EE 464 SOFTWARE PROJECT 1

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1) Introduction

In this project, we design CuK converter respect with these desired values:

- Input Voltage: 9 V
- Output Voltage: -12 V
- Output Current: 3 A
- Switching frequency: 100 kHz
- Max. Output voltage ripple: 2%

2) Part a. Choosen a Suitable Capacitor and Inductance That Can Produce the Output within Given Tolerances Under Under CCM.

Input Voltage	9V
Output Voltage	-12V
Output Current	3A
Switching Frequency	100 kHz
Max. Output Voltage Ripple	2%

For duty cycle of Cuk Converter:

$$D = \frac{Vo}{Vo+Vd} = \frac{12}{12+9} = 0.5714$$

By assume ideal condition, Poutput=Pin

Then, $I_d = I_o * \frac{Vo}{Vi} = \frac{3*12}{9} = 4\ A$ $\qquad I_d = I_o * \frac{1-D}{D} = 4\ A$

Selection of Inductors

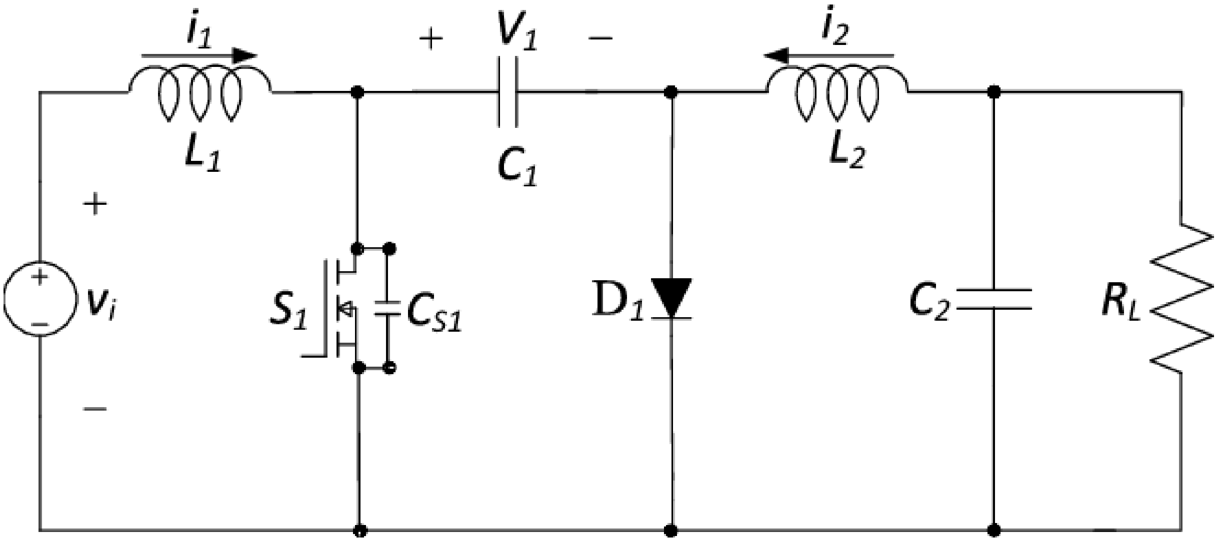


Figure 1: Circuit Schematic of Cuk converter

In the figure 1, average current of inductor (L_2) is equal to output current I_o and average current of inductor (L_1) is equal to input current I_d :

$I_{L1} = I_d = 4$ A

$I_{L2} = I_o = 3$ A

To calculate inductance value of L_1 and L_2, ΔI_{L1} assumed to be % 25 ripple:

$\Delta I_{L1} = 0{,}25*4 = 1$ A

As a proporties of CuK converter $\Delta I_{L1} = \Delta I_{L2} = 1$ A

During switch is on, inductor voltage is equal to input voltage.

$V_{L1} = L_1 * \frac{\Delta IL1}{\Delta t}$

$V_d = L_1 * \frac{\Delta IL1}{D*Ts}$

I_{L1}= 56 µH   is chosen.

