Electronic Circuits-1

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CONTENT

1. BJT Amplifier
2. FET Amplifier
3. Frequency Response of Amplifier
4. Operational Amplifier
5. Audio Power Amplifier
6. Linear-Digital ICs
7. Power Supplies
8. IC Technology (optional)

Chapter 6: Audio Power Amplifier

6.1 Introduction

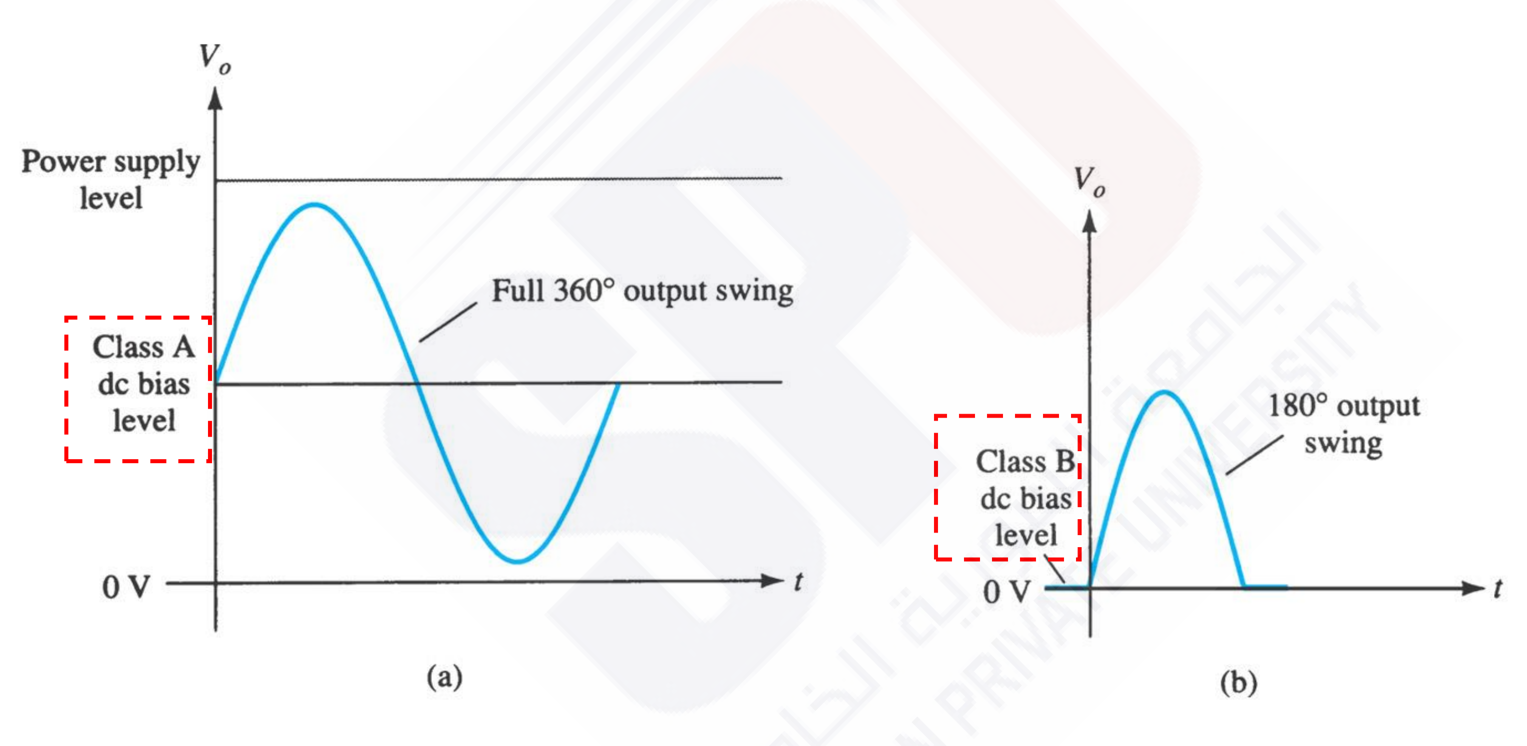
Voltage Amplifier:
Small swing, Power efficiency & Power handling are of little concern

Power Amplifier: Large swing, Power efficiency , Power handling and Impedance matching are the main Concern.

Characterizing Power Amp By classes: A , AB , B , C , D.

Amp Classes represent the amount of O/P signal varies over one cycle of operation for a full cycle of I/P signal.

6.1 Introduction



Amplifier operating classes

Comparison of Amplifier Classes

Amplifier Class	A	AB	B	C	D
Power Cycle	360°	180° to 360°	180°	Less than180°	Pulse Operation
Power Efficiency	25% to 50%	Between 25% (50%) and 78.5%	78.5%	Better than 78.5%	Over 90%

The input power from the voltage supply is

$$P_i(\text{dc}) = V_{CC} I_{C_Q}$$

The power developed across the load (R_C) by the ac signal can be expressed in a number of ways.

$$P_o(\text{ac}) = I_C^2(\text{rms})R_C = \frac{V_{CE}^2(\text{rms})}{R_C}$$

$$= \left(\frac{I_C(\text{peak})}{\sqrt{2}}\right)^2 R_C = \frac{V_{CE}^2(\text{peak})}{2R_C}$$

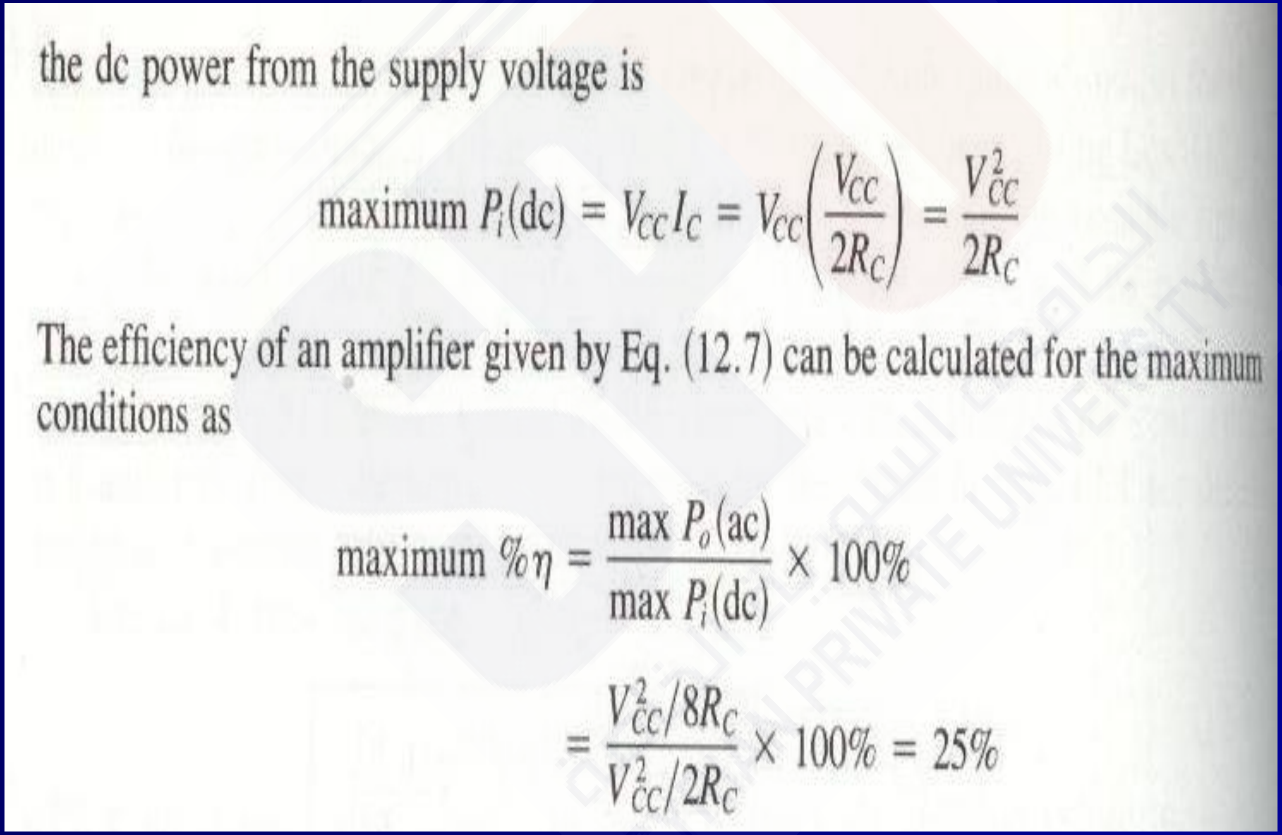
$$= \frac{I_C^2(\text{p-p})R_C}{8} = \frac{V_{CE}^2(\text{p-p})}{8R_C}$$

$$\text{maximum } V_{CE}(\text{p-p}) = V_{CC}$$

$$\text{maximum } I_C(\text{p-p}) = \frac{V_{CC}}{R_C}$$

$$\text{maximum } P_o(\text{ac}) = \frac{I_C(\text{p-p})V_{CE}(\text{p-p})}{8} = \frac{(V_{CC}/R_C)V_{CC}}{8} = \frac{V_{CC}^2}{8R_C}$$

For the quiescent point of $I_C = \dfrac{V_{CC}/R_C}{2}$



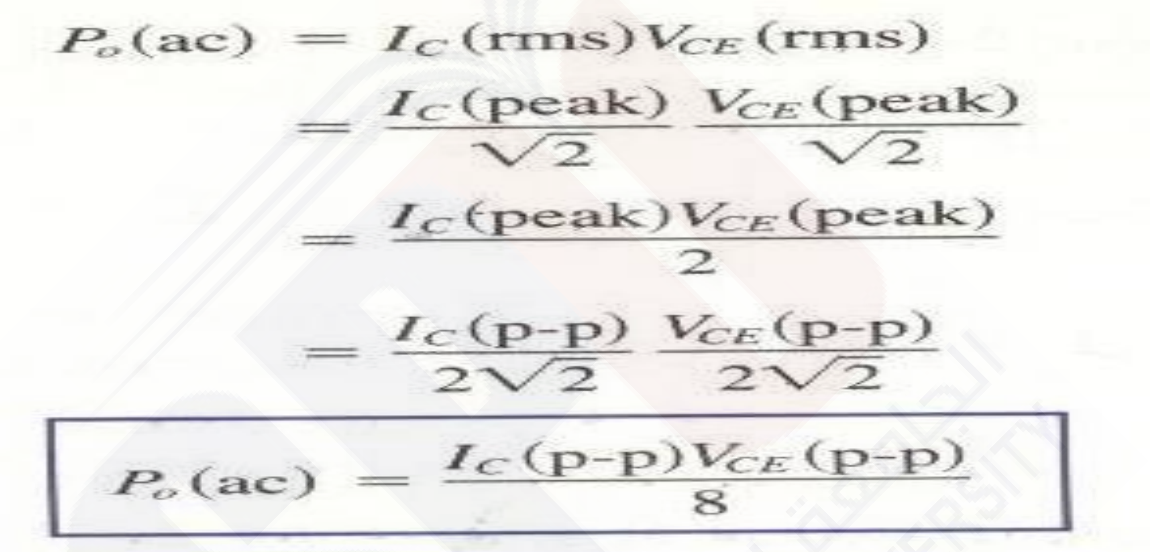
the dc power from the supply voltage is

$$\text{maximum } P_i(\text{dc}) = V_{CC}I_C = V_{CC}\left(\frac{V_{CC}}{2R_C}\right) = \frac{V_{CC}^2}{2R_C}$$

The efficiency of an amplifier given by Eq. (12.7) can be calculated for the maximum conditions as

$$\text{maximum } \%\eta = \frac{\max P_o(\text{ac})}{\max P_i(\text{dc})} \times 100\%$$

$$= \frac{V_{CC}^2/8R_C}{V_{CC}^2/2R_C} \times 100\% = 25\%$$



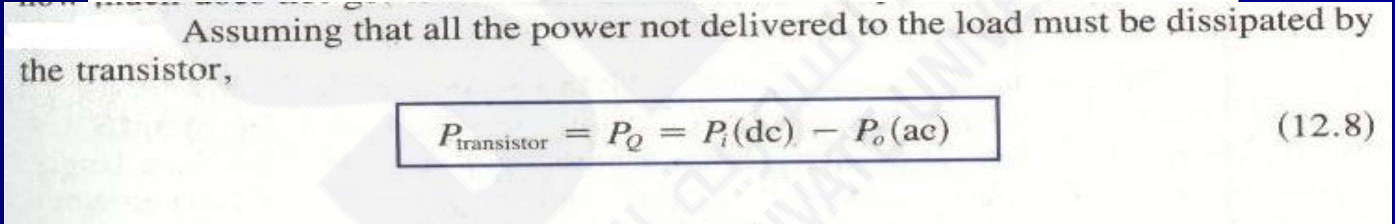
$$P_o(\text{ac}) = I_C(\text{rms})V_{CE}(\text{rms})$$

$$= \frac{I_C(\text{peak})}{\sqrt{2}}\,\frac{V_{CE}(\text{peak})}{\sqrt{2}}$$

$$= \frac{I_C(\text{peak})V_{CE}(\text{peak})}{2}$$

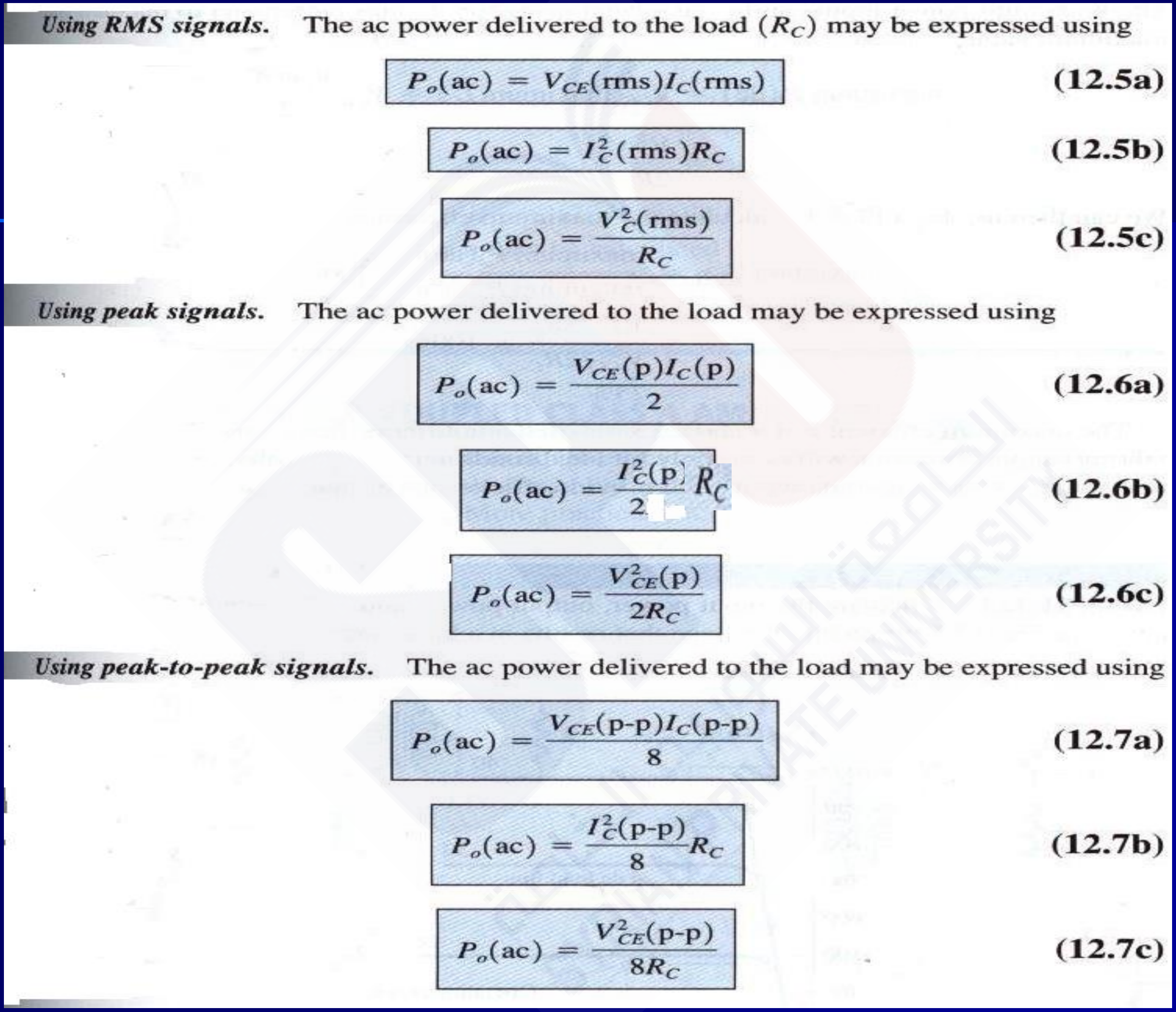
$$= \frac{I_C(\text{p-p})}{2\sqrt{2}}\,\frac{V_{CE}(\text{p-p})}{2\sqrt{2}}$$

$$\boxed{P_o(\text{ac}) = \frac{I_C(\text{p-p})V_{CE}(\text{p-p})}{8}}$$



Assuming that all the power not delivered to the load must be dissipated by the transistor,

$$\boxed{P_{\text{transistor}} = P_Q = P_i(\text{dc}) - P_o(\text{ac})} \qquad (12.8)$$



