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EEE419 Lab 1 Preliminary

Introduction:

In this experiment, a negative (inverting) buck converter is designed.

Methdology:

To find the V_d and V_o voltages, I used the equations given and find 12V and 5.5V respectively. Therefore, I used the second circuit given in the instruction sheet. Duty cycle is calculated as D=0.458. To determine R_a, R_b, C, and T_s values, I used the equations given for NE555 pulse generator IC. Equations are given below.

$$t_L = 0.693\mathrm{C}\mathrm{R}_B$$

$$\mathrm{T}_s = 0.693\mathrm{C}(\mathrm{R}_A + 2\mathrm{R}_B)$$

Also, $R_a + R_b$ value should sum up to 10KΩ. Therefore I choose R_a as 3KΩ and R_b as 6.8KΩ. To use standard values, I choose C value as 1.8nF. Plugging in these variables in to the equation gives me T_s=21.4µs. As calculated earlier, V_d=12V. R_1, R_2, and R_3 values are calculated as 2.4KΩ, 12KΩ, and 600Ω respectively. Becuase some of them are not standard resistor values, in the lab I will whether try to obtain these values by series/parallel connections or choose the nearest standard resistor values. Fig. 1 shows the circuit schematic.

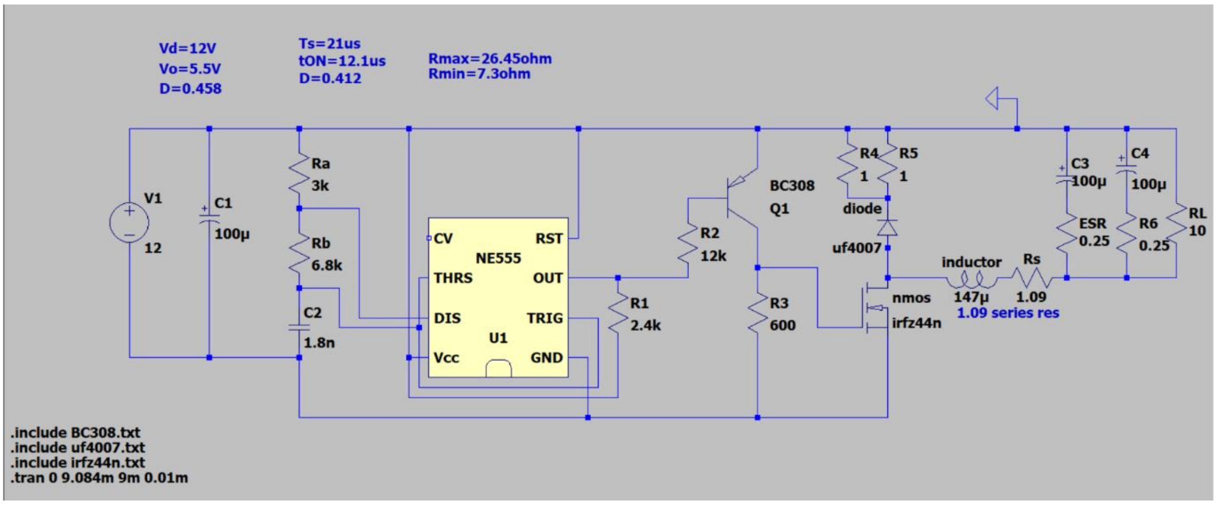

Fig. 1: Circuit Schematic

Questions:

a) To find the maximum value of the load resistor, continuous mode will be considered with the boundary case where $i_L(0)=0$. The equation is given below.

$$I_o = \frac{V_o}{R} \geq I_{OB}$$
$$I_{OB} = \frac{T_s V_d}{2L} \times (D - D^2) = 0.208A$$
$$I_o = \frac{5.5}{R} \geq 0.208 \rightarrow R \leq 26.45\Omega$$

To find the minimum value of the load resistance where $i_{Lpeak} \leq 1.5A$, I used the following equation.

$$I_{OB} = \frac{i_{Lpeak}}{2} = 0.75A$$
$$I_o = \frac{5.5}{R} = 0.75 \rightarrow R = 7.3\Omega$$

b) The load resistances in the range $7.3\Omega < R_{L1} < 26.45\Omega$ are 8.2Ω, 10Ω, and 15Ω. I choose 10Ω as the load resistance. Because $I_O \geq I_{OB}$, continuous mode is considered. Duty cycle can be calculated by the equation below.

$$D = \frac{V_o}{V_d} = 0.458$$

c) To estimate the diode current, I need to find the i_{Lpeak} value.

