10.1

10.1.

$$Z_p = R_p // [1/(j\omega C_p)] = \frac{R_p}{1 + j(f/f_p)};$$

$f_p = \frac{1}{2\pi R_p C_p}$; $Z_s = R_s + \frac{1}{j\omega C_s} = R_s \frac{1 + j(f/f_s)}{j(f/f_s)}$,

$f_s = \frac{1}{2\pi R_s C_s}$; $\frac{V_p}{V_o} = \frac{Z_p}{Z_p + Z_s} = \frac{1}{1 + Z_s/Z_p}$;

$$\frac{V_p}{V_o} = \frac{1}{1 + \frac{R_s}{R_p} \frac{[1 + j(f/f_s)][1 + j(f/f_p)]}{j(f/f_s)}}$$

$$= \frac{1}{1 + \frac{R_s}{R_p} \frac{1 - f^2/(f_p f_s) + jf(1/f_p + 1/f_s)}{j(f/f_s)}}.$$

Let $f_o = 1/\sqrt{f_p f_s}$. Then, for $f = f_o$, we obtain

$$\frac{V_p}{V_o} = \frac{1}{1 + \frac{R_s}{R_p}\left(1 + \frac{f_s}{f_p}\right)} = \frac{1}{1 + \frac{R_s}{R_p} + \frac{C_p}{C_s}}.$$

For a sustained sinusoid we want $A = 1 + R_s/R_p + C_p/C_s = 1 + R_2/R_1$.

This requires $R_2/R_1 = R_s/R_p + C_p/C_s$.

10.2

$T(s) = \frac{1 + R_2/R_1}{3 + s/\omega_o + \omega_o/s}$, $\omega_o = 2\pi 10^3$ rad/s,

$1 + R_2/R_1 = 3.21, 3.00, 2.81$. To find the poles, impose $T(s) = 1$. This yields

$$(s/\omega_o)^2 - (R_2/R_1 - 2)(s/\omega_o) + 1 = 0$$

$s = \omega_o \frac{(R_2/R_1 - 2) \pm [(R_2/R_1 - 2)^2 - 4]^{1/2}}{2}$. For $R_2/R_1 =$ 2.21, 2.00, and 1.81, we get, respectively,

(10.2)

$s = (+0.1050 \pm j0.9945)2\pi 10^3$ Complex Np/s

$s = \pm j 2\pi 10^3$ rad/s

$s = (-0.0950 \pm j0.9955)2\pi 10^3$ Complex Np/s.

10.3 (a) Since OA_1 keeps the bottom terminal of R_p at virtual ground potential, we can apply the results of Problem 10.1 and write

$B(jf_0) = \frac{V_{p2}}{V_0} = \frac{1}{1 + R_s/R_p + C_p/C_s}$, $f_0 = \frac{1}{2\pi(R_pR_sC_pC_s)^{1/2}}$.

By the superposition principle we have $V_o = -(R_2/R_1)(-R_3/R_p)V_{p2} + (1+R_2/R_1)V_{p2}$, or

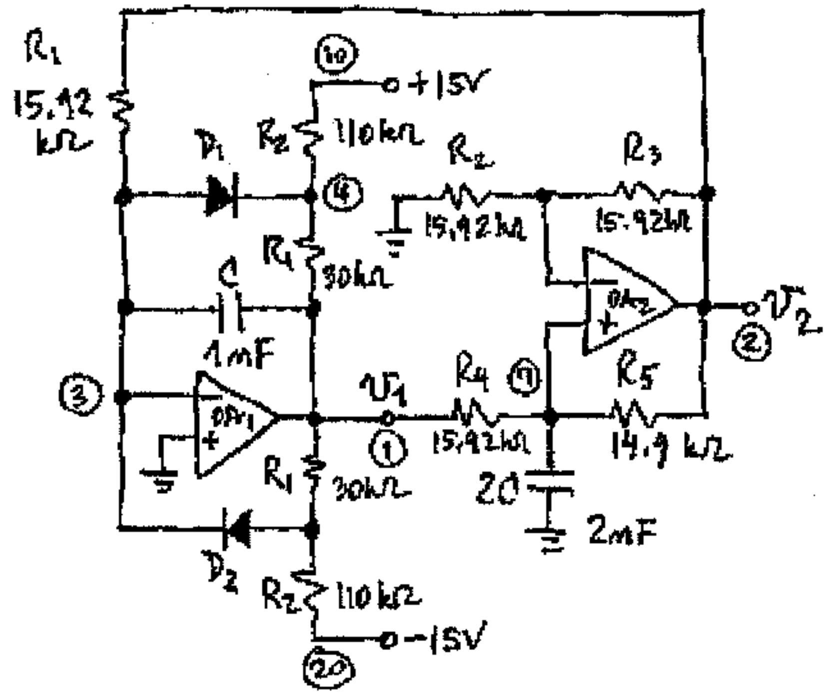
$A = \frac{V_o}{V_{p2}} = 1 + \frac{R_2}{R_1}\left(1 + \frac{R_3}{R_p}\right)$. Imposing $AB(jf_0) = 1$ gives $(R_2/R_1)(1 + R_3/R_p) = R_s/R_p + C_p/C_s$.

(b) Letting $R_2/R_1 = C_p/C_s$ gives $(R_2/R_1) \times (R_3/R_p) = R_s/R_p$, or $R_3 = (R_1/R_2)R_s$.

(c) $215\ \text{Hz} \le f_0 \le 21.5\ \text{kHz}$.

10.4 Let $C = 1\ \text{nF}$, $2C = 2\ \text{nF}$. Then, $R = 1/(2\pi 10^4 \times 10^{-9}) = 15.915\ \text{k}\Omega$ (use $15.8\ \text{k}\Omega$, 1%). Implement the variable resistance with a 14.7-kΩ resistor in series with a 2-kΩ pot. For a peak amplitude of 5V, impose $5 = (R_1/R_2)(15+0.7)+0.7$, which gives $R_2/R_1 = 3.65$. Use $R_1 = 30\ \text{k}\Omega$, $R_2 = 110\ \text{k}\Omega$.

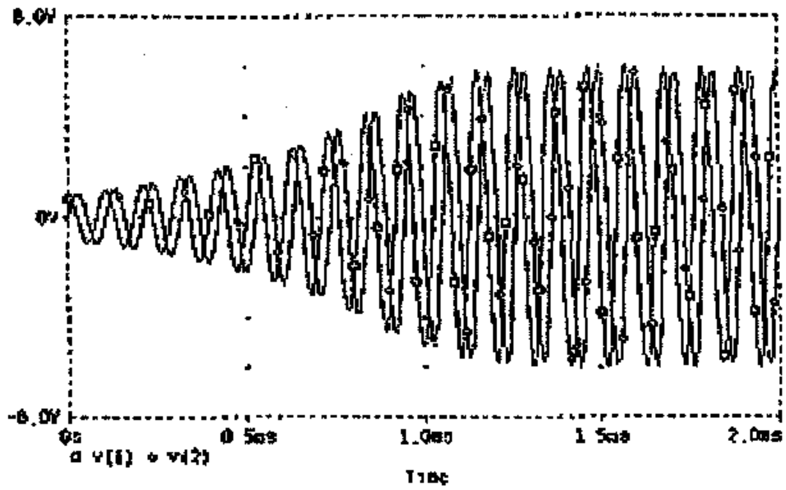
10.3

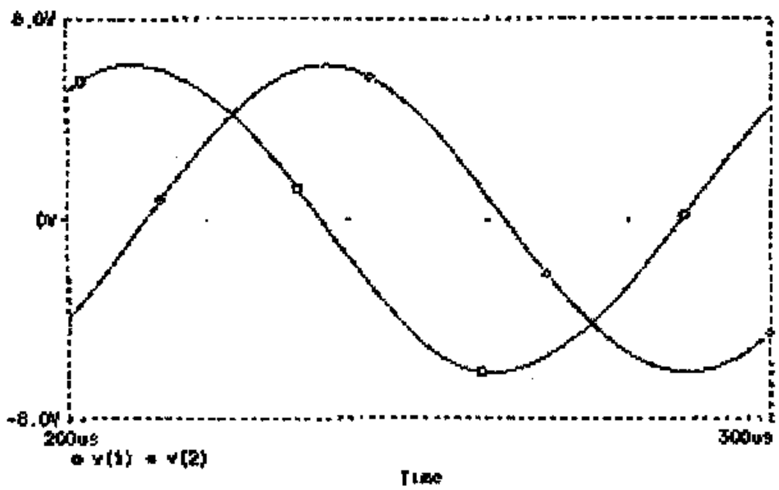


Running the accompanying PSpice program with two different sets of initial conditions gives the plots shown. Because of nonidealities, the actual frequency of oscillation is 9.74 kHz.

```
Problem 10.4
.lib eval.lib
VCC 10 0 dc 15V
VEE 20 0 dc -15V
C 1 3 1nF IC=1V
D1 3 4 D4148
D2 5 3 D4148
.model D4148 D(IS=0.1p Rs=16 CJO=2p Tt=12n Bv=100 Ibv=0.1p)
R2UP 4 10 110k
R1UP 4 1 30k
R1DN 1 5 30k
R2DN 5 20 110k
R1 3 2 15.92k
R2 0 6 15.92k
R3 6 2 15.92k
R4 1 7 15.92k
R5 7 2 14.9k
C+C 7 0 2nF IC=0
XOA1 0 3 10 20 1 uA741
XOA2 7 6 10 20 2 uA741
.tran 10us 2ms 0s 10us UIC
.probe
.end
```

