Even when the correct power converter(s) have been chosen from the wide product range in the POWERBOX POWER CONVERSION GUIDE, if care is not taken with installation and the design of the distribution wiring problems can arise. Often difficulties which at first appear to be power supply shortcomings are due to incorrect power distribution. Typical symptoms are poor regulation at the load, low voltage at the load, inadequate noise margins, excessive crosstalk between circuits, oscillatory behaviour and overheating.

Some important guidelines which help to avoid such problems are summarised as follows:

- Be on the generous side when selecting equipment wire ratings
- Keep all wiring as short as possible
- Connect signal and power zero volt common conductors separately to a single star earth connection
- Avoid creating additional earth connections by careless use of mounting screws, stand offs, brackets etc.
- Do not bundle wires together in looms indiscriminately
- Use separate twisted pairs for output/return wires
- Keep unfiltered mains input wiring outside the equipment - where this is impossible use short runs of twisted pairs, if necessary shielded by a grounded conductive sheath
- Ensure that mounting screws do not bridge safety clearance distances
- Never switch on power until the safety earth continuity has been checked
- Keep ventilation slots clear – excess operating temperatures are the major cause of unreliability – force cool when in doubt

Equipment Wire Rating

Examination of the effects of wiring resistance on regulation for the simple case of a single power converter connected to a single load show how easy it is to degrade regulation performance in circuits with modest power requirements.

No. of strands x diameter / strand (mm)	Near equivalent AWG	Typical specific resistance moHm/ m at 20°C
7 x 0.2	24	88
16 x 0.2	22	40
24 x 0.2	20	25
32 x 0.2	18	20

Multi-stranded tinned copper equipment wire

AWG	Approx diameter mm	Near equivalent SWG	Typical specific resistance moHm/ m at 20°C
14	1.60	16	8.3
18	1.00	19	21
22	0.64	23	53
26	0.40	27	133
30	0.25	31	338

Single strand annealed copper connecting wire

Table 1. Resistivity of popular sizes of equipment wire

Assume a 5A load is a half metre away from a 5V converter and the equipment wire (18 AWG) has a specific resistance of 20mΩ/metre. Total additional loop resistance is 20mΩ so the volts drop at full load is 5 x 20 x 10-3 volts i.e. 0.1V, 2% of the nominal output voltage. Load regulation has been degraded by a factor of 20 times, if the converter load regulation is specified as 0.1% at the output terminals. If for the sake of neatness the interconnect wire is taken around the periphery of an equipment box, at least a further half metre could be added to the two wires, increasing the total volts drop to 0.2V. At 4.8V, compared with 4.75V minimum supply voltage specified for many logic circuits there would be no margin left for further voltage reduction due to temperature coefficient, initial setting error or long term drift.

Connectors and Printed Circuit Boards

Connectors and printed circuit boards are major causes of excessive voltage drops in power distribution systems. Connectors give problems because of inadequate contact rating and lack of cleanliness. Corrosion, dust and dirt must be removed, otherwise local heating can eventually have a runaway effect with total breakdown of the contact. Where parallel pins are provided at the output of a power converter all the pins should be used for power distribution.

On printed circuit boards, because of the pressure on the designer for high packing densities, power bus and zero volt tracks often become too narrow.

Rather than suffer the consequences of this, the system designer should insist on adding low impedance power distribution buses in the form of vertically mounting conductive strips. When allocating pin assignments in PCB connectors it is essential to use sufficient numbers of pins to the power circuits.

Remote Sensing

Many power converters, especially those with higher current ratings and low output voltages incorporate remote sensing. This feature enables the voltage at the load, rather than at the converter output to be fed back for comparison with the internal reference to provide the difference signal for regulation. By this means the voltage at the load is regulated, and voltage drops in the connecting wires are automatically compensated. This results in a higher voltage than nominal at the converter output terminals. Most units with this feature have two wire remote sensing (output and return) and are limited to 0.5V overall volts drop (0.25V per wire). There is usually a limit on sense lead lengths, typically 1 metre. Because they carry very low currents they are susceptible to noise pick up. It is recommended that they are a twisted pair and if necessary shielded (as shown in Fig. 1).

