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THERMOELECTRIC CONVERSION SYSTEMS

KM3 Series

Revised June 2018

100W Maximum Power Point Tracking Converter for Thermoelectric Generators

The KM3 converter builds on the reliable performance of the KM2 converter, considerably expanding input and output operating range and power rating. A proprietary algorithm ensures top-level MPPT performance during both transients and steady thermal conditions. An optional touchscreen display shows input/output current and voltage measurements.

Operational Features

- Interface to & charge of **12V or 24V** batteries at the output
- **Innovative** MPPT method for effective tracking of steady-states and transients
- Low heat dissipation due to Electrical Efficiency up to **98.3%**
- Wide Input Voltage range: **2V – 75V** with 100V input/output voltage transient capability
- Fixed frequency switching provides predictable EMI performance
- Delivers in excess of **150 W** Output Power with Natural Convection (See Fig. 13)

Control and Communication Features

- **I2C** Communication Interface for measurement data, limits and control
- Analogue Input and Output Current **measurement** outputs
- Optional Touch-Screen **Display** with Input/Output voltage, current and power information
- **Seamless** operation with the monTEG device (if used)
- Forced MPPT (within battery safe limits) or battery charging management modes

Mechanical Features

- Available with screw **connectors** or with headers for easy integration to the backplane
- Dimensions: **85 x 65 x 25 mm^3**
- Total weight: **100 grams**
- Side notches ensures reliable mechanical connection to the backplane during vibrations

Protection Features

- Input under-voltage lockout and output under/over voltage and current limit
- Input/output reverse voltage protection (external fuse required to prevent damage)
- Thermal shutdown protects the KM3 converter from abnormal environmental conditions

Quick Description

The KM3 converter is a Maximum Power Point Tracking (MPPT) converter for thermoelectric power generating arrays (TEGs). It operates the TEGs at their optimal operating point and efficiently transfers electricity to the necessary output battery (not included). Battery charging management improves the state of charge of the output battery and can be deactivated by jumper selection. 12V and 24V batteries are currently supported and 48V batteries will be supported from the beginning of 2018.

The proprietary MPPT algorithm tracks fast thermal transients and recognises steady states to increase the thermal-to-electrical efficiency of the system. The KM3 converter interfaces TEGs whose voltage can be either lower or higher than that of the output battery. It starts its voltage step-up operation with input voltages as low as 2V and continues harvesting electrical power provided that the TEG open-circuit voltage does not exceed 85V. The KM3 converter uses synchronous rectification to operate in Boost, Buck-Boost or Buck modes. Its innovative construction design minimises heat dissipation and EMI and allows extremely high power densities. No external heat-sink is required and all components are mounted on the top-side of the PCB.

The KM3 converters can communicate to other devices through I^2C. It answers to an I^2C master using the TCS communication protocol, based on the PMBus protocol. An optional touch-screen display shows input and output voltage, current and power and controls the operation of the converter.

Diagram of Connections

The KM3 requires a 12V or 24V battery at the output. Please refer to Fig. 1 and Fig. 2 for the connection diagrams. The output is not isolated from the input, *i.e.* TEG- is connected to BAT-.

