Switching Power Supplies

Acknowledgements: Developed by Lou Frenzel, Technology Editor for Electronic Design Magazine. Special thanks to Electronic Workbench for providing this simulation as a stand-alone activity.

Special Notes: This simulation should be completed after the section titled DC-DC Converters and before starting the DC-DC Converters Lab.

Approximate Time Required: 1 hour

Simulation Summary: The purpose of this interactive simulation is to prepare you for the DC-DC Converter hands-on laboratory. This circuit simulation lab illustrates the use of a charge pump circuit to produce a DC supply voltage of the opposite polarity from an existing DC supply and to illustrate how voltage multiplier sections can be used to increase the output voltage beyond the input DC supply voltage.

Simulation Goal: Observe the operation of the charge pump circuit and experiment with values of switching frequency, filter capacitor values, and load values to see the effect upon the DC output and ripple voltages. The simulation is also used to show the effect on the output voltage on adding extra diode-capacitor sections.

Learning Objectives

1. Describe the operation of a charge pump circuit.
2. Compare the output of the simulation circuit when the input parameters are changed.
3. Compare the output of the simulation circuit when the additional diode-capacitors are added to the circuit.

Grading Criteria: Your lab grade is determined by your performance on the simulation and answers to the lab questions.

Simulation Preparation

1. Print this entire procedure to use as a reference, schematic, and workbook while completing the simulation.
2. Read the Introduction (below).
3. Review the Simulation Procedures (below).

Software Alert: When performing circuit simulations, failing to read and follow directions exactly can result in incorrect circuit operation and data measurements. For instance, if you fail to stop or pause the circuit at the appropriate times and leave circuits running, functions within Multisim 7 may become inoperative.

Introduction:

The simplest DC-DC converter is a charge pump. It uses a free-running multivibrator circuit as a source of high speed DC pulses. These pulses are manipulated by diode-capacitor charge sections to produce a value of DC output that can be used to power other circuits. A common application is to use the charge pump circuit to produce a voltage whose polarity is opposite that of the main DC power supply and at approximately the same value. It is also used to produce an output voltage that is higher than the voltage available from the main DC supply.

Many linear circuits especially those using op amps and some digital interface circuits require equal value voltages at opposite polarities and sometimes voltages higher than the supply voltage. A typical example is ±12 volt supplies derived from a 5 volt DC logic power supply. The DC-DC converter eliminates the need to provide additional expensive power supplies.

The experimental circuit uses the popular 555 timer IC. The external resistors and capacitors are used to set the frequency of oscillation. That frequency is:

$$f = 1/[0.69(R_1 + 2R_2)C_1]$$

In most cases, the frequency is over 5 kHz but less than 500 kHz. The higher the frequency, the lower the ripple voltage for a given filter capacitor value. The lower frequencies are often used because standard silicon rectifier diodes can be used. At frequencies over 100 kHz, these diodes do not work well because of the slow switching response and excessive capacitance. Schottky diodes are the preferred type of rectifier at the higher frequencies because of the fast response, low capacitance, and lower forward voltage drop.

The 555 timer produces output pulses at approximately 45% duty cycle at an amplitude slightly less than the DC supply voltage value which is usually in the 5 to 15 volt range. These pulses are then used by a voltage multiplier circuit to produce the opposite polarity voltage. Additional diode-capacitor sections can be added to boost the output voltage well beyond the DC supply value.

