SynQor®

MPFIC-115-3PD-28R-FG
Power Factor Correction
Full-brick

Military-Grade AC or DC Power Conditioning Module

3-Phase 115 Vrms L-N or 270 Vdc	0 to 800 Hz	4250 V	28 Vdc	330W	100 °C	>0.99	1.5%	92.0%
Input Voltage	Input Frequency	Isolation	Output Voltage	Output Power	Baseplate Temp	PF	THD	Full Load Efficiency

The MilCOTS 3-Phase AC or DC input MPFICQor Isolated Power Factor Correction module is an essential building block of an AC-DC or DC-DC power supply running from a source as defined by MIL-STD-704. It rejects voltage fluctuations from both AC and DC sources and provides Power Factor Correction when operated from an AC source. The MPFIC also rejects pulsed loads, preventing large load transients from being passed back to the AC or DC source. It is designed to comply with a wide range of military standards and is manufactured in the United States.

MPFICQor™

Designed and manufactured in the USA

Operational Features

- Full-brick form factor
- 330W continuous @ 100 °C baseplate temp from AC or DC source
- Compatible with Military Standard 60 Hz, 400 Hz & var. freq. systems
- Compatible with Military Standard 270 Vdc sources
- Meets military standards for harmonic content
- Enables systems with repetitive load transients to pass MIL-STD-461 CE101 requirement by offering superior load current rejection
- Minimal inrush current
- Balanced phase currents
- High power factor (0.98 at 400 Hz / 330 W)
- Minimal external output capacitance requirement
- Supports full load current during startup ramp
- Additional input filters available to meet full EMI requirements

Control Features

- All control pins referenced to separate floating return
- Asynchronous serial data interface
- Input and and Ouput Power Good outputs
- MPFIC Enable and Battle Short inputs
- 3.3 V always-on standby power output
- Clock synchronization output

Mechanical Features

- Industry standard Full-brick-size
- Size: 2.486" x 4.686" x 0.512" (63.14 x 119.02 x 13.0 mm)
- Weight: 11.3 oz (320 g)

Compliance Features

MPFIC series converters are designed to meet:
(With an MCOTS 3-Phase AC input filter)
- MIL-STD-704 (A-F)
- MIL-STD-461 (C, D, E, F)
- MIL-STD-1399 (at 200 Vrms L-L)
- MIL-STD-810G
- RTCA/DO-160

Protection Features

- Output current limit and auto-recovery short circuit protection
- Auto-recovery input under/over-voltage protection
- Auto-recovery output over-voltage protection
- Auto-recovery thermal shutdown

Contents

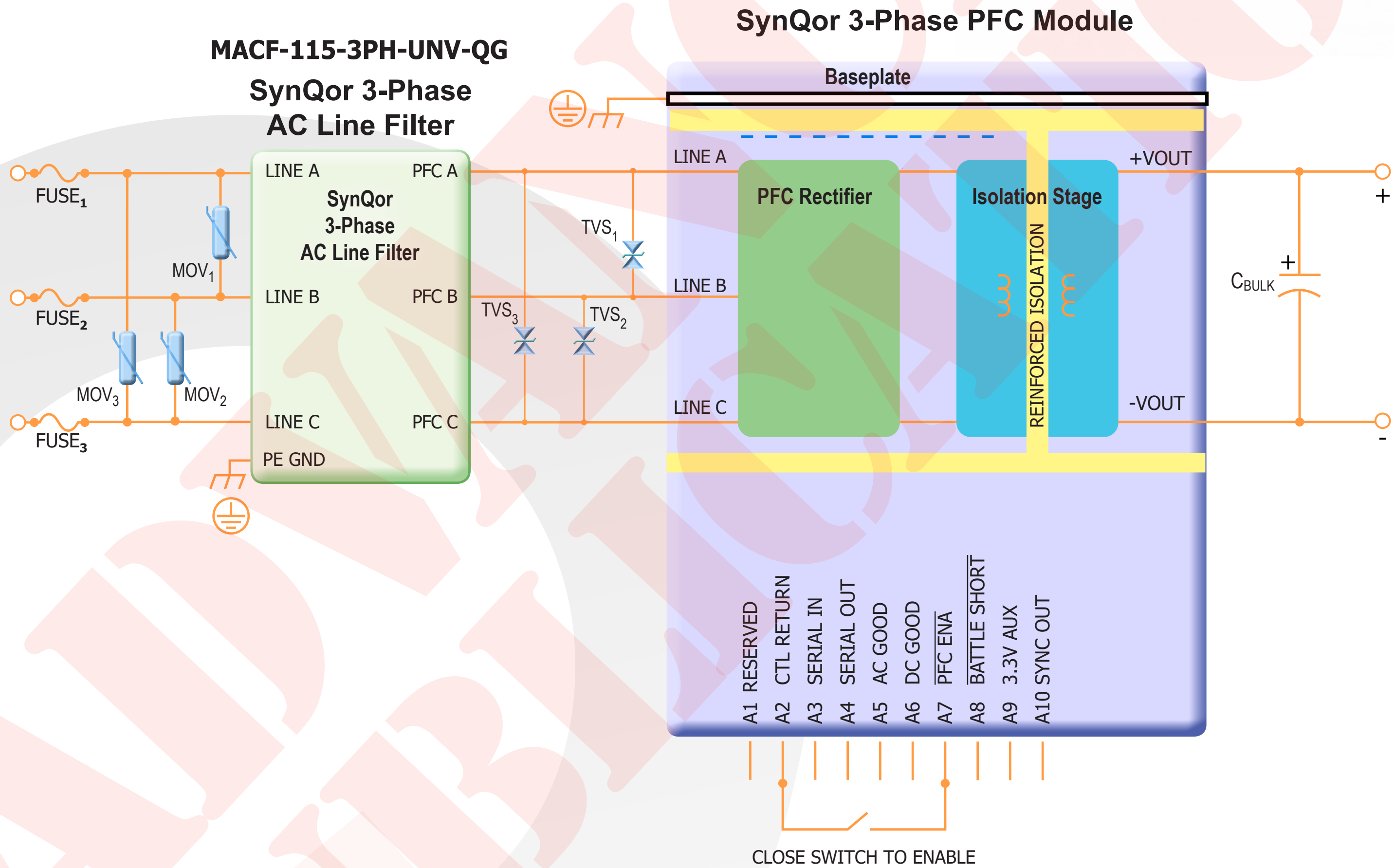
Safety Features

(Pending)
- Input to output reinforced isolation 4250Vdc
- Input/Output to baseplate isolation 2500Vdc

MPFIC-115-3PD-28R-FG

Input: 3Φ 115 Vrms (L-N) or 270 Vdc
Output: 28 Vdc
Power: 330W

Typical Application



Suggested Parts:

MOV 1-3 :	300 Vrms, 60 J; EPCOS S10K300E2
TVS 1-3 :	430 Vpk, 20 J; Littelfuse AK3-430C or Bourns PTVS-430C-TH
Fuse 1-3 :	250 Vrms, 10 A; Littelfuse 0216010.XEP

Figure A: *Typical application of the Isolated PFCQor module*

MPFIC-115-3PD-28R-FG Electrical Characteristics

Operating Conditions: 115 Vrms L-N (199 Vrms L-L) 3-Phase 400 Hz; 330W output; baseplate temperature = 25 °C; output capacitance = 1.3mF unless otherwise noted. Full operating baseplate temperature range is -45 °C to +100 °C. Specifications subject to change without notice.