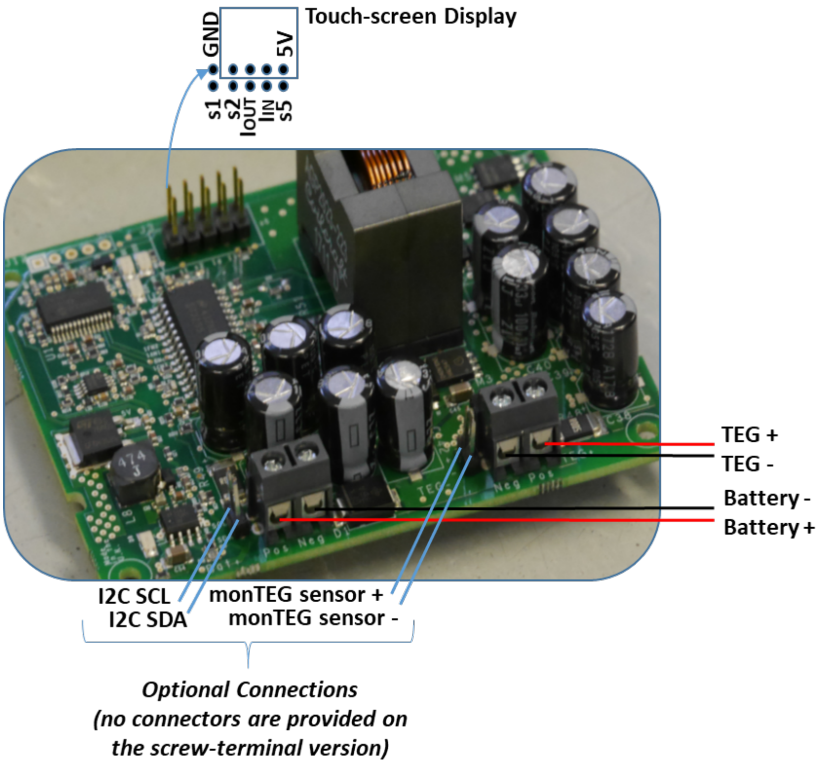

Figure 1: Diagram of connections to the KM3 converter with screw connectors

KM3-series: MPPT Converter for TEGs

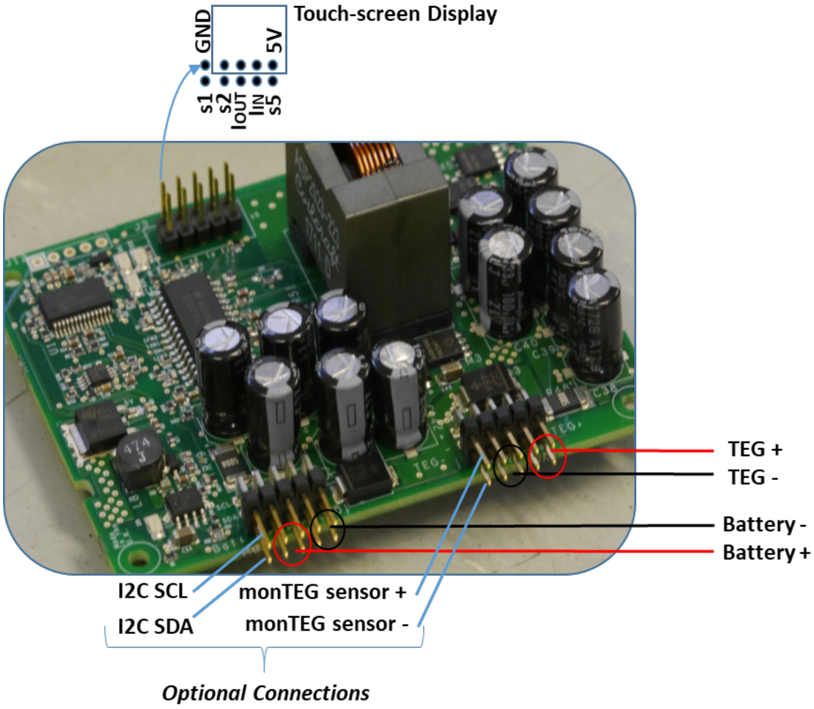

Figure 2: Diagram of connections to the KM3 converter with pin headers connectors

- A jumper shorting s1 to GND activates jumpers s2 and s5 which can be used when no screen is connected. A jumper shorting s2 to GND selects 24V batteries (default is 12V). A jumper shorting s5 to 5V enables "always MPPT"-mode with hard limits at Minimum and Maximum Output Voltages for turn-on (default is battery management). (Jumpers are not provided)

- The KM3 does not require any information about the TEG devices to which it is connected, i.e. it automatically selects the operating point. It optimises systems using the monTEG (sold separately by TCS) connected to the KM3 monTEG sensor +/- connectors.

- Iout and Iin are buffered analogue values representing the output current and input current, respectively, scaled by 4. Hence, to obtain the "real" value, multiply it by 4.

- The touch-screen display is sold separately by TCS. It must be connected as per Fig. 2. The KM3 checks for screen connection every 60 sec. The screen provides measurement data (input/output current/voltage/power) and options to enable features and set parameters.

- The monTEG sensor's positive and negative terminals should be left unconnected if a monTEG device is not used. Depending on the KM3 version purchased, to properly operate with the monTEG device the KM3 code might need to be upgraded or the related option selected using the touch-screen display.

Display Operation

The display, available on request, shows the operating values of the converter and the TEG array connected to it. It also allows setting operational parameters: battery voltage type, use of monTEG pellets measurement, battery management and turn on/off and I2C address.

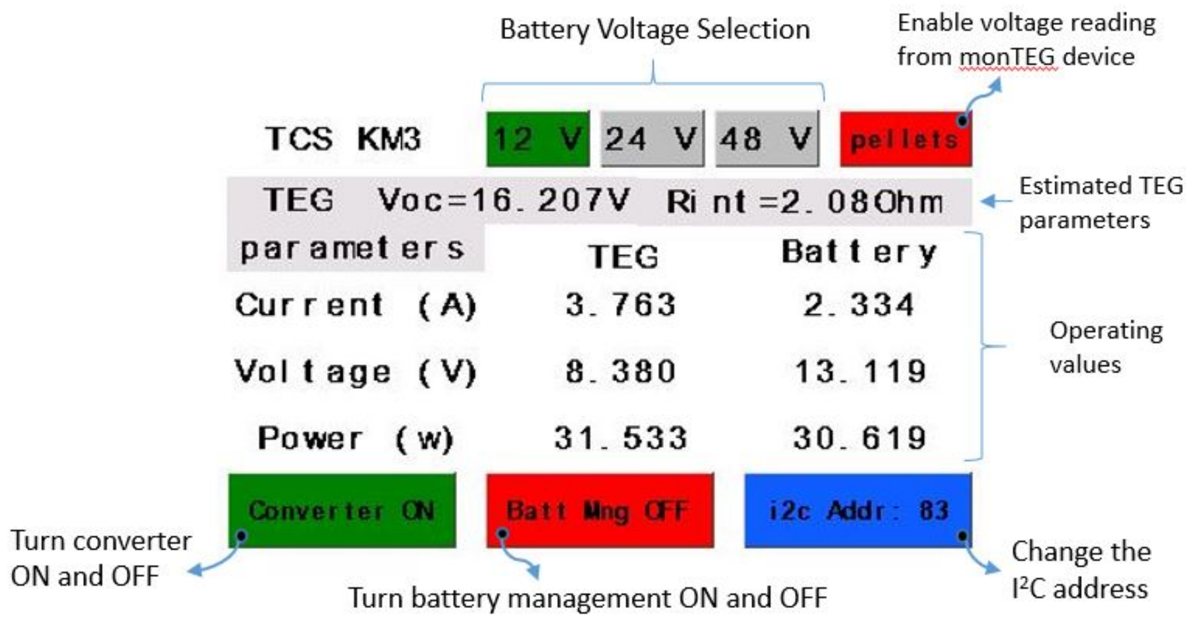

Figure 3: Description of screen operation.

