1. INTRODUCTION

Virtually every piece of electronic equipment in the world today is powered from a DC source; this source may be either a battery or a power supply. Most electronic equipment requires not only DC power source, but one that is well-filtered and well-regulated as well. There are three types of electronic power conversion devices in common use today: the AC/DC power supply, the DC/DC converter, and the DC/AC inverter. Each has its own specific areas of application. Of the three, AC/DC power supplies and DC/DC converters are the most commonly used and are the subject of the technical section.

Power supplies have evolved through the years from the large rack-mounted units employing vacuum tubes and dangerously high voltages to today’s compact solid state power supplies with their lower, and relatively safe, DC voltages. Since power supplies, and DC/DC converters are so widely used in electronic equipment, these devices now comprise a worldwide segment of the electronics market in excess of $5 billion annually. Furthermore, this market is growing in step with the total worldwide electronics market.

Power converters have not only evolved into compact solid-state devices, but the basic technology has advanced from linear power supplies to modern switching power supplies which are not only smaller and lighter, but also much more efficient than their linear counterparts. Linear power supplies employ conventional 50/60 Hz power transformers followed by a rectifier, filter, and linear regulator. These supplies, still widely used, are about 40 to 55% efficient.

Switching power supplies, on the other hand, are generally "off-line" devices; that is, they directly rectify and filter AC line voltage without first using a 50/60 Hz transformer. Then the filtered DC is chopped by the power switch and high frequency transformer, and is finally rectified and filtered again. Because of the fast switching rate, which is from 20kHz to 500kHz, the transformer and the capacitors are much smaller than their 50/60Hz counterparts. Switching power supplies are from 60 to 80% efficient.

DC/DC converters, similar to switching power supplies in their operation, are used to change one DC voltage to another, and are usually well-regulated. These devices are important where electronic equipment must be operated from a battery or other DC source.

Power supply technology has changed rapidly over the past decade, and modern switching power supplies and DC/DC converters are much more difficult devices to design and produce reliably than were the simpler linear power supplies of the past.
2. LINEAR POWER SUPPLIES

A power supply converting AC line voltage to DC power, performs several important functions:

- Voltage transformation: changing the AC line voltage into another more suitable voltage.
- Rectification: changing AC to DC.
- Filtering: smoothing the ripple of the rectified voltage.
- Regulation: controlling the output voltage to give a constant value with line, load, and temperature changes.
- Isolation: electrically separating the input and output of a power supply.

An ideal power supply would have several important characteristics: constant output voltage regardless of variations in line voltage, load current, ambient temperature, or time; output impedance of zero for all frequencies; 100% conversion efficiency; and finally no ripple or noise on the output voltage.

Figure 1 illustrates the load regulation and output ripple of a "real" power supply. Although well-regulated, the output voltage does change with load; also line voltage, temperature and time regulation can be measured.

Figure 1 Ideal and Real Power Supply Characteristics

LINEAR POWER SUPPLY CIRCUITS

Figure 2 illustrates two common linear power supply circuits in current use. Both circuits employ full-wave rectifiers to achieve minimum output ripple.

Figure 2 Linear Power Supply Circuits

The center-tapped transformer configuration uses only two diodes and has just one diode drop in the path from the transformer to the capacitor filter. These diodes, however, must withstand twice the reverse voltage compared to the diodes in the bridge configuration. The latter circuit avoids the transformers center-tap but has two diode drops on the path from the transformer to filter capacitor.

The pulsating full-wave rectified DC voltage is shown in Figure 3. The filter capacitor \( C_1 \) is a large value electrolytic capacitor which must hold its charge between half-cycles while supplying the regulator and load currents. The time between half-cycle peaks is 8.33 msec. for 60Hz AC and 10 msec. for 50Hz AC.

Figure 3 Full Wave Rectification And Filtering

\( C_1 \) is actually charged out by short current pulses near the peak of each half-cycle, as shown in the figure. The capacitor voltage then decays until the next current pulse arrives. The value of \( C_1 \) is determined from the value of peak ripple voltage permitted.

\( C_2 \) is the output capacitor of the supply after the linear regulator circuit. This capacitor is usually a lower value than \( C_1 \) and gives the power supply a low AC output impedance.

The linear regulator circuit provides the precise line and load regulation required at the output of the power supply. It also suppresses the output ripple voltage because of its speed and regulating capability.

Dual output power supplies are commonly used to power linear circuits such as operational amplifiers, data converters, and other signal processing circuits; these circuits typically require ±12VDC or ±15VDC. A dual output supply, shown in Figure 4, is simply two single output supplies in series, using the same power transformer. A center-tapped transformer with a bridge rectifier is used. Each output has its own linear regulator, although in some cases the negative output regulator is slaved to the positive one, providing tracking of the two output voltages.

Figure 4 Dual Output Linear Power Supply

LINEAR POWER SUPPLY COMPONENTS

The various components used in a power supply each perform an important function in the operation of the supply.

Transformer. The transformer provides both isolation and voltage transformation. Isolation gives electrical separation between AC neutral or ground and the power supply output common. The transformer also matches the power supply to the various world-wide standard AC lines voltages of 100, 115, 220, and 240VAC. Table 1 lists the line voltages and frequencies for a number of different countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>Volt.</th>
<th>Freq.</th>
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<tbody>
<tr>
<td>Argentina</td>
<td>220</td>
<td>50</td>
</tr>
<tr>
<td>Australia</td>
<td>240</td>
<td>50</td>
</tr>
<tr>
<td>Austria</td>
<td>220</td>
<td>50</td>
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<tr>
<td>Belgium</td>
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</tr>
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<td>Brazil</td>
<td>127</td>
<td>60</td>
</tr>
<tr>
<td>Canada</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td>Denmark</td>
<td>220</td>
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<td>Finland</td>
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<td>France</td>
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<tr>
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<td>50</td>
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<td>50</td>
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<tr>
<td>Spain</td>
<td>127/220</td>
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<td>50</td>
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<tr>
<td>Switzerland</td>
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<td>Taiwan</td>
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<td>60</td>
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<td>United Kingdom</td>
<td>240</td>
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<td>U.S.A.</td>
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<td>60</td>
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<tr>
<td>U.S.S.R.</td>
<td>127</td>
<td>50</td>
</tr>
<tr>
<td>Venezuela</td>
<td>120</td>
<td>60</td>
</tr>
</tbody>
</table>