For chosen inductor values, our ΔI_{L1}= 0.918 A

$V_c - V_O = L2 * \frac{\Delta I_{L2}}{D*Ts}$

I_{L2}= 56 µH

$I_{L1,max}$ = 4 +0.918/2 = 4.459 A $I_{L1,min}$= 4-0.918/2 = 3.541 A

$I_{L2,max}$= 3+0.918/2 = 3.459 A $I_{L2,min}$= 3-0.918/2= 2.541 A

Therefore, our inductors should be able to carry 4.5 A, so we chose inductor with 6.2 A current rating. Our inductor values are same, so same inductor can be used and its link is shown below.

https://www.digikey.com/product-detail/en/bourns-inc/PM2110-560K-RC/M8765-ND/775304

Figure 2: Selected Inductor

Capacitor Selection

Outout voltage ripple is restricted with % 2, so we choose same ripple value for C1.

$V_{C1} = V_d+V_O$

$\Delta V_{C1}= 0.02*(12+9)=0.42$ V

In switch off duration, C_1 capacitor is charging thourh I_{L1} which is equal to 4 A. Then;

$I_{C1} = C_1* \Delta V_{C1}/((1-D)*Ts)$

C1= 47 µF is chosen.

For output capacitor calculation,

$\Delta V_O=0.02*12=0.24$ V

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

C= 6.8 µF is chosen.

For chosen capacitor values, our $\Delta V_O=0.17$ V

For commercial product, we chose ceramic capacitor because of low ESR. These capacitor should also carry at least 12 V. Chosen capacitor links are shown below:

C_1:

https://www.digikey.com/product-detail/en/murata-electronics-north-america/GRM32EC81C476KE15L/490-10531-2-ND/5027615

C_O:

https://www.digikey.com/product-detail/en/tdk-corporation/CGA4J1X7S1C685M125AC/445-16113-2-ND/4712729

