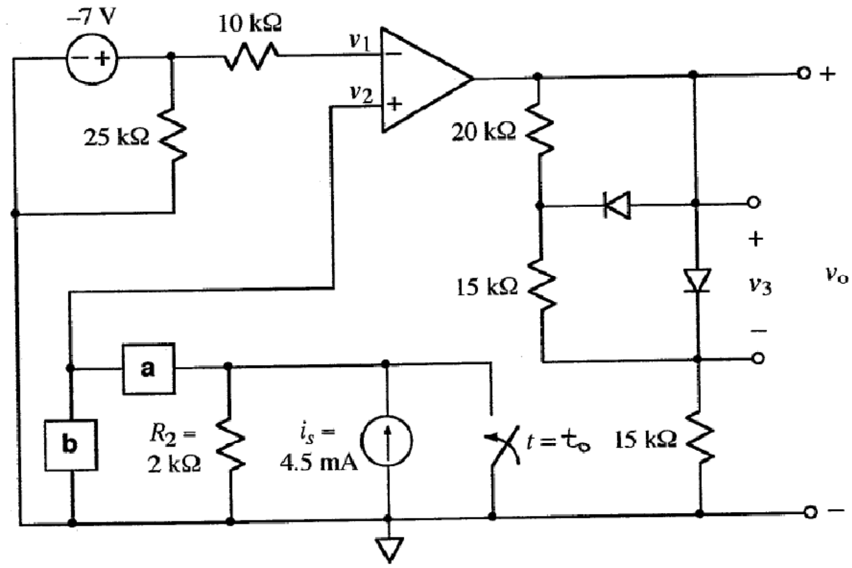
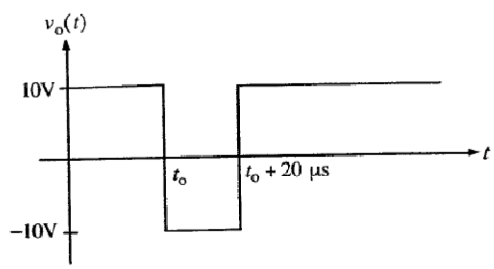
1.



Rail voltages = ±10 V

After being open for a long time, the switch closes at time $t = t_o$.



Choose either an R or C to go in box **a** and either an R or L to go in box **b** to produce the v_o(t) shown above. Use an R value of 3 kΩ. Also, note that v_o stays high forever after $t_o + 20$ μs. Specify which element goes in each box and its value.

We have a comparator, since the op-amp lacks negative feedback.

v_1 is a fixed voltage. Since the 25 kΩ is across the −7V source, it has no effect on v_1. Since no current flows into the op-amp, the voltage drop across the 10 kΩ resistor is zero, and the 10kΩ also has no effect on v_1.

$\therefore v_1 = -7V$ (at all times)

To obtain the waveform given in the problem for $v_o(t)$, the voltage for v_2 must be more positive than $v_1 = -7V$ for $t < t_o$ and $t > t_o + 20\ \mu s$. The voltage for v_2 must also be more negative than $v_1 = -7V$ for $t_o < t < t_o + 20\mu s$.

To determine what components to put in box **a** and box **b**, we consider each of the possibilities.

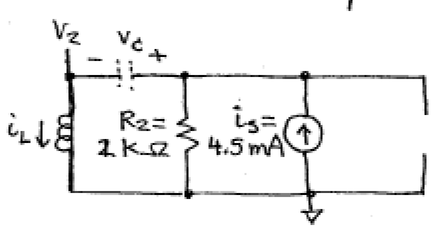
case I: $a = R \quad b = R$

This fails because v_2 would never be negative. Thus, v_2 would never be less than v_1.

case II: $a = C \quad b = L$

Although this type of circuit is beyond the scope of this course, we may consider whether such a circuit might work.

