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Power Supply Technical Guide

Global Power Solutions

Our mission

> To inspire our people to be The Experts in Power delivering genuine value to our customers.

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Power Supply Technical Guide

Launched in 2005 and some 10,000 copies later; we are pleased to present issue 2 of XP's Power Supply Technical Guide.

Fully updated to include the latest trends and legislation in the power industry, such as the no load power consumption of external psu's, and taking into account the growing Asian market, the legislation necessary for shipping to the Far East.

For those who want to understand more about power supply design techniques, the benefits of using a configurable supply or how to select commercial modules for military applications, we have added a number of technology editorials towards the back of the guide.

Whether it's a simple power supply term that's been puzzling you, how to select the right cooling for your enclosure or what the difference is between a fly-back and forward converter, this technical guide is a must for anyone designing-in or specifying a power supply.

THE XPERTS IN POWER

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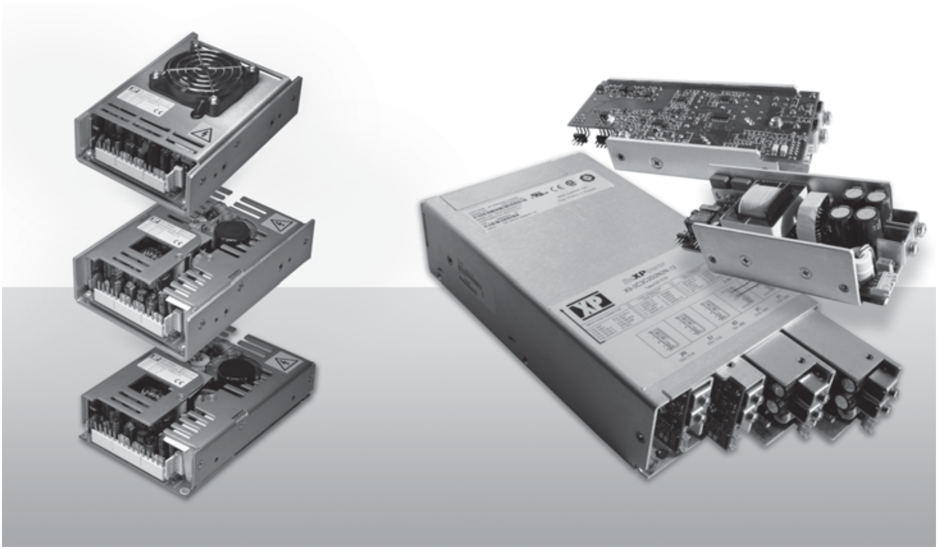
Power Supply Technical Guide



Edited by Gary Bocock

Issue 2

Introduction to Power Conversion

• Introduction

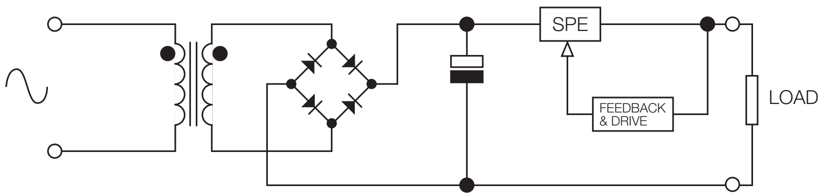
Virtually every piece of electronic equipment is powered from a low voltage DC supply. This source will be either a battery, a combination of battery and DC/DC converter or a power supply converting AC mains into one or more low voltage DC supplies, suitable for electronic components. Electronic components require a DC supply that is well regulated, has low noise characteristics and provides a fast response to load changes. AC power supplies, and most DC/DC converters, also provide isolation from the input to the output for safety, noise reduction and transient protection.

As electronic equipment has become smaller, the market has demanded that power converters do the same. Since the introduction of switch mode techniques, this has been an evolutionary rather than a revolutionary process. Conversion efficiency has increased, materials and components allowing higher switching frequencies have become available and packaging techniques have advanced. At the same time, unit cost has fallen as volumes have increased. With the global market for electronics becoming a reality, power supply systems operate from wide input ranges to cover worldwide AC mains supply variations.

There are a number of basic topologies used in power converters, which are suited to various power levels, cost criteria and performance levels. These are briefly discussed below.

• Linear Power Supplies

Linear power supplies are typically only used in specific applications requiring extremely low noise, or in very low power applications where a simple transformer rectifier solution is adequate and provides the lowest cost. Examples are audio applications (low noise) and low power consumer applications such as alarm panels (low cost).



Linear Power Supply

The 50/60Hz mains transformer reduces the voltage to a usable low level, the secondary AC voltage is peak-rectified and a Series Pass Element (SPE) is employed to provide the necessary regulation. The benefits of this solution are low noise, reliability and low cost. On the downside, these units are large, heavy and inefficient with a limited input voltage range. In order to significantly reduce the size and increase efficiency, most applications utilize a Switch Mode Power Supply (SMPS).

• Switch Mode Power Supplies

The use of switch mode topologies has reduced the size and improved the efficiency of power supplies by increasing the frequency of operation, reducing the physical size of transformers, inductors and capacitors, and utilizing an 'on or off' switching element to increase efficiency. The compromises in adopting this technique are increased ripple and noise on the output DC supply and the generation of both conducted and radiated EMI which have to be managed.

As switching frequency increases, so do switching losses. This has lead to the introduction of resonant topologies, which ensure that either the voltage or the current is at zero when the switching transition occurs, almost eliminating these switching losses and allowing even higher operating frequencies. These schemes are normally referred to as zero voltage switching (ZVS) or zero current switching (ZCS) topologies and they have further reduced the overall volume of power supplies, or increased power density, for a given output power.

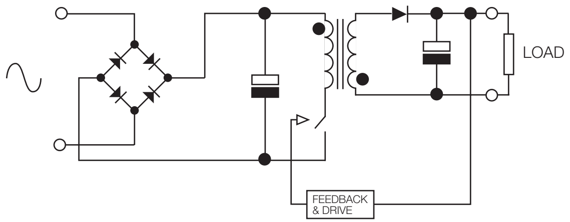
The introduction of low voltage semiconductors and the consequent high output current demands have driven the development of synchronous output rectifier schemes, where the output diodes are replaced by power MOSFETs to reduce power dissipation in the secondary and achieve high efficiency solutions for these applications.

Resonant topologies and synchronous rectification are discussed in more detail in the technology editorials 'Designing smaller and more efficient AC/DC power supplies' (page 113) and 'Synchronous rectification joins the mainstream' (page 121). There are a number of topologies used in switch mode converters which can be arranged in Pulse Width Modulated (PWM), Zero Voltage Switching (ZVS), Zero Current Switching (ZCS) and synchronous rectification schemes.

• Topologies

Isolated Fly-back Converter

Isolated fly-back converters are typically used in power converters up to 150W. The topology uses only one major magnetic component, which is a coupled inductor providing both energy storage and isolation. Energy transfer to the secondary and the load occurs during the switching element off-time.

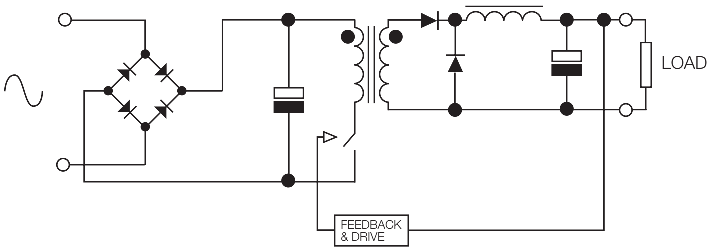


Isolated Fly-back Converter

This topology is a low cost means of converting AC to DC power to approximately 150W due to its simplicity and low component count. The power level is restricted by the high levels of ripple current in the output capacitor and the need to store high levels of energy in the coupled inductor in a restricted volume. The fly-back converter is used in DC/DC converters but only at low power (<50W) due to the low input voltage and consequent high ripple currents.

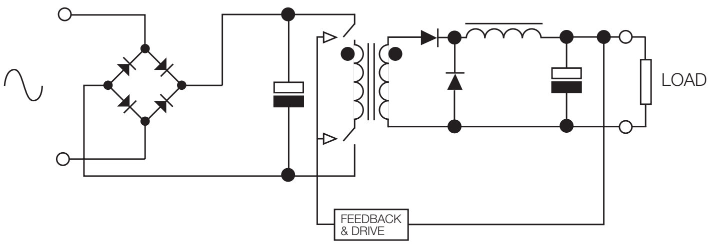
Forward Converter

Forward converters are typically used in power supplies which operate in the range 100-300W. This topology uses two major magnetic components; a transformer and an output inductor. Energy transfer to the secondary and the load occurs during the switching element on-time. Forward converters are used in both AC power supplies and DC/DC converters.



Forward Converter

There is no energy stored in the transformer; energy is stored in the output stage of the converter in the inductor and capacitor. The output inductor reduces the ripple currents in the output capacitor and the volume of the transformer is dependent on switching frequency and power dissipation. At the higher end of the power spectrum, two transistor forward converters can be employed (see below). The two switching elements operate simultaneously, halving the voltage on each switching element and allowing the use of a device with a higher current rating.

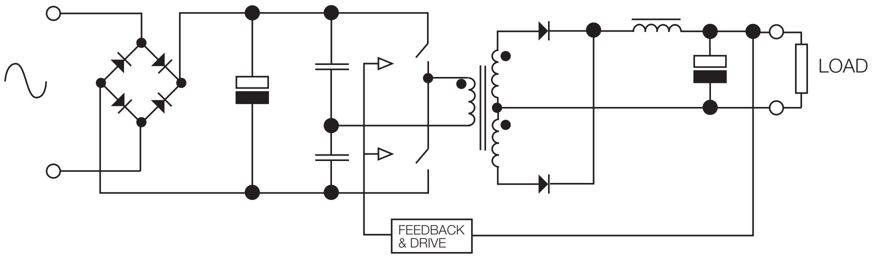


Two Transistor Forward Converter

As the power rating increases, it is desirable to utilize the transformer core more efficiently by driving it through two quadrants of its available area of operation, rather than the one utilized in forward converters. This is achieved in half bridge or full bridge converters.

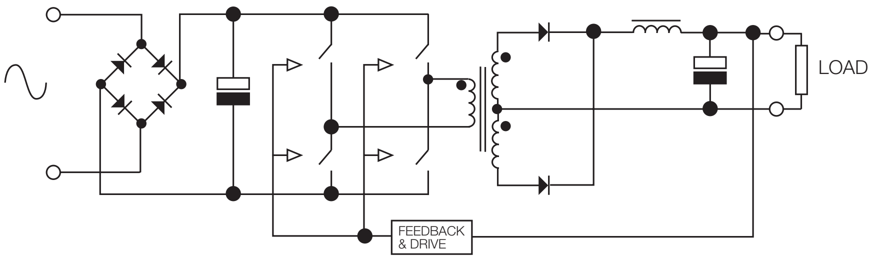
Half Bridge & Full Bridge Converters

Half bridge converters are utilized in power supplies in the power range of 150-1000W. This topology also uses two major magnetic components, a transformer and an output inductor, but in this case the transformer core is better utilized than in a forward converter. The switching elements operate independently, with a dead time in between, switching the transformer primary both positive and negative with respect to the center point.



Half Bridge Converter

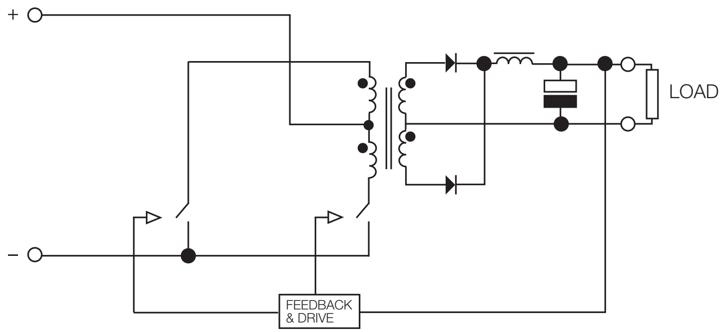
Energy is transferred to the secondary and the load during each switching element on-time by utilizing a split secondary winding. This has the added benefit of doubling the switching frequency seen by the secondary, helping to reduce the volume of the output inductor and capacitor required and halving the voltage seen by each switching element. In higher power solutions a full bridge converter can be employed (see below).



Full Bridge Converter

This topology will provide double the output power for the same primary switching current, but increases the complexity of switching element drive circuits, compared to the half bridge. Half bridge and full bridge converters are used in AC input power supplies. There is also a trend to utilize this topology in low voltage bus converters.

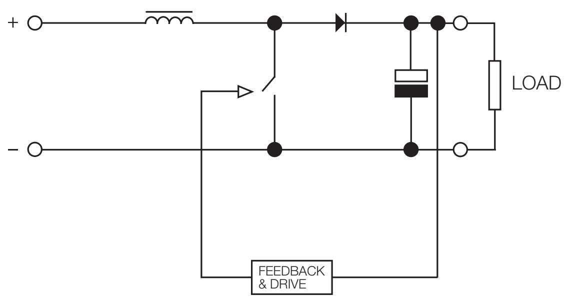
In DC/DC converters a very similar topology to the half bridge is employed, called a push-pull converter. As the voltage applied to the switching element is typically low, this arrangement is designed to halve the primary switching current in each switching element, otherwise operation is similar to a half bridge.



Push-Pull Converter

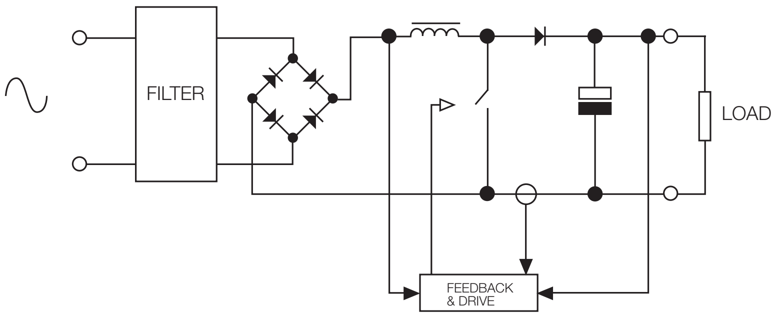
Boost Converters

Boost converters are used to step up the input voltage to produce a higher output voltage. They can be used to boost DC supplies but are most commonly used in AC input power supplies above 100W configured to provide active Power Factor Correction (PFC). The following are diagrams of a standard boost converter and a boost converter in a PFC application.



Standard Boost Converter

Energy is stored in the inductor during the switching element on-time, the voltage across the inductor is added to the input voltage and transferred to the output capacitor during the switching element off-time. Output voltages of up to five times the input voltage can be achieved.



PFC Boost Converter

In active PFC configurations, the pulse width of the switching current is controlled so that the average input current to the boost converter is proportional to the magnitude of the incoming AC voltage. This forces the input current to be sinusoidal. The input filter removes the switching frequency ripple.

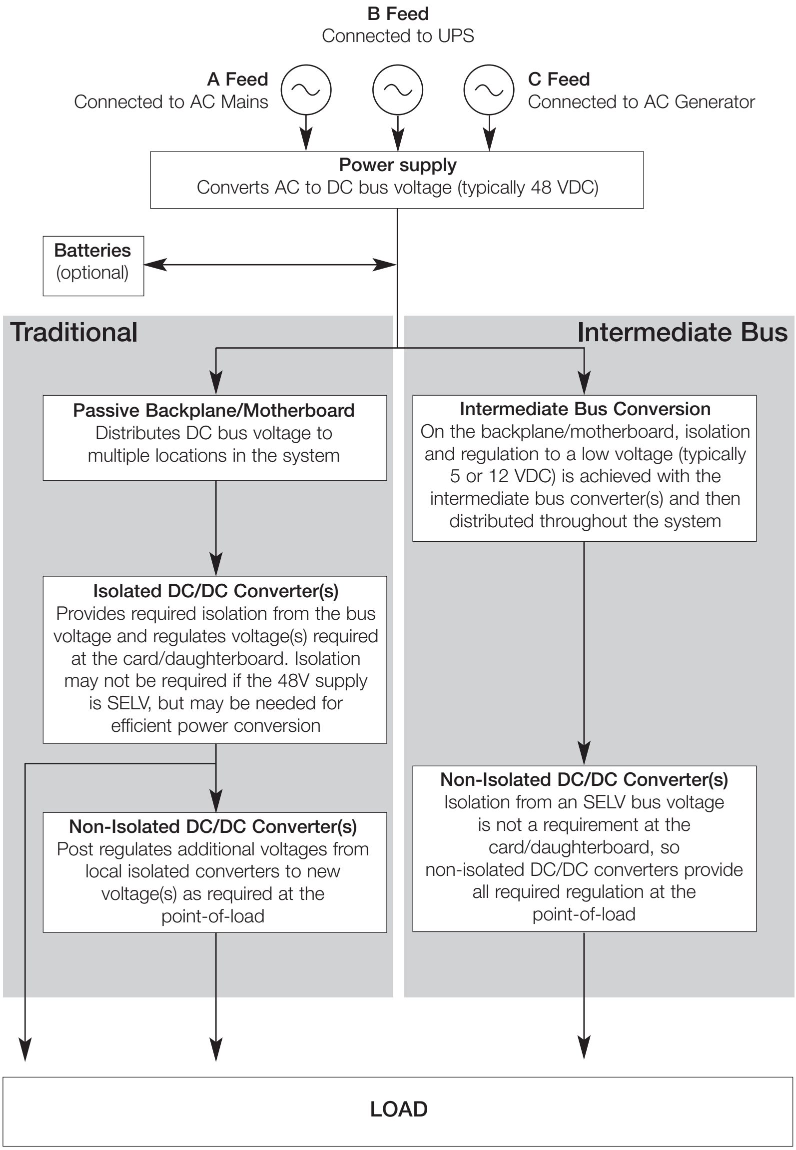
• Distributed Power Architectures

Distributed power architectures (DPA) deliver power utilizing multiple power components throughout the system. Typical components found in traditional DPA and intermediate bus DPA systems are outlined in the diagram (next page).

The power supply provides the primary point of isolation between AC mains high voltage and the end user. The type of power supply used in distributed power applications is typically referred to as front end or rectifier. Front end power supplies and rectifiers have similar functions, such as hotplug/ hot-swap capability, redundant operation, blind-mate connection and various status and control options.

Front ends are most often used in enterprise, network and data storage equipment. Front ends provide a regulated bus voltage throughout all regions of the system. Redundancy is usually gained by protecting the input VAC with multiple input sources, such as AC mains, UPS systems and/or generated power and multiple power supplies. This approach ensures that the loss of one input source or power supply does not result in a catastrophic system shut-down. The DC bus voltage in this type of system is regulated and should never swing by more than ±10% from the power supply's 48 VDC output setting. For this reason, intermediate bus converters which have a narrow input range of only 42-53 VDC may be used in this type of system.

Rectifiers are most often used in telecommunications equipment where redundancy is gained by backing up the DC bus voltage with batteries. A rectifier must be capable of driving both the system load and battery recharging load requirements. The bus voltage in a rectifier power system can vary more widely due to changes in the status of the batteries during charge and discharge modes. For this reason, traditional intermediate bus converters that have a narrow input range of only 42-53 VDC may not be used in this type of system.



Distributed Power Architecture

Input Considerations

• Power Sources

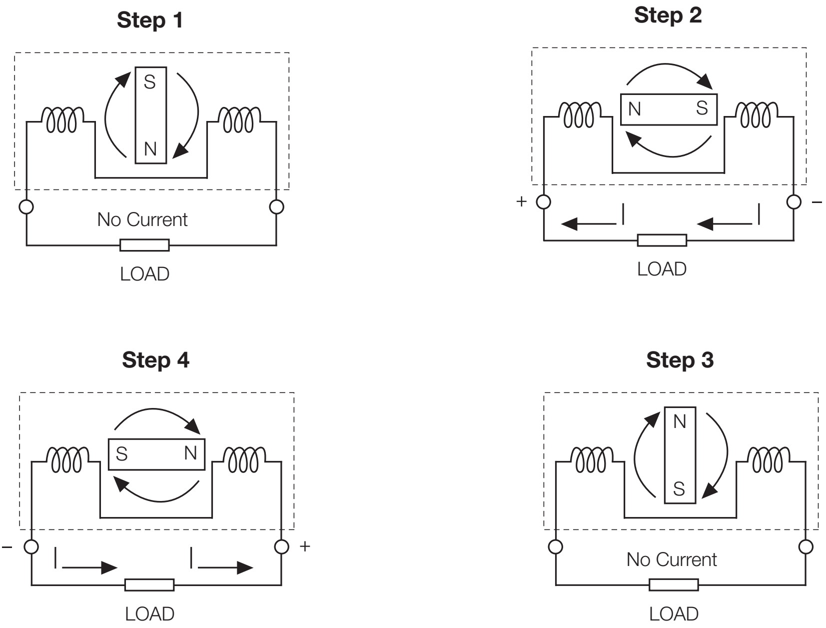
Sources of electricity (most notably rotary electro-mechanical generators) naturally produce voltages alternating in polarity, reversing positive and negative over time, known as alternating current (AC). AC power is typically derived from the local power company grids, either as single or three-phase source. This is then converted to DC within the majority of electronic equipment.

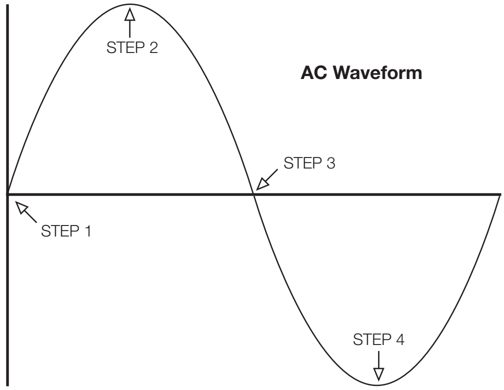
AC Power Sources

In applications where electricity is used to dissipate energy in the form of heat (heaters, light bulbs), the polarity or direction of current is irrelevant so long as there is enough voltage and current to the load to produce the desired heat (power dissipation). However, with AC it is possible to build electric generators, motors and power distribution systems that are far more efficient than a DC equivalent. For this reason, AC is used predominantly in high power applications.

AC generator/source:

In order to construct an AC generator, a magnetic field is rotated around a set of stationary wire coils, the resultant AC voltage/potential produced as the field rotates being in accordance with Faraday's Law of electromagnetic induction. The basic operation of the AC generator, also known as an alternator, can be seen below:





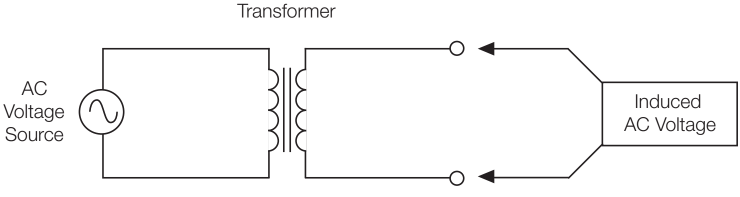
The polarity of the voltage across the wire coils reverses as the opposite poles of the rotating magnet pass by. Connected to a load, this reversing voltage polarity creates a reversing current direction in the circuit.

The frequency of the resultant wave form is dependent on the speed of the rotating magnetic field.

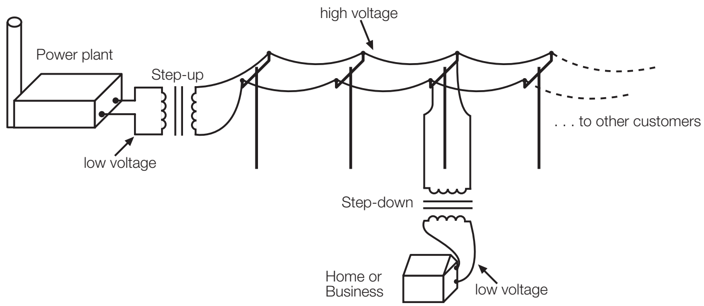
Frequency	=	**No. of cycles/second**
	=	**No. of revolutions/second**

AC generators and AC motors are generally simpler in construction than DC generators and DC motors. In addition to this, AC generators & motors benefit from the effect of electromagnetism, also known as mutual induction, whereby two or more coils of wire are positioned so that the changing magnetic field created by one induces a voltage in the other.

The diagram below shows two mutually inductive coils. Energising one coil with AC voltage creates an AC voltage in the other coil. This device is known as a transformer:



The transformer's ability to step AC voltage up or down gives AC an advantage unmatched by DC in power distribution. When transmitting electrical power over long distances, it is far more efficient to do so with stepped-up voltages and hence stepped-down currents (smaller-diameter wire with lower resistive power losses), then to step the voltage back down and the current back up for industry, business or consumer use.



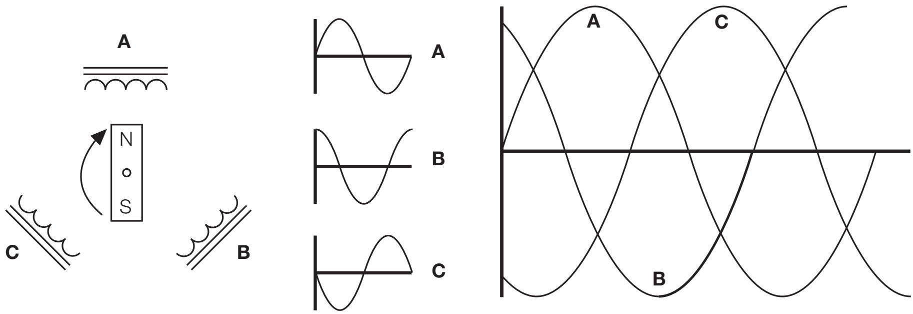
Power distribution

Transformer technology has made long-range electric power distribution practical. Without the ability to efficiently step voltage up and down, it would be prohibitively costly to construct power systems for anything but close-range use, within a few miles at most.

Three Phase AC Source

The power delivered by a single-phase system pulsates and falls to zero during each cycle, whereas the power delivered by a three-phase circuit also pulsates, but never to zero. In a balanced three-phase system, the conductors need be only about 75% the size of the conductors for a single-phase two-wire system of the same kVA rating.

If three separate coils are spaced 120° apart, the three voltages are produced 120° out of phase with each other, when the magnetic field cuts through the coil.

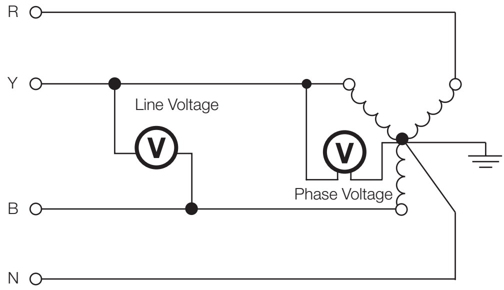


Three-phase power never falls below zero

There are two basic three-phase connections used:

Star or Wye Connection

Connecting one end of each of the coils together as shown right makes a star or wye connection. The phase voltage (or phase to neutral voltage) is the voltage measured across a single coil. The line voltage (phase to phase voltage) is measured across two coils.



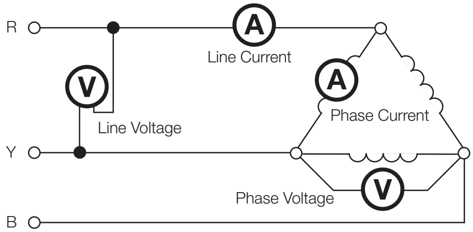
In a star- or wye-connected system, the line voltage is higher than the phase voltage by a factor of the square root of 3 (1.732).

$$V_{LINE} = V_{PHASE} \times \sqrt{3}$$
$$V_{PHASE} = V_{LINE} / \sqrt{3}$$

This system would be a 4-wire plus earth supply.

Delta Connection

The three separate coils are connected to form a triangle in a delta-connected system, which derives its name from the fact that a schematic diagram of this connection resembles the Greek letter delta.



In this configuration the line voltage and phase voltages are the same.

$$V_{LINE} = V_{PHASE}$$

However, the line current is higher than the phase current by a factor of the square root of 3 (1.732). The reason for this difference in current is that current flows through different windings at different times in a three-phase circuit.

At times, current will flow between two lines only, at other times current will flow from two lines to the third.

This system would be a 3-wire plus earth supply.

Worldwide Single Phase Voltages & Frequencies

Region	Voltage / Countries	
Africa -	**220-240 V / 50 Hz**	
exceptions:	Liberia	120 V / 60 Hz
	Libya(1)	127 V / 50 Hz
Asia-Pacific	**220-240 V / 50 Hz**	
exceptions:	Philippines, South Korea(2)	220 V / 60 Hz
	American Samoa, Micronesia, Palmyra Atoll	120 V / 60 Hz
	Guam, Taiwan	110 V / 60 Hz
	Okinawa	100 V / 60 Hz
	Japan	100 V / 50/60 Hz
	Tahiti	110/220 V / 60 Hz
Caribbean	**100-127 V / 60 Hz**	
exceptions:	Dominica, Grenada, Guadeloupe, St. Vincent	230 V / 50 Hz
	Martinique	220 V / 50 Hz
	St. Lucia	240 V / 50 Hz
	Antigua, Montserrat, St Kitts & Nevis	230 V / 60 Hz
	Barbados	115 V / 50 Hz
	Jamaica	110 V / 50 Hz
	Cuba(3)	110/220 V / 60 Hz
	Netherlands Antilles(4)	127/220 V / 50 Hz
Central America	**100-127 V / 60 Hz**	
exceptions:	French Guyana	220 V / 50 Hz
	Guyana(5)	240 V / 60 Hz
	Belize	110/220 V / 60 Hz
Europe	**220-240 V / 50 Hz**	
Middle East	**220-240 V / 50 Hz**	
exceptions:	Saudi Arabia	127/220 V / 60 Hz
North America	**120 V / 60 Hz**	
South America	**220-240 V / 50 Hz**	
exceptions:	Colombia	110 V / 60 Hz
	Nicaragua, Venezuela	120 V / 60 Hz
	Ecuador	120-127 V / 60 Hz
	Brazil(6)	110/220 V / 60 Hz
	Peru(7)	220 V / 60 Hz

Notes

(1) Libya - Barce, Benghazi, Derna, Sebha and Tobruk 230 V

(2) South Korea - 110 V can be found in older buildings.

(3) Cuba - older hotels 110 V, new hotels 220 V.

(4) Netherlands Antilles - Saba, St. Eustasius 110 V / 60 Hz, St. Martin 120 V / 60 Hz.

(5) Guyana - both 120 V and 240 V at either 50 Hz or 60 Hz can be found in Georgetown.

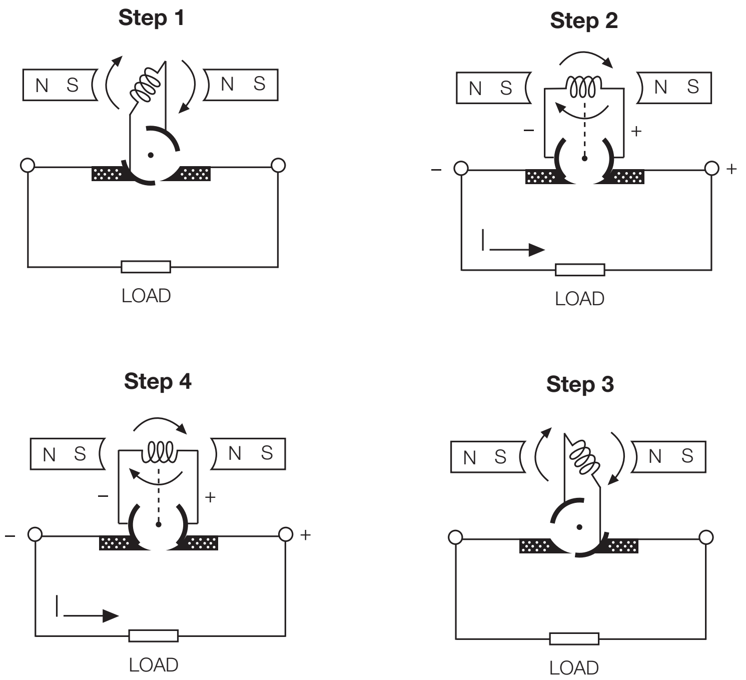
(6) Brazil - voltage varies from state to state.

(7) Peru - Talara both 120 V and 220 V available

DC Power Sources

DC power sources are either generated by rectifying an AC source or produced by an electrochemical reaction in the form of a battery or by a DC generator.

While DC generators work on the same general principle of electromagnetic induction, their construction is not as simple as that of their AC counterparts. With a DC generator, the coil of wire is mounted in the shaft where a magnet would be found in an AC generator, and electrical connections are made to this spinning coil via stationary carbon ‘brushes’ contacting copper strips on the rotating shaft. This is necessary to switch the coil's changing output polarity so that the external circuit sees a constant polarity:



The generator shown above will produce two pulses of voltage per revolution of the shaft, both pulses in the same polarity. In order for a DC generator to produce constant voltage, rather than brief pulses of voltage once every half revolution, there are multiple sets of coils making intermittent contact with the brushes. The diagram above is a simplified representation of the action of a DC generator.

Batteries

There are three main categories of rechargeable batteries available.

Automotive batteries
Used to supply primary power to start engines on cars, boats and other vehicles. They provide a short burst of high current to get the engine started.

Standby/industrial batteries
Designed to be permanently connected in parallel with a critical load and a rectifier/charger system, where the rectifier/charger forms the primary source of power for the load and the battery provides the secondary source in the event of a primary source failure.

Portable batteries
Designed to power portable equipment such as consumer products and tools such as drills, mobile phones, laptop computers and so on.

The latter two categories can be further broken down by the chemistries used in the construction of the battery.

> **Nickel-cadmium (NiCd) (vented & semi-sealed)** - mature but have moderate energy density. Nickel-cadmium batteries have generally been used where long life, high discharge rate and extended temperature range is important. Nickel-cadmium batteries contain toxic metals and are generally being phased out.
>
> **Nickel-metal-hydride (NiMH)** - have a higher energy density compared to nickel-cadmium at the expense of reduced cycle life. Contain no toxic metals.
>
> **Lithium-ion (Li-ion)**- fastest growing battery technology offering high energy density and low weight. Requires protection circuits to limit voltage and current for safety reasons.
>
> **Lead-acid (vented & valve-regulated) batteries**
> Most economical for larger power applications where weight is of little concern.

One of the main differences between the above battery types is the initial purchase cost of the battery. However, when selecting a battery, the initial cost can give a very misleading impression of the total cost to the user during the system's lifetime.

The selection of a battery based on cost alone can have a major impact on the life cycle cost of the system being supported due to such factors as installation, replacement, maintenance, testing and downtime cost.

In many instances, the selection of the most suitable battery for a particular application can be a very complex calculation that can only be performed by the end user as a number of the factors relating to life cycle cost are outside the control of the battery supplier maintenance for example. However, some basic logic can be applied by the supplier assuming some data has been provided, including location and access to site, site ambient temperature and the nature of the application. It would be logical to select a nickel-cadmium battery for a remote unmanned site in the Middle East with an ambient temperature of 45°C during the day and 5°C at night, where the load being supported is vital to the production of oil. However, if the equipment was to be housed within an air-conditioned room in a well-maintained oil production facility it would be reasonable to utilize valve-regulated lead acid batteries.

Terms Associated with Standby Batteries

Cell A cell comprises a number of positive and negative charged plates immersed in an electrolyte that produces an electrical charge by means of an electrochemical reaction. Lead acid cells generally produce an electrical potential of 2V while Nickel-cadmium cells generally produce an electrical potential of 1.2V.

Battery A battery is a number of cells connected together.

String/bank A battery string or bank comprises a number of cells/batteries connected in series to produce a battery or battery string with the required usable voltage/potential e.g. 6V, 12V, 24V, 48V, 110V.

Ah The Ah or Ampere/hour capacity is the current a battery can provide over a specified period of time, e.g. 100Ah @ C10 rate to EOD of 1.75V/cell. This means the battery can provide 10 Amps for 10 hours to an end of discharge voltage of 1.75V per cell.

Different battery manufacturers will use different Cxx rates depending on the market or application at which their batteries are targeted. Typical rates used are C3, C5, C8, C10 and C20. Because of this it is important, when comparing batteries from different manufacturers having the same Ah rate, to confirm on what Cxx rate this figure is based.

Example:
An application requires a 100Ah battery at the C3 rate, based on a load profile of 33 Amps for 3 hours to an end discharge of 1.8V per cell. However, when two battery manufacturers are asked to tender for this project, the only data they are given is that a 100Ah battery is required.

		Standby Time (Hrs)							
		1	**2**	**3**	**5**	**8**	**10**	**12**	**20**
Manufacturer 'A'	Current	80.9	47.4	**35.0**	23.2	16.2	13.57	11.4	5.9
	Ah (Cxx rate)	80.9	94.8	**105.0**	116.0	129.6	135.7	136.8	138.0
Manufacturer 'B'	Current	66.9	38.5	27.7	18.2	12.3	**10.2**	8.6	5.77
	Ah (Cxx rate)	66.9	77.0	83.1	91.0	98.4	**102.0**	103.2	115.4

As can be seen above, both manufacturers can offer a 100Ah battery based on the limited specification provided, but only the battery from manufacturer A is capable of supporting the intended load profile.

