SMPS CONVERTER CIRCUIT TOPOLOGIES—THE "BUCK" OR “FORWARD” CONVERTER

There are several circuit topologies that have evolved and are used in switch mode power supplies (SMPS). We shall classify them into the following groups, based on their operating principle:

1. the "buck" converter—also known as the forward converter;
2. the "boost" converter—also known as the "fly back" converter;
3. the "buck-boost" version of the "fly back" converter;
4. the Cuk converter.

1 “BUCK" CONVERTER CONFIGURATION AND WORKING PRINCIPLE

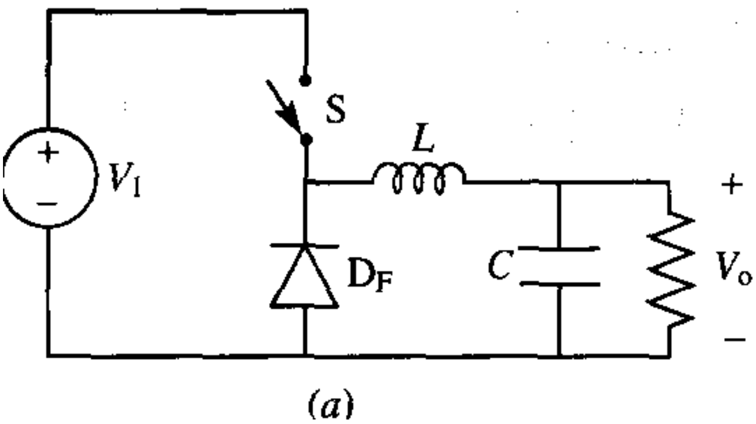


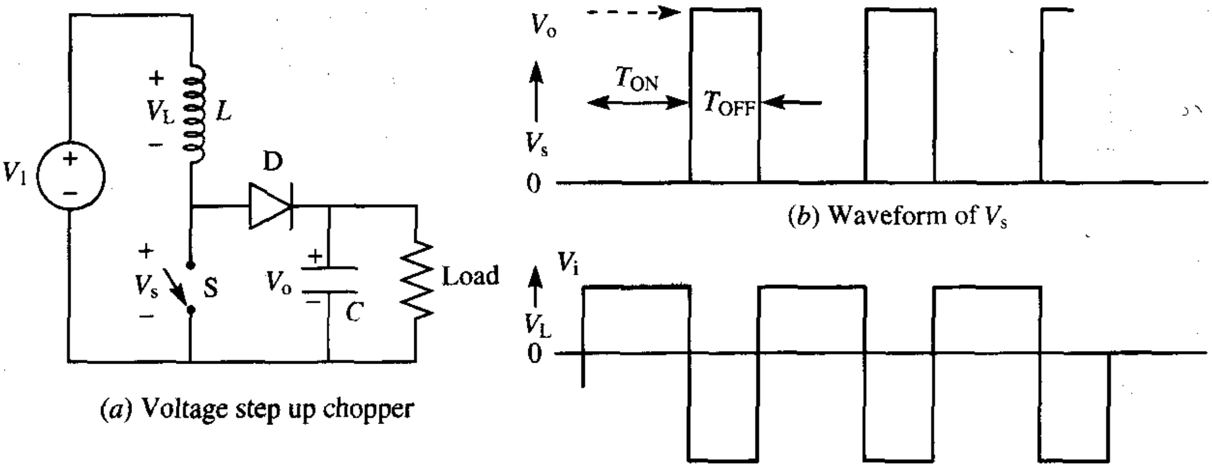
Figure 1. The “buck” converter topology (step down chopper)

If the controlled switch S is being repetitively operated with a duty cycle *D,* the output DC voltage under ideal assumptions is given by *Vo* = *D Vi.* D is the freewheeling diode. The inductance L and capacitor C contribute to the filtering. The output voltage is controlled by the duty cycle of the switch is defined as $D=t_{ON}/T$. The output voltage is always lower than the input voltage *Vi* — hence the name "***buck***" converter. The transition of energy from the input to the output occurs when the switch S is ON. If the ON switching is viewed as the "forward" operation of the switch the; energy transfer takes place during the forward operation—hence the name "***forward***" converter.

2 THE "BOOST" CONVERTER CONVERTERS — THE "FLYBACK" MODE

The "boost" converter and also the "buck-boost" converter topologies employ the so-called "flyback" mode of operation.

