SIMULATIONS WITH THE BUCK-BOOST TOPOLOGY

EE562: POWER ELECTRONICS I

COLORADO STATE UNIVERSITY

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PURPOSE: The purpose of this lab is to simulate the Buck-Boost converter using OrCAD ® to better familiarize the student with some of its operating characteristics. This lab will explore some of the following aspects of the boost converter:

- Discontinuous Conduction Mode
- Inductor sizing
- Differential voltage across the inductor
- Time it takes for the converter to reach steady state
- Output Ripple voltage and selection of the capacitor.
- Ripple current through the capacitor
- Equivalent Series Resistance (ESR) of the output capacitor.
- Effects of changing and removing load resistance
- Effects of the ON resistance of the switch
- Efficiency
- Effects of changing frequency

NOTE: The simulations that follow are intended to be completed with OrCAD ®. It is assumed that the student has a fundamental understanding of the operation of OrCAD ®. OrCAD ® provides tutorials for users that are not experienced with its functions.

PROCEDURE:

Part 1: Build the schematic shown in Figure 1, using the Layout feature in Capture.

V1 is a DC voltage source (VDC) from the source library. It needs to be set for 24 volts.

L1 is an ideal inductor from the Analog Library. Set for 200μH.

R2 is an ideal resistor from the Analog Library. Set for 50Ω.

D1 is an ideal diode and can be found in the Breakout library.

C1 is an ideal capacitor from the Analog library. Change the value to 50μF.

S1 is a voltage controlled switch and can be found in the Analog library. Change RON from 1Ω to 1mΩ.

V2 is a pulsed voltage source and is intended to act as the output of a pulse width modulator. V2 needs the following parameters set:

DC=0, AC = 10, V1=0, V2 = 10, TR=10ns, TF=10ns, PW = 20μ , PER = 40μ.

This results in a switching frequency of 25 kHz.

R1 is set to 1000 kΩ. The purpose of R1 is to prevent any floating nodes.

Two **voltage markers** need to be placed as shown in the schematic of figure 1.

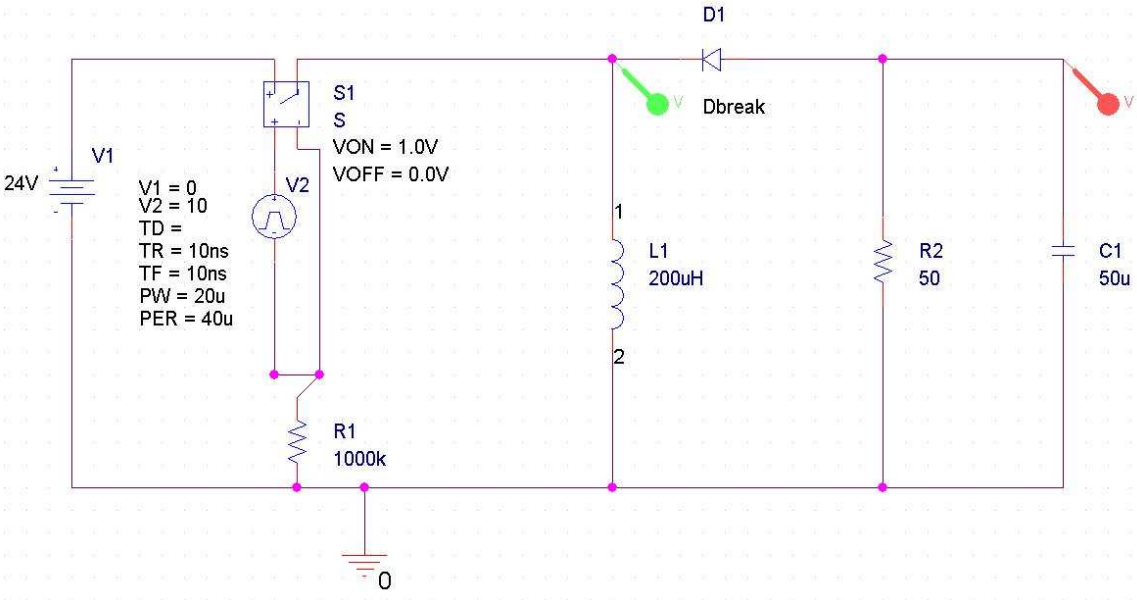


Figure 1. Buck-Boost schematic on OrCAD®

Once the above schematic is captured, the simulations can be ran. First, the type of simulation will need to be specified. Most of these simulations are Transient simulations. The Transient simulation can be set by navigating through OrCAD, New Simulations Profile, and selecting Transient under Analysis type. The "Run to Time" will need to be changed to 600µsec. Running the simulation will result in the following output.

