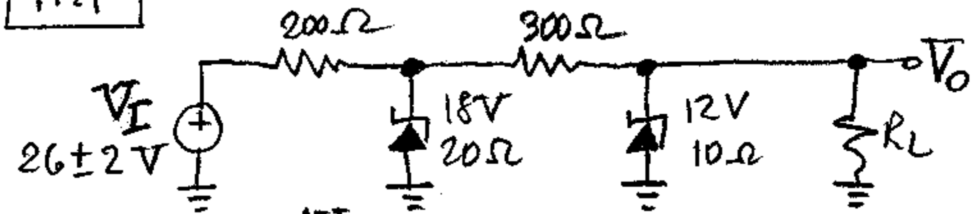
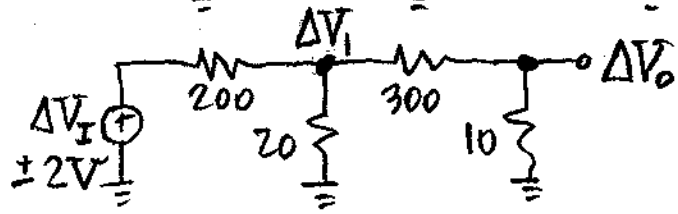
(11.1)

11.1





$$\Delta V_1 = \frac{20 \| 310}{200 + 20 \| 310}(\pm 2) = \pm 171.7 \text{ mV}$$

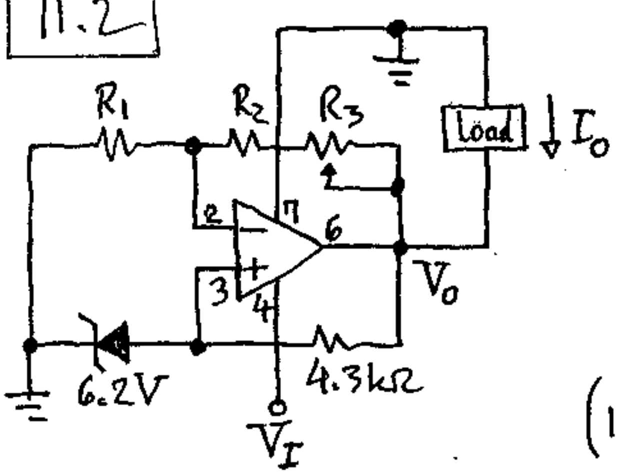
$$\Delta V_O = \frac{10}{300+10}(\pm 171.7 \text{ mV}) = \pm 5.54 \text{ mV}$$

Line regulation = 2.77 mV/V ≅ 0.023%.

Load regulation $= -10 \| [300 + (200 \| 20)] \cong -9.7$ V/A $= -9.7$ mV/mA $\cong -0.08\%$/mA.

$R_{L(min)} \cong 12 / [(18-12)/300] = 600\ \Omega$.

11.2



Wiper at left:

$$\left(1 + \frac{R_2}{R_1}\right)6.2 = 10$$

$$\Rightarrow R_2 = 0.613 R_1$$

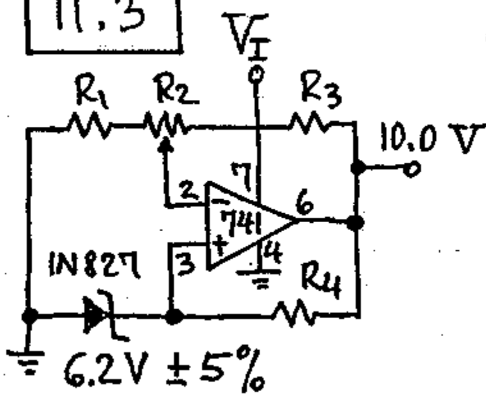
Wiper at right:

$$\left(1 + \frac{R_2 + 10}{R_1}\right)6.2 = 15$$

$\Rightarrow R_1 = 12.4$ kΩ, $R_2 = 7.68$ kΩ. Allowing 2 V of leeway, $-36\text{ V} \le V_I \le -17\text{ V}$. Moreover, $|I_O| \le 25$ mA.

(11.2)

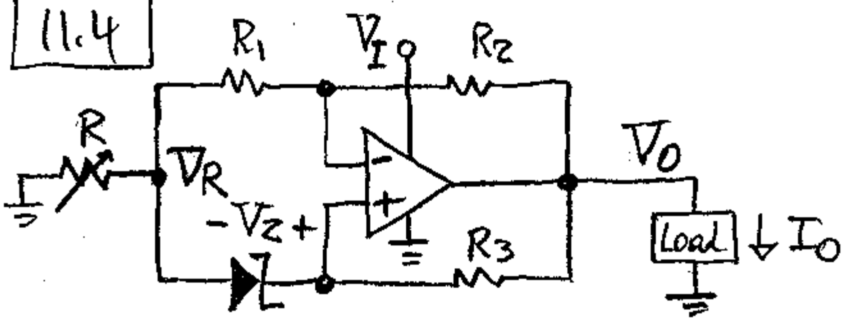
11.3



(a) $R_4 = (10-6.2)/7.5 = 507\ \Omega$ (use $511\ \Omega$). Using 1% resistors, the wiper voltage range must be $6.2\text{V} \pm (5+2)\%$, or $5.77\ \text{V} \le V_2 \le 6.63\ \text{V}$. To be on the safe side, impose $5.7\ \text{V} \le V_2 \le 6.7\ \text{V}$. Let R_2 be a 10-kΩ pot, so $I_{R_2} = (6.7-5.7)/10 = 0.1$ mA; $R_1 = 5.7/0.1 = 57\ \text{k}\Omega$ (use $56.2\ \text{k}\Omega$); $R_2 = (10-6.7)/0.1 = 33\ \text{k}\Omega$ (use $32.4\ \text{k}\Omega$).

(b) $\Delta V_Z = 10^{-6} V_Z \times \Delta T \times TC(V_Z) = 10^{-6} \times 6.2 \times 70 \times 10 = 4.34\ \text{mV}$; $\Delta V_{OS} = (5\ \mu\text{V}/°\text{C}) \times (70°\text{C}) = 0.35\ \text{mV}$; $\Delta V_{O(max)} = (10.0/6.2) \times (4.34 + 0.35) \cong 7.6\ \text{mV}$.

11.4



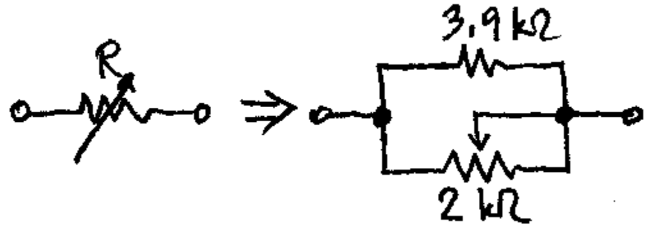
(a) $V_O = V_R + (R_1+R_2)V_Z/R_1$, $I_Z = V_{R_3}/R_3 = V_{R_2}/R_3 = R_2 \times I_{R_2}/R_3 = R_2 I_{R_1}/R_3 = R_2 V_Z / R_1 R_3$.

(b) $V_R = R \times (I_{R_1} + I_Z) = R[V_Z/R_1 + R_2 V_Z / R_1 R_3] = (R V_Z/R_1)(1 + R_2/R_3)$. $V_O = V_Z \times$

(11.3)

$[1 + R_2/R_1 + (R/R_1)(1 + R_2/R_3)]$.

