Contents

Introduction

A Buck converter is a powerful tool in the world of power electronics, allowing for efficient conversion of high input voltages to low output voltages through the use of controlled pulses. This type of converter is made up of a switch and energy storage elements, such as an inductor and capacitor, which work together to regulate the voltage supplied to the load.

This report will use the final circuit developed in assignment 1 to produce the desired output for the Buck converter, investigate the effects of capacitor equivalent series resistance (ESR).

This report will select two types of capacitor and evaluate the ripple voltage performance using the ESR values. According to different parameter values, different conclusions are drawn.

Buck Converter Circuit

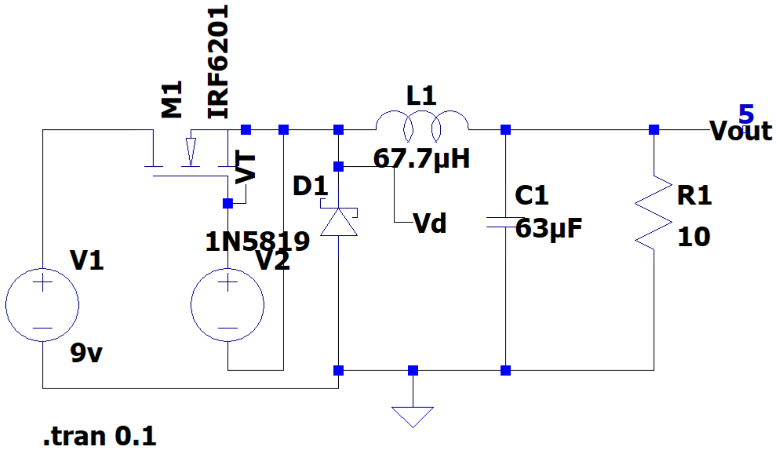

Figure 1 Buck Converter Circuit ESR=0.0031

ESR Value =0.0031ohms

Parameter	Value
Input Voltage	9 V
Output Voltage	5.01 V
Ripple Voltage	40 mV
Ripple %	8%
Inductor Voltage	9 V
Maximum Diode Current	908.61mA
Minimum Diode Current	-30.57uA
T_{on}	0.006 ms
T_{period}	0.02 ms
Frequency	40 kHz
Duty Cycle	0.567
Maximum Capacitor Current	421.39 mA
Minimum Capacitor Current	-423.56 mA
Maximum Inductor Current	915.72 mA
Minimum Inductor Current	75.83 mA
Output Current	0.5 A

Inductor	67.7 uH
Capacitor	62 uF
ESR	0.0031 ohms
τc	0.047 ohms
Δi_c	844.95 mA
Δi_L	839.89 mA

Table2 Buck Converter All Parameter Value

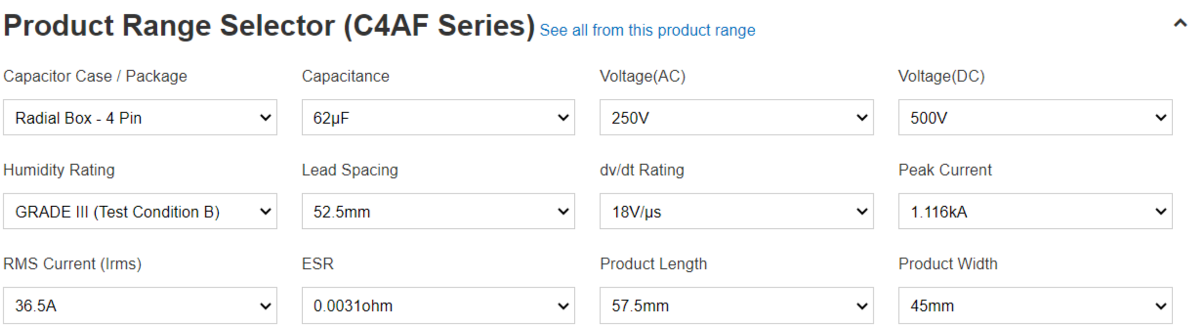

Figure2 Capacitor Value = 62uF ESR Value =0.0031ohms

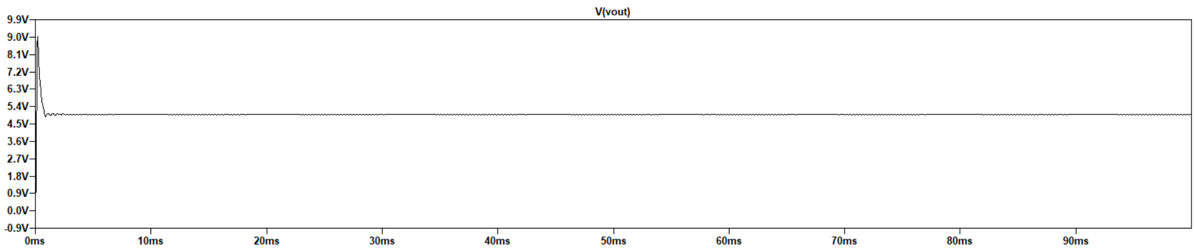

Figure3 Output Voltage Waveform

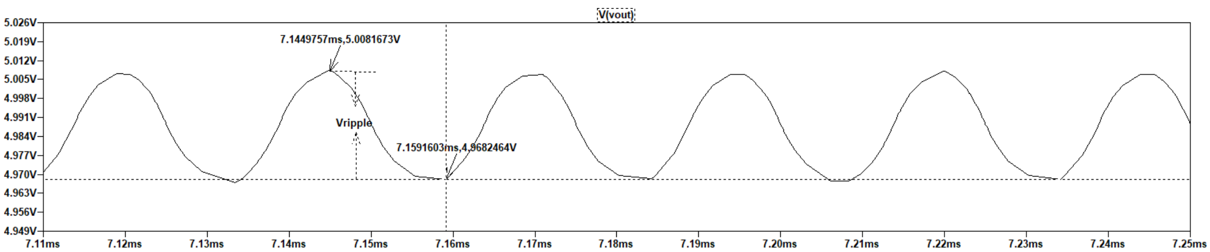

Figure4 Ripple Voltage Waveform

Ripple Voltage:

