Göksenin Hande BAYAZIT
METU

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ELE613 – SWITCH MODE POWER SUPPLIES
HOMEWORK 1

Q1) The topology to be analyzed and simulated in this homework is a buck converter with the following specifications:

- $V_d = 8\,Vdc$
- $L = 10\mu H, r_L = 10m\Omega$
- $C = 100\mu F$
- $R_{load} = 0.5\ \Omega$
- $f_s = 50\ kHz$
- $D = 0.75$

For simulations, Simulink environment is preferred and the simulation model is shown in Figure 1, below.

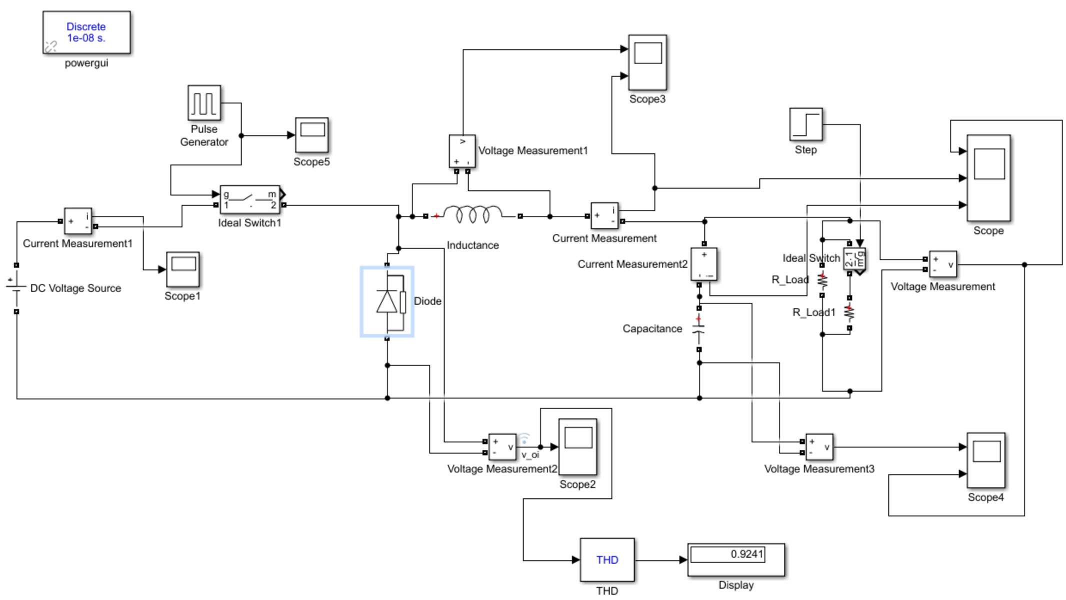


Figure 1: Simulation Model of the Buck Converter

Inductor voltage and current waveforms (for part (a)) and output voltage, inductor current and capacitor current waveforms (for part (b)) are provided in Figures 2 and 3, respectively.

