SynQor®

MCOTS-C-28-9R6-HZ
Single Output
Half-brick

MILITARY COTS DC-DC CONVERTER

16-40 V Continuous Input	16-55 V Transient Input	9.6 V Output	52 A Output	95% @ 26 A / 94% @ 52 A Efficiency

Operation: -55°C to +100°C

The MilQor® series of Mil-COTS DC-DC converters brings SynQor's field proven high-efficiency synchronous rectification technology to the Military/Aerospace industry. SynQor's ruggedized encased packaging approach ensures survivability in demanding environments. Compatible with the industry standard format, these converters operate at a fixed frequency, and follow conservative component derating guidelines. They are designed and manufactured to comply with a wide range of military standards.

MilCOTS™

Designed and Manufactured in the USA

Safety Features

- 2250 V, 30 MΩ input-to-output isolation
- Certified 62368-1 requirement for basic insulation (see Standards and Qualifications page)

Mechanical Features

- Industry standard half-brick pin-out
- Size: 2.49" x 2.39" x 0.51" (63.1 x 60.6 x 13.0 mm)
- Total weight: 5.2 oz. (146 g)
- Flanged baseplate version available

Operational Features

- High efficiency, 94% at full rated load current
- Operating input voltage range: 16-40 V
- Fixed frequency switching provides predictable EMI
- No minimum load requirement
- Available: High-Capacitance option for very large output capacitances and extreme transient applications

Specification Compliance

MCOTS series converters (with an MCOTS filter) are designed to meet:

- MIL-HDBK-704 (A-F)
- RTCA/DO-160E Section 16
- MIL-STD-1275 (B,D)
- DEF-STAN 61-5 (Part 6)/(5 or 6)
- MIL-STD-461 (C, D, E, F)

Control Features

- On/Off control referenced to input return
- Remote sense for the output voltage
- Wide output voltage trim range of +10%, -50%
- Optional: Active current share for parallel applications

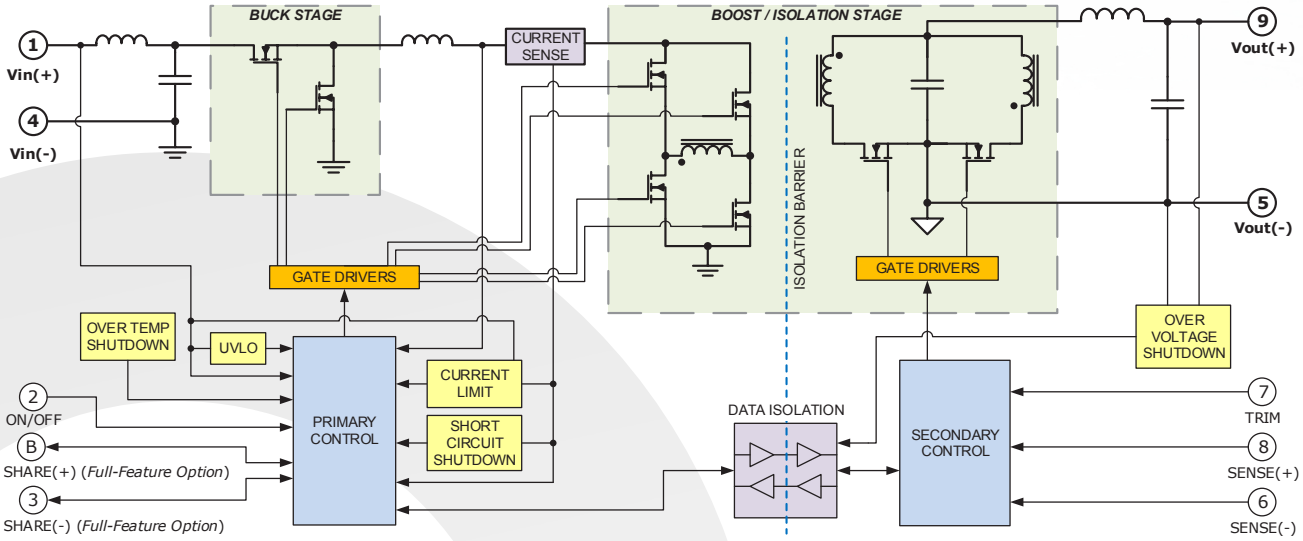
Protection Features

- Input under-voltage lockout
- Output current limit and short circuit protection
- Active back bias limit
- Auto-recovery output over-voltage protection
- Thermal shutdown

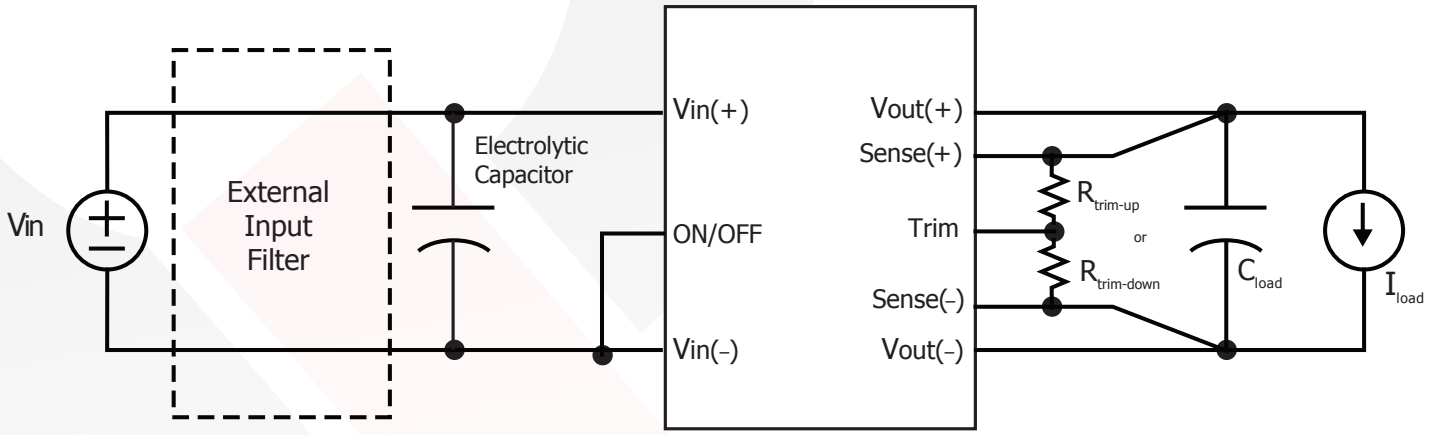
Screening/Qualification

- AS9100 and ISO 9001 certified facility
- Qualified to MIL-STD-810
- Available with S-Grade or M-Grade screening
- Pre-cap inspection per IPC-A-610, Class III
- Temperature cycling per MIL-STD-883, Method 1010, Condition B, 10 cycles
- Burn-In at 100 °C baseplate temperature
- Final visual inspection per MIL-STD-883, Method 2009
- Full component traceability

BLOCK DIAGRAM



TYPICAL CONNECTION DIAGRAM



MCOTS-C-28-9R6-HZ ELECTRICAL CHARACTERISTICS

Ta = 25 °C, Vin = 28 Vdc unless otherwise noted; full operating temperature range is -55 °C to +100 °C baseplate temperature with appropriate power derating. Specifications subject to change without notice.

Parameter	Min.	Typ.	Max.	Units	Notes & Conditions
ABSOLUTE MAXIMUM RATINGS					
Input Voltage					
Non-Operating	-1		60	V	Continuous
Operating			40	V	Continuous
Operating Transient Protection			55	V	100 ms transient, square wave
Isolation Voltage					
Input to Output			2250	Vdc	Basic Insulation, Pollution Degree 2
Input to Baseplate			2250	Vdc	
Output to Baseplate			2250	Vdc	
Operating Temperature	-55		100	°C	Baseplate temperature
Storage Temperature	-65		135	°C	
Voltage at ON/OFF input pin	-2		18	V	
INPUT CHARACTERISTICS					
Operating Input Voltage Range	16	28	40	V	55 V transient for 100 ms
Input Under-Voltage Lockout					
Turn-On Voltage Threshold	15.1	15.4	15.7	V	
Turn-Off Voltage Threshold	14.2	14.5	14.8	V	
Lockout Voltage Hysteresis	0.5	0.9	1.5	V	
Recommended External Input Capacitance		470		µF	Typical ESR 0.1-0.2 Ω
Recommended Input Cap (Hi-Cap Option)		Varies			See Figure 15
Input Filter Component Values (C_1\L\C_2)		47\0.34\23		nF\µH\µF	Internal values; see Figure E
Maximum Input Current			38	A	At low line, Full load and 10% trim up
No-Load Input Current		300	380	mA	
Disabled Input Current		3	8	mA	
Response to Input Transient		0	25	mV	100 µF load cap; 0.25 V/µs transient; See Figure 12
Input Terminal Ripple Current		480		mA	RMS
Recommended Input Fuse			50	A	Fast acting external fuse recommended
OUTPUT CHARACTERISTICS					
Output Voltage Set Point	9.52	9.60	9.68	V	
Output Voltage Regulation					See Note 1
Over Line		±0.25\24	±0.35\34	%\mV	
Over Load		±0.25\24	±0.35\34	%\mV	
Over Temperature		0	±0.13	V	
Total Output Voltage Range	9.36		9.84	V	Over sample, line, load, temperature & life
Output Voltage Ripple and Noise					20 MHz bandwidth; See Note 2
Peak-to-Peak		200	400	mV	Full Load
RMS		50	100	mV	Full Load
Operating Output Current Range	0		52	A	Subject to thermal derating
Output DC Current-Limit Inception	57	62.4	68	A	Output Voltage 10% Low
Output DC Current-Limit Shutdown Voltage		4		V	See Note 3
Back-Drive Current Limit while Enabled	4	5.5	7	A	Negative current drawn from output
Back-Drive Current Limit while Disabled	0	3	6	mA	Negative current drawn from output
Maximum Output Capacitance			18	mF	52 A Resistive Load; limited by stability
Maximum Output Capacitance (Hi-Cap Option)			3000	mF	No load during startup
Output Voltage During Load Current Transient					
Step Change in Output Current (0.1 - 5 A/µs)		250		mV	50% to 75% to 50% Iout max, 470 µF load cap
Settling Time		1		ms	To within 1% Vout nom
Step Change in Output Current (Hi-Cap Option)		600		mV	0% to 100% to 0% Iout max, 25 mF load cap
Settling Time (Hi-Cap Option)		3		ms	To within 1% Vout nom
Output Voltage Trim Range	-50		10	%	Across Pins 8 & 6; Figure C
Output Over-Voltage Protection	12.0	12.5	13	V	Over full temp range
EFFICIENCY					
100% Load		94		%	See Figure 1 for efficiency curve
50% Load		95		%	See Figure 1 for efficiency curve

