11.1

Refer to Fig 11.2. The upper limit of the output voltage is determined by the saturation of Q_1 as

$$v_{O\max} = V_{CC} - V_{CEsat}$$
$$= 5 - 0.3 = 4.7 \text{ V}$$

The corresponding input is

$$v_I = 4.7 + 0.7 = 5.4 \text{ V}$$

The bias current I is

$$I = \frac{0 - (-V_{CC} + V_{BE2})}{R}$$
$$= \frac{5 - 0.7}{1} = 4.3 \text{ mA}$$

The lower limit of v_O is determined by either Q_1 cutting off,

$$\frac{-v_O}{R_L} = I \Rightarrow v_O = -4.3 \text{ V}$$

or by Q_2 saturating,

$$v_O = -V_{CC} + V_{CEsat} = -4.7 \text{ V}$$

Obviously, $v_{O\min} = -4.3$ V

and the corresponding input is

$$v_I = -4.3 + 0.7 = -3.6 \text{ V}$$

If the emitter-base junction area of Q_3 is 14 made twice as large as that of Q_2, I becomes one half its previous value,

$$I = \frac{4.3}{2} = 2.15 \text{ mA}$$

and thus the lower limit of v_O changes to

$$v_{Omin} = -IR_L = -2.15 \text{ V}$$

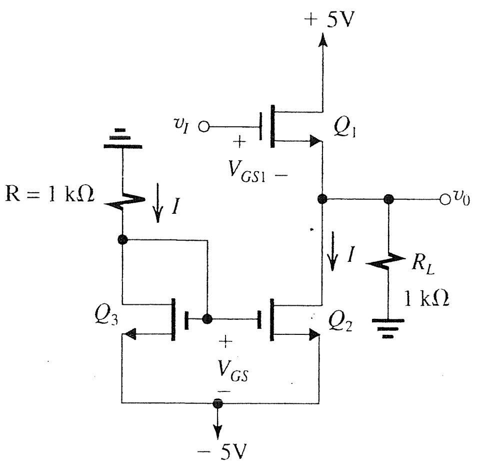
The corresponding value of v_I is

$$v_I = -2.15 + 0.7 = -1.45 \text{ V}$$

The upper limit does not change.

11.2

First we determine the bias current I as follows:



$$I = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_t)^2$$

But $V_{GS} = 5 - IR$

$$= 5 - I$$

Thus

$$I = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(5 - I - V_t)^2$$

$$I = 10(5 - I - 1)^2$$
$$\Rightarrow I^2 - 8.1I + 16 = 0$$
$$I = 3.416 \text{ mA and } V_{GS} = 1.584 \text{ V}$$

The upper limit on v_O is determined by Q_1 leaving the saturation region (and entering the triode region). This occurs when v_I exceeds V_{DI} by V_t volts,

$$v_{I\max} = 5 + 1 = +6 \text{ V}$$

To obtain the corresponding value of v_o we must find the corresponding value of V_{GS1}, as follows:

$$v_o = v_I - V_{VSI}$$
$$i_L = \frac{v_o}{R_L} = \frac{v_I - V_{GSI}}{1}$$
$$= v_I - V_{GS1} = 6 - V_{GS1}$$
$$i_1 = I + i_L$$
$$= 3.416 + 6 - V_{GS1}$$
$$= 9.416 - V_{GS1}$$

But $i_1 = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS1} - V_t)^2$

Thus, $9.416 - V_{GS1} = 10(V_{GS1} - 1)^2$

$$\Rightarrow V_{GS1}^2 - 1.9\, V_{GS1} + 0.0584 = 0$$
$$V_{GS1} = 1.869 \text{ V}$$
$$v_{O\max} = 6 - 1.869$$
$$= +4.131 \text{ V}$$

The lower lmit of v_o is determined either by Q_1 cutting off,

$$v_o = -IR_L = -3.416 \times 1 = -3.416 \text{ V}$$

or by Q_2 leaving sturation,

$$v_o = V_{GS} - V_t$$
$$= -5 + 1.584 - 1 = -4.416 \text{ V}$$

Thus, $v_{O\min} = -3.416$ V

The corresponding value of v_I is determined by moving that since Q_1 is on the verge of cut-off,