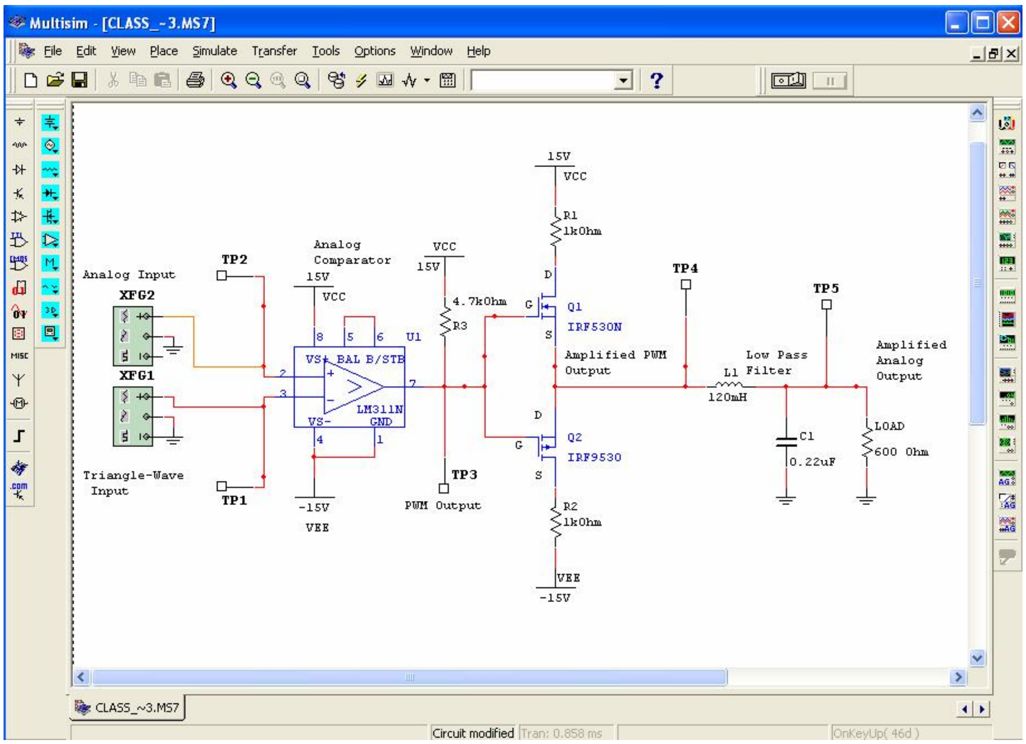
The charge pump circuit works well but because of the current drive capability of the 555 astable circuit and capacitive charge limitations, the useable output current is low, typically less than about 50 mA. Regulation is also relatively poor so only applications with constant loads and minimal current requirements are useful. The greater the number of diode-capacitor sections used the lower the current capability and the worse the regulation.

Simulation Procedures

NOTE: The schematics used in the simulation are at end of this document.

Using Multisim

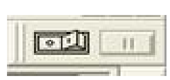
1. Download the Multisim demo from the WRE Module Learning Resource tab.
2. Open the file called **555charge**.



a. The simulation circuit is in the center of the screen.

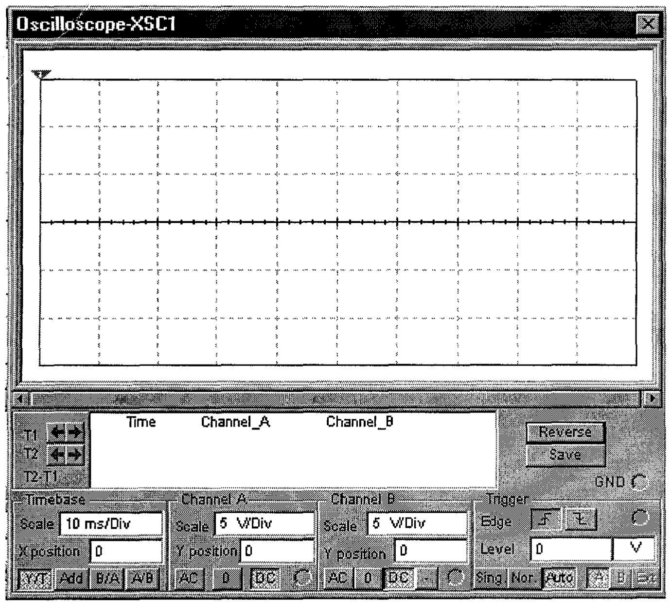
NOTE: The screen shown here is an example only. The schematics for this simulation are at the end of this procedure.

b. The Run/Stop and Pause/Resume simulation buttons are on the tool bar near the Help (?) button. Run/Stop is on the left and Pause/Resume is on the right.



c. The instrument toolbar is on the right border. As you move your mouse over the instrument, the name should appear. For this simulation, you will use the multimeter and the two channel oscilloscope. They have already been wired in to the circuit.

d. To use an instrument, place your mouse over the instrument and double click. This will open the view like the oscilloscope shown here.



e. The slide bar below the oscilloscope screen can be used to adjust the wave image in the screen when the simulation is paused.

f. To set or change values, positions, or other parameters, place your mouse over the entry you want to change. When the hand appears, click once and up/down arrows will appear to allow you to scroll through preset values. Be sure to note the measurement units.

g. To get the most accurate reading, adjust the scale so the wave is as large as it can be without clipping.

