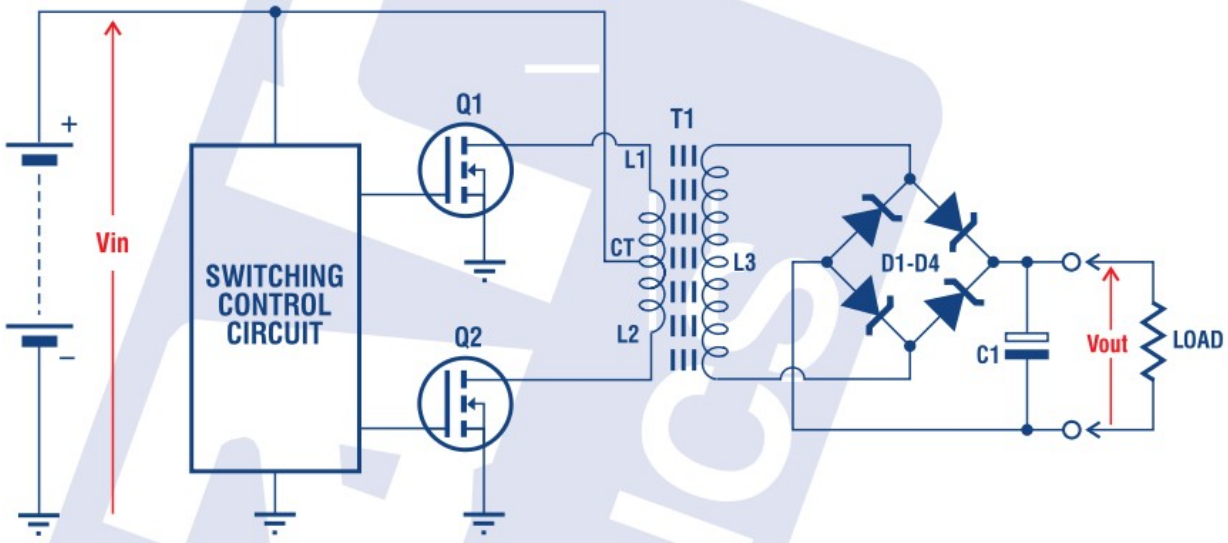


Fig.7: The basic circuit for a Forward converter, in its most popular push-pull form.

Forward converter

In contrast with the flyback converter, where there are two distinct phases for energy storage and delivery to the output, the **forward** converter uses the transformer in a more traditional manner, to transfer the energy directly between input and output in the one step.

The most common type of forward converter is the push-pull type, and the basic circuit for this type is shown in Fig.7. As you can see there are now two switching MOSFETs, Q1 and Q2, connected to either end of a centre-tapped primary winding on the transformer. The positive side of the input voltage source is connected to the centre tap.

In operation, the switching control circuit never turns Q1 and Q2 on at the same time; they're turned on alternately. And since their sources are connected back to the negative side of the input voltage, this means that the input voltage is first connected across one half of the primary winding, and then across the other. So current flows first in L1, and then in L2.

This cycle is repeated over and over, continuously and at a relatively high rate — often many tens or even hundreds of kilohertz. So in effect, the action of Q1 and Q2 is to convert the DC input voltage into a high frequency AC square wave.

As a result the transformer's secondary delivers the same

AC square wave, with a peak voltage (during each half-cycle) equal to:

Vac(pk) = Vin x (L3/L1)

Where L3 and L1 (=L2) are the number of turns on each winding, not the inductance. So if secondary winding L3 has 10 times the number of turns as each side of the primary, the transformer's peak output voltage will be 10 times the input voltage.

As you can see, diodes D1-D4 are connected directly across the secondary winding as a bridge rectifier. So the AC square wave that appears across L3 will be rectified back into high voltage DC, to feed the load and maintain the charge on filter capacitor C1. And if we ignore the diode voltage drops, the DC output voltage Vout will be equal to the peak AC output from the transformer — or in other words,

Vout = Vin x (L3/L1)

If you like, then, the forward converter is basically just a way of being able to use a transformer for DC, by converting the DC energy into AC so the transformer can handle it. After being transformed the AC is then rectified back into DC.

