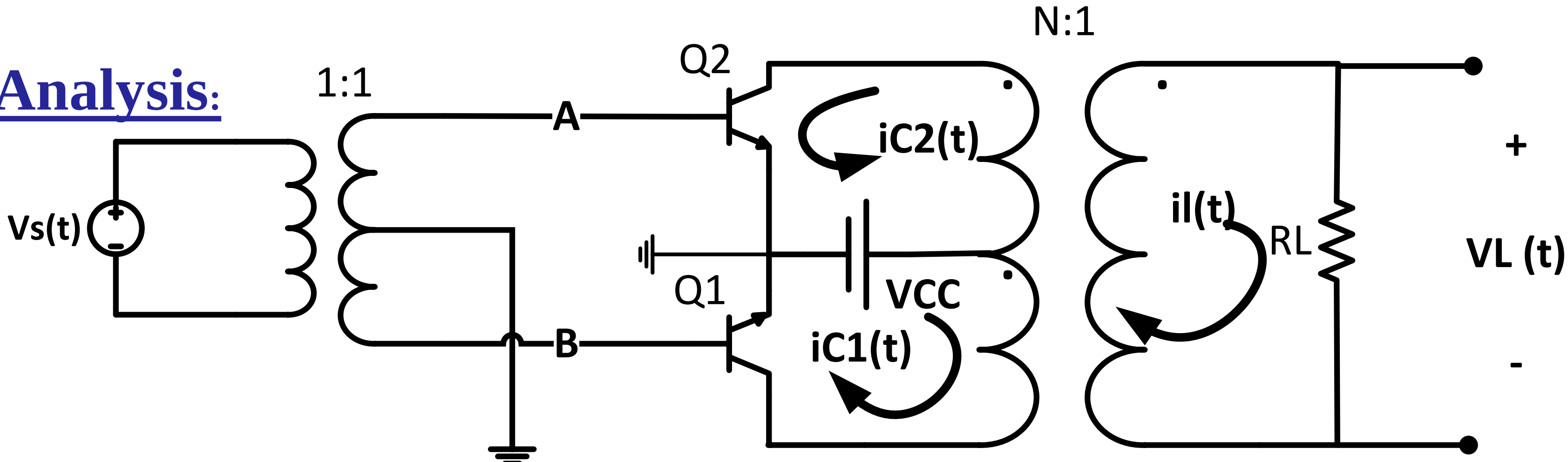
$$I_{CQ1} = I_{CQ2} = 0$$

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

$$V_L = 0 \quad I_L = 0$$

Class B Push-Pull Power Amplifier:

AC Analysis:



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

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

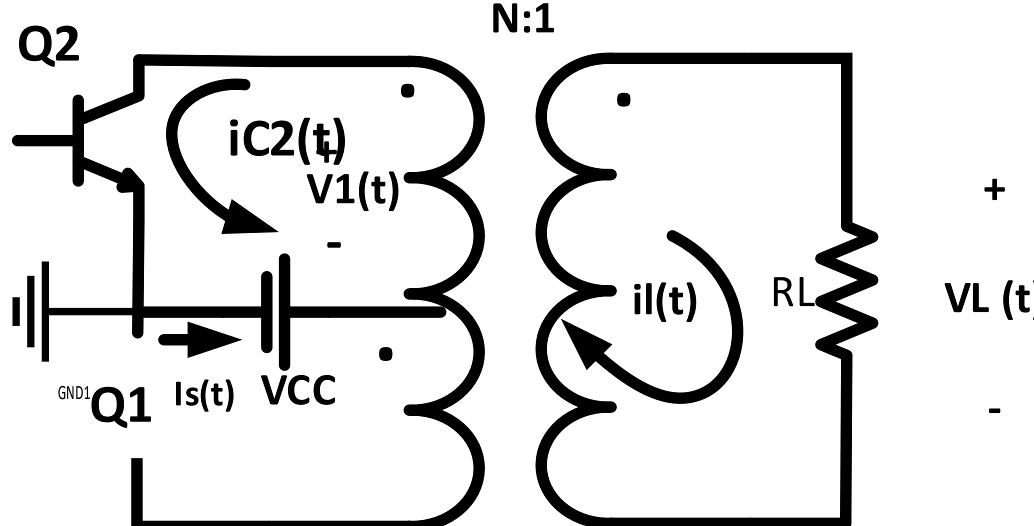
$v_B(t) < 0\ ;\quad Q_1\ is\ off$

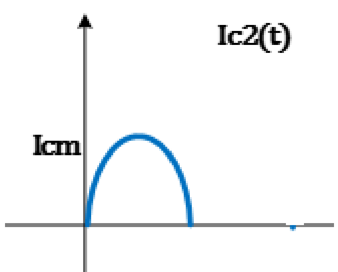
$\therefore i_L(t) = -N i_{C2}(t)$

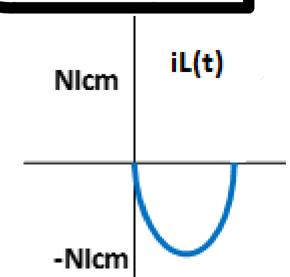
and

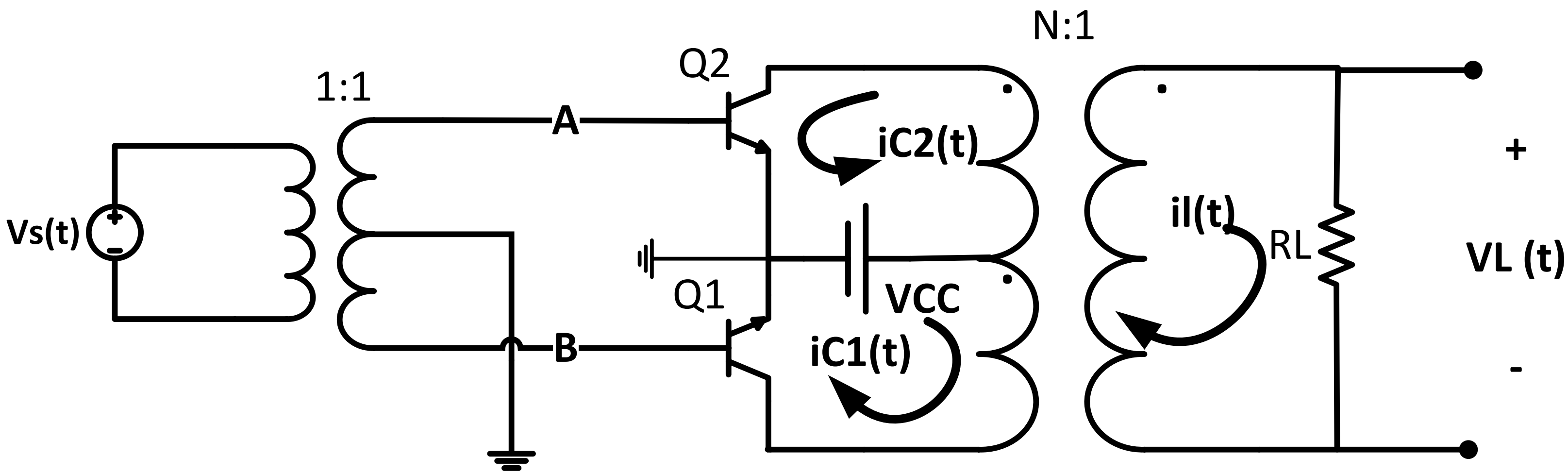
$i_s(t) = i_{C2}(t)$

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









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

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

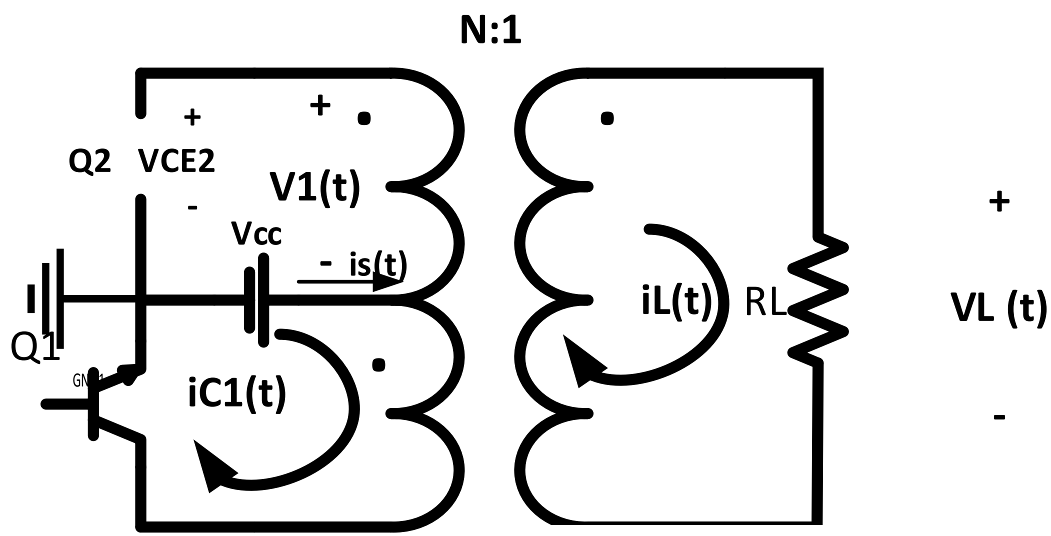
$v_B(t) > 0\ ; \quad Q_1\ is\ on$

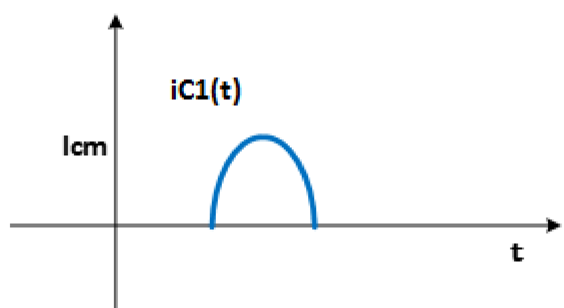
$\therefore\ i_L(t) = +N\, i_{C1}(t)$

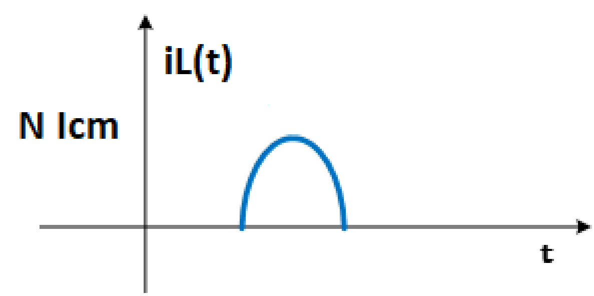
and

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

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







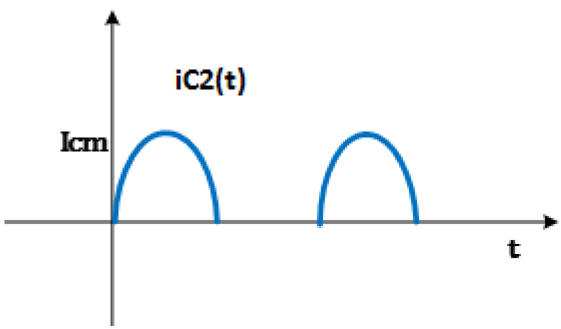
Class B Push-Pull Power Amplifier:

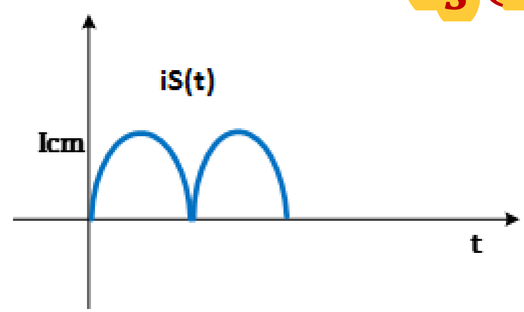
AC Analysis:

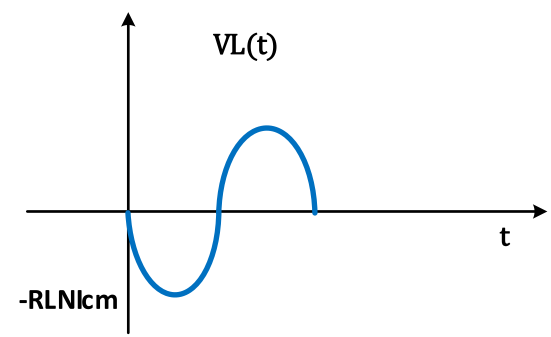
c) for the complete cycle

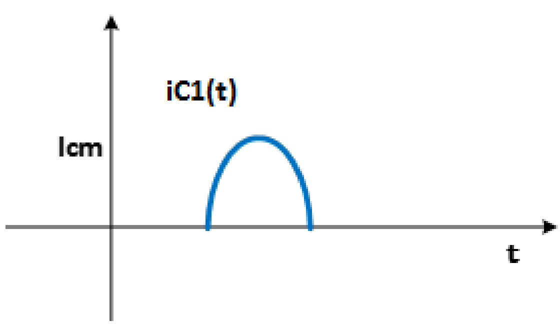
$$i_L(t) = N\left(i_{C1}(t) - i_{C2}(t)\right)$$

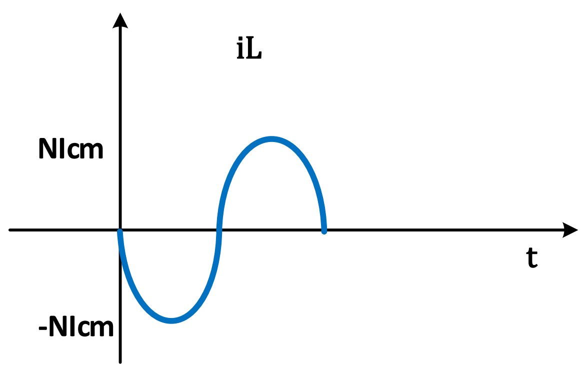
$$i_s(t) = i_{C2}(t) + i_{C1}(t)$$





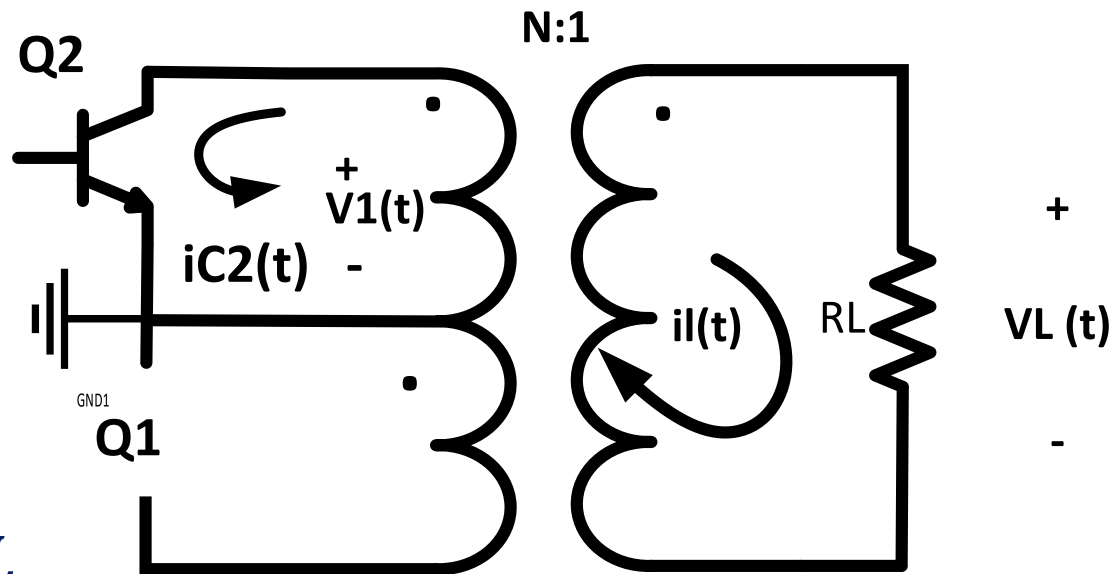






Class B Push-Pull Power Amplifier:

AC Load Line for Q2:



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

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

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

$$R_l' = N^2 RL$$

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

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

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

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

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

Class B Push-Pull Power Amplifier:

AC Load Line for Q2:

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

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

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

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

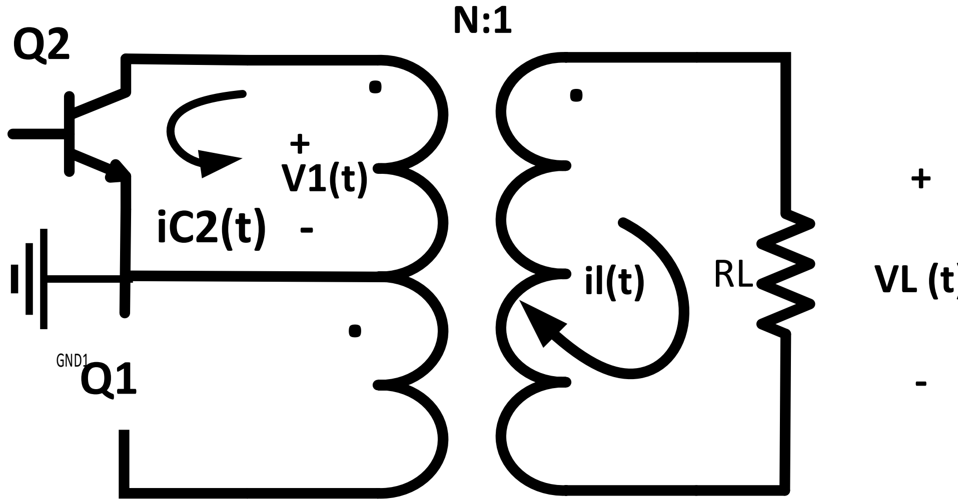
$$I_{cm2,max} = \frac{V_{cc}}{R_l'}$$

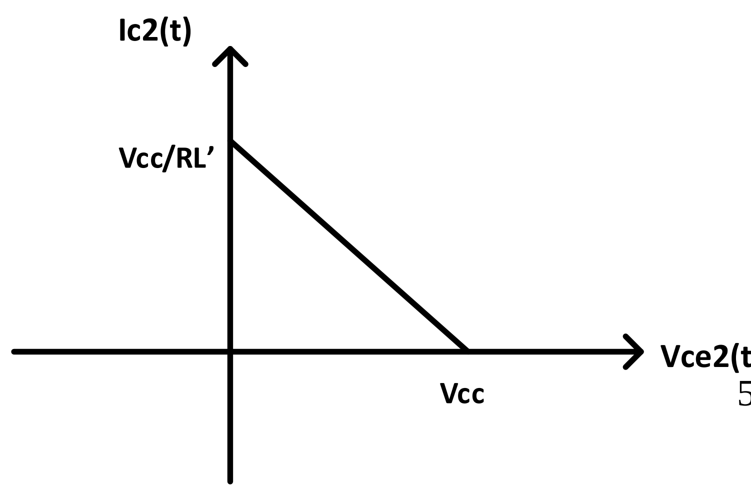
To find $v_{CE}(t)_{,max}$

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

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

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





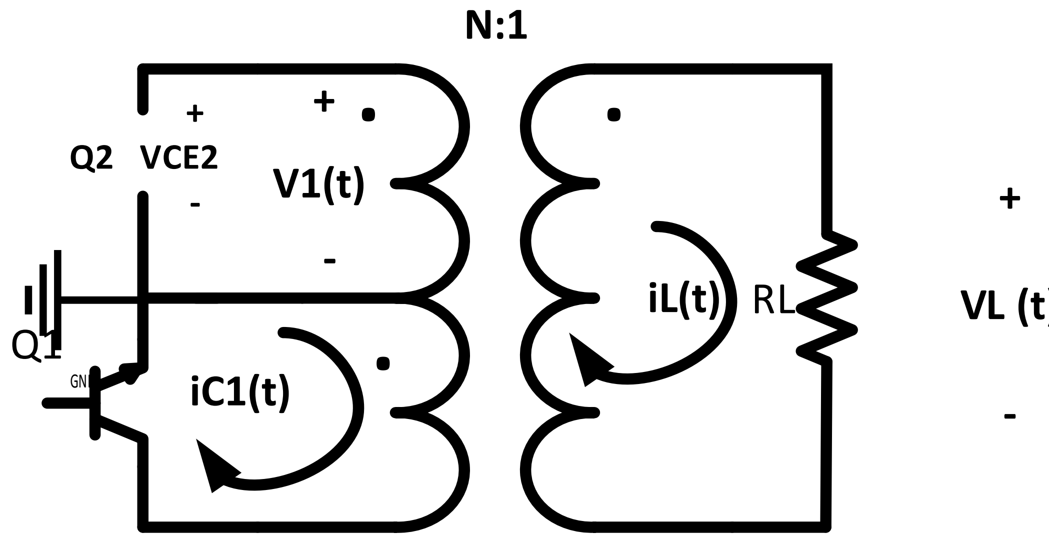
Class B Push-Pull Power Amplifier:

AC Load Line for Q2:

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

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

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



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

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

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

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

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

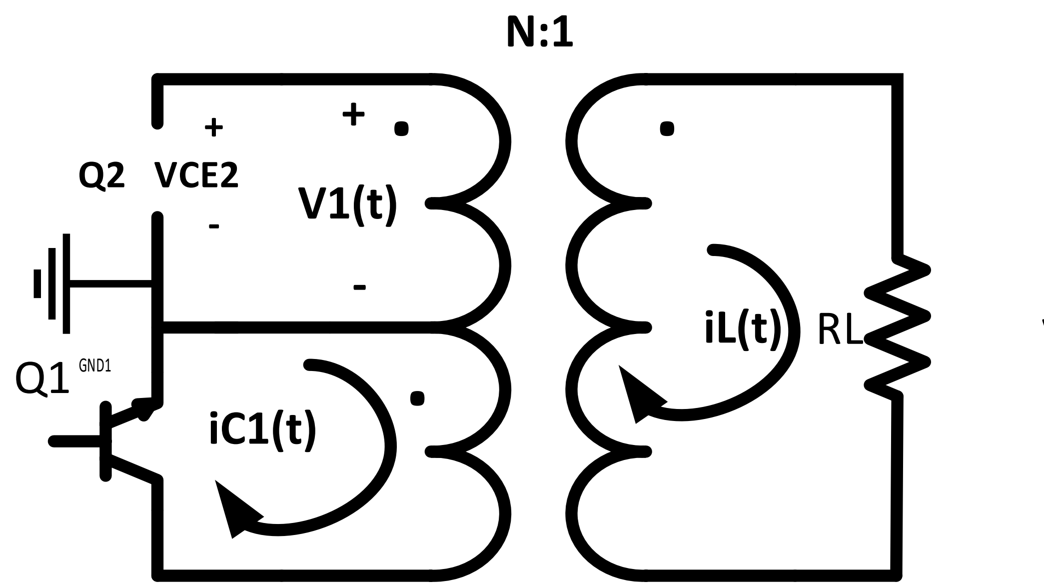
$$v_{CE2}(t) = V_{cc} + N^2\, R_L\, i_{C1}(t)$$