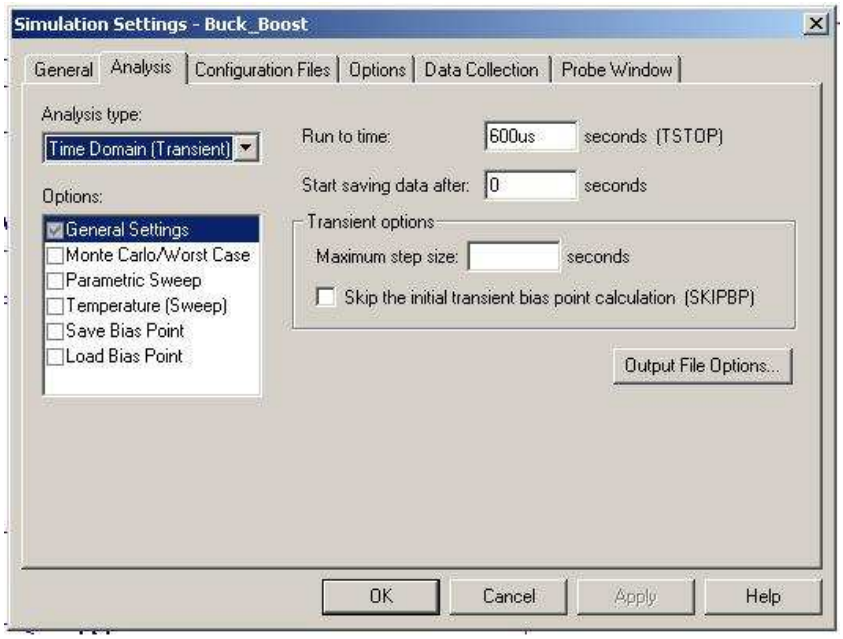
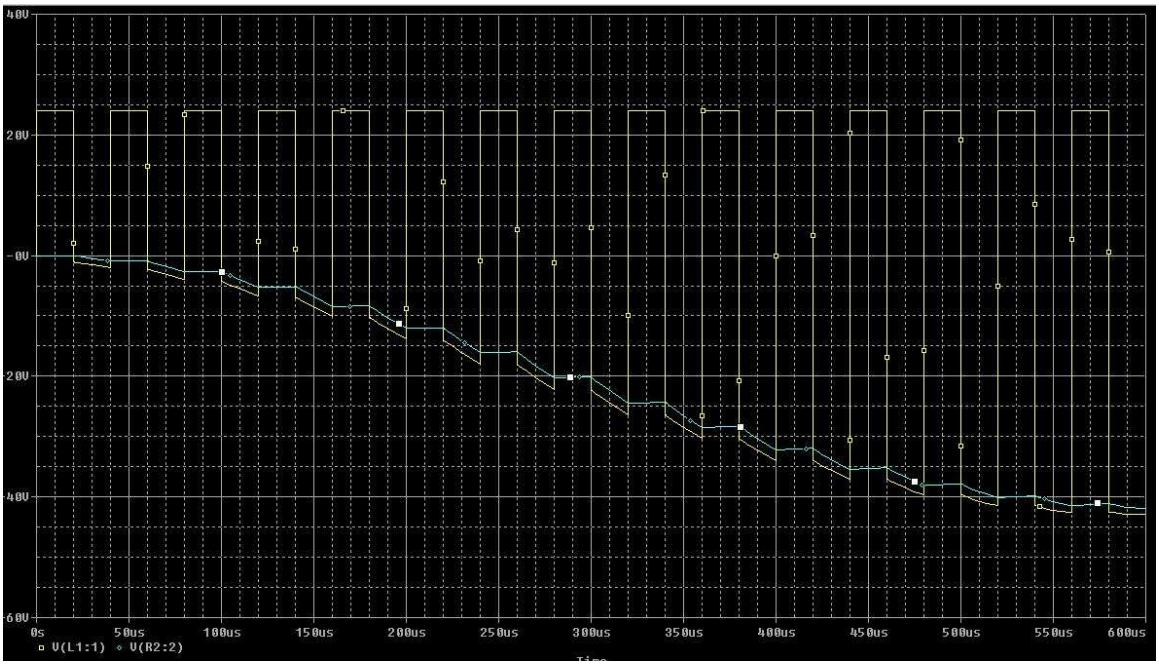
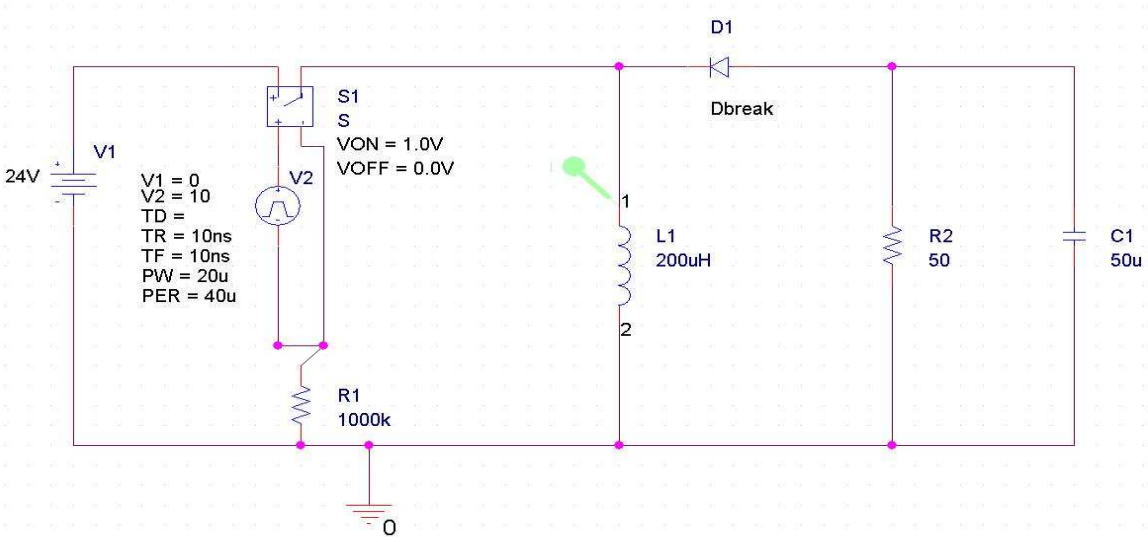


Figure 2. Transient Analysis setup.



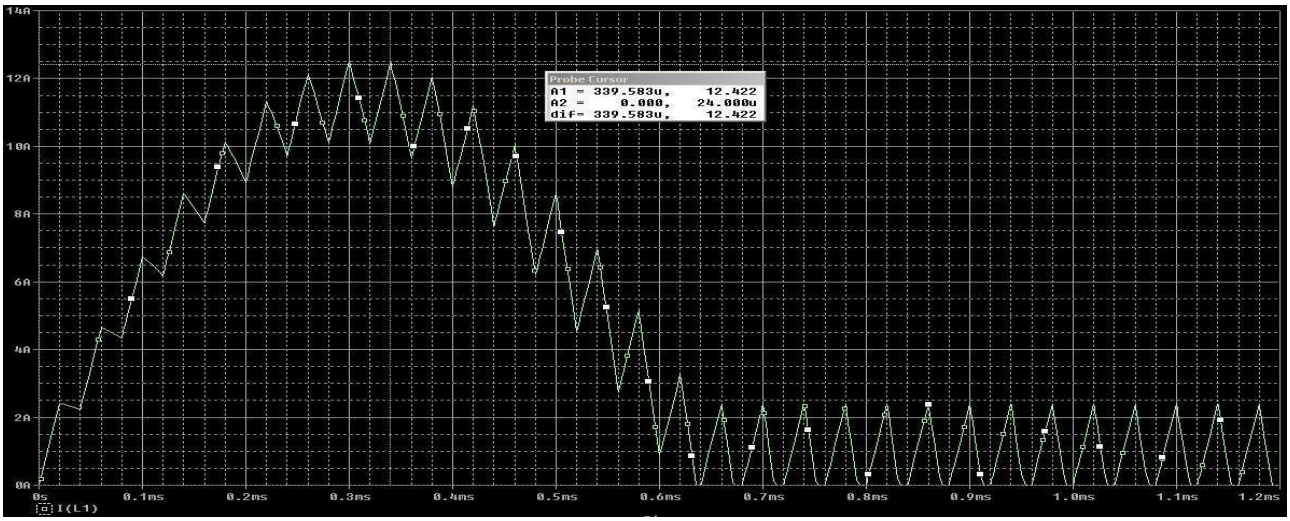
This shows the output voltage rising to near negative 45 volts, a Buck-Boost converter. We can also see the voltage across the inductor during the switch off time is near the output voltage, and during the switch on time is near the input voltage.