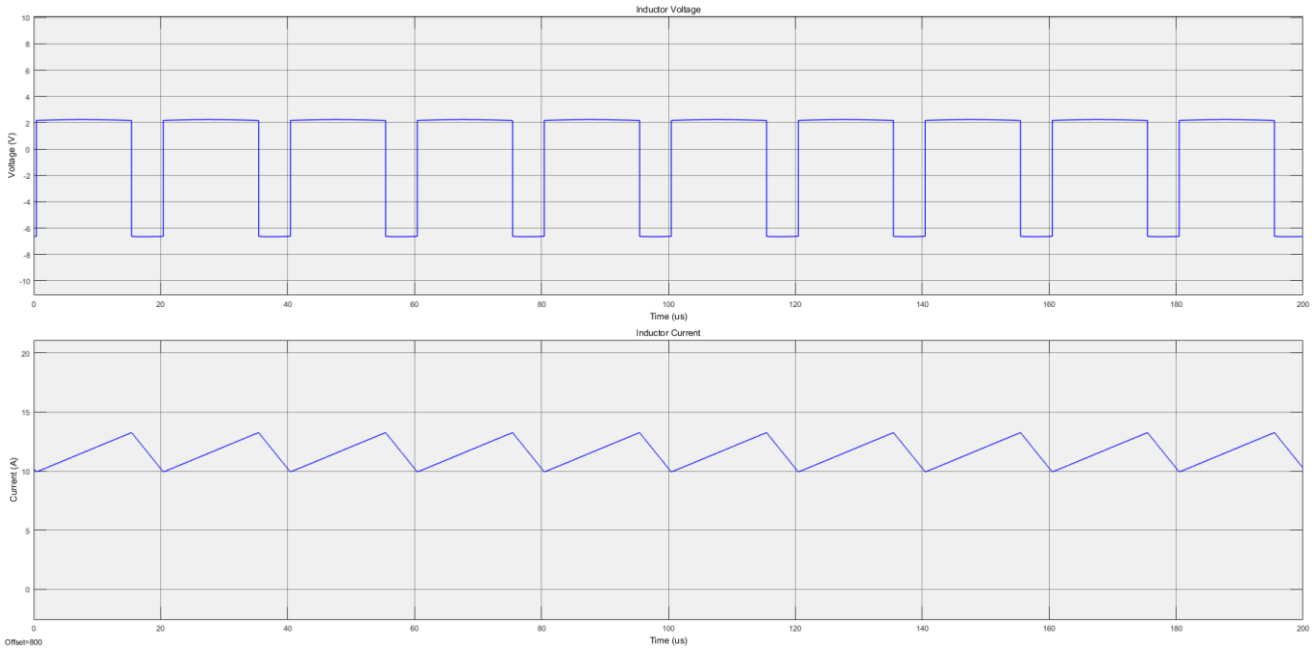


Figure 2: Inductor Voltage and Current

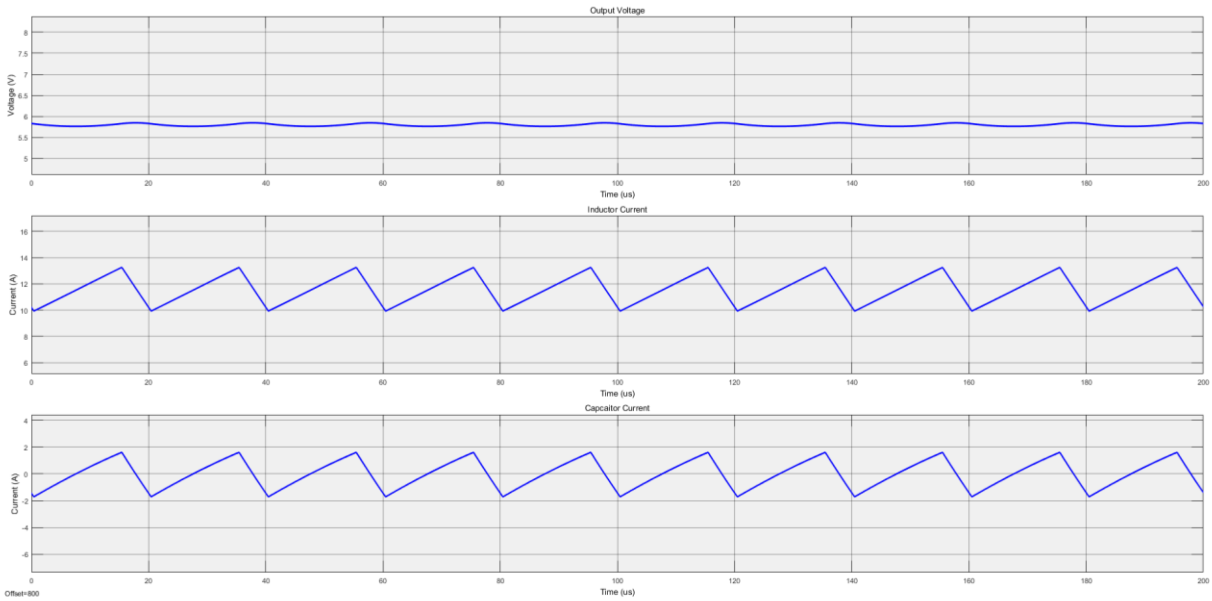


Figure 3: Output Voltage, Inductor Current and Capacitor Current

Q2) FFT analysis is performed using powergui toolbox of Simulink. Harmonic components are shown with respect to their orders, on the graph given in Figure 4, below.

