Introduction

On any given day we come in contact with a wide variety of electronic devices. Additionally, there is a plethora of instrumentation, control systems, communication devices, and any number of miscellaneous electronic devices or systems in place in the background of society as a whole upon which we depend on a daily basis.

No matter what type of electronic device, be it a consumer-based product such as computers, cell phones, game systems and the like or more industrially-based OEM monitoring and control systems, they all have one common requirement for their operation-- a reliable and stable source of DC power.

There are three types of power conversion devices in use today: the AC/DC power supply, the DC/DC converter, and the DC/AC inverter. Of the three, AC/DC power supplies and DC/DC converters are the most commonly used.

Whether an AC/DC main power converter, or an embedded DC/DC converter in a larger distributed power system, no other single component has as direct an affect on overall system reliability and performance as the ubiquitous power supply.

The power supply provides not only reliable power to the device, but also is called upon to meet user safety, emissions, and MTBF specifications as well as meet system ambient thermal requirements.

Years ago, conventional linear converter solutions were often bulky and inefficient, while the more efficient and compact switching solutions were just coming into their own and the selection of switching power solutions was limited to specialized types of products geared primarily to the aerospace and military markets.

Luckily for today's system designer, advances in power semiconductors and control elements in the past 20 years have led to the development of a vast array of efficient, reliable, and packaged power conversion products from literally hundreds of worldwide manufacturers at economical prices. Prior to this, the designer had few packaged power converters to select from, and often had to resort to designing their own power product for use in their system.

This off the shelf availability has freed the system designer from having to "home-brew" his or her own power supply solution and from having to contend with the myriad safety agency requirements related to power supplies and power systems. In many respects, power supply design and manufacturing is a unique branch unto itself, and power converter designers are best able to provide the most reliable and economical solution for virtually any application.

This designer's guide seeks to acquaint the system designer with the specification and implementation guidelines for power converters. Being a key design element of any system or product, selecting the correct power converter product and required features will assure overall system performance and reliability.

Linear Vs. Switch Mode Power Conversion

The rapid evolution of power supply technology over the past 25 years has resulted in power converter products moving from the largely inefficient, and sometimes rack-mounted units of the past to the compact, efficient, and highly reliable units of today.

Since AC/DC power supplies are so widely used in electronic equipment, and coupled with the explosive growth of computers and personal electronic devices, power supplies now comprise a worldwide segment and electronics market in excess of $20 billion annually.

Not only have power supplies evolved into the compact solid-state devices of now available, but the basic technology has advanced from linear power supplies to more modern switching power designs which are not only smaller and lighter, but also more efficient than their linear counterparts. Linear power supplies utilize conventional 50/60 Hz power transformers followed by rectifier, filter and a linear regulator. These supplies, still widely used in low output noise requirement applications, are large in size related to output power achieved and are about 40-50% efficient.

Conversely, switching power supplies are generally "off-line" devices. They directly rectify and filter the AC line voltage without first using a 50/60 Hz transformer. The filtered DC is chopped by the input power switch and high frequency transformer and is then rectified and filtered again. Because of this stepped up switching rate, which can run from 20 kHz to 500 kHz, the transformer and capacitors can be much smaller than the 50/60 Hz linear counterparts, reducing overall size and boosting output power per square inch of size. Switching power supplies can reach efficiencies between 70% to 80%.

Linear Power Supply

The linear power supply, by converting AC line voltage to DC output power perform several functions:

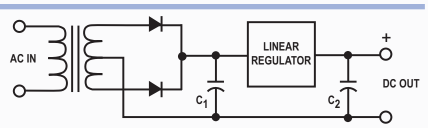
-- Input transformer: changes the high AC line voltage via step down to a more suitable low-voltage as required by the system circuitry - usually from 3.3V to 24V.

-- Input rectifiers: changes the stepped-down AC voltage to DC voltage

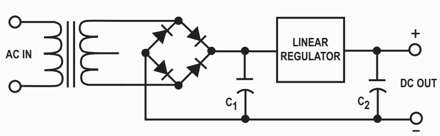
-- Filtering: through the use of output capacitors, smooths the ripple of the rectified AC voltage to an average sustainable level.

-- Output regulation: through the use of series regulator components, provides constant output voltage in relation to line, load, and temperature changes.

-- Isolation: electrically separates the input and output of the power supply to provide both safety and line noise isolation.



(a) Center-Tapped Transformer



(b) Bridge Rectifier

The diagram illustrates the common linear power supply circuit normally used, with the basic transformer, rectification, filtering, and regulation elements shown.

Linear power supplies have many desirable characteristics such as design simplicity, low output ripple and noise, and fast recovery time. They are not however, noted for high-efficiency, especially when compared to today's modern switching power supplies.

The following table illustrates the primary specification differences between linear and switching power supplies.

Linear Vs. Switching Power Supply Comparison

The differences between the two power converter topologies is readily apparent. Switching power supplies have gained in popularity due to their high efficiency and high power density. The key specification of note between the two is the output ripple. Due to the propagation of the higher frequency chopping used in the switching supply, output ripple is generally higher than that of a linear supply, in the range of 100 mV. This can be problematic in low noise requirements such as instrumentation, but these effects can be mitigated with output filtering circuitry. Switching supplies also have slower transient recovery times than linears, but have much longer output holdup times, a characteristic which is important in many computer and instrumentation applications. A more detailed explanation of both transient recovery and hold up time specifications can be found in the glossary at the end of this sourcebook.

Specification	Linear Supplies	Switching Supplies
Output Ripple	.05-2mV RMS	25-100mV Pk-Pk
Input Voltage Range	+/-10-15%	+/-100%, Univ. In.
Efficiency	50-56%	70-90%, w/PFC
Power Density	0.5-1W/In³	5-18W/In³
Transient Response	50µSec	300µSec
Hold-Up Time	2mSec	20-32mSec

The switching power supply has the advantage of a wider input voltage range than its linear counterpart. The linear power supply input range is usually +/-10% and has a direct effect on the efficiency of the supply. With a switching supply, there is little or no effect of the input voltage swing on the efficiency, and the input range is usually 50- 100% by use of universal or auto switch line controls.

The inherent wider input voltage range of a switcher makes the power supply useful under brownout conditions. Also, by using auto switch or universal input control circuitry, switching power supplies no longer require mechanical import range jumpers to automatically adapt to worldwide input line voltage differences, greatly simplifying their application.

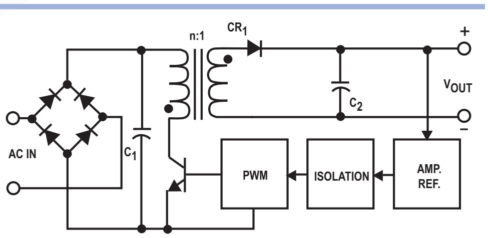
AC Line Voltages of Selected Countries

Country	Volt VAC	Freq. Hz	Country	Volt. VAC	Freq. Hz
Argentina	220	50	Mexico	127	60
Australia	240	50	Netherlands	220	50
Brazil	127	60	China	220	50
Canada	120	60	South Africa	220	50
Denmark	220	50	Spain	127/220	50
Finland	220	50	Taiwan	110	60
France	127/220	50	UK	240	50
Germany	220	50	USA	120	60
Ireland	220	50	Russia	127	50
Japan	100	50	Venezuela	120	60

Lastly, the overall efficiency gains of switching supplies, and the reduction in heat dissipation requirements have given them a distinct power density advantage over linear types. The increased efficiency factor alone has contributed more to the replacement of linear power supplies in most applications to that of switching power supplies.

Switched Mode Power Conversion Basics

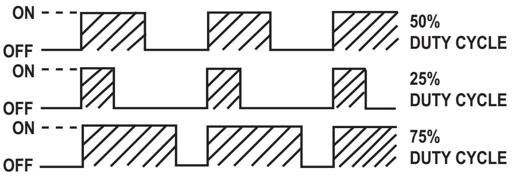
The diagram here shows the simplest form of a common flyback type switching power supply. This type of switcher is normally referred to as an off-line type because of the fact that the DC voltage to the inputs is developed directly from the AC line without first passing through an AC line transformer, as is the case with linear type designs. This line rectified voltage is then stored in capacitor C1, commonly referred to as the input bulk capacitor. Essentially the circuit converts one DC voltage into another by regulating the output voltage duty cycle by means of a pulse width modulation (PWM) control circuit. Pulse width modulation is the method of controlling the



Flyback Switching Supply

ratio of on time to off time of a switching element. In the flyback type shown, the longer the on-time is compared to that of the off time, the more energy is stored in the transformer and then transferred to the output load.

The switching transistor is controlled by the pulse width modulator circuit, and serves as a chopper inverter of the input DC voltage, stepping it up in both frequency and amplitude. When the transistor is on, the current increases linearly in the primary of the transformer storing substantial energy in its core. When the transistor turns off, the field in the transformer core begins to collapse, and causes current to flow in the secondary of the transformer. The secondary current charges the output capacitor and also flows into the load. If the output load increases it is only necessary to increase the on-time of the transistor during which additional current builds up to a higher value, to which a higher current flows in the secondary during the off time. The opposite occurs for a lighter output load, with the output current decreasing in value. By comparing the output voltage difference with a reference voltage in the feedback loop of the PWM, the output is tightly controlled and the PWM automatically keeps the output voltage at a constant value respective of the load demand. This configuration is commonly used for power levels of up to 150W



Pulse-Width Modulation

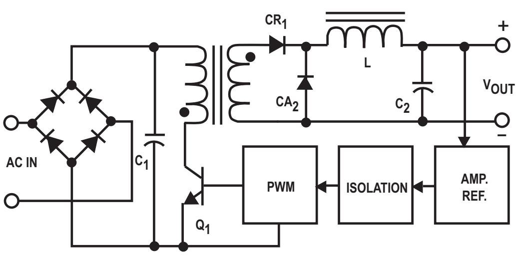
It is important to note, that while directly connected to the output and fed back to the PWM and high power switching elements, this loop must contain isolation in order to separate the DC output from the AC line input for acceptable compliance to safety agency requirements. This is normally accomplished by using an opto isolator, or in some cases, an isolated transformer winding.