For $t = 0^-$, (assume $t_o = 0$), we have L = wire and C = open:



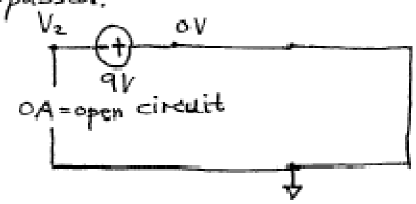
$$v_2(0^-) = 0V \quad > v_1 = -7V \quad ✓ \text{ ok}$$

$$i_L(0^-) = 0\ A$$

$$v_c(0^-) = i_s R_2 = 4.5 mA \cdot 2k\Omega$$

$$\quad '' \quad = 9V$$

At $t=0^+$, we have $i_L(0^+) = i_L(0^-) = 0A$ and $v_C(0^+) = v_C(0^-) = 9V$, whereas the voltage on the right side of the C will be 0V owing to the now-closed switch. i_{S2} and R_2 are bypassed.



$$v_2 = -9V < v_1 = -7V \quad \checkmark \text{ ok}$$

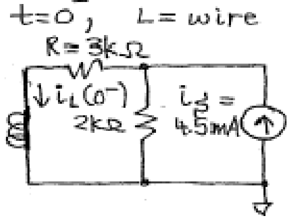
For $t \to \infty$, we have a situation similar to $t=0^-$, except there is no R.

Without a resistor in the circuit, the energy stored in the circuit at $t=0^-$ will remain in the circuit forever. It back and forth from the C to the L and causes an oscillating voltage at v_2. This would cause $v_o(t)$ to repeatedly go high and low.

Thus, the L and C solution will not work.

case III: $a = R$ $\quad b = L$

For $t=0^-$, $L =$ wire and $v_2(0^-) = 0V$ ✓ ok

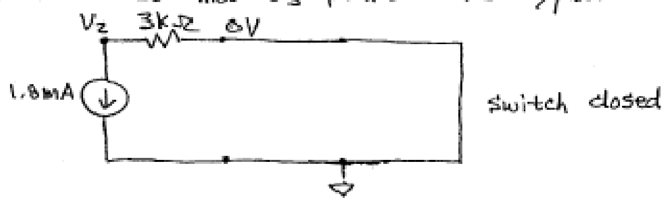


We have a current divider:

$$i_L(0^-) = i_s \cdot \frac{2k\Omega}{2k\Omega + 3k\Omega}$$

$$\text{"} \quad = 4.5\,mA \cdot \frac{2}{5} = 1.8\,mA$$

For $t=0^+$, $i_L(0^+) = i_L(0^-) = 1.8\,mA$.
$2k\Omega$ and i_s source are bypassed.



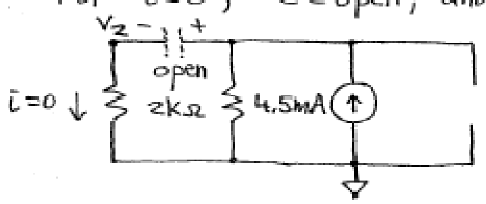
$$v_z(0^-) = 0V - 1.8mA \cdot 3k\Omega = -5.4V$$

But $-5.4V > -7V$ doesn't work!

The last possibility must be considered.

Case IV: $a = C$ $b = R$

For $t=0^-$, C = open, and $v_z = 0V$ ✓ok

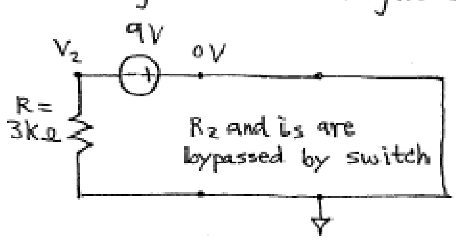


Since the C is open, v_z is pulled down to ref by the R below it.

The voltage on C is $v_c(0^-) = 4.5mA \cdot 2k\Omega$.

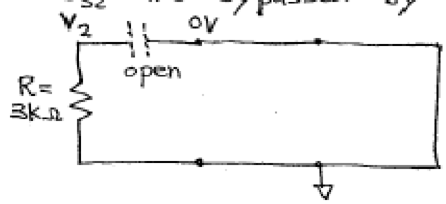
$$v_c(0^-) = 9V.$$

For $t=0^+$, $v_c(0^+) = v_c(0^-) = 9V$, and the closed switch makes the voltage on the right side of C 0V.



We have $v_z(0^+) = -9V < -7V$ ✓ok

For $t \to \infty$, the C is open and R_2 and i_{s2} are bypassed by the switch.