Electrical Characteristics

T_A = 23 ˚C, no forced airflow; specifications subject to change without notice.

Absolute Maximum Ratings

	Value		
	Min	**Max**	**Unit**
Input Voltage Open-circuit	-0.5	100	V
Input Voltage At-load	1.5	80	V
Output Voltage	10	100	V
Input power	0	150** (225*)	W
Input Current	0	12**	A
Output Current	-0.15	12***	A
Operating Temperature	-25	95	˚C
Storage Temperature	-40	110	˚C

** With 10 CFM Forced Air Cooling*

*** This value can be sinked only for certain input electrical conditions, please refer to the "Typical Characteristics" section of this document*

**** This value can be sourced only for certain output electrical conditions, please refer to the "Typical Characteristics" section of this document*

General Electrical Characteristics

Minimum Input Open-circuit voltage for turn-on	3	V
Maximum Input Open-circuit voltage for turn-on	85	V
Off-state Power Consumption Without Display	< 0.25	W
Off-state Power Consumption With Display	< 1.6	W
Maximum Output Peak-Peak Voltage Ripple	2*	%
Maximum Input Peak-Peak Voltage Ripple	2	%
Switching Frequency	125	kHz
Maximum Thermal Transient Tracking Frequency	1	Hz
MPPT Efficiency in Steady-State	Constant temperature 99.85	%
	Constant heat 104.7	%
MPPT Efficiency during Thermal Transients	98.7	%
	1	Hz

** This value reduces to 1% when the KM3 converter is mounted on a TCS Backplane*

Electrical Characteristics for 12V-Battery Output (Vbat)

Minimum Output Voltage for turn-on	10.2	V
Maximum Output Voltage for turn-on	14.4	V
Off-state Power Consumption Without Display	0.2	W
Off-state Power Consumption With Display	1	W
Maximum Input Peak-Peak Voltage Ripple	Buck-Boost & Buck 2	%
	Boost 0.5	%
Maximum Output Peak-Peak Voltage Ripple	Buck-Boost & Buck 2*	%
	Boost 0.5	%
Minimum Input Open-circuit voltage for turn-on	3	V
Boost to Buck-Boost Transition	Approx. (Vbat – 1.75)	V
Buck-Boost to Boost Transition	Approx. (Vbat – 2.5)	V
Buck-Boost to Buck Transition	Approx. (Vbat + 2.5)	V
Buck to Buck-Boost Transition	Approx. (Vbat + 1.75)	V
Maximum Output Current	12.5	A
Trickle Charge Output Current	0.2	A
Battery Low-voltage range for trickle charge	10.2 – 10.8	V
Battery Voltage threshold for charge management	13.8	V
Electrical Efficiency in Boost Mode	10% Rated Power 94.5	%
	50% Rated Power 96.9	%
	100% Rated Power 96.2	%
Electrical Efficiency in Buck-Boost Mode	10% Rated Power 93.5	%
	50% Rated Power 94.1	%
	100% Rated Power 93.2	%
Electrical Efficiency in Buck Mode	10% Rated Power 95.6	%
	50% Rated Power 97.0	%
	100% Rated Power 96.7	%

** This value reduces to 1% when the KM3 converter is mounted on a TCS Backplane*

Electrical Characteristics for 24V-Battery Output (Vbat)

Minimum Output Voltage for turn-on		20.4	V
Maximum Output Voltage for turn-on		28.8	V
Off-state Power Consumption Without Display		0.22	W
Off-state Power Consumption With Display		1.2	W
Maximum Input Peak-Peak Voltage Ripple	Buck-Boost & Buck	2	%
	Boost	0.5	%
Maximum Output Peak-Peak Voltage Ripple	Buck-Boost & Buck	2*	%
	Boost	0.5	%
Minimum Input Open-circuit voltage for turn-on		6	V
Boost to Buck-Boost Transition		Approx. (Vbat – 2.5)	V
Buck-Boost to Boost Transition		Approx. (Vbat – 3.5)	V
Buck-Boost to Buck Transition		Approx. (Vbat + 3.5)	V
Buck to Buck-Boost Transition		Approx. (Vbat + 2.5)	V
Maximum Output Current		7.5	A
Trickle Charge Output Current		0.2	A
Battery Low-voltage range for trickle charge		20.4 – 21.6	V
Battery Voltage threshold for charge management		27.6	V
Electrical Efficiency in Boost Mode	10% Rated Power	94.5	%
	50% Rated Power	96.9	%
	100% Rated Power	96.2	%
Electrical Efficiency in Buck-Boost Mode	10% Rated Power	93.5	%
	50% Rated Power	94.1	%
	100% Rated Power	93.2	%
Electrical Efficiency in Buck Mode	10% Rated Power	95.6	%
	50% Rated Power	97.0	%
	100% Rated Power	96.7	%

