Design of Buck-Boost Converter Using Multisim Software

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Abstract

The demand for switching power supply devices is rapidly increasing in this scientific era. The design engineers never get the particular supply voltage which they wish to use in their work. So, to regulate the desired voltage supply we need a converter or inverter. In case we consider a DC-DC Converter, we can step up the voltage level using a boost converter or step down the voltage level using a buck converter. Here, in this paper we have discussed about the design of buck-boost converter using multisim software, where after necessary simulations we convert a supply voltage of 21V to 12V and this output voltage can be used in the applications which require 12V supply voltage.

1. Introduction

To work in today's technical environment we have to deal with a rapidly changing market of electronic products and components. As new technology develops, integrated circuits function works faster and are smaller in size. Still today many integrated circuits still require a voltage of 12 Volts or 24 Volts in order to function. The DC-DC converters are widely used in regulated switch-mode dc power supplies and in dc motor drives applications. Often the input of these converters is an unregulated dc voltage, which is obtained by rectifying the line voltage, and therefore it will fluctuate due to changes in the line voltage magnitude. Switch-mode DC-DC converters are used to convert the unregulated dc input into a controlled dc output at a desired voltage level.

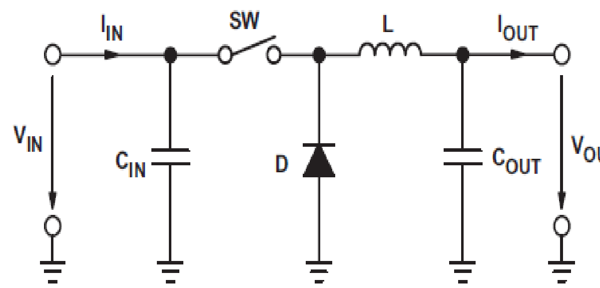
Here, our aim is to get a 12 to 13 V output from a 21 V input voltage supply. So, for this voltage regulation we have designed a Buck-boost converter. It will buck (step down) the supply voltage first and then it will boost (step up) the output of buck converter so as to get the desired 12 to 13 V.

In this paper we have the introduction in Section 1, the basic configuration of buck converter and the basic configuration of boost converter in Section 2, the basic calculations on which the design is done in Section 3,the simulation of buck converter, boost converter and the buck-boost converter in Section 4 and conclusion at the end.

2. Basic Configurations

Basic Configuration of Buck Converter

Following figure shows the basic configuration of a buck converter where switch is integrated in the selected integrated circuit (IC). Certain converters have diode replaced by a second switch that is integrated into the converter .



To calculate the power stage of a converter, following four parameters are always considered. They are:

1.Input voltage range: VIN(min) and VIN(max)
2.Nominal output voltage, VOUT
3.Maximum output current, IOUT(max)
4.An integrated circuit used to build the buck converter

So, to get into the basic configuration, firstly we need to determine the duty cycle, D, for the minimum input voltage. The minimum input voltage is used as it leads to the maximum switch current.

$$\text{Maximum Duty Cycle: } D = \frac{V_{OUT} \times \eta}{V_{IN(max)}}$$

VIN(min) = minimum input voltage
VOUT = output voltage
η = efficiency of the converter(say 90%)

The efficiency is added to the duty cycle calculation, since the converter also has to deliver the energy dissipated. Thus, this calculation gives a more realistic duty cycle than just the formula without the efficiency factor.

The next step in determining the maximum switch current is to find the inductor ripple current.

$$\text{Inductor Ripple Current: } \Delta I_L = \frac{(V_{IN(max)} - V_{OUT}) \times D}{f_S \times L}$$

VIN(max) = maximum input voltage
VOUT= desired output voltage
D = duty cycle calculated
fs = minimum switching frequency of the converter
L = selected inductor value

Now, it has to be determined if the selected IC can deliver the maximum output current.

$$\text{Maximum output current of the selected IC: } I_{MAXOUT} = I_{LIM(min)} - \frac{\Delta I_L}{2}$$

$I_{LIM(min)}$ = the minimum current limit value of the integrated switch
ΔIL = inductor ripple current calculated

If the calculated value for the maximum output current of the selected IC, IMAXOUT, is below the system's maximum output current, the switching frequency has to be increased to reduce the ripple current. Again, a higher inductance reduces the ripple current and thus increases the maximum output current of the selected IC. If the calculated value is above the maximum output current of the application, the maximum switch current in the system is calculated:

$$\text{Application specific maximum switch current: } I_{SW(max)} = \frac{\Delta I_L}{2} + I_{OUT(max)}$$

