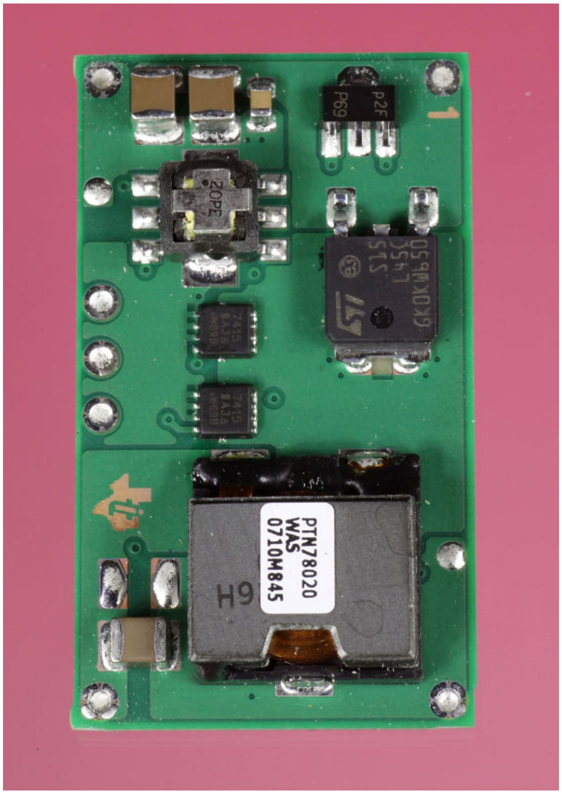

Figure 17-9. *Another adjustable DC-DC converter. The output voltage is determined by adding an external resistor or trimmer potentiometer. External smoothing capacitors are required, as shown in the component's datasheet.*

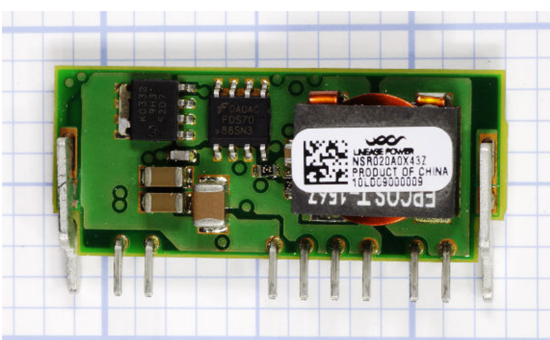

Figure 17-10. *Another adjustable DC-DC converter. The output voltage is determined by adding an external resistor or trimmer potentiometer. External smoothing capacitors are required, as shown in the component's datasheet.*

often allow equipment to be usable internationally, on any voltage ranging from 100VAC to 250VAC, at a fequency of 50Hz or 60Hz, without any adaptation.

Output Voltage

As previously noted, many converters allow the output voltage to be adjusted by adding an external resistor or potentiometer. Alternatively, there may be multiple fixed output voltages, accessible via different pins on the package. They may also provide a positive voltage and equally opposite negative voltage relative to a ground pin.

Input Current and Output Current

Because input voltage and output voltage are likely to be different, the current alone is not a reliable guide to power handling.

A datasheet should specify input current with no load (open circuit on the output side). This current will have to be entirely dissipated as heat.

Load Regulation

This is usually expressed as a percentage and suggests the extent to which output voltage may be pulled down when the load on a DC-DC converter increases. If V_{nil} is the measured output voltage with no load, and V_{max} is the measured output voltage with the maximum rated load:

$$\text{Load regulation} = 100 * (V_{nil} - V_{max})/V_{max}$$

However, note that some converters are designed with the expectation that they will never be used with zero load across the output. In these cases, V_{nil} will be the voltage at minimum rated load.

Efficiency

This is a measure of how much input current must be dissipated as heat. A converter with a 12-volt input, drawing a maximum 300mA input current, will consume 3.6 watts (3,600mW). If it is 80% efficient, it will have to dissipate roughly 20% of its power as heat, or 720mW.

Ripple and Noise

Sometimes abbreviated R/N, this may be measured in mV or as a percentage. Check the specification carefully to determine whether the ripple-and-noise values require use of external smoothing capacitors. Often, this is the case.