** This value reduces to 1% when the KM3 converter is mounted on a TCS Backplane*

Typical Characteristics

All tests are carried out with the equipment setup shown in Fig. 2. The input power supply unit (PSU) in series with a power resistor emulates the electrical characteristic of a TEG. The output battery is emulated by the output PSU with electronic load in parallel to the KM3 output. The open-circuit voltage measurement (VOC) and the input TEG current (IIN) are measured by the input PSU. The input (VTEG) and output (VBAT) voltages are measured by a Keysight 34972A datalogger, which also measures the voltage drop across a high-precision 1mΩ sense resistor in line with the output (“A” in Fig. 3). When using a similar test setup the electronic load is set in current mode to a value greater than the maximum output current expected to be generated by the KM3 converter. Concurrently, the output PSU current setting is greater than this value to provide power to the electronic load when the (TEG) input is off.

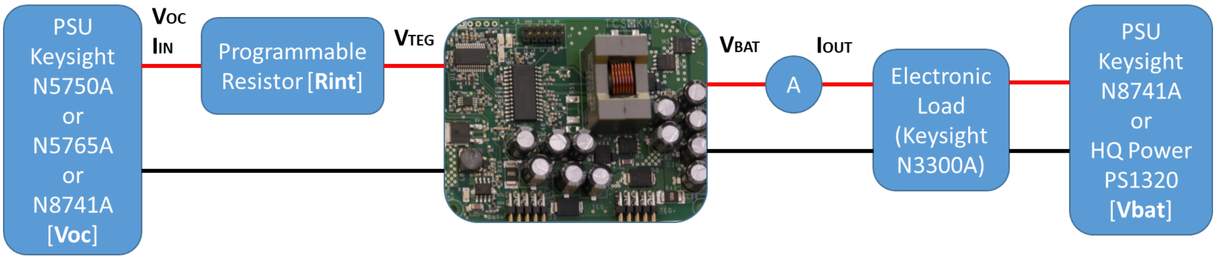

Figure 4: Test Setup for all measurements carried out on the KM3 converter.

Electrical Efficiency

T_A = 23 ˚C, no forced airflow, KM3 PCB located directly on top of a cardboard surface; specifications subject to change without notice.