We $v_2(t \to \infty) = 0V$, (pulled down to ref by 3kΩ R).

$$v(t \to \infty) = 0V > -7V \quad \checkmark \text{ ok}$$

This circuit will work!

Using the general form of sol'n for RC problems, we have the following result:

$$V_2(t) = v_2(t \to \infty) + [v_2(0^+) - v_2(t \to \infty)]\, e^{-t/RC}$$

Here, the R is 3kΩ, as the 2kΩ is bypassed for $t > 0$.

$$v_2(t) = 0V + [-9V - 0V]\, e^{-t/3k\Omega \cdot C}$$

or

$$v_2(t) = -9V e^{-t/3k\Omega \cdot C}$$

We want $v_o(t)$ to go high at $t = 20\mu s$. The transition of $v_o(t)$ from low to high occurs when $v_1 = v_2$. Using our expression for $v_2(t)$ with $t = 20\mu s$ and $v_2(20\mu s) = v_1 = -7V$ we have

$$-7V = 9Ve^{-20\mu s/3k\Omega \cdot C}$$

or

$$\frac{7}{9} = e^{-20\mu s/3k\Omega \cdot C}$$

or

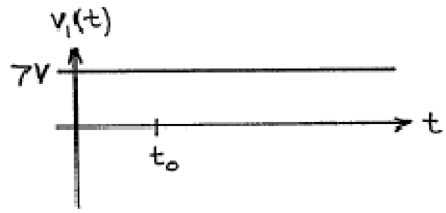
$$\ln \frac{7}{9} = -20\mu s/3k\Omega \cdot C$$

or

$$C = -20\mu s/[\ln(7/9) \cdot 3k] = 26.5\,nF$$

2. Sketch $v_1(t)$, showing numerical values appropriately.

$v_1(t) = -7V$ at all times.



3. a) Sketch $v_2(t)$, showing numerical values appropriately.

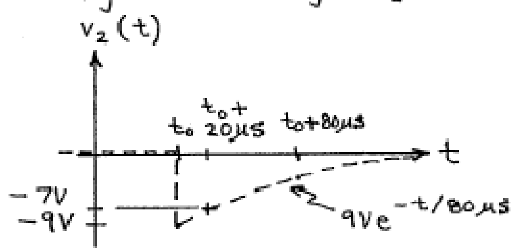
$v_2(t) = 9V e^{-t/3k\Omega \cdot 26.5nF}$

where $t_o = 0$ is assumed, and $t > 0$

Our time constant is

$$\tau = 3k\Omega \cdot 26.5\,nF = 79.6\,\mu s \approx 80\,\mu s$$

In time τ, $\approx$ 2/3's of the total change in voltage $v_2(t)$ occurs.

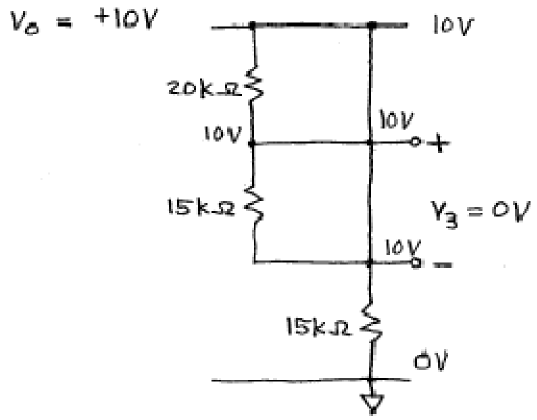


we have $v_2(t=0^-)$ is 0V because no current flows thru $R = 3k\Omega$. We also have $v_2(t=20\mu s) = -7V$.

b) Sketch $v_3(t)$. Show numerical values for $t < t_0$, for $t_0 < t < t_0 + 20\ \mu s$, and for $t > t_0 + 20\ \mu s$. Use the ideal model of the diode: when forward biased, its resistance is zero; when reverse biased, its resistance is infinite.

When v_o is high ($10V = v_{rail}$), the two diodes will be forward biased. (Otherwise, they would be open circuits. But that would result in positive v-drops across the diodes, which is a contradiction.)