Table 1 AC Line Voltages of Selected Countries

Some applications require very low capacitive coupling between the input and output of the power supply to minimize AC leakage current. This is accomplished by employing an electrostatic grounded shield called a Faraday shield between the primary and secondary windings of the transformer. For an illustration of this see the "Power Conversion Glossary".
Capacitors. Electrolytic capacitors, either aluminum or tantalum, are critical components in power supplies. The required capacitance for a filter capacitor is indirectly proportional to the load current and inversely proportional to the desired voltage ripple. An important parameter of filter capacitors is “effective series resistance”, or ESR. Figure 5 illustrates the low frequency equivalent circuit of an electrolytic capacitor. Since the capacitor is charged not by a single sine wave but a train of pulses shown in Figure 3, these pulses through the ESR cause internal heating of the capacitor core and increased ripple voltage. The ripple current together with the working voltage of the capacitor determine the rating of the capacitor for a given application.

Linear Regulators. A linear regulator may be either a discrete circuit or an IC regulator, depending on the particular power supply. While it is convenient to have a single IC do this function, many times a discrete regulator is used to enhance certain performance parameters.

The linear regulator performs several important functions:

- Provides a constant output voltage with line and load variations
- Suppresses output ripple voltage by means of its regulating action.
- Provides output current limiting to protect the power supply from overload and short circuit conditions.

Figure 6 shows a typical series regulator circuit. The voltage reference is a compensated zener diode which has a low temperature coefficient. It is biased by a current source in order to reduce the effect of input voltage variations.

Capacitors must be carefully chosen for optimum performance in a power supply so that their recommended temperature rating is not exceeded under any operating condition of the power supply.

PROGRAMMABLE POWER SUPPLIES

Some power supplies, generally used in test systems, have programmable output voltages. This is useful because the output voltage can be rapidly changed from one value to another while going through a test sequence. The programming can be done in several ways: resistance, voltage, or digital programming. As shown in Figure 8, a programmable power supply is effectively a power operational amplifier in which a high gain linear regulator circuit is used. The output can therefore be programmed by changing the value of the feedback resistor $R_2$ while $R_1$, the reference resistor, remains constant. The output voltage equation is shown in the diagram. By this means the output can be programmed from zero up to some maximum output voltage.

The operational amplifier acts as a high gain error amplifier which compares a fraction of the output voltage with the voltage reference. The amplifier drives the series regulator transistor which keeps the output voltage constant. The output voltage equation is:

$$V_{out} = V_R \left( \frac{R_1 + R_2}{R_2} \right)$$

To remain in regulation, the collector of $Q_1$ must always be above a specified minimum voltage; this minimum varies with the particular regulator used and may be lower in a discrete regulator circuit.

The short circuit protection circuit senses the voltage across $R_s$, the current sampling resistor, and the base-emitter drop of $Q_1$. When this voltage exceeds a preset value the circuit reduces the drive to the base of $Q_1$ and limits the output current.

OVERVOLTAGE PROTECTION

An important feature on many power supplies is overvoltage protection on the output. This is particularly important for 5 volt supplies which are used to power TTL logic circuits. These TTL circuits have an absolute maximum supply voltage of 7.0V so that if, due to an internal fault condition, the power supply output voltage were to rise above this voltage, all of the logic circuits could be destroyed. This could be an expensive failure in a complex system.

To prevent this, an overvoltage crowbar or clamp circuit can be used. A possible crowbar circuit shown in Figure 7, uses a zener diode, resistor, and a silicon controlled rectifier, or SCR. If the output voltage for any reason exceeds the 6.2V breakdown of the zener, a current flows through the resistor producing enough voltage to trigger the SCR. When the SCR turns on, it places a short circuit directly across the output, thereby protecting the load circuitry. This short remains in place until the power supply is turned off and reset.
3. SWITCHING POWER SUPPLIES

While linear power supplies have many desirable characteristics such as simplicity, low output ripple and noise, excellent line and load regulation, and fast recovery time, they are not particularly noted for high efficiency.

SWITCHING VS. LINEAR SUPPLIES

Switching power supplies, on the other hand, are becoming popular due to high efficiency and high power density. Table 2 compares some of the salient features of both linear and switching power supplies. Line and load regulation are usually better with linear supplies, sometimes by as much as an order of magnitude, but switching power supplies frequently use linear post-regulators to improve output regulation.

<table>
<thead>
<tr>
<th>TABLE 2 LINEAR VS. SWITCHING SUPPLIES</th>
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<tbody>
<tr>
<td>SPECIFICATION</td>
</tr>
<tr>
<td>Line Regulation</td>
</tr>
<tr>
<td>Load Regulation</td>
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<tr>
<td>Input Voltage Range</td>
</tr>
<tr>
<td>Efficiency</td>
</tr>
<tr>
<td>Power Density</td>
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<tr>
<td>Transient Recovery</td>
</tr>
<tr>
<td>Hold-Up Time</td>
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</tbody>
</table>

The output voltage ripple of a switcher, generally in the range of 25 to 100mV peak-to-peak, is higher than that of a linear supply. While the RMS value of this ripple is much lower, it is the peak-to-peak value that is more significant with switchers. Switchers also have slower transient recovery times than linear supplies, but have much longer hold-up times, a characteristic which is important in computer applications. Transient recovery time and hold-up time are both defined in the "Power Conversion Glossary".

Finally, the switching power supply has the advantage of wider input voltage range than its linear counterpart. The linear supply input range is usually ±10% and has a direct affect on the efficiency of the supply. With a switcher, however, there is little or no affect of input voltage range on efficiency, and the input range is usually ±50%, making the supply useful under brown-out conditions.