Using RMS signals. The ac power delivered to the load (R_C) may be expressed using

$$\boxed{P_o(\text{ac}) = V_{CE}(\text{rms})I_C(\text{rms})} \tag{12.5a}$$

$$\boxed{P_o(\text{ac}) = I_C^2(\text{rms})R_C} \tag{12.5b}$$

$$\boxed{P_o(\text{ac}) = \frac{V_C^2(\text{rms})}{R_C}} \tag{12.5c}$$

Using peak signals. The ac power delivered to the load may be expressed using

$$\boxed{P_o(\text{ac}) = \frac{V_{CE}(\text{p})I_C(\text{p})}{2}} \tag{12.6a}$$

$$\boxed{P_o(\text{ac}) = \frac{I_C^2(\text{p})}{2}R_C} \tag{12.6b}$$

$$\boxed{P_o(\text{ac}) = \frac{V_{CE}^2(\text{p})}{2R_C}} \tag{12.6c}$$

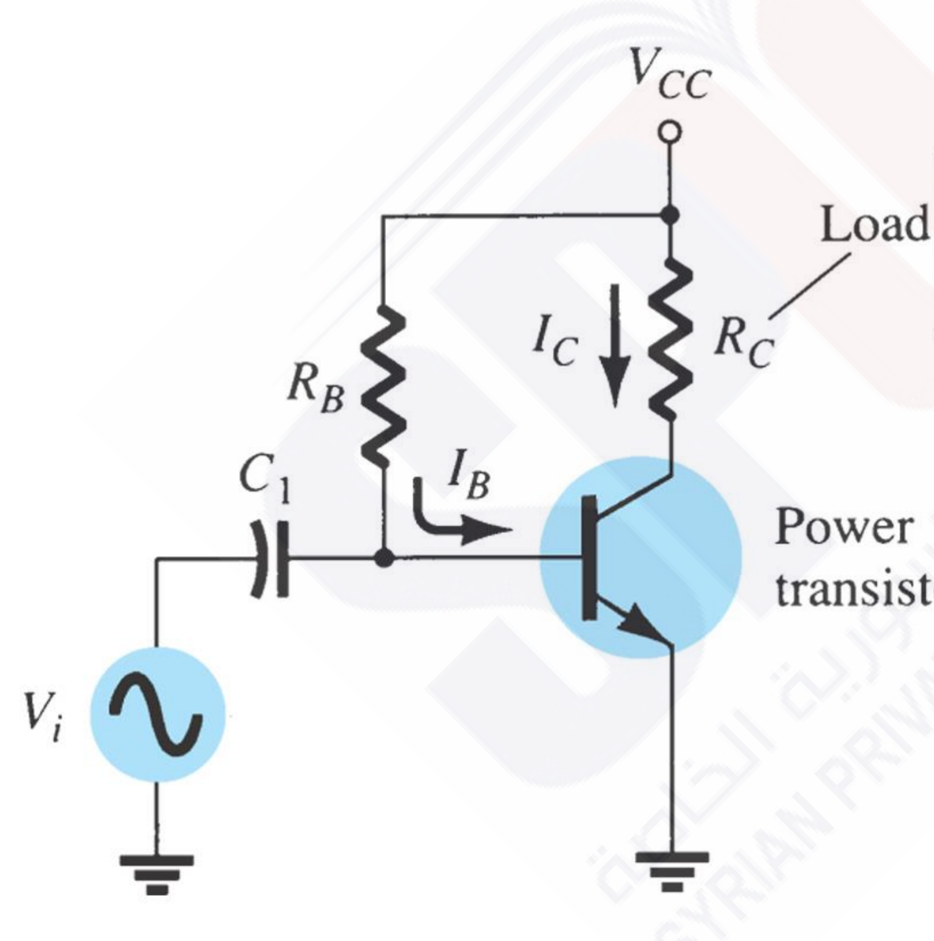
Using peak-to-peak signals. The ac power delivered to the load may be expressed using

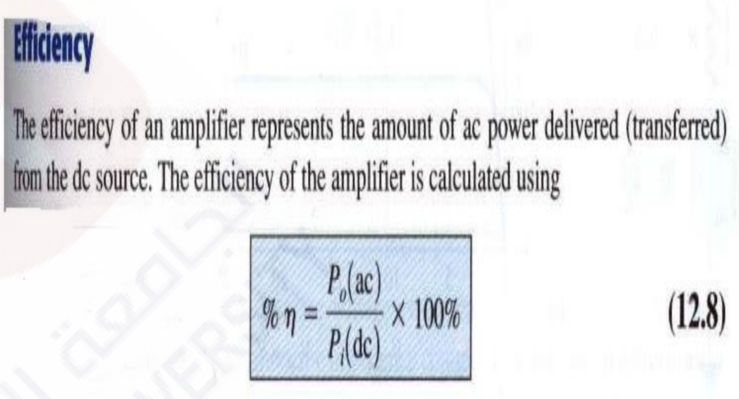
$$\boxed{P_o(\text{ac}) = \frac{V_{CE}(\text{p-p})I_C(\text{p-p})}{8}} \tag{12.7a}$$

$$\boxed{P_o(\text{ac}) = \frac{I_C^2(\text{p-p})}{8}R_C} \tag{12.7b}$$

$$\boxed{P_o(\text{ac}) = \frac{V_{CE}^2(\text{p-p})}{8R_C}} \tag{12.7c}$$

6.2 Series-Fed Class-A Amplifier



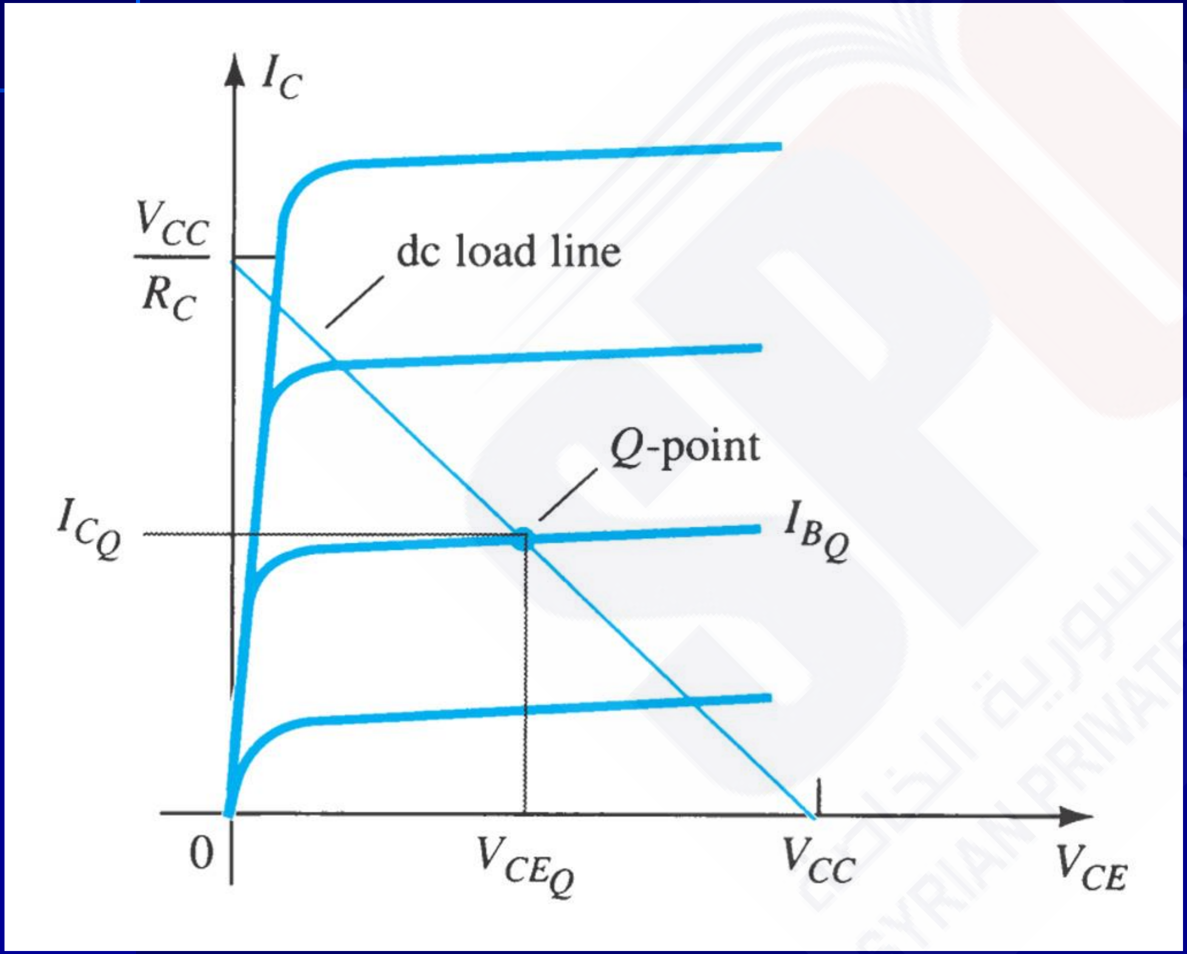


Efficiency

The efficiency of an amplifier represents the amount of ac power delivered (transferred) from the dc source. The efficiency of the amplifier is calculated using

$$\boxed{\%\eta = \frac{P_o(\mathrm{ac})}{P_i(\mathrm{dc})} \times 100\%} \tag{12.8}$$

Transistor characteristic showing load line and *Q*-point



$$\eta = \frac{P_o(ac)}{P_i(dc)} \times 100\%$$

$$P_o(ac) = \frac{V_{CE}(p) I_C(p)}{2}$$

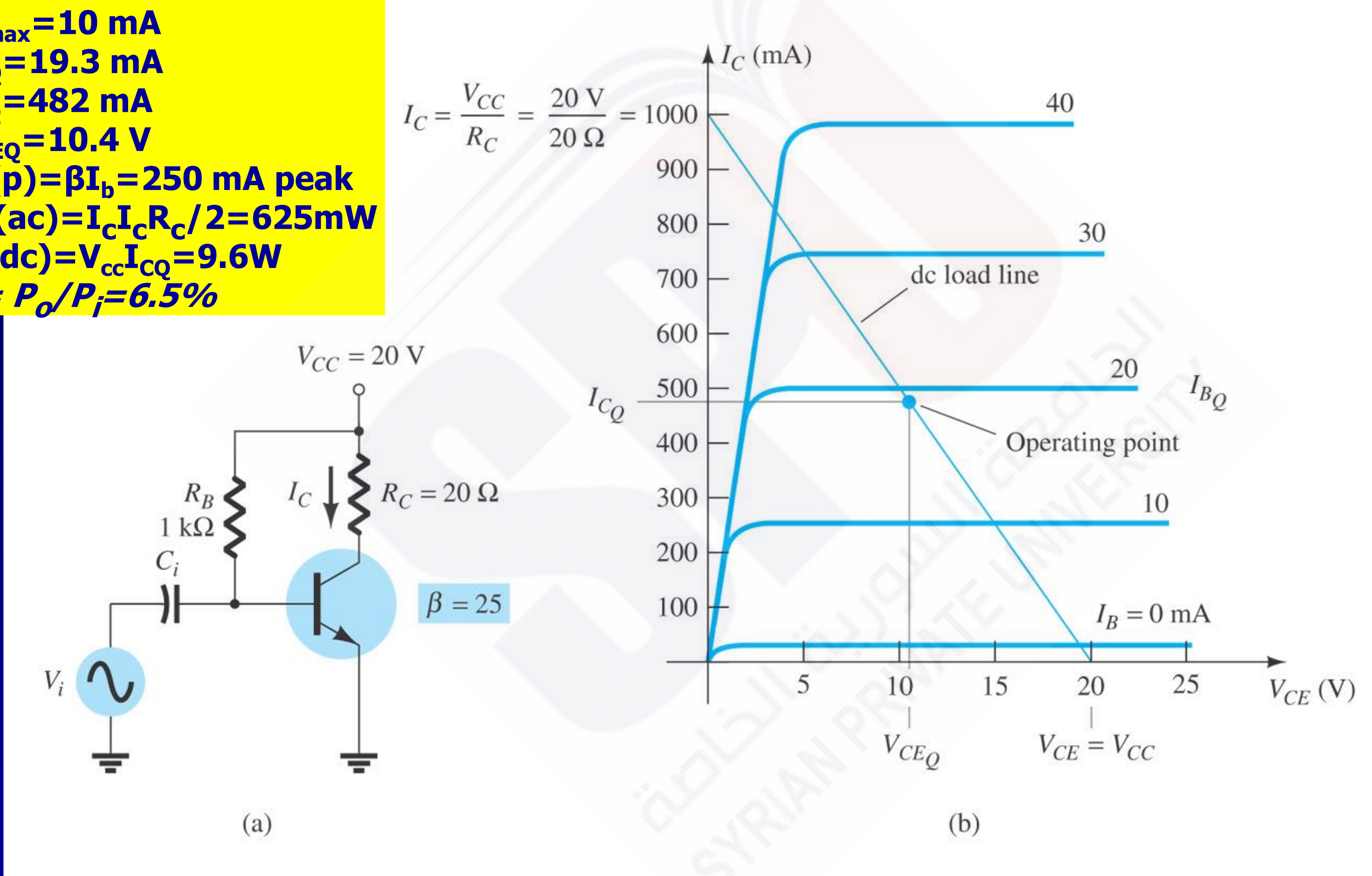
$$P_o(ac)_{\max} = \frac{V_{CC}(V_{CC}/R_C)}{8}$$

$$P_i(dc) = V_{CC} I_{CQ} \quad , \quad P_i(dc)_{\max} = V_{CC} I_{C\max}$$

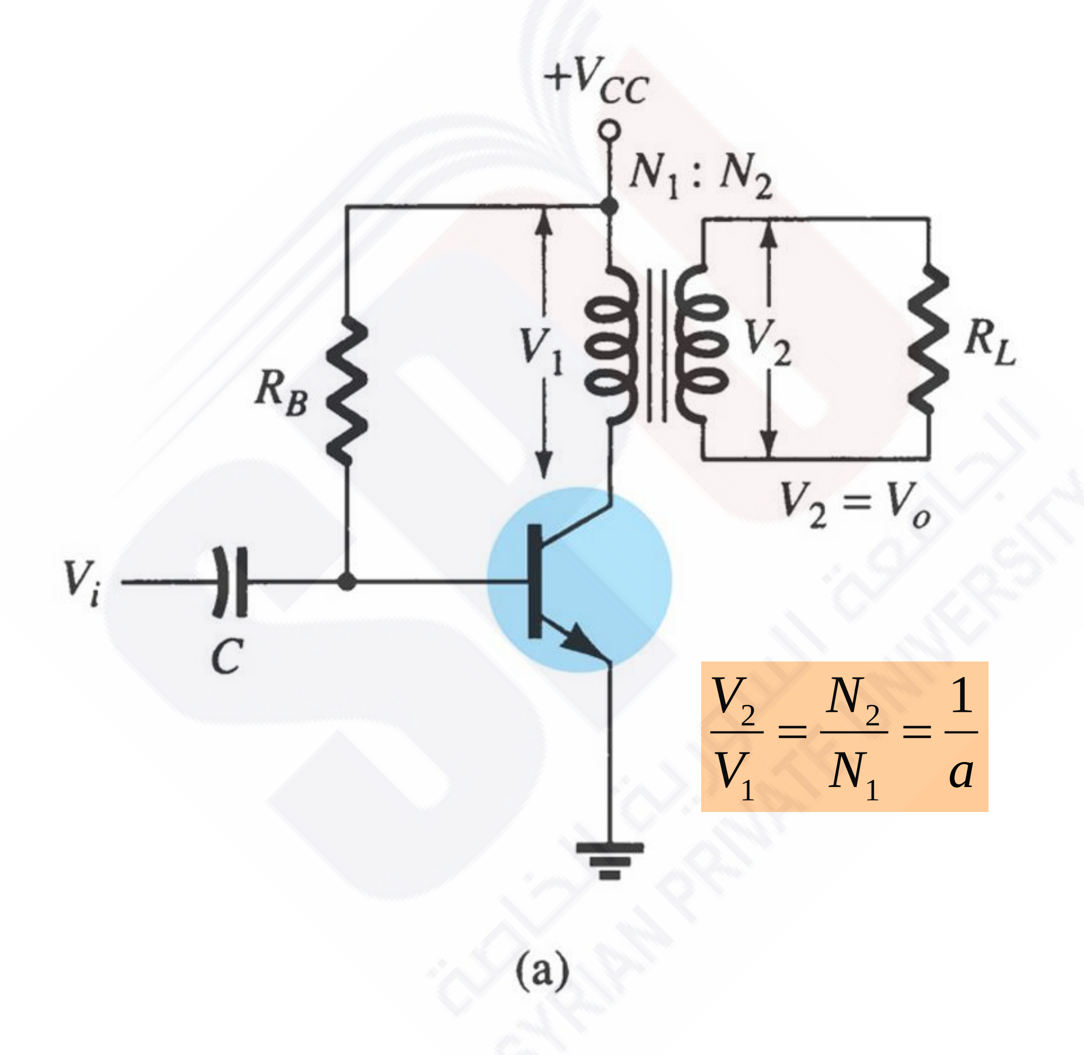
$$\eta_{\max} = \frac{V_{CC}^2 / 8R_C}{V_{CC}^2 / 2R_C} = 25\%$$

Example

I_{bmax}=10 mA
I_{BQ}=19.3 mA
I_{CQ}=482 mA
V_{CEQ}=10.4 V
$I_c(p)=\beta I_b$=250 mA peak
$P_o(ac)=I_cI_cR_c/2$=625mW
$P_i(dc)=V_{cc}I_{CQ}$=9.6W
$\eta= P_o/P_i$=6.5%



6.3 Transformer-Coupled Class-A amplifier



(a)

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{1}{a}$$

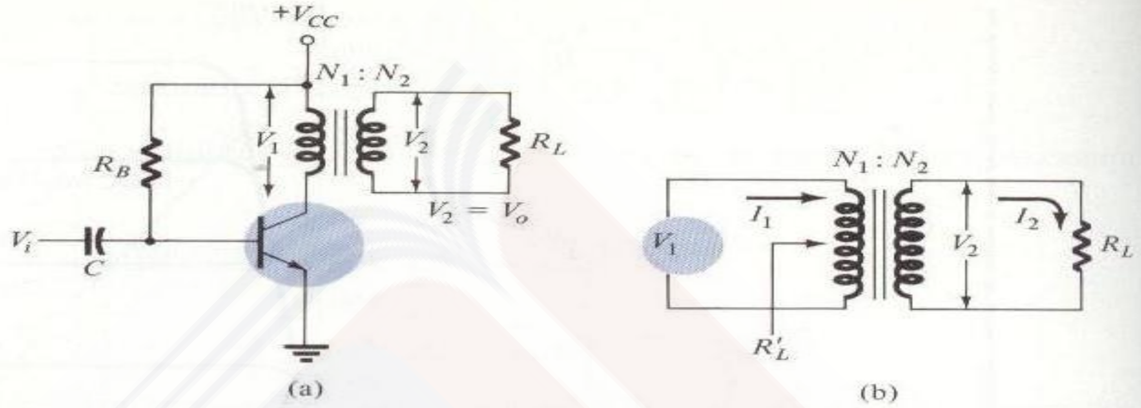


Figure 12.5 Transformer-coupled audio power amplifier.

