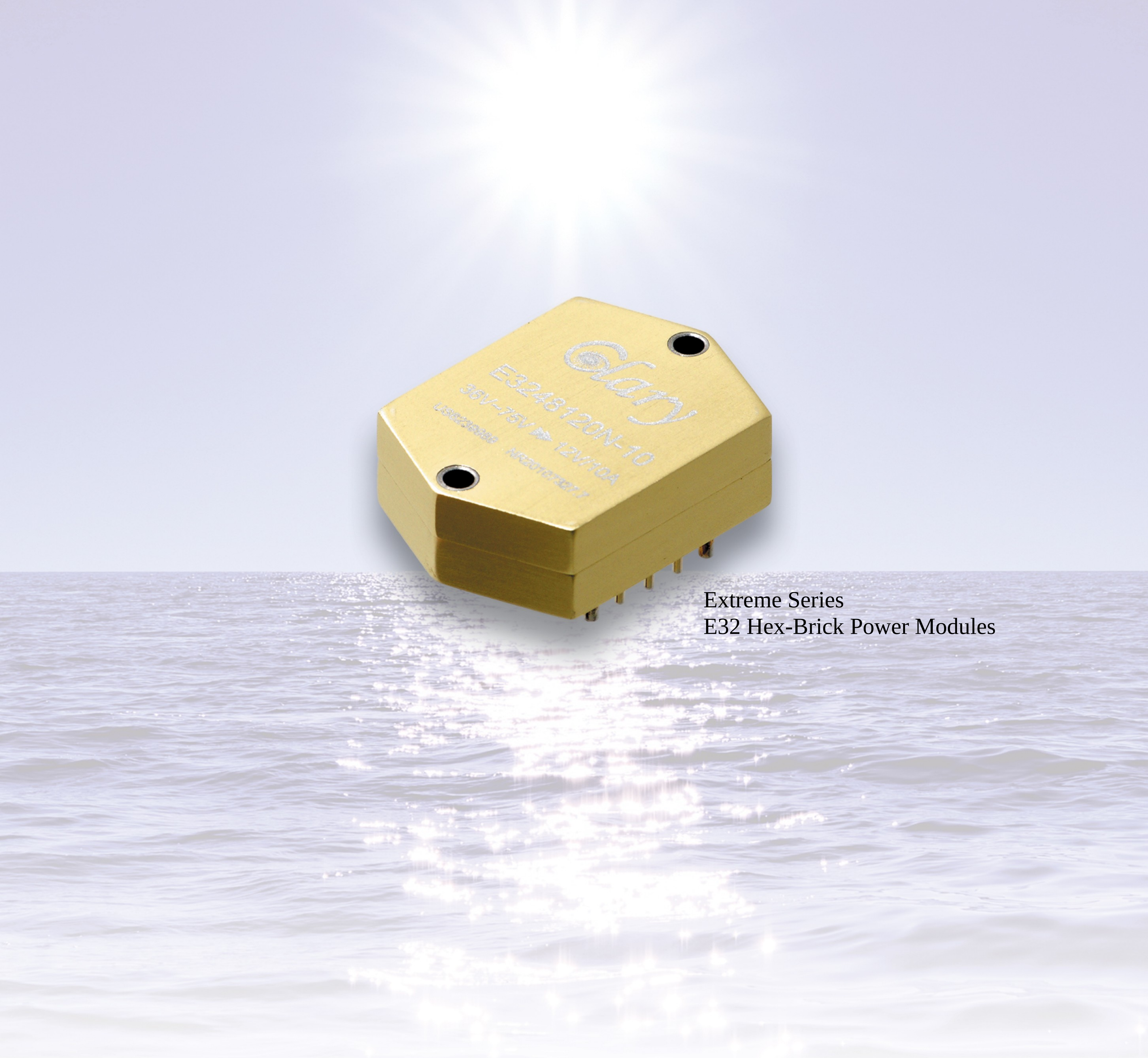
From the Sea to the Sky

Beyond the Limit & Discover the World



Extreme Series
E32 Hex-Brick Power Modules

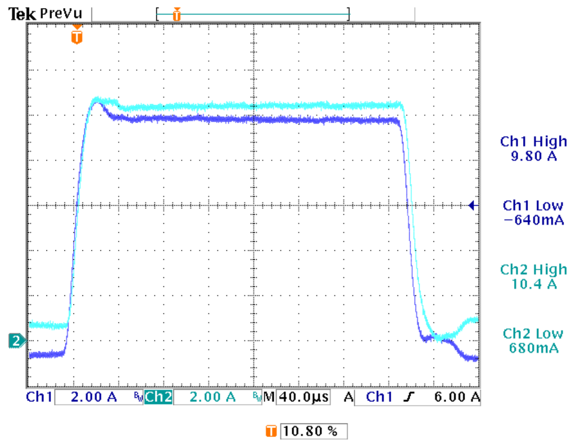
E32 series from Glary Power Technology is designed for those equipments and instruments operated under extreme conditions such as deep water, high-altitude low pressure, high-G acceleration, harsh vibration and extended temperature range from polar to boiler side. A 230W/in^3 of power density is achieved by packing a 120W converter core into the unique Hex-Brick package, which is special designed metallic case for providing better protection, effective cooling and easy installation. Beyond the limit of conventional power module, the E32 series provides superior conversion performances with enhanced environmental resistances by employing new materials and advanced circuit technologies for eliminating some long existed technical difficulties, which are mostly two important requirements of power module mutually constrained and affected by each other in a complexed relation.

• Efficiency vs Power Density

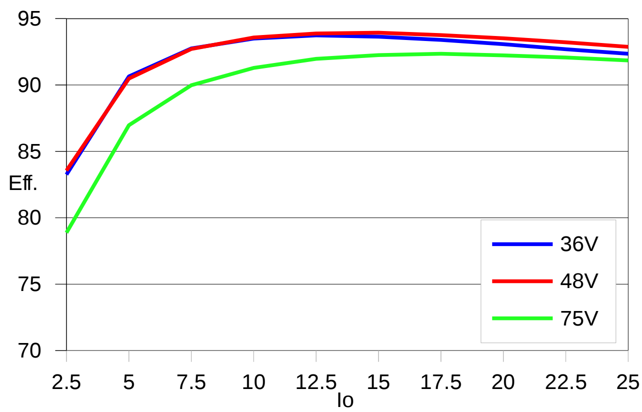
Background: Conventional isolated power module can achieve nearly 90% of efficiency for converting 36~75V input to 5V/20A output by utilizing hard-switching and SR technologies for operating at 100~250kHz frequency range. The switching loss on the used semiconductor switches is proportional to the operating frequency, which also limits the minimum sizes of the used magnetic elements and capacitors.