Switching power supplies are not new. They were developed in the 1960’s and used primarily in military and aerospace systems. However, in recent years switching technology has improved and the cost of switching components has come down significantly, leading to practical industrial and consumer grade switching power supplies.

Switchers began replacing the large linear supplies in which both size and heat dissipation were problems, and have been gradually working their way down to lower power levels.

EFFICIENCY

A linear power supply converts an unregulated DC voltage (from the transformer secondary, which is rectified) to a lower regulated voltage by “throwing away” the difference between the two voltages as heat. Although the 50/60Hz transformer is very efficient, the output rectifiers and linear “pass transistor” dissipate considerable amounts of heat. Consequently, the linear power supply is inherently inefficient - typically 45% for a 5V output regulator.

By contrast, a switching power supply converts a similar unregulated DC voltage to a lower regulated voltage by storing the difference in a magnetic field “bank account”. When the magnetic field grows to a pre-determined level, the unregulated DC is switched off and the output power is provided by the energy stored in the magnetic field “bank account”. When the field has sufficiently depleted, the unregulated DC is switched on again to deliver power to the output, while the excess voltage is again stored in the magnetic field. Consequently, the switching power supply is efficient - typically 75% for a 5V output regulator.

THE FLYBACK REGULATOR

The basic circuit upon which many lower power switchers operate is the flyback regulator shown in Figure 9. This circuit converts one DC voltage into another, regulating the output by means of pulse-width modulation (PWM). Pulse-width modulation is a method of controlling the ratio of on-time to off-time of a switch. In a flyback type switching supply, the longer the on-time compared to the off-time, the more energy is stored in the transformer and transferred to the load.

Figure 10 illustrates pulse-width modulation.

The flyback regulator operates as follows:

The switching transistor Q1, is controlled by the pulse-width modulator circuit. When Q1 is on, the current increases linearly in the primary of the transformer. This transformer is actually an inductor with a secondary winding and, unlike a normal transformer, stores substantial energy in its core.

When Q1 turns off, the field in the transformer core begins to collapse and therefore cause I2 to flow in the secondary. I2 charges capacitor C and also flows into the load Figure 11 illustrates the current pulses I1 and I2 during the on-time and off-time of the switching transistor. While I1 builds up during the on-time, I2 decays during the off-time and maintains the voltage across capacitor C.

If the output load increases, it is only necessary to increase the on-time of Q1 during which I1 builds up to a higher value, and as a result a higher I2 flows in the secondary during the off-time. The reverse occurs for a lighter output load, with I2 decreasing in value.

If the output voltage is compared with a reference voltage and the difference used to control the pulse-width modulator, the loop is closed and the circuit automatically keeps the output voltage at a constant value.

The ideal flyback regulator circuit is lossless since at any time the switching element has either zero voltage or zero current. In practice, however, there are some switching and conducting losses in Q1 and also losses in the transformer, diode and capacitors. But these losses are small compared with those in a linear regulator circuit.
OFF-LINE SWITCHING SUPPLY

Based on the flyback regulator circuit, a complete off-line switching supply is shown in Figure 12. The switcher is called "off-line" because the DC voltage to the switch is developed right from the AC line without first going through the 50 or 60Hz transformer. This is accomplished by means of a bridge rectifier circuit which charges a filter capacitor.

This circuit also shows the feedback loop completed from the output back to the switching transistor. This feedback loop must have isolation in order for the DC output to be isolated from AC line, and this is normally accomplished by a small transformer or an opto-isolator.

THE FORWARD CONVERTER

Another popular switching configuration is known as the forward converter circuit and is illustrated in Figure 13. Although this circuit looks much like the flyback circuit, there are some fundamental differences. The forward converter does not store significant energy in the transformer but, rather, in the output inductor. The polarity of the dots on the transformer shows that when the transistor switch is on, an output voltage is generated at the secondary and current flows through diode CR 1 into the inductor. The longer the on-time of the switch relative to the off-time, the higher the average secondary voltage and the higher the output load current.

When Q 1 is off, the current in the inductor cannot change instantaneously and continues to flow through CR 2 . Thus, unlike the flyback circuit, current flows from the energy storage element during both halves of the switching cycle. The forward converter therefore has lower output ripple voltage than the flyback circuit for the same output power.

MULTI-OUTPUT SWITCHERS

Most switching power supplies have more than one output. Typically in addition to a 5V logic output, there may be a +12V, -12V, +24V and -5V outputs. These outputs are used in systems to power other devices such as floppy and hard disk drives, printers, CRT terminals, RS-232 circuits, and analog interface circuits. Figure 14 shows a multiple output flyback switcher. The 5V output is fed back to the pulse-width modulator to regulate the entire circuit. This means that the auxiliary outputs are not as well regulated as the main output. In some applications such as disk drives this is not critical. In other more critical applications the auxiliary outputs have linear post-regulators to provide better regulation as shown in the diagram.

Standard switching power supplies are usually available with up to five different outputs.

OTHER TOPOLOGIES

Buck Regulator. There are a number of other topologies for switching supplies which are shown in simplified form in Figure 15. The first of these is the "buck regulator". For simplicity the front-end rectifier and filter are not shown in these circuits. The buck regulator operates like the forward converter except that a transformer is not used and there is no input to output isolation for the circuit. The input DC voltage is regulated to a lower value by pulse-width modulation of the switch. This circuit is frequently employed as a three-terminal high efficiency regulator.
Boost Regulator. A similar circuit is the "boost regulator", in Figure 15b which operates like the buck regulator except that the output voltage is higher than the input voltage. In fact the output voltage is equal to the input voltage plus the voltage determined by the switching of the transistor.

Push-Pull Converters. Figure 15c shows a push-pull converter which is another variation of the forward converter except that two switches are used on the primary side of the transformer.

Full and Half-Bridge Converters. Figure 15d and e show two more variations on the forward converter called full-bridge and half-bridge converters, respectively. The only differences from the previous circuit are the manner in which the transformer primary is driven.

INPUT VOLTAGE SELECTION

Older switching power supplies accommodate either 115 or 220VAC inputs, selectable by a single jumper wire. Figure 16 shows how this is accomplished.

