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Friday

ELE 613

Switch Mode Power Supply

Homework 1

Problems:

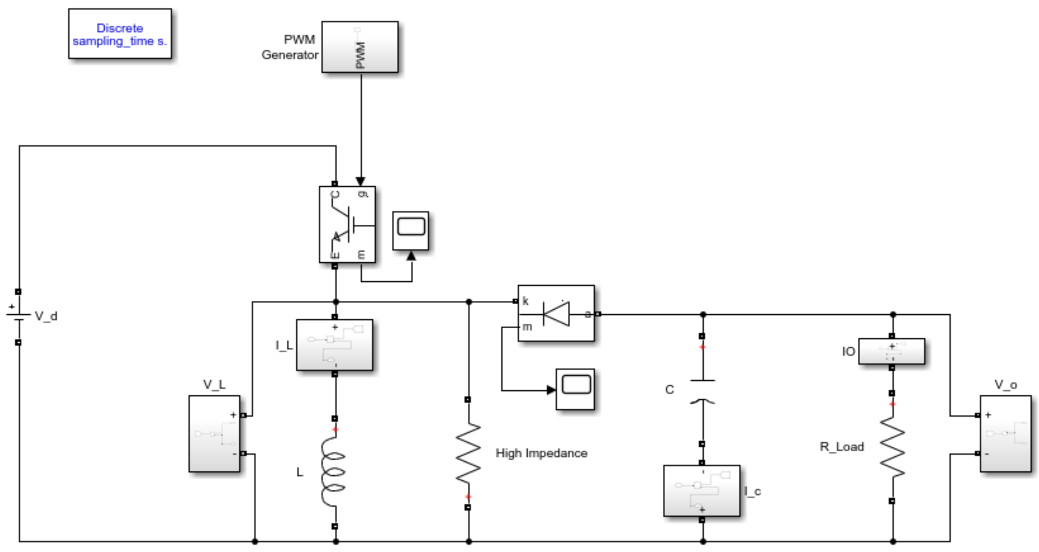

Figure 1 Step-down/Up dc-dc (Buck-Boost) Converter

At Figure 1, Buck-Boost Converter circuit schematic is shown . Buck-Boost converter can regulate voltage in higher or lower output voltage than input. The output voltage is negative-polarity.

Nominal Values are shown in Table 1.

Table 1 Nominal Values of Circuit Parameters

Parameters	Values
V_d	$8.5\ V_{dc}$
L	$10\mu\ H$
r_L	$10m\Omega$
C	$100\mu\ F$
R_{load}	8Ω
f_s	$100\ kHz$
D	0.75

1.

In steady state, average voltage of inductor in one period is zero and average capacitor current in one period is zero, too.

The inductor voltage and current, the output voltage and current, the capacitor current observed in one period is enough to deduce the characteristic of the converter.

