VACATION TASKS

SET-1

Step up and Step Down converters and substitutes

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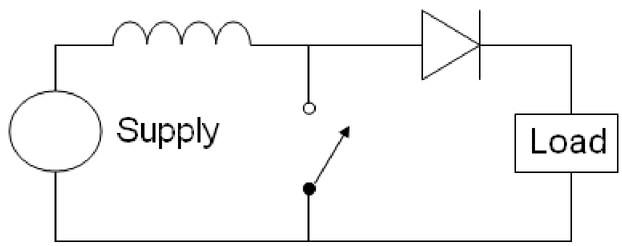
Step-up converter

A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element: a capacitor, inductor, or the two in combination.

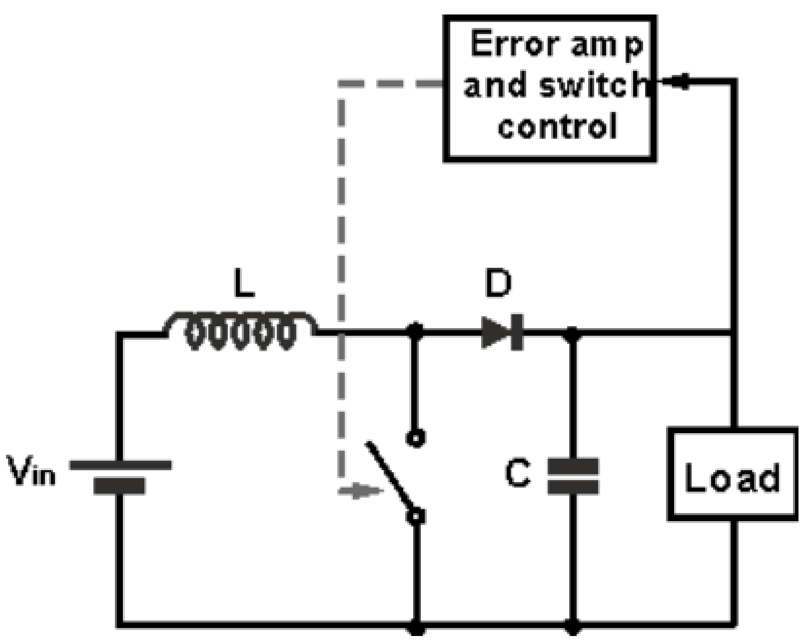
To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).



Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. Since power (P=VI) must be conserved, the output current is lower than the source current.

Step-up boost converter basics

The boost converter circuit has many similarities to the buck converter. However the circuit topology for the boost converter is slightly different. The fundamental circuit for a boost converter or step up converter consists of an inductor, diode, capacitor, switch and error amplifier with switch control circuitry.



The circuit for the step-up boost converter operates by varying the amount of time in which inductor receives energy from the source.

In the basic block diagram the operation of the boost converter can be seen that the output voltage appearing across the load is sensed by the sense / error amplifier and an error voltage is generated that controls the switch.

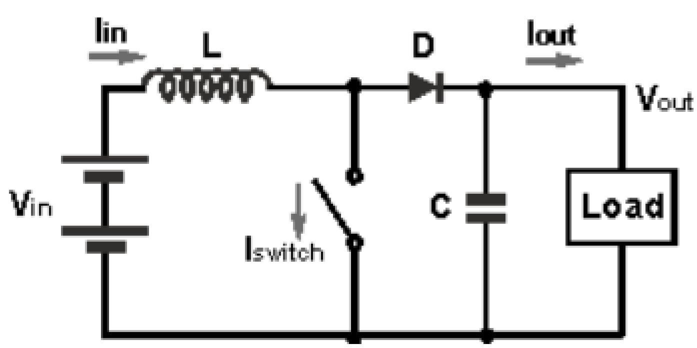
Typically the boost converter switch is controlled by a pulse width modulator, the switch remaining on of longer as more current is drawn by the load and the voltage tends to drop and often there is a fixed frequency oscillator to drive the switching.

