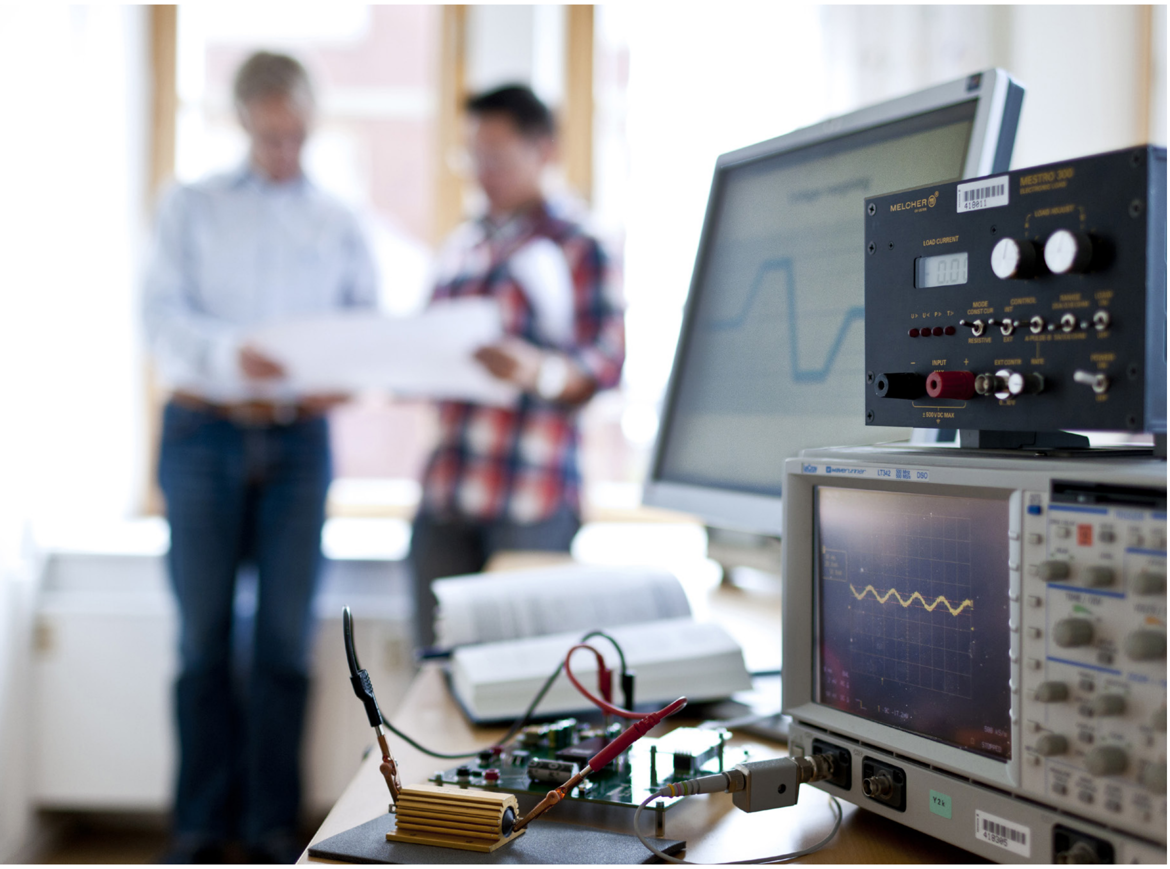
DC/DC Power Modules Basics



Design Note 024

Flex Power Modules

Abstract

This design note covers basic considerations for the use of on-board switch mode DC/DC power modules, also commonly known as BMPS, i.e. board mounted power supplies.

