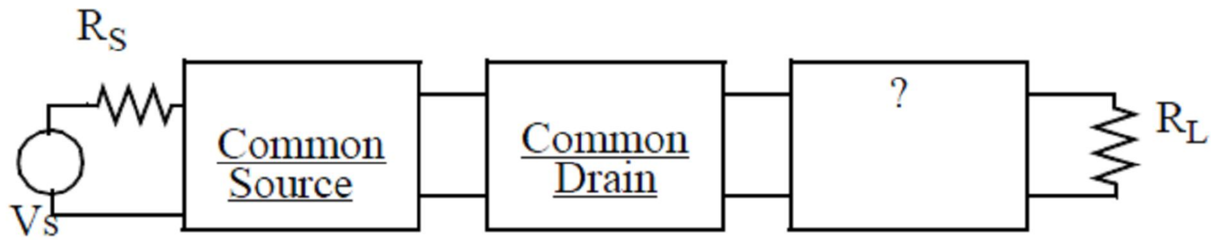
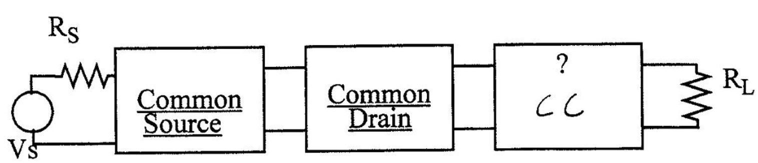
Fayoum University - Faculty of Engineering Department of Electrical Engineering- Communication and Electronics Section		Final Exam - Fall 2009 Time allowed:-3 hrs
Electronics I Second Year		January 21, 2010 Dr:- Rania A. Abul Seoud

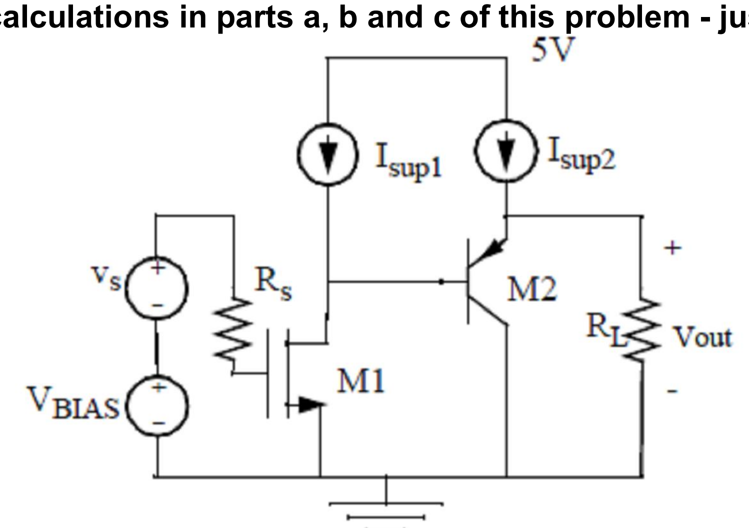
The following multistage amplifier is meant to deliver a voltage signal to a relatively small ohmic load of 1K□. Mark your choice of the last stage, and write a brief justification.





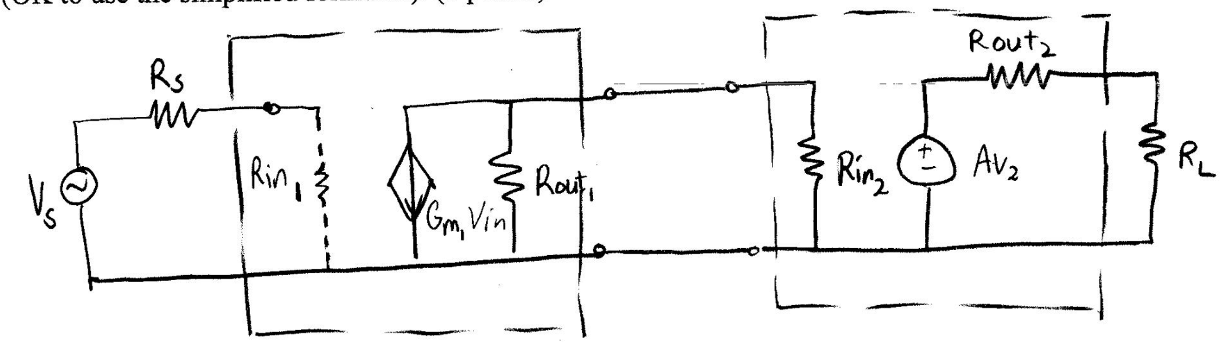
A CC has very low output resistance (less than a CD) and a high input resistance. It makes a good final stage voltage buffer