MCOTS-C-28-9R6-HZ ELECTRICAL CHARACTERISTICS

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Parameter	Min.	Typ.	Max.	Units	Notes & Conditions
DYNAMIC CHARACTERISTICS					
Turn-On Transient					
Turn-On Time	24	35	40	ms	Full load, Vout = 90% nom.
Turn-On Time (Hi-Cap Option, No Load)		400		ms	470 uF load cap, Vout = 90% nom.; See Note 5
Turn-On Time (Hi-Cap Option, Full Load)		3000		ms	2000 uF load cap, Vout = 90% nom.; See Note 5
Output Voltage Overshoot			2	%	No Load, 5 mF load cap
Output Voltage Overshoot (Hi-Cap Option)			0	%	No Load, 1000 mF load cap
ISOLATION CHARACTERISTICS					
Isolation Voltage (Dielectric Strength)		2250		V	
Isolation Resistance		30		MΩ	
Isolation Capacitance (Input to Output)		1000		pF	See Note 4
TEMPERATURE LIMITS FOR POWER DERATING CURVES					
Semiconductor Junction Temperature			125	°C	Package rated to 150 °C
Board Temperature			125	°C	UL rated max operating temp 130 °C
Transformer Temperature			125	°C	
Maximum Baseplate Temperature, Tb			100	°C	
FEATURE CHARACTERISTICS					
Switching Frequency	230	240	250	kHz	Isolation stage switching freq. is half this
ON/OFF Control					
Off-State Voltage	2.4		18.0	V	
On-State Voltage	-2.0		0.8	V	
ON/OFF Control					
Pull-Up Voltage		15	18	V	
Pull-Up Resistance		50		kΩ	
Over-Temperature Shutdown OTP Trip Point		135		°C	Average PCB Temperature
Over-Temperature Shutdown Restart Hysteresis		10		°C	
RELIABILITY CHARACTERISTICS					
Calculated MTBF per MIL-HDBK-217F (GB)		4.1		10^6 Hrs.	Tb = 70 °C
Calculated MTBF per MIL-HDBK-217F (GM)		0.92		10^6 Hrs.	Tb = 70 °C
Field Demonstrated MTBF				10^6 Hrs.	See our website for details

Note 1: Line and load regulation is limited by duty cycle quantization and does not indicate a shift in the internal voltage reference.
Note 2: For applications requiring reduced output voltage ripple and noise, consult SynQor applications support (e-mail: support@synqor.com).
Note 3: If the output voltage falls below the Output DC Current Limit Shutdown Voltage for more than 50 ms, then the unit will enter into hiccup mode, with a 500 ms off-time.
Note 4: Higher values of isolation capacitance can be added external to the module.
Note 5: Add 25 ms to Full-Feature Turn-On Time to allow for synchronization.

STANDARDS COMPLIANCE

Parameter	Notes & Conditions
STANDARDS COMPLIANCE	**Pending**
UL 62368-1	Basic Insulation
CAN/CSA C22.2 No.62368-1	
EN 62368	

Note: An external input fuse must always be used to meet these safety requirements. Contact SynQor for official safety certificates on new releases or

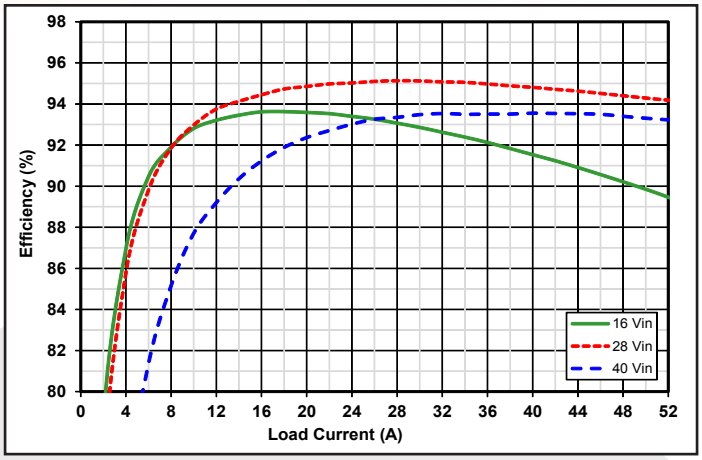


Figure 1: Efficiency, *at nominal output voltage vs. load current for minimum, nominal, and maximum input voltages at 25 °C.*

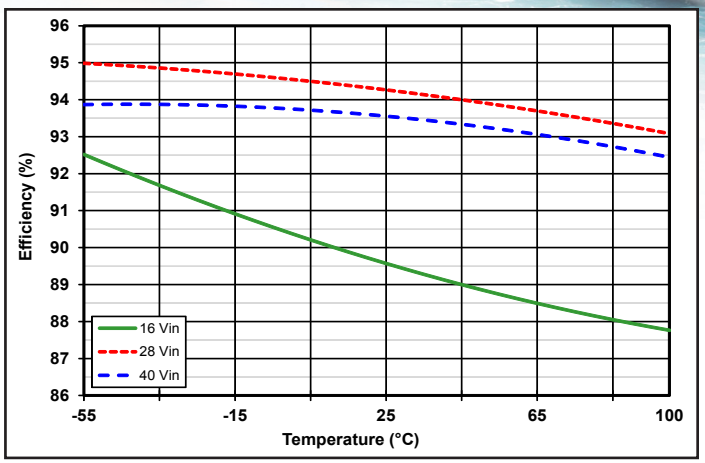


Figure 2: Efficiency, *at nominal output voltage and 60% rated power vs. case temperature for minimum, nominal, and maximum input voltages.*

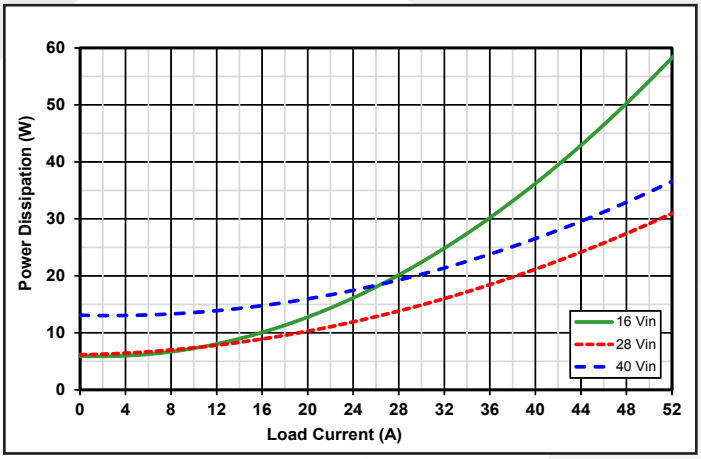


Figure 3: Power Dissipation, *at nominal output voltage vs. load current for minimum, nominal, and maximum input voltages at 25 °C.*

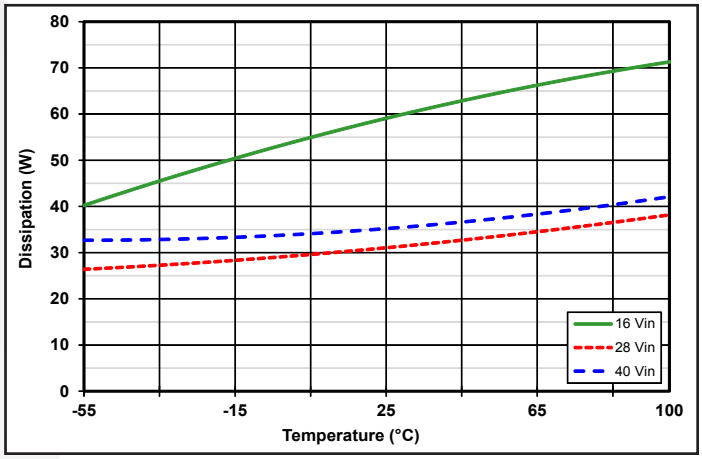


Figure 4: Power Dissipation, *at nominal output voltage and 60% rated power vs. case temperature for minimum, nominal, and maximum input voltages.*

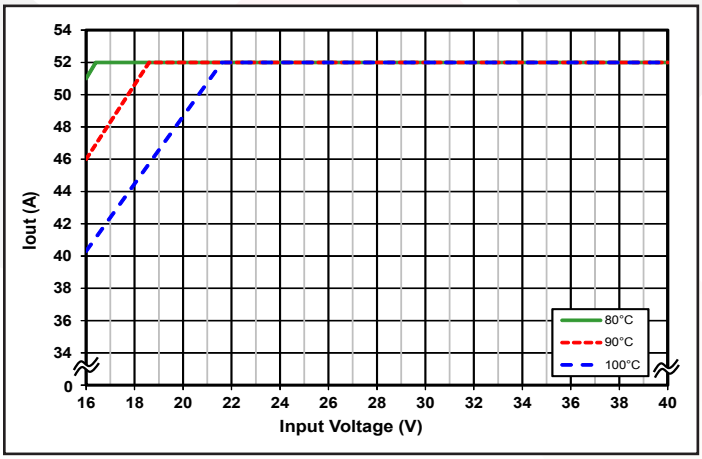


Figure 5: Thermal Derating, *(maximum output current vs. continuous input voltage) at selected baseplate temperatures.*
Note: Transients lasting ≤100 ms need no further derating.

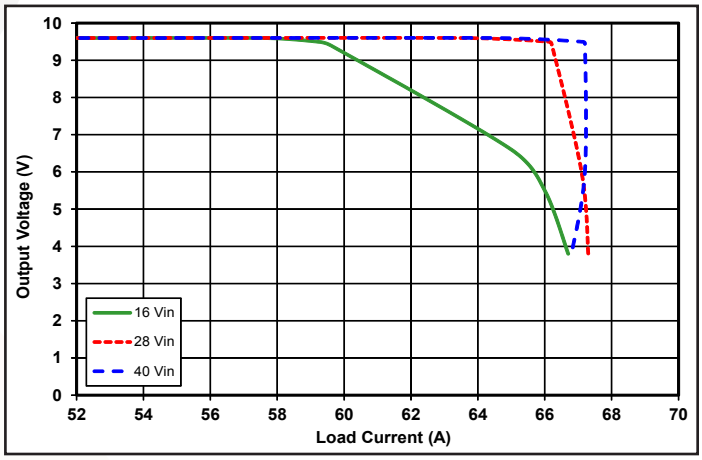


Figure 6: Output I-V Characteristics, *(output voltage vs. load current) showing typical current limit curves. See Current Limit section in the Application Notes.*