Ideally, the flyback regulator circuit is lossless since at any time since the switching element is either at zero voltage or zero current. In practical application however, there are always some switching and losses in the circuit elements due to the high currents involved, particularly in the switching transistor, transformer, diode, and capacitors.To minimize these losses, specialty high power MOSFET switching components and low ESR (equivalent series resistance) capacitors are used. The combination of the switching power design and specialized components make the overall efficiency much higher than that of a conventional linear regulator power supply.

Forward Converter

Another popular switching configuration as shown below is known as the forward converter. Although the forward converter bears some similarity to the flyback type, there are some key differences. The forward converter does not store significant energy in the transformer, but rather in the output inductor. When the transistor switches on, and output voltages generated in the secondary current flows through the diode 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 open load current.

When the switch is off, the current in the inductor cannot change instantaneously. Because of this, current flows from the energy storage element during both halves of the switching cycle, unlike that of the flyback type circuit. Because of this, the forward converter exhibits lower output ripple voltage than a flyback circuit for the same output power level. This type of configuration is used for power levels up to 250W.

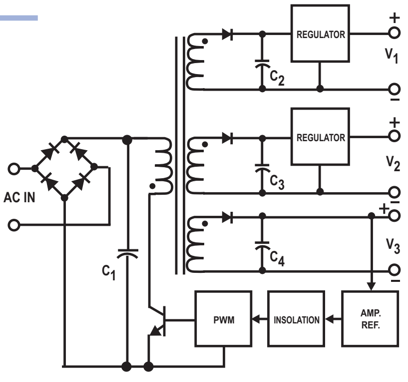


Forward Converter Switching Supply

Multiple Output Switchers

While the examples of switching power supplies to this point have shown single output versions, it is not uncommon for many applications to require multiple and varied outputs. These may range from a switcher with a main +5V logic power output, coupled with dual +/- 12 V outputs, as an example, or +/-15V or simply an additional 24 V output for relays or control loop requirements.

The to the right shows a multiple output flyback switcher. The main 5 V output is fed back to the pulse width modulator to regulate the entire supply. The additional outputs are not directly regulated by the PWM control loop. Some external devices powered from these auxiliary outputs may not require tightly regulated output voltages. However, in applications that require highly regulated output, post regulation circuitry will be used.



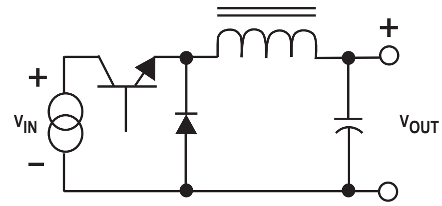
Multiple Output Flyback Switching

Common AC/DC Switching Power Circuit Topologies

There are a number of other topologies for switching power supplies which are commonly employed, and are shown below in simplified form, excluding the common input rectification and filtering sections.

Buck Converter

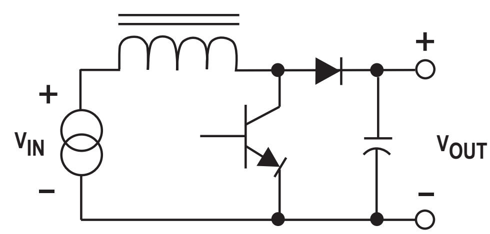
Often used in switching power supplies with output power levels up to 1000 W, the buck regulator shown below operates like a forward converter and there is no input-output isolation for the circuit. The high input DC voltages regulated to a lower level by pulse width modulation of the switch.



Buck Regulator

Boost Regulator

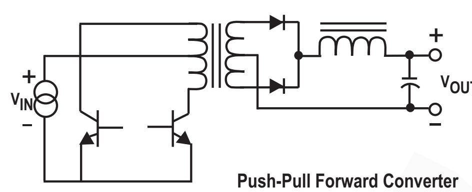
A similar circuit is the boost regulator shown below, which operates like a buck regulator except that the output voltage in this case is higher than the input voltage. The output voltage is equal to the input voltage plus the voltage determined by the switching element.



Boost Regulator

Push-Pull Converter

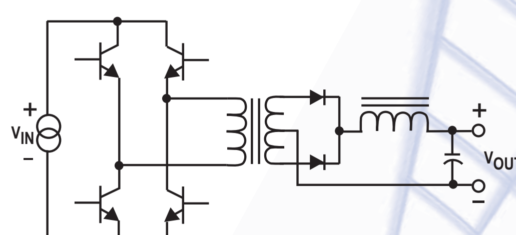
The push pull converter is a variant of the forward converter, with the exception that two switch elements are used on the primary site of the transformer.



Push-Pull Forward Converter

Full and Half Bridge Converters

Another commonly employed topology is the half or full bridge converters, which have variations of the forward converter. The only difference here is the difference in which the transformer primary is driven.



Full Bridge Forward Converter

A Note on Input Voltage Section

Older power supply designs normally employed a mechanical jumper or jumper block to switch in or out transformer windings to accommodate various input voltages, usually ranging from 100 VAC to 240VAC.

Modern switchers utilize “universal input”, which allows these devices to operate from any worldwide line voltage without the need for physical jumper wires. This universal input function can take two forms:

Continuous universal input types rectify the input AC voltage by storing the energy in the input bulk capacitor. This method accommodates any worldwide line voltage from 90 VAC to 260VAC, typically, and it is normally used on switchers below the 200 W level. In contrast, stepped input methods utilize input circuitry to detect a 115 or 220 VAC nominal input, which in effect, sets an internal “jumper wire”, similar in function as the manual jumper technique described above.

Power Factor Correction

The intricacies of power factor effects are complex and far beyond the scope of this technical section. In essence, the power factor of an AC power system is defined as the ratio of the real power flowing to load to the apparent power, normally quantified as a number between 0 and 1, frequently expressed as a efficiency rating percentage, (ie: 0.5 power factor = 50%, 0.9 power factor = 90%, etc.)

In an electric power system, a load with low power factor draws more current than one with high power factor for the same amount of useful power that is transferred. These higher currents increase the energy loss in power distribution systems and require larger wires and equipment to minimize their effects. Because of the costs required for additional power equipment to supplant the wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where greater power is used due to low power factor ratings.

Switch mode power supplies, by nature of their design draw current from the AC line in short pulses when the mains instantaneous voltage exceeds the voltage across the bulk input capacitor during the remaining portion of the AC cycle that this capacitor provides energy to the power supply circuitry. This results in high harmonic content and relatively low power factor, creating extra load on the utility lines. These harmonics can be removed through the use of filter banks, but such large filtering capability can be expensive to implement.

In 2001 the European Union put standards in place per the IEC/EN61000-3-2 to set limits on harmonics of the AC input current for power supplies above the 75 W power level. To comply with these requirements, which have been adopted worldwide, switching power supplies normally include an additional power factor correction (PFC) stage in their design. Such power factor correction circuitry can take two forms, either passive, or active.

Passive PFC uses a filter section as a simple and low cost way to control the harmonic current by using a filter design that passes current only at line frequency (50-60Hz). This type of filter requires large value and high current inductors, which can be bulky and expensive to implement on compact power supply products.

Active PFC utilizes an additional boost converter circuit element to maintain a constant DC voltage on its output while drawing current that is always in phase with and at the same frequency as the line voltage. These control and synchronization elements are available in specialized semiconductor form designed specifically for use in switch mode power supplies, greatly simplifying active PFC implementation.

In comparing the two types of power factor correction, switch mode power supplies with passive PFC filtering can achieve power factor ratings in the range of 0.7-0.75. Active PFC control techniques can yield power factor ratings of up to 0.9 -0.99. By contrast, a conventional switch mode power supply without any PFC correction has a typical power factor rating of only 0.55-0.65.

Whether of an active or passive type, the additional components required make PFC enabled power supplies more expensive than their non-PFC counterparts. Therefore, careful consideration should be given to the level of PFC that may be required.

Key Switching Power Supply Parameters

When specifying a switching power supply, there are a number of factors to be considered. Some of these key specifications are described in this section. Please be aware that these descriptions are for general information, and the manufacturer's product data sheet should be referenced for detailed parametric information.

Input Voltage and Frequency

Most switching power supplies are rated for nominal 120 VAC or 220 VAC operation, with the input range specified over 85-264VAC to account for variances in the input AC supply line. Often, with a switching power supply, either AC or DC input is acceptable. The frequency of the AC mains is generally 50 Hz or 60 Hz. Taking into account a normal deviation of +/-3 Hz mode, switching power supplies are designed to except input frequency within the range of 47-63 Hz. In some applications and input frequency of 440 Hz may be acceptable but may result in increased leakage current.