Difficulty: Lower switching frequency leads higher efficiency but tend to reduce power density due to the increased volume of the frequency dependent components such as inductors, transformers and capacitors and vice versa.

Solution: The E32 module achieves 230W/in^3 of power density with nearly 94% of efficiency for converting 36~75V input to 5V/20A output by utilizing proprietary Buck-Reset topology and partial-resonant SR technology, which enable the module to operate at nearly 500kHz frequency with minimized power loss to achieve high power density and high efficiency without compromise. A new ferrite material suitable for 500kHz~1Mhz operating is also selected to overcome potential high core loss at such high frequency.



Operating waveforms of Buck-Reset Topology



Conversion Efficiency of E32 module

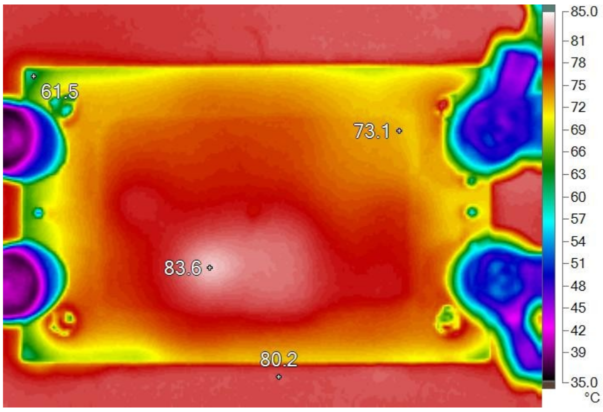
• Power Density vs Cooling

Background: Low power density power module occupies large system space, which inherently has large surface area for dissipating the heat. Since the system space or the board space of the modern electronic equipments can be limited either by the cost of the board (high layer count FR-4 or RF-PCB) or the available total space of the equipments (deep-sea probe), a high power density power module often been requested for saving the space. However! The smaller volume of the high power density power module has relatively smaller surface area limiting the heat transfer, which may lead the module operating at higher temperature with degraded reliability.