$$V_{ripple} = 5.01\text{-}4.97 = 40mV$$

$$\Delta V_{out} = V_{ripple} = V_{out} * \text{ripple } \%$$

ripple % :

$$\text{ripple } \% = \frac{\Delta V_{out}}{V_{out}}$$

$$\text{ripple } \% = \frac{0.04}{5.01}$$

$$\text{ripple } \% = 0.8\%$$

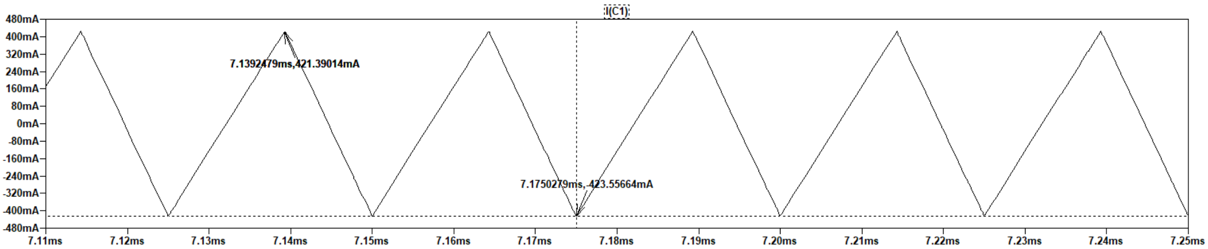

Figure5 Capactor Current Waveform

$$\Delta i_c = 421.39\text{-}(\text{-}423.56) = 844.95\text{mA}$$

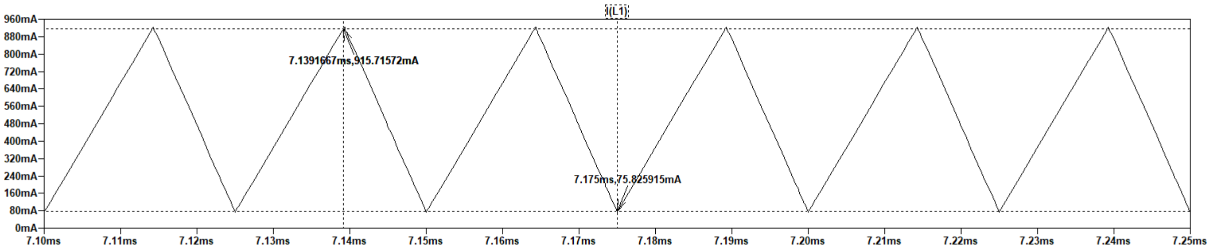

Figure6 Inductor Current Waveform

$$\Delta i_L = 915.72\text{-}75.83 = 839.89 \text{ mA}$$

$$\Delta i_L \approx \Delta i_c$$

$$\Delta V_{out} * \text{ESR} = \Delta i_c * \tau c$$

$$\tau c = \frac{\Delta V_{out}}{\Delta i_c}$$

$$\tau c = \frac{0.04}{0.845} = 0.047 \text{ ohms}$$

$$C = \frac{10^{-5}}{0.047} = 212.8 \text{ uF}$$

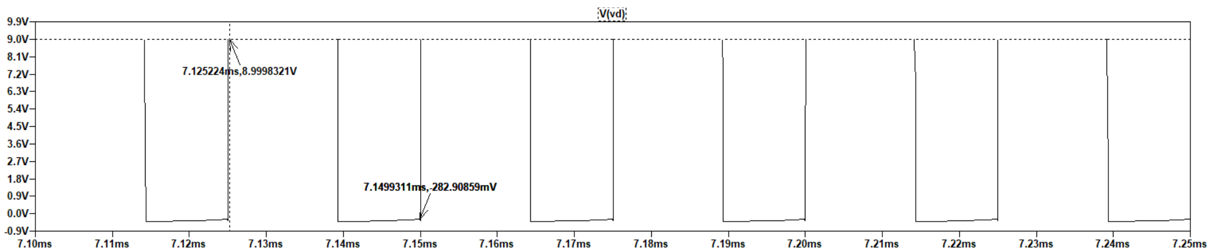

Figure7 Inductor Voltage Waveform

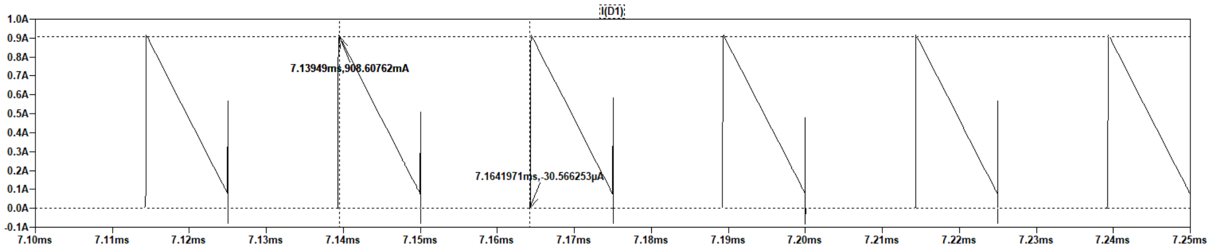

Figure8 Diode Current Waveform

Maximum Diode Current= 908.61mA

Minimum Diode Current= -30.57uA

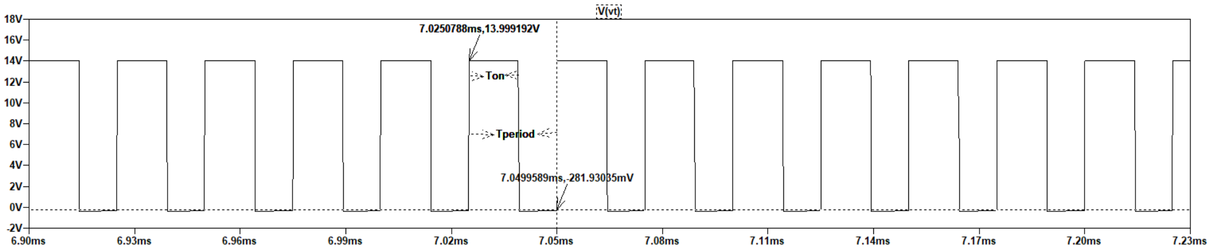

Figure9 Period Time Waveform

T_{on} =7.039- 7.03= 0.006 ms

T_{period} = 7.05 -7.03 =0.02 ms

ESR Value =0.0005 ohms