ΔI_L = inductor ripple current calculated
$I_{OUT}(max)$ = maximum output current necessary in the application.
$I_{OUT(max)}$ is the peak current that the inductor, the integrated switch and the external diode have to withstand.
Again, the higher the inductor value, the higher is the maximum output current since the ripple current is reduced.
The inductor must always have a higher current rating than the maximum output current as current increases with the decreasing inductance.
For parts where no inductor range is given, the following equation is a good estimation for the choice of inductor:

$$L = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{\Delta I_L \times f_S \times V_{IN}}$$

V_{IN} = input voltage
V_{OUT} = desired output voltage
f_s = minimum switching frequency of the converter.
ΔI_L = estimated inductor ripple current
The inductor ripple current cannot be calculated from the previous equation as the inductor value is unknown. So, a good estimation for the inductor ripple current is 20% to 40% of the output current, i.e,

$$\Delta I_L = (0.2 \text{ to } 0.4) \times I_{OUT(max)}$$

ΔI_L = estimated inductor ripple current
$I_{OUT}(max)$ = maximum output current necessary in the application
Now coming to diode selection, we know to reduce losses, we use Schottky diodes. The forward current rating needed is equal to the maximum output current:

$$I_F = I_{OUT(max)} \times (1 - D)$$

I_F = average forward current of the rectifier diode
$I_{OUT}(max)$ = maximum output current necessary in the application.
Schottky diodes have a much higher peak current rating than average rating. Therefore the higher peak current is not a problem. The other parameter that has to be checked, is the power dissipation of the diode. It has to handle:

$$P_D = I_F \times V_F$$

I_F = average forward current of the rectifier diode
V_F = forward voltage of the rectifier diode
D = duty cycle calculated
Again, for selecting the capacitor, the minimum value for the input capacitor is taken because it is necessary to stabilize the input voltage due to the peak current requirement of a switching power supply. The best practice is to use low-equivalent series resistance (ESR) ceramic capacitors. Otherwise, the capacitor loses much of its capacitance due to dc bias or temperature. The value can be increased if the input voltage is noisy.
With external compensation, the following equation can be used to adjust the output capacitor value for a desired output voltage ripple:

$$C_{OUT(min)} = \frac{\Delta I_L}{8 \times f_S \times \Delta V_{OUT}}$$

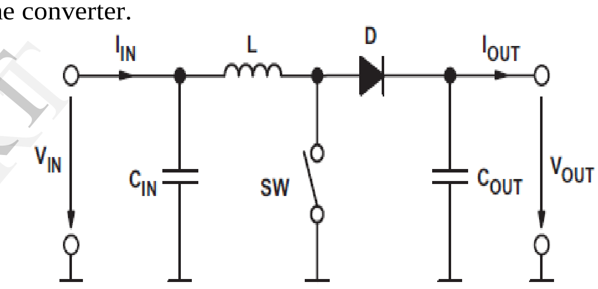
$C_{OUT}(min)$ = minimum output capacitance
ΔI_L = estimated inductor ripple current
f_s = minimum switching frequency of the converter
ΔV_{OUT}= desired output voltage ripple
The ESR of the output capacitor also adds some more ripple and the output voltage is given by:

$$\Delta V_{OUT(ESR)} = ESR \times \Delta I_L$$

$\Delta V_{OUT(ESR)}$ = additional output voltage ripple due to capacitors ESR
ESR = equivalent series resistance of the output capacitor
ΔI_L = inductor ripple current
The selection of the output capacitor is not driven by the steady-state ripple, but by the output transient response. The output voltage deviation is caused by the time it takes the inductor to catch up with the increased or reduced output current needs.

Basic Configuration of Boost Converter

The following figure shows the basic configuration of a boost converter where the switch is integrated in the integration circuit(IC).In case of lower power converters the diode is replaced by a second switch integrated into the converter.