3) Part.B

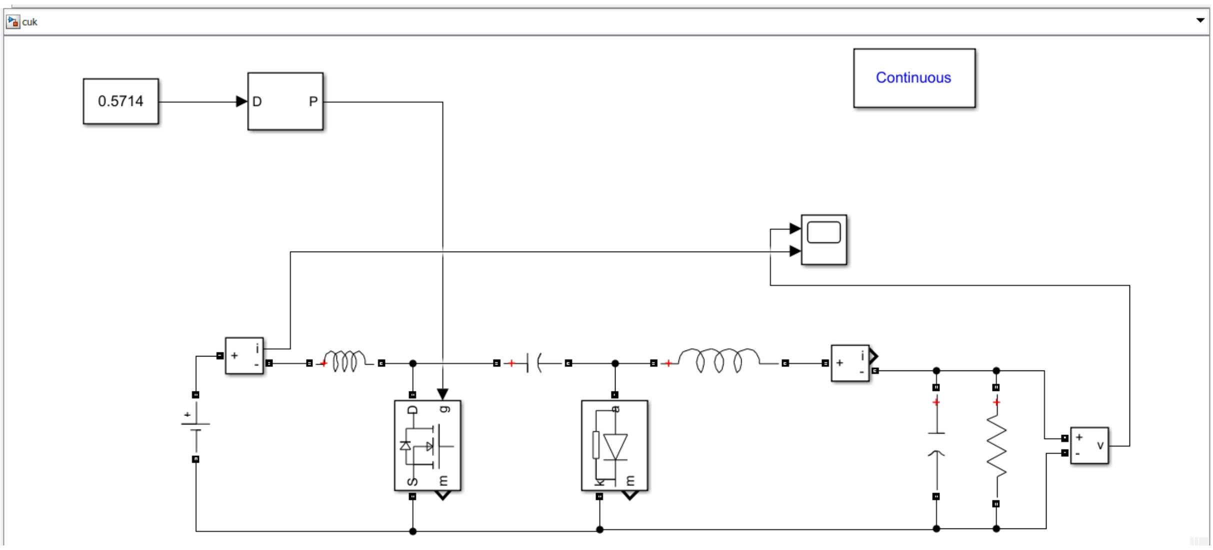


Figure 4: Design of Cuk Converter

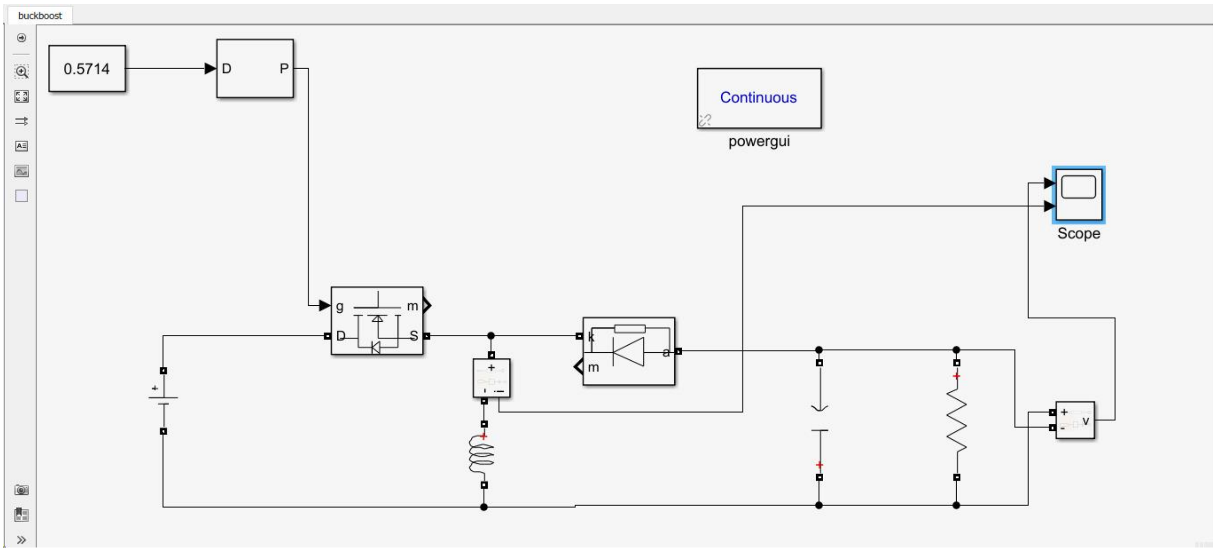


Figure 5: Design of same sized Buck-Boost Converter

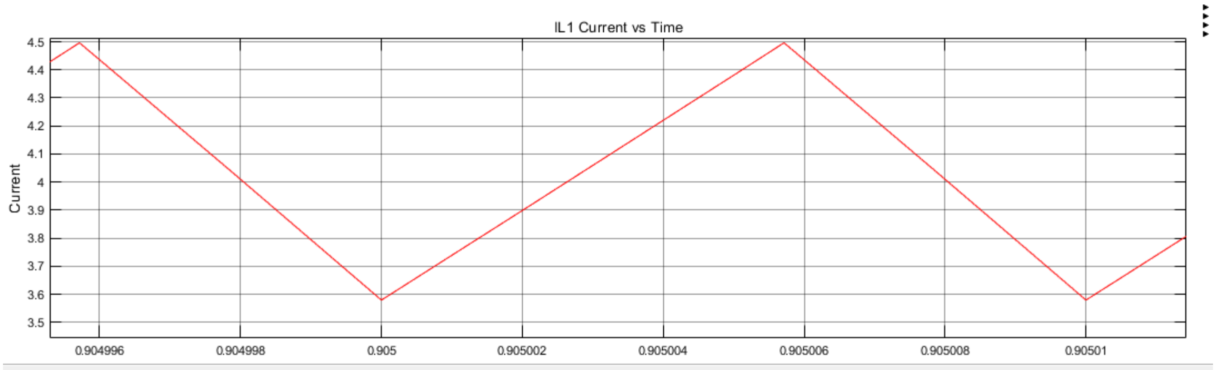


Figure 6: Input Current Waveform of Inductor(L1) in CuK Converter Design

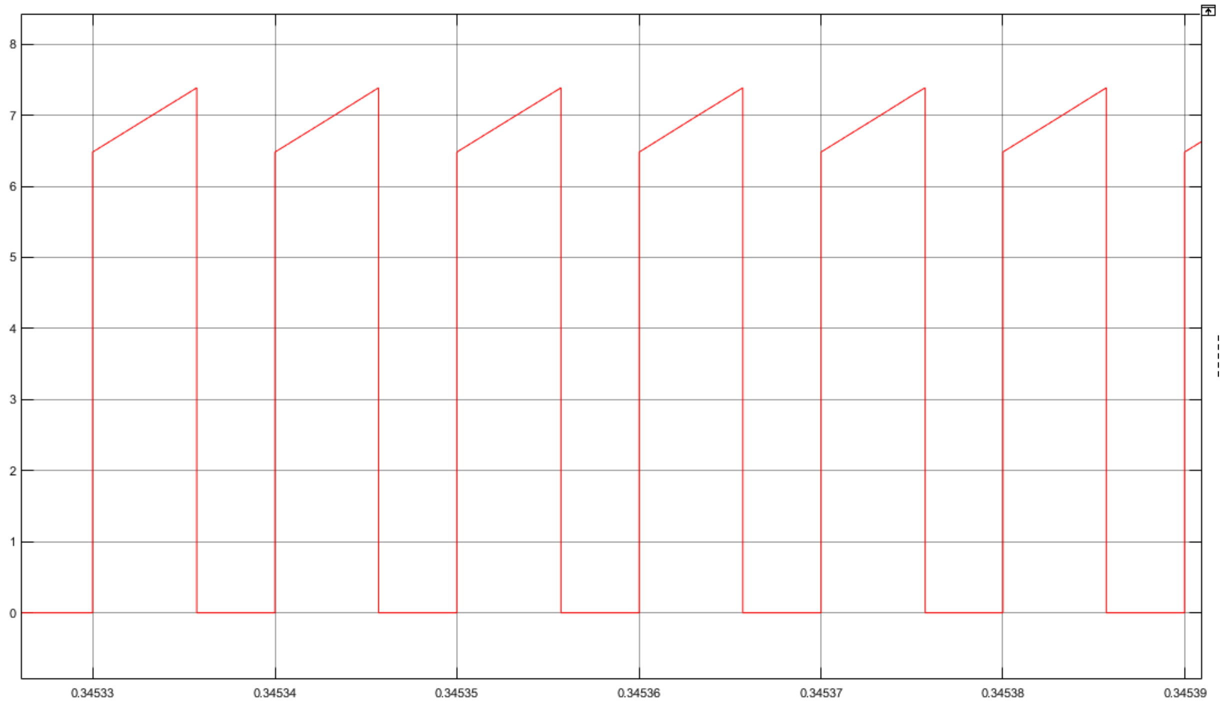
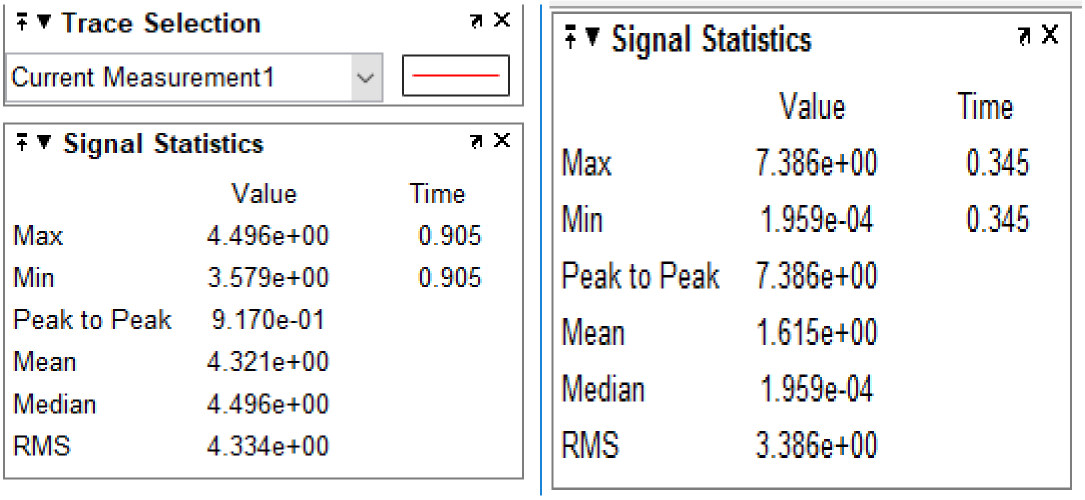


Figure 7 : Input Current Waveform of Inductor(L1) in Same Sized Back-Boost Converter Design

When we compared Cuk converter and same sized Back-Boost converted, as seen these figures, there is a discontinuous current flow in buck-boost converter because there is no path for current when the switch is off. Therefore, this leads to high ripple, bad harmonic and badly effect on the grid side. However, in CuK converter, there is no such a ripple and continuos current drawn from grid.