Remove the voltage markers, and use a **current marker** to measure the inductor L1 current. Place the marker in series next to L1. To change Analysis setting go to “Edit Simulation Profile" Change the Transient Analysis Run to Time to 1.2msec.



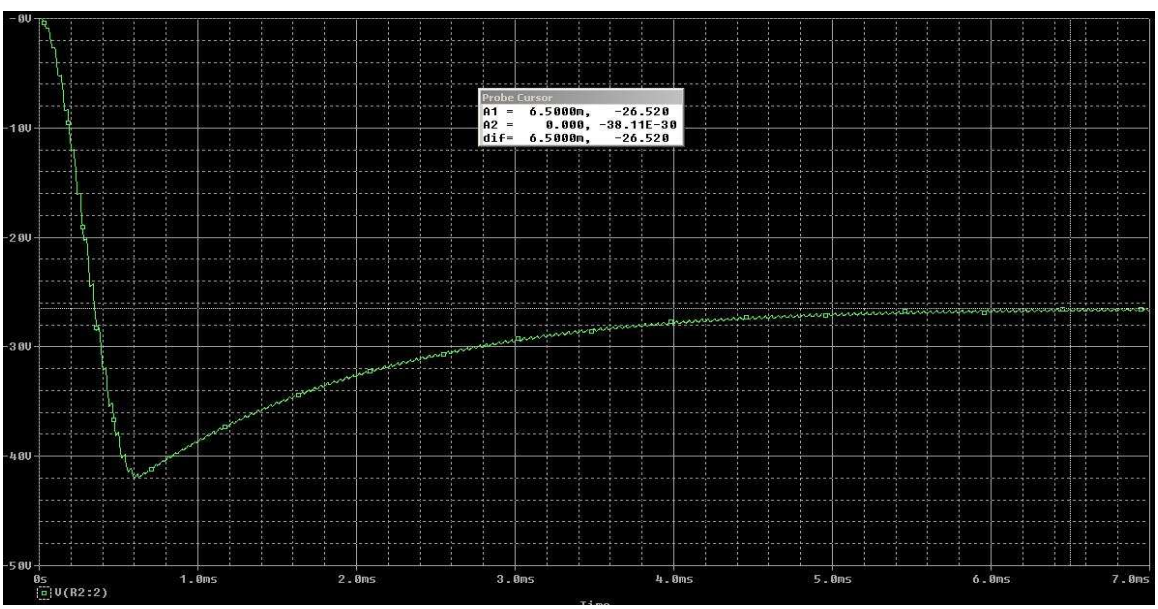
QUESTION 1: What is the peak operating current, and what is the operating mode of the converter? Verify mathematically the mode and the peak current.

Hint: $K = \frac{2L}{RTs}$, $Kcrit = D(1-D)^2$



From the picture above we can see that the converter is operating in the discontinuous conduction mode with an average operating current of about 1.5 amps, and a peak inrush current of about 12.4 amps

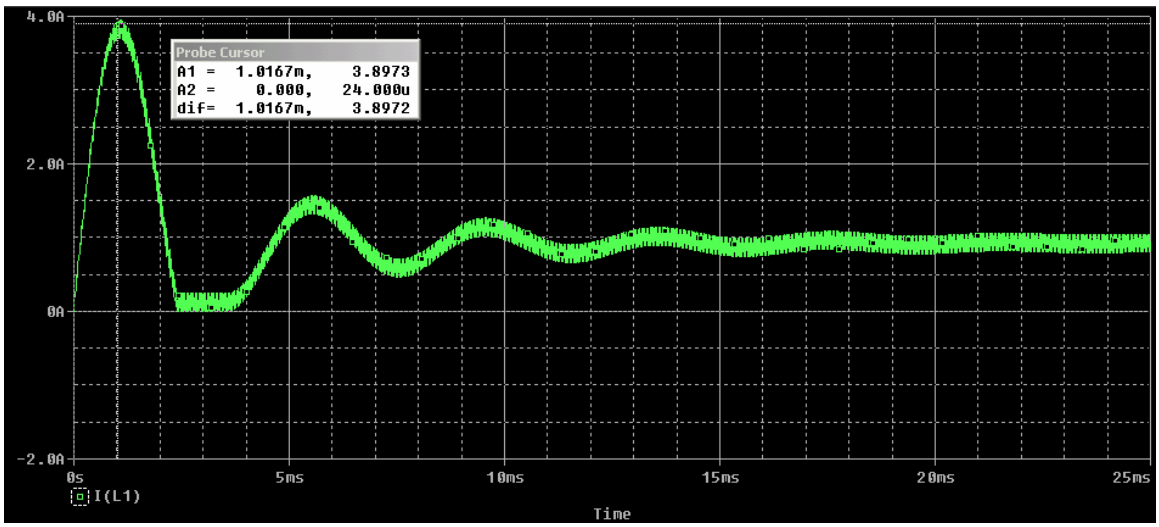
QUESTION 2: What is the output voltage of the converter at steady state? Verify your results mathematically.



The picture above shows that the converter reaches the steady state after approximately 6.5 ms with an output voltage of –26.52V.