The design note focuses on the input and output characteristics, thermal and EMC considerations and fault monitoring provisions and is based upon the implementation and designs used in Flex DC/DC power modules which may vary from those of other suppliers. However, the content of this document should prove useful as a general guide when using BMPS products. All of the topics covered in this document are explained in more detail in other Flex publications such as design notes and application notes found on our web site: www.Flex.com/powermodules

General

Flex offers both isolated and non isolated DC/DC power modules. The naming convention used by Flex identifies these products in two categories; DC/DC converters and DC/DC regulators.

DC/DC converters:
This group contains DC/DC converters with galvanic isolation between input and output. Typical values for this isolation voltage is 1500 Vdc. Flex can provide documentation of the appropriate approvals upon request, and the insulation meets applicable safety standards (IEC/EN/UL60950).

DC/DC regulators:
This group contains non-isolated Point of Load modules. The input voltage is below 60 Vdc and is regarded as Safety Extra Low Voltage (SELV) by the applicable safety standards (IEC/EN/UL60950).

Input

DC/DC Converters

DC/DC converters have isolation between input and output and meet applicable international safety standards. Flex DC/DC converters are designed to operate efficiently and reliably over wide ranges of input voltage. Some common input voltage ranges for DC/DC converters are 9-36 Vdc, 18-36 Vdc, 18-75 Vdc and 36-75 Vdc. An example of a DC/DC converter is shown in figure 1.

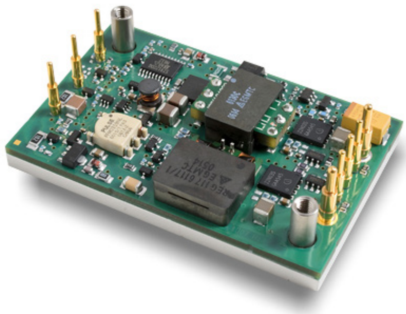


Figure 1 - Example of DC/DC converter

Input capacitance
Due to their constant output power behavior, i.e. when input voltage decreases the current increases, DC/DC converters inherently have a negative input impedance characteristic. If there is significant inductance (greater than 5 µH) in series with the DC/DC converter input, instability can occur. The instability can result in inadequate regulation or audible noise. Most users will have some sort of EMC filter in front of the DC/DC converter that contains inductance and that can create this instability.

Fortunately, the possible instability is easily avoided by using external capacitance directly at the DC/DC converter input as defined below. For most DC/DC converters with tight output regulation requirements, use an electrolytic capacitor with a value of 1 µF per watt of output power. For not regulated DC/DC converters, such as some intermediate bus converters, a value between 0.2 and 0.5 µF per watt of output power is recommended.

Remote control

DC/DC converters are available with either positive or negative remote control (RC) logic on their primary side. With positive logic, the DC/DC converter will automatically start up with application of input voltage if the RC pin is logic high. For Flex Power Modules' products this means that the RC pin should typically be left open or floating. To inhibit or turn off the DC/DC converter, the RC pin must be logic low. For Flex Power Modules' products this means that the RC pin should typically be connected to the negative input pin. With negative logic, the DC/DC converter will be inhibited and not start up if the RC pin is logic high. For Flex Power Modules' products this means that the RC pin should typically be left open or floating. To start the module, the RC pin must be logic low. For Flex Power Modules' products this means that the RC pin should typically be connected to the negative input pin. Flex DC/DC converters have an internal pull up resistor connected to the RC pin. If you measure the voltage of the open/floating RC pin you will get a reading in the range of 3-15 V. To change the status, you typically need to lower this voltage to a value of 1 V or less. The maximum RC pin sink current for any Flex product is only 1 mA, so the RC pin can easily be driven by a variety of standard analog or digital semiconductor devices as well as a physical contact closure. Design note DN021 contains additional details and recommendations on this topic.