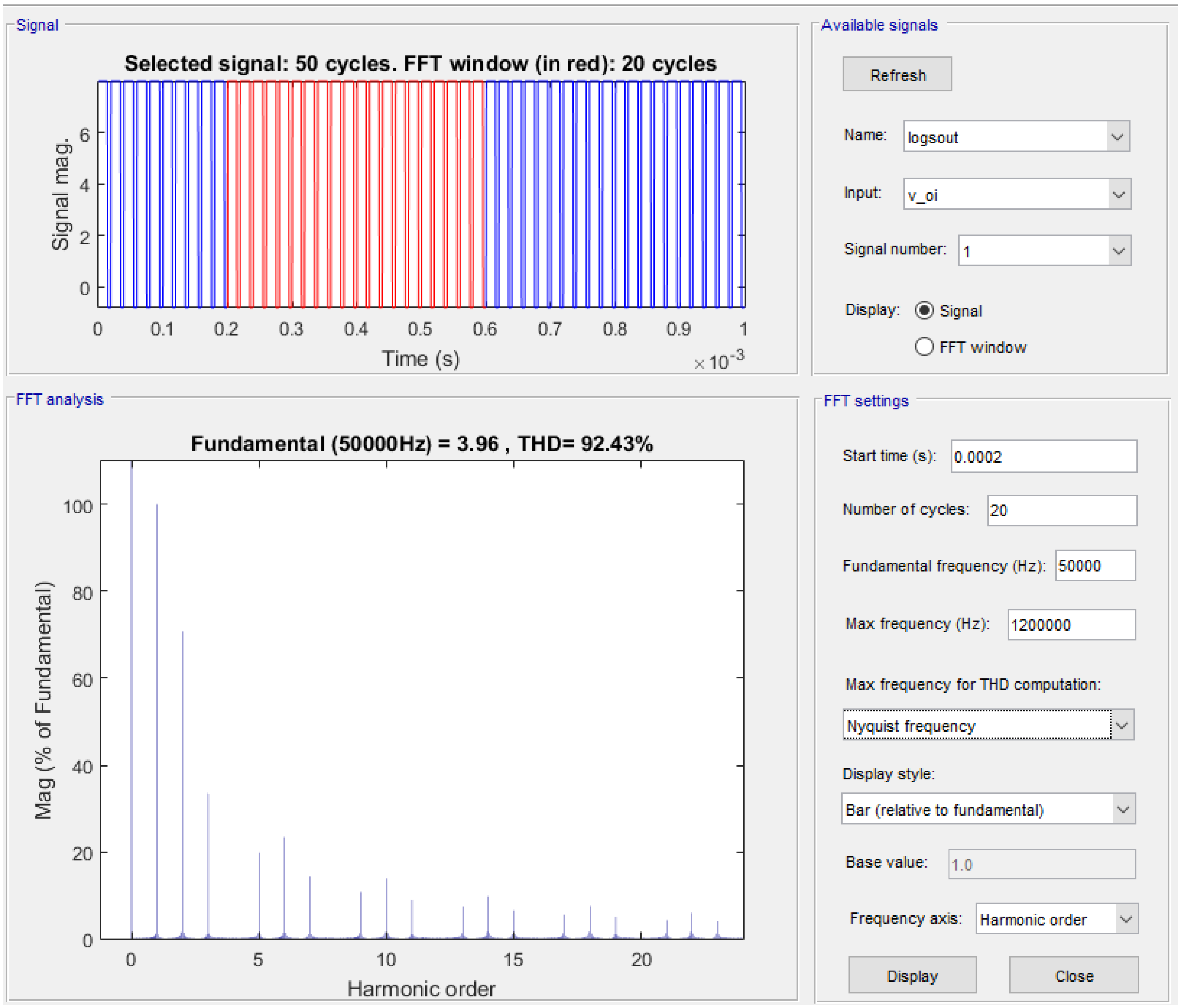


Figure 4: FFT Analysis Results

Q3) Discontinuous mode inductor voltage and current waveforms and output voltage waveform are given in Figure 5 and 6, respectively.