Isolated or Non-Isolated

This crucial piece of information is often found near the top of a datasheet, not in the detailed specifications.

How to Use it

Because a converter creates electrical noise, it should be prevented from affecting other components by adding substantial *bypass capacitors* as close as possible to its input and output pins. For most converters, external capacitors are mandatory, and their *effective series resistance* (ESR) should be as low as possible (see the **capacitor** entry in this encyclopedia for an explanation of ESR). Tantalum capacitors are preferable to electrolytics for this reason, and are also more durable. Some manufacturers recommend placing a tantalum capacitor in parallel with an electrolytic. A small ceramic capacitor, typically 0.1µF, is often recommended in an addition to larger-value capacitors on the output side.

The voltage rating of each capacitor should be twice the voltage at the point in the circuit where it is used. The capacitance value will usually be higher for higher-current converters. Values of 100µF are common, but for high amperage, a value may be as high as 1,000µF.

While datasheets are often inadequate for some types of components, datasheets for DC-DC converters usually include detailed instructions regarding bypass capacitors. Following these instructions is essential. In the relatively rare instances that a datasheet makes no mention of bypass capacitors for a converter, this does not necessarily mean that the capacitors are unnecessary. The manufacturer may assume that they will be used as a matter of course.

Converters are used in a very wide range of devices, supplying power ranging from a few milliamps to tens of amps. At the lower end of the scale, devices such as cellular telephones, portable computers, and tablets contain subcircuits that require different voltages, some of which may be higher than the voltage of a single battery or battery pack that powers the device. A converter can satisfy this requirement. Because a converter can be designed to maintain a fixed output in response to a range of input voltages, it can also compensate for the gradual decline in voltage that occurs during battery usage.

A boost-type converter can be used to double the voltage from a single 1.5V battery in an LED flashlight where 3 volts are required to power the LED. Similarly, a boost-type converter can provide the necessary voltage to run a cold-cathode fluorescent tube that provides backlighting in an LCD computer display.

On a circuit board that is primarily populated with 5VDC components and is fed by a single 5VDC power supply, a converter can be used to supply 12VDC for one special purpose, such as an analog-digital converter or a serial data connection.

If electromechanical **relays** or other inductive loads share a common ground with components ,such as *logic chips* or **microcontrollers**, it may be difficult to protect the sensitive components from voltage spikes. A A flyback converter with a transformer separating the output from the input can allow the “noisy” section of the circuit to be segregated, so long as the converter itself does not introduce noise. Since the electromagnetic interference (EMI) introduced by converters varies widely from one model to another, specifications should be checked carefully.

Very low-power components can pick up EMI from the wires or traces leading into and out of a converter. In this type of circuit, adequate noise suppression may be impossible, and a converter may not be appropriate.

What Can Go Wrong

Electrical Noise in Output

Electrolytic capacitors may be inadequate to smooth the high frequencies used. Multilayer ceramic capacitors or tantalum capacitors may be necessary. Check the manufacturer's datasheet for minimum and maximum values. Also check the datasheet for advice regarding placement of capacitors on the input side as well as across the output.

Excess Heat with No Load

Some converters generate substantial heat while they are powered without a load. The manufacturer's datasheet may not discuss this potential problem very prominently or in any detail. Check the input rating, usually expressed in mA, specified for a no-load condition. All of this current will have to be dissipated as heat, and the very small size of many converters can result in high localized temperatures, especially since many of them allow no provision for a heat sink.

Inaccurate Voltage Output with Low Load

Some converters are designed to operate with at least 10% of full rated load across their output at all times. Below this threshold, output voltage can be grossly inaccurate. Read datasheets carefully for statements such as this: "Lower than 10% loading will result in an increase in output voltage, which may rise to typically double the specified output voltage if the output load falls to less than 5%." Always use a meter to verify the output voltage from a converter at a variety of different loads, and perform this test before installing the converter in a circuit.

DC-AC inverter

18

A power inverter must not be confused with a *logic inverter*, which functions as a digital component in *logic circuits* to invert the state of a low-voltage DC input from high to low or low to high. Logic inverters are discussed in Volume 2.