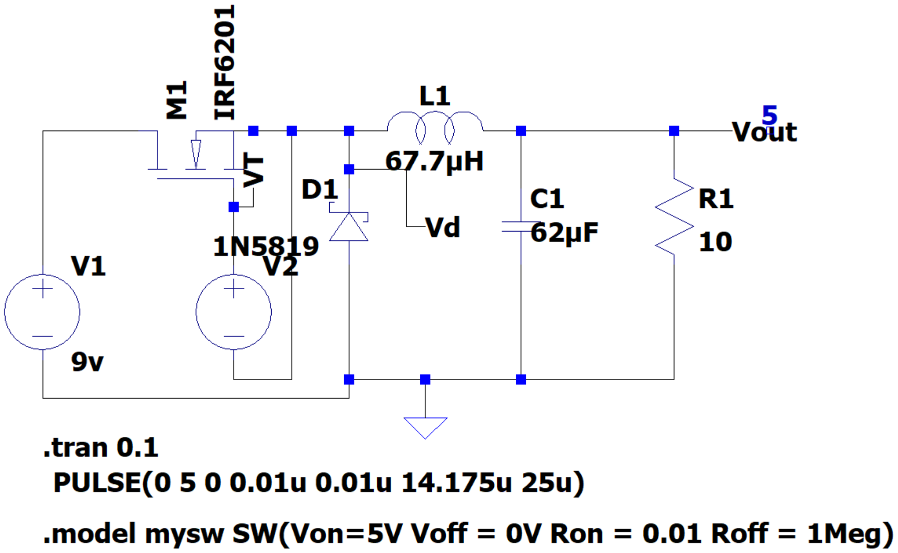

Figure 30 Buck Converter Circuit ESR=0.0005

Features

- Self-Inductance as low as 11nH
- ESR as low as 0.5 mΩ
- Low profile
- High thermal conductivity
- Life expectancy as high as 100 Khrs
- Integrated mounting flanges
- Flame retardant UL94- V0

Figure11 Capacitor Value = 62uF ESR Value =0.0005ohms

Parameter	Value
Input Voltage	9 V
Output Voltage	5.01 V
Ripple Voltage	40 mV
Ripple %	8%
Inductor Voltage	9 V
Maximum Diode Current	914.78mA
Minimum Diode Current	-31.94uA
T_{on}	0.02 ms
T_{period}	0.03 ms
Frequency	40 kHz
Duty Cycle	0.567
Maximum Capacitor Current	422.07 mA
Minimum Capacitor Current	-414.30 mA
Maximum Inductor Current	917.62 mA
Minimum Inductor Current	75.98 mA

Output Current	0.5 A
Inductor	67.7 uH
Capacitor	62 uF
ESR	0.0005 ohms
τc	0.048 ohms
Δi_c	836.37 mA
Δi_L	841.64 mA

Table2 Buck Converter All Parameter Value

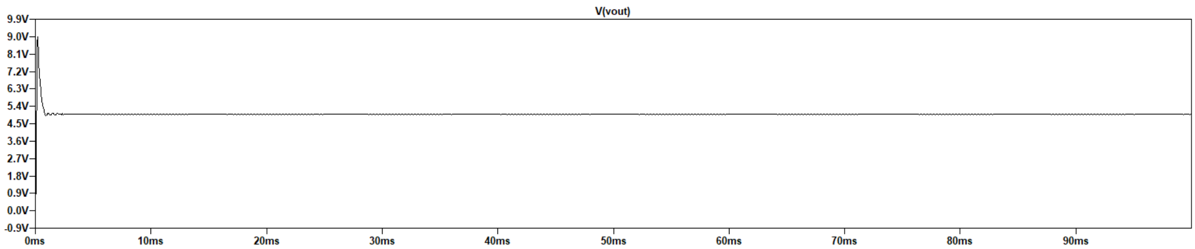

Figure12 Output Voltage Waveform

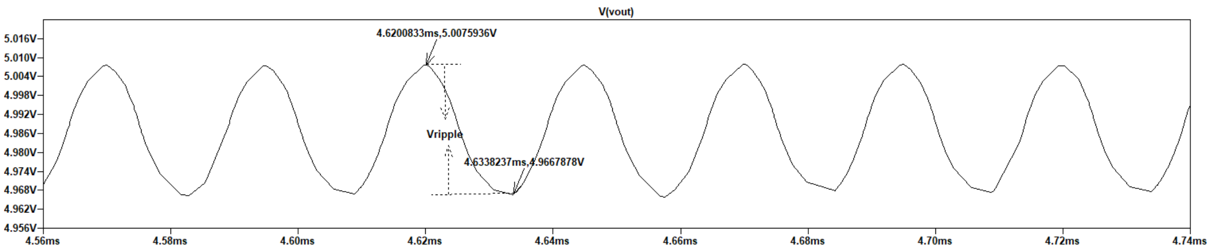

Figure13 Ripple Voltage Waveform

Ripple Voltage:

$$V_{ripple} = 5.01\text{-}4.97 = 40\text{mV}$$

$$\Delta V_{out} = V_{ripple} = V_{out} * \text{ripple } \%$$

ripple % :