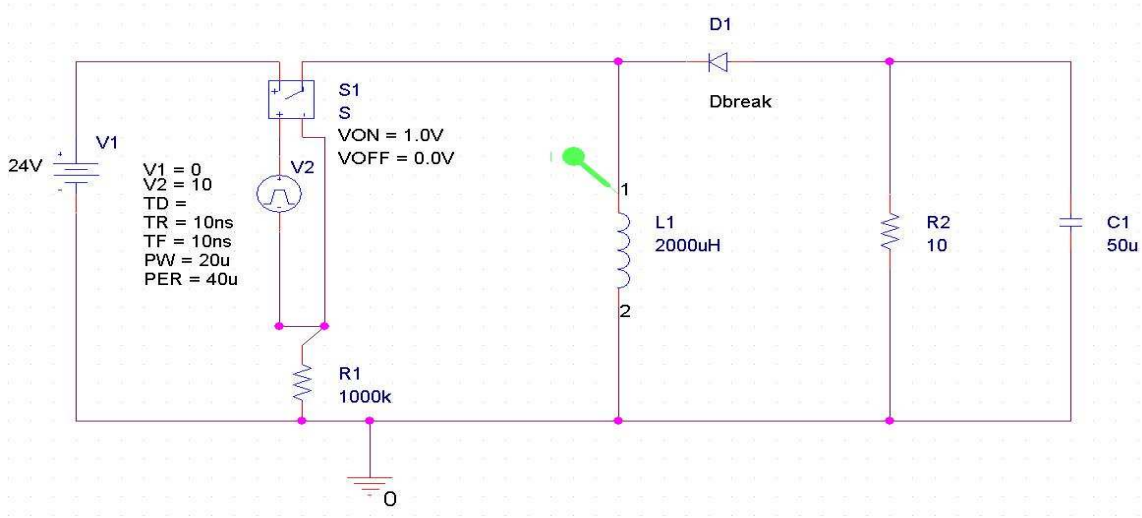
Now change L1 from 200µH to 2000µH and rerun the simulation. Remember you can vary the "Final Time" in "Transient Analysis". (Hint: Start this analysis with a "Run to Time" = 3ms)

QUESTION 3: What is the peak operating current now? What is the operating mode of the converter (remember that you can observe this by zooming in)?

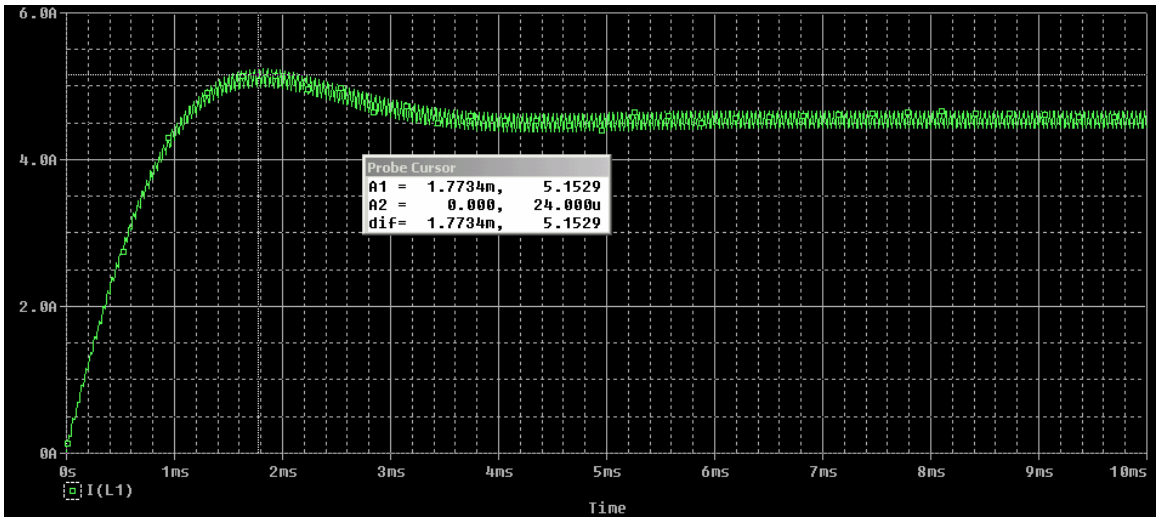


From the picture above we can see that the peak operating current is much smaller than in the previous case. It is approximately 3.9A. It reaches steady state at about 25msec. The converter operates for part of the time in the discontinuous conduction mode (at around 3msec) and in the continuous conduction mode for the rest of the time.

Leaving the Inductor at 2000uH, change the load resistance from 50Ω to 10Ω. Change the Run to Time of the simulation to 10msec. Run the simulation.



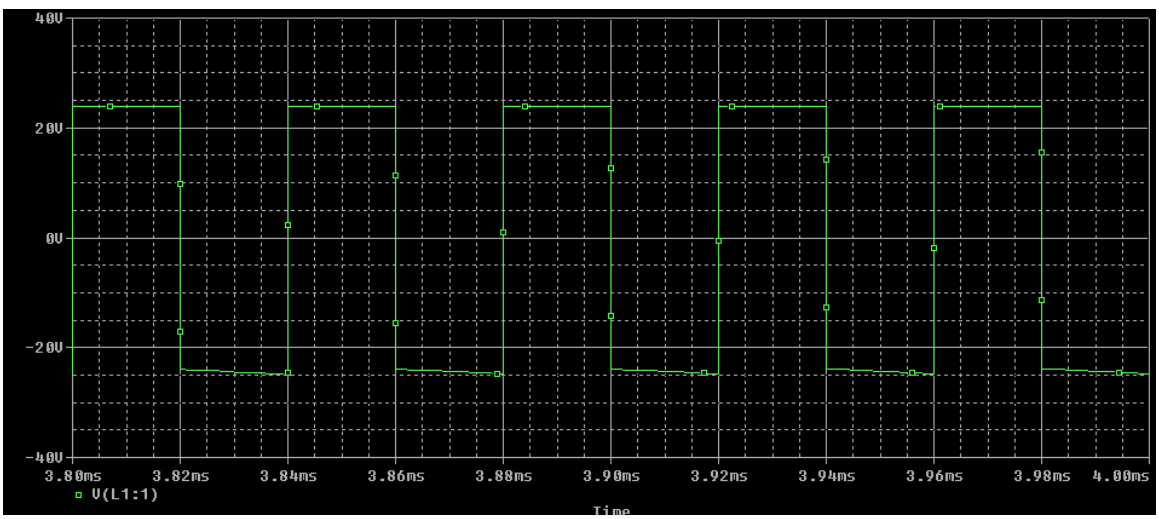
QUESTION 4: What operating mode is the converter in?