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

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

Class B Push-Pull Power Amplifier:

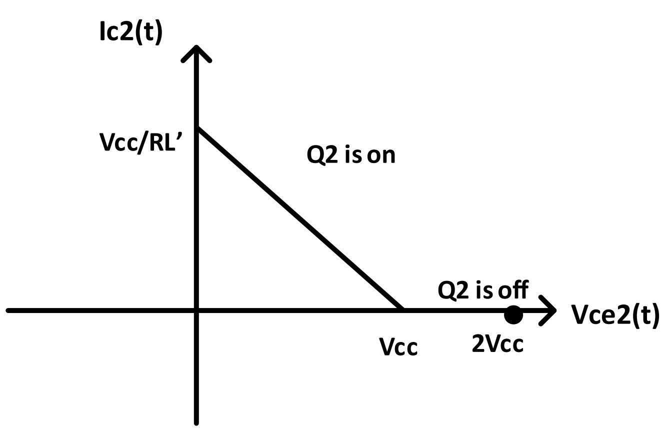
AC Load Line for Q2:



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

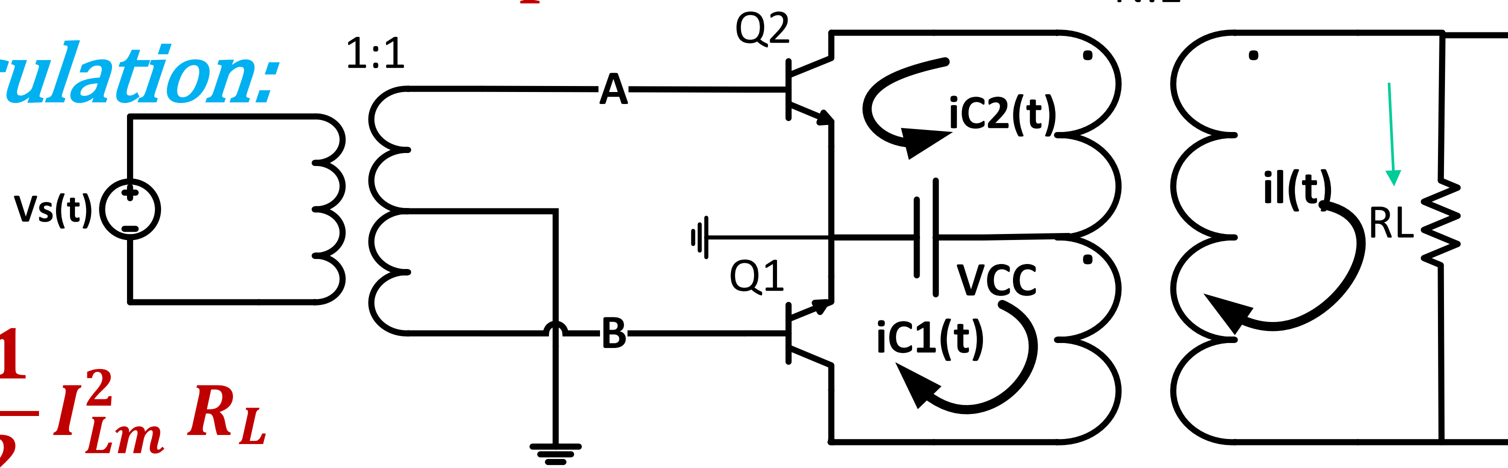
$$v_{CE2}(t)_{,max} = V_{cc} + V_{cc}$$

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



Class B Push-Pull Power Amplifier:

Power calculation:



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

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

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

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

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

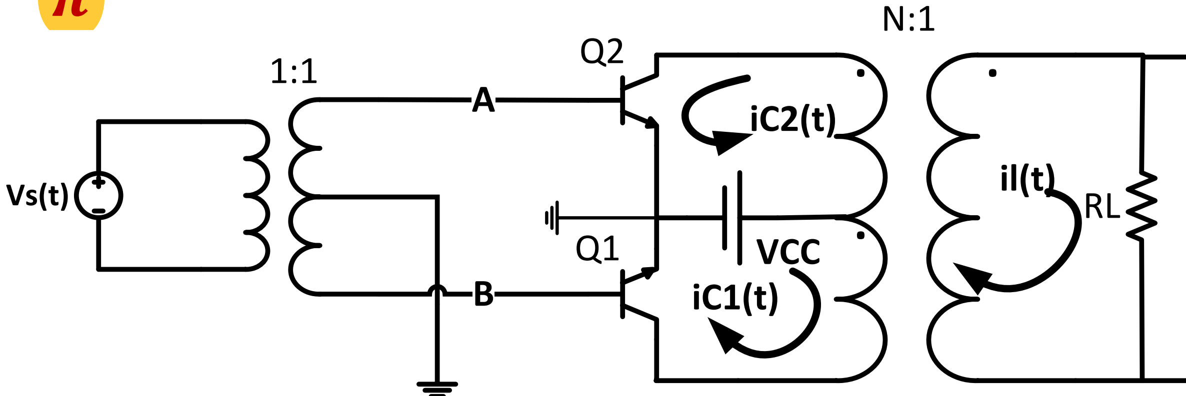
Class B Push-Pull Power Amplifier:

Power calculation:

$$P_{cc} = \frac{1}{T}\int_0^T V_{cc}\, i_s(t)dt = \frac{2V_{cc} I_{cm}}{\pi}$$

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

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



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

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

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

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

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

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

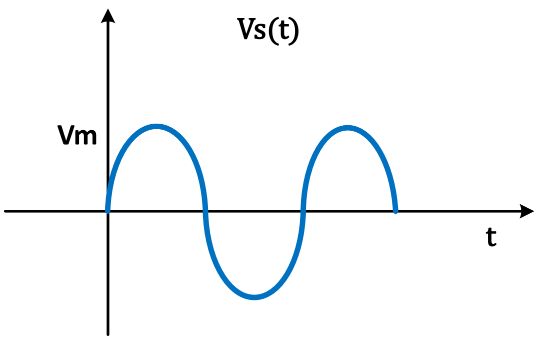
$$\eta_{,max} = \frac{\pi}{4} * 100\% = 78.5\%$$

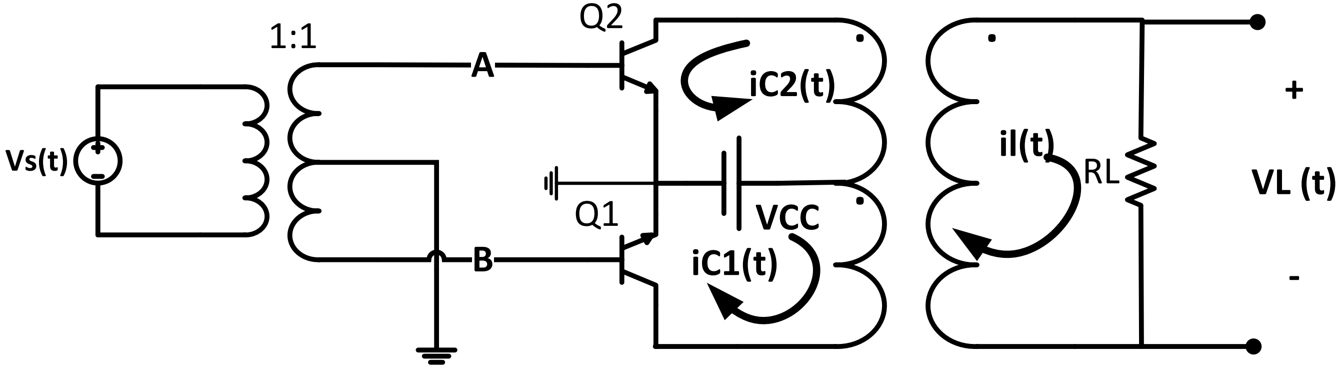
$$\gamma = \frac{Pc,max}{(PL,ac),max}$$

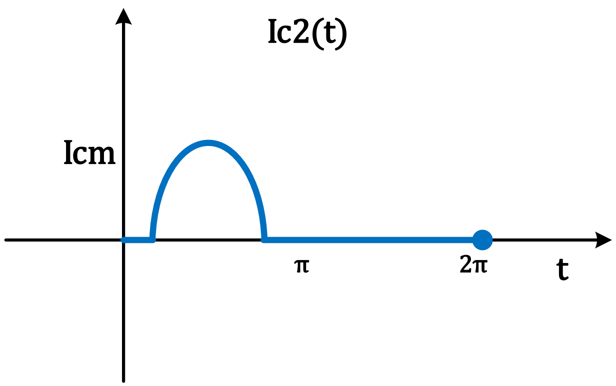
$$\gamma = \frac{2}{\pi^2} \cong 0.2$$

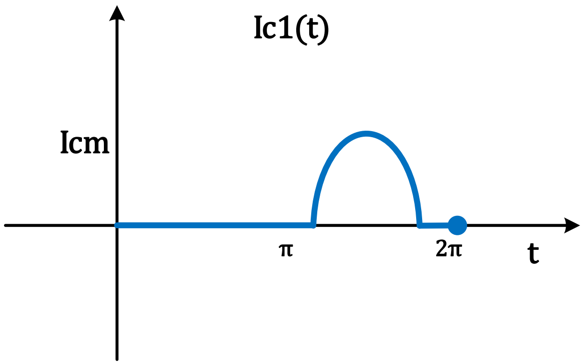
Class B Push-Pull Power Amplifier:

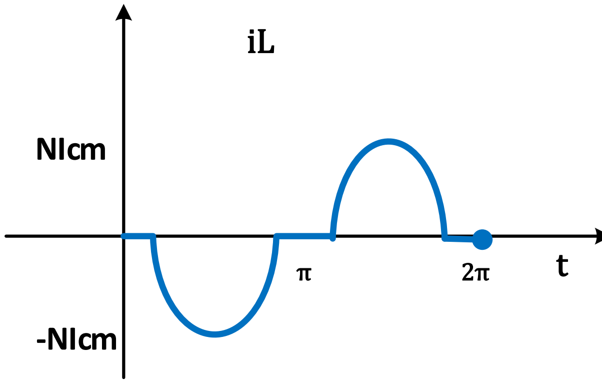
Cross Over Distortion:







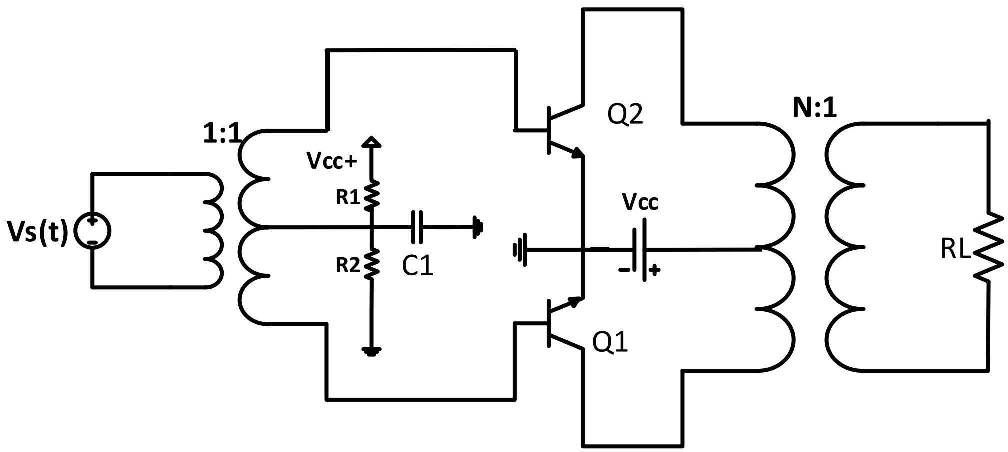




Class AB Push-Pull Power Amplifier:

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:

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

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

Complementary symmetry Class B push pull Power Amplifier

VBE1 +VEB2 = 0

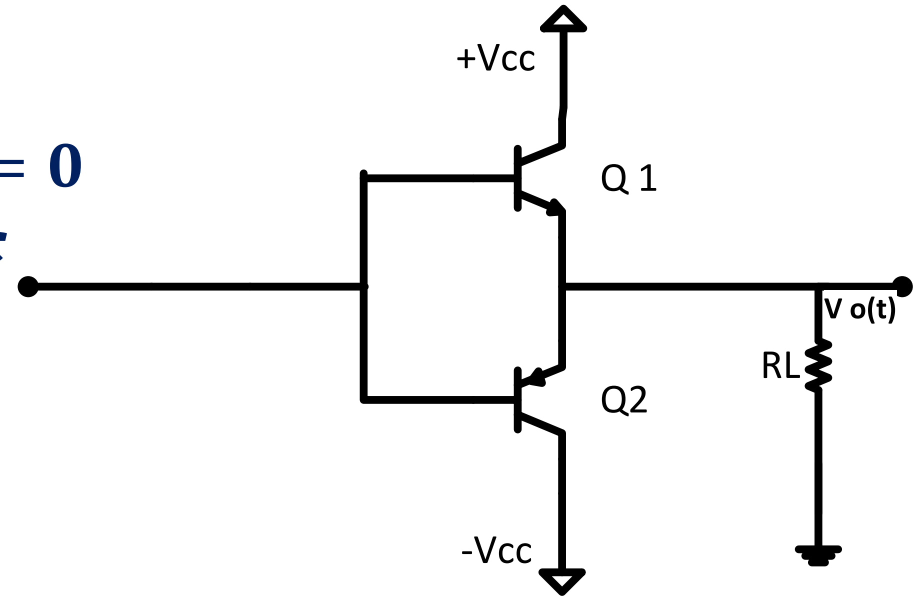
$\therefore Q1\ and\ Q2$ are in cutoff

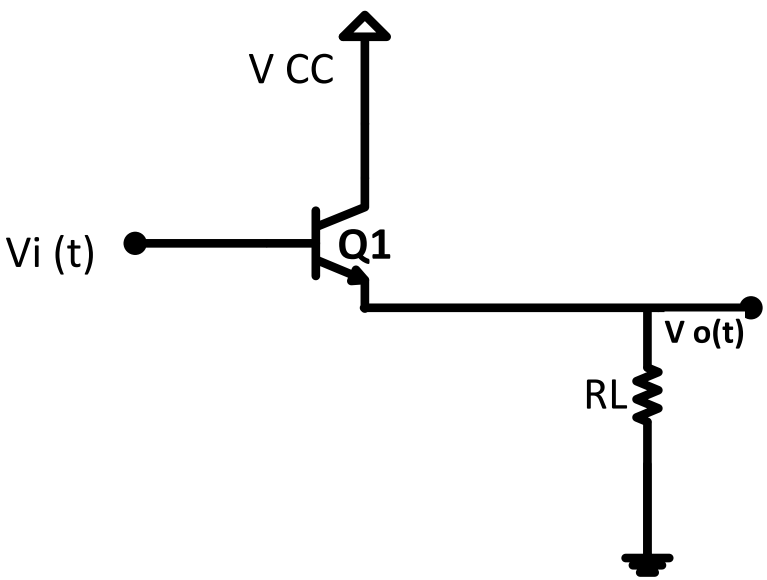
$ICQ1 = ICQ2 = 0\ , IL = 0\ \ , Vo = 0$

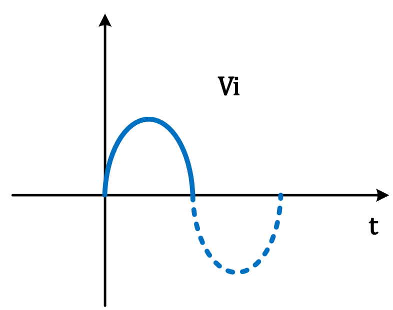
$VCEQ1 = Vcc\ , VECQ2 = Vcc$

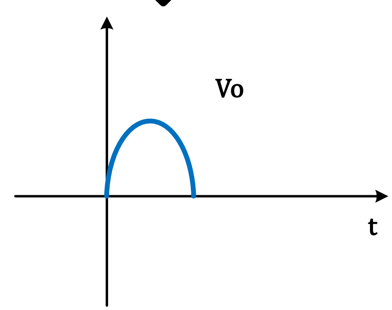
When Vi(t) > 0

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



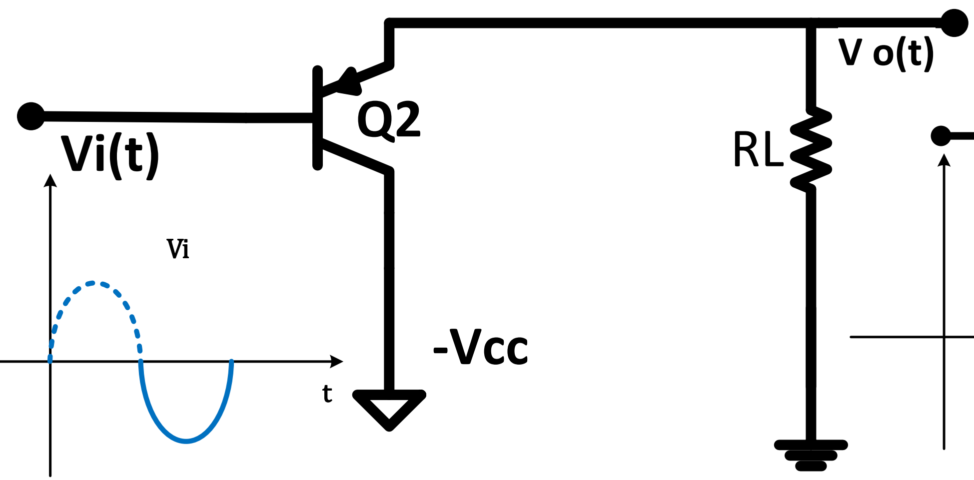


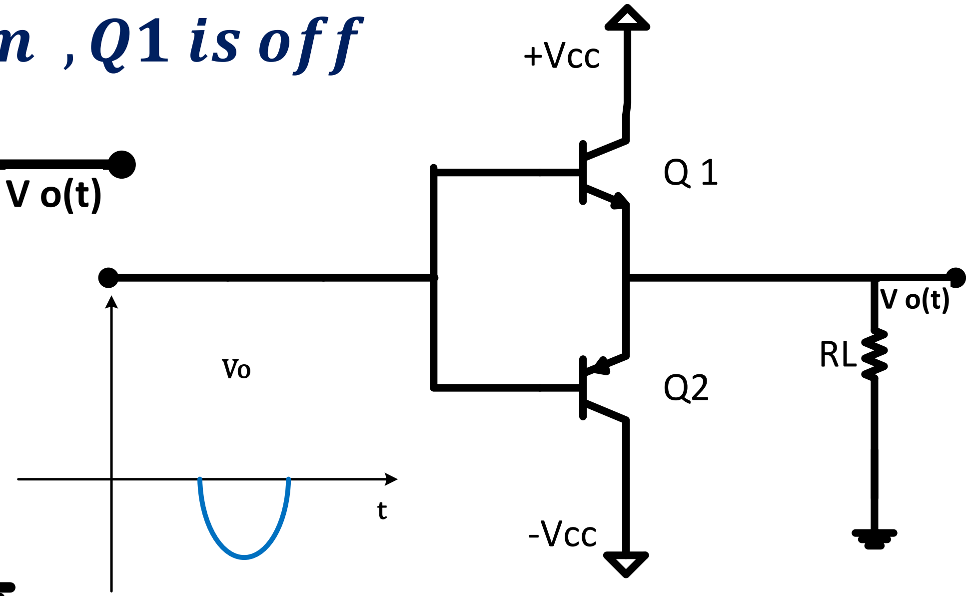




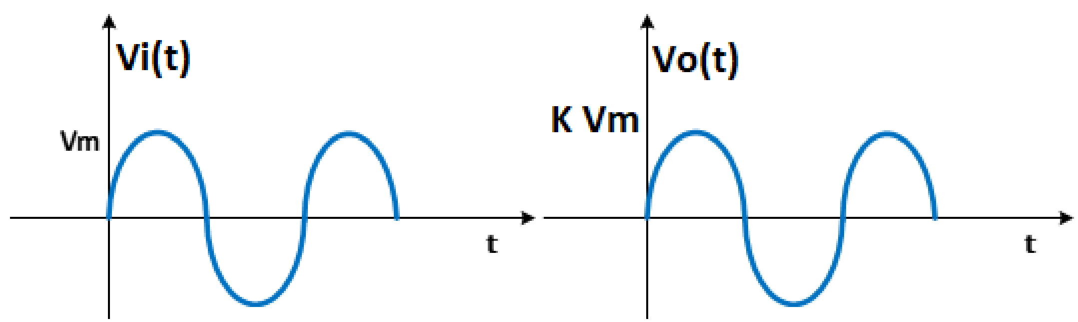
Complementary symmetry Class B push pull Power Amplifier