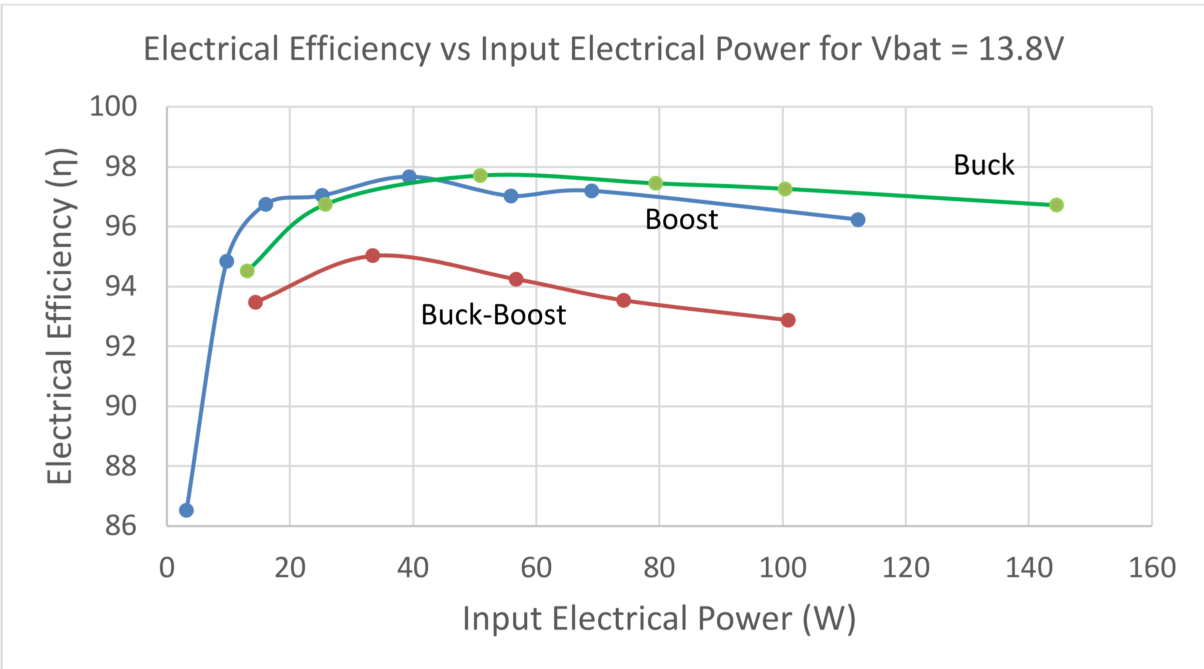

Figure 5: η vs P_{IN} for V_{BAT}=13.8V

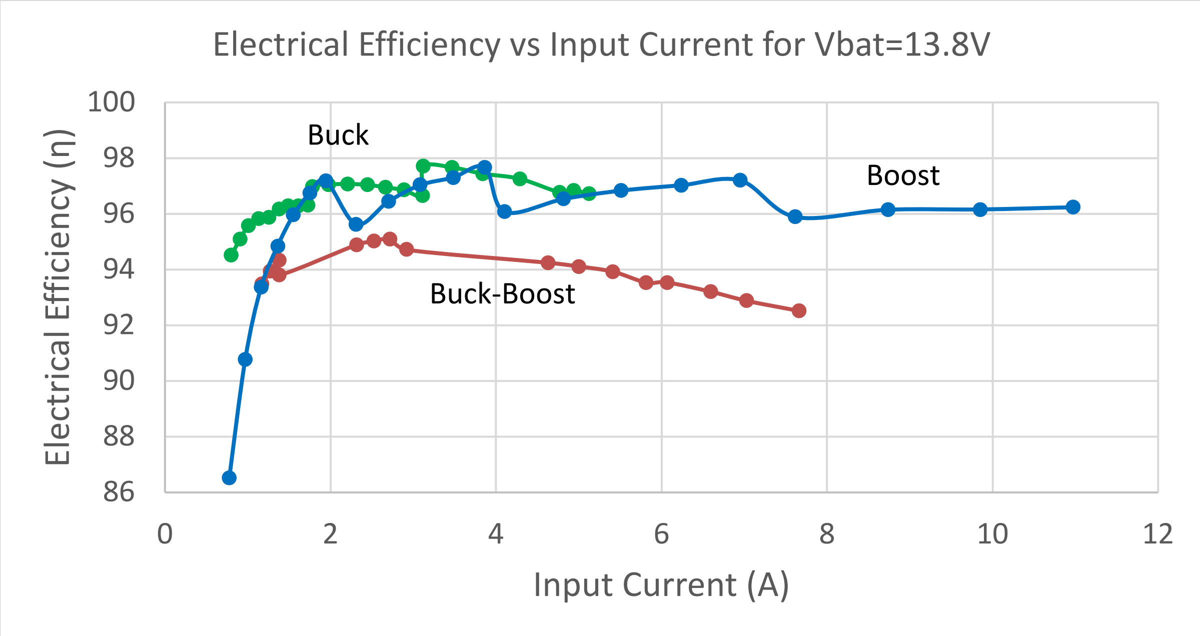

Figure 6: η vs IIN for VBAT=13.8V

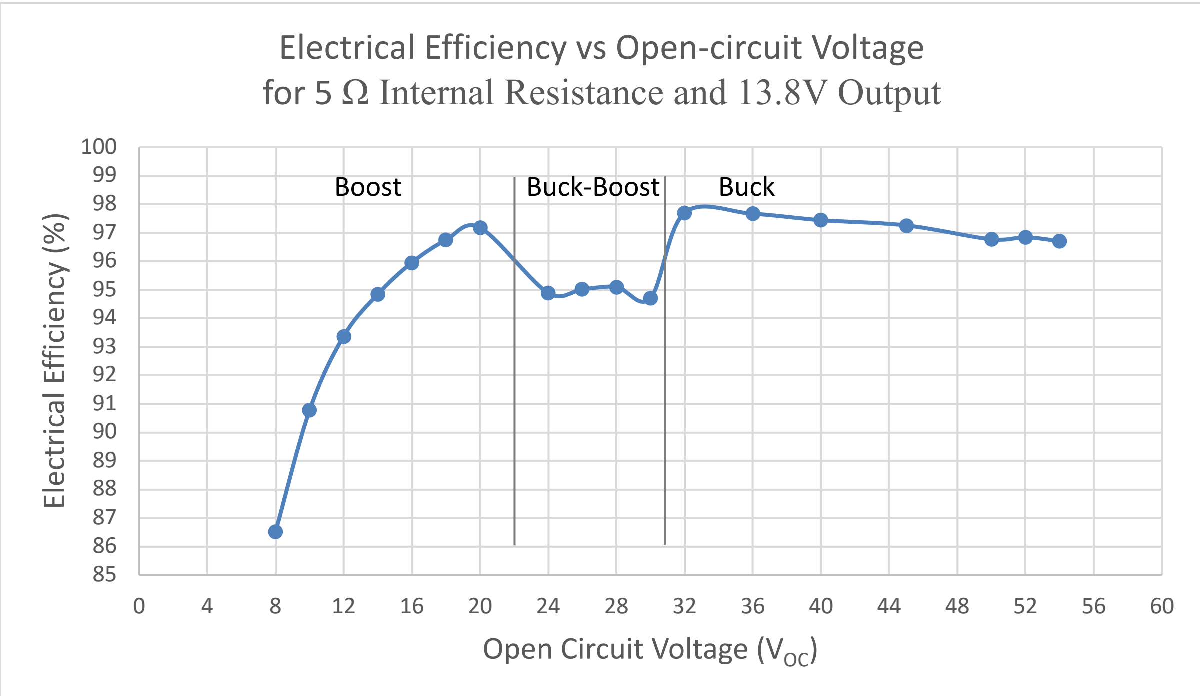

Figure 7: η vs VOC for RINT=5Ω and VBAT=13.8V

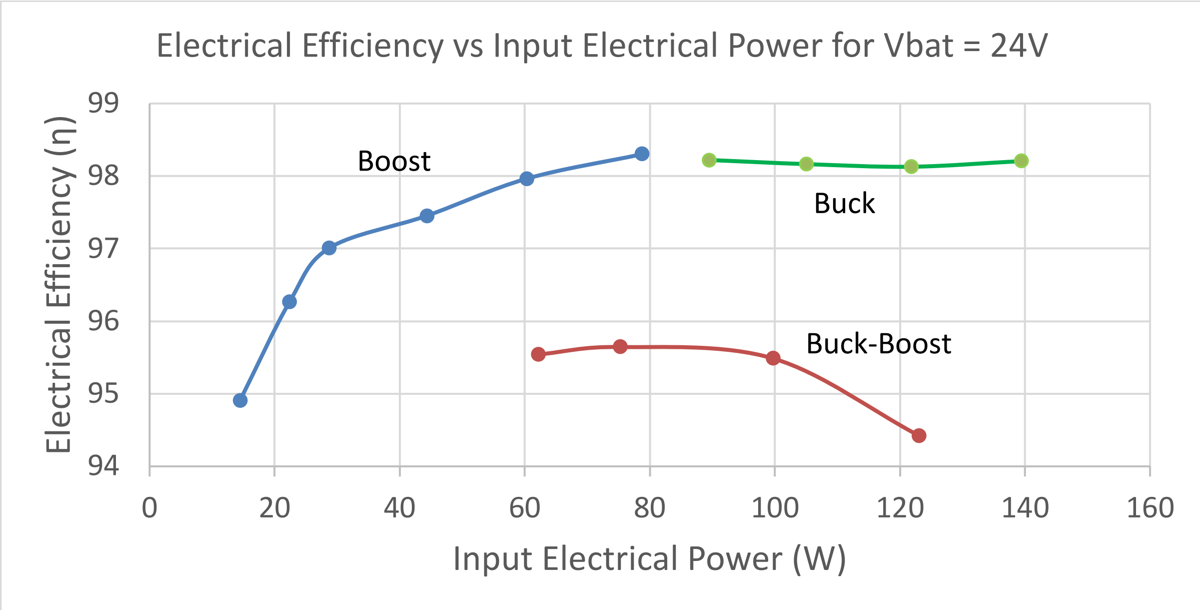

Figure 8: η vs PIN for VBAT=24V

Turn-on and turn-off waveforms

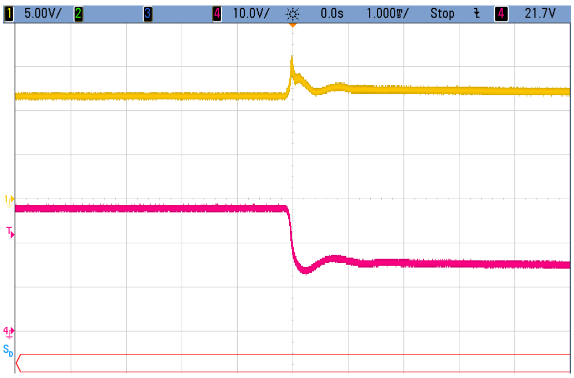

Figure 9: Typical turn-on waveforms. Input voltage in pink and output voltage in yellow.