Figure 2(a) shows the conventional voltage step up chopper circuit. In this circuit, assuming continuous current flow in *Vi* and *L* and ideal elements, the waveform of the voltage labeled *Vs* across the switch is as shown in Fig. 2(b). The amplitude will be zero when the switch is ON and equal to *Vo* when it is OFF, because the diode D will be conducting when the switch is OFF.



(a) Voltage step up chopper

(b) Waveform of V_s

(c) Waveform of V_L

The input voltage *Vi* will be equal to the DC component of *Vs*, the AC component being absorbed across the inductance *L*. Therefore

$$Vi = Vo(T_{OFF}/T) = Vo(1-D) \quad \text{and} \quad Vo = Vi/(1-D)$$

and the output voltage Vo is always greater than the input voltage *Vi*, since *D* is always less than unity. Because of this voltage step up feature, we call this a ***boost*** converter.

Figure 2(c) shows the waveform of the voltage across the inductor L, which is labeled V_L. It is this inductor, which receives energy from the input source when the switch S is ON, and then, pumps energy into the output side, during the flyback of the switch. Energy flows from the input side to the output side when the switch is turned OFF, that is, when it is made to "flyback"—hence the name ***flyback*** converter.

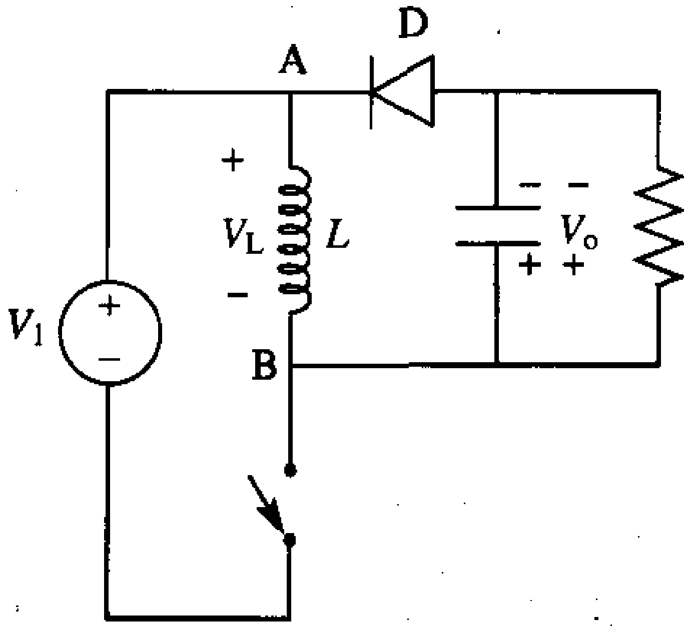
If the switch S is kept OFF all the time (duty cycle = 0) there will still be an output voltage, $Vo = Vi$

3. THE "BUCK-BOOST" (FLYBACK) CONVERTER

We shall now make a simple modification of the circuit. This consists in transferring the connections from the output side from across the switch to across the inductor *L,* as shown in Fig. 3. The voltage across AB, labeled V_L in the figure, during *TON*, is equal to Vi. During T_{OFF}, the voltage $V_L = -Vo$.

Equating the positive and the negative volt-seconds,

$$Vi \cdot T_{ON} = Vo \cdot T_{OFF}$$



This gives

$$Vo = Vi \cdot \frac{T_{ON}}{T_{OFF}} = Vi \cdot \frac{D}{1-D}$$

This shows that the output can be less or more than the input, depending on the duty cycle.

For $D < 0.5$, it is a **buck** converter.

For $D > 0.5$, it is a **boost** converter.

In both cases, it is a flyback converter, but there is no isolation between input and output.

4 THE "CUK" CONVERTER

In the forward (buck) converter, the energy transfer from the input to the output side occurs when the static switch is in the ON state.

In the flyback converter (buck-boost), this transfer takes place when the static switch is turned OFF. In both cases, the energy transfer is not continuous.

We overcome this limitation by providing adequate filtering. The filter consists of energy storage elements such as an inductor or capacitor or both, which serve as reservoirs of energy and ensure that the flow of energy into the load is continuous and ripple-free.