$$i_L(0) = \frac{V_o}{R} - 0.5 * \frac{V_d - V_o}{L} * t_{ON} = 0.326A$$

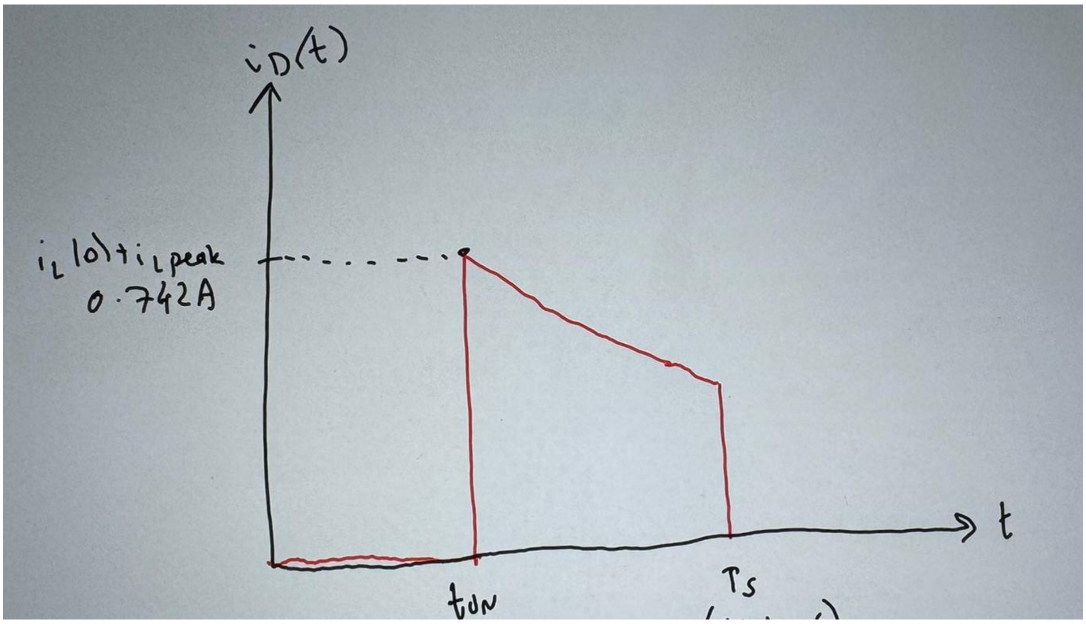

Fig. 2: Estimated diode current with R_L=10

$$\Delta i_L = \frac{V_d - V_o}{L} = 0.416A$$

To show the diode voltage, t_{ON} time period is shown too short, however t_{ON} is greater than t_{OFF} normally.

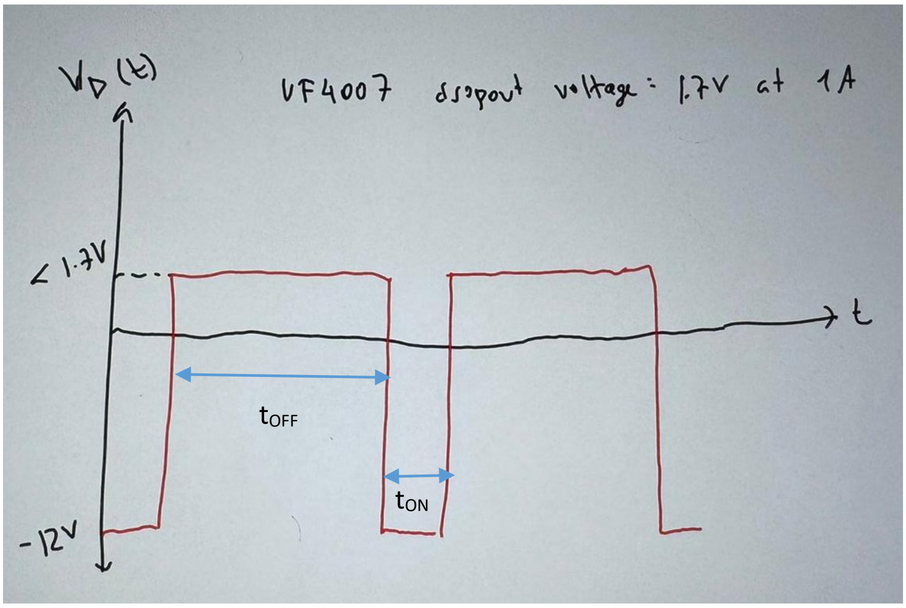

Fig. 3: Estimated Diode voltage with R_L=10

d) When a single 100µF capacitor with ESR=0.25Ω used, output ripple is measured around 0.0.52V. To lower the output ripple, two 100µF capacitors are connected in series to lower the equivalent ESR value. Because ESR is the dominant mechanism for the output ripple, following equation will be used.

$$\Delta i_L = i_{Lpeak} - i_L(0) = 0.416A$$
$$\Delta V_{ESR} = \Delta i_L * R_{ESR} = 0.052V$$