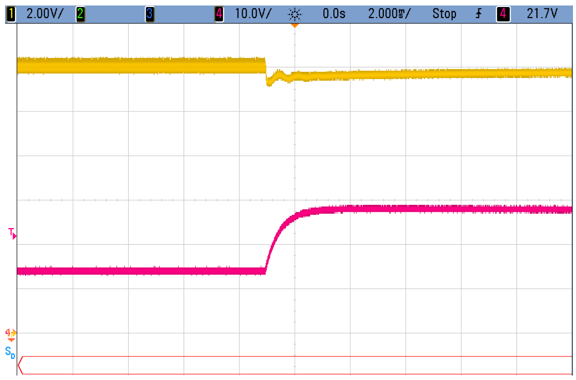

Figure 10: Typical turn-off waveforms. Input voltage in pink and output voltage in yellow.

Thermal Performance

T_A = 23 ˚C, no forced airflow, KM3 PCB located directly on top of a cardboard surface; specifications subject to change without notice.

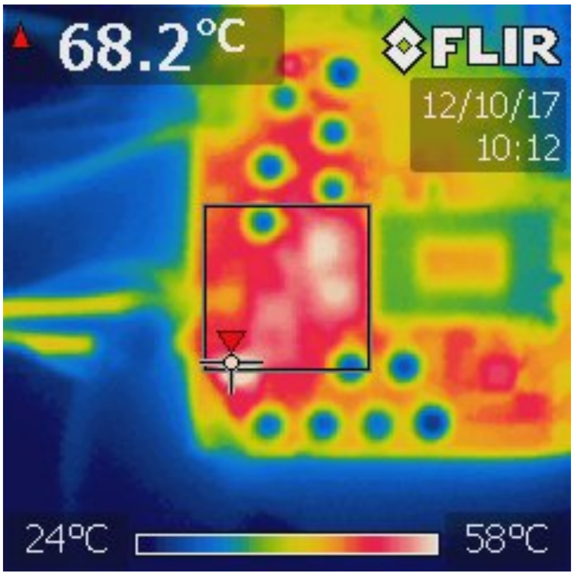

Figure 11: Thermal image of the KM3 converter operating in Boost mode with Voc=16V, Rint=0.8Ω and Vbat=13.8V. Pin=80.0W, η=95.7%