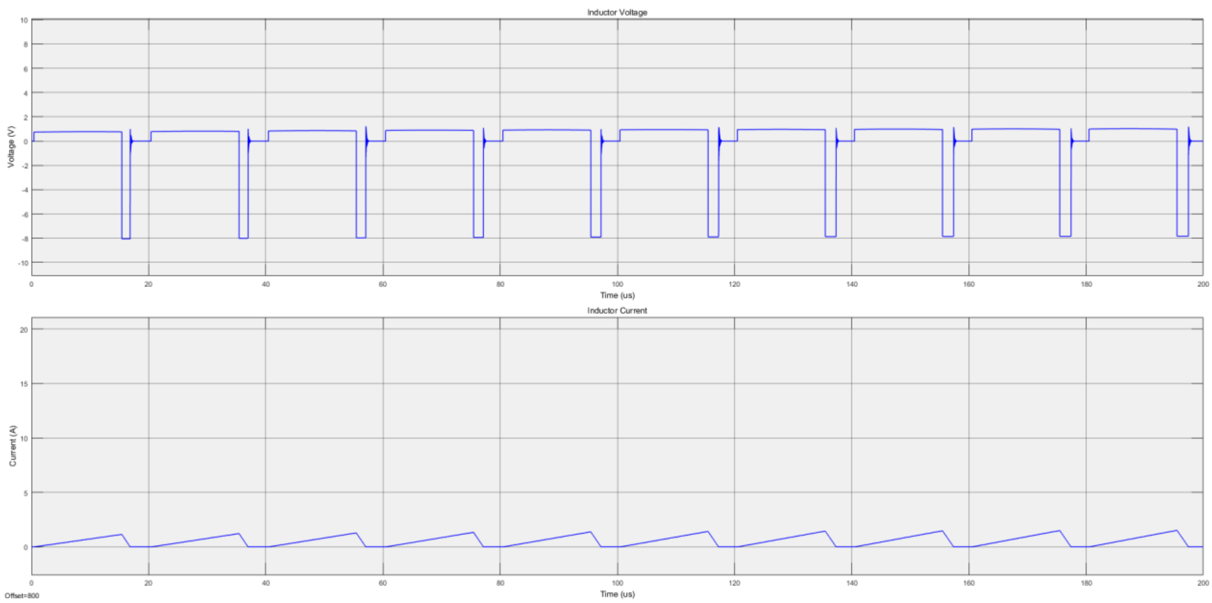


Figure 5: Discontinuous Mode Inductor Voltage and Current

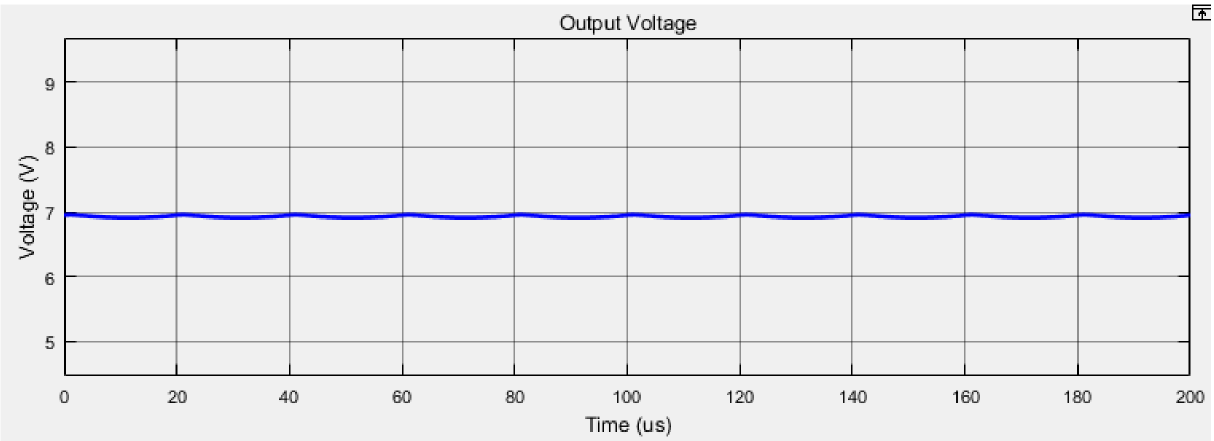


Figure 6: Discontinuous Mode Output Voltage Waveform

Simulation results should agree with the following equation:

$$\frac{V_o}{V_d} = \frac{D^2}{D^2 + \frac{1}{4}\left(\frac{I_o}{\frac{V_d}{8Lf_s}}\right)}$$