Inrush Current

Because switching power supplies utilize a large capacitor across the input, a sizeable input peak current is required to charge this empty bulk capacitor when the AC is initially turned on. This momentary peak is called the inrush current and the magnitude varies according to the type of current limiting circuit that is being used within the supply. Switching supplies commonly use a thermistor on the input line to limit the inrush current. The high initial resistance of the thermistor limits inrush current at start up. While this high inrush current is only momentary, it may be enough to blow fast acting input line fuses. As such, an appropriately sized slow blow fuse should be used. Additionally, to minimize the accumulation of inrush effects, the power supply should not be cycled on and off rapidly. Generally, after turning off the supply, there should be a delay of several seconds before re-powering.

Leakage Current

The leakage current is defined as the small currents flowing from earth ground to the system ground (such as the case). Due to EMI requirements in a switching power supplies, there are "Y" capacitors connected between AC line and neutral in the earth ground. Due to this configuration, a low current will flow through the Y caps to the frame ground. In practice, leakage current is regulated to comply with applicable safety standards, typically IEC 60950, where leakage current should be less than 3.5 mA for portable Class I equipment, 0.75 mA for handheld Class I equipment, and 0.25 mA for Class II equipment. In the case of medically approved power supplies, the IEC 60601-1 specification may be more stringent.

Input/Output Isolation

Isolation of the DC output section from the AC mains input is an essential safety feature of switching power supplies. In general, this breakdown voltage rating is 3KV AC for commercial products and 4KV AC for medically rated products. Per safety agency requirements, this specification is 100% tested at the factory to assure compliance.

Output Voltage Tolerance and Adjustment

The nominal output voltage of the switching supply is specified as being measured directly at the output terminals with minimum load as specified, usually 5% of the total rated power output. In general the tolerance specification takes into account line regulation, load regulation, cross regulation, and initial setup tolerance. Typically, an output adjustment potentiometer is provided to compensate for initial and wire losses for remote located loads, and usually provides -5/+10% adjustment range. When adjusting the voltage, care should be taken not to exceed the overall voltage rating as referenced to the output connections of the power supply. In addition, increasing the output folder each above nominal will reduce the maximum output current that can be supplied with out triggering the overcurrent protection circuitry.

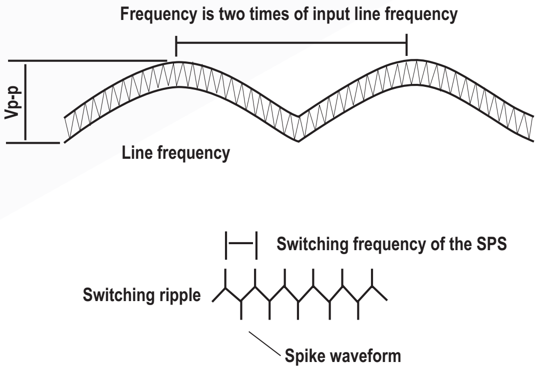
Maximum Output Current/Power

Simply put, maximum output of a power supply is defined as Iout x Vout. If the nominal output voltage is increased through adjustment as described above, the output current must be reduced proportionately as to not exceed the overall power rating of the power supply. As an example, a power supply with a 50 W rating can provide 5V at 10 A. Even slightly adjusting the output to 5.5V reduces the output current to 9A. Exceeding this rating places stress on the power semiconductor components and reduces overall operational life (MTBF).

Ripple and Noise

Due to the high frequency switching of higher voltages encountered in switching power supplies, the DC output contains two AC components known as ripple and noise. The first component, from the sine wave rectification is a low frequency which is approximately 2 times the input frequency. The second component is that of the higher switching frequency, normally 25 kHz or more. An equivalent waveform is shown.

In some applications, such as low noise instrumentation, the effects of output ripple and noise may be troublesome. The addition of 0.1μF and 47μF capacitors from output to ground can minimize these effects. Output wiring and PCB runs should be kept as short as possible to minimize propagated noise.



Output Ripple & Noise

Nominal Load

Due to their inherent design, switching power supplies often require a minimum output load to maintain regulation of the output voltage to stated specification tolerances. This minimum is typically 5% of the total output power, though may be as low a requirement as 1%. In cases where the minimum load cannot be maintained during steady-state operation, a pre-load resistor may be required on the output. This resistor must be rated to continuously sustain the minimum load power dissipation.

Setup Time, Rise Time and Hold Up Time

Setup time is the time required for the power supply to reach 90% of the rated output voltage per regulation specifications. This specification is directly related to output load, and may be as long as1 to 2 seconds in duration.

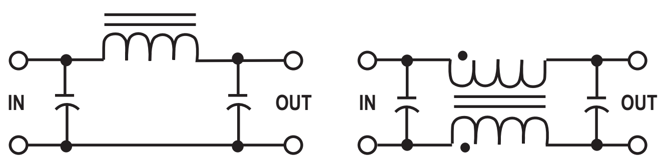
Rise time is the time it takes for the output voltage to rise from 10% to 90% of the rated output and assumes a minimum starting load of 10%. The specification is usually within the range of 50 ms.

Holdup Time is the time that the DC output sustains itself down to 90% of rated output once the AC power is shut off, typically 16 to 32mS. This specification is important when the system is used in conjunction with a UPS or other backup power system, in that it gives the backup power time to switch in before the output of the power supply collapses. This holdup time also serves to isolate the power supply output from the effects of momentary line sags or dropouts.

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 the short burst of high frequency energy caused by the rapid switching voltage and current transients in the power supply and are repeated at the switching frequency of the power supply.

Conducted EMI/RFI is the noise fed back from the power supply onto the AC power line, which can then present itself at other AC line connected components. To minimize these effects, an input Pi filter for differential mode noise or balun and capacitor filter for common-mode noise can be used. Examples of each are shown here.



Input Filters for Switching Power Supplies

Over Current/Over Load Protection

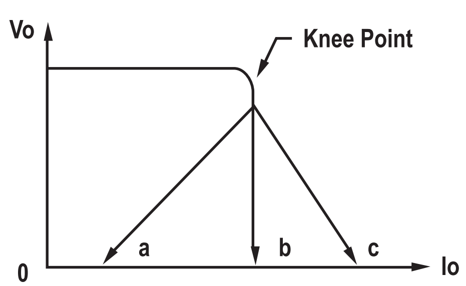
To safeguard the system circuitry and prevent power supply damage in cases of temporary catastrophic overload, most switching power supplies include over current and over load protection on the output. In general, this range is between 105% to 150% of the rated output. This protection may take several forms as illustrated in the diagram below:

1. Foldback current limiting: the output current is folded back to 20% or less of the rated load current (curve A)
2. Constant current limiting: the output current remains constant and within the specified range while the output voltage drops to a low-level (curve B)
3. Overpower limiting: the output power remains constant. As the output load increases, output voltage decreases in proportion (curve C)
4. Hiccup or pulsed current limiting: under overload conditions, the output will keep pulsing on and off repeatedly when the protection is active. The power supply will recover when the fault condition is cleared on the next pulse.
5. Shut off: the output voltage and current are cut off and locked when the output power reaches of protection range.

Recovery of the power supply from the over current protection mode usually occurs in one of the following ways:

-Auto recovery: the power supply recovers automatically on the next cycle when the over current with the over load condition is removed.

-Repower: the power supply requires a manual restart by cycling the input AC power off and on.



Over Load/OVP Operation

Over Voltage Protection

In the case of an output regulation malfunction, the output voltage of the power supply may rise above the rated value. Under this condition, the OVP circuit will trigger to prevent catastrophic system component damage. This OVP protection takes two forms:

1. Shut off: the output shuts down completely and can be restarted by cycling the AC input power off and on.
2. Hiccup voltage limiting: similar to over current protection, the output voltage keeps pulsing on and off repeatedly when the protection is activated. The power supply automatically recovers when the fault condition is cleared on the next pulse.

In general, consideration should be given to the type of loads that are being driven by switching power supplies to prevent erroneous or premature triggering of either the over current protection or over voltage protection functions. Static resistive loads have virtually no effect in false triggering of these functions. Highly capacitive or inductive loads, such as those from motors or electrically driven mechanical actuators can present high levels of “out rush” currents or back/reverse EMF voltages that can trigger the current overload protection or OVP circuitry. Care should be taken to minimize these effects through the use of blocking diodes or similar means of protection. In extreme cases, output fusing may be required to prevent repeated events that may damage the power supply protection features or the power supply itself. It may be necessary in some instances to utilize a larger power output supply to accommodate these loads.

Additionally, proper grounding and ground loop elimination practices should be used. Modifying or disabling the OVP or current overload protection circuitry should never be attempted, as this can lead to circuit damage and possible personal injury.

Output Power Derating Factors

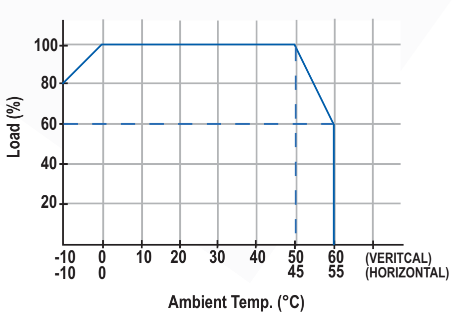
The output power and overall performance of the switching power supply is affected by two primary conditions: ambient temperature and input voltage.

Output Power Rating Vs. Temperature

The graph shown to the right illustrates the relationship between the ambient temperature and output power rating of the switching power supply. Ambient temperature affects all electronic systems, none more so than the power supply, due to the self heating caused by power conversion process itself.