When operating from "220VAC" (180-260VAC), the jumper is removed and the input circuit charges the two capacitors, as if they were just one capacitor, to the line voltage peak – about 320VDC. When operating from "115VAC" (90-130VAC), the jumper is in place and the two capacitors are each alternately charged to the line voltage peak. The voltage across both capacitors in series is also about 320VDC.

Newer switchers incorporate "universal input" which allows them to operate from any worldwide line voltage without the need to physically move a jumper wire. Universal input can take two forms. "Continuous universal input" switchers simply rectify the input AC voltage, storing the energy in a single capacitor. This scheme accommodates any worldwide line voltage from 90VAC to 260VAC, and is typically found on switchers below 200 watts.

"Autostrap universal input", by contrast, uses a special violate sensing circuit to detect either 115 or 220VAC input, which appropriately sets an electronic "jumper wire." The autostrap's electronic "jumper wire" performs the same function as the manual jumper described above. Autostrap is usually found on switchers above 200 watts.

SWITCHER EFFICIENCY AND SIZE

One of the great advantages of switchers, in addition to high efficiency, is the high power density, or power-to-volume ratio. This of course is the result of the reduction in size of various components for 20kHz and higher operation compared with 50/60Hz operation. Mainly, the large 50/60Hz power transformer is replaced with a miniature ferrite core transformer and the filter capacitors are likewise much smaller. The only exception to this is the input filter capacitor which must filter a full-wave rectified 50/60Hz sine wave.

Another important component used with switchers is either a fast-recovery or Schottky diode for rectifying or controlling the direction of the output current. These fast diodes are required to prevent significant power losses due to the stored charge of conventional rectifier diodes. In addition, Schottky diodes have a much lower forward voltage drop than conventional diodes, further boosting efficiency.

EMI AND RFI

Switching power supplies, unlike linear supplies, can be a source of electromagnetic and radio frequency interference. There are two basic types of interference: conducted and radiated. The source of this interference is a short burst of high frequency-content energy caused by the rapid switching voltage and current transients in a switcher. These bursts of energy are repeated at the switching frequency of the supply.

Conducted EMI/RFI is noise fed back from the power supply onto the AC power line. This noise can be effectively suppressed using a pi input filter for differential mode noise and a balun and capacitor filter for common mode noise. These filters are illustrated in Figure 17 and must use components which are effective at RFI frequencies. Figure 18 shows the definition of differential mode noise and common mode noise.

While switching supplies have an internal input filter to suppress the conducted EMI/RFI, for those that don't, an external filter can be employed for this purpose.

Radiated EMI/RFI is electrical noise transmitted through the air that might interfere with nearby electronic equipment. Power supplies radiate some EMI, even though Computer Products’ engineers minimize it as much as possible. Also, digital circuitry powered by the supply itself radiates EMI from PCB traces.

The FCC and VDE regulatory agencies have set limits on the permissible amount of radiated EMI from the system. Since this noise can be generated by almost any part of a circuit, reducing radiated noise is most effectively solved at the system level. This is usually done by shielding the entire system, rather than just the power supply.
4. 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 a high noise content.

LOCAL POWER DISTRIBUTION

A common use of DC/DC converters is in local power distribution applications such as the one shown in Figure 19. 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 ±12VDC, ±15VDC 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 48VDC, 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

Figure 20 shows the classical, or Royer, type DC/DC converter circuit. The transistor switches operate in a push-pull configuration with a center-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 the transistor, turning it on hard. This switch remains on until the magnetic flux of the transformer saturates the core, causing the transformer voltages to reverse, thereby turning off the first transistor and turning on the second one.

The output voltage is compared with a reference voltage 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.

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 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 operating point. As input voltage increases, the drop across the series pass element and the dissipation increase directly. When the series pass element reaches its maximum operating temperature, the other operating point is established. Therefore, to maintain reasonable efficiency, the input voltage range is usually limited to ±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 Figure 22. 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 of converter, output power levels to 300 Watts are achievable. The configuration is the same as that of the buck regulator described in the section on switching power supplies.
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 Figure 20. 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 Figure 17. This filter effectively smoothes the current spikes to a peak-to-peak value that is few percent of the DC input current; typically the current ripple 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 Figure 20. 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 affect 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 cost, and size. There is no additional feedback circuitry to consume additional area and add cost. Since there is no linear output regulator, a smaller sized device will deliver the same output power as a larger linear regulated converter.

An unregulated DC/DC converter is shown in Figure 25. It is basically identical to the classical converter design except 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.

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 Figure 26. 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 ±10%, the output voltage will change by only ±1% which is satisfactory for many applications.
5. POWER CONVERTER TESTING

This section discusses some of the circuits and techniques used to test and verify power converter performance characteristics and specifications. While not all power converter test circuits can be covered in a short space, the most important ones are covered here.

MEASUREMENTS

Standard four-terminal, or Kelvin, measurement practices should always be observed in making power converter measurements. The output terminals of a power converter by means of separate contacts which do not carry load current. If contacts carrying load current are used for measurement, an erroneous reading of many millivolts can result.

GENERAL TEST-SET-UP

Most power converter tests are done with the general test set-up shown in Figure 28. Except where otherwise required, the following conditions apply:

- Input voltage is set to 115VAC, 60Hz, by the autotransformer or to nominal DC input voltage for a DC/DC converter.
- The load is set to the rated output load for the power converter.
- The ambient temperature is 25°C.

LOAD REGULATION

Make and record the following measurements at nominal line voltage at 25°C:

- Output voltage with rated load connected to the output.
- Output voltage with no load, or the minimum specified load, for the power converter.

Load regulation is the difference between the two measured output voltages as a percent of output voltage at rated load. It should be noted that many switching power supplies specify load regulation at 60% ±40% rated load. This gives a ±load regulation value for the range of 20% to 100% of rated load.