555 Charge Pump Circuit

Instructor's Note: Student answers may not match exactly but should be relatively close. Students are asked to provide their Timebase and Channel Scale for each reading.

3. Use the 555 Charge Pump Circuit diagram, calculate the switching frequency using the given values of R1, R2, and C1.

   f = _______________

4. Using your knowledge of the circuit from the module, estimate the amplitude and polarity of the output voltage.

   V_{out} = __________________

5. Start the simulation by clicking on the Run/Stop switch.

6. Double click on the multimeter (XMM1) symbol to see the DC output voltage. Record its value.

   V_{out} = ____________________

7. Double click on the oscilloscope symbol (XSC1) to observe the ac output ripple.

8. Stop the display by pressing the Pause/Resume button next to the Run/Stop button. Adjust the scale and position of the wave on the oscilloscope grid to see the ripple wave form. Determine the frequency and voltage value.

   f = ___________________

   V_{ripple} = _____________

   Timebase Scale = ________ Channel A Scale = __________

9. Explain any difference between your calculated and estimated values and actual simulation values.

10. Press Run/Stop to stop the simulation.
11. Double click on the symbol for C1. Change its value from 10 nF to 1 nF.
12. Calculate the frequency of operation.

    f = _______________

13. Start the simulation by clicking on the Run/Stop switch.
14. Double click on the multimeter (XMM1) symbol to see the DC output voltage. Record its value.

    V_{out} = ____________________

15. Double click on the oscilloscope symbol (XSC1) to observe the ac output ripple.
16. Stop the display by pressing the Pause/Resume button next to the Run/Stop button. Adjust the scale and position of the wave on the oscilloscope grid to see the ripple wave form. Determine the frequency and voltage value.

    f = ___________________

    V_{ripple} = _____________

    Timebase Scale = ________ Channel A Scale = __________

17. Press Run/Stop to stop the simulation.
18. Change the value of C1 back to 10 nF.
19. Change the value of the load resistance R3 from 1k to 10k ohms.
20. Restart the simulation and again measure the DC and ripple output voltages.

    V_{out} = ___________________

    V_{ripple} = _____________

    Timebase Scale = ________ Channel A Scale = __________

21. Stop the simulation.
22. Change the load value R3 to 100 ohms.

23. Restart the simulation and again measure the DC and ripple output voltages.

    V_{out} = ___________________

    V_{ripple} = _____________

    Timebase Scale = ________ Channel A Scale = __________

24. Stop the simulation.
25. Change the load value of R3 back to 1k ohm.
26. Change the values of filter capacitors C3 and C4 from 10 uF to 100 uF.
27. Restart the simulation and again measure the DC and ripple output voltages.

    V_{out} = ___________________

    V_{ripple} = _____________

    Timebase Scale = ________ Channel A Scale = __________

28. Stop the simulation.
29. Close out the file **555charge**. When it asks you to save your changes, say no.
30. Load the Multisim file **555Vmult**. This circuit is similar to the previous charge pump circuits but it has several additional diode-capacitor sections.
31. Start the simulation and measure the DC and ripple output voltages.