10.4





$\boxed{10.5}$ At power turn-on, when the limiter is not yet operative, we have $V_1 = -(1/sRC)V_2$. According to Fig. 2.6(b), the voltage developed by the 2C capacitance is $V_{2C} = \frac{V_1}{R}\left(R_0 \| \frac{1}{s2C}\right)$, where $R_0 = -R/\varepsilon$, by Eq. (2.17). Substituting, we get $V_2 = (1+R/R)V_{2C} = 2 \times (V_1/R) \times (-R/\varepsilon)/[1-s(R/\varepsilon)2C] = -2V_1/(\varepsilon - sR2C)$.

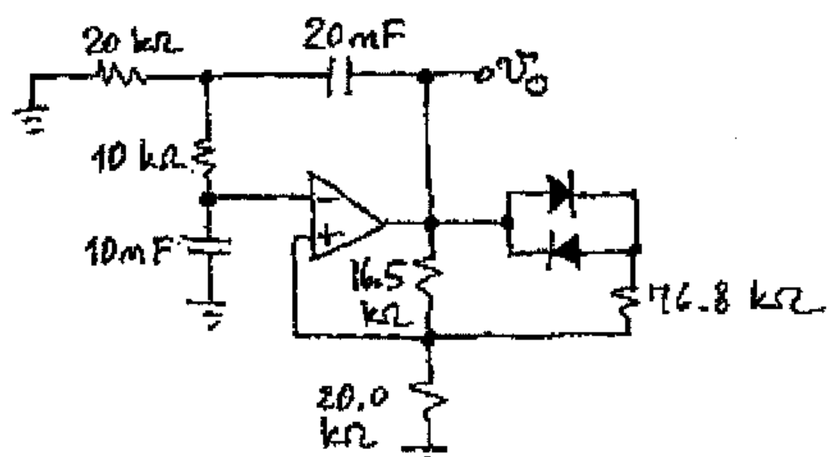
$T(s) = \frac{V_2}{V_1} \times \frac{V_1}{V_2} = \left(-\frac{2}{\varepsilon - s2RC}\right) \times \left(-\frac{1}{sRC}\right) =$

(10.5)

$\frac{2}{\varepsilon sRC - s^2 2(RC)^2}$. Imposing $T(s) = 1$ gives $2(RC)^2 s^2 - \varepsilon RCs + 2 = 0$, whose solutions are $s = \frac{\varepsilon \pm (\varepsilon^2 - 16)^{1/2}}{4RC} \cong \frac{\varepsilon/4 \pm j1}{RC}$.

10.6 (a) With the given component values we get $Q = 2/(7-4K)$. For oscillation to start, we need $Q < 0$, or $K > 7/4 \Rightarrow R_B/R_A > 3/4$; for oscillation to be sustained, we need $R_B/R_A = 3/4$. Let $R_A = 20.0$ kΩ. Then, $(3/4)R_A = 15$ kΩ. Implement R_B with a 16.5 kΩ resistor, and a diode limiter with a resistance of $1/13.6 - 1/16.5 = 76.8$ kΩ, as shown.

(b) $f_0 = 1/(2\pi \times \sqrt{20 \times 10 \times 10^6 \times 20 \times 10 \times 10^{-18}})$ $\cong 796$ Hz.



10.7 KCL when $v_O = +13\text{ V}$:

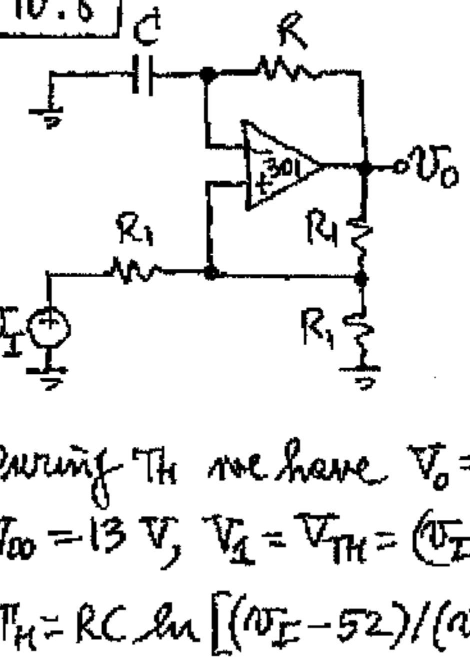
$$\frac{13-V_{TH}}{20} = \frac{V_{TH}}{10} + \frac{V_{TH}-(-15)}{30} \Rightarrow V_{TH} = 0.82\text{V}.$$

KCL when $v_O = -13\text{ V}$:

$$\frac{0-V_{TL}}{10} = \frac{V_{TL}+13}{20} + \frac{V_{TL}+15}{30} \Rightarrow V_{TL} = -6.27\text{V}.$$

$\tau = 330 \times 10^3 \times 10^{-9} = 330\,\mu s$. $T_H = 330 \times \ln[(13+6.27)/(13-0.82)] = 151.4\,\mu s$. $T_L = 330 \times \ln[(-13-0.82)/(-13+6.27)] = 237\,\mu s$. $f_0 = 1/(237+151) = 2.57$ KHz. $D = 100 \times 151/(151+237) = 39\%$.

10.8



Superposition:

$$v_P = \frac{R_1 \| R_1}{R_1 \| R_1 + R_1}(v_I + v_O) = (v_I + v_O)/3$$

$$v_O = \pm V_{sat} = \pm 13\text{V}$$

$$\Rightarrow V_T = (v_I \pm 13\text{V})/3.$$

During T_H we have $V_0 = V_{TL} = (v_I - 13)/3$ V, $V_\infty = 13$ V, $V_1 = V_{TH} = (v_I + 13)/3$ V; by Eq. (10.3), $T_H = RC \ln[(v_I - 52)/(v_I - 26)]$.

During T_L we have $V_0 = V_{TH}$, $V_\infty = -13$V, $V_1 = V_{TL}$, so $T_L = RC \ln[(v_I + 52)/(v_I + 26)]$.

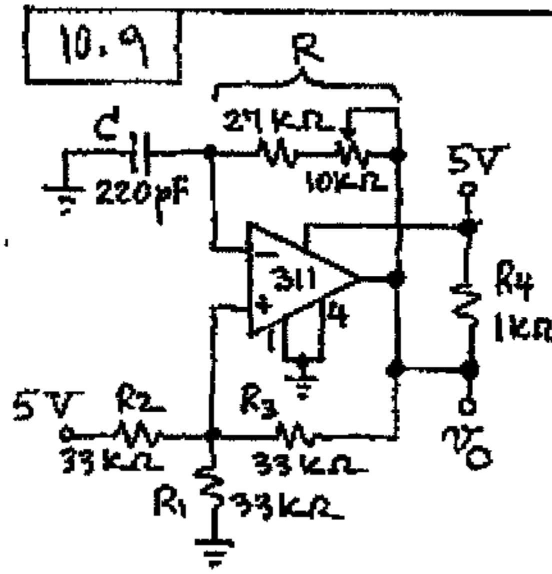
$$D = 100/(1 + T_L/T_H) = \frac{100}{1 + \left(\ln \frac{v_I + 52}{v_I + 26}\right) / \left(\ln \frac{v_I - 52}{v_I - 26}\right)}$$

(10.7)

$$f_0 = \frac{1}{T_L + T_H} = \frac{1}{RC \ln[(v_I^2 - 52^2)/(v_I^2 - 26^2)]}.$$

To prevent the arguments of the logarithms from becoming negative, we must restrict v_I within the range $-26\,V < v_I < 26\,V$.