TEMPERATURE COEFFICIENT

With the power converter in a temperature test chamber, with rated output load, make the following measurements:

- Output voltage at 25°C ambient temperature.
- Set the chamber for maximum operating ambient temperature and allow the power converter to stabilize for 15 to 30 minutes. Measure the output voltage.
- Set the chamber to minimum operating ambient temperature and allow the power converter to stabilize for 15 to 30 minutes. Measure the output voltage.
- Divide each percentage voltage deviation from the 25°C ambient value by the corresponding temperature change from 25°C ambient.

The temperature coefficient is the higher of the two values calculated above, expressed as percent per degree Centigrade.

OUTPUT RIPPLE AND NOISE

This is an AC measurement at the output of a power converter at rated load and 25°C ambient temperature. The measurement is made in either millivolts RMS or millivolts peak-to-peak. For a linear AC/DC power supply, the output ripple voltage is a reasonably smooth 120Hz waveform with little high frequency content. This can be readily measured on a low bandwidth oscilloscope for peak-to-peak value or with a true RMS voltmeter for RMS value.

In the case of switching power supplies and DC/DC converters, the output ripple voltage is a series of small pulses with high frequency content, and for this reason is almost always specified as peak-to-peak rather than RMS value. A 50 millivolt peak-to-peak output ripple from a DC/DC converter can have a very low RMS value—perhaps just 5V—but this type of specification would be of questionable value to the designer who must specify the power supply for his system.

Because of the high frequency content of this ripple, special measurement techniques must be employed so that correct measurements are obtained. First, a 20MHz bandwidth oscilloscope is normally used for the measurement so that all significant harmonics of the ripple spikes are included.

Figure 29 shows a complex ripple waveform that may be present on the output of a switching power supply. There are three components of the waveform; first is a 120Hz component that originates at the input rectifier and filter; next is the component at the switching frequency of the power supply; finally, there are small high frequency spikes imposed on the high frequency ripple.

OUTPUT VOLTAGE ACCURACY

With nominal input voltage and rated output load from the test set-up, the DC output voltage is measured with an accurate, calibrated DC voltmeter. Output voltage accuracy is the difference between the measured output voltage and specified nominal value in percent.

LINE REGULATION

Make and record the following measurements with rated output load at 25°C:

- Output voltage at nominal line (input) voltage.
- Output voltage at high line (input) voltage.
- Output voltage at low line (input) voltage.
A 12 inch twisted pair of no. 16 AWG copper wire is connected to a 47 µF capacitor of proper polarity and voltage rating. The oscilloscope probe ground lead should connect right to the ground ring of the probe and be as short as possible. The oscilloscope bandwidth should be 50 MHz or greater and the oscilloscope should be connected to AC ground.

REFLECTED RIPPLE CURRENT

Reflected ripple current was discussed in the section on DC/DC converters. Since this is an input current measurement with high frequency components, it must also be measured properly. Probably the simplest and most straightforward way to make the measurement, although not the only way, is to use a wideband current probe and oscilloscope as shown in Figure 33. Here the current probe and oscilloscope have a bandwidth of 20MHz to give an accurate wideband measurement.

A non-inductive current sampling resistor to make a voltage measurement is another method, but it takes considerably more care to give accurate results.

COMMON MODE NOISE CURRENT

This is another current measurement with high frequency components from the switching of the power supply or DC/DC converter. The noise current is common to each terminal and circulates from the output back to the input through the external ground connection shown. This measurement is made identically to the reflected ripple current with a wideband current probe as shown in Figure 34.
6. POWER CONVERTER APPLICATION

Some designers, unfortunately, believe that powering their electronic equipment is the last step in the design process for their system and think that this simply involves choosing a power supply or DC/DC converter of the correct input and output voltages and sufficient load current capacity.

Nothing could be further from the truth. In fact, much effort and skill is involved in choosing the right power converter and applying it in a system design so that trouble-free operation results. Not only must the power supply be chosen with care to achieve good results over the lifetime of the equipment, but so must the power supply manufacturer be carefully chosen.

The result of quickly chosen and poorly thought out power systems can be usually traced to improper power distribution schemes and trouble-causing ground loops. The common symptoms of poorly designed system are poor regulation at the load, excessive noise at the load, crosstalk between circuits, system oscillation, and thermal problems.

The following guide to the application of power converters should help avoid many of these problems.

**CONDUCTOR SIZE**

The simplest power supply application is that of a single power converter connected to a single load as shown in Figure 35. Here a 5V output supply is shown with a 4 ampere load.

In addition to choosing a power converter with the desired output current and regulation, the resistance of the load conductors is an important factor. In this example, no. 18 AWG copper wire is used for the 18 inch length. The conductors turn out to have a total loop resistance of 19.2 milli-ohms. This resistance, with a 4A load current, causes a 76.8 millivolt drop in the line, which is 1.5% of the 5V output. Now, if the power supply itself has 0.1% load regulation, it is causes a 76.8 millivolt drop in the line, which is 1.5% of the 5V resistance of 19.2 milliohms. This resistance, with a 4A load current, affects the power supply output compensates for the voltage drop in the load wires by producing a higher output circuit of the power supply. The power supply output compensates for the voltage drop in the load wires by producing a higher output voltage at the supply terminals so that the voltage at the load is precisely the correct value. In this manner the power supply can compensate for load conductor drops of up to 1.0V.

**CONTACT RESISTANCE**

In the connection of power supplies to their loads, especially at high load currents, it is most important that good contacts be made at both ends of the power path. Many an engineer has been embarrassed by a regulation problem that was not the result of the power supply, but rather a poorly made power connection such as a wrapped wire, alligator-clip connection, or corroded terminal.

Such contacts can result in many milliohms of contact resistance and degrade the regulation at the load just as a long load conductor can. It is important to remember a couple of basic figures for reference purposes: a 5V output with 0.1% regulation changes by 5mV from no load to full load; a 12V output with 0.02% regulation changes by 2.4mV from no load to full load.

Obviously then, all high current contacts should be properly wrapped and soldered. Spade lugs, banana plugs, etc. should be carefully cleaned to remove corrosion. Edge type circuit board connections should be clean and have several connections in parallel for high load currents.