$V_{GS1} = V_t = 1$ V and

$$v_I = -3.416 + 1 = -2.416 \text{ V}$$

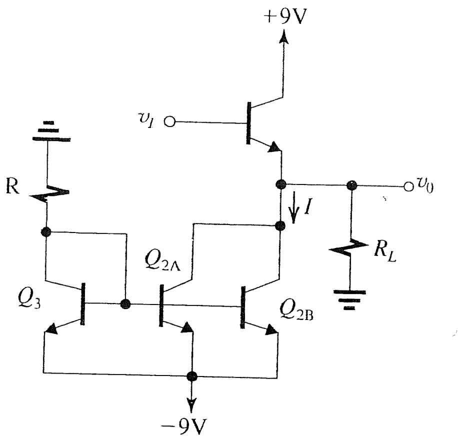
11.3

Refer to Fig. 11.2. With $V_{CC} = +9$ V, the upper limit on v_o is 8.7 V, which is greater than the required value of +7 V. To obtain a lower limit of −7V we select I so that

$IR_L = 7$

$\Rightarrow I = 7$ mA

Since we are provided with four devices, we can minimize the total supply current by paralleling two devices to form Q_2 as shown below.



The resulting supply current will be $3 \times \frac{I}{2}$ rather than $2I$ which is the value obtained in the circuit of Fig. 11.2. Then the supply current is 10.5 mA. The value of R is found from

$$R = \frac{8.3 \text{ V}}{3.5 \text{ mA}} = 2.37 \text{ k}\Omega$$

In a practical design we would select a standard value for R that results in I somewhat larger than 7 mA. Say, R=2.2kΩ

11.4

Refer to Fig. 11.2. For a load resistance of 100 Ω and v_o ranging between −5 V and +5 V, the maximum current through Q_1 is

$I + \frac{5}{0.1} = I + 50$, mA and the minimum current is $I - \frac{5}{0.1} = I - 50$, mA.

For a current ratio of 10,

$$\frac{I + 50}{I - 50} = 10$$

$\Rightarrow I = 61.1$ mA

$$R = \frac{9.3 \text{ V}}{61.1 \text{ mA}} = 152 \ \Omega$$

The incremental voltage gain is $A_v = \frac{R_L}{R_L + r_{e1}}$

For $R_L = 100 \ \Omega$;

At $v_o = +5$ V , $I_{E1} = 61.1 + 50 = 111.1$ mA

$$r_{e1} = \frac{25}{111.1} = 0.225 \ \Omega$$

$$A_v = \frac{100}{100 + 0.225} = 0.998 \text{ V / V}$$

At $v_o = 0$ V, $I_{E1} = 61.1$ mA

$$r_{e1} = \frac{25}{61.1} = 0.409 \ \Omega$$

$$A_v = \frac{100}{100.409} = 0.996 \text{ V / V}$$

At $v_o = -5$ V, I_{E1}=61.1−50=11.1 mA

$$r_{e1} = \frac{25}{11.1} = 2.25 \ \Omega$$

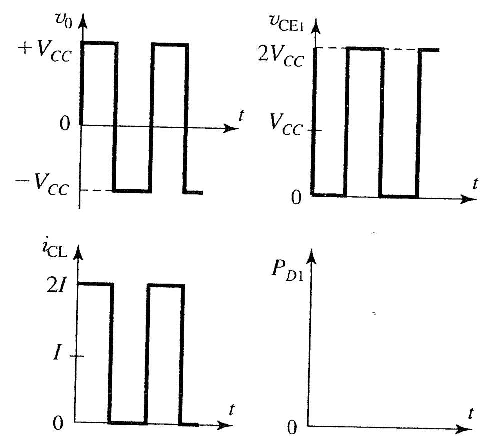
$$A_v = \frac{100}{102.25} = 0.978 \text{ V / V}$$

Thus the incremental gain changes by 0.998−0.978 = 0.02 or about 2% over the range of v_o .

11.5

Refer to Fig. 11.2 and 11.4

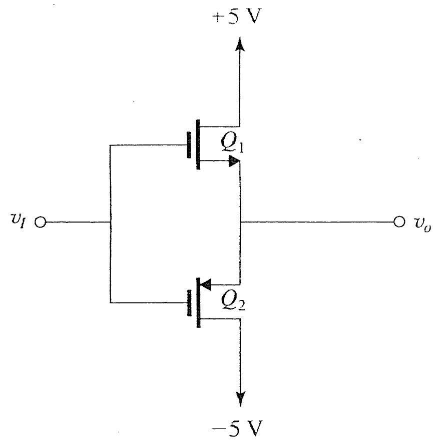
For v_o being a square wave of $\pm V_{CC}$ levels:



$P_{D1}|_{average} = 0$ For the corresponding sine wave curve [Fig. 11.4], $P_{D1}|_{avg} = \frac{1}{2} V_{CC} I$

For v_o a square wave of $\pm V_{CC}/Z$ levels :

11.10



Devices have $|V_t| = 0.5$ V

$\mu C_{ox} \frac{W}{L} = 2$ mA/V^2

For $R_L = \infty$, the current is normally zero, so $V_{GS} = V_t$

$\therefore v_o = v_I - V_{GS1} = 5 - 0.5 = 4.5$ V

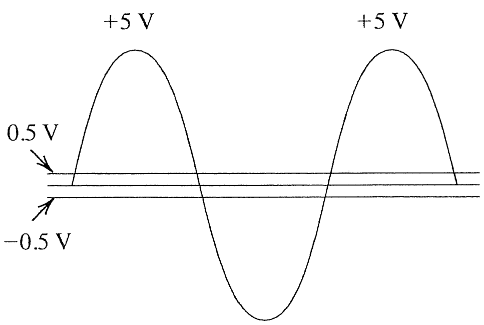
The peak output voltage will be 4.5 V

$\sin\theta = \frac{0.5}{5} \Rightarrow \theta = 5.74°$

Crossover interval $= 4\theta = 22.96°$

$= \frac{22.96}{360} \times 100$

$= 6.4\%$

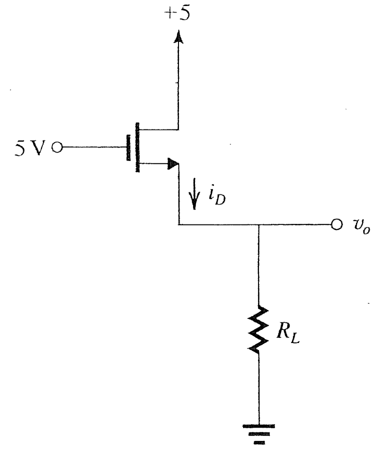


For $v_I = 5$ V, $v_o = 2.5$ V

$\therefore V_{GS} = 5 - 2.5 = 2.5$ V

$i_D = \frac{1}{2}\mu C_{ox}\frac{W}{L}(V_{GS} - V_t)^2$

$= \frac{1}{2} \times 2 \times (2.5 - 0.5)^2$



$i_D = 4$ mA and $R_L = \frac{2.5 \text{ V}}{4 \text{ mA}} = 625\ \Omega$

11.11

For $V_{CC} = 10$ V and $R_L = 100\ \Omega$, the maximum sine-wave output power occurs when $\hat{V}_o = V_{CC}$

and is $P_{L\max} = \frac{1}{2}\frac{V_{CC}^2}{R_L}$

$= \frac{1}{2} \times \frac{100}{100} = 0.5$ W

Correspondingly,

$P_{S+} = P_{S-} = \frac{1}{\pi}\frac{\hat{V}_o}{R_L}V_{CC}$

$= \frac{1}{\pi} \times \frac{10}{100} \times 10 = 0.318$ W

For a total supply power of

$P_s = 2 \times 0.318 = 0.637$W

The power conversion efficency η is

$\eta = \frac{P_L}{P_S} \times 100 = \frac{0.5}{0.637} \times 100 = 78.5\ \%$

For $\hat{V}_o = 5$ V,

$P_L = \frac{1}{2}\frac{\hat{V}_o^2}{R_L} = \frac{1}{2} \times \frac{25}{100} = \frac{1}{8}$ W

$P_{S+} = P_{S-} = \frac{1}{\pi}\frac{\hat{V}_o}{R_L}V_{CC}$

$= \frac{1}{\pi} \times \frac{5}{100} \times 10 = \frac{1}{2\pi}$

$P_{S'} = \frac{1}{\pi}$ W $= 0.318$ W

$\eta = \frac{1/8}{1/\pi} \times 100 = \frac{\pi}{8} \times 100 = 39.3\ \%$

11.12

$V_{CC} = 5\text{ V}$

For maximum η,

$\hat{V}_o = V_{CC} = 5\text{ V}$

The output voltage that results in maximum device dissipation is given by Eq. (12.20),

$$\hat{V}_o = \frac{2}{\pi}V_{CC}$$

$$= \frac{2}{\pi} \times 5 = 3.18\text{ V}$$

If operation is always at full output voltage, $\eta = 78.5\%$ and thus

$$P_{\text{dissipation}} = (1-\eta)P_s$$

$$= (1-\eta)\frac{P_L}{\eta} = \frac{1-0.785}{0.785}P_L = 0.274P_L$$

$$P_{\text{dissipation / device}} = \frac{1}{2} \times 0.274P_L = 0.137P_L$$

For a rated device dissipation of 1 W, and using a factor of 2 safety margin,

$$P_{\text{dissipation / device}} = 0.5\text{ W}$$

$$= 0.137P_L$$

$$\Rightarrow P_L = 3.65\text{ W}$$

$$3.65 = \frac{1}{2} \times \frac{25}{R_L}$$

$$\Rightarrow R_L = 3.425\ \Omega \text{ (i.e. } R_L \geq 3.425\ \Omega\text{)}$$