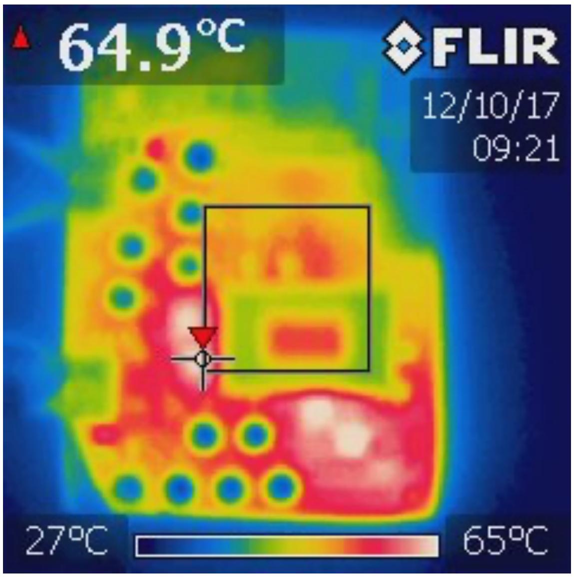

Figure 12: Thermal image of the KM3 converter operating in Buck-Boost mode with Voc=30V, Rint=2.5Ω and Vbat=13.8V. Pin=87.4W, η=93.6%

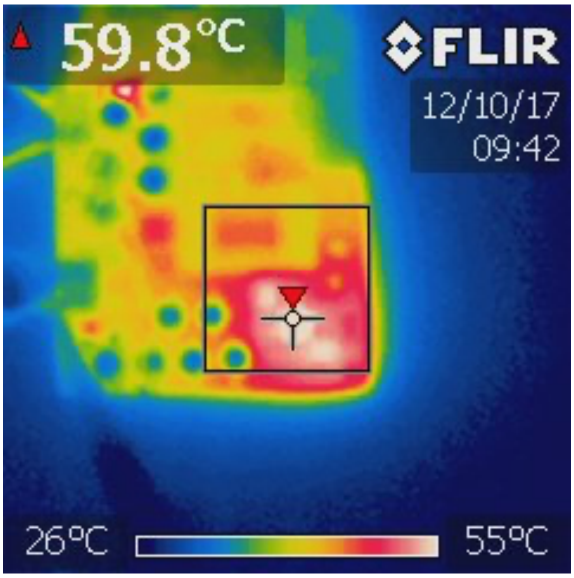

Figure 13: Thermal image of the KM3 converter operating in Buck mode with Voc=50V, Rint=5Ω and Vbat=13.8V. Pin=123W, η=96.9%.

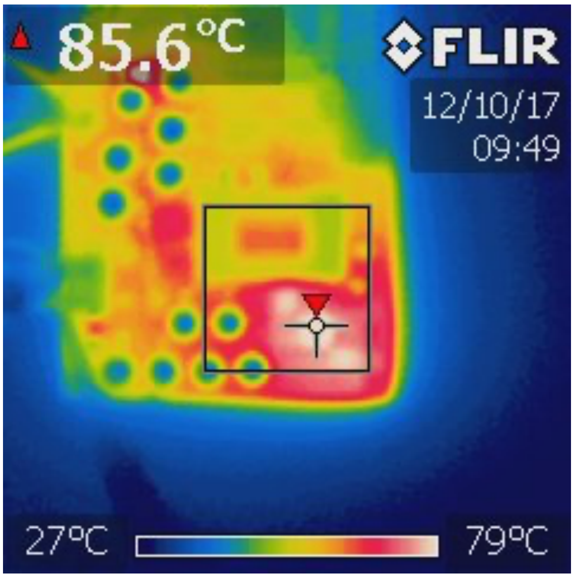

Figure 14: Thermal image of the KM3 converter operating in Buck mode with Voc=56V, Rint=5Ω and Vbat=13.8V. Pin=154W, η=96.5%

Input and Output Voltage Ripple

T_A = 23 ˚C, no forced airflow, KM3 PCB located directly on top of a cardboard surface; specifications subject to change without notice.

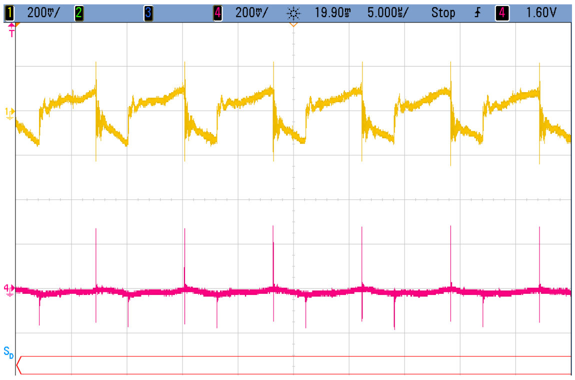

Figure 15: Input (pink) and output (yellow) voltage ripple at Boost operation with Voc=18V, Rint=0.8Ω and Vbat=13.8V. Pin=96.1W, η=95.8%