**REMOTE SENSING**

The problem of preserving the load regulation specification of a power supply right at the load is solved by a power supply feature known as remote sensing. Many high output current supplies have this feature where the connection to the internal regulator is made by special sense leads run directly to the load. Hence the name "remote sense".

Figure 36 shows the connection of the sense leads. There is one lead for each output terminal, designated +S and -S. These leads carry a very low current compared with the load leads and are usually shielded as shown to prevent noise pickup by the regulation circuit of the power supply. The power supply output compensates for the voltage drop in the load wires by producing a higher output voltage at the supply terminals so that the voltage at the load is precisely the correct value. In this manner the power supply can compensate for load conductor drops of up to 1.0V.

As shown in Figure 36 there is generally a resistor or diode inside the power supply connected between each sense terminal and power output terminal to prevent the output voltage from rising excessively should the sense leads be inadvertently disconnected from the load. If the remote sense is not used, then the sense leads are shorted to their respective output leads and the supply operates in its normal manner with local sensing.

**POWER DISTRIBUTION**

**Parallel Distribution.** An important part of power supply application is the proper connection of distributed loads to the power supply. A common mistake in power converter connections is shown in Figure 37. Here the voltage at each load is dependent on the current drawn by the other loads and DC ground loops are developed. Load number 3 has the lowest voltage across it. Except for low current applications where the voltage drop in the load conductors is negligible, this distribution method should not be used.

![Figure 36 Remote Sensing Connections](image)

![Figure 37 Parallel Power Distribution](image)

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**TABLE 3 RESISTANCE* OF ANNEALED COPPER WIRE**

<table>
<thead>
<tr>
<th>AWG</th>
<th>Ω/FOOT</th>
<th>AWG</th>
<th>Ω/FOOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.00</td>
<td>22</td>
<td>16.14</td>
</tr>
<tr>
<td>12</td>
<td>1.59</td>
<td>24</td>
<td>25.67</td>
</tr>
<tr>
<td>14</td>
<td>2.53</td>
<td>26</td>
<td>40.81</td>
</tr>
<tr>
<td>16</td>
<td>4.02</td>
<td>28</td>
<td>64.90</td>
</tr>
<tr>
<td>18</td>
<td>6.39</td>
<td>30</td>
<td>103.2</td>
</tr>
<tr>
<td>20</td>
<td>10.15</td>
<td>32</td>
<td>164.1</td>
</tr>
</tbody>
</table>

*At 20°C. NOTE: Wire diameter halves for every three wire sizes.
Radial Distribution. A better way to distribute power is by the radial distribution method shown in Figure 38. A single pair of terminals is designated as the positive and negative distribution terminals. A pair of heavy wires is connected from the power converter to these terminals and separate leads go from these terminal to each individual load. The result is that there are no ground loops and little affect of one load upon another.

Mixed Distribution. Of course complete radial power distribution may be impossible, but the concept should be adhered to as closely as possible, particularly with the heaviest loads. Circuits can be grouped in a logical manner, and each group can be distributed radially. If at all possible, a single ground point should always be used to eliminate ground loops.

Figure 39 shows a mixed distribution system where heavy leads are used from the power supply. Here the group 1 loads draws the heaviest current and are therefore the closest to the power converter output.

Group 2 loads draw small currents and cause negligible voltage drops in the distribution lines. Therefore they can use parallel distribution and are farthest from then power converter output.

Analog and Digital Circuits. Proper separation and grounding of analog and digital circuits is extremely important. Poor ground current management in this area causes untold problems.

One common error is to allow low level analog signals to share conduction paths with digital or power returns. Figure 40 shows the proper connection and separation of analog and digital power supplies. Notice that there is but a single ground point and no shared paths between the analog and digital supplies.

It should be mentioned here that many triple output power supplies have separate digital (5V) and analog (±12V or ±15V) output common terminals just for this purpose.

To prevent the injection of unwanted DC levels or logic transients into sensitive analog circuits, follow this rule: Analyze each analog ground path separately to make sure that it goes directly to the single ground with no shared paths. This is an area where the design engineer must work closely with his layout drafter to assure the correct physical layout of signal and power paths in his circuit board.

BYPASSING AND DECOUPLING

All power supplies have some output resistance and inductance and so do the power distribution leads. Loads which are fast analog or digital circuits need to be decoupled by a local decoupling capacitor right at the load.

Figure 41 shows such a load decoupling circuit which serves to minimize the resonant affects of the series line impedance with stray capacitance and the affect of rapidly changing load currents with the series inductance. A load current transient through an inductance will cause a significant voltage spike to be generated, and this can harm or falsely trigger other circuits.

Figure 41 shows both 0.1 µF ceramic and 1 µF electrolytic capacitors in parallel at the load for bypassing. This makes an effective medium and high frequency bypass. Such practice will go long way in preventing cross-talk between multiple loads.

In bypassing analog and digital circuits individually, the capacitor should not simply be connected from each supply lead to ground in the general vicinity of the circuit. Rather, the following important rule should be followed: Use a bypass capacitor to close the signal current loop by the shortest possible path.

This means that the AC signal does not have to return through the power converter and back again. Notice in Figure 42 the capacitors physically go directly from each input power terminal at the circuit to the load connection point to common or ground. Here the capacitor connection should be as direct as possible with minimum lead lengths.

SERIES AND PARALLEL CONNECTION

Series Connection. In general, power converters can be operated with outputs connected in series. However, it is wise to check with the manufacturer in some cases just to make sure. With switching supplies and DC/DC converters it is possible that one output could affect the feedback loop of another power converter. Also, there will be an addition of ripple voltage at the outputs since the power converters in general will not have synchronous ripple voltages.

The only other limitation on series connection is that the total output voltage should not exceed the working breakdown voltage of any one of the power converters. This may be substantially less than the dielectric test voltage.
A common practice in the series connection of power converters is to connect reverse biased diodes across the output of each series connected power supply as shown in Figure 43 in order to protect each output from the reverse voltage of the other output in the event that the output load is shorted.