From the picture above we can see that the converter is operating in the continuous conduction mode with a peak current of 5.15A.

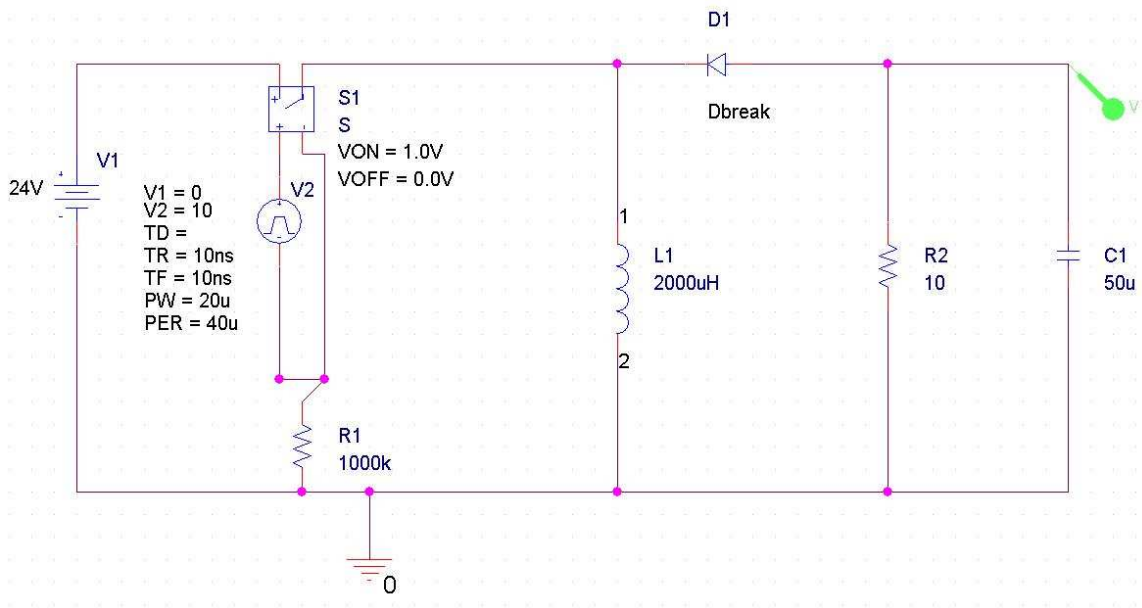
Remove the current marker and add a **differential voltage marker** (located between the Voltage and Current marker buttons in OrCAD Capture) across L1. Change the Run to Time of the simulation to 4m, and change the "Start Saving data after:" from 0 to 3.8m. Run the simulation.

QUESTION 5: What can be said about the differential voltage measurement across L1?

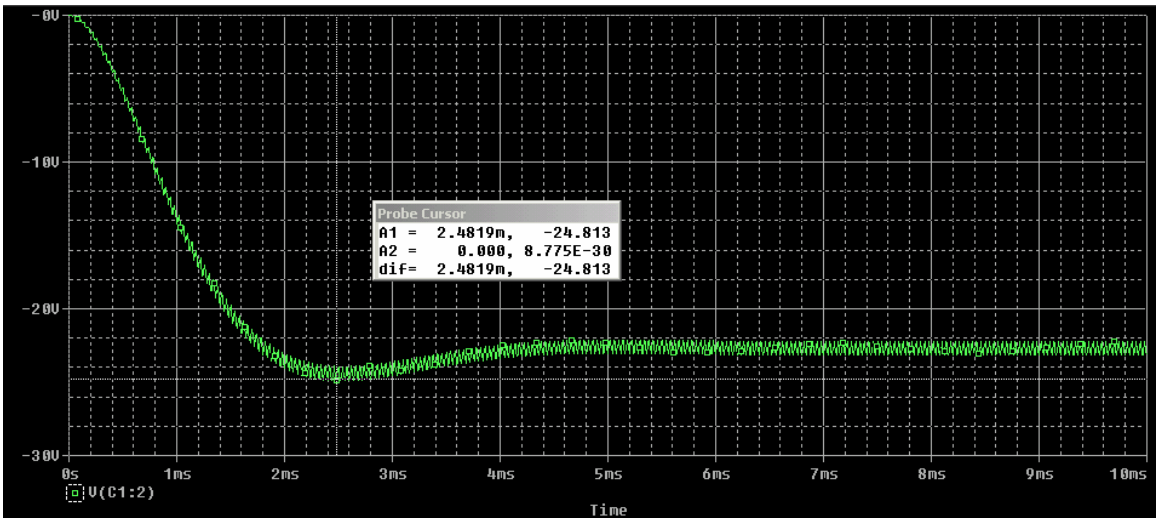


From the picture above we can see that the average voltage of the inductor is approaching zero, confirming the volt second balance required for an inductor.

Now change the “Run to Time” to 10m and remove any value in “Start Saving Data after” from the Transient Analysis setup. Remove the differential voltage markers across L1 and add a voltage marker to the top of C1.



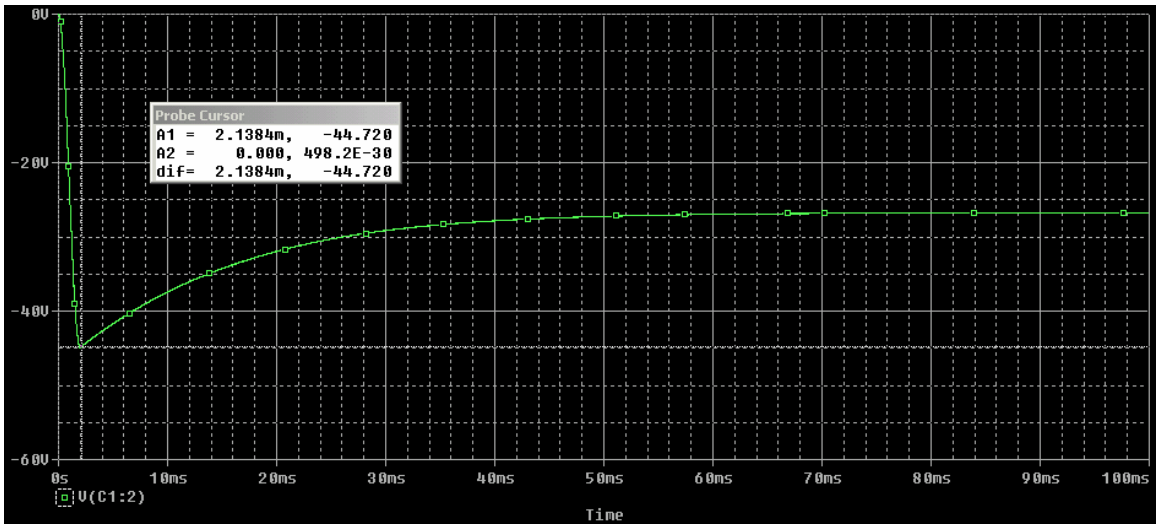
QUESTION 6: How long does it take for the output voltage to reach its final value? What is the peak to peak ripple on the output voltage? What is the average final value? Prove your simulation results mathematically (for final Vout).