EMC

To meet international regulations for radio frequency interference (RFI) on equipment and system level there is often a need for some sort of EMC filter on the input side of the DC/DC converters. Usually, a single filter on each circuit board will handle the EMC requirements for all of the DC/DC converters on that board. If the user is designing to EN55022 class B (corresponding to CISPR22) requirements, it is important to realize that the required filter may occupy a significant amount of circuit board real estate. Planning for this at the beginning of the design process will eliminate a layout/packaging problem that sometimes occurs with inexperienced users. Flex provides extensive support for the design of the system EMC filter.
The technical specification for each product offers design suggestions for filters that will meet class B requirements for that particular product, as well as a plot of actual measured EMC performance vs. the class B specification. Examples are shown in figures 2 and 3. Also, design note DN009 is available and offers more generalized suggestions for the design and implementation of suitable EMC filters.

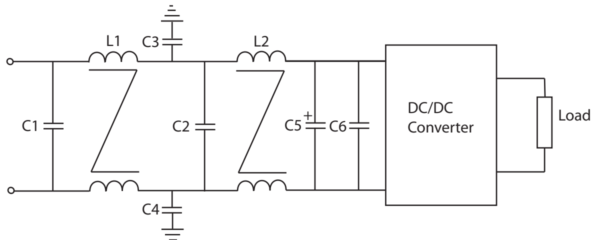


Figure 2 - Example of EMC filter design, from DC/DC converter technical specification

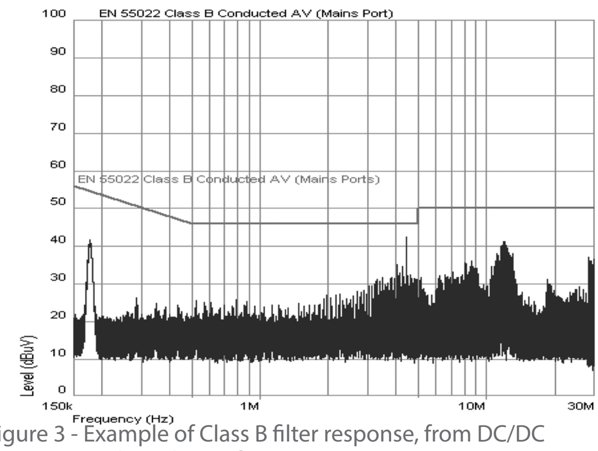


Figure 3 - Example of Class B filter response, from DC/DC converter technical specification

DC/DC Regulators

Because they are non-isolated, DC/DC regulators tend to be physically smaller than DC/DC converters. DC/DC regulators are typically distributed around the printed circuit board and located as close to their load circuits as possible, hence they are often called POL (point-of-load) regulators. Their input power is obtained from an isolated DC voltage, often 3.3 V, 5 V or 12 V. The output voltage is usually adjustable over a wide range by means of an external programming resistor, although fixed pre-set output voltages are also available. An example of a DC/DC regulator is shown in figure 4.

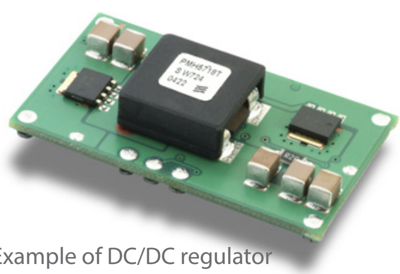


Figure 4 - Example of DC/DC regulator

Input capacitance

DC/DC regulators tend to be very easy to design into a system and are quite robust in their intended environment. The most common detail that users sometimes neglect to provide is the recommended capacitance on the input. Without external capacitance at the input, the input capacitors internal to the DC/DC regulator may be subjected to excessive stress and the DC/DC regulator reliability degraded over time. This problem can be easily eliminated by providing external capacitance at the input of the DC/DC regulator. Guidelines for the value and type of this capacitor can be found in the product technical specifications as well as in application note AN204.

Remote control
There are several options for turning DC/DC regulators on and off via the remote control (RC) pin. Some of these techniques are described in design note DN021.