Replacing the variables as follows:

$$f_s = 50\ kHz$$
$$D = 0.75$$
$$I_o = \frac{V_o}{10}$$
$$L = 10\mu H$$
$$V_d = 8V$$

We get the following equality:

$$\frac{V_o}{8} = \frac{\frac{9}{16}}{\frac{9}{16} + \frac{1}{4}\left(\frac{V_o}{10} * 50 * 10^3 * 10 * 10^{-6}\right)}$$
$$\frac{V_o}{8} = \frac{9}{9 + \frac{V_o}{5}}$$
$$V_o = 6.93\ V$$

This result is verified with the output voltage waveform of simulation, given in Figure 6.

Q4) Analytical calculation can be done as follows:

$$\Delta v_c = \frac{\Delta i_L}{8 f_s C} = \frac{\Delta i_L}{40}$$

In Figures 7, 8 and 9, capacitor voltage and inductor current ripple waveforms and their peak to peak values are given, respectively.

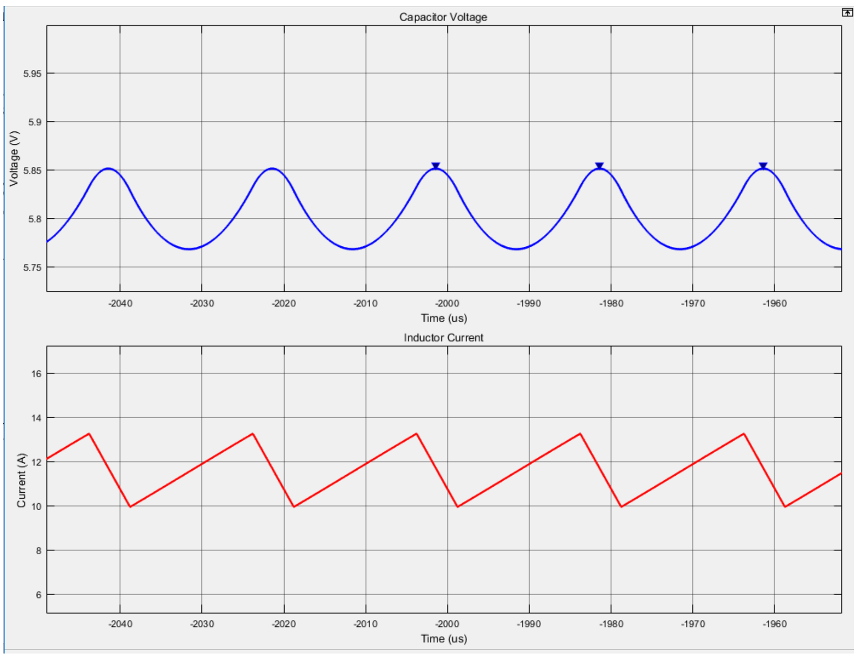
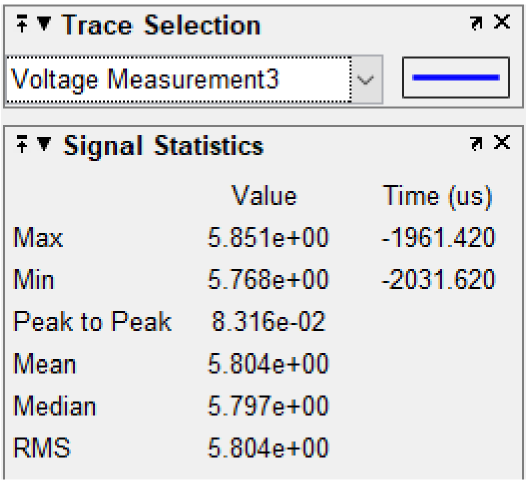