The following is a two stage voltage amplifier employing a n-channel CS stage, and a pnp CC stage. Note that there are no numerical substitutions or calculations in parts a, b and c of this problem - just symbolic expressions!



a) **Draw the small signal model for this two stage voltage amplifier.**

(OK to use the simplified formulae). (6 points)



b) Derive the *expressions* for the quantities shown below, in terms of the device parameters (OK to use the simplified formulae).

a. R_{in1}, R_{out1} for the first stage.

b. R_{in2}, R_{out2} and A_{v2} for the second stage.

Parameter	Expression
Gm_1	g_{m_1}
R_{in1}	∞
R_{out1}	$r_{o_1} \parallel r_{oc_1}$
Av_2	1
R_{in2}	$r_\pi + \beta_o (r_{o2} \parallel r_{oc_2} \parallel R_L)$
R_{out2}	$\frac{1}{g_{m2}} + \frac{R_{out_1}}{\beta_o}$

a) Derive *expressions* for the A_v, R_{in}, R_{out}, as well as v_{out} / v_s in terms of the device parameters.

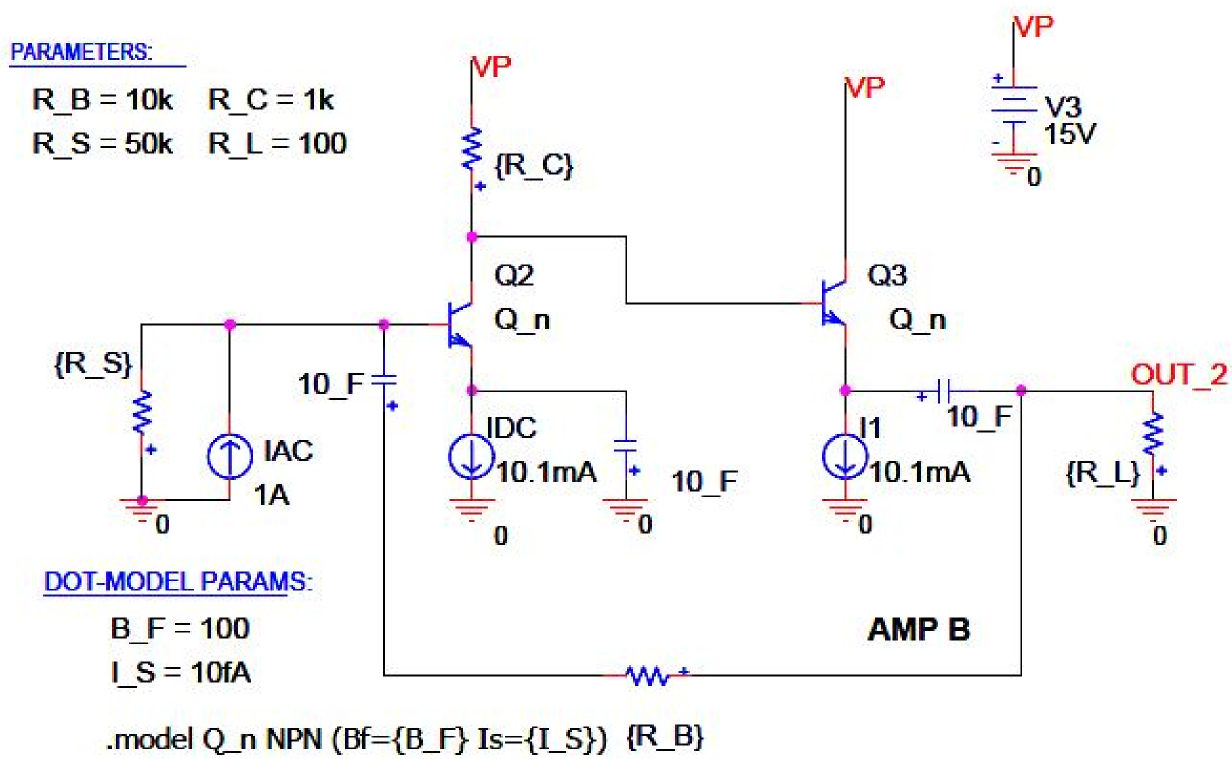
b) Assume that V_{BIAS} = 1.5V, and that the minimum voltage across the current sources is 0.5V. Find the maximum and minimum voltages at the drain of M1 and at the emitter of M2. Make sure you mention the limiting <u>reason</u> for each case (i.e. transistor X falls out of saturation, or current source Y hits its minimum voltage drop, etc.)