10.9



In Fig. 10.9a let $R_4 = 1\,k\Omega$, $R = R_1 = R_2 = R_3 = 33\,k\Omega$.

Then, $C = 1/(R f_0 \ln 4)$

$= \frac{1}{10^5 \times 33 \times 10^3 \ln 4}$

$= 220$ pF. For R, use a 10-kΩ pot in series with a 27-kΩ resistor.

In Fig. 10.12a let $C = 220$ pF. Then, for $V_T = V_{DD}/2$, we get $R = 1/2.2Cf_0 = 20$ kΩ. Implement R with a 15-kΩ resistor in series with a 10-kΩ pot, and let $10R = 200$ kΩ.

10.10 (a) Use the circuit of Fig. 10.9a. Assume $V_{OL} = 0\,V$ and $V_{OH} = V_{CC}$, and arbitrarily impose $V_{TL} = (1/2)V_{TH}$. Letting $T_H/(T_L + T_H) = 0.6$ gives

$$\frac{\ln[(V_{CC} - V_{TL})/(V_{CC} - V_{TH})]}{\ln 2 + \ln[(V_{CC} - V_{TL})/(V_{CC} - V_{TH})]} = 0.6, \text{ or}$$

10.8

$(\ln x)/(\ln 2 + \ln x) = 0.6$, $x = (V_{CC} - V_{TL})/(V_{CC} - V_{TH})$. Solving gives $x = \exp(1.5 \ln 2)$, or $\exp(1.5 \ln 2) = (V_{CC} - V_{TL})/(V_{CC} - 2V_{TL})$. Solving, $V_{TL} = V_{CC}[\exp(1.5 \ln 2) - 1]/[2\exp(1.5 \ln 2) - 1] = 0.3926\, V_{CC}$, and $V_{TH} = 0.7853\, V_{CC}$. By Eq. (9.13),

$$\frac{1}{R_2} = 0.6464\left(\frac{1}{R_1} + \frac{1}{R_3}\right), \quad \frac{1}{R_1} = 0.2735\left(\frac{1}{R_2} + \frac{1}{R_3}\right).$$

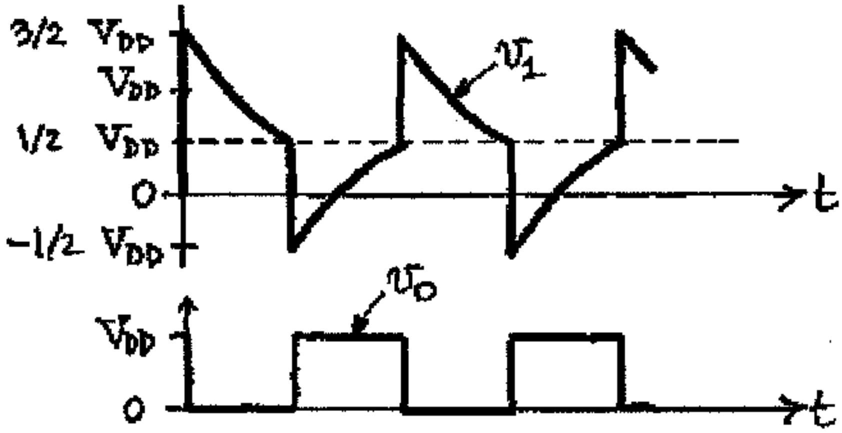
Let $R_4 = 2.2\,\mathrm{k\Omega}$ and $R_3 = 100\,\mathrm{k\Omega}$. Then, $R_1 = 182.8\,\mathrm{k\Omega}$ (use $182\,\mathrm{k\Omega}$) and $R_2 = 100\,\mathrm{k\Omega}$.

(b) We now get $x = \exp[(\ln 2)/1.5]$, which results in $V_{TL} = 0.2701 V_{CC}$ and $V_{TH} = 0.5402\, V_{CC}$. Use $R_4 = 2.2\,\mathrm{k\Omega}$, $R_3 = 100\,\mathrm{k\Omega}$, $R_1 = 58.74\,\mathrm{k\Omega}$ (use $59.0\,\mathrm{k\Omega}$), and $R_2 = 100\,\mathrm{k\Omega}$.

10.11 (a) Let $C = 220\,\mathrm{pF}$. Then, $R = 1/(2.2 \times 10^5 \times 220 \times 10^{-12}) = 20.7\,\mathrm{k\Omega}$ (use $20.5\,\mathrm{k\Omega}$).

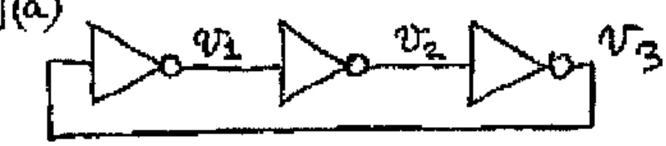
(b) It is readily seen that f_0 is maximized when V_T is halfway between 0 and V_{DD} ($V_T = 2.5\,\mathrm{V}$), and minimized when V_T is farthest away from 2.5V ($V_T = 4\,\mathrm{V}$). We have $f_0(V_T = 2.5\,\mathrm{V}) = 100\,\mathrm{kHz}$, and $f_0(V_T = 4\,\mathrm{V}) = 84.42\,\mathrm{kHz}$, indicating a percentage deviation of $100 \times [(84.42 - 100)/100] = -15.58\%$ maximum.

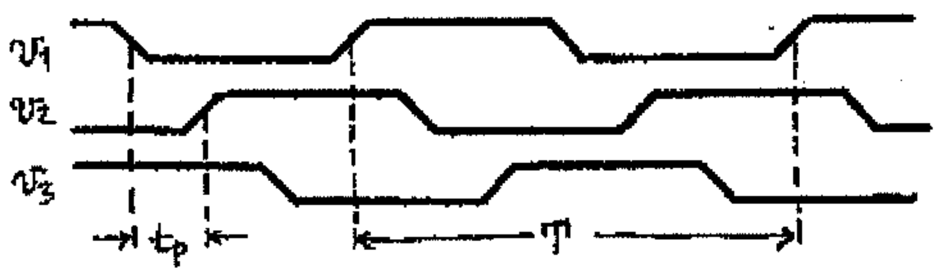
10.12 Letting v_1 denote the voltage at the node common to the resistors and the capacitor, we have the accompanying waveforms.



Applying Eq. (10.11), $f_0 = 1/2.2RC$.

10.13 (a)





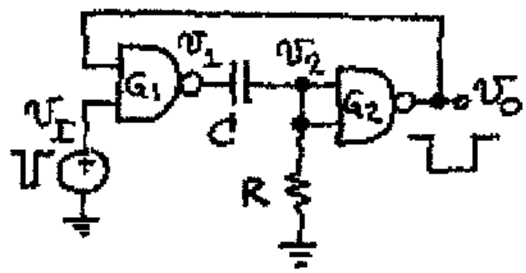
$T = 6t_p = 1/f_0 \Rightarrow t_p = 1/6f_0$.

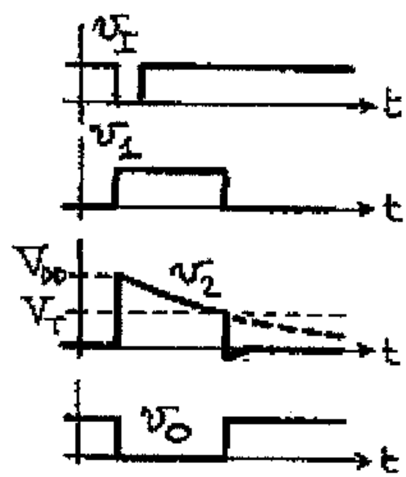
(b) To oscillate, the circuit needs an odd number of gates within the loop. With an even number, feedback is positive and the circuit will just sit in one of its two possible states permanently.

10.14 Let $C = 330$ pF. Then, $R = 10\times10^{-6}\times(0.69\times330\times10^{-12})^{-1} = 43.7$ kΩ (use 43.2 kΩ).

(b) $T_{(typ)} = 0.69\times43.2\times10^{3}\times330\times10^{-12} = 0.69\times14.26 = 9.88\ \mu s$; $T_{(min)} = 14.26\ \ln[5/(5-1.1)] = 3.54\ \mu s$. $T_{(max)} = 14.26\ \ln[5/(5-4)] = 22.94\ \mu s$. $100(3.54-9.88)/9.88 = -64\%$; $100(22.94-9.88)/9.88 = 132\%$. Thus, $-64\% < \Delta T(\%) < 132\%$.