Manufacturer A - 105Ah @ C3 Rate to 1.8V/cell (i.e. 3 hour discharge rate)
Manufacturer B - 102Ah @ C10 Rate to 1.8V/cell (i.e. 10 hour discharge rate)

EOD voltage End of discharge voltage is the level to which the battery string voltage or cell voltage is allowed to fall to before affecting the load i.e. 1.75V or 21V on a nominal 24V system.

End of life factor This is a factor included within the battery sizing calculation to ensure the battery is able to support the full load at the end of the battery design life, calculated by multiplying Ah by 1.25.

Temperature derate factor As the energy stored within a battery cell is the result of an electrochemical reaction, any change in the electrolyte temperature has an effect on the efficiency or rate of reaction. i.e. an increase in temperature increases the efficiency/rate whereas a decrease in temperature reduces the efficiency/rate of reaction. As a result of this, all battery manufacturers' discharge data will be specified at a recommended temperature (typically 20-25°C) with temperature corrections provided for operation above and below these values.

Typical temperature correction factors for Valve Regulated Lead Acid (VRLA) batteries

Discharge/ charge rate duration	Temperature Correction Factors to be applied to 20°C data at:								
	0°C	**5°C**	**10°C**	**15°C**	**20°C**	**25°C**	**30°C**	**35°C**	**40°C**
5 minutes to 59 minutes	0.800	0.860	0.910	0.960	1.000	1.037	1.063	1.085	1.100
1 hour to 24 hours	0.860	0.900	0.930	0.970	1.000	1.028	1.050	1.630	1.070

Typical reduction in design life against temperature

	Temperature						
	20°C	**25°C**	**30°C**	**35°C**	**40°C**	**45°C**	**50°C**
% Expected Float Life	100%	100%	80%	60%	40%	20%	10%

High temperatures will reduce the service life of VRLA batteries dramatically and can, in extreme cases, cause thermal runaway, resulting in high oxygen or hydrogen gas production and battery swelling. Batteries will not recover from this condition and must be replaced.

Temperature compensation

As previously detailed, the energy stored within a battery cell is the result of an electrochemical reaction, so any change in the electrolyte temperature has an effect on the rate of reaction provided all other factors (charge voltage and current) relating to the reaction remain constant.

Therefore, if we alter these factors to compensate for the effect of temperature, we can minimize the effect of temperature on battery life by maintaining the amount of gas evolved within a VRLA or semi-sealed nickel cadmium battery to approximately the normal operating limit.

The simplest way of maintaining the rate of reaction within design parameters is to alter the charge voltage at a rate proportional to the change in temperature, i.e. decrease the charge voltage with an increase in temperature above 20-25°C and increase the charge voltage with a decrease in temperature below 20-25°C. The typical change in charge voltage is 3 mV / °C.

Boost charge

Charge given to a battery to correct voltage imbalance between individual cells and to restore the battery to fully charged state.

Charge

The process of replenishing or replacing the electrical charge in a rechargeable cell or battery.

Cycle life

The number of cycles (charge/discharge) a battery provides before it is no longer usable. A battery is considered non-usable if its nominal capacity falls below 60 to 80 percent.

Electrolyte

A non-metallic conductor of electricity between the positive and negative electrodes of a battery. The current is carried by the physical movement of ions.

Equalize charge

See Boost charge.

Fast charge

Term generally associated with NiCd batteries. The typical fast charge time is between one and three hours. The fast-charger detects the state of charge and switches to trickle charge when full charge is reached.

Float charge

Similar to trickle charge. Compensates for the self-discharge of a lead acid battery.

Memory

Reversible capacity loss in NiCd and NiMH batteries. The modern definition of memory commonly refers to a change in crystalline formation from the desirable small size to a large size. Memory is often used to describe any reversible capacity loss on nickel-based batteries.

Nominal voltage

The cell voltage that is accepted as an industrial standard. (Cell voltages of 1.20 and 1.25V are used for NiCd and NiMH batteries).

Quick charger

A charger that charges a battery in three to six hours.

Rapid charger

Same terminology as quick charger.

Self-discharge	Capacity loss during storage due to the internal leakage between the positive and negative cell plates.
Slow charge	Typically an over-night charge lasting 10 to 16 hours at a charge current of 0.1CA (0.1 x Ah capacity in Amps). The battery does not require instant removal when fully charged.
Thermal runaway	A condition whereby an electrochemical cell will overheat and destroy itself through internal heat generation. This may be caused by overcharge or high current discharge and other abusive conditions.
Trickle charge	Maintenance charge to compensate for the battery's self-discharge.

Minimum information required to select and size a battery

In order to size a standby battery the following data is generally required:

System nominal voltage. The nominal voltage that the load requires e.g. 24V, 48V.

Load rating. Either current or power taken by the load during normal & primary power source failure. If load rating is given in Watts, the battery should not be sized by dividing the nominal voltage to convert to Amps as the specified battery will be too small to support the load for the required standby period.

Battery standby or autonomy time.

Load voltage limits. The voltage range over which the load will safely operate. Load voltage limits need to be evaluated to determine whether the system will need some form of DC/DC converter/regulator between the load and battery to protect the load from over or under voltage due to the voltage range of battery.

Normal operating or ambient temperature in which the battery will be operating.

Battery type.

Battery Sizing Constant Current Method

The following example demonstrates how a battery is sized using the constant current calculation method. This method is not recommended where DC-DC converters are utilized as the load.

A 24V control system requires 50 Amps constant current and operates satisfactorily down to a minimum of 21V. The battery is required to support the load in the event of a mains failure for 2 hours in an ambient temperature of 20°C.The battery will be housed within the main equipment panel, which will be located within the site’s main control room.

As the battery is to be used in a controlled environment, the most cost-effective solution would be to use twelve VRLA cells. The following calculation can be used:

Minimum allowable volts per cell	**=**	**minimum voltage/number of cells**
	=	**21V/12 cells**
	=	**1.75V/cell**

Cell performance required is 50 Amps constant current to 1.75V/cell.

By referring to the sample constant current performance table below relating to 1.75 Volts per cell, it can be seen that cell type "F" is the smallest available to perform the standby duty required.

If the specification is now modified so that the system is operating in an outdoor enclosure where the ambient temperature during the winter is known to fall to 0°C and the sizing is checked again using the temperature correction factor table, it is found that:

At 0°C the current available from cell type 'F' is reduced to 55 A x 0.86 = 47.3 A, and hence too low.

The next cell size "G" at 0°C has available 75.2 A x 0.86 = 64.6 A. The revised battery selection should comprise 12 x "G" cells.

Discharge Currents (Amperes Per Cell) at 20°C to 1.75V/Cell

Cell Type	Standby Time (Hrs)							
	1	2	3	5	8	10	12	24
A	12.70	7.40	5.40	3.50	2.40	1.97	1.66	0.85
B	25.30	14.80	10.70	7.00	4.80	3.90	3.30	1.70
C	38.00	22.30	16.10	10.50	7.00	6.00	4.80	2.54
D	71.30	41.40	30.40	20.00	14.00	11.80	9.80	5.10
F	95.00	55.10	40.40	26.80	18.70	15.50	13.20	6.80
G	131.00	75.20	55.50	36.60	25.40	21.40	18.10	9.40
H	143.00	82.70	60.80	40.30	28.10	23.40	19.80	10.20

Discharge/ charge rate duration	Temperature Correction Factors to be applied to 20°C data at:								
	0°C	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C
5 minutes to 59 minutes	0.800	0.860	0.910	0.960	1.000	1.037	1.063	1.085	1.100
1 hour to 24 hours	0.860	0.900	0.930	0.970	1.000	1.028	1.050	1.630	1.070

Battery Sizing Constant Power Method

The following example demonstrates how to size a battery using the constant power calculation method. Recommended for DC-DC converter loads.

Example A

A 110V sub-station control system requires 5kW constant power and operates satisfactorily at a minimum voltage of 94.2V. Under full load conditions there is approximately 3V drop between the battery and the control panel input terminals due to cable resistance. A battery is required to support the load in the event of a mains failure for an eight hour standby period in an ambient temperature of 20°C. The batteries will be housed within a separate battery room.

Based on the above, either VRLA or vented lead acid cells could be used.

Minimum allowable volts per cell = min Voltage/no. cells
= (94.2+3V)/54 cells
= 1.8V/cell

Watts per cell = total Watts/no. cells
= 5000/54 cells
= 92.59W/cell

Cell performance required is 92.59 W/cell constant power to 1.8 V/cell.

By referring to the sample constant power performance table below relating to 1.8 Volts per cell, it can be seen that cell type 'F' is the smallest available to perform the standby duty required.

Discharge Power (Watts Per Cell) at 20°C to 1.8V/Cell

Cell Type	Standby Time (Hrs)							
	1	2	3	5	8	10	12	24
A	194.0	115.0	85.0	57.7	40.1	32.2	27.5	14.5
B	266.0	158.0	115.0	77.1	54.0	45.0	38.1	19.8
C	361.0	212.0	154.0	103.0	73.0	60.0	51.0	26.0
D	390.0	234.0	170.0	117.0	82.0	68.0	58.0	31.4
F	439.0	263.0	191.0	131.0	93.0	77.0	66.0	35.0
G	541.0	330.0	239.0	163.0	124.0	96.4	82.1	44.1
H	563.0	356.0	264.0	180.0	125.0	103.0	87.0	48.0

Battery Charging

The time taken to recharge any battery is dependent on the voltage and current applied. If the recharge current or voltage is too low, then the recharge time will be relatively long; if the current or voltage is high then the recharge time will be short.

However, as all batteries involve an electrochemical reaction, care must be taken to ensure the charging characteristics of both battery and charger are matched correctly.

These unique needs must be met to obtain reliable service and long life. The table below summarizes the general need of each battery type and advises proper handling of each battery type.

Optimal handling may not always be practical. Deviations from the ideal are acceptable but will lower the life expectancy of the battery to some degree, heat being the greater detrimental factor.

Charging
Nickel-cadmium (NiCd) Fully discharge the battery before charging. Do not leave battery in charger for more than two days because of memory effect. Avoid getting battery too hot during charge. **Charge methods:** Constant current, followed by trickle charge when full. Fast-charge preferred over slow charge. Slow charge = 16h, Rapid charge = 3h, Fast charge = 1h+
Nickel-metal-hydride (NiMH) Discharge every three months. Over-cycling is not advised. Do not leave battery in charger for more than two days because of memory effect. Avoid getting battery too hot during charge. **Charge methods:** Constant current, followed by trickle charge when full. Slow charge not recommended. Battery will get warm towards full charge. Rapid charge = 3h, Fast charge = 1h+
Lithium-ion (Li-ion) Charge the battery often. The battery lasts longer with partial rather than full discharges. Do not use if the pack gets hot during charge. **Charge methods:** Constant voltage to 4.20V/cell (typical). No trickle-charge when full. Li-ion may remain in the charger (no memory). Battery must remain cool. No fast-charge possible. Rapid charge = 3h
Lead-acid (Sealed or flooded) Charge the battery immediately after use. Lead-acid must always be kept in a charged condition. The battery lasts longer with partial rather than full discharges. Over-cycling is not advised. **Charge methods:** Constant voltage to 2.40/cell (typical), followed by float held at 2.25V/cell. Battery must remain cool. Fast charge not possible; can remain on float charge. Slow charge = 24h, Rapid charge = 10h

Discharging
Nickel-cadmium (NiCd) NiCd is one of the most hardy and durable chemistries and is not harmed by a full discharge cycle.
Nickel-metal-hydride (NiMH) Avoid too many full discharge cycles because of wear. Use 80% depth-of-discharge. NiMH has higher energy density than NiCd at the expense of shorter cycle life.
Lithium-ion (Li-ion) Avoid full cycle because of wear. 80% depth-of-discharge recommended. Recharge more often. Avoid full discharge. Low voltage may cut off safety circuit.
Lead-acid (Sealed or flooded) Avoid full cycle because of wear. 80% depth-of-discharge recommended. Low energy density generally limits the use of lead-acid batteries to automotive and fixed standby applications.
Service needs
Nickel-cadmium (NiCd) Discharge to 1V/cell every 1 to 2 months to prevent memory.
Nickel-metal-hydride (NiMH) Discharge to 1V/cell every 3 months to prevent memory.
Lithium-ion (Li-ion) No maintenance needed. Loses capacity due to aging whether used or not.
Lead-acid (Sealed or flooded) Apply topping charge every 6 months. Occasional discharge/charge may improve performance.
Storage
Nickel-cadmium (NiCd) Best to store at 40% charge in a cool place. Open terminal voltage cannot determine state-of-charge. 5 years and longer storage possible. Recharge battery if stored longer than 6 months.
Nickel-metal-hydride (NiMH) Store at 40% charge in a cool place. Open terminal voltage cannot determine state-of-charge. Recharge battery if stored longer than 6 months.
Lithium-ion (Li-ion) Store at 40% charge in a cool place (40% state-of-charge reads 3.75-3.80V/cell at open terminal). Do not store at full charge and at warm temperatures because of accelerated aging.
Lead-acid (Sealed or flooded) Store fully charged. Apply topping-up charge every 6 weeks.
Disposal
Nickel-cadmium (NiCd) Do not dispose of; contains toxic metals; must be recycled.
Nickel-metal-hydride (NiMH) Should be recycled. Low volume household NiMH may be disposed of.
Lithium-ion (Li-ion) Should be recycled. Low volume household Li-ion may be disposed of.
Lead-acid (Sealed or flooded) Do not dispose of; must be recycled.

• Input Protection

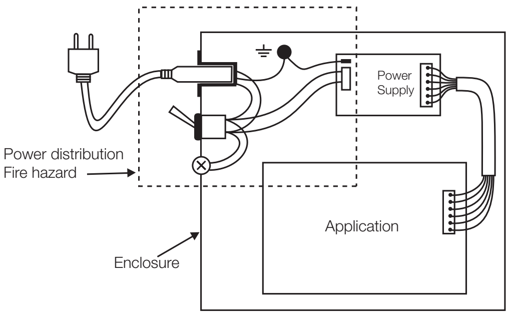
Input Current Protection

Input protection is implemented in power supplies and DC/DC converters in order to ensure safety. The input fuse fitted within a power supply is not intended to be field-replaceable. It is rated such that only a catastrophic failure of the power supply will cause it to fail. It cannot be damaged by overloading as the power supply will have some other form of overload protection, usually electronic. The fuse will often be soldered into the PCB rather than being a replaceable cartridge type fuse.

The power supply fuse is listed as a critical part of the safety approval process and is used to ensure that the power supply does not catch fire under a fault condition. If the fuse fails the most likely cause is that the switching transistor has failed short circuit presenting a short circuit to the mains supply. In the event of this happening the fuse will clear very quickly.

As previously discussed, the fuse in the power supply is not intended to be field-replaceable, and should only be replaced by competent service personnel after the power supply has been repaired. When using a component power supply, invariably there will be additional mains wiring within the enclosure before the power supply and its fuse. This is where an additional fuse or circuit breaker as a protection device needs to be fitted to ensure that the wiring and associated components do not present a hazard.

When the end-user equipment is tested for safety it will also go through fault analysis to ensure that it will not catch fire under a fault condition. If a fault were to occur, then many hundreds of Amps can flow causing wires to heat up very quickly, in turn causing noxious fumes to be given off from the melting plastic insulation and creating a fire hazard.



Typical Application

Input Voltage Protection

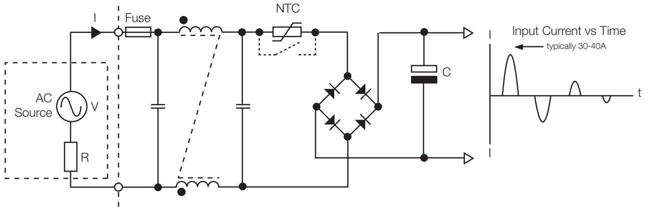
The input of the equipment can be subjected to a number of transient voltage conditions. These differ slightly depending on whether AC or DC systems are being discussed.

AC Systems	Switching transients Lightning strike Surges
DC Systems	Engine cranking transients DC line transients Reverse polarity

The AC system transients are catered for in the EN61000-4-x series of standards. The DC transients relate to DC systems in vehicle, traction and telecommunications applications. See page 27.

Inrush Current

An AC mains system is a power source with a very low impedance, which means that it can supply a large amount of current. In a power supply, at the instant of switch-on, the reservoir capacitor is discharged, giving the appearance of a short circuit. Without any additional precautions the input current would be very large for a short period of time until the capacitor is charged.

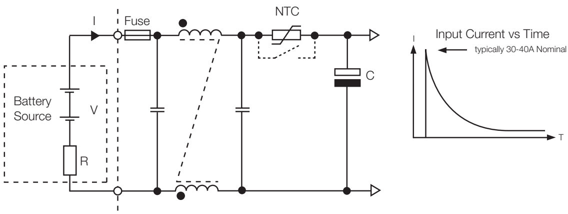


Typical power supply input circuit

Precautions need to be taken to limit the inrush current as this will cause disturbances on the supply line and could damage any switches or relays and nuisance-blow fuses or circuit breakers. Any fuse or circuit breaker fitted will need to be of a size and characteristic to be able to cope with this inrush without nuisance tripping.

The most commonly used technique, due to its simplicity and low cost, is the fitting of a Negative Temperature Coefficient (NTC) thermistor. These devices have a high resistance when cold and a low resistance when hot. Inrush current is often specified from a cold start and at 25°C due to thermal inertia and the time it takes for the thermistor to cool down following switchoff of the power supply. In some applications, in order to solve this problem and improve efficiency, the thermistor is shorted by a relay following the initial inrush. There are other techniques using resistors and triacs but these are more complex and therefore less common. A typical value of inrush current in an AC power supply is 30-40A lasting 1-2ms but can it be as high as 90-100A in some products. There is a trade off to be made between lower inrush current and higher efficiency due to the power dissipated in the thermistor.

The same principles apply with DC circuits as with AC circuits; again this is a source with a very low impedance, only this time it is a battery and not the mains supply. As with the AC circuit the peak will be over within a millisecond or so.



Typical DC/DC converter input circuit

Batteries have short circuit ratings measured in thousands of Amps and when the reservoir capacitor is discharged there appears to be a short circuit. Once again, the protection devices need to be sized to be able to cope with this. Inrush current levels tend to be higher, as is the nominal current, due to the efficiency trade-off. Often the inrush current will specified as a multiple of the nominal current.

Sizing of Fuses & Circuit Breakers

So that the rating of the fuse or breaker can be determined, the nominal input current of the power supply needs to be established. If the application has more than one power supply or other mains powered equipment these will need to be taken into account.

To determine the input current, we need first to determine the input power and, in AC systems, remember to take into account the power factor.

Input Power = Output Power / Efficiency

Input Current = (Input Power / Input Voltage) / Power Factor

Choose fuse or CB rating at least 1.5 x Input Current - Time Lag

It is advisable to use a time-lag fuse or breaker to avoid nuisance tripping on start up. The 1.5 x input current rating is to overcome the ageing effects of fuses.

Fuses are often labelled FF, F, T, TT (ranging from super fast to long time lag). For power supplies it is recommended that time lag T or TT types are used to prevent nuisance tripping.

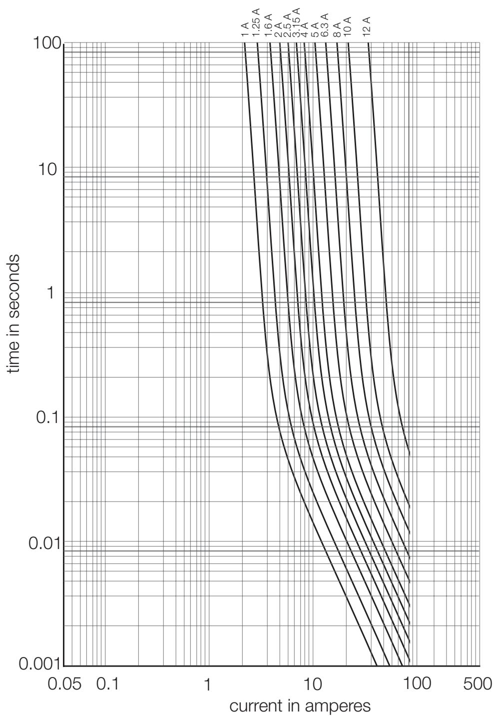
Circuit breakers are often rated A-K (very fast to long time delay). For power supplies, C or above would be recommended.

Fuse Characteristics

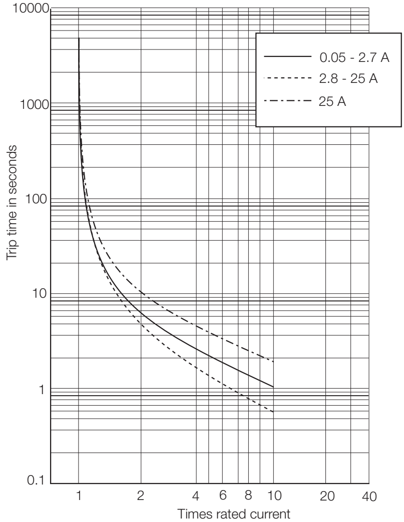
A fuse is a thermal device and does not react instantly, even if it is a fast-blowing type. It is important to look at the actual rupture current of a given fuse. See the graph to the right.

Looking at the curve for a 1A fuse, it can be seen that it will not clear at 1A or 2A. It would take 0.5 seconds before the fuse clears at 3A. It would need 20A to clear this fuse in 3ms. This should be taken into account when ensuring nuisance tripping does not occur.

Looking at the 5A fuse, it would take 80ms to clear the fuse at a current of 30A.



Circuit Breakers - Thermal



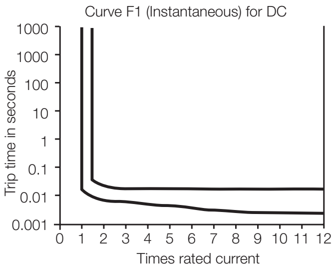
Circuit breakers are available in two basic technologies, thermal and magnetic. The thermal types have similar characteristics to a fuse and it is necessary to ensure there is adequate time lag to prevent nuisance tripping.

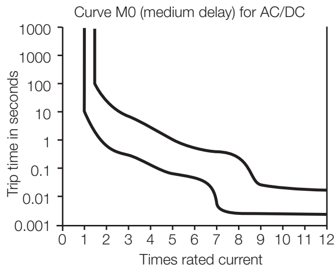
In the case opposite, for the 0.05-2.7A breaker at 10 times the rated current, it would take 1 second for the break to occur. The temperature derating of the device should also be considered to ensure that it complies with the environmental parts of the specification.

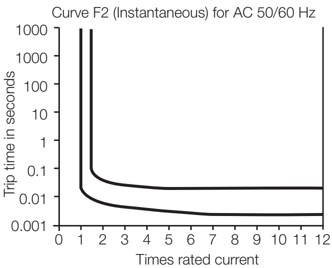
If a battery source is being used, it is also important to check the short circuit rating of the battery and the interrupt capacity of the circuit breaker. Because it has contacts, excessive current may cause it to weld shut rather than break.

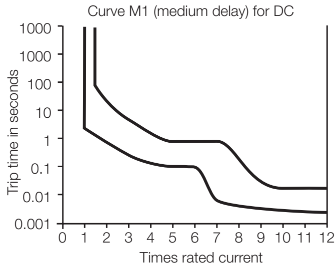
Circuit Breakers – Magnetic

The other type of circuit breaker is a magnetic type, which is far more accurate and is manufactured to allow for different delay times, allowing accurate selection of a device suitable for the application.









The important issues are the same; ensuring that there is adequate time delay to prevent tripping during the initial inrush, and the breaking current, if it is being used in a battery application.

Input Voltage Transient Protection

Input overvoltage comes in many forms, including spikes, surges and fast transients. These are created by the switching of other loads (spikes), motors and fluorescent lamps (fast transients) and surges, which are created by lightning strikes. These transients are regulated to the following standards

EN61000-4-4	Electrical fast transient/burst immunity test	Switching transients
EN61000-4-5	Surge immunity test	Near lightning strikes

There are four levels within these standards, plus one user-defined level. The four levels are:

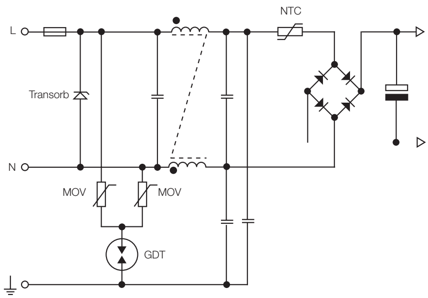
EN61000-4-4		EN61000-4-5			
		Common Mode		Differential Mode	
Level 1	0.5kV	**Level 1**	0.5kV	**Level 1**	N/A
Level 2	1kV	**Level 2**	1kV	**Level 2**	0.5kV
Level 3	2kV	**Level 3**	2kV	**Level 3**	1kV
Level 4	4kV	**Level 4**	4kV	**Level 4**	2kV

The standards differ in that EN61000-4-4 specifies a short pulse with little energy while EN61000-4-5 specifies a longer pulse, which contains substantially more energy.

The devices listed below are the major components used to protect electronic equipment from damage caused by these transients. These components have varying response times and energy absorption capabilities and are usually used in combination to provide effective protection.

Transorb	**- Semiconductor device** Sharp characteristics Fast response low energy
MOV (Metal Oxide Varistor)	**- Voltage dependent resistor** Soft characteristics Medium response high energy
GDT (Gas Discharge Tube)	**- Gas-filled spark gap** Slow response very high energy Used in conjunction with MOV
Electronic protection	**- Used for vehicle traction applications** Linear regulator or open circuit

The diagram on the right shows a typical application of a GDT and MOVs providing a high level of protection. The MOV prevents the fuse blowing when the GDT fires and the two MOVs are in series across line and neutral providing protection against differential disturbances.

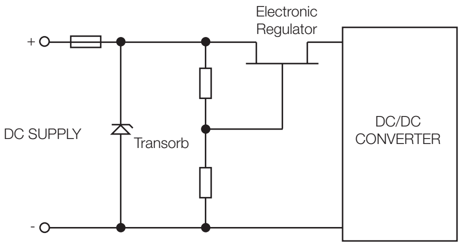


Typical application of GDTs and MOVs

In some DC applications, such as vehicle applications or train and traction applications, none of the devices listed previously are adequate, due to the size and duration of the transients which are higher energy. More complex solutions are required. Practical solutions include the addition of a regulator prior to the DC/DC converter or a circuit to disconnect the DC/DC converter during the transient using capacitors to provide hold-up during the disconnect period.

In the diagram to the right, the regulator is controlled so that its output voltage does not exceed the input voltage of the DC/DC converter.

The disconnect method works in a similar way but with the regulator being replaced with an electronic switch, such as a MOFSET. In this method, the switch is opened when the input voltage is too high. The output is held up using additional capacitance either at the input of the DC/DC converter or at the load.

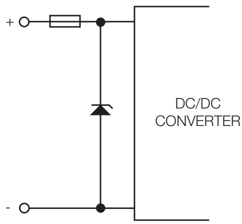


Typical application of DC input surge protection

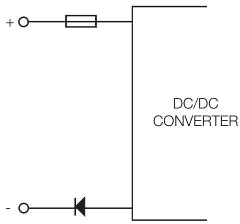
Reverse Polarity Protection

For reverse polarity protection there are two commonly-used techniques; shunt and series diodes.

In the shunt technique the fuse blows if the input is reverse-connected, as the diode is forward biased. This will prevent damage to the DC/DC converter but means that the fuse will need to be replaced. In this configuration the diode must be sized so that it will not fail before the fuse ruptures.



Shunt diode/transorb



Series diode

The second option is to implement a series diode which, in the event of reverse connection, will simply be reversed biased. The fuse will not blow and no damage will occur. The disadvantage of the method is that the diode is permanently in circuit causing inefficiency and raising the minimum input operating voltage of the DC/DC converter solution. These effects can be reduced by replacing the diode with a MOSFET in critical applications.

• AC Input Current & Harmonics

Power Supply Harmonic Distortion

As a result of the peak rectification techniques used in power supplies, harmonic currents are generated. To limit these harmonics, legislation has been introduced, the detail of which can be found in EN61000-3-2.

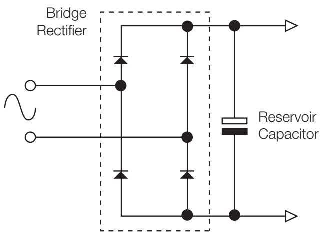
EN61000-3-2 establishes four classes of equipment, each with their own limits for harmonic emissions.

Class D - T.V.'s, personal computers & monitors consuming ≤600 W
Class C - Lighting equipment
Class B - Portable tools
Class A - Everything else

Equipment Classes A & B have absolute limits for harmonics whatever the input power, Class C equipment has limits expressed as a percentage of the 50 Hz current consumed and for Class D equipment the harmonic current limits are proportional to the mains power consumed. Equipment categorised in Classes C & D will normally require power supplies incorporating active power factor correction.

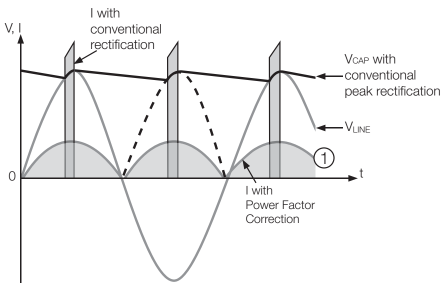
In the diagram below right, the incoming AC voltage wave form is identified as V_{LINE}, the dotted line represents the rectified AC voltage following the bridge rectifier.

The bulk capacitor is charged during the conduction angle and is discharged slowly by the power stage of the power supply (V_{CAP}). As soon as the input sine wave voltage falls below the bulk capacitor voltage then the diode in the bridge rectifier is reverse biased and no current flows until the incoming rectified sine wave is once again higher than the bulk capacitor voltage. The conduction angle is typically 2-3ms.



The complex input current waveform generates the harmonics which are of concern to the power generator. The harmonics contribute to the apparent power. Real power and apparent power are discussed later in more detail. The current wave form shown will result in a power factor of around 0.5 - 0.6.

The ideal input current wave form is labelled ① .



Why is Harmonic Distortion a Problem?

The utility provider must supply the voltage and all of the current, even though some of the current is not turned into useful output power – *See the section entitled Real and Apparent Power on page 32*. The provider has no means of charging for the extra current because the power is charged in kWh.

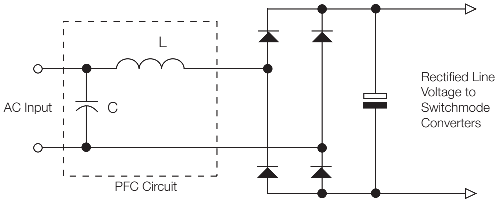
The combined effect of millions of power supplies is to clip the AC voltage because all of the current is drawn at the peak of the sine wave. Power conductors must be sized to carry the extra current caused by the low power factor. Neutral conductors can overheat because they are typically not sized to carry all of the harmonic currents which do not exist for high power factor loads.

Solutions for Power Supplies

In order to meet the legislation for harmonic distortion there are two main solutions available for power supplies:

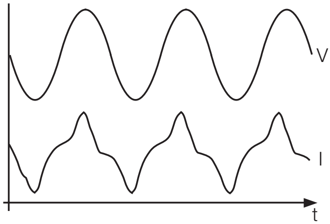
Passive Power Factor Correction

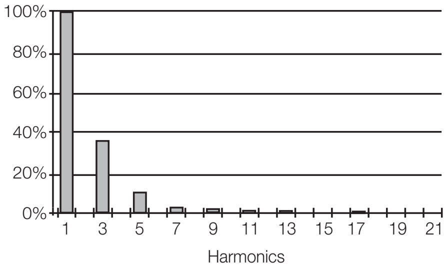
Passive power factor correction typically involves the addition of a line frequency inductor or resistor into the AC line. The effect of the inductor is to squash the current wave shape as the inductor is a reactive component which resists change in current. The effect of the resistor is to reduce the peak current.



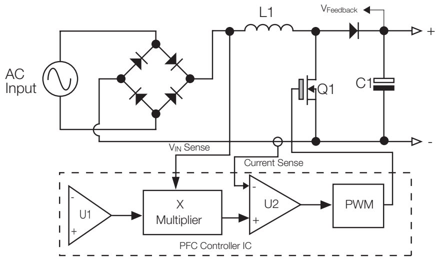
The smoother the current wave-shape the less harmonic distortion will be present.

This is a very simple solution which has some advantages and some disadvantages. It is not really practical in power supplies above 300W due to the size of the components required to provide adequate inductance at 50/60Hz and to keep the resistive losses low enough. This solution is not adequate in lighting, personal computing or color television applications, but is a viable solution for Class A equipment. The diagram below shows real time measurement of passive power factor correction and the harmonic current levels.



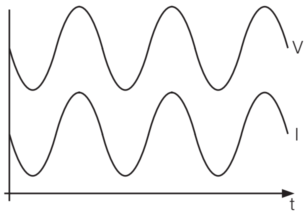


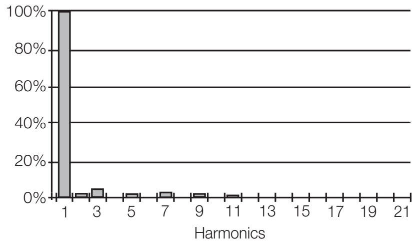
Active Power Factor Correction



Active power factor correction uses a boost converter running at high frequency to electronically control the wave-shape of the input current. The incoming AC voltage is monitored and used as a reference to determine the pulse width of each current pulse of the high frequency switched current.

The current is drawn in a series of square pulses at around 100kHz which equates to 2000 pulses per cycle of the mains voltage. The low pass EMC filter takes the high frequency element and filters it out so that the current seen by the mains supply is sinusoidal. The system regulates the DC output at approximately 400VDC. The diagram below shows real time measurement of active power factor correction.





Comparison between Active and Passive Power Factor Correction

Passive Power Factor Correction

Advantage	Disadvantage
Simple	Heavy and bulky components
Cost effective	AC range switching required
Rugged and reliable	Low power factor
Noise (EMI)	Cannot use multiple PSUs in a system
Assists filtering	

Active Power Factor Correction

Advantage	Disadvantage
High power factor >0.9	High cost
Low input current	High complexity
Universal input	High component count
Regulated high Voltage Bus	Lower calculated MTBF
Hold up time	
Multiple PSUs can be used	

• Real and Apparent Power

What is Power?

Power is simply the rate at which work is done. The more power available in a system, the more work can be completed in the same period of time. In terms of electricity, increasing power means the ability to do more electrical work (energy) in the same number of seconds, for example, running more appliances, spinning a motor faster, or running a faster CPU. Power is measured in Watts (W). One Watt equals one Joule of energy expended in one second:

Power (W) = Work or Energy (J) / Time (seconds)

Conversely, the amount of energy used by a device can be computed as the amount of power it uses multiplied by the length of time over which that power is applied:

Work or Energy (J) = Power (W) x Time (seconds)

Computing electrical power can be very simple or very complicated. With direct current, power (in Watts) is just the product of the voltage (in Volts) and the current (in Amps) of the circuit:

P (W) = V (V) x I (A)

More work is done when electrons push with more force (higher voltage) and when there are more of them per period of time (higher current). Since P = V x I, and I = V/R, another way to express power is:

P = V2 / R

In a DC system power is measured and calculated as shown above. In an AC system it becomes more complicated because phase shift and wave form shape must be taken into consideration.

Real Power

Real, true or active power is the measurement of power dissipated in the load.

It can be shown as:

P (W) = V (V) x I (A)

Real power is measured in Watts.

Reactive Power

Reactive power is power which is merely supplied to the load and returned to the source, rather than being dissipated in the load.

This is caused by the reactive elements in an AC circuit, specifically inductors and capacitors which tend to charge and discharge during normal operation.

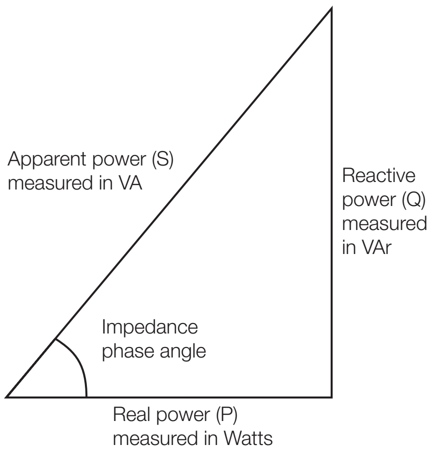
Reactive power is measured as Volt-Amps-reactive (VAr).

Apparent Power

This is the total power in a circuit at any one time. It includes both dissipated (real) and returned (reactive) power.

Apparent power is measured in Volt-Amps (VA).

The relationship between these three types of power can be described using the power triangle as shown below.



Real, reactive and apparent power are trigonometrically related to each other.

Each power type can be described as follows:

P (real power) is the adjacent length
Q (reactive power) is the opposite length
S (apparent power) is the hypotenuse

In this form we can see that the opposite angle gives us the impedance of the circuit. Using the cosine of this angle provides the 'power factor' of the circuit.

What is Power Factor?