- $V_{dmin} = V_{GS} - V_T = 1.5V - 1V = \boxed{0.5V}$ $\therefore V_{emin} = 0.5V + 0.7V = \boxed{1.2V}$
- $V_{dmax} \neq 4.5V$ because $V_e = 4.5V + 0.7V = 5.2V > V_{DD}$

  $V_{emax} = \boxed{4.5V}$ $\therefore V_{dmax} = 4.5V - 0.7V = \boxed{3.8V}$

Node	Min Voltage	Reason for Min Voltage	Max Voltage	Reason for Max Voltage
drain of M1	0.5V	V_{Dsat} of M1	3.8V	Min voltage across I_{SUP2} & V_{EB} of M2
emitter of M2	1.2V	V_{dsat} of M1 & V_{EB} of M2	4.5V	Min voltage across I_{SUP2}

FB amplifier

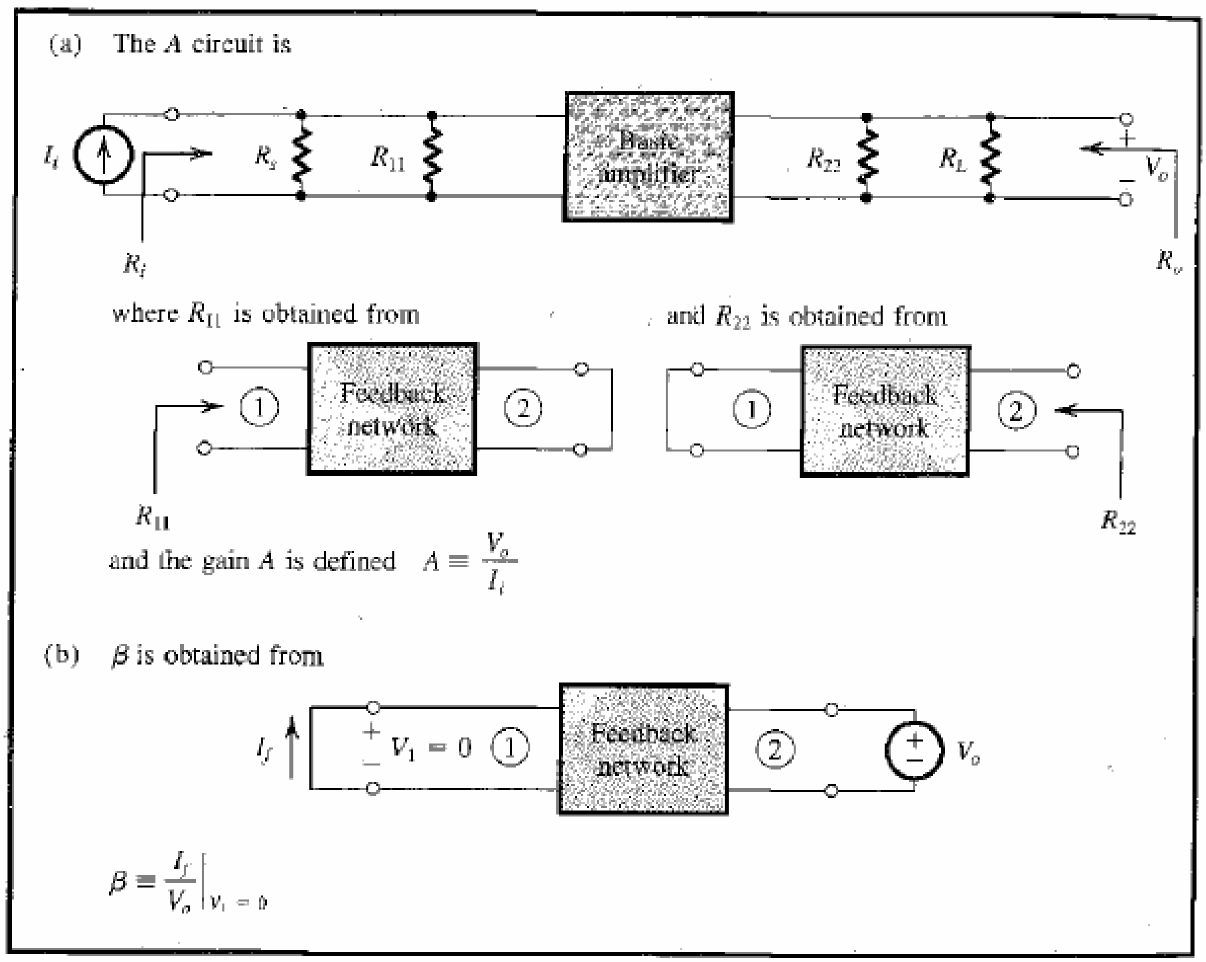


For the shown FB Amplifier,

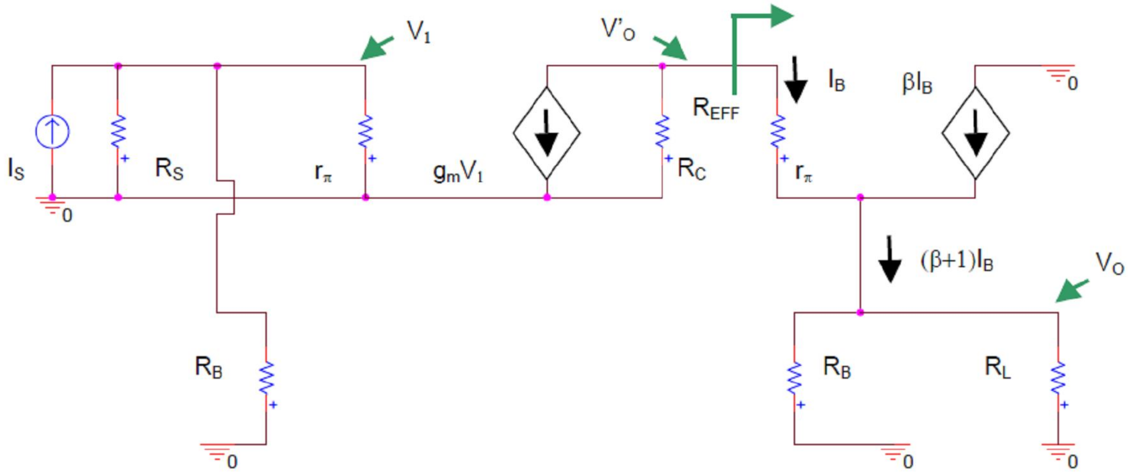
1. Identify the topology of the FB. what kind of amplifier (V/V, A/A etc.) is Amp A? Amp B? Explain in your outline

Answer: Both amplifiers are transresistance amplifiers.
Outline: Both amplifiers can be arranged as shown in Figure 2, so both are shunt-shunt FB amps → current input and voltage output or transresistance gain.