(c) $R_1 = 39\ k\Omega$, $R_2 = 24\ k\Omega$, $R_3 = (10-6.2)/7.5 = 511\ \Omega$. $R = 0 \Rightarrow V_O = 10\ V$; $R = R_{max} \Rightarrow V_O = 20\ V \Rightarrow 6.2(R_{max}/39)(1 + 24/0.511) = 10$ $\Rightarrow R_{max} = 1.31\ k\Omega$. Use a 2-kΩ pot in parallel with a 3.9 kΩ resistor:



$\boxed{11.5}$ (a) $V_{REF} = V_{BE1} + R_1 I_{C1}$. $V_N = V_P \Rightarrow R_2 I_{C2} = R_1 I_{C1}$. Moreover, $R_2 I_{C2} = R_2 \times (V_{BE1} - V_{BE2})/R_3 = (R_2/R_3) \ln(I_{C1}/I_{C2}) V_T$. Substituting $I_{C1}/I_{C2} = R_2/R_1$ yields $V_{REF} = V_{BE1} + K V_T$, $K = (R_2/R_3) \ln(R_2/R_1)$.

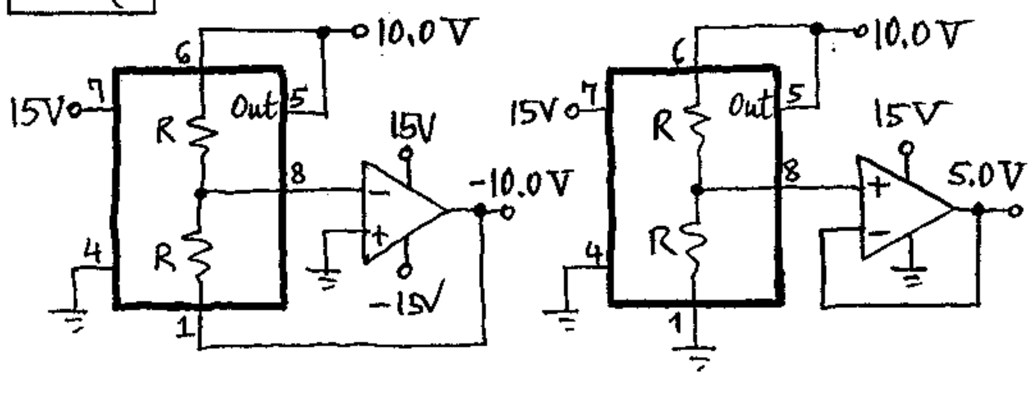
(b) Recycling Eq. (11.14), $K = (V_{G0} - V_{BE1})/V_T + 3$. Let $I_{C1} = 0.2\ mA$, so that $V_{BE1} = 25.7 \ln[0.2\times10^{-3}/(5\times10^{-15})] = 0.627\,V$. Then, $K = (1{,}205 - 627)/25.7 + 3 = 25.5$. $R_1 = (V_{REF} - V_{BE1})/I_{C1} = (1.282 - 0.627)/0.2 = 3.27\ k\Omega$ (use $3.24\ k\Omega$). Let $I_{C2} = (1/5) I_{C1}$. Then, $R_2 = 5R_1 = 16.35\ k\Omega$ (use $16.5\ k\Omega$). $R_3 = (R_2/K)\ln(R_2/R_1) = (16.35/25.5)\ln 5 = 1.03\ k\Omega$ (use $1.02\ k\Omega$). Summarizing, $R_1 = 3.24\ k\Omega$, $R_2 = 16.5\ k\Omega$, $R_3 = 1.02\ k\Omega$.

11.4

11.6 (a) $KV_T = R_2 I_{C2} = R_2 I_{R_3} = R_2(V_{BE1} - V_{BE2})/R_3 = (R_2/R_3)V_T \ln(I_{C1}/I_{C2}) \Rightarrow K = (R_2/R_3)\ln(I_{C1}/I_{C2})$.

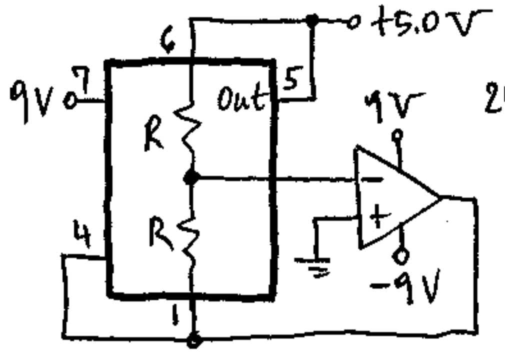
(b) For $TC(V_{REF}) = 0$ we need, by Eq. (11.14), $(R_2/R_3)\ln(I_{C1}/I_{C2}) = (V_{G0} - V_{BE3})/V_T + 3$, or $(R_2/R_3)\ln 5 = 1205/25.7 - \ln(0.2\times 10^{-3}/2\times 10^{-15}) + 3$, or $R_2/R_3 = 15.26$. But, $R_3 = V_{R_3}/I_{C2} = (V_{BE1} - V_{BE2})/I_{C2} = V_T[\ln(I_{C1}/I_{C2})/I_{C2} = [(25.7\text{ mV})/(40\ \mu\text{A})]\ln 5 = 1.03\text{ k}\Omega$, so $R_2 = 15.8\text{ k}\Omega$; $R_1 = (V_{REF} - V_{BE1})/I_{C1} = (1.282 - 0.651)/0.2 = 3.16\text{ k}\Omega$; $R_6 = (5 - 1.282)/(0.2 + 0.2/5 + 0.2) = 8.45\text{ k}\Omega$.

11.7

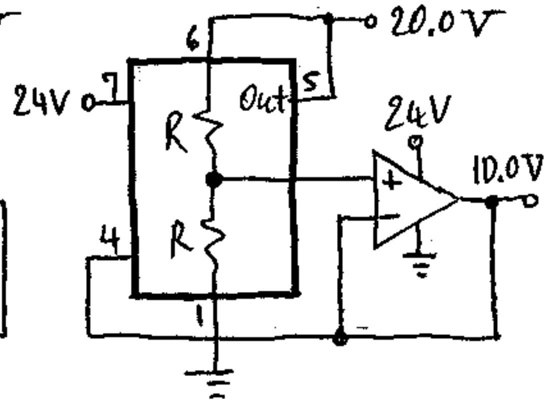


(a) (b)

11.5

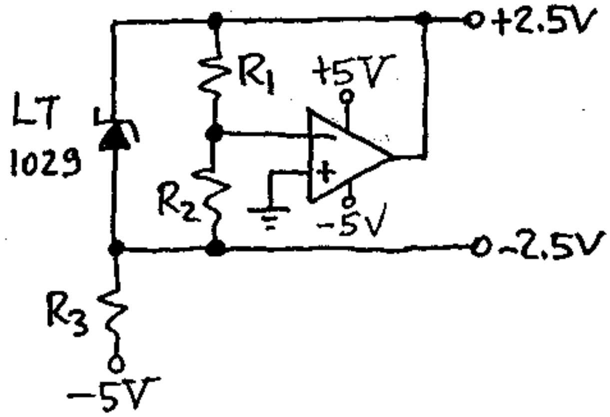


(c)



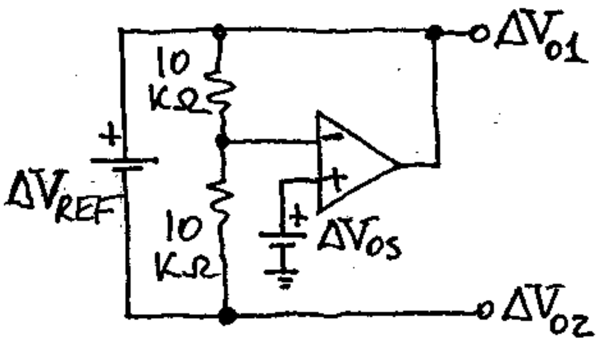
(d)

11.8



Let $R_1 = R_2 = 10.0$ kΩ. Impose $I_Z = 1$ mA. Then,

$$R_3 = \frac{2.5}{1 + 2.5/10} = 2\ \text{k}\Omega.$$



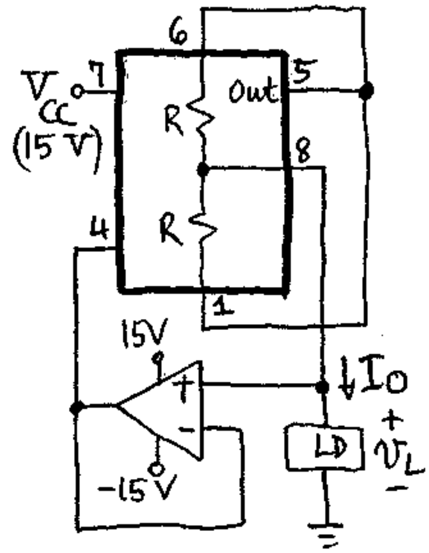
To investigate thermal drif, use the model on the left. Then,

$$|\Delta V_{O1}| = \Delta V_{OS} + 10 \times \Delta V_{REF}/(10+10) = \Delta V_{OS} + \Delta V_{REF}/2$$

Likewise, $|\Delta V_{O2}| = \Delta V_{OS} + \Delta V_{REF}/2$. The contribution from the op amp is about $6\,\mu V/°C = 10^6 \times 6 \times 10^{-6}/2.5 \cong 2.5$ ppm. Thus, the outputs can drift by as much as $2.5 + 20/2 = 12.5$ ppm.