Power factor is a characteristic of AC circuits only. It is always a number between zero and one, the closer to one, the better the system's power factor.

Power Factor = Real Power/Apparent Power

Using the previously discussed data, it is now possible to add in this third element to the formula:

Power (W) = Apparent Power (VA) x Power Factor (PF) or
Apparent Power (VA) = Power (W)/PF

Power factor is a measure of the efficiency of energy transfer from source to load. The greater the efficiency the closer to unity power factor.

If power is not being dissipated in the load but simply circulates round the reactive elements of the circuit (inductors and capacitors), then energy transfer is not as efficient and the power factor will be less than unity.

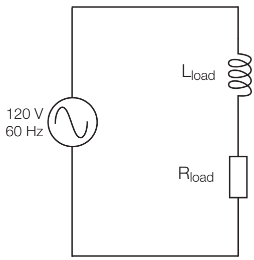
Two key elements affect the power factor of any system. These are known as phase shift and harmonics.

Effects of Phase Shift on Power Factor

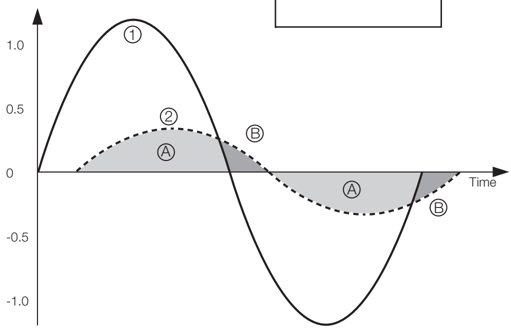
To understand how phase shift affects the power factor of any system, here are a couple of practical examples:

AC Motor Load

The diagram to the right shows a simple circuit description of a motor load. The load is primarily inductive (motor windings) with a small resistive component (the resistance of the windings).



If the voltage is plotted against current in this system, two waveforms appear out of phase with each other, as shown right.



Key:
① The voltage wave form
② The current wave form
Ⓐ Real power
Ⓑ Reactive power

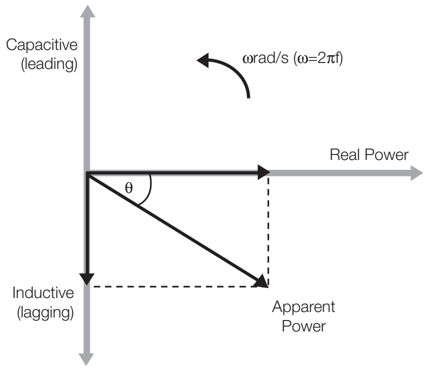
The current waveform is lagging behind the voltage wave form. This lagging phase shift is measured as an angle. One cycle of the mains is a full 360 degrees, any difference along the horizontal axis can be shown as a phase angle measured in degrees.

This phase angle can be used to calculate the PF of the system.

While the voltage and current are in phase i.e. both positive or both negative real power is delivered Ⓐ. When voltage and current are out of phase then reactive power is delivered to and returned by the load Ⓑ.

The phasor diagram, see below, can be used to illustrate the phase relationship. This is shown static but is continuously rotating through 360 degrees.

Here, active or real power is shown on the horizontal portion of the phasor diagram, the apparent power as a lagging phasor, reactive power being shown on the vertical.



Phasor diagram of motor load

This is the origin of the power triangle discussed earlier.

If the triangle has its vertical (reactive portion) positive, then the reactive portion is capacitive. If the vertical is negative then the reactive portion is inductive.

If the angle of the opposite is 30 degrees, then the cosine of this angle will give us the power factor of this system:

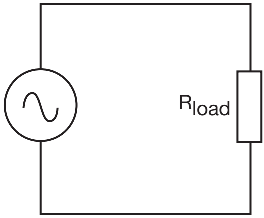
Cos 30 = 0.87 lagging

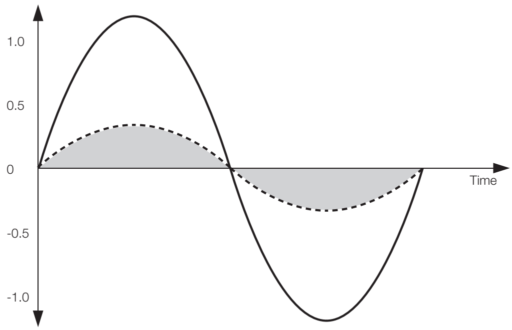
87% of the energy supplied by the source is being dissipated in the load. The other 13% is circulating currents not being dissipated in the load (reactive power).

AC Resistive Load

A simpler example is a resistive load on an AC supply.

Below are the circuit diagram of a resistive load and the voltage and current waveforms. There are no reactive elements, and because of this there is no phase shift between voltage and current.





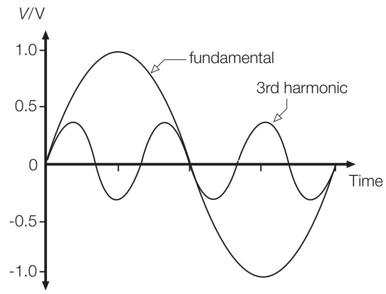
The phase angle between voltage and current is zero, the two elements are in phase.

Cos θ = 1

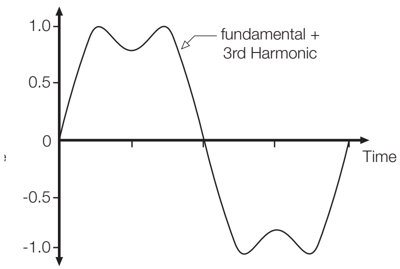
Therefore the power factor of the system is unity. All of the energy supplied by the source is dissipated by the load. The energy transfer is 100% efficient.

Effects of Harmonics on Power Factor

The following diagrams show how a waveform is distorted by adding the 3rd harmonic to the fundamental.



The resultant waveform is shown below;



Any waveform that is not sinusoidal contains harmonics.

Any distortion or harmonic content will cause the power factor of the system to fall.

As with phase shift, any power not being dissipated as useful power to the load is known as reactive power.

The effects of harmonic currents within a system cause a reduction in power factor and therefore reduce the efficiency of energy transfer from source to load.

Effects of a Low System Power Factor

Both phase shift and harmonics can cause a reduction in the power factor of the system.

This reduction in power factor means that more current has to be generated at source to deliver the power to the load. This in turn means that, unless power factor correction is applied to loads, a number of problems are caused.

Power factor correction can be either passive or active. Whichever form it takes, it will be used to ensure that the amount of harmonics specifically within a system is reduced; this will increase the power factor of the system and increase the source-load energy transfer efficiency.

In phase shift applications (e.g. motor load), passive power factor correction can be applied (adding inductance or capacitance to circuit) to correct any phase shift between voltage and current. This again will increase source-load energy transfer efficiency.

Common examples of problems with low power factors within a system can be seen in the list below:

Mains voltage distortion	Caused by harmonics which can cause problems such as light flicker.
Oversizing of conductors	Necessary as circulating currents must also be allowed for when cable sizing.
Overheating of neutral conductors	Caused because protection is generally in the live wire only.
Electromagnetic load failures	Generally occur when harmonics present cause the magnetic device to heat up.
Circuit breakers tripping	Circulating currents, due to reactive power, not considered.

• Earthing / Grounding

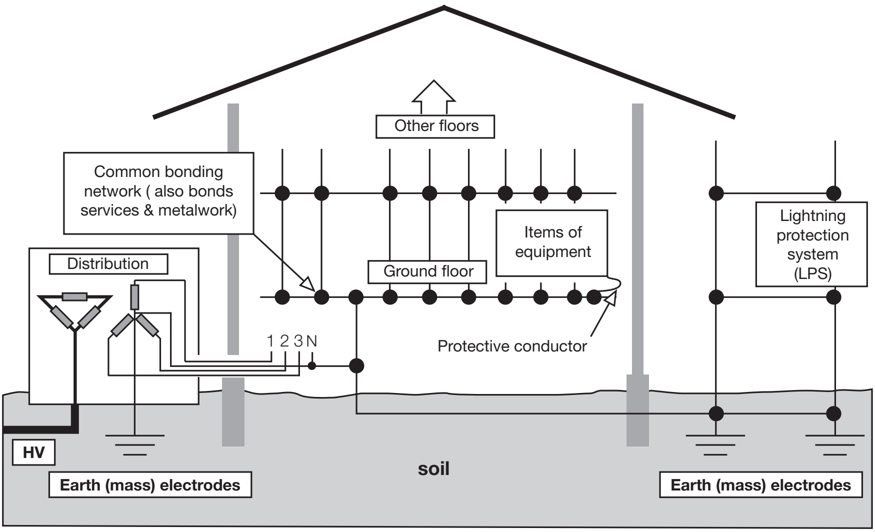
Earth means different things to different people. In this context it means a place of zero potential, a place where fault currents can be directed of sufficient capacity to enable fuses to rupture. In reality it is usually the substance beneath our feet and we connect to this in a number of different ways.

Buildings are connected to the ground and therefore the floors on which we stand are at the same potential.

The electrical connections that come into our homes and offices need to be safe. This is why the earth connection in a domestic location is usually made to a metal pipe (generally the mains water supply) somewhere close to where it enters the ground.

The distribution transformer has an earth connection, usually in the form of a copper rod anchored in the ground.

Lightning conductors that are found on tall buildings will also be rooted in the ground, so that in the event of a lightning strike the current passes harmlessly to ground and not into the structure of the building, saving the building from damage.



Earthing overview

Ground Resistivity

The wetter the ground, the less resistance it will have. This is the reason buildings have their own earth connection and do not rely on the earth point at the distribution transformer.

Type of ground	Ground resistivity *p* (Ωm)	
	Range of values	Typical value
Boggy ground	2 - 50	30
Adobe clay	2 - 200	40
Silt & sand-clay ground, humus	20 - 260	100
Sand and sandy ground	50 - 3,000	200 (moist)
Peat	200+	200
Gravel (moist)	50 - 3,000	1,000 (moist)
Stony and rocky ground	100 - 8,000	2,000
Concrete: 1 part cement + 3 parts sand	50 - 300	150
Concrete: 1 part cement + 5 parts gravel	100 - 8,000	400

Earthing for Safety

For an electrical system to be safe, a sufficient level of protection must be provided. This can be achieved by the use of insulation and earthing. The table below details the level of protection (LOP) provided by different types of insulation and earth.

Abbr.	Earth Type	Level of Protection (LOP)
FE	Functional Earth	0
PE	Protective Earth	1

Abbr.	Insulation Type	Level of Protection (LOP)
OP	Operational (Functional)	0
B	Basic	1
S	Supplementary	1
D	Double	2
R	Reinforced	2

For a system to be safe a total LOP of 2 must be provided.

The next table specifies the distance required between two conductors for the different types of insulation for IT and industrial applications. Basic insulation does not require such a large gap as double or reinforced and therefore provides a lower level of protection.

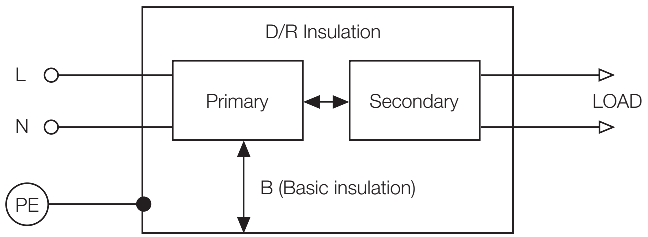
Insulation Type	Clearance	Creepage
Functional	1.5mm	3.2mm
Basic/Supplementary	2.0mm	3.2mm
Double/Reinforced	4.0mm	6.4mm

The distances above are based on a 300 VAC working voltage. The working voltage is the voltage between the two circuits to be isolated. The lower the working voltage, the lower the creepage and clearance distances required.

To ensure that the insulation is correct and not damaged or manufactured incorrectly a test voltage must be applied. The table below shows the test voltages for a 300 VAC working voltage.

Insulation Type	Test Voltage
Functional	1500VAC
Basic/Supplementary	1500VAC
Double/Reinforced	3000VAC

Two types of earth can be present in a system.
FE – Functional Earth – This does not provide a safety function.
PE – Protective Earth – This provides protection against electric shock in a class 1 system.



The diagram above represents a complete class 1 power supply. Primary to earth protection is provided by basic insulation and protective earth (LOP 2). Primary to secondary protection (240VAC to 12VDC) is provided by double/reinforced insulation (Total LOP 2).

Earthing for EMC

Full details of earthing for EMC can be found in the legislation section (page 93).

DC Output Considerations

• Output Regulation

Line Regulation

Line regulation is a static performance measure of how well a power supply holds the output voltage constant in the face of a changing input.

Line regulation defines the change in output voltage or current resulting from a change in the input voltage over a specified range.

% Line Regulation = $V_{OUT(Max)}$-$V_{OUT(Min)}$ / $V_{OUT(Normal)}$ x 100

where $V_{OUT(Normal)}$ is the output voltage at nominal line input voltage
$V_{OUT(Max)}$ is the output voltage at maximum line input voltage
$V_{OUT(Min)}$ is the output voltage at minimum line input voltage

> **Example:** A power supply's output is nominally 5.02V but when the AC input is varied from its minimum to maximum value the output varies from 5.015V to 5.03V.
>
> % Line Regulation = (5.03 – 5.015) / 5.02 x 100 = 0.29 %

Load Regulation and Cross Regulation

Load regulation is a static performance measure, which defines the ability of a power supply to remain within specified output limits for a predetermined load change. Expressed as a percentage, the range is dependent upon the product design and is specified in the product data sheet.

% Load Regulation = $V_{OUT(Load\ Max)}$-$V_{OUT(Load\ Min)}$ / $V_{OUT(Normal)}$ x 100

where $V_{OUT(Normal)}$ is the nominal output voltage
$V_{OUT(Load\ Max)}$ is the output voltage at maximum output current
$V_{OUT(Load\ Min)}$ is the output voltage at minimum output current

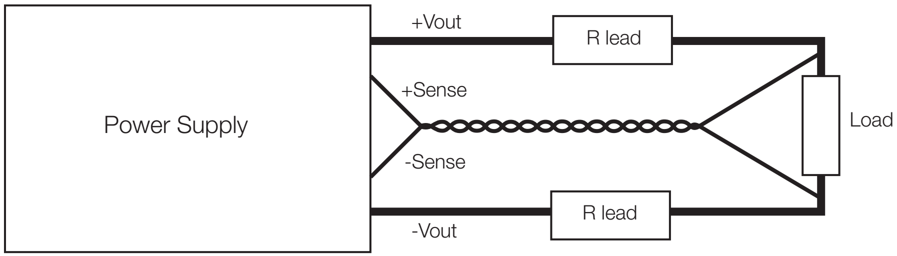
> **Example:** A power supply manufacturer specifies that for a load change of 5% to 100% its power supply output changes from 5.02V to 5.05V around a nominal voltage of 5.02V.
>
> % Load Regulation = (5.05 – 5.02) / 5.02 x 100 = 0.6 %

For multiple output power supplies, another factor affecting the output voltage is cross regulation. This is an extension of the load regulation test and determines the ability of all the power supply outputs to remain within their specified voltage rating for a load current change on another output. It is calculated in the same manner as load regulation and is often specified as a percentage change in output voltage for a percentage change in another output load, e.g. V1 cross regulation = 1% per 10% change in V2.

Remote Sensing

Many power supplies provide remote sensing, which enables the output voltage regulation to be maintained at the load itself rather than at the output pins. This is achieved by using two sense lines connected from the remote sense pins of the power supply to the load which may be located at some distance from the power supply.

Remote sense can compensate for voltage drops in the order of hundreds of mV, typically a maximum of 500mV. The sense lines (one to the load, and one return from the load) monitor the voltage at the load and regulate the power supply output, thus compensating for drops in voltage across the load cables. Remote sense is normally used when the load current varies resulting in irregular lead voltage drop. If the load is constant and the voltage drop is fixed it is recommended that the trim adjustment feature be used to compensate for the voltage drop over the load line.



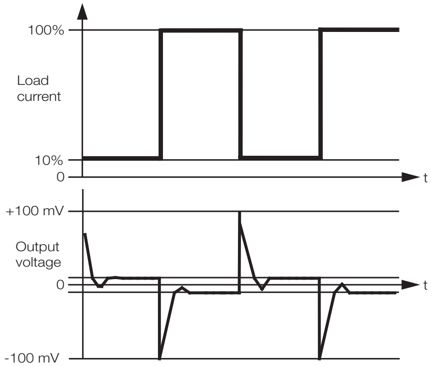
The voltage drop between the power supply output terminals and load is mainly caused by the lead resistance. However, when there is substantial inductance between the load cables or circuit traces from the supply to the load, a dynamic Ldi/dt drop may be significant. This dynamic Ldi/dt drop and noise formation can be minimised by connecting a 0.1µF ceramic capacitor in parallel with a 10µF electrolytic capacitor at the load. Remote sense leads should be twisted to minimize noise.

If ORing diodes are used in a redundant application, remote sensing can also be used to compensate for the forward voltage drop across the ORing diodes. Such a forward drop depends on magnitude of current and the ORing diode's junction temperature. Trimming or adjustment can also be used to compensate for this drop, if the drop is of a known value.

The maximum amount of remote sense voltage compensation is specified in the power supply's data sheet. However, the raising of output voltage at the pins as the result of remote sensing and output trimming must not exceed the maximum output voltage rating, to prevent activation of OVP (over voltage protection).

Transient Load Response

Transient response measures how quickly and effectively the power supply can adjust to sudden changes in current demand. The figure below shows the behaviour of a typical converter during a load-current transient and the resultant output voltage wave form.

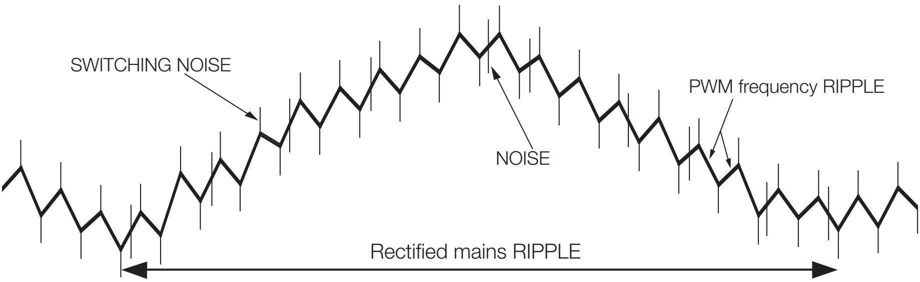


The output filter of a switching regulator, bar flyback converters, is composed of an inductor and capacitor which is a second-order lag system. Therefore, it takes a finite time to recover from load current transients and settle to its new output voltage.

The transient load response is normally specified as a maximum percentage change and recovery time of the output to a step load change, e.g. 4% maximum deviation, 500μs recovery for a 25% step load change.

• Ripple and Noise

Switching power supplies and DC/DC converters have the fundamental advantage of smaller size and higher efficiencies when compared to linear voltage regulators. However, the switching technique has the associated disadvantage of relatively high AC content on the output.



Typical output ripple and noise trace

Four AC components can be identified:

Low frequency ripple at two times the AC mains input frequency.
High frequency ripple due to pulse width modulation (PWM) to obtain the required line and load regulation.
The switching noise, which is high frequency pulse noise.
Aperiodic noise that is not related to the AC source frequency and/or the switching frequency of the converter.

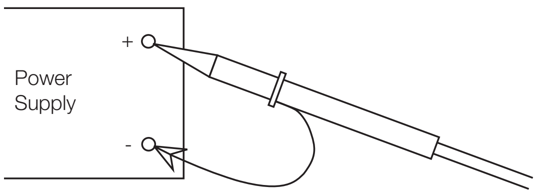
These AC components are normally specified by the peak to peak noise amplitude so that the best method for testing is by an oscilloscope with the bandwidth set as specified in the data sheet, often 20 MHz. Some data sheets also specify the requirement to fit external components to the measurement point, such as electrolytic capacitors, to mimic typical applications.

Accurate measurement of the output noise and ripple requires special attention to the equipment used, measuring probes and an understanding of noise being measured. The switch mode converter switches large amounts of power quickly when compared to the amplitude of the noise being measured. This means that even a few inches of ground wire loop in the oscilloscope probe will pick up fractions of Volts of noise. These probes must be properly connected to the measurement point.

Measurement of the noise is performed as close as physically possible to the converter's output terminals to reduce radiated noise pick-up. The greatest source of error is usually the unshielded portion of the oscilloscope probe. Voltage errors induced in the loop by magnetic radiation from the supply can easily swamp the real measured values.

To reduce these measurement errors, keep unshielded leads as short as possible. The figure below shows the wrong method, because the ground wire of the probe can collect radiated noise and the oscilloscope display is strongly dependent on the probe position and ground lead length.

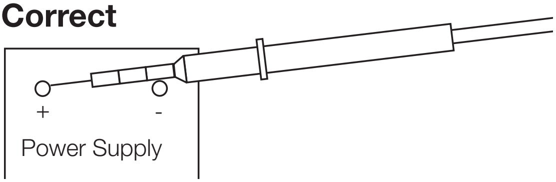
Incorrect



To prepare the probe for high frequency measurement, first remove the clip-on ground wire and the probe body fishhook adapter.

Then attach a special tip and ground lead assembly as shown in the figure below.

Correct



The ground ring of the probe is pressed directly against the output ground of the power supply and the tip is in contact with the output voltage pin.

• Output Protection

Output protection is implemented on power supplies and DC/DC converters in order to prevent damage to the power supply and the end equipment. Power supplies are protected against overload and the end equipment against over-voltage and excessive fault current.

Overload Protection

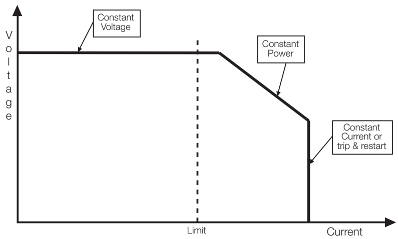
In the case of an overload or short circuit being applied to the output, circuits are employed to limit the current or power that the unit will supply, protecting both the power supply and the load from excessive current. Overload protection is typically implemented using one of the techniques listed below:

Constant power limit
Trip & restart or 'Hiccup' mode
Constant current limit
Fold-back current limit
Fuses or circuit breakers

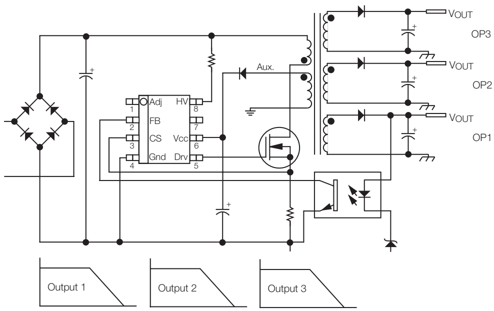
Constant Power Limit

Constant power overload limits are normally used in multiple output power supplies where the primary power is monitored and limited. This has the benefit of allowing power trading across the outputs while ensuring that the overall load is not exceeded.

This technique is also used on single output supplies in battery-charging applications as the current is maintained during an overload with the output voltage falling. Normally the constant power output will be maintained until the current reaches a point where damage may be caused, at which point the power supply will either go into a constant current mode or a trip & restart mode. When the overload condition is removed the power supply will recover automatically. See curves below.



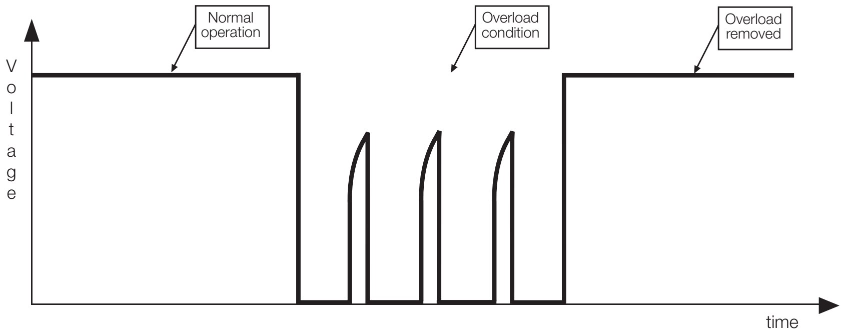
Single output power limit



Multiple output power limit

Trip & Restart or 'Hiccup' Mode

IIn this mode, the power supply detects an overload condition and the controller shuts the power supply off for a given time. After this time the power supply will try to start again. If the overload condition has been removed the power supply will start and operate normally. If the overload condition remains then the supply will switch off again, repeating the previous cycle. This condition will repeat until such time as the overload is removed. The off-time period may vary and the voltage reached will vary with the impedance of the overload. A typical wave form is shown below.

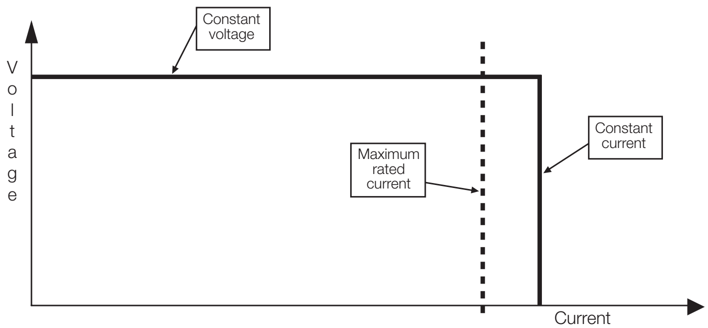


Trip & restart, or 'hiccup' mode

This type of overload limit is not suitable for high inrush loads, such as capacitive loads and lamps or for battery-charging applications. These applications will require either constant power or constant current characteristics.

Constant Current Limit

In this case the current is held constant at a pre-determined level at a point where the load current exceeds the maximum allowed limit.

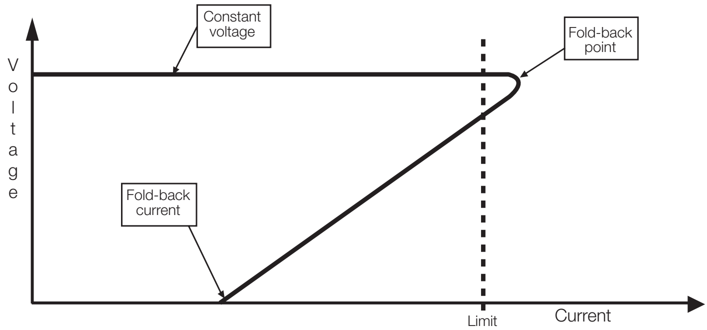


Constant current limit

This technique allows high inrush capacitive loads, lamps, motors etc to start and is often utilised in battery-charging and standby battery applications. In some instances a reduction in current will occur below a certain voltage limit. The power supply will recover, following the curve, when the overload condition is removed.

Fold-back Current Limit

Fold-back current limit decreases both the voltage and the current when an overload condition is detected. The voltage and current decrease simultaneously as the load impedance decreases. This technique is employed extensively on linear power supplies to prevent excessive dissipation in the series pass element and where crowbar over-voltage protection is employed, limiting the fault current.



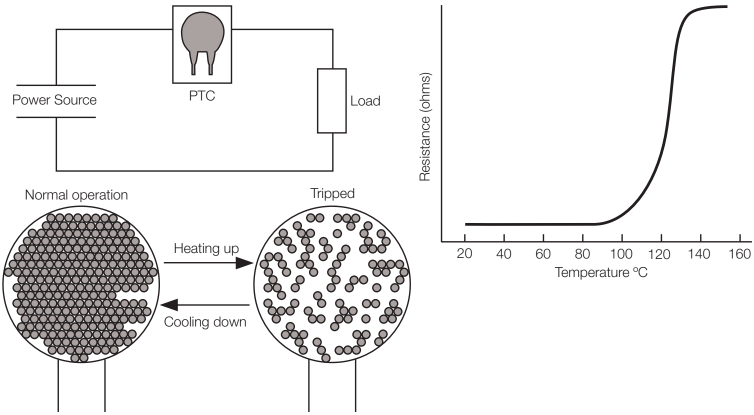
Fold-back current limit

The output voltage will recover once the overload condition is removed, following the overload curve as the load impedance increases. This technique is not suitable for high inrush or battery applications.

Fuse or Circuit Breaker Protection

Fuses and circuit breakers are generally only used in large output distribution and battery systems. If there are many branches in an output distribution system then each individual branch needs to be protected against excessive current flow. Circuit breakers are also employed where batteries are used as there is the potential for extremely high fault currents due to the low impedance of the source. Clearly, both of these require manual intervention to reset following the removal of the fault.

In some multiple output power supplies a resetting fuse is used, in the form of a Positive Temperature Coefficient (PTC) thermistor. An overload condition will cause the thermistor to heat up to a point where a very sharp transition of resistance occurs creating a high impedance and restricting the current. The unit will require an off/on cycle or the complete removal of the load to reset.



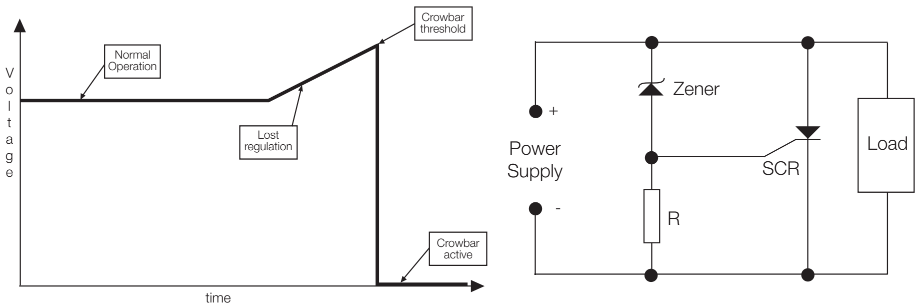
Resetting PTC thermistor fuse characteristics

Over-voltage Protection

Over-voltage protection is implemented using one of two basic techniques; crowbar protection, where the output is clamped by a thyristor or Silicon Controlled Rectifier (SCR), and electronic protection, where the unit is shut down by an independent control loop.

Crow-bar Over-voltage Protection

Should the output voltage exceed the limit set by the zener diode then the SCR is fired, clamping the output to around 1VDC and forcing the power supply into an overload condition. The clamp remains in place until the power supply is turned off and reset. This technique must be used in conjunction with a fold-back current limit.



Crow-bar over-voltage protection

Electronic Control Loop Over-voltage Protection

If an excursion of the output voltage is detected beyond the set limit, the power supply output is turned off via a second feedback loop. The second loop is utilized as it may be that the fault has arisen due to a failure in the main feedback loop. This is usually a latching condition that requires an off/on cycle to be performed to enable reset.

The characteristics of the output will be identical to the crowbar example, though the time for the output to fall to zero will depend upon the load applied. This system is utilized in most modern switching power supplies.

• Status Signals and Controls

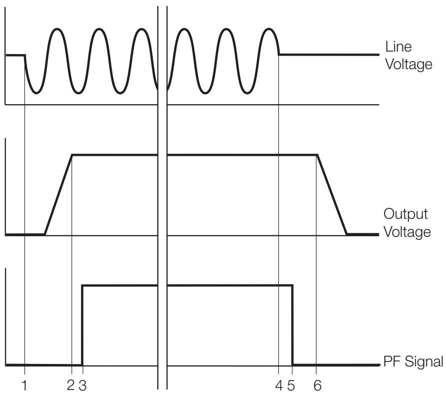
Status signals and controls provide the user with the ability to remotely monitor the condition of certain parameters within a power converter and to remotely control the power converter using signal level instructions. Signals provide information and have no influence on the function of the power supply. Controls allow for changes in parameters or function.

Status Signal Outputs

Common status signal outputs include power fail or AC OK, DC OK or power good, fan fail, fan speed and over-temperature. Interfaces include remote enable, remote inhibit, current share, voltage programming and voltage margining.

Power Fail (PF) or AC OK

This signal indicates the condition of the input voltage to the power supply. The signal changes condition following the application of an in-specification input voltage. This signal is most useful at mains failure as it is normally set to change condition several milliseconds prior to the output falling from specification. This allows data save routines to be carried out. These signals often require the converter to be running as they can be generated on the secondary side of the main power transformer.



Timing diagram for a typical power fail/AC OK signal

1 = Line voltage is switched on
2 = Output voltage established
3 = PF signal changes state indicating input within tolerance
4 = Line voltage fails or is switched off
5 = PF signal detects line failure
6 = Output voltage falls outside tolerance
5 – 6 = PF warning period

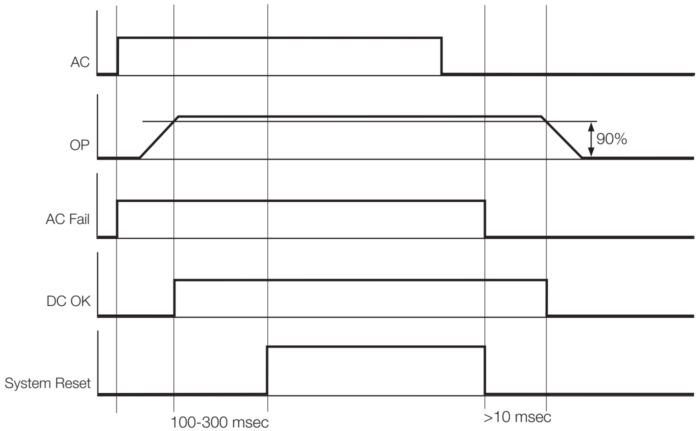
DC OK or Power Good

This signal indicates that the output voltage is within a set tolerance, usually above a minimum. This is normally only of interest at start-up as there is little or no warning of impending failure. Typical use of this signal is to ensure that a voltage rail is within tolerance and stable before enabling a load or to detect unit/output failure in redundant applications.

This signal can be used in combination with a PF or AC OK signal to enable a warning period prior to the output falling from tolerance in a line failure condition. This is often used in critical applications such as VME and is known as system reset (SRS).

System Reset (SRS/VME) Signals

The system reset signal indicates that the system voltage is OK. It is a combination of AC Fail (ACF) and DC OK. When ACF and DC OK are high and after a delay of 100-300ms the SRS signal changes to high. If either ACF or DC OK changes to low then SRS changes to low.



The System reset signal is the only signal that is described in a standard (the VME standard) and is typically used in industrial computing applications. The user may not see the ACF & DC OK signals as these are used internally to create the SRS signal.

Control Interfaces

Remote On/Off, Inhibit and Enable

This interface is used to switch a power converter on and off via a signal level control, without the need to switch the input supply. This removes the need for large and expensive switch gear, has the added advantage that there is no inrush current once the unit has been powered for the first time and ensures faster response at the output on switch-on. On many configurable multiple output power supplies the outputs can be switched on and off independently, enabling control of output sequencing.

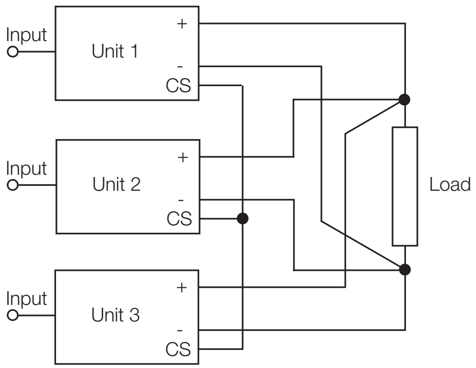
An Inhibit interface requires that the user intervenes to inhibit or switch off the unit. An Enable interface requires that the user intervenes to enable or switch the unit on. Where a converter is fitted with an enable signal, the output will not be present when the input power is applied until the user intervenes.

Signals can be active high or low and often open or short circuit to allow for simple relay control.

Current Share, Power Share or Single Wire Parallel

This interface is used to allow converters to communicate with each other when connected in parallel to ensure that the load is distributed evenly amongst the available resources. Typical load share accuracy is around +/-10%. This ensures that no individual supply is overloaded.

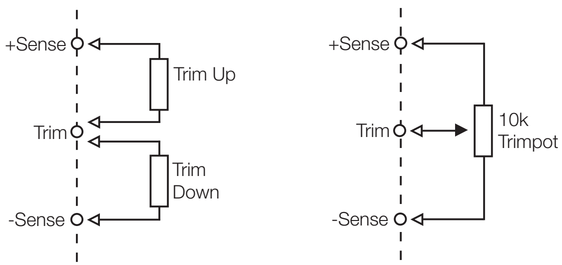
In low voltage redundant applications, where remote sensing of the output voltage is necessary, this interface will be needed to ensure load sharing and has the added benefit of reducing the stress on individual units and further improving reliability.



The connection between the units interfaces directly with the internal regulation circuit. The output current is monitored and the output voltage adjusted until the load current is shared equally.

Voltage Adjustment and Programming

The most common means of adjusting the output voltage of a power converter is via the internal adjustment potentiometer. Normally the output can be adjusted by up to +/-10%. Many converters can also be adjusted via an external potentiometer or resistor connected via the trim interface, an example of which is shown below.



Another option on some converters is the ability to program the output voltage using an external voltage or current. Common programming voltages are 0-5VDC or 0-10VDC for a 0-100% change in output voltage. Current programming can also be implemented where a 4-20mA standard module can be utilized.

Because the programming signals interface directly with the converter's regulation circuit, precautions against noise interference should be implemented.