Parameter	Min.	Typ.	Max.	Units	Notes & Conditions
ABSOLUTE MAXIMUM RATINGS					
Input Voltage			575	Vpk L-L	Differential across any two line inputs
SERIAL IN and PFC ENA inputs	-2		7	V	Relative to CTL RETURN pin
AC GOOD, DC GOOD, and BATTLE SHORT outputs					
Pull Up Voltage	-2		7	V	Relative to CTL RETURN pin
Sink Current			10	mA	
Operating Temperature	-45		100	°C	Baseplate temperature
Storage Temperature	-45		135	°C	
INPUT CHARACTERISTICS					
Input Voltage Range, Operating					See app section "Power Ratings"
Continuous	100		140	Vrms L-N	173 to 242 Vrms L-L
	240		350	Vdc	
Transient (≤ 1 s)	60		180	Vrms L-N	104 to 312 Vrms L-L
	147		440	Vdc	
Input Overvoltage Protection (Between any two line inputs)	485	500		Vpk L-L	Threshold levels guaranteed by design
Operating Input Frequency	0		800	Hz	
Source Inductance			2	mH	per Phase
Recommended Operating Range with Line Imbalance					
Amplitude Imbalance			5	Vrms L-N	
Phase Imbalance			5	deg	
Thresholds for Phase Drop Warning & Shutdown					Warning causes BATTLE SHORT pin to go high
Amplitude Imbalance		37		Vrms L-N	0.25s shutdown delay
Phase Imbalance		18		deg	
Inrush of AC Input Current			5	A	Output cap is charged later during startup ramp
Power Factor		0.99			
Reactive Power (per phase)					See note 1. Scales with AC line frequency.
400 Hz, Zero load or Disabled;		35		VAR	Leading
400 Hz, Pout > 120 W		0		VAR	See app section "Reactive Power at Fundamental"
Total Harmonic Distortion of AC Input Current		1.5	2.5	%	Full load (see Figure 4 for data vs. load)
Enabled Input Power, No Load (sum of phases)					
400Hz		9		W	
60Hz or DC		7		W	
Disabled Input Power (sum of phases)					
400Hz		6		W	
60Hz or DC		4		W	
Input Current Imbalance			±1	%	
Maximum Input Current (per phase)			1.5	Arms	Provided for rating of circuit / fuse
ISOLATED OUTPUT CHARACTERISTICS					
Output Steady-State Voltage	27.5	28.0	28.5	V	Zero Load
Output Voltage Regulation		-0.5		V	Full Load
Operating Output Current Range	0		12	A	
Output Current Limit			16	A	
Output Steady-State Voltage Ripple			84	mVrms	With minimum +VOUT capacitance and balanced line
Recommended Output Capacitance	1.0		25	mF	Use R || D for additional cap
Output Over-Voltage Limit Threshold (Full Temp Range)	31		39	V	Not tested, guaranteed by design
EFFICIENCY					
100% Load (330W)		92.5		%	400 Hz (0.3% higher at 60 Hz)
50% Load (165W)		92.0		%	400 Hz (0.5% higher at 60 Hz)
DYNAMIC CHARACTERISTICS					
Turn-On Transient					
Startup Delay Time		45		ms	From PFC ENA to 10% nominal VOUT, see Figure 19
Total Turn-On Time		500		ms	From PFC ENA to DC GOOD, see Figure 19
VOUT Overshoot			1	%	
Auto-Restart Time		1		s	See "Protection Features" in application section
RELIABILITY CHARACTERISTICS					
Calculated MTBF (MIL-217) MIL-HDBK-217F		549		10^3 Hrs.	Ground Benign, Tb = 70 °C
Calculated MTBF (MIL-217) MIL-HDBK-217F		85		10^3 Hrs.	Ground Mobile, Tb = 70 °C
Field Demonstrated MTBF				10^3 Hrs.	See our website for details

Note 1: Includes contribution from MACF-115-3PH-UNV-QG EMI filter

MPFIC-115-3PD-28R-FG Electrical Characteristics (continued)

Operating Conditions: 115 Vrms L-N (199 Vrms L-L) 3-Phase 400 Hz; 330W output; baseplate temperature = 25 °C; output capacitance = 1.3mF unless otherwise noted. Full operating baseplate temperature range is -45 °C to +100 °C. Specifications subject to change without notice.

Parameter	Min.	Typ.	Max.	Units	Notes & Conditions
FEATURE CHARACTERISTICS					
SERIAL IN					
Idle / Stop State Input Voltage	2.4			V	
Zero / Start State Input Voltage			0.8	V	
Internal Pull-Up Voltage		3.3		V	
Internal Pull-Up Resistance		10		kΩ	
SERIAL OUT					
Idle / Stop State Output Voltage	2.9	3.1		V	4 mA source current
Zero / Start State Output Voltage		0.2	0.4	V	4 mA sink current
INPUT GOOD (positive logic)					Startup inhibited until INPUT GOOD output high
Input Voltage Low Threshold	90	95	100	Vrms L-N	INPUT GOOD low below this threshold
	220	230	240	Vdc	
Input Voltage High Threshold	145	150	155	Vrms L-N	INPUT GOOD low above this threshold
	350	367	380	Vdc	
Hysteresis of Input Voltage Thresholds		1		Vrms L-N	Raises low threshold and lowers high threshold
Line Frequency Low Treshold	-	-	-	Hz	No minumum frequency, MPFIC runs from DC
Line Frequency High Threshold	860	900	940	Hz	INPUT GOOD low above this threshold
Hysteresis of Line Frequency Tresholds		0		Hz	
Low State Output Voltage		0.2	0.4	V	2 mA sink current
Internal Pull-Up Voltage		3.3		V	
Internal Pull-Up Resistance		10		kΩ	
DC GOOD (positive logic)					DC Power Good output
Rising threshold		25		V	DC GOOD high above this threshold
Falling threshold		18		V	DC GOOD low below this threshold
Low State Output Voltage		0.2	0.4	V	2 mA sink current
Internal Pull-Up Voltage		3.3		V	
Internal Pull-Up Resistance		10		kΩ	
PFC ENA (negative logic)					PFC enable input (pull low to enable unit)
Off State Input Voltage	2.4			V	
On State Input Voltage			0.8	V	
Internal Pull-Up Voltage		3.3		V	
Internal Pull-Up Resistance		10		kΩ	
BATTLE SHORT (negative logic)					Battle short input (pull low to disable protection)
Normal State Input Voltage	2.4			V	
Protection-Disabled State Input Voltage			0.8	V	
Internal Pull-Up Voltage		3.3		V	
Internal Pull-Up Resistance		10		kΩ	
3.3V AUX					3.3 V output always on regardless of PFC ENA state
Output Voltage Range	3.19	3.30	3.43	V	Over line, load, temp, and life
Source Current			100	mA	
SYNC OUT					Synchronization output at switching frequency
High State Output Voltage	2.9	3.1		V	4 mA source current
Low State Output Voltage		0.2	0.4	V	4 mA sink current
Switching Frequency	190	196.5	203	kHz	Over temp and life
ISOLATION CHARACTERISTICS					
Any pin to Baseplate			2150	Vdc	Basic Isolation
Pins 2, 3, & 4 to Pins 7 & 9			4250	Vdc	Reinforced Isolation
Pins 2, 3, & 4 to Isolated Control Pins			4250	Vdc	Reinforced Isolation
Capacitance					
Pins 2, 3, & 4 to Baseplate		1		nF	
Pins 2, 3, & 4 to Pins 7 & 9		1		nF	
Isolation Resistance		100		MΩ	
TEMPERATURE LIMITS FOR POWER DERATING CURVES					
Semiconductor Junction Temperature			125	°C	
Board Temperature			125	°C	
Transformer Temperature			125	°C	
Maximum Baseplate Temperature, Tb			100	°C	
Over-Temperature Protection					Measured at surface of internal PCB
Disable Threshold		125		°C	
Warning Threshold		120		°C	Warning causes BATTLE SHORT pin to go high
Enable Threshold		120		°C	

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

Mil-COTS Converter and Filter Screening

Screening	Process Description	S-Grade	M-Grade
Baseplate Operating Temperature		-45 °C to +100 °C	-45 °C to +100 °C
Storage Temperature		-45 °C to +135 °C	-45 °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	-45 °C, +25 °C, +100 °C
Final Visual Inspection	MIL-STD-883F, Method 2009	•	•

Power Topology Overview

As seen in Figure A on page 2, this PFC rectifier takes nominal 115 Vrms (L-N) / 199 Vrms (L-L) 3-phase delta AC, or nominal 270 Vdc, at its LINE A/B/C inputs, and uses an active-PFC buck converter and a Bus Converter to create a regulated isolated DC output. This is a true 3-phase rectifier topology, as opposed to a composite of three single-phase rectifiers. A boost converter between the active PFC and the bus converter's input supports the output during input line sags and brownouts

The term "line-to-neutral (L-N) voltage" is used throughout this document even though this converter does not utilize a neutral wire. If a neutral wire is present in the application, it should not be connected to the PFC.