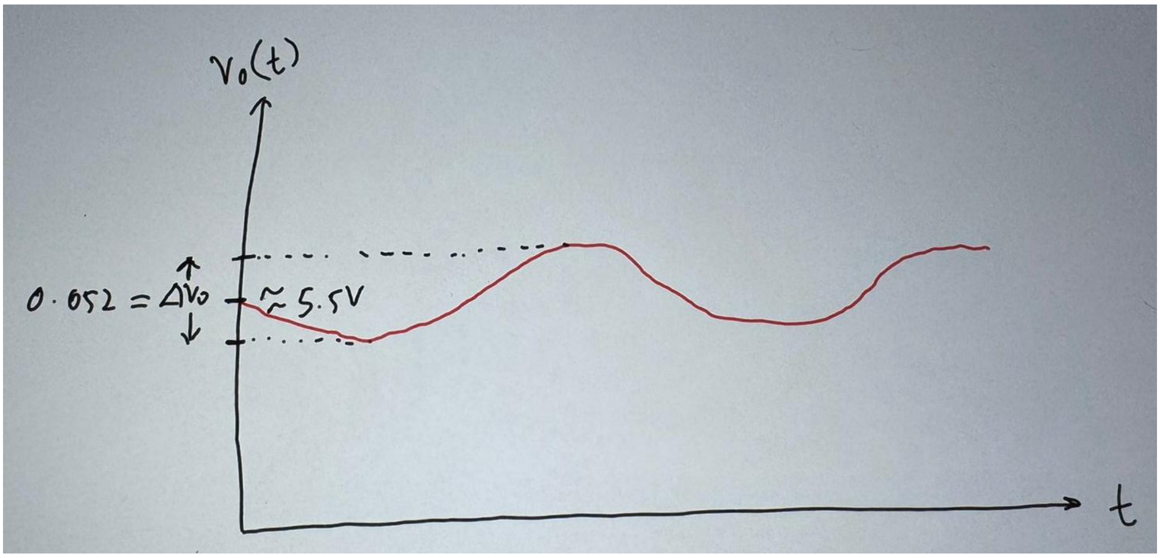

Fig. 4: Estimated output ripple voltage (positive valued)

e) R_{max} value calculated as 26.45Ω. R_{L2} value is choosed as 47Ω. As a result, because the output current will be less than I_{OB}, discontinuous mode is going to be considered.