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



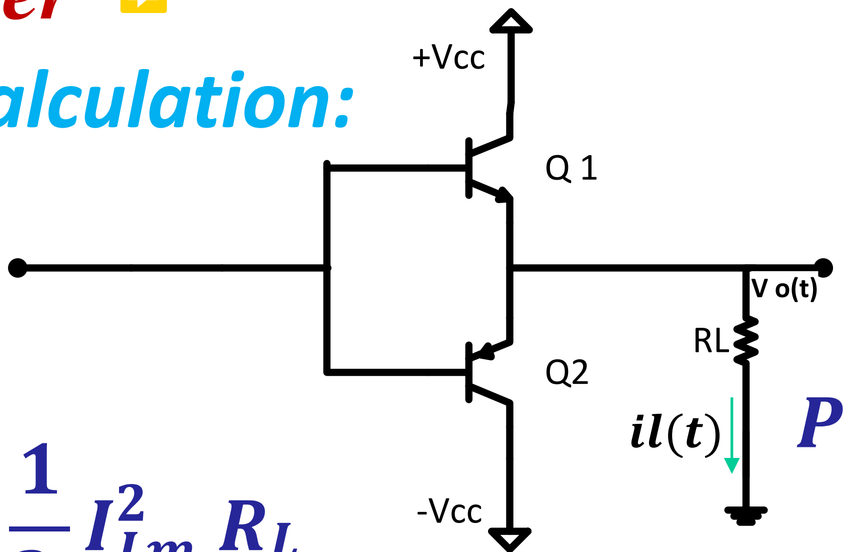


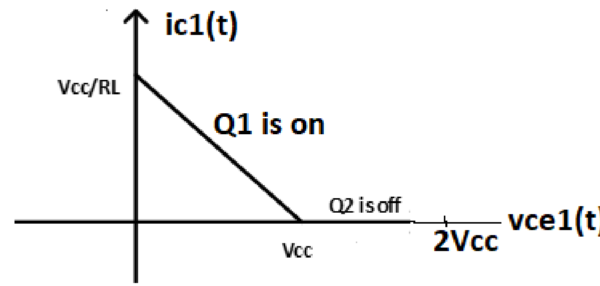
For the complete cycle



Complementary symmetry Class B push pull Power Amplifier

Power calculation:





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

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

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

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

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

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

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

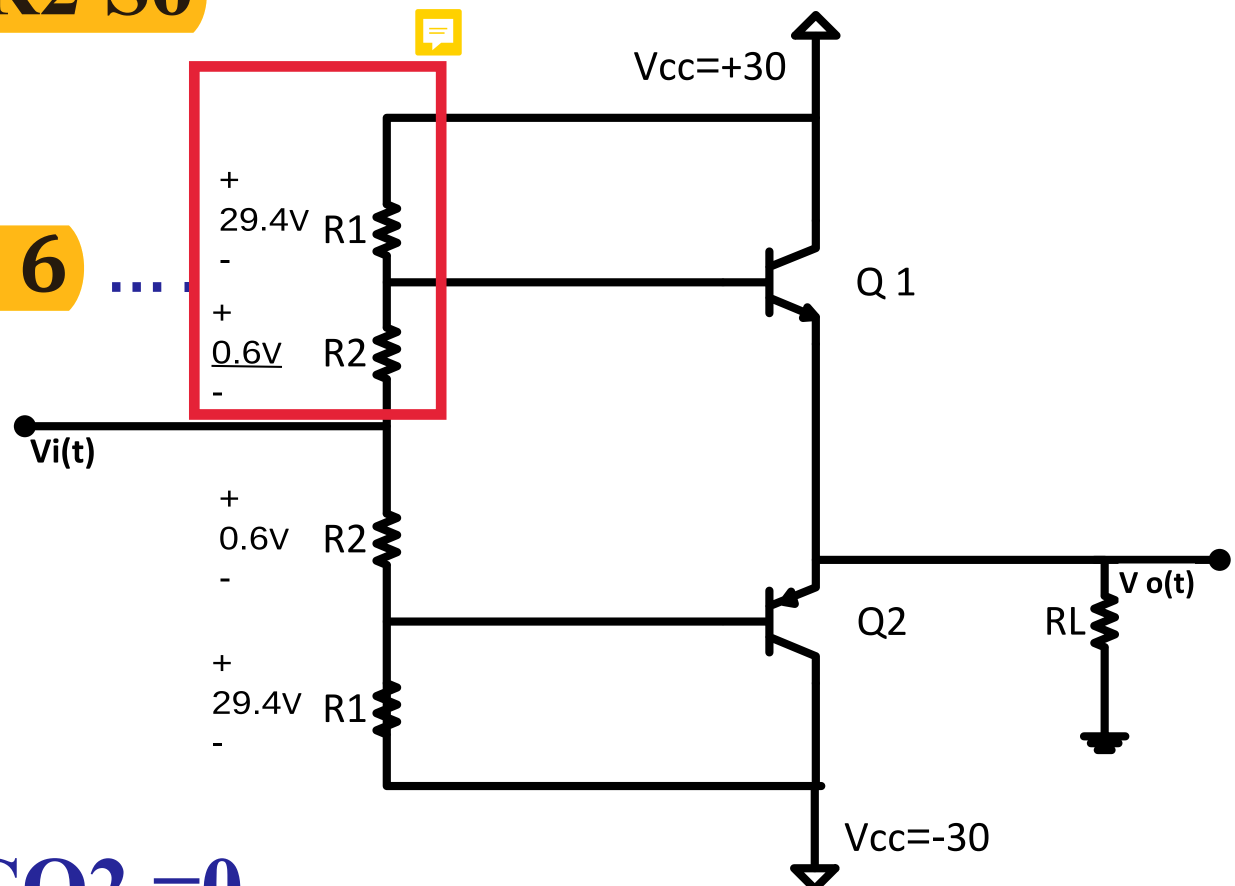
$$\eta_{,max} = \frac{\pi}{4} * 100\%$$

$$= 78.5\%$$

Complementary symmetry Class AB push pull Power Amplifier

We Choose R1 & R2 So that:

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



VBE1 = VEB2 = 0.5 , 0.6 , …

So that ICQ1 ≈ ICQ2 =0 and Vo = 0

Complementary symmetry Class AB push pull Power Amplifier

Practical Class AB Power Amplifier

To Provide Bias Stability

1)Small Re for bias Stability .

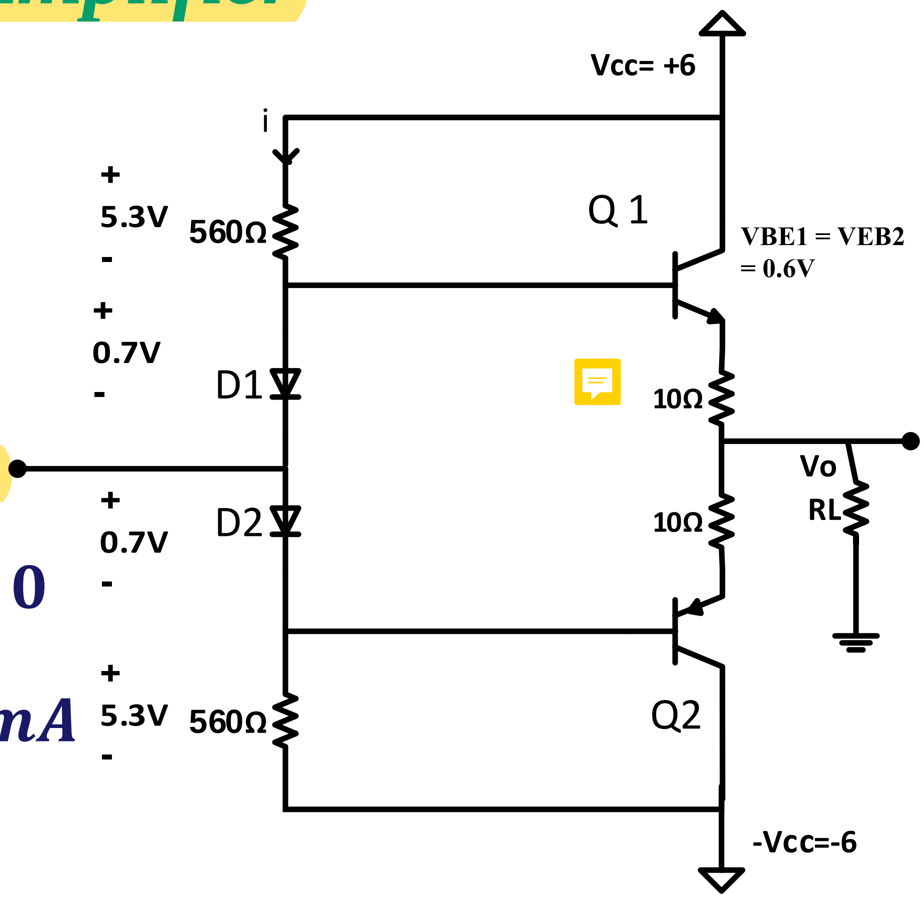
2)Diodes D1 and D2 for Temperature Compensation.