Performance

Efficiency and Power Dissipation

The efficiency of the converter at 270VDC and 115VAC is shown in Figure 1, the corresponding power dissipation is shown in Figure 2.

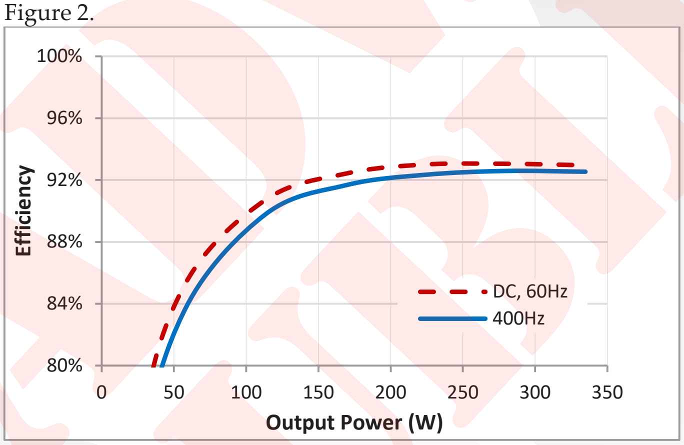


Figure 1: Efficiency vs. output power. Input: 3-phase 115 Vrms (L-N) and 270V DC. Baseplate temperature: 30 °C.

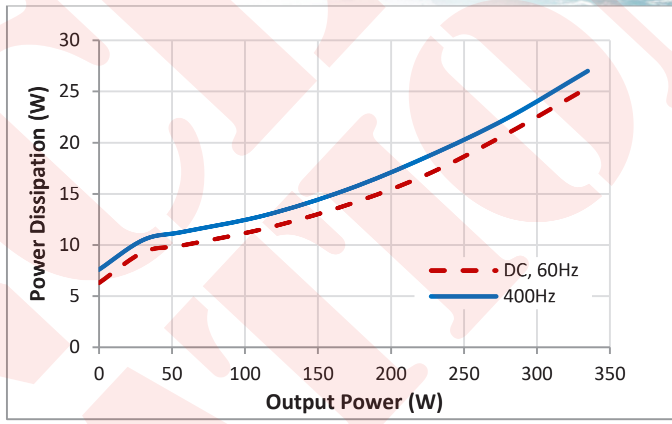


Figure 2: Power dissipation vs. output power. Input: 3-phase 115 Vrms (L-N) and 270V DC. Baseplate temperature: 30 °C.

The efficiency and dissipation are identical with 270VDC or 60Hz AC inputs; with a 400Hz AC input, the dissipation increases about 1.5W, due to the increased (reactive) currents in the input filter damping elements.

Input Current Distortion & Harmonics

Legacy diode rectifier solutions typically use bulky magnetics, while having relatively high distortion at line harmonics. In contrast, this modern PFC rectifier switches at high frequency, providing for very low distortion while using small and light internal magnetics. Active current control yields low harmonic content and well-balanced phase currents, even with phase and/or amplitude imbalance on the line inputs.

Input current harmonic content is minimal above 33% of rated output power, increasing somewhat at light loads due to buck converter discontinuous mode operation (see Figure 3). Input current THD will also increase slightly with higher input voltage.

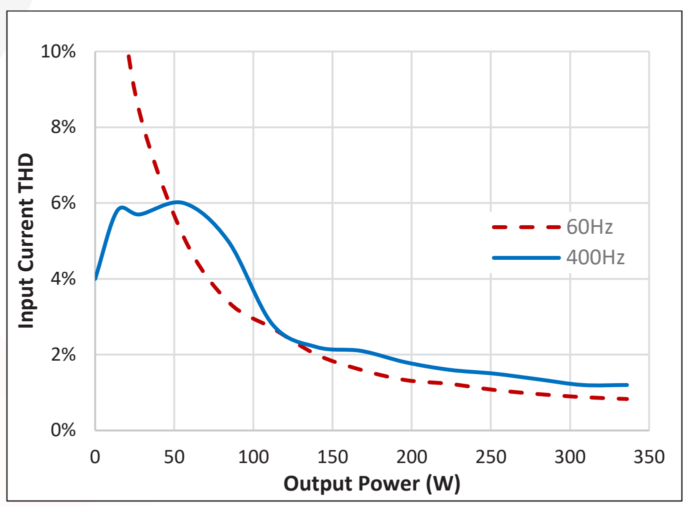


Figure 3: Input current THD over full load range at 115 Vrms (L-N). Includes MACF-115-3PH-UNV-QG external input filter module.

Typical 400Hz line-current harmonics at full power are shown in Figure 4. All are more than 40dB below the fundamental, and indeed all are below the 10mA "disregard" threshold of RTCA DO-160G section 16.7.1.

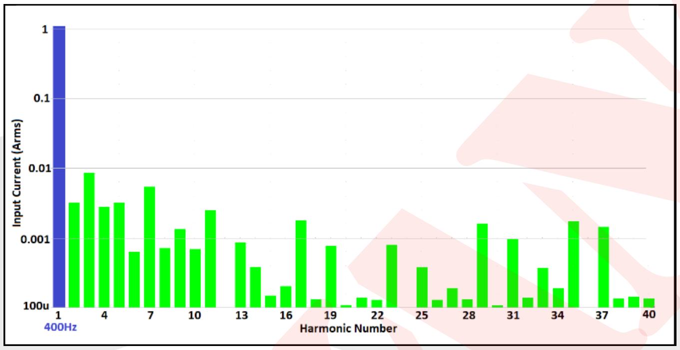


Figure 4: Typical input-current harmonic content. 115 Vrms (L-N) 400Hz, 330W out.

Reactive Power at Fundamental

Line capacitance is necessarily integral to the input EMI filter circuitry, which is divided between internal filtering and the external MACF-115-3PH-UNV-QG input filter module. Total leading reactive power (including that of the external input filter module) scales with line frequency; it is approximately 35 VAR (300mA rms) per phase at 115V rms, 400 Hz.

At all but light loads, however, the PFC actively draws currents that lag input voltage slightly – to cancel the VAR of all the input filter capacitors. This can be seen directly in Figure 5, where, even at 400Hz, at 75% load and above, the input current is in phase with the applied input voltage. Only below 50% load is the leading current due to the filter capacitors evident.

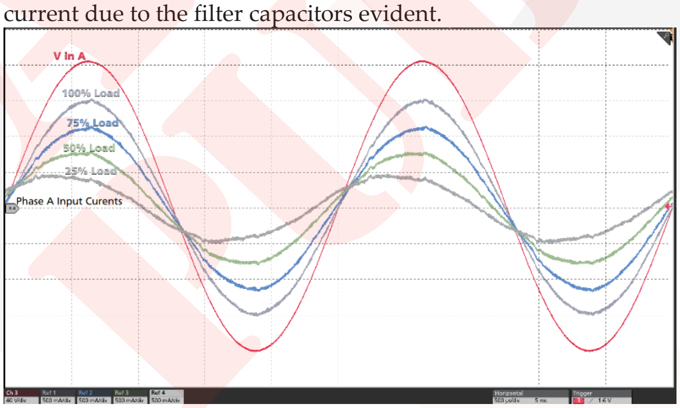


Figure 5: Typical 400 Hz input current waveforms (Phase A shown) at 25%, 50%, 75%, and 100% load. Includes currents in an MACF-115-3PH-UNV-QG external input filter module. 500μs/div.

