Problem 1: Consider the level shifter circuit shown in Fig. 1 below. It was designed to generate $V_{L,dc} = 1.2V$ across a load resistor, $R_L = 1.2$ kOhm by shifting down a constant 2V input by one forward diode drop, $V_{D,ON} = 0.8V$. Assume T = 300K.

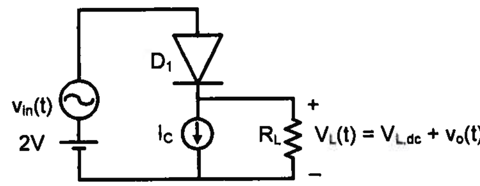


Figure 1

(a) Calculate the level shifter output, $v_o(t)$, if $v_{in}(t) = 10\sin(10t)$ mV. Assume $I_C = 9$mA.
(b) What should be the minimum value of I_C such that $|v_o(t)/v_{in}(t)| \geq 0.99$?
(8 + 12 = 20 points)
Solution:

a.) $I_C = 9\ mA$

$I_{R_L} = 1.2V / 1.2K = 1\ mA. \Rightarrow I_D = 10\ mA.$

$r_d = \frac{26mV}{10\ mA} = 2.6$ ohms.

Small signal model:

$V_o(t) = \left(\frac{R_L}{r_d + R_L}\right)(10mV \sin(10t))$
$= 9.98 \sin(10t).$

b.) $\left|\frac{V_o(t)}{V_{in}(t)}\right| > 0.99. \Rightarrow \frac{R_L}{r_d + R_L} > 0.99.$

$\Rightarrow r_d < 12.1$ ohms.

$\Rightarrow I_D > 2.14\ mA.$

$\Rightarrow I_C + I_L > 2.14\ mA.$

$\Rightarrow I_C > 2.14mA - 1mA > 1.14mA.$

Problem 2: Consider the circuit shown in Figure 2. Assume that the diodes are identical with $V_{D,ON} = 0.8V$, that $V_{ab}(t) = 5\cos(2\pi x 10^6 t)$ for all $t \geq 0$, and that all capacitors have zero initial charge.

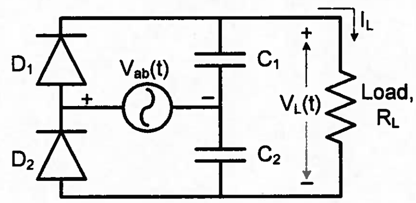


Figure 2

(a) (3 points) What do you think is the purpose of this circuit? Limit your answer to one sentence.

(b) (7 points) Sketch the output voltage waveform, $V_L(t)$, for the first two cycles of $V_{ab}(t)$ after $t = 0$. Assume that $C_1 = C_2 = C$ and that the time constant $R_L C$ is much greater than the period of $V_{ab}(t)$.

(c) (5 points) What is the minimum diode breakdown voltage magnitude to ensure proper operation?

(d) (10 points) Calculate the ripple in $V_L(t)$ in the steady state, given that $C_1 = C_2 = 100nF$ and $R_L = 100kOhms$.

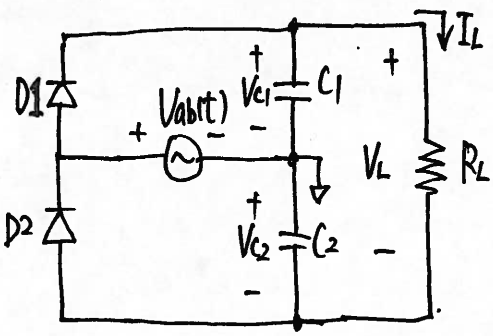
(e) (Bonus question: 10 points) Due to inevitable errors in the printed circuit board assembly process, C_2 ended up being only half of C1 i.e. $C_1 = 100nF$, but $C_2 = 50nF$. Calculate the new steady state peak-to-peak value of $V_L(t)$.

Note: The bonus question will be graded only if you have made non-trivial attempts at all other parts of the Problem #2.