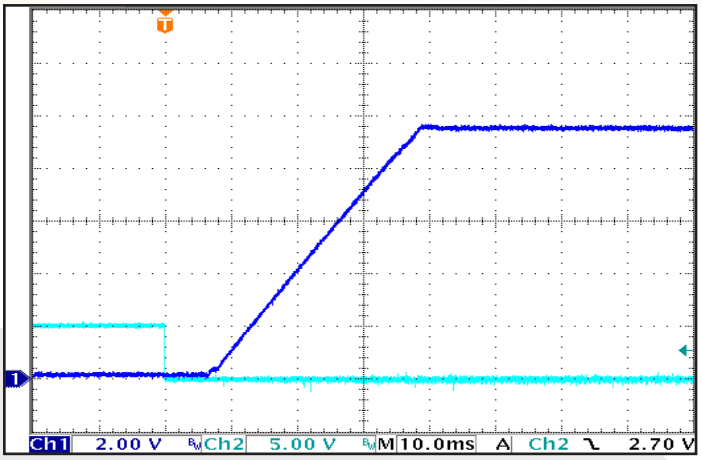


Figure 7: Typical Startup Waveform, *input voltage pre-applied. Ch 1: Vout (2 V/div); Ch 2: ON/OFF Pin (5 V/div). Timescale: 10.0ms/div.*

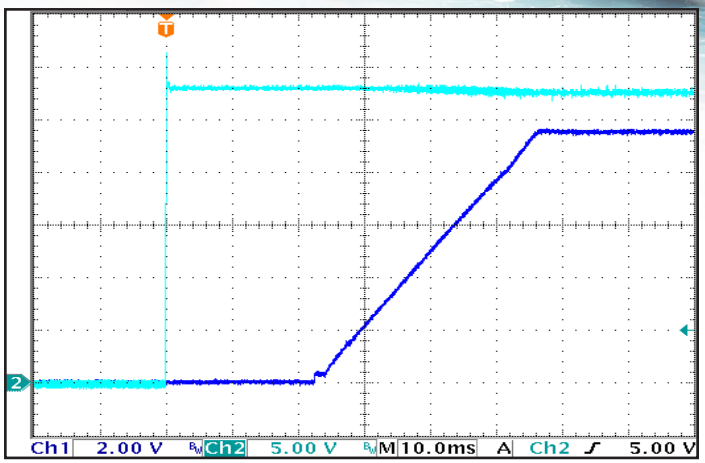


Figure 8: Turn-On Transient, *at full resistive load and zero output capacitance, initiated by Vin. Ch 1: Vout (2 V/div); Ch 2: Vin (5 V/div). Timescale: 10.0ms/div.*

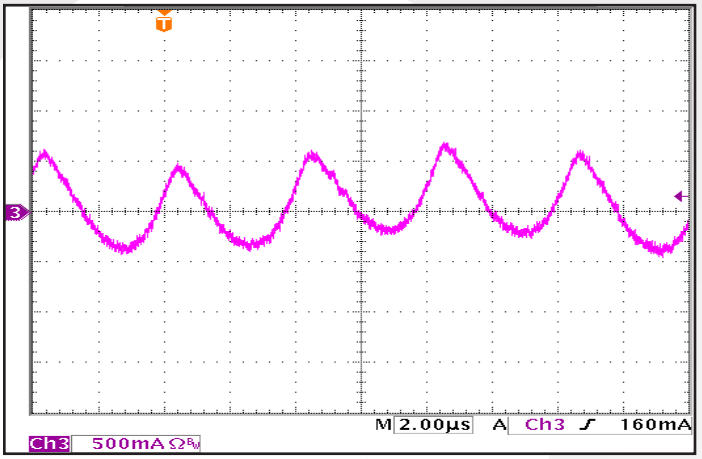


Figure 9: Input Terminal Current Ripple, i_c, *at full rated output current and nominal input voltage with a 470 µF electrolytic capacitor (500 mA/div). Bandwidth: 20 MHz. Timescale: 2.00µs/div. See Figure 13.*

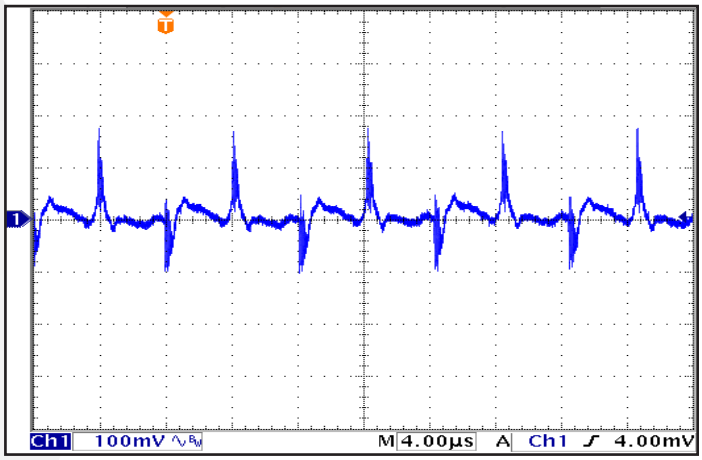


Figure 10: Output Voltage Ripple, *Vout, at nominal input voltage and rated load current (100 mV/div). Load capacitance: 1 µF ceramic and 470 µF electrolytic capacitors. Bandwidth: 20 MHz. Timescale: 4.00µs/div. See Figure 13.*

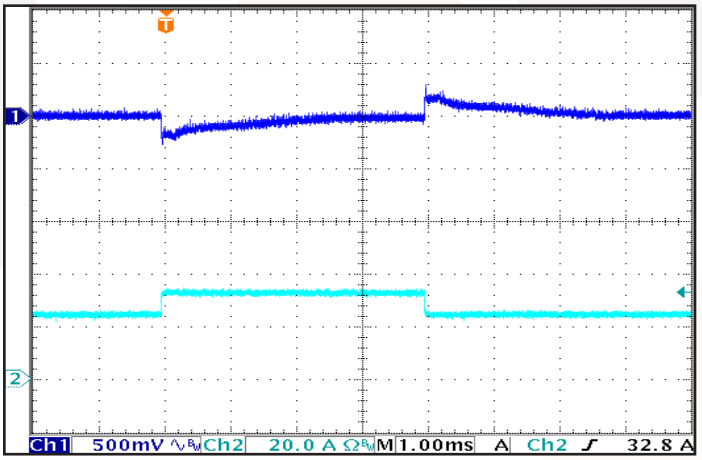


Figure 11: Output Voltage Response to Step-Change in Load Current, *(50%-75%-50% of Iout(max); di/dt = 5 A/µs). Load capacitance: 1 µF ceramic and 470 µF electrolytic capacitors. Ch 1: ΔVout (0.5 V/div); Ch 2: Iout (20 A/div). Timescale: 1.00ms/div.*

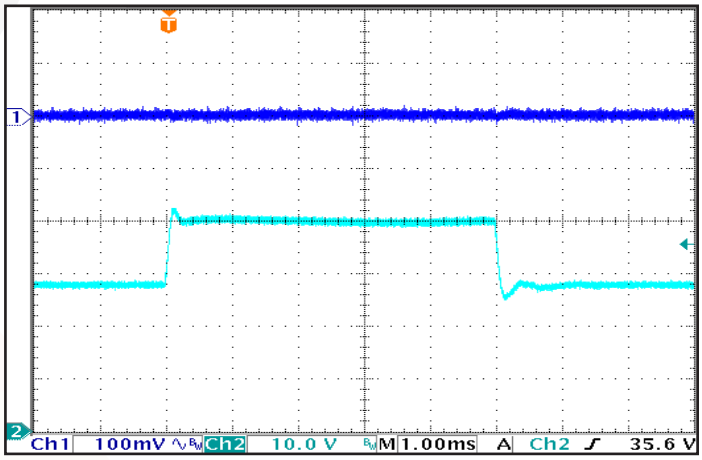


Figure 12: Output Voltage Response to Step-Change in Input Voltage, *(dV/dt = 250 V/ms). Load capacitance: 1 µF ceramic and 470 µF electrolytic capacitors. Ch 1: ΔVout (0.1 V/div); Ch 2: Vin (10 V/div). Timescale: 1.00ms/div.*

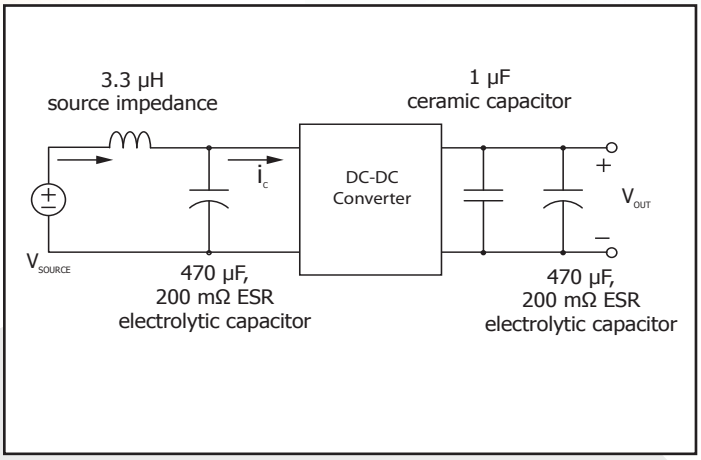


Figure 13: Test Set-Up Diagram, *showing measurement points for Input Terminal Current Ripple (Figure 9) and Output Voltage Ripple (Figure 10).*

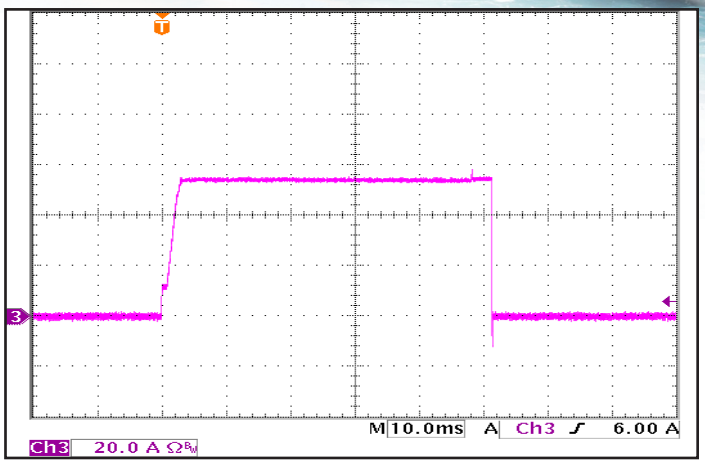


Figure 14: Output Short Load Current, *(20 A/div) as a function of time (10ms/div) when the converter attempts to turn on into a 1 mΩ short circuit.*

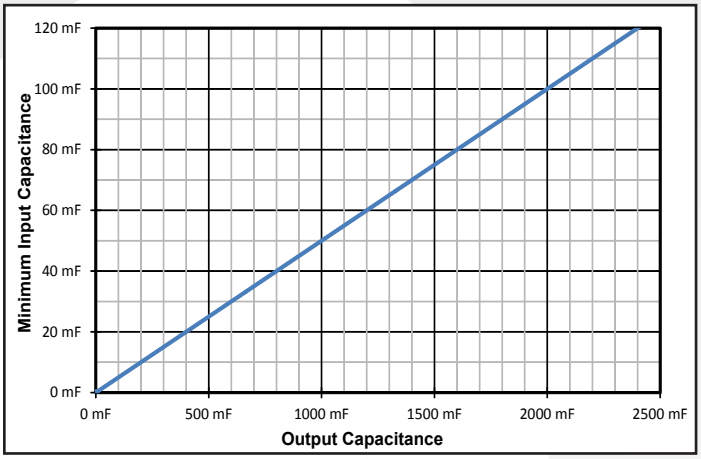


Figure 15: Minimum Recommended Input Capacitance, *low-ESR capacitors preferred.*