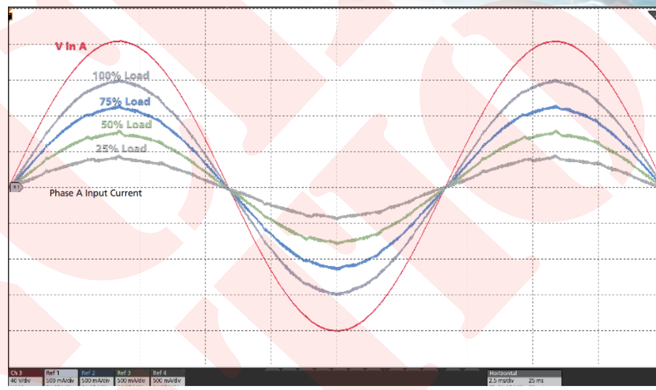


Figure 6: Typical 60 Hz input current waveforms (Phase A shown) at 25%, 50%, 75%, and 100% load. Includes currents in an MACF-115-3PH-UNV-QG external input filter module. 2.5ms/div.

Figure 6 shows that at 60Hz, input currents are in phase with input voltage at all power levels above 25%. Both these results are also illustrated in Figure 7 as leading power factor vs. output power at both 400Hz and 60Hz.

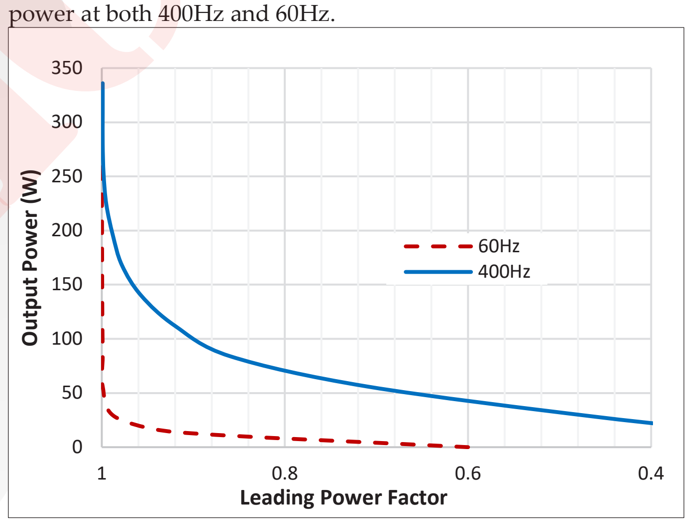


Figure 7: Input leading power factor as a function of operating power level; includes MACF-115-3PH-UNV-QG external input filter module.

At 60Hz, the power factor is essentially unity for all power levels above 50W, while at 400Hz it exceeds 0.95 above 125W and reaches unity at 250W.

Power Circuitry Overview

Inrush and Startup

Only a small amount of EMI capacitance resides before the main switches. The PFC buck topology affords excellent control over startup current. Even very large holdup capacitors can be charged gracefully with an actively controlled current limit (see Figure 7).

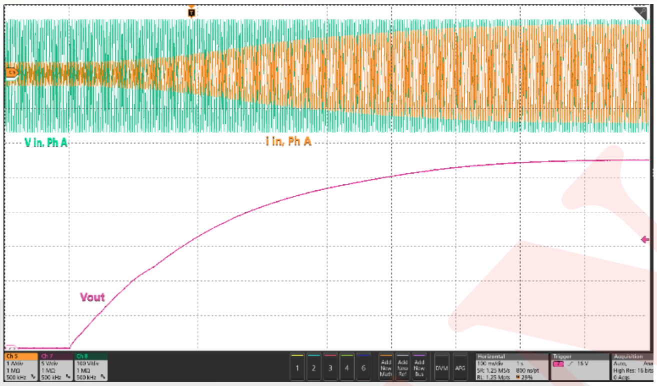


Figure 8: Full-Load (Resistive) startup into 10mF, (for clarity, only Phase A of the input voltage and current are shown). 100 ms/div

Startup will only proceed after the INPUT GOOD signal is high. The unit will turn on when all three of the following conditions are met:

1) the $\overline{\text{PFC ENA}}$ pin is pulled low
2) the input voltage is 100 - 140 Vrms (L-N) or 240 – 350 Vdc.
3) the input frequency is below 800 Hz

Line Transients

The input stage blocks even severe line transients from reaching the output, allowing generous headroom above typical operating input voltage levels. To both keep input current distortion low and facilitate operation from inductive sources, the input impedance is designed to be resistive down to 2 ms timescales. Figure 9 shows the input current and output voltage response to a line-voltage step from 115 Vrms to 140 Vrms and back. The resistive input characteristic requires that the unit initially increase its current draw in response to the increased voltage. This results in a 2ms slug of energy being transferred from the input to the bulk cap at the output.

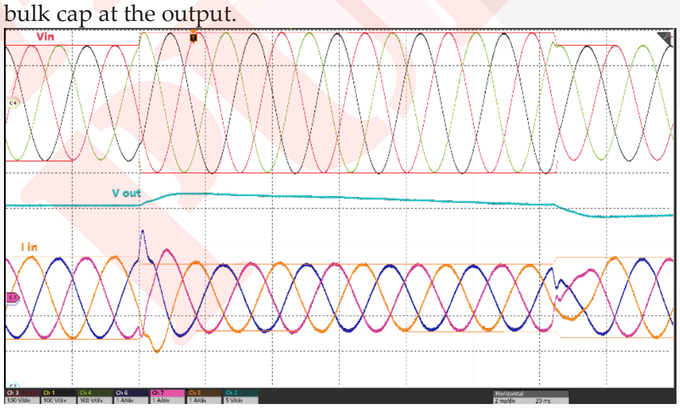


Figure 9: Input current and output voltage response to a 115 Vrms to 140 Vrms line voltage transient. 400Hz, 75% output power, 2ms/div.

Line Frequency and Phase Rotation

The PFC does not use an internal phase-locked loop, allowing seamless fast input frequency transients over the full 45 Hz – 800 Hz operating range.

The unit operates equally well with either ABC or CBA input voltage phase rotation. If Line Frequency is queried over the serial interface, the returned value will be positive for ABC rotation and negative for CBA rotation.

AC Line Brownouts

The PFC can regulate its output indefinitely over the continuous operating range of 100 < Vin < 140 Vrms. When Vin dips below 100 Vrms, or 210 Vdc, an internal boost converter runs briefly to keep the output in regulation. The boost can run for a few seconds (the actual time is determined by line voltage, load, and temperature) after which it is disabled and the output voltage falls to the steady-state value. This behavior is illustrated in Figure 8.

Data TBD

Figure 10: Full Load Output Voltage during Line Brownouts

VOUT Load Transient Response

To maintain low distortion and harmonic content of the input current the regulation response is intentionally quite slow; the recovery time constant from load transient is about 100 ms. Higher-speed load transients must be handled by output capacitance and downstream converters. Figure 10 illustrates the device's load transient response.

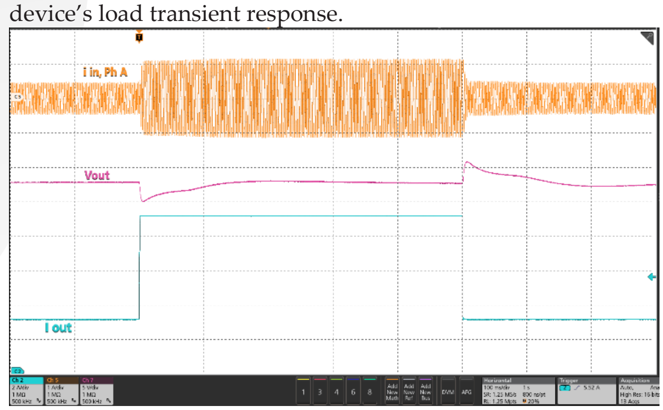


Figure 11: Responses to 25%-75%-25% load transient steps: Cext=10mF. 100 ms/div.

