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EE419/519 Homework Assignment #2

"I completed this homework assignment independently."

Introduction:

The purpose of this homework is designing a Buck converter which takes 320V as input voltage and give 3.3V as output voltage with R_L=5Ω.

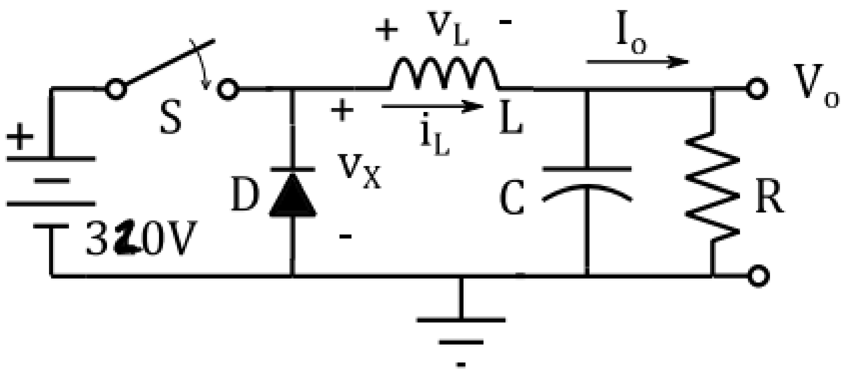

Fig. 1: Circuit Diagram

Design Specifications:

a) Switching frequency is calculated as 30kHz. The formula for the duty cycle is given below for continuous mode operation.

$$V_O = V_D * D$$

Using this equation, D (duty cycle) is found as 0.01, so t_{ON}=0.33µs, where T_s=33.3µs.

b) In order to find the minimum L value, I need to consider where $i_L(0)=0$ and $I_O \geq I_{OB}$. The formulas are given below.

$$I_O = \frac{V_O}{R} = \frac{3.3V}{5\Omega} = 0.66A$$
$$I_{OB} = \frac{T_s V_d}{2L} * (D - D^2)$$
$$i_{lpeak} = 2I_{OB} = 0.33A$$

Using these equation, minimum L value is calculated as 79.92µH. Because it is written choose at least twice this value, 160µH value is chosen.

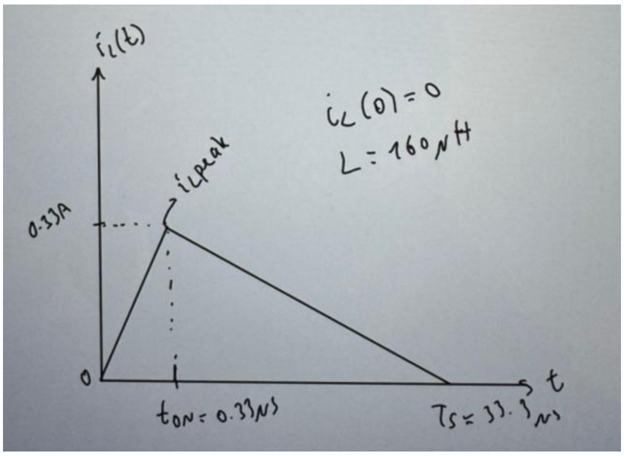

Fig. 2: $i_L(t)$ graph with $i_L(0)=0$ (boundary case)

c) To obtain 15mV output ripple with zero ESR, following formula is going to be used to determine the capacitor value.

$$\Delta V_O = \frac{1}{8C} * \frac{{T_s}^2 V_O}{L} * (1-D)$$

From this equation, C value is calculated as 188µF.

Now, taking into consideration the ESR, following formula will give us the output voltage ripple due to ESR of the capacitor.

$$\Delta V_{ESR} = \frac{8LC}{(1-D)T_s \frac{V_O}{L} R_{ESR}}$$

From this equation, peak-to-peak output voltage ripple due to ESR is calculated as 0.1V.

d) I choose L value as 10µH for this case. Using the formula below, V_O value will be calculated.

$$V_O = \frac{D^2}{D^2 + \frac{I_O}{4 * I_{OBMAX}}} * V_d \qquad where\ I_{OBMAX} = \frac{T_s V_d}{8L}$$

V_O value is calculated as 12.8V when D is preserved. The new I_O value is 2.56A where I_{OB}=5.27A. It is seen that the Buck converter is in discontinuous mode. i_{Lpeak} value is calculated as 20.45A, where Δ_1 value is calculated as 0.48. The formula for Δ_1 and i_{Lpeak} are given below for discontinuous mode.