As shown for a typical switching supply with an ambient operating range of 0-50°C, the power output capability rolls off dramatically above 50°, and shuts down completely upon reaching 60°C. Conversely, temperatures lower than 0° affect the efficient startup and operation of the power supply, due to the higher component resistance encountered at low temperatures. To minimize the derating vs temperature effects, proper ventilation and mounting of the power supply for maximum convection airflow should be considered. If necessary, fan cooling should be provided.

Output Power Vs. Temperature Derate

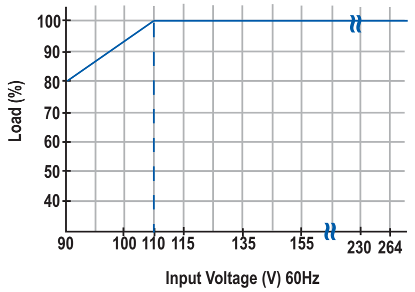


Output Power Rating Vs. Input Voltage

The curve to the right shows the relationship of output power to input voltage for a switching power supply with a rated input specification of 110 VAC to 264 VAC.

If the input AC power drops below the 110 VAC lower limit, the efficiencies caused by dynamic component operation in the input section of the power supply circuitry limits the capability of full power operation, and must be derated accordingly. Should the input voltage drop below the lower limit, as in the case of severe brownout conditions, the input fuse may blow or the power supply may shut down completely.

Output Power Vs. Input Voltage Derate



Temperature Coefficient

Stated as a percentage of output change under normal operating conditions and directly related to ambient temperature, is expressed in terms of %/º C. Typical specification for temp coefficient is +/-0.03%/º C over the rated operating temperature range. Once the power supply is turned on and stabilized, temperature coefficient effects, though additive to regulation, are usually minimal.

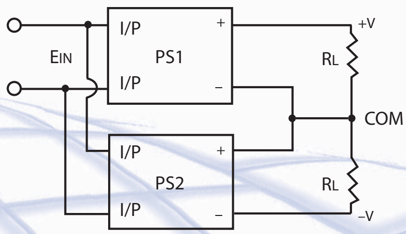
Remote On/Off Control Operation

A number of switching power supplies and DC/DC converters offer a remote On/Off control function of the output. Most types utilize a Logic Level Inhibit operation where Logic "1" = Power On, and Logic "0" = Power Off. Generally, these are designed to be operated by pulling the ON/OFF ("Control") Pin low (Minus input or Output Return in some cases) to inhibit converter operation. If this function is not utilized, the Control pin may be left floating, as it is pulled high internally. Refer to the manufacturer's detailed specification sheets concerning this feature.

Series Operation

In application situations requiring output voltages outside of the normally available standard outputs, power converters can be operated with the outputs connected in series as shown in the diagram to the right.

However, it is important to note some limitations:
1. The output of one converter could affect the feedback loop of another.
2. The ripple voltage of the outputs will be additive.
3. The total combined output voltage should not exceed the working breakdown voltage of any one of the converters.
4. Reverse bias diodes should be utilized across the output of each supply to protect each output from the reverse voltage of another.

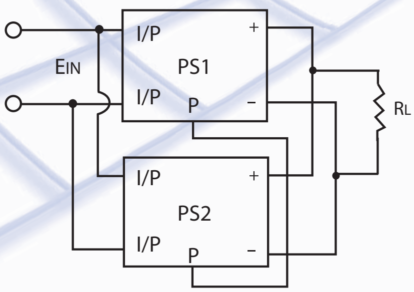


Series Operation

Parallel Operation for Increased Power Output

Unless the power supply is specifically designed for parallel operation, parallel operation is not recommended. Two output voltages from two discrete fixed output converters cannot be held exactly equal. The converter with the higher output will try to provide the full load, causing it to go into premature current limit. The second supply will then do the same. Even if an adjust function is used to set the outputs, any drifts with time and temperature will cause the same reaction. An example of parallel operation with power supplies equipped with this function is shown to the right.

General guidelines for parallel operation:
1 Output voltage tolerance should be as small as possible, < +/-2%
2. Parallel connections between the power supply outputs should be kept as short as possible and use large AWG sized wire.
3. Maximum output power should be limited to 90% to assure continuous operation.

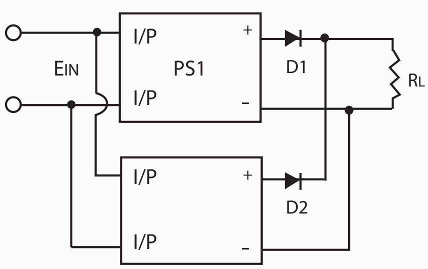


Parallel Operation with Control

Parallel Operation for Redundancy

Connecting standard power converters in parallel for power redundancy is an acceptable practice. The converters must have their outputs connected in parallel through two blocking diodes, as shown to the right.

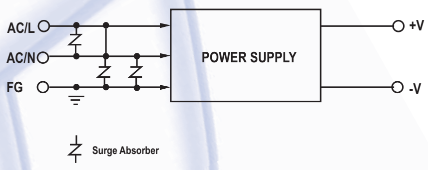
Each converter must be capable of driving the full load. The diodes permit one output to fail without affecting the other. The blocking diodes should be sized and heatsunk, if necessary, to accommodate the individual power supply's maximum power output.



Input Surge Suppression

In situations where power converters may share the main AC trunk line with heavy industrial equipment, the power supply input may be subjected to surge voltages in excess of the rated line specification due to the effects of the shared heavy equipment cycling off and on. In addition, the local power grid in some countries may be subject to frequent sag and surge conditions. In either of these situations, it is prudent to provide some form of protection on the power supply AC input.

Methods for protection include basic zener diodes, thermistors, or the new generation of protection that is afforded by self-resetting Tranzorb™ or PolySwitch™ devices.



Input Surge Protection

Extreme Environments

In extreme applications, power supplies and their associated electronic systems may be subjected to physical phenomena, such as lightning strikes, that far exceed the power supply ratings as well as those of the protection devices that may be used. Classic methods employed may include fast acting circuit breakers and/or gas discharge tube protection devices. While these may provide complete protection under remote strike and effect conditions, in reality, most electronic devices will not survive a direct or near strike of this magnitude. External grounded shielding or enclosures rated for industrial or outside use are the best protection under these circumstances.

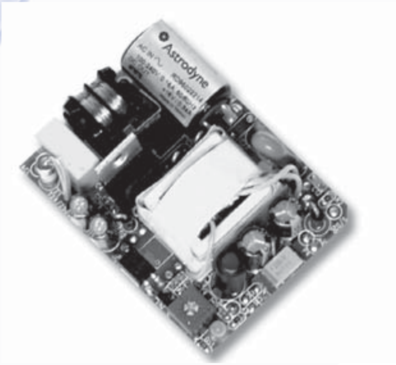
Switching Power Supply Package Styles and Attributes

Switching power products are available in a number of package styles that are suited to particular application requirements. Some offer broad range application use, while others are geared to conform to a particular set of mechanical, environmental, or industry-specific defined performance and certification requirements.

Open Frame

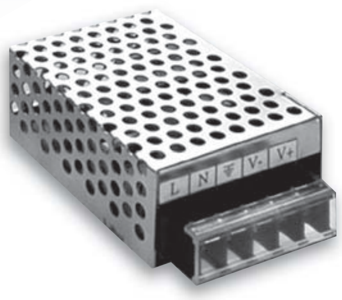
Perhaps the most widely used of all switching power supply formats, the open frame style offers the designer both moderate to high power density and low-cost. Available in sizes ranging from 1" x 2" miniature module types up to 7" x 4.25" high power versions with single and multiple outputs, the open frame switching supply is available in both commercial and medical versions. The most popular format for this product type is the industry standard 3" x 5" package, which is available in power levels up to 125 W.

interconnections are typically made utilizing standard type locking pin connectors, though screw connections and ultraminiature connectors are also offered. Features may include universal input, power factor correction, OVP, and EMI filtering.



U-Channel and Enclosed

Incorporating an open frame type design with a rigid three sided metal enclosure, the U- channel style enclosure provides not only mechanical stability but a greater degree of user protection over open frame configurations. The additional metal shell also provides needed heat sinking surface to extend the ambient operating range and overall MTBF of these higher power products. Interconnections are typically made via either locking style pin connectors or screw terminal blocks. Integral threaded holes in the U-channel simplify mounting. The fully enclosed variant of the U-channel incorporates a top cover to fully shield all components of the power supply. This provides not only full user protection, but may also incorporate a ventilation fan into the top cover to provide additional power supply cooling in extreme ambient conditions. Since it is enclosed, this type of packaging can be used internally to a system, or adapted for open air use as in DIN channel type mounting configurations.



Encapsulated Modules

Due to their fully encapsulated construction, these types of modular products are ideally suited for applications that may be subjected to shock and vibration or humid and dirty ambient environments. Available in either pin styles for onboard use or screw terminal versions for wall or bulkhead mounting, encapsulated modules were originally offered as linear power types though switching power types are now the standard.

Besides providing hermetic protection for the internal power supply components, the encapsulation material is thermally conductive. This eliminates both internal hotspots within the device as well as extends the ambient operating range of the power supply through efficient dissapation. The encapsulation material also provides a high degree of internal isolation, making medical versions of this type of product commonplace. Though more costly than open frame styles, the small size and ruggedness of the encapsulated power supply make it the ideal choice for many environmentally harsh applications.