mary resistance may be expressed as follows:

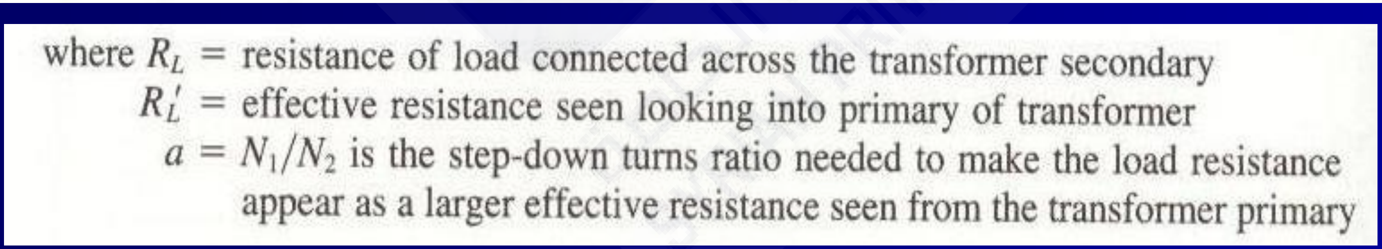
$$\frac{R'_L}{R_L} = \frac{V_1/I_1}{V_2/I_2} = \frac{V_1}{I_1}\frac{I_2}{V_2} = \frac{V_1}{V_2}\frac{I_2}{I_1} = \frac{N_1}{N_2}\frac{N_1}{N_2} = \left(\frac{N_1}{N_2}\right)^2$$

where $V_1/V_2 = N_1/N_2$ and $I_2/I_1 = N_1/N_2$. Hence the ratio of the transformer input and output resistance varies directly as the *square* of the transformer turns ratio:

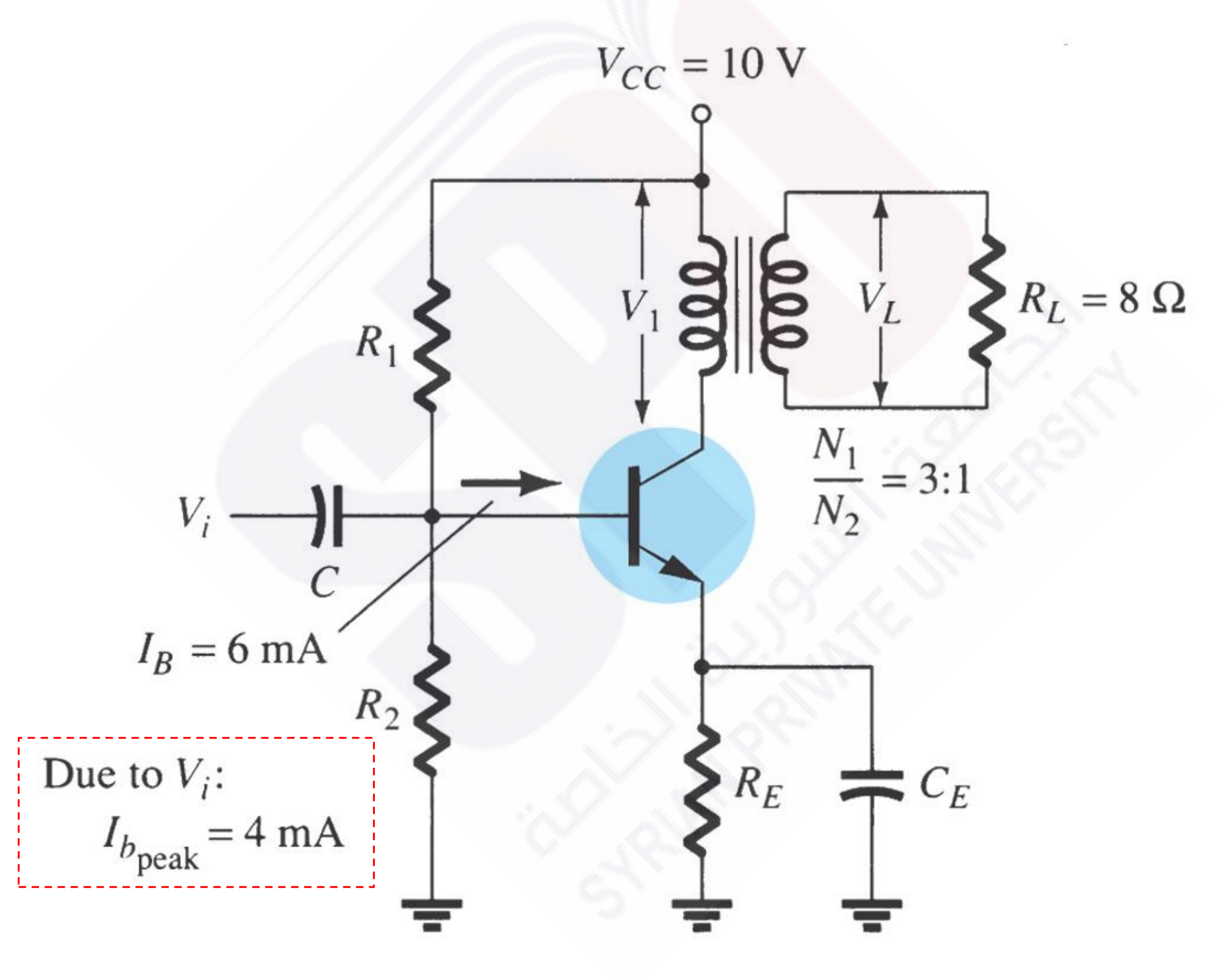
$$\boxed{\frac{R'_L}{R_L} = \left(\frac{N_1}{N_2}\right)^2 = a^2} \qquad (12.9)$$

and

$$\boxed{R'_L = a^2 R_L = \left(\frac{N_1}{N_2}\right)^2 R_L} \qquad (12.10)$$

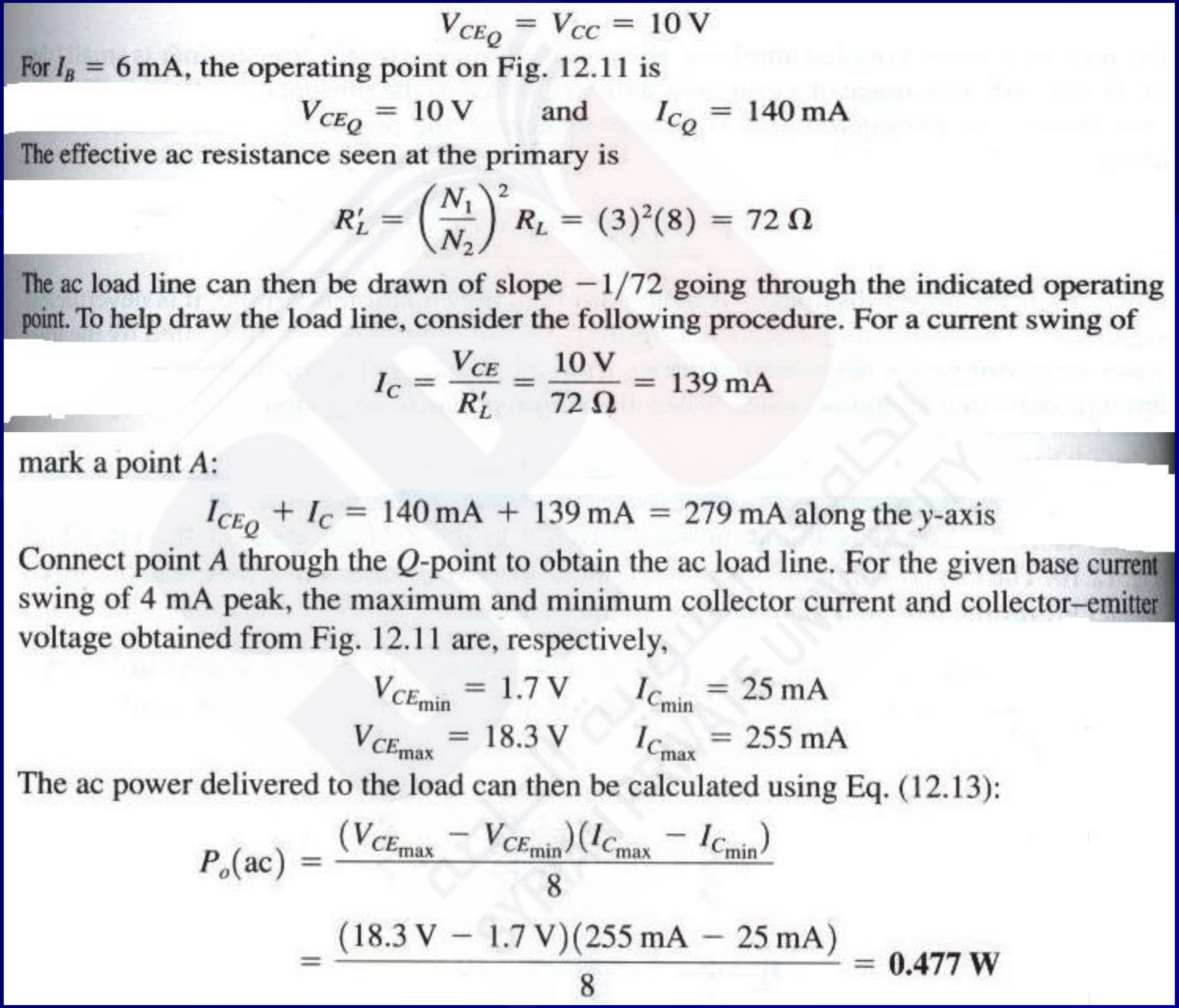

where R_L = resistance of load connected across the transformer secondary
R'_L = effective resistance seen looking into primary of transformer
$a = N_1/N_2$ is the step-down turns ratio needed to make the load resistance appear as a larger effective resistance seen from the transformer primary

Transformer-coupled class A amplifier: Example



Due to V_i:

$I_{b_{peak}} = 4\text{ mA}$



$$V_{CE_Q} = V_{CC} = 10\ \text{V}$$

For $I_B = 6\ \text{mA}$, the operating point on Fig. 12.11 is

$$V_{CE_Q} = 10\ \text{V} \qquad \text{and} \qquad I_{C_Q} = 140\ \text{mA}$$

The effective ac resistance seen at the primary is

$$R'_L = \left(\frac{N_1}{N_2}\right)^2 R_L = (3)^2(8) = 72\ \Omega$$

The ac load line can then be drawn of slope $-1/72$ going through the indicated operating point. To help draw the load line, consider the following procedure. For a current swing of

$$I_C = \frac{V_{CE}}{R'_L} = \frac{10\ \text{V}}{72\ \Omega} = 139\ \text{mA}$$

mark a point A:

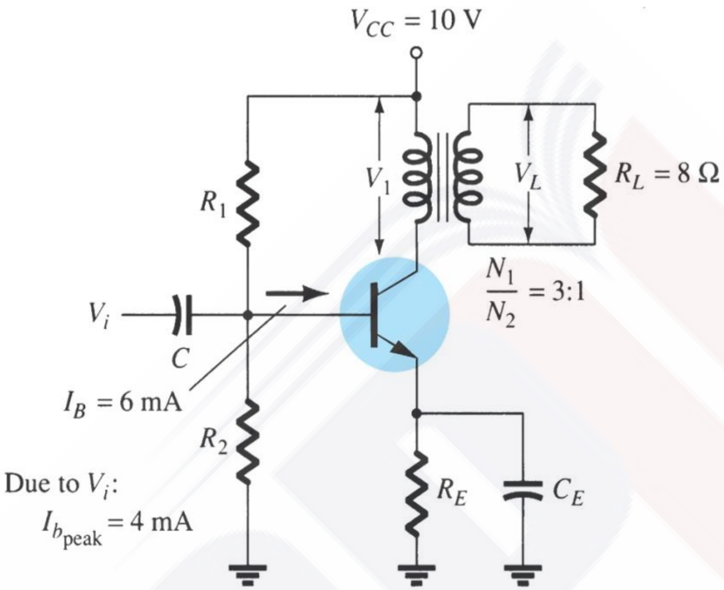
$$I_{CE_Q} + I_C = 140\ \text{mA} + 139\ \text{mA} = 279\ \text{mA along the } y\text{-axis}$$

Connect point A through the Q-point to obtain the ac load line. For the given base current swing of 4 mA peak, the maximum and minimum collector current and collector–emitter voltage obtained from Fig. 12.11 are, respectively,

$$V_{CE_{\min}} = 1.7\ \text{V} \qquad I_{C_{\min}} = 25\ \text{mA}$$
$$V_{CE_{\max}} = 18.3\ \text{V} \qquad I_{C_{\max}} = 255\ \text{mA}$$

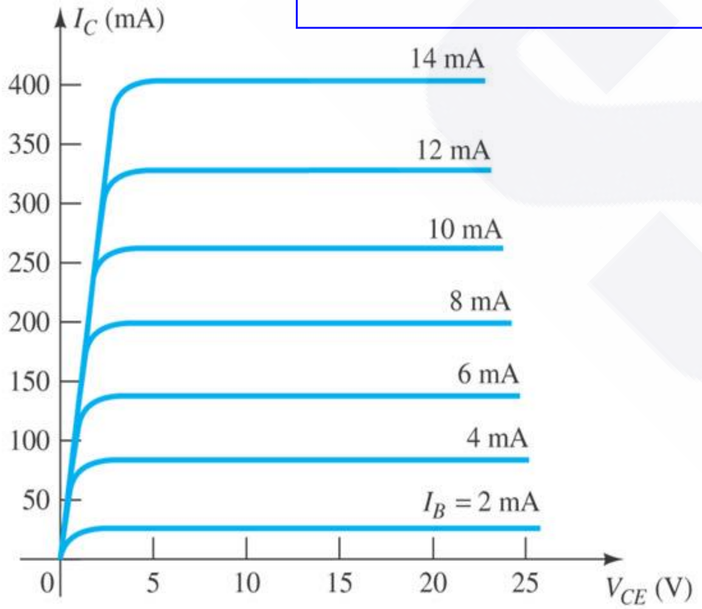
The ac power delivered to the load can then be calculated using Eq. (12.13):

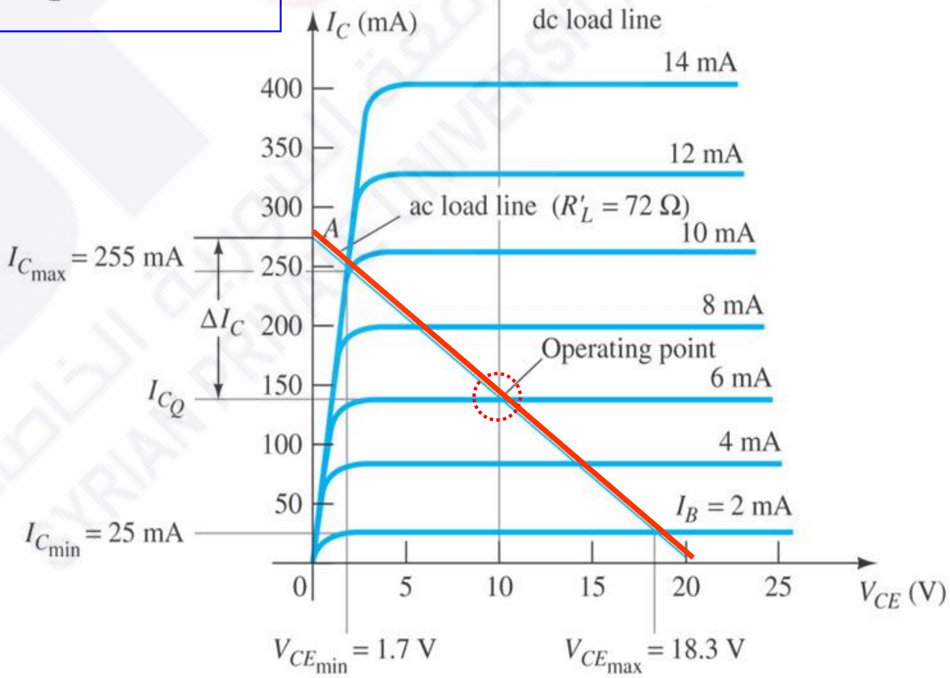
$$P_o(\text{ac}) = \frac{(V_{CE_{\max}} - V_{CE_{\min}})(I_{C_{\max}} - I_{C_{\min}})}{8}$$
$$= \frac{(18.3\ \text{V} - 1.7\ \text{V})(255\ \text{mA} - 25\ \text{mA})}{8} = \mathbf{0.477\ W}$$