(11.6)

11.9 (a) $i_O = (v_5 - v_4)/(R \| R) = (10\text{V})/(10\text{ k}\Omega) = 1\text{ mA}.$

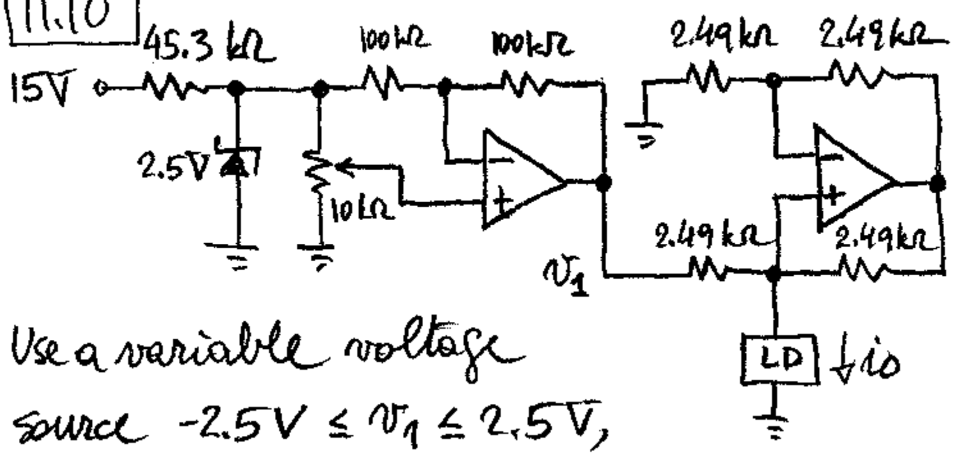


(b) The input voltage range of Fig. 11.7 indicates that $V_{DO} = 13.5 - 10 = 3.5\text{V}$. So, $v_{L(max)} = V_{CC} - V_{REF} - V_{DO} = 15 - 10 - 3.5 = 1.5\text{V}$. If a wider compliance is desired, then V_{CC} must be raised accordingly.

Since $TC(V_{OS}) \ll TC(V_{REF}) \ll TC(R) = 50\text{ ppm}/°C$, it follows that the primary source of error is $TC(R)$, so $TC(I_O) = 50\text{ ppm}/°C$, which corresponds to $\Delta I_O = [(50/10^6) \times 10^{-3}] = 50\text{ nA}/°C$.

(c) By Fig. 11.7, the trim range is from $(-0.1\text{ V})/(10\text{ k}\Omega) = -10\ \mu A$ to $+0.250/10 = 25\ \mu A$.

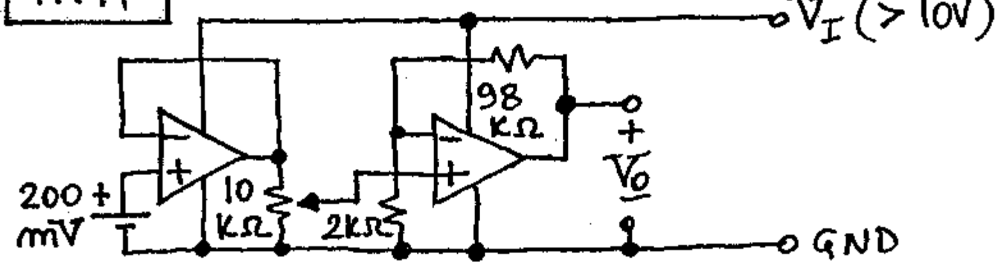
11.10



Use a variable voltage source $-2.5\text{V} \le v_1 \le 2.5\text{V}$, followed by a Howland current pump.

(11.7)

11.11

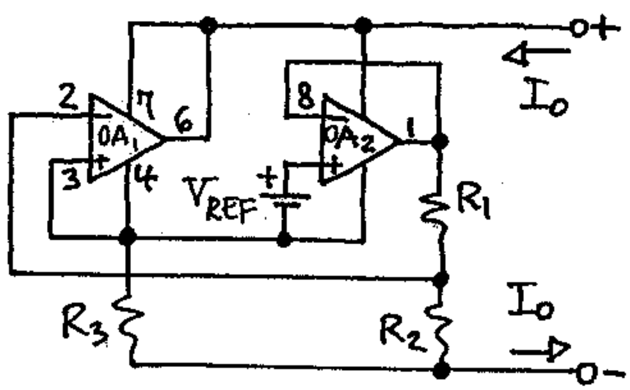


(a)

(b) The op amps contribute a drift of $2\times5 = 10\ \mu V/°C = 100\times 10\times10^{-6}/(200\times10^{-3}) = 0.005\%/°C$. Thus, the worst-case output drift is $0.003+0.005 = 0.008\%/°C$.
$90\ dB \Rightarrow 31.6\ \mu V/V$; $2\times(31.6+31.6/2) = 95\ \mu V/V = 100\times95\times10^{-6}/(200\times10^{-3}) = 0.047\%/V$. Thus, the worst-case line regulation is $0.001 + 0.047 = 0.048\%$.

11.12

(a) $I_O = I_{R_2} + I_{R_3}$. By OA_1's action, $V_{R_2} = V_{R_3}$.



By OA_2's action, $V_{R_1} = V_{REF}$

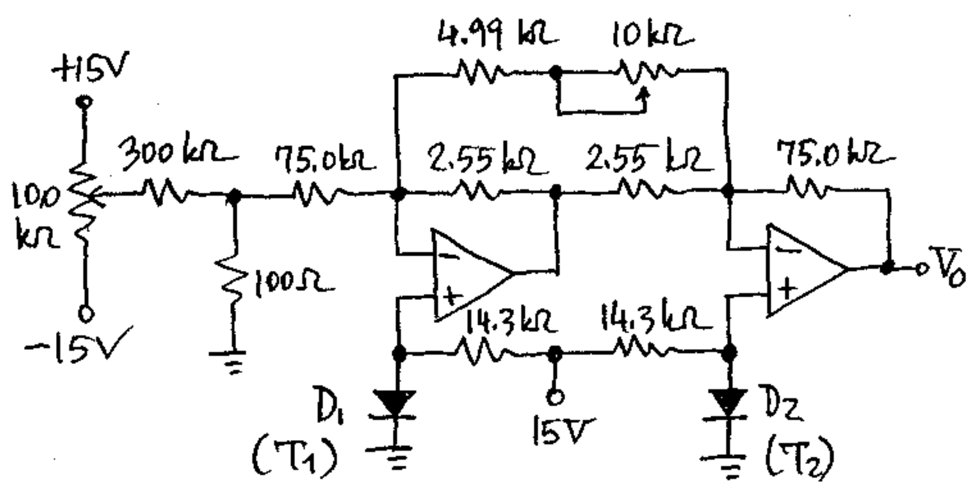
Thus, $I_{R_2} = I_{R_1} = V_{REF}/R_1$.