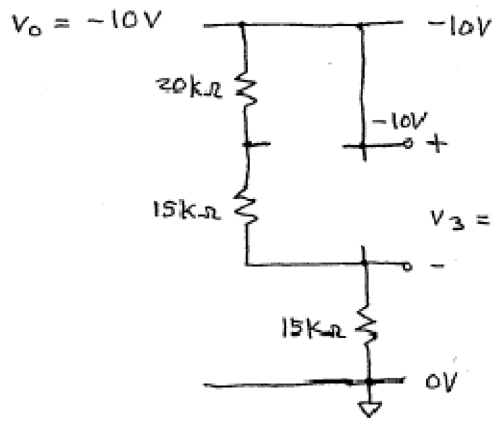
Thus, we replace the diodes with short-circuits:



We have $v_3 = 0V$.

When v_o is low $(-10V = -v_{rail})$, the two diodes will be reverse biased. Otherwise, they would be short circuits. But that would result in negative v-drops across the diodes, which is a contradiction.)

Thus, we replace the diodes with open-circuits:

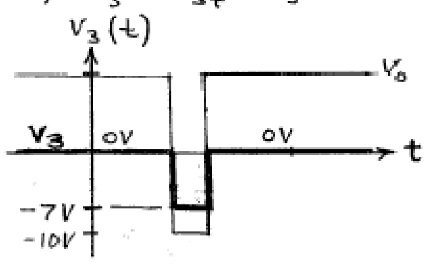


We find voltages from V-divider eq'ns:

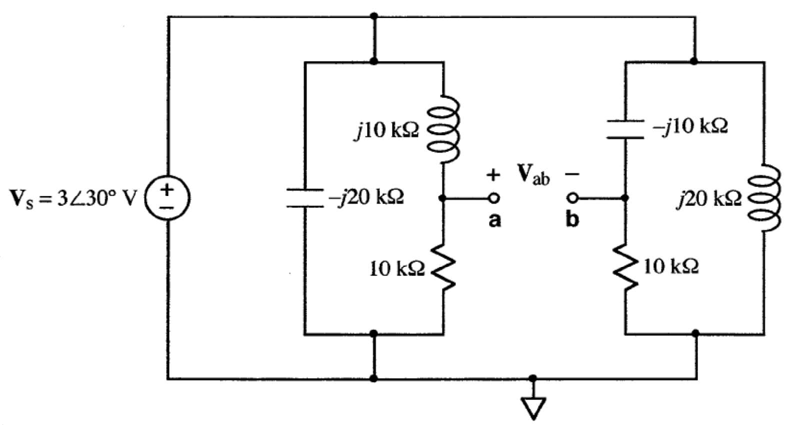
$$V_{3-} = -10V \cdot \frac{15k\Omega}{15k\Omega + 15k\Omega + 20k\Omega} = -3V$$

$$V_{3+} = -10V$$

Thus, $V_3 = V_{3+} - V_{3-} = -10V - (-3V) = -7V$



4.



A frequency-domain circuit is shown above. Write the value of phasor voltage $\mathbf{V}_{ab}$ in polar form.

We have four branches directly across V_s. We may solve each branch separately. For the voltages V_a and V_b, we have two voltage dividers:

$$V_a = V_s \cdot \frac{10\,k\Omega}{10\,k\Omega + j10\,k\Omega} \quad \text{and} \quad V_b = V_s \cdot \frac{10\,k\Omega}{10\,k\Omega - j10\,k\Omega}$$

$$\therefore V_{ab} = V_a - V_b = V_s\left(\frac{1}{1+j} - \frac{1}{1-j}\right)$$

$$= 3\angle 30^\circ \left(\frac{1-j}{2} - \frac{1+j}{2}\right) = 3\angle 30^\circ \cdot \left(-j\frac{2}{2}\right)$$

$$V_{ab} = 3\angle 30^\circ \cdot 1\angle -90^\circ\,V = 3\angle -60^\circ\,V$$

5.

Given ω = 500k rad/s, write a numerical time-domain expression for $v_{ab}(t)$, the inverse phasor of $\mathbf{V}_{ab}$.

$$v_{ab}(t) = 3\cos(500kt - 60^\circ)\ V$$