DIN Rail Mount

DIN rail mount power supplies are characterized by the unique package and mounting style as defined by the former German DIN 46277 standards, now European standard EN50022 (35mm width), 50045 (15mm width), or 50023 (7.5mm width) mounting rail. Originally specified for use in Europe, it has become a worldwide standard for mounting power supplies, circuit breakers and industrial control equipment inside standardized equipment racks and system enclosures.

Besides the mechanical standardization, DIN power supplies are designed to meet the UL508 electrical performance standards for use in industrial equipment. The unique package shape and mounting allows multiple DIN power supplies to “stacked” side by side on the rail for secure mounting and connection of electrical wiring via screw terminal connections, and allows easy addition or replacement as required.

External Power Adapters

With the development of portable electronic products it became impractical to include a power supply within the design, not only because of the additional weight but also the small size of the device itself often precluded a built-in power supply. As such, the external power adapter has come into wide use today. Common configurations range from the wall plug type most often seen with cell phones or portable entertainment devices, to the higher power external boxes commonly associated with laptop computers and associated peripherals. Taking the power “out of the box” of the system itself presents several advantages to the designer. First and foremost, by having the high power line connected components remote to the system eliminates the need for safety agency approval of the entire system, making product updates and revisions easier to do without the need of safety recertification. Also, since the power supply is usually a prime source of heat, overall system thermal considerations are significantly reduced.

The external power adapter is most often a high impact plastic package surrounding an open frame switching power supply. An IEC 320 type power socket and universal input allows one basic design to be used in a variety of countries with differing inputs voltages and plug configurations by simply utilizing an input line cord with connectors specific to that country. In the case of wall-mounted external adapters, snap in plug adapters allow easy configuration for multicountry use. Because of these design advantages external adapters are now used in most consumer products as well as many test instrumentation and portable medical devices.

Specialty LED Lighting

A new class of power supply and packaging has been developed specifically for the LED lighting markets, where NEMA 3 enclosures and UL1310 class 2 compliant outside wet location operation is required. Similar in appearance to conventional fluorescent light fixture ballast packages, this class of power supplies offer power factor correction, IP64 level isolation, and constant current control operation to meet the requirements of LED lighting systems. The specific packaging style of these power supplies allows retrofit of existing standard enclosures for LED lighting, while assuring compliance to all safety specifications. Moreover, input and open connections are made through standard stripped wire leads and can be installed and serviced by qualified electricians per applicable construction and wiring codes.

DC/DC Power Conversion

When assessing a product or system's power requirements, the designer is often faced with a mix of logic, analog processing, and control circuit elements, each with their attendant unique power demands. In defining the power architecture as a whole, different voltage requirements, along with the varied output power needs of each can result in greatly varied levels. As an example, common to most modern electronic products and systems, there is a mix of microprocessor/logic circuitry. These diverse branches can range from tens of amps on the main circuitry, to tens of milliamps on the lesser support portions. If limited in number, such as 5V and +/-12V, a single multiple output AC/DC power source may suffice. If more varied, as in a system with +3.3V, +5V, and +/-12 and +/-15V requirements, a single power source may be impractical from a cost or packaging standpoint, or at worst, not available at all.

To address these limitations, the DC/DC converter is often used to meet the "point of power" needs of each circuit section. In addition, the use of a DC/DC can simplify system power routing by reducing the number of branches needed, often to a single "bulk" power main. There are other advantages that single point or distributed DC/DC power conversion can provide beyond simple power conversion.

DC/DC Application

Use of DC/DC converters in any application falls into one of two primary methods - local or distributed power. A typical "on-board" or single point application is shown below. A primary power supply main voltage is presented at the circuit board, and an in-board DC/DC converter is used to derive the necessary differing voltage for the local circuit. In some cases, a non-isolated IC type DC/DC may be used. Many handheld or other battery-operated portable consumer type devices utilize this approach.

In more power demanding (5W to 20W) applications, a discrete modular DC/DC converter is required to not only derive the required voltages, but also galvanically isolate and tightly regulate the sub-circuit power.

In distributed power applications, the single point DC/DC converter configuration is replicated across numerous system boards, utilizing the same or different output DC/DC converters as required by each sub-circuit in the system. The distributed power concept has several advantages over routing a main supply's multiple outputs throughout the system:

1) Reduction of wiring: In systems requiring high current, multi-voltage power, routing multiple power outputs (such as +5V, +/-12V, +3.3V) throughout a system requires complex power harnessing, and may be physically impractical due to the large AWG sizes required. Voltage drops and power-to-signal noise crosstalk can develop, especially in high frequency logic or communications systems.

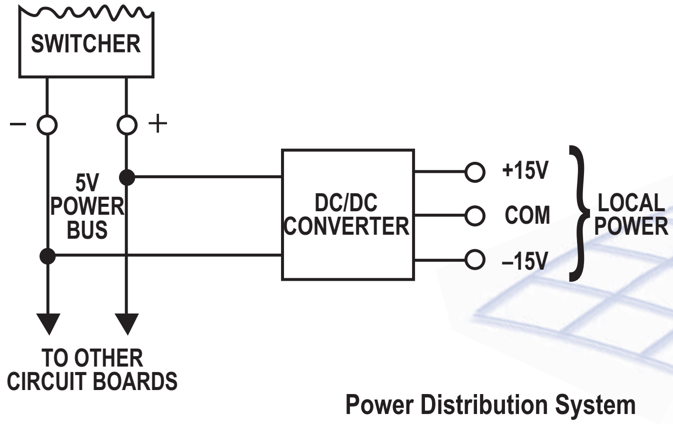
2) End point adaptability: As newer technology develops, updating legacy systems may require the introduction of new voltage levels on portions of the system circuitry, as seen by the recent migration of logic and instrumentation circuitry from the +5 V to the +3.3 V power standard. Another requirement may be to provide a differential dual output (such as +/-12V or +/-15V as often required for analog control or instrumentation amplifiers) from a single-output +5V main supply. In power-hardwired systems such a change would necessitate additional power wiring to be added, or in some cases, replacement of the main system power supply itself.

DC/DC converters are an efficient and convenient way to upgrade sub-circuit sections without complete power architecture revisions.

3) Circuit isolation: In mixed-signal systems containing both high-speed logic and sensitive analog instrumentation circuitry, the galvanic isolation and common mode power and ground isolation provided by DC/DC converters becomes mandatory in preserving system signal separation and integrity.

4) Voltage regulation: In distributed power systems where a large bulk power supply is used for main branch power, tight regulation of the output may be affected by AC line variances, or in the case of generator or battery-backed systems, by inherent instability of these sources. Due to the lower branch circuit power demands, DC/DC converters can provide significantly improved output power regulation at the point of power.

5) Fault tolerance: By separating power demands into distinct isolated branches powered at the local level with DC/DC converters, failure of one circuit within a system will not result in failure of the entire system. Repair of encounter problems can be addressed quickly by hot swapping out the affected sub circuit with a replacement board.



Power Distribution System

DC/DC Topologies

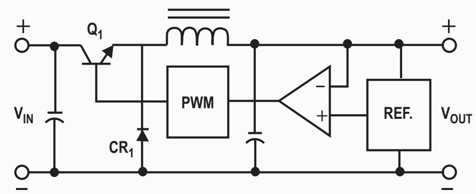
DC/DC Converters as a whole fall into two self evident categories: up converter or down converter. The up converter “steps up” the input mains voltage to a more suitable higher-level output voltage. The down converter, often referred to as a regulator, reduces the input mains voltage to the required lower voltage output.

Unregulated DC/DC Converters

In applications where the input voltage is applied by a regulated main power supply and output load is fairly constant, an unregulated DC/DC may suffice. The main advantages of this approach are low cost and smaller size, often in IC form. With constant loading, typical regulation is within +/-2%, acceptable in many applications.

Switching Regulator

The diagram to the right illustrates a typical three terminal, non-isolated switching regulator, most often used to convert a higher DC voltage into a lower one. The advantages of this type of circuit is that it often provides a wide range input voltage, as high as 4:1 and may be used for output power levels up to several hundred watts. The configuration is identical to that of a buck regulator as described in the section on switching power supplies. The output voltage is compared with a reference voltage and the difference drives a pulse width modulator which in turn drives a switch. The energy stored and delivered in the inductor is determined by the on- to off-time ratio of the switch. There is no input-output isolation, as the common ground is shared between the input and output sections of the device.



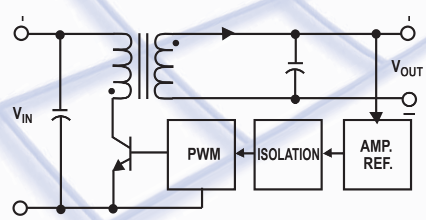
Three-Terminal DC/DC Converter

Wide Range Input DC/DC Converters

To achieve the full benefit of DC/DC conversion in relation to input line variances, typically +/-20% or greater and with high efficiency, the converter must operate like switching power supply by utilizing pulse width modulation, either in a flyback or forward converter topology.

Flyback Converter

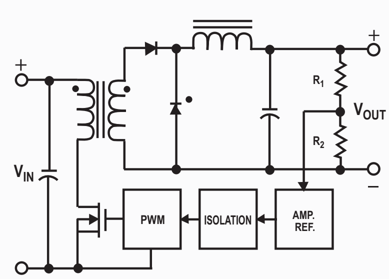
The figure here shows a DC/DC using the flyback conversion method. Operation is identical to the flyback type switching power supply. DC/DC converters of this type are isolated from input to output, requiring the feedback loop to be also isolated, often with an opto isolator circuit.