Output Margining

Margin interfaces are used to increase or decrease the output by 5 to 10% by connecting the margin pin to plus or minus sense. This function is most commonly used in parallel systems or standby battery applications to test system elements without exposing the load.

In parallel systems, the approach is to shift the load to the higher output voltage unit to ensure that it can supply the full load. The remaining units are still operating so that there is no risk to the load should the output of the unit under test collapse.

In standby applications the charger output is reduced, shifting the load to the battery. Should the battery not support the load then the charger or rectifier is still present to ensure that the load is not dropped.

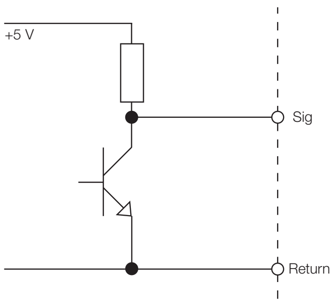
Common Topologies for Signals

Signal outputs can be presented in a number of topologies varying from converter to converter and manufacturer to manufacturer. The most common topologies are TTL compatible, open collector and volt free opto-couplers & relay contacts.

TTL Compatible Signals

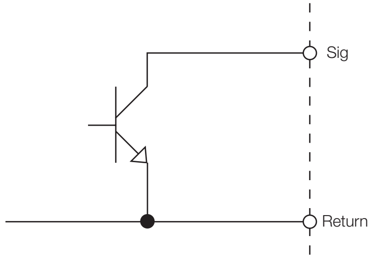
Signal outputs are designed to interface directly with TTL logic circuits. They provide a signal output of 0VDC or 5VDC and can be active high or active low.

Signal outputs follow the standard rules for TTL circuits where a low signal is <0.8V and a high signal is >2.8V. A standard TTL signal will sink and source a minimum of 16mA. The TTL signal output from a power converter is typically formed from a signal transistor with a pull up resistor to an internal auxiliary 5V rail.



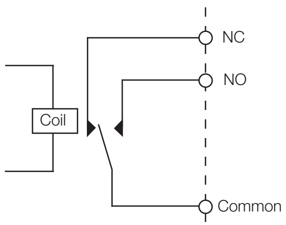
Open Collector Signals

Open collector signals provide a signal transistor with its emitter connected to the zero volt output of the converter and the collector left floating. This allows the user to connect the signal as the application demands using external components, the limit being the voltage and current ratings of the transistor used.

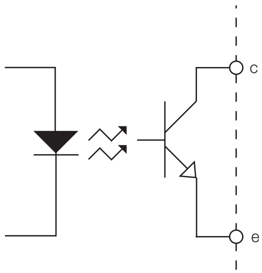


Isolated Signal Outputs

Isolated signal outputs are provided as opto-coupler transistors or relay contacts. These signals allow the user to configure the signals as either high or low as the application demands. Relay contacts also provide easy interface with industrial Programmable Logic Controllers (PLCs) and the inhibit interfaces of downstream DC/DC converters. Relay interfaces are typically small signal relays able to switch up to 1A at 24VDC and 0.5A at 120VDC.



Relay Signal Output



Opto-coupler Signal Output

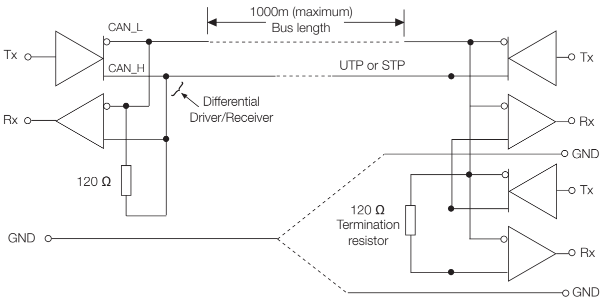
Another benefit of isolated signals is that multiple converters can be used in series or parallel combinations allowing the user to create combined series or parallel signal outputs, regardless of positive or negative output configurations.

Digital Communication Interfaces

Direct communication with power supplies is becoming increasingly popular as power supplies become integrated into control systems or building management systems. Alarm status can be requested from, or flagged by, the power supply and operating parameters such as alarm trip levels, output voltage and current limit levels can be maintained or programmed during operation. In some cases, power supplies will have their serial number or build dates available for system interrogation. Three common digital buses are described on the next page.

Controller Area Network (CAN) Bus

The CAN bus is a differential 2 wire system used for data communication at high speeds (1Mbps, 40m line length) or slow speeds (10kbps, 1km line length). The CAN bus was designed by Bosch for automotive use and is therefore ideally suited to use in harsh, electrically noisy environments. Because of this, the CAN bus is widely used in industrial environments and many controller devices are available to implement a network. Data is transmitted serially using a Non-Return to Zero (NRZ) format for both efficiency of message length and integrity of data. The CAN bus standard defines the data packet makeup for transmission and this may be built in to the bus controlling devices but there are higher level protocols, such as CANopen and DeviceNet which can be used to simplify their use. These allow easy programming of a communication system using a variety of different manufacturers' controllers.



Inter Integrated Circuit (I^{2}C) Bus

The I^{2}C bus was developed by Philips Semiconductors in the 1980s as a method of bi-directional data transmission between ICs. The bus has been adopted for communication between general parts of circuits and application specific circuits. The bus is serial and consists of two wires, one called SDA (Serial DAta) for data and the other called SCL (Serial CLock) for clocking. A ground return is also required. The bus utilises a master/slave architecture in which there can be multiple masters, though when one has control, the others act as slaves. The bus will operate at speeds of 100kbps as standard though there is a fast mode of 400kbps or a high speed mode with speeds of up to 3.4Mbps. The faster modes have tighter limits on the amount of noise that can be present. The maximum line length is typically 3-4m though if the clock speed is reduced to 500Hz, the line length could be as long as 100m. Normally, the limiting factors are the amount of noise pick up, which can obliterate the data, and data loss due to volt drops. Active current sources can be used to help to compensate for this.

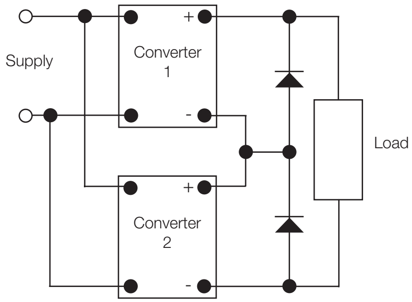
Power Management (PM) Bus

The PM bus is an open power system standard, with a defined language, which is used to provide communications between power supplies/converters and othe devices utilized in a power system. The PM bus protocol is implemented using the System Management (SM) bus which has become an industry standard serial interface for low speed system management communications. The PM bus is designed to allow programming, control and monitoring of suitably designed power conversion products.

• Series & Parallel Operation

Series Operation

In general, power supplies can be operated with outputs connected in series. Some care will need to be taken to ensure that one power supply doesn't affect the operation of the other. Care also needs to be taken to ensure that the total output voltage does not exceed the working output to earth breakdown voltage of either one of the power supplies.



Common practice when putting two power supplies in series is to connect reverse-biased diodes across the output of each series connected supply. This protects the output from the reverse voltage of the other in the event of a failure.

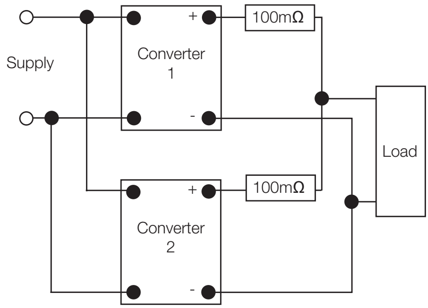
Only power supplies with constant current power limit should be considered for series operation. If a power supply with foldback current limit is used, lock-out can occur at switch-on because of the differing ramp-up times of the units.

A frequent application of power supplies in series is when using a dual output converter in order to obtain one single output of a higher voltage. In this configuration 24V, 30V, or 48V outputs can be achieved from +/-12, +/-15 or +/-24 volt dual output power supplies.

Parallel Operation

If greater power is needed, a common solution is to connect two power supplies in parallel. This is usually performed with two power supplies which both have a constant current overload characteristic. The connections will normally be made with the load in a star formation, with the load being the star center. This will ensure that the lead lengths are very nearly equal. One power supply should not be looped to the next as connectors could be overloaded and sharing willl be poor.

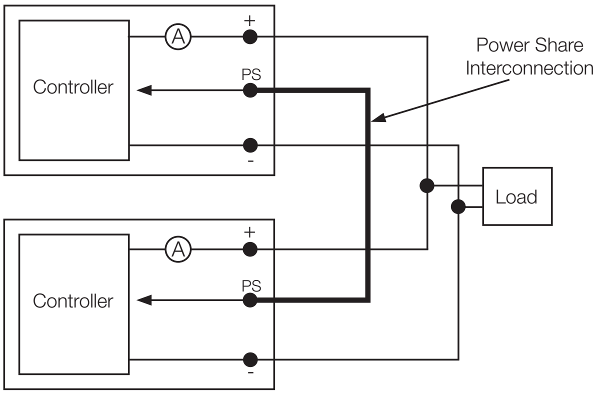
Sharing can be created by adjusting output voltages so that they are as close as possible and matching the impedances of the load cables, i.e. equivalent wire lengths and ring-crimped terminals.



It is the case that the power supply with the highest voltage will supply all of the load and this unit may run in current limit, depending on how much power is drawn. If this happens the output voltage will drop to the voltage of the other power supply. This condition can be alleviated by the use of series resistors to balance the output load currents, but even this method is not 100% accurate. Assuming that the two resistors are exactly equal, small output voltage differences will still cause large current imbalances. This method does have a number of other downsides. Firstly, the use of the series resistors will degrade the output regulation. Secondly, allowing for the possible imbalances of up to 50%, each power supply must be capable of supplying not just 50% of the load current but up to 75%.

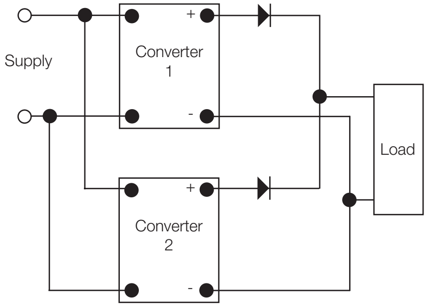
Active Power Sharing

In active power sharing each unit has an additional control terminal through which the power supplies are interconnected. This connection has many different names, the most common being Power Share or Current Share. This connection enables the control circuits of the two power supplies to communicate and adjust the output voltage so that they share the load equally.
In practice the units will typically share within +/-10%.



• Redundant Operation

Redundancy is required when continuous operation of the system is required in mission critical applications. Some of the most common areas are in communications, oil and gas, and other applications where revenue is generated by the system.

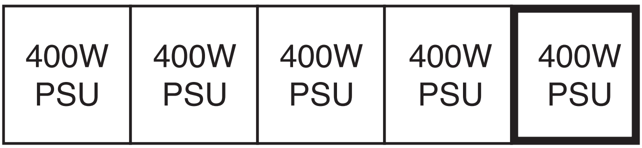


Diodes are used in redundant systems so that if one power supply fails the other will continue to operate without the 'dead' power supply pulling down the output rail. Diodes should always be rated higher than the power supply output current limit.

Adding diodes in the output lines of a power supply causes degradation of the output regulation due to the voltage drop across the diode at different current levels and reduced system efficiency. This needs to be considered when using a redundant system as a solution as the load must be able to accept the poorer regulation. To get around this problem it is possible to use the remote sense function and connect it after the diode. When doing this, the current share connection will also need to be made. This will allow the power supply to compensate for the diode voltage drop.

N+M Redundancy

It is common to have a dual redundant system, whereby a single unit or a number of units are required to support the load and another unit or number of units complete the system in order to provide 100% redundancy. In some applications it is not cost-effective to have 100% redundancy, although this approach will offer a sixty times improvement in reliability over a standalone PSU. A much more common approach is to use N+M redundancy, where N is the number of units required to support the load and M is the number of redundant units. In the example below a 4+1 system is shown, using 4x 400W to support the 1600W load and 1x 400W unit in redundancy. This solution offers a twenty-fold increase in system reliability.

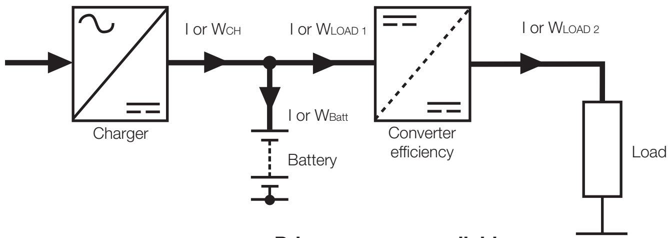


• DC Standby Systems

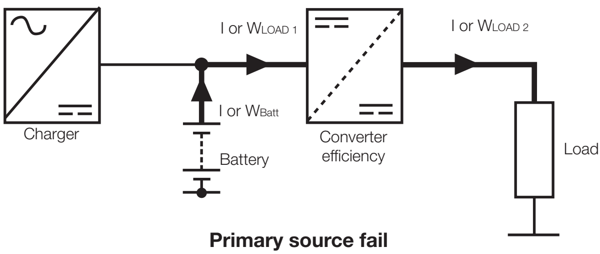
DC standby systems can be broken down into five sections as shown below:

a. AC/Primary Power Source
b. Rectifier/Charger
c. Control/Management
d. Battery
e. Load Distribution

When designing a DC standby system it is important to always start at the load and work back to the AC source, taking into account the efficiency of any load voltage regulation devices such as DC/DC converters, step-up converters or diodes when sizing the battery.



Primary source available



Primary source fail

Care should be taken as the load rating on the system may change when the primary source is not available as this may change the battery Ah capacity required.

AC/Primary Power Source

The AC/Primary power source will typically be derived from the national power grid. For small installations, a single-phase supply will generally be sufficient. For large arrays of single-phase rectifiers or high current applications a three-phase supply may be more suitable.

Rectifiers/Chargers

Rectifier/charger designs are based around switch-mode technology, offering the advantage of being lightweight, robust and more compact than traditional transformer/thyristor based equipment.

Rectifiers/chargers should provide a regulated output, <1%, along with ripple of less than 1% (as excessive ripple will result in battery plate damage) and withstand variations on the incoming AC line voltage of at least ±10%.

Voltage & current protection circuitry, boost/equalizing charging and temperature compensation will commonly be incorporated in addition to remote control and alarm reporting.

Batteries

The most important part of the DC power system is the battery. A full section of this guide is given to battery sizing and selection. See pages 18-20 in the Input Considerations section.

Control and Monitoring

Remote control and monitoring facilities are often provided on DC standby systems to provide the user with real-time information concerning the ability of the system to provide back-up power. Power management functions such as on-line/off-line charging, low voltage disconnect and charger current control can be designed into the system to give a high level of functional independence and high levels of redundancy.

Care should be taken not to overcomplicate the control and monitoring systems in a particular application. While it may be advantageous to be able to establish the remaining battery capacity in large telephone exchange systems, this level of complexity would not normally be required on a fire/intruder alarm back-up unit.

The following features should be considered on most systems:

Temperature Compensation

The simplest way of maintaining the optimum rate of reaction within a battery while charging. The charge voltage is adjusted at a rate proportional to the change in temperature (i.e reduce charge voltage for increase in ambient temperature). A typical change in charge voltage is -3mV/°C for a VRLA battery. This will maximize battery life and protect against thermal runaway.

Low Voltage Disconnect

When using VRLA batteries, care should be taken not to over-discharge the battery below 1.65V/Cell to avoid permanent damage to the battery. This can be achieved by either disconnecting the battery or load from the system by tripping the battery/load MCB (manual reset), or by opening a contactor/relay (automatic reset).

Battery Protection

Unlike most other DC power sources, batteries do not have any built-in current-limiting devices, so if short-circuited the current available from a battery will be limited only by the battery's internal resistance and any components connected between the battery and the short (cable, terminals etc).

This current may be greater than 100 x the operating system current, resulting in damage to cable insulation or even fire within the system. This current needs to be interrupted before it can do any damage. The best way to do this is to include within the system suitably-rated battery fuses or MCBs sized to break these high DC currents (battery protection should be fitted as close to the battery terminals as is practically feasible).

Distribution

DC power distribution is generally achieved by using circuit breakers or fuses, sized to allow either manual or automatic interruption to current flow under overcurrent fault condition.

When designing secure power systems or routing cables carrying both AC and DC, lead inductance and coupling of noise into the DC distribution system may cause problems in some installations.

Inadequate sizing of conductors and interface points to bus-bars and other components may result in an appreciable voltage drop at the load.

System Sizing

In order to size any DC system there is a minimum of data required before you can start:

- System nominal voltage e.g. 24V, 48V, 110V.
- Load rating - either current or Watts drawn by the load during normal & primary power source failure.
- Standby time.
- Load voltage limits – the voltage range in which the load will safely operate.
- Normal operating/ambient temperature in which the battery will be operating.
- Battery type preferred, if known.
- Incoming supply parameters.

• Topologies

Technology Overview

An uninterruptible power supply is designed to provide a battery-based source of AC power, such that under mains fail conditions the load can be supported for a specified period of time.

This time is generally dictated by the period required to shut down equipment in an orderly fashion to allow for generator-starting time or for an engineer to attend site. In a high percentage of cases utility failure is for less than five minutes – consequentiy most standard UPS without external battery packs support the load for between five and ten minutes.

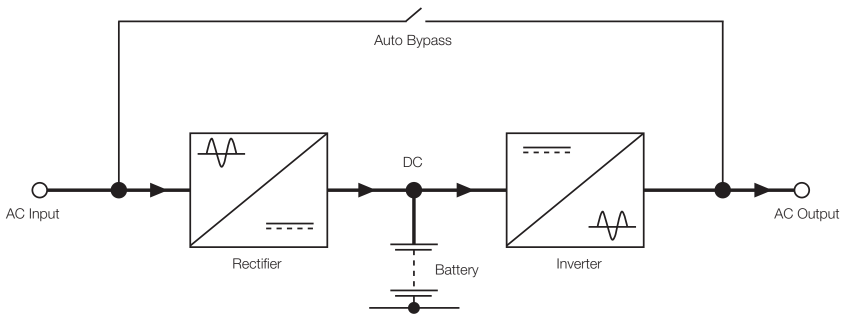
This period is often only a bridge between mains fail and generator starting.

Basic Description and Operation

On-line: 700VA to 800kVA single and three-phase input and output versions

Under normal conditions, mains is fed into the rectifier, which provides both DC power to the inverter and DC to charge the batteries. The inverter then feeds the load continuously. If mains fails, then the UPS continues to supply the load via the inverter but the inverter is now fed its power from batteries rather than from the rectifier. The load therefore sees no change during transfer from mains to inverter or vice versa. The static switch or auto-bypass provides a fail-safe mechanism in UPS fault conditions of the inverter, rectifier or battery. This type of UPS provides a true sine wave output under all circumstances and in the order of 60 - 90 decibels of noise attenuation.

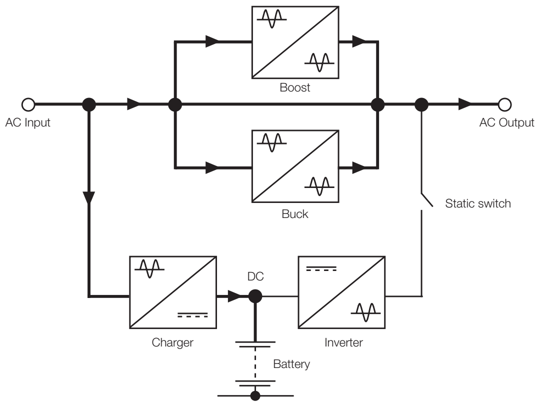
This topology offers the advantage of having its run time (autonomy) extended by adding additional battery modules. This is generally not true of off-line or line interactive UPS as their inverters are not designed to run for extended periods of time.



The bold arrows show normal operation (mains available)

Line Interactive: 400VA to 5kVA single phase only

During normal operation, mains power is supplied to the load via a buck/boost circuit in the UPS and the batteries are float-charged simultaneously. There is a switch over time of 2 – 10ms between inverter and utility or vice versa. There is a small amount of line conditioning. Input to output noise attenuation is 20 – 30 decibels.



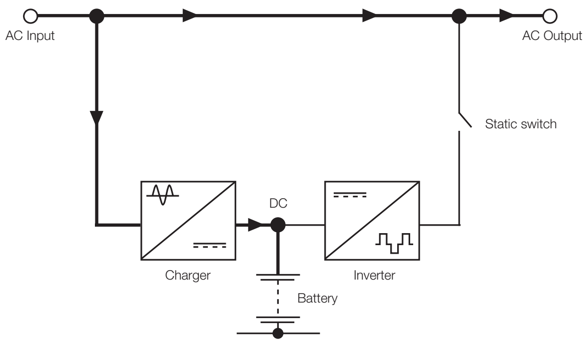
The bold arrows show normal operation (mains available)

Off-line: 250VA to 800VA single phase only

During normal operation, mains is fed directly to the load and the batteries are float-charged. When a power failure occurs there is a small switch time to inverter of 2 – 10ms. The load is then supported by battery via the inverter. Typically the inverter is low cost and has a quasi sine wave output. There is a very small amount of line conditioning and input to output noise attenuation is typically 5 decibels.

Off-line UPS units are not suitable for supporting a critical load. The user is reliant on the inverter switching on when it is needed most, which means that a failure could occur at the most critical moment when mains fails.
In these applications only online UPS units should be used.

In addition, most off-line units are unsuitable for magnetic loads such as transformers, motors or linear power supplies. The quasi-sine wave can saturate the input magnetics of these devices causing damage.



The bold arrows show normal operation (mains available)

Block Descriptions

Charger/Rectifier

This module converts AC (Utility/Mains) power to DC power. This DC then charges the battery and, in the case of an on-line UPS, also provides DC power to the input of the inverter.

Battery

The battery in any UPS system is the energy storage device. It provides DC power to the inverter under mains fail conditions.

Inverter

This module converts DC from the battery to AC, which supplies the load. It can be quasi sine wave (square wave output) for lower cost units like off-line or line interactive (low end models) and sine wave for high end line interactive or on-line models.

Static Switch/Auto Bypass

This is an intelligent switch which looks at both mains input and inverter output, switching automatically between them depending on which source of power is available (utility or inverter). It also provides an overload route if the inverter in an on-line UPS is asked to provide more power than it can deliver. The bypass protects the load against inverter failure or rectifier failure.

The control or power module houses the charger, bypass switch and inverter. On smaller UPS below 3kVA the batteries are also housed within the same chassis.

Advantages/Disadvantages of Different UPS Topologies

Off-line UPS

Advantages	Disadvantages
Very high efficiency	No line conditioning
Low cost	Inverter off until needed most
Small size	No AC regulation
	Minimal run time
	Inverter quasi-sine wave
	Very few options available
	Software functions are basic
	2-10ms break to/from inverter

Line Interactive UPS

Advantages	Disadvantages
High efficiency	Very little line conditioning
Lower cost than on-line	Can be quasi-sine at low powers
Provides AC regulation	Inverter off until needed most
Software and control are more comprehensive than off-line	2-10ms break to/from inverter
Full function display	

On-line UPS

Advantages	Disadvantages
Very good line conditioning	Larger physical size
Inverter always on	Higher costs
Fail safe technology (bypass)	Less efficient than off-line / line interactive
Full function UPS control	
Multiple options cards	
Extended autonomy solutions	
Maintenance bypass options	
Designed for critical load support	

• Accessories

UPS options and accessory products

Accessory products for UPS tend to be available only for on-line models because of cost implications. They include:

19" rack kits providing racking guides or shelves for 19" cabinet mounting of UPS and battery modules.

Option cards for mounting within UPS. Option slots include:

> **Volt-free or dry contact cards** for contact closure remote advice of mains fail, battery low, bypass or UPS alarm.
>
> **USB cards** to replace older style RS232 connection for modern windows operating systems such as Windows XP.

SNMP/network adapters allow UPS units to be accessed via the network. Network managers can also ensure that UPS units advise them of any power problems using SNMP communications protocol.

Extended battery packs/modules allow run time or autonomy to be increased for up to 8 hours. Typical extended support times tend to be one hour or less.

Maintenance bypass units are added to on-line UPS systems to ensure that under fault conditions the UPS can be taken out of circuit for repair/replacement. It is recommended that all on-line systems have a maintenance bypass unit.

• Software

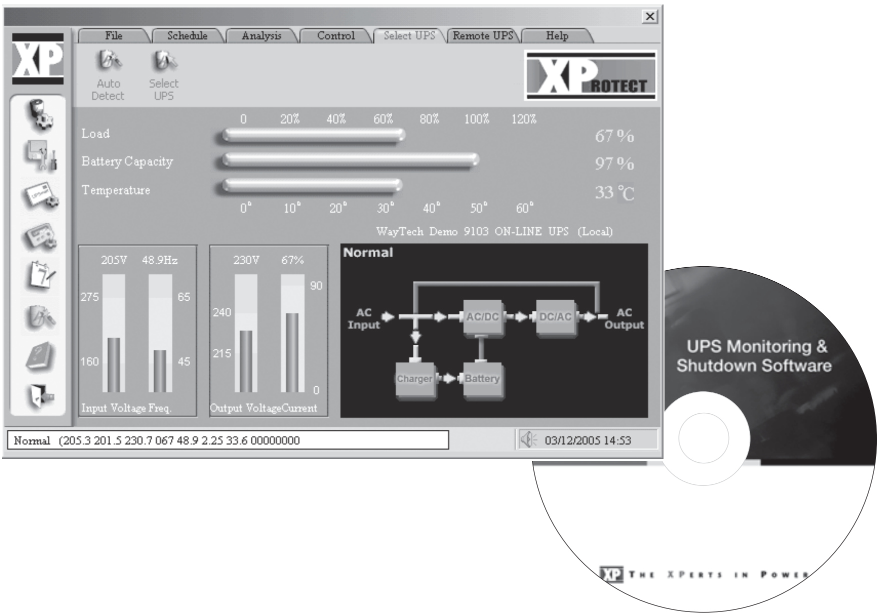
Virtually all models of UPS are provided as standard with shutdown and monitoring software. This software is supplied on a CD and typically covers all windows-based platforms. Connection is usually via a supplied RS232 cable.

The key reason for utilizing shutdown software is to ensure that when a mains fail or battery low signal is received from the UPS, the computer powered by the UPS is shut down in an orderly fashion, saving all files and avoiding loss of data.

Control is via the console in the software and allows the user, via a serial connection, to schedule battery tests, shut down the system and carry out general UPS housekeeping.

In combination with its flexible shutdown features, the software also lets the user know which programs were shut down at last mains failure to ensure that no saved files are missed.

A typical software screen shot and CD are shown below.



Inverters, Frequency Converters & Static Switches

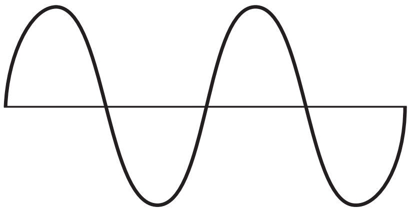
• DC/AC Inverters

DC/AC inverters are used to produce an AC supply from a DC power source and are available in numerous shapes and sizes. Inverters are utilized within UPS systems to ensure a continuous source of power in the event of a mains failure.

As a standalone item they can be used in a wide range of fixed and mobile applications, each with their own particular requirements and limitations. Following are some of the features to consider when specifying or evaluating an inverter for a particular application.

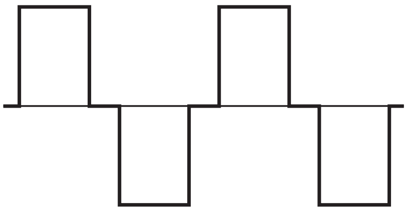
Output Waveform

There are 2 major waveform types of inverters, sine wave (or true sine wave), and modified sine wave (actually a square wave).



Sine Wave

Sine wave inverters generate a waveform similar to that supplied by the utility company. These inverters have the advantage that they will work with virtually all mains-powered equipment with the same corresponding voltage. Some appliances, such as motors, will only produce full output with sine wave power. A few appliances, such as light dimmers and some older battery chargers, require a sine wave in order to work at all.



Modified Sine Wave (quasi-sine)

A modified sine wave inverter actually has a waveform more like a square wave, but with a dwell period at zero cross-over. This type of inverter can readily be used with switch mode power supplies as the load.

Input Voltage

The DC voltage available for a particular application will affect the rating and efficiency of an inverter due to the higher currents being drawn from low voltage power sources. Typical input ranges are detailed in the table below.

Nominal Battery Voltage (V)	Voltage Ranges (V)
12	10.2 - 14.4
24	20.0 - 32.0
48	40.0 - 60.0
110	88.0 - 132.0
220	176.0 - 264.0

Surge Rating

Inverters typically have a continuous rating and a surge rating. The surge rating is specified in Watts or VA for a fixed time period (normally several seconds). The surge capacity varies considerably between inverters, even within the same brand, and may range from as little as 20% to as much as 300%. Generally, a three to fifteen second surge rating is enough to cover 99% of applications. Pump motors, for example, have a surge of approximately half a second on start-up.

Synchronization Signal

If the inverter is to be used in conjunction with a static bypass switch, the inverter switching frequency and phase relation of the output must be synchronized to that of the mains, or alternative AC source, in order to reduce disturbance in load supply during transfer.

Reverse Input Protection

With mobile inverters, where the input supply is likely to be connected and disconnected multiple times during the product's lifetime, it is recommended that some form of reverse input protection is fitted to ensure the unit is not damaged if the supply is accidentally reversed.

Alarms & Controls

Most inverters come with some form of monitoring, either front panel LEDs or Volt-free/ dry contacts. Typical alarm types are:

- DC OK
- Low DC voltage
- Overload
- Output healthy
- Inverter ON

More complex alarms and control options can be added. However, it should be remembered that the more complex the system, the less reliable it becomes.

• Frequency Converters

The advent of the universal input PSU has enabled the majority of electrical and electronic equipment manufacturers to market their equipment almost anywhere in the world.

However, there are some applications incorporating motors/compressors/timers/avionics etc. where the frequency can have a dramatic effect on the functionality of the product used.

Typical frequency conversions are:

50Hz to 60Hz or 60Hz to 50Hz
50Hz or 60Hz to 400Hz

There are two types of frequency converters available; rotary and static.

Rotary Converter

A rotary converter comprises an electric motor and alternator, the incoming supply being converted to electro-mechanical energy; this is then converted back to the required frequency and voltage via the alternator. These types of converters tend to be employed for high power avionics applications.

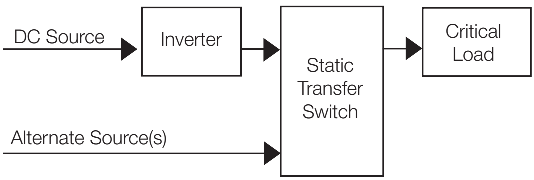
Static Converters

In a static converter, the frequency change is achieved by first converting the primary AC source into DC via an AC/DC rectifier, before conversion back to AC at the required frequency/voltage via a DC/AC inverter. In this way, the output characteristic of the converter is independent from the input source, providing a clean and stable power source.

Some commercial UPS have the option of setting the output frequency independently from the input by inhibiting the static switch enabling them to be used as frequency converters.

• Static Transfer Switches

Static Transfer Switches (STS) are solid-state switches designed to automatically or manually switch between two synchronized AC power sources with minimal interruption of the power to the load. This interruption is typically no longer than a quarter of a cycle in case of failure of one source or by manual initiation for test or maintenance.



Static transfer switch system

The switching action is designed to ensure that two power sources are not connected together, and is based around the Silicon Controlled Rectifier (SCR).

The basic configuration is back-to-back SCRs on the preferred and alternate sides of the switch. Figure 1 (right) shows a single-phase, two-source version. The three-phase and/or three-source STS is merely an extension of the same fundamental concept.

An SCR allows conduction only in the forward direction.

During normal operation, SCRs associated with the preferred source are in the ON-state, while those associated with the alternate source are in the OFF-state (in Figure 1, the bold lines denote conduction).

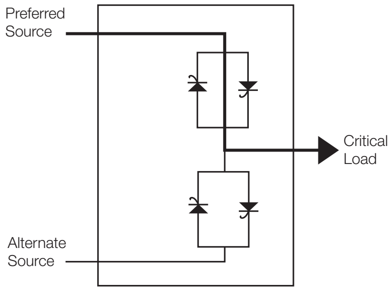


Figure 1

Current-sensing circuits constantly monitor the states of the preferred and alternate sources and feed the information to the supervisory microprocessor controller.

Upon sensing the loss of the preferred source, the microprocessor control instructs the gate-driven SCRs on the alternate side to turn ON (denoted by the bold lines in Figure 2). The transfer from the preferred to the alternate source is so fast (less than a quarter electrical cycle), that even the most sensitive electrical or electronic loads are unable to determine its occurrence.

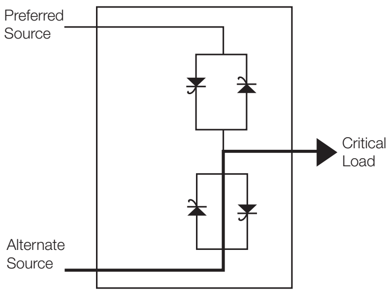


Figure 2

Since it is entirely based on solid state technology, the static transfer switch has no mechanical moving parts and requires minimal maintenance. It has an AC-to-AC efficiency in excess of 99%, a small footprint and requires no batteries when used as an alternative to the UPS.

Thermal Management

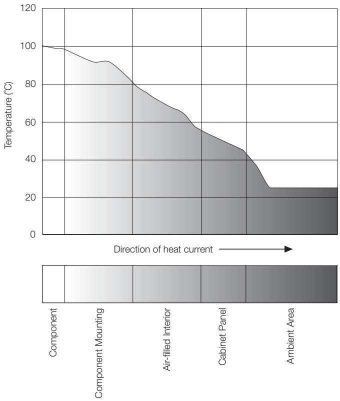
• System Cooling Fan Selection

Power Losses

Power losses occur in all electronic components. The effect of these losses becomes greater as more and more components are squeezed into smaller spaces. The result of this 'miniaturisation' is higher levels of heat per cubic volume of space. This waste heat can be considered to be system losses and expressed as follows:

Input power = output power + losses
Efficiency = output power/input power (always less than 1)

Losses can be in the form of heat, noise, light or work, and are expressed in Watts. The heat generated by a component does not only pass into the air around that component, it is also absorbed by adjacent components, the PCB and the equipment case. This 'waste' heat affects the performance of the adjacent components causing them to operate in higher ambient temperatures. Although modern design aids such as 'fluid dynamic analysis' can assist in the thermal design of equipment, the costs associated with the system often restrict its use. The majority of equipment designers must rely upon experience and knowledge to assist in the selection of a cooling system.



Representation of the temperature gradient of a device

The designer's dilemma is whether equipment can be designed to ensure that all waste heat can be removed by convection alone, or whether 'best practice' calls for the incorporation of forced cooling. The thermal control of electronic equipment should be considered as part of the overall design specification which, when achieved, will result in a coherent design, exhibiting greater reliability and life expectancy.

Establish Allowable Temperature Rise

First, it is necessary to establish the maximum operating temperature in which either the power supply or the electronics can safely operate. For example, this could be 50°C, the typical maximum operating temperature of a power supply. If the enclosure in which it is contained is to be used in a non air-conditioned environment, where the maximum temperature could reach as high as 40°C, the maximum temperature rise allowed is 10°C.

Establish Power to be Dissipated

If our example has all the load within the equipment then the total power dissipated within the enclosure is the power dissipated by the load, and the power dissipated by the power supply due to its inefficiency.

The load power is 260W
+
The power lost due to the inefficiency of the power supply,
which is 80% efficient, so the power lost is 65W
=
Total power to be dissipated is 325W

The airflow needed through a system can be calculated as follows:

$$\textbf{Air flow (m}^3\textbf{/hr)} = \frac{\textbf{2.6 x Power (W)}}{T_c}$$

Where Tc is the allowable temperature rise of the air in the equipment in °C, calculated as the maximum air temperature required minus the maximum temperature of air coming into the equipment (the ambient temperature). Airflow is measured in m^3/hr, and the power in Watts is the amount of heat dissipated into the box.

The power supply often has its flow rate given as a linear figure, while fan manufacturers typically specify a volumetric flow rate. To convert from one to the other, convert the volumetric flow rate in m^3/hr to m^3/s (divide by 3600), then divide the resultant figure by the active area of the fan. The active area of the fan is the area traced by the tips of the blades minus the area of the central hub (which is not directly contributing to air movement).

$$\text{Linear flow rate (m/s)} = \frac{\text{Volumetric flow rate (m}^3\text{/s)}}{\text{Active fan area (m}^2\text{)}}$$

Therefore in our example:

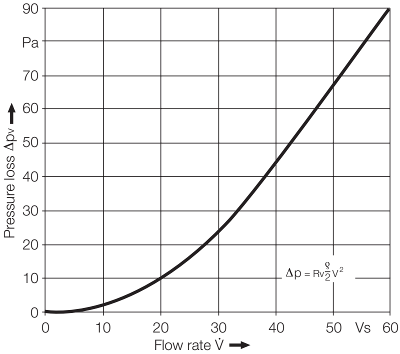
$$\text{Air flow (m}^3\text{/hr)} = \frac{\text{2.6 x total power dissipated (W)}}{\text{Allowable temp rise (°C)}}$$

$$= \frac{2.6 \times 325\ \text{W}}{10\ \text{°C}}$$

$$= \textbf{84.5 m}^3\textbf{/hr (49.77 CFM)}$$

To convert m^3/hr to cubic feet per minute (CFM) multiply by 0.589.