Figure 7: Capacitor Voltage and Inductor Current



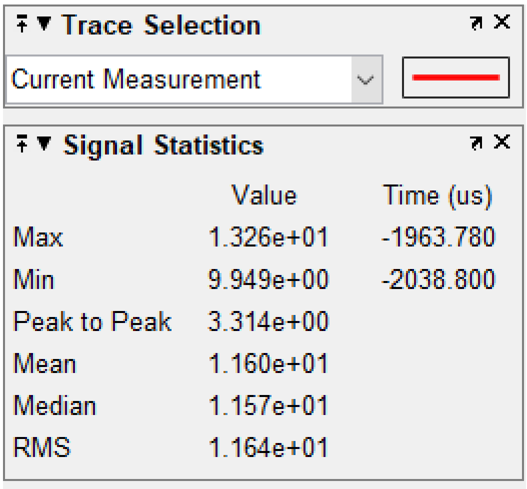
Trace Selection

Voltage Measurement3

Signal Statistics

	Value	Time (us)
Max	5.851e+00	-1961.420
Min	5.768e+00	-2031.620
Peak to Peak	8.316e-02	
Mean	5.804e+00	
Median	5.797e+00	
RMS	5.804e+00	

Figure 8: Capacitor Voltage Peak-To-Peak Value



Trace Selection

Current Measurement

Signal Statistics

	Value	Time (us)
Max	1.326e+01	-1963.780
Min	9.949e+00	-2038.800
Peak to Peak	3.314e+00	
Mean	1.160e+01	
Median	1.157e+01	
RMS	1.164e+01	

Figure 9: Inductor Current Peak-To-Peak Value

As provided in figures, capacitor voltage ripple is 40 times larger than the inductor current ripple, which actually agrees with the analytical calculations.

Q5) Capacitor current swing is equal to inductor current swing and average of the capacitor current is zero, therefore it can be calculated as the RMS of a triangular wave with amplitude $\frac{\Delta i_L}{2}$.

$$I_{C,rms} = \frac{\Delta i_L}{2\sqrt{3}} = \frac{V_o(1-D)}{2\sqrt{3}Lf_s} = I_o * R_{load} * \frac{0.25}{2\sqrt{3} * 0.5} = 0.072 I_o$$

Q6) In the presence of ESR, we may assume that output voltage ripple is caused only by voltage drop on ESR. Therefore it can be calculated as:

$$\Delta v = \Delta i_c * r_{ESR}$$

Here, we know that current ripple on the capacitor is equal to that of the inductance, hence:

$$\Delta v = \Delta i_L * r_{ESR} = \frac{V_o(1-D)}{Lf_s} * r_{ESR} = 4 * 0.1 = 0.4\ V$$

Simulation results for this part are given in Figures 10, 11 and 12.