OTHER RELATED COMPONENTS

- **AC-DC power supply** (See Chapter 16)
- **DC-DC converter** (See Chapter 17)

What It Does

A power inverter is included here as counterpoint to a **power supply** or *AC adapter*, since it has the opposite function. The inverter receives an input of *direct current* (typically 12VDC from a car battery) and delivers an output of *alternating current* (AC) in the range 110VAC-120VAC or 220VAC-240VAC, suitable to power many low-wattage appliances and devices. The interior of a low-cost inverter is shown in Figure 18-1.

Figure 18-1. *The interior components in a 175-watt inverter.*

How It Works

The first stage of an inverter typically raises a 12VDC input to a higher DC voltage via an internal **DC-DC converter**, then uses a switching circuit to create an approximation of the sinusoidal profile that is characteristic of AC voltage.

Digital switching components naturally tend to create square waves, whose simple appearance conceals the presence of higher frequencies, or *harmonics*, that are ignored by some devices (especially those that convert electricity into heat) but can be troublesome in consumer electronics equipment. A primary objective of inverter design is to adapt or combine square waves to emulate a classic AC sine wave with reasonable fidelity. Generally speaking, the more accurately an inverter emulates a sine wave, the more expensive it tends to be.

The most primitive inverter would create a plain square wave such as that shown in red in Figure 18-2, superimposed on a comparable sine wave (in green). Note that alternating current rated at 115 volts actually peaks at around 163 volts because the number 115 is the approximate *root mean square* (*RMS*) of all the voltage values during a single positive cycle. In other words, if the voltage is sampled x times during a cycle, an

RMS value can be derived by squaring each sample, adding all the samples, dividing by x, and then taking the square root of the result. The RMS value is important as a means to calculate actual power delivered because it can be multiplied by the current to obtain an approximate value in watts.

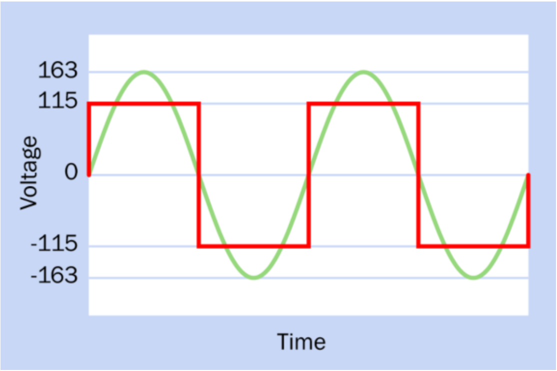

Figure 18-2. *Comparison of an AC voltage sine wave (green) and a square wave of the same frequency (red), both delivering a roughly similar amount of power.*

Variants

As a first step toward a better approximation of a sine wave, gaps of zero voltage can be inserted between square-wave pulses. This "gapped" square wave is shown in Figure 18-3.

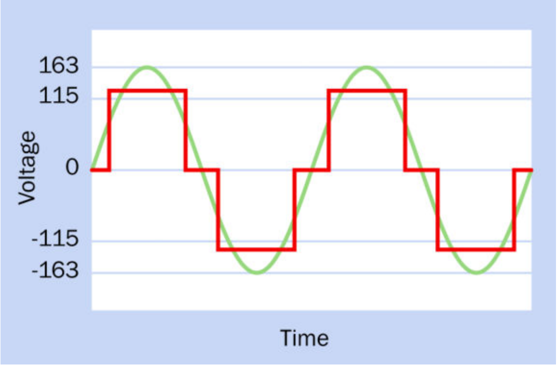

Figure 18-3. *Introducing pauses or gaps of zero voltage between square-wave pulses can produce slightly improved resemblance to a sine wave.*

A further improvement can be achieved if an additional, shorter pulse of higher voltage is added to each primary pulse, as shown in Figure 18-4. Outputs of this kind are referred to as *modified sine wave*, although they are actually square waves modified to emulate a sine wave. Their inaccuracy is expressed as *total harmonic distortion* (*THD*). Some authorities estimate that the THD of gapped square-wave output is around 25%, whereas the addition of shorter square waves reduces this to around 6.5%. This is a topic on which few people agree, but there is no doubt that a "stacked" sequence of square waves provides a closer emulation of a sine wave.