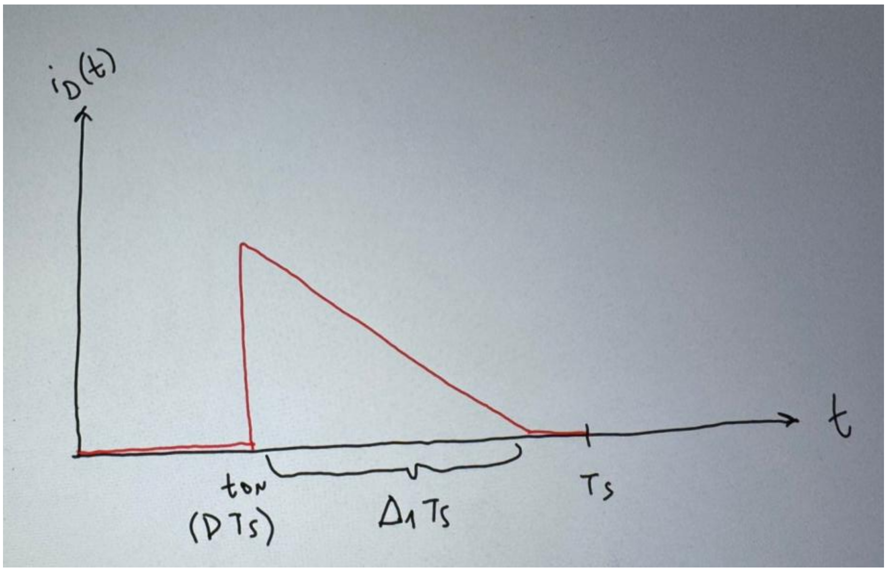

Fig. 5: Estimated diode current with R_L=47

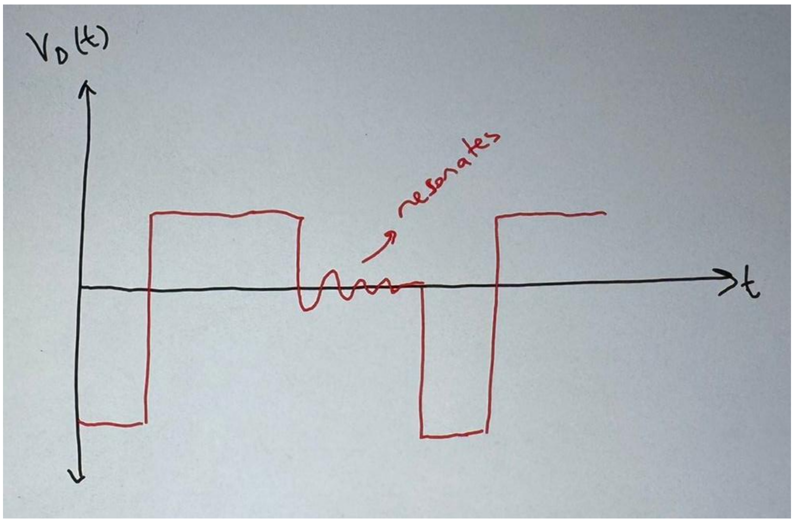

Fig. 6: Estimated diode voltage with R_L=47

f) Initially, duty cycle value is 0.458, which gives the output voltage as -7.1V. To make this output voltage value -5.5V, a change in duty cycle has to be made. The equation for the duty cycle calculation is given below.

$$D = \frac{V_o}{V_d} * \sqrt{\frac{\frac{I_O}{I_{OBmax}}}{1 - \frac{V_o}{V_d}}} = 0.388$$

$$I_{OBmax} = \frac{T_s * V_O}{2 * L} = 0.3A$$

g) Duty cycle is measured from the inductor current. Figure below shows the inductor current waveform and t_{ON} value.

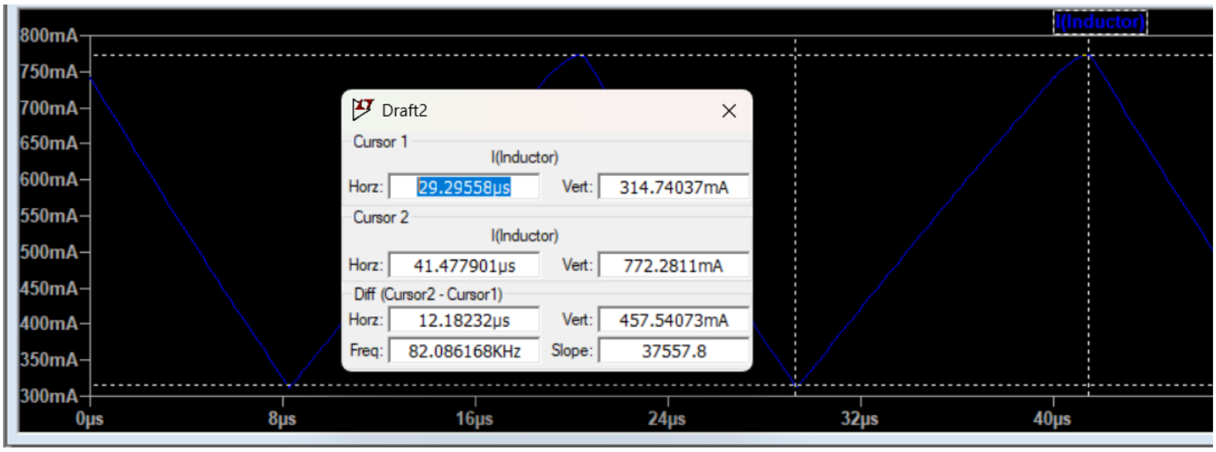

Fig. 7: t_{ON} value from the inductor current waveform

Ts value is 21.4µs. Corresponding duty cycle D=0.57. Value found at b) is 0.458. As expected, duty cycle in the simulation is greater than the calculated value because of the voltage drops across the diode and resistors.

h) Figures below shows the diode current $i_D(t)$ and diode voltage $v_x(t)$ respectively.