Moreover, $I_{R_3} = V_{R_2}/R_3 = R_2(V_{REF}/R_1)/R_3$. Finally, $I_O = (V_{REF}/R_1)(1 + R_2/R_3)$.

(b) R_3 must conduct at least 0.5 mA to keep the circuitry on. Impose $I_{R_3} = 1\,mA$. Then, $I_{R_1} = I_{R_2} = 4\,mA$. $R_1 = 0.2/4 = 50\,\Omega$ (use $49.9\,\Omega$). $1 + R_2/R_3 = 5/4 = 1.275 \Rightarrow R_2 = 0.275 R_3$. Let $R_3 = 1.00\,k\Omega$, $R_2 = 274\,\Omega$.

(c) $(V^+ - V^-)_{min} = 1.1 + V_{R_3} = 2.1\ V$.

11.13 Assuming diode currents of 1 mA, we have, at $T = 25°C$, $V_D = 25.7 \ln(10^{-3}/2\times10^{-15}) = 692\,mV$, $TC(V_D) = -(1.205 - 0.692 + 3\times25.7\times10^{-3})/(273.2+25) = -1.977\,mV/°C$. $A = 0.1/(1.977\times10^{-3}) = 50.57\ V/V$. Use a dual-op-amp IA with a $\pm 5\,mV$ offset adjustment and a $50 \pm 10\ V/V$ gain adjustment



Adjust the 100-kΩ pot for $V_O = 0$ with $T_1 = T_2$.

(11.9)

Adjust the 10-kΩ pot for the desired sensitivity, e.g. for $V_O = 10$ V when $T_1 - T_2 = 100$ °C.

11.14 Since 1°C = (9/5)°F, the sensitivity of the AD590 is (5/9) μA/°F. Thus, $R_2 = (10\ mV/°F)/(5/9\ \mu A/°F) = 18\ k\Omega$. We want $V_0(T) = 0$ V for $T = 0°F = 273.2 - (\frac{5}{9})32 = 255.42$ °K. At this temperature, $I(T) = 255.42\ \mu A$. To eliminate this offset, we need $R_1 = (10V)/(255.42\ \mu A) = 39.15\ k\Omega$. Use 38.3 kΩ in series with a 2kΩ pot. For R_2, use 16.9 kΩ in series with another 2kΩ pot.

To calibrate, adjust R_1 for $V_0 = 0.0V$ with $T = 0°F$. Then, adjust R_2 for $V_o = 2.120$ V with $T = 212$ °F.

11.15 Let $I_{sc} = i_{O(max)}\big|_{v_O=0}$ and $I_{fb} = i_{O(max)}\big|_{v_O=V_{REG}}$; let $R_{sc} = V_{BE3(on)}/I_{sc}$. We need to satisfy two equations:

(a) @ $v_O = 0$: $V_{BE3(on)} = \frac{R_4}{R_3+R_4} R_{fb} I_{sc} - 0$.

This gives $R_{sc} = \frac{R_4}{R_3+R_4} R_{fb} \Rightarrow \frac{R_3}{R_4} = \frac{R_{fb}}{R_{sc}} - 1$

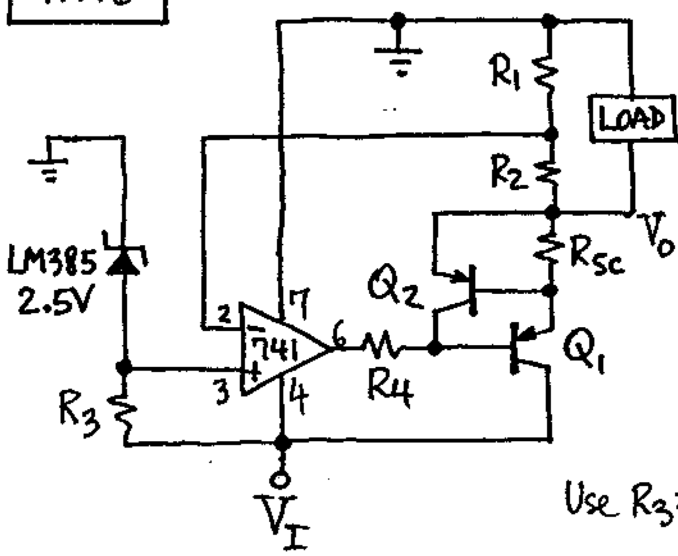
(b) @ $v_O = V_{REG}$: $V_{BE3(on)} = \frac{R_4}{R_3+R_4}(V_{REG} + R_{fb} I_{fb}) - V_{REG}$.

11.10

Using $R_4/(R_3+R_4) = R_{sc}/R_{fb}$ and $V_{BE3(on)} = R_{sc} I_{sc}$ gives, after suitable manipulations,

$$\frac{1}{R_{fb}} = \frac{1}{R_{sc}} - \frac{I_{fb} - I_{sc}}{V_{REG}}$$

11.16



$\left(1+\frac{R_2}{R_1}\right)2.5 = 12$

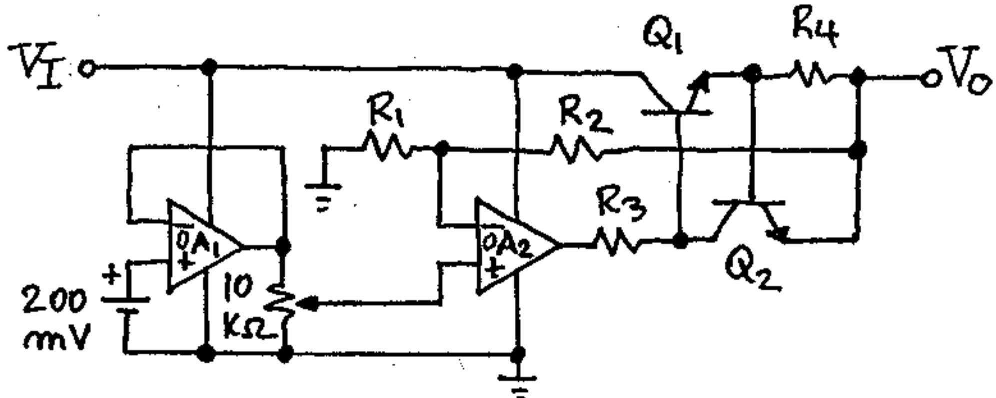
$\Rightarrow R_2 = 3.8 R_1$.

Use $R_1 = 10.0\,\Omega$, $R_2 = 38.3\,k\Omega$.

$R_{sc} = 0.7/0.1 = 7\,\Omega$ (use $6.8\,\Omega$).

Use $R_3 = 33\,k\Omega$, $R_4 = 510\,\Omega$.

11.17



As V_{P2} is varied from 0 to 0.2 V, V_o must vary from 0V to 15V. Thus, $(1+R_2/R_1) = 15/0.2 = 75$. Use $R_1 = 200\,\Omega$, $R_2 = 15.0\,k\Omega$. Note that R_2 must be derived from V_o! Moreover, $R_4 = 0.7/0.1 = 7\,\Omega$ (use $6.8\,\Omega$).

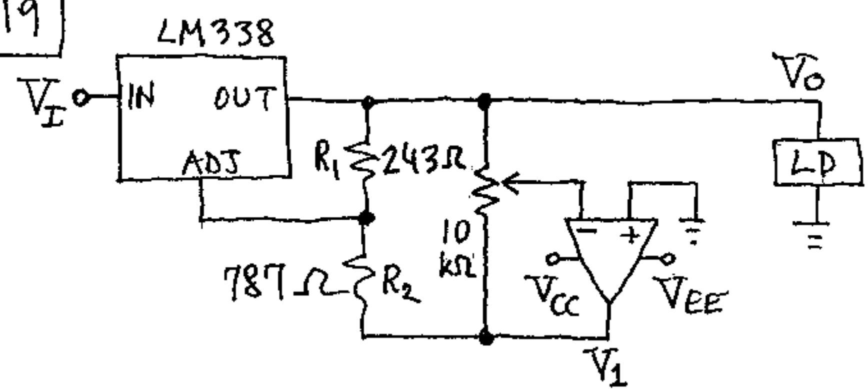
11.11

Let $R_3 = 1\,k\Omega$. Assuming $\beta_1 = 100$ and keeping in mind that OA_2 swings from rail to rail, we have $V_{I(min)} \cong V_{OA2(max)} = V_{O(max)} + V_{BE1(on)} + V_{R_4(max)} + R_3 I_{B1(max)}$
$= 15 + 0.7 + 0.7 + 1 \times 100/101 \cong 17.5\,V$.