2. Find the feedback parameter β_{FB}.



3. Draw the amplifier without FB.



4. Find gain, input resistance and output resistance without FB.

$$PF_B = 1 + \beta_{FB} A_{LB} = 1 + \frac{1}{R_B} g_m (R_C // R_{EFF})(R_S // R_B // r_\pi)$$

$$R_{EFF} = r_\pi + (\beta+1)(R_B//R_L).$$

EQ. 6

$$\frac{V'_O}{I_S} = -g_m (R_C // R_{EFF})(R_S // R_B // r_\pi).$$

The gain V_O/V'_O is just the gain of the VF, which is nearly unity. More exactly,

EQ. 7

$$\frac{V_O}{V'_O} = \frac{R_L // R_B}{R_L // R_B + r_E} \approx 1.$$

Hence, provided $R_L//R_B >> r_E$, we can use EQ. 6 as the gain of Amp B. That is,

EQ. 8

$$\frac{V_O}{I_S} = \frac{V'_O}{I_S}\frac{V_O}{V'_O} \approx -g_m (R_C // R_{EFF})(R_S // R_B // r_\pi)$$

With this approximation the PF for Amp B is

EQ. 9

$$PF_B = 1 + \beta_{FB} A_{LB} = 1 + \frac{1}{R_B} g_m (R_C // R_{EFF})(R_S // R_B // r_\pi),$$

with A_{LB} = loaded gain for Amp B, namely, $A_{LB} = -g_m (R_C // R_{EFF})(R_S // R_B // r_\pi)$.

5. Find the voltage gain, input resistance and output resistance of the shown FB Amplifier. Hint: neglect r_o

A_L/PF

<u>Question 3 [Power Amplifiers]:-</u> Consider the output stage shown in Fig. 5. The BJT has β = ∞ and initially assume that V_{BE}=0.7 V when it is on.

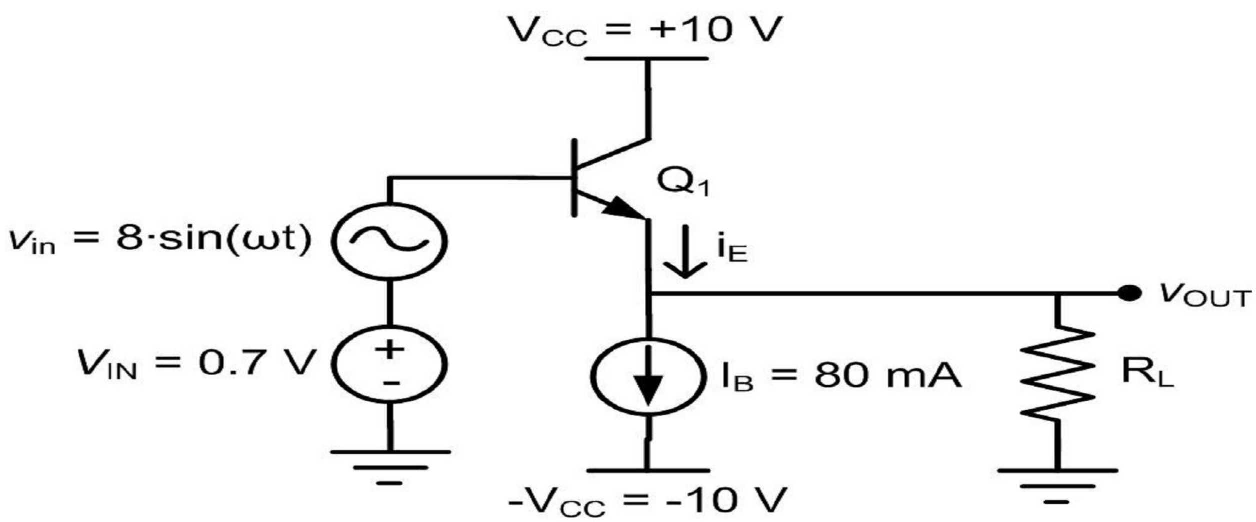


Figure 5: BJT output stage.

a) **Choose R_L so that 0.32 W of power is dissipated in the load under the given input conditions.**

b) **What class of operation is the output stage in under this condition?**

(a) For voltage follower, $V_{OUT} = V_{IN} = 8 \cdot \sin\omega t$.

$\therefore P_L = \left(\frac{8}{\sqrt{2}}\right)^2 \cdot \frac{1}{R_L} = 0.32 \Rightarrow R_L = \frac{64}{2 \cdot 0.32} = 100\,\Omega$.

(b) When $V_{OUT} = -8$ V, $I_{RL} = \frac{8}{100} = 80$ mA, supplied by I_B

$\therefore$ class A.