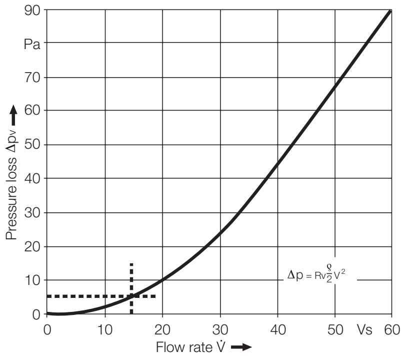
Characteristic Curves for Equipment Pressure Drop



Airflow figures published for fans are given in free air. In practice, an enclosure provides resistance to air movement. It's rather like trying to blow up a balloon. This resistance will change with each equipment design due to PCB sizes and positions and the effect of other components which will provide resistance to airflow. Luckily, there is an approximation to back pressure which can be applied. This graph is an approximation or an average, based on accumulated historical data from fan manufacturers and is applicable to most electronic equipment. The graph shows the flow rate along the horizontal axis in litres per second and the back pressure on the vertical axis in Pascals.

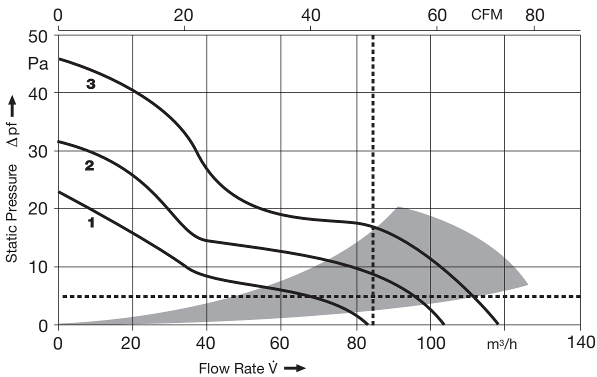
Estimating Back Pressure

The graph above is then used to estimate the back pressure, so for a system which requires 14.2l/s, the back pressure is 5 Pascals.



Using Fan Characteristic Curves

We know that the back pressure is 5 Pa and we require 84.5m³/hr. Therefore, from the graph below it can be seen that fan 2 is the suitable selection.



Curve	Type
1	FAN 1
2	FAN 2
3	FAN 3

• Cooling power supplies

Power supplies generate waste heat which has to be dissipated. They typically have either convection cooled or forced cooled ratings or, in some cases, both. Forced cooled power supplies may incorporate a cooling fan, or may specify the user cooling required to operate the unit at maximum load and ambient temperature.

Where user cooling is required it is most important that the power supply cooling is adequate for both safe operation and adequate service life. It is very application specific and dependent on the ambient temperature, applied load and physical location with respect to the cooling fan and other system assemblies.

The main difference between convection and force cooled products is in the power density offered for a given efficiency, convection cooled products offering a lower power density meaning that they occupy a larger volume. A power supply on a 3” x 5” industry standard footprint may have a convection rating of 100W while the force cooled version may have a rating as high as 200W.

Convection cooling

Where the power supply has a convection cooled rating, it is intended to be used in an environment where there is free air. The system designer must ensure that there is adequate space around and above the unit for free air convection currents to cool the unit and must also ensure that the ambient temperature local to the power supply is controlled to a level within its maximum ratings.

Forced cooling

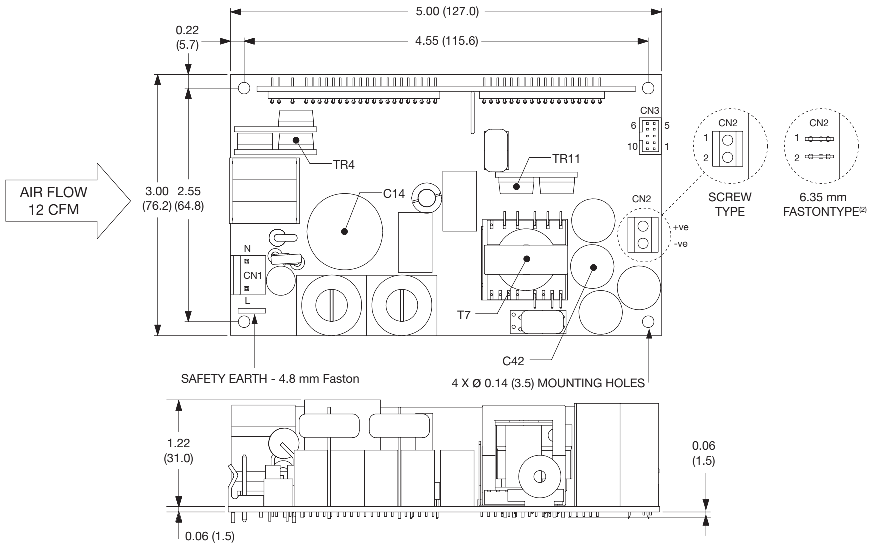
Force cooled products with integral cooling fans are relatively easy to apply as it is a simple matter of ensuring that the maximum specified ambient temperature is not exceeded for a given load rating and that the intake and exhaust areas are not obstructed.

Typically, power supplies that require the user to provide forced air cooling will specify a minimum required airflow. This is usually for operation at 100% of the power rating at the maximum ambient temperature allowed.

The required airflow is often specified in Cubic Feet per Minute (CFM) which is also the common rating for cooling fans. The effectiveness of cooling fans installed in enclosures must be given consideration, as discussed earlier in this section, and the CFM rating deals in volume of air rather than air speed, which is the important factor. The object is to maintain the components used within the power supply at a safe operating temperature and to ensure adequate service life.

When the required airflow is specified in CFM it assumes that the power supply is installed in an area which is relatively similar to it’s own cross sectional area. This is rarely the case as the power supply is typically used as a sub-assembly within a complete equipment enclosure. It will also assume that the air is directed at the power supply, which may also not be the case, so converting to Linear Feet per Minute (LFM) or meters per second (m/s) provides a more valid criterion as linear air speed measurements specify where the air is flowing and directly relate to heat transfer.

Example based on an EMA212 power supply



In the case above, the power supply requires forced air of 12 CFM in the direction indicated by the arrow. The cross sectional area is:-

3” x 1.34” = 4 inches^2 or 0.028 feet^2

Therefore the air velocity required is:-

12/0.028 = 429 LFM or 2.17 m/s

This air speed can be measured locally to the power supply to ensure that sufficient forced air cooling is being applied.

Evaluation of the application

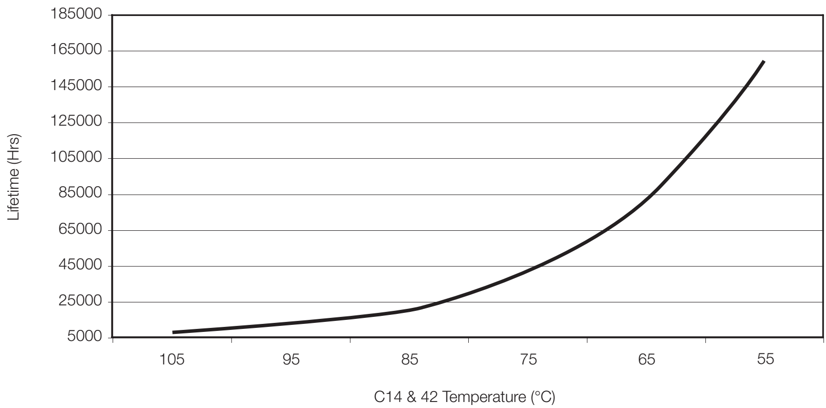
As discussed earlier, the object is to maintain the components used within the power supply at a safe operating temperature and to ensure adequate service life. Given the huge potential for variation between one application and another, the only real test is measurement of the temperature of the critical components within the power supply assembly when installed within the end application under the worst case external ambient conditions. The other option is to model the application exactly using a suitable software simulation.

The criteria for safe operation will be specified for the power supply in question or can be obtained from the manufacturer. For the example above, the specific component temperatures for safe operation for the EMA212 are given on the next page; these are typical for a power supply of this type.

Temperature Measurements (Ambient ≤50 ºC)	
Component	Max temperature ºC
TR4 case	110 ºC
C14	105 ºC
C42	105 ºC
TR11 case	110 ºC
T7 coil	120 ºC

While these figures will ensure safe operation they do not give any indication of the service life that can be expected. The lifetime of a power supply is largely determined by the temperature of the electrolytic capacitors, which have a wear out mechanism. As a general rule, capacitor lifetime can be doubled for every 10 °C drop in operating temperature.

The graph below indicates the expected service life of the EMA212 power supply based on measurement of two key electrolytic capacitors.



• Cooling Power Modules

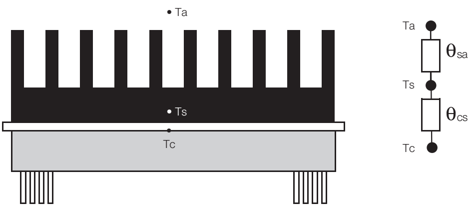
Typically, power supplies and DC-DC converters have pre-defined thermal ratings for both convection and forced cooling. However, when power modules are used, additional thermal management is normally required.

In order to maximize the benefit of thermal management, it is necessary to begin early in the design stage with an analysis of which components will be subject to high temperatures and what will be required to cool these devices. Since operating temperature directly affects the lifetime and reliability of a power supply, it is necessary to obtain an operating temperature that falls below the maximum permitted operating temperature. The definition of thermal resistance is:

$$\theta = \frac{\Delta T}{Q}$$

where θ is thermal resistance in °C/W
ΔT is the temperature difference between two reference points in °C
Q is the heat flux or power passing through the two points in Watts.

This definition allows the calculation of junction temperatures using a thermal circuit similar to an electrical circuit:



θ_{SA} is thermal resistance heatsink–to–ambient ˚C/W

θ_{CS} is thermal resistance case–to–heatsink ˚C/W

Thermal resistance to the flow of heat from the power module to the ambient temperature air surrounding the package is made up of several elements. These are the thermal resistances of the case–to–heatsink and heatsink–to–ambient interfaces and can be added together to give an overall thermal resistance from power supply to ambient θ_{CA}.

Just as Ohm’s Law is applied in an electrical circuit, a similar relationship is applied to heatsinks.

$$T_C = T_A + P_D (\theta_{CA})$$

where T_C = maximum power supply temperature
T_A = ambient temperature
P_D = power dissipation
θ_{CA} = case to ambient thermal resistance

From this equation, power module temperature may be calculated, as in the following examples.

> **Example:** A power module package must operate in ambient temperature of +30 ˚C. What is its baseplate temperature? Let P_D = 5 W and θ_{CA} = 11.0 ˚C/W.
>
> $$T_C = T_A + P_D\,\theta_{CA} = 30 + (5 \times 11.0) = +85.0\ ˚C$$

Where operation in a higher ambient temperature is necessary, the maximum power module temperature can easily be exceeded unless suitable measures are taken.

> **Example:** The same device to be used at an ambient temperature of +50 ˚C, what is its case temperature?
>
> $$T_C = T_A + P_D\,\theta_{CA} = 50 + (5 \times 11.0) = +105.0\ ˚C$$

This exceeds most power module maximum operating temperatures and therefore some means of decreasing the case–to–ambient thermal resistance is required.

As stated earlier, θ_{CA} is the sum of the individual thermal resistances; of these, θ_{CS} is fixed by the design of device and package and so only the case–to–ambient thermal resistance, θ_{CA}, can be reduced.

If θ_{CA}, and therefore θ_{JA}, is reduced by the use of a suitable heatsink, then the maximum T_{amb} can be increased:

> **Example:** Assume that a heatsink is used giving a θ_{CA} of 3.0 ˚C/W. Using this heatsink the above example would result in a baseplate temperature given by:
>
> $$T_C = T_A + P_D\,\theta_{CA} = 50 + (5 \times 3.0) = +65.0\ ˚C$$

It should be noted that these calculations are not an exact science. This is because factors such as θ_{CA} may vary from device type to device type, and the efficacy of the heatsink may vary according to the air movement in the equipment.

Where it is impossible to improve the dissipation capability of the heatsink, forced air cooling can become necessary, and although the simple approach outlined above is useful, more factors must be taken into account when forced air cooling is implemented.

• Baseplate Cooling

The use of power supplies in harsh or remote environments brings with it many fundamental design issues that must be fully understood if long-term reliability is to be attained.

Under these conditions, it is generally accepted that electronic systems have to be sealed against the elements. This makes the removal of unwanted heat particularly difficult. The use of forced-air cooling is undesirable as it increases system size, adds the maintenance issues of cleaning or replacing filters, and the fan being prone to wear out, particularly in tough environments.

A commonly adopted solution is to use a standard power supply and modify the mechanical design to enable removal of heat from the sealed system. However, this simple compromise does not really address the fundamental issues of power supply design for the applications described. A more practical approach is to select a power supply which has been designed specifically for sealed enclosure applications.

The power supply design has to take into account two main thermal factors.

The extremes of ambient temperature encountered in remote sites can range from -40 ºC to over +40 °C. It is common for the temperature within the enclosure to rise some 15 to 20 °C above the external temperature. The positioning of the power supply within the enclosure can help minimize the ambient temperature in which it operates and this can have a dramatic effect on system reliability. As a rule of thumb, MTBF (mean time between failures) halves with every 10°C rise in temperature. The power supply therefore needs to be able to operate from –40 °C to +65 °C as a minimum specification.

System enclosures are typically sealed to IP65, IP66 or NEMA 4 standards to prevent ingress of dust or water. Removal of heat from other electronic equipment and power supplies in a situation with negligible airflow is the challenge. From the power system perspective, the most effective solution is to remove the heat using a heatsink that is external to the enclosure. However, most standard power supplies cannot provide an adequate thermal path between the heat-dissipating components within the unit and the external environment.

Conventional power supplies dissipate heat into small on-board heatsinks or onto a chassis. The basic construction is shown in Figure 1. Most of the heat is dissipated within the enclosure in which the power supply is used. Such units typically have to be derated from 50 °C, delivering 50% of their full rated power at 70 °C. The derating specification is a general guide based on individual components within the power supply not exceeding their maximum operating temperatures.

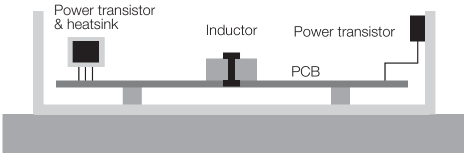


Figure 1
Construction of typical industrial AC-DC power supply

Fundamentally, the successful design of a power supply for use within sealed enclosures relies on creating a path with low thermal resistance through which conducted heat can be passed from heat-generating components to the outside world.

The components that generate the most heat in a power supply are distributed throughout the design, from input to output. They include the power FET used in an active PFC circuit, the PFC inductor, power transformers, rectifiers, and power switches. Heat can be removed from these components by mounting them directly onto a substantial base-plate that in turn can be affixed to a heatsink, rather than on to the PCB. As mentioned earlier, the heatsink is then located outside of the enclosure.

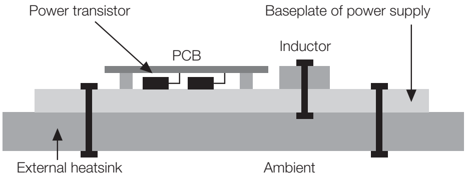


Figure 2. Basic construction of baseplate cooled PSU with all of the major heat-generating components fixed directly to the baseplate

This construction does demand accurate pre-forming of the leads of the components mounted on the baseplate, and accurate positioning of the PCB with respect to the baseplate but there is no significant increase in manufacturing complexity or costs.

With the appropriate heatsink, removal of heat can be so effective that there is no need to derate the unit until the ambient temperature reaches +70°C. This eliminates the need to over-engineer the power supply for the application.

Dissipating the Heat: Heatsink Calculations

Three basic mechanisms contribute to heat dissipation: conduction, radiation and convection. All mechanisms are active to some degree but once heat is transferred from the baseplate to the heatsink by conduction, free convection is the dominant one.

Effective conduction between the baseplate and heatsink demands flat surfaces in order to achieve low thermal resistance. Heat transfer can be maximized by the use of a thermal compound that fills any irregularities on the surfaces. System designers should aim to keep thermal resistance between baseplate and heatsink to below 0.1 °C/W. This is the performance offered by most commonly used thermal compounds when applied in accordance with manufacturers' instructions.

Radiation accounts for less than 10% of heat dissipation and precise calculations are complex. In any case, it is good practice to consider this 10% to be a safety margin.

The degree of convection cooling depends on the heatsink size and type. Heatsink selection involves the following steps:

1. Calculate the power dissipated as waste heat from the power supply. The efficiency and worst case load figures are used to determine this using the formula:

$$\textbf{Waste heat} = \left\{\frac{1 - \text{Eff\%}}{\text{Eff\%}}\right\} \times P_{out} \quad \text{or} \quad \left\{\frac{1}{\text{Eff\%}} - 1\right\} \times P_{out}$$

2. Estimate the impedance of the thermal interface between the power supply baseplate and the heatsink. This is typically 0.1°C/W when using a thermal compound.

3. Calculate the maximum allowable temperature rise on the baseplate. The allowable temperature rise is simply:

$T_B – T_A$ where T_A is the maximum ambient temperature outside of the cabinet and T_B is the maximum allowable baseplate temperature.

4. The required heatsink is defined by its thermal impedance using the formula:

$$\theta H = \frac{T_B - T_A}{\text{Waste Power}} - 0.1$$

5. The final choice is then based on the best physical design of heatsink for the application that can deliver the required thermal impedance. The system's construction will determine the maximum available area for contact with the baseplate of the power supply and the available space outside of the enclosure will then determine the size, number and arrangement of cooling fins on the heatsink to meet the dissipation requirement.

Conclusion

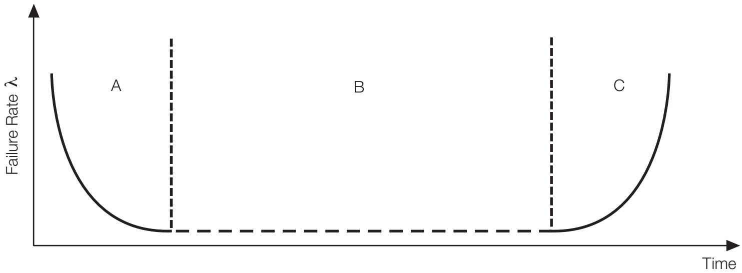
The reliability of remotely-sited electronic equipment is fundamentally dependent upon power supply reliability. The most cost-effective approach to power system design is to use power supplies designed for the application, which conduct heat via large, flat baseplates to heatsinks that can be mounted outside of the enclosure.

Reliability

• Terminology

Failure Rate λ

The failure rate is defined as the percentage of units failing per unit time. This varies throughout the life of the equipment and if λ is plotted against time, a characteristic bathtub curve (below) is obtained for most electronic equipment.



The curve has three regions, A - Infant mortality, B - Useful life, C - Wear out.

In region A, poor workmanship and substandard components cause failures. This period is usually the first few tens of hours and a burn-in is often employed to prevent these failures occurring in the field, although burn-in may not get us to the bottom of the curve. This does not stop the failures occurring, it just ensures that they happen within the manufacturing location rather than at the customer's premises or in the field .

In region B the failure rate is approximately constant and it is only for this region that all of the following analysis applies.

In region C, components begin to fail through reaching end of life, rather than by random failures. Electrolytic capacitors dry out, fan bearings seize up, switch mechanisms wear out and so on. Well-implemented preventative maintenance can delay the onset of this region.

Reliability is defined as the probability that a piece of equipment operating under specified conditions shall perform satisfactorily for a given period of time.

Probability is involved since it is impossible to predict the behavior with absolute certainty. The criterion for satisfactory performance must be defined as well as the operating conditions such as input, output, temperature, load etc.

MTBF – Mean Time Between Failures
MTTF – Mean Time To Failure

MTBF applies to equipment that is going to be repaired and returned to service, MTTF to parts that will be thrown away on failing. MTBF is the inverse of the failure rate and is often misunderstood. It is often assumed that the MTBF figure indicates a minimum guaranteed time between failures. This assumption is wrong, and for this reason the use of failure rate rather than MTBF is highly recommended.

The mathematics are expressed as follows:

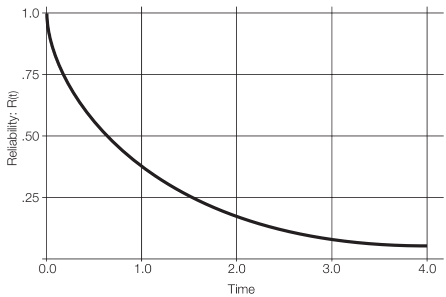
$$m = \frac{1}{\lambda}$$

$$R_{(t)} = e^{-\lambda t} = e^{-(t/m)}$$

$$m = \frac{t}{\log_{(n)}\left\{\frac{1}{R_{(t)}}\right\}}$$

Where $R_{(t)}$ **= reliability**
e = exponential (2.178)
λ **= failure rate**
m = mtbf
t = time

This shows that for a constant failure rate, plotting reliability '$R_{(t)}$' against time 't' gives a negative exponential curve. When t/m = 1, i.e. after a time 't', numerically equal to the MTBF figure 'm', then



$$R_{(t)}=e^{-1}=0.37$$

This equation can be interpreted in a number of ways:

a) If a large number of units are considered, only 37% of them will survive for as long as the MTBF figure.

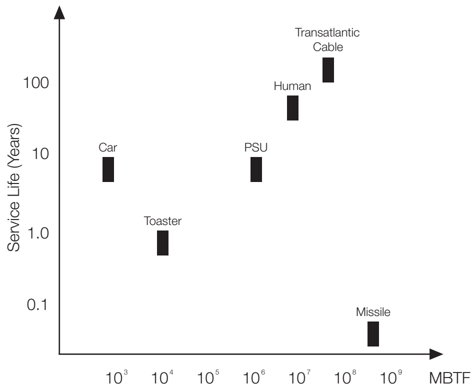
b) For a single unit, the probability that it will work for as long as its MTBF figure is only 37%.

c) The unit will work for as long as its MTBF figure with a 37% Confidence Level.

In order to put these numbers into context, consider a power supply with an MTBF of 500,000 hrs (or a failure rate of 0.2 failures per 1000hrs), or as the advertisers would put it, an MTBF figure of 57 years. Using the above equation, R(t) for 26,280 hours (three years) is approximately 0.95 and if such a unit is used 24 hours a day for three years the probability of it surviving is 95%. The same calculation for a ten year period will give an R(t) of 84%. If 700 units are used, on average 0.2%/1000hrs will fail, or approximately one per month.

Service Life

There is no direct connection or correlation between service life and failure rate. It is perfectly possible to design a very reliable product with a short life. A typical example is a missile, which has to be very very reliable (MTBF of several million hours), but its service life is only around 4 minutes (0.06hrs). 25-year-old humans have an MTBF of about 800 years, (failure rate of 0.1% per year), but not many have a comparable service life! If something has a long MTBF, it does not necessarily have a long service life.



• Factors Affecting Reliability

The most important factor is good, careful design based on sound experience, resulting in known safety margins. Unfortunately, this does not show up in any predictions, since they assume a perfect design.

Many field failures of electronic equipment are not due to the classical random failure pattern discussed here, but to shortcomings in the design and in the application of the components, as well as external factors such as occasional voltage surges. These may be outside of the specification but no one will ever know as all that will be seen is a failed unit. Making the units rugged through careful design and controlled overstress testing is a very important part of making the product reliable.

The failure rate of the equipment depends on these three factors.

Complexity Keep things simple, because what isn’t there can’t fail but, conversely, what isn’t there can cause a failure. A complicated or difficult specification will invariably result in reduced reliability. This is not due to the shortcomings of the design staff, but to the resultant component count. Every component used will contribute to the equipment's unreliability.

Stress For electronic equipment, the most prominent stresses are temperature, voltage, vibration and temperature rise due to current. The effect of each of these stresses on each of the components must be considered. In order to achieve good reliability, various derating factors have to be applied to these stress levels. The derating has to be traded off against cost and size implications. Great care and attention to detail is necessary to reduce thermal stresses as far as possible. The layout has to be such that heat-generating components are kept away from other components and are adequately cooled. Thermal barriers are used where necessary and adequate ventilation needs to be provided.

The importance of these provisions cannot be overstressed since the failure rate of the components will double for a 10ºC increase in temperature. Note that decreasing the size of a unit without increasing its efficiency will make it hotter, and therefore less reliable.

Generic Generic reliability (also known as inherent reliability) refers to the fact that, for example, film capacitors are more reliable than electrolytic capacitors, wirewrap connections more reliable than soldered ones, fixed resistors more reliable than potentiometers. Components have to be carefully selected to avoid the types with high generic failure rates. Quite often there is a cost trade-off, as more reliable components are usually more expensive.

Estimating the Failure Rate

The failure rate should be estimated and measured throughout the life of the equipment.

During the design, it is predicted.
During the manufacture, it is assessed.
During the service life, it is observed.

The failure rate is predicted by evaluating each of the factors affecting reliability for each component and then summing these to obtain the failure rate of the whole equipment. It is essential that the database used is defined and used consistently. There are three databases in common use: MIL-HDBK-217, HRD5 and Bellcore. These reflect the experiences of the US Navy, British Telecom and Bell Telephone respectively.

In general, predictions assume that the design is perfect, the stresses known, everything is within ratings at all times, so that only random failures occur; every failure of every part will cause the equipment to fail and that the database is valid. These assumptions are wrong. The design is less than perfect, not every failure of every part will cause the equipment to fail, and the database is likely to be at least 15 years out of date. However, none of this matters as long as the predictions are used to compare different topologies or approaches rather than to establish an absolute figure for reliability. This is what predictions should be used for.

Prediction

Parts stress method

In this method, each factor affecting reliability for each component is evaluated. Since the average power supply has over 100 components and each component about seven factors (stress ratio, generic, temperature, quality, environment, construction and complexity), this method requires considerable effort and time. Predictions are usually made in order to compare different approaches of topologies, i.e. when detailed design information is not available and the design itself is still in a fluid state. Under such circumstances it is hardly worthwhile to expend this effort and the much simpler and quicker Parts count method is used.

Parts count method

In this method, all like components are grouped together, and average factors allocated for the group. So, for example, instead of working out all the factors for each of the 15 electrolytic capacitors used there is only one entry of capacitor with a quantity of 15. Usually only two factors are allocated, generic and quality. The other factors, including stress levels, are assumed to be at some realistic level and allowed for in the calculation. For this reason, the factors are not interchangeable between the two methods. In general, for power supplies, HRD5 gives the most favourable result closely followed by Bellcore, with MIL-217 the least favorable. This depends on the mix of components in the particular equipment, since one database is ‘unfair’ on ICs, and another on FETs. Hence the importance of comparing results from like databases only.

Assessment	This is the most useful and accurate way of predicting the failure rate. A number of units are put on life test, at an elevated temperature, and so the stresses and the environment are controlled.

During life tests and reliability demonstration tests it is usual to apply greater stresses than normal, so that the desired result is obtained more quickly. Great care has to be applied to ensure that the effects of the extra stress are known and proven to be calculable and that no hidden additional failure mechanisms are activated by the extra stress. The usual extra stress is an increase of temperature and its effect can be calculated as long as the maximum ratings of the device are not exceeded.

Prototype Testing

With all the sophisticated computer analysis available, there is still no substitute for thoroughly testing products or components. One way of doing this would be to perform HALT testing. HALT (highly accelerated life test) is used to test as many different conditions as possible and cycling the temperature, input and load independently.

Manufacturing Methods

Suppliers must be strictly controlled and deliver consistently good product with prior warning of any changes to processes. Because of the supply chain JIT and QA practices this can be achieved by dealing with a small number of trusted suppliers.

Manual assembly is prone to errors and to some random, unintentional abuse of the components by operators, such as ESD. This causes defects, which will show themselves later.

Changing settings produces inconsistency and side effects. A good motto is ‘if it works leave it alone, if it does not, find the root cause.’ There must be a reason for the deviation and this must be found and eliminated, rather than masked by an adjustment.

The results from the HALT test can be used to set test limits for production screening. Highly Accelerated Stress Screening (HASS) uses the same equipment as for HALT tests but knowing the operating and destruct (where possible) limits can be used to screen HALT tested products in production. This process differs from conventional stress screening in that the climatic and mechanical stimuli are much higher and consequently the test times are much shorter. HASS can be summed up as a process used in manufacturing to allow discovery of process changes and prevent products with latent defects from getting into the field.

• System Reliability

There are two further methods of increasing system reliability.

More reliable components	MIL standard or other components of assessed quality could be used but in industrial and commercial equipment this expense is not normally justified.
Redundancy	In a system where one unit can support the load and two units are used in parallel, the system is much more reliable since the system will still work if one unit fails. Clearly, the probability of both units failing simultaneously is much lower than that of one unit failing.

Redundancy has a size and cost penalty so normally an n+1 system is used, where n units can support the load, but n+1 units are used in parallel, 2+1 or 3+1 being the usual combinations. Supposing the reliability of each unit under the particular conditions is 0.9826, the system reliability for an n+1 system where n=2 would be 0.9991, an improvement of 20 times. (Nearly 60 times in a 1+1 system).

There are downsides to this approach. More units, higher cost and the need for faulty units to be brought to the operator's attention so that they can be replaced, changing units must not make the system fail (hot swap). The extra circuitry required to monitor all aspects and ensure reliability in itself increases the failure rate and cost of the system (see page 58 for more details on redundant operation).

Comparing Reliability

When comparing reliability figures, the following points must be satisfied.

- The database must be stated and must be identical. Comparing a MIL-HDBK-217F prediction with a MIL-HDBK-217E prediction or an HRD5 prediction is meaningless as there is no correlation.
- The database must be used consistently and exclusively. The result is meaningless if a different database is used for some components.
- The external stresses and environment must be stated and be identical. (input, load, temperature etc). The result is meaningless if all the environmental details are not stated or are different.
- The units must be form-fit function interchangeable. If, for example, the ratings are identical, but one needs an external filter and the other does not then there is no comparison (although you could work out the failure rate of the filter and add it to the failure rate of the unit).

There is no magic; if one manufacturer predicts 200,000 hours and another states 3,000,000 hours for a comparable product, then they must have used a different database, a different stress level or a different environment.

• Power Supply Safety

Legislation requires electrical equipment to be designed to reduce the likelihood of injury or damage due to:

- Electric shock
- Fire
- Radiation
- Energy related hazards
- Heat-related hazards
- Chemical hazards

A safe power supply is an inherent part of any electrical product and must comply with the relevant safety standard. There are several standards which could be used for power supplies and the decision on which to use depends on the intended application of the end product.

In future there will be an international product specific standard for power supplies which will need to be used to demonstrate compliance with the safety requirements and this will be part of the IEC61204 range of standards. At time of writing, the particular standard relating to low voltage DC power supplies has not been published in the European Official Journal (OJ) which means it cannot be used.

Instead, one of the product family standards must be used which are application dependant. Most power supplies will use an information technology equipment standard (60950), a medical equipment standard (60601) or less commonly a standard for equipment used for measurement, control and laboratory use (61010). This latter standard covers equipment intended for professional, industrial process and educational use such as equipment for testing or measuring non-electrical quantities, controlling output quantities to specific values or laboratory equipment which measures, analyses or prepares materials.

Another standard which is sometimes used in conjunction with one of the above is UL508C which covers industrial equipment intended to power control systems for electrical motors. It is common for DIN rail power supplies to have approval to this standard.

The standard for information technology equipment, IEC60950, covers a wide range of product types and is commonly used. Approvals are separately granted by a number of national test laboratories depending on the target markets. UL (Underwriters Laboratories, UL60950) are commonly used for approvals in North America, CSA (Canadian Standards Association, CSA22.2 No.60950) for Canada and there are a number of European test laboratories which will grant approval for EU wide use, EN60950. UL & CSA also operate a scheme to grant approvals for both markets.

In the major Asian markets other approvals are required. The rules are essentially as laid out in IEC60950 with some additional testing in some instances, including EMC.

China	CCC	(China Compulsary Certification)
Taiwan	BSMI	(Bureau of Standards, Metrology & Inspection)
Japan	PSE	(Product Safety Electric Appliance & Materials)
Korea	KETI	(Korean Electrical Testing Institute)

There are many other approval bodies in existence which may need to be considered depending on the equipment target markets.

Electrical Safety

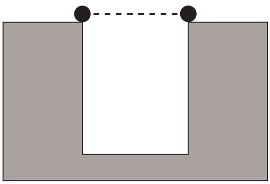
An electrically safe system relies on the use of safety earthing, the insulation of hazardous voltage and the controlling of leakage currents.

Insulation

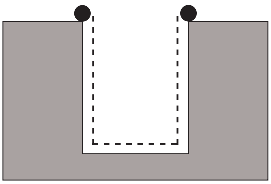
The five different types of insulation grades are listed below.

Operational/functional insulation	Insulation that is necessary only for the correct functioning of the equipment and does not provide any protection against electric shock.
Basic insulation	Insulation applied to live parts to provide basic protection against electric shock.
Supplementary insulation	Independent insulation applied in addition to basic insulation in order to provide protection against electric shock in the event of a failure of *basic insulation*.
Double insulation	Insulation comprising both *basic insulation* and *supplementary insulation*.
Reinforced insulation	Single insulation system applied to live parts which provides a degree of protection against electric shock equivalent to *double insulation.*

Creepage and clearance spacing specified in the safety standard must also be met. The requirement depends on the insulation type, working voltage and pollution degree. The insulation barriers must then undergo a high voltage test.



Clearance is the distance between two points through air



Creepage is the distance between two points over the surface

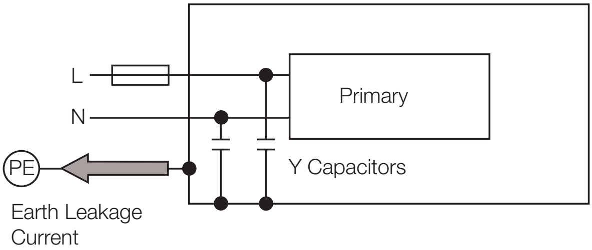
Earthing/Grounding

The two types of earth are listed below:

Functional earth	This does not provide any safety function, for example the screen on an external psu output lead.
Protective earth	This provides protection against electric shock in a class I system and must meet certain performance criteria, such as resistance.

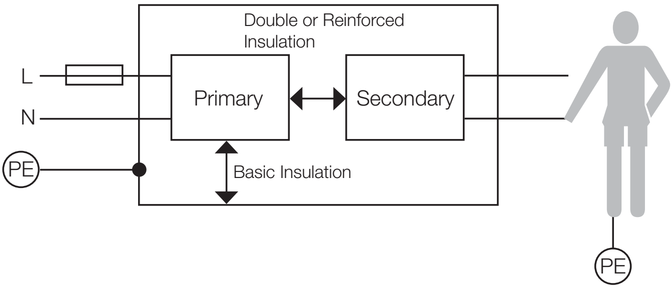
Earth Leakage Current

Current that flows down the earth conductor is defined as earth leakage current. To prevent the risk of electric shock in the event of the earth becoming disconnected, the maximum value is defined in the safety standard under touch current and is normally 3.5mA for pluggable equipment. Higher values are permissible if the equipment is permanently connected. Within the power supply the main contributor to the leakage current is normally the EMC filter Y capacitors.



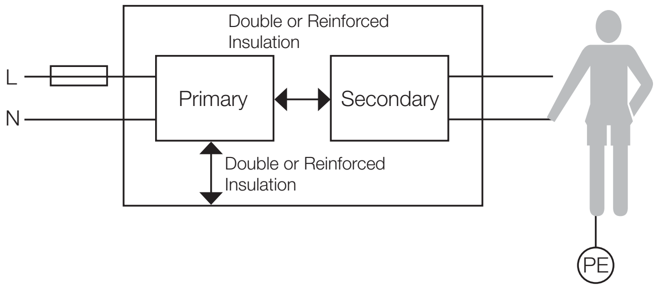
Class I Systems

Class I systems rely on earthing and insulation to provide a means of protection. In the event of the basic insulation between live and earth failing the protective earth provides a path for the fault current to flow, causing a fuse or circuit breaker to trip. The diagram below shows the insulation diagram of a class I power supply.



Class II Systems

Class II systems rely on insulation only to protect against electric shock. The diagram below shows the insulation diagram of a class II power supply.



• Medical Safety

IEC60601-1 is the generic safety standard for medical equipment used within the patient vicinity. EMC is considered as safety critical within a medical device. The EMC requirements and tests are also included within part 1 of the standard. Product specific standards that relate to a particular type of product are covered under part 2 of the standard.

The principles of a safe system are the same as those applied to non-medical equipment meeting IEC60950. The differences relate to creepage and clearance distances, test voltages and leakage current where the requirements are more stringent. There are also additional requirements to consider if direct contact is to be made to the patient.