DC Component

$$Assume\ that\ I_B very\ small \rightarrow 0$$

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

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

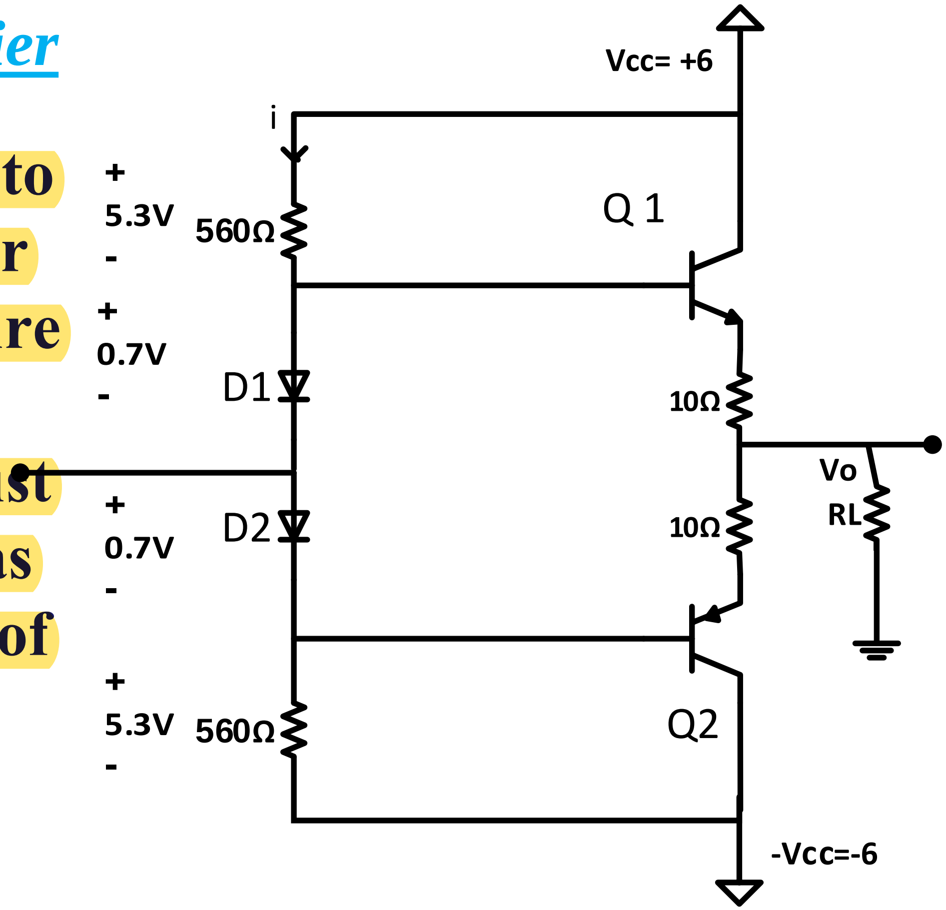


Complementary symmetry Class AB push pull Power Amplifier

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***

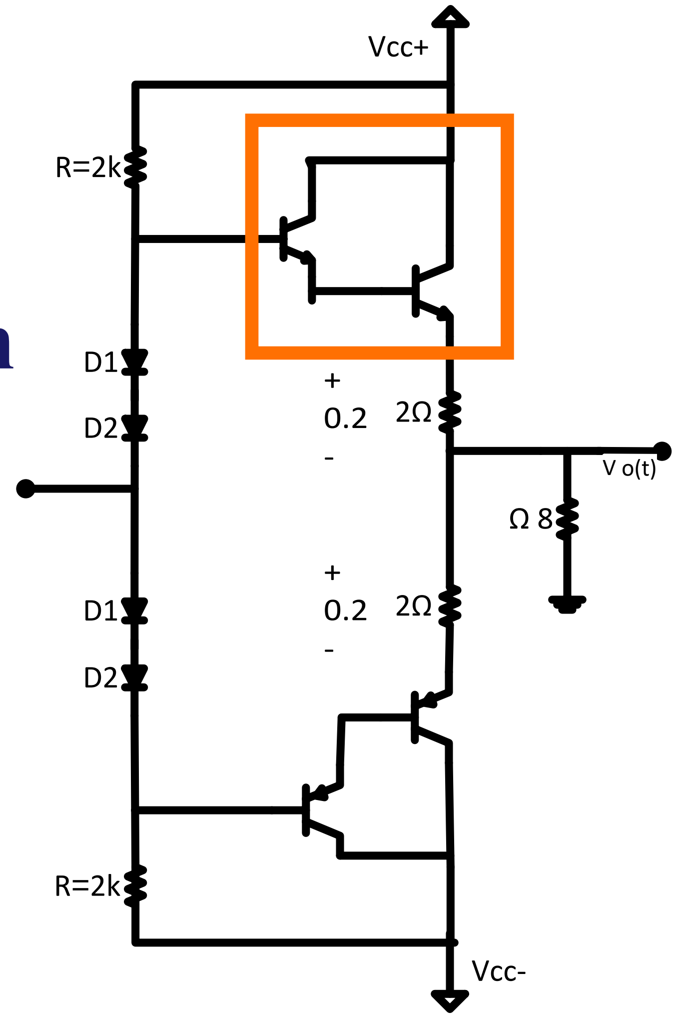


Complementary Class AB Power Amplifier using Darlington:

1. This circuit gives a higher power
2. The loading effect is very small

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

Show that



Complementary Class AB Power Amplifier using VBE Mutiplier

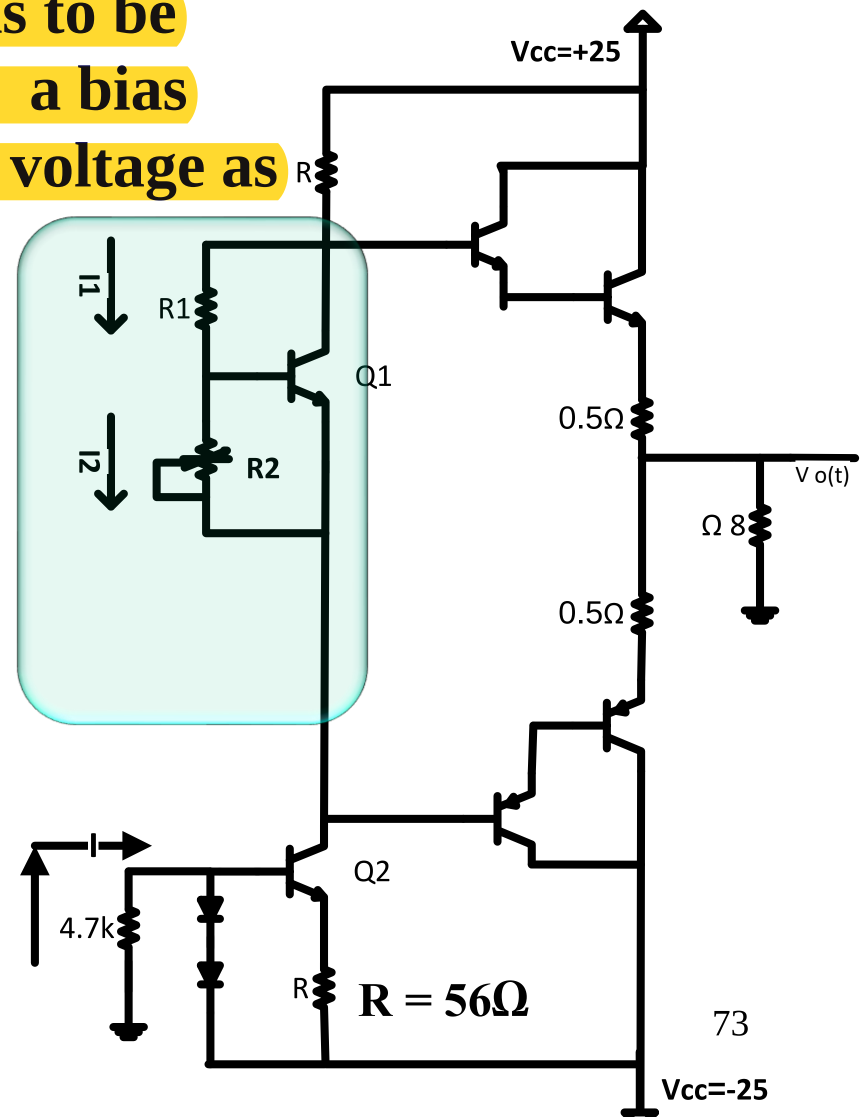
- If a stable quiescent current is to be maintained , we must provide a bias circuit that decreases the bias voltage as the temperature increase .

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

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

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

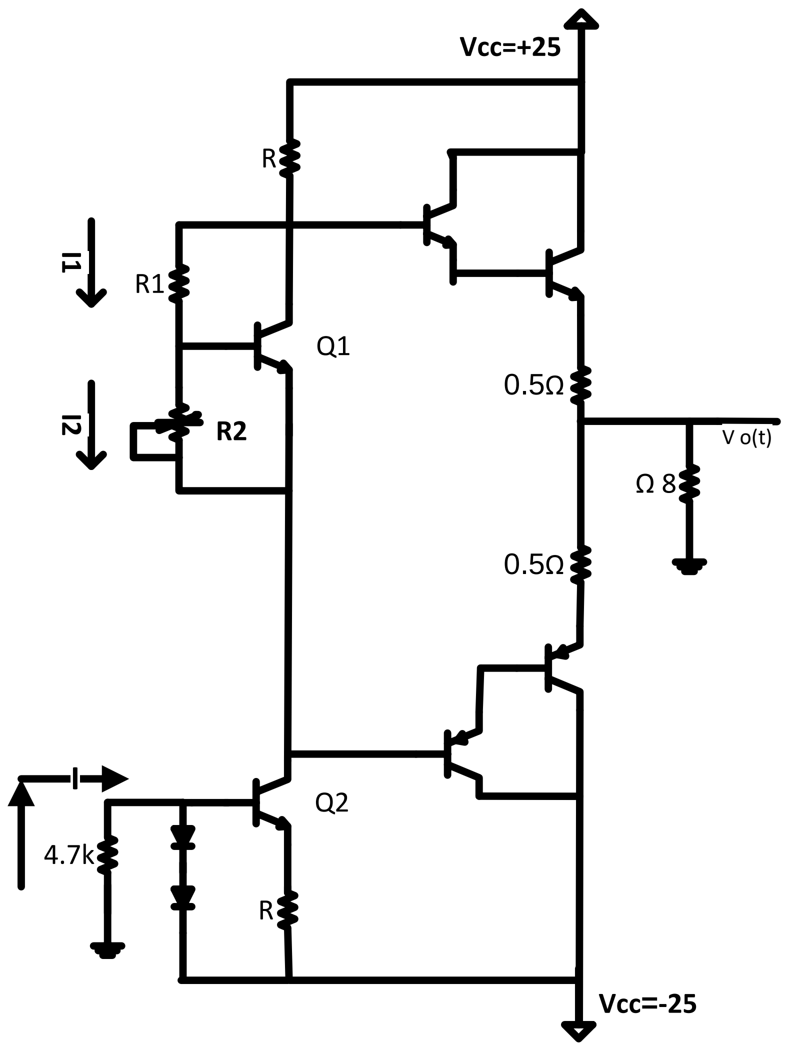
$$\therefore \; I_1 = I_2 = \frac{V_{BE}}{R_2}$$



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

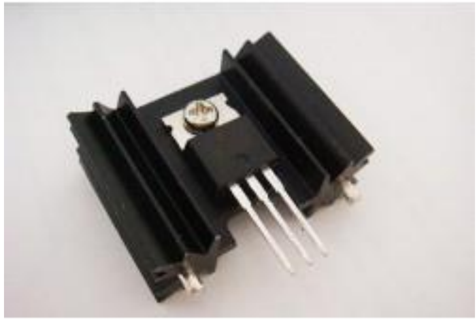
$$V_{Bias} = \left(1 + \frac{R_1}{R_2}\right)V_{BE}$$