Output

DC/DC Converters

Ripple and noise
Suppliers use different methodology for ripple and noise measurement. The techniques and definitions used by Flex are described in design note DN022. If there is a need for very low values of ripple and noise from a DC/DC converter, a simple LC filter is recommended and will give very good results.
Refer to design note DN011 for the details. A good starting value for the inductor is 2.2 to 3.3 µH. The inductor can be followed by low ESR ceramic capacitors at the load. Typical capacitor values are from 4.7 to 22 µF.

Max capacitive load on the output
For normal tightly regulated DC/DC converters, a maximum output capacitance of 100 µF per amp of output current is recommended. Exceeding this value or having a very low output capacitor ESR (<50 milliohms) could cause instability as well as affect the regulation bandwidth. Further information can be obtained from the technical specifications of each product.
For not regulated DC/DC converters, such as some intermediate bus converters, there is no limit on the value of output capacitance that may be used. The user should be aware, however, that large values of capacitance will affect the ramp-up time of the DC/DC converter output voltage during start-up.

Voltage adjust
Flex Power Modules' products have the output voltage adjust referenced to the output side of the DC/DC converter or regulator except for the PKF and PKR product families that have the voltage adjust on the primary side. Formulas for calculating the output voltage as a function of resistance are provided in the technical specification for each product. To minimize noise pickup, the circuit traces to the programming resistor should be as short as possible, ideally less than 5 cm.

Sense
Long sense leads may be a source of noise injection into the DC/DC converter. When used, sense leads should be as short and direct as possible. The best situation, when possible, is to not use remote sense, but instead connect the sense pin directly to the DC/DC converter output power pin. Note that the sense pin must always be connected for proper operation of the DC/DC converter.

Load Regulation
Load regulation is the output voltage dependency on load current. To maintain the output voltage within the specified limits during different load conditions the pulse width modulation (PWM) has to compensate for the voltage drops and corresponding power losses in the DC/DC conversion circuitry. The PWM is controlled by feedback of the output voltage and the reference voltage. The feedback circuitry is designed to maintain stable operation at different input and output conditions and it could also be designed to allow direct paralleling of several DC/DC converter outputs. Typically the load regulation is specified from 10% to 100% load. Some DC/DC converters with diode rectification in the output circuitry exhibit increasing output voltage at very low or zero load due to limitations in PWM control circuitry, see figure 5. In the past this was compensated for by introducing a "dummy" load across the output that discharged the output capacitor. Obviously this is devastating for the efficiency and is not used in modern designs. The output voltage at zero load is defined by the "idling voltage" specification. DC/DC converters and regulators with synchronous FET rectification does not suffer from these limitations in the PWM control circuitry due to the inherent discharge path provided by the output synchronous FET rectifier. A graph showing the load regulation curve for each product is shown in its technical specification. See example in figure 6.

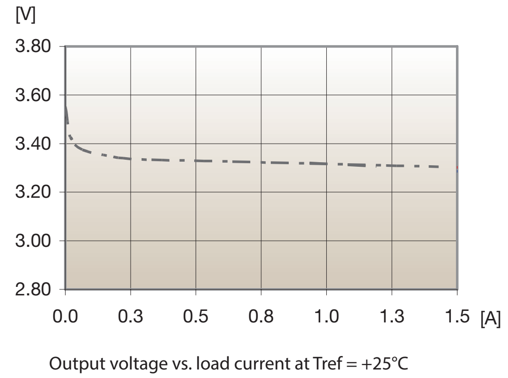


Figure 5 - Example of load regulation for DC/DC converter with diode rectification