10.15

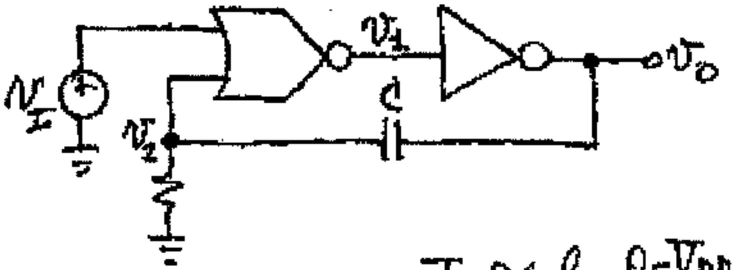




v_I must be a negative-going pulse and R must be returned to ground to ensure a logic high at the upper input to G_1. Using $V_0 = V_{DD}$, $V_\infty = 0$, $V_1 = V_T$, and $\Delta t = T$ in Eq. (10.3) we obtain $T = RC\ \ln(V_{DD}/V_T)$.

10.11

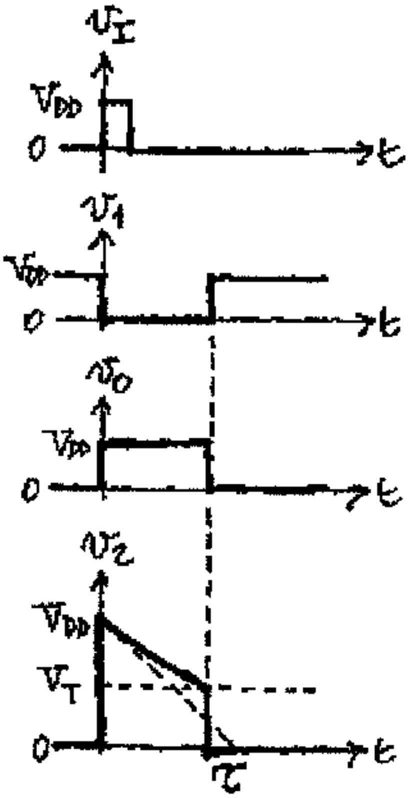
10.16



$$T = RC \ln \frac{0 - V_{DD}}{0 - V_T} = RC \ln \frac{1}{0.4}$$

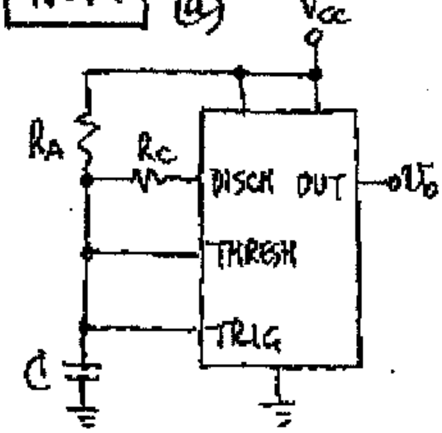
$$= 10^5 \times 220 \times 10^{-12} \ln 2.5$$

$$= 20.16\ \mu s.$$



10.17

(a)

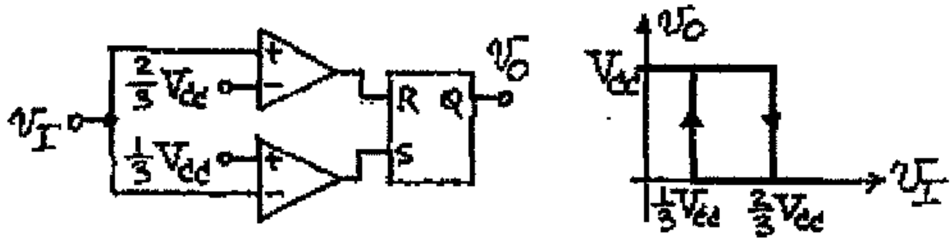


When Q_0 inside the 555 is OFF, C charges toward V_{CC} via R_A, so $T_H = R_A C \ln 2$. When Q_0 is saturated, C discharges toward $V_D = \frac{R_C}{R_A + R_C} V_{CC}$

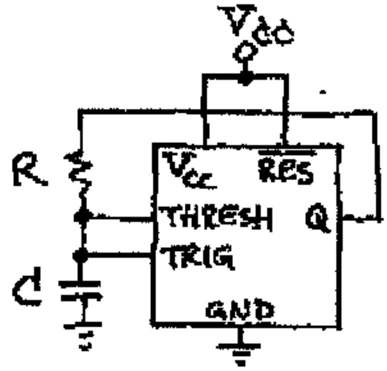
via the parallel $R_A \| R_C$. Applying Eq. (10.3) with $V_0 = (2/3)V_{CC}$, $V_1 = (1/3)V_{CC}$, $V_\infty = R_C V_{CC}/(R_A + R_C)$, and $\Delta t = T_L$ we get, after simplification, $T_L = (R_A \| R_C) C \ln \frac{2R_A - R_C}{R_A - 2R_C}$. For $D = 50\%$, impose $T_L = T_H$, or $\frac{R_A R_C}{R_A + R_C} C \ln \frac{2R_A/R_C - 1}{R_A/R_C - 2} = R_A C \ln 2$, or $R_A/R_C = \left[\ln \frac{2R_A/R_C - 1}{R_A/R_C - 2}\right] / [\ln 2] - 1$. Solving by iteration gives $R_A/R_C = 2.36218$

(b) Let $C = 1$ nF. With $D = 50\%$, $T = 2T_H \Rightarrow T_H = 1/2f_0 = 1/(2\times10^4) = 50\,\mu s$. Then, $R_A = T_H/C\ln 2 = 72.13$ kΩ (use 71.5 kΩ). Then, $R_C = 71.5/2.36218 = 30.27$ kΩ (use 30.1 kΩ).

10.18 (a) Since CMOS swings from rail to rail, $V_{OH} = V_{CC}$, $V_{OL} = 0$V. Moreover, $V_I < \frac{1}{3}V_{CC} \Rightarrow Q = \text{HIGH} \Rightarrow V_O = V_{OH}$; $V_I > \frac{2}{3}V_{CC} \Rightarrow Q = \text{LOW} \Rightarrow V_O = V_{OL}$. Thus, VTC is as shown:

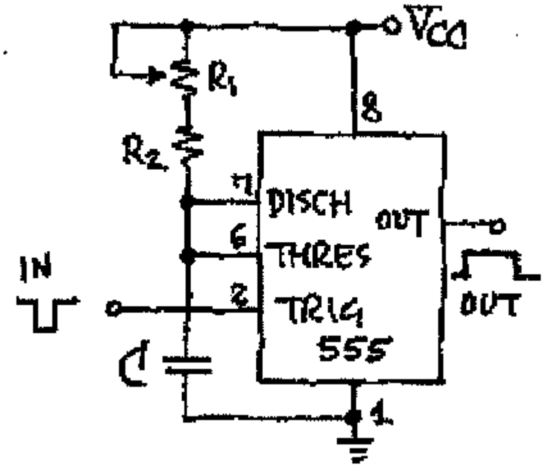


(10.13)



(b) Try $C = 330$ pF. Then, $R = \dfrac{1}{10^5 \times 330 \times 10^{-12} \ln 4} =$ 22 kΩ. Since the thresholds are symmetric, the duty cycle is 50%.

10.19 $T = 1.1RC$. $T = 1$ ms $\Rightarrow 10^{-3} = 1.1 \times (0 + R_2)C$.



$T = 1$ s $\Rightarrow 1 = 1.1 \times (10^6 + R_2)C$. Solving gives $C = 1\ \mu$F and $R_1 = 1$ kΩ.

10.20 $T = RC \ln[1/(1 - V_{TH}/V_{cc})]$, where $RC = 10 \times 10^{-6}/\ln 3$. Imposing $20 \times 10^{-6} = (10^{-5}/\ln 3) \times \ln[1/(1 - V_{TH}/15)]$ gives $V_{TH} = (8/9)15$ V. Likewise, imposing $5 = (10/\ln 3)\ln[1/(1 - V_{TH}/15)]$ gives $V_{TH} = (1 - 1/\sqrt{3})15 = 6.34$ V.

10.21 $f_0 = 10$ kHz $\Rightarrow T = 100\ \mu$s. Let $T_L = 25\ \mu$s, so $T_H = 75\ \mu$s. Following Example 10.3, we get $C = 1$ nF, $R_A = 72.1$ kΩ, $R_B = 36.1$ kΩ. Eq. (10.13):

(10.14)

$T - 25\mu s = (108.2\mu s)\ln[(1-0.5V_{TH}/5)/(1-V_{TH}/5)$.