Approval to these standards and the national deviations are granted by the same bodies as for industrial and IT equipment certified to IEC60950.

Leakage Currents

There are four different types of leakage current. Earth leakage, enclosure leakage and patient leakage current are all determined by the power supply performance.

Earth Leakage	Current flowing in the protective earth conductor.
Enclosure Leakage	Current flowing to earth via the patient or operator from the enclosure.
Patient Leakage	Current flowing to earth via the patient from the applied part.
Patient Auxiliary	Current flowing between two applied parts.

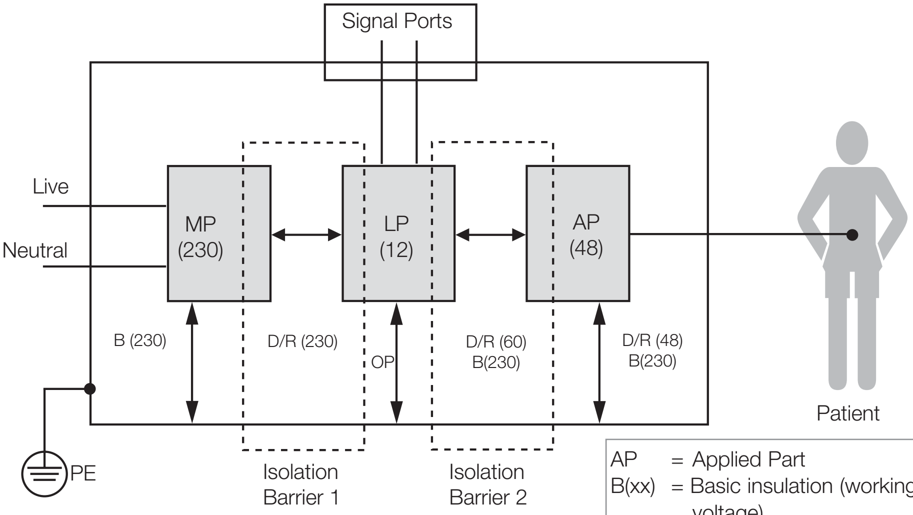
Applied Parts

There are three different types of applied parts. An applied part is a part that in normal use will come into contact with the patient or needs to be touched by the patient. These are classified as B, BF or CF. For BF and CF applied parts an additional level of isolation is often required between the output of the power supply and the patient to meet the patient leakage limits and ensure that the patient is isolated from earth.

Leakage Current	Type B		Type BF		Type CF	
	NC	SFC	NC	SFC	NC	SFC
Earth Leakage Current*	500µA	1mA	500µA	1mA	500µA	1mA
Enclosure Leakage Current	100µA	500µA	100µA	500µA	100µA	500µA
Patient Leakage Current	100µA	500µA	100µA	500µA	10µA	50µA

NC = Normal Conditions **SFC** = Single Fault Conditions
*US earth leakage current 300µA Figures quoted are for portable equipment

Below is a typical isolation diagram for a power supply meeting the requirements of a BF and CF applied part. Isolation barrier 1 is contained within a standard 230VAC - 12VDC power supply. Isolation barrier 2 is contained within a 12V - 48V DC/DC converter.



Typical medical device with patient connection

AP = Applied Part
B(xx) = Basic insulation (working voltage)
D = Double insulation
LP = Live part
MP = Mains part
OP = Operational insulation
R = Reinforced insulation

• Electromagnetic Compatibility (EMC)

EMC is a way of describing how pieces of electrical and electronic equipment interact with each other when they act as either sources or receivers of noise. These two types of interaction are described as emissions and immunity.

Emissions

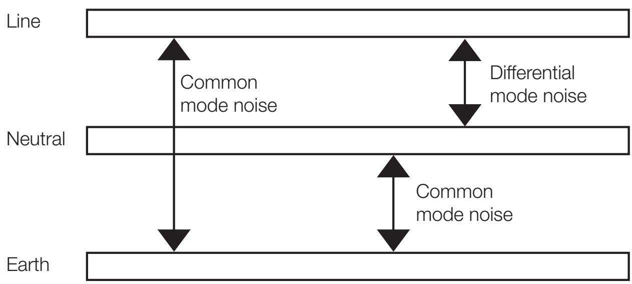
Emissions are electrical noise generated by the power supply or its electronic load and transmitted along the input and output cables as conducted noise or from the outer casing & cables as radiated noise. If left unchecked electrical noise could interfere with the correct and safe operation of nearby electrical equipment and it is therefore a requirement to restrict the amount of noise generated. The EMC directive was introduced in Europe in 1992 (89/336/EEC) with the aim of imposing limits on the amount of noise that equipment can emit. In the USA, the limits are set by the FCC (Federal Communications Commission). VCCI (Voluntary Control Council for Interference by Information Technology Equipment) limits are the Japanese equivalent. In Asia the CISPR and FCC standards are widely accepted by the various approval bodies.

Conducted Noise

Conducted noise is that which travels along physical routes between pieces of equipment. We usually think of these paths as being the mains cables which can transmit noise generated by one piece of equipment along the mains supply (within an installation, a single building or even separate buildings) and which can then affect other pieces of equipment connected to the same mains system, or as the cables which directly connect one piece of equipment to another, such as DC cables or signal and control wires.

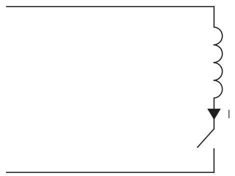
The noise takes one of two forms according to whether it is common to the ground system or exists between differing parts of the electrical circuit.

Common mode noise exists within different parts of the circuit and is common to the ground plane. On the mains input to a piece of electrical equipment it can be measured between the line conductor and the earth conductor, or between the neutral conductor and the earth conductor. Differential mode noise exists between parts of the circuit with different potentials. On the mains input to electrical equipment it can be measured between the line conductor and the neutral conductor.



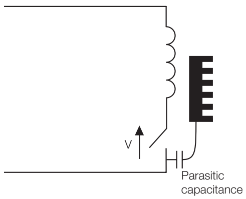
Differential Mode Noise

Differential mode noise is primarily generated by rapid changes in current. Within a switch mode power supply, the primary circuit is opened and closed by means of a switching device such as a BJT or MOSFET. The current flowing through the circuit therefore goes through a continuous cycle of changing from a maximum value to zero and vice versa as the switch opens and closes. The rate of current change is very fast, perhaps in the order of 50ns, and if the primary current was in the order of 1A, the change would be 1A in 50ns or put another way, 20 million A/s. The impedance of the printed circuit traces will be significant at current changes of this magnitude and unwanted voltages will be generated along the traces in the form of noise.



Common Mode Noise

Common mode noise is primarily generated by changes in voltage. The same switching device which is breaking the current in the primary circuit is also breaking a voltage. The voltage could be as high as 600V and this may be being interrupted in the order of 50ns meaning that there could be a voltage change rate of 12V/ns or 12,000 million volts per second. The unwanted capacitances found around the switching element, for example between its case and the heatsink to which it is attached will be significant at these levels of voltage change and significant voltages in the form of noise will be generated.



Radiated Noise

Electrical noise can radiate from the enclosure or casing of the equipment and from its connecting cables. It will escape through the seams, ventilation slots, display areas and so on and travel in any direction through the air. In order to successfully propagate through air, the wavelength will be shorter than for conducted emissions meaning that frequencies will be higher. While conducted emissions are measured up to a frequency of 30MHz, radiated emissions are measured up to 1GHz.

Standards

In the US, EMC standards are written and enforced by the FCC. FCC 20870 covers both radiated and conducted noise. The FCC standard is harmonized with CISPR standards, and these are sometimes used instead to show compliance.

In Europe, the EMC directive does not define what the required levels are which need to be met so we must rely on international standards. There are three different types published. Product-specific standards define the allowable EMC performance of particular types of product. If a product-specific standard exists, then it MUST be used. Where a type of equipment doesn’t have an associated product standard, generic standards can be used. As the term generic suggests, they contain requirements which cover many types of equipment and therefore some of the tests listed cannot be relevant or even adhered to. The product specific and generic standards refer to basic standards. These are the ones which define the exact test set up as well as the limits allowed. In Asia the CISPR and FCC standards are widely accepted.

For power supplies, the product-specific standard, IEC61204-3, will take precedence over the generic standards. For emissions, it defines the following basic standards:

CISPR22 for conducted emissions (maximum of level B)
CISPR22 for radiated emissions (maximum of level A)
IEC61000-3-2 for harmonic currents
IEC61000-3-3 for voltage flicker

Sometimes there are other basic standards which need to be applied. For example, EN55014 is applicable to motor operated household equipment, CISPR11 is applicable to industrial, scientific and medical equipment. These basic standards will be called into use by product family standards which may be applicable to end user equipment.

Methods of Measurement

Noise measurement techniques are defined by the relevant basic standard. The techniques will be generally similar whether it is an IT standard such as CISPR22 which is applicable or a military standard such as MIL 461 or DEF STAN 59-41.

Conducted Noise

Conducted noise values will largely be dependent upon the local impedance of the mains system at the location at which the measurement is being done. Mains impedances will vary throughout a network and they could be vastly different throughout the world. A Line Impedance Stabilization Network (LISN), also known as an Artificial Mains Network (AMN) is used to give a defined mains impedance to the measurement system of 50 Ohms. In the case of the IT standard CISPR22, the noise will be measured from 150kHz to 30MHz and two readings must be taken. These are a quasi peak measurement and an average measurement. Both must be under their respective limit lines in order for the equipment to pass.

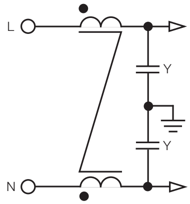
Radiated Noise

The services of a dedicated test house will normally be required to measure radiated noise. This is because the test should be performed on a large area known as an Open Area Test Site (OATS) which will not only be free of reflecting surfaces but will also be calibrated so that the influence of any reflections from far away is known as the reflections will either add to the original signal, or detract from it depending upon the phase shift of the reflection. The measuring equipment will consist of an antenna which will feed into a receiver. The emissions from all sides of the equipment must be taken and for each face the antenna will be moved between heights of one and four meters to obtain the worst case reading. In addition to this, the antenna will be positioned with its elements alternately horizontal and vertical, again to obtain the worst case reading.

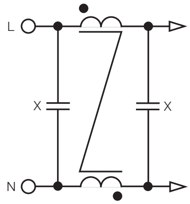
As this setup is impractical for most companies, alternative techniques are normally used to give an indication of the radiated emissions. This may consist of using near field probes to ‘sniff’ around the enclosure of the equipment or using conducted emission techniques to measure at frequencies into the hundreds of MHz band. This is a relevant test as it will often be the cables themselves that are the source of the radiation.

EMC Filtering

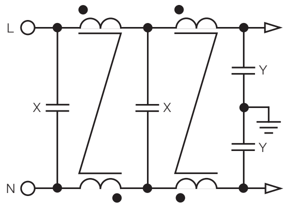
A power supply or DC/DC converter will have an in-built input filter to reduce the conducted emissions. It will have two parts; one to reduce the common mode noise, the other to reduce the differential mode noise. Common mode noise can be reduced by use of Y capacitors between line and ground and another one between neutral and ground in conjunction with a common mode inductor.



Differential mode noise can be reduced by use of an X capacitor between the line and the neutral in conjunction with a differential mode inductor. In some instances the differential mode inductor is formed from the leakage inductance of the common mode inductor so that there is only one visible wound component.



When combined the resulting filter may look like this:



Sometimes the built-in filter will give an inadequate performance for a given application. This may be where the power supply is designed to meet the lesser requirements of an industrial environment but is being used in the more stringent light industrial or residential environment. Perhaps several power supplies are being used in a single piece of equipment and the resulting emissions must be reduced, or perhaps noise from the load itself is being coupled into the input of the power supply. In all these instances some form of external filtering will be required.

Filter Selection

There are some basic steps to follow when choosing a filter, some of which are straightforward and others less so.

Mechanical format — Is the filter going to be mounted within the equipment where it can be fixed to a panel or should it also provide the extra functions of being the mains input connector and perhaps contain an on/off switch? If it is the former, a chassis mount filter can be used. These will generally have faston terminals for easy connection but may also come with flying leads. IEC inlet filters can have built-in on/off switches and even fuse holders. They can be mounted by either screwing them down to the equipment or by use of self locking lugs. Generally, for metal chassis equipment, the bolt-down variety will provide a lower impedance earth path for the circulating noise down to ground.

Input current	The filter should be able to pass the maximum working current of the equipment so as not to overheat but generally the lower the current capacity within a filter series, the higher its filtering performance.
Attenuation required	A filter will be required to reduce the noise at certain frequencies. By how much and at which frequencies is information which will not readily be known without having first performed a conducted noise measurement. Filters have differing amounts of attenuation and, for a given current rating, the higher the attenuation the larger the filter. As there will be a practical limit on the size of filter components, large amounts of attenuation will require the use of multi-stage filters.

Immunity

Immunity is concerned with how a piece of equipment will behave when subject to external electrical or magnetic influences in the form of noise. The noise will exist as either conducted or radiated noise and will be from natural sources such as lightning, electrostatic build up or solar radiation or may be from man made sources such as radio or mobile phone transmissions, commutation noise from electrical motors or emissions from power supplies and other switching devices.

Conducted Immunity Phenomena

A power supply or piece of electrical equipment will be subject to conducted noise either via the mains connection, a DC output or via the signal and control lines. The noise could take various forms from brown-outs of the mains, to single short duration but high voltage spikes, to RF frequency noise coupled into the cables and conducted into the equipment.

Radiated Immunity Phenomena

Noise can also directly enter a system via the air in the form of electrical or magnetic fields. The field is picked up by the cables attached to a piece of equipment or by the internal PCBs themselves and can be in the form of electromagnetic fields generated by a mobile phone or the magnetic field generated from a nearby transformer.

Standards

The product standard for power supplies, EN61204-3, lists all of the basic immunity standards that are applicable to a power supply. These are listed below. For each type of test there are two important factors: the test severity level and the performance criteria which defines how the equipment operates while the test is being carried out.

Performance criteria A	There is no change in operating status of the equipment. For a power supply this means that it will continue to operate within specification and no signals will change state.

Performance criteria B	There is a loss of function while the test is being applied, but when the test stops, the operating parameters automatically return to normal. For a power supply, this means that the output may go out of regulation and signals may change state but only during the test.
Performance criteria C	There is a loss of function while the test is being applied and a manual reset or intervention is required to restore the original operating parameters.

Electrostatic discharge: IEC61000-4-2

There are three types of test specified in the standard; contact discharge, air discharge and discharge onto a coupling plane. The test is to simulate the effect of a person charging themselves up (to many kV) and then touching either the equipment directly or adjacent equipment which could in turn affect the equipment's behavior. For open frame power supplies, this test is not normally applicable but for other power supplies, the pass conditions are ±4kV for contact discharge and ±8kV for air discharge and coupling plane discharge, all with minimum performance criteria B.

RF electromagnetic field: IEC61000-4-3

This test simulates the fields given off by mobile phones and DECT phones. The field is generated by a sweeping signal generator with a 1kHz modulation function. The signal is amplified and radiated using an antenna. The field strengths are high enough and in the frequency band (80MHz to 1GHz) to prevent local radio and TV stations and more importantly emergency services communications from working so the test must be performed in a screened chamber. For power supplies intended to operate in a light industrial or residential environments, the field strength is 3V/m but for industrial power supplies the required field strength is 10V/m. Minimum performance criteria is B in both cases.

Electrical fast transients: IEC61000-4-4

This test is to simulate switching transients generated by motor or solenoid activation or perhaps from fluorescent lighting. The pulse is very short, only 50ns with a 5ns rise time and is applied between the two lines and the earth. Generally, the test is only applied to the AC input as the DC lines and the signal and control lines on a power supply are normally too short. For power supplies intended to operate in light industrial or residential environments the pulse is ±1kV but for industrial power supplies the required pulse is ±2kV. Minimum performance criteria is B in both cases.

Voltage surge: IEC61000-4-5

This test is to simulate the effects of a lightning strike. The duration and energy content of the pulse are much greater than for the EFT test with the duration being 50μs with a 1.2μs rise time. The pulse is applied between each line and earth and also between lines themselves. For power supplies the pulse is ±2kV common mode, ±1kV differential, with a minimum of performance criteria B in both cases.

RF conducted: IEC61000-4-6

This test is similar to the RF radiated electromagnetic field test and must be applied under similar conditions within a screened chamber though the frequency range is 150kHz to 80MHz. For power supplies intended to operate in a light industrial or residential environments, the coupled noise is 3Vrms but for industrial power supplies the coupled noise is 10Vrms. Performance criteria B is the minimum applicable in both cases.

Voltage dips and interruptions: IEC61000-4-11

A voltage dip represents the brown-out conditions experienced from time to time on the power grid, while a voltage interruption represents a complete black out condition. There are 3 parts to the test; a 30% dip for 10ms with minimum performance criteria B, a 60% dip for 100ms with minimum performance criteria C and a >95% interruption for 5 seconds with minimum performance criteria C.

• CE marking

CE marking within Europe was established as a means of identifying a product as meeting all the relevant European directives. These directives have been introduced as a way of allowing free trade within the EU member states as individual members are no longer allowed to prevent trade on technical grounds. By displaying the CE mark, the product is identified to customs and border controls as complying with the necessary directives. There are many directives which are applicable for CE marking and these include:

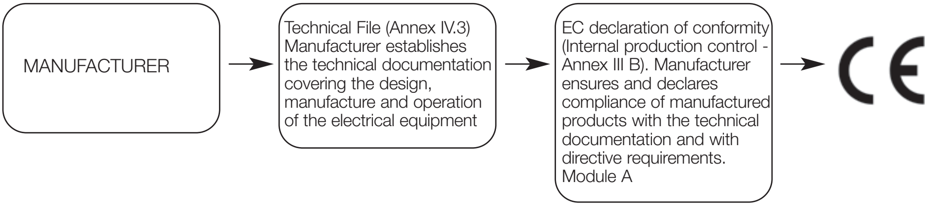
- Low voltage equipment
- Toys
- Electromagnetic compatibility
- Personal protection equipment
- Active implantable medical devices
- Hot water boilers
- Medical devices
- Recreational craft
- Refrigeration appliances
- Telecommunications terminal equipment
- Radio & telecommunications terminal equipment
- Simple pressure vessels
- Construction products
- Machinery
- Non automatic weighing machines
- Gas appliances
- Civil explosives
- Potentially explosive atmospheres
- Lifts
- Pressure equipment
- In vitro diagnostic medical devices

For power supplies, only two directives are applicable, the Low Voltage Directive (LVD) and the EMC directive.

Low Voltage Directive (LVD) 2006/95/EC

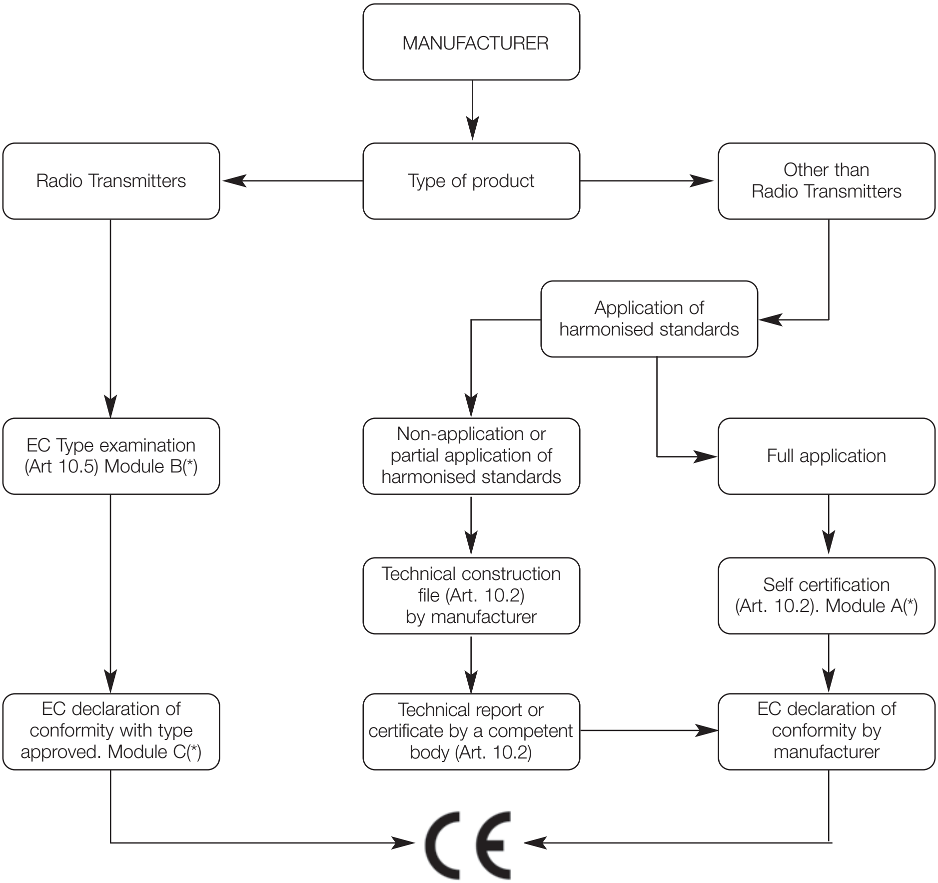
This is applicable to equipment designed for use with a voltage rating of between 50 and 1000 VAC and between 75 and 1500 VDC. The directive itself does not define how to comply with it but by conforming to one of the relevant standards, such as the IT safety standard EN60950, compliance is demonstrated. The route to compliance is by generating a Technical Construction File (TCF) which includes the following:

- General description of the electrical equipment
- Conceptual design and manufacturing drawings
- Description and explanation of these designs and drawings
- Listing of the product standards used as safety reference
- Results of design calculations and examinations
- Test reports



The file must be kept within Europe by the manufacturer or importer of the equipment and be available for inspection within 48 hours. For power supplies, it is common for the TCF to be based on a competent body test certificate such as TUV.

Electromagnetic Compatibility Directive 89/336/EEC



(*) These procedures were approved before the adoption of Council Decision 90/683/EEC (as amended by Decision 93/465/EEC) on conformity assessment procedures (modules). Their provisions may therefore not be identical to those of the modules.

This directive is applicable to apparatus liable to cause electromagnetic disturbance or the performance of which is liable to be affected by such disturbance. Again, the directive does not state how compliance should be achieved, but there are two routes to compliance. The first is the standards route whereby the product is tested against either product specific or generic standards. The second is the technical construction file route. This would be chosen where a piece of equipment may be too large to undergo testing, or it may be that some of the tests are just not relevant. The arguments for this would be laid down in the TCF which would be assessed and signed off by a competent body.

The CE mark should be accompanied by a declaration of conformity. This will list:

- Name & address of the manufacturer
- Description of the equipment
- Reference to harmonized product standards used
- Name of the signatory and their position
- Last two digits of the year in which the CE marking was affixed

This is a self declaration that the manufacturer (or person who places the product on the market in the EU) has taken all necessary steps to ensure compliance with all the relevant directives.

The two directives treat power supplies in different ways. The LVD states that all apparatus, which includes open frame power supplies as well as externals, should be CE marked. However, the EMC directive states that components, which includes open frame power supplies must not be CE marked. Therefore, the CE mark on an open frame power supply is showing that it complies only to the LVD, whereas the CE mark on an external power supply is showing that it complies with both the LVD and the EMC directive.

• No Load Power Consumption and Efficiency of External Power Supplies

Two important reasons for wanting to control the power taken by an external power supply are continuity of the energy supply and reduction of environmental impacts. Targets are given for external supplies because of the quantity in use. They normally do not have an off button and they are commonly left plugged into the AC supply.

At the time of writing there are around 1.5 billion external power supplies in the US which account for 6% of the national electric bill and it is estimated that left unchecked this could rise to 30% by 2010. In 1992 the US Environmental Protection Agency (EPA) started a voluntary program to promote energy efficiency and reduce pollution which became the Energy Star program. The California Energy Commission (CEC) declared that these requirements would be mandatory and from 1st July 2006 limits applied to applicable external power supplies. Washington State and Arizona State also now have mandatory requirements and it is expected that other States will follow. These requirements are aimed at consumer appliances and therefore it is single output external power supplies which are used with laptop computers, mobile phones, printers, print servers, scanners, PDAs and digital cameras which are applicable. From July 2007 the scope is increased to include other applications. It is not expected that industrial or commercial applications will require the limits to be met from a legal point of view though they may do from a marketing stand point. This position may change over time.

In Europe, security of energy supply is paramount as energy reserves are used up. Reducing the no load power consumption of external supplies is expected to save between 1-5 TWh per year by 2010 and defining the minimum active mode efficiency will save another 5 TWh per year. In 2005 the EU drafted a Code of Conduct (C of C) on external power supplies which is a voluntary agreement limiting standby and active mode power losses. The active mode efficiency is closely based on the Energy Star requirements however the no load power consumption limits are more stringent than the US requirements.

On July 6th 2005 the EU released the Energy Using Products (EuP) Directive. It is currently expected that this will come into force in 2008 at which point there will be mandatory limits imposed. It should be noted however that this is applicable to high volume products i.e. ones that would ship more than 200,000 pieces per year.

In all cases, the limits will become more severe over time. In Europe the C of C limits changed on 1st Jan 2007, in the US the Energy Star and CEC limits change on 1st Jan 2008.

The following tables show the limits imposed by the three bodies. The average efficiency is taken as the mean of individual efficiencies at 25%, 50%, 75% and 100% loads

Summary of Limits

No load power limits	
Rated power	**No load consumption**
0W to <10W	0.5W
≥10W to 250W	0.75W
Active mode power limits	
Rated power	**Average efficiency**
0W to 1W	0.49 x Rated power
>1W to 49W	≥[0.09 x Ln(Rated power)] + 0.49
>49W	≥0.84

Energy Star - Jan 1st, 2005 limits

No load power limits	
Rated power	**No load consumption**
0W to <10W	0.3W
≥10W to 250W	0.5W
Active mode power limits	
Rated power	**Average efficiency**
0W to 1W	Not yet known
>1W to 49W	Not yet known
>49W	Not yet known

Energy Star - Jan 1st, 2008 limits

No load power limits	
Rated power	**No load consumption**
0W to <10W	0.5W
≥10W to 250W	0.75W
Active mode power limits	
Rated power	**Average efficiency**
0W to 1W	0.49 x Rated power
>1W to 49W	≥[0.09 x Ln(Rated power)] + 0.49
>49W	≥0.84

California Energy Commission - July 1st, 2006 limits

No load power limits	
Rated power	**No load consumption**
0W to <10W	0.3W
≥10W to 250W	0.5W
Active mode power limits	
Rated power	**Average efficiency**
0W to 1W	0.5 x Rated power
>1W to 49W	≥[0.09 x Ln(Rated power)] + 0.5
>49W	≥0.85

California Energy Commission - Jan 1st, 2008 limits

EU Code of Conduct

No load power limits	
Rated power	**No load consumption**
0.3W to <15W	0.3W
≥15W to <50W	≤0.5W
≥50W to <60W	≤0.75W
≥60W to <150W	≤1.00W
Active mode power limits	
Rated power	**Average efficiency**
0W to <1.5W	≥0.3
≥1.5W to <2.5W	≥0.4
≥2.5W to <4.5W	≥0.5
≥4.5W to <6W	≥0.6
≥6W to <10W	≥0.7
≥10W to <25W	≥0.8
≥25W to 150W	≥0.9

Jan 1st, 2005 limits

No load power limits	
Rated power	**No load consumption**
0.3W to <60W	≤0.3W
≥60W to 150W	≤0.5W
Active mode power limits	
Rated power	**Efficiency (1)**
0W to <1W	0.49 x Rated power
>1W to <49W	≥[0.09 x Ln(Rated power)] + 0.49
>49W	≥0.84 (2)

Jan 1st, 2007 limits

Notes

(1) Readings can be taken at 100% load or, to be in full harmonisation with Energy Star requirements are an average of 4 points of load (25%, 50%, 75% and 100%).

(2) Externals above 75W having a PFC circuit have a 4% allowance i.e. min efficiency can be reduced to 80%.

Measurement Technique

The US EPA has devised a procedure for measuring the no load power consumption and active mode efficiency of external supplies. This procedure has been adopted as an acceptable test method to demonstrate compliance with Energy Star, California Energy Commission and the EU Code of Conduct. The document can be found on the www.energystar.gov website and is titled 'Test Method for Calculating the Energy Efficiency of Single-Voltage AC-DC and AC-AC Power Supplies'. This document sets out a standardized test method including test room conditions, accuracy of measuring instruments, quality of applied mains voltage and accuracy of load conditions. The document also details the information that is required for the test report.

Marking Requirements

For the EU's C of C there is currently no requirement to mark the product. However, when the EuP Directive becomes mandatory, the CE mark applied to the product will indicate that it is compliant with all applicable Directives and this will include the no load power and active mode efficiency requirements. To demonstrate compliance with the Energy Star and CEC requirements a mark must be placed on the product. Before this can be done, the product details and test results must be submitted to the EPA. The mark is made up of a Roman numeral and should now be a minimum of III to show compliance with July 1st 2006 limits or a IV to show compliance with the January 1st 2008 requirements.

Summary

Whilst we believe that the customers and applications that utilize XP's external power supplies do not require them to be compliant with these requirements, as an environmentally aware company we have plans to introduce compliant product as soon as reasonably possible and will have most of the power range covered by the end of 2007.

• Military EMC and Immunity Standards

For power supplies operated in a military environment there are standards maintained by government or international organisations. Examples of EMC specifications are:

US Department of Defense:	MIL-STD 461 C/D/E
UK Ministry of Defence:	DEF STAN 59-41
French Military:	GAM-EG 13B
NATO:	AECTP500 (proposed replacement for MIL-STD 461E)

Many countries use the MIL-STD series of standards, maintained by the US Department of Defense, but have national deviations covering specific conditions or equipment used by their armed forces.

Military EMC standards are typically organized by: Service (Air Force, Army, Navy etc.); environment (e.g. above or below decks); test details, equipment and limits.

Military EMC standards typically contain both immunity and emissions limits for both conducted and radiated noise. The measurement techniques differ from commercial specifications.

For example: CE (Conducted Emissions)
MIL-STD 461C Measurement made in dBµA using a current probe.
MIL-STD 461D/E Measurement made in dBµV using a LISN.
DEF STAN 59-41 Measurement made in dBµA using a LISN and current probe.

Example of Immunity and Input Voltage Specifications

US Department of Defense: aircraft: MIL-STD 704 A-F, military vehicles: MIL-STD-1275 A/B
UK Ministry of Defence: military vehicles, naval vessels and aircraft: DEF STAN 61-5

Typically, military standards such as MIL-STD-1275 A do not state pass or fail criteria for the power system this is up to the user to define. For example, a power supply being damaged by a surge voltage would generally be deemed a failure, but a power supply showing higher levels of output ripple during a conducted susceptibility test will be deemed to have passed or failed by the tester.

The main susceptibility tests are: Abnormal operating voltage such as generator-only or emergency power; surges, spikes and dropouts, usually defined as a Volt second product with differing source impedances and input ripple, usually defined in amplitude across a wide range of frequency. The tables on the following page outline the input voltage variations specified in MIL-STD-704 and 1275 A.

Aircraft Power Systems	Cat	28 VDC Steady State			28 VDC				DC power (max) sec
		Normal	Abnormal	Emergency	High Transients		Low Transients		
					Voltage	Time	Voltage	Time	
MIL-STD-704A	A	24.0-28.5	23.5-30.0	17.0-24.0	80	0.05	10	0.05	0.05-7.0
	B	23.0-28.5	22.5-30.0	16.0-24.0	80	0.05	8	0.05	0.05-7.0
	C	22.0-29.0	21.5-30.0	15.0-24.0	80	0.05	7	0.05	0.05-7.0
MIL-STD-704B		22.0-29.0	20.0-31.5	18.0-29.0	50	0.01	18	0.015	5.0-7.0
MIL-STD-704C		22.0-29.0	20.0-31.5	16.0-29.0	50	0.01	18	0.015	5.0-7.0
MIL-STD-704D		22.0-29.0	20.0-31.5	16.0-29.0	50	0.01	18	0.015	7.0
MIL-STD-704E		22.0-29.0	20.0-31.5	18.0-29.0	50	0.01	18	0.015	7.0
		Normal	Gen. Only	Batt. Only					
28 V vehicle systems MIL-STD-1275A(AT)		25.0-30.0	23.0-33.0	20.0-27.0	100.0	0.05	15.0	0.5	

Aircraft Power Systems	270 VDC Steady State			270 VDC			
	Normal	Abnormal	Emergency	High Transients		Low Transients	
				Voltage	Time	Voltage	Time
MIL-STD-704B	250-280		240-290	475	0.01	125	0.05
MIL-STD-704C	250-280		240-290	475	0.01	125	0.05
MIL-STD-704D	250-280	245-285	240-290	475	0.01	125	0.05
MIL-STD-704E	250-280	240-290	240-290	475	0.02	200	0.01

Aircraft Power Systems	Cat	400 Hz AC Steady State			AC Transients				DC power (max) sec
		Normal	Abnormal	Emergency	High Transients		Low Transients		
					Voltage	Time	Voltage	Time	
MIL-STD-704A	A	110-118	104-124	106-122	180	0.1	64	0.05	0.05-7.0
	B	108-118	104-124	104-122	180	0.1	58	0.05	0.05-7.0
	C	104-118	98-124	100-122	180	0.1	48	0.05	0.05-7.0
MIL-STD-704B		108-118	100-125	102-124	180	0.01	80	0.01	7.0
MIL-STD-704C		108-118	100-125	104-122	180	0.01	80	0.01	7.0
MIL-STD-704D		108-118	100-125	104-122	180	0.01	80	0.01	7.0
MIL-STD-704E		108-118	100-125	108-122	180	0.01	80	0.01	7.0

Technology Editorial 1

• An Innovative Topology for Configured Power Supplies

Contents

• Introduction

Power supplies are traditionally the last sub-system to be specified and the first to be needed for system prototype testing. They are also frequently impacted by late changes elsewhere in the system, whether by the need for more current, or even for additional voltages. Designers have traditionally struggled to balance project budgets and the need for fast time-to-market, where custom designs become inappropriate.

As companies focus on core competences designing power supplies in-house has become less attractive, even when using building-block modules or combining multiple self-contained units. What is needed is a flexible topology that can be configured to customer requirements, using off-the-shelf tested and proven modules, and shipped as a complete sub-system.

This editorial explores an alternative approach to this problem that simplifies configuration while assuring full agency approvals, even for medical equipment. The result is not a kit of parts but a complete, configured and tested sub-system using versatile packaging to accommodate up to fourteen outputs and with a wide mix of output voltages and currents. This production-ready topology also enables maximum benefit to be gained from combining innovative design with low cost module manufacturing in Asia and local final assembly.

• A different approach

Using DC/DC modules as building blocks can produce configurable power supplies but in many applications it is issues of heat, mechanics, control and monitoring that need customization. It's just these aspects that designers have to sort out for themselves. Although standard brick DC/DC modules handle raw power conversion, design work is still required to create the power sub-system. True configurability revolves around dividing the system into two parts: input and output. Within its total power rating, the input section is capable of supplying any number of customer-specified output combinations. Each output is specific for a given voltage and maximum current. Many technical and commercial issues influence the division between input and output, perhaps nowhere more crucially than at the transformer. Unfortunately, building the transformer primary as part of the input and making the secondary part of the output module means that every configuration requires assembly of a custom transformer. XP uses a different topology that allows for easy local configuration at recognised centers around the world.

The problem is resolved by separating input and output at the off-line 380 VDC rail, making each module fully testable electrically, and making configuration a simple plug-in exercise. The input includes protection, EMC filtering and a power factor correcting boost converter, to deliver stabilized bulk power at 380 V DC from mains input between 90 – 264 V AC, 47 – 63 Hz. Although different models can support different combinations of output sections, depending on their power rating and physical size, modules will fit in any chassis within a family, using a mechanical and electrical interface. This has the additional benefit that as new output modules are added to the current list of single and dual models, they become immediately useable with any input stage in the family.

• Taking the heat

As equipment gets smaller, waste heat remains a key consideration for any power supply sub-system so thermal and mechanical design is critical to flexibility. To emphasize the importance of packaging, lower power models using this topology are designed to fit within a 1U system chassis and are just 39.7mm high, despite offering configurable power up to 450 W in total. The same thermal design has been applied to higher power models, enabling the enclosure of a 2,400 W multi-output, configurable PSU with less than 124 mm overall height by packaging 2 chassis together in an X10 ‘double decker’.

