EE315 - Electronics Laboratory

Experiment - 2 Simulation

Rectifier Circuits

Name : Emre Nedim Hepsağ **Number :** 250206012

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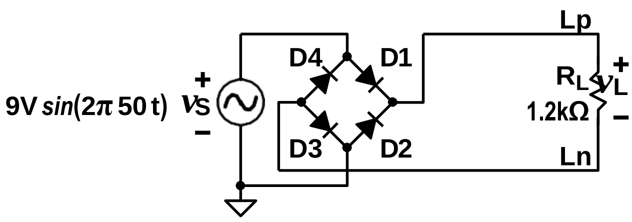
Preliminary Work

1. Build the following circuit. Use a voltage source to obtain the specified AC input voltage.

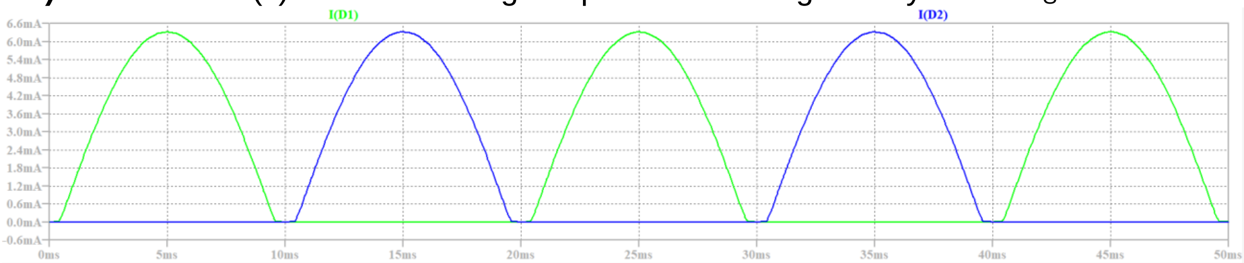


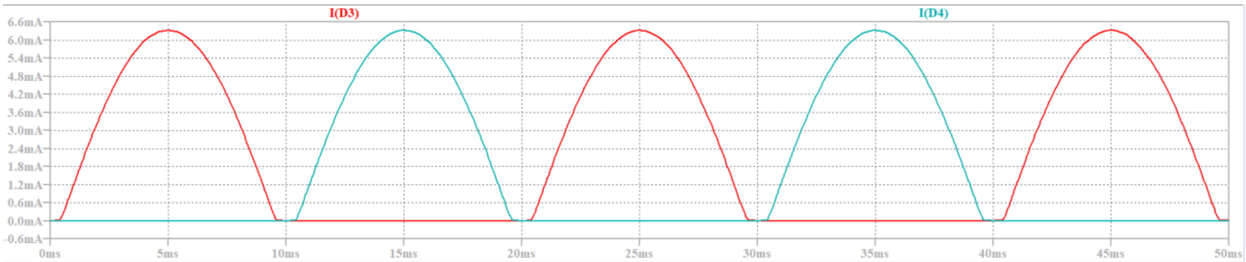
Verify the amplitude and frequency of the output waveform on the load resistor, $\mathbf{R_L}$.

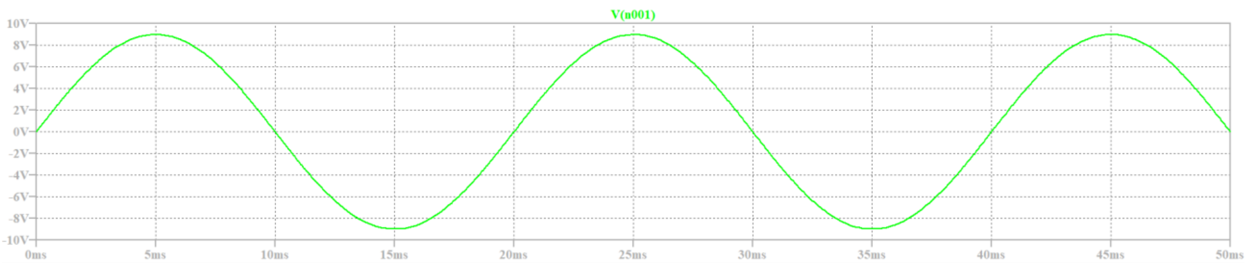
Peak voltage: 7.5830331V

Waveform period: 9.9891127ms Frequency 100.10899Hz

1.a) Which diode(s) is/are on during the positive and negative cycles of v_S?







>>We can say that a diode is on when it is conducting. This happens when the voltage across the diode is greater than turn on voltage which is 0.7 volt. So, as we can see from the graphs, D1 and D3 are on during the positive cycle. On the other hand, D2 and D4 are on during the negative cycle of v_S.

1.b) v_S frequency is 50 Hz. Why the v_L frequency is 100 Hz?