Boost converter operation

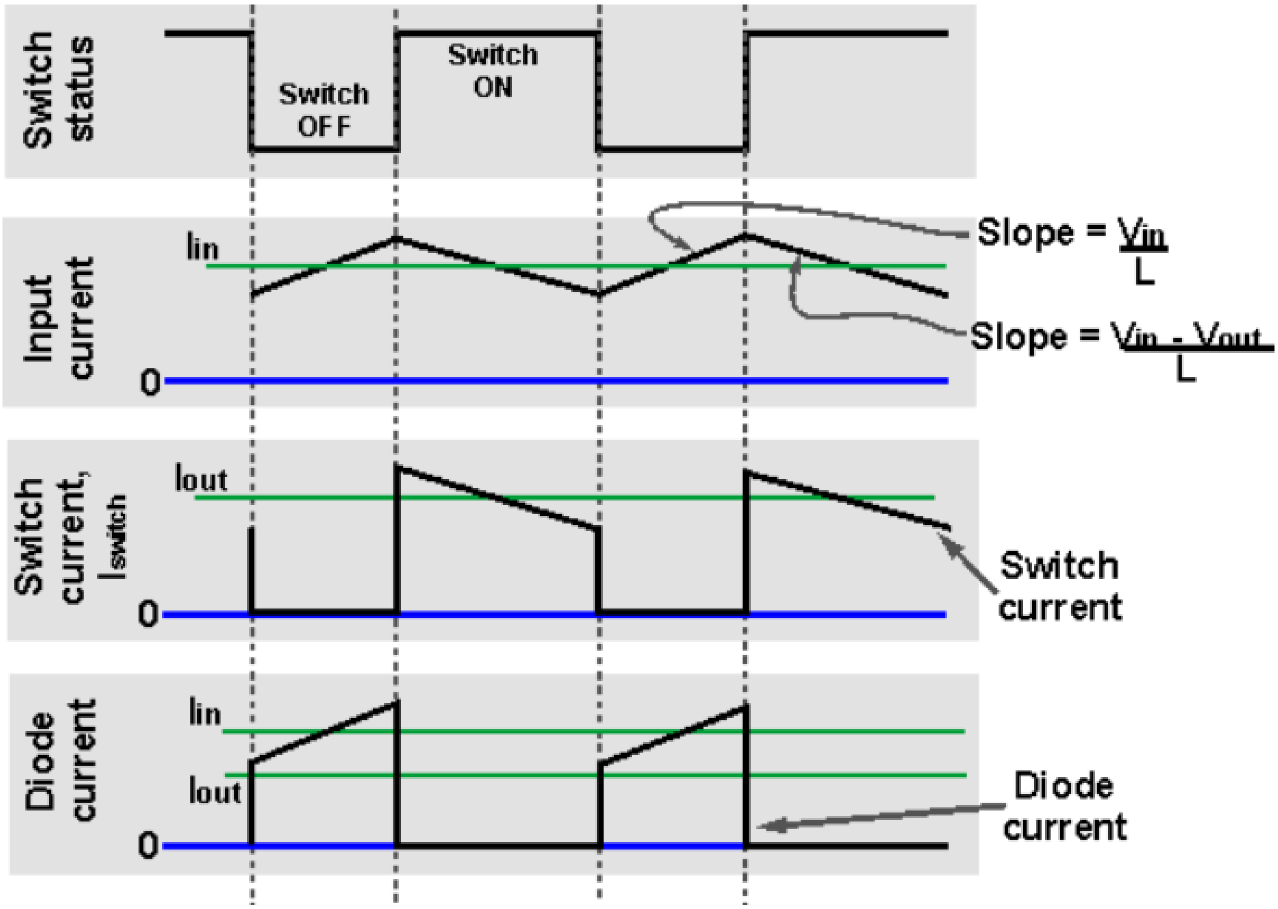
The operation of the boost converter is relatively straightforward.

When the switch is in the ON position, the inductor output is connected to ground and the voltage Vin is placed across it. The inductor current increases at a rate equal to Vin/L.

When the switch is placed in the OFF position, the voltage across the inductor changes and is equal to Vout-Vin. Current that was flowing in the inductor decays at a rate equal to (Vout-Vin)/L.



Referring to the boost converter circuit diagram, the current waveforms for the different areas of the circuit can be seen as below.



It can be seen from the waveform diagrams that the input current to the boost converter is higher than the output current. Assuming a perfectly efficient, i.e. lossless, boost converter, the power out must equal the power in, i.e. Vin · Iin = Vout · Iout. From this it can be seen if the output voltage is higher than the input voltage, then the input current must be higher than the output current.