Trace Selection

Current Measurement1

Signal Statistics

	Value	Time
Max	4.496e+00	0.905
Min	3.579e+00	0.905
Peak to Peak	9.170e-01	
Mean	4.321e+00	
Median	4.496e+00	
RMS	4.334e+00	

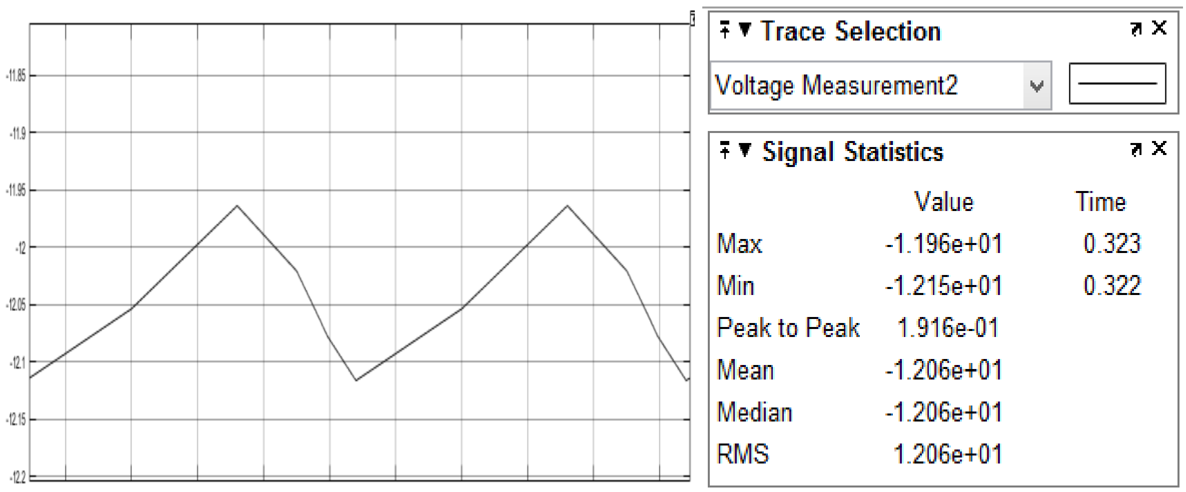
Signal Statistics

	Value	Time
Max	7.386e+00	0.345
Min	1.959e-04	0.345
Peak to Peak	7.386e+00	
Mean	1.615e+00	
Median	1.959e-04	
RMS	3.386e+00	

Figure 8: Current Measurement of CuK converter and Buck-Boost

4) Part.c

These values is calculated from part a for selection capacitor and inductor values.



Trace Selection

Voltage Measurement2

Signal Statistics

	Value	Time
Max	-1.196e+01	0.323
Min	-1.215e+01	0.322
Peak to Peak	1.916e-01	
Mean	-1.206e+01	
Median	-1.206e+01	
RMS	1.206e+01	

Figure 9: Output capacitor voltage waveorms of CuK converter

As seen in figure 8 and 9, our ripple values are 0.917 A and 0.1916 V. Our analytical values are 0.918 A and 0.17 V. These values are same as we expected.