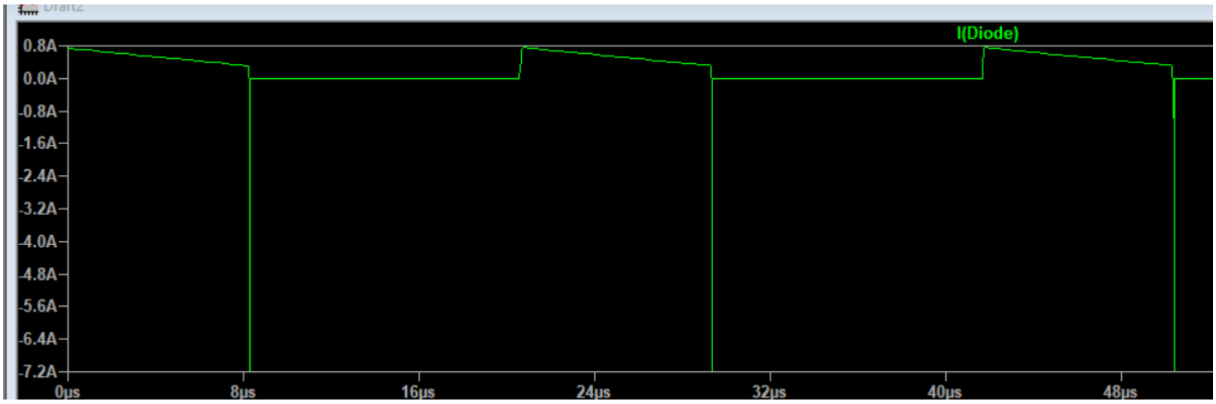

Fig. 8: Diode current waveform

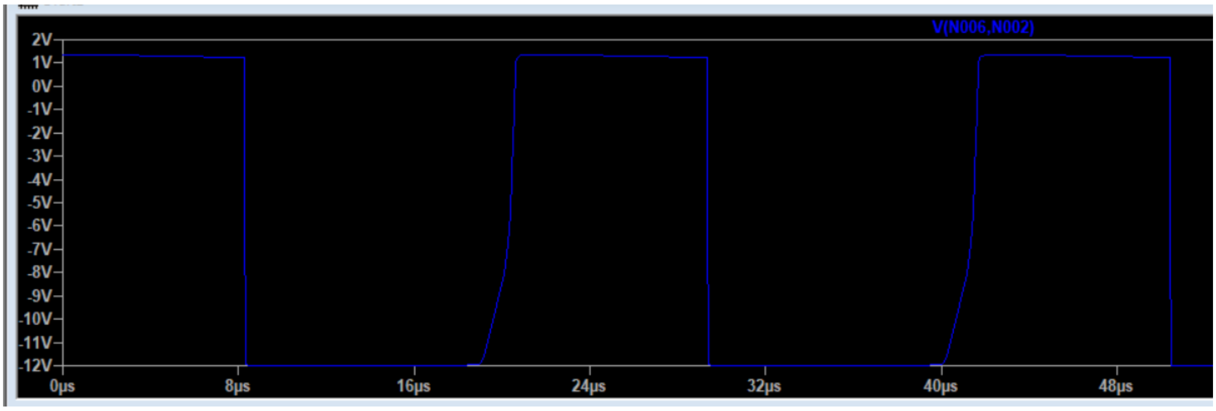

Fig. 9: Diode voltage waveform

i) The output voltage waveform is given below. The pk-to-pk ripple is measured as 56mV. The average value of the output voltage is -5.49V. V_o value is calculated as -5.5V at the beginning.

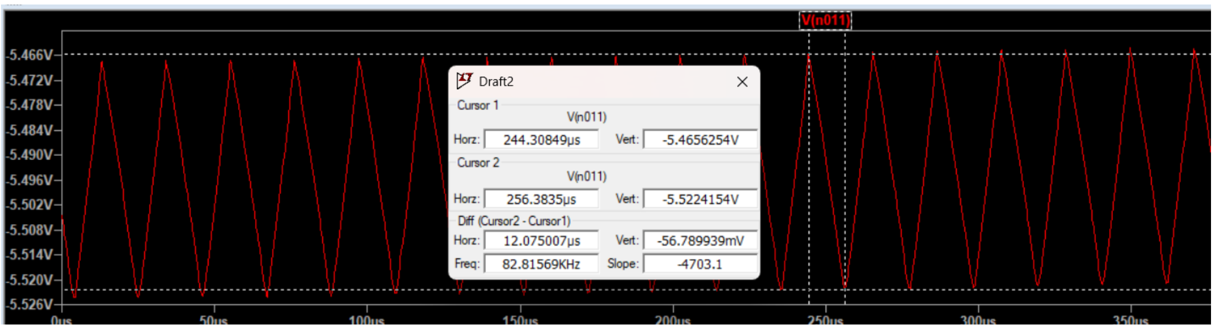

Fig. 10: Output voltage in PSS and p-p ripple value

j) To find the converter's efficiency, following equations are going to be used.