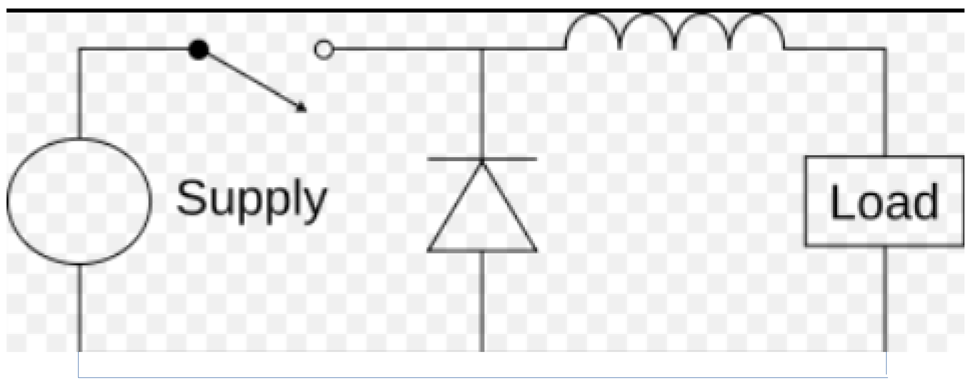
In reality no boost converter will be lossless, but efficiency levels of around 85% and more are achievable in most supplies.

Step-down converter

A buck converter (step-down converter) is a DC-to-DC power converter which steps down voltage (while stepping up current) from its input (supply) to its output (load).

It is a class of switched-mode power supply (SMPS) typically containing at least two semiconductors (a diode and a transistor, although modern buck converters frequently replace the diode with a second transistor used for synchronous rectification) and at least one energy storage element, a capacitor, inductor, or the two in combination.

To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).



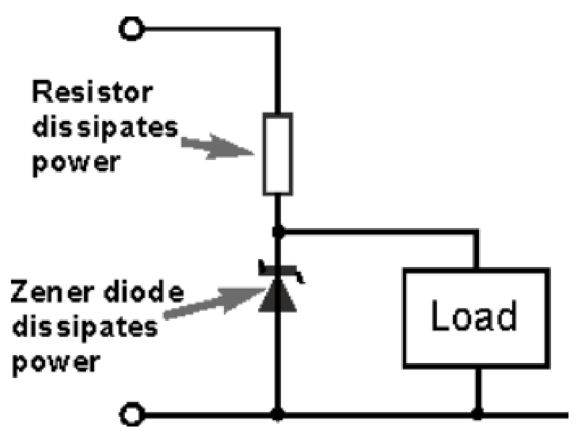
Buck converters can be highly efficient (often higher than 90%), making them useful for tasks such as converting a computer's main (bulk) supply voltage (often 12 V) down to lower voltages needed by USB, DRAM and the CPU (1.8 V or less).

Although a resistor would enable voltage to be dropped, power is lost, and in applications such as the many battery powered items used today, power consumption is a crucial element.

As a result step down switch mode converters or as they are more commonly termed, buck regulators are widely used.

Linear step down

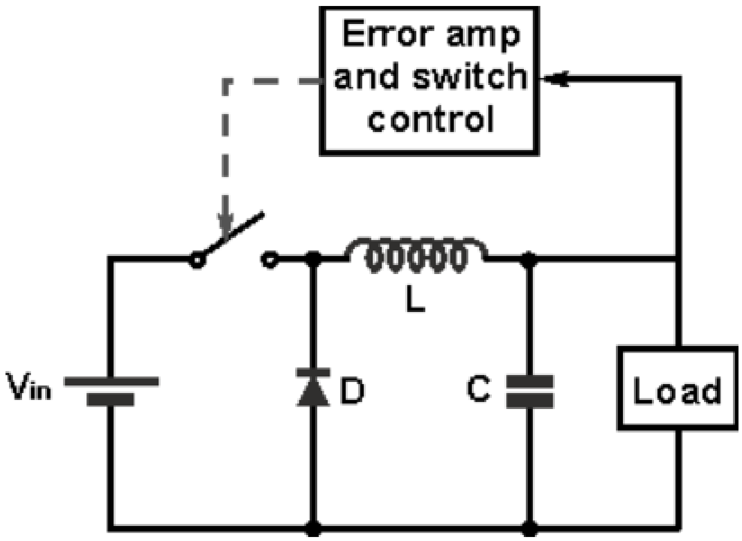
The most basic form of step down transition is to use a resistor as a potential divider or voltage dropper. In some cases a zener diode may also be used to stabilize the voltage.