The first step is to determine the duty cycle, D, for the minimum input voltage. The minimum input voltage is considered as this leads to the maximum switch current. So, duty cycle is :

$$D = 1 - \frac{V_{IN(min)} \times \eta}{V_{OUT}}$$

$V_{IN}(min)$ = minimum input voltage
V_{OUT} = desired output voltage
η = efficiency of the converter
Here, efficiency is added to the duty cycle calculation, as the converter has to deliver the energy dissipated.
The next step to get the maximum switch current is to determine the inductor ripple current.

$$\Delta I_L = \frac{V_{IN(min)} \times D}{f_S \times L}$$

$V_{IN}(min)$ = minimum input voltage
D = duty cycle calculated in previous equation
f_s = minimum switching frequency of the converter
L = selected inductor value
Now it has to be determined if the selected IC can deliver the maximum output current, i.e ,

$$I_{MAXOUT} = \left(I_{LIM(min)} - \frac{\Delta I_L}{2}\right) \times (1 - D)$$

$I_{LIM}(min)$ = minimum current limit value of the integrated switch.
ΔI_L = inductor ripple current.
D = duty cycle calculated in the previous equation.
A higher inductance reduces the ripple current and thus increases the maximum output current. If the calculated value is above the maximum output current of the application, then maximum switch current in the system is calculated:

$$I_{SW(max)} = \frac{\Delta I_L}{2} + \frac{I_{OUT(max)}}{1-D}$$

ΔI_L = inductor ripple current
$I_{OUT(max)}$ = maximum output current necessary in the application
A good estimation for the choice of inductor value is given as:

$$L = \frac{V_{IN} \times (V_{OUT} - V_{IN})}{\Delta I_L \times f_S \times V_{OUT}}$$

V_{IN} = input voltage
V_{OUT} = desired output voltage
f_s = minimum switching frequency of the converter
ΔI_L = estimated inductor ripple current
The inductor ripple current cannot be calculated with the previous equation the inductor value is unknown. A good estimation for the inductor ripple current is 20% to 40% of the output current, given by:

$$\Delta I_L = (0.2 \text{ to } 0.4) \times I_{OUT(max)} \times \frac{V_{OUT}}{V_{IN}}$$

ΔI_L = estimated inductor ripple current
$I_{OUT(max)}$ =maximum output current necessary in the application
Here also, the best practice is to use low ESR capacitors to minimize the ripple on the output voltage. With external compensation, to adjust the output capacitor values for a desired output voltage ripple:

$$C_{OUT(min)} = \frac{I_{OUT(max)} \times D}{f_S \times \Delta V_{OUT}}$$

$C_{OUT}(min)$ = minimum output capacitance
$I_{OUT}(max)$ = maximum output current of the application
D = duty cycle
f_s = minimum switching frequency of the converter
ΔV_{OUT} = desired output voltage ripple
The ESR of the output capacitor also adds some ripple, given by:

$$\Delta V_{OUT(ESR)} = ESR \times \left(\frac{I_{OUT(max)}}{1-D} + \frac{\Delta I_L}{2}\right)$$

$\Delta V_{OUT(ESR)}$ = additional output voltage ripple due to capacitors ESR
ESR = equivalent series resistance of the used output capacitor
$I_{OUT(max)}$ = maximum output current of the application
D = duty cycle
ΔI_L = inductor ripple current
Thus, the basic configuration of buck and boost converter cited above is used in the designing of buck-boost converter.

3. Basic Calculations

Based on the above formulae, the following calculations were done.

<u>BUCK CONVERTER :</u>

Assuming input voltage, V_{IN} = 21V, maximum output voltage, V_{OUT} = 12V and maximum current, Imax= 900mA, the following values are calculated using the above equations:
1. Duty Cycle, D = 0.63
2. Inductor ripple current, I_L =270 mA
3. Inductor value, L = 1.26 uF
4.Average forward current of the rectifier diode, I_F = 360mA
5.Maximum output capacitance, C_{OUT} = 0.02uF

<u>BOOST CONVERTER :</u>

Assuming the input voltage, V_{IN} =8V, output voltage, V_{OUT} = 12V, maximum output current, I_{MAX} = 900mA, the following values are calculated using the above equation:
1. Duty cycle, D = 0.59
2. Inductor ripple current, I_L =562.5 mA
3. Inductor value, L = 6.58 uH
4. Average forward current of rectifier diode, I_F = 90 mA
5. Output capacitance, C_{OUT} = 2.5uF