Flyback Type DC/DC Converter
for Wide Range Input Voltage

Forward Converter

Another example of a wide input range configuration shown to the right is the forward converter, and utilizes a power MOSFET switch which operates at higher switching frequencies than bipolar, increasing overall efficiency and reducing component size. The circuit functions identically to the forward converter switching power supply, and can operate with greater than a 2:1 input voltage range.



Forward DC/DC Converter
Using Power FET Switch

Synchronous Rectification

Conversion efficiency can be a deciding factor when specifying DC to DC converters, as the conversion process dissipates power due to the inherent inefficiencies of the components used. Flyback and forward types of DC/DC converters operate in the 65% to 75% efficiency range, depending on load variation. In sub-30 W power applications, such efficiency ratings are acceptable. In higher power applications of 50 W to several hundred watts, higher efficiency, and the resultant lower power dissipation is key to overall system reliability.

Synchronous rectification techniques can increase overall DC/DC converter efficiency up to 80-90%. This efficiency improvement can have dramatic thermal reduction results, greatly reducing heat sink and/or fan cooling requirements. Essentially, synchronous rectification is where the output rectifier diodes are replaced with high-power MOSFETs, resulting in lower conduction losses. In addition, unlike conventional diodes that are self conducting during the conversion cycle, the MOSFETs are turned on and off by means of control circuitry that is synchronized to the load demands and response required on the operation of the converter circuitry.

The introduction of intelligent synchronous rectification controllers by power IC manufacturers make this task easier to do. While adding some additional cost and circuit complexity, the benefits of greatly improved efficiency and reduced thermal stress on the overall system make synchronous rectification a must in any high output demand distributed power system.

DC/DC Converter Package Types

DC/DC converters are available in a number of package and pin-out styles to fit virtually any output power and size requirement.

Single In-Line Package (SIP)

The SIP package offers the ultimate in a small (0.24"x0.77"x0.4") package size for power needs of under 1W. Available in single and dual outputs on standard footprints, these solid encapsulated devices offer isolation up to 500V, and internal filtering. Input voltage is fixed, within +/-5% being typical.

Dual In-Line Package (DIP)

Formatted on the standard (0.8"x1.25"x0.4") 24 pin DIP socket pinout, these DC/DC's are available in single and dual outputs at power levels up to 6W. Fully encapsulated and isolated to 500 V, the DIP style is commonly specified for on-board use due to a standardized pinout.

Modular and Open Frame Packages

Most commonly offered in the standard 1"x2" and larger power 1.6"x2" encapsulated pin module styles, this group of products have become available in recent years in the "open-frame" non-encapsulated format to meet the unique needs of telecom applications. With power output up to 15W, and wide input voltage ranges of up to 4:1, this class of DC/DC converters has seen widespread use across many applications, from instrumentation to telecomm. In addition, the larger format over those of SIP/DIP packages allows isolation up to 1500V and greater internal filter capability, thus simplifying overall system design. Metal cases on the encapsulated versions, and integral finned heat sinks on the open frame types extend their overall operating temperature range and MTBF rating.

Large Format Open Frame with Case

Designed for use in applications requiring 50W or greater, this type of DC/DC converter uses an open frame board and metal case/heatsink configuration similar to U or enclosed switching power supplies. Though a pin module in connection form, the additional case/heatsink surface greatly improves power dissipation in the higher power operating ranges of these products. Available in single and multi-outputs with isolation of 1500V and efficiencies to 85%, these products are commonplace in large distributed power telecom systems.

Key DC/DC Converter Parameters

Input Voltage Range

When specifying a DC/DC converter, beyond the obvious output voltage/current needs, input voltage considerations are critical. While most input voltage sources such as bulk power supplies, are stable and well regulated, battery or similar unregulated power sources can be subject to wide voltage swings. As an example, in the case of a “standard” 12V battery, the output can vary from 9V to 16 volts, with the nominal low-load output being 14V. Fixed input range DC/DC products that are specified at 12Vinput at +/- 10%, offer a 10.8V - 13.2V range - unacceptable for battery sourced applications. A more acceptable 9-18V input range DC/DC is required in this case. Similar loosely regulated sources such as industrial loop power (+24-28V), or aerospace power architectures can present challenging wide input voltage swings.

While most fixed input DC/DC converters are found in the sub-2W range, most other products today offer 2:1 or as high as 4:1 ranges, from 9V to 72V input. Common 2:1 ranges available are 9-18V (for 12V nominal), 18-36V (for 24V nominal), 36-72 (for 48V nominal). For 4:1 ranges, 9-36V and 18-75V are readily available. For maximum useable range, is is best to select an input range with a mid-point closest to the nominal (loaded) source voltage.

Input Surge Voltage

On occasion, rapid on/off cycling or primary power surges may subject the DC/DC to an input voltage surge in excess of its rated value. Input surge is specified as a maximum voltage level over a fixed duration period, ie: 50V @ 10mS. This feature is only intended to withstand momentary surge conditions, not sustained levels, which will result in damage to the DC/DC converter.

Startup Voltage

Startup voltage is defined as the minimum input voltage required for the DC/DC to initially turn on and reach specified output levels, with nominal load applied. Unless specified otherwise, the minimum startup voltage should be the lowest voltage specified by the input range. The startup voltage can be adversely affected when the DC/DC is driving highly capacitive or inductive loads.

Output Initial Accuracy

Like any switching power device, a DC/DC output voltage accuracy is dependent upon the manufacturer’s recommended minimum operating requirements, usually at 10% of output full load with nominal input voltage, as measured directly at the output of the DC/DC. Under these conditions, initial output accuracy is specified in terms of percent of the nominal output voltage, typically +/-1%.

Output Voltage Trim

Many DC/DC converters provide a trim connection, where an external adjustment potentiometer may be connected to provide output voltage adjustment to compensate for output voltage drops due to remote-located loads. Typical adjustment range is in the order of +/-10%. It should be noted that even a slight increase in output voltage over that nominally specified can reduce total output current capability. Under no condition should total power exceed the specified rating of the converter.

Line and Load Regulation

Line and load regulation are specified from 20%-100% of full load. Though small percentages, these, as well initial accuracy, are additive when considering total regulation performance.

Switching Frequency

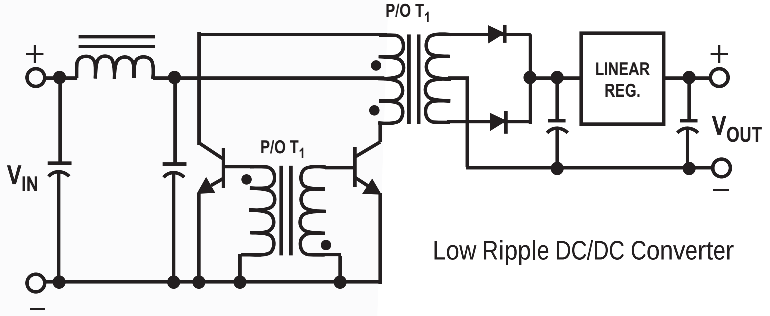
Like AC/DC switching supplies, DC/DC converters rely upon the same input voltage chopping and frequency stepped techniques to reduce component size and provide high power per square inch performance. Typical DC/DC operating frequencies are in the range of 200Khz - 450Khz. Depending on the design, this frequency may be fixed or may vary with load and line changes. Because of the potential EMI and conducted noise issues that may result, care should be taken in ground loop prevention and shielding to minimize propagation of the potential frequency effects throughout the system, especially where sensitive instrumentation circuits are used. Modular DC/DC products utilize internal shielding or metal case shields to minimize the "broadcast" effects, though good PCB layout guidelines should be observed to locate on-board sensitive circuitry away from the DC/DC section of the board.

Ripple and Noise Effects

As with AC/DC switching power supplies, the high frequency of operation can produce unwanted switching noise superimposed as an AC component on the DC level, usually specified as a peak to peak value. This noise takes two forms: input reflected ripple and output ripple and noise. A key consideration when using DC/DC converters is the effects of input reflected ripple current, which is generated at the input of the DC/DC and fed back to the input voltage source. This ripple may then be carried to circuitry directly connected to the main power source, such as 5V logic power, where it may cause unwanted spurious effects.

This ripple can be suppressed to a low percentage by using an input Pi type filter. Most higher performance DC/DC converters include such a filter internally, though if required, a simple Pi filter, as shown in the AC/DC switching power section of this guide can be implemented externally.

A circuit technique utilized by power supply designers to reduce the amount of reflector ripple current is to separate the drive transformer from the power transformer, as shown in the circuit diagram below By having the oscillator and associated drive take place in a small transformer during saturation substantially reduces the cost of reflected ripple current.



Low Ripple DC/DC Converter

Output Ripple and Noise

Output ripple and noise, also specified as a peak to peak component, is typically in the range of 50 mV to 100 mV. In most cases, the output ripple can be adequately suppressed by using a 33µ or 47µF electrolytic capacitor in parallel with a 0.1µF capacitor placed across the positive to common output(s). Such bypass components may also be used directly at the pins of sensitive components in the circuit itself. More complex filtering may be required in some instances, but usually the simple capacitive filtering will provide adequate ripple and noise suppression.

