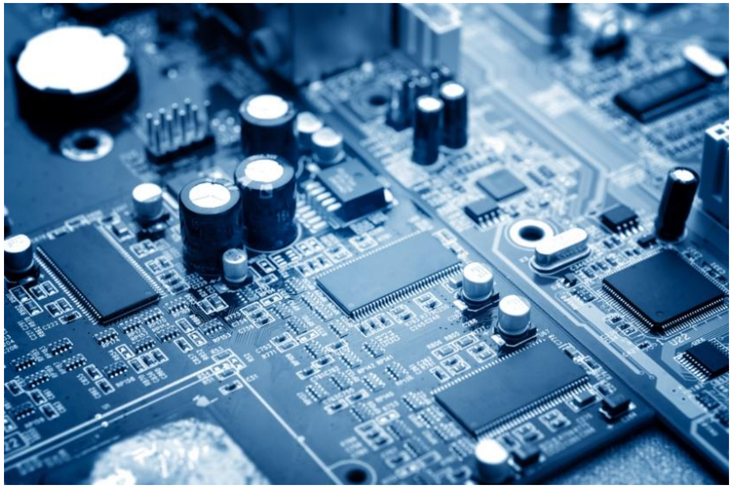
ENEE3304 ELECTRONICS2



Instructor : Mr.Mohammad AL-Jubeh

ENEE3304 - ELECTRONICS 2

3 Credit Hours , two 75 – minute lecture sessions /week

Instructor : Mr. Mohammad Al - Jubeh Office: Masri 220

Textbook: Microelectronic Circuits, Sedra / Smith, Seventh edition , 2014

References :

1- Electronic Devices and Circuit Theory, R .Boylestad &L.Nashelsky, Prentice Hall , 2009 10th Edition.

2- Electronic Circuits, Discrete and Integrated
By: Schilling, Belove.

Course Description :

Audio-frequency linear power amplifiers and heat sinks, current sources and their applications in IC, integrated differential and operational amplifier, applications of operational amplifiers, feedback amplifiers, discrete and integrated oscillators, voltage regulators, using simulation tools for the design, and analysis of electronic circuits.

Prerequisite: ENEE2303

Specific outcomes of instructions :

By the end of the course the students are

1. **Able to analyze the basic building blocks of linear integrated circuits including differential amplifiers and current sources.**
2. **Able to design the basic building blocks of linear integrated circuits including differential amplifiers and current sources.**
3. **Able to analyze class A , class B , ,and class AB power amplifiers .Understand negative feedback , its basic configuration and its application to control input/output impedance , frequency response..**
4. **Able to analyze a variety of popular op amp circuits, including signal converters ,instrumentation , signal conditioning circuits, and comparators .**
5. **Able to design a variety of popular op amp circuits, including signal converters ,instrumentation , signal conditioning circuits, and comparators .**
6. **Able to identify different types of feedback that may be applied to amplifiers to shape their performance.**
7. **Able to analyze harmonic, square wave and triangle oscillators using BJTs, FETs, and OP-AMP .**
8. **Able to design harmonic, square wave and triangle oscillators using BJTs, FETs, and OP-AMPs**
9. **Able to analyze discrete and integrated voltage regulators.**
10. **Able to design discrete and integrated voltage regulators.**
11. **Are able to use the circuit simulator PSPICE for analysis and design of electronic circuits.**

Course addresses ABET students outcome(s) :

a) an ability to apply knowledge of mathematics, science, and engineering

c) an ability to design a system, component, or process to meet desired needs

k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Brief list of topics to be covered :

Chapter 6 Single-stage Integrated- Circuit Amplifiers
Chapter 7 Differential and Multistage Amplifiers
Chapter 9 Feedback
Chapter 12 Signal Generators and Waveform – Shaping Circuits
Chapter 14 Output Stages and Power Amplifiers
Chapter A Operational Amplifiers and their Applications
Chapter B DC Voltage Regulation

<u>Grading</u> :

--	First and second Exams	35%
--	Course Works	20%
--	Final Exam	45%

		100%

Mohamed Atalla

From Wikipedia, the free encyclopedia

Mohamed Atalla (August 4, 1924 – December 30, 2009), also known by the alias **Martin "John" M. Atalla**, was an Egyptian-American engineer, physical chemist, cryptographer, inventor, and entrepreneur. His pioneering work in semiconductor technology laid the foundations for modern electronics. His invention of the MOSFET (metal-oxide-semiconductor field-effect transistor, or MOS transistor) in 1959, along with his earlier surface passivation and thermal oxidation processes (the basis for silicon semiconductor technology such as monolithic integrated circuit chips), revolutionized the electronics industry. He is also known as the founder of the data security company Atalla Corporation, which he founded after he invented the first hardware security module (HSM) in 1972. He received the Stuart Ballantine Medal (now the Benjamin Franklin Medal in physics) and was inducted into the National Inventors Hall of Fame for his important contributions to semiconductor technology as well as data security.

Born in Port Said, Egypt, he was educated at Cairo University and then Purdue University, before joining Bell Labs in 1949. He made a series of breakthroughs in semiconductor technology during 1956–1962, starting with his development of the surface passivation and thermal oxidation processes (which became the basis for planar technology and silicon integrated circuit chips), followed by his invention of the MOSFET (with Dawon Kahng) in 1959, then the PMOS and NMOS fabrication processes, then his proposal of the MOS integrated circuit chip in 1960, and then the development of practical Schottky diodes. Atalla's pioneering work at Bell laid the foundations for modern electronics and the Digital Revolution. The MOSFET in particular is the basic building block of modern electronics and the most widely manufactured device in history, with the US Patent and Trademark Office calling it a "groundbreaking invention that transformed life and culture around the world".

His pioneering work was initially overlooked at Bell, which led to him resigning from Bell and joining Hewlett-Packard (HP), founding its Semiconductor Lab in 1962 and then HP Labs in 1966, before leaving to join Fairchild Semiconductor, founding its Microwave & Optoelectronics division in 1969. His work at HP and Fairchild included further research on Schottky diodes, in addition to research on gallium arsenide (GaAs), gallium arsenide phosphide (GaAsP), indium arsenide (InAs) and light-emitting diode (LED) technologies, contributing to the development of high-frequency network analyzers, developing the first practical LED displays, and proposing the use of LEDs for indicator lights and optical readers.

After leaving the semiconductor industry in 1972, he became an entrepreneur in cryptography and data security. After he invented the first hardware security module, the "Atalla Box" which encrypted PIN and ATM messages, he founded the data security company Atalla Corporation in 1972. The "Atalla Box" went on to secure the majority of the world's ATM transactions. In recognition of his work on the Personal Identification Number (PIN) system of information security management, Atalla has been referred to as the "Father of the PIN". Atalla also launched an early online transaction processing security system in 1976 and the first network security processor (NSP) in 1979, and he later founded the internet security company TriStrata Security in the 1990s. He died in Atherton, California, on December 30, 2009.

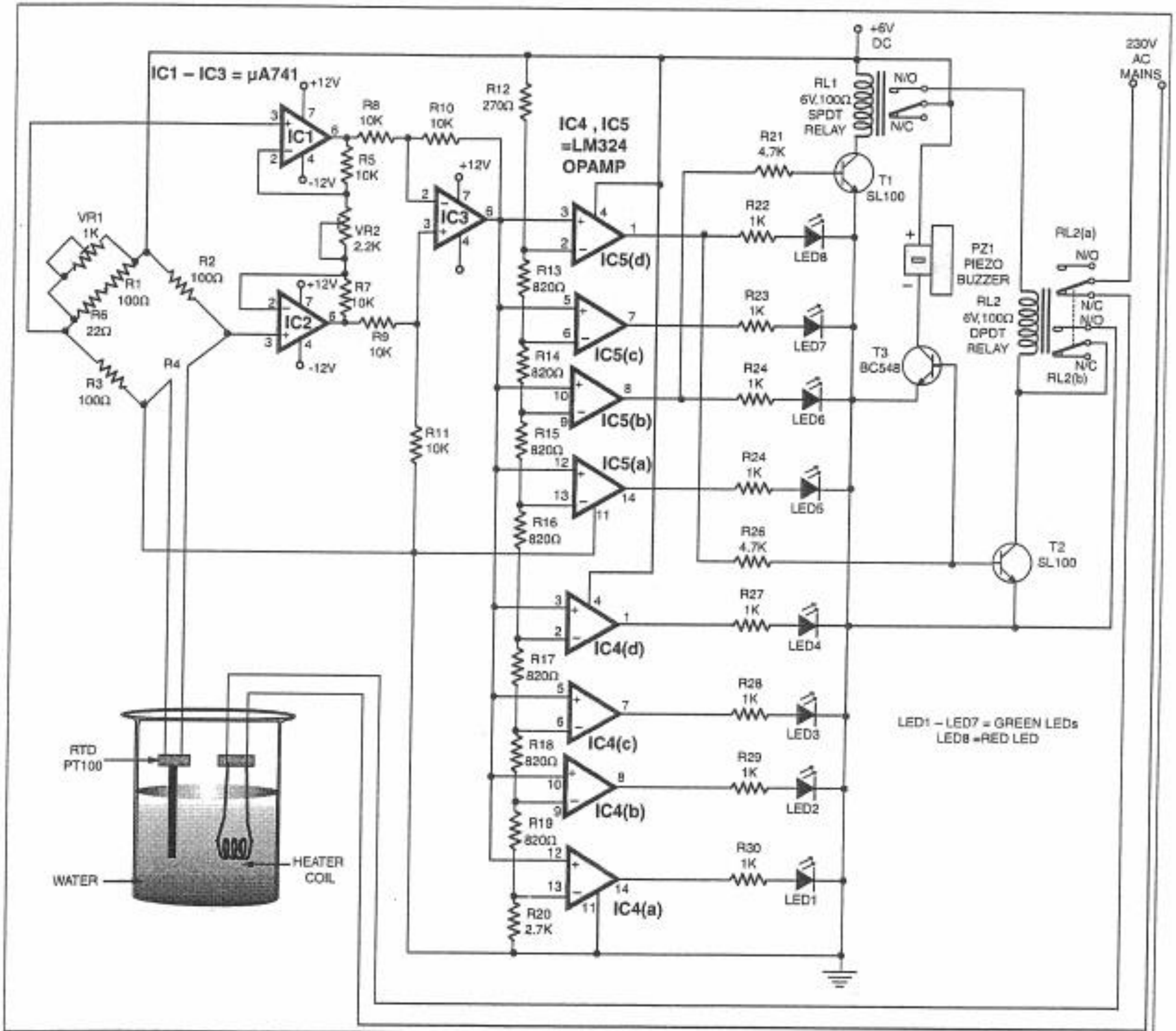
Contents [hide]

Mohamed Atalla

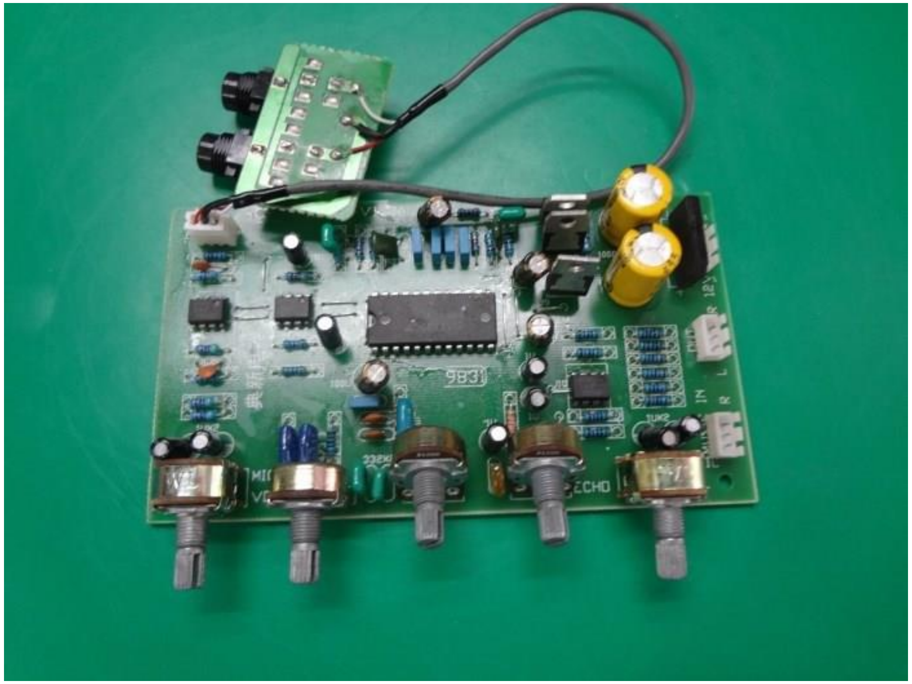
Mohamed Atalla as Director of Semicond
Research at HP Associates in 196

Born	August 4, 1924 Port Said, Egypt
Died	December 30, 2009 (age Atherton, California, United States
Nationality	Egyptian American
Other names	Martin "John" M. Atalla
Education	Cairo University (BSc) Purdue University (MSc,
Known for	MOSFET (MOS transistor

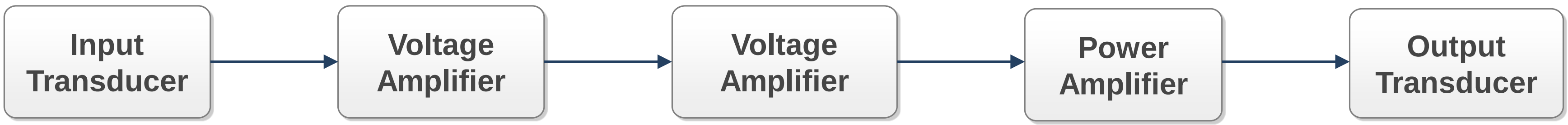
ENEE3304 Project1 : Water Temperature Controller

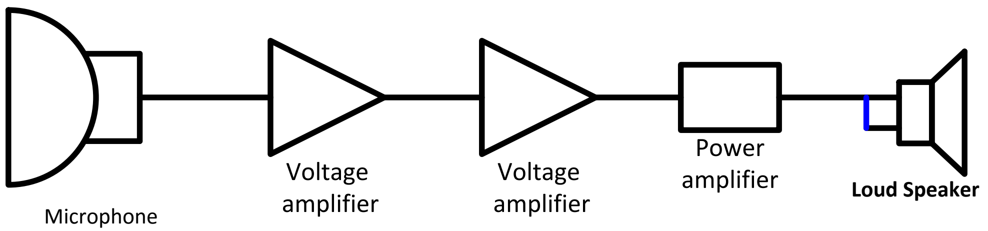


Power Amplifiers



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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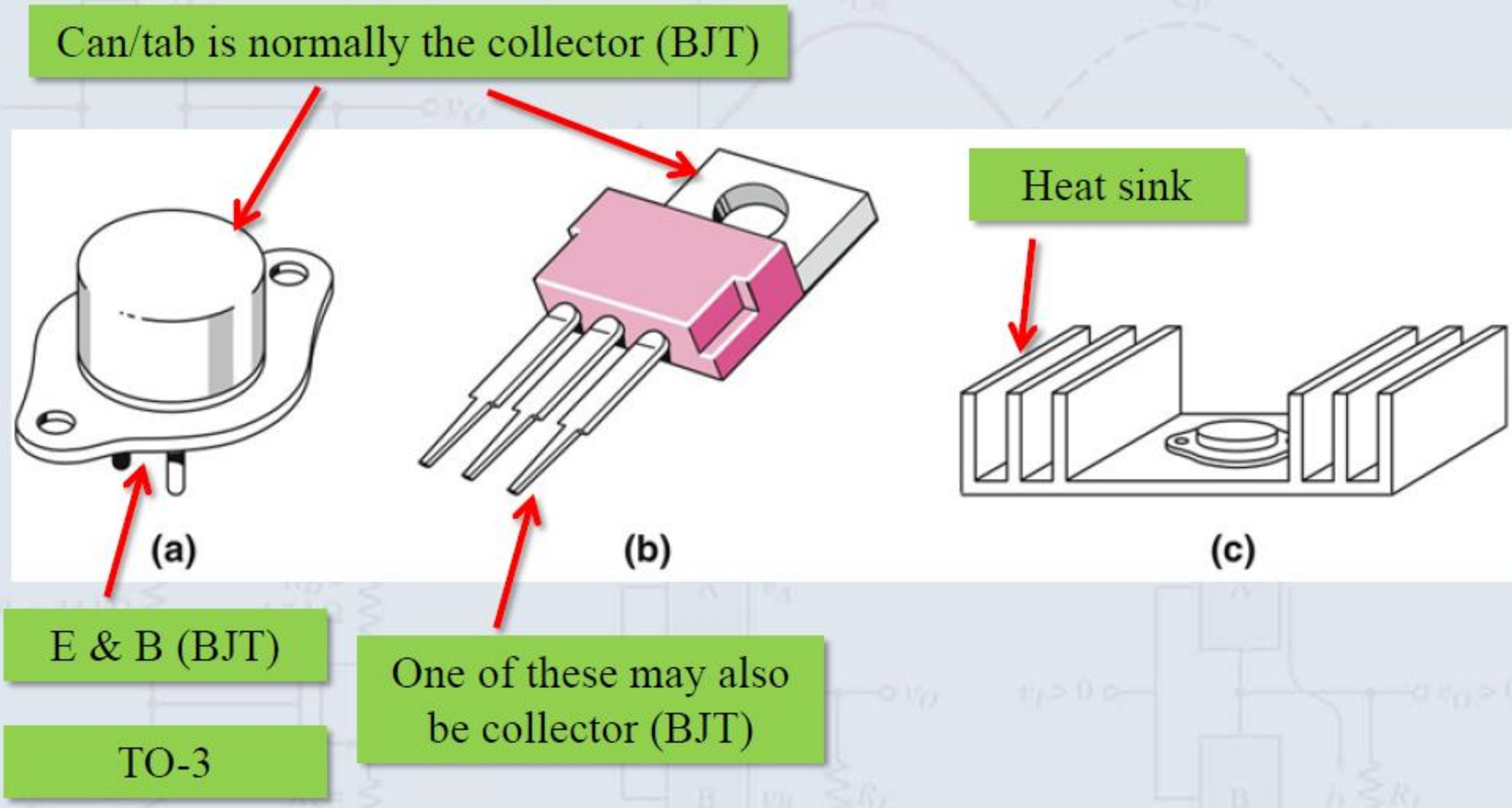
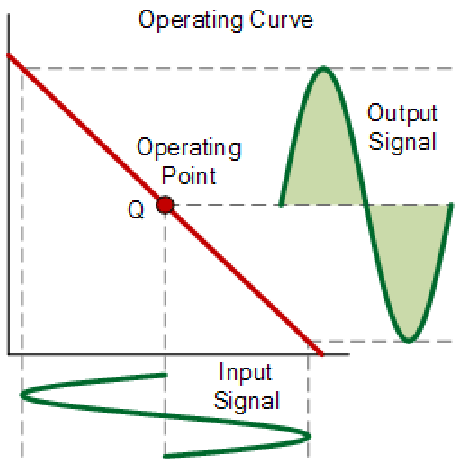
Packaging Schemes



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.

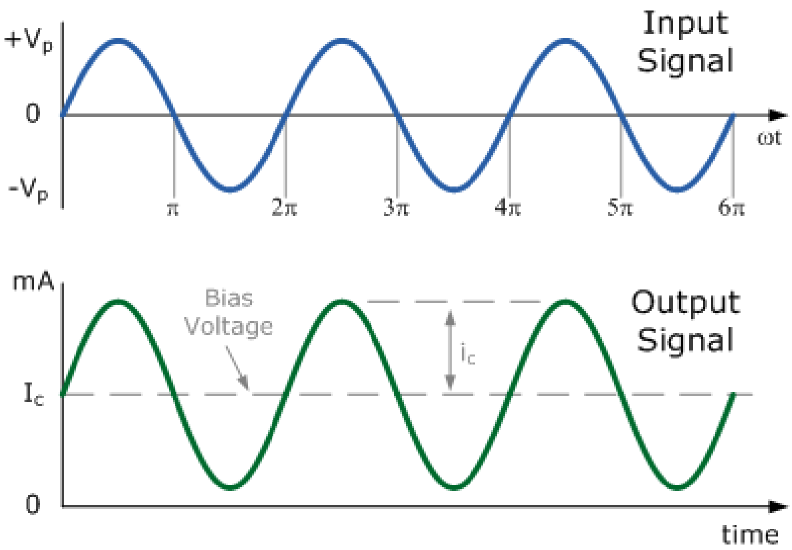
* For a class A power Amplifier, the Q point is designed to meet maximum symmetrical swing

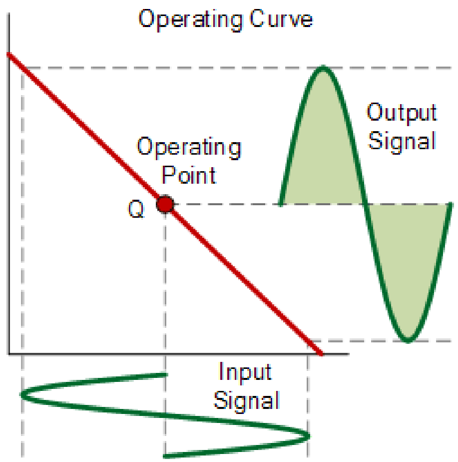


Classes of Power Amplifiers

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

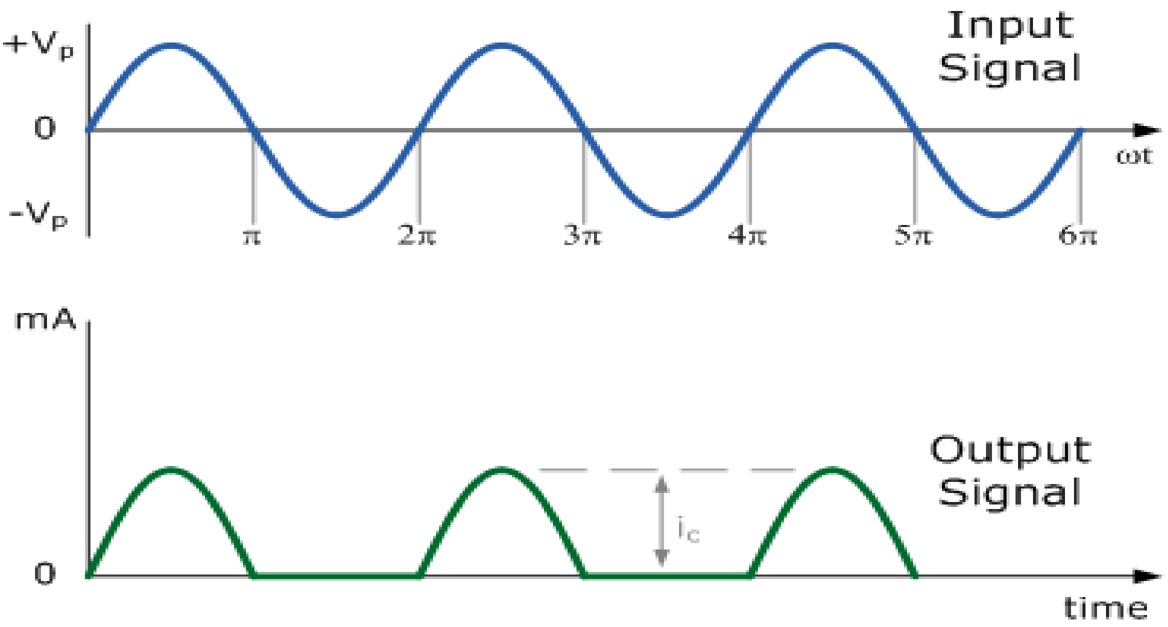
1) Class A Power Amplifier: $\theta = 360°$