$$\text{ripple } \% = \frac{\Delta V_{out}}{V_{out}}$$

$$\text{ripple } \% = \frac{0.04}{5.01}$$

$$\text{ripple } \% = 0.8\%$$

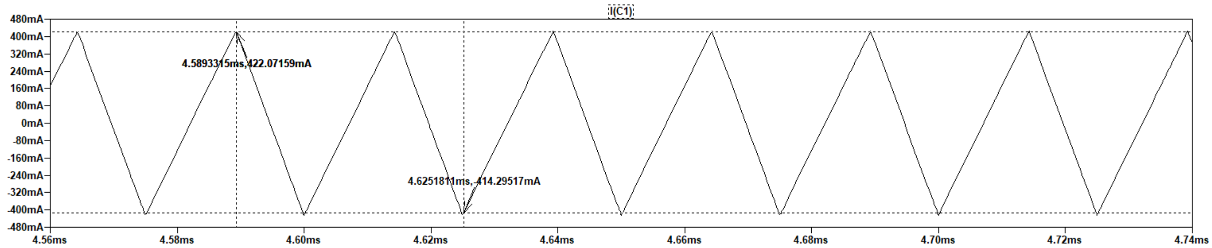

Figure14 Capacitor Current Waveform

$$\Delta i_c = 422.07\text{-}(-414.30)\text{=}836.37\text{mA}$$

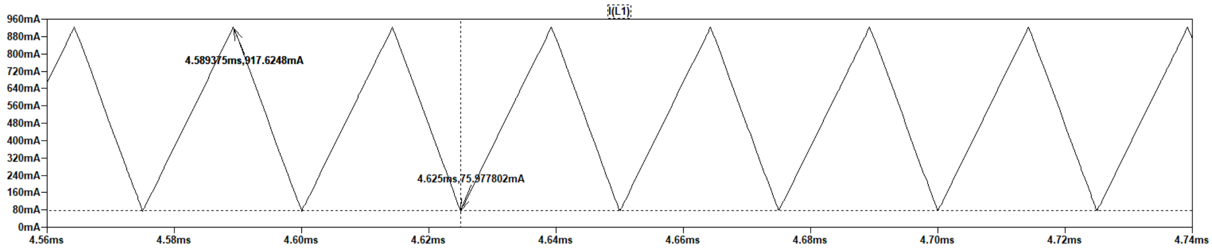

Figure15 Inductor Current Waveform

$$\Delta i_L = 917.62\text{-}75.98\text{=}841.64 \text{ mA}$$

$$\Delta i_L \approx \Delta i_c$$

$$\Delta V_{out} * \text{ESR}= \Delta i_c * \tau c$$

$$\tau c = \frac{\Delta V_{out}}{\Delta i_c}$$

$$\tau c = \frac{0.04}{0.836} = 0.048 \text{ ohms}$$

$$C= \frac{10^{-5}}{0.048} = 208.3 \text{ uF}$$

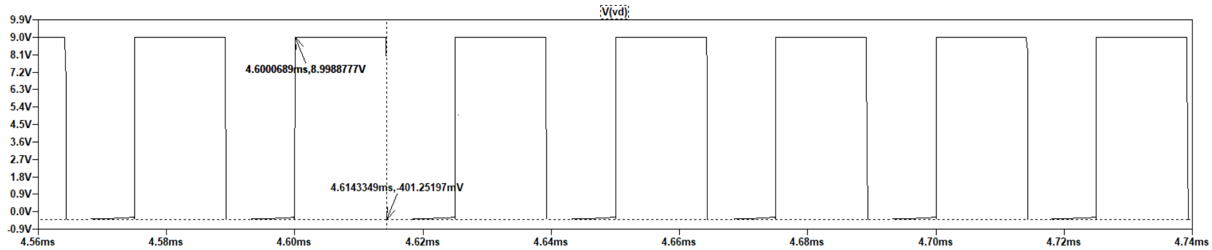

Figure16 Inductor Voltage Waveform

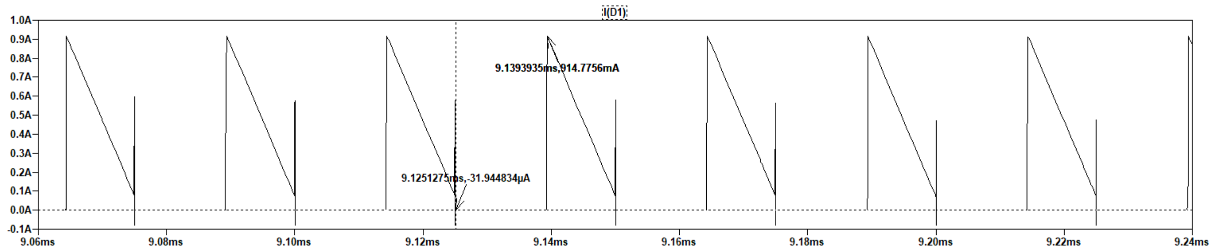

Figure17 Diode Current Waveform

Maximum Diode Current= 914.78mA

Minimum Diode Current= -31.94uA

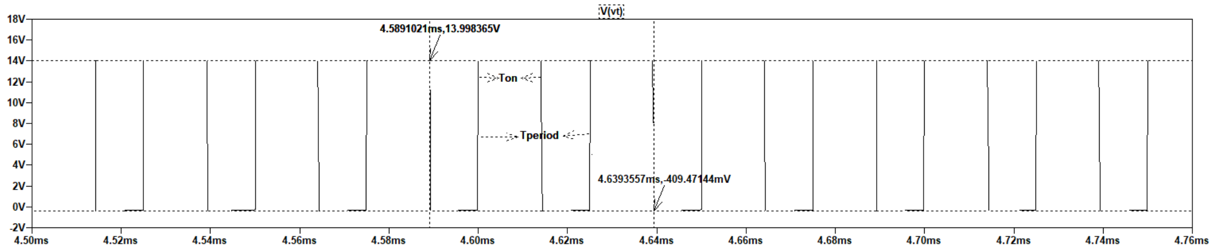

Figure18 Period Time Waveform

T_{on} =4.64-4.62= 0.02 ms

T_{period} = 4.65-4.62 =0.03ms

From figure3, figure4, figure12, figure13, we observe higher ESR values result in increased fluctuations in the output voltage because ESR introduces an additional voltage drop. Because the two ESR values are similar, the ripple voltage changes very little. From figure5 and figure14, the difference between the maximum current and the minimum current when the capacitor is charged and discharged, it can be seen that the higher the ESR value, the greater the difference of the current (844.95mA >836.37mA) , so high ESR will cause the harmonic increase of the capacitor current waveform, affecting the capacitor's operation. From figure6 and figure15, high ESR will cause the harmonic increase of inductor current waveform and affect the operation of inductor. From figure7 and figure16, The voltage drop introduced by ESR leads to increased fluctuations in the inductor voltage. From figure9 and figure18, a higher ESR results in a higher frequency. To sum up, different ESR has different effects on each parameter, and the most appropriate circuit should be selected when selecting ESR.