$$P_{in} = V_d * I_d = 4.21W$$

$$P_{out} = \frac{{V_o}^2}{R_L} = 3.02W$$

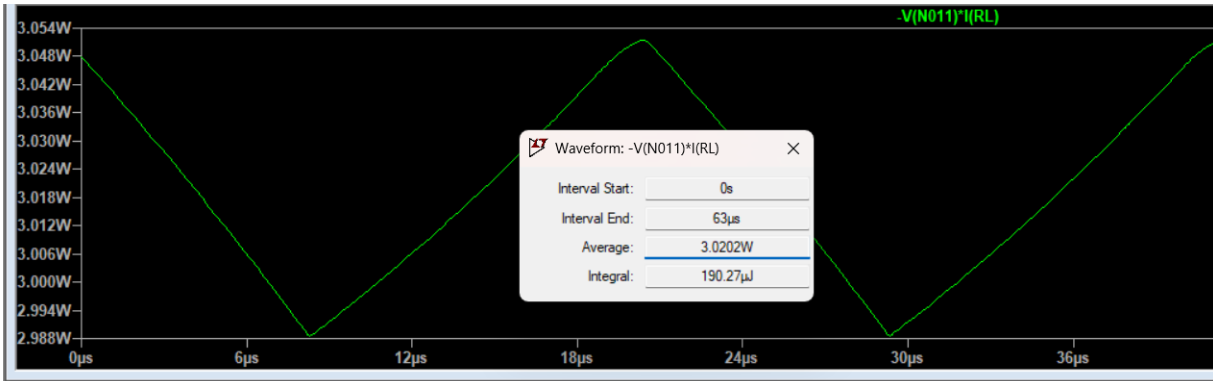

Fig. 11: Input power

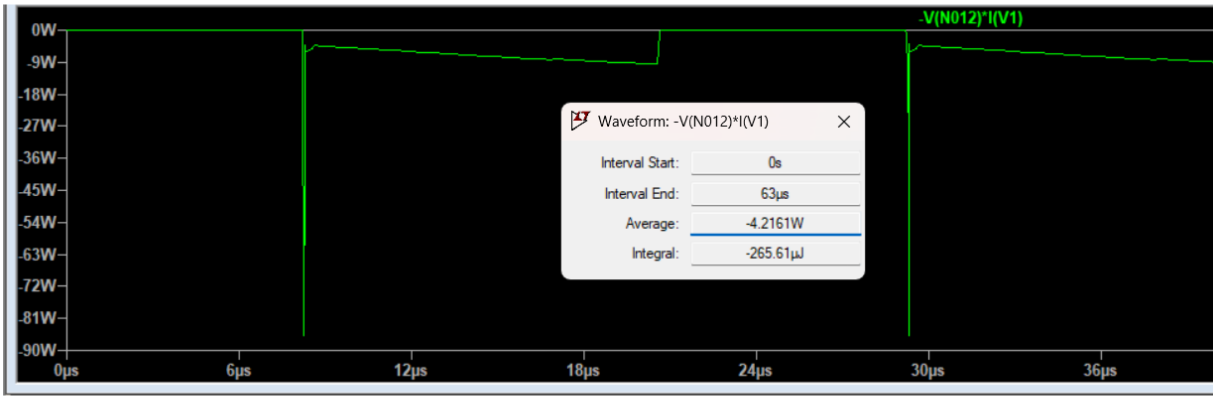

Fig. 12: Output power

$$\eta = \frac{P_{out}}{P_{in}} = 72\%$$

The efficiency of the system is calculated as 72%.

k) In part f), duty cycle is calculated as 0.388. Therefore a value near to this is going to be obtained in the simulation and the output voltage will be checked. Fig. 13 shows the T_S value of the circuit and Fig. 14 shows the t_{ON} value with R_L=47Ω. To get a value close to D=0.388, R_A value is set to 9KΩ and R_B value is set to 1KΩ.