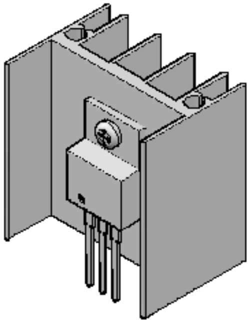
V_{Bias} ***may be adjusted***



Transistor and Heat sink

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





Different types of heat sink

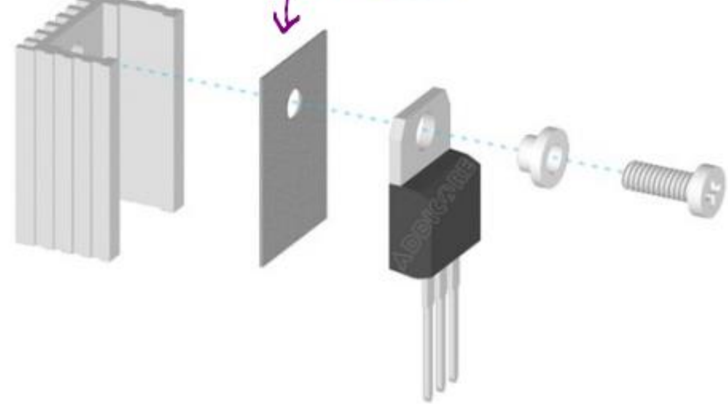
Clip Mount

Screw mount

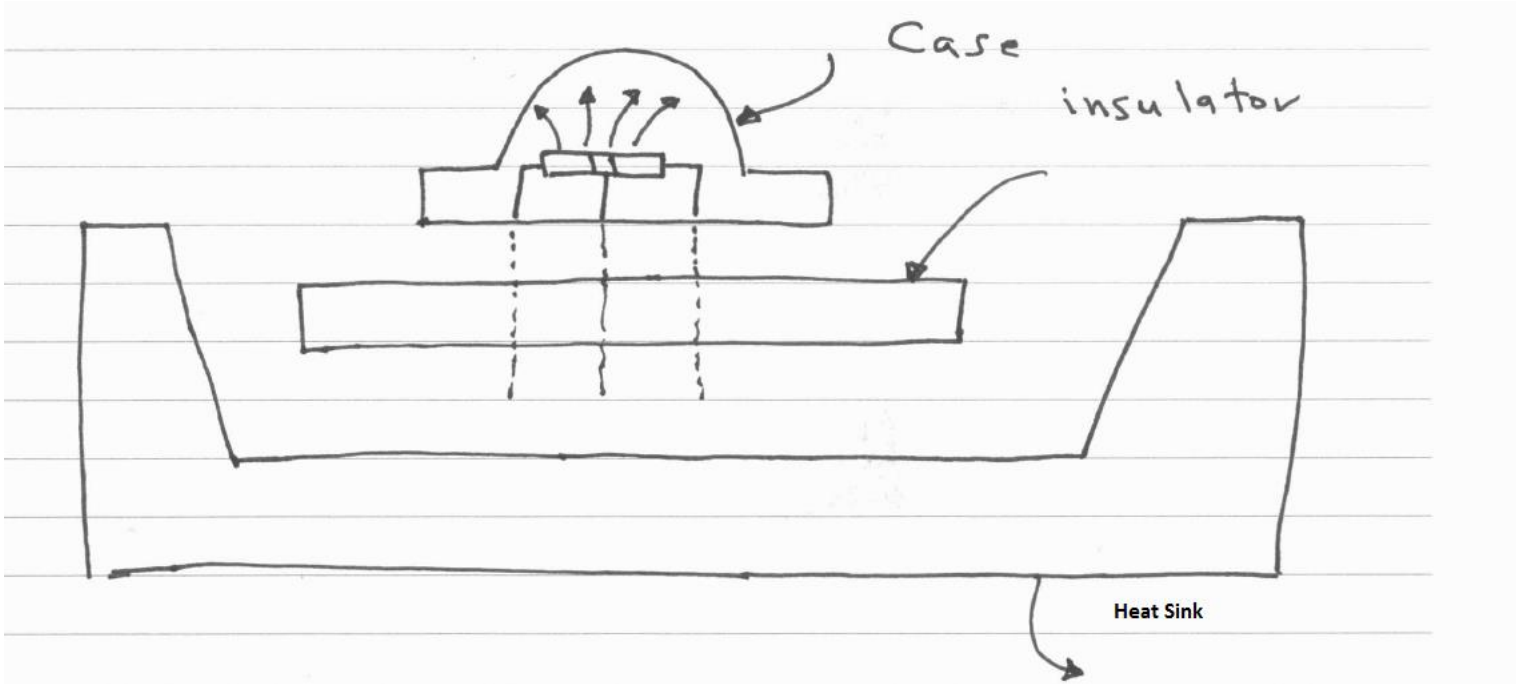
Thermal paste

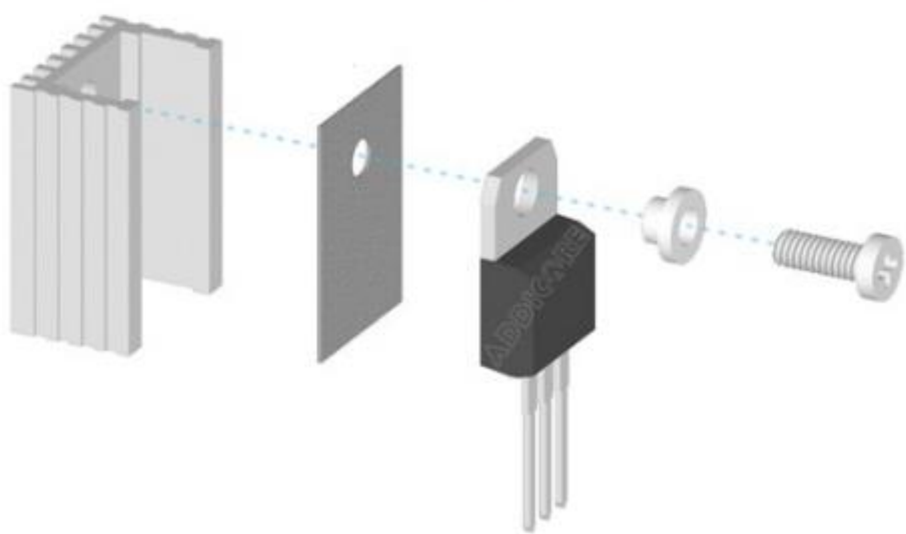
OR

Thermal pad

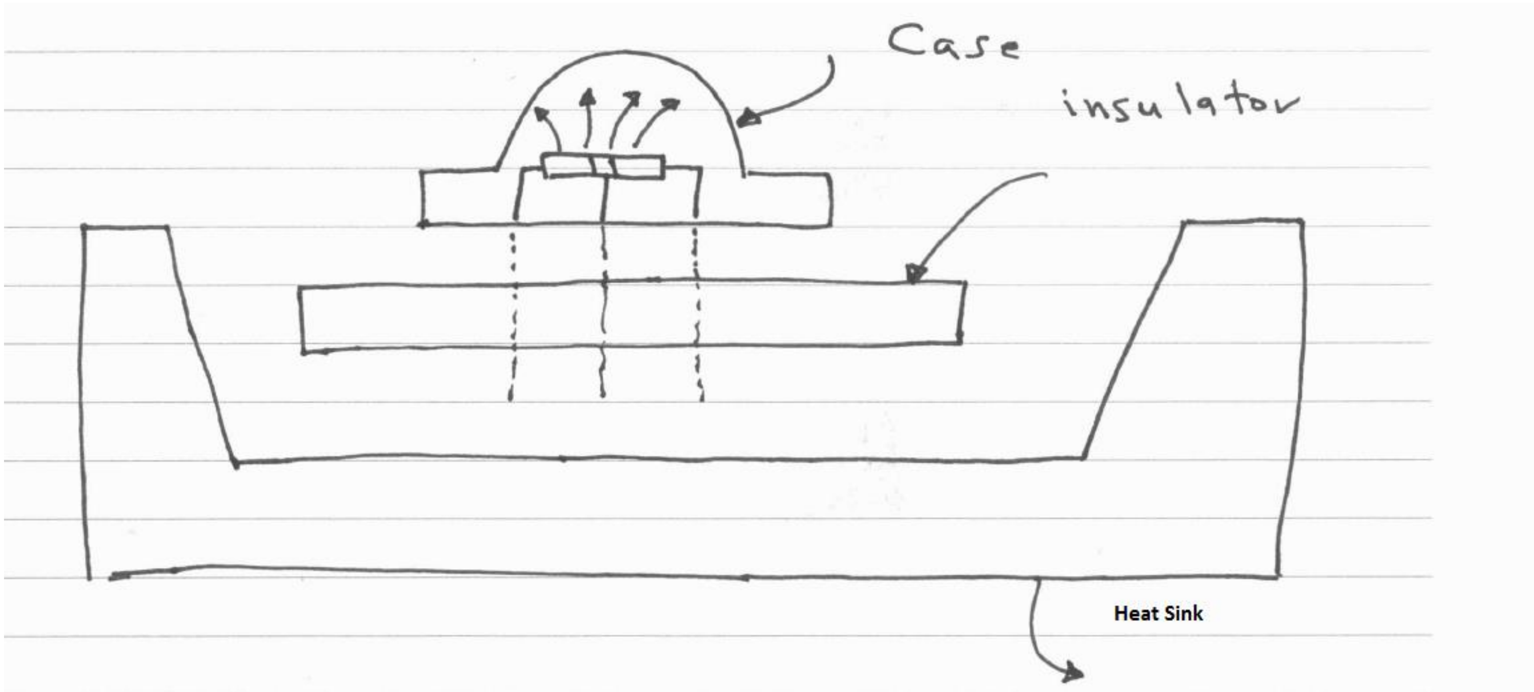


Transistor and Heat Sink



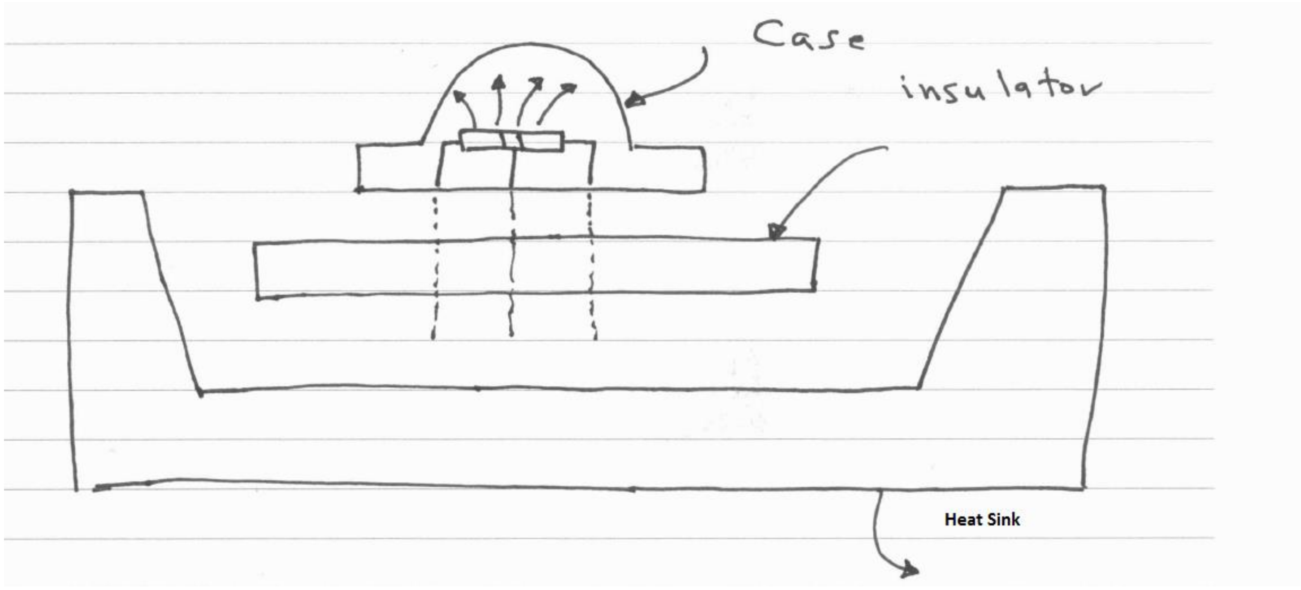


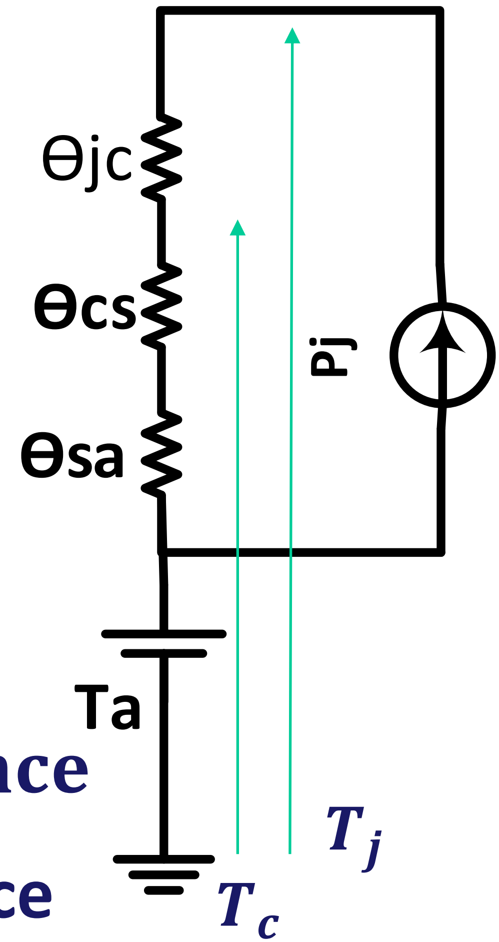
Transistor and Heat Sink



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

Transistor and Heat sink





$\Theta_{jc} \equiv$ **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"**

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

Transistor and Heat sink

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

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

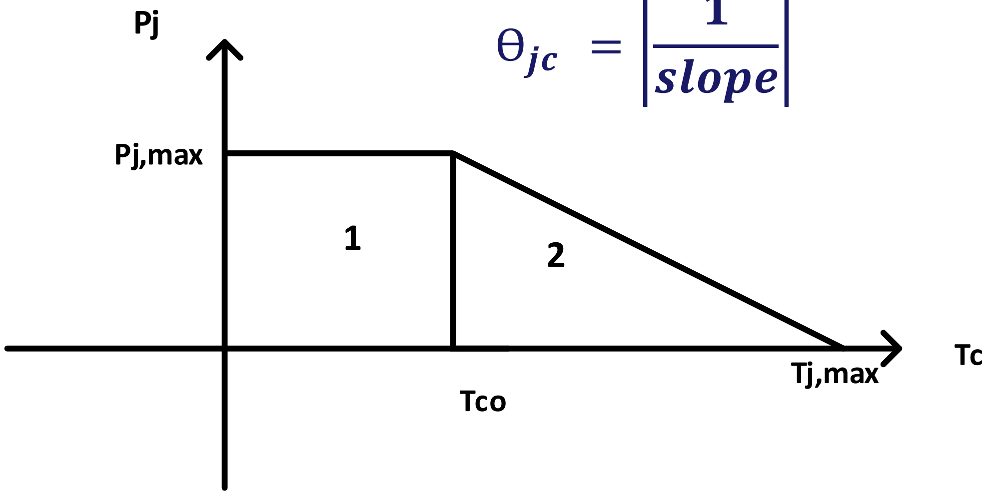
θ_{cs}: Depends on the interface between case and sink , silicon grease or without.

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

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

Transistor and Heat sink

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:

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

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

Transistor and Heat sink

Power Derating Curve

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

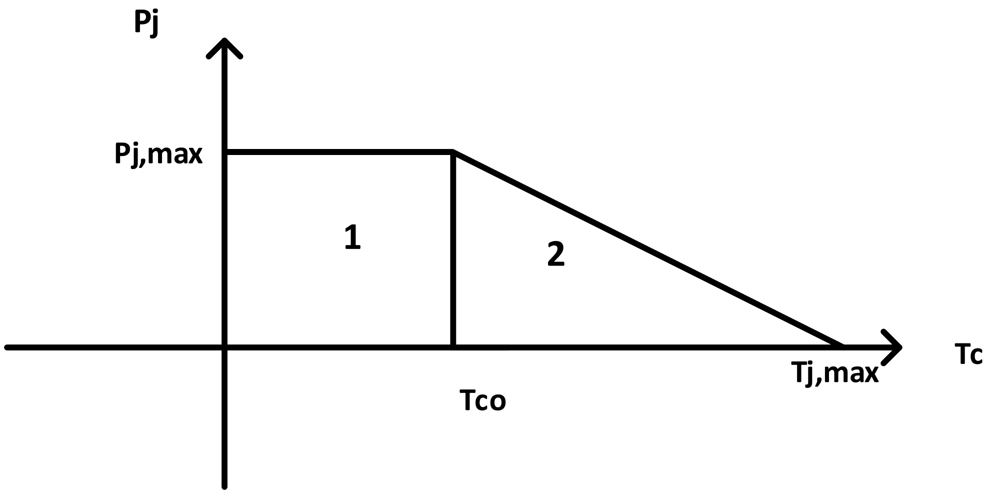
$$region\ \ 2 \rightarrow\ \ T_j = T_{j,max}$$

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

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

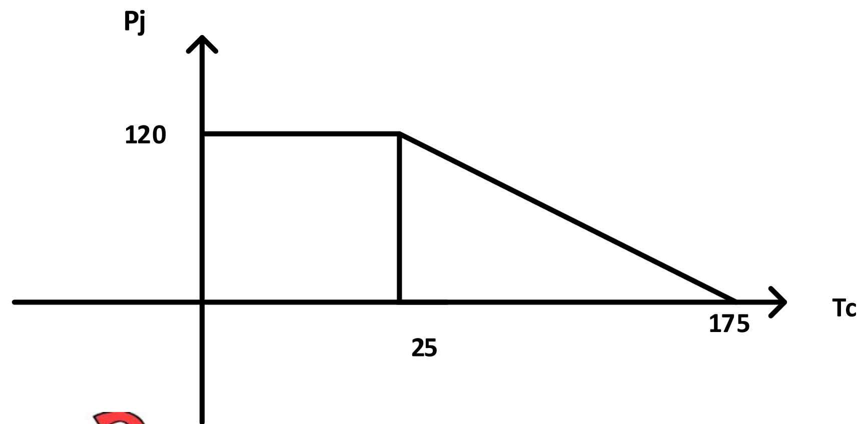
$$\Theta_{jc} = \frac{T_{j,max} - T_c}{P_j}$$