Needless to say, once we have the energy in the form of AC we can use the transformer to do pretty well anything we want — step it up, step it down, or any combination of the two. This becomes simply a matter of manipulating the turns on the secondary winding, adding other secondary windings if we want to have multiple outputs, and so on.

Because the forward converter reverses the polarity of magnetic flux in the transformer core for each alternate half-cycle, there's much less tendency to cause saturation than in the flyback converter. So the transformer can be significantly smaller, for the same power level. This together with the 'tighter' and more predictable relationship between input and output voltage makes the forward converter much more suitable for **high power** applications.

One important application for forward converters is in car hifi amplifiers, where they're used to step up the relatively low battery voltage to higher voltage supply rails, to allow the amplifiers to develop higher power output.

Another common use for the forward DC-DC converter is as the heart of many modern multi-voltage 'switch mode' power supplies, as found in computers, TV sets and many other types of electronic equipment. In these cases the incoming AC mains voltage is generally rectified straight away to produce 340V DC (in the case of 240V mains voltage), which is then used to drive the forward converter. There may be three, four or even more secondary windings on the transformer, to produce the various low voltage DC supplies needed by the electronic circuitry.

Efficiency

As mentioned earlier, the perfect DC-DC converter would be one where none of the incoming DC energy is wasted in the converter; it would all end up converted and fed to the output. Needless to say this doesn't occur in the real world.

Inevitably practical converters have losses — voltage drops due to resistance in the inductor or transformer windings, 'on resistance' in the MOSFETs, forward voltage drop in the rectifier diodes, eddy current and hysteresis losses in the inductor or transformer, and so on. It's the job of the

converter designer to reduce all of these losses to the lowest possible level, to make the converter as *efficient* as possible.

You may have wondered, for example, why we've shown MOSFETs used as switches in most of the converter circuits. That's because modern MOSFETs make the most efficient electronic switches of high DC currents. When they're 'off' they are virtually an open circuit, and when they're 'on' they are very close to a short circuit — typically only a few milliohms. So they waste very little power.

For the same reason, the diodes used in most modern DC-DC converters are of the Schottky or 'hot carrier' metal-semiconductor junction type (as shown in our schematics). These have a significantly lower forward voltage drop than silicon diodes, and hence waste less power.

Synchronous rectification

For even *higher* efficiency, some converters drop the diodes altogether and use extra MOSFET switches instead — driven by the same circuitry used to drive the main switching MOSFETs, so they're turned on at just the right time for efficient gating or rectification of the output. This is known as **synchronous rectification**.

Synchronous rectification can be used in virtually any of the DC-DC converters we've looked at here. All that's involved is replacing each diode or diodes used in the basic converter with a suitable MOSFET, driven with a control signal that turns it on during the same part of the converter's cycle that the diode would normally conduct.

As a conducting MOSFET has much lower voltage drop than a conducting diode (even a Schottky diode), this achieves a very worthwhile further increase in converter efficiency. Even buck-type stepdown converters with 2-3V output can use synchronous rectification to achieve efficiencies as high as 94% — about 5% higher than is possible with Schottky diodes.

Operating frequency

Finally, you may be wondering why most modern DC-DC converters operate at a relatively high frequency, compared with the 50-60Hz of the AC power mains.

The answer is simple: when you use a high frequency, this allows the use of smaller inductors, transformers and capacitors in order to handle the same power level. And this in turn allows a reduction in both the size and material cost of the converters.

Of course moving to a higher operating frequency also increases some kinds of losses. Once you go beyond a few hundred hertz iron can't be used in the inductor or transformer core, for example — its losses are too great. So ferrite material must be used instead, but this allows very efficient operation at many hundreds of kilohertz.

Progress is being made all the time in developing materials and components that work efficiently at high frequencies, though, and already some DC-DC converters operate very efficiently at around 1MHz. In the future, they'll probably go even higher as engineers strive to make them even smaller and more efficient.