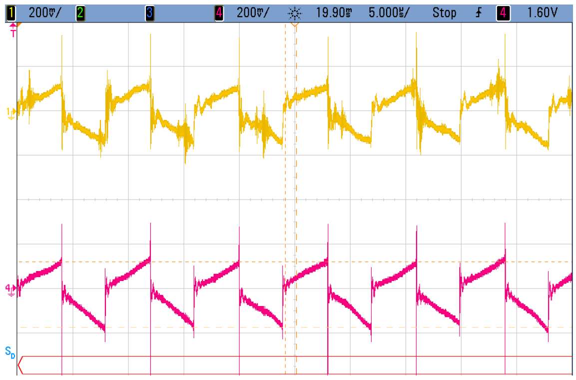

Figure 16: Input (pink) and output (yellow) voltage ripple at Buck-Boost operation with Voc=30V, Rint=2Ω and Vbat=13.8V. Pin=96.4W, η=93.1%

Figure 17: Input (pink) and output (yellow) voltage ripple at Buck operation with Voc=50V, Rint=5Ω and Vbat=13.8V. Pin=123.0W, η=96.9%

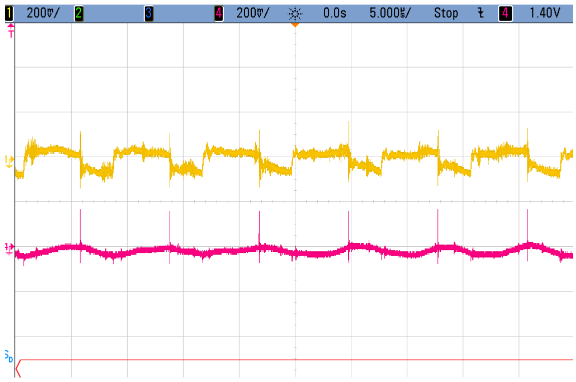

Figure 18: Input (pink) and output (yellow) voltage ripple at Boost operation with Voc=30V, Rint=3.3Ω and Vbat=24V. Pin=66.1W, η=97.7%

Figure 19: Input (pink) and output (yellow) voltage ripple at Buck-Boost operation with Voc=45V, Rint=5Ω and Vbat=24V. Pin=95.2W, η=95.5%

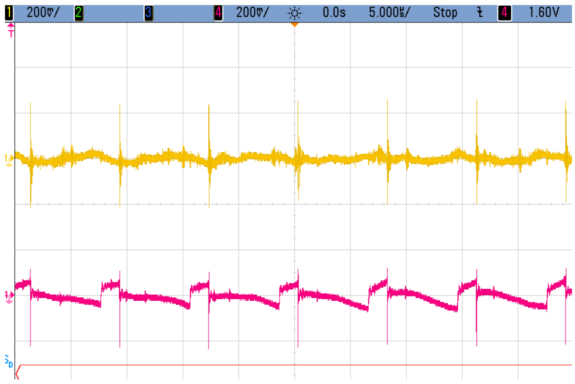

Figure 20: Input (pink) and output (yellow) voltage ripple at Buck operation with Voc=60V, Rint=10Ω and Vbat=24V. Pin=89.5W, η=98.2%

Thermal Considerations

In order to ensure safe operation of the KM3 in the end-use equipment, the temperature of the components listed in the table below must not be exceeded. Temperature should be monitored using thermocouples placed on the hottest part of the component (out of direct air flow).

Temperature Measurements (At maximum ambient)	
Component	**Maximum Temperature (˚C)**
Power Inductor	150
Electrolytic Capacitors	105
PG-TDSON-8 MOSFETs	125
Other components	85

Service Life

The estimated service life of the KM3 is determined by the cooling arrangements and load conditions experienced in the end application. Due to the uncertain nature of the end application this estimated service life is based on the actual measured temperature of components within in the product when installed in the end application.

Mechanical Drawings

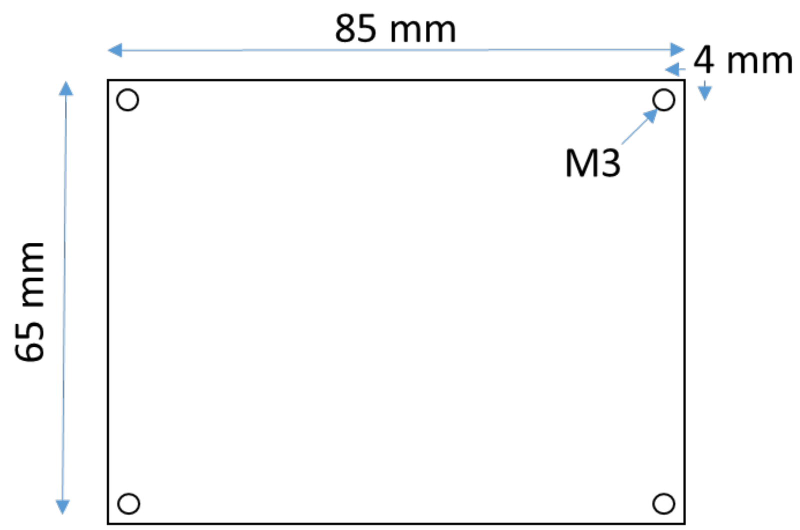

Figure 21: Mechanical Drawing of the KM3 PCB