One frequent application of the series connection is in using a dual output power converter as a higher voltage single output converter as shown in Figure 44. The outputs are already series connected by means of the common output terminal, so it is only necessary to float the common and connect the load directly across positive and negative output terminals as shown.

In this manner 24, 30, or 36V outputs can be realized from ±12, ±15, or ±18 dual output power converters respectively.

### Parallel Connection

The parallel connection of power converter outputs is a much more difficult problem than series connection. In fact, as a general rule it should not be done unless the power converters are specifically designed for parallel operation or the manufacturer says it can be done.

The problem with parallel operation is that it is nearly impossible to get equal load sharing between two power converters. First of all, two output voltages from fixed-output power converters such as modular power supplies and DC/DC converters will not be exactly equal. The converter with the larger output voltage will tend to provide the entire load current.

Even if the outputs can be adjusted so that they are precisely equal, a difference in output impedance and also drift with time and temperature will cause the loads to become unbalanced.

A method sometimes recommended is that of using individual series resistors to balance the output load currents as shown in Figure 45. Even this is difficult to do with good results.

Assuming that the two resistors are exactly equal, small output voltage differences will nevertheless cause large current imbalances. The table shown with Figure 45 gives the amount of current imbalance produced by small voltage differences between the outputs. The circuit assumes 5V nominal output voltages with the load drawing 2A total current.

For example, a 0.2V difference in outputs causes a 100% difference in output currents; this means that one output is supplying the entire load current. Even a 50mV output difference results in a 25% current imbalance.

While the above parallel connection may be useful in a few applications, two things should be noted. First, the series resistors degrade the output regulation seriously. In this example load regulation will be degraded to at least 2%, and this assumes that the output currents are balanced. Secondly, allowing for possible imbalances of say 50% means that each supply must be capable of supplying not just 50% of the load current but 75% of it.

Some specialized power supplies have provision for master-slave operation as shown in Figure 46. Here the master supply provides a control signal to the slave and this regulates its output current to give approximately equal load sharing.

Another valid method of parallel operation is where the power converter outputs have a constant current output characteristic above the rated output current. When the two power converters are connected in parallel, the two output voltages will become equal when one of the units is operating beyond the knee of the voltage-current output curve. Therefore one current will be supplying its full output current and the other will supply the remainder of the required load current.

This technique is called AMP-REG™ and is a trademark of Computer Products, Inc.; the method is employed on some of their DC/DC converters.
Redundancy. A good reason for parallel operation of power converters is in providing power redundancy. In Figure 47, two power converters have their outputs connected in parallel through two diodes. For 100% redundancy each power converter must be capable of supplying the total load. In this case it does not matter whether the load current is shared equally, however it is desirable for each output to provide at least part of the load current.

![Figure 47 Redundant Parallel Connection](image)

The diodes permit one output to fail without affecting the other which continues to power the load. This configuration is useful for critical applications where a power supply failure cannot be tolerated. Note that one of the power supplies could just as well be replaced with a battery of the same output voltage to give an uninterruptible DC power system.

AC CONNECTIONS AND FUSING

**AC Line Connections.** The AC input line to an AC/DC power supply has three wires: AC live, AC neutral, and safety ground. In all power supply and electronic system connections, these wires should be properly connected and their integrity maintained. The proper connection is shown in Figure 48.

![Figure 48 AC Power Line Connections](image)

The safety ground should always be connected to the power supply chassis and the system chassis. In those cases where there is no power supply chassis, such as with open board power supplies, the system case or chassis should be used.

A fuse or switch must be placed in the AC hot line so that when power is turned off or the fuse blows, the AC hot line will always be interrupted. For maximum safety a double pole switch may be used to interrupt both live and neutral AC lines.

AC live and neutral lines should never be interchanged since they are different potentials with respect to ground, and interchanging them will result in a circulating ground current.

**Fusing.** In general, power supply inputs should always be fused for maximum protection and safety. Since some power supplies, such as encapsulated power modules, do not have internal fuses, the fuse should be provided externally.

The best practice is to find out what external fuse the manufacturer recommends either in his published specifications or by calling him. As a general rule, however, use a fuse with 150% to 200% of the AC input current to the supply at the rated load. Also be sure to check on whether the manufacturer recommends fast-blow or slow-blow fuses.

LINE NOISE AND TRANSIENTS

A potential problem with both AC/DC power supplies and DC/DC converters is input line noise and transients. This is not an uncommon problem particularly in the industrial environment where various power devices such as motors, generators, relays, and welding apparatus cause noise and transient pulses that contaminate both AC and DC power lines. Other sources of noise include switching of reactive loads, fluorescent lighting systems, ignition systems, lightening, and the interruption of high current power lines.

**Power Line Noise.** Input power noise is generally suppressed by pi filters on both AC/DC supplies and DC/DC converters. While these filters are primarily used to suppress back ripple current fed onto the power line, they also prevent power line noise from being fed through the power converter to the load.

Power converter transformer coupling capacitance is one of the culprits in permitting such noise to be coupled right through the supply. In this regard, low coupling capacitance such as that provided by many DC/DC converters and also by linear AC/DC power supplies which employ split-bobbin wound transformers minimizes this problem.

In some cases a power supply with a Faraday shield may be required to effectively reduce the coupling capacitance to a minimum value. Another solution is to use a separate isolation transformer ahead of the system power supply.

**Power Line Transients.** Power line transients can cause damage to the DC/DC converter or power supply. If voltage transients in a given application can exceed the maximum rated input voltage of a power converter, it may be necessary to provide external protection devices.

Figure 49 shows two transient protection methods commonly used. In the first, an AC/DC power supply input is protected by a fuse and metal oxide varistor, or MOV. The MOV effectively absorbs and dissipates transient voltages above its breakdown voltage. MOV’s are available with breakdown voltages of 25V and higher.

The second protection circuit in Figure 49 (b) uses a small resistor and zener diode to protect the input of a DC/DC converter from an input transient. This circuit is useful for voltage transients less than 25V. It should be noted, however, that the input resistor will decrease the conversion efficiency.