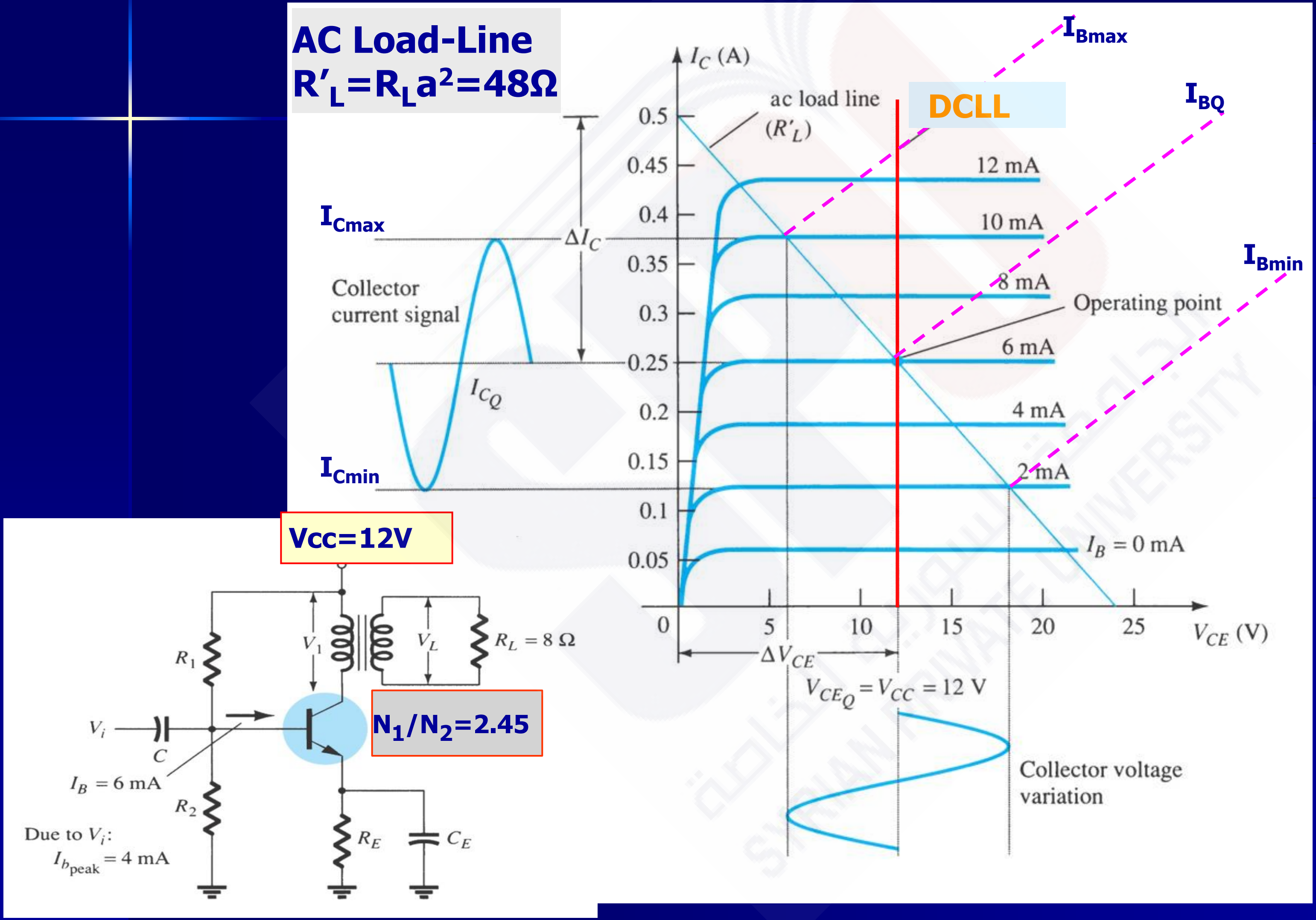
$$I_L(\text{rms}) = \frac{N_1}{N_2} I_C(\text{rms})$$

$$P_L = I_L^2(\text{rms})\, R_L$$





Load lines for class A transformer-coupled amplifier



AC Load-Line

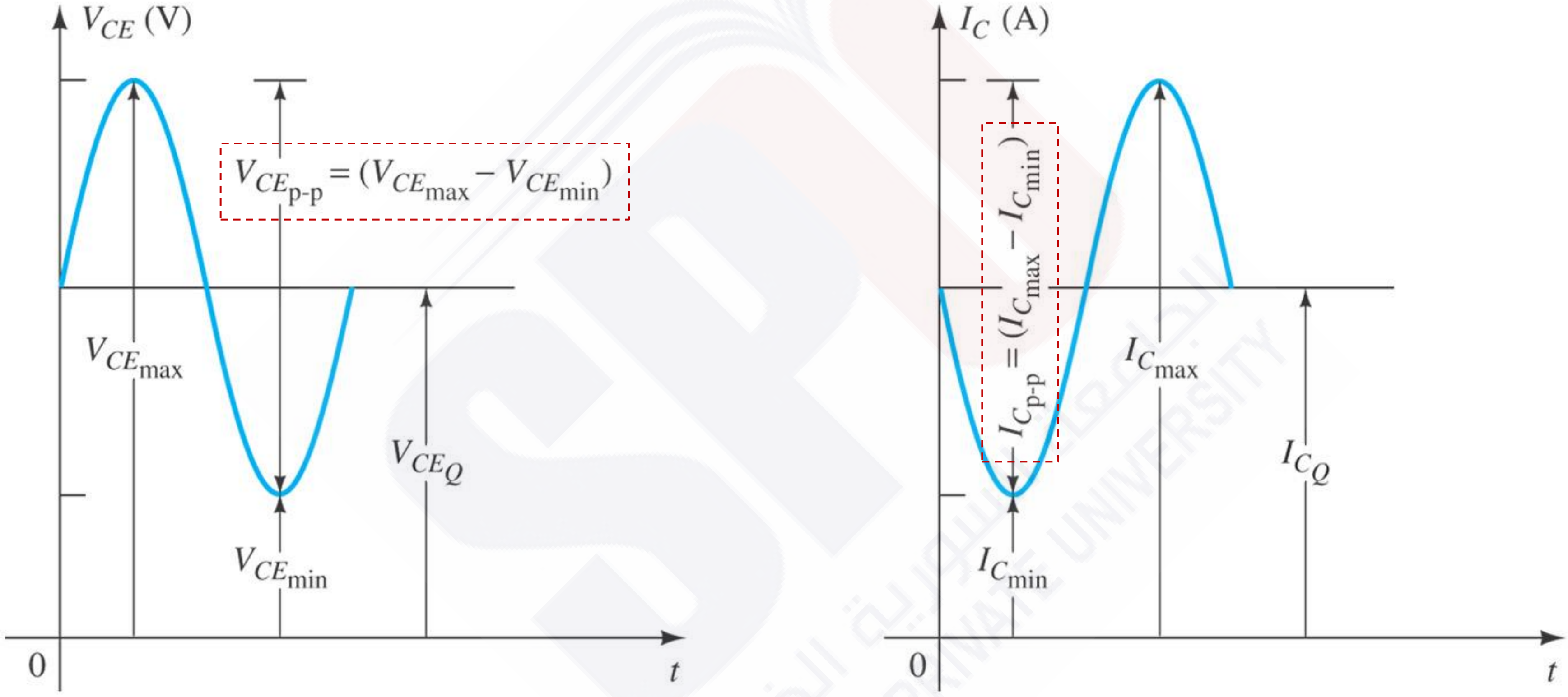
$R'_L = R_L a^2 = 48\Omega$

DCLL

Vcc=12V

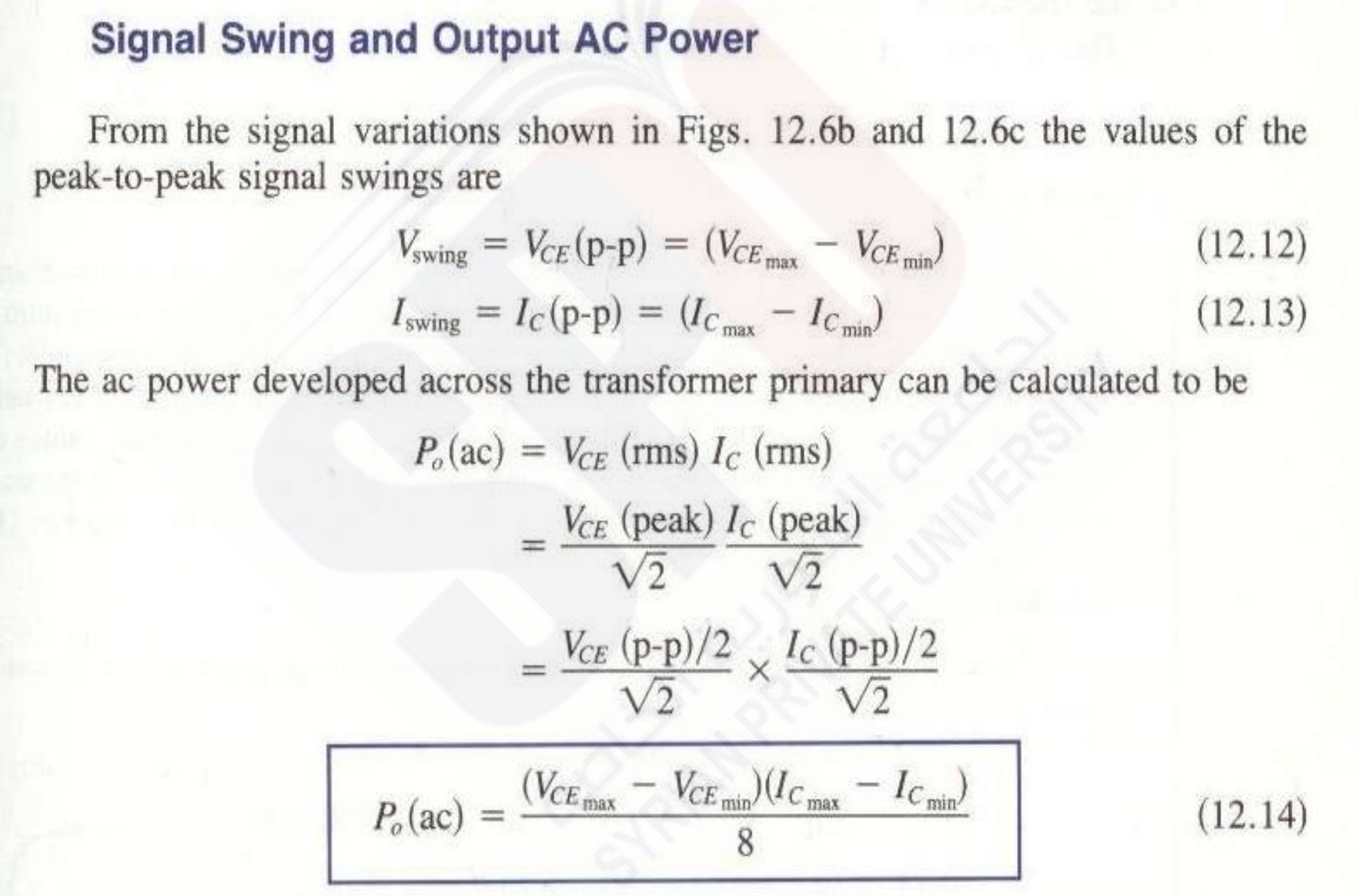
$N_1/N_2 = 2.45$

Graphical operation of transformer-coupled class A amplifier



$$P_o(ac) = \frac{(V_{CE_{\max}} - V_{CE_{\min}})(I_{C_{\max}} - I_{C_{\min}})}{8}$$

$$P_Q = P_i(dc) - P_o(ac) : \text{Dissipated Power by Transistor}$$



Signal Swing and Output AC Power

From the signal variations shown in Figs. 12.6b and 12.6c the values of the peak-to-peak signal swings are

$$V_{\text{swing}} = V_{CE}(\text{p-p}) = (V_{CE_{\text{max}}} - V_{CE_{\text{min}}}) \tag{12.12}$$

$$I_{\text{swing}} = I_C(\text{p-p}) = (I_{C_{\text{max}}} - I_{C_{\text{min}}}) \tag{12.13}$$

The ac power developed across the transformer primary can be calculated to be

$$\begin{aligned} P_o(\text{ac}) &= V_{CE}\,(\text{rms})\; I_C\,(\text{rms}) \\ &= \frac{V_{CE}\,(\text{peak})}{\sqrt{2}}\,\frac{I_C\,(\text{peak})}{\sqrt{2}} \\ &= \frac{V_{CE}\,(\text{p-p})/2}{\sqrt{2}} \times \frac{I_C\,(\text{p-p})/2}{\sqrt{2}} \end{aligned}$$

$$\boxed{P_o(\text{ac}) = \frac{(V_{CE_{\text{max}}} - V_{CE_{\text{min}}})(I_{C_{\text{max}}} - I_{C_{\text{min}}})}{8}} \tag{12.14}$$

Maximum Theoretical Efficiency

(Transformer-Coupled)

$$\eta_{\max,th} = \frac{P_{Oth}}{P_i} = \frac{(V_{CE_{\max}} - V_{CE_{\min}})(I_{C_{\max}} - I_{C_{\min}})}{8V_{CC}I_{CQ}} = \frac{(V_{CE_{\max}} - V_{CE_{\min}})^2}{(R_C)8V_{CC}I_{CQ}}$$

$$V_{CC}I_{CQ} = \frac{(V_{CE_{\max}} + V_{CE_{\min}})}{2} I_{CQ} = \frac{(V_{CE_{\max}} + V_{CE_{\min}})}{2} \frac{V_{CC}}{R_C} = \frac{(V_{CE_{\max}} + V_{CE_{\min}})^2}{4R_C}$$

$$\eta_{\max,th} = 50\% \frac{(V_{CE_{\max}} - V_{CE_{\min}})^2}{(V_{CE_{\max}} + V_{CE_{\min}})^2} = 50\% \quad at \quad V_{peak} = 12V$$

$$\eta_{\max,th} = 50\% \frac{(V_{CE_{\max}} - V_{CE_{\min}})^2}{(V_{CE_{\max}} + V_{CE_{\min}})^2} = 12.5\% \quad at \quad V_{peak} = 6V$$

$$= 50\% \frac{(V_{CE_{\max}} - V_{CE_{\min}})^2}{(V_{CE_{\max}} + V_{CE_{\min}})^2} = 1.39\% \quad V_{peak} = 2V$$

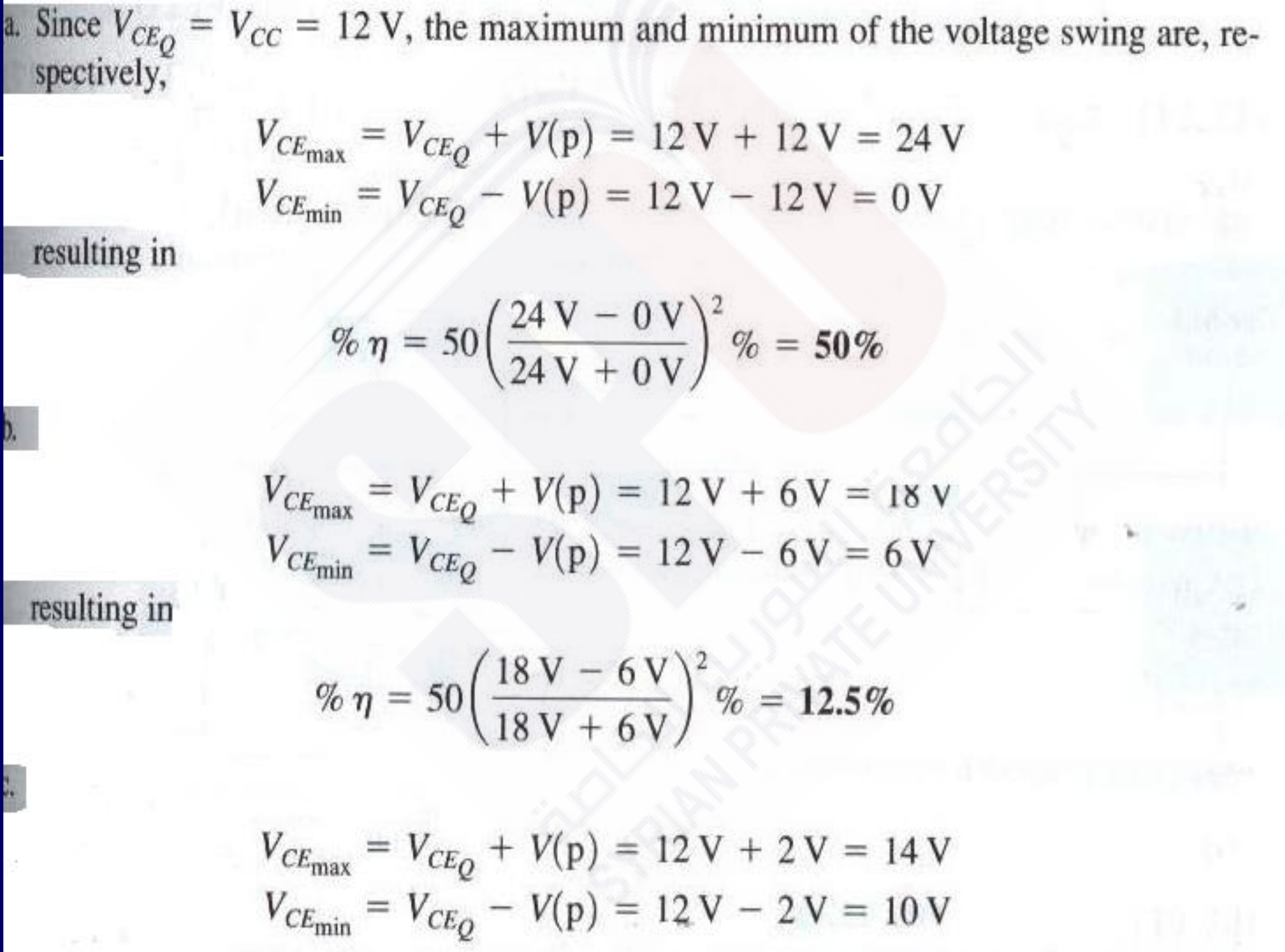
Find η for o/p:

V(peak)=12V

V(peak)=6V

V(peak)=2V

If $V_{CEQ}=V_{CC}$



a. Since $V_{CE_Q} = V_{CC} = 12\text{ V}$, the maximum and minimum of the voltage swing are, respectively,

$$V_{CE_{\max}} = V_{CE_Q} + V(\text{p}) = 12\text{ V} + 12\text{ V} = 24\text{ V}$$
$$V_{CE_{\min}} = V_{CE_Q} - V(\text{p}) = 12\text{ V} - 12\text{ V} = 0\text{ V}$$

resulting in

$$\%\eta = 50\left(\frac{24\text{ V} - 0\text{ V}}{24\text{ V} + 0\text{ V}}\right)^2\% = \mathbf{50\%}$$

b.