ESR & No ESR

ESR

We believe that the voltage above the capacitor cannot be sudden change, when a current is suddenly applied to the capacitor, the capacitor will start to rise from 0 because of its own charge. However, with ESR, the resistor itself will produce a voltage drop, which leads to a sudden change in the voltage at both ends of the capacitor, and ESR causes the capacitor to fail to completely smooth the output current, which will undoubtedly reduce the filtering effect of the capacitor, resulting in an increase in the ripple of the output voltage.

No ESR

Ideally, no ESR capacitors can smooth the output current more efficiently and reduce ripple voltage. The output voltage fluctuation is small, which improves the stability of the power supply.

Select Capacitor

ESR=0.0005

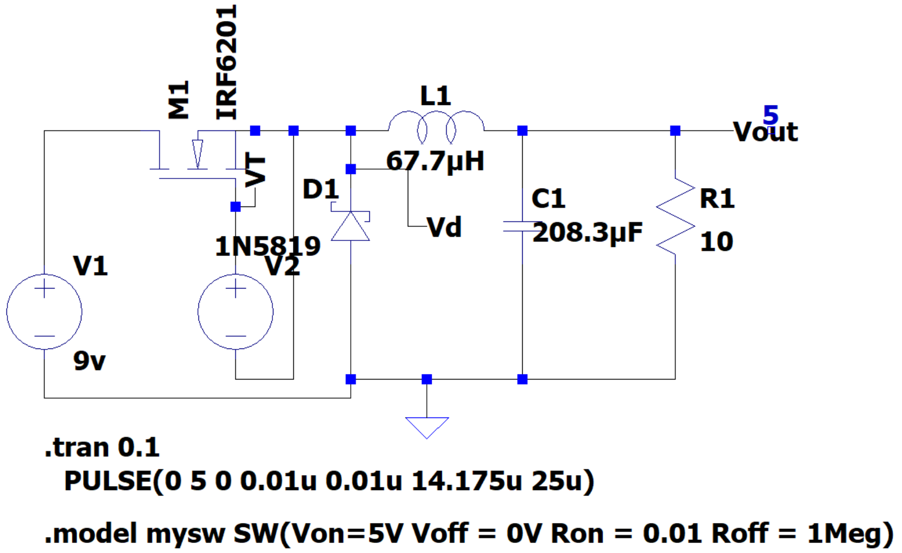

Figure49 Buck Converter Circuit ESR=0.0005

Parameter	Value
Input Voltage	9 V
Output Voltage	4.99 V
Ripple Voltage	10 mV
Ripple %	0.24%
Inductor Voltage	9 V
Maximum Diode Current	910.17mA
Minimum Diode Current	-50.08uA
T_{on}	0.01 ms
T_{period}	0.02 ms
Frequency	40 kHz
Duty Cycle	0.567
Maximum Capacitor Current	419.36 mA
Minimum Capacitor Current	-421.61 mA
Maximum Inductor Current	921.32 mA
Minimum Inductor Current	76.82 mA
Output Current	0.5 A

Inductor	67.7 uH
Capacitor	208.3 uF
ESR	0.0005 ohms
τc	0.049 ohms
Δi_c	830.97 mA
Δi_L	844.5 mA

Table3 Buck Converter All Parameter Value

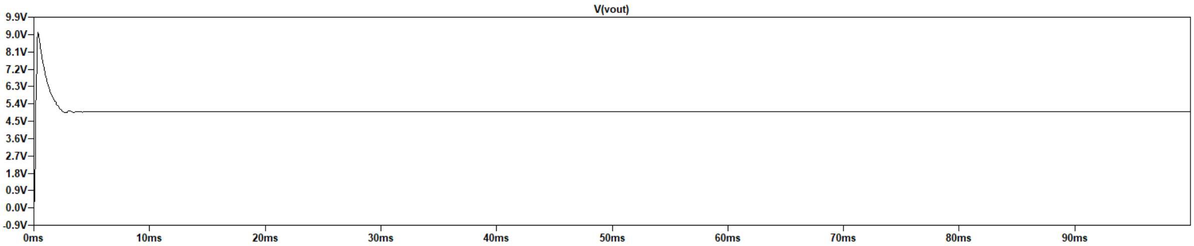

Figure20 Output Voltage Waveform

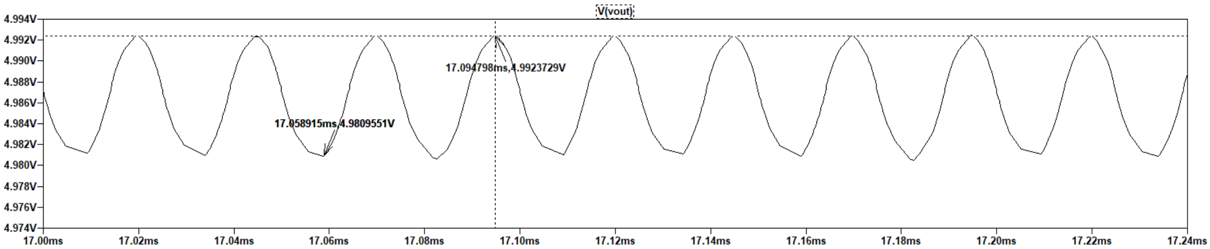

Figure21 Ripple Voltage Waveform

Ripple Voltage:

$$V_{ripple} = 4.992\text{-}4.980 = 0.012V$$

$$\Delta V_{out} = V_{ripple} = V_{out} * \text{ripple } \%$$

ripple % :