$$\Delta_1 = \frac{I_O}{4 * I_{OBmax} * D}, where\ I_{OBmax} = \frac{T_s V_d}{L}$$

$$i_{Lpeak} = \frac{V_O \Delta_1 T_s}{L}$$

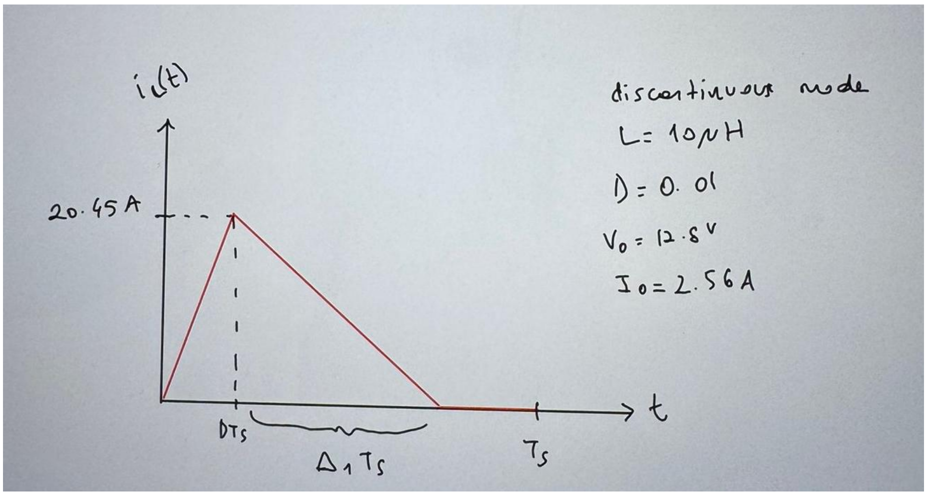

Fig. 3: $i_L(t)$ graph when L=10µH, V_O=12.8V, and D=0.01 in discontinuous mode

e) Again using the equation above, the new duty cycle D is calculated as $3.59*10^{-3}$, so t_{ON}=0.119µs. I_O value is the same as the initial value which is 0.66A. The corresponding Δ_1 value is calculated as 0.69. i_{Lpeak} value is calculated as 7.58A.

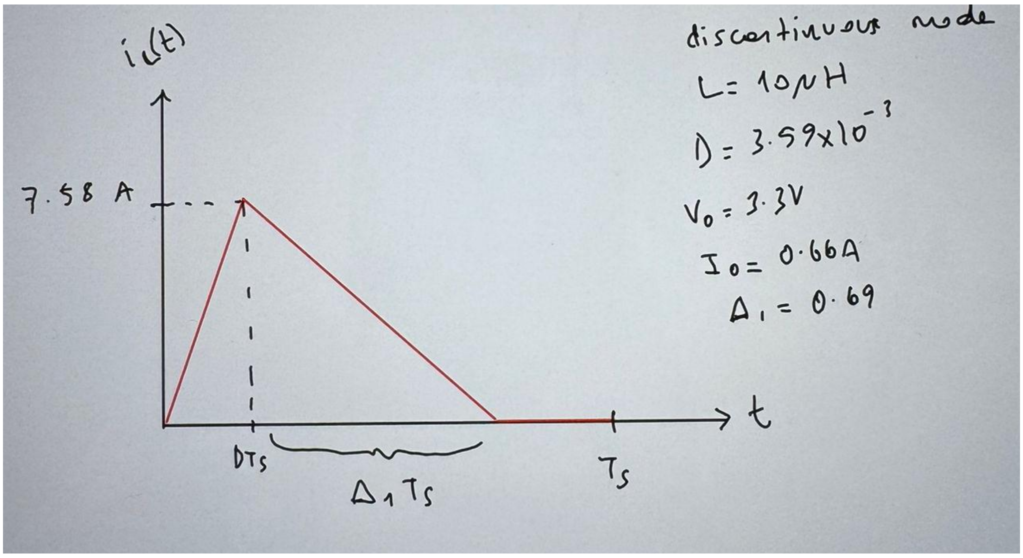

Fig. 4: D=$3.59*10^{-3}$, L=10µH, and V_O=3.3V in discontinuous mode $i_L(t)$ graph

f) Figure below shows the switching period value measured from the inductor current $i_L(t)$.