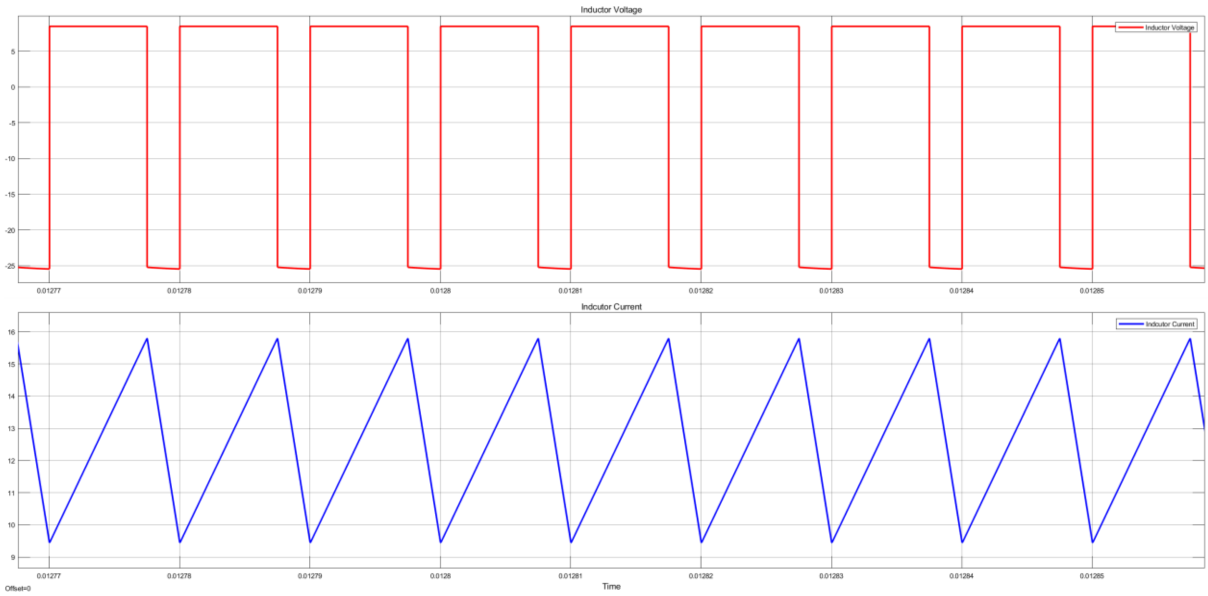

Figure 2 Inductor Voltage and Current Waveform

At Figure 2 shows the inductor current and voltage waveforms. From the waveform, non-zero inductor current, it is understood that the converter works in CCM (Continuous-Conduction Mode). In addition, the voltage of ınductor has no DC components in steady state. (Voltage-Second Balance)

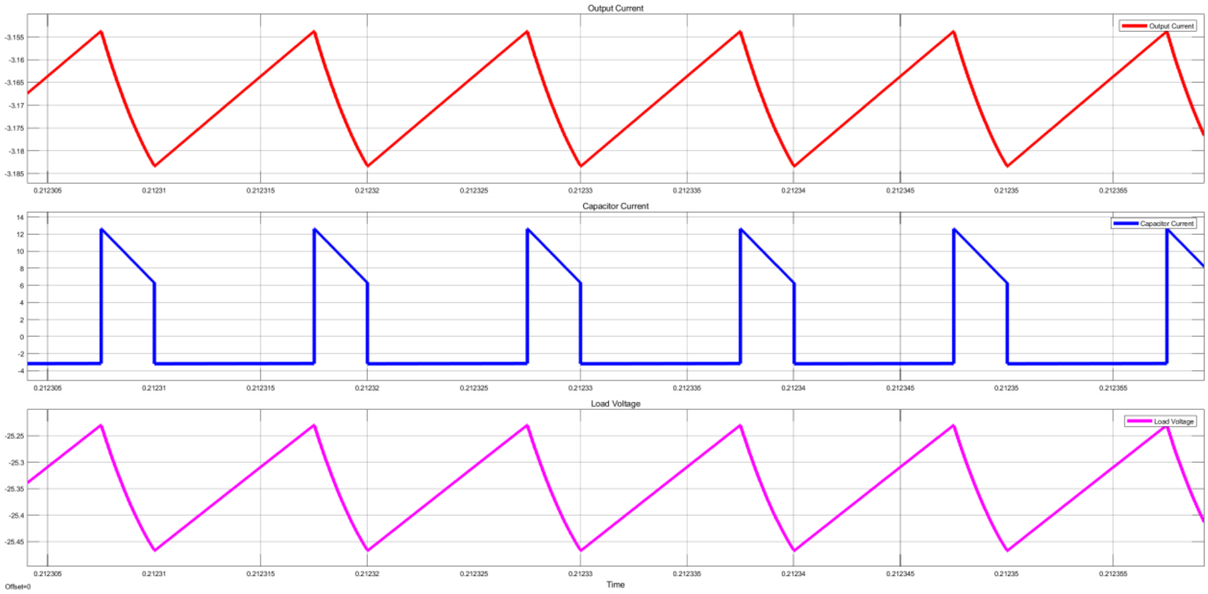

Figure 3 Output Voltage, Current and Capacitor Current Waveform

As can be seen Figure 3, the output voltage and current have the same waveform because of only resistive load and the capacitor current has no DC components in steady-state.(Charge-Second BaLance)

In CCM mode, the output voltage is directly calculated by using input voltage and duty cycle if the parasitic components are ignored.

$$V_o = \frac{-D}{1-D} V_{in}$$

2.