![Figure 49 Input Protection Circuits](image)

OVERLOAD

Almost all modern power converters have built-in output overload protection circuitry. Basically there are three types of overload protection:

- **Power Foldback**
- **Current Limiting**
- **Current Foldback**

Power foldback is probably the most popular and least expensive method to protect against output shorts. It is used in many switching power supplies and DC/DC converters. An output short is detected by the primary circuit, which then reduces all output voltages and currents to a very low value. Normal operation resumes when the short is removed.

Linear AC/DC power supplies and classical type DC/DC converters generally employ either output current limiting or foldback current limiting. Figure 50 shows the V-1 characteristic and load lines for both methods.
7. THERMAL MANAGEMENT AND RELIABILITY

Thermal management and reliability are important and interrelated considerations in the application of power converters. Often, too little attention is given to this matter by both manufacturers and users of power converters.

RELIABILITY AND MTBF

The failure rate \( \lambda \) of a power converter is shown in Figure 51. This familiar bathtub type curve applies to most electronic devices and equipment. Section A of the curve portrays the early life failure rate which is also known as the infant mortality period. This period of higher than normal failures in practice is controlled by a program of carefully monitoring and analyzing failed units returned to the manufacturer and by judicious use of burn-in.

Section B portrays the useful operating life of a power converter during which the failure rate is relatively low, and section C shows the higher failure rate during the wear-out period.

During the useful life of the unit, reliability is measured by the “mean time between failure” or MTBF. MTBF can be established in one or two ways: by actual statistics on the hours of operation of a large population of units, or by calculation from a known standard such as MIL-HDBK-217 and its revisions.

MTBF, the mean time between failures, and \( \lambda \), the failure rate, are related as follows:

\[
MTBF = \frac{1}{\lambda} \quad (1)
\]

Reliability is defined by the equation:

\[
R(t) = e^{-\lambda t} = e^{-\frac{t}{MTBF}} \quad (2)
\]

Reliability is the probability that a power converter will survive for a specified number of hours of operation. This equation is plotted in Figure 52 where \( R(t) \) is shown versus units of MTBF.

A number of observations can be made from this equation:

- If a power converter is operated for a time equal to its MTBF, its probability of survival will be 0.37.
- When operated for a time equal to 10% of MTBF, a power converter will have a 0.90 probability of survival.

The small table shown with Figure 52 gives additional values of \( R(t) \), which are not shown on the curve.

CALCULATING MTBF

MTBF, when calculated in accordance with MIL-HDBK-217, involves the summation of the failure rates of each individual component at its operating temperature. The failure rate of each component is determined by multiplying a base failure rate for that component by its operating stress level. The result is \( \lambda \), the failure rate per million operating hours for that component. Then

\[
\lambda = \lambda_1 + \lambda_2 + \ldots + \lambda_n \quad (3)
\]

where \( \lambda \) is the sum of all individual component \( \lambda \)'s and

\[
MTBF \text{ (hours)} = 10^6 \frac{1}{\lambda} \quad (4)
\]

In this manner, MTBF can be calculated both at 25°C ambient temperature, and at other temperatures as well.

THERMAL EQUATIONS

Heat is the number one killer of power converters. Since they all dissipate power internally, the heat must be effectively removed or else the internal temperature of the power converter will rise excessively and shorten operating life.

The amount of input power converted to heat is a function of efficiency. Figure 53 illustrates the relationships of a power converter operating in thermal equilibrium. Usually the output power and efficiency are given by the manufacturer's data, whereas the input power is an unknown. Working from the definition

\[
\text{Efficiency} = \eta = \frac{P_{\text{out}}}{P_{\text{in}}} \quad (5)
\]

the other relationships are derived as shown in Figure 53.
Thermal Design. The maximum operating temperature for a power converter is determined by the internal temperature rise of its components. At an ambient temperature of 70°C the internal temperature of some components may be over 100°C. The internal temperature of any component must never exceed its maximum operating temperature, and for this reason many power converters specify derated outputs at higher operating temperatures. In other cases the power converter is specifically designed with special components and thermal techniques to allow operation at full load to 71°C with no derating.

The point is that in a conservative thermal design the manufacturer has measured the internal temperature of critical components and specifies a derating, so that long operating life is assured. For a reliable power converter, choosing the right manufacturer is as important as choosing the right converter.

It is also important to determine whether the manufacturer specifies operating temperature range as ambient air temperature or case temperature. Obviously the conservative approach is to use ambient air temperature, but there are some manufacturers who use case temperature.

Thermal Practice. It is important to determine the actual ambient temperature in the vicinity of an operating power supply. This temperature is affected not only by other dissipative components in the vicinity, but by the power converter itself.

Good thermal practice allows sufficient space around the power converter for good air circulation and escape. If this is not possible, and particularly if ambient air temperature exceeds 50°C, one of the following alternatives can be employed:

- Forced air cooling
- Heat sinking to a metal chassis
- Using a heat sink with fins
- Operating with derated output

The general affect of these methods on the output rating of a power converter is shown in Figure 56. If the basic converter is derated from 50°C to 71°C as shown, additional cooling methods will shift the operating area toward the ideal of no derating as shown. Therefore heat sinking, forced air, or a combination of both can be used.
AFFECT ON MTBF

Good thermal practice is not just to keep a power converter operating within its specified operating area, but to extend the life of the unit. Whether or not the unit is derated at higher temperatures, it is a good idea to provide additional cooling above 50°C ambient temperature.

This fact can be no more clearly illustrated than by examining the affect of higher temperature operation on the operating life of a power converter.

Figure 57 shows a specific case of the calculated MTBF of a power supply for operating ambient temperatures between 25°C and 75°C. While not all power converters will follow this particular curve, it does illustrate the type of life reduction which can occur. However, lest this curve seem depressing it should be pointed out that the unit still has an MTBF of 5.1 years at 50°C and 1.86 years at 75°C (One year is 8766 hours).

Finally, thermal specification and management are so important that the user of power converters should always check with the manufacturer when in doubt about his application.