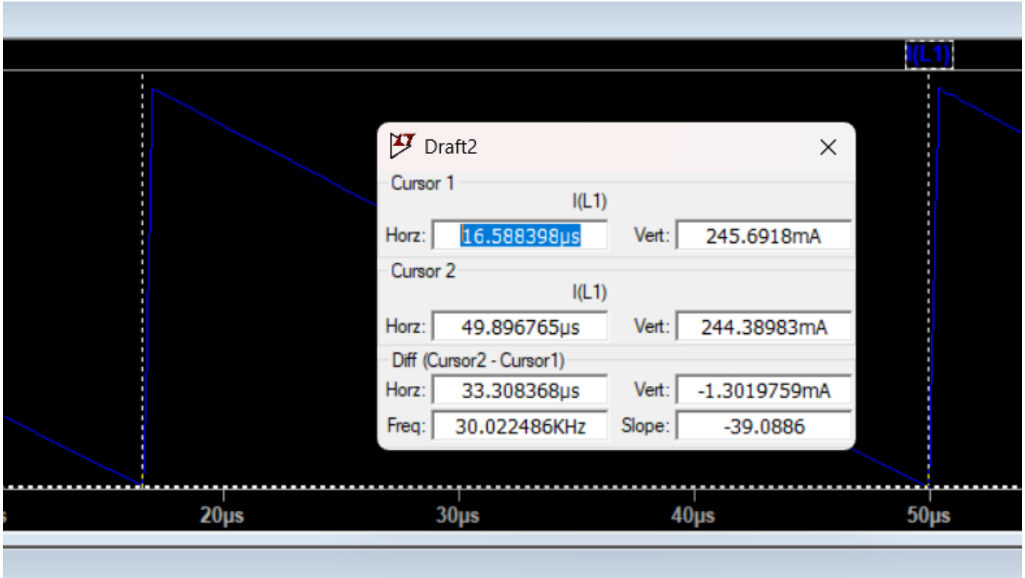

Fig. 5: Ts value

As calculated in the beginning, switching period is measured as 33.3µs. Figure below shows the waveform of the inductor current graph.

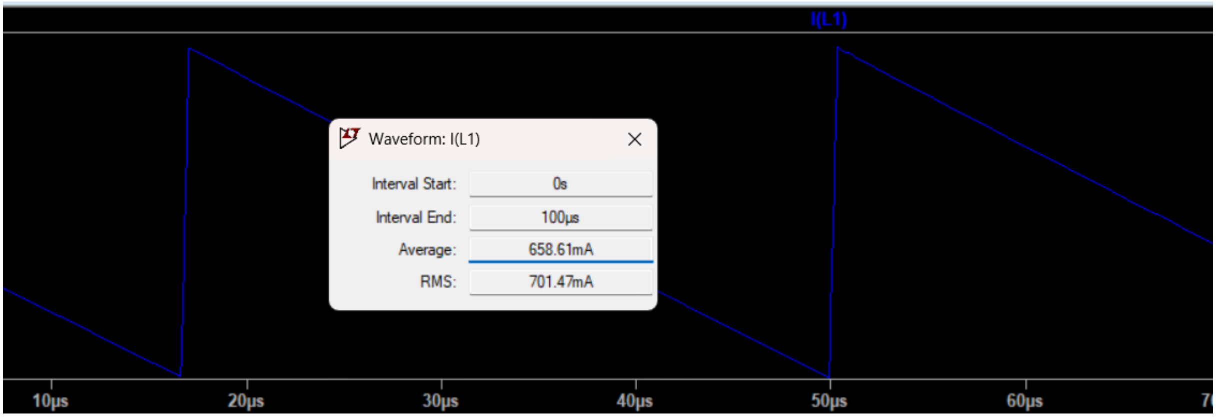

Fig. 6: Inductor current

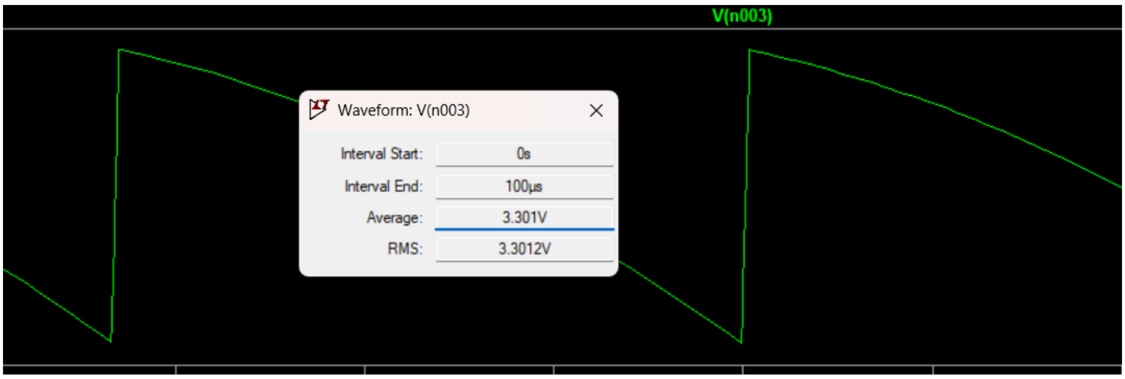

Fig. 7: Output voltage graph with value V_O=3.3V

In the beginning, the t_{ON} value is calculated as 0.33µs, however, due the voltage drop across the diode, some adjustments are done and finally t_{ON}=0.37µs value is used in the circuit.