Radiated Noise

To a lesser degree, though worth consideration when DC/DC converters are used in sensitive circuitry, is the EMI radiated noise that may occur with any high-frequency component. To minimize these effects, most DC/DC converter products include shielding, either in the form of internal copper shields within a plastic cased device, or by means of the case itself, in metal cased devices. Because of the standardized design practices, EMI noise effects of any substantial level are rare. To minimize the potential of EMI effects, sensitive circuitry should be located away from the DC/DC converter.

Overcurrent Protection

DC/DC converter products typically include some level of overcurrent protection to prevent destruction of the device during overload or short-circuit conditions. This protection may take the form of thermal limiting, though more often it is in the form of output current monitoring and control, which will shut down the converter when overload conditions are sensed. The converter will attempt to self start via automatic reset, or “hiccup” mode. Overcurrent protection trigger sensitivity varies, but is typically within the range of 110% to 150% of the rated output current of the device. Response time is set wide enough to eliminate accidental triggering during load spikes.

Overvoltage Protection

Should the internal regulation circuitry fail and cause the output voltage to rise above the specified level, output protection will short or “clamp” the output power to prevent catastrophic damage of external circuitry. This shorting action will also activate the overcurrent protection, effectively shutting down the converter.

On/Off Control

Some DC/DC converters offer a convenient way to turn the converter on or off using a logic level control signal. This functionality allows the designer to control power to a particular portion of circuitry without the interruption of the main power source. This on/off control can also provide an easily implemented means of sequencing power to various sections of the system circuitry.

Idle Current

When placed in shutdown mode by use of the on/off logic control, the DC/DC converter will be placed in an “Idle” or quiescent state. Output power is effectively shut off, and input current drops to a low standby level, to assure instantaneous restart when the on/off control is activated back to the on state. This input idle current is of a minimal level, typically 1-10mA.

Efficiency

Due to their dissipative operation as regulator elements, coupled with their small size, DC/DC converter efficiency becomes important as a main contributor to overall thermal rating and reliable operation of the system as a whole. Simply put, efficiency is the ratio of output power to input power, and for a typical modular DC/DC converter, efficiency is in the 75% to 85% range. The 15% to 25% difference manifests itself primarily as heat. To maximize efficiency, DC/DC converters are design-optimized for, and should be operated within the manufacturer’s stated conditions, usually at 100% output load and nominal input voltage. Lower input and load yields lower efficiencies, where higher load and higher input voltages yield higher efficiency factors. Correct input voltage range and output power demands sizing of the converter is important to maximize efficiency and reduce overall contribution to thermal stress. An example of these combined specifications and their effect on efficiency is shown below for a typical 10W DC/DC converter.

V input	V output	I output	I input	Efficiency
9-18Vdc	5 V	2 A	1.1 A	81%
9-18Vdc	15 V	0.67 A	1.05 A	85%
9-18Vdc	+/-5 V	+/-1 A	1.05 A	81%
18-75Vdc	5 V	2 A	0.26 A	82%
18-75Vdc	+/-5 V	+/-1 A	0.26 A	82%
18-75Vdc	+/-12 V	+/-0.416 A	0.25 A	84%
18-75Vdc	+/-15 V	+/-0.333 A	0.25 A	84%

Isolation

Isolated modular DC/DC converters typically offer input-output galvanic isolation from 500 V to 1500 V, as specified by applying a sustained high potential (or HiPot) voltage between input to output, input to ground, or differentially. This isolation not only provides user and sensitive circuitry safety protection, but can also reduce overall common mode noise effects from ground loop coupling of signal abberations between inputs and outputs throughout the system. In applications where user safety is mandated, check the manufacturer specifications to assure that the converter is approved for compliance to the appropriate safety standards.

Balanced Loading

In the case of dual output DC/DC converters, output load demands for each output should be maintained within specified minimum and maximum ranges for each side to avoid excessive load regulation variance. Highly imbalanced loading between outputs can also result in premature overload protection triggering and will contribute to an overall reduction in converter efficiency performance. Ideally, output load variance between outputs should be held to within +/-10% to +/-20%.

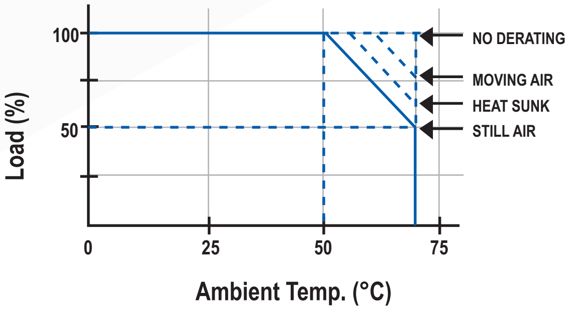
Input Fusing

Should safety requirements or best practice design rules require input fusing of the DC/DC converter, the manufacturer may specify an appropriate fuse value for the converter based on input voltage and total output power demands. The primary specification to note is that of input surge current, usually specified with nominal input voltage and maximum rated output current conditions for a resistive load. If using the DC/DC converter to drive highly capacitive or inductive loads, output filtering and suppression circuitry should be used to minimize the instantaneous current demands or back EMF presented by these types of devices, which can greatly increase the surge current beyond that which is specified.

Operating Temperature and Derating

Much like switching AC/DC power supplies, DC/DC converters are subject to similar temperature derating factors. Output power vs ambient temperature is usually specified under free air convection conditions, as shown in the example to the right.

DC/DC converter products may specify output power vs case temperature of the device itself, also under free air convection conditions. In many cases, operational temperature performance can be extended by forced air cooling across the converter, usually provided by a fan and rated at a particular level of cubic feet/minute (CFM) airflow. Due to their often small overall size and high power output/square inch ratios, converter performance declines dramatically once critical maximum temperature is reached. Exceeding the maximum rating for an extended period will almost certainly result in protection shutdown of the converter, and under worst-case conditions, irreparable damage to the device.



Derating Under Various Operating Conditions

Packaging Considerations

DC/DC converters are available in a variety of package styles, but invariably are of an open frame or encapsulated modular format. Industry-specific requirements for a particular system may dictate the use of one type or another, as in the preference for open frame DC/DC products in the telecom and communications industries. Likewise, industrial control systems typically mandate the use of encapsulated products, as the environment can be subject to moist atmospheres or high vibration conditions. Open frame converter products often rely upon controlled airflow systems to maintain performance, and to enhance cooling, the manufacturer may offer integrated or clip-on cooling fin-type heatsinks that attached directly to the device.

Encapsulated converters are more often used in pure convection cooled environments, and as such, rely upon the encapsulation material and case surfaces to provide adequate cooling.

Where no pre-existing preference is dictated, overall consideration must be given to the type and amount of cooling that can be provided to ensure long product life and overall high MTBF of the system itself.

Whichever format type is selected, the designer must keep in mind that DC/DC converter products have higher power densities per square inch of package size vs those of AC/DC switching power supplies, and may be more imbedded within a system's physical construction. Because of these issues, proper layout orientation and thermal control play a larger role in the overall reliability of DC/DC converter products.

Thermal Considerations and Guidelines

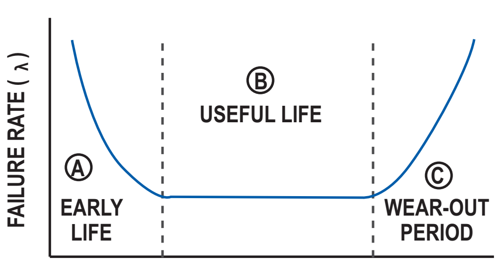
For any electronic product or system, the prime factor affecting useful life is that of heat. Over time, heat will take its toll in the form of either reduced or intermittent performance, leading to eventual failure. All products have anticipated lifespans, but reaching that point or even extending a product or system's useable life beyond it requires a good design, quality components, and effective thermal management.

Reliability Ratings

In the graph to the right, the typical failure rate (often expressed as) over time for a power converter is shown. The A portion defines the early life operation when "brand new" and failures during this period occur during manufacturer burn-in and are classified as infant mortality. Manufacturing flaws or marginal component failures are usually responsible for failure in this period. Manufacturers test and monitor failures at this point and will burn in product under load to eliminate sporadic failures prior to shipment. Should failure rates rise to unacceptable levels, detailed failure analysis is done to correct any design, manufacturing process, or component flaws.

Section B illustrates the anticipated life of the converter when used within all specified parameters, particularly those of line, load, and ambient temperature. To better determine this theoretical life, the manufacturer, in addition to burn in, may subject test lots to HALT (Highly Accelerated Life Testing) procedures to prematurely "age" the power converter while monitoring degradation in key performance specifications. Though requiring more costly environmental simulation and test equipment, HALT tests provide actual parametric measurement of product lifespan, and is mandatory for most high reliability and military applications.

Section C shows the wear out or degradation period when converter performance falters, eventually leading to complete failure.



Reliability Curve for Power Converters

MTBF

More commonly used in predicting power converter as well as other products lifespan is through the statistical MTBF (Mean Time Before Failure) method, as defined by the generally accepted MIL-HDBK-217 specification at a 25ºC ambient temperature. In essence, MTBF calculation via this method involves summation of the failure rates of all the individual components of the power converter. Mathematically, where:

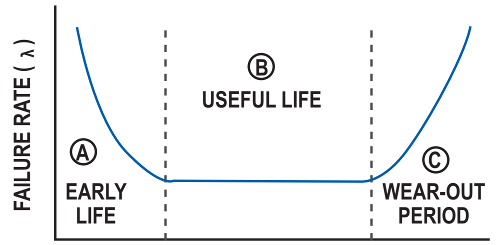
= 1 + 2 + 3+............ n, where is the sum of the individual component's failure rates as expressed by , and:

MTBF (hours) = 10,000,000/

In this manner, MTBF is expressed in hours. Typical power converters have MTBF ratings of 100,000 to 500,000 hours, at 25ºC ambient operating temperature.