(c) See plot.

(d) $P_S = 20 \cdot 80E{-}3 = 1.6$ W

$\therefore \eta = \frac{P_L}{P_S} = \frac{0.32}{1.6} = 20\%$

c) **What is the conversion efficiency of the output stage under these conditions?**

$$\eta_{C\,\%} = \frac{P_{av}}{P_{DC}} * 100 = \frac{\frac{1}{2}\frac{V_m^2}{R_L}}{2V_{CC}I} * 100 = 25\frac{V_m^2}{V_{CC}(IR_L)}$$

$$V_{m,\max} = V_{CC} \qquad R_{L,\min} = \frac{(V_{CC} - V_{CE\,2,sat})}{I} \cong \frac{V_{CC}}{I}$$

$$IR_{L,\min} = V_{CC}$$

$$\eta_{C,\max\,\%} = 25$$

d) **Find the maximum conversion efficiency.**

(i) If R_L is large: $I > i_L$

$$-V_{CC} + v_{CE2Sat} = v_{o\min}$$

$I > i_L$
$I > v_{omin}/R_L$

$$I \geq \frac{|-V_{CC} + V_{CE2sat}|}{R_L}$$

$$IR_L > (V_{CC} - V_{CE2,sat}) \qquad R_L > \frac{(V_{CC} - V_{CE2,sat})}{I}$$

$$R_{L,\min} = \frac{(V_{CC} - V_{CE2,sat})}{I}$$

a) **Find the maximum power delivered to the load**

(b) The power delivered to the load

$$P_{av} = \frac{1}{2} V_m I_m = \frac{1}{2} \frac{V_m^2}{R_L}$$

The maximum power delivered to the load

$$V_{m,\max} = V_{CC} \qquad V_{\min} = -V_{CC} + V_{CE2,sat} \Big|_{when\ Q_2 is\ sat} \cong -V_{CC}$$

$$P_{av,\max} = \frac{1}{2} \frac{V_{CC}^2}{R_L} \qquad V_{\max} = V_{CC} - V_{CE1,sat} \Big|_{when\ Q_1 is\ sat.} \cong V_{CC}$$

e) **Plot v_{out} and i_E in the space provided in Fig. 2.**

PROBLEM 5 (cont'd)