$$V_{CE_{\max}} = V_{CE_Q} + V(\text{p}) = 12\text{ V} + 6\text{ V} = 18\text{ V}$$
$$V_{CE_{\min}} = V_{CE_Q} - V(\text{p}) = 12\text{ V} - 6\text{ V} = 6\text{ V}$$

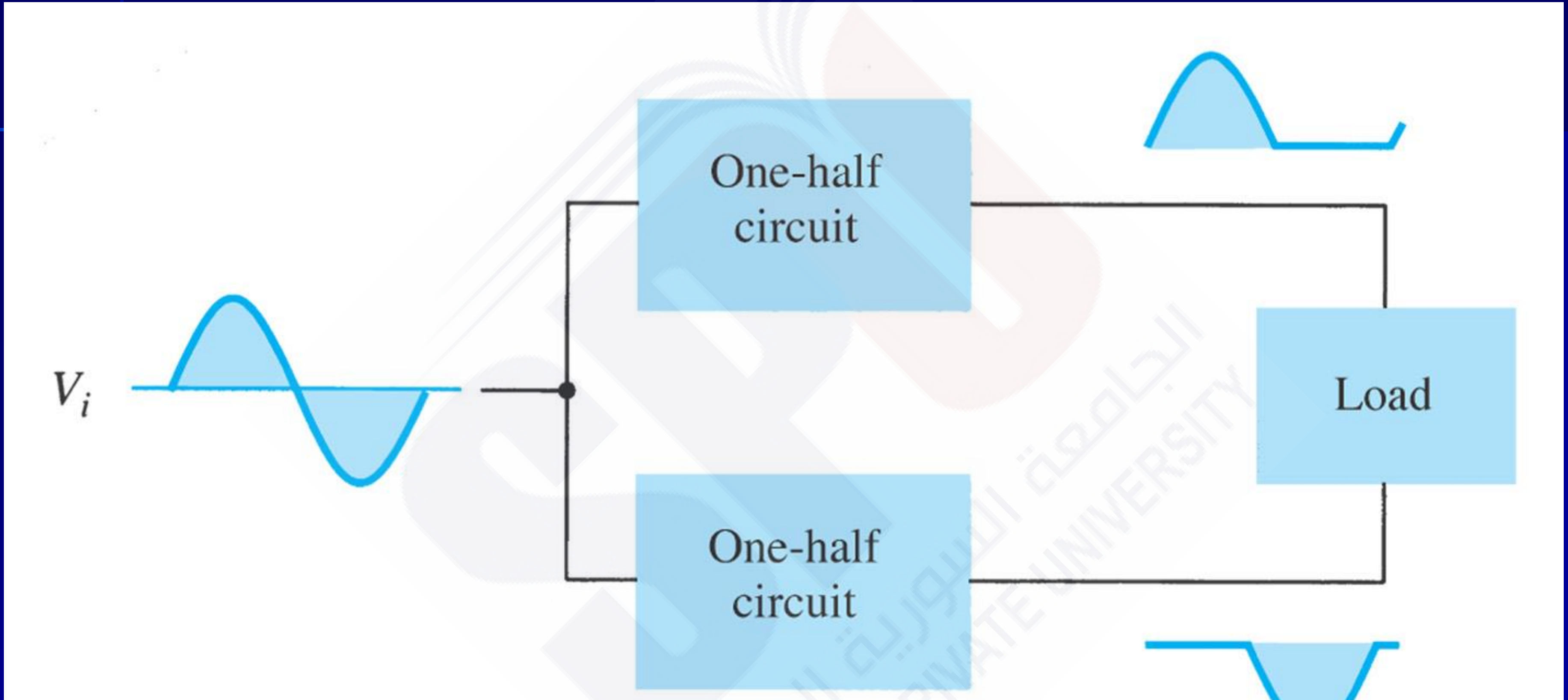
resulting in

$$\%\eta = 50\left(\frac{18\text{ V} - 6\text{ V}}{18\text{ V} + 6\text{ V}}\right)^2\% = \mathbf{12.5\%}$$

c.

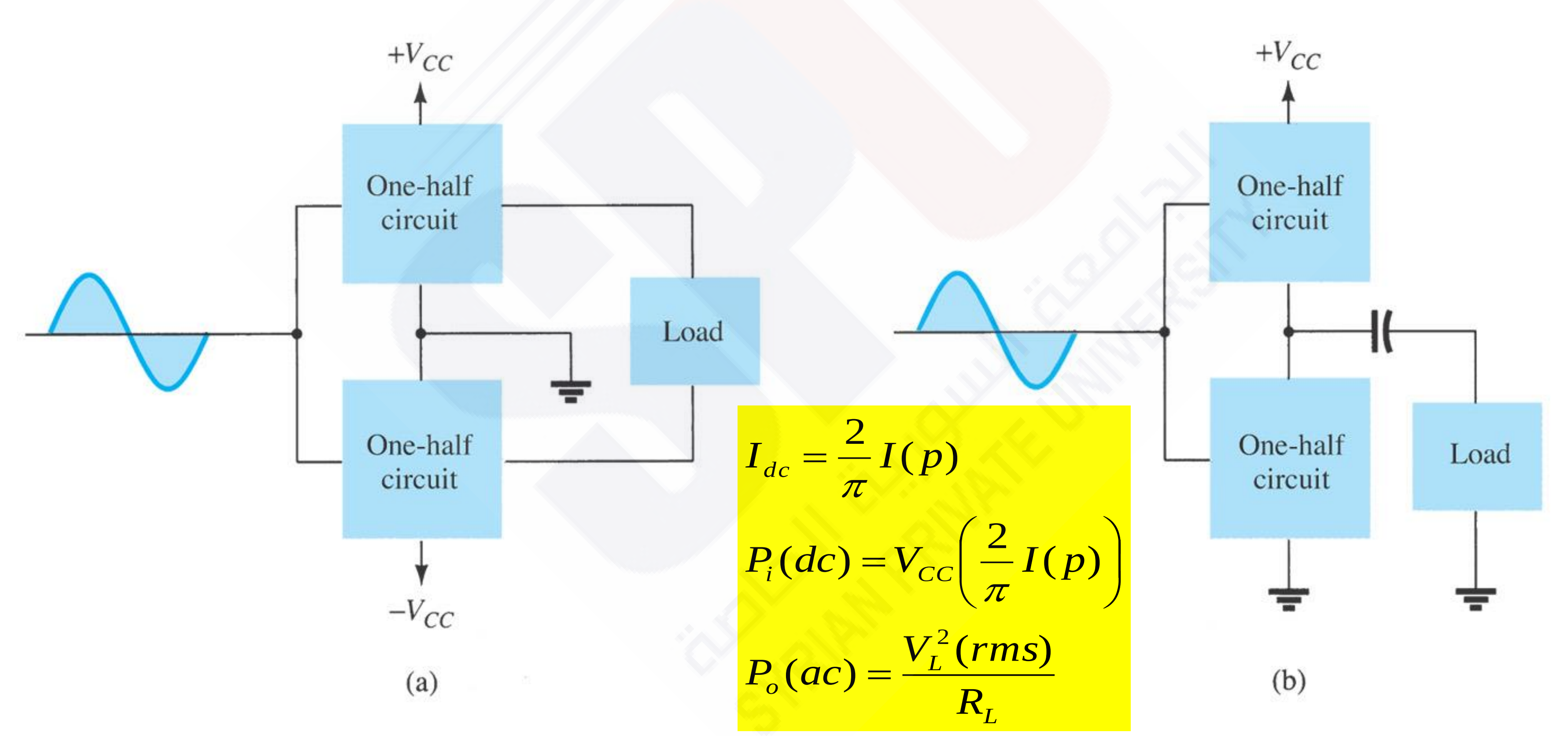
$$V_{CE_{\max}} = V_{CE_Q} + V(\text{p}) = 12\text{ V} + 2\text{ V} = 14\text{ V}$$
$$V_{CE_{\min}} = V_{CE_Q} - V(\text{p}) = 12\text{ V} - 2\text{ V} = 10\text{ V}$$

6.4 Class-B Amplifier Operation



Push-Pull Power Amplifier

Connection of push–pull amplifier to load: (a) using two voltage supplies; (b) using one voltage supply



$$I_{dc} = \frac{2}{\pi} I(p)$$

$$P_i(dc) = V_{CC}\left(\frac{2}{\pi} I(p)\right)$$

$$P_o(ac) = \frac{V_L^2(rms)}{R_L}$$

Efficiency of Class-B Amplifier

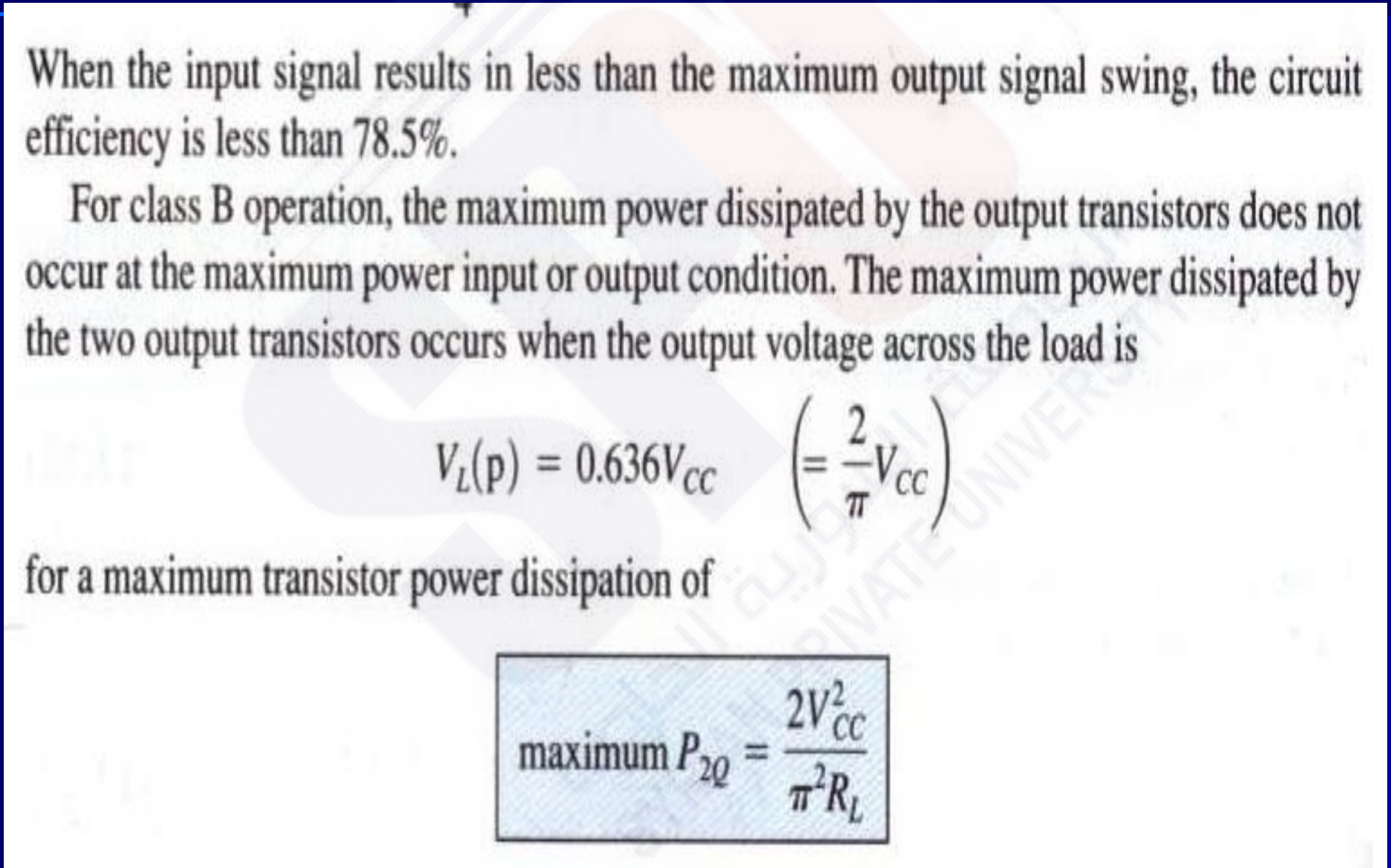
$$\eta = \frac{P_o(ac)}{P_i(dc)} \times 100\%$$

$$\eta = \frac{V_L^2(p)/2R_L}{V_{CC}\left[(2/\pi)I(p)\right]} \times 100\% = \frac{\pi}{4}\frac{V_L(p)}{V_{CC}} \times 100\%$$

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

$$P_{2Q} = P_i(dc) - P_o(ac)$$

P_{2Q} : The Power Dissipated by O/P Transistors



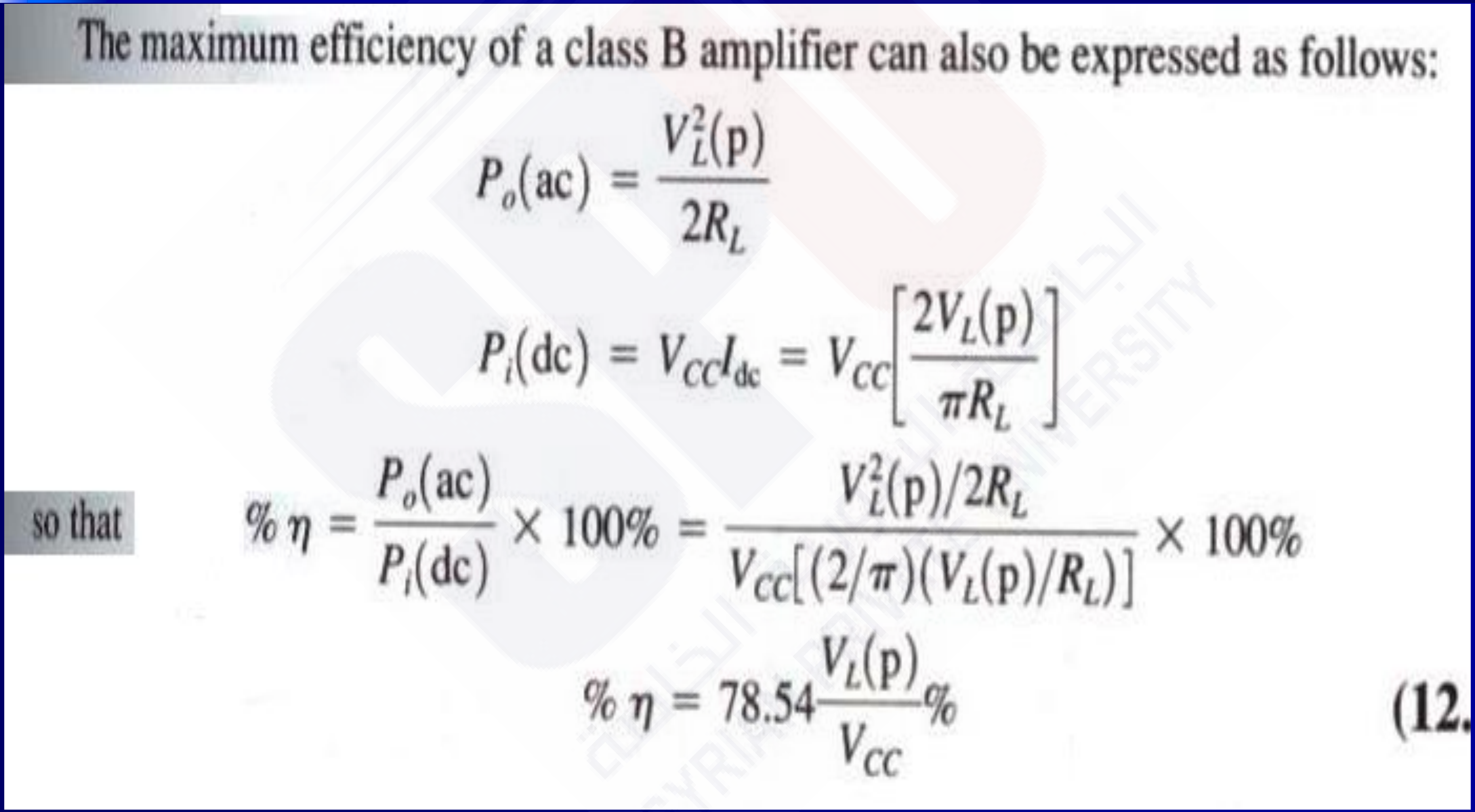
When the input signal results in less than the maximum output signal swing, the circuit efficiency is less than 78.5%.