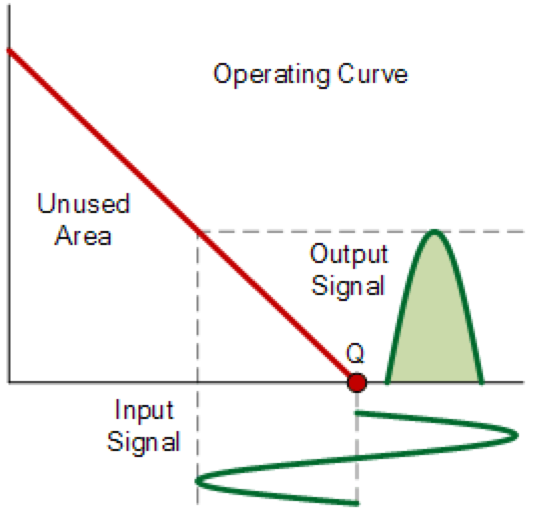




Classes of Power Amplifiers

2) Class B Power Amplifier : θ =180°

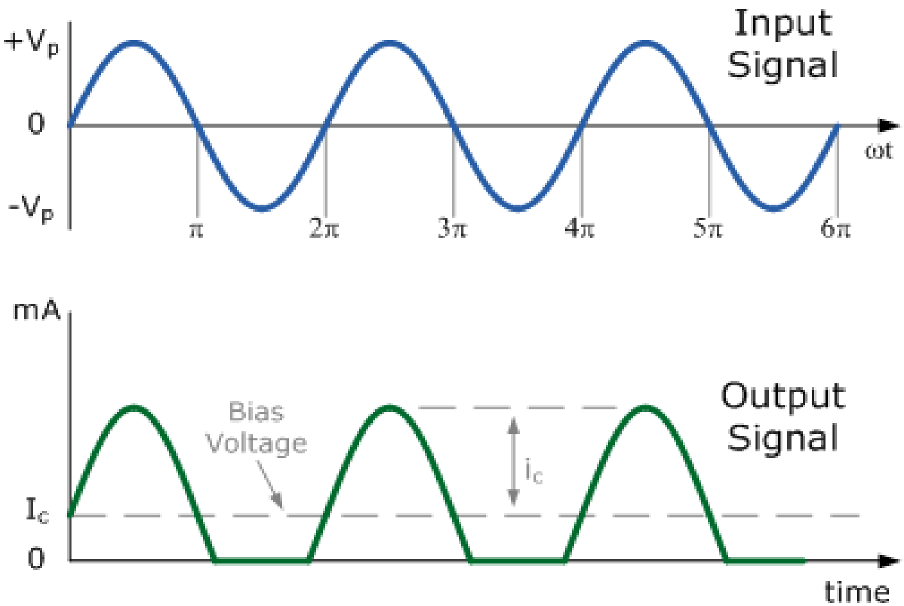


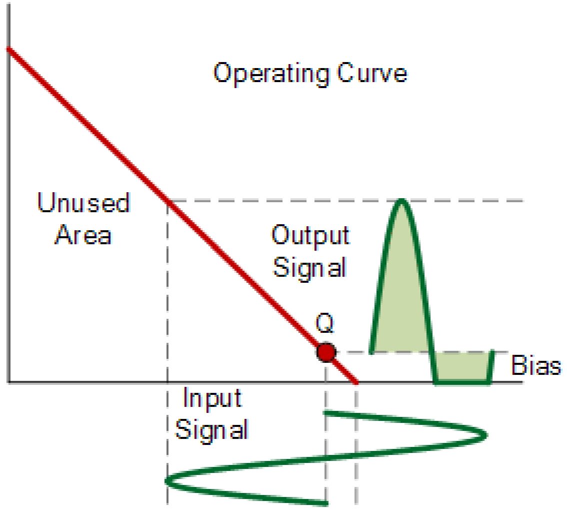


Classes of Power Amplifiers

3) Class AB Power Amplifier

360° > θ > 180°



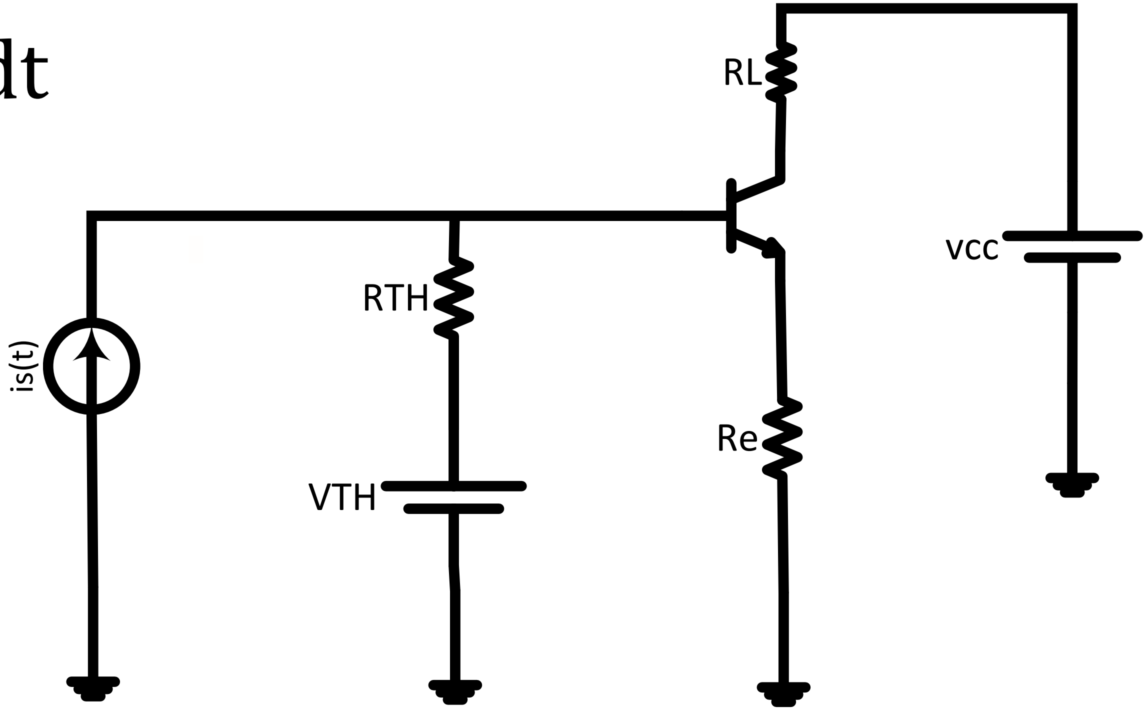


Class A Power Amplifier

Power Calculation :

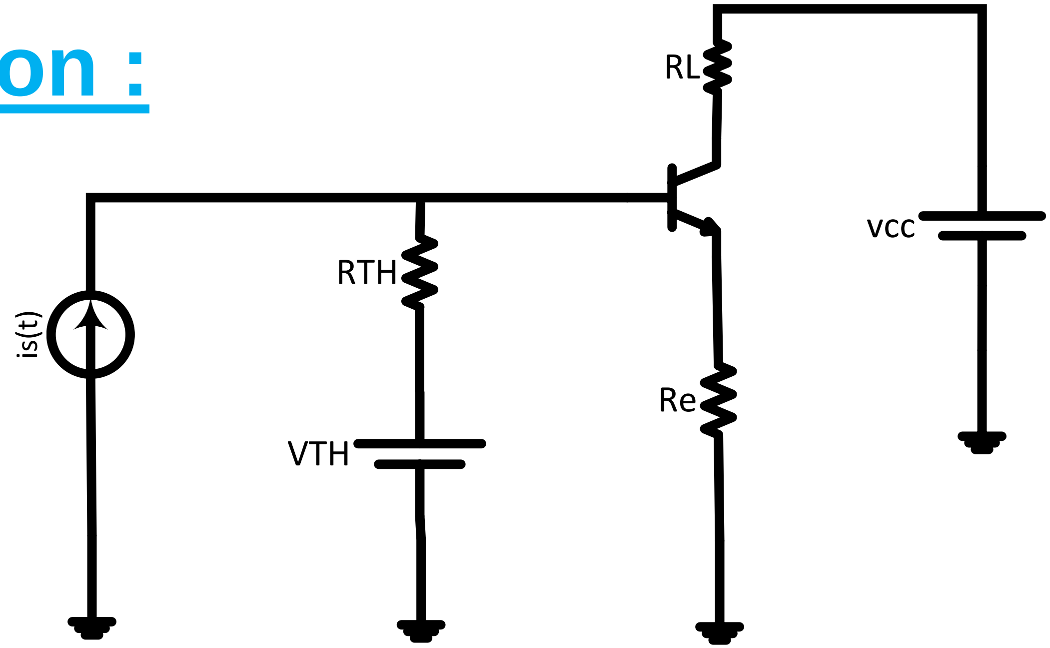
The average power supplied or dissipated by any linear or nonlinear device is :

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



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)**

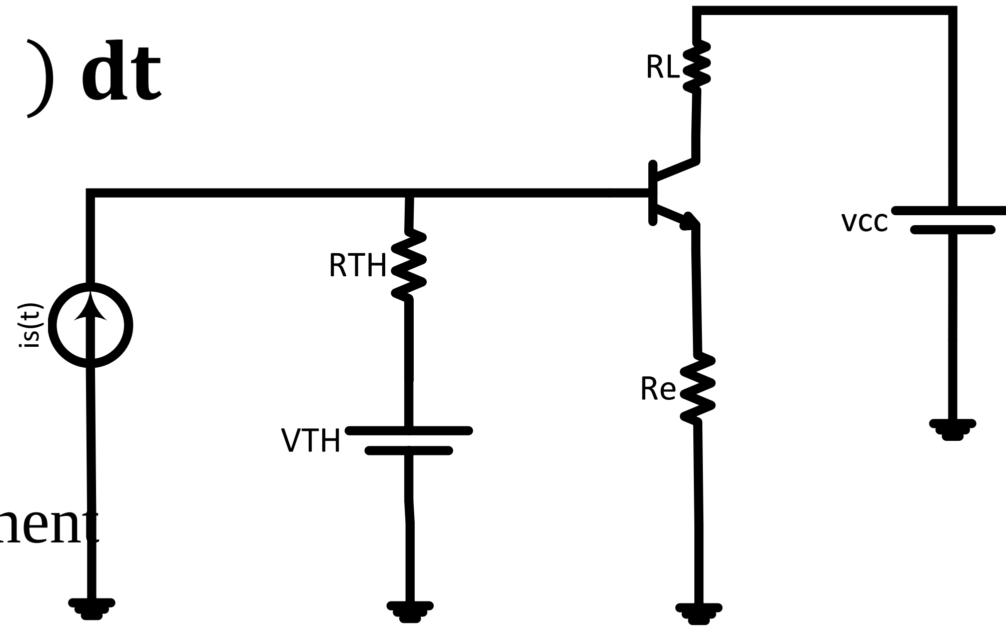
$i(t) = I + i$

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

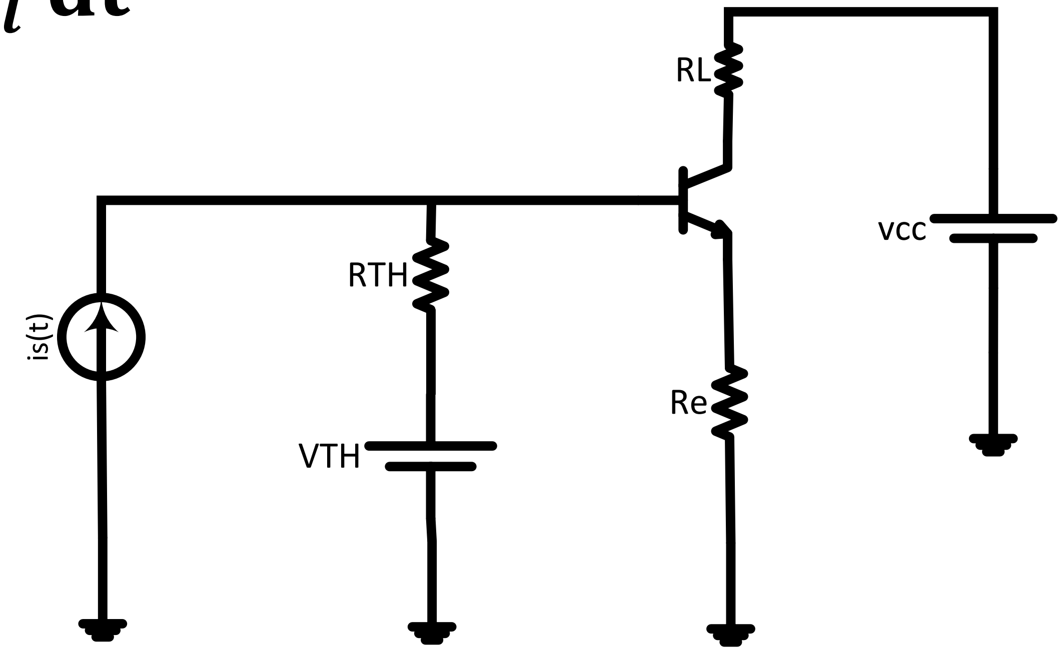
The average power dissipated or supplied by a device consists of the sum of the power in AC and DC terms .

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

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

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

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



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

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

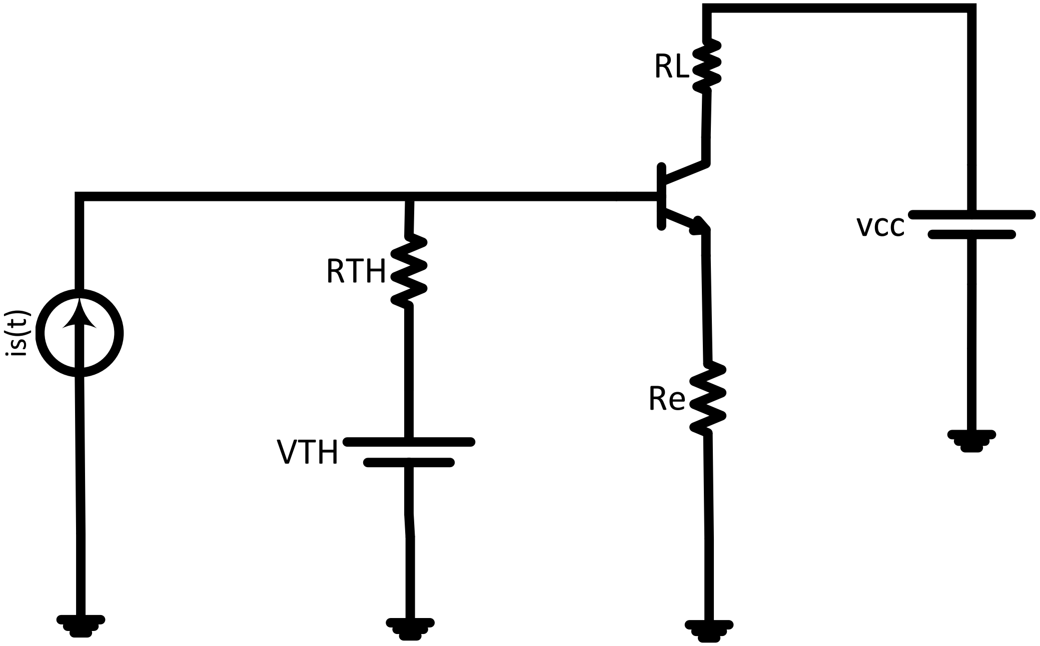
$$I_{cm\,,\,max} = I_{CQ}$$

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

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

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

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



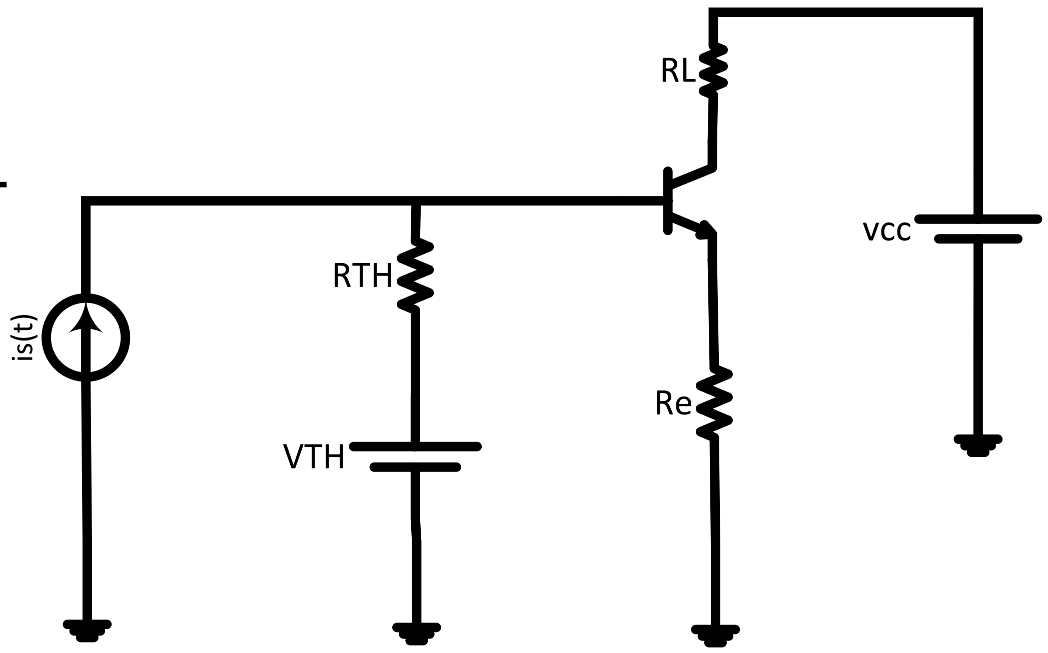
The Average Power Dissipated in The Load

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

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

$$If\ R_e << R_l$$

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



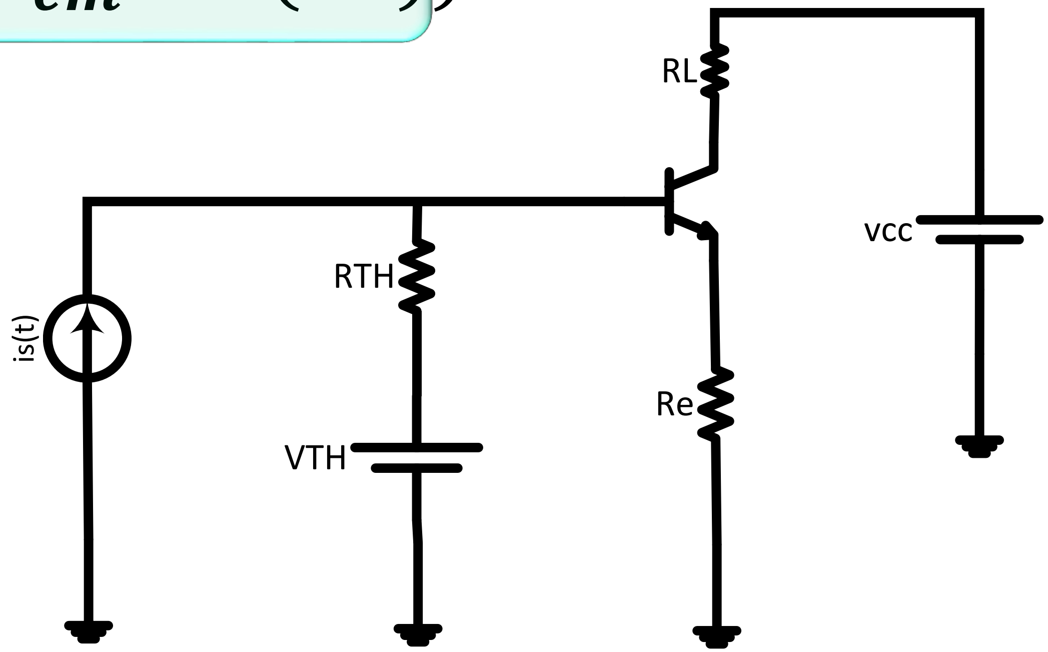
Average Power Delivered by the Supply : P_{cc}

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

$i_C(t)$

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

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



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

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

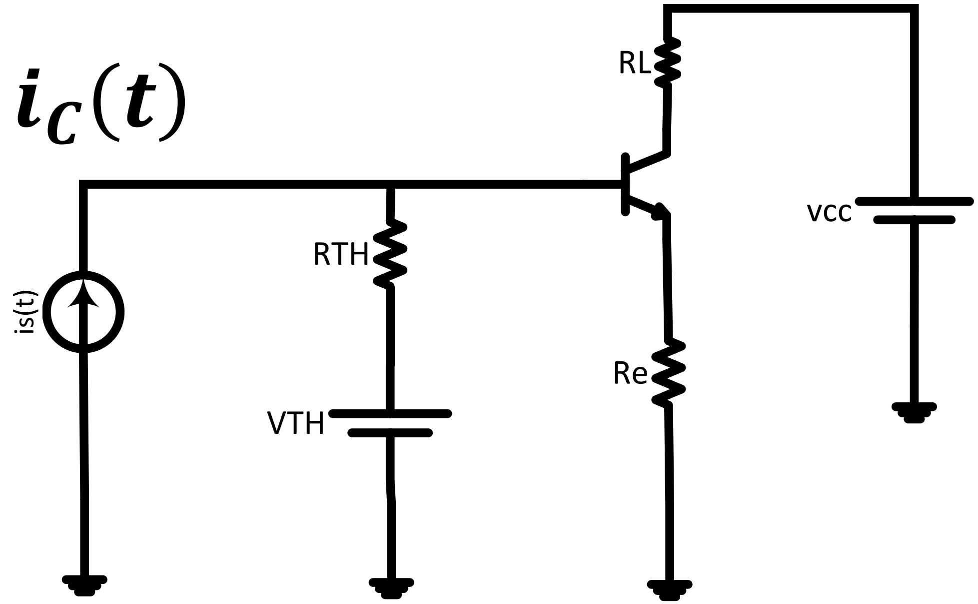
$$If\; R_e << R_l$$

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

Average Power Dissipated in the Transistor :P_c

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

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



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

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

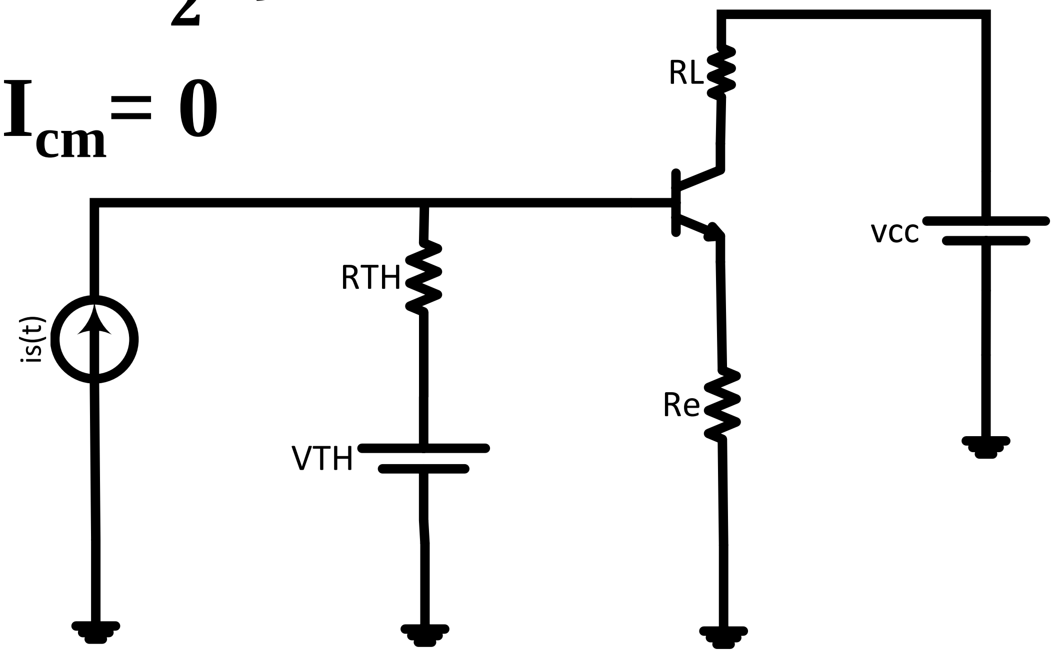
P_{cc}

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

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 $I_{cm} = 0$



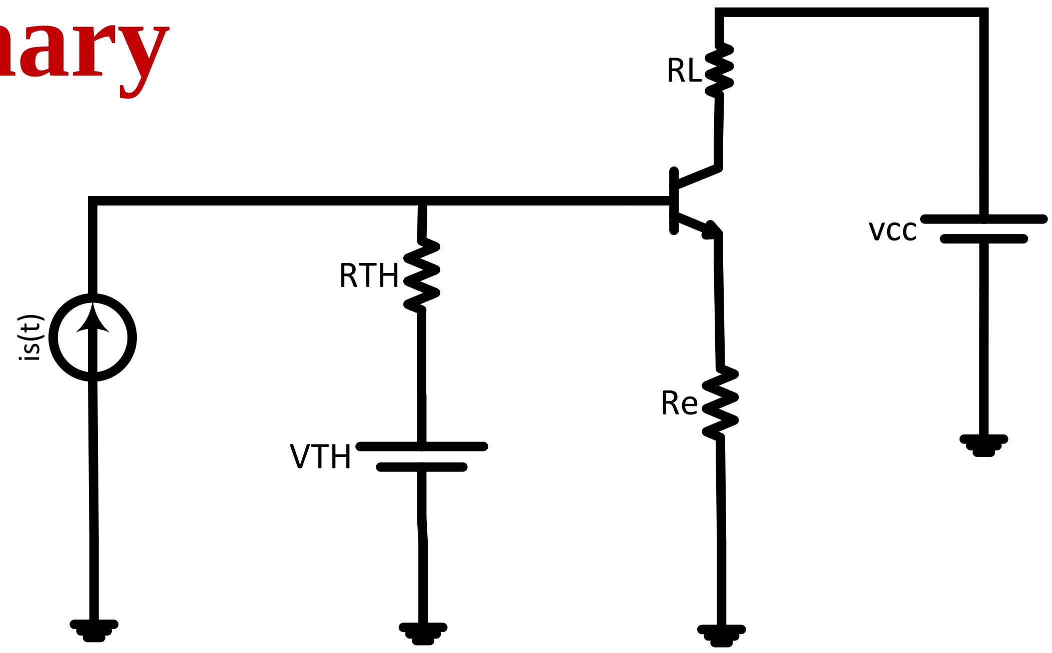
$$\therefore P_{c,max} = P_{cc} - (R_{l+}R_e)(I_{CQ}{}^2)$$