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



Transistor and Heat sink

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



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

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

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

$P_{j,max} = 120\mathrm{W}$

Transistor and Heat sink

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

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

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

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

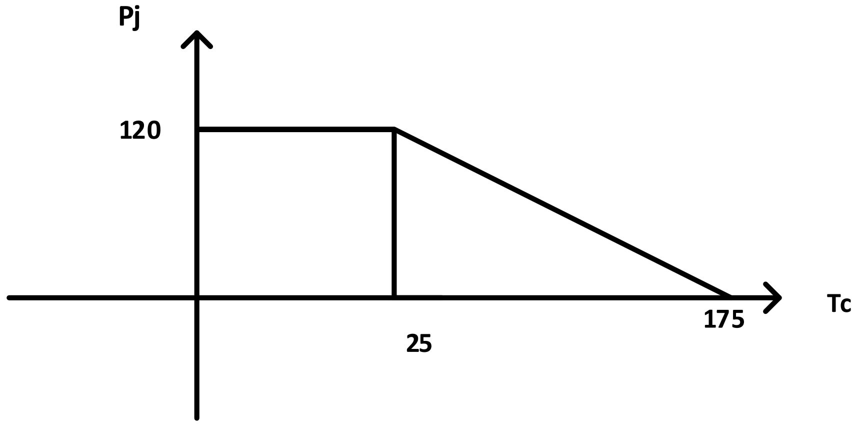
$$,\ \ and\ \ T_a = 40^{\circ}$$

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

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

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

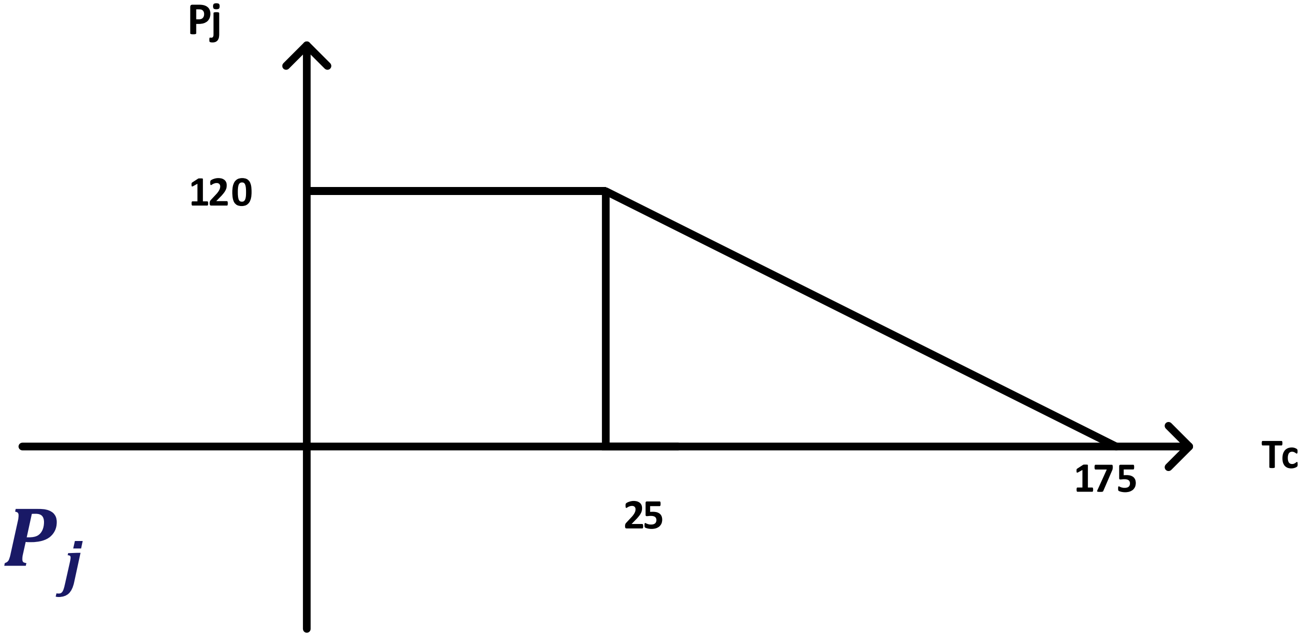
$$\theta_{ja} = \theta_{jc} + \theta_{cs} + \theta_{sa}$$



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

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

$$To\ find\ Tc:$$



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

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

$$T_c = 121.5°C$$

$$T_c > T_{co}$$

Region 2 as assumed

Transistor and Heat sink

If we are using infinite heat sink

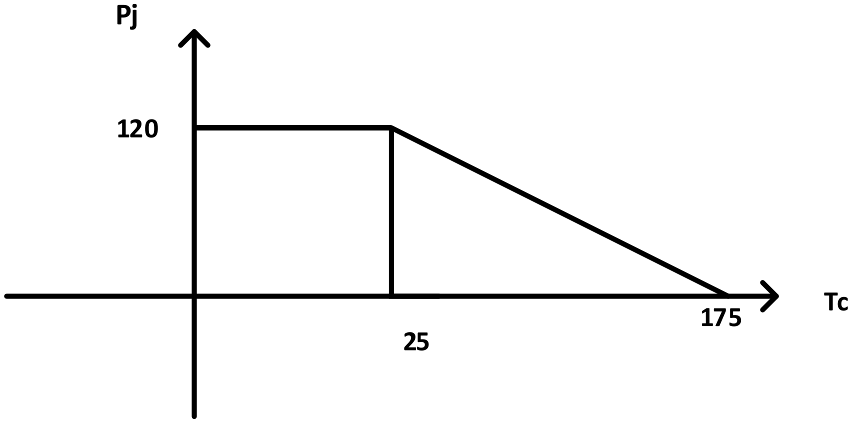
$$\therefore \; T_c = T_a$$

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

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

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

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



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*

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

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