$$\text{ripple } \% = \frac{\Delta V_{out}}{V_{out}}$$

$$\text{ripple } \% = \frac{0.012}{4.992}$$

$$\text{ripple } \% = 0.24\%$$

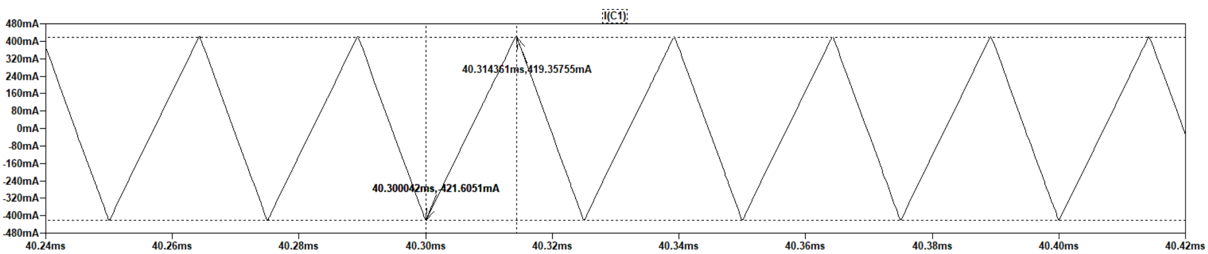

Figure22 Capacitor Current Waveform

$$\Delta i_c = 419.36\text{-}(\text{-}421.61) = 830.97\text{mA}$$

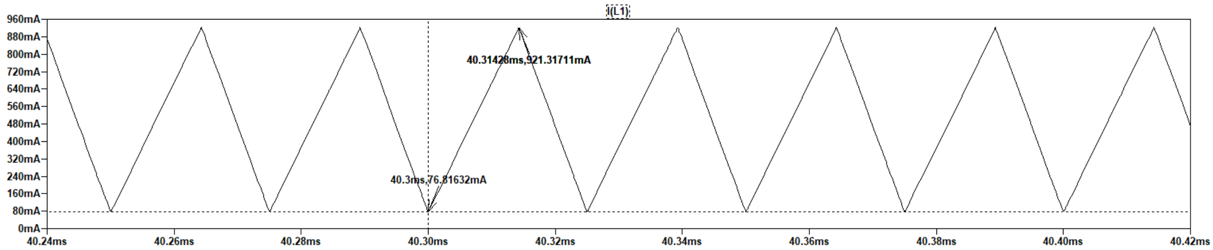

Figure23 Inductor Current Waveform

$$\Delta i_L = 921.32\text{-}76.82 = 844.5\ \text{mA}$$

$$\Delta i_L \approx \Delta i_c$$

$$\Delta V_{out} * \text{ESR} = \Delta i_c * \tau c$$

$$\tau c = \frac{\Delta V_{out}}{\Delta i_c}$$

$$\tau c = \frac{0.012}{0.8445} = 0.0142\ \text{ohms}$$

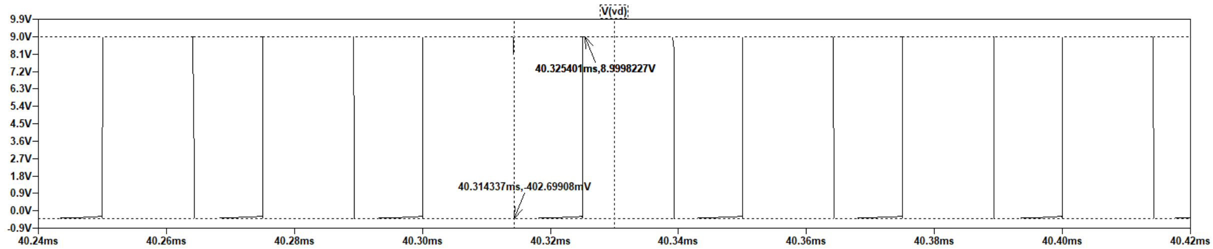

Figure24 Inductor Voltage Waveform

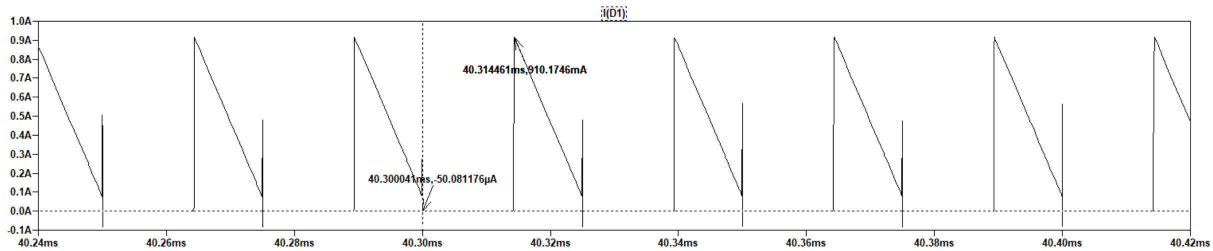

Figure25 Diode Current Waveform

Maximum Diode Current= 910.17mA

Minimum Diode Current= -50.08uA

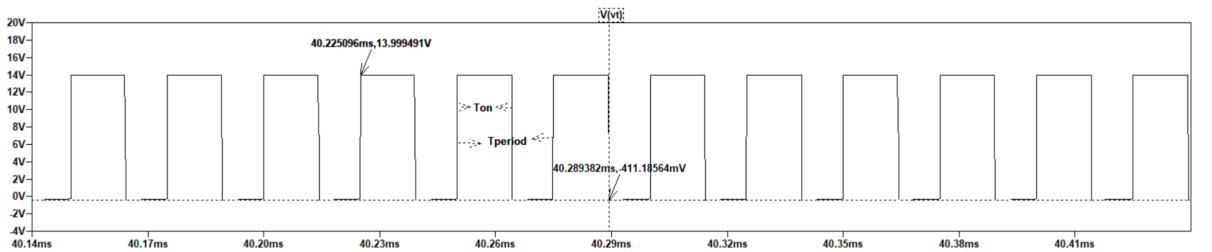

Figure26 Period Time Waveform

T_{on} =40.24-40.23= 0.01 ms

T_{period} = 40.25-40.23=0.02ms