At buck-boost converter, diode carries the average of the output current because the output capacitor cannot transfer dc current at steady state. Thus, the DC components of diode current is equal to output current.

To obtain diode current by means of Fourier analysis, the fundamental of diode current is chosen as switching frequency. In addition, resolution of FFT is chosen as 1kHz by using 100 cycles of fundamental period.

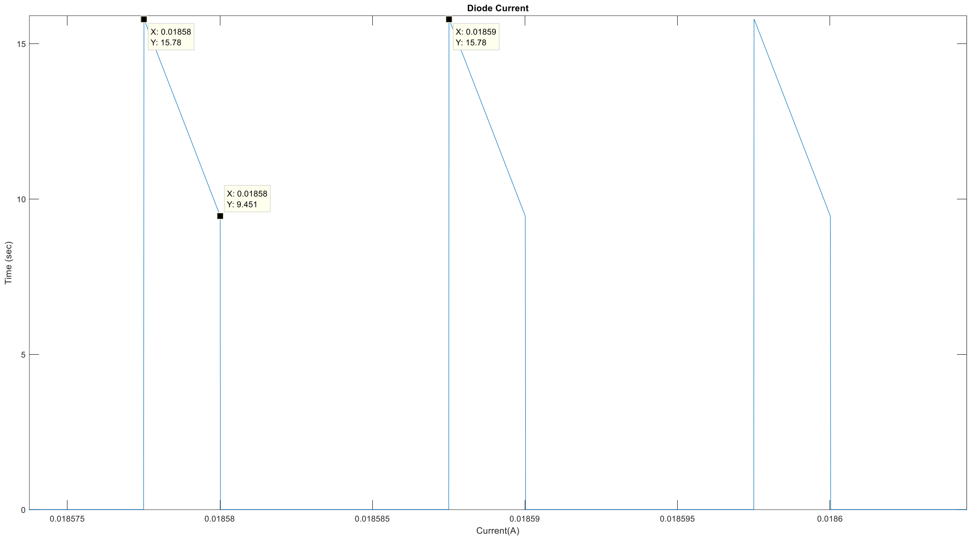

Figure 4 Diode current Waveform

Table 2 Harmonic Components of the Diode Current

Frequency	Harmonic coefficient	Percentage wrt DC	Real Value
0 Hz	DC	100	3.169 A
100 kHz	Fundamental	180.34	4.042 Arms
200kHz	2nd	128.47	
300kHz	3rd	63.03	
400kHz	4th	15.94	
500kHz	5th	37	
600kHz	6th	42.32	
700 kHz	7th	26.22	
800 kHz	8th	8	
900 kHz	9th	20.89	
1000 kHz	10th	25.37	
1100 kHz	11th	16.42	
1200 kHz	12th	5.36	
1300 kHz	13th	14.65	
1400 kHz	14th	18.11	
1500 kHz	15th	11.88	
1600 kHz	16th	4.06	
1700 kHz	17th	11.33	
1800 kHz	18th	14.08	
1900 kHz	19th	9.26	
2000 kHz	20th	3.28	
2100 kHz	21st	9.28	
2200kHz	22nd	11.51	
2300kHz	23rd	7.55	
2400kHz	24th	2.77	
2500kHz	25th	7.88	
2600kHz	26th	9.73	
2700kHz	27th	6.35	
2800kHz	28th	2.40	
2900kHz	29th	6.86	
3000kHz	30th	8.43	

Simulink FFT Tool :

Sampling Time: 1e-08 s

Sample per Cycle= 1000

DC Component = 3.169

Fundamental = 5.716 peak

THD= 247.73 %

3.

Increasing load resistance causes the light load for converter and it can make the converter pass to DCM mode. If the inductor current crosses the zero, the converter works in DCM mode. It disturbs the relation between output and input.