$f_0 = 5kHz \Rightarrow T = 200\mu s \Rightarrow 200-25 = 108.2\times$

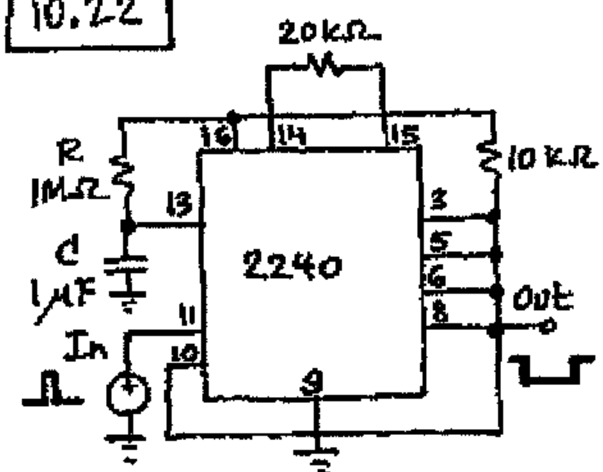
$\ln[(1-0.1V_{TH})/(1-V_{TH}/5) \Rightarrow (1-0.1V_{TH})/(1-0.2V_{TH})$

$= e^{175/108.2} \Rightarrow V_{TH} = 4.45V$. $f_0 = 20kHz \Rightarrow$

$T = 50\mu s \Rightarrow (1-0.1V_{TH})/(1-0.2V_{TH}) = e^{25/108.2} \Rightarrow$

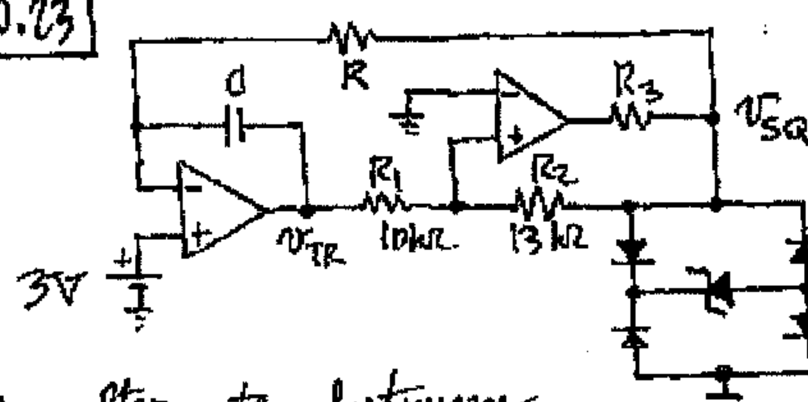
$V_{TH} = 1.71\ V$.

10.22



Let $C = 1\mu F$. Then, $R = \frac{1}{10^{-6}} = 1M\Omega$. 3 min = 180 sec = 128+32+16+4 sec. Thus, WIRE-OR pins # 3, 5, 6, and 8.

10.23

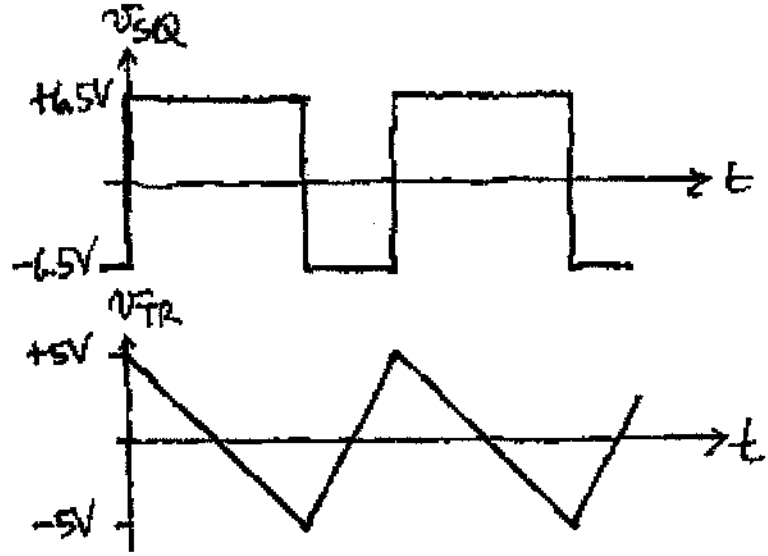


v_{SQ} alternates between

$\pm(2V_{D(on)} + V_Z) = \pm(1.4+5.1) = \pm 6.5V$;

v_{TR} alternates between $\pm(10/13)6.5 = \pm 5V$.

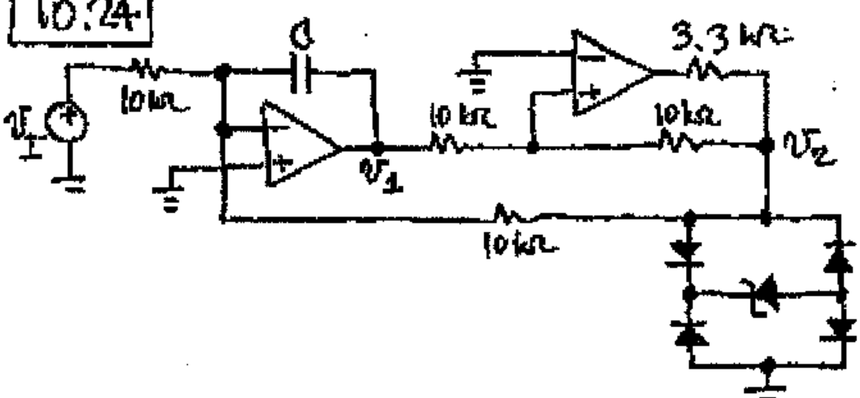
10.15



During T_H, $I_C = (6.5-3)/R = 116.6\,\mu A$, and
$T_H = \frac{C}{I_C}[5-(-5)] = \frac{10^{-9}}{116.6\times10^{-6}}10 = 85.7\,\mu s$

During T_L, $I_C = (6.5+3)/R = 316.6\,\mu A$, and
$T_L = 10^{-8}/(316.6\times10^{-6}) = 31.6\,\mu s$. $f_0 = 1/(T_L+T_H)$
$= 8.526$ kHz, D(%) = 73%

10.24



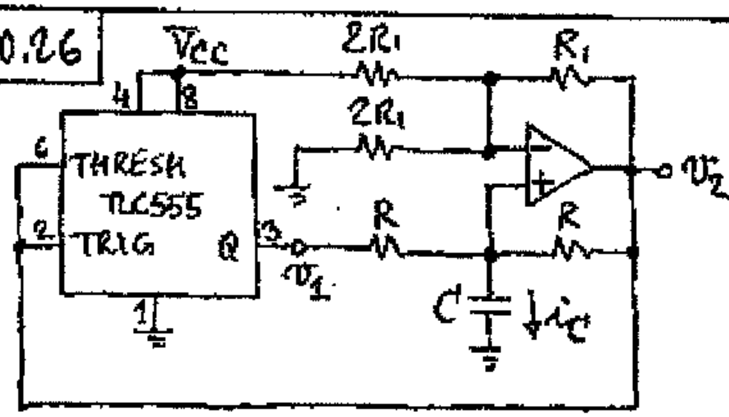
$v_2 = \pm(V_{Z5} + 2V_{D(on)}) = \pm 5V$; $V_T = \pm 5V$.
$v_2 = 5V \Rightarrow i_C(\rightarrow) = (5+v_I)/10^4 \Rightarrow C\Delta = I\Delta t$
$\Rightarrow T_H = 10RC/(5+v_I)$. $v_2 = -5V \Rightarrow i_C(\leftarrow)$
$= (5-v_I)/10^4 \Rightarrow T_L = 10RC/(5-v_I)$.

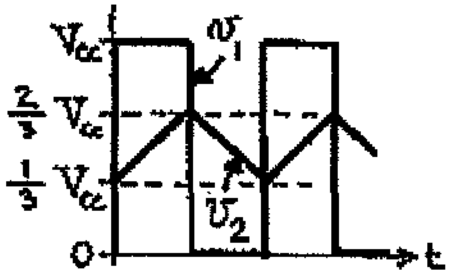
(10.16)

$D = 100\,T_H/(T_L+T_H) = 10(5-V_I)$; $f_0 = 1/(T_L+T_H)$ $= 1/4RC - v_I^2/100RC$. The permissible range is $-5V < v_I < +5V$.