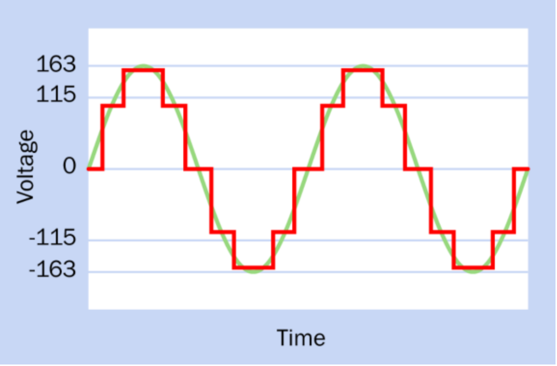

Figure 18-4. *A secondary stream of narrower square-wave pulses can improve the fidelity of an inverter's output.*

A *true sinewave inverter* typically uses *pulse-width modulation* (*PWM*) to achieve THD of less than 1%. It generates a stream of pulses much higher in frequency than that of the AC output, and varies their widths in such a way that their averaged voltage closely approximates the voltage variations in a sine wave. A simplified representation of this principle is shown in Figure 18-5.

Values

Small inverters are typically rated to deliver up to 100 watts and may be fitted with a 12VDC plug for insertion in a vehicle's cigarette lighter. Since a cheap inverter may be only 80% efficient, 100 watts at 135VAC will entail drawing as much as

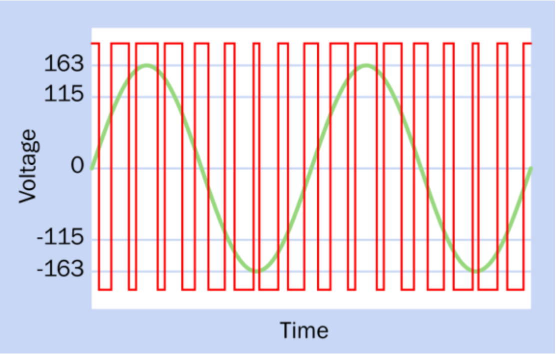

Figure 18-5. *Pulse-width modulation adjusts the widths of pulses delivered at a high frequency. The pulse widths can be averaged to generate voltage that follows a close approximation of a sine wave.*

10 amps at 12VDC. Cigarette lighters are usually fused at 15 or 20 amps, so 100 watts is a reasonable value. Inverters that are rated above 150 watts usually have cables terminating in oversize alligator clips for direct connection to the terminals of a 12V battery.

While the *cold cranking* rating of a car battery may be 100 amps or more, the battery is only designed to deliver that power for up to 30 seconds at a time. Inverters rated for as much as 500 watts will exceed the normal capacity of a single car battery, although if the battery is mounted in a vehicle, it can be supplemented by running the engine so that the alternator shares some of the load. A 500-watt inverter is better supplied by two or more 12-volt car batteries wired in parallel.

How to Use it

Small inverters are typically used in vehicles to run cellphone chargers, music players, or laptop computers. Large inverters are an integral part of off-the-grid solar and wind-powered systems, where battery power must be converted to AC house current. Uninterruptible power supplies contain batteries and inverters capable of running computer equipment for a brief period. Battery-driven electric vehicles with AC motors use inverters with an exceptionally high current rating.

There is a lack of consensus regarding possible harmful effects of powering electronics equipment with a low-cost modified sine wave inverter. Anecdotal evidence suggests that where the equipment uses its own *switching power supply* or uses an *AC adapter* (either mounted internally or as an external plug-in package), the filtering built into the power supply will block harmonics from the inverter.

Other evidence suggests that cheap inverters may have adverse effects on devices containing synchronous motors that run direct from AC. There are reports that fluorescent lighting and photographic electronic flash systems may be unsuitable for use even with modified sine wave inverters. However, differences in product design and component quality make it impossible to generalize. A cheaply made inverter may generate a wave form that is not even a close approximation of a square wave. See Figure 18-6.