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

$$If\ R_e << R_l$$

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

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

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

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

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

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

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

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

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

γ : *Figure of merit*

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

$$\gamma = 2$$

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

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

The Class A Common Emitter Power Amplifier with Choke

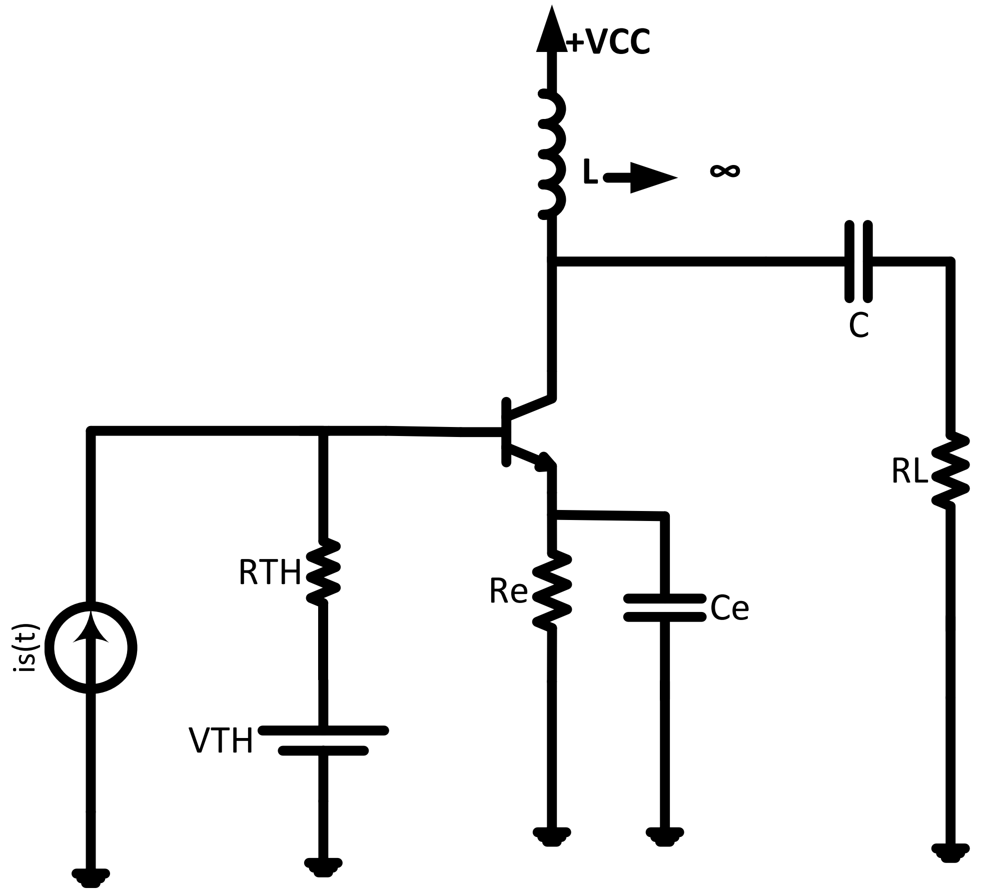
For Maximum Symmetrical swing:

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

$$R_{ac} = Rl$$

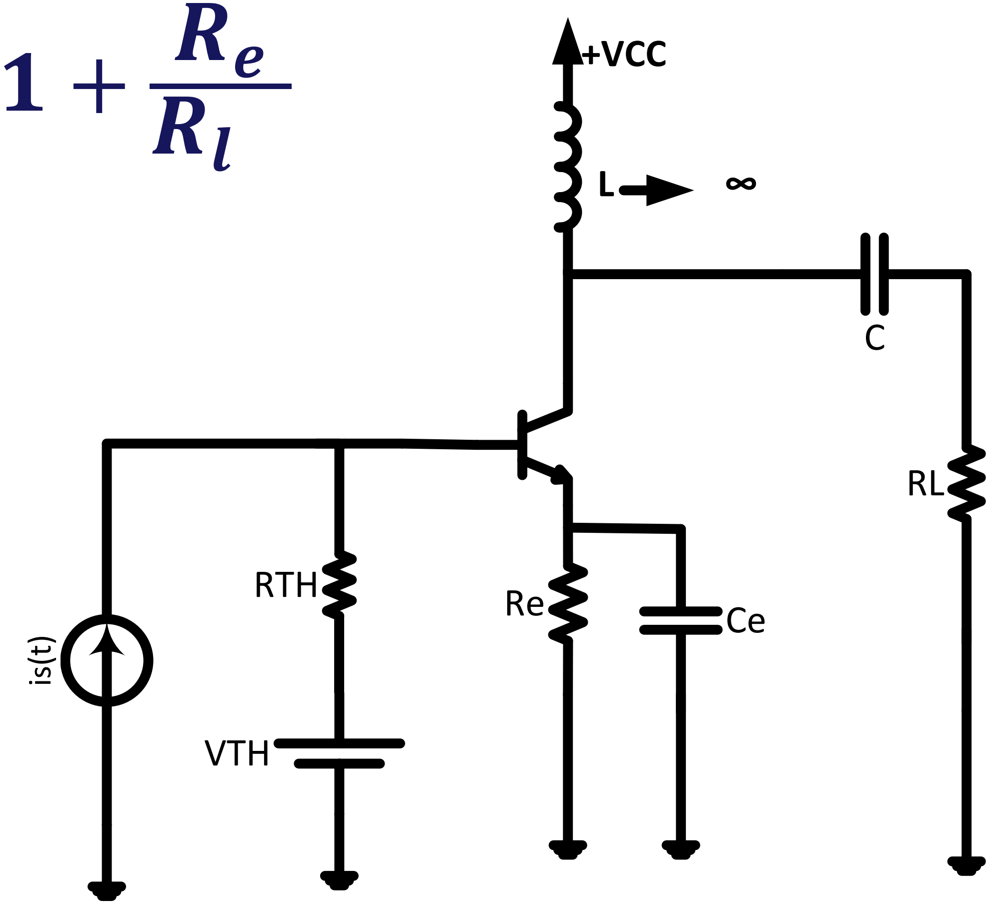
$$R_{dc} = R_e$$

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



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:

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

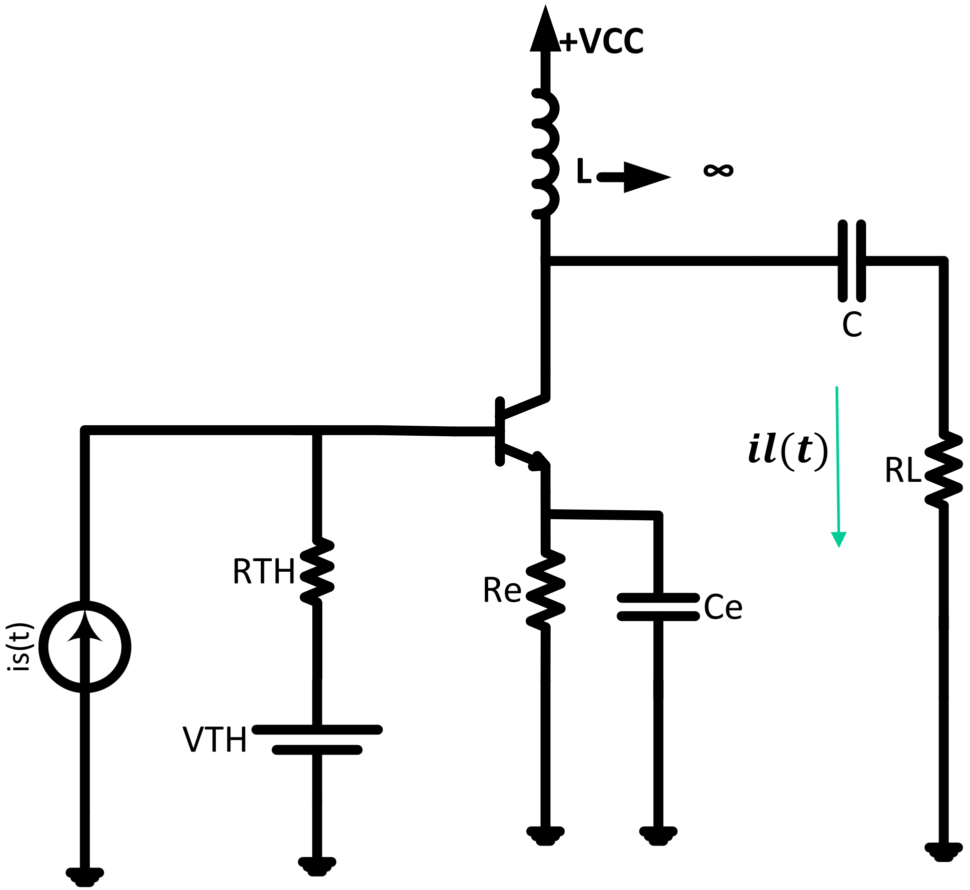
$$V_{CEQ} = V_{cc}$$

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

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

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

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

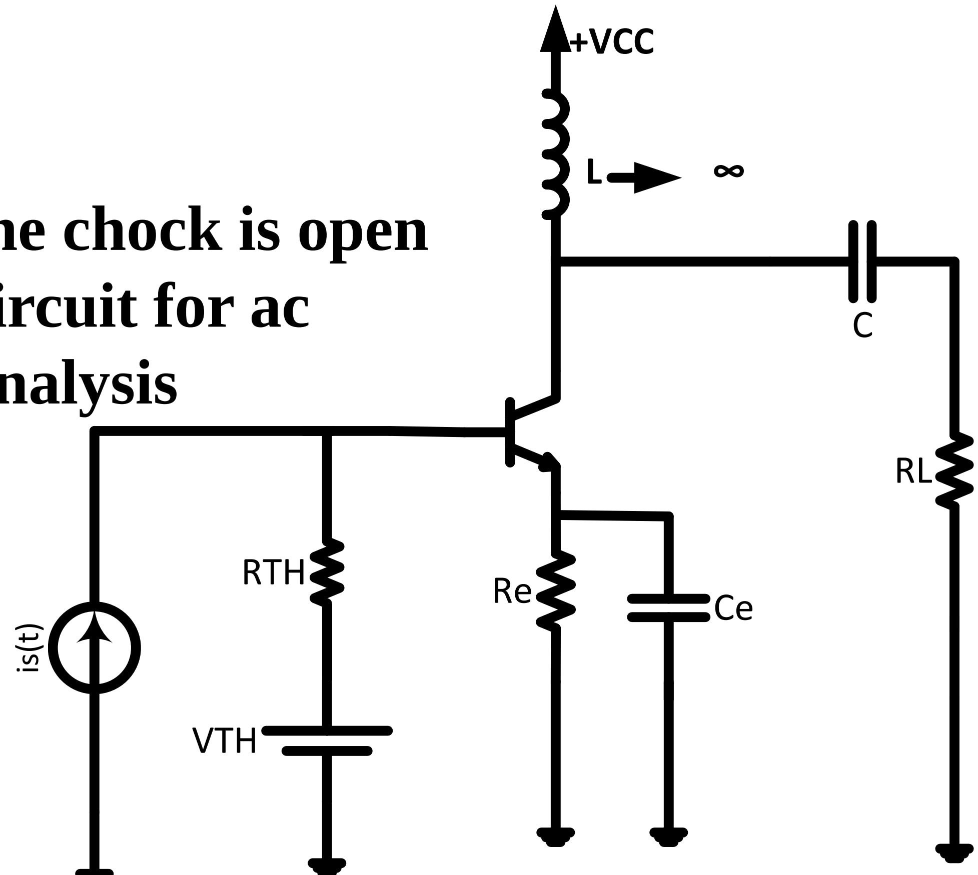


Power Calculation:

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

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

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:

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

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

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

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

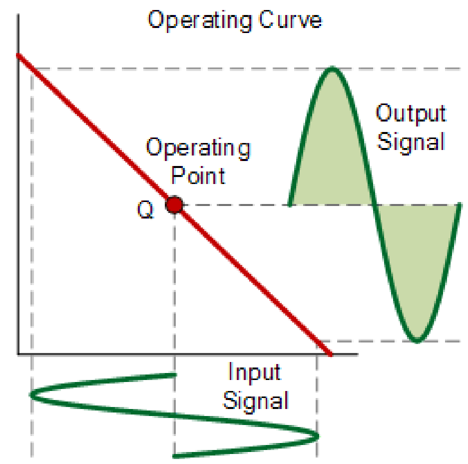
$$\gamma = \frac{P_{c\ max}}{(P_{l,ac})\ ,\ max}$$

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

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

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

Transistor Ratings:



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

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

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

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

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

Maximum Symmetrical swing

Transistor Ratings:

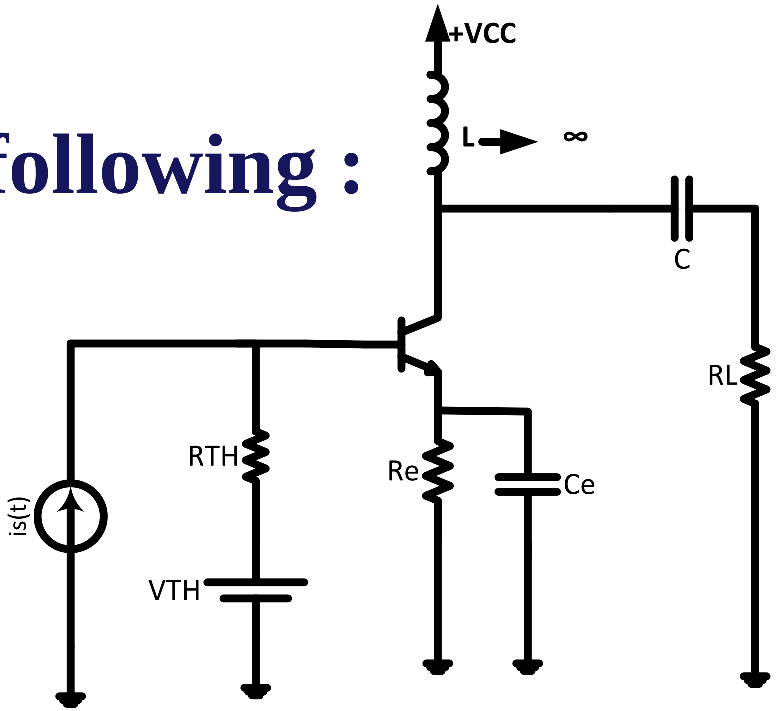
EXAMPLE:

A Power Transistor has the following :

BVCEO = 40V

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

Pc , max = 4W



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

Solution :

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

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

$$V_{CEQ} = \text{Rac} \, . \, I_{CQ} = R_l . \, I_{CQ}$$

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

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

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

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

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

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

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

Transistor Ratings:

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

Solution:

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

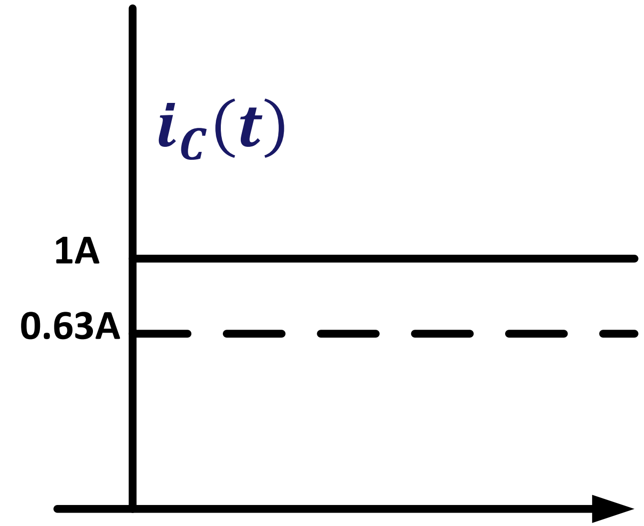
$$V_{CEQ} = \sqrt{Pc,max.RL} = 6.3\ \text{V}$$

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

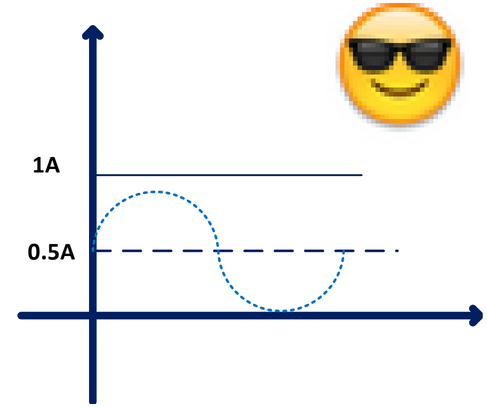
∴ Icm,max = 0.5 A

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

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

V_{CEQ} = Rac . ICQ = 5V

Vcc = V_{CEQ} = 5V



Pc,max = VCEQ*ICQ = 2.5W

$$\gamma = 2$$

Pcc = Vcc ICQ = 2.5W

Transformer coupled class A Power Amplifier:

For Maximum symmetrical swing :

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

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

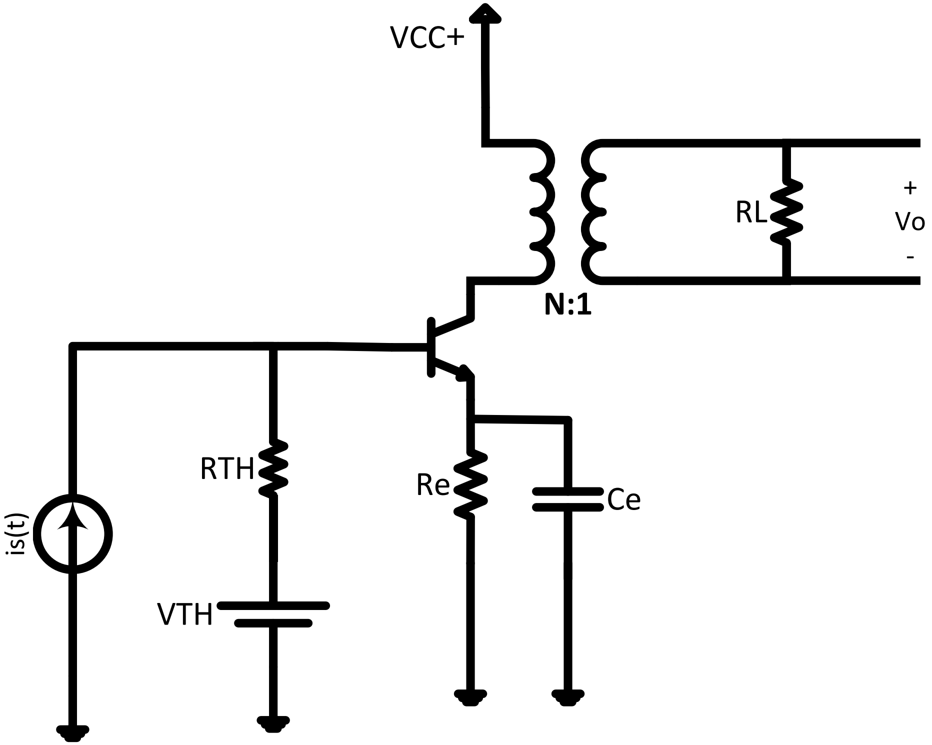
$$R_{dc} = R_e$$

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

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

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

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



Power Calculation:

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

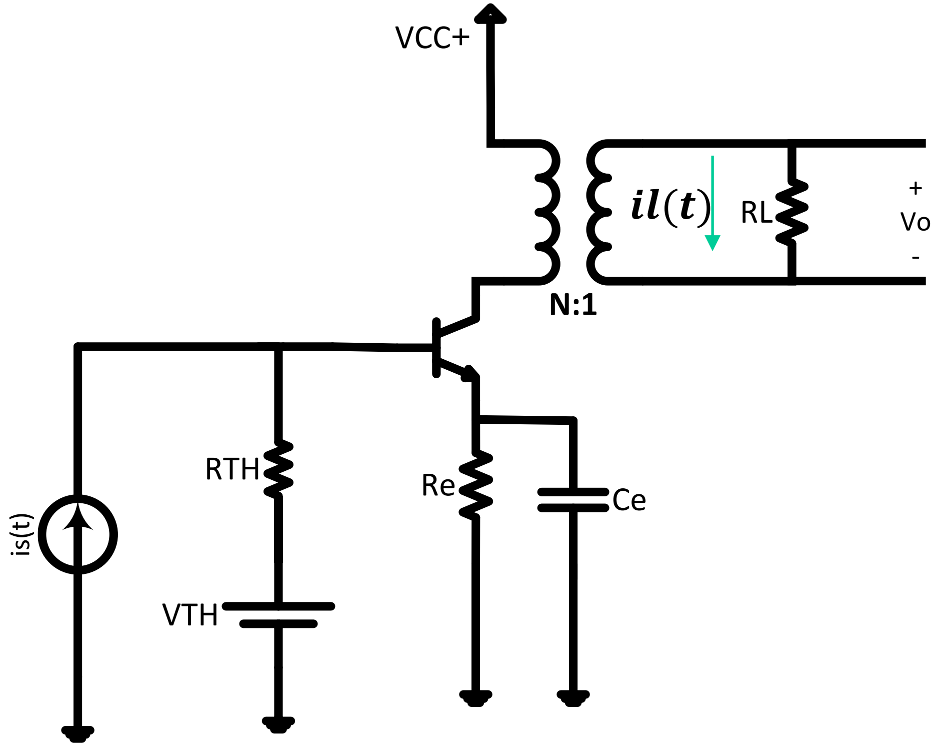
$$I_{lm} = \mathrm{N}\ .\ \mathrm{Icm}$$

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

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

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

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

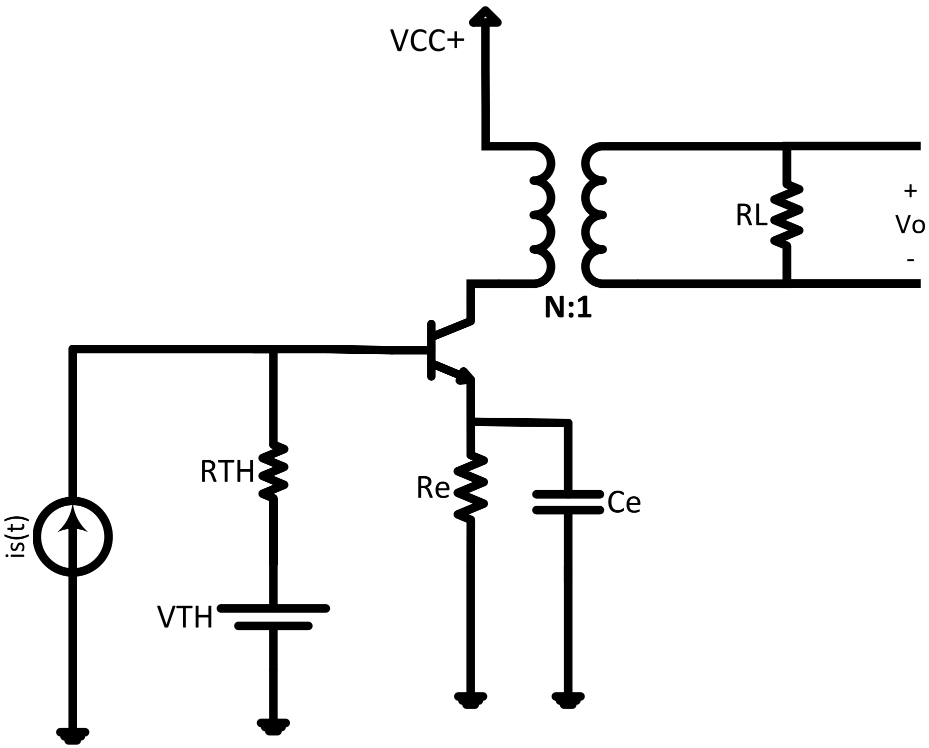


Power Calculation:

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

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

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



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

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

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

Power Calculation:

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

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

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

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

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

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

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

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} . I_{CQ} .