10.25 To ensure $V_{clamp} = 5V$, use a 3.6 V zener diode and a CA3039 diode array. Let $R_1 = 10\,k\Omega$. Then, $R_2 = [(5-0.7)/5]10 = 8.66$ $k\Omega$. Use two 2.5 $M\Omega$ pots. Then, $R_5 = 2.5$ $k\Omega$ and $R_3 = 1.5\,k\Omega$. To find C, impose $50\times 10^{-6} = 2C(10/8.66)2.5\times 10^3$. Solving, $C = 8.66\,nF$.

10.26



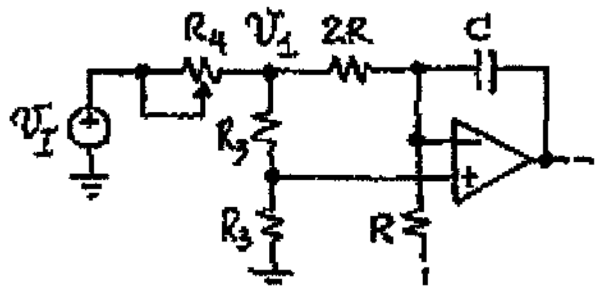


v_1 alternates between 0 and Vcc. To make i_C alternate between two symmetric values about zero, we must offset the integrator, as shown. Then, $i_C = (v_1 - V_{CC}/2)/R = \pm V_{CC}/2R$. We observe that as v_2 alternates between (1/3)Vcc and (2/3)Vcc,

(10.17)

or $\Delta v_2 = (1/3)V_{CC}$, the voltage change across the capacitor is half as large, or $\Delta V = (\frac{1}{6})V_{CC}$. Thus, $C(\frac{1}{6})V_{CC} = (V_{CC}/2R)T/2$ gives $f_0 = 1/T = 3/2RC$.

10.27 Modify the circuit by adding R_4, as shown. When the wiper is on the right,



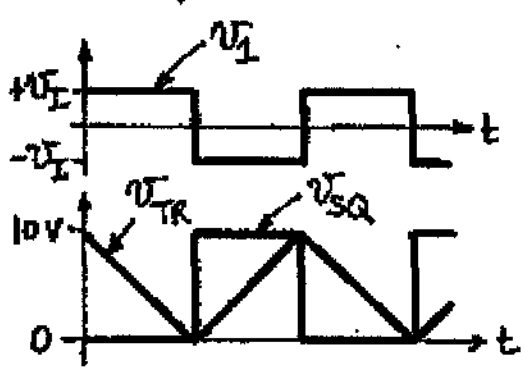
we want $f_0 = \left(1.25\frac{\text{kHz}}{\text{V}}\right)v_I$. Let $R = 10\ \text{k}\Omega$. Eq. (10.20) $\Rightarrow$

$$1.25\times10^3 = \frac{1}{8\times10^4\times C\times10}, \text{ that is, } C = 1\ \text{nF}.$$

When the wiper is at the left, we want $f_0 = \left(0.75\frac{\text{kHz}}{\text{V}}\right)v_I = \left(1.25\frac{\text{kHz}}{V_i}\right)v_1$. This yields $v_1 = 0.6v_I$, indicating that R_4 must drop $0.4v_I$ volts (max). Since $v_{N1} = v_{P1} = \frac{1}{2}v_1 = 0.3v_I$, we have, by KCL, $0.4v_I/R_4 = 0.3v_I/R_3 + 0.3v_I/(2R)$. Let $R_4 = 10\ \text{k}\Omega$ pot. Then, $0.4/10 = 0.3/R_3 + 0.3/20$, that is, $R_3 = 12\ \text{k}\Omega$. Summarizing, $R = 10.0\ \text{k}\Omega$, $2R = 20.0\ \text{k}\Omega$, $C = 1\ \text{nF}$, $R_3 = 12.1\ \text{k}\Omega$, $R_4 = 10\text{-k}\Omega$ pot.

(10.18)

$\boxed{10.18}$ CMP forms an inverting Schmitt trigger with $V_{TL} = 0$ V and $V_{TH} = 10$ V. Depending on whether M is open or closed, the gain of OA_1 is $+1$ V/V or -1 V/V, respectively. So, $v_1 = \pm v_I$, thus providing a square wave of controllable amplitude for OA_2 to integrate. Using $C\Delta V = I\Delta t$ with

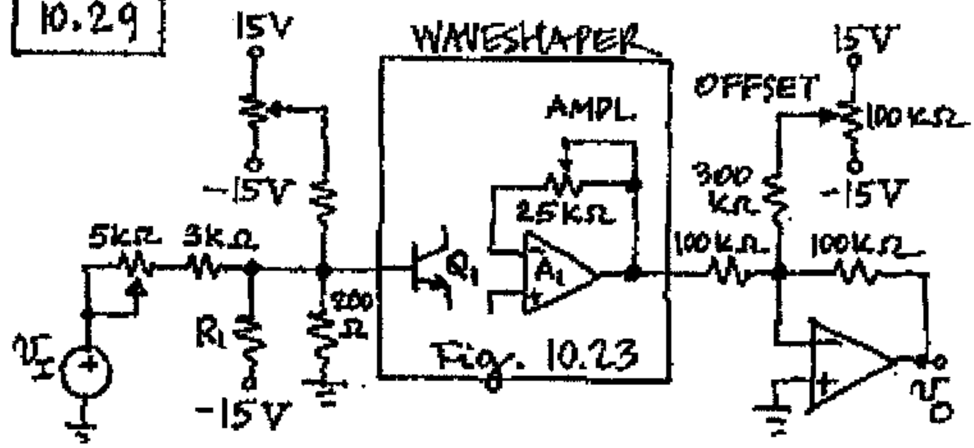


$\Delta V = 10$ V, $I = v_I/R$, and $\Delta t = T/2$, we get $T = 20RC/v_I$, or

$$f_0 = \frac{v_I}{20RC}.$$

10.19

10.29



Since the triangular wave output of the circuit of Fig. 10.21 has a 5V dc component, we use offsetting resistor R_1 to ensure that the input to Q_1 is centered around 0V. Since we want v_{B1} to vary from −172 mV to +172 mV, we find R_1 by imposing $v_{B1} = -172\,mV$ when $v_I = 0V$. Thus, $-15 \times 200/(200+R_1) \cong -0.172 \Rightarrow R_1 = 17.4\,k\Omega$. Output amplitude control is offered by the AMPL pot. Output offset control is offered by the OFFSET pot and corresponding network.

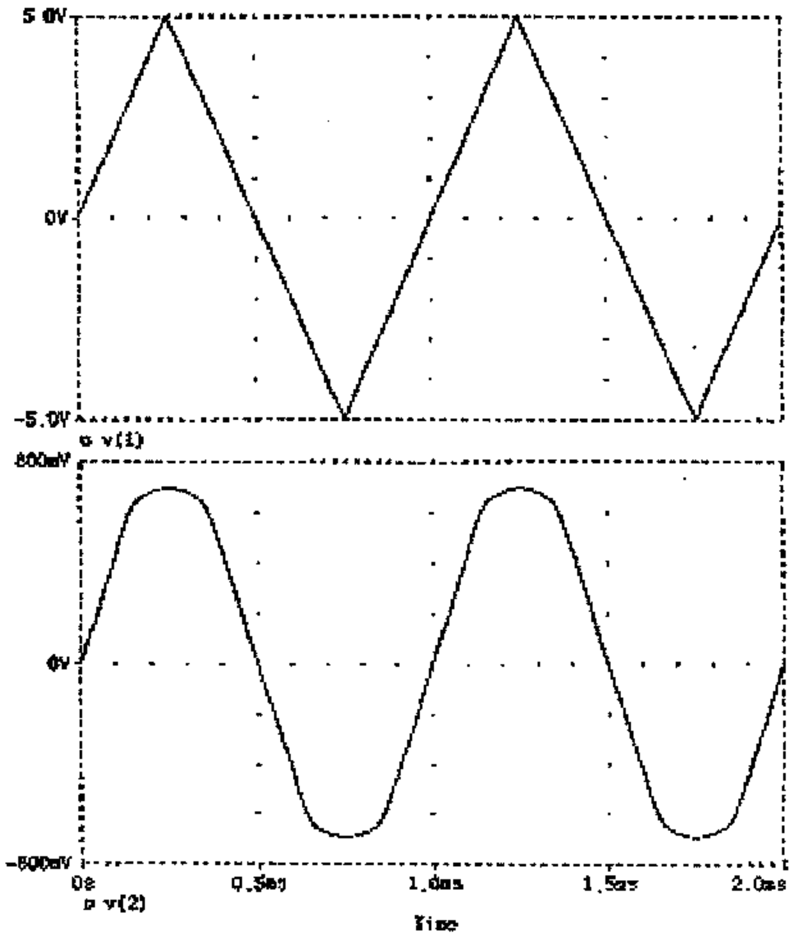
(10.20)

$\boxed{10.30}$ $v_{SIN} = 0.7 \sin 2\pi f t$; $dv_{SIN}/dt|_{t=0} = 0.7 \times 2\pi f$. The slope of a triangular wave of peak amplitude V_p and period T is $2V_p/(T/2) = 4V_p f$. Equating the slopes gives $V_p = 0.7 \times 2\pi/4 = 1.0996$ V. We have two conditions to meet: $[R_1/(R_1+R_2)]5 = 1.0996$, and $(1.0996 - 0.7)/(R_1 /\!/ R_2) = 1$ mA. Solving gives $R_1 = 512.2\ \Omega$ and $R_2 = 1.817\ k\Omega$.