Figure 5 shows the inductor current and voltage waveform for resistive load with 80 ohm.

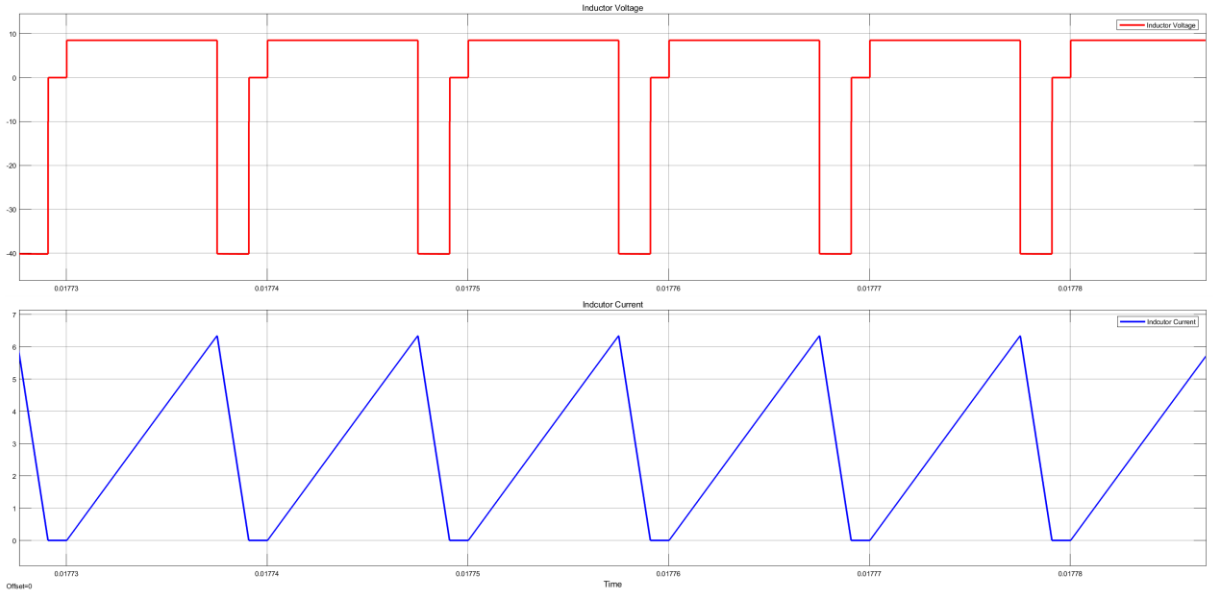

Figure 5 Inductor Current and Voltage Waveform in DCM Mode

Analytically, the relation between output and input does not depend on only duty cycle. For both volt-second law and charge-second law should be used to calculate the relation. The relation is shown at

$$D = V_o \sqrt{\left(\frac{2Lf}{R(1-D)V_s(V_s+V_o)}\right)}$$

For analytically, if it is in CCM, we observe that 25.5 V at output. However, the output voltage is bigger than the value because the converter works in DCM.

4.