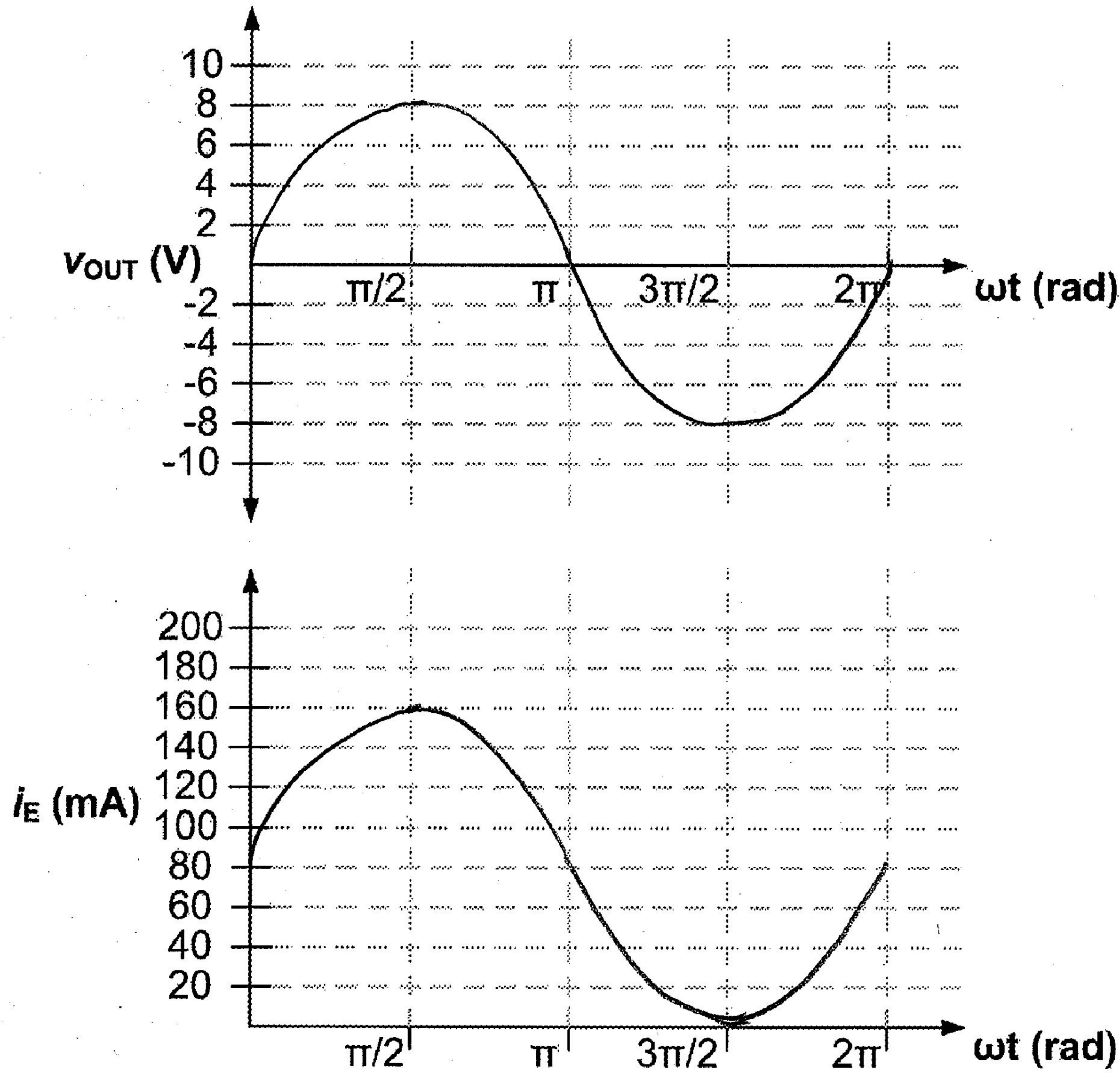
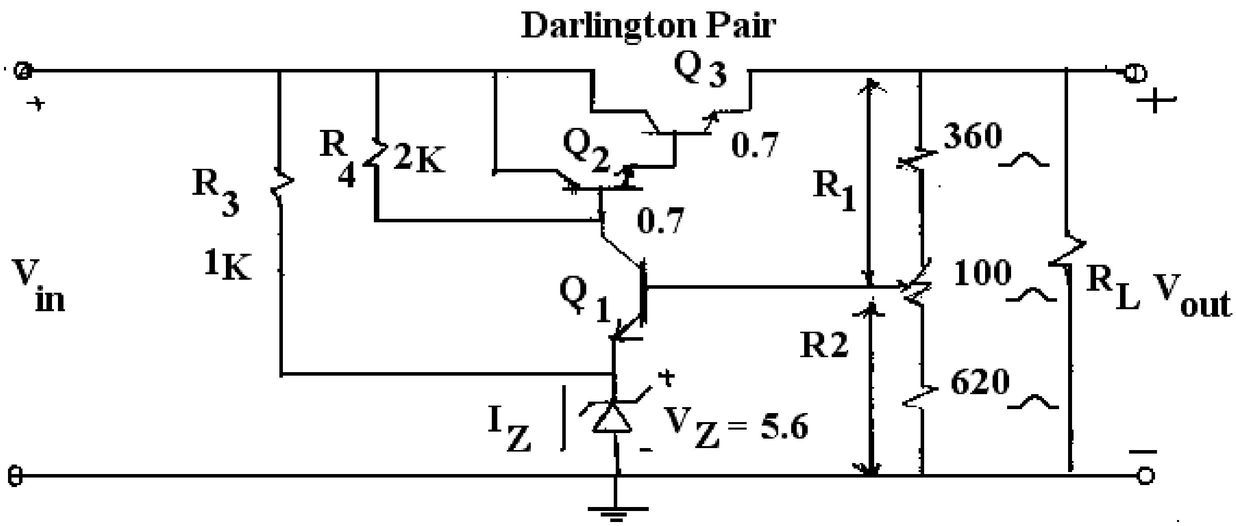


Figure 6: Power amplifier output voltage and emitter current.