11.18 (a) By op amp action, $V_{pin2} = V_{pin3}$ and $V_{pin8} = V_{pin4} + V_{REF} = V_{pin3} + V_{REF}$. Thus, $V_{R_1} = V_{REF}$ and $V_o = V_{R_2} = R_2 I_{R_2} = R_2 I_{R_1}$, that is, $V_o = (R_2/R_1)V_{REF}$.

(b) Let $R_1 = 200\,\Omega$, $R_2 = 100\,k\Omega$.
Assume $V_{BE1} = 1V$, $\beta_1 = 15$, $V_{BE2} = V_{BE3} = 0.7V$, $\beta_2 = \beta_3 = 100$. Then, $I_{B1} = 1/16 = 63\,mA$. $I_{B2} = (63 + 1/0.3)/101 = 0.65\,mA$. $I_{B3} = (0.65 + 0.7/3)/101 = 9\,\mu A$. Thus, $I_{R_5} = I_Q + I_{B2}$; $I_{R_5(max)} \cong I_{Q(max)} = 0.5\,mA$. Dropout voltage $= 1 + 0.7 + 0.7 + 3.9 \times 0.5 \cong 4.4\,V$.

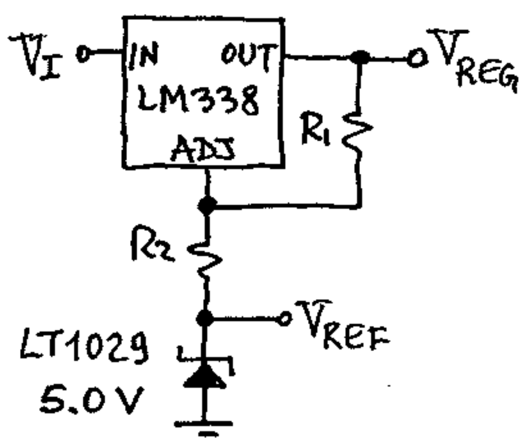
11.19



11.12

R_1 and R_2 configure the LM338 for $V_O - V_1 = 5.0\,V$, and the op amp provides the proper drive for V_1. Wiper up $\Rightarrow V_O = 0$ and $V_1 = -5V$: $V_I \le 35\,V$, $V_{EE} < -5\,V$. Wiper down $\Rightarrow V_O = 5\,V$ and $V_1 = 0\,V$: $V_I \ge 7.5\,V$, $V_{CC} > 0\,V$. Summarizing, $7.5V \le V_I \le 35\,V$, $V_{CC} > 0$, $V_{EE} < -5V$. For a 741 op amp, $V_{CC} \ge 2V$, $V_{EE} \le -7V$.

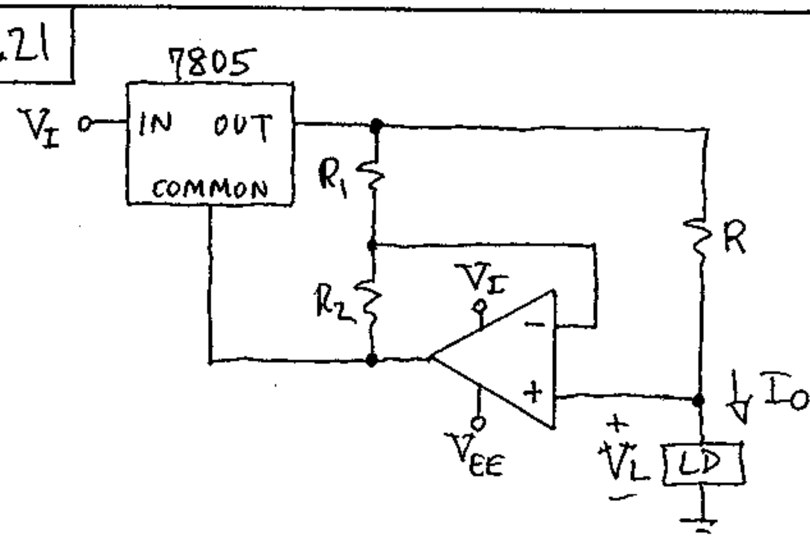
11.20



Let $I_{R_1} = 5\,mA$. Then, $R_1 = 1.25/5 = 249\,\Omega$ and $R_2 = (15 - 1.25 - 5)/5 = 1.69\,k\Omega$.

$17.5V < V_I < 35V$.

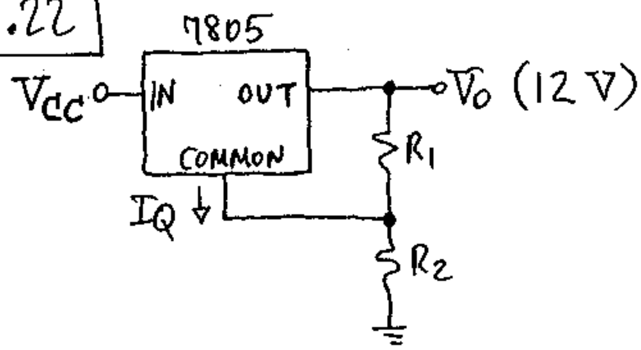
11.21



$RI_O^2 = R \times 1 < 0.25\,W \Rightarrow R \le 0.25\,\Omega$ (use $R = 0.2\,\Omega$).

(11.13) $V_R = 0.2\ V \Rightarrow 0.2/R_1 = 4.8/R_2$. Use $R_1 = 1.00\ k\Omega$, $R_2 = 24.3\ k\Omega$. $V_L \le V_I - V_{DO} - V_R = V_I - 2.2\ V$.

11.22



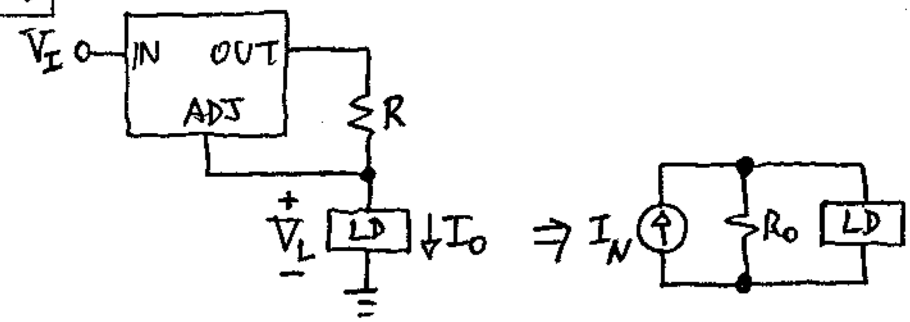
$I_Q = 4.2\ mA$ (typical). Impose $I_{R_1} = 25\ mA$; then, $R_1 = 5/25 = 200\ \Omega$, and $R_2 = (12-5)/(25+4.2) = 240\ \Omega$ (use $237\ \Omega$). $14\ V \le V_{CC} \le 47\ V$.

$\Delta V_{R_1(max)} = (100\ mV)/[(1.5-0.005)A] \cong 67\ mV/A$; $\Delta I_{Q(max)} = (0.5\ mA)/[(1-0.005)A] = 0.5\ mA/A$. $\Delta V_{O(max)} = (1+R_2/R_1)\Delta V_{R_1(max)} + R_2 \times \Delta I_{Q(max)} = (1+237/200)\,67\times 10^{-3} + 237\times 0.5\times 10^{-3} = 265\ mV/A = 100\times 265\times 10^{-3}/12 = 2.21\ \%/A$.