5) Pard.D

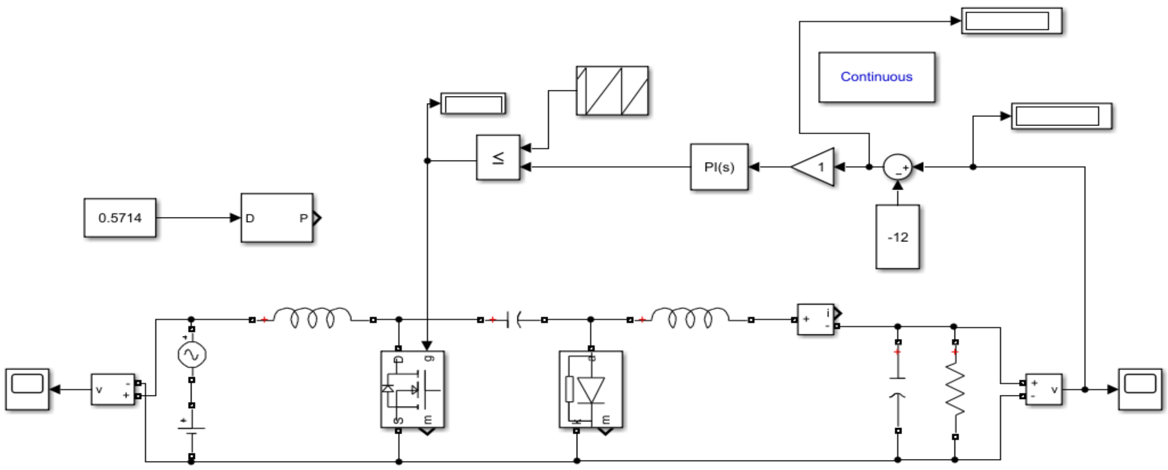


Figure 10: Design of CuK Converter with controller

Due to located harmonics voltage in input voltage (6th harmonics).We have to design controller in order to get prevent output voltage distortion. Principle of our controller : Firstly we get output voltage value to controller. Then, because of desired mean voltage 12 volt, we substract 12 volt from output voltage. At this point, in order to hold 12 volt, it is processed in PI controller. Then this PI controller control the switch . That's , when output voltage get over 12 volt value, swich is open then it decrease the output voltage. Similarly, when output voltage get below 12 volt value, swich is closed then it increases the output voltage . Thats it based on Voutput= Vd*D/(1-D). Thanks to this controller, we controller output voltage by control D (Switch time).

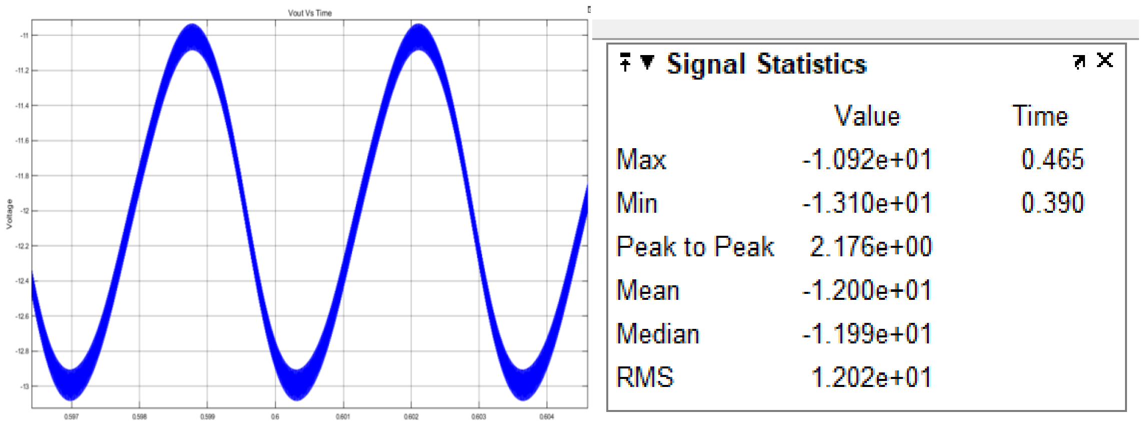


Figure 11: Output Voltage vs Time of Controller CuK Converter and its statistics

In order to get -12 V output voltage from 9 V input voltage ,according to our reseach we prefer to select bipolar voltage switching PWM controller. In this controller design, by using sawtooth generator which have 90 degree phase angle in 100kHz. Then we connect PI controller. Thans to this controller system, we get 12 volt mean as seen as output voltage simulation figure. According to Mohan book (pg 191) we fixed output signal -12 Volt.