For class B operation, the maximum power dissipated by the output transistors does not occur at the maximum power input or output condition. The maximum power dissipated by the two output transistors occurs when the output voltage across the load is

$$V_L(\mathrm{p}) = 0.636V_{CC} \qquad \left(= \frac{2}{\pi}V_{CC}\right)$$

for a maximum transistor power dissipation of

$$\boxed{\text{maximum } P_{2Q} = \frac{2V_{CC}^2}{\pi^2 R_L}}$$



The maximum efficiency of a class B amplifier can also be expressed as follows:

$$P_o(\text{ac}) = \frac{V_L^2(\text{p})}{2R_L}$$

$$P_i(\text{dc}) = V_{CC}I_{\text{dc}} = V_{CC}\left[\frac{2V_L(\text{p})}{\pi R_L}\right]$$

so that

$$\%\,\eta = \frac{P_o(\text{ac})}{P_i(\text{dc})} \times 100\% = \frac{V_L^2(\text{p})/2R_L}{V_{CC}[(2/\pi)(V_L(\text{p})/R_L)]} \times 100\%$$

$$\%\,\eta = 78.54\frac{V_L(\text{p})}{V_{CC}}\% \qquad \textbf{(12.}$$

Example

1. For Class-B amp determine: P_{imax}, P_{omax}, P_Q and η if V_{CC}=30V and RL=16Ω
2. Find η for V_o(peak)=22 V and 6 V if V_{CC}=24V

$P_O=V^2_{CC}/2R_L=28.125$ W

$P_i=2V^2_{CC}/\text{Л}R_L=35.81$ W

Max $\eta=28.125/35.81=78.54\%$

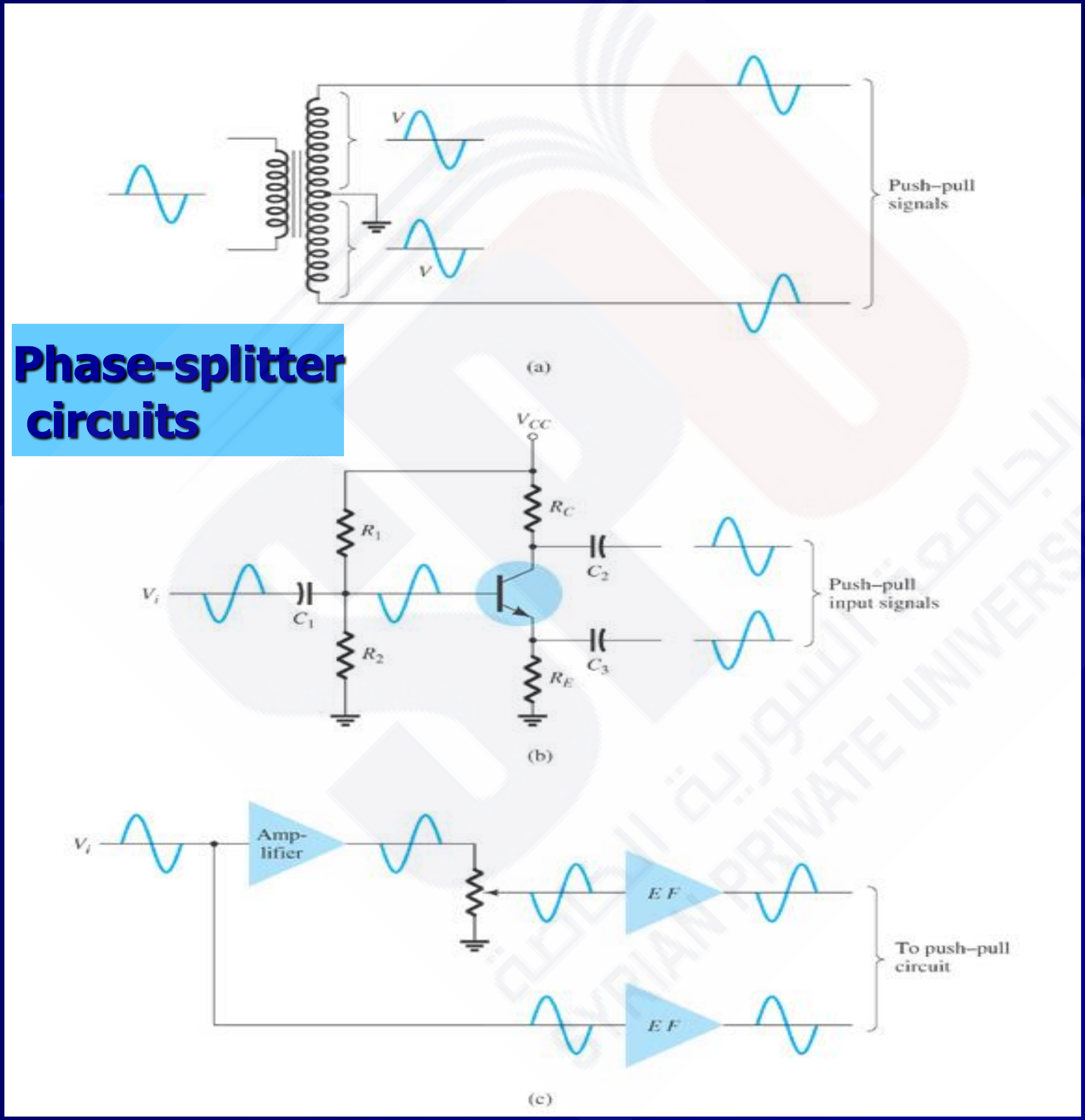
$P_Q=P_{2Q}/2=0.5(2V^2_{CC}/\ \text{Л}^2R_L)=5.7$ W

When Vo=22V : $\eta=\eta_{max}\ Vo/V_{CC}=78.54 \times 22/24=72\%$

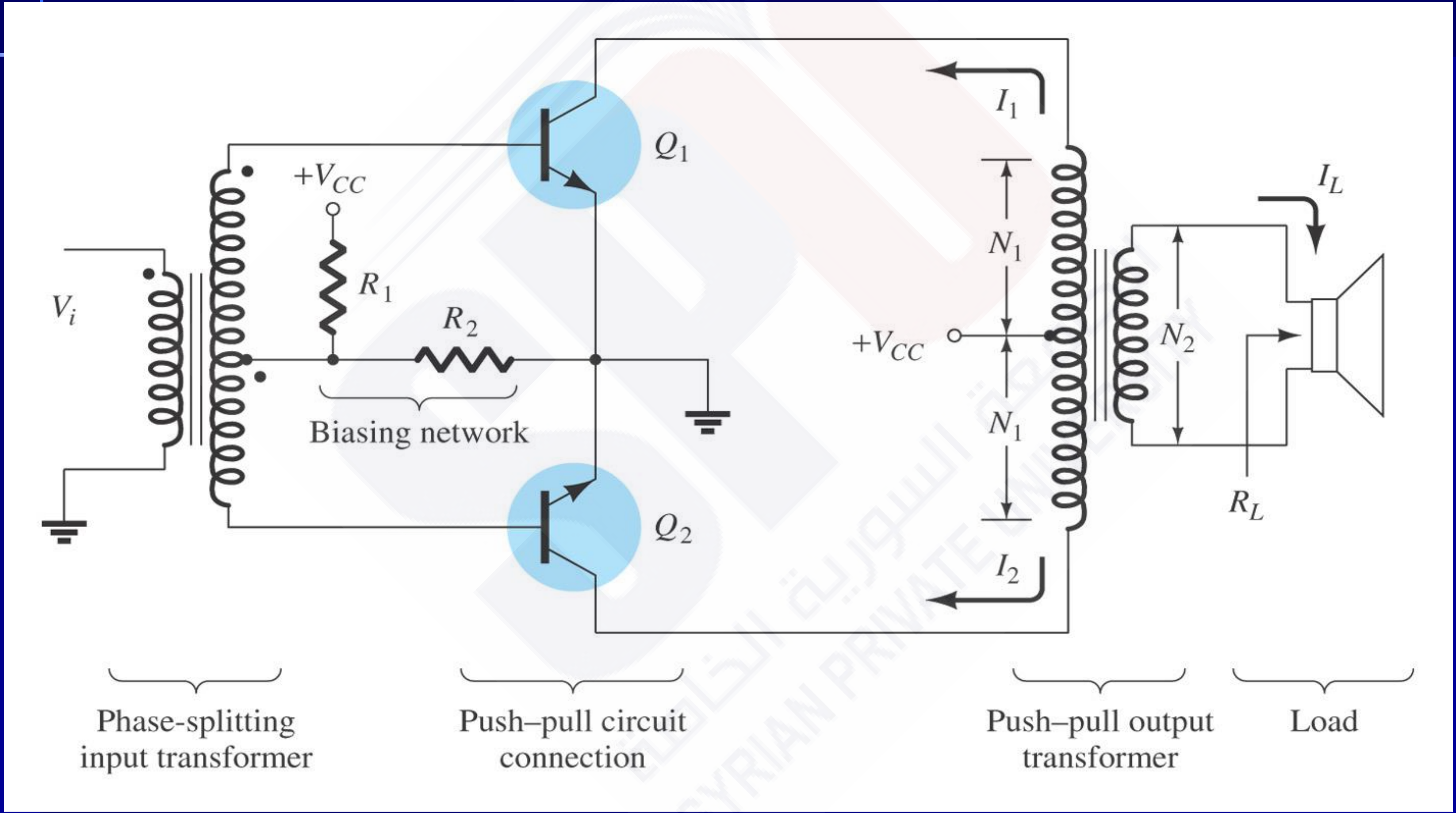
When Vo=6V : $\eta=\eta_{max}\ Vo/V_{CC}=78.54 \times 6/24=19.6\%$

6.5 Class-B Amplifier Circuits

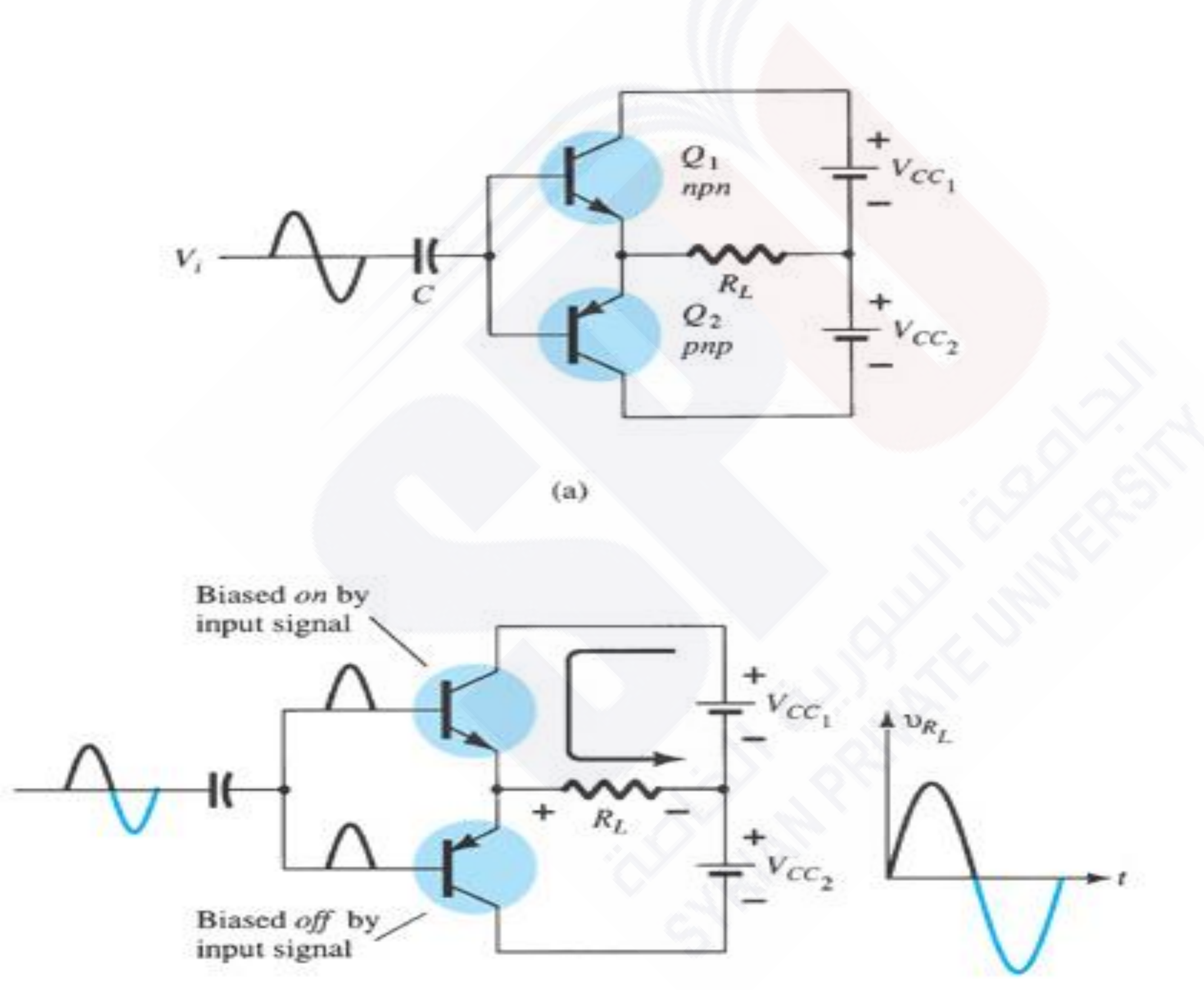
Phase-splitter circuits



Transformer-Coupled Push-Pull Amp

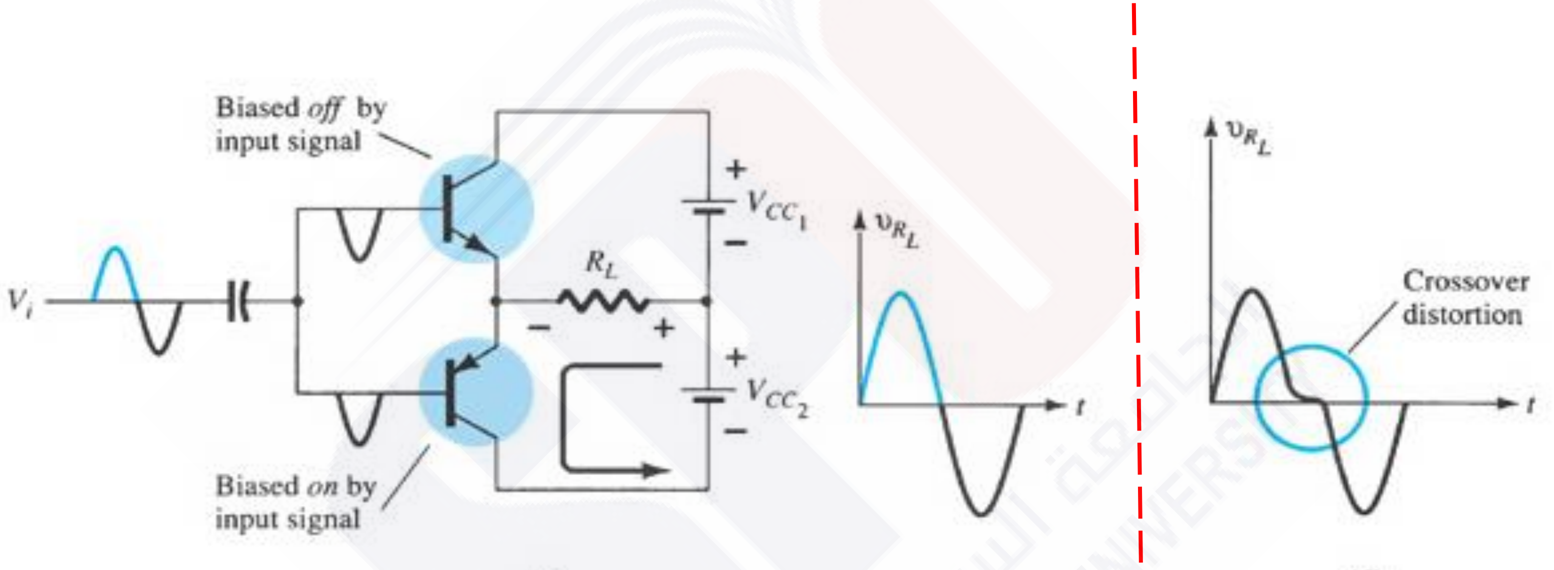


Complementary-symmetry push–pull circuit



Complementary-symmetry push–pull circuit

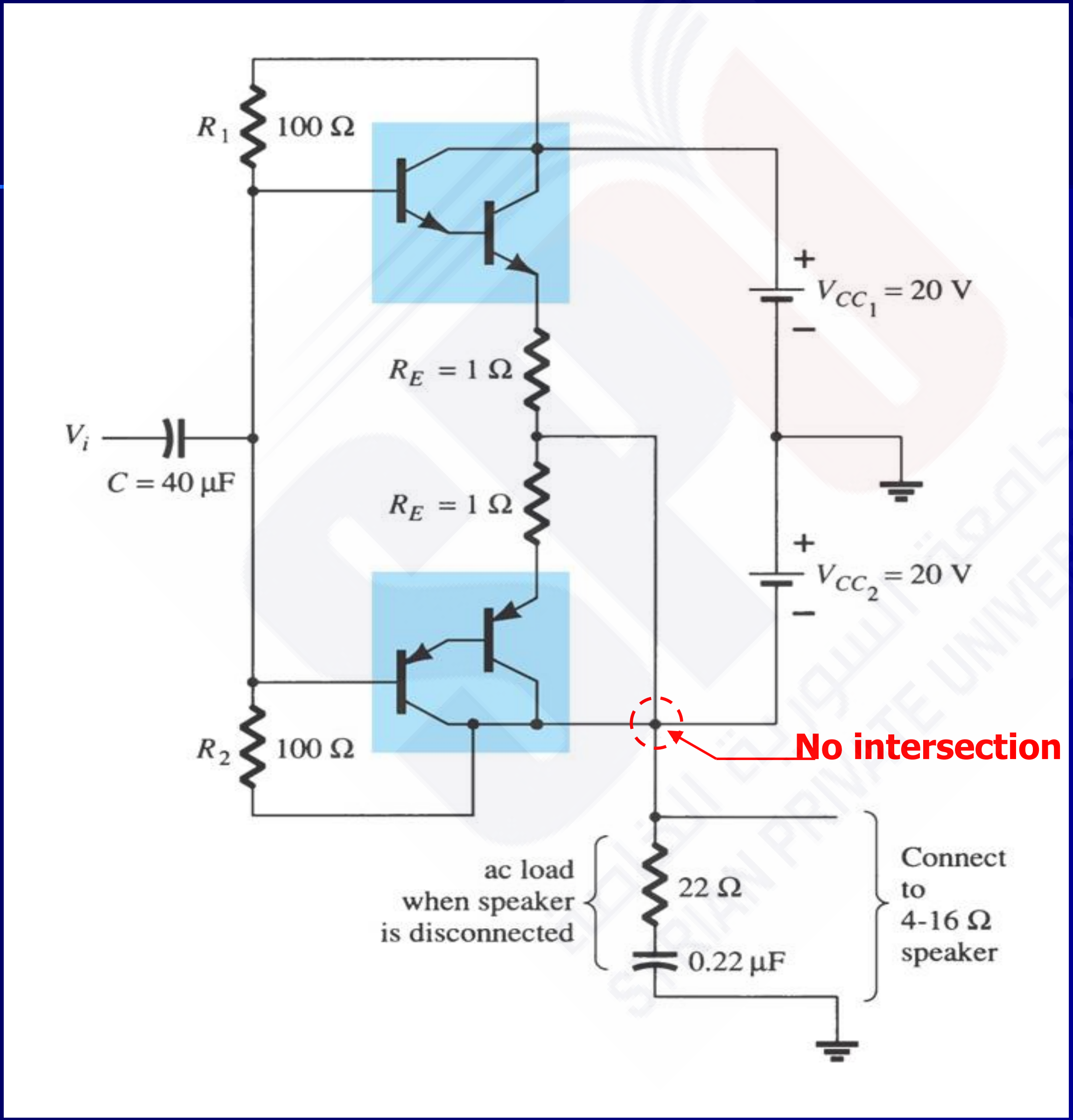
Complementary needs 2 Power Supply



(c)