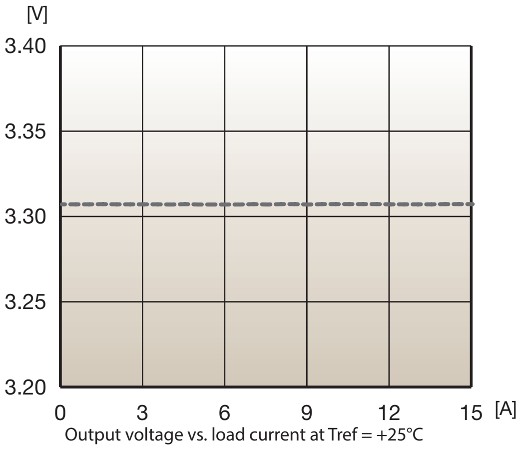


Figure 6 - Example of load regulation for DC/DC power module with synchronous rectification

DC/DC Regulators

Ripple and noise

Decoupling capacitors distributed around the load circuitry help in providing low values of high frequency noise as well as providing localized energy storage for good dynamic performance. Recommended values of capacitance for basic functionality are provided in the technical specification for each product. Most DC/DC regulators can accommodate a very wide range of output capacitance, typically up to 100 µF per amp of output current. If large values of capacitance are implemented with low ESR capacitors, it is possible to create instability due to the low total ESR value. It is recommended that the total ESR be greater than 10 milliohms. The techniques and definitions used by Flex for the measurement of output ripple and noise are described in design note DN022.

Voltage adjust

The DC/DC regulator output voltage may be adjusted by means of an external programming resistor. The user should be aware that this external resistor is actually inside the control loop of the DC/DC regulator and at a point of reasonably high impedance. As such, the user should take care to minimize the amount of external noise coupled into this path. The most effective means of accomplishing this is to use circuit traces between the external resistor and the DC/DC regulator that are as short and direct as possible.

Sense

Most DC/DC regulators provide a remote sense pin that can be used to move the voltage set point external to the DC/DC regulator and compensate for small voltage drops in the output distribution network. Because the sense line is in the regulation loop it is important to keep the traces as short as possible to minimize noise pickup. Ideally, the sense point should be within 5 cm of the DC/DC regulator. The sense pin should always be connected to get the correct output voltage and regulation characteristics from the product. In many applications, remote sensing is not required, and the sense pin can be directly connected to the DC/DC regulator output pin. This is the simplest and most effective way to avoid any concerns about using sense lines.

Load Regulation

A graph showing the load regulation curve for each product is shown in its technical specification. See example in figure 6.

Thermal design

Thermal design is extremely important for the reliability and lifetime of the system or equipment.

Low temperatures and no hot-spots are very important factors to achieve high reliability and long lifetime. Thermal design is often difficult, also for an experienced power system designer, since valid design data and guidelines are not always available. Flex has addressed this issue by publishing extensive thermal design material. Design note DN019 contains comprehensive tutorial material on thermal design and test methodologies.
The technical specification for each product contains easy to read thermal derating graphs that are based upon these methodologies. These curves will define the available DC/DC power module output current as a function of the ambient air temperature and the airflow across the product. An example of a typical thermal derating curve is shown in figure 7.