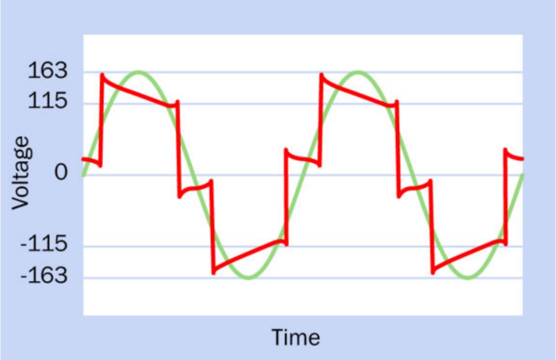

Figure 18-6. *A cheaply made inverter can generate a distorted wave form that is even higher in noise than a pure square wave. This sample is adapted from an actual oscilloscope trace.*

What Can Go Wrong

If multiple batteries are connected in parallel, using suitably heavy-gauge wire to power a large inverter, the batteries must be identical in specification and age, and must all be equally charged to prevent high and potentially dangerous flows of current among the batteries as they attempt to reach an equilibrium among themselves. Interconnections must be firmly clamped to clean battery terminals. For additional information, see the **battery** entry in this encyclopedia.

Problems associated with inverters are likely to be mundane. A 12V wiring to the inverter can overheat if items such as clothes or bedding are left on top of it; a high-wattage fan-cooled inverter can overheat if the fan is obstructed by poor placement or impaired by accumulated dirt; alligator clips may become dislodged from battery terminals; and power surges drawn by inductive loads such as motors may trigger the inverter's *breaker*, especially if they are used in conjunction with other equipment.

As always, high amperage should be treated with caution and respect, regardless of it being delivered at "only 12 volts."

voltage regulator

19

Correctly known as a *linear voltage regulator* to distinguish it from a *switching regulator* or **DC-DC converter**. However, the full term is not generally used, and "voltage regulator" is normally understood to mean a linear voltage regulator.

OTHER RELATED COMPONENTS

- **DC-DC converter** (See Chapter 17)
- **AC-DC power supply** (See Chapter 16)

What It Does

A linear voltage regulator provides a tightly controlled DC output, which it derives from an unregulated or poorly regulated DC input. The DC output remains constant regardless of the load on the regulator (within specified limits). It is a cheap, simple, and extremely robust component.

There is no single schematic symbol for a linear voltage regulator.

The general physical appearance of a commonly used type of regulator, rated for an output of around 1A DC, is shown at Figure 19-1. The LM7805, LM7806, LM7812, and similar regulators in the LM78xx series are encapsulated in this type of package, with pins that are spaced at 0.1" and have functions as shown. Other types of regulator may differ in appearance, or may look identical to this one but have different pin functions. Always check datasheets to be sure.

How It Works

All linear regulators function by taking some feedback from the output, deriving an error value by comparing the output with a reference voltage (most simply provided by a zener diode), and using the error value to control the base of a *pass transistor* that is placed between the input and the output of the regulator. Because the transistor operates below saturation level, its output current varies linearly with the current applied to its base, and this behavior gives the linear regulator is name. Figure 19-2 shows the relationship of these functions in simplified form; Figure 19-3 shows a little more detail, with a *Darlington pair* being used as the pass transistor. The base of the pair is controlled by two other transistors and a comparator that delivers the error voltage. This version of a voltage regulator is known as the *standard type*.

The voltage difference required between the base and emitter of an NPN transistor is a minimum of 0.6V. Because multiple transistors are used inside a standard-type voltage regulator, it requires a minimum total voltage difference, between its input and its output, of 2VDC. This voltage difference is known as the *dropout voltage*. If the voltage difference falls below this minimum, the regulator ceases to deliver a reliable output voltage until the input voltage rises again. *Low dropout regulators* allow a lower voltage difference, but are more expensive and less commonly used. They are described under the following Variants section.