Power Input Pins

Operation from AC Power

115 Vrms (L-N) 3-Phase AC input power is applied to the LINE A, LINE B, and LINE C input pins. The direction of phase rotation (ABC or CBA) does not matter; the inputs can be connected in any order desired.

Operation from DC Power

270 Vdc power can be applied to the LINE A, LINE B, and LINE C input pins in any connection desired; polarity does not matter. 270 Vdc can be applied to only two of the input pins, leaving the third open, but highest efficiency is obtained with the third input pin tied to either of the other two.

The MACF-115-3PH-UNV-QG 3-phase input filter can also be employed with 270 Vdc power. DC polarity is again irrelevant, and again, slightly higher efficiency will result by connecting two of the filter input & outputs together to one side of the 270 Vdc source.

Power Ratings

Thermal Management

Advanced thermal management techniques are employed to create a very low thermal resistance from power devices to baseplate, while retaining SynQor's standard SMT construction and mechanically compliant potting compound. Operating from a 3-phase AC source, the unit can deliver full rated power at baseplate temperatures up to 100°C. Operating from a DC source however, keeping internal temperatures below 125°C requires limiting the output power at baseplate temperatures above 77°C, as shown in Figure 11.

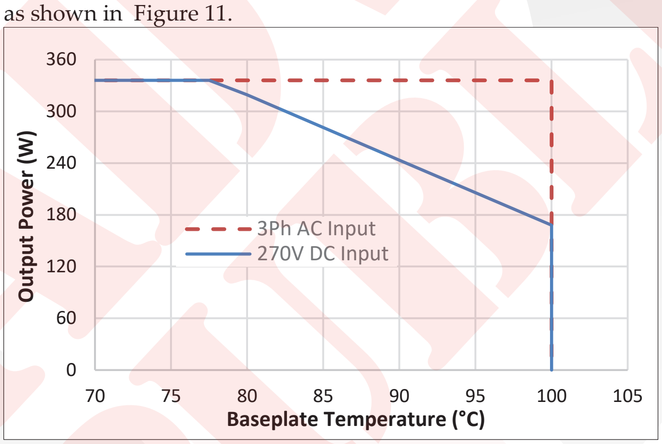


Figure 12: Thermal derating curves for both 115 Vims (L-N) 3-Phase AC and 270 Vdc input power.

Continuous Power Rating

Steady-state output power is rated to 330 W for input line voltages above 100 Vrms (L-N). This is based on a rated output current of 12 A, providing design margin against the (maximum) 16 A current limit specification. As the steady-state output voltage is reduced for input line voltages below 100 Vrms (see Figure 8), the current rating and limits remain constant. Thus, the power rating is reduced proportionately as shown in Figure 11.

Data TBD

Figure 13: Steady-state rated and limit output power vs. AC line voltage.

Note that if the PFC output is driving DC-DC converters that exhibit constant-power characteristic at their inputs, the output voltage will collapse if the PFC's current limit is reached. The collapse rate would be governed by the external output capacitance value. It is therefore recommended to operate the converter at or below rated power in steady state, approaching current limit only during transient events.

Power Interrupts and Holdup

Many systems need to operate through brief interruptions of input power. External capacitors placed at +VOUT can be used to maintain power flow to critical loads during these input power interruptions. Figure 14 shows typical behavior during and after an AC power interruption.

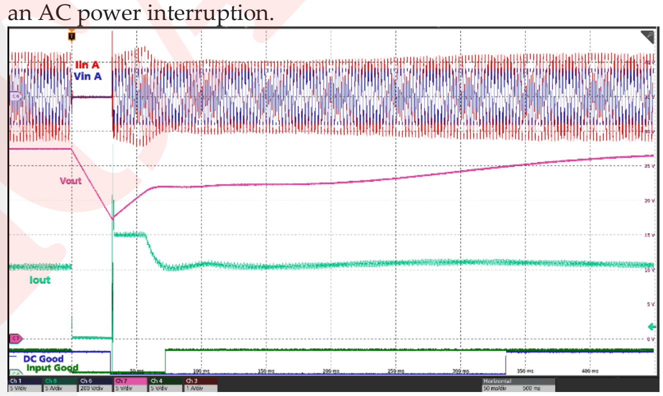


Figure 14: 30 ms power interruption and recovery. 400Hz AC in, 10A out, Cext=27mF. 50ms/div.

- During the 30ms interrupt, output current drops to 0A.
    - INPUT_GOOD is set low immediately.
    - The 10A load current is supplied by 27mF external capacitor
        - Output voltage falls from 28V to 17V as the capacitor is discharged.
    - When the output voltage crosses 18V, DC_GOOD is set low.
- When input power returns, the MPFIC operates at output current limit (~16A) to support the load and to recharge the external capacitor to 85% of nominal output voltage (~24V) as quickly as possible.
- Once the 85% level is reached, the MPFIC reduces powerflow and raises the output back to nominal voltage gently.
- 40ms after the input power returns, INPUT_GOOD is set high.
- As the output voltage crosses 25V, DC_GOOD is set high.

Holdup Capacitor Value

During an AC dropout of a given duration, the load is supplied from the bulk cap. The dropout is characterized by its energy.

$$E_{holdup} = P_{out} \cdot t_{drop}$$

where:

P_{out} is the output power during the holdup event, and
t_{drop} is the duration of the input power interruption.

Based on this energy requirement, the holdup capacitor value is

$$C_{holdup} > \frac{2 \cdot E_{holdup}}{(V_s^2 - V_f^2)}$$

where:

V_s is the initial holdup capacitor voltage immediately before the input power interruption, and
V_f is the minimum capacitor voltage during the transient.

V_f should be chosen to be above the minimum acceptable voltage for the loads attached.

The required value for C can become quite large if the PFC's entire load is to be maintained through long dropouts. In this case it may be valuable to partition the load into portions that need to be maintained and other portions that can be briefly interrupted. The INPUT GOOD signal can be used to gate power to non-critical loads.

External Capacitor Selection

Capacitors connected externally at +VOUT, should be rated for higher than the output voltage of the module used. Standard aluminum electrolytic capacitors have several significant drawbacks:

1) Narrow temperature ratings
2) Relatively high ESR at room temperature
3) Very high ESR at low temperature
4) Poor reliability at high temperature

Conductive polymer solid electrolytic capacitors solve all four of these problems at the expense of somewhat lower energy density:

1) Rated for full -55 °C to 125 °C temperature range
2) Good ESR at room temperature
3) Rated to maintain good ESR at low temperature
4) Much better reliability

Protection Features

Over-Temperature Shutdown

An internal sensor monitors the temperature of the PFC's internal PCB. If the sensed value exceeds 115 °C the $\overline{\text{BATTLE SHORT}}$ pin is released; if it exceeds 125 °C the unit will disable itself. The OTP shutdown can be disabled by externally holding the $\overline{\text{BATTLE SHORT}}$ pin low. When the internal temperature cools below 115 °C, $\overline{\text{BATTLE SHORT}}$ is internally driven low again and the PFC restarts automatically. See also the description of the $\overline{\text{BATTLE SHORT}}$ pin.

Input Phase Imbalance Shutdown

If the 3-phase AC input voltage should become excessively imbalanced (more than 35 Vrms amplitude or 18° angle imbalance), the INPUT GOOD pin will be de asserted and $\overline{\text{BATTLE SHORT}}$ pin will be released. Input phase drop events also appear as excessive imbalance. The PFC will attempt to maintain power flow during this imbalance for 0.25 seconds before shutting down to protect itself, the load, and/or the source. This shutdown can be disabled by externally holding the $\overline{\text{BATTLE SHORT}}$ pin low. When the AC line voltage returns to normal limits, $\overline{\text{BATTLE SHORT}}$ will be internally driven low again and the PFC will restart automatically. See also the description of the $\overline{\text{BATTLE SHORT}}$ pin.