    V_{out} = ________________

    V_{ripple} = _________________

    Timebase Scale = ________ Channel A Scale = __________

32. Stop the simulation and close the file. Do <u>not</u> save any changes.
33. Answer the Post Simulation Questions.

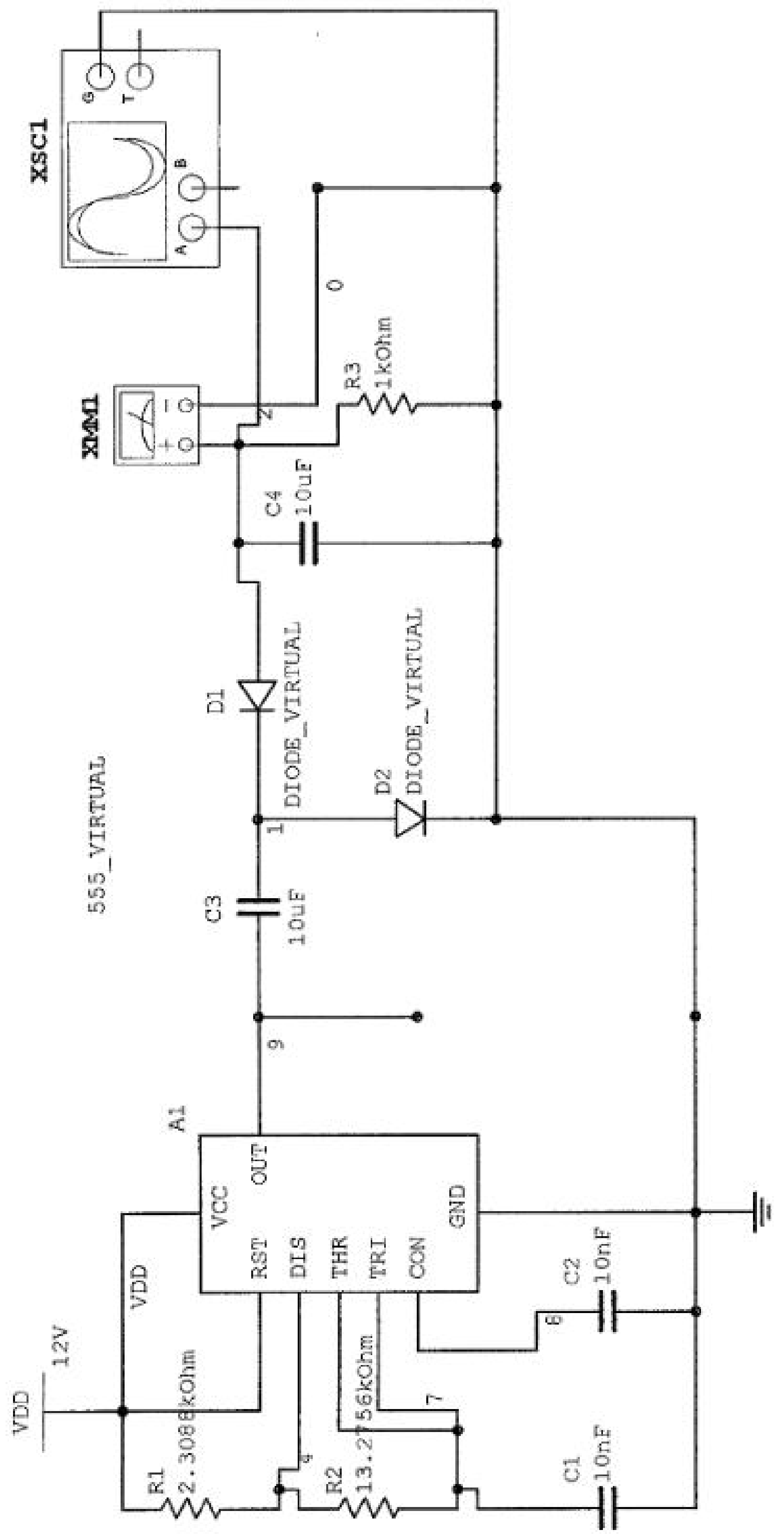
Post Simulation Questions: Record your measurements form the simulation into the table and answer the questions below.

555 Charge Pump							
Component Values				Measurements			
C_1	R_3	C_3	C_4		F	V_{out}	V_{ripple}
10 nF	1kΩ	10 µF	10 µF	Estimated			
10 nF	1kΩ	10 µF	10 µF	Actual			
1 nF	1kΩ	10 µF	10 µF	Actual			
10 nF	10kΩ	10 µF	10 µF	Actual			
10 nF	100Ω	10 µF	10 µF	Actual			
10 nF	1kΩ	100 µF	100 µF	Actual			
555 Multiplier							
V_{out}							
V_{ripple}							

1. Increasing the frequency of operation causes the output DC voltage to
   a. Increase significantly
   b. Decrease significantly
   c. Stay about the same
   d. Drop to zero

2. Increasing the frequency of operation causes the AC output ripple voltage to
   a. Increase
   b. Decrease
   c. Stay about the same
   d. Drop to zero
3. Increasing the value of filter capacitor causes the ripple voltage to:
   a. Increase
   b. Decrease
   c. Stay about the same
   d. Drop to zero
4. Decreasing the load resistance value causes the DC output to
   a. Increase
   b. Decrease
   c. Stay about the same
   d. Drop to zero
5. Decreasing the load resistance value causes the AC ripple to
   a. Increase
   b. Decrease
   c. Stay about the same
   d. Drop to zero
6. Based upon your experience with the first charge pump circuit, name two ways that the DC output voltage can be increased and the ripple reduced.

555 Charge Pump Schematic



555 Multiplier Schematic