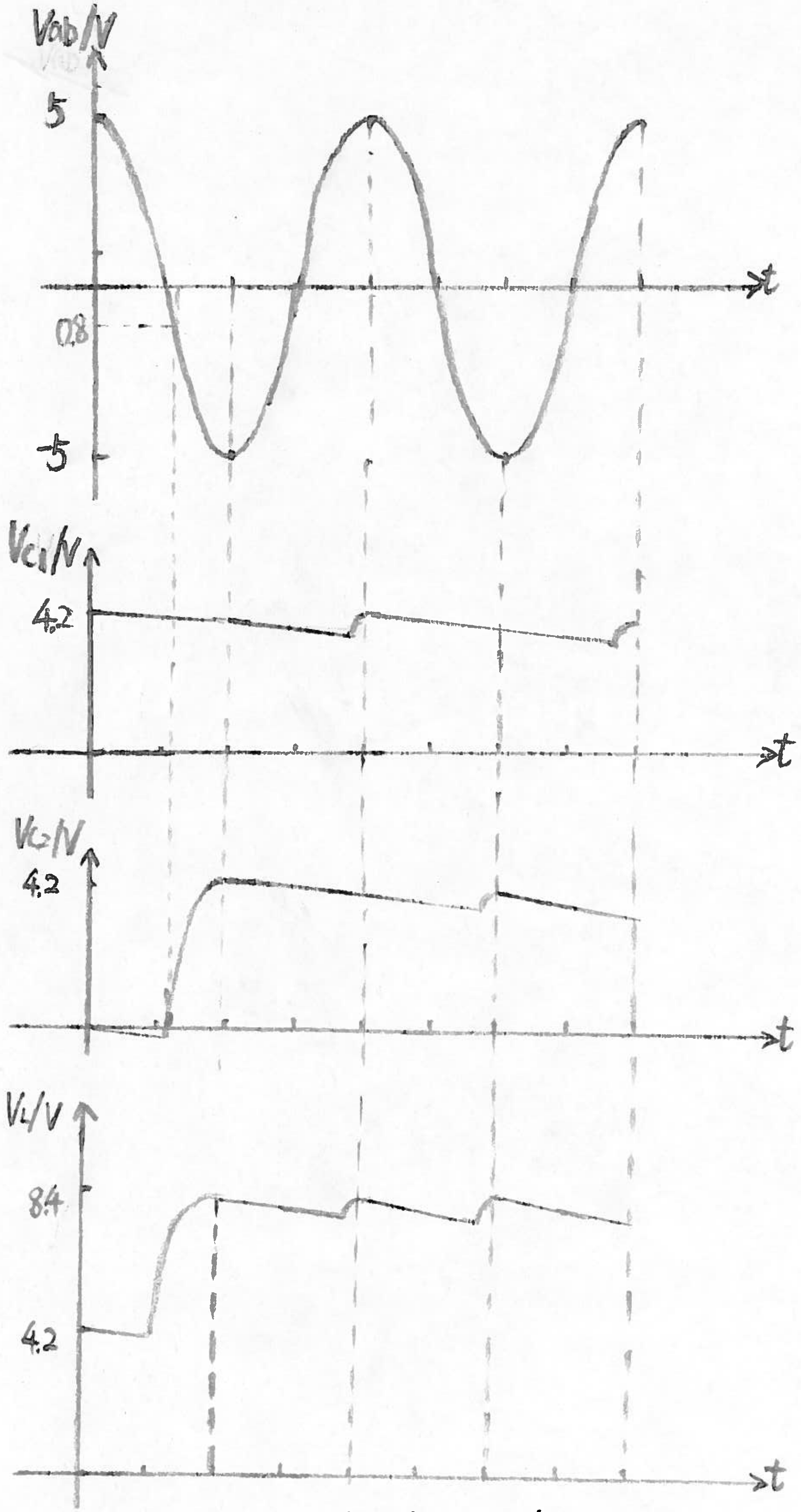
Solution:

(a) This circuit serves as a voltage doubler.

(b)



A clear way to sketch $V_L(t)$ is to investigate $V_{C_1}(t)$ and $V_{C_2}(t)$, then add them together since $V_L(t) = V_{C_1}(t) + V_{C_2}(t)$.



(c) Choose '–' side of $V_{ab}(t)$ as shown in previous figure for convenience. For D1, ~~since~~ $V_{D1,n} \approx 4.2V$ since $V_{C1} \approx 4.2V$ as the ripple of $V_{C1}(t)$ is quite small (will be shown in (d)).

The negative peak voltage of $V_{D1,p}$ is $-5V$.

Therefore the minimum break voltage for D1 should be 9.2V.

Similarly the minimum break voltage for D2 should also be 9.2V.

(d) From the plots in (b), we know the ripple of V_L is almost the ripple of V_{C1} (V_{C2}).

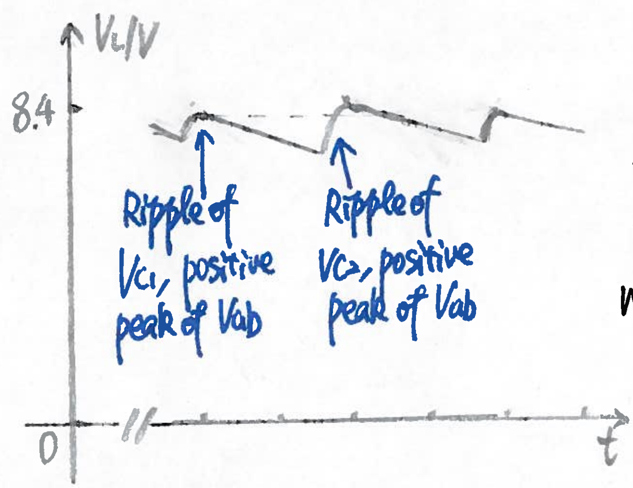
Since V_L is almost 8.4V, $I_L = \frac{V_L}{R_L} = \frac{8.4V}{100K\Omega} = 0.084mA$.