$\Delta V_{R_1(max)} = (50\ mV)/[(25-7)V] \cong 2.8\ mV/V$; $\Delta I_{Q(max)} = (0.8\ mA)/[(25-8)V] = 47\ \mu A/V$. $\Delta V_{O(max)} = (1+237/200)\,2.8\times 10^{-3} + 237\times 47\times 10^{-6} \cong 17.3\ mV/V = 100\times 17.3\times 10^{-3}/12 = 0.14\%/V$.

11.14

11.23



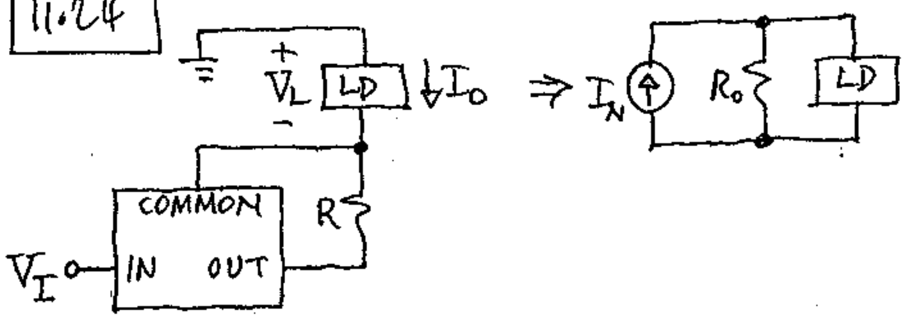
$I_N = V_{REG}/R = 1.25/2.5 = 0.5$ A. $V_L \le V_I - V_{DO} - V_{REG} = 25 - 2 - 1.25 = 21.75$ V.

$\Delta V_{R(max)} = (0.07/100)1.25 = 0.875$ mV/V;

$\Delta I_{O(max)} = \Delta I_{R(max)} + \Delta I_{Q(max)} = 0.875 \times 10^{-3}/2.5 + 5\times10^{-6}/(40-2.5) \cong 0.35$ mA/V.

$|R_{o(min)}| = (1\text{V})/(0.35\text{mA}) = 2.86$ kΩ.

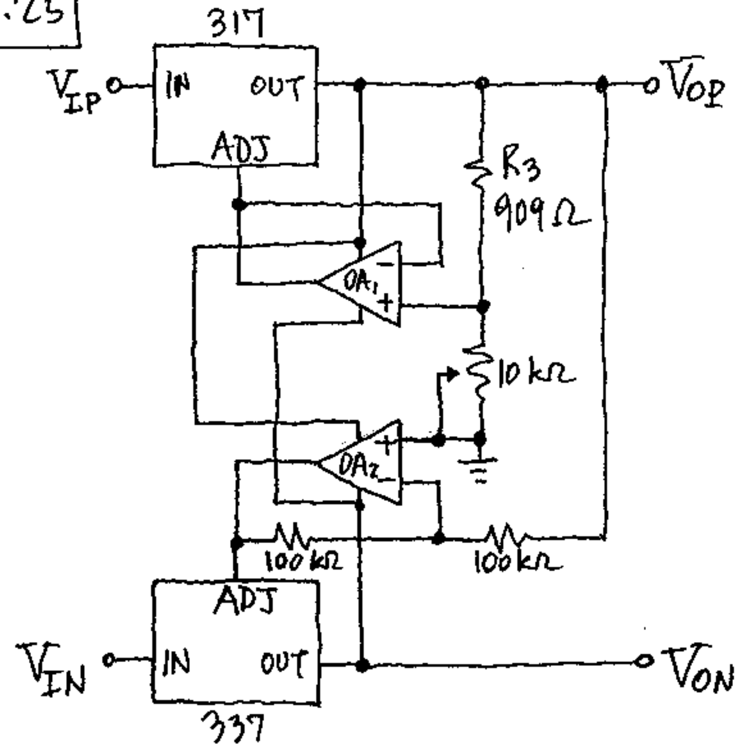
11.24



$R = 1.25/0.5 = 2.5\,\Omega$ (use $2.49\,\Omega$, 1 W); $I_N = 0.5$ A. $\Delta I_{O(max)} = (0.03/100)\times 1.25/2.49 + 0.135\times10^{-6} \cong 151\,\mu$A/V. $R_{o(min)} = (1\text{V})/(151\,\mu\text{A}) = 6.6$ kΩ.

(11.15)

11.25



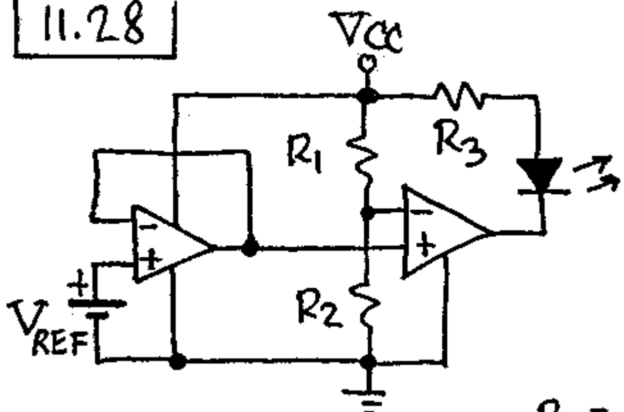
Varying the wiper from bottom to top varies V_{OP} from 1.25 V to 15.0 V. OA_2, a unity-gain inverting amplifier, forces V_{ON} to vary from −1.25 V to −15 V. As long as they saturate within less than 1.25 V of the supply rails, the op amps can be powered from V_{OP} and V_{ON}, as shown.

11.26 (a) $T_{A(max)} = T_{J(max)} - \Theta_{JA} P_{D(max)}$ $= 150 - 1 \times 60 = 90°C$.

(b) $P_D \cong (10-5)1 = 5\,W$. $\Theta_{JA(max)} = (150-50)/5 = 20\,°C/W$. A μA7805 operating in free air cannot handle it. A heat sink is required.

11.27 $I_O = 5/[(1+18/2)1] = 0.5$ A. $P_{D(max)} = (V_{IN} - V_{OUT})_{max} \times I_o = (18 - 0.5\times 1)0.5 = 8.75$ W. $\theta_{JA} = (150-60)/8.75 = 10.3$ °C/W. $\theta_{CA} = \theta_{JA} - \theta_{JC} = 10.3 - 5 = 5.3$ °C/W. Allowing 0.6 °C/W for the mounting surface, we have $\theta_{SA} = 4.7$ °C/W.

11.28



$\frac{R_2}{R_1+R_2} \times 4.75 = 0.2\text{V} \Rightarrow R_1/R_2 = 22.75$. Use $R_1 = 1.02$ kΩ and $R_2 = 23.2$ kΩ. Moreover, $R_3 \cong (5-1.5)/2 \cong 1.8$ kΩ.

11.29 Let n be the transformer's turns ratio, so that the peak secondary voltage at 80% of the nominal line is $V_p = 0.8 \times n \times 120\sqrt{2} - V_{D(on)} = n135.7 - 0.7$ V. Imposing $V_p \times R_3/(R_4+R_3) = V_{REF}$ gives $R_4/R_3 = (135.7n - 0.7)/2.5 - 1$. For instance, if $n = 1$, imposing $R_3 = 10.0$ kΩ gives $R_4 = 530$ kΩ (use 523 kΩ, 1%). Imposing $T_{DLY} \cong \frac{1}{2}\frac{1}{60} \cong 8$ ms gives $C_{UV} = 8\times 10^{-3}/12{,}500 \cong 0.68\,\mu$F. For the OV components use $R_1 = 10.0$ kΩ, $R_2 = 16.2$ kΩ, $C_{OV} = 8.2$ nF.