The issue with this form of voltage dropper or step down converter is that it is very wasteful in terms of power. Any voltage dropped across the resistor will be dissipated as heat, and any current flowing through the zener diode will also dissipate heat. Both of these elements result on the loss of valuable energy.

Basic buck converter or regulator

The fundamental circuit for a step down converter or buck converter consists of an inductor, diode, capacitor, switch and error amplifier with switch control circuitry.



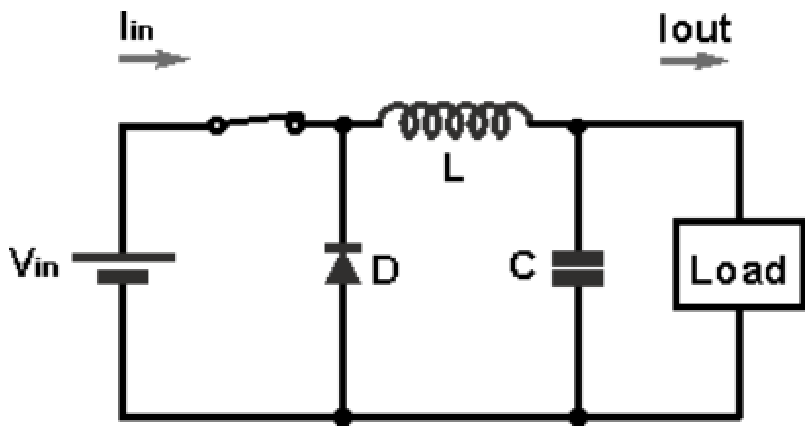
The circuit for the buck regulator operates by varying the amount of time in which inductor receives energy from the source.

In the basic block diagram the operation of the buck converter or buck regulator can be seen that the output voltage appearing across the load is sensed by the sense / error amplifier and an error voltage is generated that controls the switch.

Typically the switch is controlled by a pulse width modulator, the switch remaining on of longer as more current is drawn by the load and the voltage tends to drop and often there is a fixed frequency oscillator to drive the switching.

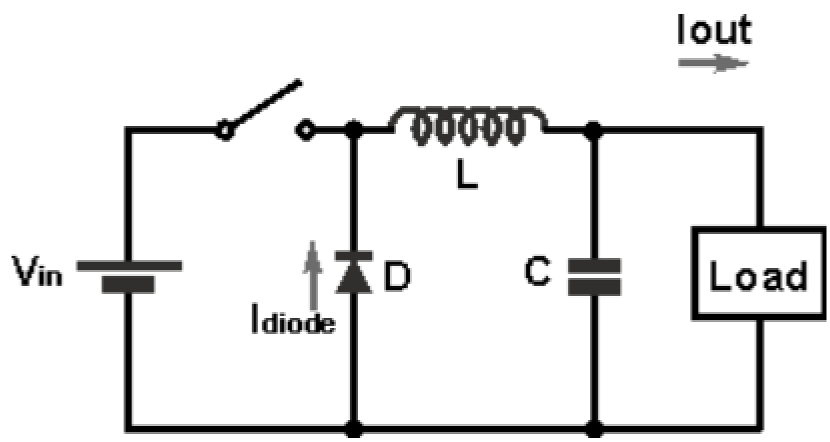
Buck converter operation

When the switch in the buck regulator is on, the voltage that appears across the inductor is Vin - Vout. Using the inductor equations, the current in the inductor will rise at a rate of (Vin-Vout)/L. At this time the diode D is reverse biased and does not conduct.