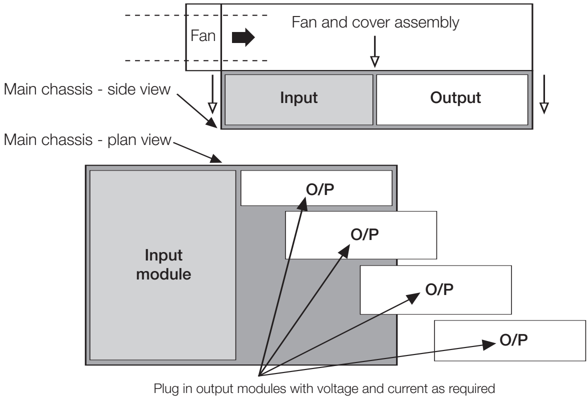


Figure 1

Each complete PSU consists of three elements (Figure 1):

1) Main power chassis
2) Cover and fan assembly
3) Plug-in output modules

Input power conversion, protection and filtering is included in the main chassis which also provides the plug-in location for the output modules. It is designed to deliver maximum airflow through the plug-in modules, irrespective of configuration. Chassis and module construction both provide a rigid, flat interface for mechanical location and efficient thermal management. Although the higher power models combine the cover and fans into the chassis, lower power chassis may be supplied without the fan and cover, further reducing cost where forced air is available within the end equipment or system.

The flexibility of this modular topology is apparent when considering the fleXPower series of power supplies. There are currently 33 single and dual output modules that use only two mechanical formats across the whole range. Every fleXPower chassis can handle every module format. Thousands of configurations are possible based on the options shown in Tables 1- 4.

Table 1: Chassis Options

Chassis Designations, Power & sizes		
Code	Power	Slots
X4	400 W Industrial	10
X5	500 W Industrial	10
X7	700 W Industrial	10
X9	900 W Industrial	12
X10	1000 W Industrial	14
XM4	400 W Medical	10
XM5	500 W Medical	10
XM7	700 W Medical	10
XM9	900 W Medical	12
XM10	1000 W Medical	14

Table 2: fleXPower - Single Output Modules

Single Output - Module Voltage/Current Rating			
Voltage	Current	Slots	Code
3.3 V	40.0 A	2	2C
3.3 V	60.0 A	3	3C
5.0 V	40.0 A	2	2D
5.0 V	60.0 A	3	3D
12.0 V	17.0 A	2	2J
12.0 V	25.0 A	3	3J
15.0 V	14.0 A	2	2L
15.0 V	20.0 A	3	3L
24.0 V	10.5 A	2	2P
24.0 V	17.0 A	3	3P
28.0 V	9.0 A	2	2Q
28.0 V	14.0 A	3	3Q
36.0 V	7.0 A	2	2U
36.0 V	11.0 A	3	3U
48.0 V	5.2 A	2	2W
48.0 V	8.5 A	3	3W
60.0 V	4.2 A	2	2Y
60.0 V	7.0 A	3	3Y

Table 3: fleXPower - Dual Output Modules

Dual Output - Module Voltage/Current Rating					
Output 1		Output 2		Slots	Code
Voltage	Current	Voltage	Current		
5.0 V	10.0 A	5.0 V	10.0 A	2	5A
5.0 V	10.0 A	3.3 V	10.0 A	2	5B
12.0 V	10.0 A	12.0 V	8.0 A	2	5D
15.0 V	8.0 A	15.0 V	6.0 A	2	5E
15.0 V	8.0 A	12.0 V	8.0 A	2	5F
12.0 V	10.0 A	5.0 V	10.0 A	2	5G
12.0 V	10.0 A	3.3 V	10.0 A	2	5H
12.0 V	10.0 A	2.0 V	10.0 A	2	5J
15.0 V	10.0 A	5.0 V	10.0 A	2	5K
15.0 V	10.0 A	3.3 V	10.0 A	2	5L
15.0 V	10.0 A	2.0 V	10.0 A	2	5M
24.0 V	6.0 A	5.0 V	10.0 A	2	5N
24.0 V	6.0 A	3.3 V	10.0 A	2	5P
24.0 V	6.0 A	2.0 V	10.0 A	2	5Q
24.0 V	6.0 A	12.0 V	6.0 A	2	5T

Table 4: fleXPower Options

Parallel Option Codes	
Code	Description
00	No parallel required
12	Modules 1 & 2
13	Modules 1 to 3
14	Modules 1 to 4
23	Modules 2 & 3
24	Modules 2 to 4
25	Modules 2 to 5
34	Modules 3 & 4
35	Modules 3 to 5
40	Modules 1 & 2, 3 & 4

Series Option Codes	
Code	Description
00	No series required
12	Modules 1 & 2
13	Modules 1 to 3
23	Modules 2 & 3
24	Modules 2 to 4
40	Modules 1 & 2, 3 & 4

Other Option Codes	
Code	Description
01	**Reverse Air**
02	**Global Enable - Logic 1**
03	Option 01 & 02
04	**Global DC OK - Logic 1**
05	Option 01 & 04
06	Option 02 & 04
07	Option 01, 02 & 04
08	**Global AC OK - Logic 1**
09	Option 01 & 08
10	Option 02 & 08
11	Option 01, 02 & 08
12	Option 04 & 08
13	Option 01, 04 & 08
14	Option 02, 04 & 08
15	Option 01, 02, 04 & 08

• Design flexibility

A 15 V supply adjusted to 12 V is still capable of its maximum current rating at 15 V. This means that 20% of its space and capability could be redundant if not used. In order to avoid this while maximizing power and space efficiency, each module features optimum output adjustment and is available at many different voltage levels between 2.0 V and 60 V. To further increase space efficiency dual and triple output models are available, offering either multiple voltages (e.g. 12 V, 12 V and 5 V) or a single voltage (e.g. dual 5 V). The LP series, for example, offers 23 different multiple output modules. Since all outputs are fully floating, it is also possible to series connect outputs to further enhance the flexibility and capability of the power system.

For example, a customer required +10V, +12V and +36V outputs. These were supplied from an off-the-shelf LP series module with standard rails of 24V, 15V & 5V as shown in Figure 2.

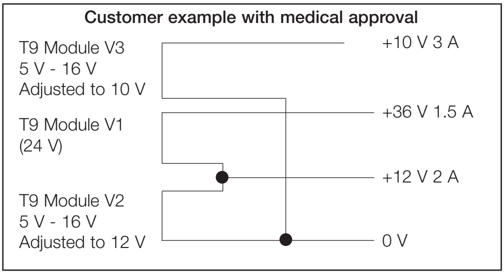


Figure 2

Overvoltage, overcurrent, remote sensing, current sharing, remote inhibit, AC and DC OK signals, together with 1% ripple, 1% load regulation and 0.1% line regulation performance are included as standard to meet virtually all requirements.

• What can you do with it?

As well as avoiding the engineering costs of custom PSU design, the flexibility of a locally configured power supply can clearly reduce the time, cost and risks normally associated with changes to power requirements. However, it is useful to remember that these changes can come from three sources:

1) Last-minute changes in system design
2) Updates or upgrades later in the system life-cycle
3) System functionality configured to individual customer requirements

With configuration and burn-in test requiring only 24 hours for sample quantities, designers can ensure that the PSU configuration matches the latest system needs, yet when specifying today’s requirement, they can be confident that future system upgrades will not make the whole power supply obsolete. As system builders look more closely at lifetime costs, such built-in future proofing can be an important benefit for end-users.

• There can be benefits to OEMs' end customers too

Using the configurable power topology described, a supplier of laser surgery equipment, for example, is able to benefit their customers who can select only those functions that they need from their laser system to minimize cost, confident that this can be reflected in the power supply fitted to their equipment. Cost is controlled, since unnecessary power supply capability is avoided, but if the customer wants to upgrade or amend the system the power supply configuration can be simply reworked accordingly. In another instance, a medical company cut costs by replacing a custom power supply with a configurable solution, working with XP to develop a custom cable harness that would fit into the existing application.

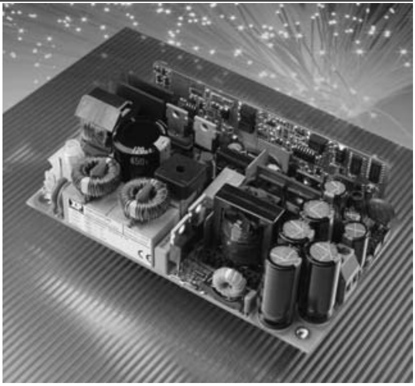
• Summary

Whether it is to meet low volume needs, where engineering costs for conventional custom designs are hard to justify, or where volume requirements contain variation or uncertainty and where time to market is key, the architecture described provides the flexibility to configure multiple output power supply subsystems and to deliver complete, tested and fully safety approved (UL, CSA & TUV) units.

In-house design and dedicated configuration facilities ensure that designers have access to the level of technical support they demand, while the topology enables maximum benefit to be gained from low-cost manufacture of all sub-assemblies. The result is a flexible configuration service delivered at competitive cost and with built-in future proofing.

Technology Editorial 2

• Designing Smaller, More Efficient AC/DC Power Supplies



Contents

• Introduction

In the case of AC/DC power units, it is not dramatic technology breakthroughs that drive the trend; it is good engineering and the inventiveness to combine the best of a whole range of techniques and technologies that separate a really innovative power supply from an average one. This article looks at AC/DC power supply design in the popular 100W to 200W range. It considers a combination of design approaches that can be brought together to minimize the size and cost of the power unit, whilst maximizing efficiency and application flexibility.

Let's start by defining some typical design goals. The power supply should be as small as possible to save space or leave room for added system functions. It should make minimal contribution to the waste heat in the system. In practice, it is microprocessors that now create most system heating but it is still important that power supplies are designed for high efficiency; smaller heat sinks can then be

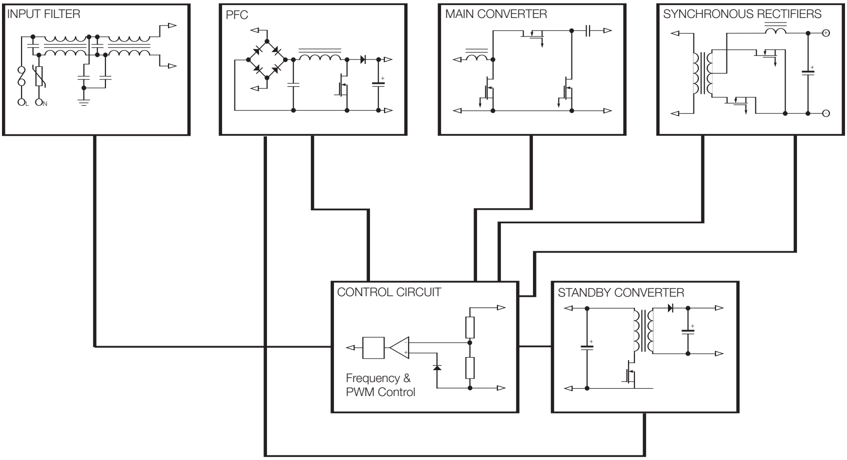


Figure 1

used to save space. For a 100W to 200W power supply, efficiency goals of 90% are not unrealistic. A 1% efficiency improvement represents 10% less heat dissipation at the upper end of the range and this can make a significant difference to the degree of cooling needed for the power supply. Cost, of course, is an ever-present consideration, both in terms of bill of materials and manufacturing complexity. Keeping the design as simple as possible is an important consideration in this respect. Finally, functionality should not be compromised. Control and alarm signals, current sharing with similar units and the ability of the power supply to maintain its performance over a wide range of AC input conditions are all important.

Looking at the main stages within an AC/DC power supply shown in Figure 1, here are some proven ways in which size and cost can be minimized without compromising performance or functionality.

• Input filter

A two-stage filter design using high permeability cores will minimize size while providing high common mode and differential noise reduction. Stacking some components vertically can save board space and improve cooling.

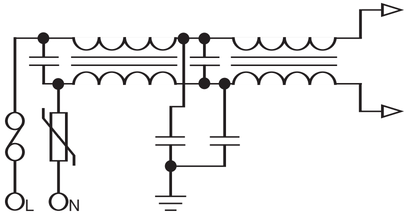


Figure 2

• Power factor correction circuit (PFC)

The use of silicon carbide diodes has become economically feasible in the last few years as component prices have fallen. Their reverse current characteristics mean that they don't require a snubber circuit, saving on 5 or 6 components. Furthermore, they contribute to a 1% typical efficiency boost. Using a stepped gap inductor provides high inductance at high input line and supports maximum flux density at low line. Using continuous conduction mode (CCM) operation throughout the input range keeps the peak switching current and input filter requirements to a minimum.

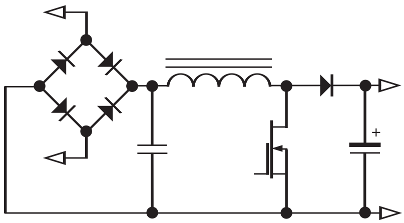


Figure 3

• Main converter

A resonant topology can virtually eliminate switching losses. This not only improves power supply efficiency but also enables smaller heat sinks to be used. In fact, compact ceramic heat sinks can sometimes be used for power transistors, rather than metal ones. Their advantages include a reduction in noise and consequently simplified filtering. This is because the heat sinks do not have capacitive coupling with the drain connections of the switching MOSFETS. In addition, smaller creepage distances, compared with those needed for metal heat sinks, can be used. This gives further savings in board space.

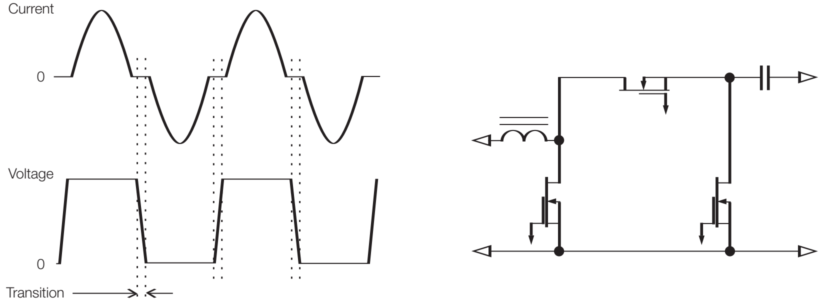


Figure 4

• Output rectifier

Using switched MOSFETS rather than output rectifier diodes improves efficiency through a significant reduction in power dissipation. For example, at 20 Amps a diode with 0.5V forward voltage gives a power dissipation of 10W. Using a MOSFET with an 'ON' resistance of, say, 14mOhms at 100 °C dissipates just 5.6W – a 44% improvement. Once again, ceramic substrates can replace conventional heat sinks.

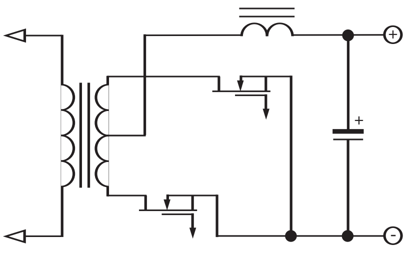


Figure 5

• Control circuit

Semiconductor manufacturers have been developing increasingly integrated control circuits for power supplies in recent times. This means savings in component count, manufacturing costs and board space, even where the integrated circuits themselves may be more expensive than a discrete component approach. One example is the IR1150 – a PFC chip that operates as a one-cycle control (OCC) device, which allows major reductions in component count without reducing power system performance. Similar, application-specific chips can provide main converter voltage control plus over-current protection, over-voltage protection and over-temperature protection. They can also control the output rectifier switching. Other desirable control options for increased application flexibility include power sharing with synchronous monotonic start-up, an inhibit circuit to shut down the power supply via logic control, a ‘power good’ signal, and the control functionality needed for a standby converter. The standby converter provides an independent 5V output whenever AC power is present.

• Summary

Today’s best-in-class AC/DC switchers are typified by XP Power’s EMA212 power supply. Using some the techniques described above, this packs 212.5W output from a 3 x 5 inch footprint with a maximum height of 1.34 inches. That’s a power density of 10.55 W per cubic inch in an industry standard footprint that fits within a 1U high enclosure. It delivers 200W from its main 12V, 24V or 48V output, plus 12V at 1A for driving fans and a 5V standby output. The unit needs just 12CFM of forced-air cooling, which is easily achievable using standard 40 x 40mm fans. Forced-air cooling is now the norm in many communications systems and 12CFM is easily achievable without complex mechanical arrangements. Finally, it achieves an efficiency of 91% at full rated load.

The possibilities for improvements in AC/DC power supply design will continue to be driven largely by improvements in semiconductor performance and functionality. Better magnetic and passive components also have a role to play, but here progress is more evolutionary than revolutionary. The best power supplies are developed from a deep understanding of the latest proven component technologies, plus a determination to explore how these technologies can be combined in new and innovative ways to achieve ever more challenging design objectives.

Technology Editorial 3

• Design Considerations for Compact & Flexible Power Supplies

Figure 1

Contents

• Introduction

Many electronic systems require DC power rails outside the standard 3.3, 5, 12, 24 and 48 V ratings, or require combinations of outputs not available from standard off-the-shelf products. Further, where multiple products or product variants are produced there are often differing requirements for each type. Commissioning custom designs can be an expensive, risky and lengthy process, especially in medium volume applications. In higher power applications modular, configurable power supplies are available from a number of vendors but these tend to become uneconomic below 300-350 W. Many applications require 100-200 W and these solutions are too expensive and typically too large.

Flexible design, from a power supply perspective, means flexibility in mechanical options, electrical options, output ratings and configurations, and careful consideration to agency requirements and manufacturing.

• Mechanical flexibility

Some applications require open frame power supplies in this power range, others are better served by U-channel or chassis mount construction. Some will require a safety cover; some will have internal fan cooling while others will require a complete sub-assembly with integral cooling. Some systems will be required to be entirely convection cooled due to noise or maintenance concerns. These issues need to be considered from the outset of the design from the PCB through thermal management and mechanical parts, as this level of flexibility is difficult to add later. Figure 1 shows 3 of the 4 mechanical versions of the same standard power supply platform, XP Power's RCL175 AC/DC switcher.

Connection to the power supply can be a key consideration depending on the volume of products to be manufactured. For simplicity and cost, screw terminals will usually be the preferred method in low volume products. For medium & higher volume products push fit connectors – usually PCB headers – offer the benefit of faster system assembly and reduced risk of interconnection errors. Designing the power supply PCB to accommodate both options adds flexibility in this area.

- **Thermal considerations**

Cooling arrangements and environmental requirements differ considerably from application to application so a flexible power supply design needs to maximize efficiency, minimize size to ease integration, minimise waste heat in the end application, and maximize lifetime. The aim is to maximize power density with a high convection-cooled rating and minimize forced cooling requirements to obtain higher power levels from one flexible product. Products requiring 20 CFM and above can present a huge challenge for the system designer, especially as systems and equipment continue to shrink and audible noise levels come under pressure. 10 – 12 CFM is much more achievable without incurring high costs and the resulting moderate levels of audible noise can be easily managed. The combination of a substantial convection cooled rating and higher power force-cooled ratings also allows the use of variable speed or thermally controlled fans which operate only at higher ambient temperatures or under high system load, enhancing reliability and further reducing the audible noise.

- **Efficiency and topology issues**

Maximizing efficiency starts with the power factor correction (PFC) stage. Here, the availability of silicon carbide diodes for this application benefits efficiency and reduces component count at a similar cost to traditional diodes and their associated snubbing components (Figure 2).

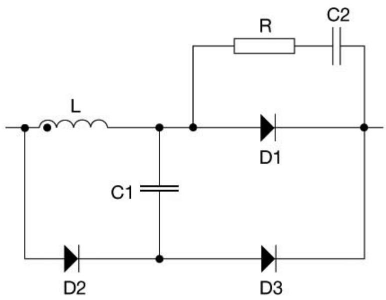


Figure 2

The choice of power converter topology for a flexible product, designed to perform in a variety of applications, is important. The fly-back converter is often the topology of choice in the 100-200 W range but does have some limitations. The power throughput is limited by the size of the transformer and hence the ability to provide peak power to complex loads such as motors, solenoids, lamps, downstream DC/DC converters and systems with large amounts of capacitance is also limited.

Other topologies, such as forward or half bridge converters have a transformer size limited only by temperature rise and are therefore capable of providing peak load requirements which occur on a momentary basis or during power up. The half bridge converter has further advantages over the forward converter. It brings a reduction in transformer size and allows the use of schottky barrier rectifiers in the higher output voltage rails further enhancing overall efficiency. The use of a coupled output inductor also enhances control of auxiliary output voltages over wide load variations.

• **Output considerations**

Many applications require multiple outputs and combinations of positive and negative polarity. Keeping outputs isolated from one other allows flexibility in connection to provide such combinations, as well as allowing parallel or series connections to provide higher output voltages or increased output current. Isolated outputs also provide the facility for separate returns. These may be desirable for digital and analogue circuits.

To allow the power supply to be easily configured to a specific requirement, the full range of outputs must be considered at the outset; designing for both the highest voltage and the highest current is key and requires care to avoid compromising overall performance. Typical requirements fall into the range from 3.3 V to 60 VDC, higher output voltage requirements being served by the ability to connect outputs in series. The challenge is to provide real flexibility in output voltages without unnecessary complexity or additional post-regulation stages that increase cost and reduce efficiency. Here a fractional turn transformer (FTT) can provide an effective solution.

Standard transformers are able to offer 1/2 turns by using E shaped cores, this not only severely restricts the choice of output voltages but can lead to problems with balancing and regulation. XP have used a different approach when designing the RCL175. This uses a separate transformer just for fractional turns, allowing the main transformer to deal only with integer turns where it is more efficient, smaller and provides better regulation.

The FTT provides significant advantages in multiple output supplies in terms of space saving, power transformer optimization, cost cutting and efficiency.

Take a power supply requiring outputs of 5 V and 12 V. Ideally the 5 V winding will be a single turn on the power transformer but the requirement for the 12 V winding becomes 2.3 turns which cannot be readily achieved. The normal solution is to increase the 5 V winding to 2T and then increase the 12 V winding to 5T, by using diodes with differing forward volt drops an approximate 12 V output can be realised. This means that the transformer size and losses are compromised, particularly as the lower voltage windings are typically copper foils and the diodes are not optimized for minimum losses.

Another common scenario in many applications is the need for 3.3 V and 5 V output combinations. The FTT largely eliminates cross regulation and, with suitable voltage sensing and control, there is no need for the post regulation usually employed to regulate the 3.3 V output. This approach removes cost, enhances efficiency and reduces size. The principle is illustrated in Figure 3.

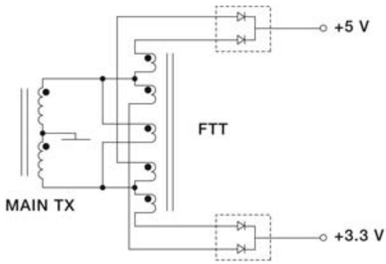


Figure 3

• Safety and EMC

The power supply is critical when it comes to achieving the necessary safety agency approvals and compliance with electromagnetic compatibility requirements in any system.

The ideal scenario for a flexible power supply is to carry approvals for IT, industrial and medical applications, and allow for both class I (with a protective earth) and class II (without a protective earth) systems. The ability to deal with both class I and class II applications is increasingly important in worldwide markets and as medical equipment in the home and residential clinics is becoming commonplace and ground connections are not always as good as they should be. This demands careful consideration of EMI filtering, PCB layout and topology to meet the requirements for increased creepage and clearance, reduced leakage current and non-earthed systems while maintaining compliance with international emissions and susceptibility standards. With appropriate design & component selection, it is possible to achieve compliance with level B conducted emissions, level A radiated emissions and level 3 susceptibility requirements.

• Manufacturing

The key consideration for manufacturing is to design the power supply on a single PCB covering all requirements. This minimises both cost and delivery times and allows part built assemblies to be configured to the application in a short time frame without compromising agency approvals. The potential to configure modified standards in a short time, produce pre-production quantities on a short lead time and manufacture volume requirements in a low cost area is a key consideration in the initial design phase.

• Agency approvals

One of the most significant delays in bringing new equipment or systems to market can be gaining the relevant agency approvals. With the right approach to design, safety testing & part numbering it is possible to gain approval for a wide range of potential output voltages and configurations without applying for re approval for each variation. This approach saves cost and, more crucially, saves significant time in removing the need for additional approval cycles of the power supply during equipment and system development.

All of the techniques described in this article have been combined in XP Power's RCL175 series shown in figure 1. The basic specification:

- 1-4 outputs
- Universal AC input with Active PFC
- Up to 120 W convection cooled, 175 W with 12 CFM
- Common PCB's for any potential variation
- Compact 3.7" x 5.5" footprint
- Agency approved for output voltage to 60VDC on individual outputs
- Industrial, IT & medical agency approvals
- Class I & class II safety approvals
- Level B conducted & level A radiated emissions
- Four optional mechanical/cooling formats
- Choice of PCB header or screw terminal connectors
- Options for conformal coating, overload characteristics & remote inhibit/enable

Technology Editorial 4

• Synchronous Rectification Joins the Mainstream

Contents

• Introduction

Synchronous rectification delivers higher efficiency and therefore more compact power conversion equipment. Early products were aimed at the premium end of the market, with premium price tags. However, using patented technology and a new topology, it has proved practical to bring the benefits of synchronous rectification to a wider range of more price-sensitive applications, and this article illustrates how high efficiency power supplies are now available at 5 V and below, within a mainstream 130 W range.

• What is synchronous rectification?

Rather than using output rectifier diodes to conduct when forward biased, synchronous rectification uses switched MOSFET transistors. The success of this technique has been driven by the rapid reduction in the cost of high current MOSFETs, combined with a significant reduction in the available 'ON' resistance values. The benefits become clear by considering losses at 20 A:

A diode with nominal 0.5 V forward voltage gives a power dissipation of:

(Using P = IV)   20 x 0.5 = 10 W

Whereas a MOSFET 'ON' resistance of 14 mOhms at 100 °C, gives a power dissipation of:

(Using $P = I^2R$)   20 x 20 x 0.014 = 5.6 W

This results in a 4.4% increase in efficiency in a 100 W power supply.

Although losses are nearly halved, it is worth noting that higher voltage MOSFETs typically have higher RDS values, so synchronous rectification is not ideal for all output voltages.

The MOSFET must be switched, and conventional designs use relatively complex ICs to provide the timing and control necessary, often offering precision performance, but at a price. Of particular importance is synchronising the switching to ensure that only one switch is ever ON and to minimize switching losses and noise generation. We shall come back to these issues later, but let us review the core benefits of the technique.

• **What are the benefits of synchronous rectification?**

Although efficiency is often used as the headline feature of PSUs, the benefits become much clearer by focusing on losses rather than efficiency. A change of 10% in efficiency from 80% to 90% represents losses dropping from 20 W to 10 W at 100 W. That represents half the power loss, and therefore half the waste heat. Even moving from 85% to 90% reduces losses from 15 W to 10 W, a 33 % reduction in waste heat.

Less dissipated power may mean no forced cooling and a reduction in the physical size of the power supply (PSU). In addition, when the PSU is mounted close to other electronics, it will not just be heating itself. Equipment failure rates typically double for every extra 10 °C increase in ambient temperature, so reduced PSU losses can improve overall system reliability. Less heat may also mean that the mounting or orientation of the PSU is less critical, since it is no longer vital to align special heatsinks with unimpeded airflow.

Because diode losses depend on I x VFD (where VFD is the diode forward volt drop), paralleling diodes does not reduce dissipation; therefore large diodes are needed at high currents. Conversely, MOSFET losses depend on I2 x RDS (where RDS is drain-source ON resistance), so splitting current between two MOSFETs reduces each current by two and the dissipation in each device by two squared, i.e. to a quarter, halving the total dissipation. The positive temperature dependence of RDS also means that MOSFETs tend to share current well. Using multiple, smaller devices gives significant mechanical flexibility to adjust form factor, height etc, and enables the use of lower cost devices.

• **The low voltage challenge**

A quick check of most power supply ranges will underline the difficulties of delivering power at 5 V and below, and it is important to check the datasheet to see whether power ratings are reduced, significantly greater airflow is specified, or the designer is left to work out how to keep a heatsink below a certain maximum temperature.

The limitations of PCB track losses for sub-3V supplies are leading to the widespread adoption of point-of-load regulation, but there is still a significant requirement for 5 V and 3.3 V PSU modules that are easy to use,compact, reliable and low-loss. By focussing on meeting this need at low cost, XP has introduced a new topology incorporating synchronous rectification and several patented innovations to reduce noise and provide power factor correction to further simplify system design. The JPS130 power supply uses the new topology.

• **Synchronous rectification for the mainstream**

Given the need to control MOSFET switching, most existing designs use complex control chips, often delivering sophisticated control and performance features, but placing the core benefits of synchronous technology outside the budget of mainstream systems. These control systems typically combine both input and output control in a single device. However, by separating the input and output control (See Figure 1) and ensuring that the primary DC bus voltage is held stable, limiting the range of duty cycle within the switching power stage, the output MOSFETs can be switched using relatively simple, and therefore inexpensive, control. Since this input stage can drive either a conventional diode output, or a synchronous rectifier output, it is possible to produce a single range that matches the output section to the rated voltage, i.e. synchronous rectification for 5 V and 3.3 V units and conventional output rectifier diodes for higher voltages, maximizing volume cost advantages.

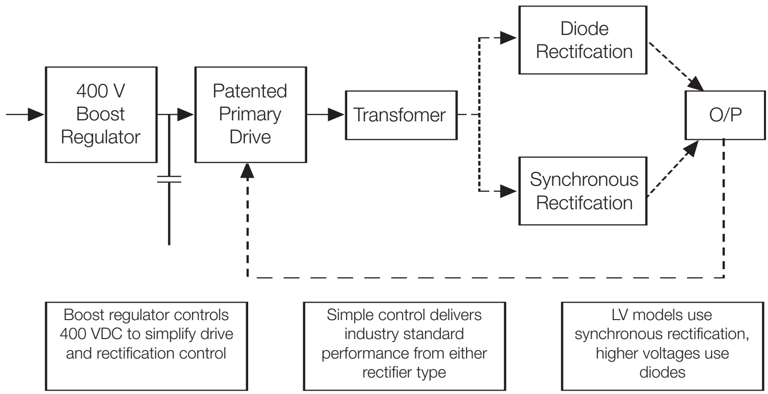


Figure 1

The input section is designed as a boost sub-system, enabling the design to maintain the DC line across the universal range of 85 – 264 VAC, from 47 – 63 Hz, with built-in active power factor correction to give a typical power factor >0.9 and enabling the low-cost output stage to deliver industry standard performance. All the usual features such as overcurrent and overvoltage protection, remote sense and high MTBF are achieved, but there are some additional issues needed to make the PSU simple and economical to use.

- **Hidden costs**

Most system designers have met the additional cost of having to provide forced airflow, with attendant concerns such as fan reliability and excessive noise, so performance should be simple to understand. The same size module is rated at 130 W in 18 CFM air, and 100 W for convection cooling, whether 48 V or 5 V output, thanks to the use of synchronous rectification for the 5 V model and below, and unlike other ranges where 5 V and 3.3 V have the same output current, the JPS130 3.3 V model delivers 25 % extra current at 25 A, compared to 20 A for the 5 V unit. As can be seen from Figure 2, convection cooling enables 100 W up to 50 °C ambient for 48, 24, 15 and 12 V models, and up to 40 °C for 5 V, with 80 W available up to 50 °C from the 3.3 V model.

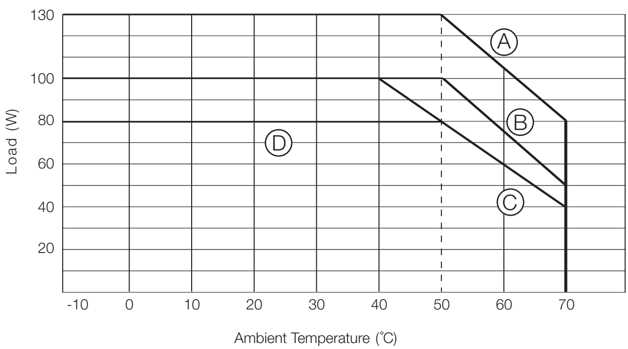


Figure 2

Ⓐ JPS130 with 18 CFM fan.

Ⓑ JPS130PS12, PS15, PS24, PS48 with convection cooling & JPS130PS03 with 18 CFM fan.

Ⓒ JPS130PS05, PT30, PT31 with convection cooling.

Ⓓ JPS130P03 with convection cooling.

Power supplies are critical to equipment EMC performance, but although system performance will naturally depend on issues such as loading and wiring, it is clear that if a power supply only just meets the required EMC standards, any locally created noise is likely to cause problems. The lower the EMI noise of the PSU, the easier it will be to achieve EMC compliance for the whole system, and since switching contributes significantly to EMI noise as well as providing another component of power loss, this aspect of PSU design is key.

• Ring-free zero voltage switching

Zero voltage switching (ZVS) has been widely explored as a way to deliver compact, efficient power conversion. Resonant circuits typically required either a large gap for the main transformer core, or an external inductor, but parasitic ringing between leakage inductance and stray capacitance introduce additional losses and unwanted noise.

By using a patented ZVS switching circuit, which automatically clamps ringing for both inductive and capacitive components, a 6 dB improvement in noise has been achieved, reducing power losses, lowering the reverse voltage rating for the secondary rectification and increasing the practical operating frequency. These benefits apply whether the output is synchronous rectification (5 V or 3.3 V) or conventional diodes (12 V and above) and contributes to the 6.7 W/in3 power density for the 5 V to 48 V models.

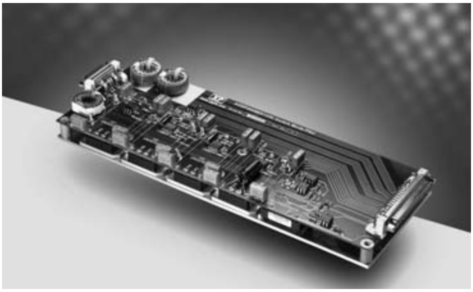
• Synchronous rectification for all

When introduced, synchronous rectification was a revolution, but perhaps it is time for system designers to move on and focus on what a given power supply will do for their system and the overall design process. With this new topology, the technology is now affordable for mainstream systems, so designers can return to looking at the fundamentals of their system needs, rather than viewing synchronous rectification as a ‘holy grail’.

Although efficiency is a common headline specification, comparing the actual power loss will give a better comparison between the system-level impacts of different PSUs, and provide a more valuable insight into factors such as cooling requirements and overall reliability. It is also important to address issues such as EMC margins and input power factor to ensure that the final system meets international standards for EMC immunity and emissions.

Technology Editorial 5

• Military Power from Commercial Modules



Contents

• Introduction

COTS (Commercial Off The Shelf) parts can provide fast, cost-effective solutions for power system design, but only when key industry standards are fully understood.

Designers of electronic equipment for military applications work under the same pressures and constraints as their commercial counterparts. The rate of product development is increasing, leading to increased time-to-market pressures. Budgets are being squeezed, so the adaptation of COTS parts is an attractive option, providing overall system performance and uncompromised reliability and ensuring that the final power units meet the requirements of the appropriate DEF-STAN, MIL-STD or relevant industry standard, depending on the end use.

Power supplies are critical system components - if power fails, the whole system fails. Also, the power supply is often key in protecting sensitive electronics from excessive input voltage variation and providing input filtering for the system. Good power supply design is a pre-requisite of reliable system design.

Some military systems designers opt to build their own power supplies from discrete components. It can appear to be a relatively cheap solution at the outset, but issues of unpredictable performance, time for experimentation and potential delays in product qualification can all add to the real costs of the product.

Buying-in a custom-designed power supply is another option. This can deliver an optimum technical solution, but with the risks of high up-front engineering charges and a lengthy design cycle. The latter often runs to between four and six months and the small volumes required by many military applications can make unit costs unacceptably high.

In many applications, the ideal solution is found in a combination of standard AC/DC or DC/DC power modules, or 'bricks', to which customised input and output circuits and customised packaging are applied. Key to the successful implementation of such a solution is a detailed understanding of military specifications and the special conditions under which the power supplies will be required to operate.

• **Environmental considerations**

Extremes of temperature are encountered in military applications and it's not just high temperatures that cause concern. Some applications require equipment that needs to be capable of operating at –40 °C or even –55 °C and, while a first glance at product datasheets might indicate that this is possible, it's an entirely different matter when the detailed performance and EMC specifications at these temperatures are considered. Compensation for degraded performance at low temperatures needs to be included in the overall power solution.

High temperatures cause similar problems but with additional implications for reliability. As a rule of thumb, the mean time between failures (MTBF) halves for every 10 °C increase in operating temperature. In some applications, designers must avoid the use of forced-air cooling. Fans are electromechanical components that can compromise system reliability. They require monitoring circuits that add to system complexity and cost, and their associated filters are prone to clogging in many environments, reducing cooling effectiveness and increasing maintenance work. Power modules with baseplates are most effective in dissipating excess heat and they need to be carefully designed into packaging that effectively conducts and convects heat away from sensitive electronics. By using appropriate power modules, baseplate operating temperatures of between 85 and 100 °C can be achieved.

Resistance to shock and vibration is another important environmental consideration. Normal potting compounds used to encapsulate DC/DC power modules are prone to crystallisation at very low temperatures, leading to damage to internal components. Specially developed soft-potting compounds and spin-fill techniques can be used to overcome these problems. Finally, the ingress of dust and moisture needs to be avoided.