4. Simulation Output with its Scope

BUCK CONVERTER

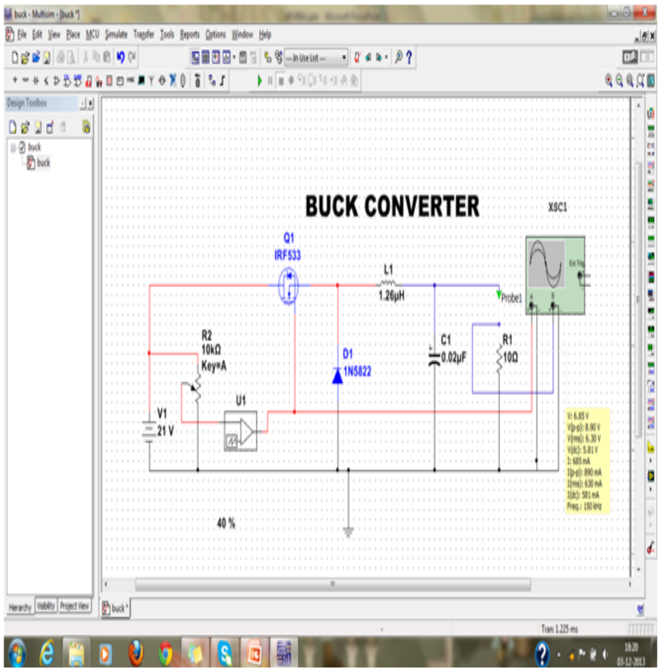


Figure 1: Design of Buck Converter

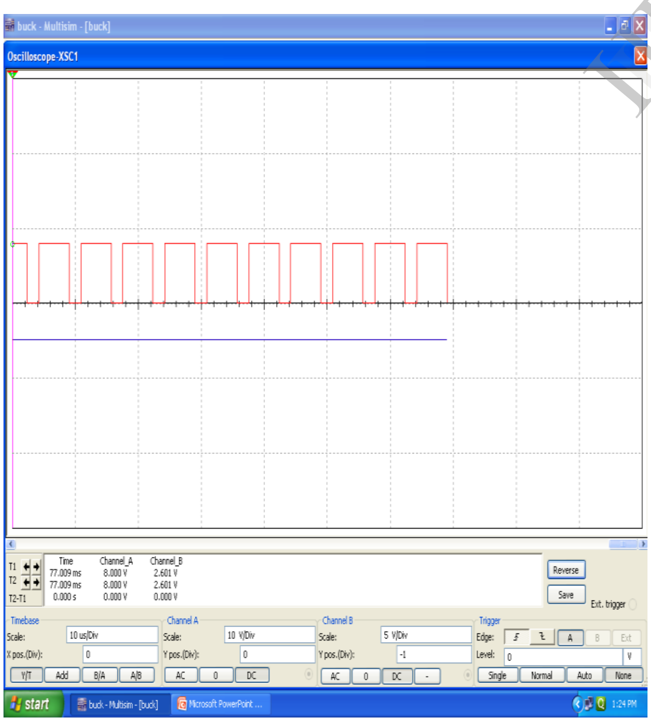


Figure 2: Output Scope of Buck Converter

BOOST CONVERTER

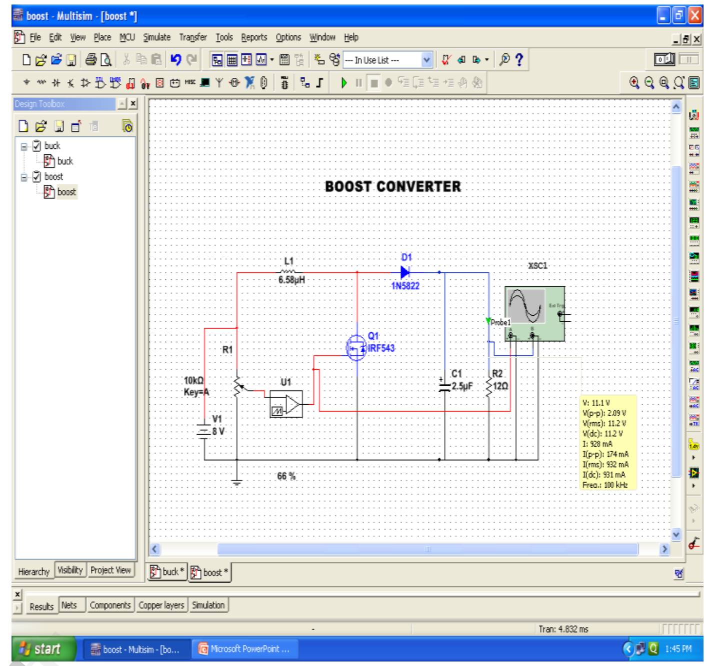


Figure 3: Design of Boost Converter

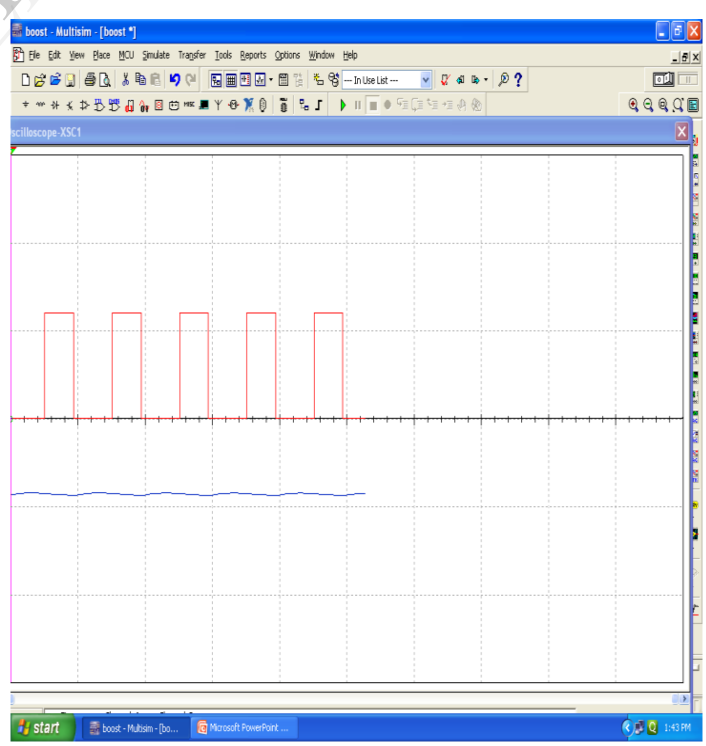


Figure 4: Output Scope of Boost Converter

BUCK-BOOST CONVERTER

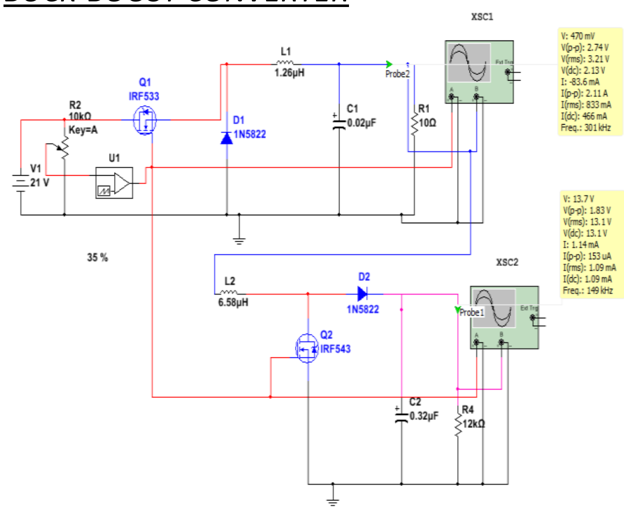


Figure 5: Design of Buck-Boost Converter

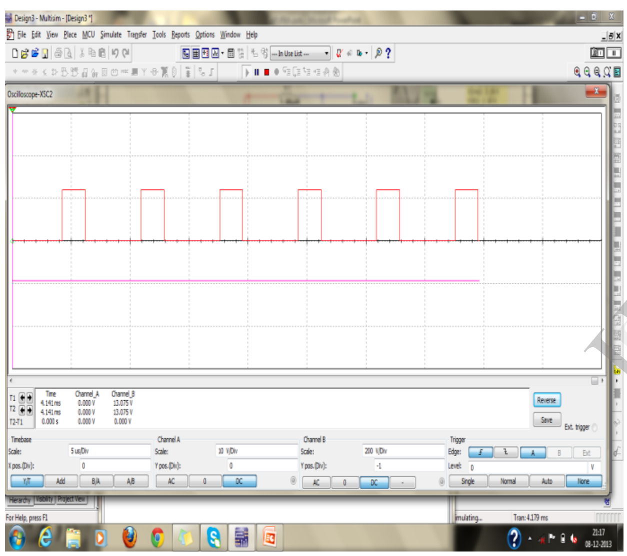


Figure 6: Output Scope of Buck-Boost Converter

5. Conclusion

Thus, the designing of buck-boost converter using multisim software is done and is verified. The input voltage supplied to the buck converter is 21V,then the obtained output of the buck converter is 3.21V(approx) is given as the input voltage to the boost converter and then the obtained output of the boost converter is 13V. So, combining the buck converter and boost converter we got the buck-boost converter output to be 13V,when 21V supply was given.

6. References

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