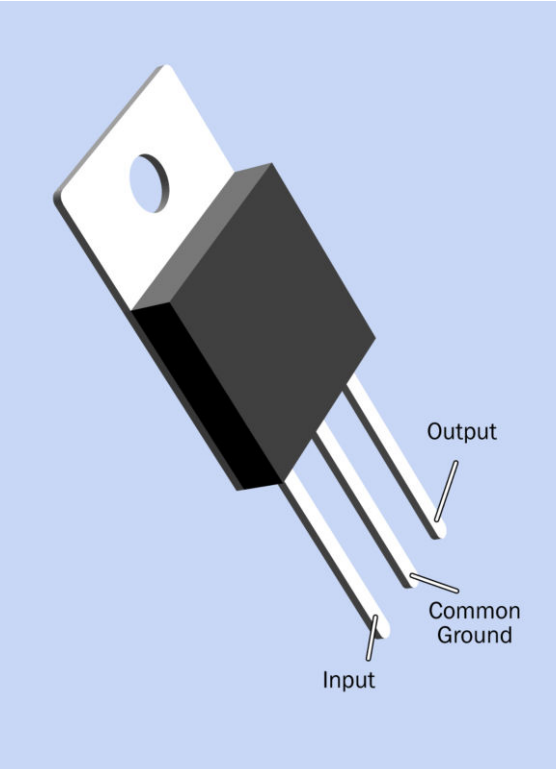

Figure 19-1. *The package design of a commonly used voltage regulator. Others may be significantly different, and the pin functions may vary. Check manufacturer datasheets for details.*

Discrete components could in theory be used to build a voltage regulator, but this ceased to be cost-effective several decades ago. The term is now understood to mean one small integrated package containing the basic circuit augmented with additional, desirable features, such as automatic protection against overload and excessive heat. Instead of burning out if it is overloaded, the component simply shuts down. Most voltage regulators also tolerate accidentally reversed power connection (as when batteries are inserted the wrong way around) and accidentally reversed insertion of the regulator in a circuit board.

Other components can satisfy the requirement to deliver power at a reduced voltage. Most simply, if two resistors in series are placed across a

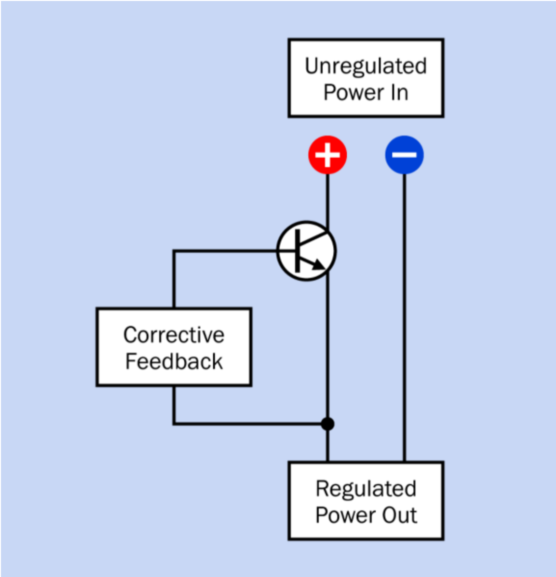

Figure 19-2. *A linear voltage regulator basically consists of a transistor whose base is controlled by corrective feedback derived from the output.*

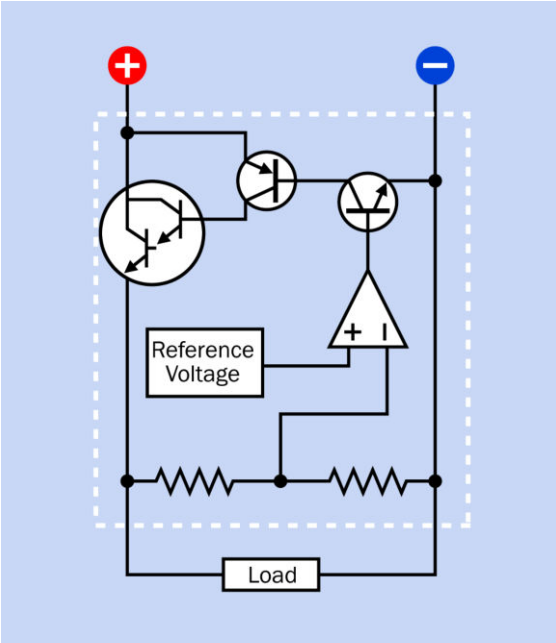

Figure 19-3. *The fundamental internal features of a standard-type voltage regulator, including a Darlington pair, two transistors, a voltage divider, comparator, and reference voltage source, shown inside the dashed white line.*