(11.17)

$\boxed{11.30}$ (a) Both in the switched capacitor (SC) and the switched inductor (SL) the energy-storage element is used to transfer energy from one point of the circuit to another. In the SC the average current through C is zero; in the SL the average voltage across L is zero. Consequently, the polarities of V_I and V_O are opposite in the SL circuit, while the polarities of V_1 and V_2 can be arbitrary in the SC circuit. This requires that the switches be bidirectional in the SC circuit; by contrast, the unidirectionality of current flow in the SL circuit allows for the second switch to be implemented with an ordinary diode, which is turned on by the kickback action of the inductor, without requiring any control signal. The duty cycle is immaterial in the SC circuit, provided C is given enough time to fully charge to V_1 and discharge to V_2. By contrast, D and V_I and V_O are related by the last equation in Eq. (11.40) in the SL circuit.

11.18

(b) $w_{cycle} = \frac{1}{2} L I_p^2 - \frac{1}{2} L (I_p - \Delta i_L)^2 =$

$\frac{1}{2} L (2 I_p \Delta i_L - \Delta i_L^2) = L (I_p - \frac{\Delta i_L}{2}) \Delta i_L = L I_L \Delta i_L.$

$P = f_s W_{cycle} = f_s L I_L \Delta i_L.$

11.31 (a) Buck: L is in series with the load, so $I_L = I_O$. Boost: L is in series with the source, so $I_L = I_I$; but, $V_I I_I = V_O I_O$, so $I_L = (V_O/V_I) I_O$. Buck-boost: $I_O = I_D = [t_{OFF}/(t_{ON} + t_{OFF})] I_L$, or $I_L = (1 + t_{ON}/t_{OFF}) I_O = (1 + |V_O|/V_I) \times I_O$. Moreover, in CCM, we have $I_p = I_L + \Delta i_L/2$, and $I_{L(min)} = \Delta i_L/2$.

(b) $I_L = I_O = 1 A$; $I_p = 1 + 0.2/2 = 1.1 A$; $I_{O(min)} = I_{L(min)} = 0.2/2 = 0.1 A$.

(c) $I_L = (12/5)1 = 2.4 A$; $I_p = 2.5 A$; $I_{O(min)} = (5/12) I_{L(min)} = (5/12)0.1 \cong 42 mA$.

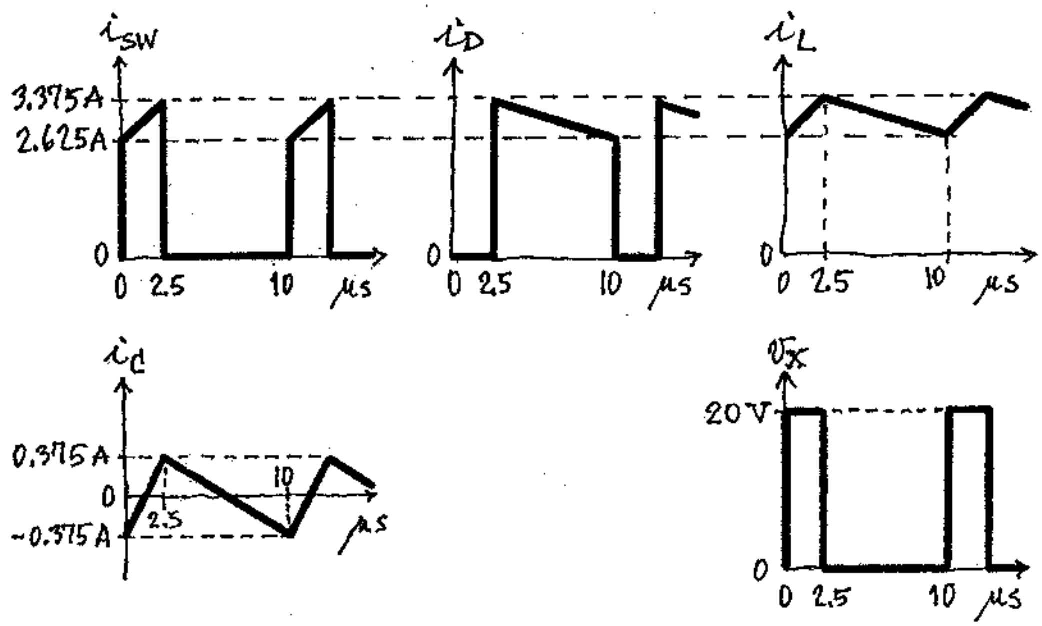
(d) $I_L = (1 + 15/5) I_O = 4A$; $I_p = 4.1 A$; $I_{O(min)} = I_{L(min)}/4 = 25 mA$.

11.32 By Eq. (11.39), $12 = \frac{D}{1-D}(V_I - 0.5) + 0.5$, $5 V \le V_I \le 10 V$. This gives $71.9\% \ge D \ge 54.8\%$.

I_I is maximum when $V_I = 5 V$. Using Eq. (11.41), $I_{I(max)} \cong (12/5)1 = 2.4 A$. For a better estimate, include also the losses in the diode and the transistor, $P_{losses} \cong 0.5 \times 2.4 = 1.2\text{W}$. Writing $I_{I(max)} \times 5 = 12 \times 1 + 1.2$ gives $I_{I(max)} = 2.64\text{ A}$.

11.33 $I_L \cong (1 + 15/15) I_O = 2 I_O$; $0.2\text{A} \le I_O \le 1\text{A}$ $\Rightarrow 0.4\text{A} \le I_L \le 2\text{ A} \Rightarrow \Delta I_L = 0.8\text{ A}$. $L = [15/(1+\frac{15}{15})]/(150 \times 10^3 \times 0.8) = 62.5\ \mu\text{H}$. Letting $\Delta v_C = 1/3\, V_{ro(max)} = 50\text{ mV}$, we get $C = [1(1+15/15)]/(150\times10^3 \times 50\times10^{-3}) = 267\ \mu\text{F}$. At full load, $\Delta i_C = \Delta i_D = I_p = I_L + \Delta i_L/2 = 2 + 0.8/2 = 2.4\text{A}$. So, $ESR = (100\text{ mV})/(2.4\text{A}) = 41.7\text{ m}\Omega$. Summarizing, $L = 62.5\ \mu\text{H}$, $C = 267\ \mu\text{F}$, $ESR \cong 42\text{ m}\Omega$.

11.34 (a) $T = 1/f_s = 10\ \mu\text{s}$; $D = 5/20 = 0.25$; $t_{ON} = 2.5\ \mu\text{s}$. $I_L = I_O = 3\text{ A}$; $\Delta I_L = [5(1-5/20)]/(10^5 \times 50 \times 10^{-6}) = 0.75\text{ A}$; $I_p = 3 + 0.75/2 = 3.375\text{ A}$.



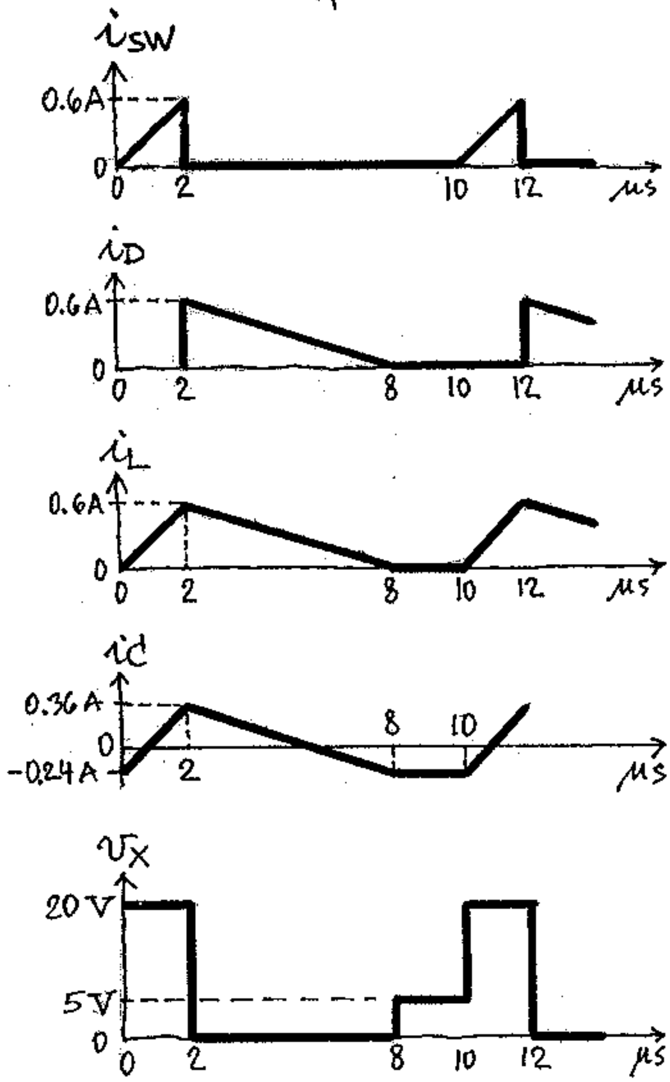
11.20

(b) During t_{ON}, $\Delta i_L = \frac{20-5}{50\times10^{-6}} 2\times10^{-6} = 0.6\,A$.