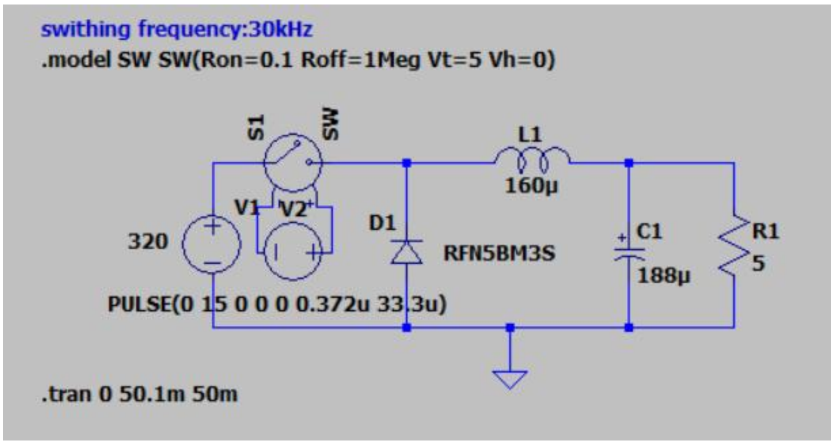

Fig. 8: Desinged Circuit

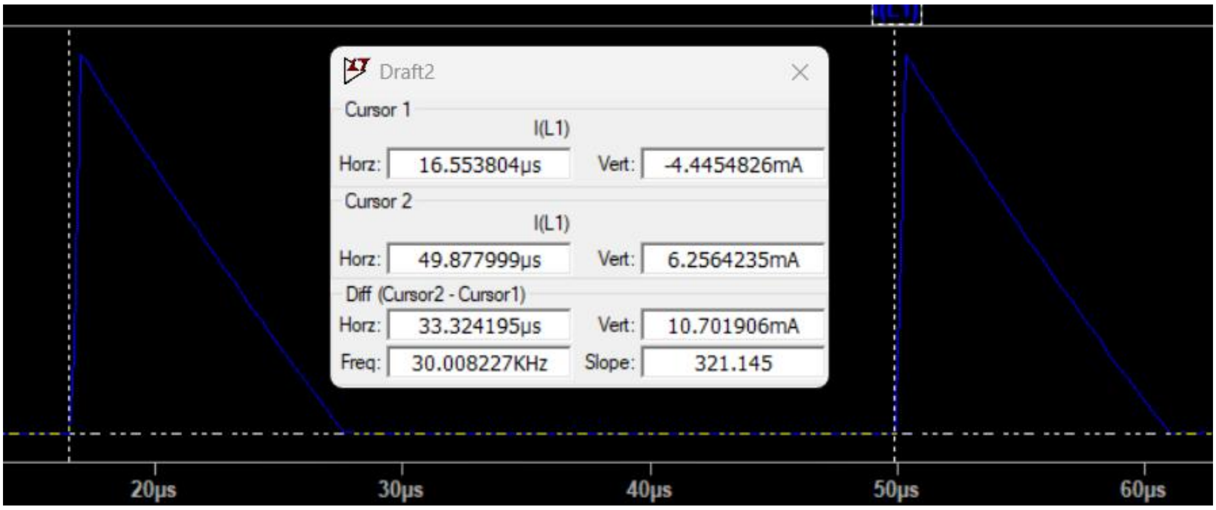

Fig. 9: Switching period in discontinuous mode

g) As seen from Fig. 7, switching period is still 33.3µs.

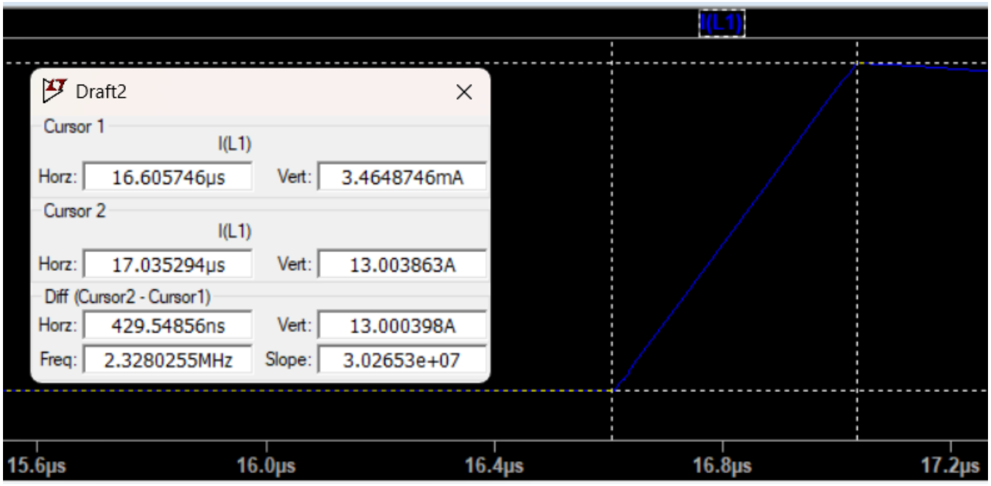

Fig. 10: t_{ON}=0.429us

The duty cycle value is calculated as D=0.012, which is nearly the same value initially calculated (initially D=0.010).