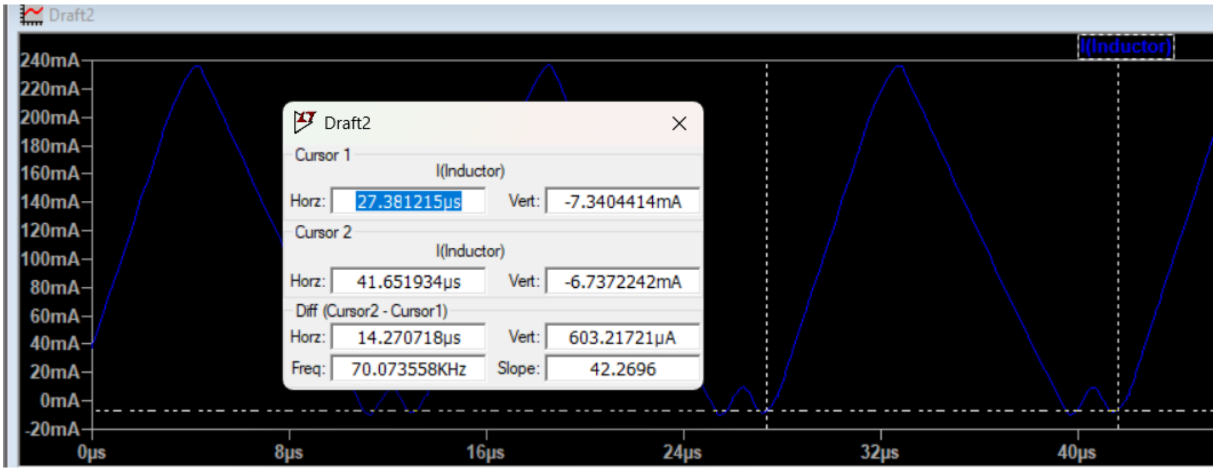

Fig. 14: Ts value with R_L=47Ω

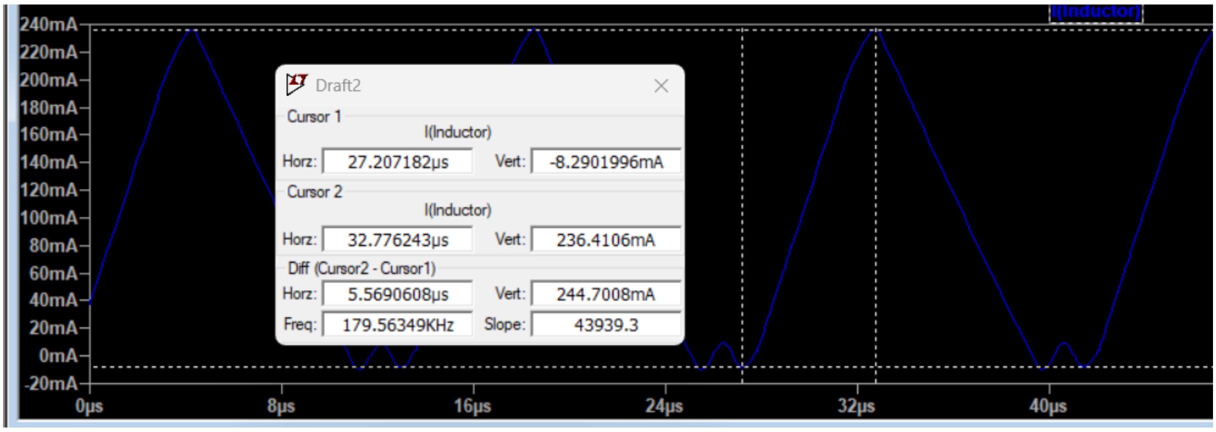

Fig. 13: t_{ON} value with R_L=47Ω

Corresponding duty cycle value is calculated as 0.389. The duty cycle value in part f) is 0.388. Fig. 15 shows the output voltage waveform. The output voltage is around -4.12V.

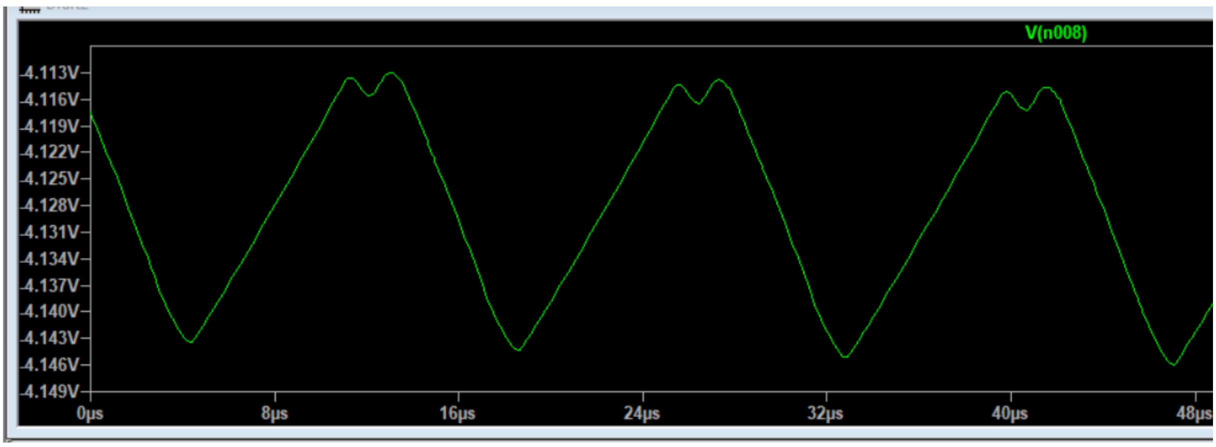

Fig. 15: Output voltage with D=0.389 and R_L=47Ω

l) In order to get the previous voltage at the output which is 5.5V, some adjustments need to be done. Currently, with R_L=47Ω, V_o=7.1V. To reduce this value to 5.5V, I swapped the R_A and R_B values. As a result, both Ts and duty cycle values are changed. New Ts value is 16.36µs (Fig. 16) and duty cycle value measured D=0.462 (t_{ON}=7.54µs) (Fig. 17). The value found at f) for duty cycle is 0.388, and here is 0.462. It is seen that due to voltage drops across diode and resistors, duty cycle has increased. Output votlage can be observed from Fig. 17, which is measured as around -5.5V.