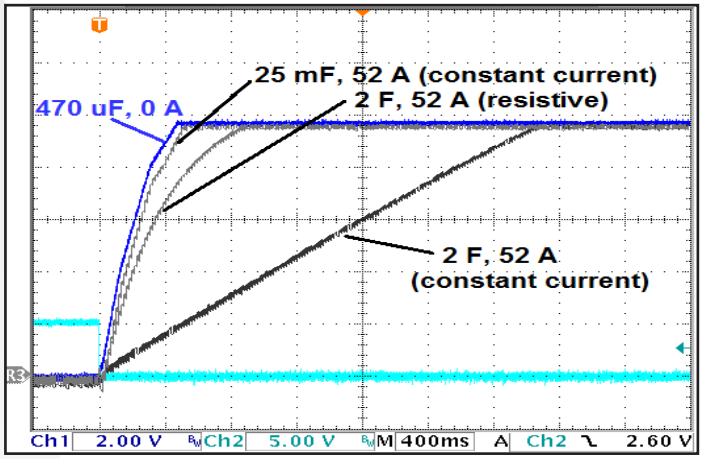


Figure 16: Hi-Cap Option Startup Waveform, *input voltage pre-applied. Ch1: Vout, 470µF, no load (2V/div); Ref1: 25mF, 52A CC load; Ref2: 2F, 52A CR load; Ref3: 2F, 52A CC load; Ch2: ON/OFF Pin (5V/div). Constant-current loads and large capacitances may slow the startup ramp. Timescale: 400ms/div.*

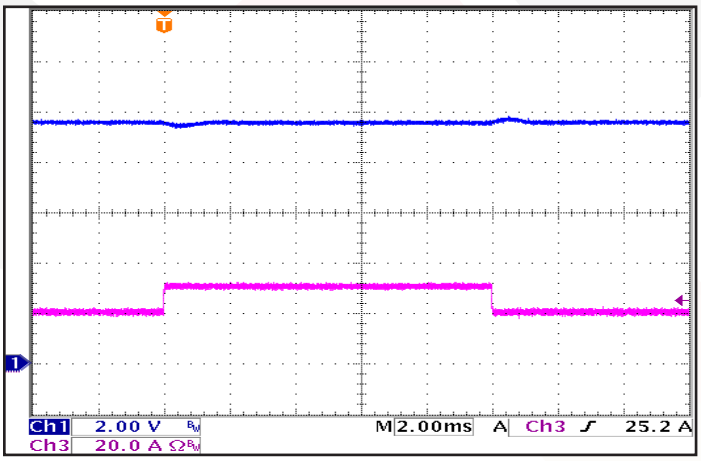


Figure 17: Hi-Cap Option Output Voltage Response to Step-Change in Load Current, *(50%-75%-50% of Iout(max); dI/dt = 10 A/µs). Load capacitance: 1 µF ceramic and 25 mF electrolytic capacitors. Ch 1: Vout (2 V/div); Ch 2: Iout (20 A/div). Timescale: 2.00ms/div.*

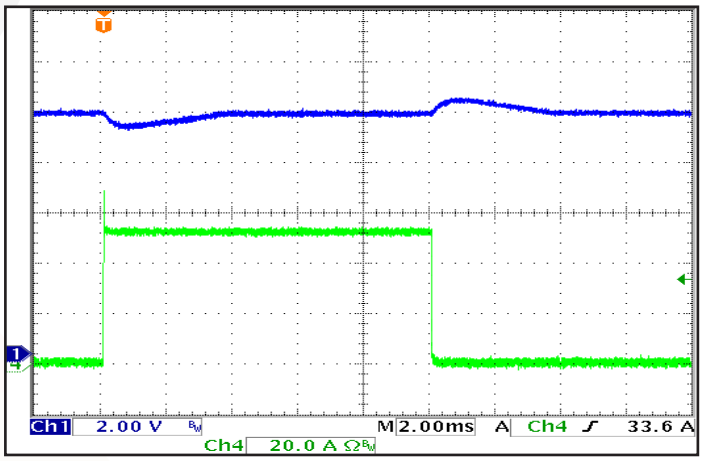


Figure 18: Hi-Cap Option Output Voltage Response to Step-Change in Load Current, *(0%-100%-0% of Iout(max); dI/dt = 10 A/µs). Load capacitance: 1 µF ceramic and 25 mF electrolytic capacitors. Ch 1: Vout (2 V/div); Ch 2: Iout (20 A/div). Timescale: 2.00ms/div.*

BASIC OPERATION AND FEATURES

This converter series uses a two-stage power conversion topology. The first stage keeps the output voltage constant over variations in line, load, and temperature. The second stage uses a transformer to provide the functions of input/output isolation and voltage step-down to achieve the low output voltage required.

Both the first stage and the second stage switch at a fixed frequency for predictable EMI performance. Rectification of the transformer's output is accomplished with synchronous rectifiers. These devices, which are MOSFETs with a very low on-state resistance, dissipate significantly less energy than Schottky diodes, enabling the converter to achieve high efficiency.

Dissipation throughout the converter is so low that it does not require a heatsink for operation in many applications; however, adding a heatsink provides improved thermal derating performance in extreme situations. To further withstand harsh environments and thermally demanding applications, the converter is available totally encased. See Ordering Information page for available thermal design options.

SynQor half-brick converters use the industry standard footprint and pin-out.

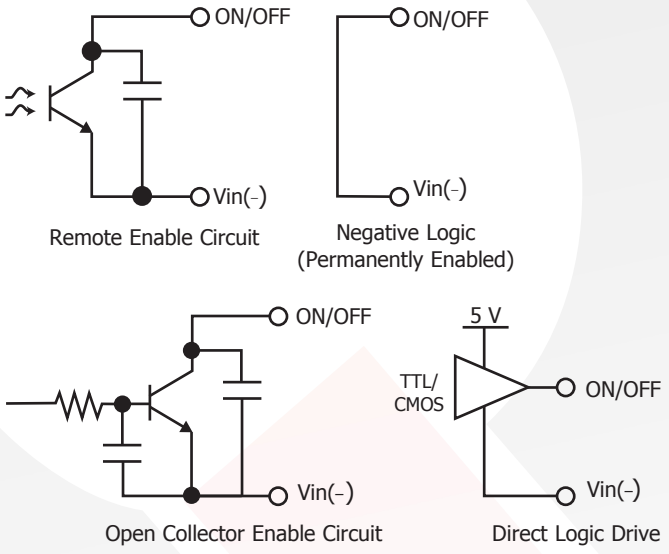


Figure A: Various Circuits for Driving the ON/OFF Pin

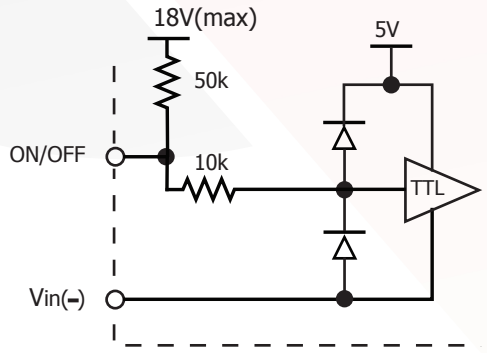


Figure B: Internal ON/OFF Pin Circuitry

CONTROL FEATURES

REMOTE ON/OFF (Pin 2): The ON/OFF input, Pin 2, permits the user to control when the converter is on or off. This input is referenced to the return terminal of the input bus, Vin(-).

In the negative logic version, the ON/OFF signal is active low (meaning that a low voltage turns the converter on). Figure A details possible circuits for driving the ON/OFF pin. Figure B is a detailed look of the internal ON/OFF circuitry.

REMOTE SENSE Pins 8(+) and 6(-): The SENSE(+) and SENSE(-) inputs correct for voltage drops along the conductors that connect the converter's output pins to the load.

Pin 8 should be connected to Vout(+) and Pin 6 should be connected to Vout(-) at the point on the board where regulation is desired. If these connections are not made, the converter will deliver an output voltage that is slightly higher than its specified value.

Note: The Output Over-Voltage Protection circuit senses the voltage across the output (Pins 9 and 5) to determine when it should trigger, not the voltage across the converter's sense leads (Pins 8 and 6). Therefore, the resistive drop on the board should be small enough so that output OVP does not trigger, even during load transients.

OUTPUT VOLTAGE TRIM (Pin 7): The TRIM input permits the user to adjust the output voltage across the sense leads up or down according to the trim range specifications. SynQor uses industry standard trim equations.

To decrease the output voltage, the user should connect a resistor between Pin 7 (TRIM) and Pin 6 (SENSE(-) input). For a desired decrease of the nominal output voltage, the value of the resistor should be:

$$\text{Rtrim-down} = \left(\frac{100\%}{\Delta\%} - 2 \right) \text{k}\Omega$$

where

$$\Delta\% = \left| \frac{\text{Vnominal} - \text{Vdesired}}{\text{Vnominal}} \right| \times 100\%$$

To increase the output voltage, the user should connect a resistor between Pin 7 (TRIM) and Pin 8 (SENSE(+) input). For a desired increase of the nominal output voltage, the value of the resistor should be:

$$\text{Rtrim-up} = \frac{\left(\frac{\text{Vnominal}}{1.225} - 2 \right) \times \text{Vdesired} + \text{Vnominal}}{\text{Vdesired} - \text{Vnominal}} \text{ k}\Omega$$

The Trim Graph in Figure C shows the relationship between the trim resistor value and Rtrim-up and Rtrim-down, showing the total range the output voltage can be trimmed up or down.

Note: The TRIM feature does not affect the voltage at which the output over-voltage protection circuit is triggered. Trimming the output voltage too high may cause the over-voltage protection circuit to engage, particularly during transients.

It is not necessary for the user to add capacitance at the TRIM pin. The node is internally filtered to eliminate noise.

Total DC Variation of Vout: For the converter to meet its full specifications, the maximum variation of the DC value of Vout, due to both trimming and remote load voltage drops, should not be greater than that specified for the output voltage trim range.

Active Trimming: Active trimming of the output voltage is supported, but dynamic active trimming with feedback is discouraged due to the potential for limit-cycling. If such trimming is necessary, control loop bandwidth should be limited to <1 Hz. A deadband which is at least as large as the line/load regulation specification is also recommended, but not required.