In d), I_O value is calculated as 2.56A, whereas in the simulation, I_O value is measured as 2.1A. The difference is 0.4A and it is due to the voltage drop across the diode and equivalent series resistance of the capacitor.

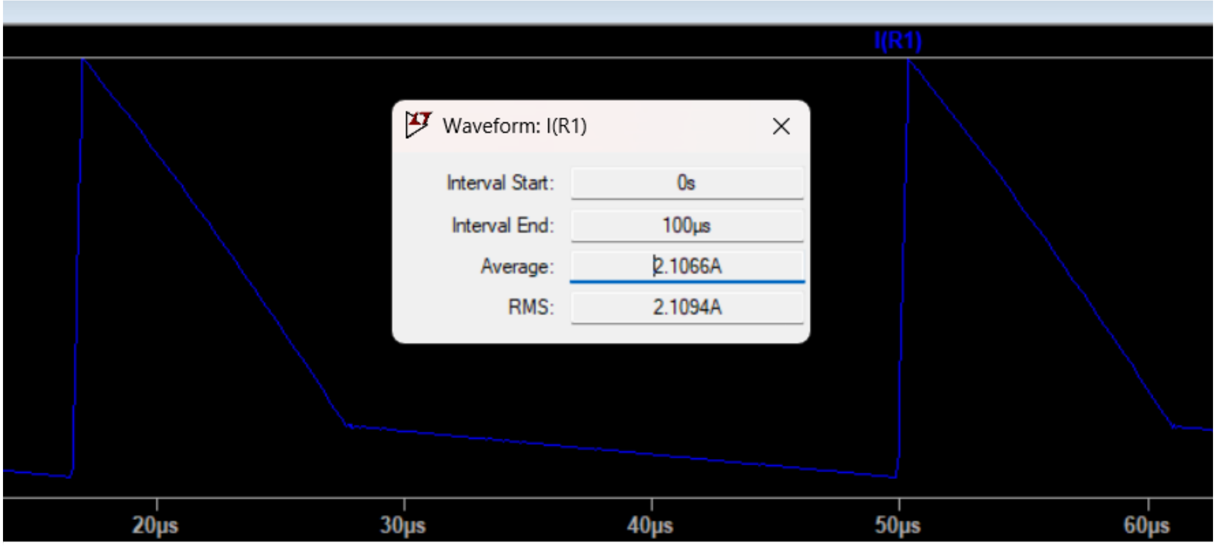

Fig. 12: I_O=2.1A in discontinuous mode

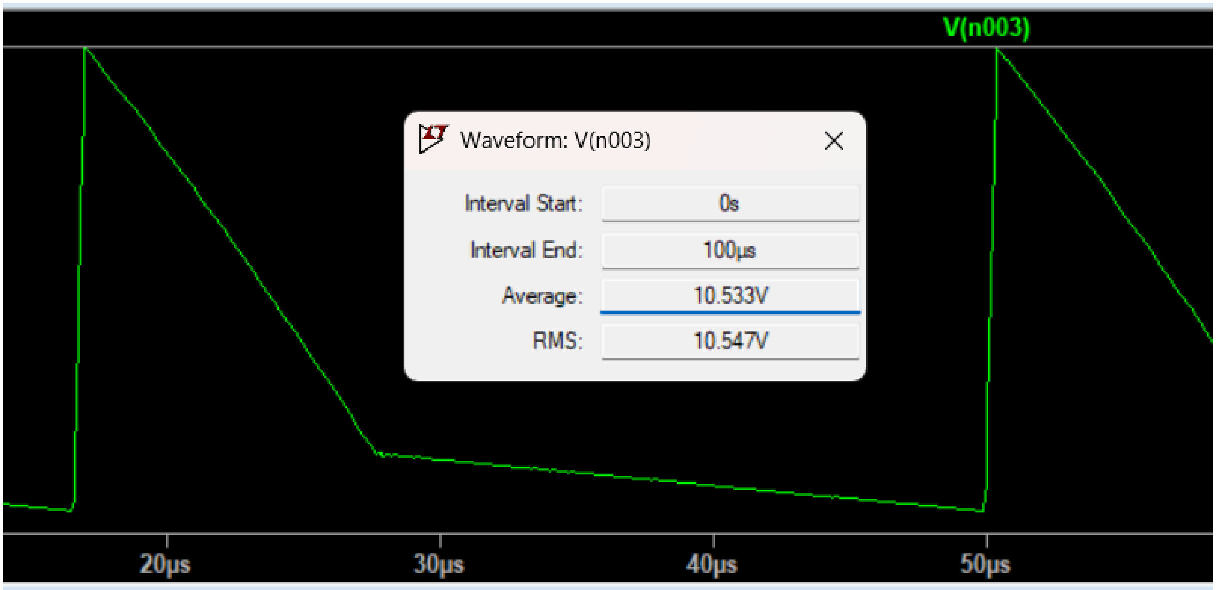

Fig. 13: Output voltage in discontinuous mode

In d), output voltage is calculated as 12.8V, however in the simulation, the measured value of it is 10.5V, again