The period of V_{ab} is $T = 1\mu s$.

Thus the ripple of V_{C1} (V_{C2}) is

$$\frac{I_L \cdot T}{C_1 \text{ or } C_2} = \frac{0.084 \times 10^{-3} A \times 1 \times 10^{-6} s}{100 \times 10^{-9} F} = 0.84\,mV.$$

(e) With the insight gained from (d), when C_2 decreases to 50nF, we would expect V_{C2} to show ~~twice~~ twice the ripple than V_{C1}. Therefore ~~the~~ ~~slope~~ $V_L(t)$, the superposition of V_{C1} and V_{C2}, is as below (in steady state).



~~We see actually two ripples, the smaller one due to V_{C1}~~

We see two bumps in one period of V_{ab}: the smaller one at the positive peak of V_{ab} for recharging C_1; the larger one at the negative peak of V_{ab} for recharging C_2.

Therefore the ripple of V_L is the ripple of V_{C2}, which is

$$\frac{I_L \cdot T}{C_2} = \frac{0.084 \times 10^{-3} A \times 1 \times 10^{-6} s}{50 \times 10^{-9} F} = 1.68\,mV.$$

Problem 3: Consider the diode-capacitor circuit shown in Fig. 3. What is the steady state voltage, $V_C(t)$, on the capacitor if the following input is applied to it, assuming $V_{D,ON} = 0$:

$$v_{in}(t) = (1 + m(t))\sin(1000t),$$

where m(t) is a zero mean, square wave of amplitude 0.2, and a period of 1 second?
(5 points)

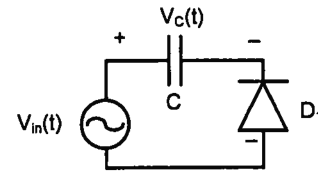
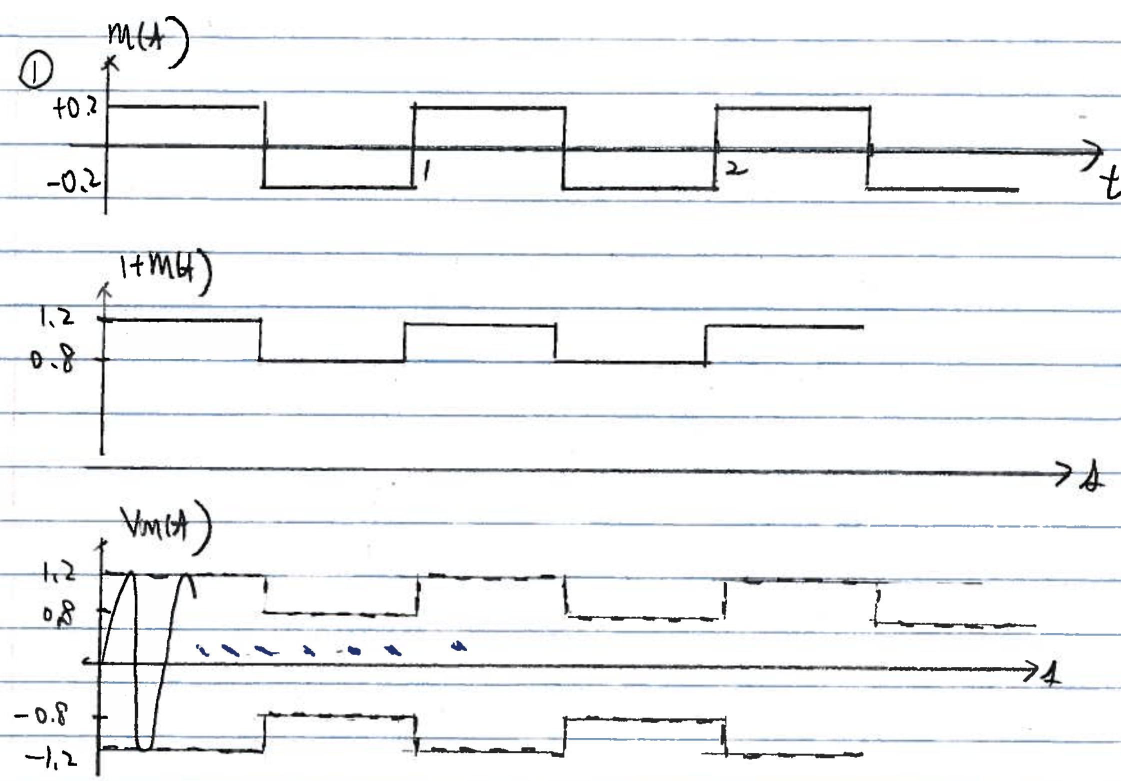


Figure 3

Solution:



② The most negative value of $V_{in}(t)$ is -1.2V

The steady state $V_C(t)$ is -1.2 V ✻