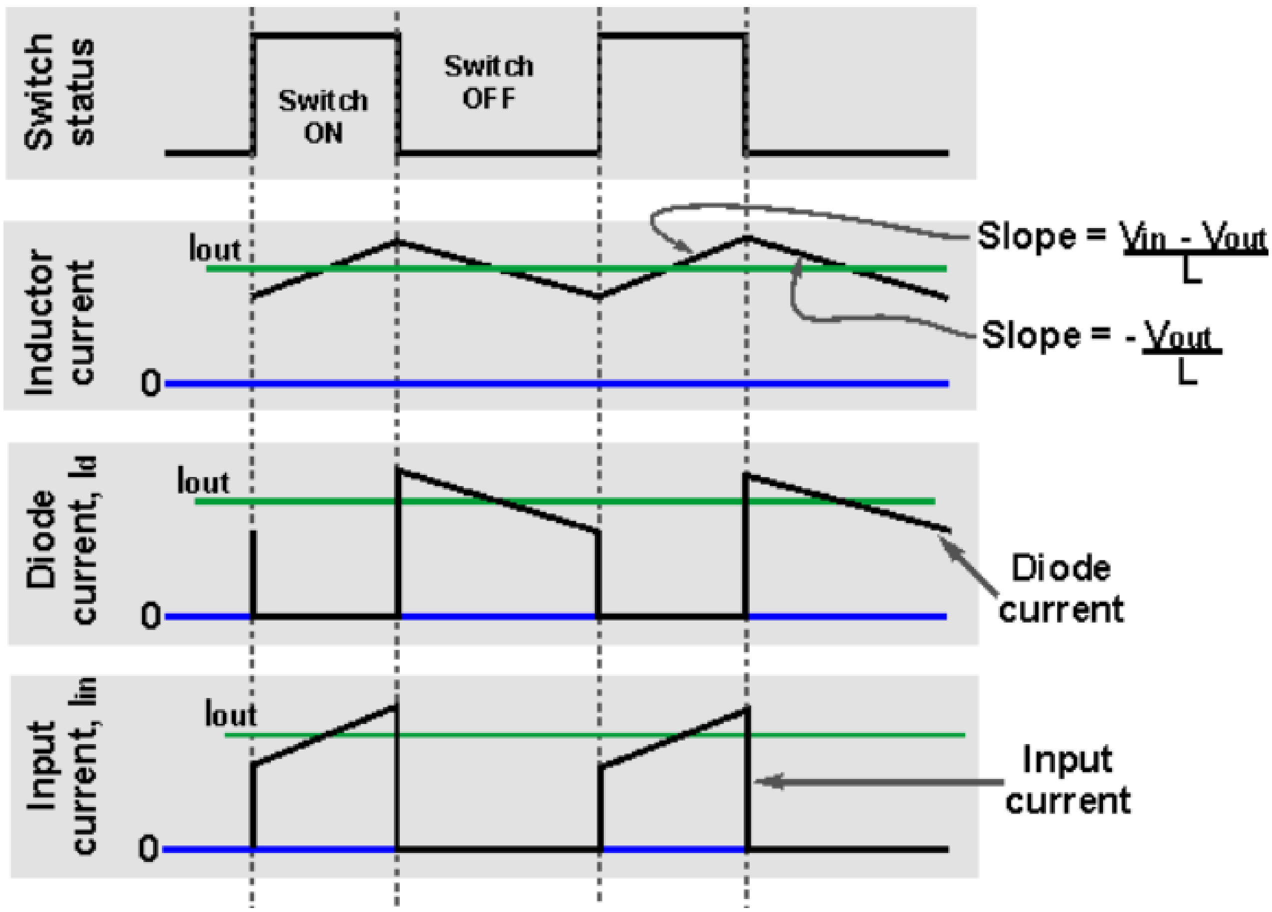


When the switch opens, current must still flow as the inductor works to keep the same current flowing. As a result current still flows through the inductor and into the load. The diode, D then forms the return path with a current Idiode equal to Iout flowing through it.

With the switch open, the polarity of the voltage across the inductor has reversed and therefore the current through the inductor decreases with a slope equal to -Vout/L.



The step down, buck converter circuit can be further explained by examining the current waveforms at different times during the overall cycle.



In the diagram of the current waveforms for the buck converter / switching regulator, it can be seen that the inductor current is the sum of the diode and input / switch current. Current either flows through the switch or the diode.

It is also worth noting that the average input current is less than the average output current. This is to be expected because the buck converter circuit is very efficient and the input voltage is greater than the output voltage. Assuming a perfect circuit, then power in would equal power out, i.e. Vin · In = Vout · Iout. While in a real circuit there will be some losses, efficiency levels greater than 85% are to be expected for a well-designed circuit.

It will also be seen that there is a smoothing capacitor placed on the output. This serves to ensure that the voltage does not vary appreciable, especially during and switch transition times. It will also be required to smooth any switching spikes that occur.

Regulator input and output filtering

A key aspect of switch mode power supply regulators is the input and output filtering. This is a particular issue because of the switching that occurs at the input.

In reality ripple voltage on the output is dependent not only on the output smoothing, but more importantly on an input filter capacitor.

Substitutes

There are alternative power conversion topologies that can be used instead of the boost converter to produce an output voltage that is higher than the input voltage. Some of the most common are the flyback, SEPIC, and buck boost converters.