Short Circuit Current Limit

In most overload conditions, the linear output current limit is sufficient to protect the unit. A backup "short-circuit current limit" circuit, however, handles severe input transients or output short-circuit events. Redundant current sense resistors and comparators are connected in series with both the positive and negative sides of the buck PFC stage, set to trip well above the linear current limit threshold. When this backup protection is activated, the unit will respond by turning off all power flow from the input for approximately 200 is, after which normal operation resumes immediately.

Input Over-Voltage Protection

If the instantaneous voltage between any two line inputs goes above the threshold of 500 V (L-L), then all power flow from the input will be interrupted, resuming 1 ms after the input voltage falls again below the same threshold. (Voltage spikes shorter than 80 µs may not trigger this protection response.) During an interruption, the output voltage will fall at a rate determined by capacitance and load current.

Input Under-Voltage Shutdown

The input voltage must be above 100 Vrms (L-N) or 220 Vdc to activate INPUT GOOD and allow the unit to start up. If the input voltage subsequently drops below 50 Vrms (L-N) or 122 Vdc for more than 1 second the unit will shut down. The unit will remain off for at least 1 second.

Output Over-Voltage Protection

A redundant hardware over-voltage protection circuit will momentarily disable the PFC if the output ever rises more than 10% above its nominal value. The unit resumes normal operation immediately after the output voltage returns below this threshold.

Output Under-Voltage Shutdown

Should the action of the current limit reduce the output voltage to less than 25% of nominal for more than 150 ms, the unit will assume a sustained overload and will shut down. Auto-restart will occur after 1 second. This feature is also present during startup and thus serves to limit energy delivered into a shorted output.

EMI Recommendations

Input Filtering

As shown in Figure A, it is recommended to pair the PFC module with the separately available MACF-115-3PH-UNV-QG quarter brick 3-phase AC input filter module.

Conducted Emissions Measurements

The MPFIC-115-3PD-28R-FG, 28 V PFC module paired with an MACF-115-3PH-UNV-QG, 3-Phase AC input line filter was demonstrated to pass MIL-STD-461 CE101 and CE102 requirements. Key measurements are presented below; the full test report is available from SynQor.

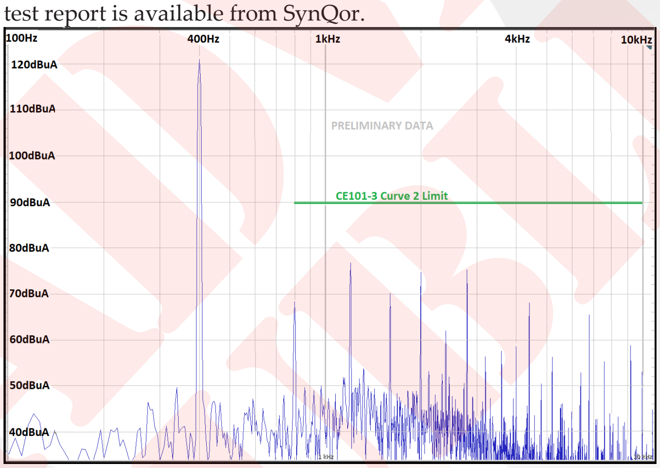


Figure 15: CE101 data at 400 Hz, 330 W output power (Phase A; Phases B & C are similar)

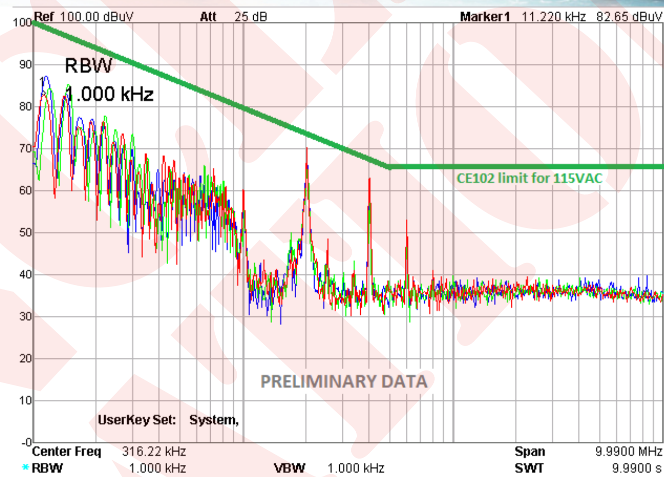


Figure 16: CE102 data at 400 Hz, 330 W output power (Phases A, B, & C)

Input Protection

The input stage implemented in this module offers far better immunity from input surges than a traditional boost topology. In a traditional boost PFC, there is no mechanism to limit current flow directly from input to output during operation, so for long duration surges, the current becomes very large and results in permanent destruction. In contrast, the buck PFC input stage used in this module is able to interrupt current flow during a voltage surge which dramatically lowers device stresses.

The PFC input lines, however, must be protected from spikes which might exceed their 575 Vpk (L-L) absolute-maximum rating. It is recommended to add external protection devices directly between the three pairs of PFC line input pins. Figure A shows an example input protection circuit consisting of clamping devices connected line-line in a "delta" configuration, one set before and one set after the external MACF-115-3PH-UNV-QG input filter module. The set of Metal Oxide Varistors (MOVs) upstream of the filter prevent local arcing during a surge event due to input wiring inductance. These MOVs have a "soft" breakdown characteristic: at high currents they will clamp at a relatively high voltage. The set of special TVS devices downstream of the filter module have far superior characteristics. These AK3-430C devices made by Littelfuse (or equivalent Bourns PTVS-430C-TH) have superb clamping voltage: even at high currents they hold the input voltage below the 575 Vpk (L-L) absolute maximum specification of the PFC module. These devices also have high energy capability: whereas standard TVS devices have a relatively small die, the AK3 series parts have many large dies stacked on top of each other. This allows the AK3 to withstand very high energy repetitive transients without damage. Protection devices in the end user application should be tailored to the expected surge requirements. Fuses rated for 5 A are recommended in series with each input line, located upstream of the input filter and MOVs.

Baseplate Electrical Connection

All circuitry in the PFC module is electrically isolated from the baseplate with a multi-layer solid insulator. This isolation barrier meets basic insulation requirements and is 100% hi-pot tested in production to 1500 Vrms. The baseplate and corner mounting posts may therefore be connected to protective earth ground in the application circuit. Maintain adequate clearance from all external circuitry to the four corner mounting posts, which are electrically connected to the baseplate.

Safety Notes

The PFC provides reinforced isolation across its input and output terminal pins. Care must be taken to avoid contact with primary-side voltages, as well as with the AC source voltage.

The MPFIC must have an input current limiting device. The Technical Application diagrams show fuses used in series with the AC or DC source.

Control Pins

3 kV of reinforced isolation is provided between all control pins and the power pins. They can be externally referenced to the input power system, the output system, or another isolated system of the users design.

RESERVED (Pin A1)

Pin A1 is not used and should be left floating.

CTL RETURN (Pin A2)

CTL RETURN serves as the ground reference for all control signals.

SERIAL IN (Pin A3)

A wide variety of operating parameters (voltages, currents, temperatures) may be accessed via the built-in full-duplex asynchronous serial interface. Commands may be transferred to the internal DSP via the SERIAL IN pin at 9600 baud (8N1 – 8 data bits, no parity, 1 stop bit). A `start' or `zero' bit is encoded as a logic low. The internal baud rate will be exactly 20.48 times slower than the SYNC OUT frequency. The tolerance of both frequencies is better than +/- 2%. The frequency tolerance of the external interface circuit should also be better than +/- 2% accuracy to ensure that the last bit of incoming serial data arrives within the proper frame time. Alternatively, the SYNC OUT signal may be used to continuously calibrate the baud rate of the external interface circuit, allowing the use of a less accurate oscillator.