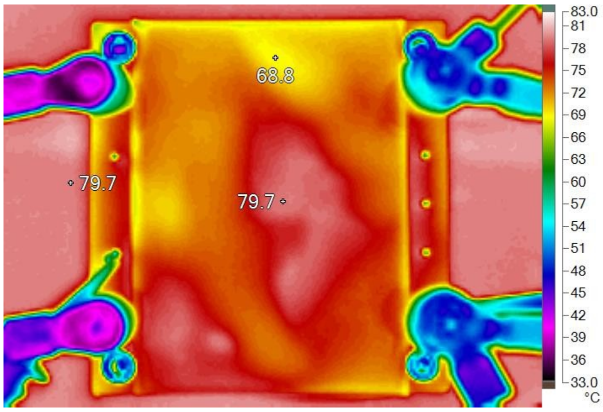
Case-A: 91% efficiency open frame 1/16 brick 100W power module (density: 213W/in^3) with 100LFM forced air cooling for full load, the dissipated power is 10W, which leads a 73ºC of temperature rise on the used semiconductor switch.

Case-B: 92% efficiency 100W open frame 1/8 brick power module (density: 130W/in^3) with 200LFM forced air cooling for delivering 5V/18.7A output, the generated heat is 8.2W, which leads a 60ºC of temperature rise on the used semiconductor switches for SR stage. An optional 0.9”×2.3” base-plate provides 13.35cm^2 of thermally high-conductivity surface area for eliminating hot spots but lower the power density to 96W/in^3.

Difficulty: Shrinking the module size or increasing the power rating tend to push the power density higher and also the transferred heat density, which result in higher averaged module temperature and also those hot spots no matter the open framed module is large or small. Additional base-plate tend to increase total volume result in lower power density.

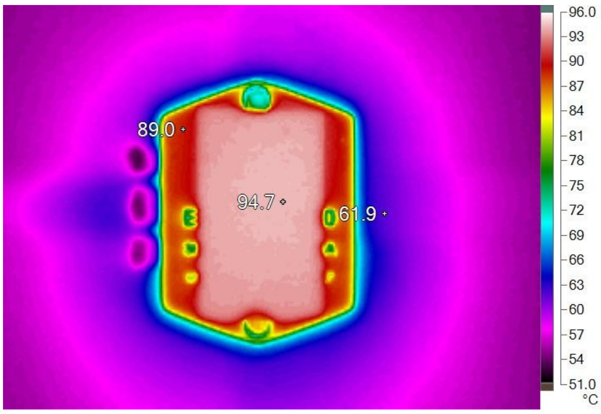


Thermal image of conventional enclosed 1/4 Brick

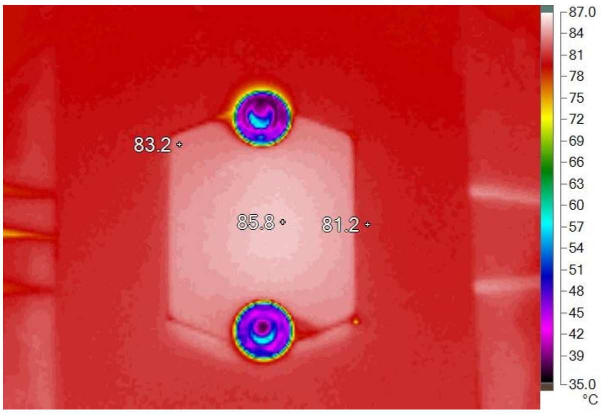


Thermal image of conventional enclosed 1/2 Brick

Solution: On E32 module, the semiconductor switches of the high efficiency converter core are attached onto the inner surface of six-sided metallic case with vacuum potted thermally conductive silicone compound, which eliminate the potential hot spots internally and providing 26.7cm^2 of thermally high-conductivity outer surface area for convection cooling. The high efficiency converter core cut 35% of the power loss, which allows the module delivering full power at 60ºC with 200LFM forced air. By simply mounting the E32 module onto external cooling plate with two screws, full power output can be obtained from -60ºC to 120ºC of case temperature, which has just 4ºC of maximum temperature deviation ensuring that the 230W/in^3 power density of E32 module can be effective for system space saving with high reliability.