Thermal Budget Considerations

In reality, most power converters will be operated in ambient conditions far above the idealized “room” temperature of 25ºC. The power supply itself, through magnetics losses, linear regulator dissipation, and capacitive ESR effects, will be a prime contributor to temperature rise within the device itself. By nature, component self heating and ambient temperature are additive. Without proper consideration, the operational range and resultant derate in output power can quickly reach maximum in relation to operational ambient temperature rise. In a typical 150W AC/DC switching power supply with a 75% efficiency, a 20ºC rise in internal temperature can be expected. Coupled with a 25ºC ambient, this raises the internal temperature of the components to 45ºC.Once maximum ambient is reached, power converters typically derate the output at 3%/ºC, resulting in rapid output power rolloff above the manufacturer’s rated maximum ambient. At 70ºC ambient, power output drops by 30%, resulting in an effective constant output capability of 105W. MTBF is also severely downgraded by elevated temperature operation, as shown in the following curve.



Thermal Control and Management

Several temperatures must be known: actual ambient immediately around the converter under normal operation (including self-heating contribution), the manufacturer’s temp rating for the converter (when properly mounted and installed), and the maximum system ambient operating specifications of the overall system itself. These combined factors will identify to the designer the temperature envelope under which reliable power converter operation is assured. If these cumulative temperatures are expected to exceed the operating specifications of the converter, heat dissipation and control methods must be employed. These can include:

- Additional heat sinking, either through mounting the unit to an outer case wall as a dissipating surface, or by use of finned heat sinks on the device itself.

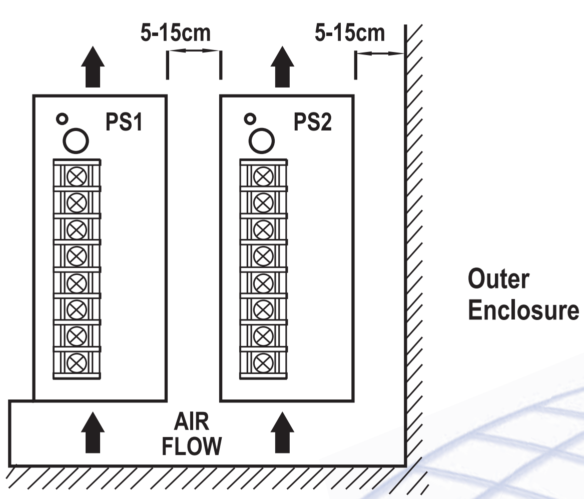
- Forced air cooling using fans, though the introduction of moving part components can greatly reduce overall system MTBF.

- Operating with a derated output power level, or oversizing the converter to conform to the manufacturer’s power derating curve specification.

- Alternative mounting and location of the converter away from other heat-generating parts of the system. The manufacturer’s recommendations for proper mount orientation and clearance spacing, if recommended and as shown below, should always be followed for maximum cooling performance. Failure to do so may result in operational ambient temperature reduction by 8-10% or more.

Any one, or a combination of these methods may be necessary to assure the full performance of the power converter product over the anticipated system operating range. It should be kept in mind that good thermal practice would be to keep the power converter operating within an ambient temperature below that of the rated maximum specification. This will contribute to the reliable and extended life operation of the power converter specifically, and the entire system as a whole.

Understanding thermal specifications and management is critical, and the designer should become familiar with all aspects of proper power converter operation related to temperature effects. Advances in power supply design and the specialized components used have resulted in highly efficient and reliable power products. Mis-application and/or poor thermal management accounts for most failures in the final application. If the designer is in doubt concerning proper thermal management, Astrodyne’s technical support staff can provide guidance in this important area.



Spacing Guideliner

Safety and Regulatory Standards

When creating a particular product or system, the designer must take into account the fact that the final product will most likely be sold and used worldwide, and may need to be compliant to international safety standards.

Electrical safety specifications in general, and particularly those related to power conversion devices, are defined at various product application and functional levels. Once consisting of a myriad of country-specific and sometimes conflicting requirements and definitions, there has been a common consolidation or "harmonization" of these specifications in recent years into those of a more standardized and understandable set as defined by IEC internationally-accepted governing bodies.

This guide outlines these commonly used specifications to give the designer a reference point for safety compliant design practice. While the individual power conversion device may carry full safety approvals itself, the incorporation of the converter into the final product or system may often require safety approval itself. Astrodyne's technical support department can provide guidance to the user concerning their power converter product safety approval specifications and best practice design procedures to help the designer meet overall system safety approval.

Because of the breadth and depth of safety specification levels and their continual update and revision, it is highly recommended that a recognized safety agency such as UL or TUV be consulted as to the exact implementation and final acceptance testing of any product using power converters.

Common Power-Related Safety Specifications

USA
UL 60950-1: 2001, 1st Edition 2007-10-31
(Information Technology Equipment- Safety-Part 1:General Requirements)

UL 60601-1, 1st Edition 2006-04-26
(Medical Electrical Equipment Part 1: General Requirements for Safety)

UL 1310 and CSA C22.2 No. 223
(Class 2 Equipment: Power supply with Extra Low Voltage and limited output power, North America only)

CANADA
CSA C22.2 No. 60950-1-03 1st Edition, 2006-07
(Information Technology Equipment- Safety-Part 1: General Requirements)

CSA-C22.2 No.601.1 M90, 2005
(Medical Electrical Equipment- Part 1: General Requirements for Safety)

GERMANY
IEC 60950-1:2001, First Edition inclusive of CENLEC Common Modifications.
IEC 60601-1: 1988, Second Edition
TUV: EN 60950-1 & EN 60601

Essential Safety Specification Definitions

The above safety specifications define the requirements that must be met for four basic concepts: Isolation, Spacing, Insulation, and Leakage Current.

Isolation/Electrical Strength

Isolation strength, commonly referred to as High Potential (HiPot) testing is done to verify the insulation materials used will prevent electrical arcing or breakdown within the circuit paths during a 1 minute duration test.

Max Input V.		EN60950 IT Equip	EN60601 Medical	UL1310
125V	P-S	2000VAC/2828VDC	3000VAC	1500VAC, P-S
125V	P-G	1000VAC/1414VDC	1000VAC	1500VAC, P-Encl.
250V	P-S	3000VAC/4242VDC	4000VAC	
250V	P-G	1500VAC/2121VDC	1500VAC	

P=Primary Side, S=Secondary Side, G=Earth Ground, Encl=Enclosure

Creepage and Clearance Spacing Requirements

Creepage and clearance distance specifications are physical spacing requirements that isolate the user from harzardous voltage levels within the system.
Creepage: Defined as the shortest allowable distance between two conductive elements or a conductive element and the outer boundary (ie: case) of the system, as measured along the surface of the insulation.
Clearance: The shortest distance between two conductive elements, or conductive and bounding surfaces, as measured through air.

Max Input V.		EN60950 IT Equip		EN60601 Medical	
		Basic	Reinforce	Basic	Reinforce
125V	Clearance, Air	1.3mm	2.6mm	1.6mm	3.2mm
125V	Creepage, Distance	1.5mm	3.0mm	3.0mm	6.0mm
250V	Clearance, Air	2.0mm	4.0mm	2.5mm	5.0mm
250V	Creepage, Distance	2.5mm	5.0mm	4.0mm	8.0mm

Insulation Strength

Insulation can take several forms:
- Solid insulating material with adequate thickness and creepage distance over the surface of the conductor itself, as in wire jacket insulation
- Adequate clearance through air spacing
- A combination of both methods

Insulation levels fall into 5 basic catagories:
Operational Insulation: Minimum level of insulation required for equipment operation.
Basic Insulation: Provides basic insulation from electrical shock.
Supplementary Insulation: Additional insulation applied to increase protection against shock in case of basic insulation failure.
Double Insulation: Construction that uses both basic and supplemental insulation.
Reinforced Insulation: A single applied insulation system that provides shock protection equivalent to double insulation.

Leakage Current

Leakage current is defined as the amount of current that flows from the product or system to earth ground. In cases where system grounding is insufficient or the earth ground connection is interrupted, potentially hazardous levels of leakage current may occur. In patient connected medical equipment applications, such leakage current specifications are more stringent, owing to the direct-connect nature of such systems.

There are three major classes of considered equipment for leakage specifications:
Class I: Protection of electrical shock is provided through the use of basic insulation and protective earth ground connection to the case of the product or system.
Class II: Assumes there is no protective earth ground connection, and relies upon double or reinforced insulation for shock protection.
Class III: Relies upon a power source supply from an SELV (Safety Extra Low Voltage) source where hazardous voltages are not presented.

Maximum Leakage Current Specifications

EN60950 IT Equipment

Class I	0.75mA (hand held equipment)
	3.5mA (all other types)
Class II	0.25mA (all)

EN60601-1 Medical Equipment

Condition	Spec.	As used with:
Non-patient contact	500µA	Printer, peripherals
Direct patient contact (isolated)	10µA	Direct electrode or pads
Non-direct patient contact (isolated)	50µA	Blood pressure cuff
Grounded enclosure	100µA	Bedframe, dental chair