V_{CEQ} = Rac . I_{CQ}

$V_{CEQ} = R_l' . I_{CQ}$

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

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

How to choose N ?

The Q point must satisfy :

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

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

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

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

$\mathbf{3.17 > N > 1.26}$

a) Let N = 2

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

V_{CEQ}= 12.6 V

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

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

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

b) Let N=3

$$I_{CQ} = 0.21\text{A}$$

V_{CEQ}= 18.9 V

Vcc= 18.9 V

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

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

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

Class A Output stage Power Amplifier:

Q1 is common collector amplifier

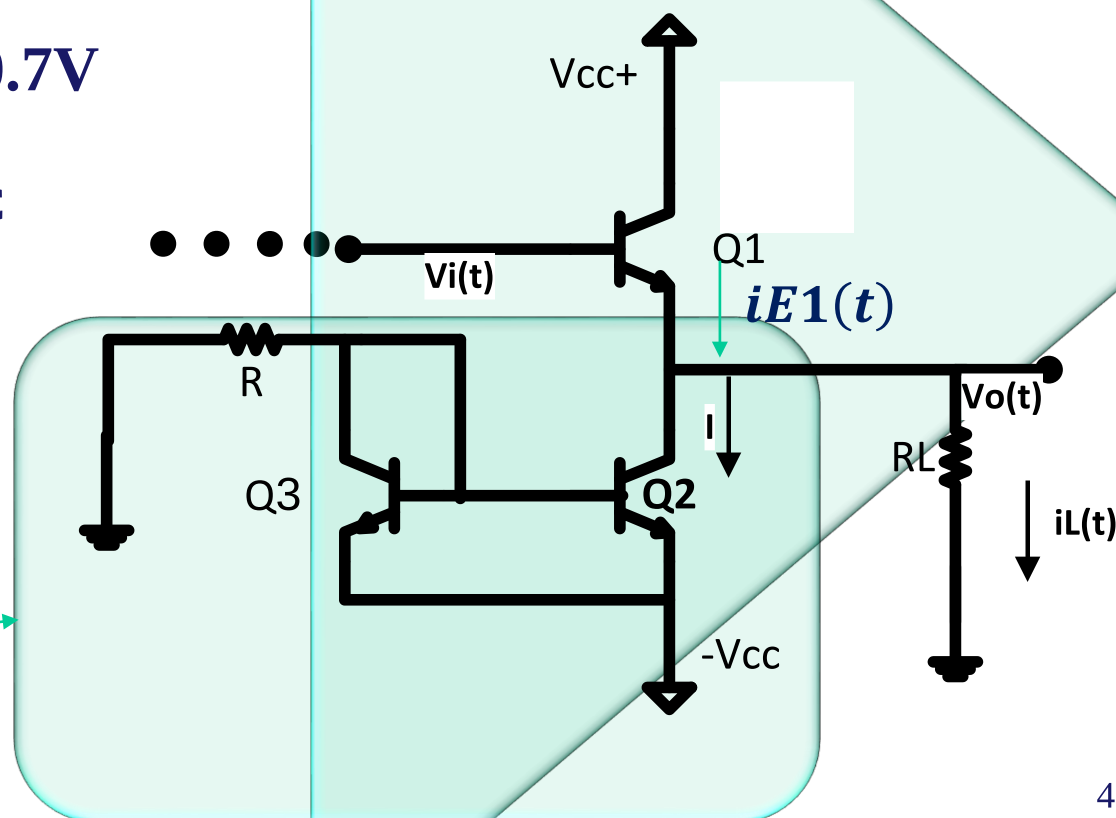
The output stage is designed so that :

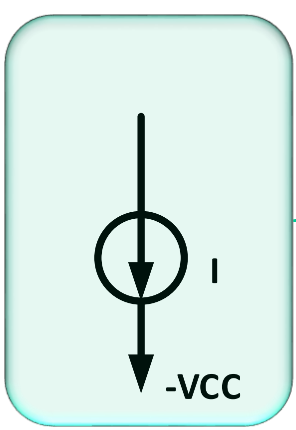
$V_o = 0$, $I_L = 0$, $V_i = 0.7V$

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

$V_o(t) = V_i(t) – V_{BE}(t)$

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





Current source

Transfer Curve:

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

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

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

(When T1 enters Saturation)

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

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

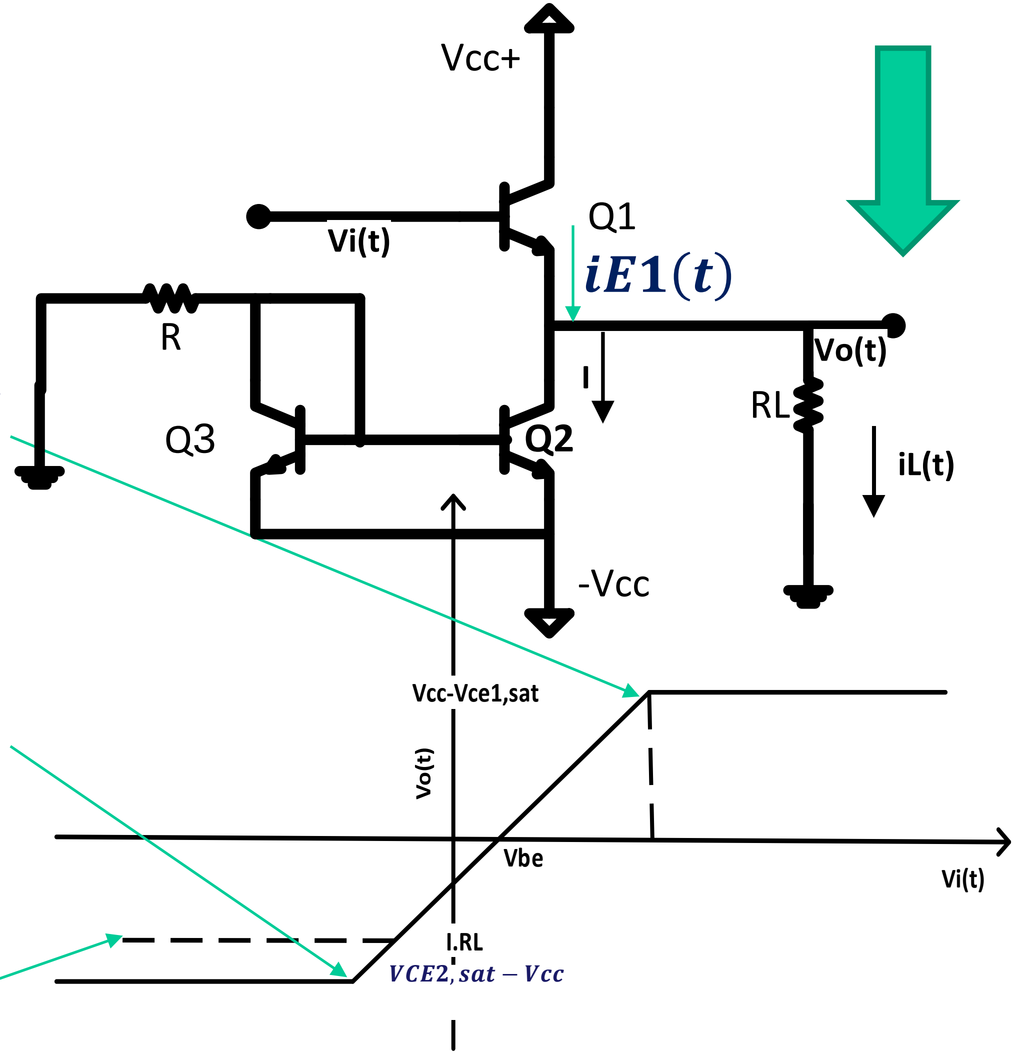
(When T enters Saturation)

Or:

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

(When T1 enters Cuttoff)

iE1(t) = 0

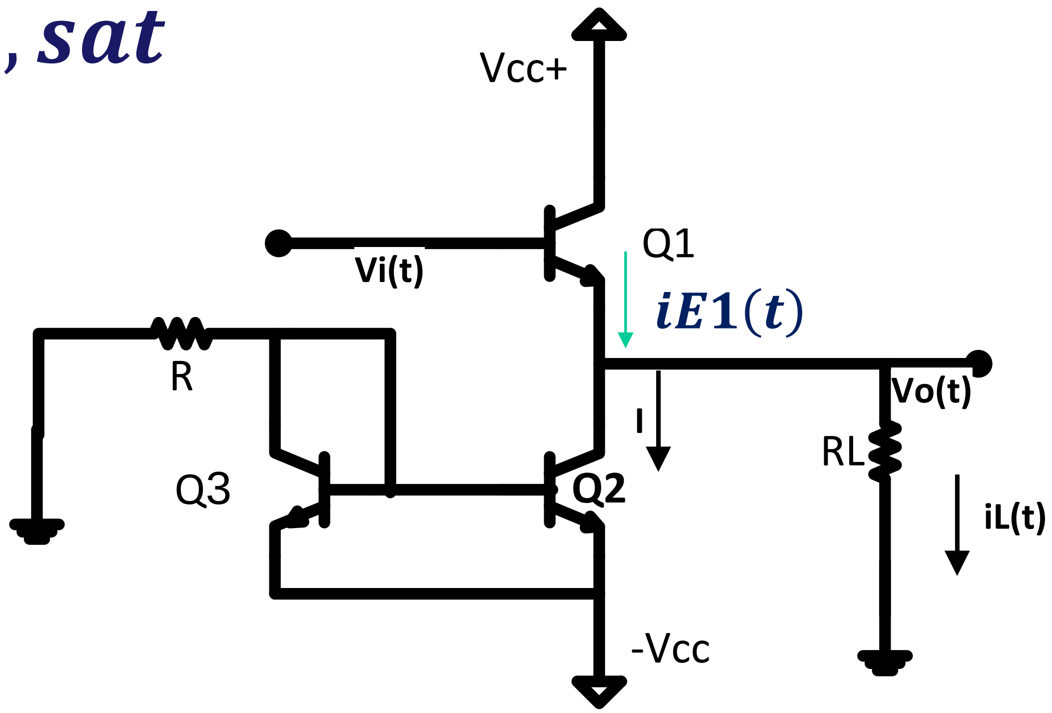


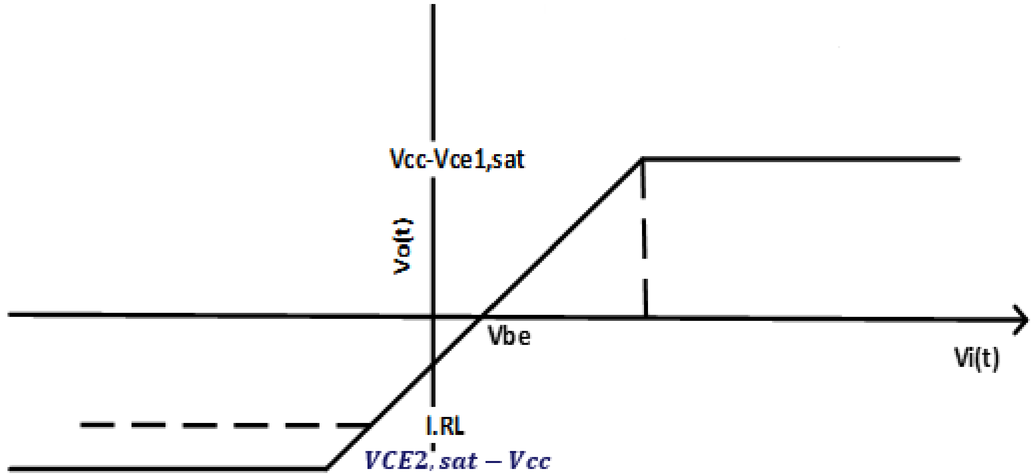
To allow Maximum symmetrical swing :

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

$$-IRL \cong -Vcc$$

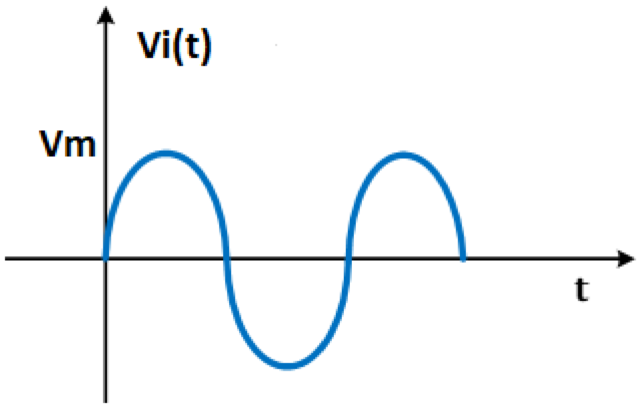
$$\therefore I = \frac{Vcc}{RL}$$

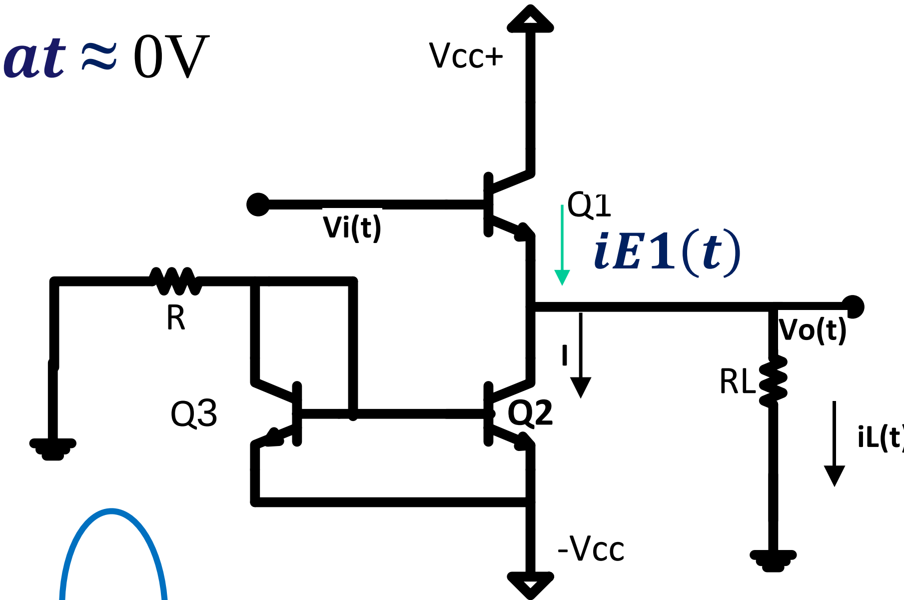


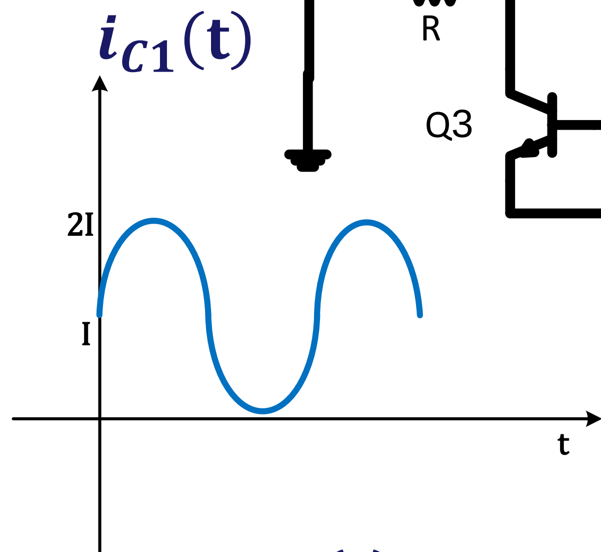


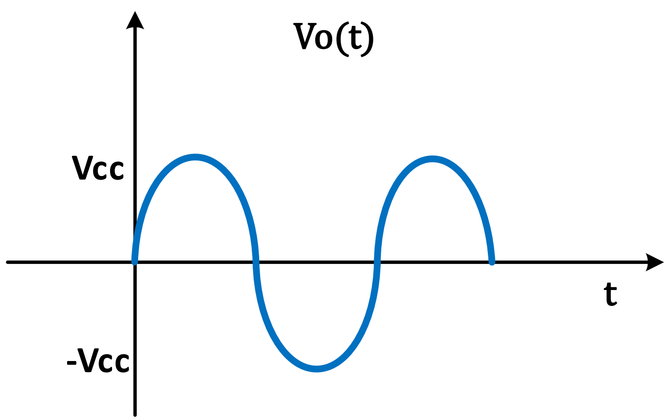
Signal Wave forms: $VCE, sat \approx 0\text{V}$

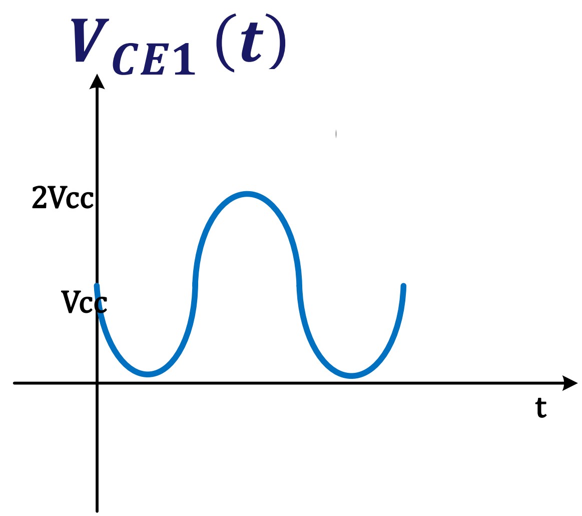
Maximum possible swing











Signal Wave forms:

$$iC1(t) \approx iE1(t) \qquad VCE, sat \approx 0\text{V}$$

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

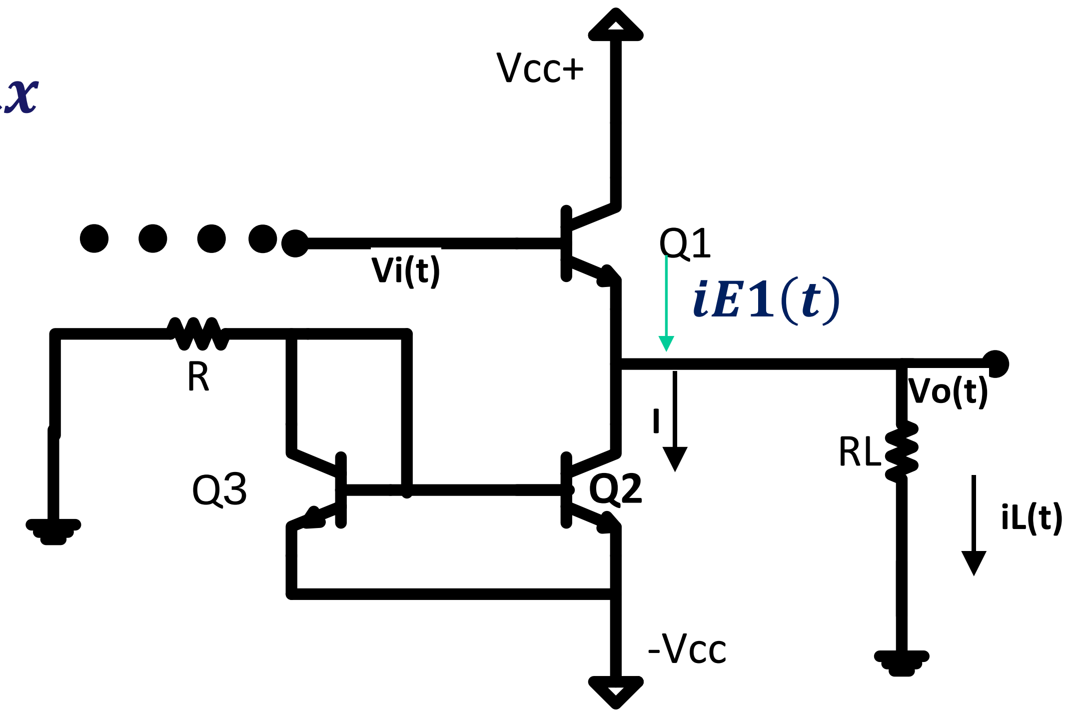
$$iE1(t), max = I + iL(t), max$$

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

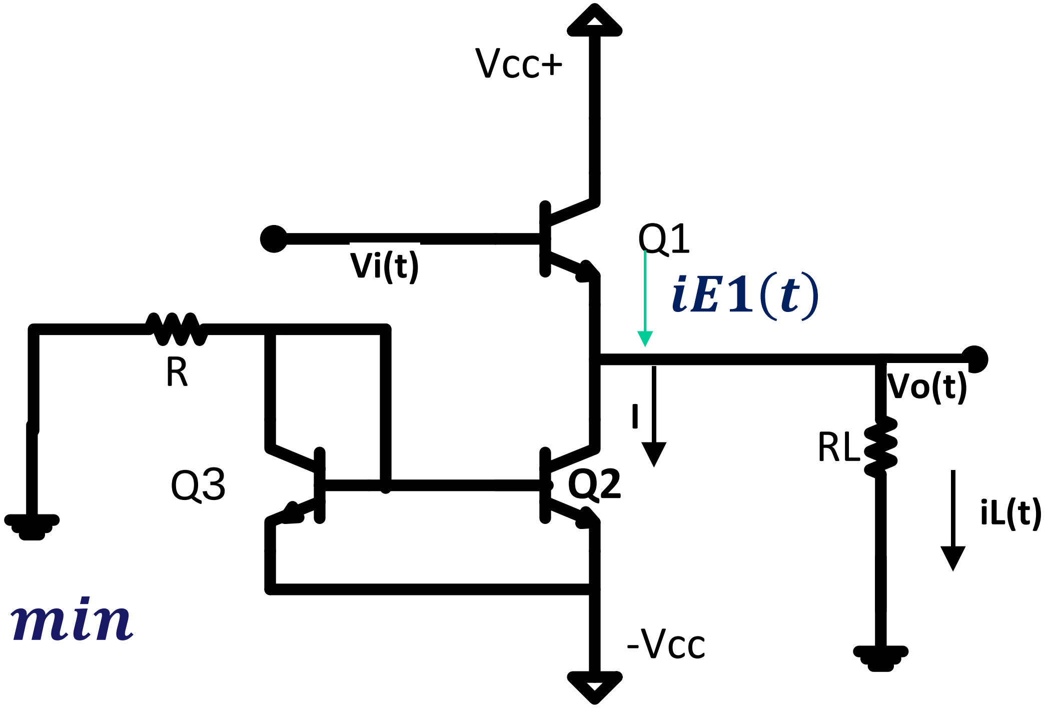
$$iE1(t), max = I + \frac{Vcc}{RL}$$

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

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



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



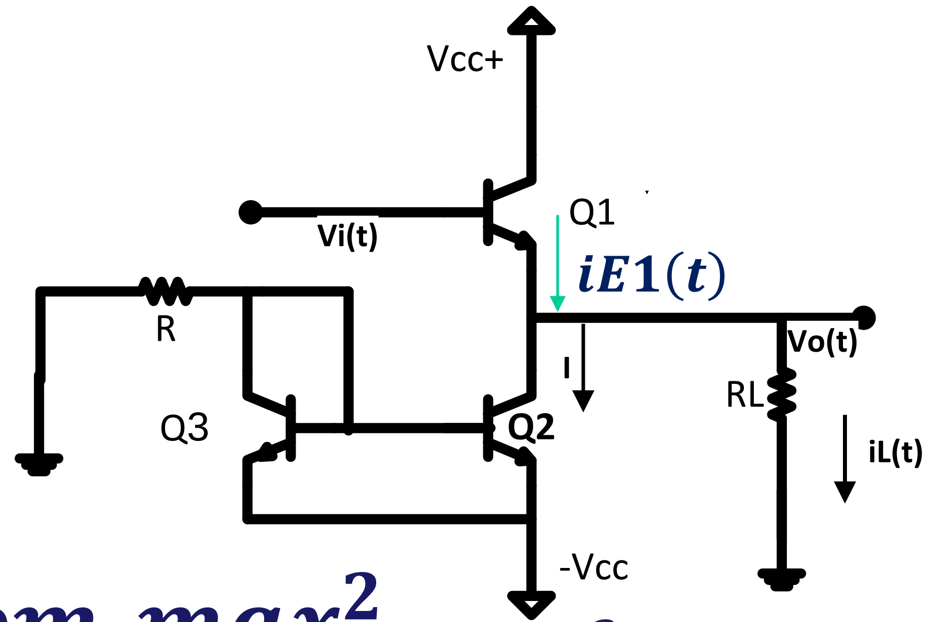
$$VCE1(t) = Vcc - Vo(t)$$

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

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

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

Power Calculation:



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

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

$$Pcc = Pcc1 + Pcc2$$

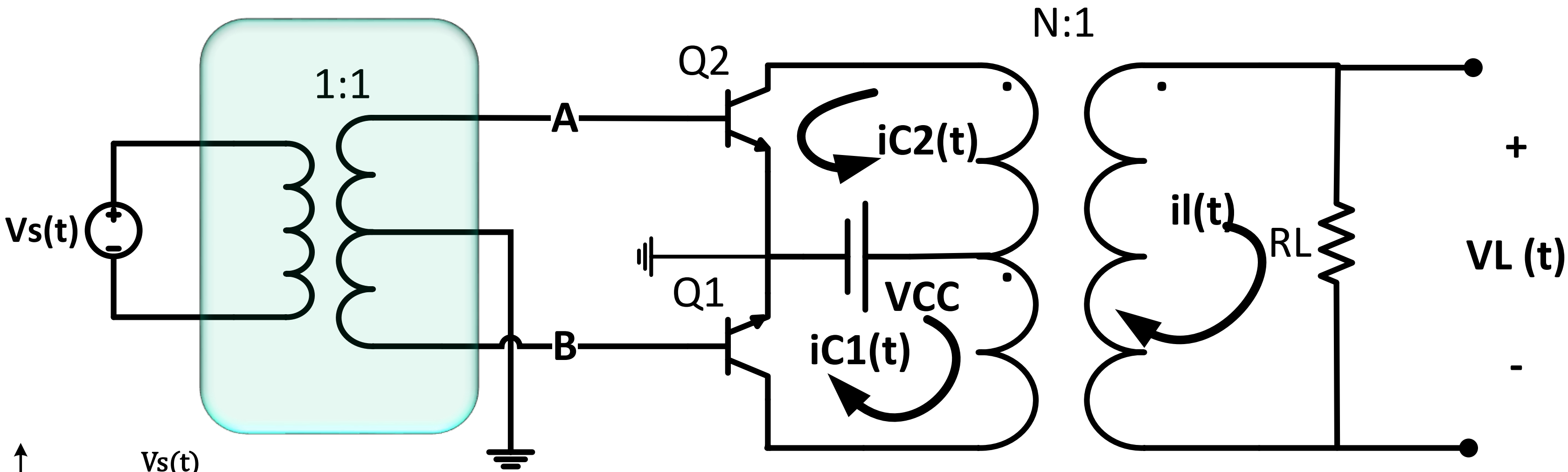
$$Pcc = 2Vcc * I$$

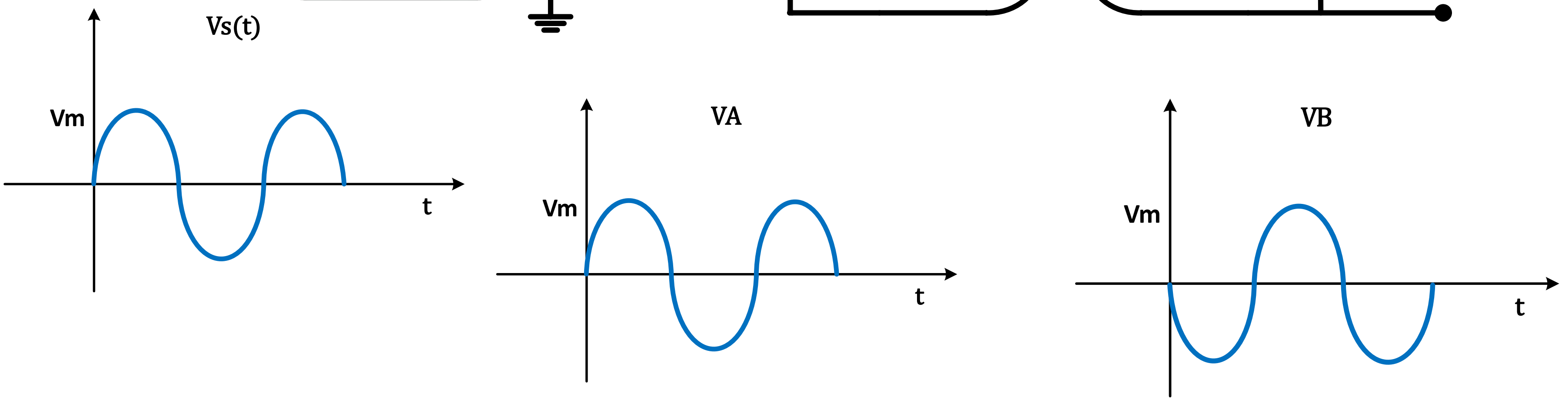
$$\eta, max = \frac{(PL, ac), max}{Pcc} * 100\%$$

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

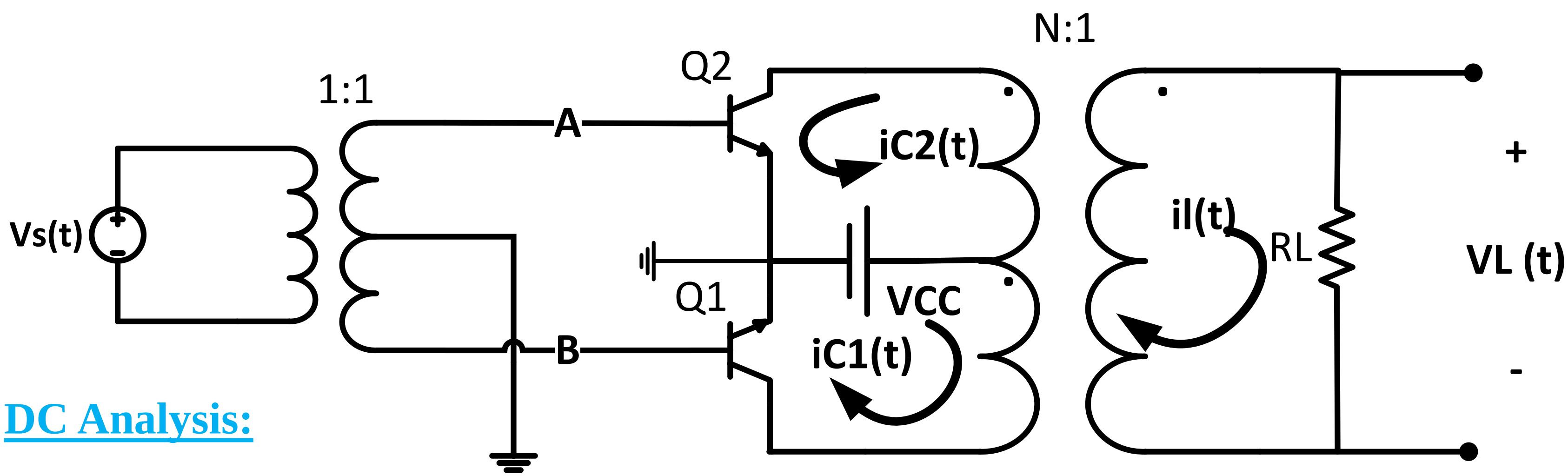
$$\eta, max = 25\%$$

Class B Push-Pull Power Amplifier:

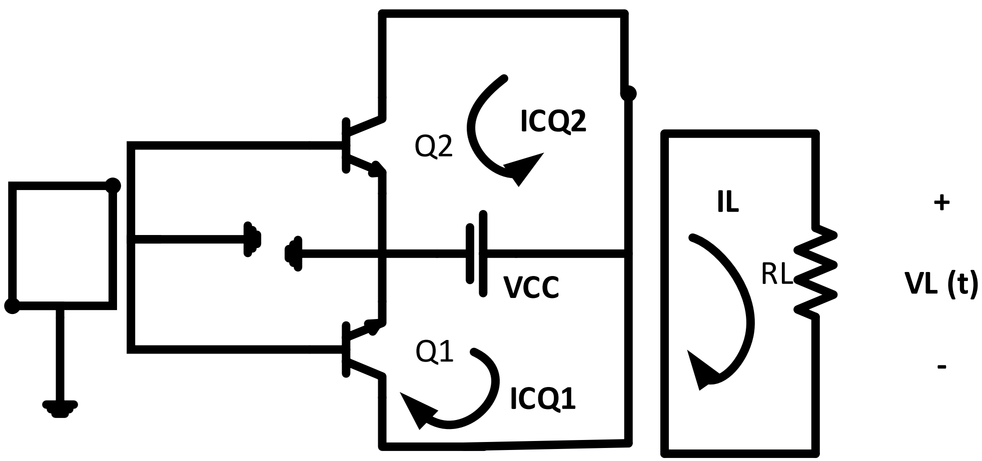




Class B Push-Pull Power Amplifier:



DC Analysis:



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

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

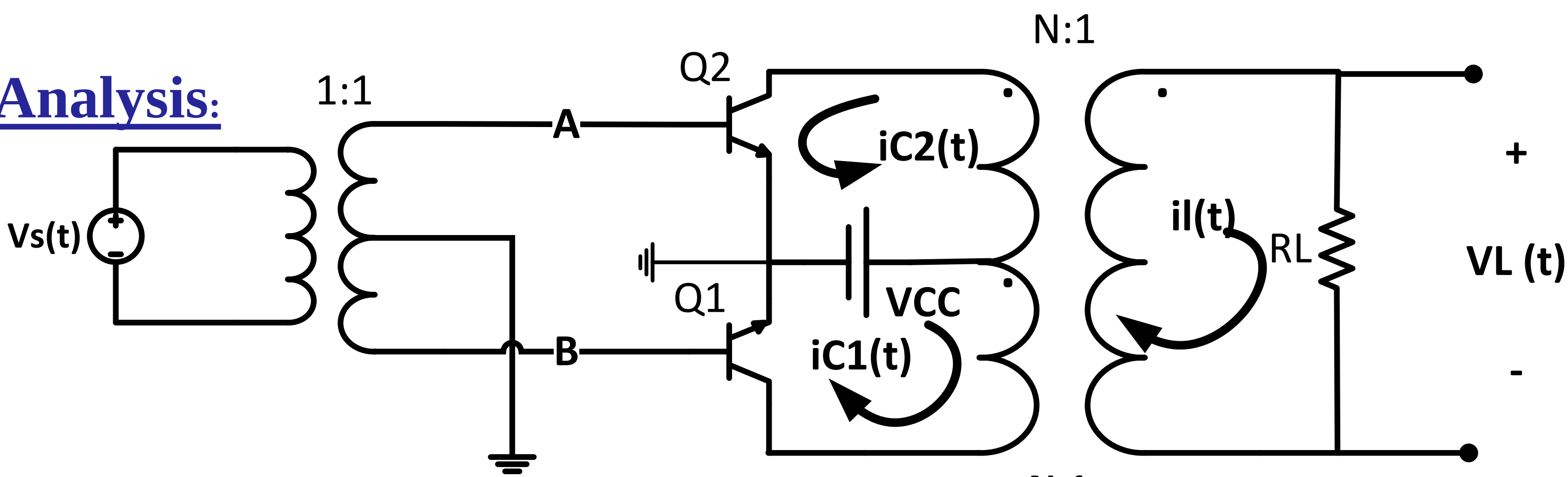
$$I_{CQ1} = I_{CQ2} = 0$$

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

$$V_L = 0 \qquad I_L = 0$$

Class B Push-Pull Power Amplifier:

AC Analysis:



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

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

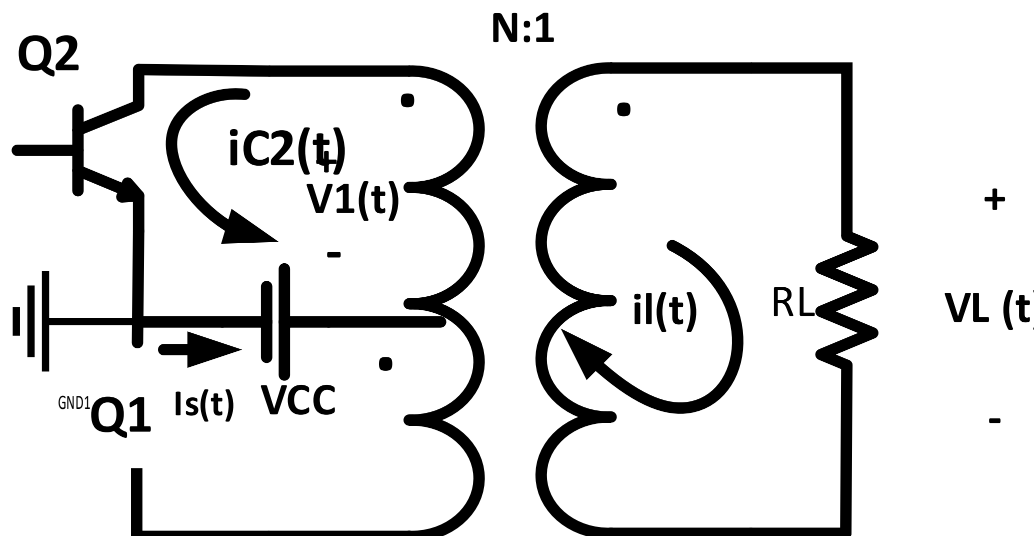
$$v_B(t) < 0\ ;\quad Q_1\ is\ off$$

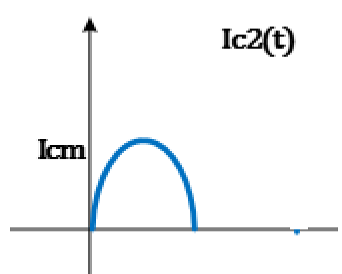
$$\therefore\ i_L(t) = -N i_{C2}(t)$$

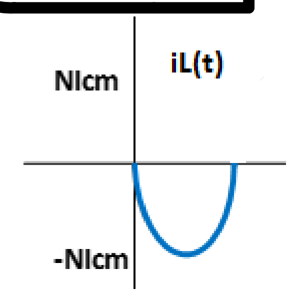
$$and$$

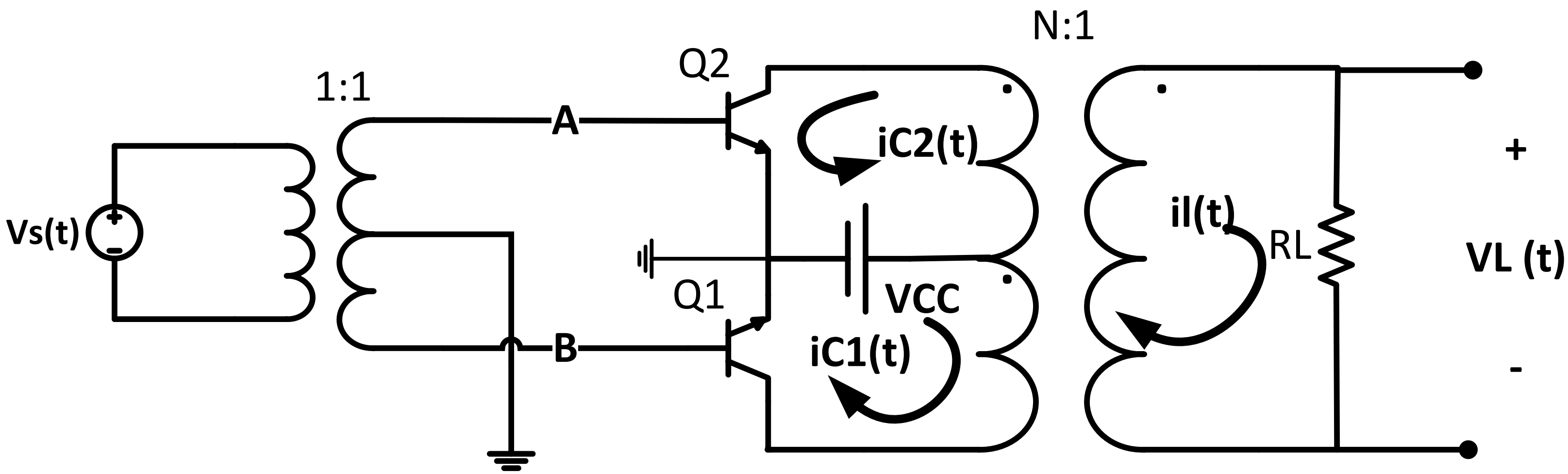
$$i_s(t) = i_{C2}(t)$$

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









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

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

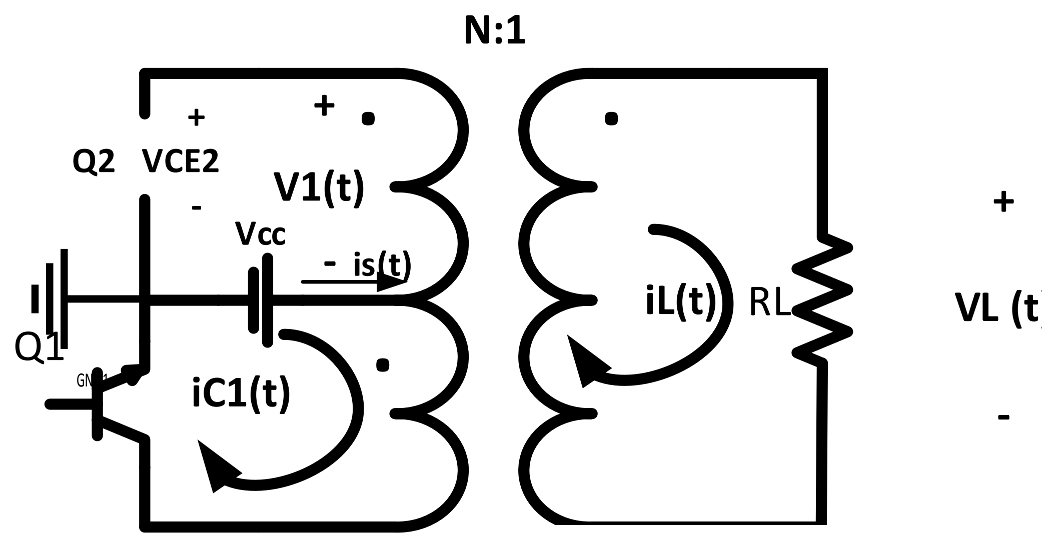
$$v_B(t) > 0\ ; \quad Q_1\ is\ on$$

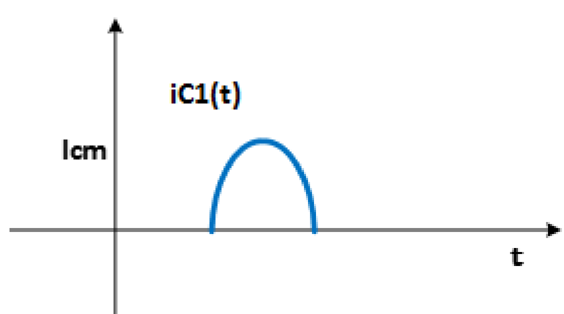
$$\therefore\ i_L(t) = \ +N\ i_{C1}(t)$$

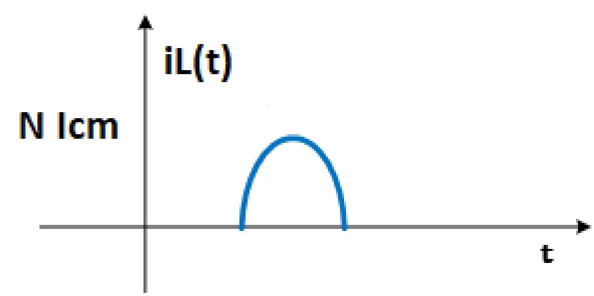
$$and$$

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

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







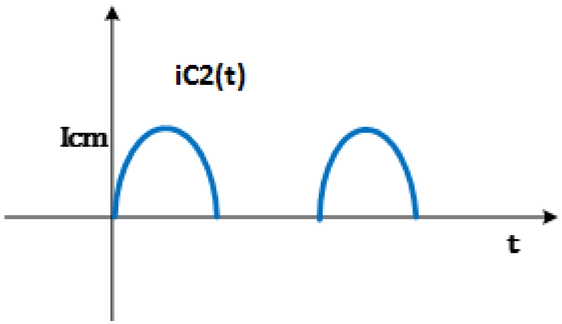
Class B Push-Pull Power Amplifier:

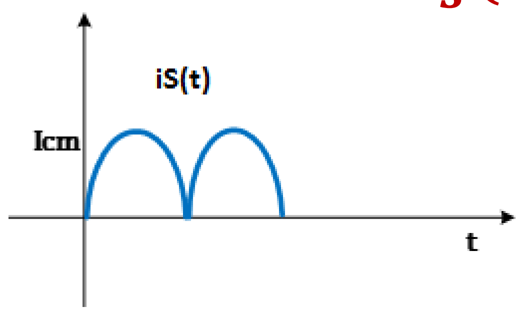
AC Analysis:

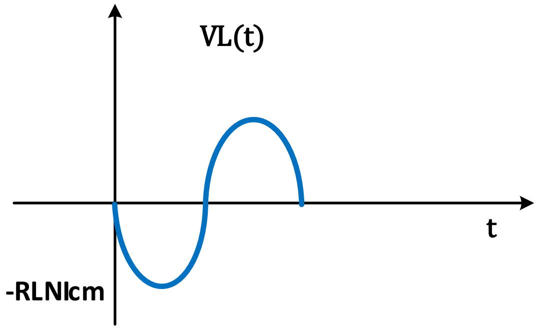
c) for the complete cycle

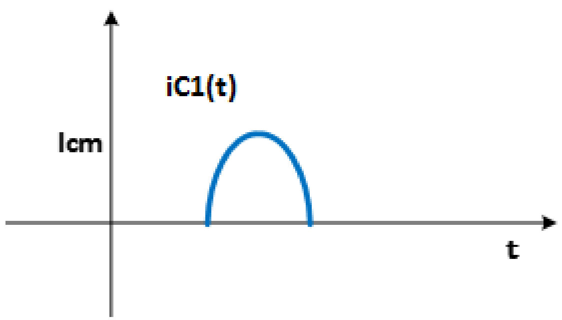
$$i_L(t) = N\left(i_{C1}(t) - i_{C2}(t)\right)$$

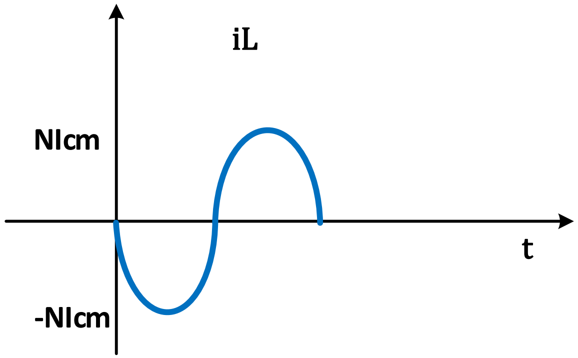
$$i_s(t) = i_{C2}(t) + i_{C1}(t)$$





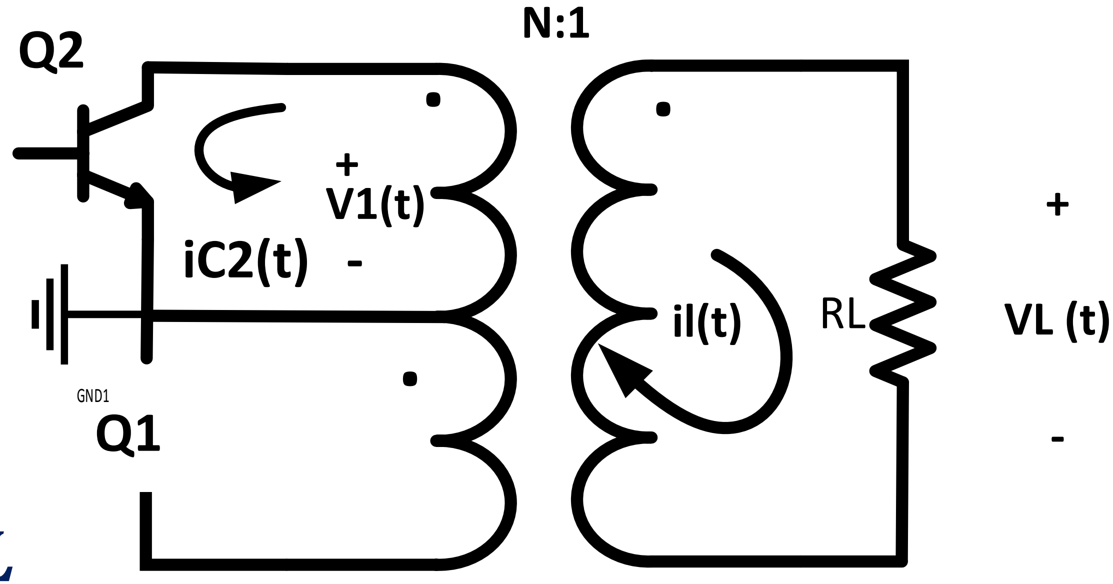






Class B Push-Pull Power Amplifier:

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:

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

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

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

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

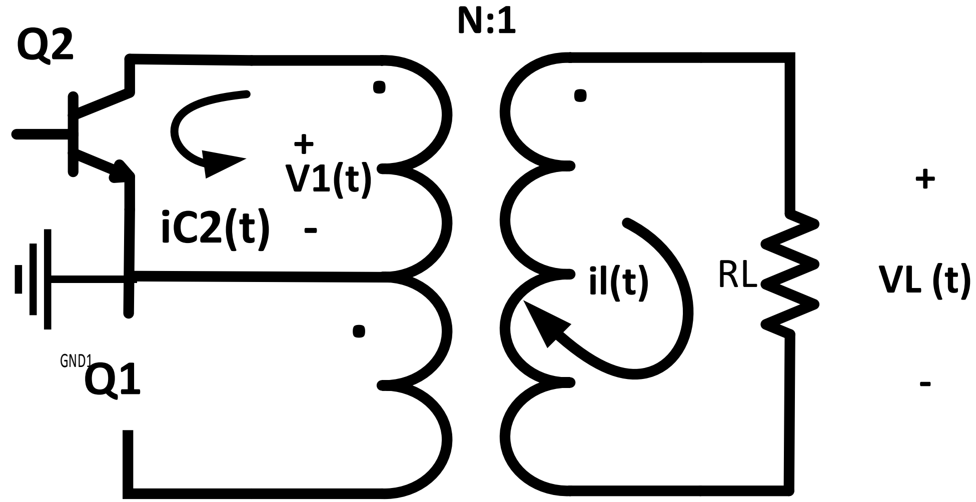
$$I_{cm2,max} = \frac{V_{cc}}{R_l'}$$

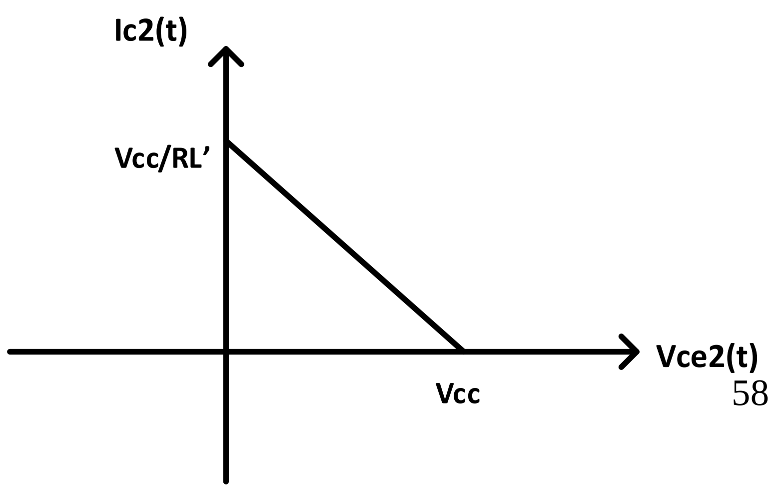
$$To\ find \quad v_{CE}(t)_{,max}$$

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

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

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





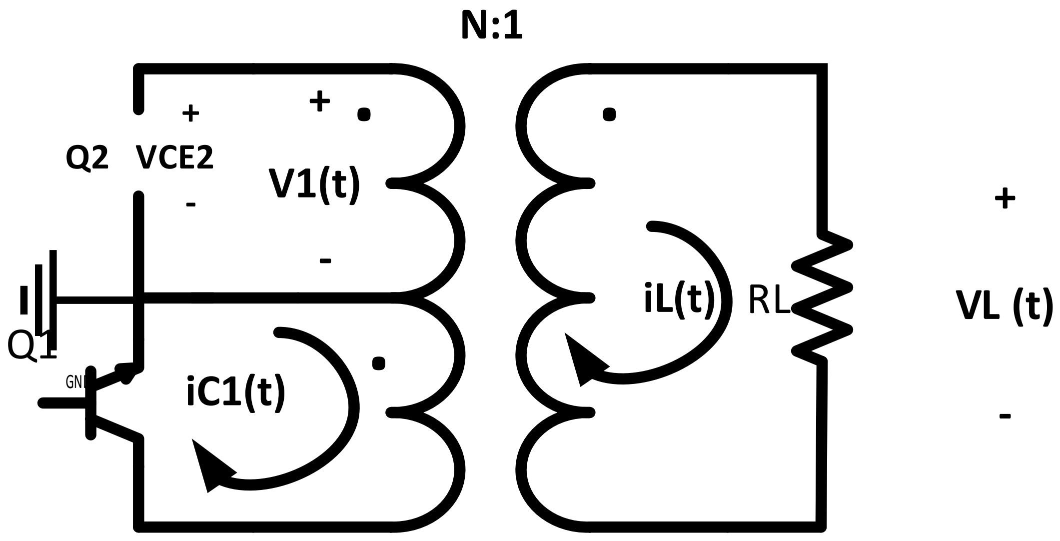
Class B Push-Pull Power Amplifier:

AC Load Line for Q2:

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

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

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



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

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

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

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

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

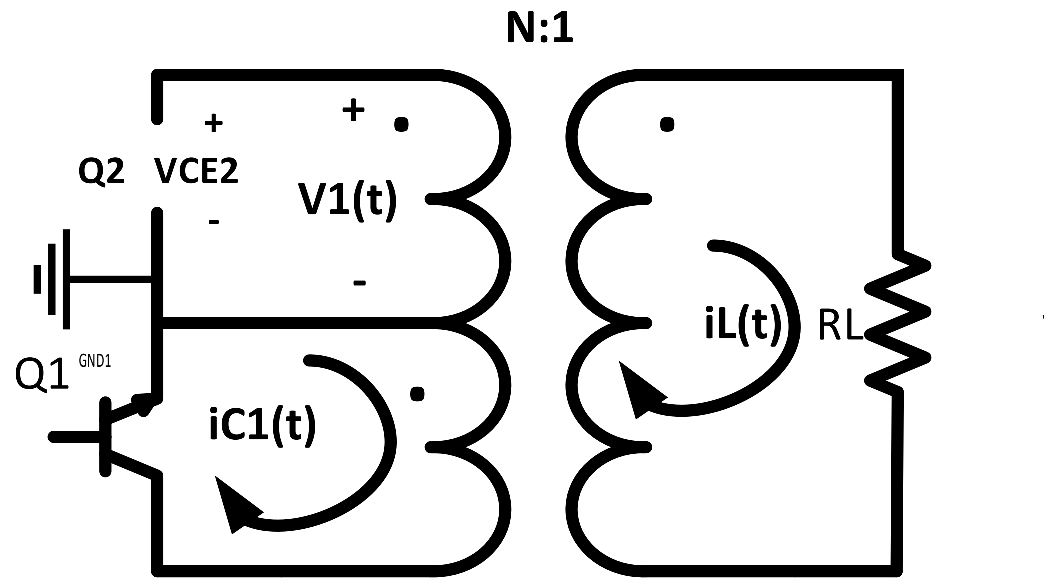
$$v_{CE2}(t) = V_{cc} + N^2\,R_L\,i_{C1}(t)$$

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

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

Class B Push-Pull Power Amplifier:

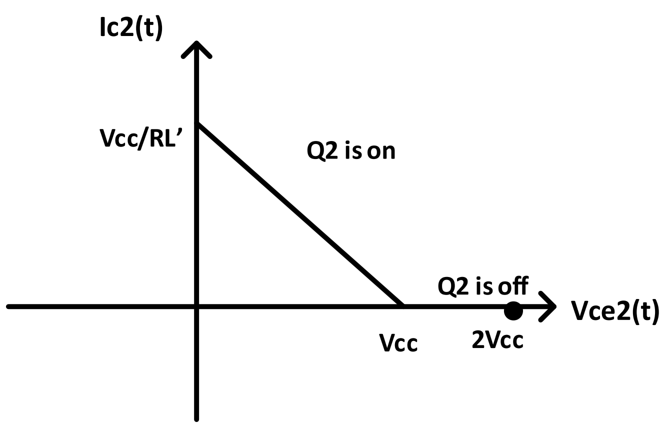
AC Load Line for Q2:



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

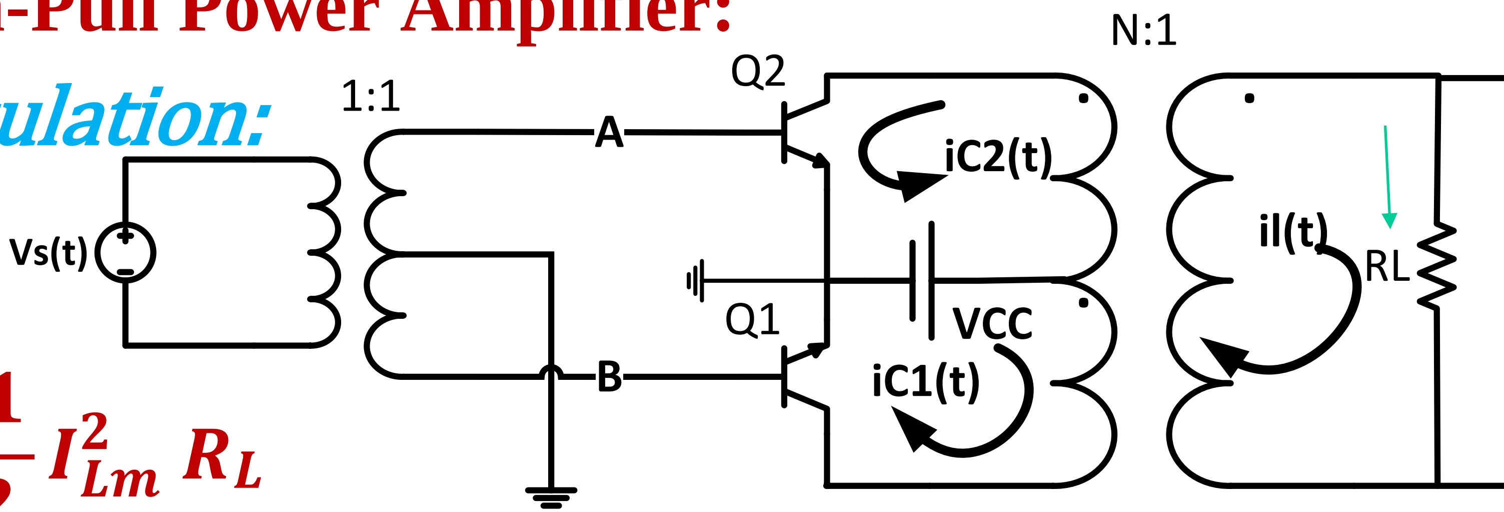
$$v_{CE2}(t)_{,max} = V_{cc} + V_{cc}$$

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



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:

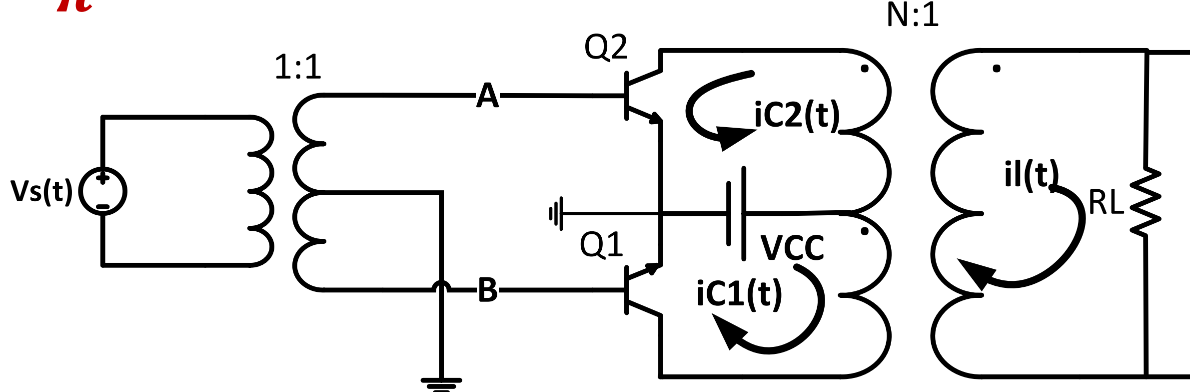
Power calculation:

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

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

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

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



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

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

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

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

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

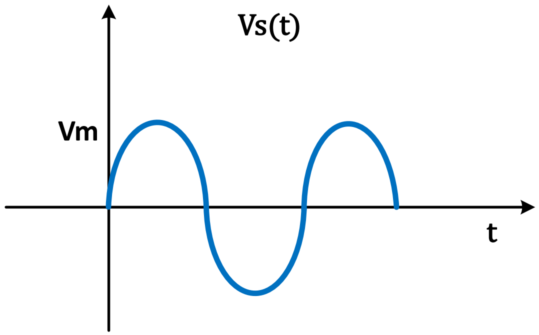
$$\eta_{,max} = \frac{\pi}{4} * 100\% = 78.5\%$$

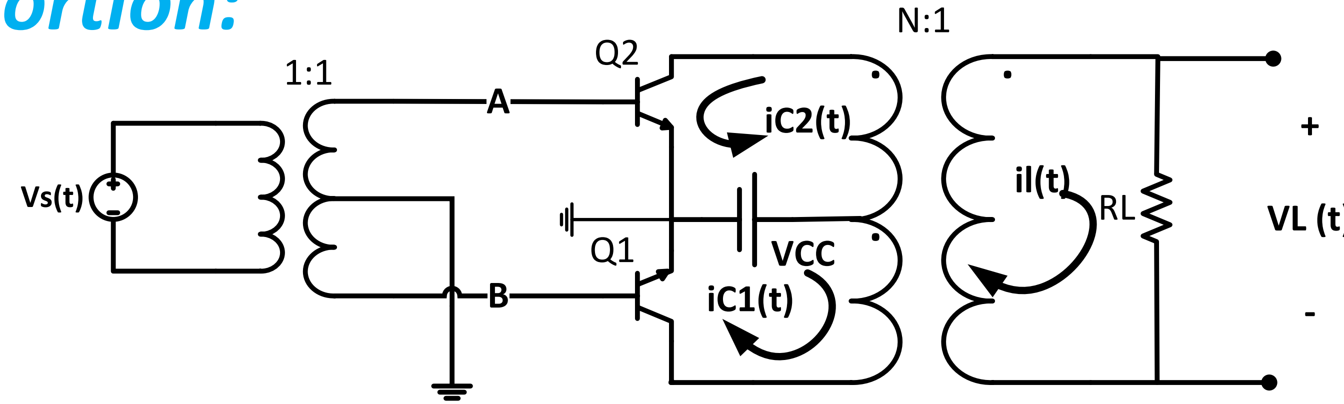
$$\gamma = \frac{Pc,max}{(PL,ac),max}$$

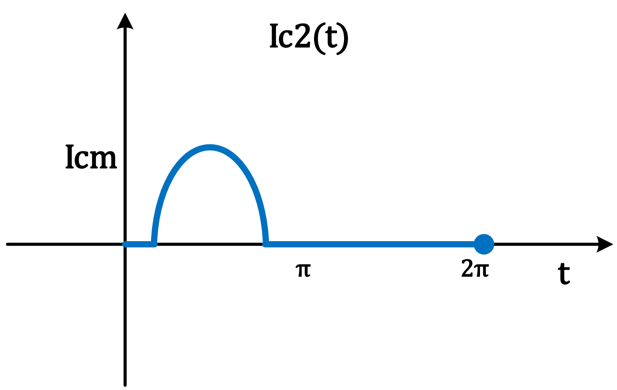
$$\gamma = \frac{2}{\pi^2} \cong 0.2$$

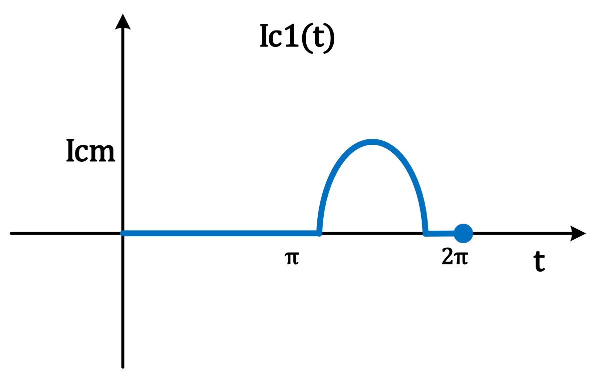
Class B Push-Pull Power Amplifier:

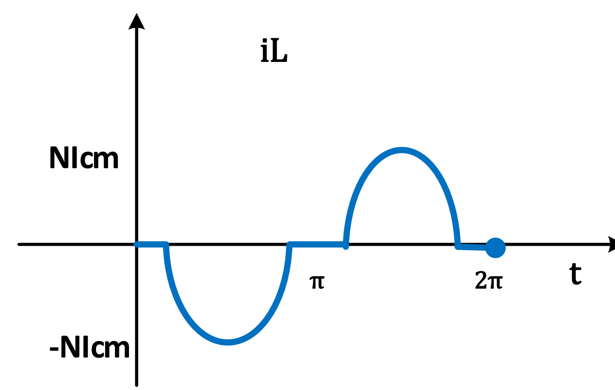
Cross Over Distortion:











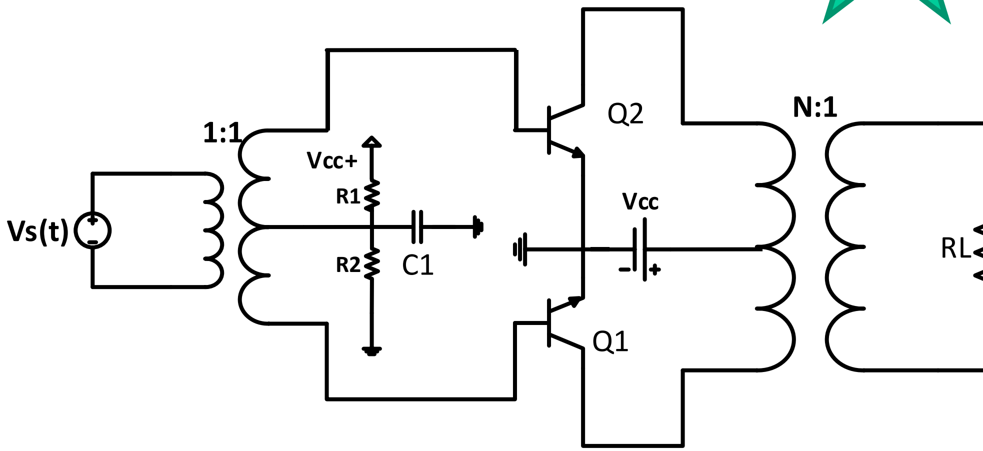
Class AB Push-Pull Power Amplifier:

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.

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.



We Choose R1 & R2 So that:

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

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

$VBE1 + VEB2 = 0$

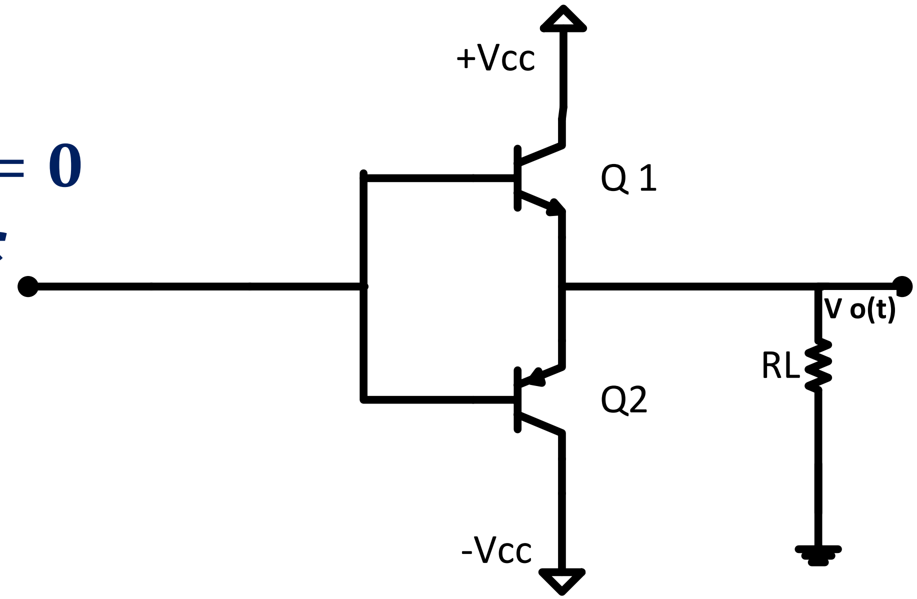
$\therefore Q1 \; and \; Q2$ are in cutoff

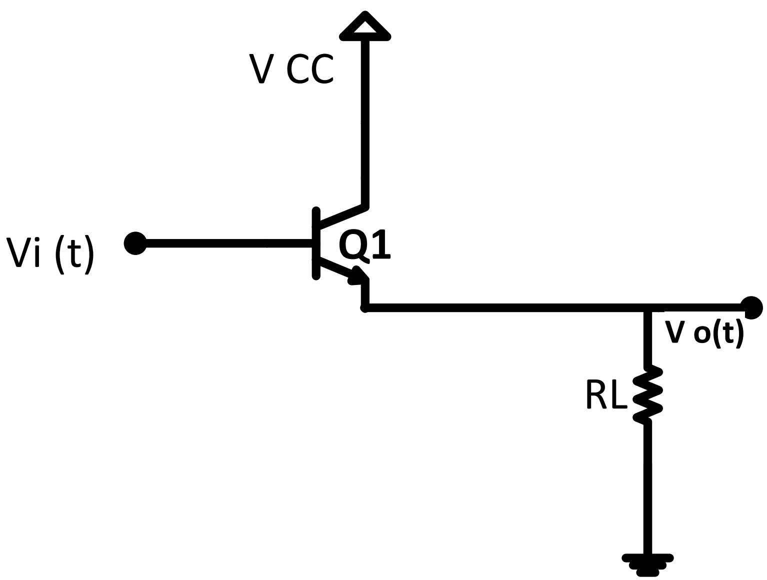
$ICQ1 = ICQ2 = 0 \, , IL = 0 \;\; , Vo = 0$