>>Because what rectifier does is flipping the negative waves to positive side to obtain as stable as possible DC voltage. This results in duplication of frequency. Basically, because of the design of this circuit, when the circuit encounters with negative voltage, the direction of the current which flows on R_L changes. Thus, we obtain as signal which is only positive wave with double frequency.

1.c) Calculate the average power dissipated on all four rectifier diodes (assume that each diode is ON for exactly one half cycle of v_S for simplicity).

$$\gg The\ averge\ powe\ formul\ is\ equal\ to\ V_{Turn\ on} \times I_{Diode}$$

According to equation of $V_{LDC} = \frac{2}{T}\int_{t=0}^{T/2} V_{SP}\, sin(\omega t)\, dt = \frac{2\, V_{SP}}{\pi}$ we can obtain I_{Diode}.

$$\gg I_{Diode} = I_{R(load)}\ which\ is\ equal\ to\ \frac{2v_s/\pi}{R(load)} = \frac{2 \times 9/\pi}{1200}$$

$$\gg Average\ power\ of\ a\ diode = \frac{V_{Turn\ on} \times 2v_s}{\pi \times 1200} = \frac{0.7 \times 2 \times 9}{\pi \times 1200} = 3.342mW$$

, ,

$$\gg The\ average\ power\ dissipated\ on\ all\ four\ diodes = 4 \times 3.342 = 13.368mW$$

1.d) How much power would have been dissipated on the diodes in total, if the same output waveform was obtained using a full-wave rectifier with a center- tapped transformer?

>>According to equation of $V_{LDC} = \frac{2}{T}\int_{t=0}^{T/2} \frac{V_{SP}}{2}\, sin(\omega t)\, dt = \frac{V_{SP}}{\pi}$, we can deduce that the total power dissipation would be half of bridge rectifier.

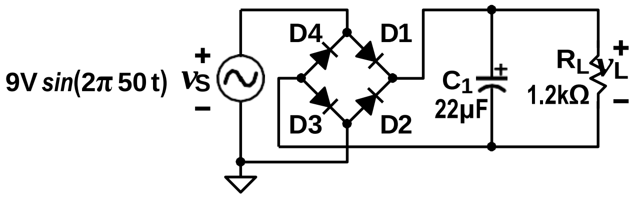
$$\gg The\ average\ power = \frac{13.368mW}{2} = 6.684mW$$

2. Measure and record the peak and average values of the voltage output for the following $\mathbf{R_L}$ values:

R_L	330 Ω	560 Ω	1.2 kΩ
V_{Lpeak}	7.5173358V	7.5446237V	7.583343V
V_{LDC}	4.3667V	4.3911V	4.4267V

>>As we can see in this table, we obtain a little greater V(LDC) and V(Lpeak) values if load resistance is increased. There is direct proportion.

3. Add a 22 μF capacitor in parallel with **R_L**



R_L	**330 Ω**	**560 Ω**	**1.2 kΩ**
V_{Lpeak}	7.5105288V	7.5284774V	7.5489169V
V_{rplPP}	4.1268411V	3.1182387V	1.8772473V
V_{LDC} measured	5.4646V	5.8938V	6.422V
V_{LDC} calculated	5.4471V	5.9694V	6.6103V
V_{LDC} Error	‰ 3.20	‰ 12.8	‰ 29.3
I_{LDC} calculated	16.506mA	10.659mA	5.508mA

>>From this table, we can deduce that there is direct proportion between load resistance and V_{Lpeak}/V_{LDC}. However, there is inverse proportion between load resistance and V_{rplPP}/I_{LDC}.

V(LDC) and I(LDC) have the same error ratio because we obtain I(LDC) from V(LDC).

3a) What is the load regulation of this circuit for $R_L = \infty$ and R_L = 330 Ω? Use the V_{LDC} measured for R_L = 560 Ω as the nominal voltage.

$$\%\ \boldsymbol{Load\ Regulation} = \frac{\boldsymbol{V_{OutFullLoad} - V_{OutMinLoad}}}{\boldsymbol{V_{OutNominal}}} \times \mathbf{100}$$

We know how to calculate load regulation percentage from the equation above.

We measured:

$V(R_L = \infty) = \mathbf{7.3042V}$

$V(R_L = 330\ \Omega) = \mathbf{5.4646V}$

$V(R_L = 560\ \Omega) = \mathbf{5.4646V}$ (Nominal Voltage)

From these data we can calculate the load regulation rate.

$$\%\ \boldsymbol{Load\ Regulation} = \frac{\mathbf{7.3042V - 5.4646V}}{\mathbf{5.4646V}} \times \mathbf{100} = \ \%\mathbf{31.21}$$

3b) Calculate the ripple factor for the three R_L values.

$$**Ripple\ Factor = {}^{V_{AC-RMS}}/_{V_{DC}}$$

$$\gg Ripple\ Factor\ of\ R_L = 330\Omega => \frac{5.6798\text{V}}{5.4646\text{V}} = 1.0394$$

$$\gg Ripple\ Factor\ of\ R_L = 560\Omega => \frac{6.0455\text{V}}{5.8938\text{V}} = 1.0257$$

$$\gg Ripple\ Factor\ of\ R_L = \infty\Omega => \frac{7.4189\text{V}}{7.3042\text{V}} = 1.0157$$

3c) Explain the effect of load resistance on the ripple voltage.