Consequently, $I_p = 0.6\,A$. The amount of time Δt it takes for i_L to return to zero is such that $0.6\,A = \frac{5}{50\times10^{-6}}\Delta t$, or $\Delta t = 6\,\mu s$. During the time intervals for which $i_L = 0$, we also have $v_L = 0$. Moreover, the average currents are found as

$$I_0 = I_L = \frac{1}{10\,\mu s}\int_0^{10\,\mu s} i_L\,dt = \frac{1}{10\,\mu s}\,\frac{(8\,\mu s)\times 0.6}{2} = 0.24\,A.$$

Thus, the waveforms are as shown.



11.35 (a) $D = 19.2\%$. $P_{SW} \cong 0.58 + 0.9 = 1.48$ W; $P_D \cong 1.72 + 0.45 = 2.17$ W; $P_{cap} \cong 0$; $P_{coil} \cong 0.25$ W; assuming $I_Q \cong$ constant, $P_{controller} \cong 30 \times 10 = 0.3$ W. $P_{diss} \cong 4.2$ W; $\eta = 100 \times 15/(15 + 4.2) = 78\%$.

(b) $D = 38.8\%$. $P_{SW} \cong 1.16 + 0.9 = 2.06$ W; $P_D \cong 1.29 + 0.45 = 1.74$ W; $P_{cap} \cong 0$; $P_{coil} \cong 0.5$W; $P_{controller} \cong 0.15$ W; $P_{diss} = 4.45$ W; $\eta = 77\%$.

11.36 $v_O/v_I = D = v_C/V_{sm}$; $dv_O/dv_C|_{v_I = V_I} = V_I/V_{sm}$.

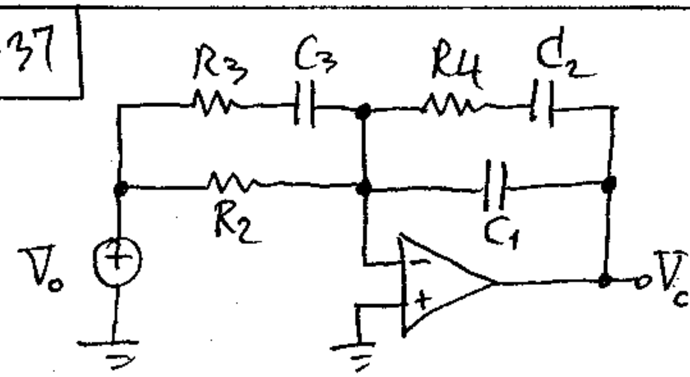
$$\frac{V_o}{V_c} = \frac{V_I}{V_{sm}} \frac{ESR + 1/sC}{R_{coil} + sL + ESR + 1/sC}$$

$$= \frac{V_I}{V_{sm}} \frac{1 + s(ESR)C}{1 + s^2LC + s(R_{coil} + ESR)C}$$

$$= \frac{V_I}{V_{sm}} \frac{1 + s/\omega_z}{1 + (s/\omega_0)^2 + (s/\omega_0)/Q}$$

$\omega_0 = 1/\sqrt{LC}$, $\omega_z = 1/ESR \times C$, $Q = 1/[(R_{coil} + ESR)\sqrt{C/L}]$.

11.37



11.22

$$\frac{1}{Z_1} = \frac{1}{R_2} + \frac{1}{R_3 + 1/sC_3} = \frac{1 + s(R_2+R_3)C_3}{R_2(1+sR_3C_3)}$$

$$\frac{1}{Z_2} = sC_1 + \frac{1}{R_4 + 1/sC_2} = \frac{sC_1(1+sR_4C_2) + sC_2}{1+sR_4C_2}$$

$$= \frac{s(C_1+C_2)[1 + sR_4C_1C_2/(C_1+C_2)]}{1+sR_4C_2}$$

$$H_{EA} = \frac{V_c}{V_o} = -\frac{Z_2}{Z_1}$$

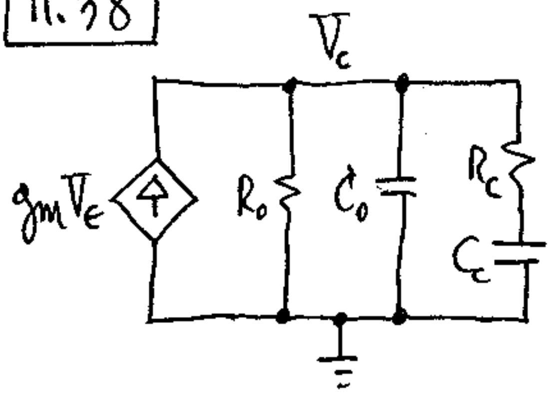
$$= -\frac{[1+s(R_2+R_3)C_3](1+sR_4C_2)}{sR_2(C_1+C_2)[1+sR_4C_1C_2/(C_1+C_2)](1+sR_3C_3)}$$

$$= -\frac{(1+j\omega/\omega_1)(1+j\omega/\omega_2)}{(j\omega/\omega_5)(1+j\omega/\omega_3)(1+j\omega/\omega_4)}$$

$$\omega_1 = \frac{1}{R_4C_2}; \quad \omega_2 = \frac{1}{(R_2+R_3)C_3} \to \frac{1}{R_2C_3}; \quad \omega_3 = \frac{1}{R_3C_3};$$

$$\omega_4 = \frac{C_1+C_2}{R_4C_1C_2} \to \frac{1}{R_4C_1}; \quad \omega_5 = \frac{1}{R_2(C_1+C_2)} \to \frac{1}{R_2C_2}.$$

11.38



$$Z_c = R_c + 1/sC_c = (1+sR_cC_c)/sC_c;$$

$$H_{EA} = V_c/V_e = g_m\left(R_o \| \frac{1}{sC_o} \| Z_c\right);$$

$$\frac{g_m}{H_{EA}} = \frac{1}{R_o} + sC_o + \frac{sC_c}{1+sR_cC_c}$$

$$= \frac{1}{R_o}\,\frac{1+s^2R_oC_oR_cC_c + s(R_cC_c + 2R_oC_c)}{1+sR_cC_c}$$

$$\cong \frac{1}{R_o}\,\frac{1+s^2R_oC_oR_cC_c + s\,2R_oC_c}{1+sR_cC_c}$$

11.23

$$H_{EA} \cong g_m R_o \frac{1+s/\omega_z}{1+(s/\omega_0)^2+(s/\omega_0)/Q}$$

$$\omega_0 = \frac{1}{(R_o C_o R_c C_c)^{1/2}}, \quad \omega_z = \frac{1}{R_c C_c}, \quad Q = \frac{1}{2}\sqrt{R_c C_o / R_o C_c}$$

```
Problem 11.38
Vepsilon 1 0 ac 1
R 1 0 1
gm 0 2 1 0 4.4m
Ro 2 0 180k
Co 2 0 3pF
Rc 2 3 1k
Cc 3 0 1uF
.ac dec 10 0.1Hz 10kHz
.probe
.end
```