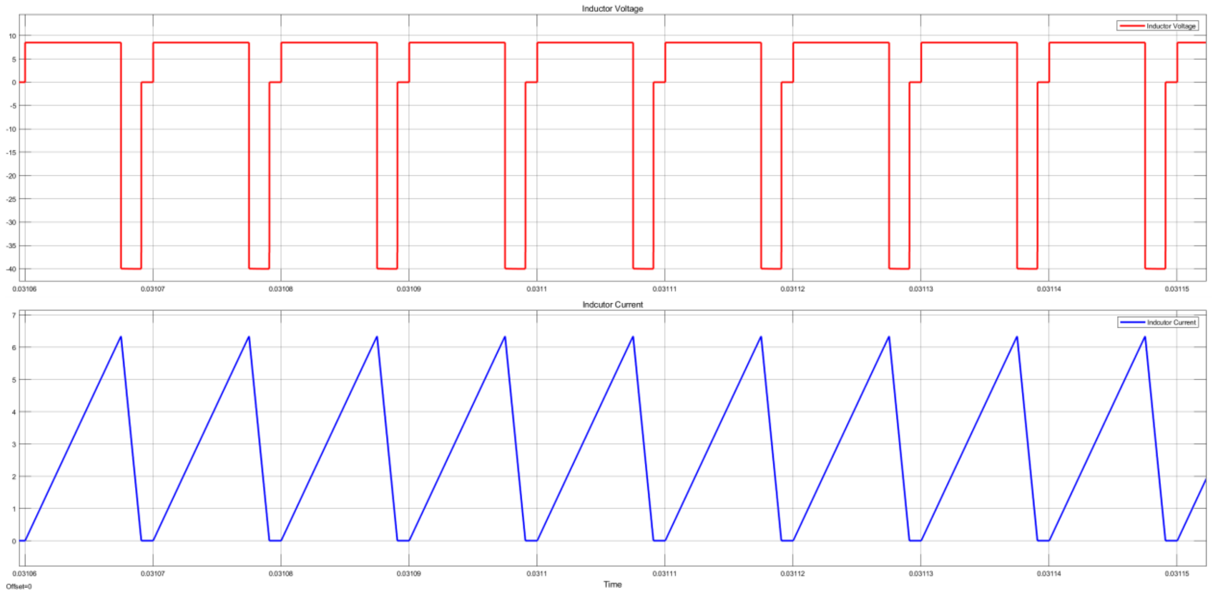

Figure 6 Inductor Current and Voltage at steady-state with resistive 80 ohm

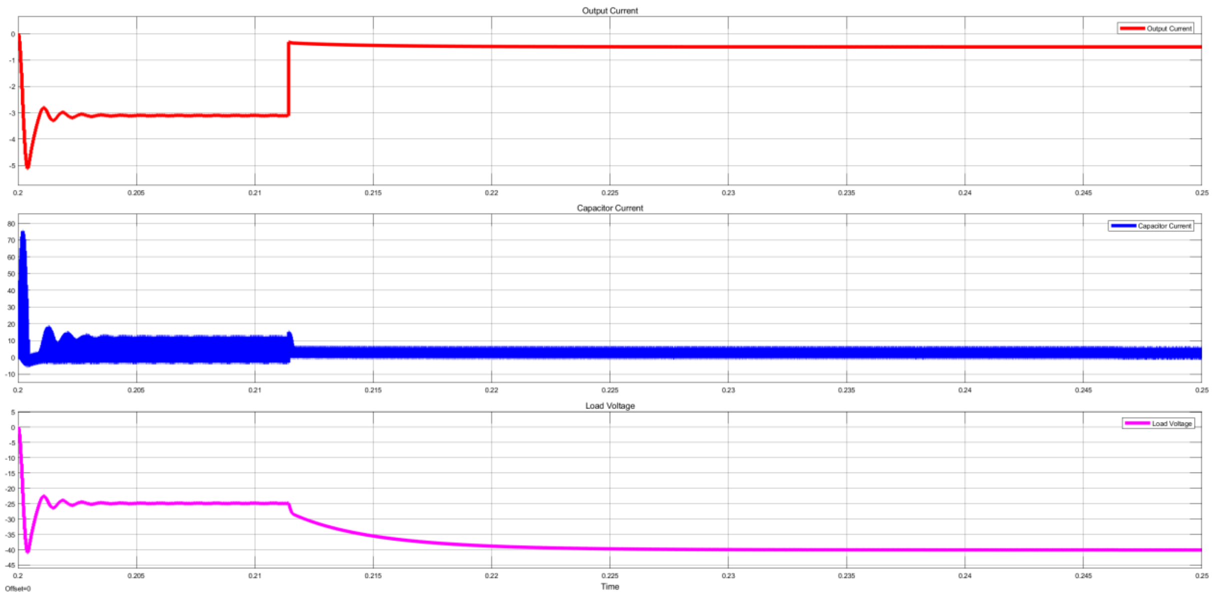

Figure 7 Output Voltage and Current Waveform for step change in load

Figure 6 and Figure 7 shows the load changes from 8 to 80 ohm. This changes led the converter transfer from CCM to DCM.