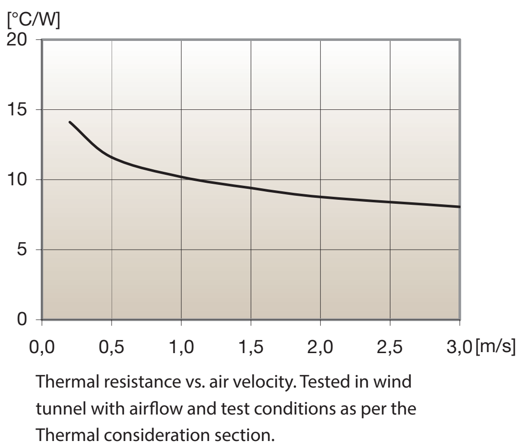


Figure 7 - Example of thermal resistance curve

Circuit Protection Features

Input side

DC/DC power modules typically contain circuitry on the input to protect against low input voltage. This is sometimes referred to as "brown out protection" or "undervoltage lockout". This is needed in switch mode power supplies to avoid excessive current thru the internal switching circuitry, since the output power is constant and the primary side currents will be inversely proportional to the input voltage. The protection circuit will inhibit operation at low values of input voltage. To achieve maximum conversion efficiency, DC/DC power modules do not provide protection against input over voltage or reversed polarity. The designer must make sure that the absolute maximum input voltage is within the product specification. To protect against propagating failures if the input of the DC/DC power module gets shorted, a fuse or fuse resistor should always be used on the primary side. The recommended device is a slow blow fuse rated at 2 to 5 times the maximum input current at the worst case load condition. This fuse protects the printed circuit board traces and avoids fire hazard.

Output side

DC/DC power modules will include circuitry to protect the load from faults on the DC/DC power module output. The level of protection is dependent upon the power level and intended application of the product. The following summary gives a generalized description of typical output protection circuits. Detailed descriptions and specifications are product family dependent and can be found in the product technical specifications.

Over-Voltage
Over voltage protection (OVP) should protect the load circuitry from over voltage conditions caused by internal malfunction of the DC/DC converter or regulator. The over voltage protection can take two forms, latching or automatic recovery. On some product families, the customer has a choice of using either implementation. With latching over voltage, the DC/DC power module shuts down upon the occurrence of an over voltage condition. To resume operation, the input voltage must be turned off and then back on again, or the remote control pin used to inhibit and then restart the DC/DC power module.
This could be done manually or with the aid of system level power management. With automatic recovery, if the overvoltage condition remedies itself the module will automatically resume normal operation without any user or system intervention. The module attempts to restart periodically, resulting in a pulsation on the output voltage as long as the fault is present. An example of output voltage waveform with automatic over voltage recovery is shown in figure 8. Although this "retry" waveform is undesirable in some applications, most customers have a preference for the automatic recovery approach. OVP is included in Flex Power Modules' products except for certain low power devices (see technical specification for detailed information).

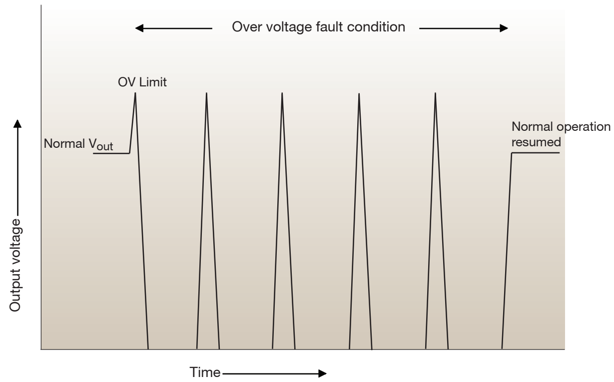


Figure 8 - Example of Over Voltage Protection with automatic recovery

Over-Current
All DC/DC power modules contain output over current protection (OCP) that prevents damage to the product in the event of an overload or a short circuit on the DC/DC power module output. Depending upon the product design, there are three different behaviors of the over current protection circuitry.

With "hiccup" over current limiting, the DC/DC power module shuts down upon an occurrence of an over current condition. After a brief time interval, it automatically tries to restart. If the restart is successful, normal operation continues. If the over current condition still exists, the DC/DC power module will again shut down. With a sustained over current condition, such as a short circuit on the output, this automatic retry behavior will result in periodic pulses of current and voltage on the output voltage bus. This rhythmic series of pulses has led to the name "hiccup". An example of a possible output current waveform with hiccup over current limiting is shown in figure 9.