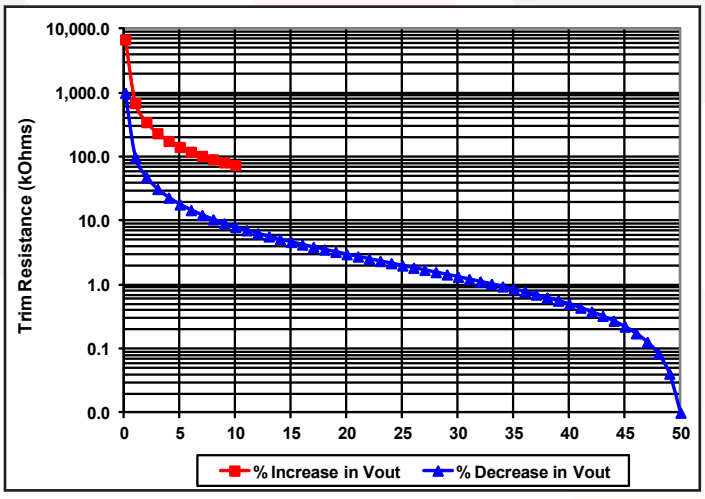


Figure C: Trim Graph

Protection Features

Input Under-Voltage Lockout (UVLO): The converter is designed to turn off when the input voltage is too low, helping to avoid an input system instability problem, which is described in more detail in the application note titled "Input System Instability" on the SynQor website. The lockout circuitry is a comparator with DC hysteresis. When the input voltage is rising, it must exceed the typical "Turn-On Voltage Threshold" value* before the converter will turn on. Once the converter is on, the input voltage must fall below the typical Turn-Off Voltage Threshold value before the converter will turn off.

Output Current Limit (OCP): If the output current exceeds the "Output DC Current Limit Inception" value*, then a fast linear current limit controller will reduce the output voltage to maintain a constant output current. If as a result, the output voltage falls below the "Output DC Current Limit Shutdown Voltage"* for more than 50 ms**, then the unit will enter into hiccup mode, with a 500 ms off-time. The unit will then automatically attempt to restart.

Back-Drive Current Limit: If there is negative output current of a magnitude larger than the "Back-Drive Current Limit while Enabled" specification*, then a fast back-drive limit controller will increase the output voltage to maintain a constant output current. If this results in the output voltage exceeding the "Output Over-Voltage Protection" threshold*, then the unit will shut down.

Output Over-Voltage Limit (OVP): If the voltage across the output pins exceeds the Output Over-Voltage Protection threshold, the converter will immediately stop switching. This prevents damage to the load circuit due to 1) excessive series resistance in output current path from converter output pins to sense point, 2) a release of a short-circuit condition, or 3) a release of a current limit condition. Load capacitance determines exactly how high the output voltage will rise in response to these conditions. After 500 ms the converter will automatically restart.

Over-Temperature Shutdown (OTP): A temperature sensor on the converter senses the average temperature of the module. The thermal shutdown circuit is designed to turn the converter off when the temperature at the sensed location reaches the "Over-Temperature Shutdown" value*. It will allow the converter to turn on again when the temperature of the sensed location falls by the amount of the "Over-Temperature Shutdown Restart Hysteresis" value*.

Startup Inhibit Period: The Startup Inhibit Period ensures that the converter will remain off for approximately 500 ms when it is shut down due to a fault. This generates a 2 Hz "hiccup mode," which prevents the converter from overheating. There are multiple ways that the converter can be shut down, initiating a Startup Inhibit Period:

- Output Over-Voltage Protection
- Current Limit
- Short Circuit Protection

* See Electrical Characteristics section.
** Certain models may have an extended on-time, longer than 50 ms. See Electrical Characteristics section.

APPLICATION CONSIDERATIONS

Input System Instability: This condition can occur because any DC-DC converter appears incrementally as a negative resistance load. A detailed application note titled "Input System Instability" is available on the SynQor website which provides an understanding of why this instability arises, and shows the preferred solution for correcting it.

Application Circuits: A typical circuit diagram, Figure D below details the input filtering and voltage trimming.

Input Filtering and External Input Capacitance: Figure E below shows the internal input filter components. This filter dramatically reduces input terminal ripple current, which otherwise could exceed the rating of an external electrolytic input capacitor. The recommended external input capacitance is specified in the Input Characteristics section of the Electrical Specifications. More detailed information is available in the application note titled "EMI Characteristics" on the SynQor website.

Output Filtering and External Output Capacitance: The internal output filter components are shown in Figure E below. This filter dramatically reduces output voltage ripple. Some minimum external output capacitance is required, as specified in the Output Characteristics area of the Electrical Characteristics section. No damage will occur without this capacitor connected, but peak output voltage ripple will be much higher.

Thermal Considerations: For baseplated and encased versions, the max operating baseplate temperature, T_B, is 100 ºC. Refer to the Thermal Derating Curves in the Technical Figures section to see the available output current at baseplate temperatures below 100 ºC.

A power derating curve can be calculated for any heatsink that is attached to the base-plate of the converter. It is only necessary to determine the thermal resistance, R_{THBA}, of the chosen heatsink between the baseplate and the ambient air for a given airflow rate. This information is usually available from the heatsink vendor. The following formula can the be used to determine the maximum power the converter can dissipate for a given thermal condition if its base-plate is to be no higher than 100 ºC.

$$P_{diss}^{max} = \frac{100\ ºC - T_A}{R_{THBA}}$$

This value of maximum power dissipation can then be used in conjunction with the data shown in the Power Dissipation Curves in the Technical Figures section to determine the maximum load current (and power) that the converter can deliver in the given thermal condition.

For convenience, Thermal Derating Curves are provided in the Technical Figures section.

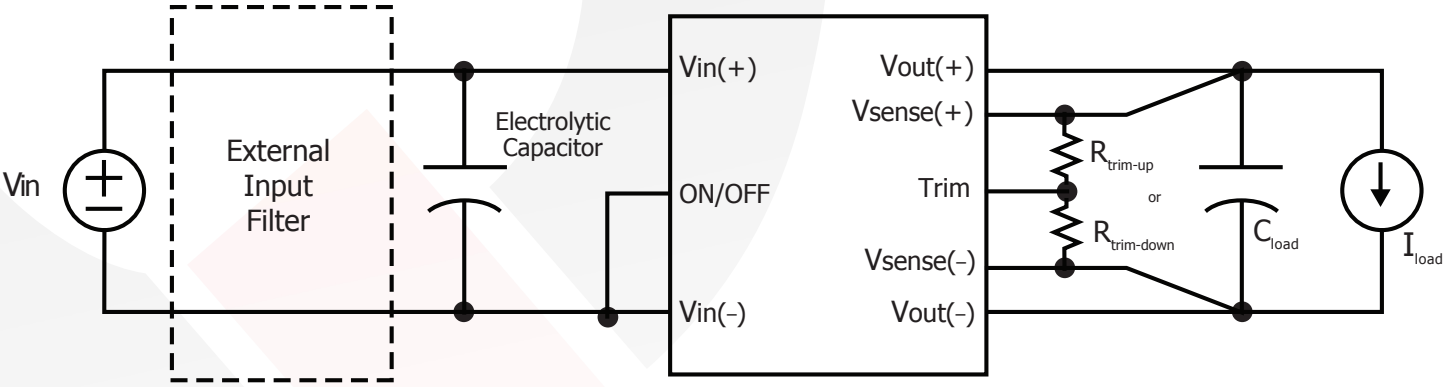


Figure D: Typical Application Circuit *(negative logic unit, permanently enabled)*

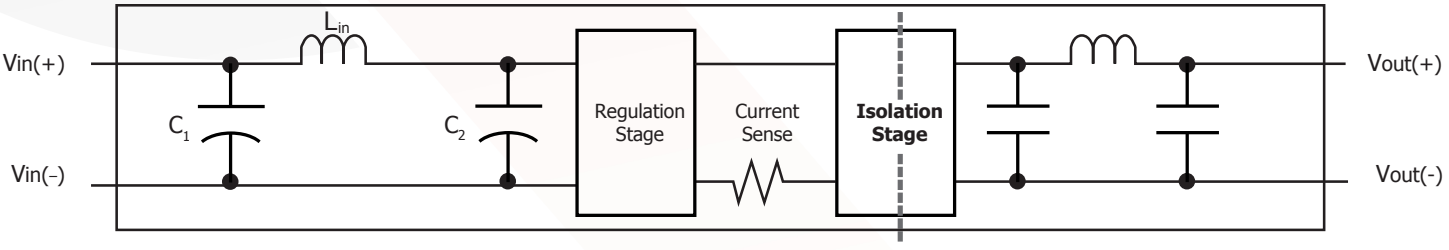


Figure E: Internal Input and Output Filter Diagram *(component values listed in Electrical Characteristics section)*

Active Current Share Application Section

Overview: The full-featured option, which is specified by an "F" as the last character of the part number, supports current sharing by adding two additional pins: SHARE(+) and SHARE(-)

Connection of Paralleled Units: Up to 100 units can be placed in parallel. In this current share architecture, one unit is dynamically chosen to act as a master, controlling all other units. It cannot be predicted which unit will become the master at any given time, so units should be wired symmetrically (see Figures F & G).

- Input power pins and output power pins should be tied together between units, preferably with wide overlapping copper planes, after any input common-mode choke.
- The SHARE(+) and SHARE(-) pins should be routed between all paralleled units as a differential pair.
- The ON/OFF pins should be connected in parallel, and rise/fall times should be kept below 2 ms.
- The SENSE(+) and SENSE(-) pins should be connected either locally at each unit or separately to a common sense point. If an output common-mode choke is used, sense lines should be connected on the module-side of the choke.
- If the TRIM pin is used, then each unit should have its own trim resistor connected locally between TRIM and SENSE(+) or SENSE(-).