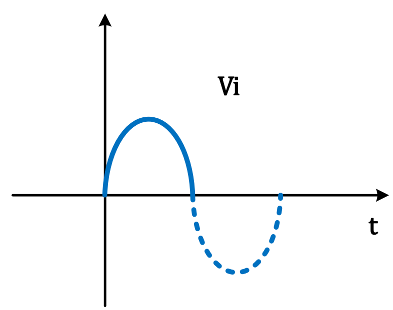
$VCEQ1 = Vcc \, , VECQ2 = Vcc$

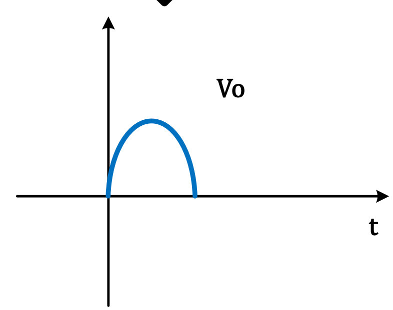
When Vi(t) $> \; 0$

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



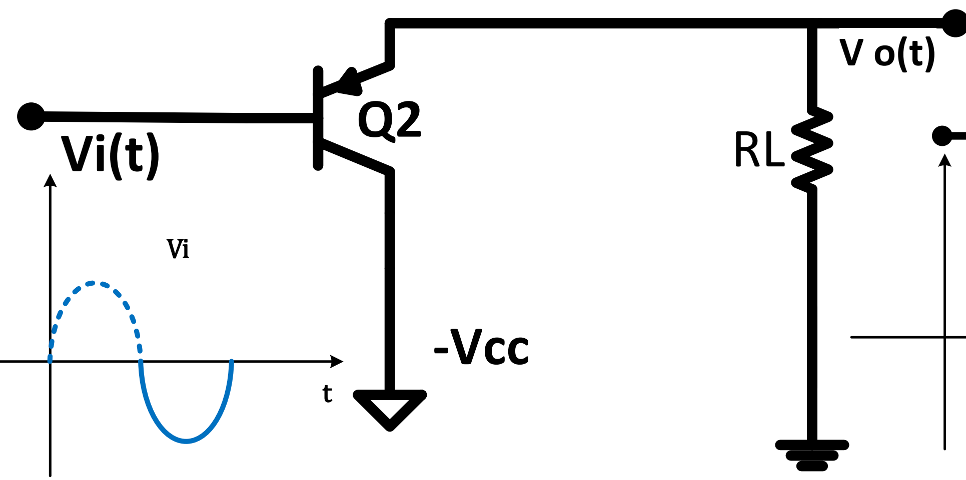


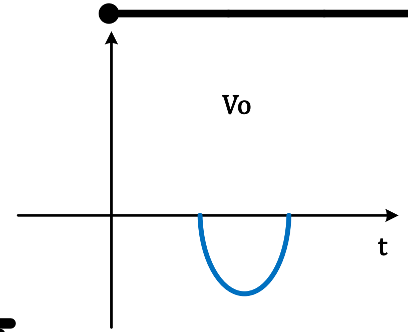


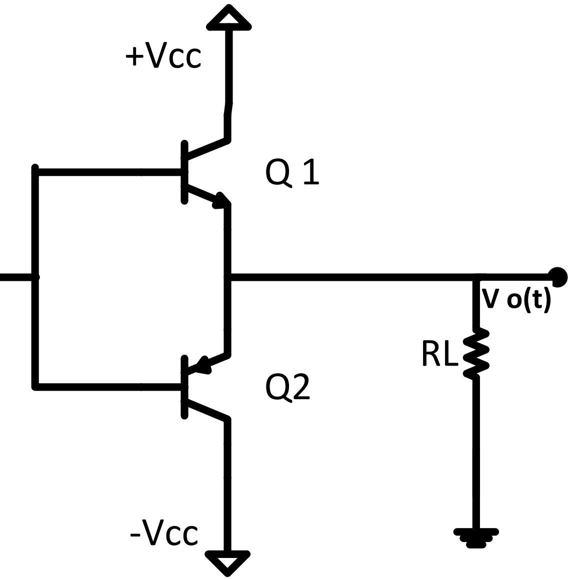


Complementary symmetry Class B push pull Power Amplifier

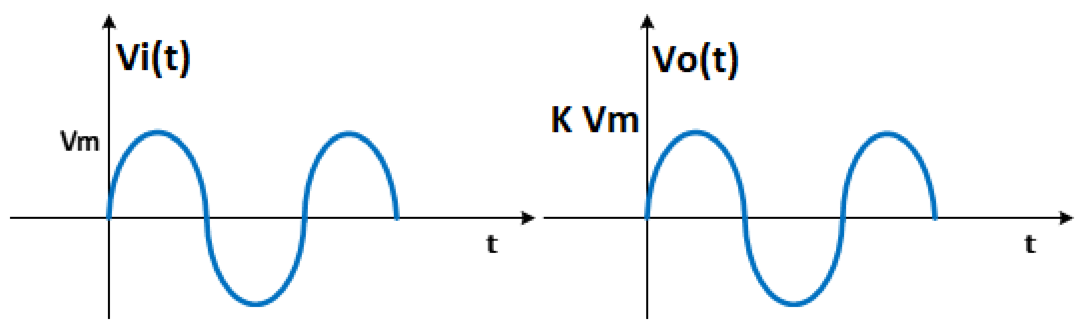
2) When Vi(t) $< 0, Q2\ is\ on\ , Q1\ is\ off$





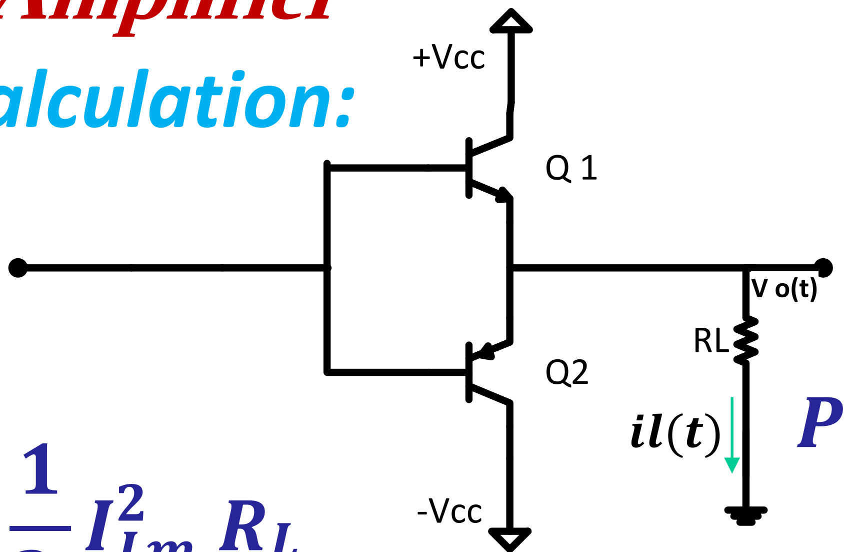


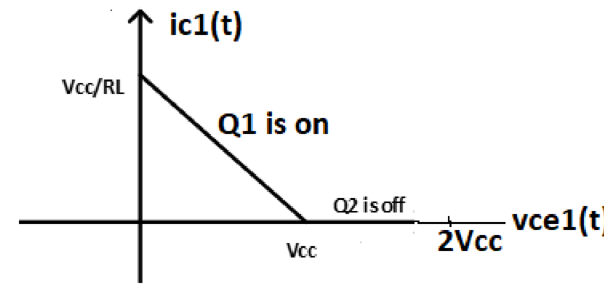
For the complete cycle



Complementary symmetry Class B push pull Power Amplifier

Power calculation:





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

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

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

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

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

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

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

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

$$= 78.5\%$$

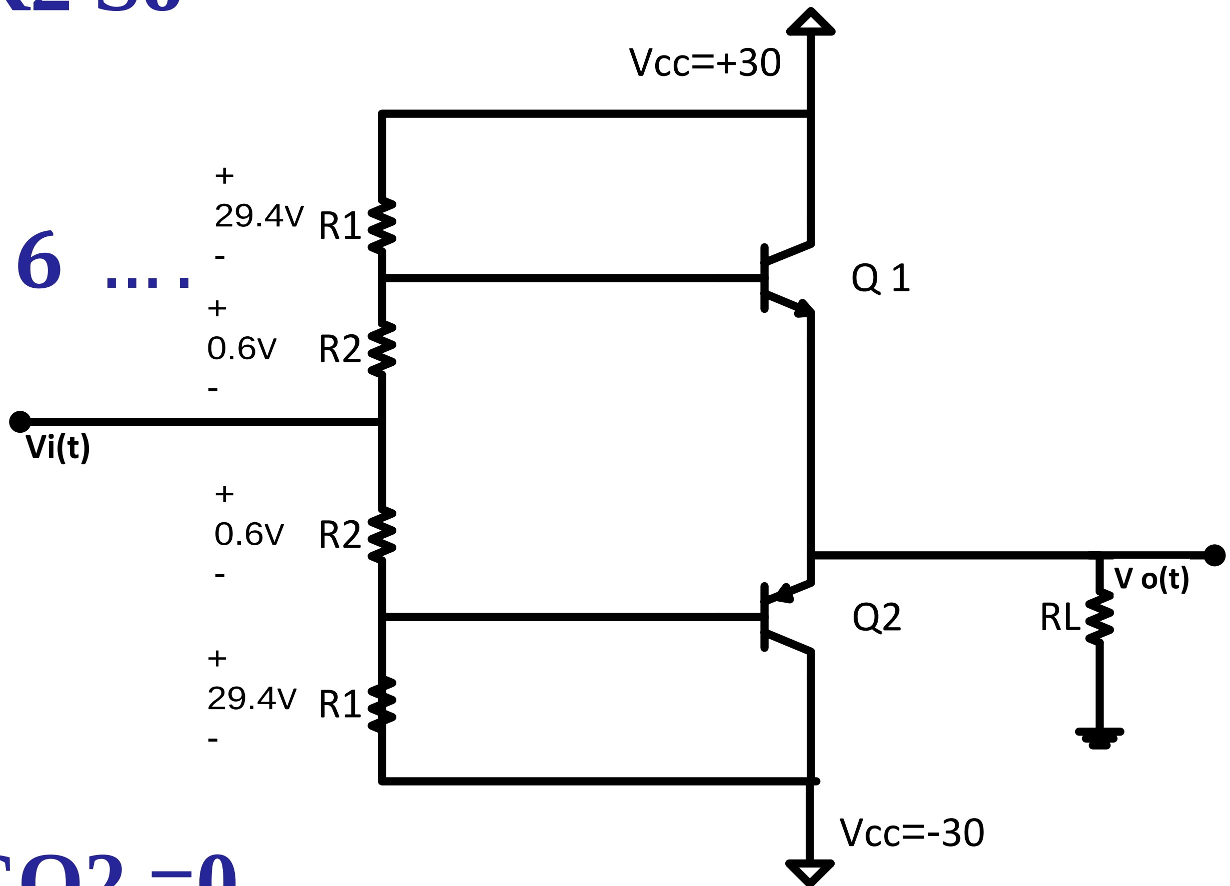
Complementary symmetry Class AB push pull Power Amplifier

We Choose R1 & R2 So that:

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

VBE1 = VEB2 = 0.5 , 0.6 , …

So that ICQ1 ≈ ICQ2 =0 and Vo = 0



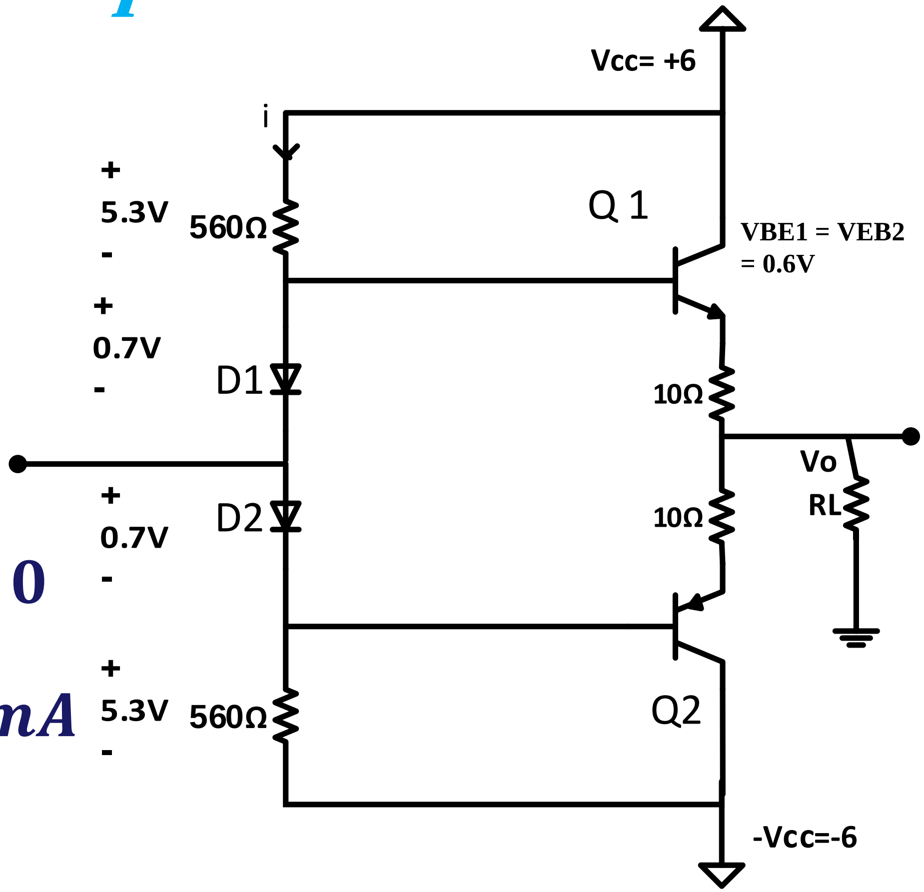
Complementary symmetry Class AB push pull Power Amplifier

Practical Class AB Power Amplifier

To Provide Bias Stability

1)Small Re for bias Stability .

2)Diodes D1 and D2 for Temperature Compensation.



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

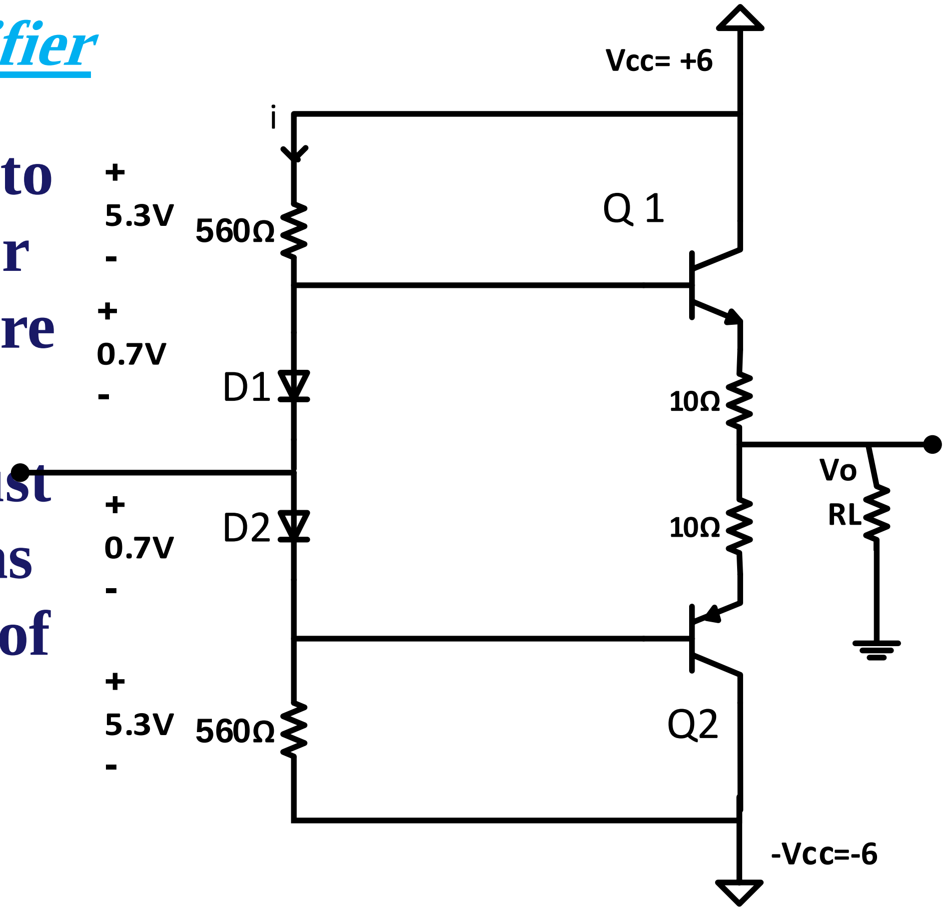
$$\therefore I = I_{D1} = I_{D2} = \frac{5.3}{560} = 9.46mA$$

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

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

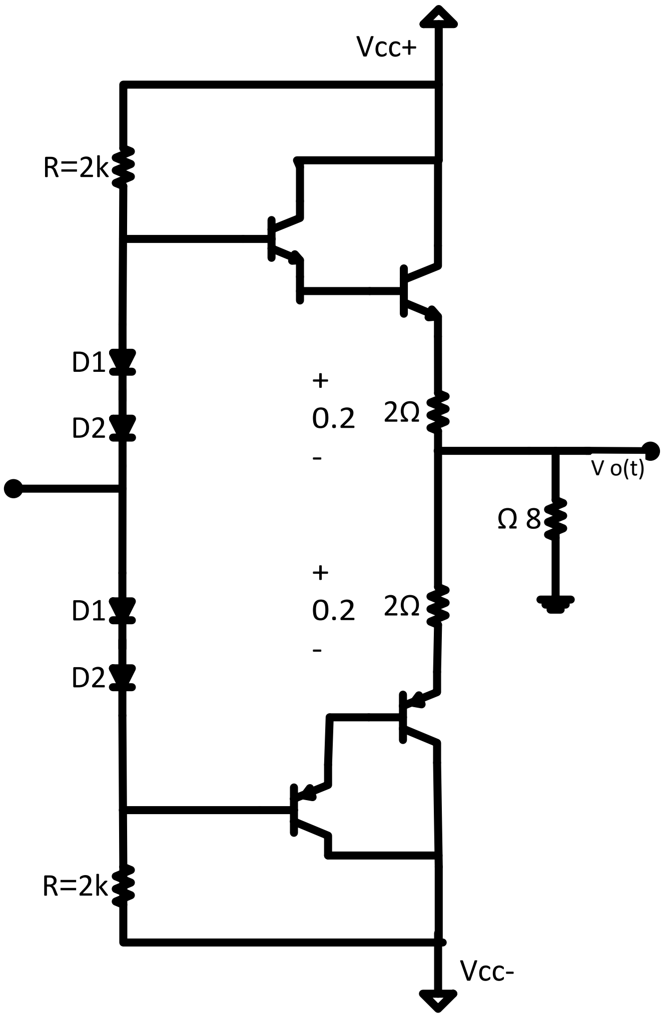
- D_1, D_2 *are always on*



Complementary Class AB Power Amplifier using Darlington:

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

Show that



Complementary Class AB Power Amplifier using VBE Mutiplier

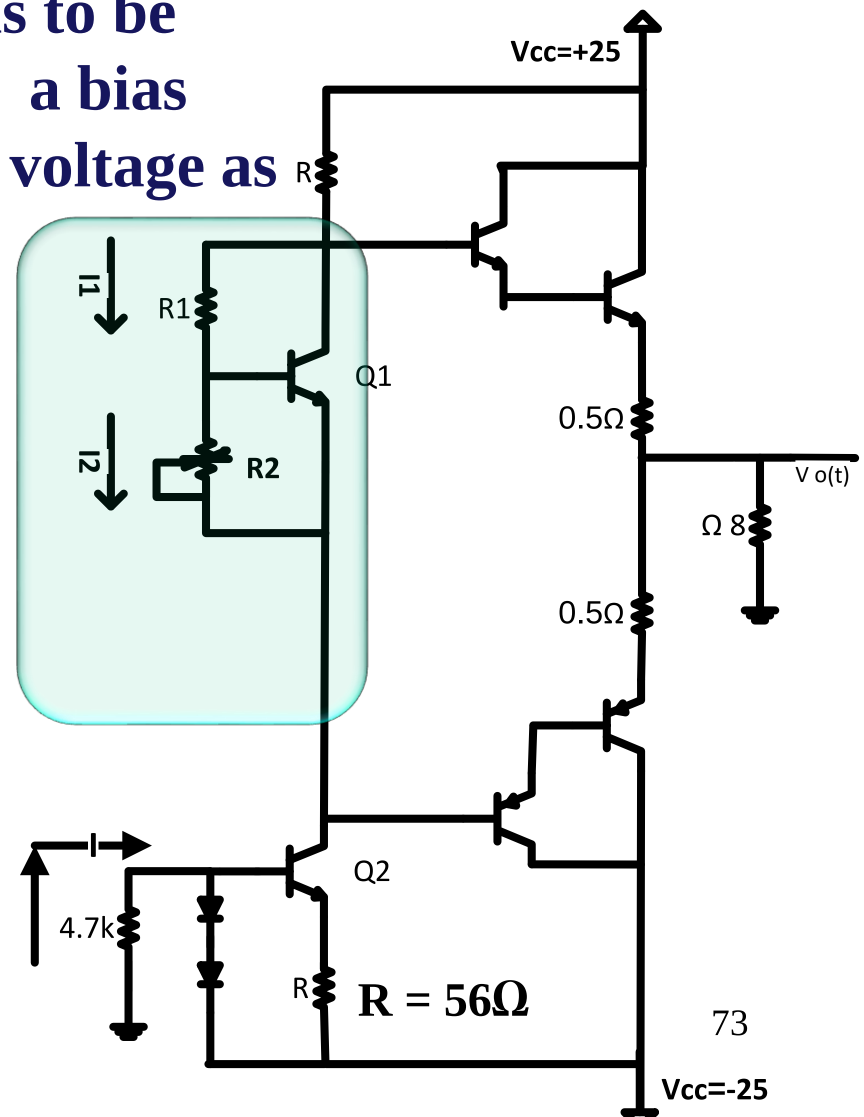
- **If a stable quiescent current is to be maintained , we must provide a bias circuit that decreases the bias voltage as the temperature increase .**

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

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

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

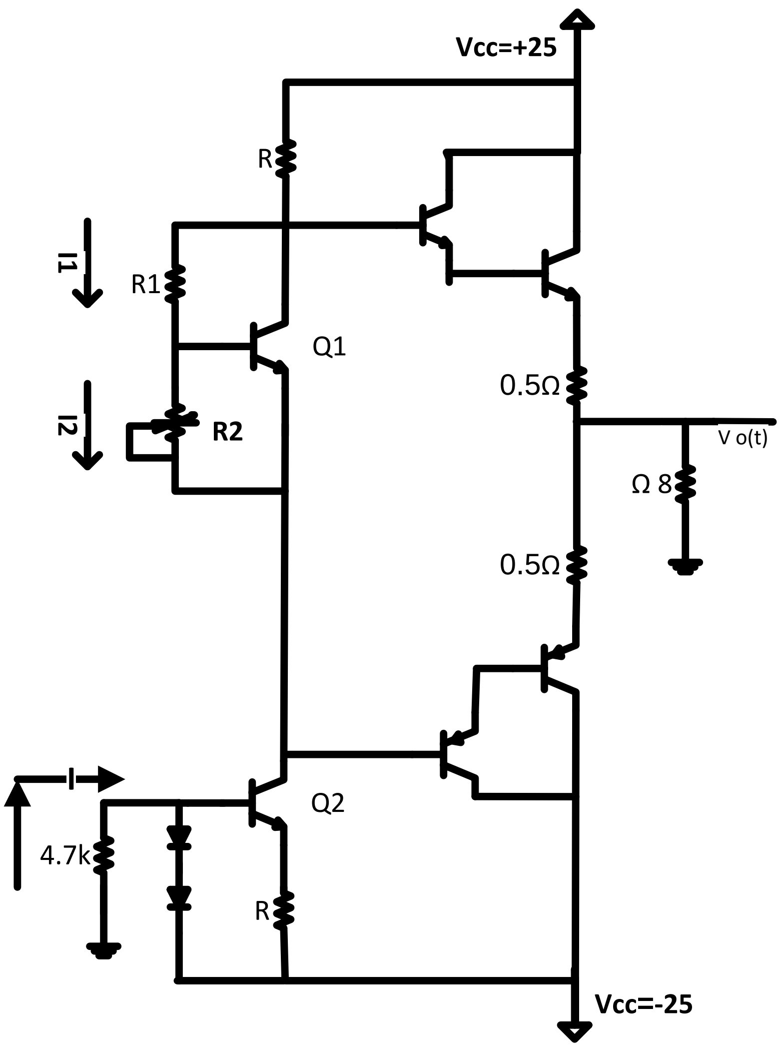
$$\therefore\ I_1 = I_2 = \frac{V_{BE}}{R_2}$$



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

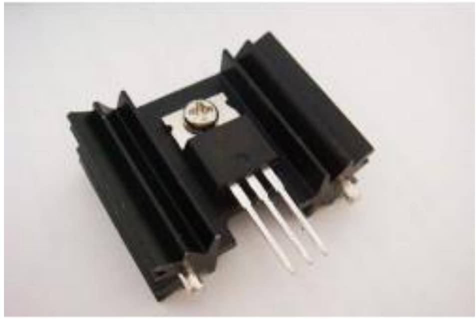
$$V_{Bias} = \left(1 + \frac{R_1}{R_2}\right)V_{BE}$$