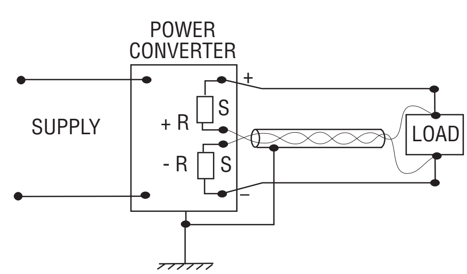

Fig 1 Using remote sensing at the load with a shielded twisted pair to minimise noise pick up

Points worth noting when using remote sensing are:

- The power converter output is running above rated voltage so the maximum current demanded should be reduced from nominal rating to remain within the overall power rating.
- The margin between the output voltage and the over voltage protection trip, if applicable, is lower. Where it is adjustable the OVP trip could be set higher by 0.25 to 0.5V.
- The sense leads are within the feedback loop of the regulating circuit so there may be some deterioration of the dynamic stability of the converter.
- Noise picked up by the sense leads can cause considerable problems.
- Remote sense only operates at the point of connection, so it may not be of much value in systems with distributed loads.
- When the remote sense facility is not used, sense links must be made at the output terminals (there will probably be resistors connected internally to prevent the output voltage from rising excessively if the sense links are left open circuit).

Power Distribution

Daisy Chain

Where multiple loads are connected to a single power converter output, it is always tempting to make “daisy chained” connections to the loads as shown in Fig. 2. The furthest load from the converter will see the lowest voltage and the connecting leads to the nearest load will carry the currents demanded by all three loads. Since these currents will almost certainly be dynamic this method of connection is a sure recipe for crosstalk.

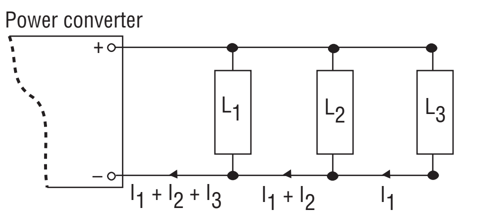

Fig 2 Shows incorrect 'daisy chain' connection of multiple loads

Star Distribution

This is the best method of connecting multiple loads to one output, each load sees the same voltage and no dynamic interference results from combined circulating currents. Sometimes it is difficult to implement this exactly as shown in Fig. 3a, so a compromise solution is shown in Fig. 3b where the wiring from the converter to the star connection points is heavy duty (a copper bus bar in high current systems).

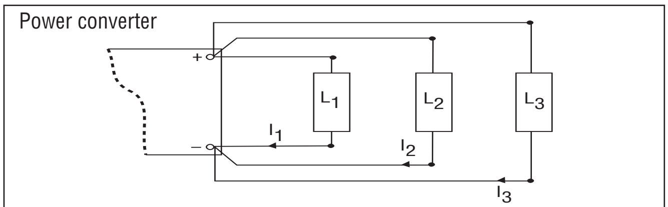

Fig 3a Shows correct method of connecting multiple loads to single source.

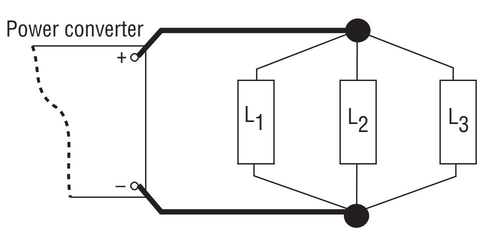

Fig 3b Alternative correct star connection of multiple loads using heavy duty wires to star connection point.

Multiple Outputs

When connecting a number of separate loads to multiple output converters it is advisable to keep each power distribution circuit completely separate.If zero volts returns are combined as shown in Fig. 4a excessive steady state voltage drops may be experienced and dynamic loads can cause crosstalk problems.

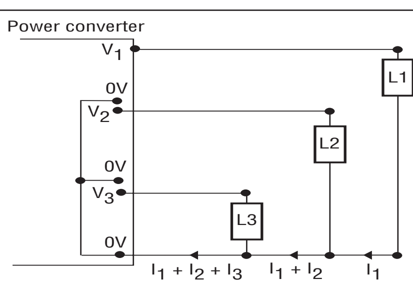

Fig 4a Incorrect (semi daisy chain) method of connecting loads to multiple output power converter

Combined zero volts returns must at all costs be avoided in systems with pulsed loads such as disk drives, printers, CRT displays and magnetic tape decks. Correct connection of such systems is shown in Fig. 4b. Although in the converter shown the zero volts lines are commoned internally, many power converters have one or more floating (galvanically isolated) outputs. This gives the designer additional flexibility in the design of the system grounding, and polarity choice. For instance it allows analogue and digital power circuits to be kept completely separate with zero volt lines individually connected to a single system earth star point.