These converters are not vulnerable to short circuit load conditions as the boost converters. These converters are step-up/step-down converters, meaning that they can produce an output voltage higher or lower than the input voltage.

Many DC-DC converter controller chips that drive these topologies feature current mode control, which features an additional level of short-circuit protection. These topologies don't inherently protect against circuit circuit loads on their own, but they can shut down in a way that stops the flow of current if a short-circuit load is detected.

Some dc-dc converter controller chips may include short-circuit protection, while others might require extra components to make this happen. All of these topologies are less vulnerable than the boost converter.

Buck-Boost Converter

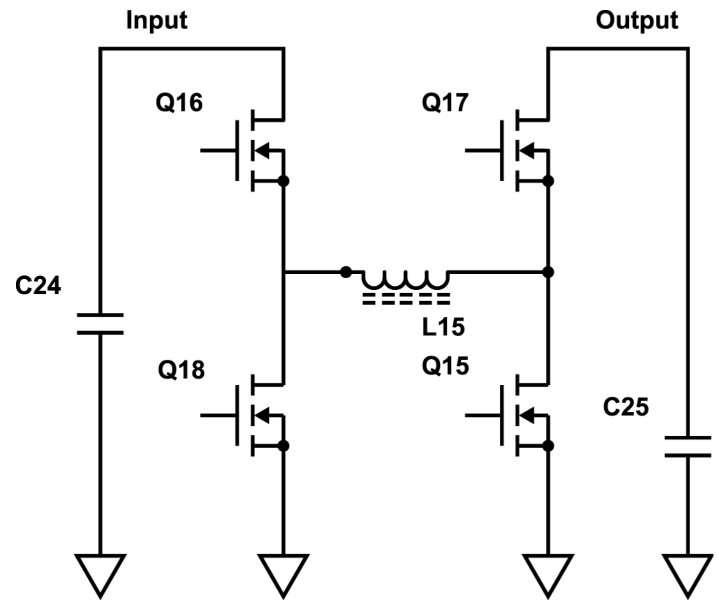
A simple buck converter can only produce voltages lower than the input voltage, and a boost converter, only voltages higher than the input. To provide voltages over the complete range a circuit known as a buck-boost converter is required.

There are many applications where voltages higher and lower than the input are required. In these situations a buck-boost converter is required.

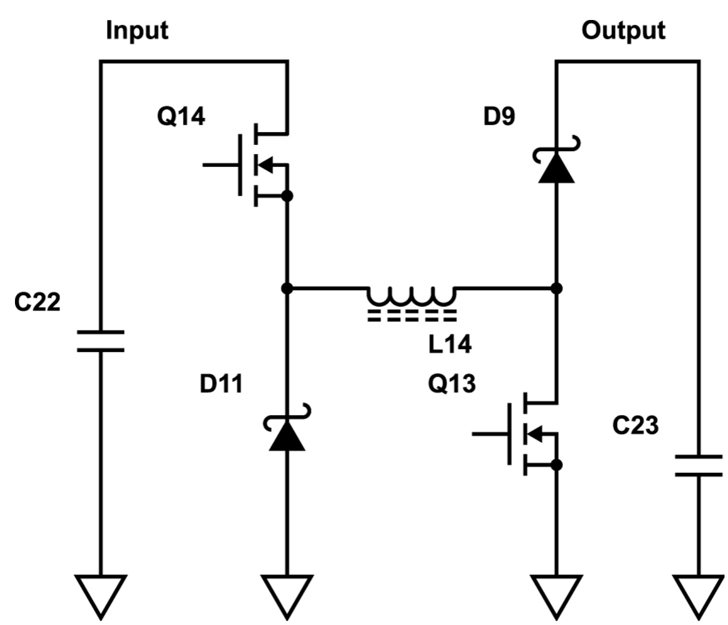
The MOSFETs can be turned off if a short circuit load is detected. Many buck-boost converters feature current mode control, which limits the inductor current, providing additional short circuit protection.

This circuit uses four switches. It uses two MOSFETs and two diodes, or comes in a high efficiency version that uses four MOSFETs.

This converter costs more than other converters because it requires specialized converter controllers that are less common than buck, boost, flyback, or SEPIC converters. The four switches also add cost.



Synchronous buck boost



Non-Synchronous buck
boost

Some advantages of the buck-boost topology include:

- Short Circuit Protection
- Step-up/step down,
- No coupled inductor.
- Some converters switch between buck and boost mode to improve efficiency.
- Work over a wide range of inputs.
- Can be implemented as a synchronous converter to improve efficiency.