ESR=0.0031

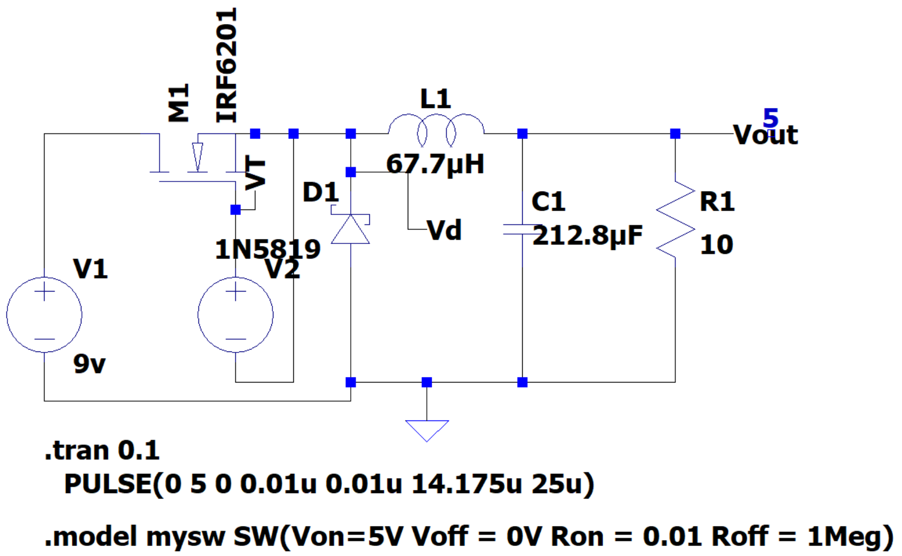

Figure27 Buck Converter Circuit ESR=0.0031

Parameter	Value
Input Voltage	9 V
Output Voltage	4.99 V
Ripple Voltage	10 mV
Ripple %	0.24%
Inductor Voltage	9 V
Maximum Diode Current	912.6mA
Minimum Diode Current	-31.75uA
T_{on}	0.014 ms
T_{period}	0.025 ms
Frequency	40 kHz
Duty Cycle	0.567
Maximum Capacitor Current	412.48 mA
Minimum Capacitor Current	-418.6 mA
Maximum Inductor Current	919.65 mA

Minimum Inductor Current	81.95 mA
Output Current	0.5 A
Inductor	67.7 uH
Capacitor	212.8 uF
ESR	0.0031 ohms
τc	0.0143 ohms
Δi_c	831.08 mA
Δi_L	837.7 mA

Table4 Buck Converter All Parameter Value

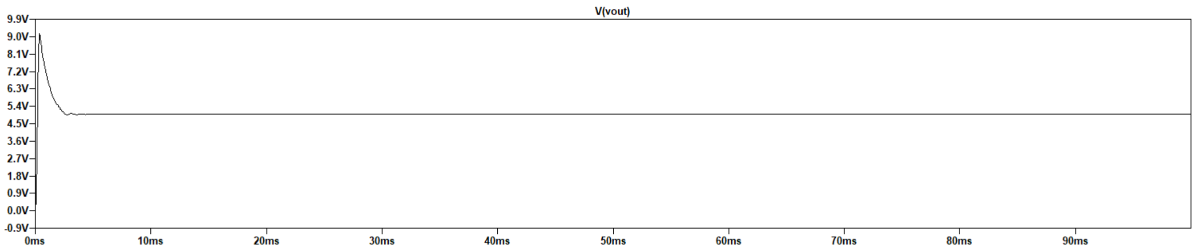

Figure28 Output Voltage Waveform

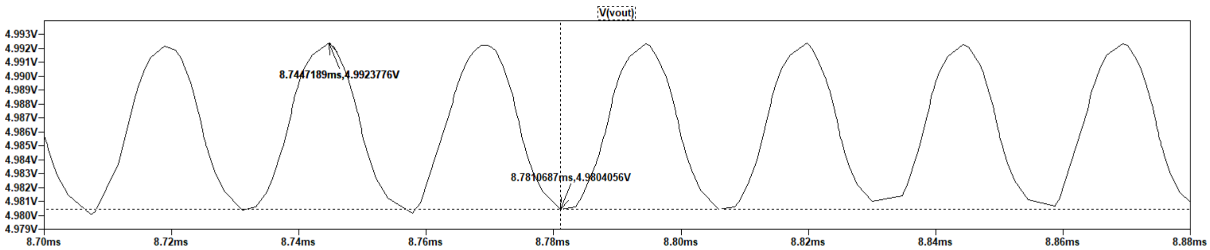

Figure29 Ripple Voltage Waveform

Ripple Voltage:

$$V_{ripple} = 4.992\text{-}4.980 = 0.012V$$

$$\Delta V_{out} = V_{ripple} = V_{out} * \text{ripple } \%$$

ripple % :