(d)

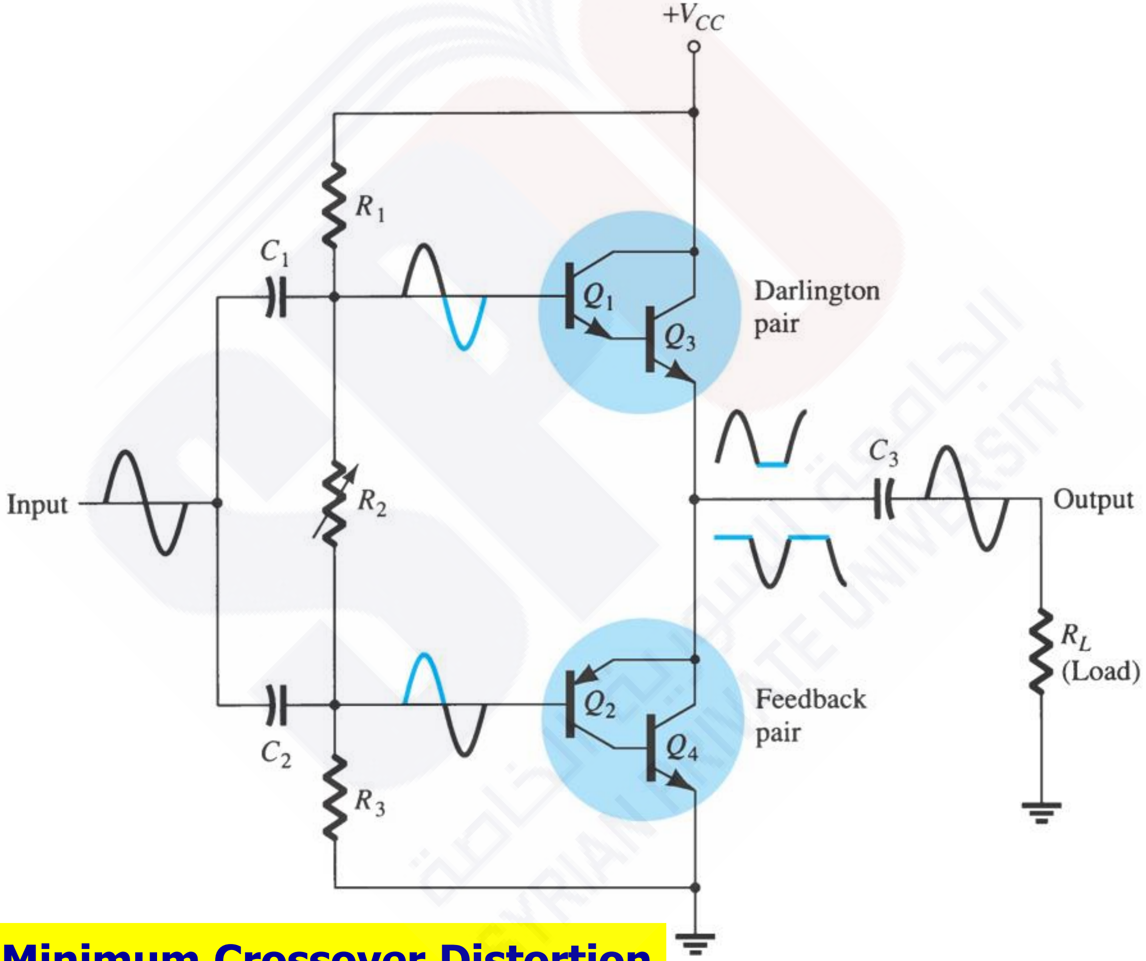
Complementary-symmetry push–pull circuit using Darlington transistors



No intersection

Quasi-complementary push–pull transformer-less power amplifier

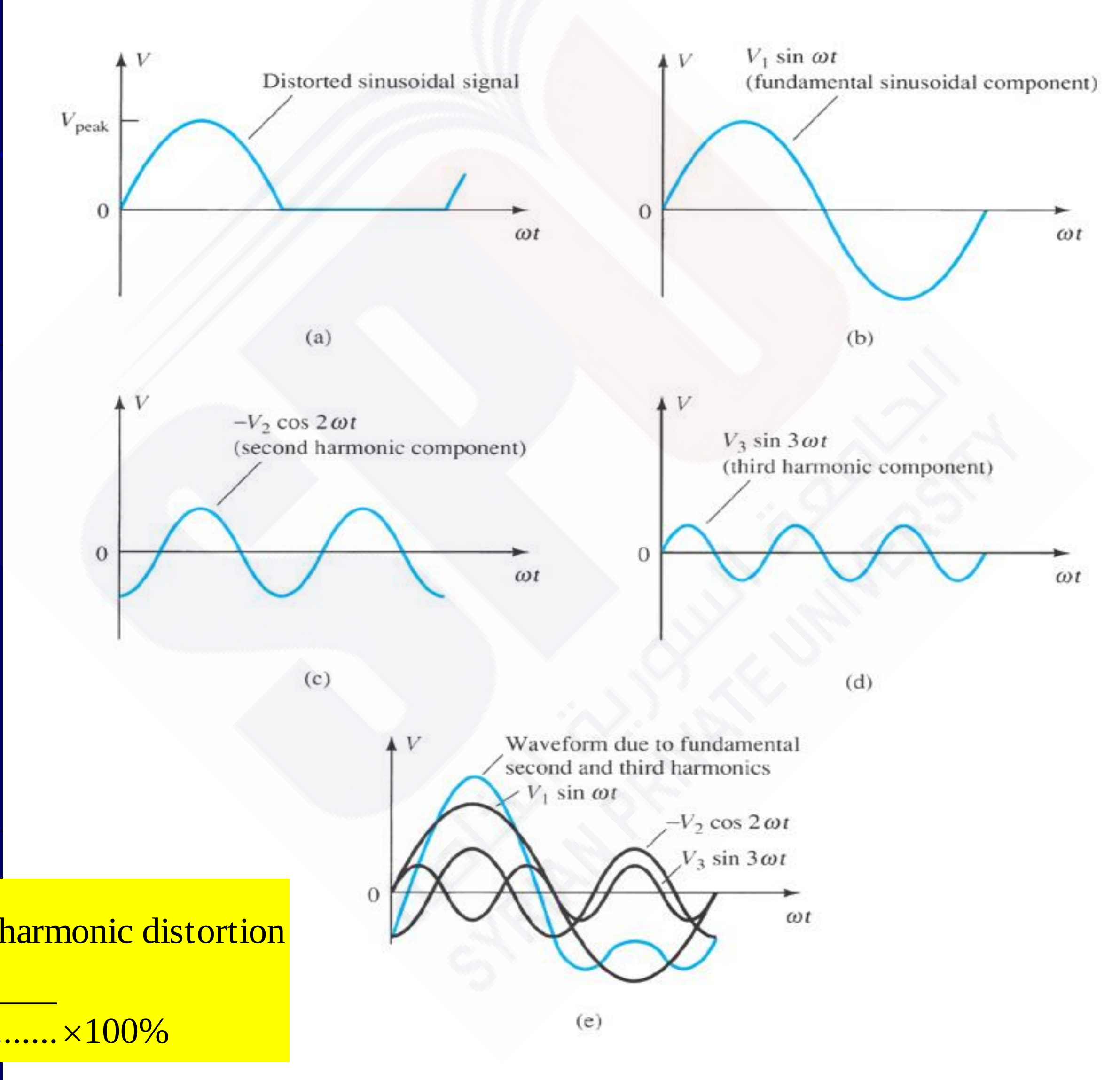
The Most Popular Form of Power Amps: Single Supply



R2: Adjust for Minimum Crossover Distortion

6.6 Amplifier Distortion

Graphical representation of a distorted signal through the use of harmonic components

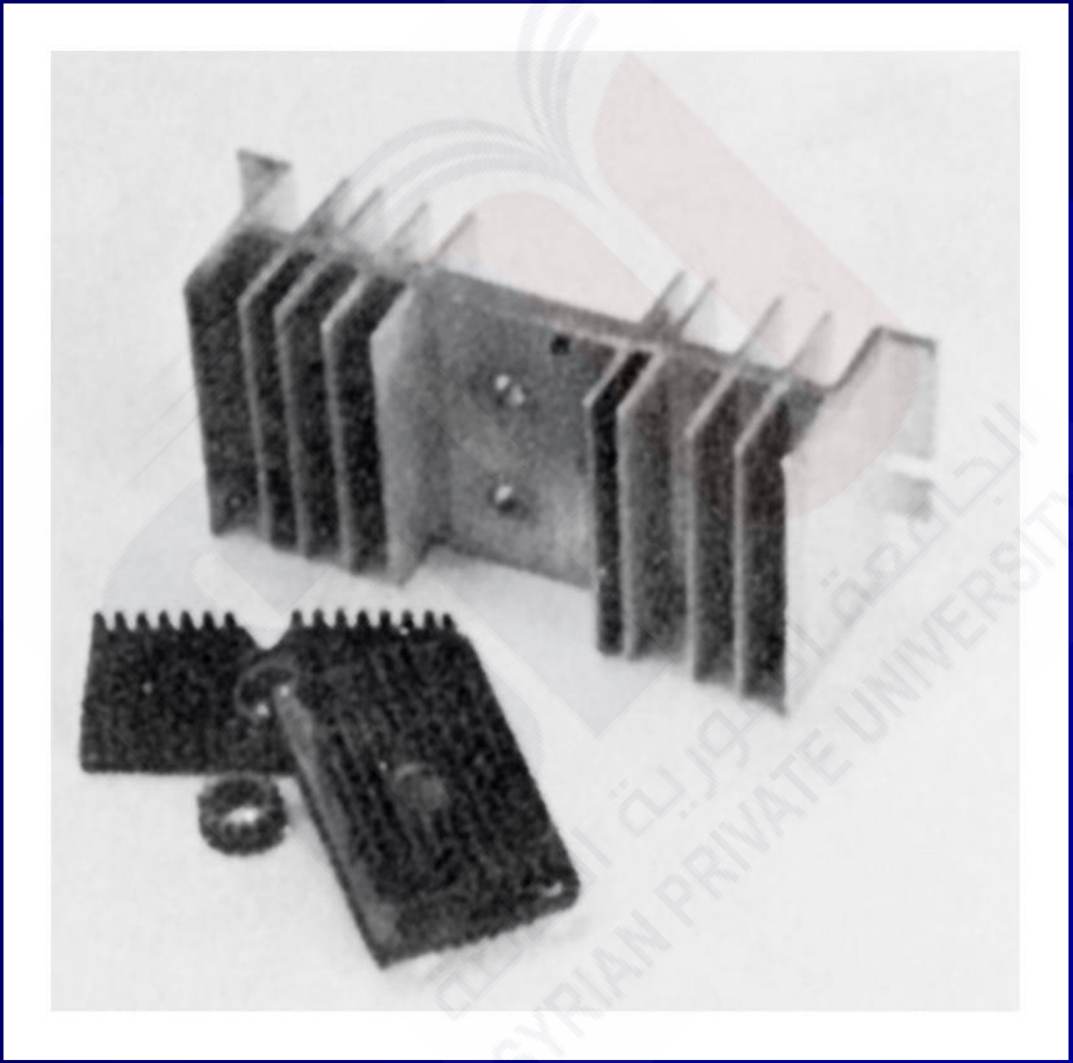


$$\%D_n = \frac{|A_n|}{|A_1|} \times 100\% : \%\ \text{nth harmonic distortion}$$

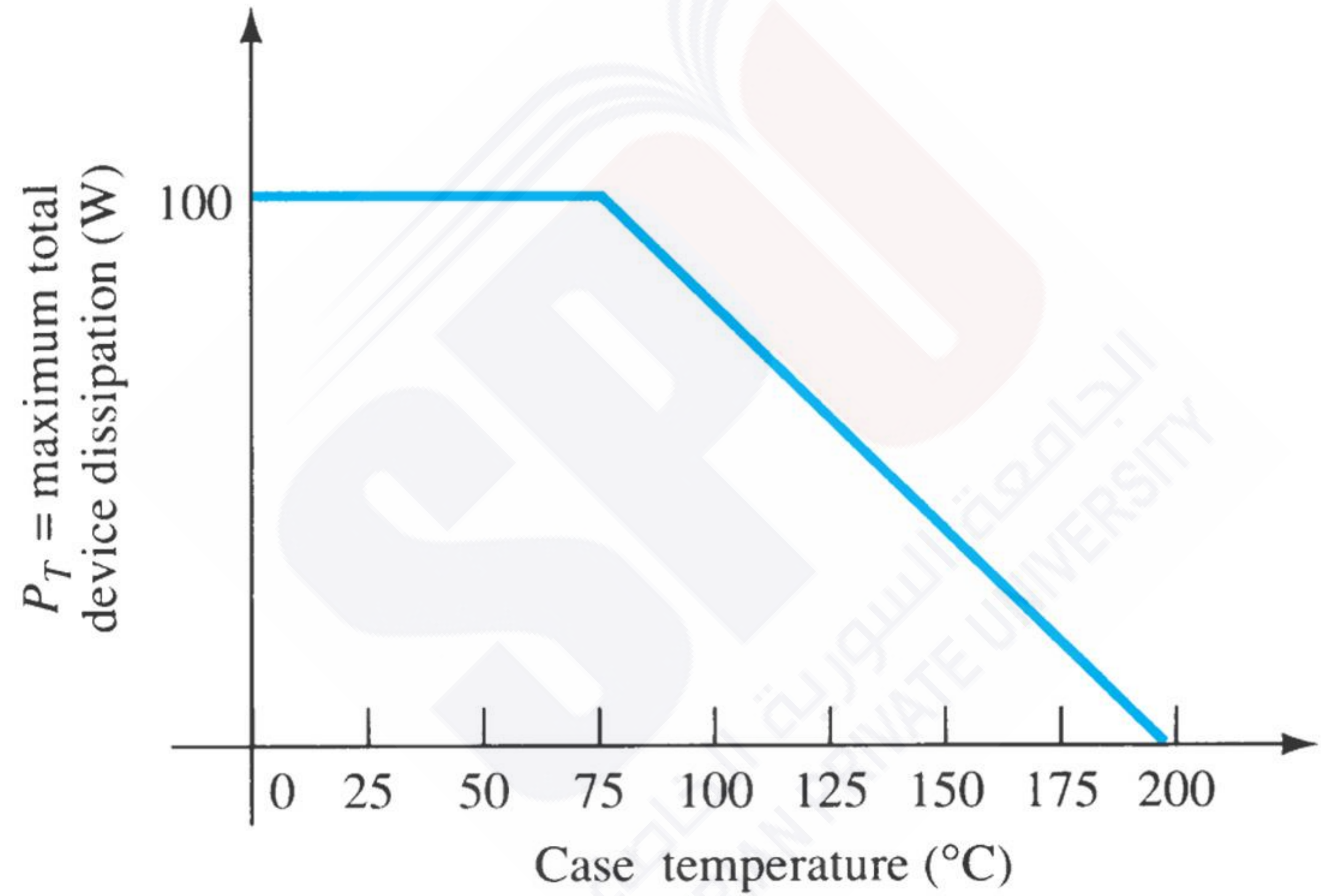
$$THD = \sqrt{D_2^2 + D_3^2 + D_4^2 + \ldots\ldots\ldots} \times 100\%$$