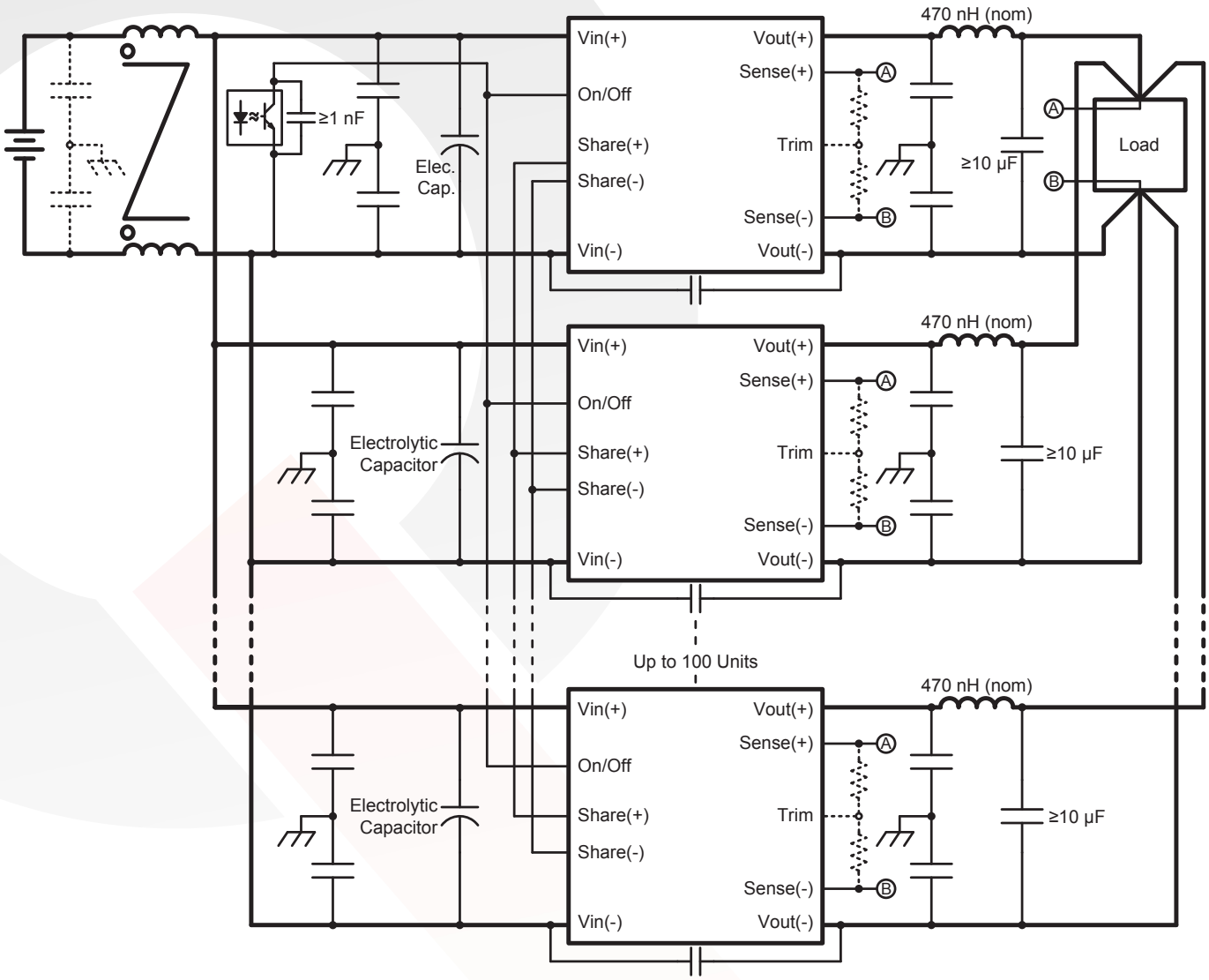


Figure F: Typical Application Circuit for Paralleling of Full-Featured Units with an Input Common-Mode Choke. *If an input common-mode choke is used, Vin(-) MUST be tied together AFTER the choke for all units. 470 nH (nominal) inductor or an output common-mode choke is required for outputs >18 V. See Figure G for output common-mode choke configuration.*

Automatic Configuration: The micro-controller inside each power converter unit is programmed at the factory with a unique chip number. In every other respect, each shared unit is identical and has the same orderable part number.

On initial startup (or after the master is disabled or shuts down), each unit determines the chip number of every other unit currently connected to the shared serial bus formed by the SHARE(+) and SHARE(-) pins. The unit with the highest chip number dynamically reconfigures itself from slave to master. The rest of the units (that do not have the highest chip number) become slaves.

The master unit then broadcasts its control state over the shared serial bus on a cycle-by-cycle basis. The slave units interpret and implement the control commands sent by the master, mirroring every action of the master unit.

If the master is disabled or encounters a fault condition, all units will immediately shut down, and if the master unit is unable to restart, then the unit with the next highest chip number will become master. If a slave unit is disabled or encounters a fault condition, all other units continue to run, and the slave unit can restart seamlessly.

Automatic Interleaving: The slave units automatically lock frequency with the master, and interleave the phase of their switching transitions for improved EMI performance. To obtain the phase angle relative to the master, each slave divides 360 degrees by the total number of connected units, and multiples the result by its rank among chip numbers of connected units.

ORing Diodes placed in series with the converter outputs must also have a resistor smaller than 500 Ω placed in parallel. This resistor keeps the output voltage of a temporarily disabled slave unit consistent with the active master unit. If the output voltage of the slave unit were allowed to totally discharge, and the slave unit tried to restart, it would fail because the slave reproduces the duty cycle of the master unit, which is running in steady state and cannot repeat an output voltage soft-start.

Common-Mode Filtering must be either a single primary side choke handling the inputs from all the paralleled units, or multiple chokes placed on the secondary side. This ensures that a solid Vin(-) plane is maintained between units. Adding a common-mode choke at the output eliminates the need for the 470 nH indcutor at the output of shared units when Vout > 18 V. If an output common-mode choke is used, sense connections must be made on the module-side of the choke.

Resonance Between Output Capacitors is Possible: When multiple higher-voltage modules are paralleled, it is possible to excite a series resonance between the output capacitors internal to the module and the parasitic inductance of the module output pins. This is especially likely at higher output voltages where the module internal capacitance is relatively small. This problem is independent of external output capacitance. For modules with an output voltage greater than 18 V, to ensure that this resonant frequency is below the switching frequency it is recommended to add a nominal 470 nH of inductance, located close to the module, in series with each converter output. There must be at least 10 µF of capacitance per converter, located on the load-side of that inductor. The inductance could be from the leakage inductance of a secondary-side common-mode choke; in which case the output capacitor should be appropriately sized for the chosen choke. When using an output common-mode choke, the Sense lines must be connected on the module-side of the common-mode choke (see Figure G).

RS-485 Physical Layer: The internal RS-485 transceiver includes many advanced protection features for enhanced reliability:

- Current Limiting and Thermal Shutdown for Driver Overload Protection
- IEC61000 ESD Protection to +/- 16.5 kV
- Hot Plug Circuitry – SHARE(+) and SHARE(-) Outputs Remain Tri-State During Power-up/Power-down

Internal Schottky Diode Termination: Despite signaling at high speed with fast edges, external termination resistors are not necessary. Each receiver has four Schottky diodes built in, two for each line in the differential pair. These diodes clamp any ringing caused by transmission line reflections, preventing the voltage from going above about 5.5 V or below about -0.5 V. Any subsequent ringing then inherently takes place between 4.5 and 5.5 V or between -0.5 and 0.5 V. Since each receiver on the bus contains a set of clamping diodes to clamp any possible transmission line reflection, the bus does not necessarily need to be routed as a daisy-chain.

Pins SHARE(+) and SHARE(-) are referenced to Vin(-), and therefore should be routed as a differential pair near the Vin(-) plane for optimal signal integrity. The maximum difference in voltage between Vin(-) pins of all units on the share-bus should be kept within 0.3 V to prevent steady-state conduction of the termination diodes. Therefore, the Vin(-) connections to each unit must be common, preferably connected by a single copper plane.

Share Accuracy: Inside each converter micro-controller, the duty cycle is generated digitally, making for excellent duty cycle matching between connected units. Some small duty cycle mismatch is caused by (well controlled) process variations in the MOSFET gate drivers. However, the voltage difference induced by this duty cycle mismatch appears across the impedance of the entire power converter, from input to output, multiplied by two, since the differential current flows out of one converter and into another. So, a small duty cycle mismatch yields very small differential currents, which remain small even when 100 units are placed in parallel.

In other current-sharing schemes, it is common to have a current-sharing control loop in each unit. However, due to the limited bandwidth of this loop, units do not necessarily share current on startup or during transients before this loop has a chance to respond. In contrast, the current-sharing scheme used in this product has no control dynamics: control signals are transmitted fast enough that the slave units can mirror the control state of the master unit on a cycle-by-cycle basis, and the current simply shares properly, from the first switching cycle to the last.

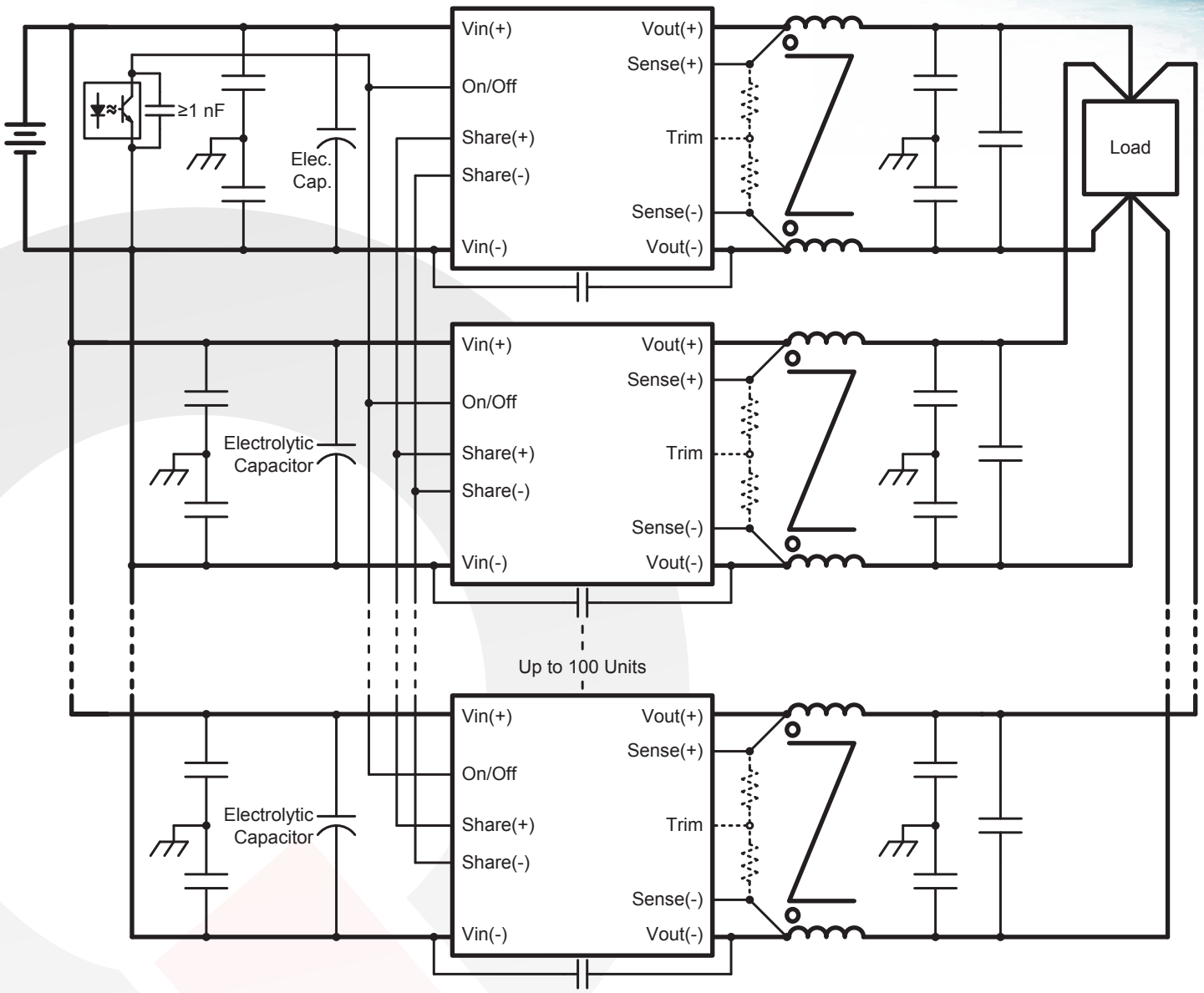


Figure G: Typical Application Circuit for Paralleling of Full-Featured Units with an Output Common-Mode Choke. *When using an output common-mode choke, SENSE lines must be connected on the module-side of the choke. See Figure F for configuration with an input common-mode choke.*

High-Capacitance (Hi-Cap) Application Section

Overview:
Certain models are available with a High-Capacitance (Hi-Cap) option, specified by a "C" or "FC" at the end of the part number. They are specially designed for stable operation with very large capacitances, extreme load pulses, and applications with demanding transient requirements, such as modern pulsed radar systems.