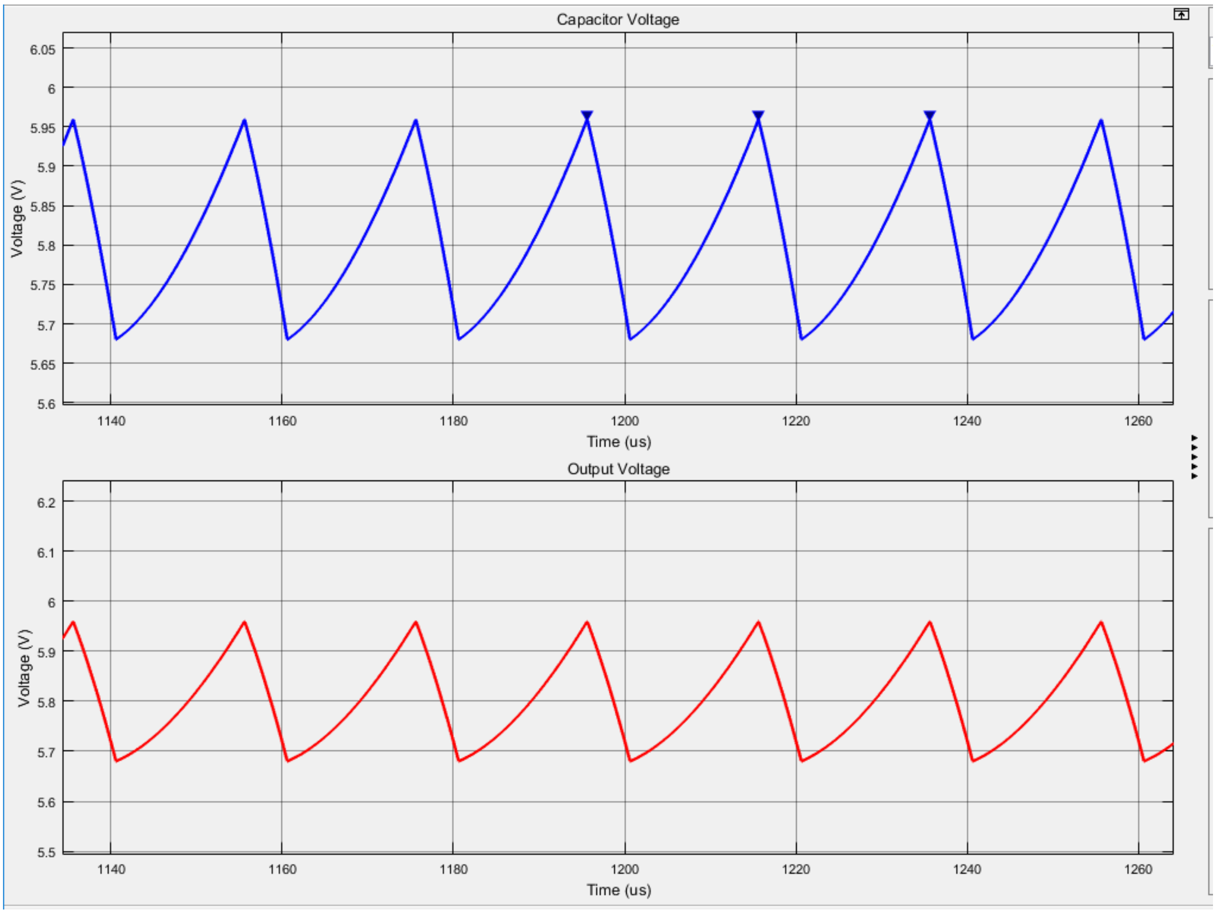
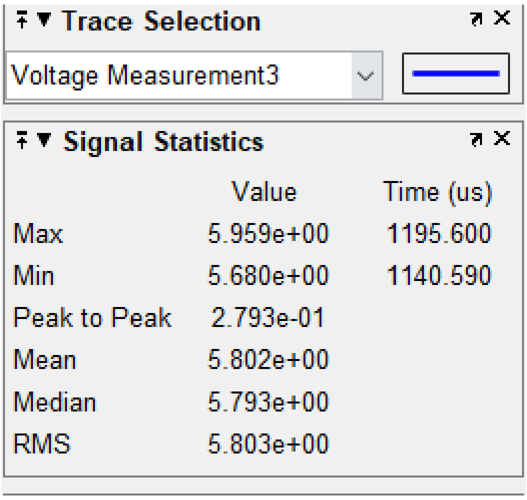


Figure 10: Capacitor and Output Voltage Waveforms



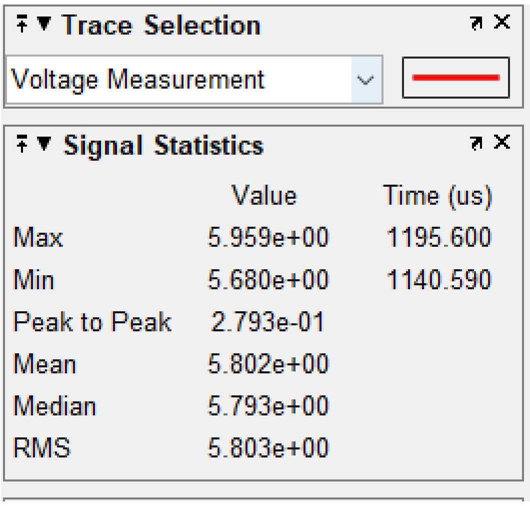
Trace Selection

Voltage Measurement3

Signal Statistics

	Value	Time (us)
Max	5.959e+00	1195.600
Min	5.680e+00	1140.590
Peak to Peak	2.793e-01	
Mean	5.802e+00	
Median	5.793e+00	
RMS	5.803e+00	

Figure 11: Capacitor Voltage Ripple



Trace Selection

Voltage Measurement

Signal Statistics

	Value	Time (us)
Max	5.959e+00	1195.600
Min	5.680e+00	1140.590
Peak to Peak	2.793e-01	
Mean	5.802e+00	
Median	5.793e+00	
RMS	5.803e+00	

Figure 12: Output Voltage Ripple

As can be observed in simulation results, capacitor (including ESR) voltage ripple is equal to output voltage ripple, which verifies the initial assumption.