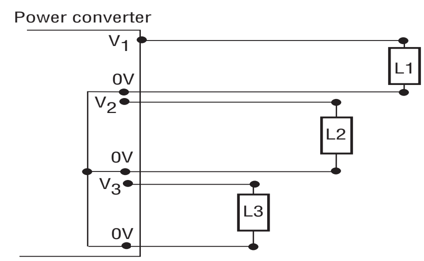

Fig 4b Correct method of connecting loads to multiple output power converters

Load Decoupling

It is impossible to wire the output of a power converter to a load circuit without adding some distributed capacitance and inductance to the output impedance of the converter. If the load demands high speed current pulses as will be the case with most logic systems, there will be resonance effects, and significant voltage spikes will be generated. To prevent false triggering it is necessary to suppress these transients by capacitive decoupling at the load. Suitable for this purpose is an electrolytic capacitor of 1μF to 10μF in parallel with a high frequency 0.1μF ceramic capacitor. It is good practice to individually decouple logic packages and it is often not sufficient to connect the capacitors across the supply lines in the general vicinity of the load. Bypass capacitors should be connected to decouple the current loop by the shortest path possible, direct connection to package pins with the shortest possible lead lengths being ideal.

Operation in Series

Most power converters can be operated in series if they have overload limitation by either constant current or constant power circuits. With some switching converters series operation is prohibited because one unit upsets the feedback regulation system of the other. With linear and switched mode units using foldback current limiting lock out at switch on can occur because of the different ramp up times of two units in series. Care must be taken not to exceed the safe working voltage at the outputs of converters in series. This may be considerably lower than the dielectric strength test voltage which is a short term test between outputs and ground. The output ripple of converters in series is additive but this of course does not change the value of ripple expressed as a percentage of total output voltage. To protect each output from the reverse voltage applied by the other unit in the event of load short circuits, reverse biased diodes are used as shown in Fig. 5. It is common practice to include these protection diodes in laboratory power supplies.

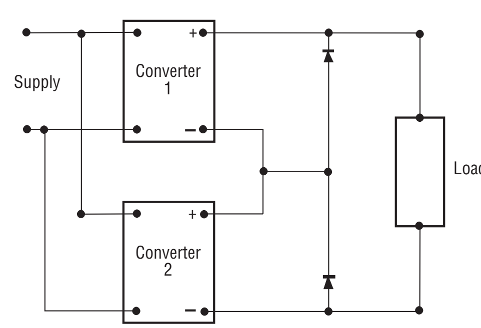

Fig 5 Outputs connected in series showing reverse voltage protection diodes

Operation in Parallel

This is only recommended with power converters specifically designed for parallel connection. A general comment is that it is much lower cost and causes far fewer problems to use a single power converter correctly rated for the application rather than two or more in parallel. However, there are power converters which feature master slave parallel operation. These units are intended for modular expansion schemes and fault tolerant parallel redundant power systems. Where power converters are overload protected by constant current limiting simple parallelling of the outputs can work to an acceptable standard. Output voltages must be set to equality as precisely as possible.

The 15 turn potentiometers on some of the DC/DC converters marketed by Powerbox are ideal for this purpose. In a two unit system the unit with the slightly higher output voltage will reach its current limit and the voltage will drop to equal that of the other unit. This converter will then supply the remaining current demanded by the load. So regulation can never be better than the difference between the output voltage settings of the two converters, and one unit will always be operating in current limit, therefore above its rating. Where current limits are adjustable to below maximum rating simple parallelling is satisfactory if the degradation of regulation can be tolerated.

To improve load current sharing precisely equal series resistors can be used as shown in Fig. 6.

For the best results the wiring resistance must also be exactly balanced. Small differences in the output voltage settings of the converter outputs still creates considerable current unbalance. In the example illustrated (Fig. 6), the load is 5V at 2A. Converter output voltage setting are 5V and if they are unequal by 0.1V, the current out of balance from the nominal 1A is ± 0.5A. This requires that each unit individually rated at 1.5A. It is clearly not a cost effective method of providing 5V 2A of stabilised power. Also note that the 100mW series resistors degrade the regulation to worse than 2%.