The SERIAL IN pin may be left open if unused, and will be internally pulled up to 3.3V AUX, corresponding to the `idle' or `stop' state. Internal circuitry is shown in Figure 14. Direct connection may be made to an external microcontroller, but an external transceiver IC is required to shift levels and polarity to drive from a standard RS-232 port (see evaluation board schematic). See the separate "SynQor 3-Phase Input PFC Serial Interface" companion document for detailed command syntax (available at www.synqor.com//3-Phase_Input_PFC_Serial_Interface.).

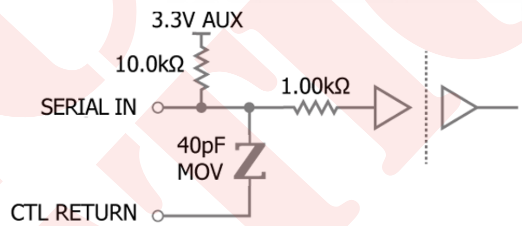


Figure 17: Internal circuitry for SERIAL IN pin.

SERIAL OUT (Pin A4)

A response to each command is sent via the SERIAL OUT pin at 9600 baud (8N1 – 8 data bits, no parity, 1 stop bit). The output is low for a `start' or `zero' bit. When not transmitting, the output is high, corresponding to the `idle' or `stop' state. Internal circuitry is shown in Figure 20. Direct connection may be made to an external microcontroller, but an external transceiver IC is required to shift levels and polarity to drive a standard RS-232 port (see evaluation board schematic). See the separate "SynQor 3-Phase Input PFC Serial Interface" companion document for detailed command syntax (available at www.synqor.com//3-Phase_Input_PFC_Serial_Interface.).

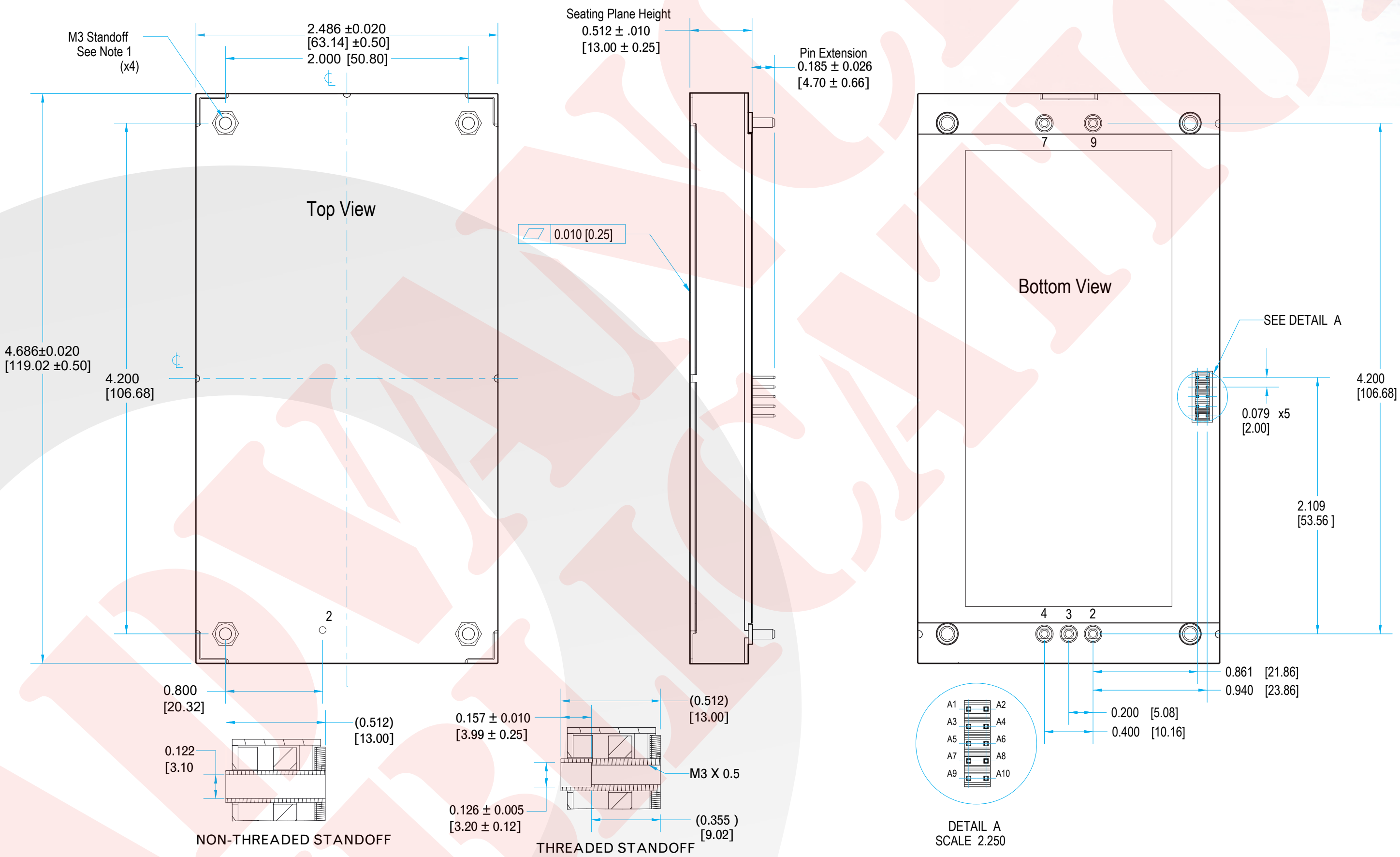
INPUT GOOD (Pin A5)

The unit will not turn on until the positive-logic INPUT GOOD output is high, typically for line inputs between 96 Vrms (L-N) and 148 Vrms (L-N), or 220 to 340 Vdc. When the unit is already running, the INPUT GOOD output will typically transition low when the input voltage (at the PFC input pins) goes below 95 Vrms (L-N) or 235 Vdc, or above 149 Vrms (L-N), 340 Vdc. Instantaneous line-to-line voltage measurements are used, so these voltage thresholds will be affected by imbalance in line phase and/or amplitude.

INPUT GOOD also responds to input line frequency. If the input line frequency goes above 900 Hz, INPUT GOOD will transition low.

INPUT GOOD generally only serves as a power interruption warning: the unit will continue to run if INPUT GOOD transitions low, the only exception being an excessive input phase imbalance. During the imbalance, the PFC will attempt to maintain power flow for 0.25 seconds before shutting down to protect itself, the load, and/or the source, unless this function is overridden by $\overline{\text{BATTLE SHORT}}$ (see "Input Phase Imbalance Shutdown" section).

The response time of INPUT GOOD to an input power interruption is less than 1 ms at 400 Hz and less than 5 ms at 60 Hz. INPUT GOOD will return to its normal high state 20 ms after the



NOTES:

1. APPLIED TORQUE PER M3 SCREW SHOULD NOT EXCEED 6 in-lb (0.7 Nm)
2. BASEPLATE FLATNESS TOLERANCE IS 0.010” (0.25 mm) TIR FOR SURFACE.
3. PINS 2-4, AND 7, AND 9 ARE 0.080” (2.03 mm) DIA. WITH 0.125” (3.18 mm) DIA. STANDOFF SHOULDERS MATERIAL: COPPER ALLOY. FINISH: MATTE TIN OVER NICKEL PLATE.
4. PINS A1-A10 ARE 0.020” X 0.020” (0.51mm X 0.51mm) MATERIAL: PHOSPHOR BRONZE, FINISH: GOLD FLASH OVER NICKEL UNDERPLATING.
5. THREADED OR NON-THREADED OPTIONS AVAILABLE
6. UNDIMENSIONED COMPONENTS ONLY FOR VISUAL REFERENCE
7. ALL DIMENSIONS IN INCHES (mm)
   TOLERANCES: X.XX IN +/-0.020 (X.X mm +/-0.5 mm)
   X.XXX IN +/-0.010 (X.XX mm +/-0.25 mm)
8. WEIGHT: 11.3 oz (320 g)