In contrast to the above, in the converter developed by Cuk, energy transfer from the input side to the output occurs both during the ON time and the OFF time of the static switch. Ideally, the Cuk converter can function with zero ripple.

Energy Transfer through an Intermediate Capacitor

In the circuit shown in Fig. 4, when the switch S is opened, the capacitor C1 is charged through the diode *D.* The capacitor receives the charge and energy from the source *Vi* and also from Li.

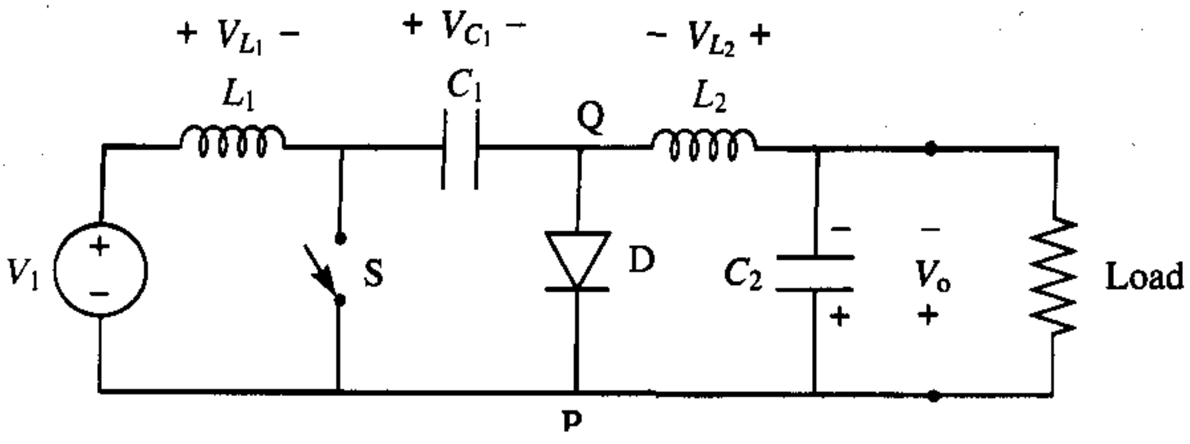


Figure 4. THE "CUK" CONVERTER

When S is closed, the diode is reverse-biased and the capacitor C1 is now connected directly across the output side of the converter, and energy is transferred from it to the output. L2 and C2 are the output filter inductance and filter capacitor respectively.

We shall assume that the switch is operating at a fixed frequency ***f*** and duty cycle *D*. We shall also assume that the capacitor C1 is very large, so that V_{C1}, can be assumed to be constant with negligible ripple.

When S is ON, the voltage across L1 is equal to Vi:

$$V_{L1} = Vi \text{ during } Ton$$

When S is OFF, the diode *D* will be conducting. We shall assume that the diode is ON for the entire OFF period of the switch. Therefore

$$V_{L1} = -(V_{C1} - Vi) \text{ during } T_{OFF}$$

For steady-state continuous operation, the waveform of V_{L1} cannot have a DC component. Therefore we equate the positive and negative volt-seconds areas under the waveform:

$$Vi\, Ton = -(V_{C1} - Vi)\, T_{OFF}$$

This gives

$$V_{C1} = \frac{Vi}{1-D}$$

Voltage across the diode. The voltage V_{PQ} across the diode will be equal to V_{C1} when the switch S is ON and zero when it is OFF. Therefore the DC component of this voltage will be given by

$$V_{PQ(DC\text{ component})} = D\, V_{C1}$$

The DC component of the voltage V_{PQ} will be the same as the output voltage *Vo* across the capacitor C2. We shall assume C2 to be large enough so that the ripple voltage is negligible. Therefore

$$Vo = D \cdot V_{C1} = \frac{D}{1-D} Vi$$

This result shows that the converter is a buck-boost converter:

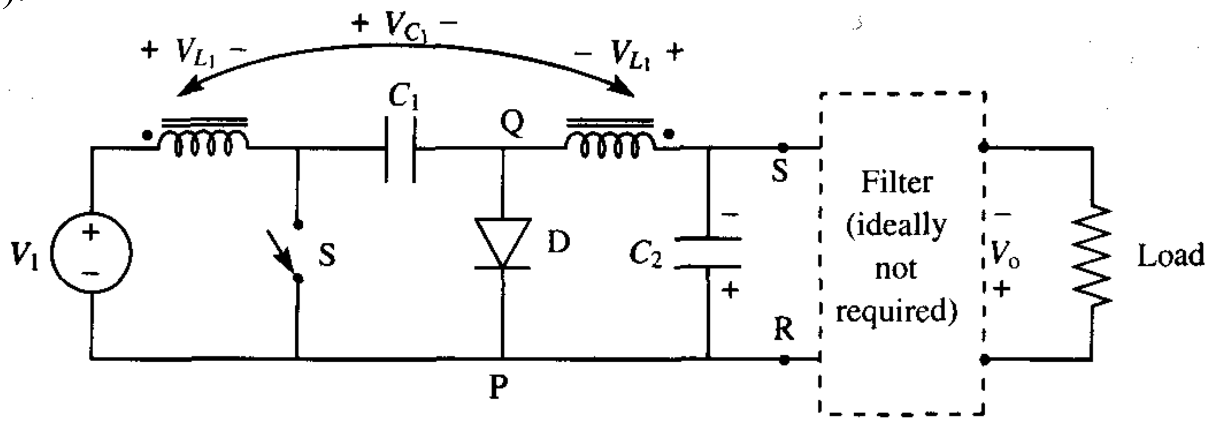
- ***buck*** for duty cycle values less than 0.5
- ***boost*** for duty cycle values greater than 0.5.

The purpose of the inductor *L2* is to absorb the AC components in the voltage across PQ. If *L2* is large enough, practically the entire ripple component will be absorbed across it. With a large values of *L2* and the filter capacitor *C2*, the output ripple voltage resulting from the flow of ripple current in the inductor will also be made small, so that the output voltage will be practically ripple-free.

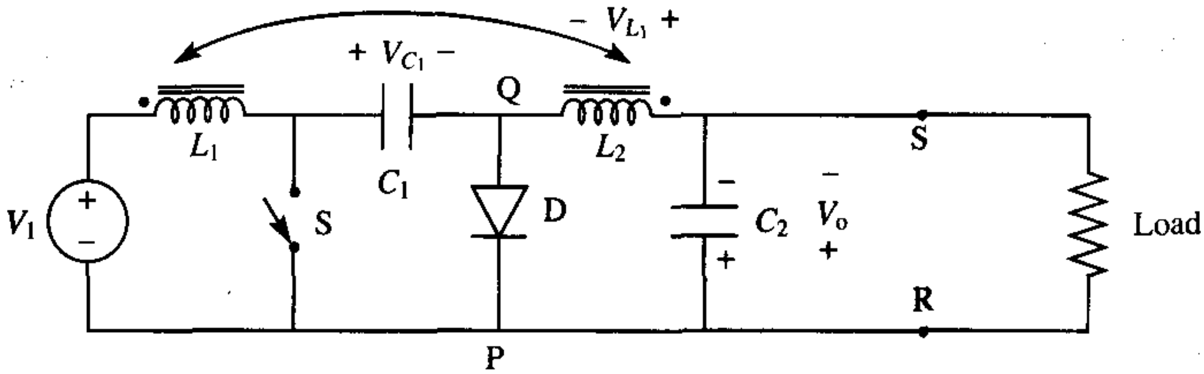
The Cuk topology in principle is designed to eliminate the need for the filter elements such as *L2* and *C2*. For this, we modify the circuit of Fig. 4 in such a way that an additional voltage is introduced in the output circuit, which exactly cancels the ripple voltage that would otherwise be present.

The ripple voltage absorbed across L2 has exactly the same waveform as the voltage across L1. Therefore, by winding a second coil with identical number of turns as Li on the same magnetic core, we can get a voltage that can balance the output ripple and provide a resultant output voltage that is ripple-free. This is illustrated by Fig. 5.

In Fig. 5(a) we have introduced on the output side an AC voltage source that is identical to V_{L1}, with the terminal polarity as marked. This AC voltage is obtained by having a second coil wound on the same magnetic core of *L1* and with the same number of turns as *L1*. The voltage induced in the second coil should be the same as V_{L1}. Therefore this filter in (a) is nonessential, and we have eliminated this block in Fig. 5(b).



(*a*)



(*b*)

Ideally, the voltage has zero ripple, and no filter is needed. In the nonideal real situation, a certain amount of filtering the capacitor C2 will be needed.)