6) Part.e

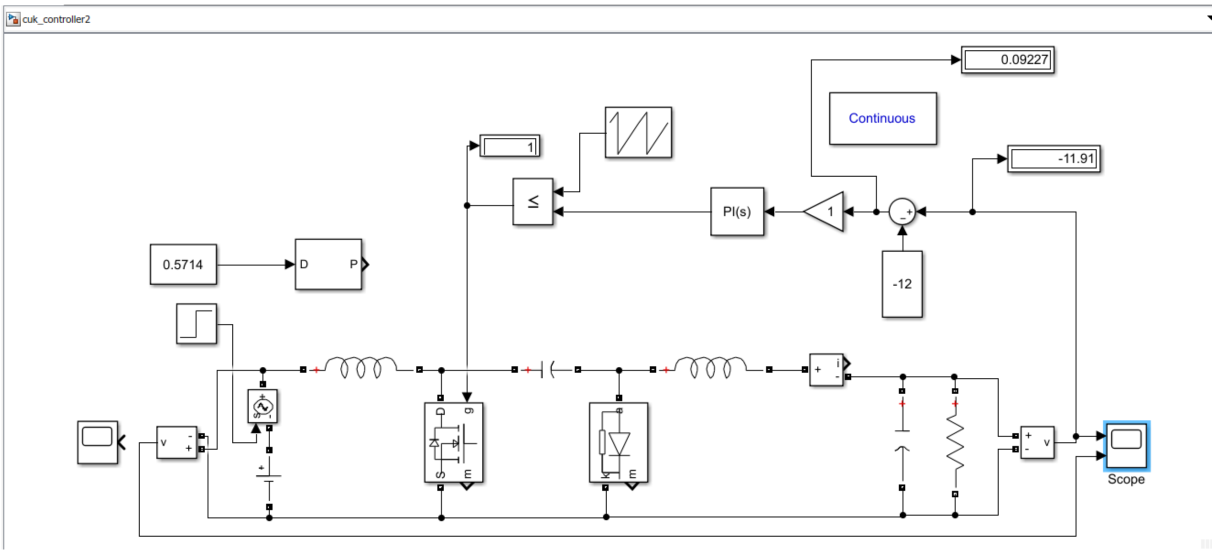


Figure 12: Cuk Converter with controller for step increase in input voltage

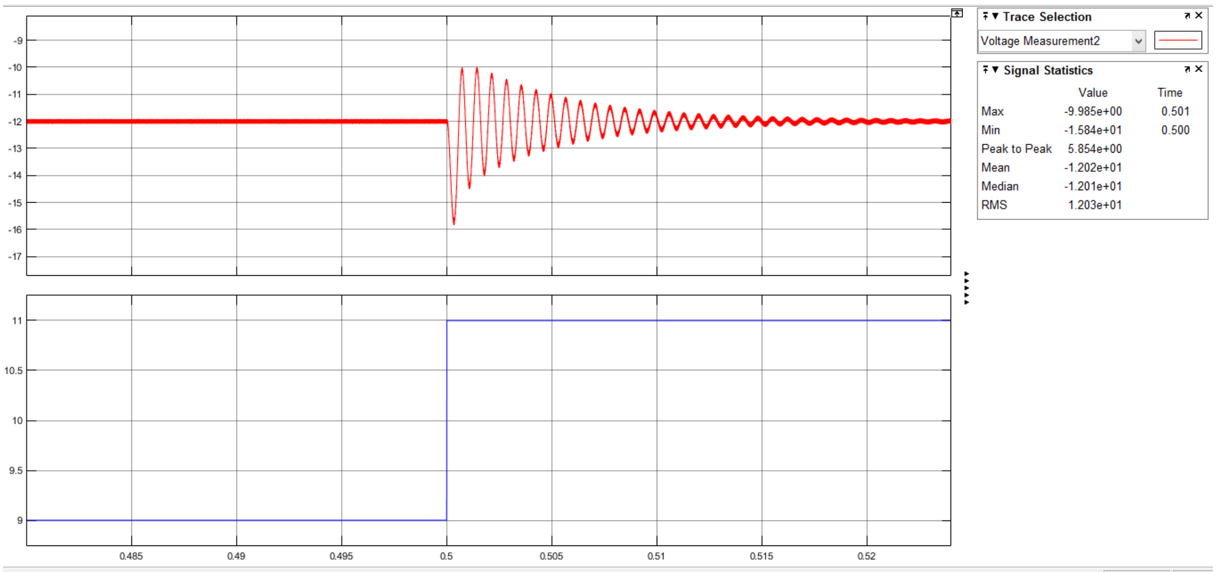


Figure 13: Input and output voltage waveform of CuK converter for step increase in input voltage

Our controller works well under that situation as seen in figure 13. At step time voltage varies between 10 and 16 V and controller stabilize that output voltage under 0.01 seconds which is good enugh.

7) Conclusion

In this project, we learned how to design cuk controller with desired output voltage and ripple values by adjusting inductors and capacitors values. We also calculated min,max and avrage values of inductor current and capacitor voltages. These values help us to choose right component by considering its rated values. After that, we saw that our analytical results are same as simulation results as we expected. We compared this converter with buck-boost converter with same size. We gained experience about cuk converter draw current from grid continuously which is good for source, but buck-boost converter draw current from grid discontinuously which is very bad for source. We learned how to control this converter with changing duty cycle by taking feedback from output voltage. These controller is good for step increase in voltage also. To sum up, we learned design characterictics of cuk converter, its control mechanism, advantages and disadvantages of using it.