From the picture above we can see that the average output voltage is reached in approximately 6milliseconds with a peak value of about -25VDC. The output also has less than 1V peak to peak ripple.

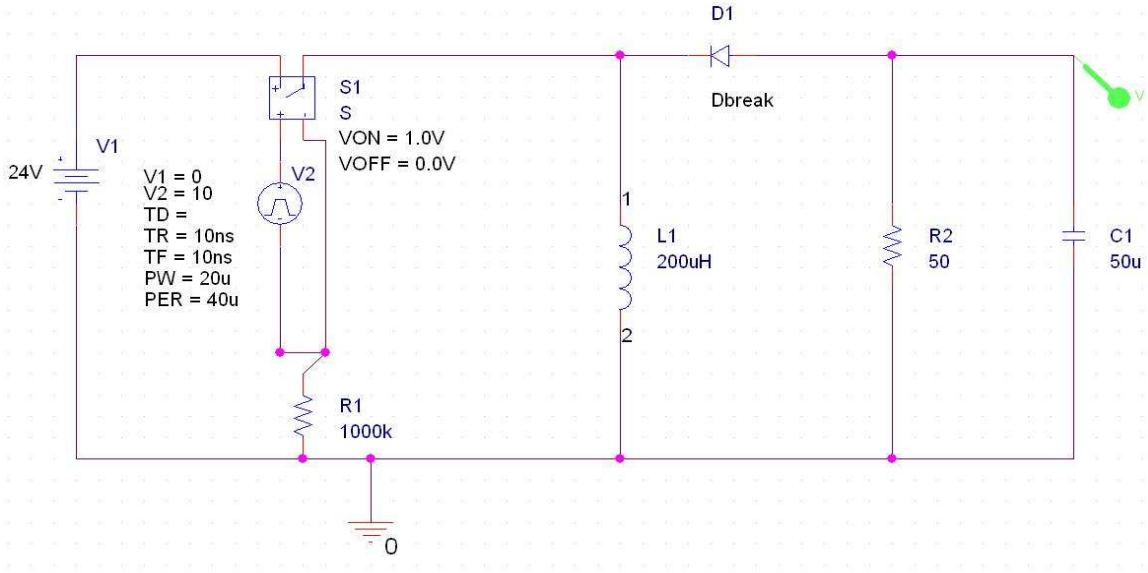
Now change the value of the load resistance from 10Ω to 500Ω. Change the "Run to Time" to 100msec.

QUESTION 7: What is the peak of the output voltage? How long does it take for the converter to reach steady state and what is that value?

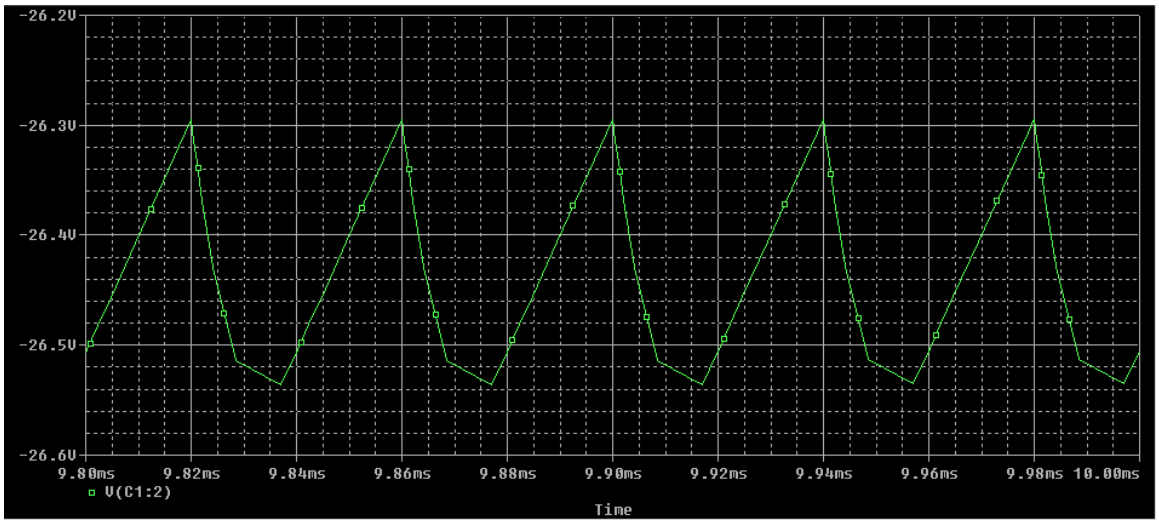


From the picture above we can see that the output voltage rises to a magnitude near twice the input voltage. This shows us that the output voltage of the Buck-Boost converter is a function of not only the duty cycle, the inductor value, and the capacitor value but also the load resistance. In this case, the duty cycle is 50 %, but the output still exceeds the value of the input voltage.

Change the load resistor back to 50Ω and the inductor to 200μH. Rerun the simulation using a "Run to Time" of 10msec with a "Start Saving Data" time of 9.8msec.