this is related to the difference in I_O values. The i_{Lpeak} value is calculated as 20.45A in d) whereas in the simulation, the peak inductor current value is measured as 12.98A.

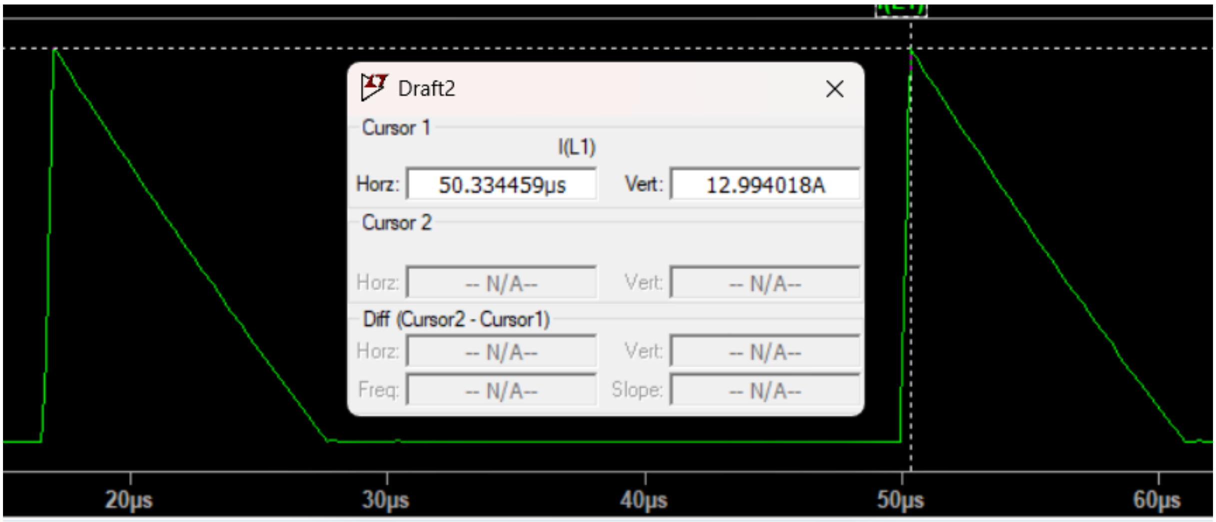

Fig. 14: i_{Lpeak} value for discontinuous mode and D=0.01

h) In e), D is calculated as $3.59*10^{-3}$, and t_{ON}=0.119µs. In the simulation, a slight adjustment was made to get 3.3V at the output. The t_{ON} value is determined as 0.1238µs and corresponding D value is $3.72*10^{-3}$.