E32 module with 60ºC 0.1m/s airflow



E32 module mounted with 80ºC metal-plate

- **Short Protection vs Start-up Capability**

Background: Power module normally is equipped with current limiting function for preventing it from the over heating or burning when the output is over loaded. The module resumes normal operation automatically when over load removed. Generally the current limiting function is 100% tested in production by using electrical load, which has 20mΩ of typical impedance for short-circuit testing. Considering the additional 5mΩ of impedance for connectors and wires, the total impedance can be roughly 25mΩ for limiting the output current.. With different drawbacks and advantages, several methods can be utilized for achieving the output current limiting. Here are three most implemented methods:

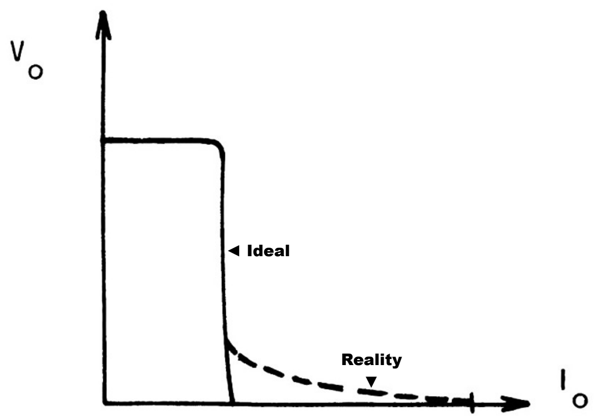
Constant Current Limiting: Power module employed constant current limiting can reduce output voltage when the output current touching the limited level. Module with constant current limiting is capable for powering non-Ohmic load such as motor, bulb and load with paralleled large capacitors. Since the propagation delay of the current control loop determines the minimum turn-ON duty generating a minimum short circuit voltage, which induces the short circuit current flowing through the impedance of the short circuit loop. High power loss comparable to full load usually unavoidable for this method.

Foldback Current Limiting: For preventing the damage from the short-circuit-current-runaway, the level of current limiting can be a ratio of the output voltage with a minimum value ranging from 50%~80% of full load, which cannot eliminate the short-circuit-current-runaway but reducing the maximum short circuit current by setting the module with lower output current level conditionally instead. The power loss of the module can be lower by implementing the foldback current limiting, which constrains the capability of powering non-Ohmic loads due to the current limiting level lower than the full load.

Hiccup Current Limiting: Based on constant current limiting, the hiccup current limiting can be realized by turning-OFF the switching device of the power module for a relatively long period after a short duration of the short circuit condition was detected. Without touching the constant current limiting level, the power module works just like that with constant current limiting. The power loss of the module with the hiccup current limiting can be much lower depending on the duty of hiccup, which also constrains the capability of powering non-Ohmic load due to the limited burst time.

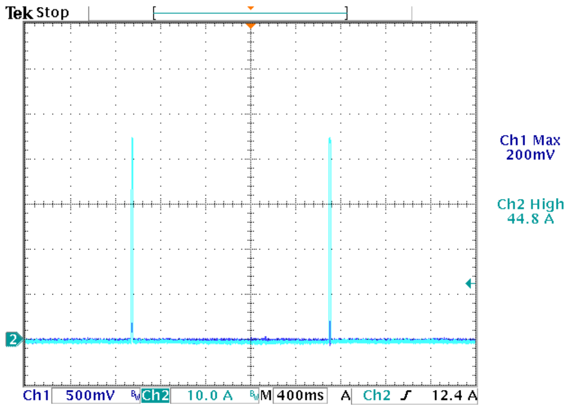
Difficulty: Considering a 250kHz 91% efficiency conventional power module delivers 5V/20A with 10W of total power loss, which come from switching loss and conduction loss equally. For simplifying the analysis, the 5W conduction loss can be assumed as the power of 20A current flowing through 12.5mΩ ESR of the power module. Since the propagation delay of the current limiting loop employed with commercial PWM controller is typically 300nS (7.5% of working duty) generating 750mV voltage internally. This voltage drops on the ESR of the power module can drive 60A of short circuit current if zero impedance short circuit load applied. Considering the 94% efficiency 500kHz high-density power module has the same ratio of conduction loss and propagation delay, the ESR of the module should be reduced to 8mΩ and the short circuit duty will be 15%, which generating 1500mV internally for driving the short circuit current to 187A, which is 3 times larger than that of conventional power module. The short circuit output current far beyond the limit often called as "short-circuit-current-runaway" exceeding the rated current of the used power components. Without properly solving the over current stress on those components, no matter if the power module utilizes any kind of current limiting or not, failure can be expected soon or later.