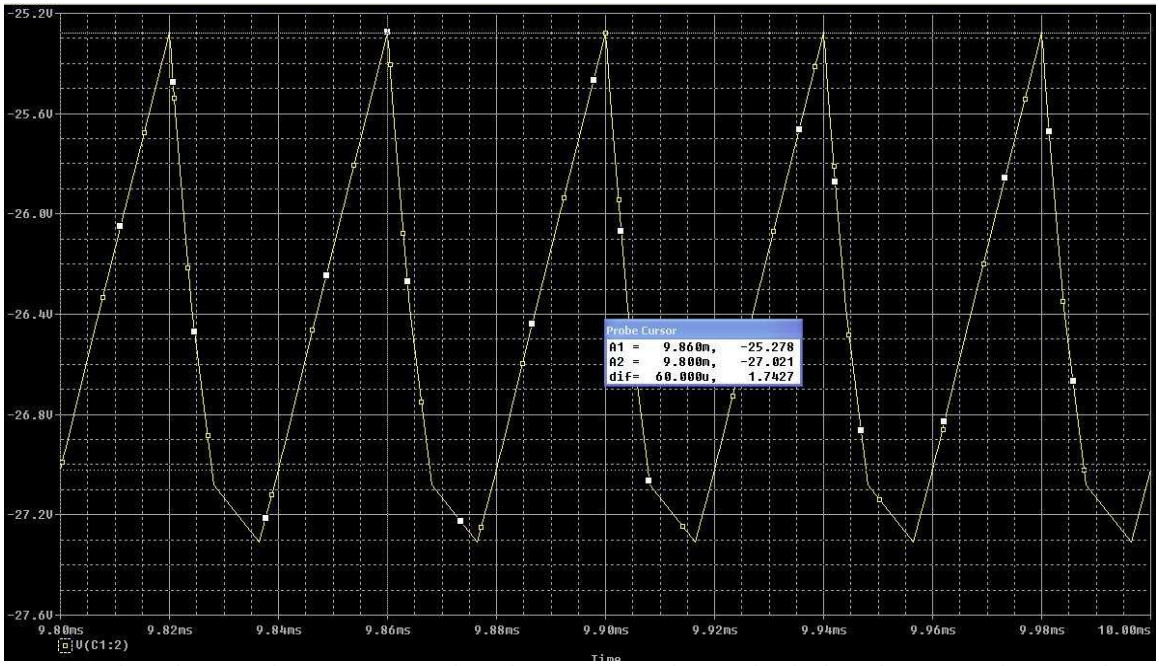


QUESTION 8: What is the peak-to-peak ripple voltage?



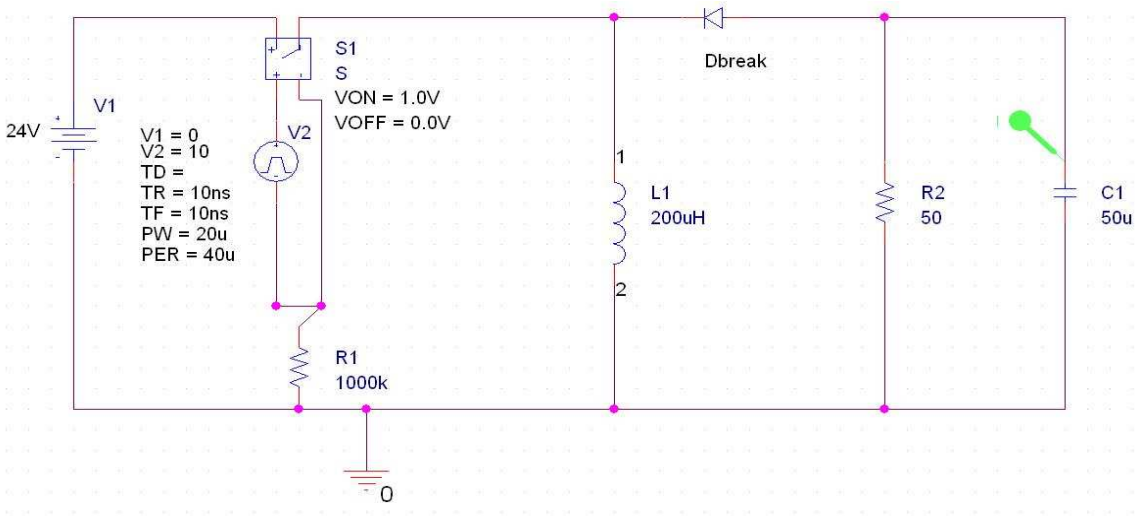
From the picture above we can see that the voltage ripple is less than 0.25V.

QUESTION 9: With everything else left as is, what would the minimum output capacitance be to limit the output voltage ripple to 2 volts peak to peak?

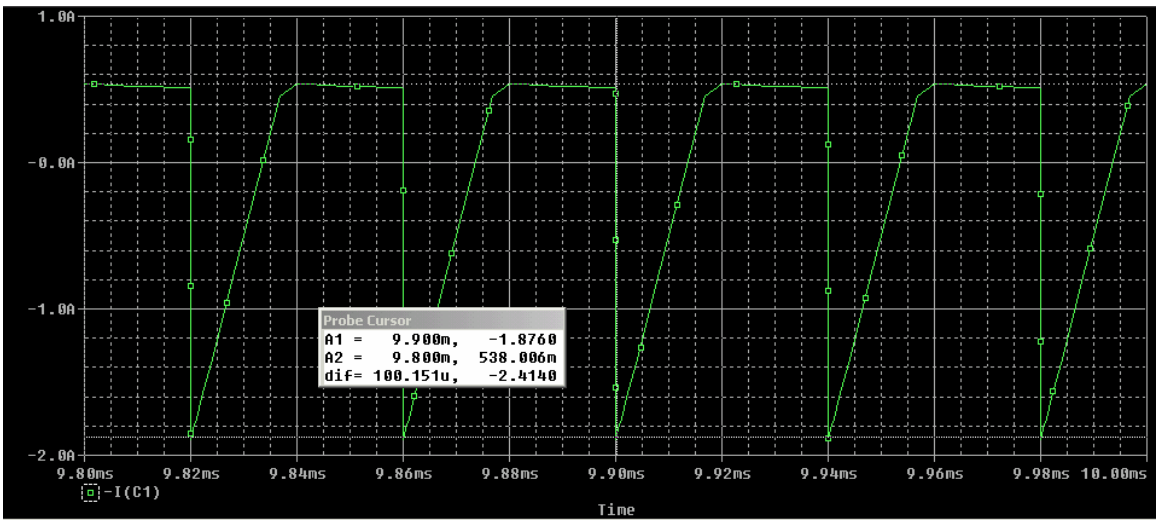


From the picture above we see that the output voltage ripple has increased to 2 volts peak to peak by reducing the output capacitance to 6μF.