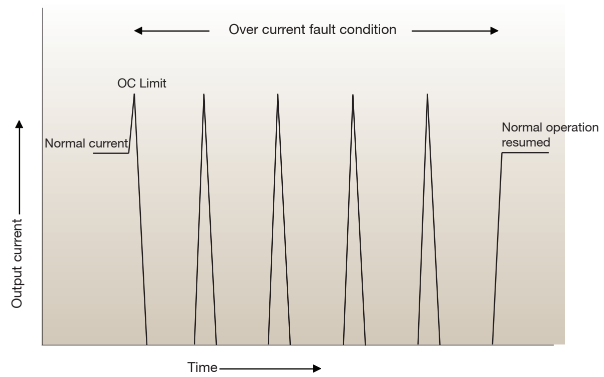


Figure 9 - Example of Over Current Protection with hiccup limiting

With “fold back” current limiting, once the over current detector trips the maximum delivered current is reduced as a function of the severity of the overload. This behavior will result in the output voltage of the DC/DC power module going to some value between zero and its normal output voltage. With more severe overloads, the output voltage may be only a few millivolts. This characteristic minimizes the stress and power dissipation on internal components during the fault condition. An example of a load line for a DC/DC converter with fold back current limiting is shown in figure 10. When the overload condition is removed, it will automatically resume normal operation without any external intervention.

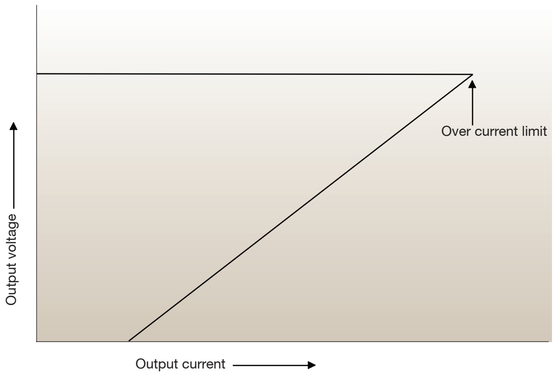


Figure 10 - Example of Over Current Protection with fold back limiting

“Constant current” over current protection is simpler than fold back because once the over current limit is reached the DC/DC power module becomes a constant current source delivering an output current at the value of the over current limit. The output voltage then becomes only a function of the resistance of the load bus and has a value between zero and the normal output voltage. In some cases, the output current may increase at very low output voltages, creating what is called a “current tail”. An example of a load line for a DC/DC converter with constant current limiting is shown in figure 11. With this type of over current protection, the system designer must design the distribution system to continuously handle the maximum value of over current. As with fold back current limiting, the DC/DC converter will automatically resume normal operation when the overload condition is removed.

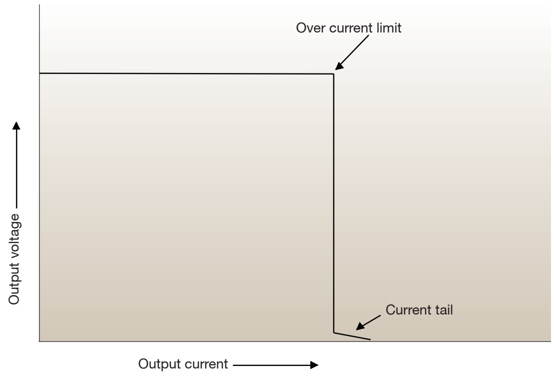


Figure 11 - Example of Over Current Protection with constant current limiting

Over-Temperature

Many DC/DC converters and regulators include over temperature protection (OTP). Critical components internal to the product are monitored, and the DC/DC power module is shut down if the temperature exceeds a value in the range of 125 to 150°C. This is done to enhance the reliability of the product and to avoid catastrophic failure. The temperature measurement is not very precise but adequate to prevent prolonged operation at high component stress levels. Low cost low current DC/DC regulators may not contain OTP. With these products, extra care should be taken when doing the thermal design.

Formed in the late seventies, Flex Power Modules is a division of Flex that primarily designs and manufactures isolated DC/DC converters and non-isolated voltage regulators such as point-of-load units ranging in output power from 1 W to 700 W. The products are aimed at (but not limited to) the new generation of ICT (information and communication technology) equipment where systems' architects are designing boards for optimized control and reduced power consumption.

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