Although the High-Capacitance converters are stable with nearly any value of output capacitance, converters *without* the High-Capacitance option may have smoother transient response when operating with no, or very little, external output capacitance.

Large Transient Output Voltage Deviation:
High-Capacitance converters are fully regulated; however, they allow temporary deviations of the output voltage during load transients. These deviations enable the converter to ride through load pulses which may be significantly larger than the rated output current. For load pulses <500 µs, this deviation also helps maximize use of the output capacitance and reject ripple, which reduces conducted EMI and lessens the demands on upstream converters. Deviations of the output voltage lasting longer than 1 ms are quickly corrected.

Voltage deviations during extremely fast load transients are the result of both lossy and lossless aspects of converter's powertrain, while slower load transients rely on the converter's control logic. The actual magnitude of the deviation will vary depending on operating conditions and will typically be larger than indicated in Table A. HZ/HY-series converters with a rated output voltage ≤18 V have a powertrain architecture that is different from higher output voltage converters. As a result, the minimum voltage deviation during fast transients depends on the rated output voltage of the converter.

Designing for Extreme Load Transients:
There are no special design requirements for DC loads, sinusoidal loads <1 kHz, pulsed loads >100 kHz, and load pulses that do not exceed 125% of the converter's rated current faster than 1 ms. Repeated operation into current limit is acceptable, provided that the average current does not exceed the converter's rated current.

In addition to linear current limit, these converters are equipped with fast short-circuit fault protection. Special requirements exist to ensure that extreme transients do not trip short-circuit protection. The easiest way for a designer to ensure smooth operation is to meet *either* of the suggested output capacitances, C_a or C_b, in Table A. High-frequency transients occurring within longer load pulses may be considered as separate events, in regard to Equations C_a and C_b. Both Equations C_a and C_b assume low-ESR capacitors and do not take into account capacitor tolerances or DC bias characteristics.

Equation C_a ensures that the output capacitance can supply the energy for the entire load pulse, without the output voltage dropping below the natural voltage deviation of the converter's powertrain. If Equation C_a is met, no intervention by the converter's control logic is required and ripple rejection is maximized.

Equation C_b provides an alternative suggested capacitance that allows the converter's control firmware to seamlessly provide additional voltage deviation. This may be easier for the system designer to meet in applications with longer load transients, where the suggested capacitance in Equation C_a may be prohibitively large.

	$Rated\ V_{out} \leq 18\ V$	$Rated\ V_{out} > 18\ V$
Min. Voltage Deviation (% of Output Voltage)	2.5%	5.0%
Equation C_a	$C_{out} \geq \frac{40 \times E_{pulse}}{{V_{out}}^2}$	$C_{out} \geq \frac{20 \times E_{pulse}}{{V_{out}}^2}$
Equation C_b	$C_{out} \geq \frac{I_{peak}}{125 \times V_{out}}$	$C_{out} \geq \frac{I_{peak}}{250 \times V_{out}}$

Table A – Suggested Capacitance for Extreme Load Transients

V_{out} = Rated output voltage of converter (volts)
C_{out} = Customer selected output capacitance (Farads)
E_{pulse} = Total energy (Joules) consumed by the load pulse
I_{peak} = Peak current (amperes) during the load pulse

Many real-world load transients only require a small fraction of the capacitance in Equations C_a and C_b. Customers with load pulses greatly exceeding the converter's rated current, but who are unable to meet either Equation C_a or C_b, can guarantee smooth performance by verifying operation at the lowest expected operating input voltage and half the planned output capacitance. Fast short-circuit fault protection is a function of inductor current and is most sensitive at lower input voltages.

Input Capacitance:
All HZ/HY-series converters are capable of significant reverse power conduction. In the event that a load dump causes the output voltage to overshoot, the converter will attempt to restore regulation by transferring some of this energy back to the input capacitor. The "Minimum Recommended Input Capacitance" chart in the Technical Specifications provides recommended values; however, actual values will depend on the source impedance and its ability to sink current.

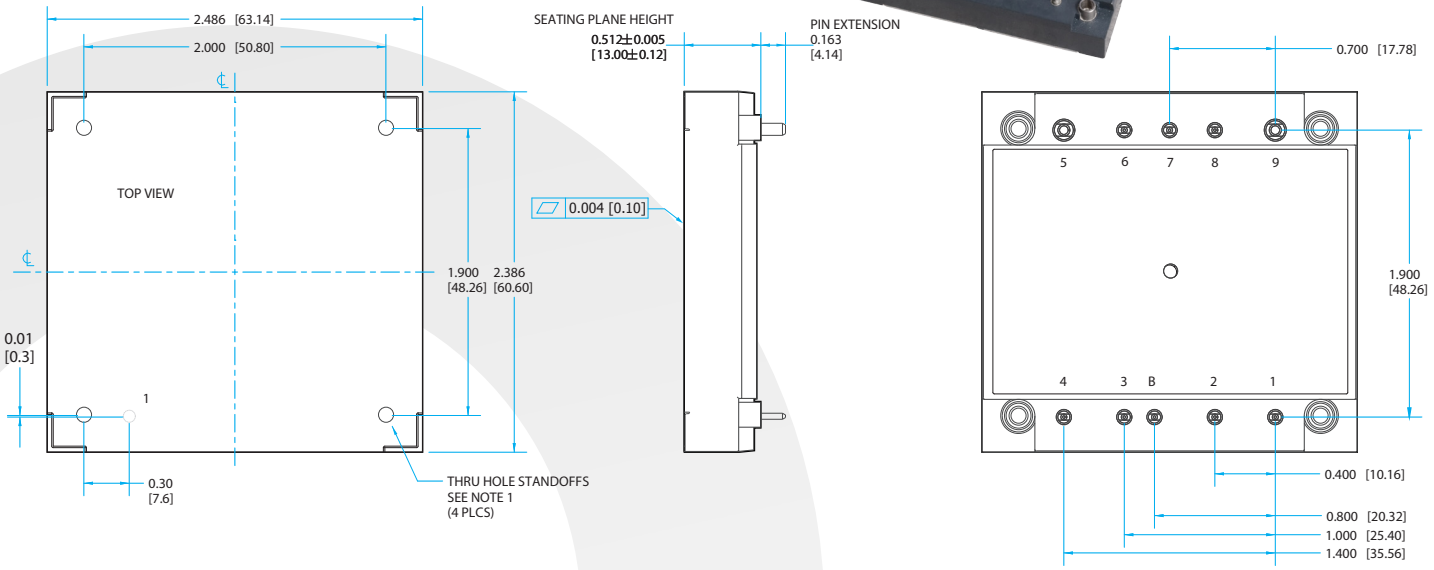
Startup Ramp:
To control capacitor charging current and limit output overshoot, models with the High-Capacitance option have a slower startup ramp rate, which further slows down as the output voltage approaches the nominal set point. Like all HZ/HY-series converters, the startup ramp is pre-programmed in firmware for consistent behavior across all operating conditions. However, the actual startup ramp may be much slower than the pre-programmed ramp if the combined payload current and capacitor charging current exceed the "Output DC Current Limit Inception" value. While the output is below the "Output DC Current Limit Shutdown Voltage", if current limit forces the average dV/dt (over a 50 ms period) to fall below the values listed in Table B, then the converter will enter hiccup mode operation until the fault clears. Output capacitance should not exceed the "Maximum Output Capacitance" specification.

	MCOTS-C-28 MCOTS-C-28E MCOTS-C-48	MCOTS-C-28V MCOTS-C-28VE
Minimum Startup dV/dt (as a % of rated V_{out})	$\frac{0.4 \times V_{out}}{second}$	$\frac{0.7 \times V_{out}}{second}$
Maximum Load Current (during startup ramp)	$I_{load} < I_{lim} - \frac{C_{out} \times V_{out}}{2.5}$	$I_{load} < I_{lim} - \frac{C_{out} \times V_{out}}{1.4}$
Maximum Capacitance (during startup)	$C_{out} < \frac{2.5\ (I_{lim} - I_{load})}{V_{out}}$	$C_{out} < \frac{1.4\ (I_{lim} - I_{load})}{V_{out}}$

Table B – Maximum Load During First Half of Startup Ramp

I_{load} = Load current during first half of startup ramp (amperes)
I_{lim} = Minimum "DC Current Limit Inception" value (amperes)