Now, change the capacitor back to 50u, place a current marker on one of the pins of the capacitor, and remove the voltage marker. Hint: Change your “Run to Time” to 10msec and your “Start saving data” value to 9.8msec.

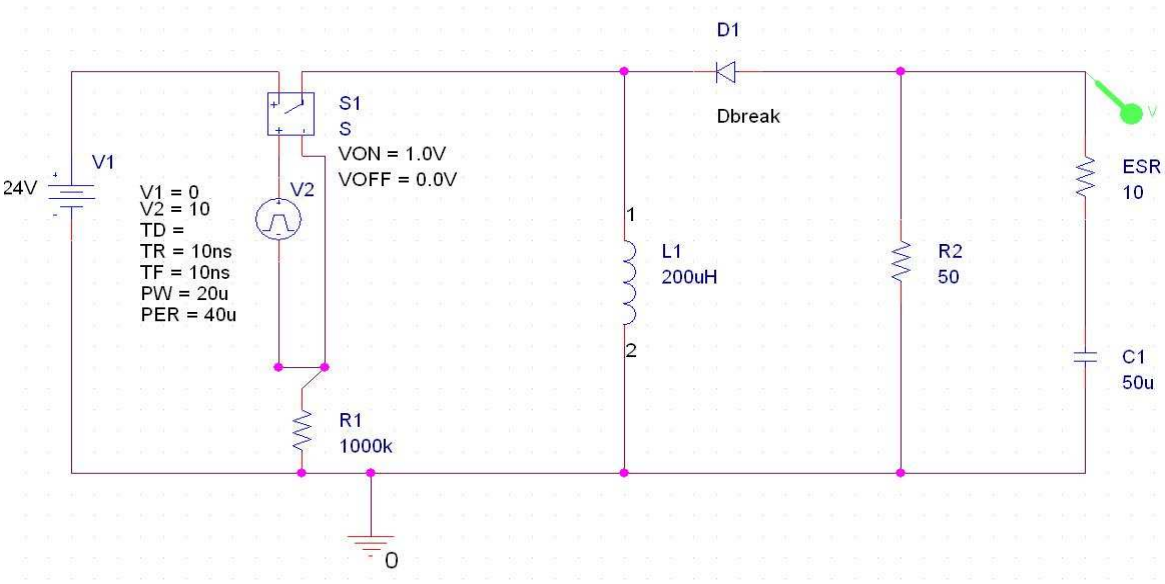


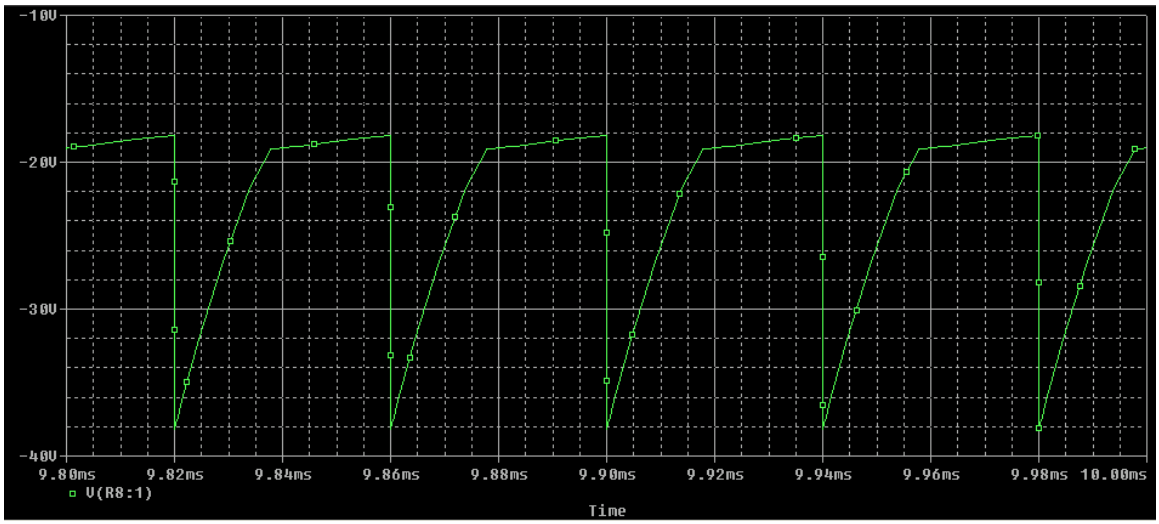
QUESTION 10: What can be said about the current through the capacitor?



From the picture above we can see that the capacitor is balancing the amp seconds, and that the peak current through the capacitor is about -1.9A.

QUESTION 11: If the ESR of the capacitor is modeled by a 10Ω resistor in series with the capacitor, what happens to the output voltage ripple and the capacitor current?





From the picture above we can see that the output voltage ripple has increased from approximately 2 volts peak to peak with no ESR, to approximately 20 volts peak to peak with 10 ohms of ESR!! However, the capacitor current has no noticeable change (slight decrease) – not shown here.

QUESTIONS 12-18:

What happens if the duty cycle of the converter is decreased from 20μsec on time to 5μsec on time in V2 set up?

Is the converter operating in the continuous conduction mode? What is the average output voltage now?

Did the output voltage ripple increase?

What observations can be made from increasing the on resistance of the switch?

What can be said about the efficiency of the converter? Comment on the different configurations of the circuit used throughout this lab.

What happens if the load resistance is removed? ? (Hint: Set a very high value for the load resistance, i.e. 10000Meg)

What can be observed by increasing the switching frequency to 100 KHz?

Hints: With everything else left as it is, change your "PW" and "PER" on PULSED voltage to 5u and 10u. Also change your "final time" in transient analysis to

$$\text{finaltime} := 25 \cdot \frac{1}{\text{Switchfrequency}}.$$

** **** Remember that your on resistance value of the switch (Question 15) will provide you a complete different output value from your classmates.