For a diode to develop 0.7 V at 1 mA we need $I_S = 2 \times 10^{-15}$ A.

```
Problem 10.30
vi 1 0 pulse(-5V 5V -0.25ms 0.5ms 0.5ms 1us 1ms)
R2 1 2 1.817k
R1 2 0 512.2
D1 2 10 Diode
D2 10 2 Diode
Vs 10 0 dc 0
.model Diode D(Is=2fA n=1)
.tran 10us 2ms 0ms 10us
.probe
.end
```

10.21



10.31 (a) By the superposition principle,

$$V_T = \frac{R_3 \| R_4}{R_3 \| R_4 + R_2} V_{CC} + \frac{R_2 \| R_3}{R_2 \| R_3 + R_4} v_I = V_{T0} - k|v_I|,$$

$V_{T0} = V_{CC}/(1 + R_2/R_3 + R_2/R_4)$, $k = 1/(1 + R_4/R_2 + R_4/R_3)$, $v_I < 0$.

(b) By Eq. (10.21),

$$f_0 = \frac{1}{RC\,(V_{T0} - k|v_I|)/|v_I|) + T_D}$$

Making $RCk = T_D$ cancels out T_D, yielding

(10.22) $f_0 = |v_I|/RCV_{T0}$. $k = (1 + R_4/R_2 + R_4/R_3)^{-1} = T_D/RC \Rightarrow R_4 = (R_2 \| R_3)(RC/T_D - 1)$.

(c) For a sensitivity of 2 kHz/V, use $C = 2.2$ nF and $R = 45.3$ kΩ. For a low-frequency amplitude of 5 V we need

$$V_{T0} = \frac{R_3 // R_4}{R_3 // R_4 + R_2} 15 = 5 \Rightarrow R_2 = 2\,(R_3 // R_4).$$

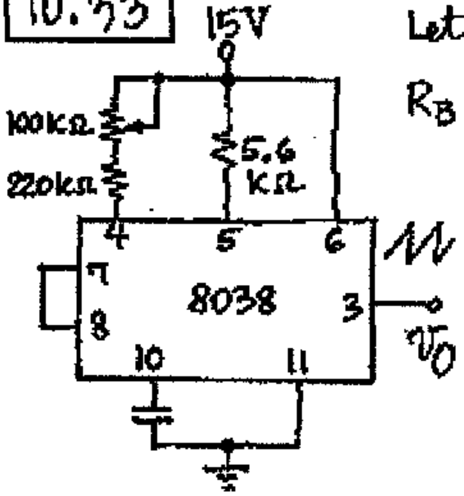
To cancel out the error due to T_D, we need

$$\frac{R_2 // R_3}{R_2 // R_3 + R_4} = \frac{T_D}{RC} = \frac{10^{-6}}{45.3\times 10^3 \times 2.2\times 10^{-9}} \cong 0.01.$$

Thus, $R_4 \cong 99\,(R_2 // R_3)$. Use $R_3 = 10.0$ kΩ, $R_2 = 19.6$ kΩ, $R_4 = 649$ kΩ, all 1%.

$\boxed{10.32}$ Use $C\Delta V = I\Delta t$, with $\Delta V = (\frac{2}{3} - \frac{1}{3})V_{CC} = \frac{1}{3}V_{CC}$, $I_H = I_A = v_I/R_A$, $I_L = 2I_B - I_A = 2v_I/R_B - v_I/R_A = v_I(2/R_B - 1/R_A)$, $\Delta t = T_H$ or $\Delta t = T_L$. Thus, $T_H = C\Delta V/I_H = \frac{1}{3} R_A C V_{CC}/v_I$;
$T_L = C\Delta V/I_L = \frac{1}{3} R_A C (V_{CC}/v_I)\, R_B/(2R_A - R_B)$.
$T = T_L + T_H = [2R_A/(2R_A - R_B)]\, \frac{1}{3} R_A C V_{CC}/v_I$.
$f_0 = \frac{1}{T} = 3[1 - R_B/(2R_A)][1/(R_A C V_{CC})]\, v_I$;
$D\% = 100\, T_H/T = 100\,[1 - R_B/(2R_A)]$.

10.33



Let $I_B = 0.5$ mA so that $R_B = (15/5)/0.5 = 6$ kΩ (use 5.6 kΩ). Eq. (10.23): $99 = 100\left(1 - \frac{5.6}{2R_A}\right) \Rightarrow R_A = 280$ kΩ. For a ±20% adjustment range, use a 220-kΩ resistor in series with a 100-kΩ pot.

Eq. (10.23): $10^3 = 3\left(1 - \frac{5.6}{560}\right)\frac{15/5}{280\times10^3\times C\times15}$

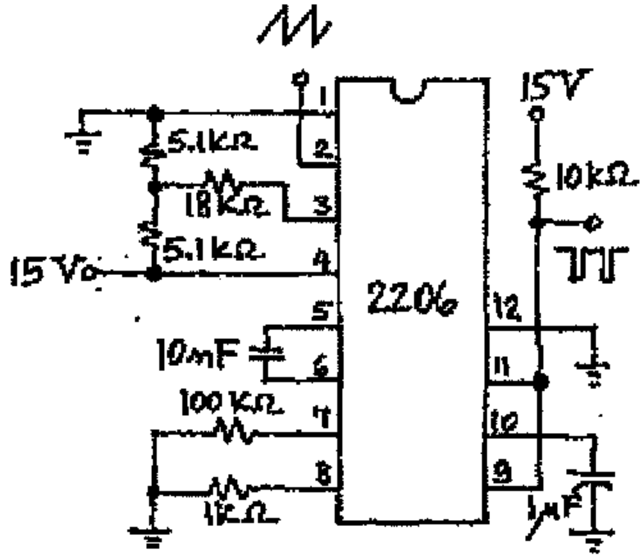
$\Rightarrow C \cong 2.2$ nF.

10.34 $v_I = 10$V $\Rightarrow i_I = 10/5 = 2$ mA $\Rightarrow I_A = I_B = 1$ mA $\Rightarrow I_C = 1$ mA. During half-period $T/2$ we have $C = (I_C T/2)/(\frac{1}{3}V_{CC}) = 10^{-3}\times\frac{1}{2}\times[1/(20\times10^3)]/5 = 5$ nF.

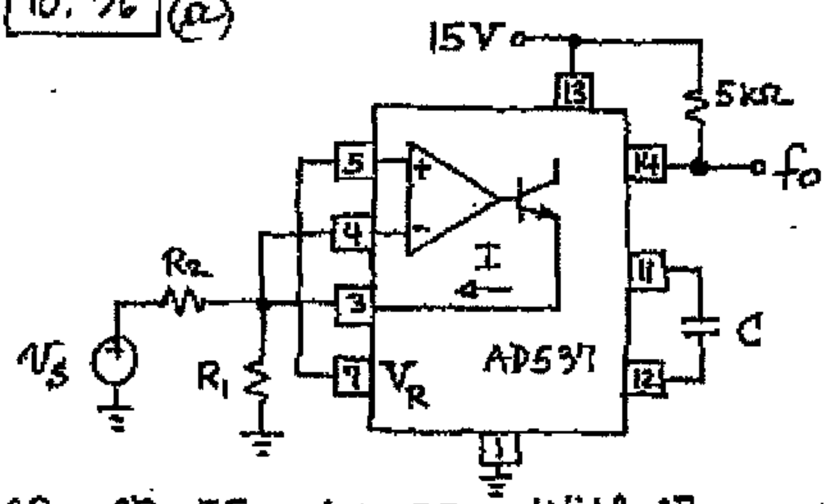
10.35 $T_H = R_1C$, $T_L = R_2C$. Thus, $f_o = 1/(T_L + T_H) = 1/[(R_1+R_2)C]$. Moreover, $D(\%) = 100R_1/(R_1+R_2) = 99\% \Rightarrow R_1 = 99R_2$. Use $R_2 = 1$ kΩ, $R_1 = 100$ kΩ. Then, $C = 1/(10^3\times101\times10^3) \cong 10$ nF. Since the dc offset is 7.5 V, use two 5.1-kΩ resistors. Since the peak amplitude is 2.5 V, the resistance seen by

(10.24)

pin 3 must be 2.5/0.120 = 20.8 kΩ. Use a series resistance of value 20.8 − (5.1∥5.1) ≅ 18 kΩ, as shown.