Switching waveforms with short circuit

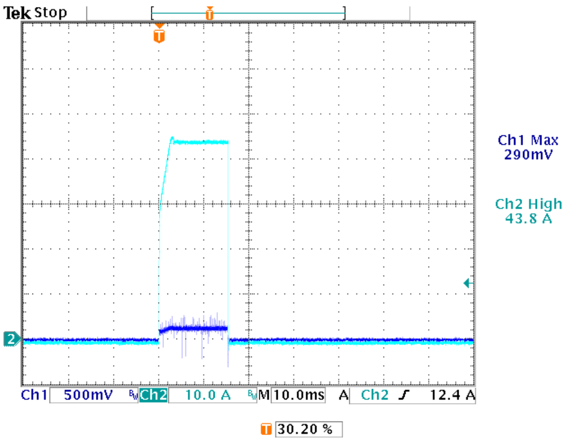


Short circuit current runaway

Solution: The 5V/25A E32 module utilizes proprietary ultra-fast current limiting technology, which can turn the switching device OFF within 80nS or even faster if the current signal exceeding the limited level. The short circuit working duty is 4%, which produces just 400mV of the minimum short circuit voltage limiting the zero impedance short circuit current not more than 50A theoretically. The ultra-fast current limiting technology extends the operating frequency range of power module to nearly 1Mhz with capability of protecting the module from the continuously output short at 100℃ of case temperature and powering different kind of loads including non-Ohmic load, which ensures the high power density feature of E32 module is a real benefit to the system designers.



Short circuit current of E32 5V/25A module



Short circuit current of E32 5V/25A module

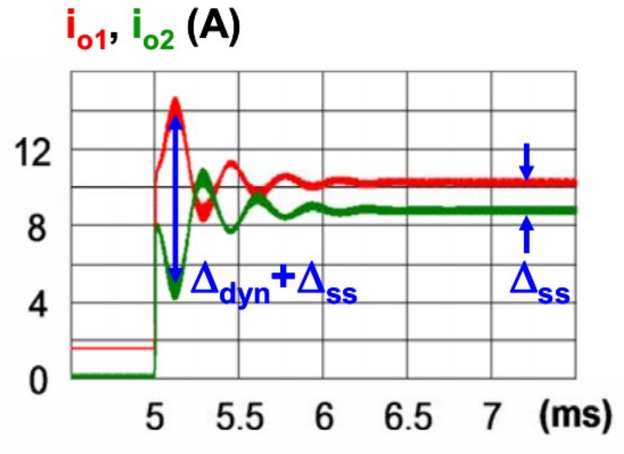
- ## Scalability vs Reliability

Background: A load sinks current exceeding the capability of a single module should be powered by higher rated power module, which normally very expensive with poor availability. Multiple modules can be paralleled for supplying high load current by using external current sharing scheme, which can be network of resistors in series with output of modules or active external current share circuit with commercial controller like the LM5080 or UCC39002. Fewer standard power modules provide internal current share function, which allows modules in parallel without external controller. For enhancing the reliability of the multiple modules system and preventing possible failure from single short circuit fault, ORing connecting each module output by using diode or MOSFET is necessary.

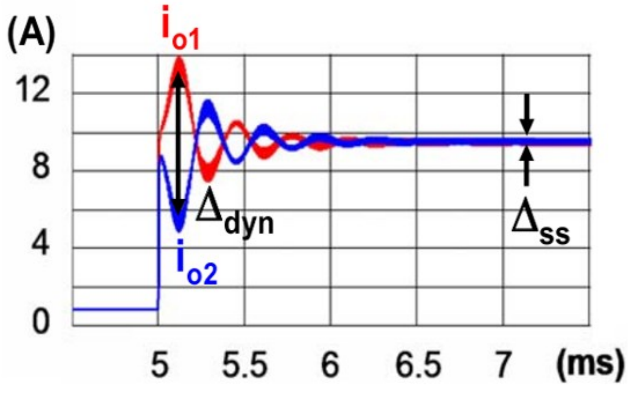
Difficulty: Since most power modules are designed as voltage source not current source, paralleling multiple power modules for higher output current is always difficult and different methods have different pros and cons. There two most implemented current sharing methods can be used for mitigating the output impedance error between modules but only at low frequency band:

Droop Current Sharing: The resistive droop method requests precisely adjusted output voltages for reliable current sharing, and uses low cost power resistors for connecting module outputs together dissipating additional power loss for current sharing. The droop current sharing also can be implemented by actively reducing the DC gain of voltage compensator in current-mode controlled power module or detecting the input or output current for inversely adjusting the output voltage. Both method can eliminate the power loss on resistors and have similar performance as resistive droop current sharing. Due to voltage droop affects the output load regulation, the equivalent resistance of the droop current sharing cannot be increased without limit. If the output voltage accuracy of the paralleled modules are reasonable loose for low cost, the sharing error can be relatively large, which effects only the frequency range that the output impedance of the modules are dominated by the effective resistance of the droop current sharing.