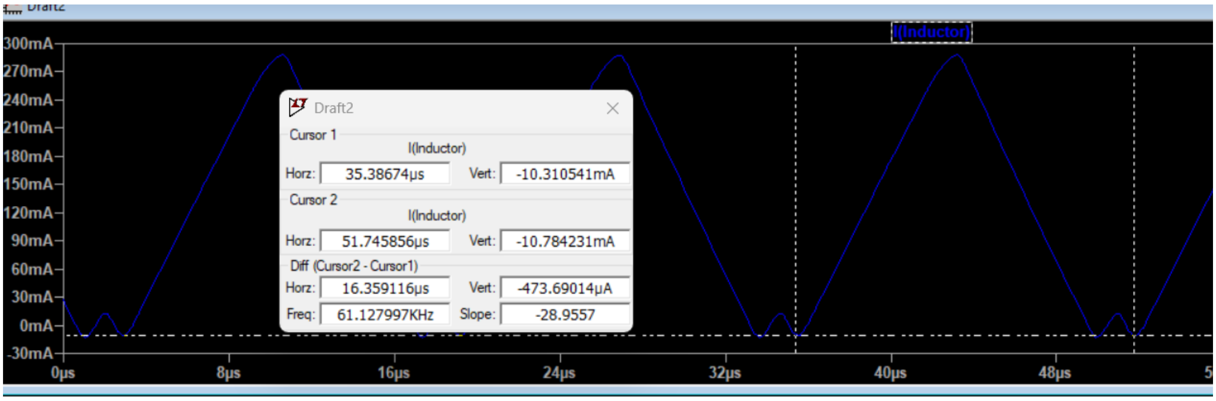

Fig. 16: New T_s value with R_L=47

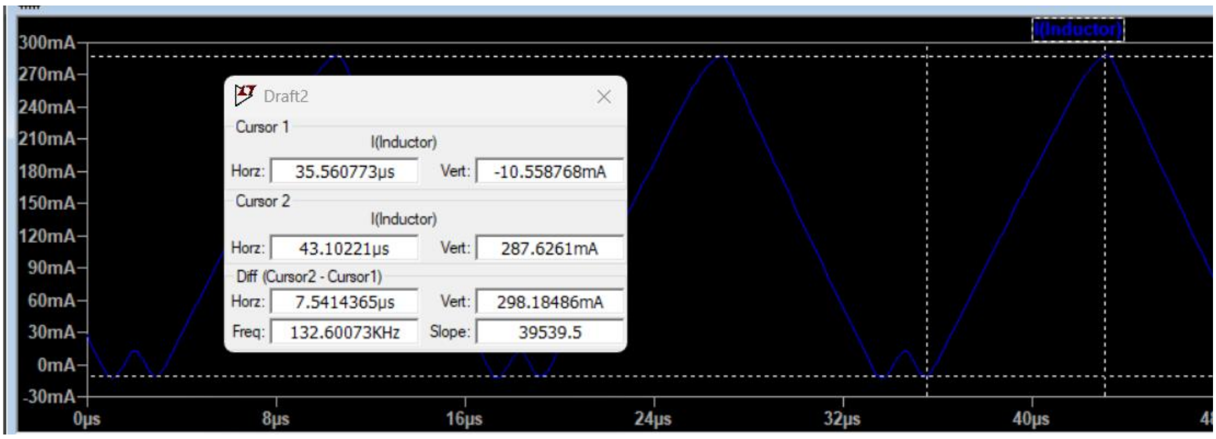

Fig. 18: t_{ON} value with R_L=47

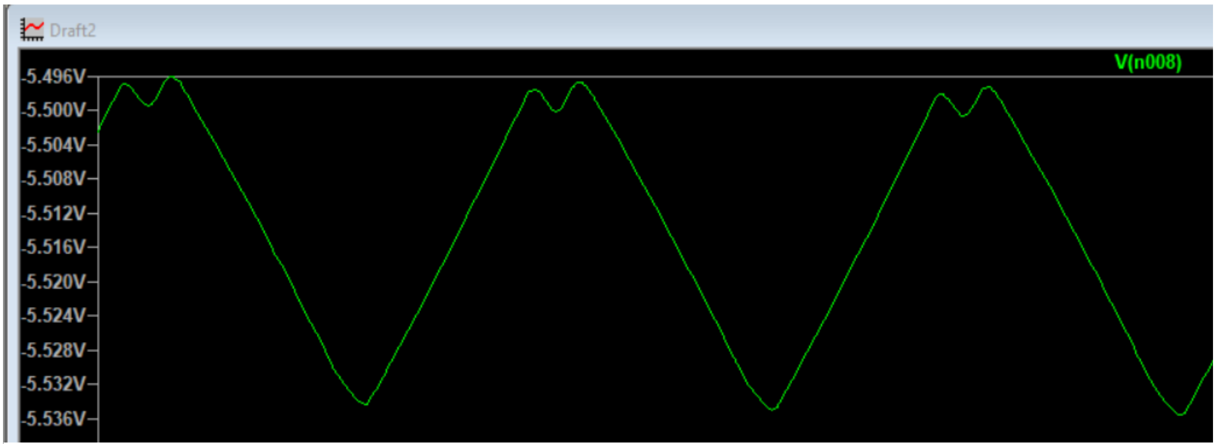

Fig. 17: Output voltage with R_L=47Ω