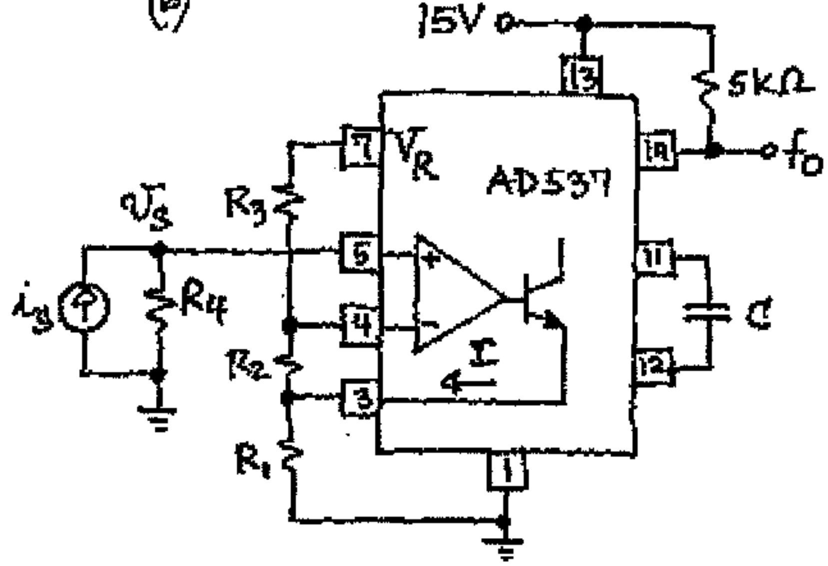
10.36 (a)



$v_N = v_P = V_R = 1.00$ V. With $v_I = +1.0$V, impose $I = 0$. This requires $R_2 = 9R_1$. With $v_I = -10$ V, impose $I = 1$mA. This requires $11/R_2 + 1/R_1 = 1$. Combining & solving, $R_2 = 20.0$ kΩ, $R_1 = 2.22$ kΩ; $20 \times 10^3 = 10^{-3}/(10C) \Rightarrow C = 5$ nF.

10.25

(b)



Use $R_4 = 50\,\Omega$ to convert i_S to a 0.2 V to 1.0 V voltage v_S. Impose $I = 0$ with $v_S = 0.2$V. Thus, $(V_R - 0.2)/R_3 = 0.2/(R_1 + R_2)$. Letting $V_R = 1.00$ V yields $R_3 = 4(R_1 + R_2)$. With $v_S = 1.0$ V, impose $I = 1$ mA and $v_3 = 1.0$V. Then, $I_{R_2} = I_{R_3} = 0$ and $R_1 = 1/1 = 1\,\text{k}\Omega$. Substituting yields $R_3 = 4(R_2 + 1)$. Use, for instance, $R_3 = 40.2\,\text{k}\Omega$ and $R_2 = 9.09\,\text{k}\Omega$. Finally, $C = 1$ nF.

10.37 $0\,^\circ F = -(5/9)32\,^\circ C = -17.78\,^\circ C = 273.2 - 17.78 = 255.4\,^\circ K$. We want $R_3/(0.2554) = R_2/(1-0.2554)$, that is, $R_2 = 2.91 R_3$. For a sensitivity of 10 Hz/°F $= (9/5)10 = 18$ Hz/°K, we want $18 = 1/(10^4 RC)$. Let $C = 2.2$ nF. Then, $R = 2.525$ kΩ. Let $R_3 = 2.55$ kΩ, 1%. Then, $R_2 = 2.91 \times 2.55 = 7.42$ kΩ (use 6.49 kΩ in series with a 2-kΩ pot). Finally, $R_1 = 2.525 - 2.55 /\!/ 7.42 = 627\,\Omega$ (use $374\,\Omega$ in series with a 500-Ω pot).

10.38 (a) $v_I > 0 \Rightarrow D_1 = \text{ON}$ & $D_2 = \text{OFF}$. Thus, $v_{P2} = 0$, $I_{R4} = 0$, and $i_{O1} = (1 + R_2/R_1) \times v_I/R_3 = v_I/R_p$, $R_p = R_3/(1 + R_2/R_1)$. $v_I < 0 \Rightarrow D_1 = \text{OFF}$ & $D_2 = \text{ON}$. This implies

$v_{P1} = v_{N1} = \left(1 + \frac{R_2 + R_3}{R_1}\right) v_I < 0$. Consequently, $i_{O1} = i_{R3} + i_{R4} = i_{R1} + i_{R4} = \frac{0 - v_I}{R_1} + \frac{0 - v_{P1}}{R_4} = -v_I/R_n$, $R_n = \frac{R_1 R_4}{R_1 + R_2 + R_3 + R_4}$. Imposing $R_n = R_p$ yields, after little algebra,

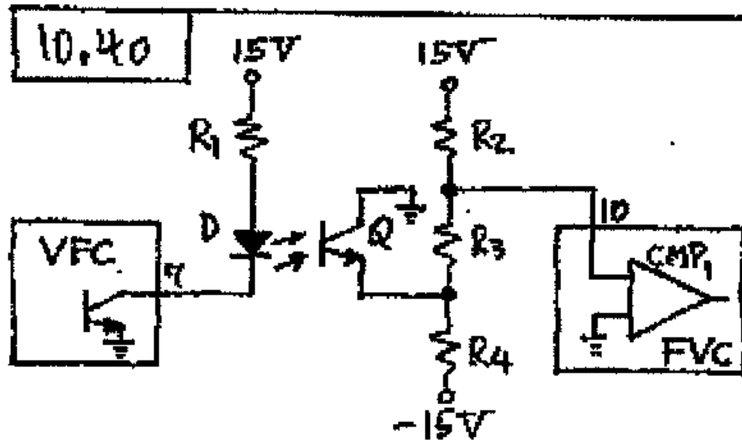
$$R_4 = R_3 \frac{R_1 + R_2 + R_3}{R_1 + R_2 - R_3}.$$

(10.27)

(b) Let $(1+R_2/R_1)=10$, so that a 1V input voltage is mapped into a 10V voltage at the output of OA_2. Use $R_1=$ 11.0 kΩ, $R_2=100$ kΩ. For $i_{O1(max)}=0.25$ mA, use $R_3=10/0.25=40$ kΩ (use 40.2 kΩ). Then, $R_4=85$ kΩ (use 84.5 kΩ). Finally, $C_1=1$ nF, $C=330$ pF (NPO).

10.39 Following Example 10.8, $C=330$ pF, $R=34.8$ kΩ in series with a 10 kΩ pot. By Eq. (10.34), $C_1=330\times10^{-12}\times7.5/0.01=$ $0.247\,\mu F$ (use $0.33\,\mu F$). Then, $\tau=RC_1=$ $40.4\times10^3\times0.33\times10^{-6}=13.3$ ms. Since $\ln(0.1/100)\cong-7$, the delay is approximately $7\times13.3\cong100$ ms.

10.40



To ensure $I_F\cong10$ mA, use $R_1=1.3$ kΩ. Impose a ±3V swing at pin 10 of the FVC. Then, when Q is off, we want

(10.28)

$v_{10} = -3V$, that is, $18/R_2 = 12/(R_3+R_4)$. When Q is on (saturation), we want $12/R_2 = 3/R_3$. This yields $R_2 = 4R_3$. We have two equations in three unknowns. Let $R_4 = 10 k\Omega$. Then, $R_3 = 6.2$ $k\Omega$ and $R_2 = 24 k\Omega$, all 5%.