

Basics of DC/DC converters

A number of readers have told us they really appreciated the article in our February issue explaining switch-mode power supplies. Here's a sequel, discussing DC/DC converters.

DC/DC converters are widely used to transform and distribute DC power in systems and instruments. DC power is usually available to a system in the form of a system power supply or battery. This power may be in the form of 5V, 24V, 48V or other DC voltages. Further, the voltage may be poorly regulated and have high noise content.

A common use of DC/DC converters is in local power distribution applications, such as the one shown in Fig.13. Here the system power source provides a regulated 5V power bus which typically goes to a number of individual circuit boards. Each circuit board in addition to its logic circuitry, requires $\pm 12V$ DC, $\pm 15V$ DC or other voltages to power operational amplifiers, A/D and D/A converters, transducers, displays or other circuits.

Therefore each system circuit board may have one or more DC/DC converters, using the 5V power bus as an input and producing the other voltages required on the board.

Another common requirement for DC/DC converters is in transforming a battery voltage into another more useful and well-regulated voltage, for powering circuits and systems. A typical battery voltage may be 12, 24 or 48V DC, each used in specific applications. The output voltage of the battery can vary over a wide range, however.

For example, a 12V vehicle battery may go to 15V or

higher during charging and as low as 6V while starting the engine. In such an application for a vehicular electronic system, the DC/DC converter is required to accept this wide input voltage range and produce a stable, well-regulated output voltage to run the electronic system.

Classical type DC/DC converter

Fig.14 shows the classical, or Royer, type DC/DC converter circuit. The transistor switches operate in a push-pull configuration with a centre-tapped transformer.

When input voltage is first applied to the circuit, one of the transistor switches begins to turn on. The transformer provides positive feedback to the base of this transistor, turning it on hard. This switch remains on until the magnetic flux of the transformer saturates, causing the transformer voltages to reverse, thereby turning off the first transistor and turning on the second one.

The circuit continues to self-oscillate and produces an output square wave of voltage which is full-wave rectified and

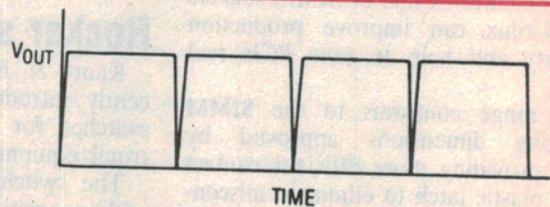


Fig.15: Converter output voltage after rectification.

filtered. This rectified square wave, before filtering, appears as shown in Fig.15. Since the square wave is of high frequency, with a relatively fast rise and fall time, it is relatively easy to filter with an electrolytic capacitor.

The rectified and filtered square wave, however, is not regulated, and any change in input voltage will be transferred directly to the output. Regulation is provided by a linear output regulator, which gives a constant DC output voltage and also provides current-limiting and short circuit protection on the output.

The classical DC/DC converter is widely used today, providing economical DC voltage conversion. Since the regulation is dissipative in this converter, overall efficiency is generally limited to about 65%. As in the linear power supply, the linear regulator must operate with sufficient voltage drop across the series pass element at the minimum input voltage to the converter. This establishes one's operating point.

As input voltage increases, the drop across the series pass element and the dissipation increase directly. Therefore, to maintain reasonable efficiency, the input voltage range is usually $\pm 10\%$ with some units as wide as -12% to $+30\%$.

The switching regulator

A popular type of DC/DC converter is the switching regulator, shown in Fig.16. This is a three-terminal, non-isolated circuit which converts a higher DC voltage into a lower one with a typically wide range input voltage; the input voltage range may be as high as 4 to 1. With this type converter output power levels to 300 watts are achievable. The configuration is the same as that of the buck regulator described earlier in the article on switching power supplies.

The output voltage is compared with a reference voltage

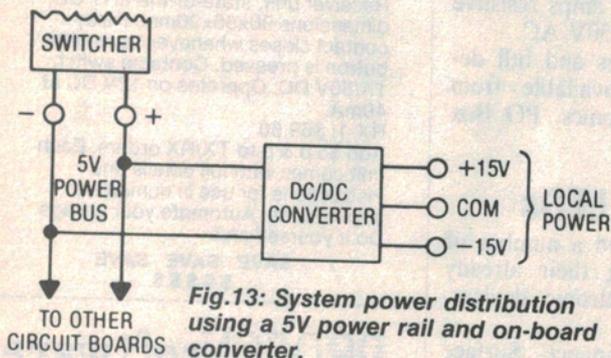


Fig.13: System power distribution using a 5V power rail and on-board converter.