>>When we change load resistance, time constant is changing in the same direction which causes the capacitor to discharge differently. Consequently, as we can deduce from the table above, if the load resistance is increased, the time constant increases and this results in less ripple voltage. Because greater time constant means that the circuit needs greater time to charge or discharge. If period is longer than five times time constant, the capacitor can discharge totally which causes highest ripple voltage. This logic applies in the opposite case also.

$$\tau = RC$$

4. Use **R_L = 330 Ω**, and connect another **22 μF** capacitor in addition to **C1** in parallel with **R_L**. Copy the first column data from above and measure and/or calculate the peak amplitude of v_L, peak-to-peak ripple voltage, DC value of v_L, and the DC load current for two capacitors in the right column.

Filter Capacitor	**22 μF**	**22+22 μF**
V_{Lpeak}	7.5105288V	7.4976295V
V_{rpIPP}	4.1268411V	2.8030332V
V_{LDC} measured	5.4646V	5.989V
V_{LDC} calculated	5.4471V	6.0961V
V_{LDC} Error	‰ 3.20	‰ 17.88
I_{LDC} calculated	16.506mA	18.473mA

>>From this table, we can say that if we have greater capacitance, we would see greater DC output because as I explained in 4b, greater capacitance causes greater time constant which results in less ripple voltage.

4.a) What is the load regulation with two 22 μF capacitors?

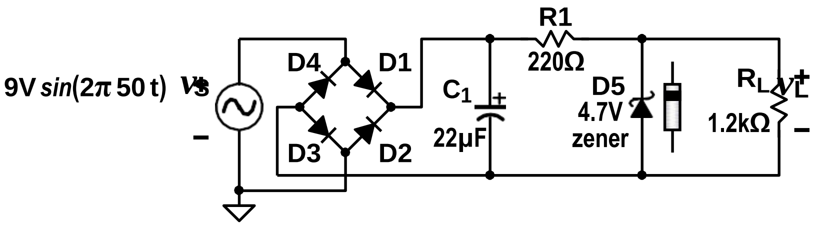
$$\gg \%\ \boldsymbol{Load\ Regulation} = \frac{\mathbf{7.2688V - 5.989V}}{\mathbf{6.3487V}} \times \mathbf{100} = \ \%\mathbf{20.16}$$

>>Because of greater capacitance, we calculate less load regulation.

4.b) Explain the effect of filter capacitance on the ripple voltage.

>>The purpose of the filter capacitor is to stabilize the voltage wave which gives use more DC like voltage signal. The change in capacitor value causes different results. Just like 3a, if the capacitance is increased, the time constant increases and this results in less ripple voltage because the capacitor discharges slower. Also the opposite case is valid. We can see the affect of filter capacitor from the table above.