MCOTS-C-28-9R6-HZ
Output: 9.6V
Current: 52A



NOTES

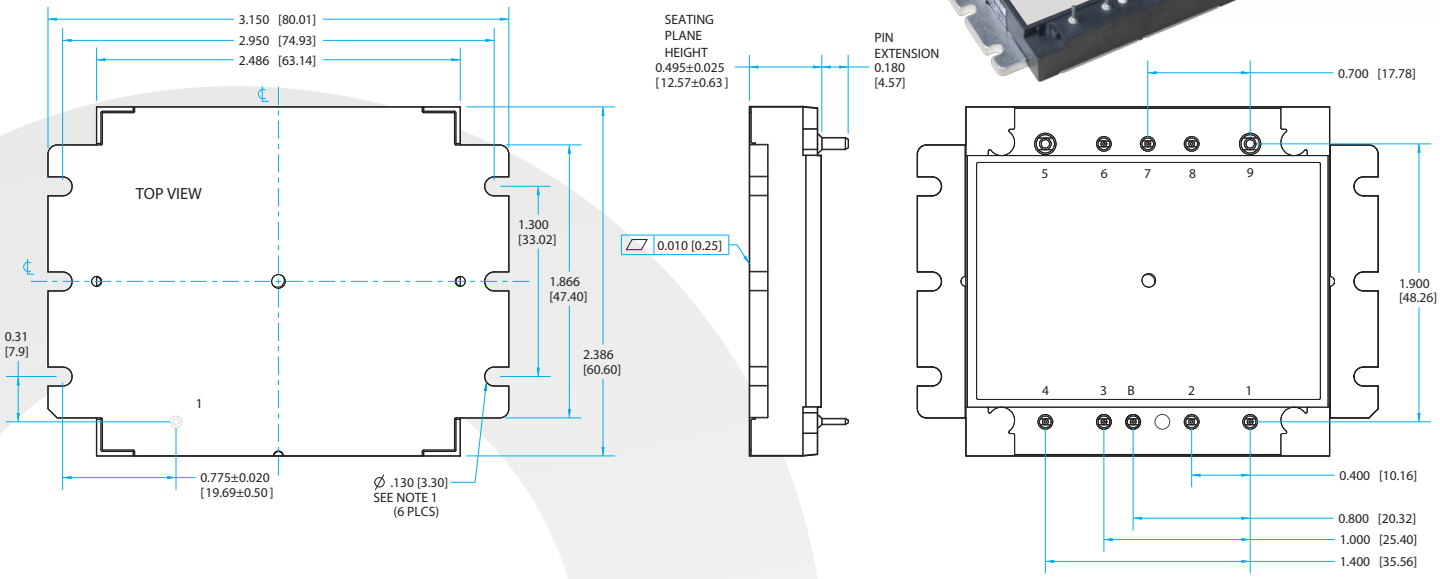
1) THREADED: APPLIED TORQUE PER M3 SCREW NOT TO EXCEED 6 in-lb (0.7 Nm).
   NONTHREADED: DIA 0.125" (3.18 mm)
2) BASEPLATE FLATNESS TOLERANCE IS 0.004" (0.10 mm) TIR FOR SURFACE.
3) PINS 1-4, B AND 6-8 ARE 0.040" (1.02 mm) DIA. WITH 0.080" (2.03 mm) DIA. STANDOFFS.
4) PINS 5 AND 9 ARE 0.080" (2.03 mm) DIA. WITH 0.125" (3.18 mm) DIA STANDOFFS
5) ALL PINS: MATERIAL: COPPER ALLOY
   FINISH: MATTE TIN OVER NICKEL PLATE
6) WEIGHT: 5.2 oz. (146 g)
7) ALL DIMENSIONS IN INCHES (mm)
   TOLERANCES: X.XX IN +/-0.02 (X.X mm +/-0.5 mm)
   X.XXX IN +/-0.010 (X.XX mm +/-0.25 mm)

PIN DESIGNATIONS

Pin	Name	Label	Function
1	Vin(+)	+VIN	Positive input voltage
2	ON/OFF	ON/OFF	TTL input to turn converter on and off, referenced to Vin(–), with internal pull up.
B	SHARE(+)	SHARE+	Active current share differential pair (see Full-Feature Application Notes)[4]
3	SHARE(–)	SHARE–	
4	Vin(–)	IN RTN	Input Return
5	Vout(–)	OUT RTN	Ouput Return
6	SENSE(–)	–SNS	Negative remote sense[1]
7	TRIM	TRIM	Output voltage trim[2]
8	SENSE(+)	+SNS	Positive remote sense[3]
9	Vout(+)	+VOUT	Positive output voltage

Notes:
1) SENSE(–) should be connected to Vout(–) either remotely or at the converter.
2) Leave TRIM pin open for nominal output voltage.
3) SENSE(+) should be connected to Vout(+) either remotely or at the converter.
4) On standard product, Pin B & Pin 3 are absent

MCOTS-C-28-9R6-HZ
Output: 9.6V
Current: 52A



NOTES

1) APPLIED TORQUE PER M3 OR 4-40 SCREW NOT TO EXCEED 6 in-lb (0.7 Nm)
2) BASEPLATE FLATNESS TOLERANCE IS 0.010" (.25 mm) TIR FOR SURFACE.
3) PINS 1-4, 6-8 AND B ARE 0.040" (1.02 mm) DIA. WITH 0.080" (2.03 mm) DIA. STANDOFFS.
4) PINS 5 AND 9 ARE 0.080" (2.03 mm) DIA. WITH 0.125" (3.18 mm) DIA STANDOFFS
5) ALL PINS: MATERIAL: COPPER ALLOY
   FINISH: MATTE TIN OVER NICKEL PLATE
6) WEIGHT: 5.4 oz. (152 g)
7) ALL DIMENSIONS IN INCHES (mm)
   TOLERANCES: X.XX IN +/-0.02 (X.X mm +/-0.5 mm)
   X.XXX IN +/-0.010 (X.XX mm +/-0.25 mm)

PIN DESIGNATIONS

Pin	Name	Label	Function
1	Vin(+)	+VIN	Positive input voltage
2	ON/OFF	ON/OFF	TTL input to turn converter on and off, referenced to Vin(–), with internal pull up.
B	SHARE(+)	SHARE+	Active current share differential pair (see Full-Feature Application Notes)[4]
3	SHARE(–)	SHARE–	
4	Vin(–)	IN RTN	Input Return
5	Vout(–)	OUT RTN	Ouput Return
6	SENSE(–)	–SNS	Negative remote sense[1]
7	TRIM	TRIM	Output voltage trim[2]
8	SENSE(+)	+SNS	Positive remote sense[3]
9	Vout(+)	+VOUT	Positive output voltage

Notes:
1) SENSE(–) should be connected to Vout(–) either remotely or at the converter.
2) Leave TRIM pin open for nominal output voltage.
3) SENSE(+) should be connected to Vout(+) either remotely or at the converter.
4) On standard product, Pin B & Pin 3 are absent

Mil-COTS Qualification

Test Name	Details	# Tested (# Failed)	Consistent with MIL-STD-883F Method
Life Testing	Visual, mechanical and electrical testing before, during and after 1000 hour burn-in @ full load	15 (0)	Method 1005.8
Shock-Vibration	Visual, mechanical and electrical testing before, during and after shock and vibration tests	5 (0)	MIL-STD-202, Methods 201A & 213B
Humidity	+85 °C, 95% RH, 1000 hours, 2 minutes on / 6 hours off	8 (0)	Method 1004.7
Temperature Cycling	500 cycles of -55 °C to +100 °C (30 minute dwell at each temperature)	10 (0)	Method 1010.8, Condition A
Solderability	15 pins	15 (0)	Method 2003
DMT	-65 °C to +110 °C across full line and load specifications in 5 °C steps	7 (0)	
Altitude	70,000 feet (21 km), see Note	2 (0)	

Note: A conductive cooling design is generally needed for high altitude applications because of naturally poor convective cooling at rare atmospheres.

Mil-COTS Converter and Filter Screening

Screening	Process Description	S-Grade	M-Grade
Baseplate Operating Temperature		-55 °C to +100 °C	-55 °C to +100 °C
Storage Temperature		-65 °C to +135 °C	-65 °C to +135 °C
Pre-Cap Inspection	IPC-A-610, Class III	•	•
Temperature Cycling	MIL-STD-883F, Method 1010, Condition B, 10 Cycles		•
Burn-In	100 °C Baseplate	12 Hours	96 Hours
Final Electrical Test	100%	25 °C	-55 °C, +25 °C, +100 °C
Final Visual Inspection	MIL-STD-883F, Method 2009	•	•

Mil-COTS MIL-STD-810G Qualification Testing

MIL-STD-810G Test	Method	Description
Fungus	508.6	Table 508.6-I
Altitude	500.5 - Procedure I	Storage: 70,000 ft / 2 hr duration
	500.5 - Procedure II	Operating: 70,000 ft / 2 hr duration; Ambient Temperature
Rapid Decompression	500.5 - Procedure III	Storage: 8,000 ft to 40,000 ft
Acceleration	513.6 - Procedure II	Operating: 15 g
Salt Fog	509.5	Storage
High Temperature	501.5 - Procedure I	Storage: 135 °C / 3 hrs
	501.5 - Procedure II	Operating: 100 °C / 3 hrs
Low Temperature	502.5 - Procedure I	Storage: -65 °C / 4 hrs
	502.5 - Procedure II	Operating: -55 °C / 3 hrs
Temperature Shock	503.5 - Procedure I - C	Storage: -65 °C to 135 °C; 12 cycles
Rain	506.5 - Procedure I	Wind Blown Rain
Immersion	512.5 - Procedure I	Non-Operating
Humidity	507.5 - Procedure II	Aggravated cycle @ 95% RH (Figure 507.5-7 aggravated temp - humidity cycle, 15 cycles)
Random Vibration	514.6 - Procedure I	10 - 2000 Hz, PSD level of 1.5 g^2/Hz (54.6 g_{rms}), duration = 1 hr/axis
Shock	516.6 - Procedure I	20 g peak, 11 ms, Functional Shock (Operating no load) (saw tooth)
	516.6 - Procedure VI	Bench Handling Shock
Sinusoidal vibration	514.6 - Category 14	Rotary wing aircraft - helicopter, 4 hrs/axis, 20 g (sine sweep from 10 - 500 Hz)
Sand and Dust	510.5 - Procedure I	Blowing Dust
	510.5 - Procedure II	Blowing Sand

Ordering Information/ Part Numbering

Example MCOTS-C-28-9R6-HZ-N-M-FC

Not all combinations make valid part numbers, please contact SynQor for availability. See product summary page for details.

Family	Product	Input Voltage	Output Voltage	Package	Heatsink Option	Screening Level	Options
MCOTS	**C:** Converter	**28:** 16-40 V **28E:** 16-70 V **28V:** 9-40 V **28VE:** 9-70 V **48:** 34-75 V	**05:** 5 V **9R6:** 9.6 V **10R2:** 10.2 V **12:** 12 V **15:** 15 V **24:** 24 V **28:** 28 V **32:** 32 V **40:** 40 V **50:** 50 V **135:** 135 V	**HZ:** Half-Brick Zeta	**N:** Normal Threaded **D:** Normal Non-Threaded **F:** Flanged	**S:** S-Grade **M:** M-Grade	**[ ]:** Standard Feature **F:** Full-Feature **C:** High-Capacitance **FC:** High-Capacitance + Full-Feature

APPLICATION NOTES

A variety of application notes and technical white papers can be downloaded in pdf format from our website.

Contact SynQor for further information and to order:

Phone: 978-849-0600
Toll Free: 888-567-9596
Fax: 978-849-0602
E-mail: power@synqor.com
Web: www.synqor.com
Address: 155 Swanson Road
Boxborough, MA 01719
USA

PATENTS

SynQor holds numerous U.S. patents, one or more of which apply to most of its power conversion products. Any that apply to the product(s) listed in this document are identified by markings on the product(s) or on internal components of the product(s) in accordance with U.S. patent laws. SynQor's patents include the following:

6,896,526 6,927,987 7,050,309 7,765,687
7,787,261 8,149,597 8,644,027

WARRANTY

SynQor offers a two (2) year limited warranty. Complete warranty information is listed on our website or is available upon request from SynQor.