Some disadvantages of the buck-boost topology include:

- Requires 4 switches.
- Controller ICs are less common than flyback, boost, SEPIC controllers and cost more.
- Each switch is a lossy element, which reduces efficiency.

A good example of a non-synchronous buck-boost controller is Texas Instrument's LM5118. It features current mode control, which limits the cycle-by-cycle inductor current. This adds an extra level of short circuit protection. A good example of a synchronous buck-boost controller is Linear Technology's LT8490 controller.

Flyback Converter

The flyback converter is a step-up/step-down DC-DC converter. The ratio between input and output voltage is $Vout/Vin = N * D/(1-D)$.

Figure below is a simplified schematic of the flyback converter. Notice that if a short circuit is detected, the MOSFET in the schematic may be turned off to protect the converter. Some flyback controller ICs feature current-mode control, which limits the inductor current.

This provides additional short circuit protection. A boost converter can be changed into a flyback by replacing the inductor with a coupled inductor.

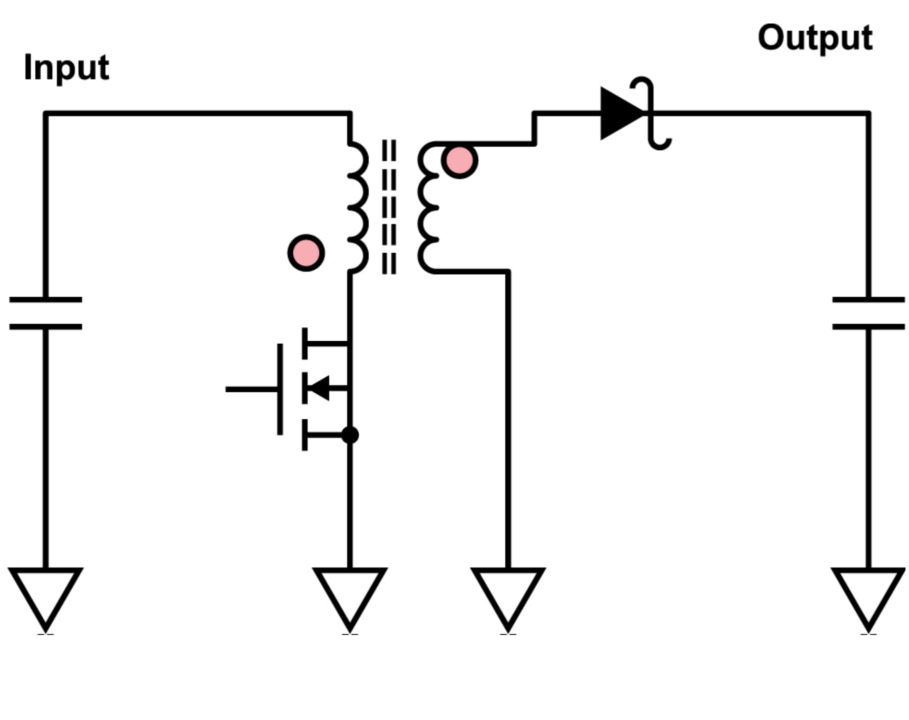
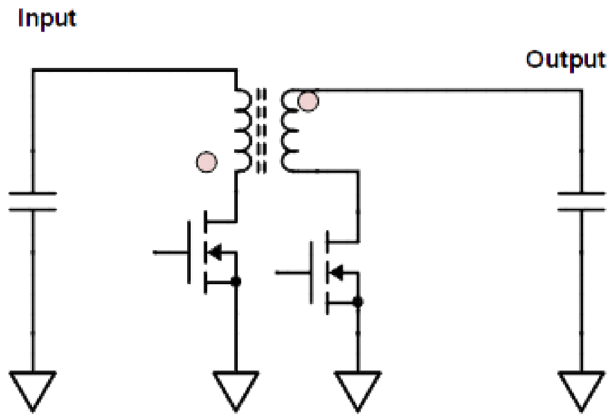


Figure below is a simplified schematic if a synchronous flyback converter. In a synchronous converter, the diode is replaced by a MOSFET to enhance efficiency.