The corresponding output power (i.e., greatest possible output power) is 3.65W.

If operation is allowed at $\hat{V}_o = \frac{1}{2}V_{CC} = 2.5\text{ V}$,

$$\eta = \frac{\pi}{4}\frac{\hat{V}_o}{V_{CC}} \text{ (Eq. 12.15)}$$

$$= \frac{\pi}{4} \times \frac{1}{2} = 0.393$$

$$P_{\text{dissipation / device}} = \frac{1}{2}\frac{1-\eta}{\eta}P_L = 0.772P_L$$

$$0.5 = 0.772P_L$$

$$\Rightarrow P_L = 0.647\text{ W}$$

$$= \frac{1}{2}\frac{2.5^2}{R_L}$$

$$\Rightarrow R_L = 4.83\ \Omega \text{ (i.e., } \geq 4.83\ \Omega\text{)}$$

11.13

$$P_L = \frac{1}{2}\frac{\hat{V}_o^2}{R_L}$$

$$100 = \frac{1}{2}\frac{\hat{V}_o^2}{16}$$

$$\hat{V}_o = 56.6\text{ V}$$

$$V_{CC} = 56.6 + 4 = 60.6 \rightarrow 61\text{ V}$$

Peak current from each supply $= \frac{\hat{V}_o}{R_L} = \frac{56.6}{16}$

$$= 3.54\text{ A}$$

$$P_{s+} = P_{s-} = \frac{1}{\pi} \times 3.54 \times 61$$

Thus, $P_s = \frac{2}{\pi} \times 3.54 \times 61$

$$= 137.4\text{ W}$$

$$\eta = \frac{P_L}{P_S} = \frac{100}{137.4} = 73\%$$

Using Eq. (12.22),

$$P_{DN\text{ max}} = P_{DP\text{ max}} = \frac{V_{CC}^2}{\pi^2 R_L} = \frac{61^2}{\pi^2 \times 16}$$

$$= 23.6\text{W}$$

11.14

$$P_L = \frac{\hat{V}_o^2}{R_L}$$

$$P_{S+} = P_{S-} = \frac{1}{2}\left(\frac{\hat{V}_o}{R_L}\right)V_{SS}$$

$$P_S = \frac{\hat{V}_o}{R_L}V_{SS}$$

$$\eta = \frac{P_L}{P_S} = \frac{\hat{V}_o^2 / R_L}{\hat{V}_o V_{SS} R_L} = \frac{\hat{V}_o}{V_{SS}}$$

$\eta_{\text{max}} = 1(100\%)$, obtained for $\hat{V}_o = V_{SS}$

$$P_{L\text{max}} = \frac{V_{SS}^2}{R_L}$$

$$P_{\text{dissipation}} = P_S - P_L$$

$$= \frac{\hat{V}_o}{R_L}V_{SS} - \frac{\hat{V}_o^2}{R_L}$$

$$\frac{\partial P_{\text{dissipation}}}{\partial \hat{V}_o} = \frac{V_{SS}}{R_L} - \frac{2\hat{V}_o}{R_L}$$

$$= 0 \text{ for } \hat{V}_o = \frac{V_{SS}}{2}$$

Correspondingly, $\eta = \frac{V_{SS}/2}{V_{SS}} = \frac{1}{2}$ or 50%

11.15

$$A_v = \frac{R_L}{R_L + R_{\text{out}}} \text{ and } R_{\text{out}} = \frac{r_e}{2} = \frac{V_T}{2I_Q}$$

Now $A_v \geq 0.98$ for $R_L \geq 100\ \Omega$

$$\therefore 0.98 = \frac{100}{100 + R_{\text{out}}}$$

$$\Rightarrow R_{\text{out}} \simeq 2\ \Omega$$

$$R_{\text{out}} = 2 = \frac{V_T}{2I_Q}$$