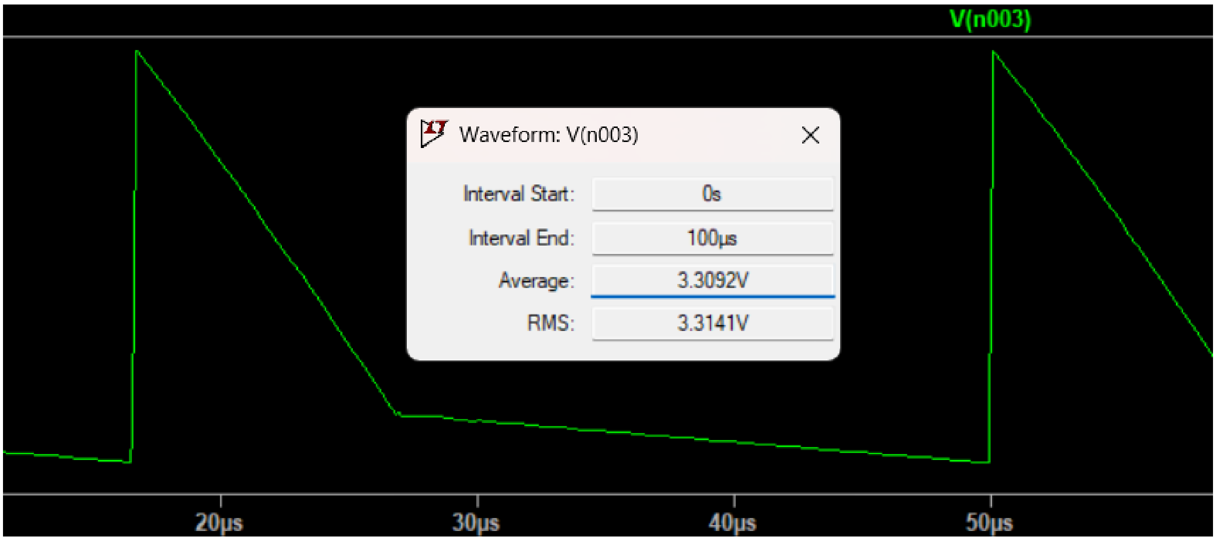

Fig. 15: 3.3V output voltage with L=10µH in discontinuous mode

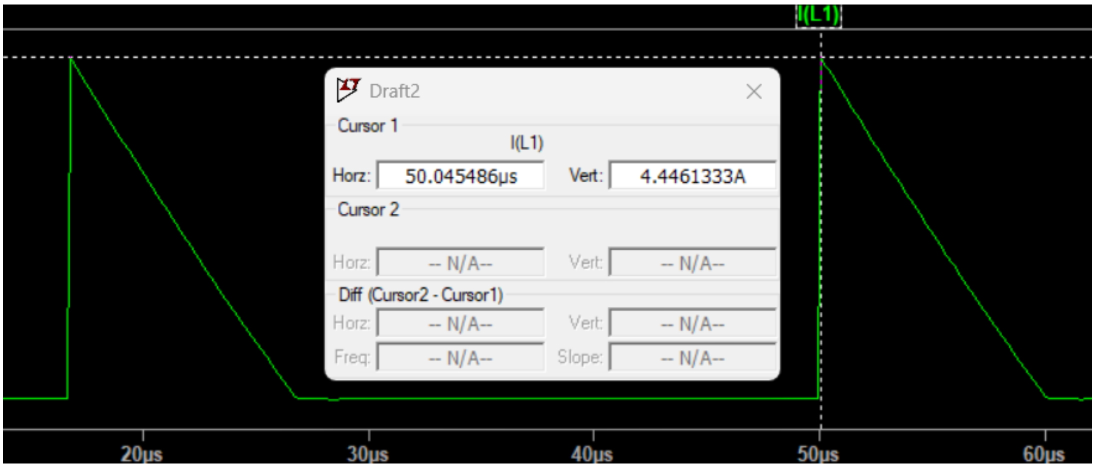

Fig. 16: Inductor current graph $i_L(t)$ with V_O=3.3V in discontinuous mode

In e), peak inductor current value is calculated as 7.58A, however in the simulation, the value is measured as 4.45A. The difference is due to the voltage drop across the components and ESR of the capacitor.

i) When both Diode and Switch are OFF, the diode voltage $v_X(t)$ starts to oscillate until the period is completed. Figure below shows that the frequency of the sinusoidal is measured as 8.01Mhz.

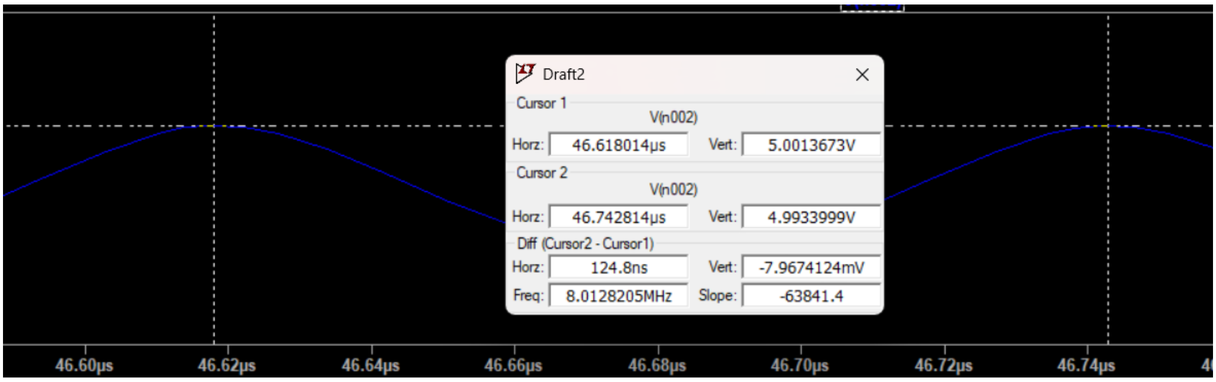

Fig. 17: Frequency of the diode voltage

The reverse bias capacitance can be found from the resonant frequency formula given below.

$$f = \frac{1}{2\pi\sqrt{LC}}$$

From there with L=10µH and f=8.01Mhz, C value is calculated as 39.5pF.

j) Including the 0.4Ω series resistance of the inductor in continuous case, figures below show the output and input power graphs respectively.