5. Build the following voltage regulator circuit with a zener diode.

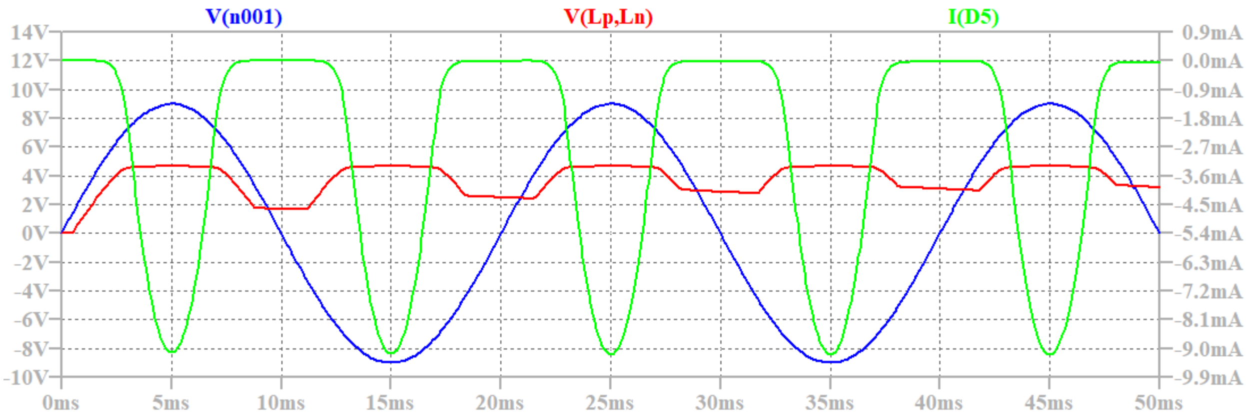


R_L	330 Ω	560 Ω	1.2 kΩ
V_{Lpeak}	4.397859V	4.6224906V	4.6591512V
V_{rplPP}	3.2468699V	2.9836703V	2.2354791V
V_{LDC} measured	2.7957V	3.2624V	3.7012V
V_{LDC} calculated	2.7744V	3.1307V	3.5414V
V_{LDC} Error	%o7.62	%4.04	%4.31
I_{LDC} calculated	8.407mA	5.590mA	2.951mA

>>According to this table, we can deduce that, there is a direct proportion between load resistance and V_{Lpeak}/V_{LDC}. On the other hand, there is a inverse proportion between load resistance and V_{rplPP}/I_{LDC} .The behavior is just like table of 3.

5.a) How can you determine when the zener diode is conducting?

>>Breakdown voltage of the Zener diode is -4.7 volt. Thus, the voltage on the Zener diode can not be under that value. When the potential difference gets close to -4.7 volt, Zener diode starts to conduct rapidly and stabilize the difference around that value. Because of the rectifier design, diode never encounters with a positive voltage difference.



(Blue = Vs, Red = Vout, Green = I(Zener))

>>From a different viewpoint, when Vs comes closer to 4.7 + 2x$V_{turn\ on}$, the diode starts to conduct as we expect. Because of this feature of the diode, it regulates the output voltage around 4.7 volt.

5.b) Roughly measure the duty cycle of current through the zener diode and estimate the average power dissipated on the zener diode for each R_L value.

$$\boldsymbol{Average\ Power} = V_Z \times \frac{v_C - V_Z}{R_S} = 4.7 \times \frac{v_C - 4.7}{220}$$

	330 Ω	**560 Ω**	**1.2 kΩ**
Duty cycle	%77.927	%75.833	%68.409
Average power	$1.771mW$	$4.646mW$	$10.075mW$

$$\boldsymbol{Average\ Power\ of\ R_L = 330\Omega} => V_Z \times \frac{v_C - V_Z}{R_S} = 4.7 \times \frac{4.7829V - 4.7}{220} = 1.771mW$$

$$\boldsymbol{Average\ Power\ of\ R_L = 560\Omega} = V_Z \times \frac{v_C - V_Z}{R_S} = 4.7 \times \frac{4.9175 - 4.7}{220} = 4.646mW$$

$$\boldsymbol{Average\ Power\ of\ R_L = 1.2k\Omega} = V_Z \times \frac{v_C - V_Z}{R_S} = 4.7 \times \frac{5.1716 - 4.7}{220} = 10.075mW$$

5.c) Display the power dissipation on the zener diode as a function of time and measure the average power dissipation for each R_L value.

R_L	**330 Ω**	**560 Ω**	**1.2 kΩ**
Calculated average power	$1.771mW$	$4.646mW$	$10.075mW$
Measured average power	906.14μW	5.5754mW	13.126mW
Error	%95	%17	%23

5.d) Compare the results of capacitor-only and zener diode filter circuits. Explain the advantages and disadvantages of each filtering technique.

>>The breakdown voltage of Zener diode is not flexible, so while designing a Zener diode filter circuit are not free. However, we are able to regulate and fix an output value with Zener diode. With capacitor only circuits, we do not have chance of regulation of output voltage, we just obtain more DC like signal of input signal. In conclusion, Zener diode filter depends on Zener diode breakdown voltage on the other hand, capacitor only filter depends on input signal. They both have dependency of something else.

Conclusion

Due to lack of information, all of the capacitors equivalent series resistance is set to 20 ohm (500 ohm on the last question) because LTspice was giving an error message and halting the simulation. Because of this, I might have gotten different results than others.

In the first question of this experiment, we figured out that how a rectifier works, how can we know that a diode is on and how can we calculate power dissipation of diodes in a rectifier circuit.
In the second question, we see the affect of load resistance on the output voltage values.
In the third question, we add a filter capacitor and tried to find out effect of load resistance, how to calculate load regulation and ripple factor and lastly relationship between load resistance and ripple factor.
In the fourth question, we see the effect of capacitance on the circuit and effect of capacitance on the ripple voltage. Also, we calculated load regulation and we see that greater capacitance results in less load regulation.
In the last question, we learned dynamics of Zener diode voltage regulator circuit. We learned how Zener diode works and how can we calculate/measure average power dissipated on Zener diode. Also, we learned differences between Zener diode filter and capacitor only filter.
To sum up, we learned the dynamics of rectifier and regulator circuits.