Active Droop Current Sharing: Most active current sharing methods shares the output current information of all involved modules together through a current share bus for actively balancing the output current of modules without big resistors. The bandwidth of the active current sharing loop is intentionally limited to just few kHz due to the noise sensitive current sharing bus can induce instability. For powering high slew rate pulsed load, the limited bandwidth of the active current sharing cannot effectively eliminate the high frequency harmonic, which can induce a high current peak deviation exceeding the over current protection level to cause system failure. Because the additional current sharing bus is must for system operation, the active current sharing scheme is not as reliable and robust as resistively drop method dose but the effective bandwidth is higher normally.

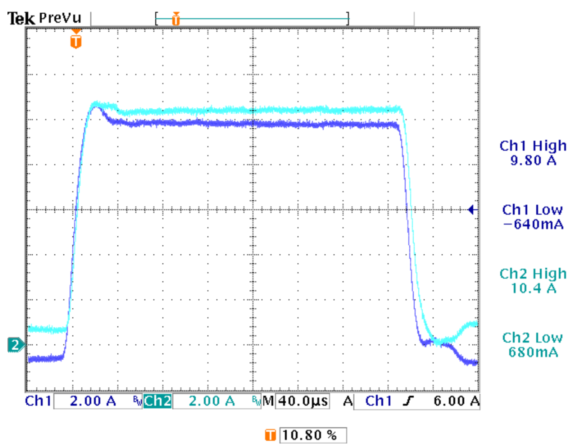


Step-load waveforms of droop current sharing



Step-load waveforms of active current sharing

Solution: The E32 module is equipped with proprietary drop method current sharing scheme and high output voltage accuracy to ensure the reliable current sharing can be achieved without unwanted power loss. No external components or current sharing bus, by directly connecting the output of multiple E32 modules together can easily scale up the total output current. The bandwidth of the current sharing loop is comparable to that of voltage loop, which can response to high current slew rate load transient without high current peak deviation. By properly configuring the remote sensing terminals of E32 module with a suitable resistor, the voltage drop of the power bus can be compensated and the load regulation caused by the droop method current sharing also can be adjusted for meeting special system requirements.



0%~100% Step-load waveforms of current shared E32 modules

• Temperature Range vs Pressure Range

Background: Environmental stresses influence conversion performances of power module greatly as temperature higher leading the conductivity of the conductor lower, which causes efficiency drop significantly at high temperature. The other example is the non-solid type electrolyte of electrolytic capacitor can loss its capacitance due to frozen at low temperature or dried-out at high temperature. Combined environmental stresses can be even more harmful as the life of the electrolytic capacitor can be shorten or even exploded by applying high temperature with low pressure near vacuum. High power density module is even more difficult to deal with those factors especially for fulfilling the requirements of the wide temperature and pressure ranges at once.

Difficulty: Power module can be operated at even more critical environment, where the temperature and pressure factors are changing quickly such as the equipments on aircraft or the scientific instruments aboard sounding rocket. As materials tend to change their volume positively correlated with temperature but negatively with the pressure, the approaches for dealing with those factors are conflict in most case. The real difficulty for adapting high pressure is that the internal pressure of the power module should be hydrostatically balanced by filling the internal voids of the power module with potting compound without bobbles, which can cause thermomechanical stress due to the different thermal expansion coefficient of the used components and the potting compound under different temperatures. The power module for better environmental resistance such as preventing the oil and dust pollutions or mechanical impact from outside typically equipped with a large and rigid metallic case, which helps the module to withstand the pressure but worsen the thermomechanical stress due to the even lower thermal expansion coefficient of metals.

Solution: The high density E32 module is enclosed by using a high strength metallic case, which resists the unfriendly environmental conditions for protecting the converter core. Since the power density of the converter core is high, the size of the metallic case can be small, which also ensures the high power density of E32 module. Actually the metallic case is intentionally designed to be as small as possible for reducing the potential mechanical stresses and can be deformed elastically with high thermomechanical stress. The potting compound is selected with high thermal conductivity and low thermal expansion coefficient for conducting the heat to outer surface effectively and minimizing the thermomechanical stress. The converter core is surrounded by laminated potting compounds for reducing the stress on the components and creating a prefect hydrostatic balancing internally for withstanding high pressure. The metallic case is riveted by using high strength stainless steel poles during potting process with per-stressed assembly process for preventing the module from fatigue failure caused by the temperature and pressure cycles.

Actual size of E32 module