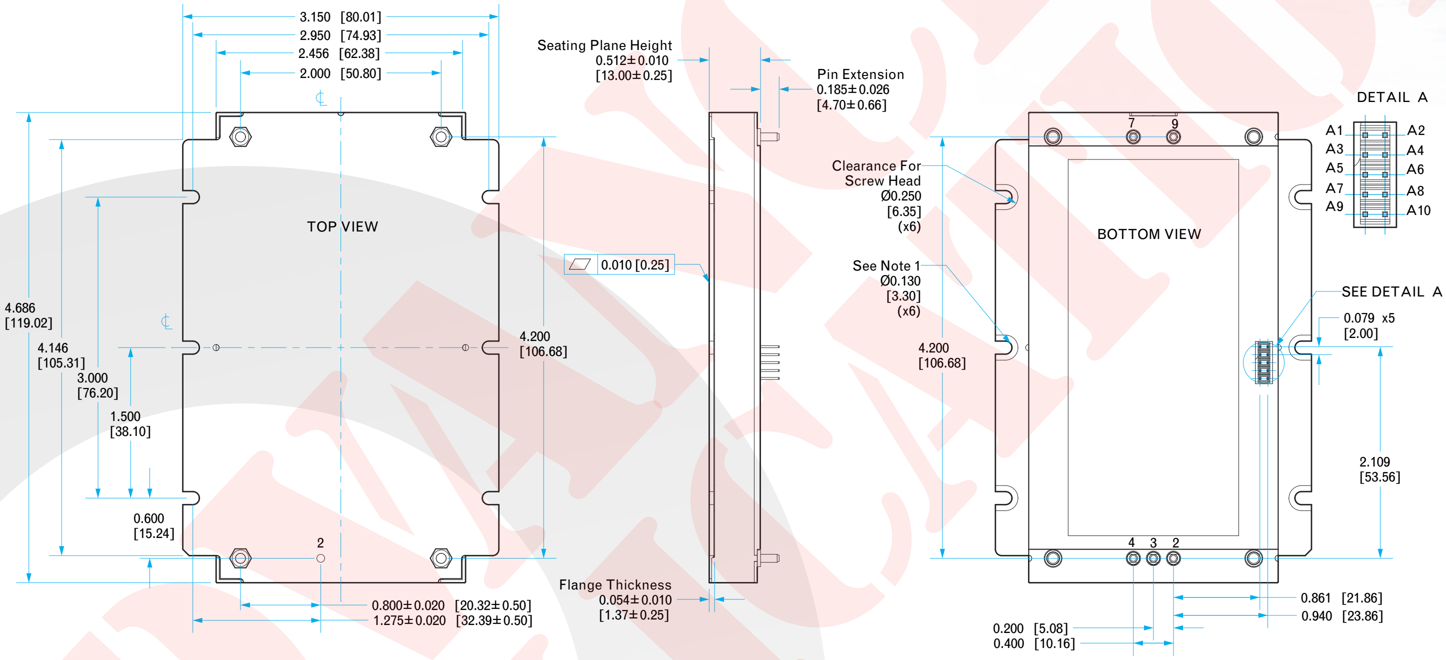
PIN DESIGNATIONS

Pin	Label	Name	Function
2	LINE A	LINE A	AC Line A Input
3	LINE B	LINE B	AC Line B Input
4	LINE C	LINE C	AC Line C Input
7	-VOUT	VOUT(−)	Negative Return for +VOUT
9	+VOUT	VOUT(+)	Positive Boost Output Voltage
A1	RESERVED	RESERVED	No Connect
A2	CTL RETURN	CTL RETURN	Isolated Ground Reference for Pins A1 - A10
A3	SERIAL IN	SERIAL IN	Serial Data Input (High = Stop/Idle)
A4	SERIAL OUT	SERIAL OUT	Serial Data Output (High = Stop/Idle)
A5	INPUT GOOD	INPUT GOOD	Input Power Good Output (High = Good)
A6	DC GOOD	DC GOOD	DC Power Good Output (High = Good)
A7	PFC ENA	PFC ENA	Pull Low to Enable Unit
A8	BATTLE SHORT	BATTLE SHORT	Pull Low to Disable OTP / Phase Drop Shutdown
A9	3.3V AUX	3.3V AUX	3.3V @ 100mA Always-On Power Output
A10	SYNC OUT	SYNC OUT	Switching Frequency Synchronization Output

MPFIC-115-3PD-28R-FG

Input: 3Φ 115 Vrms (L-N) or 270 Vdc
Output: 28 Vdc
Power: 330W

Encased Mechanical with Flange



NOTES:

1. APPLIED TORQUE PER M3 OR 4-40 SCREW SHOULD NOT EXCEED 6 in-lb (0.7 Nm)
2. BASEPLATE FLATNESS TOLERANCE IS 0.010" (0.25 mm) TIR FOR SURFACE.
3. PINS 2-4, 7 AND 9 ARE 0.080" (2.05 mm) DIA. WITH 0.125" (3.18 mm) DIA. STANDOFF SHOULDERS.
   MATERIAL: COPPER ALLOY. FINISH: MATTE TIN OVER NICKEL PLATE.
4. PINS A1-A10 ARE 0.020" X 0.020" (0.51mm X 0.51mm)
   MATERIAL: PHOSPHOR BRONZE, FINISH: GOLD FLASH OVER NICKEL UNDERPLATING
5. UNDIMENSIONED COMPONENTS ONLY FOR VISUAL REFERENCE
6. ALL DIMENSIONS IN INCHES (mm)
   TOLERANCES: X.XX IN +/-0.020 (X.X mm +/-0.5 mm)
   X.XXX IN +/-0.010 (X.XX mm +/-0.25 mm)
   X.XXX IN +/-0.010 (X.XX mm +/-0.25 mm)
7. WEIGHT: 11.6 oz (326 g)

PIN DESIGNATIONS

Pin	Label	Name	Function
2	LINE A	LINE A	AC Line A Input
3	LINE B	LINE B	AC Line B Input
4	LINE C	LINE C	AC Line C Input
7	-VOUT	VOUT(–)	Negative Return for +VOUT
9	+VOUT	VOUT(+)	Positive Boost Output Voltage
A1	RESERVED	RESERVED	No Connect
A2	CTL RETURN	CTL RETURN	Isolated Ground Reference for Pins A1 - A10
A3	SERIAL IN	SERIAL IN	Serial Data Input (High = Stop/Idle)
A4	SERIAL OUT	SERIAL OUT	Serial Data Output (High = Stop/Idle)
A5	INPUT GOOD	INPUT GOOD	Input Power Good Output (High = Good)
A6	DC GOOD	DC GOOD	DC Power Good Output (High = Good)
A7	PFC ENA	PFC ENA	Pull Low to Enable Unit
A8	BATTLE SHORT	BATTLE SHORT	Pull Low to Disable OTP / Phase Drop Shutdown
A9	3.3V AUX	3.3V AUX	3.3V @ 100mA Always-On Power Output
A10	SYNC OUT	SYNC OUT	Switching Frequency Synchronization Output

MPFIC-115-3PD-28R-FG

Input: 3Φ 115 Vrms (L-N) or 270 Vdc
Output: 28 Vdc
Power: 330W

Ordering Information

Part Numbering Scheme						
Family	**Input Voltage**	**Output**	**Regulation**	**Package Size**	**Thermal Design**	**Screening Level**
MPFIC	**115-3PD:** 3-Phase 115 Vrms L-N, or 270 Vdc	**12:**12V **24:** 24V **28:** 28V **48:** 48V **54:** 54V	**R:** Regulated output	**FG:** Full-brick Giga	**N:** Normal Threaded **D:** Non-Threaded **F:** Flanged Baseplate	**S:** S-Grade **M:** M-Grade

Example:MPFIC-115-3PD-28R-FG-N-M

PART NUMBERING SYSTEM

The part numbering system for SynQor's ac-dc converters follows the format shown in the example.

APPLICATION NOTES

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

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

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

WARRANTY

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

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:

7,765,687 7,787,261

8,149,597 8,644,027