• **Input and output voltages**

The input voltages needed for military applications rarely coincide with those used in commercial ones. Military specifications are stringent for other input characteristics too, including low and high line conditions and the capability of power supplies to handle voltage spikes, surges and excessive input ripple. Not only do these special input requirements demand flexibility from the DC/DC power module manufacturer but they also mean that input conditioning circuits are invariably required. Output voltages are often non-standard when compared with commercial products. A power module manufacturer that offers a very wide product choice may well be able to provide something with an output that is trimmable to the required voltage but it's important to remember that over- and undervoltage trips will probably not move to accommodate the change in nominal output voltage.

A few manufacturers will adapt DC/DC power modules for user-defined output voltages, with appropriate over- and under-voltage trip points. Trip points can be set or deleted depending upon design requirements.

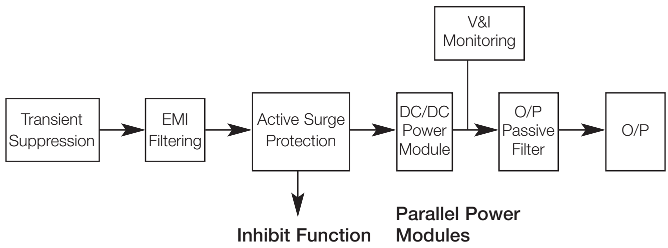
• **EMC compliance**

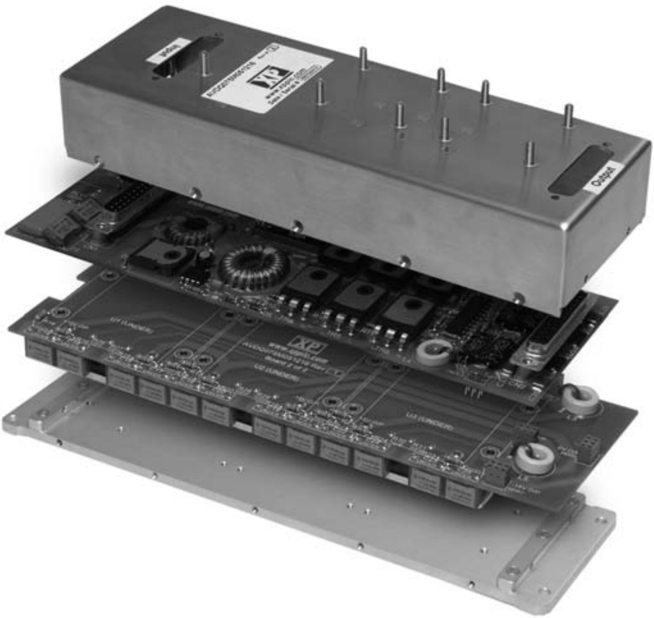
Military standards typically specify limits from 10Hz to 1GHz as well as a range of conducted and radiated susceptibility and emissions requirements. Once again input and output conditioning are needed to achieve compliance. EMC filtering can be achieved using discrete components or filter modules. Active filters remove spikes and filter both conducted emissions and conducted susceptibility such as transients or input ripple appearing at the output. Radiated emissions are dealt with by complete screening of the final power supply.

• **COTS solutions**

Companies such as XP can produce reliable and cost-effective power supplies for military applications based upon COTS DC/DC power modules. The block diagram of a typical design is shown below. Successful designs demand an in-depth understanding of the special requirements of military systems and access to the widest possible range of reliable DC/DC power modules.

XP provides analogue design for the input and output circuits and 3D mechanical modelling of power supplies based on COTS units. The company also carries out pre-compliance testing and assists customers in the final product qualification process.





Glossary

Abnormal Failure
An artificially induced failure of a component, usually as a result of ‘abnormal’ testing for regulatory agency safety compliance.

Ambient Temperature
The still-air temperature in the immediate vicinity of a power supply.

Apparent Power
A value of power for AC circuits which is calculated as the product of RMS current times RMS voltage, without taking the power factor into account.

Autoranging Input
An input voltage sensing circuit in the power supply which automatically switches to the appropriate input voltage range (90-132 VAC or 180-264 VAC).

Balun
A transformer which presents a high impedance to common-mode signals and a low impedance to differential-mode signals. It is commonly used on the input of switching power supplies to suppress common-mode noise. See Figure 1.

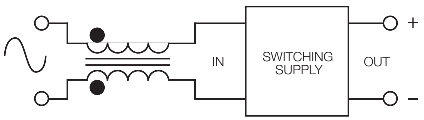


Figure 1

Bandwidth
A range of frequencies over which a certain phenomenon is to be considered.

Basic Insulation
According to international safety standards (e.g. UL60950, EN60950) basic insulation provides basic protection against electric shock i.e. one level of protection, and the test voltage used is 1500 VAC. Quite frequently, safety standards call for basic insulation between secondary circuits (e.g. between a telecom network and SELV circuits).

Bode Plot
A graphic plot of gain versus frequency for a control loop, typically used to verify control loop stability, including phase margin.

Breakdown Voltage
The maximum AC or DC voltage which may be applied from input to output and/or chassis of a power supply. See Figure 2.

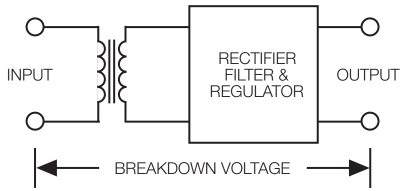


Figure 2

Bridge Rectifier
A full wave rectifier circuit employing four rectifiers in a bridge configuration.

Brown-out
Condition during peak usage periods when electric utilities reduce their nominal line voltage by 10% to 15%.

BSMI
Bureau of Standards Metrology & Inspection. Certification body for Taiwan.

Burn-in
Operating a newly manufactured power supply, usually at rated load and elevated temperature, for a period of time in order to force component infant mortality failures or other latent defects before the unit is delivered to a customer.

Capacitive Coupling
Coupling of a signal between two circuits, due

to discrete or parasitic capacitance between the circuits.

CCC
China Compulsary Certification. Certification body for China for product safety and EMC.

Center Tap
An electrical connection made at the center of a transformer or inductor winding, usually so as to result in an equal number of turns on either side of the tap.

Centering
The act of setting the output voltage of a power supply under specified load conditions, usually an auxiliary output of a multiple output power supply with all outputs at half load.

CISPR
International Special Committee on Radio Interference.

Clearance Distance
The shortest distance (through air) separating two conductors or circuit components.

Common-mode Noise
The component of noise that is common to both the live and neutral conductors with respect to ground, also the component of noise that is common to both the DC output and return lines with respect to input ground.

Compliance Voltage
The output voltage of a constant current power supply.

Conducted Immunity
The immunity of a product to bursts of short duration, fast rise time transients that may be generated by the switching of inductive loads, contactors etc.

Configurable
See *Modular*

Constant Current Limiting Circuit
Current-limiting circuit which holds output current at some maximum value whenever an overload of any magnitude is experienced.

Constant Current Power Supply
A power supply which regulates its output current, within specified limits, against changes in line, load, ambient temperature and time.

Constant Voltage Power Supply
A power supply designed to regulate the output voltage for changes in line, load, ambient temperature and drift resulting from time.

Creepage Distance
The shortest distance between two conducting parts measured along the surface or joints of the insulating material between them.

Crest Factor
In an AC circuit, crest factor is the mathematical ratio of the peak to RMS values of a waveform. Crest factor is sometimes used for describing the current stress in AC mains supply wires for a given amount of power transferred, the RMS value and hence the losses become greater with increasing peak values.

Cross Regulation
In a multiple output power supply, the percentage voltage change at one output caused by the load change on another output.

Crowbar
An overvoltage protection circuit which rapidly places a low resistance shunt across the power supply output terminals if a predetermined voltage is exceeded. See Figure 3.

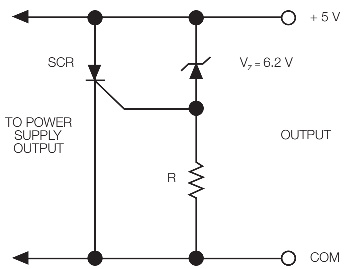


Figure 3

CSA
Canadian Standards Association. An independent Canadian organization concerned with testing for public safety.

Current Limiting
See *Output Current Limiting.*

Current Limiting Circuit
A circuit designed to prevent overload of a constant-voltage power supply. It can take the form of constant, foldback or cycle-by-cycle current limiting.

Current Share
The accuracy with which two or more power supplies share a load current. An active share control connection is sometimes employed which may be described as a current share or power share connection.

Derating
The specified reduction in an operating parameter to improve reliability. Generally for power supplies it is the reduction in output power at elevated temperatures. See Figure 4.

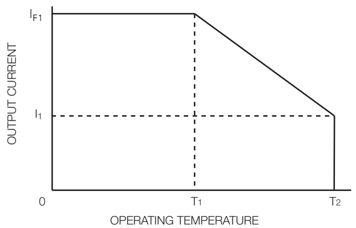


Figure 4

Differential Mode Noise
The component of noise measured between the live and neutral conductors, and also the component of noise measured between the DC output and output return. See *Ripple and Noise*.

Dips and Interruptions
Short input interruptions to simulate the utility supply under various conditions.

Double Insulation
Insulation comprising both basic insulation and supplementary insulation. Double insulation provides two levels of protection and the test voltage is 3000 VAC for IT and industrial equipment, and 4000 VAC for medical equipment.

Distributed Power Architecture (DPA)
This is a power distribution system where the conversion to lower voltages is effected locally near the load. An interim DC voltage is provided from the AC mains or DC bus by a converter. This is then distributed to smaller DC/DC converters. Some versions of this system are also known as Intermediate Bus Architecture (IBA). See page 6.

Drift
The change in output voltage of a power supply over a specified period of time, following a warmup period, with all other operating parameters such as line, load, and ambient temperature held constant.

Dropout
The lower limit of the AC input voltage where the power supply begins to experience insufficient input to maintain regulation.

Dynamic Current Allocation
A system for dual positive outputs such as 5V & 3.3V where the full amount of current may be taken from either output in whichever combination is required. For instance, in a 6A system any value of current from 0A to 6A may be taken from the 3.3V output and the remainder from the 5V or vice versa.

Dynamic Load Regulation
See *Transient Response.*

Earth Leakage Current
The current that flows through the earth conductor of a piece of equipment under normal conditions. This is limited by legislation. Limits depend upon the application.

Efficiency
The ratio of output power to input power. It is generally measured at full-load and nominal line conditions. In multiple output switching power supplies, efficiency is a function of total output power.

EFT/Burst
See *Conducted Immunity*.

Eighth Brick
An industry standard package size and pin-out for DC/DC converters. The package size is 2.3" x 0.9" with the pins on a 2.0" spacing. The height is typically 0.3".

Electromagnetic Interference (EMI)
Also called radio frequency interference (RFI), EMI is unwanted high frequency energy caused by the switching transistors, output rectifiers and zener diodes in switching power supplies. EMI can be conducted through the input or output lines or radiated through space.

Enable
The ability to turn on electrically the output of a power supply from a remote location.

Equivalent Series Resistance (ESR)
The amount of resistance in series with an ideal capacitor which exactly duplicates the performance of a real capacitor. In high frequency applications low ESR is very important.

Electrostatic Discharge (ESD)
Discharge of static electricity built up when two insulating materials are rubbed together.

ETSI
The European Telecommunications Standards Institute (ETSI) is a non-profit-making organization whose mission is to determine and produce the telecommunications standards that will be used for decades to come. It is an open forum which unites 696 members from 50 countries, representing administrations, network operators, manufacturers, service providers and users.

FCC
The FCC (Federal Communications Commission) is an independent United States government agency, directly responsible to Congress and charged with regulating interstate and international communications by television, radio, wire, satellite and cable.

Filter
A frequency-sensitive network that attenuates unwanted noise and ripple components of a rectified output.

Floating Output
An output of a power supply that is not connected or referenced to any other output usually denotes full galvanic isolation. They generally can be used as either positive or negative outputs. Non-floating outputs share a common return line and so are referenced to one another.

Fly-back Converter
The fly-back converter is the simplest type of switcher. In most cases, it uses one switch and only needs one magnetic element - the transformer. Practical output power from flyback converters is limited to less than 150W.
See Figure 5 and page 2.

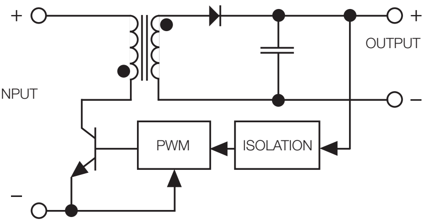


Figure 5

Foldback Current Limiting Circuit
Current limiting circuit that gradually decreases the output current under overload conditions until some minimum current level is reached under a direct short circuit. See Figure 6.

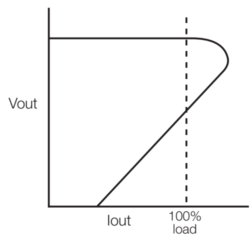


Figure 6

Forward Converter
Similar to a fly-back converter but the forward converter stores energy in the output inductor instead of the transformer. See page 3.

Front End
A particular type of AC/DC converter (usually high power) used in distributed power architecture (DPA) and Intermediate Bus Architecture (IBA) systems which provides the DC voltage that is bussed around the system.

Full Brick
An industry standard package size and pin out for DC/DC converters. The package size is 2.4” x 4.6” with the pins on a 4.2” spacing. The height is typically 0.5” without a heatsink. Four mounting holes are provided for the attachment of heatsinks and to the customer’s board.

Full Bridge Converter
A power switching circuit in which 4 transistors are connected in a bridge configuration to drive a transformer primary. See page 4.

Galvanic Isolation
Two circuits which have no significant ohmic connection are considered to be “galvanically isolated” from each other. Galvanic isolation (separation) is achieved by using a transformer, opt-coupler, etc.

Ground
An electrical connection to earth or some other conductor that is connected to earth. Sometimes the term “ground” is used in place of “common”, but such usage is not correct unless the connection is also made to earth.

Ground Loop
An unwanted feedback condition caused by two or more circuits sharing a common electrical ground line.

Half Brick
An industry standard package size and pin-out for DC/DC converters. The package size is 2.40” x 2.28” with the pins on a 1.90” spacing. The height is typically 0.50” without a heatsink. Four mounting holes are provided for the attachment of heatsinks and to the customer’s board.

Half Bridge Converter
A power switching circuit similar to the full bridge converter except that only two transistors (or diodes) are used, with the other two replaced by capacitors. See page 4.

Harmonic Currents
Current distortion generated by non-linear loads such as the input to a switch mode power supply.

Heatsink
Device used to conduct away and disperse the heat generated by electronic components.

Hiccup Mode
See *Trip & Restart Current Limiting*

Hi-Pot Test
High potential test. A test to determine if the breakdown voltage of a transformer or power supply exceeds the minimum requirement. It is performed by applying a high voltage between the two isolated test points.

Hold-up Time
The time during which a power supply’s output voltage remains within specification following the loss of input power.

Hot Swap
Redundant units which may be removed and replaced without the need to power down equipment.

IEC
International Electrotechnical Commission.

Induced Noise
Noise generated in a circuit by a varying magnetic field produced by another circuit.

Inhibit
The ability to electrically turn off the output of a power supply from a remote location via a logic level signal.

Input Line Filter
A low-pass or band-reject filter at the input of a power supply which reduces line noise fed to the supply. This filter may be external to the power supply.

Input Voltage Range
The high and low input voltage limits within which a power supply or DC/DC converter meets its specifications.

Inrush Current
The peak instantaneous input current drawn by a power supply at turn-on.

Inrush Current Limiting
A circuit which limits the inrush current during turn-on of a power supply.

Intermediate Bus Architecture (IBA)
See *Distributed Power Architecture (DPA)*.

Inverter
A power converter which changes DC input power into AC output power.

Isolation
The electrical separation between input and output of a power supply by means of the power transformer. The isolation resistance (normally in mega ohms) and the isolation capacitance (normally in pico farads) are generally specified and are a function of materials and spacings employed throughout the power supply.

Isolation Voltage
The maximum AC or DC voltage that may be applied for a short, defined duration from input to output and/or chassis of a power supply.

KETI
Korean Electrical Testing Institute. Certification body for safety and EMC in Korea.

Line Frequency Regulation
The variation of an output voltage caused by a change in line input frequency, with all other factors held constant. This effect is negligible in switching and linear power supplies.

Line Regulation
The variation of an output voltage due to a change in the input voltage, with all other factors held constant. Line regulation is expressed as the maximum percentage change in output voltage as the input voltage is varied over its specified range.

Linear Regulator
A common voltage-stabilization technique in which the control device (usually a transistor) is placed in series or parallel with the power source to regulate the voltage across the load. The term 'linear' is used because the voltage drop across the control device is varied continuously to dissipate unused power.

Load Regulation
Variation of the output voltage due to a change in the output load, with all other factors held constant. It is expressed as a percentage of the nominal DC output voltage.

Local Sensing
Using the output terminals of the power supply as sense points for voltage regulation.

Logic Enable
The ability to turn a power supply on and off with a TTL signal. A logic low generally turns the supply off; logic high turns it on.

Long Term Stability
Power supply output voltage change due to time with all other factors held constant. This is expressed in percent and is a function of component ageing.

Magnetic Amplifier
A magnetic device used to improve the cross regulation of multiple output AC/DC converters.

Margining
Adjusting a power supply output voltage up or down from its nominal setting in order to verify system performance. This is usually done electrically by a system-generated control signal.

Minimum Load
The minimum load current/power that must be drawn from the power supply in order for the supply to meet its performance specifications. Less commonly, a minimum load is required to prevent the power supply from failing.

Modular
A physically descriptive term used to describe a power supply made up of a number of separate subsections, such as an input module, power module, or filter module.

MOSFET
Metal oxide semiconductor field effect transistor. The device of choice for the main switch in many switch mode power supplies, having much better switching characteristics than bipolar transistors.

MTBF
Mean time between failures. The failure rate of a system or component, expressed in hours, established by the actual operation (demonstrated MTBF) or calculated from a known standard such as MIL-HDBK-217.

Noise
Noise is the aperiodic, random component of undesired deviations in output voltage. Usually specified in combination with ripple. See *PARD and Ripple*.

Nominal Value
The stated or objective value for a quantity, such as output voltage, which may not be the actual value measured.

Off-line Power Supply
A power supply which operates off the AC line directly, without using a power transformer prior to rectification and filtering.

Open Frame
A power supply with no external metal chassis; the power supply is provided to the end user essentially as a printed circuit board which provides mechanical support as well as supporting the components and making electrical connections.

Operational Insulation
Operational insulation is needed for the correct operation of the equipment, but does not protect against electric shock. Operational insulation provides no levels of protection and typically the test voltage is ≤ 500 VDC.

Operating Temperature Range
See *Temperature Range, Operating*.

Operational Power Supply
A power supply with a high open loop gain regulator which acts like an operational amplifier and can be programmed with passive components.

Output Current Limiting
An output protection feature which limits the output current to a predetermined value in order to prevent damage to the power supply or the load under overload conditions. The supply is automatically restored to normal operation following removal of the overload.

Output Good
A power supply status signal which indicates that the output voltage is within a certain tolerance. An output that is either too high or too low will deactivate the output good signal.

Output Impedance
The ratio of change in output voltage to change in load current.

Output Noise
The AC component which may be present on the DC output of a power supply. Switch-mode power supply output noise has two major components; a lower frequency component at the switching frequency of the converter and a high frequency component due to fast edges of the converter switching transitions. Noise should always be measured directly at the output terminals with a probe having an extremely short grounding lead. See page 45.

Output Voltage
The nominal value of the DC voltage at the output terminals of a power supply.

Output Voltage Accuracy
For a fixed output supply, the tolerance in percent of the output voltage with respect to its nominal value under all minimum or maximum conditions.

Output Voltage Trim
The adjustment range of a power supply or DC/DC converter via a potentiometer or external programming of voltage, current or resistance.

Overload Protection
An output protection feature that limits the output current of a power supply under overload conditions so that it will not be damaged.

Overshoot
A transient change in output voltage, in excess of specified output accuracy limits, which can occur when a power supply is turned on or off or when there is a step change in line or load. See Figure 7.

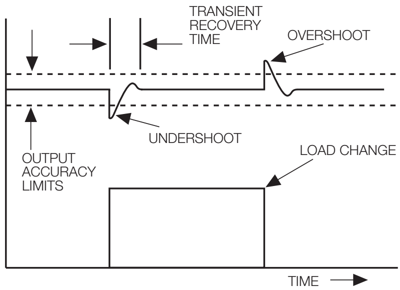


Figure 7

Over Temperature Protection
A protection system for converters or power supplies where the converter shuts down if the ambient temperature exceeds the converter's ratings. OTP is intended to save the converter and any downstream equipment in the event of a failure of a fan or such. OTP usually measures the hottest item on board the converter rather than ambient temperature.

Over Voltage Protection (OVP)
A power supply feature which shuts down the supply, or crowbars or clamps the output, when its voltage exceeds a preset level. See Crowbar.

Parallel Operation
The connection of the outputs of two or more power supplies of the same output voltage to obtain a higher output current than from either supply alone. This requires power supplies specifically designed to share the load.

PARD
Periodic and random deviation. A term used for the sum of all ripple and noise components measured over a specified bandwidth and stated in either peak-to-peak or RMS values. See Figure 8.

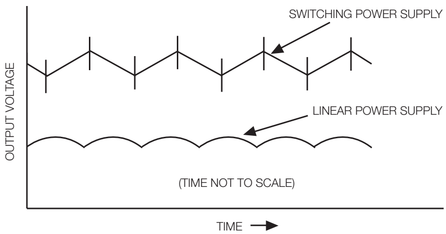


Figure 8

Peak Power
The absolute maximum output power that a power supply can produce without immediate damage. Peak power capability is typically well beyond the continuous reliable output power capability and should only be used within the defined specification.

Power Factor Correction (PFC)
Standard AC/DC converters draw line current in pulses around the peaks in line voltage. This may be undesirable for several reasons. PFC circuits ensure that the line current is drawn sinusoidally and in phase with the sinusoidal line voltage. See page 30.

Pi Filter (π filter)
A commonly-used filter at the input of a switching supply or DC/DC converter to reduce reflected ripple current. The filter usually consists of two parallel capacitors and a series inductor and is generally built into the supply.
See Figure 9.

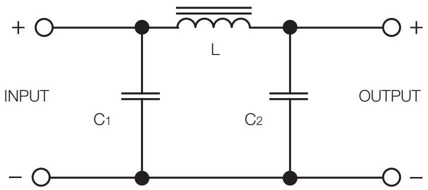


Figure 9

Post Regulation
A linear regulator used on the output of a switching power supply to improve line and load regulation and reduce output ripple voltage.
See Linear Regulator.

Power Density
The ratio of output power per unit volume. Typically specified in W/In^3.

Power Factor
The ratio of true power to apparent power in an AC circuit. In power conversion technology, power factor is used in conjunction with describing the AC input current to the power supply.

Power Fail Detection
A power supply option which monitors the input voltage and provides an isolated logic output signal when there is loss of line voltage.

Power Foldback
A power supply feature whereby the input power is reduced to a low value under output overload conditions.

Power Sharing
See *Current Share*.

Pre-load
A small amount of current drawn from a power supply to stabilise its operation. A bleed resistor usually provides a pre-load. See also *Minimum Load*.

Pre-regulation
The regulation at the front-end of a power supply, generally by a type of switching regulator; this is followed by output regulation, usually by a linear type regulator.

PSE
Product Safety Electric Appliances and Materials. Certfication for Safety and EMC in Japan.

Primary
The input section of an isolated power supply that is connected to the AC mains and hence has dangerous voltage levels present.

Programmable Power Supply
A power supply with an output controlled by an external resistor, voltage, current or digital code.

Pulse Width Modulation
A method of voltage regulation used in switching supplies whereby the output is controlled by varying the width, but not the height, of a train of pulses that drive a power switch.

Push-Pull Converter
A power switching circuit which uses a center tapped transformer and two power switches which are driven on and off alternately. This circuit does not provide regulation by itself.

Quarter Brick
An industry standard package size and pin-out for DC/DC converters. The package size is 1.45” x 2.28” with the pins on a 2.0” spacing. The height is typically 0.50” without a heatsink. Four mounting holes are provided for the attachment of heatsinks and to the customer’s board.

Radiated Electromagnetic Interference
Also called radio frequency interference (RFI), EMI is unwanted high-frequency energy caused by the switching transistors, output rectifiers and zener diodes in switching power supplies. The

portion that is radiated through space is known as radiated EMI. Most radiated EMI measurements are done between 30MHz and 1GHz.

Radiated Immunity
The immunity of a product to electromagnetic fields.

Rated Output Current
The maximum load current which a power supply was designed to provide at a specified ambient temperature.

Redundancy (N+1)
Power supplies connected in parallel operation so that if one fails, the others will continue delivering enough current to supply the maximum load. This method is used in applications where power supply failure cannot be tolerated. See page 58.

Reference
The stable voltage, generally a zener diode, from which the output voltage of a regulated supply is controlled.

Reflected Ripple Current
The AC current generated at the input of a power supply or DC/DC converter by the switching operation of the converter, stated as peak-to-peak or RMS.

Reinforced Insulation
Single insulation system applied to live parts which provide a degree of protection against electric shock equivalent to double insulation. Reinforced insulation provides two levels of protection and the test voltage used is 3000VAC for IT and industrial equipment, and 4000VAC for medical equipment.

Regulation
The ability of a power supply to maintain an output voltage within a specified tolerance as referenced to changing conditions of input voltage and/or load.

Reliability
The ability of a system or component to perform its required functions under stated conditions for a specified amount of time.

Remote Enable
Power supply interface signal, often TTL compatible, which commands the power supply to start up one or all outputs.

Remote Inhibit
Power supply interface signal, often TTL compatible, which commands the power supply to shut down one or all outputs.

Remote ON/OFF
One or other of remote enable or remote inhibit, or a combination of both.

Remote Sensing
A technique of regulating the output voltage of a power supply at the load by means of sensing leads which go from the load back to the regulator. This compensates for voltage drops in the load leads. See Figure 10 and page 43.

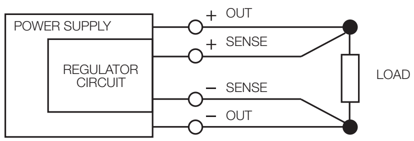


Figure 10

Resolution
For an adjustable supply, the smallest change in output voltage that can be realised by the adjustment.

Resonant Converter
A class of power converter topology which reduces the level of switching losses by forcing either zero voltage across, or zero current through the switching device when it is turned on or off.

Return
The name for the common terminal of the output of a power supply; it carries the return current for the outputs.

Reverse Voltage Protection
A feature which protects a power supply against a reverse voltage applied at the input or output terminals.

RFI
See *Radiated Electromagnetic Interference*.

Ripple and Noise
The magnitude of AC voltage on the output of a power supply, expressed in millivolts peak-to-peak or RMS, at a specified bandwidth. This is the result of feed through of the rectified line frequency, internal switching transients and other random noise. See also PARD & Noise.

Rise Time
The time required for the voltage in a switching electronic circuit to rise from 10% to 90% of its nominal final value.

Safety Approvals
Third party or agency approvals to internationally recognised safety standards.

Safety Ground
A conductive path to earth that is designed to protect persons from electrical shock by shunting away any dangerous currents that might occur due to malfunction or accident.

Secondary
The output section of an isolated power supply which is isolated from the AC mains and specially designed for safety of personnel who might be working with power on the system.

SELV
Safety extra low voltage. A term generally defined by the regulatory agencies as the highest voltage that can be contacted by a person and not cause injury. It is often specifically defined as 42.4 VAC or 60 VDC.

Sequencing
The desired order of activation of the outputs of a multiple output power supply.

Shock and Vibration
A specification requirement for which a power supply is designed or tested to withstand, such as 20G shock for 11 milliseconds and 10G random vibration for 2 hours over a 2-2000 Hz bandwidth.

Short Circuit Protection
A feature which limits the output current of a power supply under short circuit conditions so that the supply will not be damaged.

Signals
Output interface, often at TTL level, of various operational conditions such as power fail and DC OK.

Sixteenth Brick
An industry standard package size and pin-out for DC/DC converters. The package size is 1.3” x 0.9” with the pins on a 1.1” spacing. The height is typically less than 0.4”.

Soft Start
A technique for gradually activating a power supply circuit when the power supply is first turned on. This technique is generally used to provide a gradual rise in output voltages and to limit inrush current.

Standby Current
The input current drawn by a power supply when shut down by a control input (remote inhibit) or under no load.

Start-up Rise Time
The time between the output voltage starting to rise and reaching the desired level.

Start-up Time (Start-up Delay)
Time between the application of input voltage and the output voltage being within regulation.

Supplementary Insulation
Independent insulation applied in addition to basic insulation in order to provide protection against electric shock in the event of a failure of basic insulation. Supplementary insulation provides one level of protection and has a test voltage of 1500VAC.

Surface Mount Technology (SMT)
A space-saving technique whereby special lead-less components are soldered onto the surface of a PCB rather than into holes in a PCB. The parts are smaller than their leaded versions and PCB area is saved.

Surge
Part of the conducted immunity suite of tests, designed to simulate a nearby lightning strike.

Switching Frequency
The rate at which the DC voltage is switched on and off during the pulse width modulation process in a switching power supply.

Synchronous Rectifiers or Rectification
A circuit arrangement where the output rectifier diodes of a power supply are replaced with active switches such as MOSFETs. The switches are turned on and off under control and act as rectifiers. This results in considerably lower losses in the output stage and subsequently much higher efficiency. They are particularly useful with low voltage outputs.

Temperature Coefficient
The average percent change in output voltage per degree centigrade change in ambient temperature over a specified temperature range.

Temperature Derating
Reducing the output power of a power supply with increasing temperature to maintain reliable operation.

Temperature Range, Operating
The range of ambient or case temperatures within which a power supply may be safely operated and meet its specifications.

Temperature Range, Storage
The range of ambient temperatures within which a non-operating power supply may be safely stored with no degradation of its subsequent operation.

Thermal Protection
See *Over Temperature Protection*.

Topology
The design type of a converter, indicative of the configuration of switching transistors, utilization of the transformer, and type of filtering. Examples of topologies are fly-back, forward, half-bridge, full-bridge, and resonant.

Tracking
A characteristic of a dual or other multiple output power supply whereby one or more outputs follow another output with changes in line, load and temperature, so that each maintains the same proportional output voltage, within specified tracking tolerance, with respect to common.

Transient Response
The time required for the output voltage of a power supply to settle within specified output accuracy limits following a step change in output load current or a step change in input voltage.

Trip & Restart Current Limiting
Current limiting circuit which switches off the output when an overload condition is reached. The unit will then try to restart periodically until the overload is removed.

TUV
TUV Rheinland Product Safety Group. An independent German organization which tests products for safety.

UL
Underwriter's Laboratories Incorporated. An independent, U.S. organization which tests products for safety.

Undershoot
A transient change in output voltage, below output accuracy limits, which can occur when a power supply is turned on or off, or when there is a step change in line or load. See *Overshoot*.

Universal Input
A power supply's ability to accept a wide input voltage range (90VAC to 264VAC) without the selection of input range, either manually or electronically (as in auto-ranging input).

UPS
Uninterruptible power supply. A power supply that continues to supply power during a loss of AC input power. This is accomplished by means of a back-up battery and a DC/AC inverter or DC/DC converter.

Under Voltage Lock Out (UVLO)
A protection system for power converters where the converter is deliberately shut down if the input voltage drops below a pre-defined level. Some hysteresis is usually present to prevent the converter oscillating on and off. UVLO is usually needed with battery systems where the voltage decreases gradually with time rather than turning off quickly.

VDE
Verband Deutsche Elektrotechniker. A German organization which tests equipment for public safety and emitted noise.

Voltage Balance
The percentage difference in magnitude between the two output voltages of a dual output power supply where the voltages have equal nominal values with opposite polarities.

Warm-up Drift
The initial change in output voltage of a power supply from turn-on until it reaches thermal equilibrium at nominal line, full load, 25°C ambient temperature.

Warm-up Time
The time required, after initial turn-on, for a power supply to meet its performance specifications.

Zero Current Switching (ZCS)
See *Resonant Converter*.

Zero Voltage Switching (ZVS)
See *Resonant Converter*.

• Prefix Codes

Prefix Multipliers

Prefix	Symbol	Multiplier
exa-	E	1,000,000,000,000,000,000
peta-	P	1,000,000,000,000,000
tera-	T	1,000,000,000,000
giga-	G	1,000,000,000
mega-	M	1,000,000
kilo-	k	1,000
hecto-	h	100
deca-	da	10
deci-	d	0.1
centi-	c	0.01
milli-	m	0.001
micro-	µ	0.000 001
nano-	n	0.000 000 001
pico-	p	0.000 000 000 001
femto-	f	0.000 000 000 000 001
atto-	a	0.000 000 000 000 000 001

• SI Unit Codes

SI Base Units

Quantity	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric Current	ampere	A
Thermodynamic Temperature	kelvin	K

SI Derived Units

Quantity	Name	Symbol
Area	square meter	m^2
Volume	cubic meter	m^3
Speed/Velocity	meter per second	m/s
Acceleration	meter per second squared	m/s^2
Current Density	ampere per square meter	A/m^2
Magnetic Field Strength	ampere per meter	A/m

SI Derived Units With Special Names

Quantity	Name	Symbol	Expression in terms of other units	Expression in terms of SI base units
Frequency	Hertz	Hz		s^{-1}
Energy/ Work/ Quantity of heat	Joule	J	Nm	$m^2\ kg\ s^{-2}$
Power/ Radiant Flux	Watt	W	J/s	$m^2\ kg\ s^{-3}$
Electric Potential/ Potential Difference/ Electromotive Force	Volt	V	W/A	$m^2\ kg\ s^{-3}\ A^{-1}$
Capacitance	Farad	F	C/V	$m^{-2}\ kg^{-1}\ s^4\ A^2$
Electric Resistance	Ohm	Ω	V/A	$m^2\ kg\ s^{-3}\ A^{-2}$
Magnetic Flux	Weber	Wb	V s	$m^2\ kg\ s^{-2}\ A^{-1}$
Magnetic Flux Density	Tesla	T	Wb/m^2	$kg\ s^{-2}\ A^{-1}$
Inductance	Henry	H	Wb/A	$m^2\ kg\ s^{-2}\ A^{-2}$
Celsius Temperature	degree Celsius	°C		K
Electric Field Strength	Volt per meter	V/m		$m\ kg\ s^{-3}\ A^{-1}$

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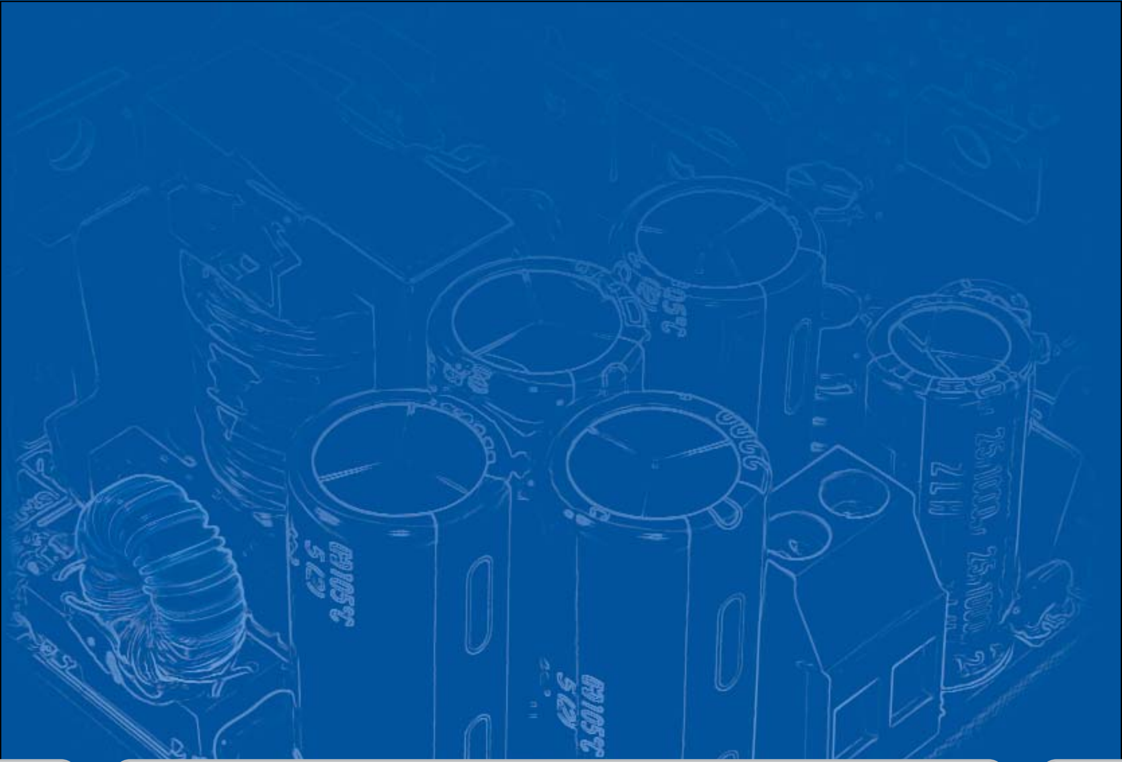

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