Synchronous flyback converter

Some advantages of the flyback topology include:

- Short circuit protection.
- Needs only one MOSFET and one diode.
- Better wide range regulation than a boost converter
- Can be isolated.
- Can be a cheap solution

Some disadvantages of the flyback topology include:

- Needs a coupled inductor.
- MOSFET sees higher voltage spikes because of transformer
- May need a snubber circuit to dissipate the voltage spikes.

Examples of a synchronous flyback controller is Microchip's MCP19115. The MCP19915 is a flyback and boost controller that integrates a microcontroller. It can do synchronous or non-synchronous converters.

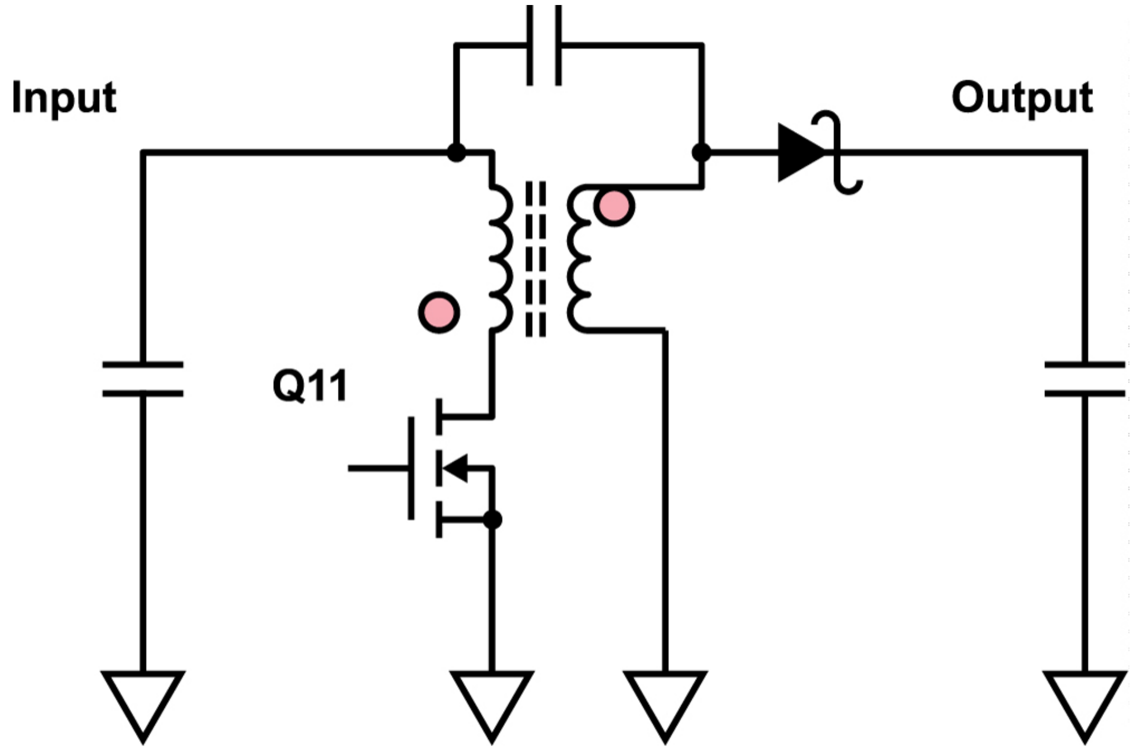
An example of a non-synchronous flyback controller is Linear Technology's LT3748.

SEPIC Converter

The SEPIC converter is a flyback with a DC blocking capacitor placed between the windings. The ratio between input and output voltage is Vout/Vin = D/(1-D).

Figure below is a simplified schematic of the flyback converter. This schematic shows a SEPIC built using a coupled inductor, to reduce board space.

If a short circuit is detected, the MOSFET in the schematic may be turned off to protect the converter. The DC blocking capacitor also adds short circuit protection.
Some SEPIC controller ICs feature current-mode control, which limits the inductor current. This provides additional short circuit protection. A boost converter can be changed into a SEPIC converter by adding a DC blocking capacitor, and using a coupled inductor or 2 separate inductors.



Some advantages of the SEPIC tology are:

- Step-up/step down converter.
- Needs only one MOSFET and one diode.
- Short circuit Protection.

Disadvantages:

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- Needs a second inductor or a coupled inductor.
- More complicated circuit to stabilize.
- DC Blocking Cap needs to be rated to carry all load current.

A good example of a switching controller than be used to build a SEPIC converter is Microchip's MCP1630, although any boost controller chip can drive a SEPIC controller.