5.

Load is fed from capacitor during on-state transistor. Then, the output voltage ripple depends on current (constant) from load, capacitance value, switching period and duty cycle.

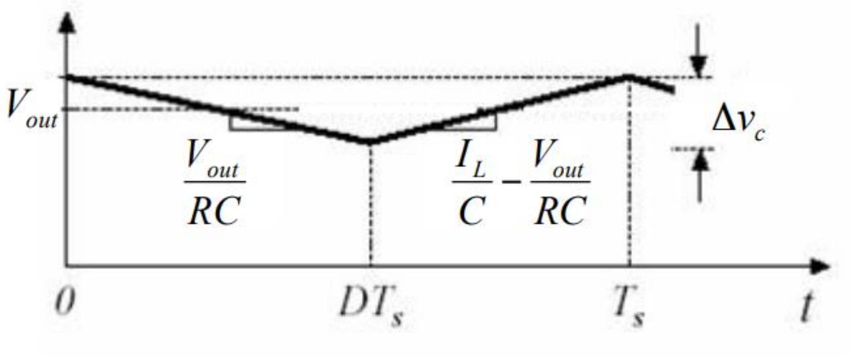

Figure 8 Output Voltage Ripple of Buck-Boost Converter

Output ripple can be calculated by using Figure 8 and equation below.

$$\Delta v_c = \frac{V_{out}}{RC}.D.T_s$$

For our case, peak-to-peak voltage ripple is ‘0.248’ V by analytically.

