

## More Detailed Operation of a dc/dc Converter

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*This article explains the operation of dc/dc converters in more detail*

If you have any suggestions for improving this application note, please drop us a line at: [enquiries@electronworks.co.uk](mailto:enquiries@electronworks.co.uk)

### Introduction

Before reading this article, please refer to 'dc/dc converters explained' to get an insight into the basics of dc/dc converter operation.

We have established so far that a device dissipates power if it has a current flowing through it at the same time a voltage is across it. We have also established that a switch has theoretically zero power dissipation.

We will now look in more detail how a switched mode power supply works.

Firstly, we need to consider the basic operation of an inductor. Inductors behave according to the equation:

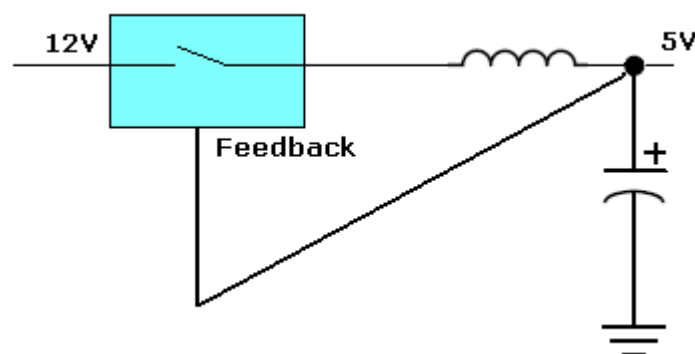
$$V = L \frac{di}{dt}$$

Where V is the voltage across the inductor, L is the inductance value and di/dt is the change in current with time. To make things easier, a constant di/dt looks like a current ramping up over time.

Thus if a fixed voltage is applied to a fixed value inductor, the current will ramp linearly over time according to:

$$\frac{V}{L} = \frac{di}{dt}$$

The basic circuit of a dc/dc converter is shown in FIG 1.



**FIG 1**

When the switch is closed, assuming the output voltage is constant (which at any instant we can assume this will be approximately true), there will be a fixed voltage across the inductor

and the current will ramp linearly over time. If we switch off this current, there will be a certain amount of energy stored in the inductor.

Using real life component values, if the input voltage is 12V and the output voltage is 5V, when the switch is closed there will be 7V across the inductor. If the inductor has a value of 100uH ( $100 \times 10^{-6}\text{H}$ ) the current will ramp up at

$$\frac{7}{100 \times 10^{-6}} = 70,000$$

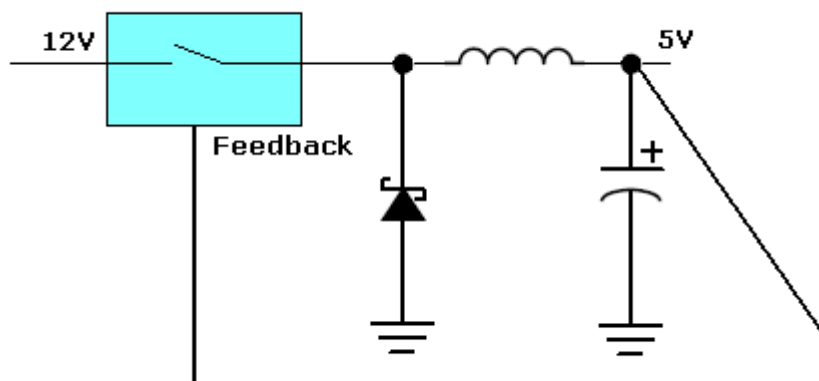
Or 70,000 Amps per second.

This seems a lot, but if we open the switch after 10us ( $10 \times 10^{-6}$  seconds), the current will only rise to 700mA (not so bad!).

Now, inductors do not like having the current going through them suddenly turned off. If we open the switch, this is exactly what we are doing. They try to maintain the current going through them immediately before the switch was opened (in this case 700mA). They do this by turning themselves into a (kind of) battery. The end connected to the switch develops a negative voltage and the other end develops a positive voltage. Thus the 'positive' end of the inductor pushes current out of the inductor and the 'negative' end pulls current into the inductor. Now, the 'positive' end of the inductor is clamped to the output voltage, leaving the 'negative' end to fly negative. This has the effect of maintaining the current magnitude and direction that was present immediately before the switch was opened.

You can see that if the switch is open there is no current path connected to the negative end of the inductor so no current can flow. The effect of this is that this end of the inductor flies negative until something blows up. Yes the voltage will get bigger until something arcs to an adjacent track.

If we want to generate a high voltage, this is one way of doing it. However if we want to have control over the operation of the circuit, we put a fast acting 'Schottky' diode into the circuit to catch the negative spike as shown in FIG 2.



**FIG 2**

Referring to FIG 2, when the inductor tries to fly negative, the diode conducts clamping the junction of the diode and the inductor at about -0.5V. This causes a current to flow in a clockwise direction through the inductor, into the capacitor and up through the diode. In doing this, we are pumping current into the capacitor and the capacitor charges.

If this is repeated continually (the switch is closed, the inductor charges etc), the voltage on the capacitor increases. If we monitor the voltage on the capacitor we can stop the switch



oscillating when we have reached our desired voltage and have hence produced a power supply that regulates a higher voltage down to a lower voltage.

Since the switch has a very low 'on' resistance, very little power is dissipated in this type of circuit and we have managed to convert 12V to a lower voltage with very little power being wasted. In a mobile phone, this means more power is saved hence longer talk time. Since hardly any heat is dissipated in the circuit, we do not need a heat sink so can make the mobile phone very small.

The above theory is true for small power supplies (inside mobile phones) to large power supplies used in cars.

In practice the switch and inductor have a very small resistance, so there will always be a small amount of heat wasted and the main area of research for these companies is in getting the resistance down while maintaining small package sizes.

The following kit is very similar to the circuit above. It regulates a car battery voltage down to 2 preset levels (either 3.8V or 5V) to enable pretty much any portable electronics to be powered from a car battery

<http://www.electronworks.co.uk/ck10.htm>