Question 4 [Voltage Regulator]:-

For the following Voltage Regulator shown in the Figure,



For the following Voltage Regulator shown in Fig. 5,

a) **What are the minimum and maximum output voltages in the above circuit?**

b) **If V_{out} = 10 V, R_L = 5 Ω, β_1 (for Q_1) = β_2 =100, β_3 = 50 and V_{in} = 20 V, what is the current through the Zener diode?**

c) **Calculate the power dissipation of the Q_3 for a load voltage of 10 V and a load current of 2 A when V_{in} = 20 V**

[1] What are the minimum and maximum output voltages in the above circuit?

$$\therefore V_{out} = \frac{1}{\beta}(V_Z + V_{BE_1})$$

where $\beta = \frac{R_2}{R_1 + R_2} \Rightarrow A_f = \frac{1}{\beta} = 1 + \frac{R_1}{R_2}$

$$\therefore A_{f_{Max}} = 1 + \frac{360 + 100}{620} = 1.74$$

and $$A_{f_{min}} = 1 + \frac{360}{620+100} = 1.5$$

$$\therefore \; V_{out_{Max}} = 1.74 \, (5.6 + 0.7) \cong 11 \, V$$

$$V_{out_{Min}} = 1.5 \, (5.6 + 0.7) = 9.45 \, V$$

[2] if $V_{out} = 10V$, $R_L = 5\,\Omega$, $\beta_1 = \beta_2 = 100$ of Q_1 of Q_2

$\beta_3 = 50$ of Q_3 and $V_{in} = 20V$

<u>What is the Current through the Zener diode ?</u>

$$I_Z = I_{R_3} + I_{C_1 \, Q_1} \quad (1)$$

where $$I_{R_3} = \frac{V_{in} - V_Z}{R_3} = \frac{20 - 5.6}{1K} = 14.4 \, mA$$

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where $I_{R_3} = \frac{V_{in} - V_Z}{R_3} = \frac{20 - 5.6}{1k} = 14.4 \text{ mA}$

(3)

and

$$I_{C_1} = I_{R_4} - I_{B_2 Q_2} \quad (2)$$

where

$$I_{R_4} = \frac{V_{in} - V_{B_2}}{R_4} = \frac{20 - [0.7 + 0.7 + 10]}{2}$$

$$I_{R_4} = 4.3 \text{ mA}$$

and $I_{B_2} = \frac{I_{C_2}}{\beta_2} = \frac{1}{\beta_2} \frac{I_{C_3}}{\beta_3} \cong \frac{1}{\beta_2 \beta_3} I_L$

and $$I_{B_2} = \frac{I_{C_2}}{\beta_2} = \frac{1}{\beta_2} \frac{I_{C_3}}{\beta_3} \cong \frac{1}{\beta_2 \beta_3} I_L$$

where $$I_L = \frac{V_{out}}{R_L} = \frac{10\,V}{5\,\Omega} = 2\,A$$

$$\therefore I_{B_2} = \frac{2 * 1000}{100 * 50} = 0.4\,mA$$

from (2) $$\therefore I_{C_1} = 4.3 - 0.4 = 3.9\,mA$$

and

$$\therefore I_{B_2} = \frac{2 * 1000}{100 * 50} = 0.4\,mA$$

from (2) $$\therefore I_{C_1} = 4.3 - 0.4 = 3.9\,mA$$

and from (1)

$$I_Z = 14.4 + 3.9 = \underline{\underline{18.3\,mA}}$$

[3] Calculate the power dissipation of the Q_3 for a load Voltage of 10 V and a load Current of 2 A when $V_{in} = 20V$

$$P_{D_{Q_3}} = V_{CE_3} \, I_{C_3}$$

$$P_{D_{Q_3}} = V_{CE_3} \, I_{C_3}$$

$$= (V_{in} - V_{out}) \, (I_L)$$

$$\boxed{P_{D_{Q_3}} = (20 - 10)(2) = 20 \, W}$$

** !!