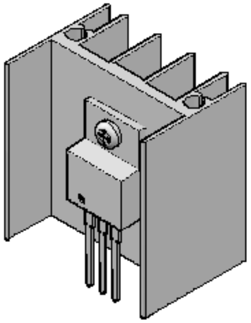
V_{Bias} ***may be adjusted***



Transistor and Heat sink

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

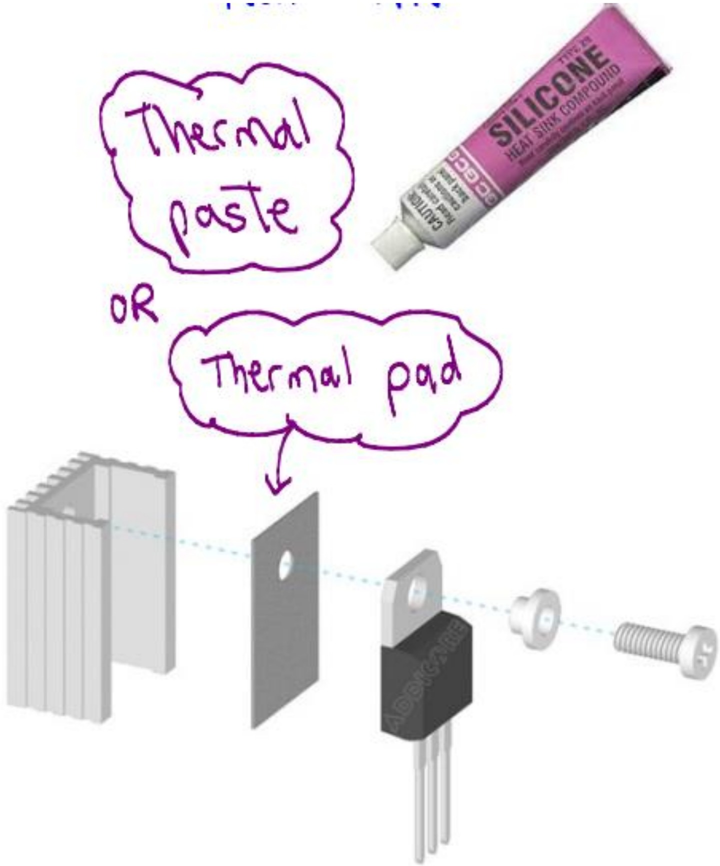




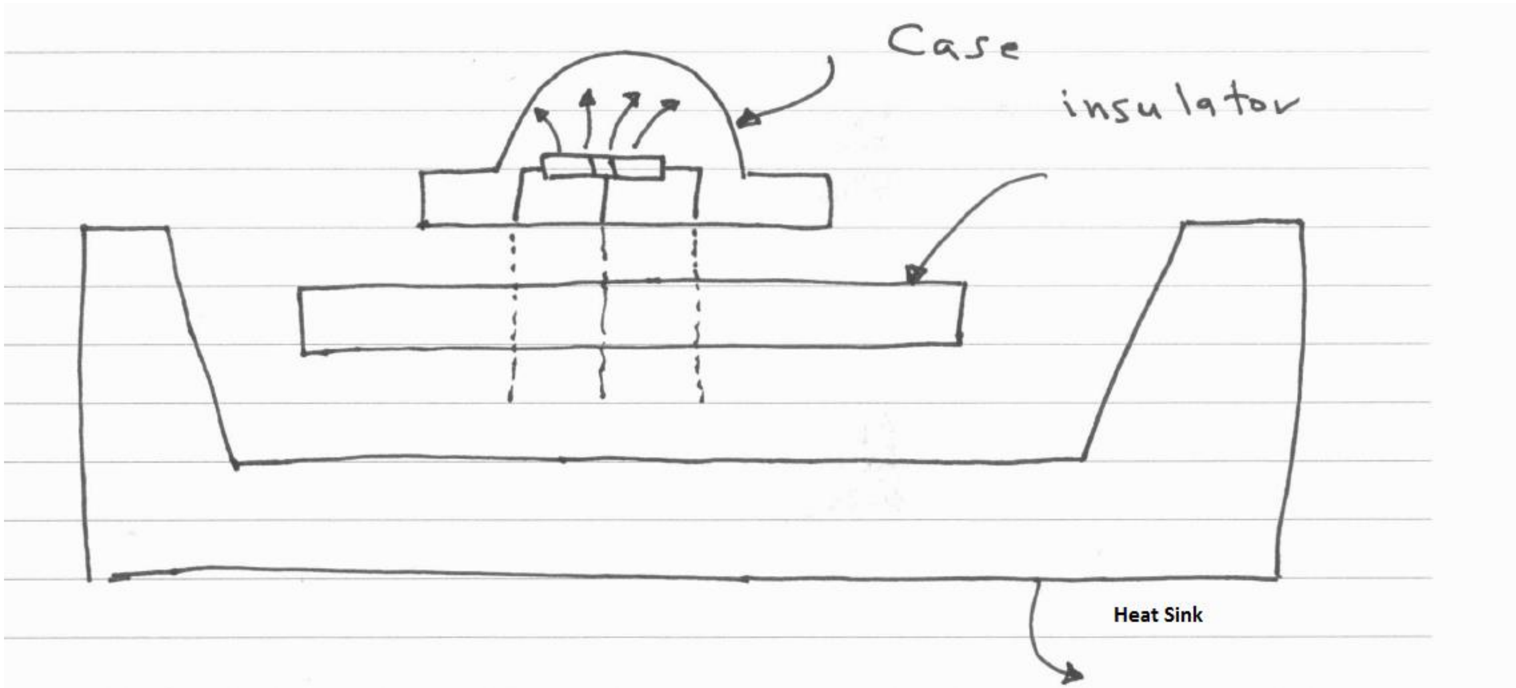
Different types of heat sink

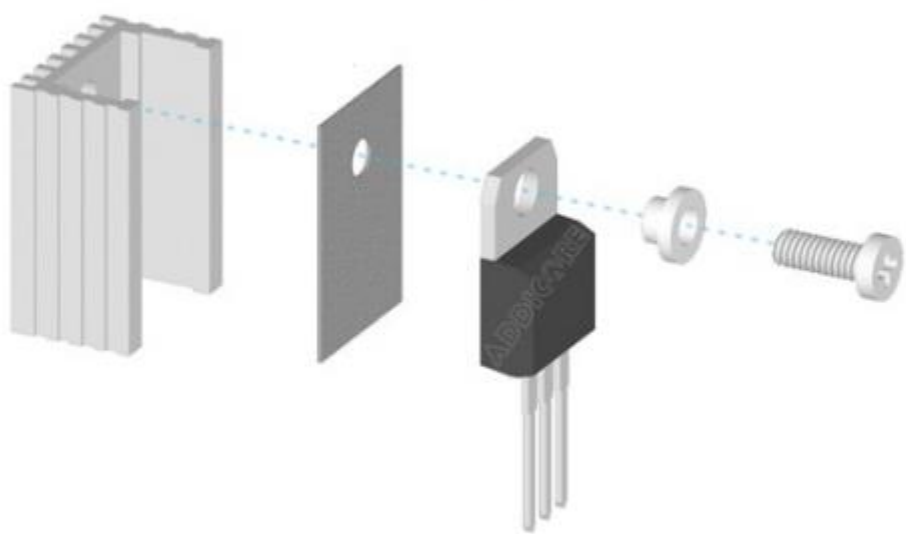
Clip Mount

Screw mount

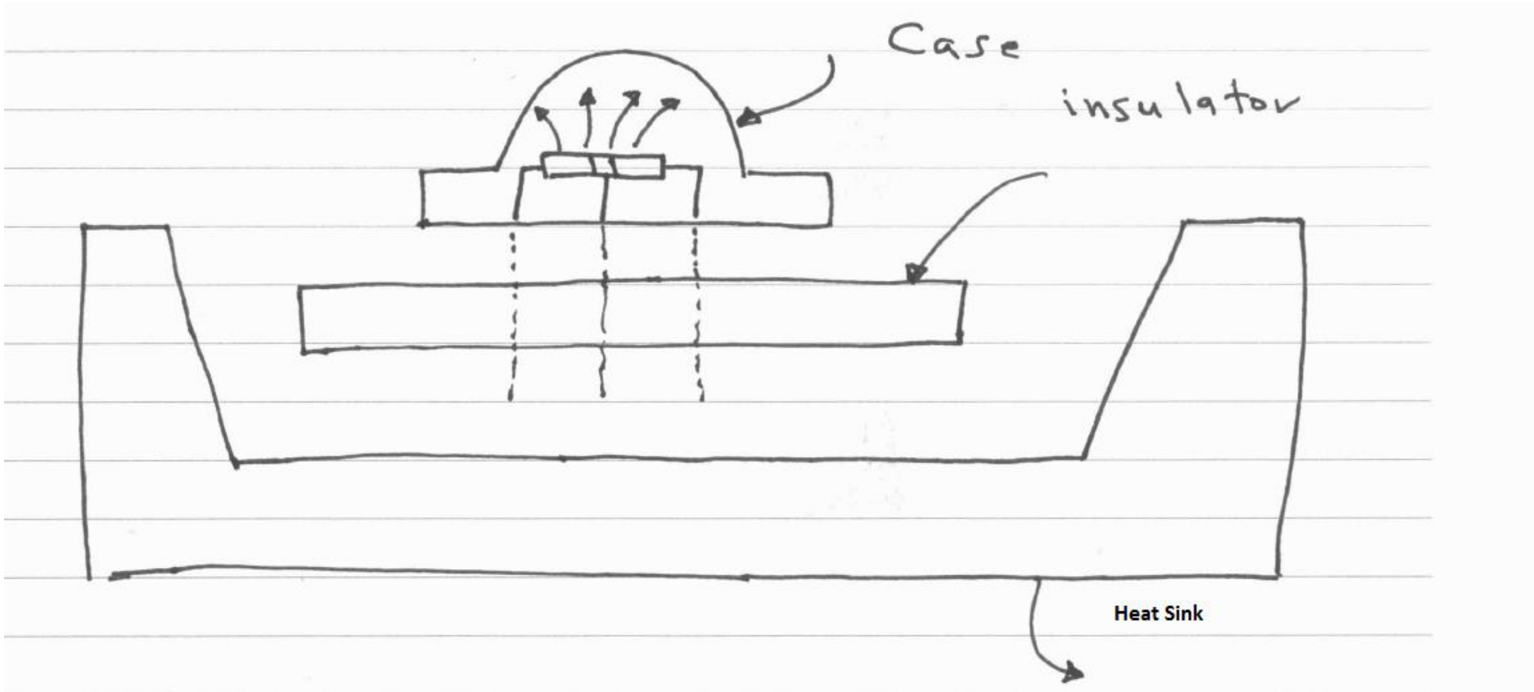


Transistor and Heat Sink



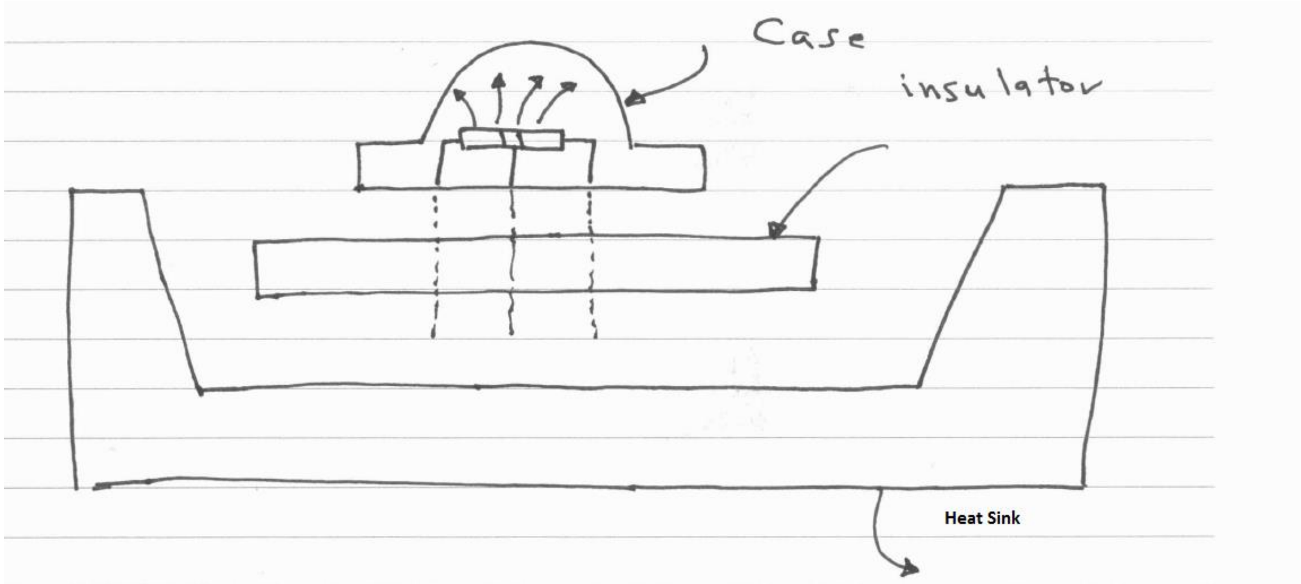


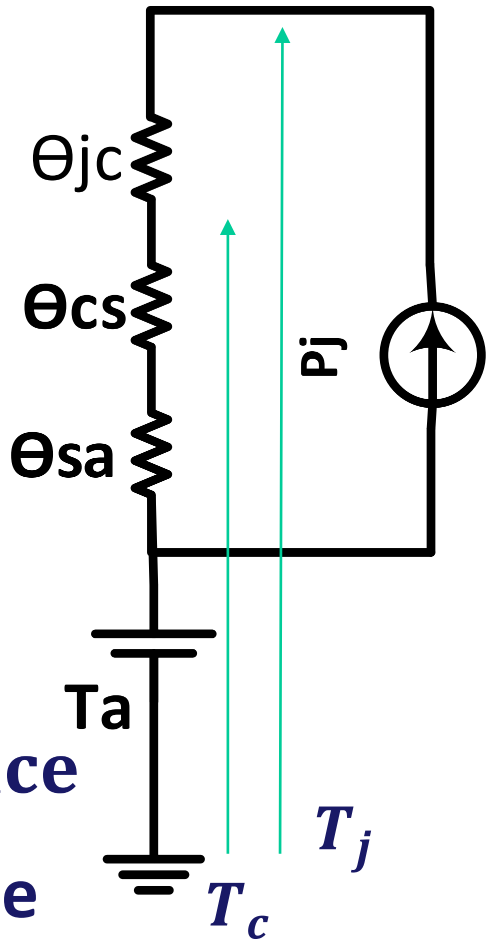
Transistor and Heat Sink



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.

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

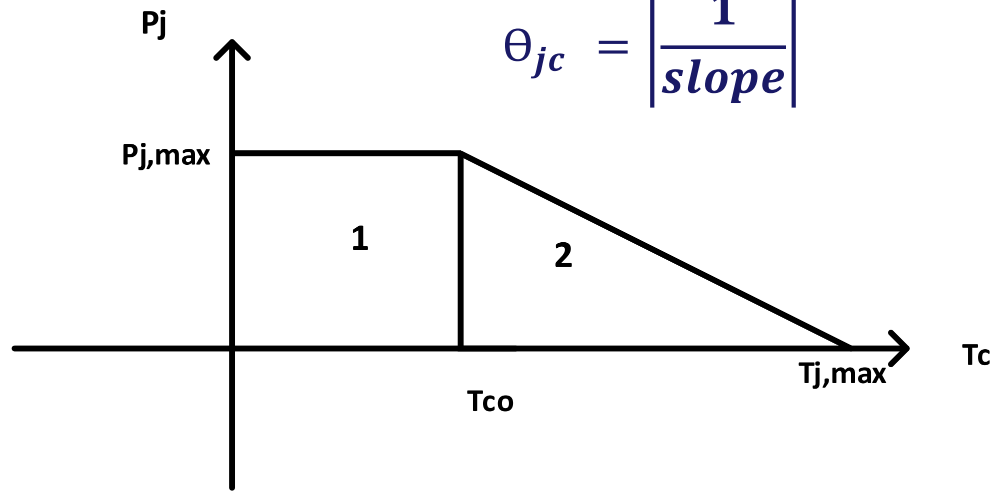
θ_{cs}: Depends on the interface between case and sink , silicon grease or without.

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

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

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

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

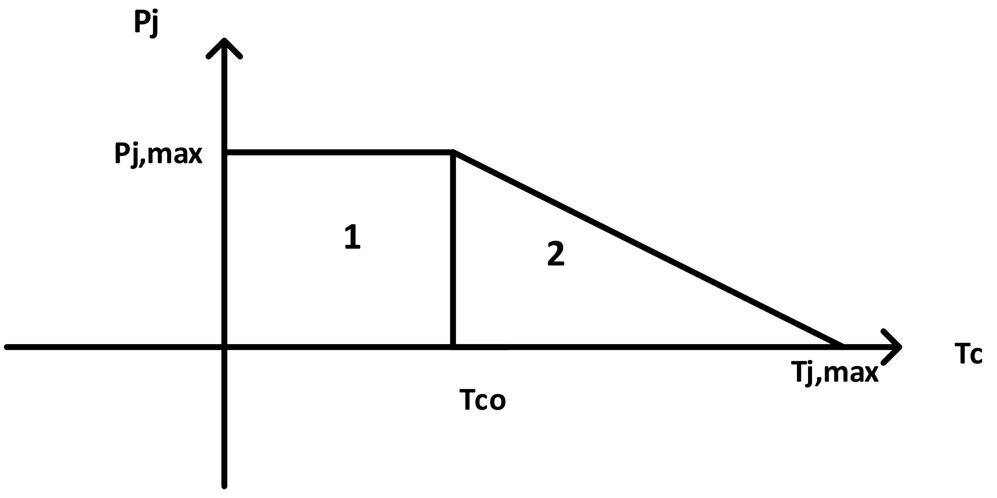
$$region\ \ 2 \rightarrow\ \ T_j = T_{j,max}$$

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

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

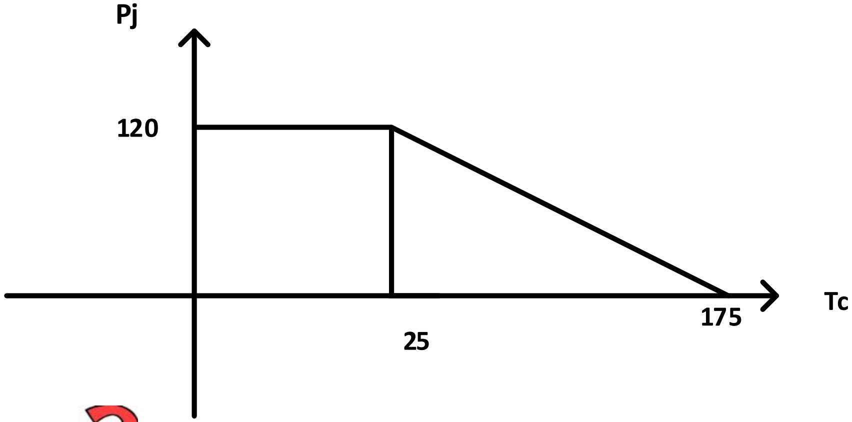
$$\Theta_{jc} = \frac{T_{j,max} - T_c}{P_j}$$

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



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 $T_a = 40°\mathrm{C}$ ***?***

$T_{j,max} = 175\ °\mathrm{C}$

$T_{co} = 25\ °\mathrm{C}$

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

Transistor and Heat sink

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

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

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

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

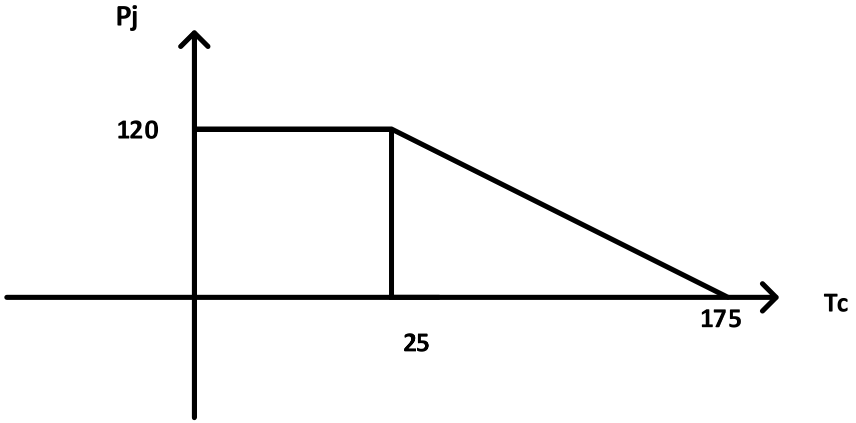
$$,\qquad and\quad T_a = 40^{\circ}$$

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

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

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

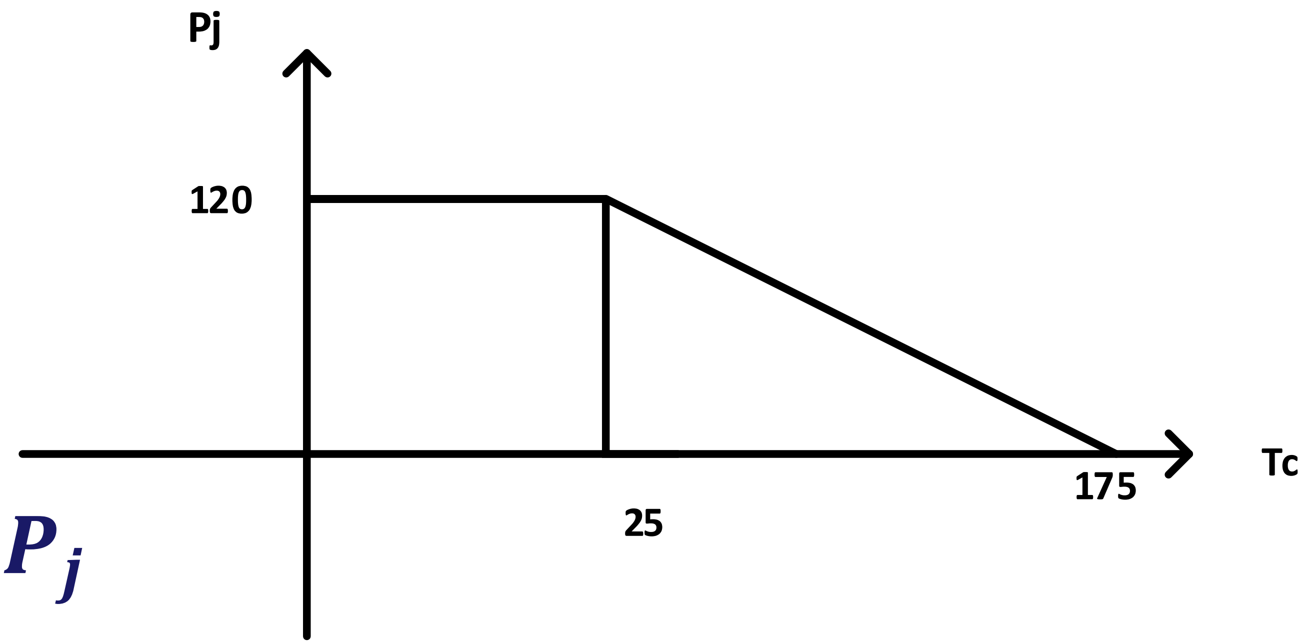
$$\theta_{ja} = \theta_{jc} + \theta_{cs} + \theta_{sa}$$



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

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

$$To\ find\ Tc:$$



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

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

$$T_c = 121.5℃$$

$$T_c > T_{co}$$

Region 2 as assumed

Transistor and Heat sink

If we are using infinite heat sink

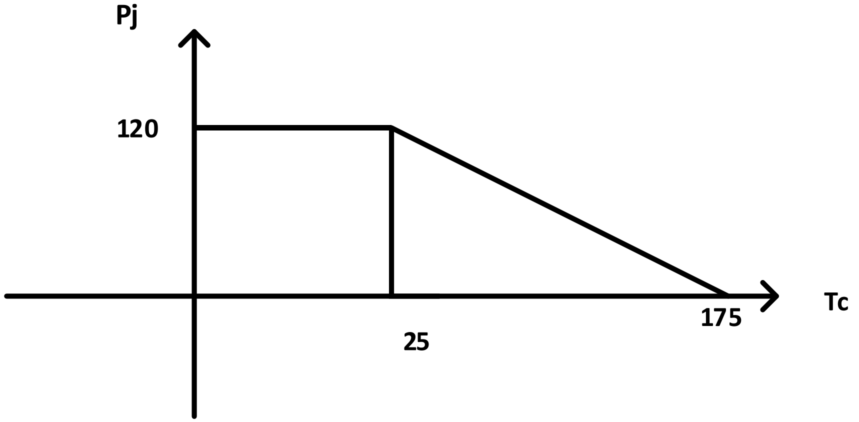
$$\therefore \; T_c = T_a$$

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

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

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

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



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*

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

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