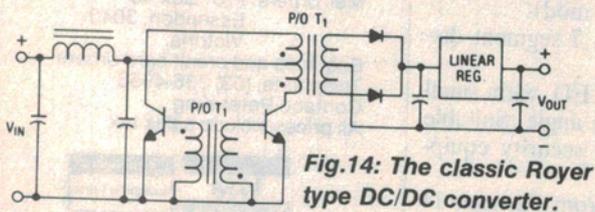


Fig.14: The classic Royer type DC/DC converter.

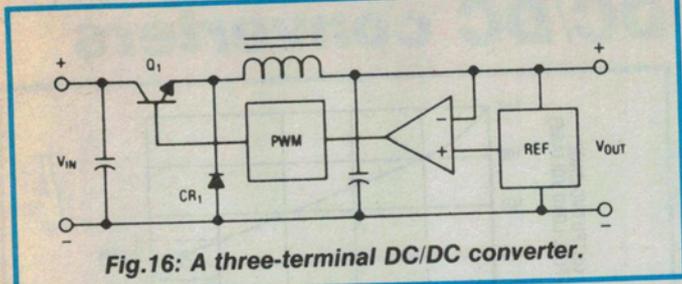


Fig.16: A three-terminal DC/DC converter.

and the difference is amplified to drive a pulse-width modulator, which in turn drives the switch. The energy stored in the inductor is determined by the on-time to off-time of the switch. Current flows through the inductor during both halves of the switching cycle, either through Q1 or through CR1.

Wide-range input DC/DC converters

To achieve a wide input voltage range of $\pm 20\%$ or greater with high efficiency, a DC/DC converter must operate like a switching power supply, employing pulse-width modulation with either a flyback or forward conversion circuit.

Fig.17 shows such a DC/DC converter circuit using the fly-

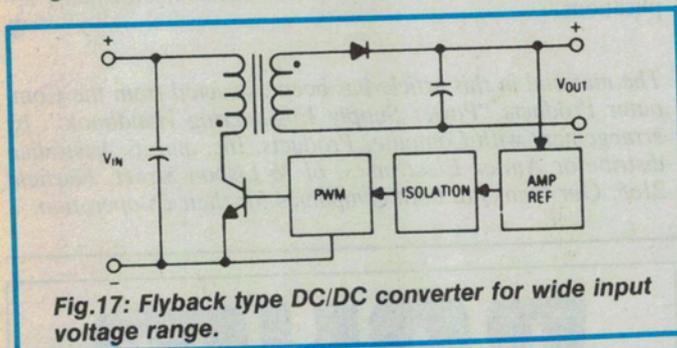


Fig.17: Flyback type DC/DC converter for wide input voltage range.

back conversion technique. This circuit works identically to the flyback type switching power supply described earlier. Most DC/DC converters are isolated from input to output, and this requires that the feedback loop be isolated. The isolation is normally provided by a small transformer or opto-isolator circuit.

An example of a DC/DC converter using forward conversion is shown in Fig.18. This circuit employs a power MOS-FET switch, which can operate at higher frequencies than bipolar transistors. When the switch is on, the voltage is transferred to the secondary winding and applied to the output inductor which stores energy. This circuit operates just like the forward converter switching power supply described previously and can operate with greater than a 2 to 1 input voltage range.

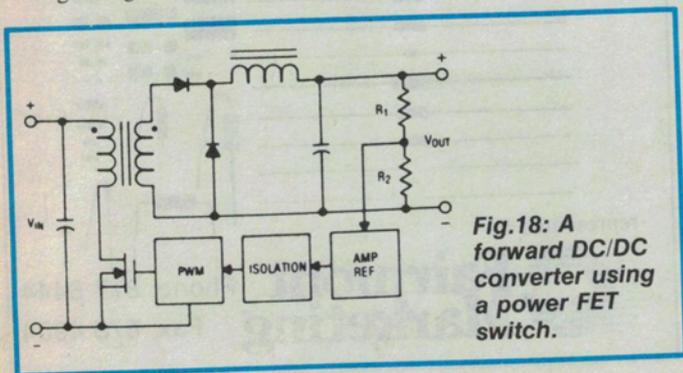


Fig.18: A forward DC/DC converter using a power FET switch.

Reflected ripple current

An important specification for DC/DC converters is the input reflected ripple current. This is defined as the AC current generated at the input of a DC/DC converter by the switching operation of the converter, and is fed back to the DC voltage source. It is usually stated as a peak-to-peak current.