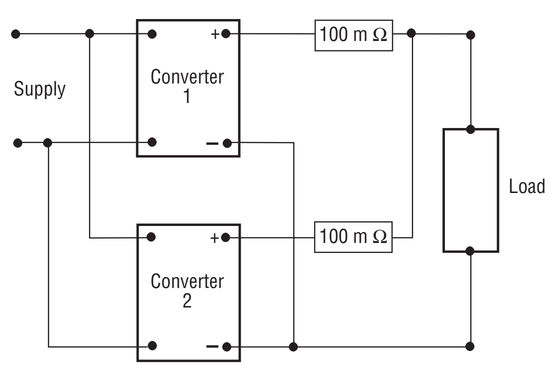

Fig 6 Current sharing resistors used to parallel two converters

Fault Tolerant Power Systems

In critical applications where continuous operation is essential, parallel redundant power systems are often specified. The system has to keep running even when a power unit fails. Current sharing is not such an important criterion since each power unit must be rated to supply the total load. But to enable both units to be continuously monitored for faults it is advisable that some measure of current sharing takes place. Both units are then always operating. Isolating series diodes which are continuously rated at the full load current allow either power converter to continue operation unaffected by a fault in the other. Matching the forward resistance of the diodes and balancing the wiring resistance helps with the current sharing. However, these series impedances degrade the regulation. Some power converters, which are specifically designed for use in fault tolerant systems allow remote sensing downstream of the parallelling diodes to maintain full regulation at the load. In the parallel redundant scheme illustrated in Fig. 7 one of the power converters could be replaced by a battery, or a battery followed by a DC/DC converter to provide a no-break power system in the event of main supply failure.

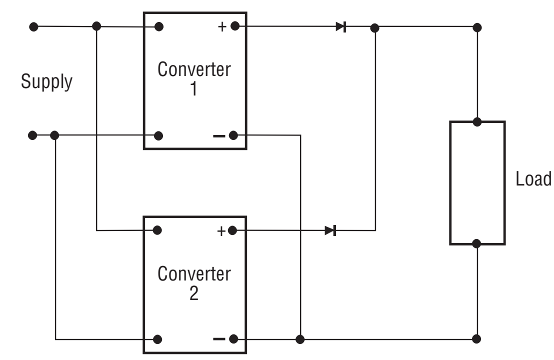

Fig 7 Isolating diodes used for parallel redundant connection of two converters

Thermal considerations

The size of power converters has been reduced quite dramatically since the first commercial switched mode converters became available about 20 years ago. At that time a typical target benchmark for power density (output power/volume) was 60 Watts per litre (1 watt per cu.in.) Today converters operating at three times that power density are relatively common, and some advanced technology DC-DC converters are designed to operate at more than ten times that early benchmark. Efficiency has improved, but has not kept pace with the reduction in volume. Whereas efficiency was typically 65% to 70% it is now 75% to 90%. A useful comparison is the heat to be dissipated per litre from a 67.5% efficient converter with 60 watts/litre output and a 72.5% efficient converter with 180 watts/litre output power. The heat to be expelled per litre goes up from 29 watts to 68 watts.

In fact to bring the internal heat losses down to 29 watts for each litre of volume, the efficiency of the 180 watts/litre (3 watts per cu.in.) converter would have to be 86%.

In the early days of switched mode converters it was thought that 60 watts/litre was about the maximum power density possible for convection cooling. Taking the same "rule of thumb" for 180 watts/litre converters, forced cooling is needed if the operating efficiency is less than 86%.

This does not apply to converters designed for military applications where complex internal structures are used to conduct heat away from all internal components, and the components are specified for higher operating temperatures. Also encapsulated converters, where the encapsulant has good thermal conductivity, and the high heat dissipating components are bonded to a high conductivity substrate do not obey the same "rule of thumb". It is usually important that such converters are adequately bonded to external cold plates or heatsinks to keep their surface temperatures within specification.

Temperature and Reliability

Operation at too high a temperature is the major cause of unreliability in power converters and it is absolutely vital that the user ensures that positive steps are taken to remove the heat lost in the converter so that the immediate environment around it does not exceed the specified maximum operating temperature.

As power converters get smaller more emphasis must be placed on cooling requirements. The heat lost in the converter will not be absorbed internally! Getting rid of 60 watts from a litre of volume needs some help! The best possible help is moving air. Where convected cooling is specified, plenty of space must be allowed for convected action to take place. If in doubt, use forced air. Even a relatively gentle breeze disperses internal hot air pockets and has a very beneficial effect on internal operating temperatures and therefore component life. Every 10°C increase in operating temperature halves expected life.

It is essential to be sure what manufacturers specifications mean when temperature operating range is specified. Is it case temperature range or ambient surrounding air? It is generally better to take the conservative view and assume that it is case temperature. If this is unsatisfactory, clarification should be sought from the manufacturer.