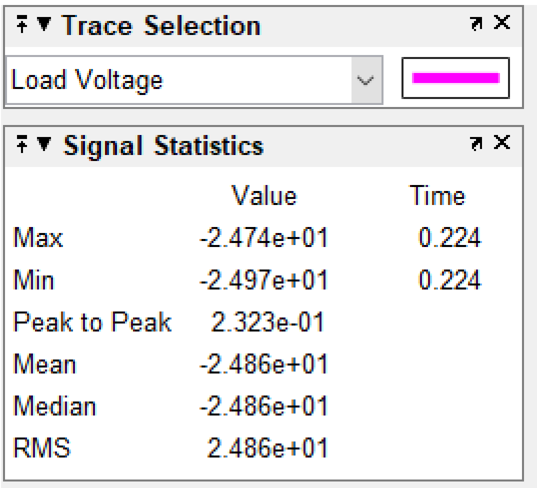

Figure 9 Output Voltage Statistics

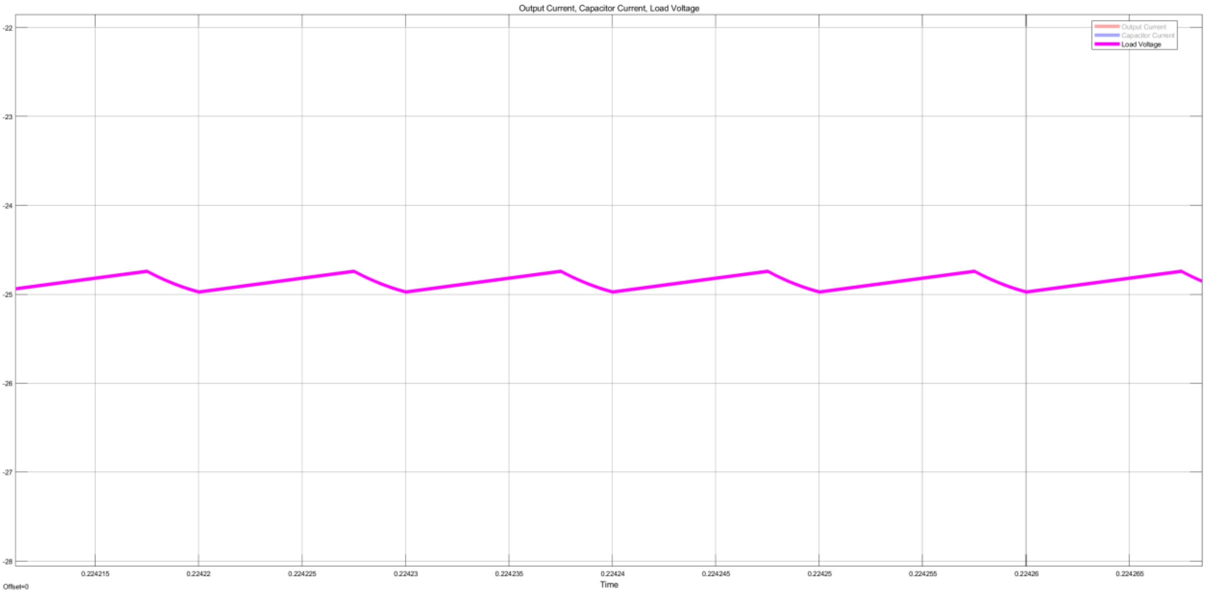

Figure 10 Output Voltage Waveform

Analytically and simulation results are almost the same.

6.

Capacitor current is ramp-on- square wave as shown Figure 11

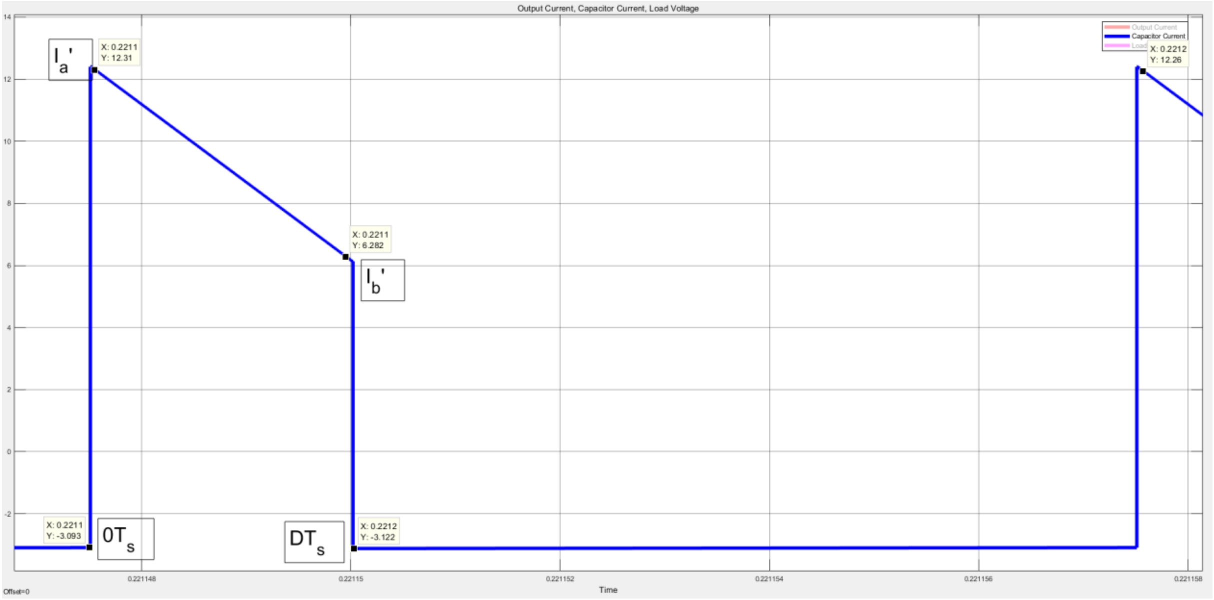

Figure 11 Ramp-on-square Waveform of Capacitor Current

RMS value of this waveform depends on $I_a,\ I_b$ (stem from I_a' *and* I_b' subtracted I_{dc}) and Duty cycle.

$$I_{rms} = \sqrt{D.\frac{I_a^2 + I_b^2 + I_a.I_b}{3}}$$

$$I_{rms} = 3.184\,A \quad (I_{dc} = 3.169\; I_a = 9.141\; I_b = 3.113\; D = 0.25)$$

$$\frac{I_{rms}}{I_o} = \frac{3.184}{3.169} = 1.004$$