One of the ways in which reflected ripple current is generated can be seen in Fig.14. With the classical type DC/DC converter circuit, there is a very short period of time when the transformer core goes into saturation and the converter input looks like a low impedance. This means that a large current pulse is drawn for a fraction of a microsecond, while the conducting transistor is turning off.

Reflected ripple current is present not only in DC/DC converters but also in switching power supplies. In both cases this ripple current can be suppressed by an input pi filter as shown in Fig.14. This filter effectively smooths the current spikes to a peak-to-peak value that is a few percent of the DC input current; typically the current ripple is reduced by a factor of 100 by the input filter.

Most high performance DC/DC converters have an internal pi filter for this purpose.

Another circuit technique that reduces the amount of reflected ripple current is separating the drive transformer from the power transformer in a DC/DC converter such as the one shown in Fig.14. The self-oscillation and transistor drive then takes place at a much lower power level by having a smaller transformer go into saturation. This substantially reduces the effect which causes reflected ripple current.

Unregulated DC/DC converters

There are many applications of DC/DC converters where the input voltage is from another regulated power supply and also where load current is relatively constant. In such cases, in addition to those applications where regulation is not a critical requirement for other reasons, an unregulated DC/DC converter is frequently used.

The advantage of an unregulated DC/DC converter is that it has a significantly higher efficiency than the classical converter, in many cases achieving 80% efficiency or higher. Because of this it is usually possible to deliver more output power to the load from the same size package.

An unregulated DC/DC converter is shown in Fig.19. It is basically identical with the classical converter design except

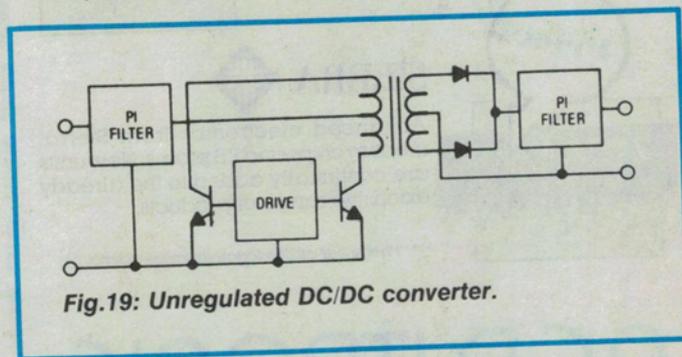


Fig.19: Unregulated DC/DC converter.

that there is no linear output regulator. Instead, there is additional output filtering done by a pi filter to reduce output voltage ripple.

Unregulated DC/DC's usually have a special output short circuit protection circuit, since there is no linear output regulator.

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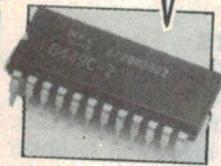
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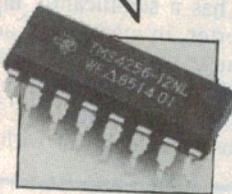


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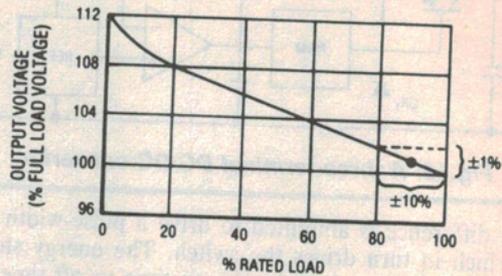


Fig.20: Load regulation for unregulated DC/DC converter.

Since this circuit is unregulated for either line or load, any changes in input voltage feed directly through to the output. A typical load regulation curve is shown in Fig.20. As the load current decreases from 100% rated load to 20%, the output voltage rises by 8%. However, if the load is relatively constant at say 90% of rated load $\pm 10\%$, the output voltage will change by only $\pm 1\%$, which is satisfactory for many applications.

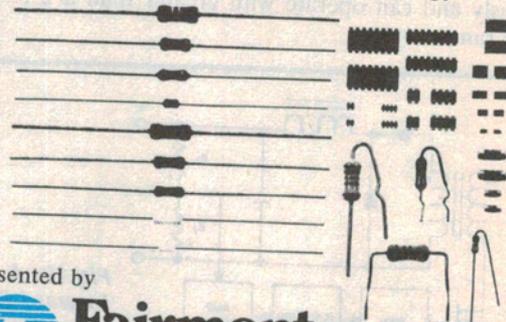
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