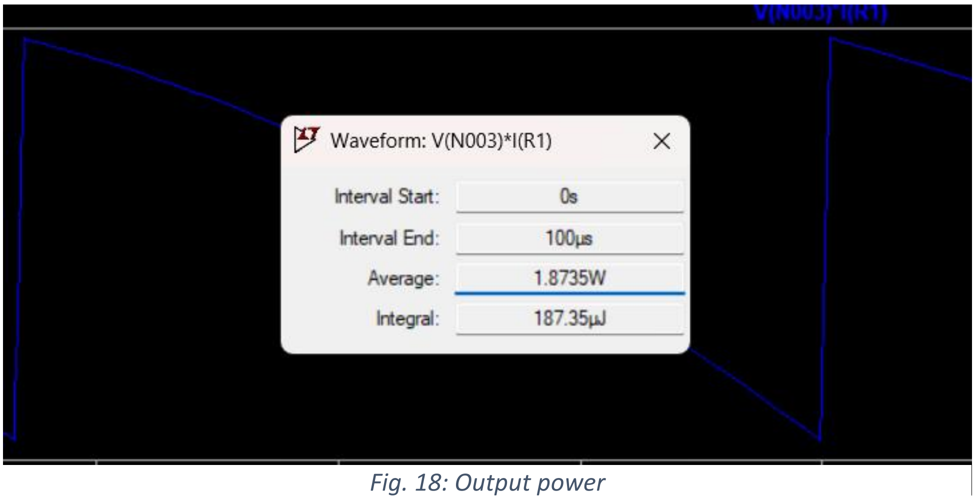

Fig. 18: Output power

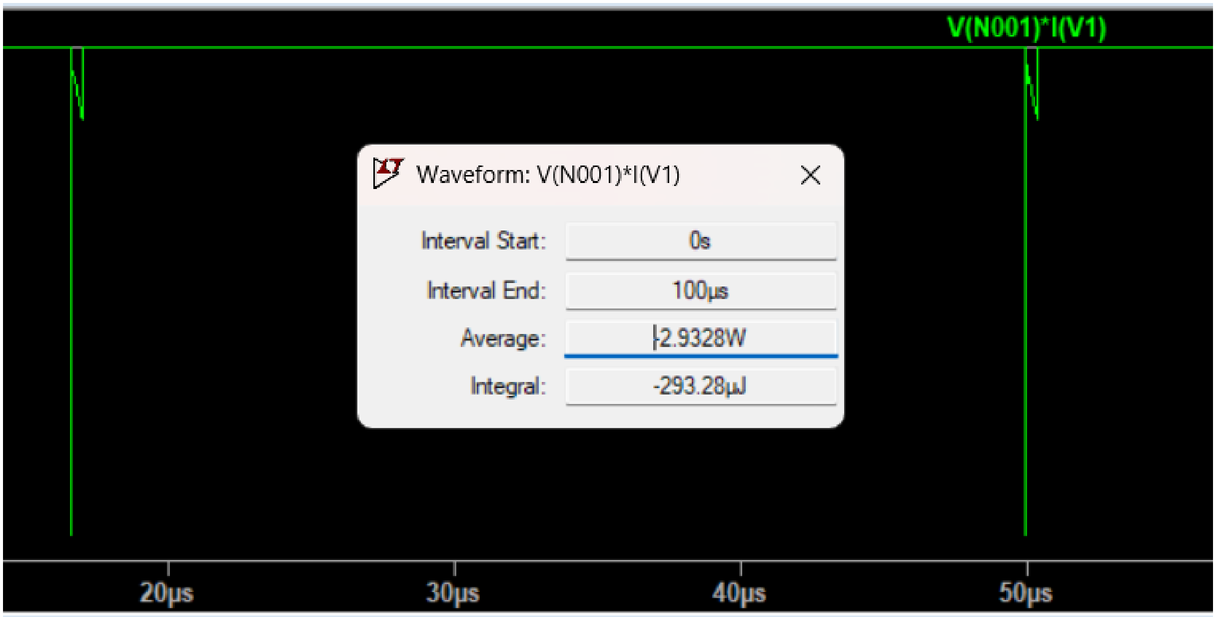

Fig. 19: Input power

$$\eta = \frac{P_{out}}{P_{in}} * 100$$

Using the above equation, the efficiency of the converter is calculated as 63.8%.