6.7 Power Transistor Heat Sinking

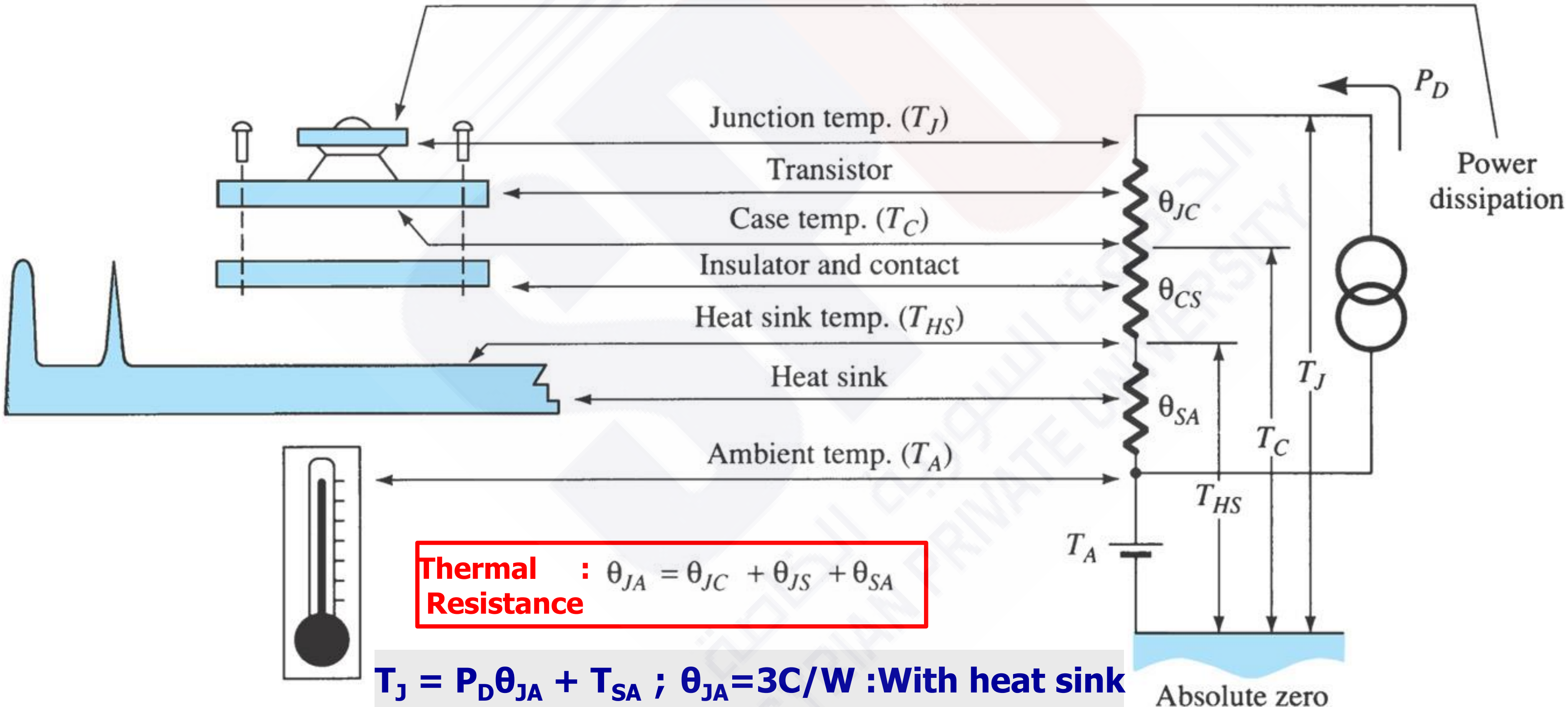
Typical power heat sinks



Typical power derating curve for silicon transistors



Thermal-to-electrical analogy

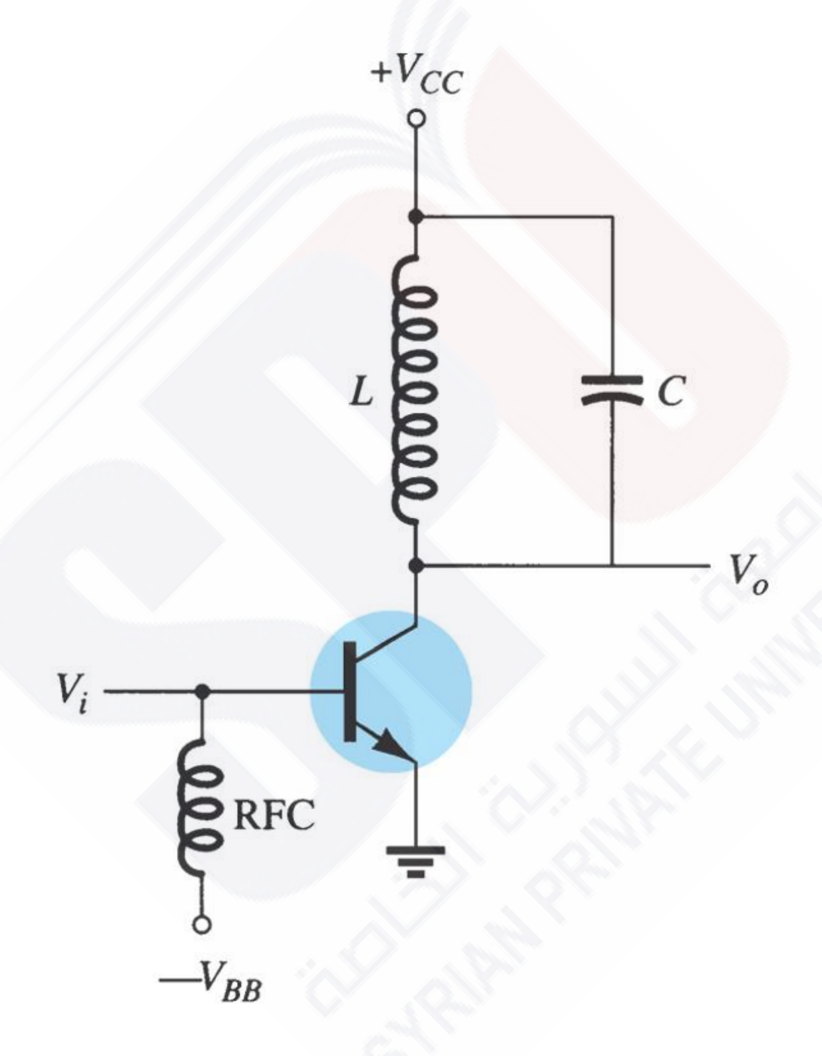


Thermal Resistance : $\theta_{JA} = \theta_{JC} + \theta_{JS} + \theta_{SA}$

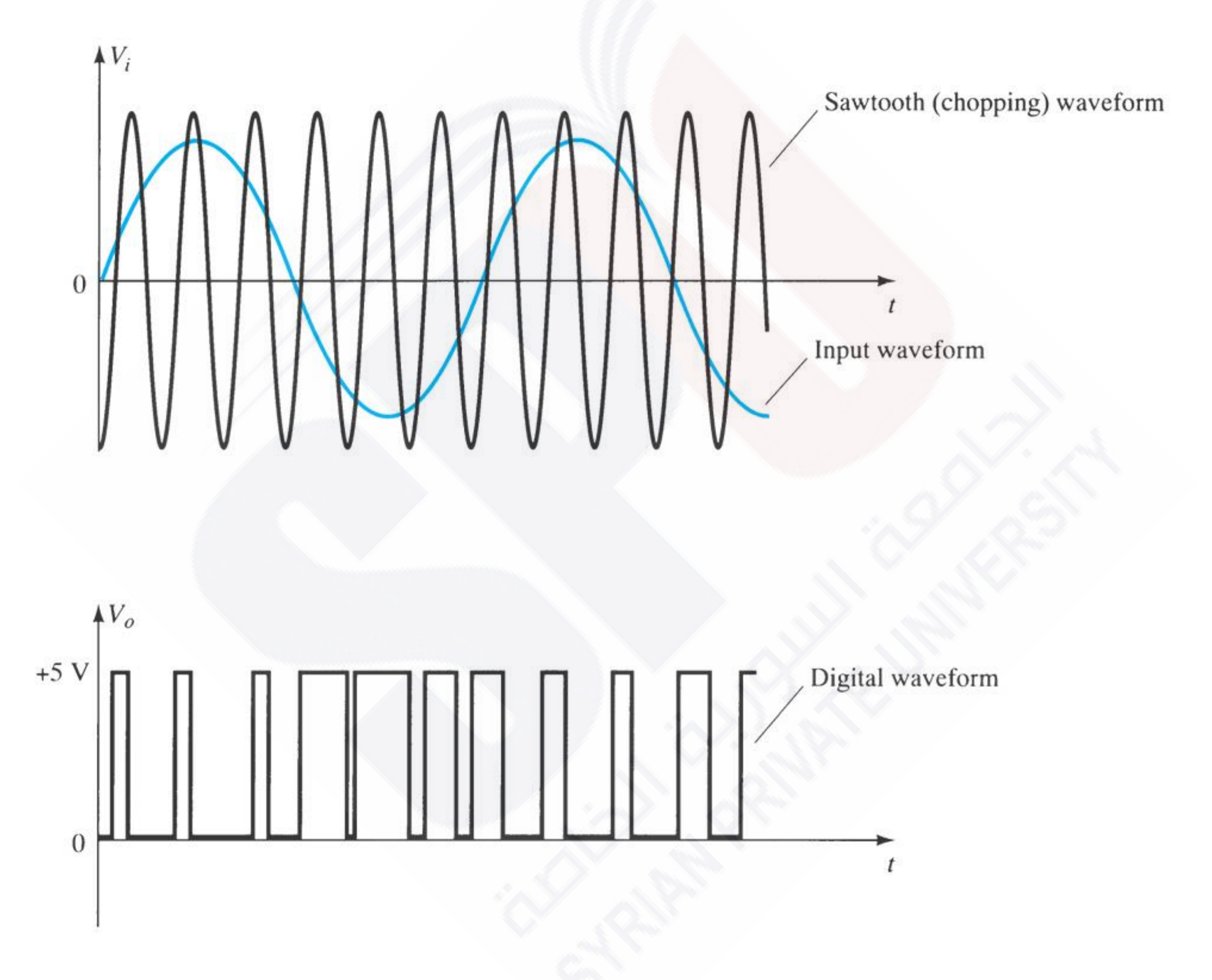
$T_J = P_D\theta_{JA} + T_{SA}$; θ_{JA}=3C/W :With heat sink
=40C/W (into free air)

6.8 Class-C and Class-D Amplifiers

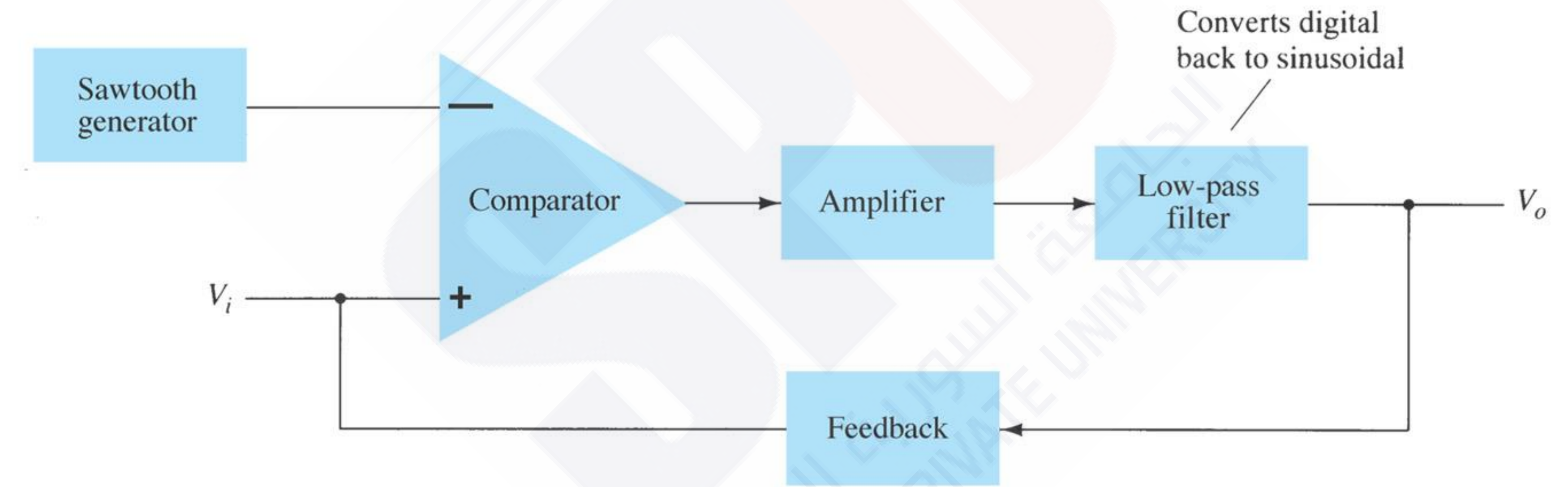
Class C amplifier circuit



Chopping of a sinusoidal waveform to produce a digital Waveform

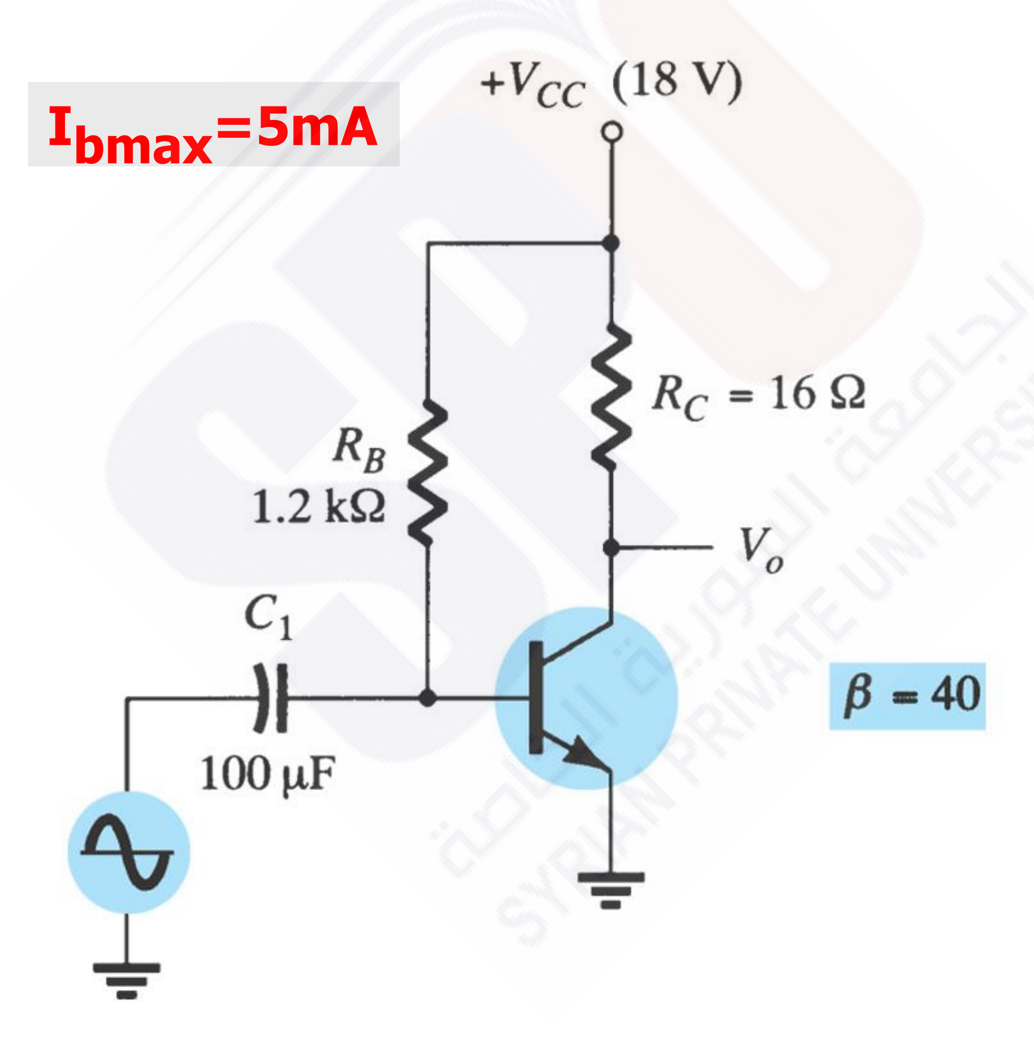


Block diagram of class D amplifier



Po: Transistor I only for very short time → very high eff.

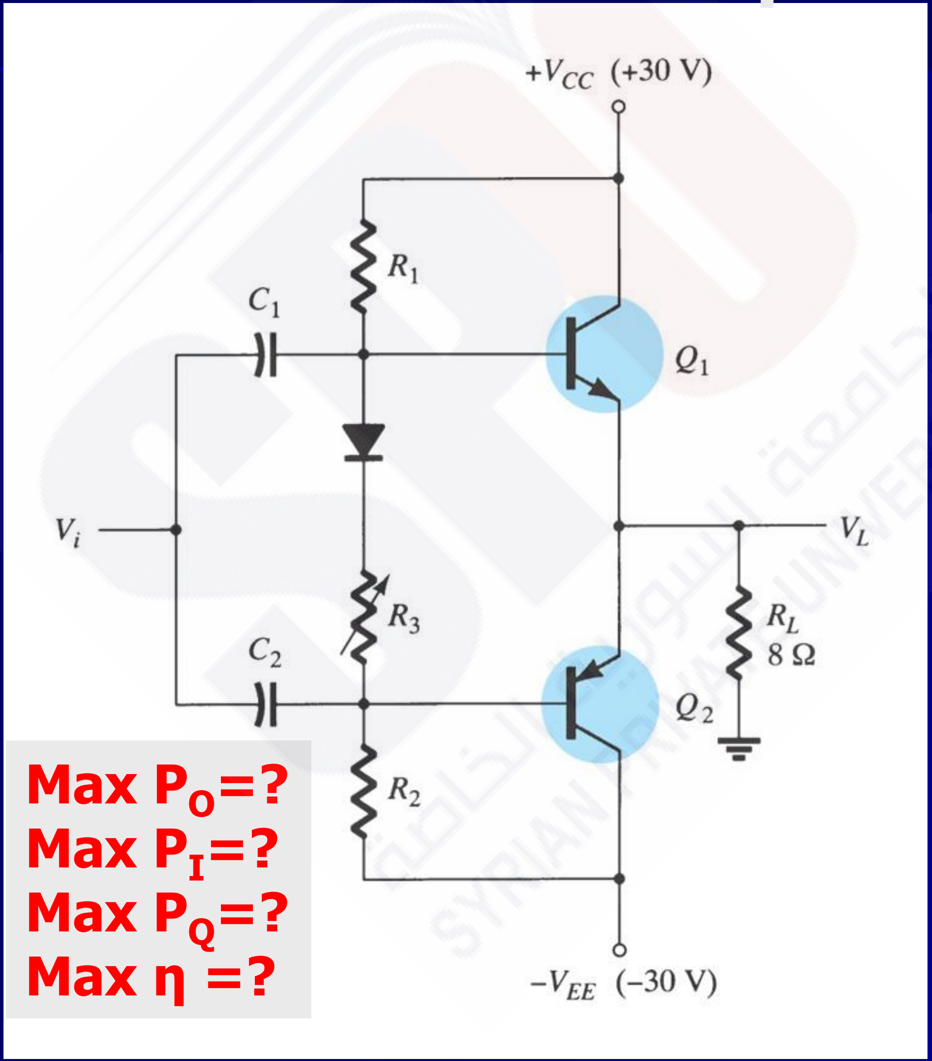
Examples
Series-Fed Class A amplifier



I_{bmax}=5mA

Example:

Class B amplifier Circuit >Refer to p.682 to solve this example



Max P_O=?
Max P_I=?
Max P_Q=?
Max η =?