$$\text{ripple } \% = \frac{\Delta V_{out}}{V_{out}}$$

$$\text{ripple } \% = \frac{0.012}{4.992}$$

$$\text{ripple } \% = 0.24\%$$

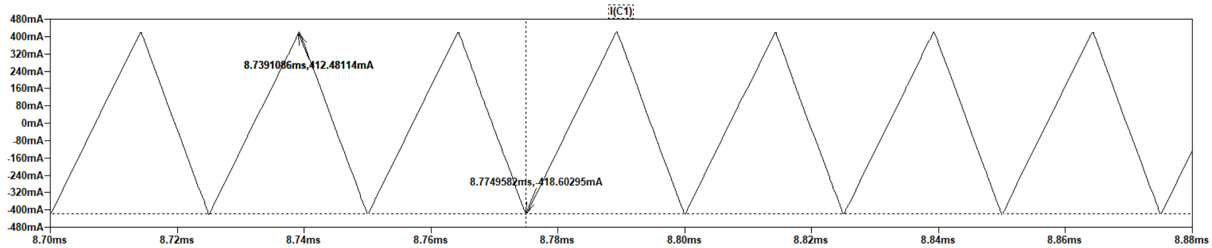

Figure30 Capacitor Current Waveform

$$\Delta i_c = 412.48\text{-}(-418.6)\text{=}831.08\text{mA}$$

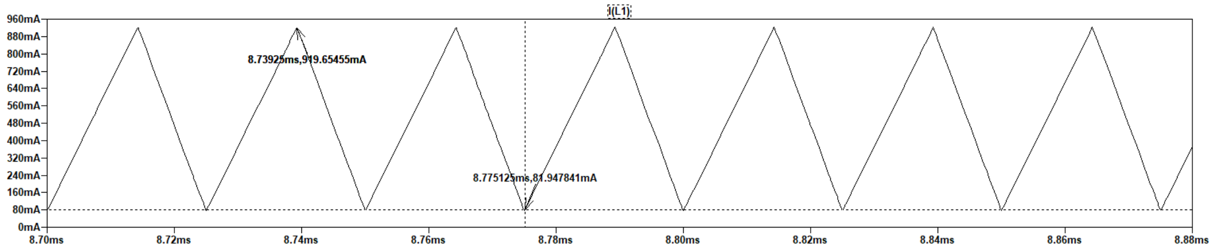

Figure31 Inductor Current Waveform

$$\Delta i_L = 919.65\text{-}81.95\text{=}837.7 \text{ mA}$$

$$\Delta i_L \approx \Delta i_c$$

$$\Delta V_{out} * \text{ESR}= \Delta i_c * \tau c$$

$$\tau c = \frac{\Delta V_{out}}{\Delta i_c}$$

$$\tau c = \frac{0.012}{0.8377} = 0.0143 \text{ ohms}$$

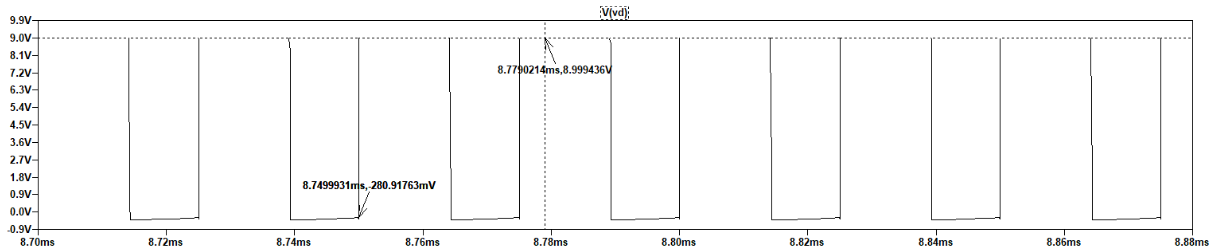

Figure32 Inductor Voltage Waveform

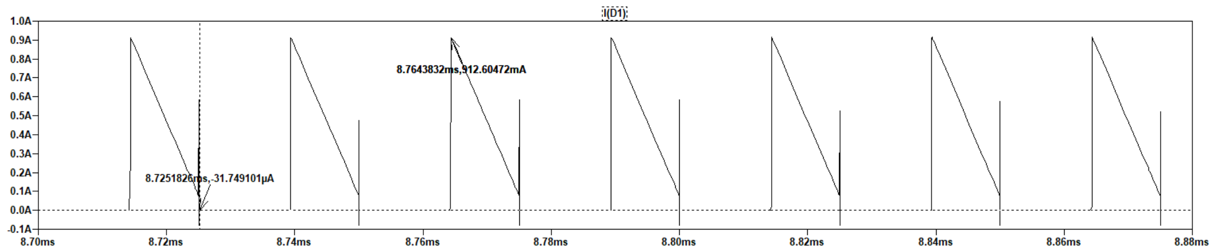

Figure33 Diode Current Waveform

Maximum Diode Current= 912.6mA

Minimum Diode Current= -31.75uA

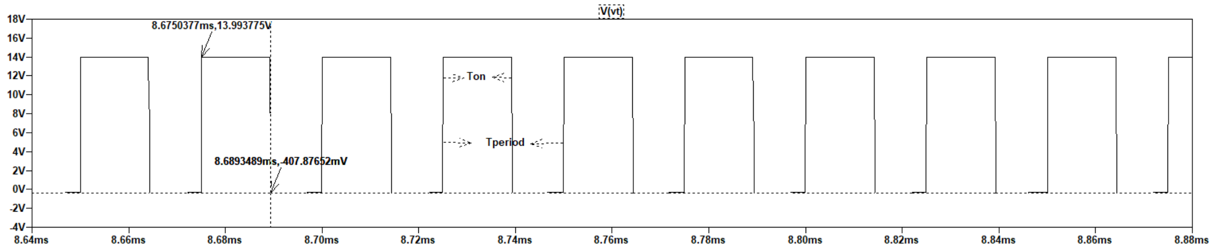

Figure34 Period Time Waveform

T_{on} =8.739-8.725= 0.014 ms

T_{period} = 8.75-8.725=0.025ms

Increasing the capacitance value usually reduces the output ripple voltage. Larger capacitors can better smooth the output current, reduce ripple, improve the output voltage stability, improve the frequency response of the control loop, make the system easier to adjust, and increase the ESR will cause the output capacitor to not completely smooth the output current, thereby increasing the output ripple voltage. The output voltage stability is reduced, the current waveform is not smooth, resulting in the increase of inductor current ripple, which reduces the stability of the system. Increasing the capacitance will reduce the ripple, while increasing the ESR will increase the ripple voltage, and the two will interact to keep the circuit stable.Therefore, appropriate capacitance and ESR values should be selected.

Conclusions

Reflections

This report analyses the DC-DC Buck converter is its ability to act as a voltage regulator, using a MOSFET switch to control the flow of current to the load. It is widely used in applications that require a steady, reliable output voltage.

This report mainly analyzes the influence of ESR in buck circuit. According to the two different types of ESR value of capacitors, through the debugging analysis of the voltage reduction circuit, high ESR value will cause a sudden voltage drop of the capacitor, which will cause the increase of ripple voltage, thus affecting the fluctuation of the output voltage and reducing the stability of the system. In addition, the fluctuation of the voltage and current of the inductor will increase, thus affecting the operation of the inductor. The introduction of ESR also has an impact on the frequency in the control loop.

A further analysis of the circuit in this report finds that an increase in the capacitance value will reduce the filter, thus reducing the ripple voltage and making the output voltage more stable, increasing the stability of the system, therefore in the actual design, it is necessary to balance the capacitance value and ESR to meet the performance requirements of the specific application.

With ESR and no ESR, ESR will increase the ripple voltage and affect the stability of the output voltage. No ESR is the ideal state to reduce ripple voltage and increase system stability.

Referencing

D, (no date) *TPSD227K010R0050 - surface mount tantalum capacitor, Farnell*. Available at: https://ie.farnell.com/avx/tpsd227k010r0050/cap-220-f-10v-10-2917-reel/dp/2217465 (Accessed: 03 December 2023).