MATRIX Prometheus

Thermal Energy Harvesting Module

Features & Benefits

Highest performance

- Starts up from a temperature difference as low as 0.5°C
- Operating temperature range of -40°C to +85°C, satisfying common industrial and commercial operating requirements

Highly integrated thermal energy harvesting modules

- Combines high performance TEG with world's most efficient energy harvesting boost converter
- Perfect electrical impedance matching

Easy to use

- Select the appropriate thermal impedance for application
- Add heat sink and mount to heat source

Applications

Wearables

Industrial Process Monitoring

Waste Heat Harvesting

Description

MATRIX Prometheus is a family of energy harvesting modules designed for converting thermal energy between small temperature gradients into useful electrical output. Each Prometheus module integrates a MATRIX Gemini Thermoelectric Generator (TEG) with a MATRIX Mercury Energy Harvesting Boost Converter. These patented technologies ensure perfect electrical impedance matching between the TEG and its companion Boost Converter.

Depending on the application, there are multiple thermal impedance options between 2K/W and 37K/W that may be selected. Optimally matched heat sinks are available for each of these options.

There are many maximum output voltages between 2V and 5V available, allowing the module to directly power integrated circuits, or charge various battery chemistries without needing additional charger circuitry. Integrated V_{OUT} regulation prevents voltage overshoot, securing reliable operation with various battery types.

Prometheus is available as 4-pin modules with 18mm × 30mm × 5.1mm and 34mm × 46mm × 5.1mm form factors. Custom form factors are also available by request.

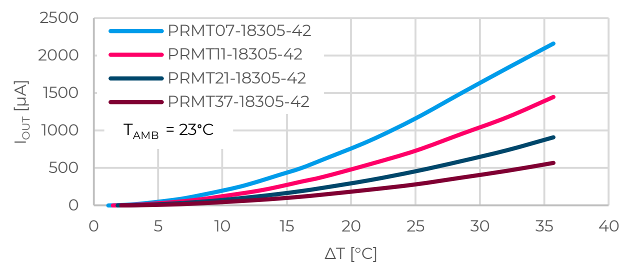

Figure 1. Prometheus (standard variants) output current I_{OUT} vs temperature difference ΔT between hot side and ambient. Assuming ideally matched heat sinks, ambient temperature of 23°C, and output voltage of 4.2V.

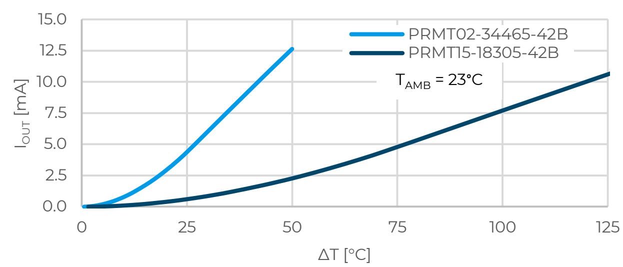

Figure 2. Prometheus (high power variants) output current I_{OUT} vs temperature difference ΔT between hot side and ambient. Assuming ideally matched heat sinks, ambient temperature of 23°C, and output voltage of 4.2V.

MORE INFORMATION

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Absolute Maximum Ratings

Parameter	Min	Max	Unit
Cold side operating temperature range	-40	85	°C
Hot side operating temperature limit		150	°C
Storage temperature range	-55	120	°C
Compression	0	150	MPa
VOUT voltage to GND	-0.5	7	V
Electrostatic discharge (ESD) for Human Body Model (HBM) according to ANSI/ESDA/JEDEC JS-001-2014	-2	2	kV

Package and Pinout

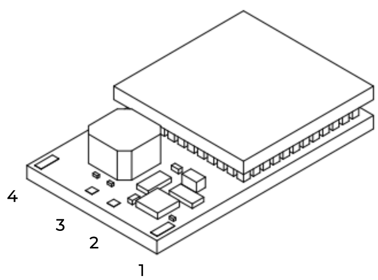

*Figure 3. Pinouts for PRMT**-18305-****

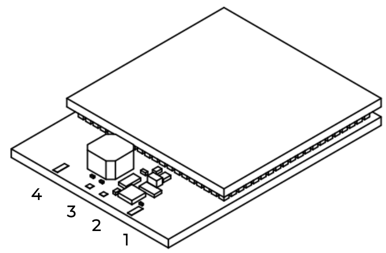

*Figure 4. Pinouts for PRMT**-34465-****

Pin Description

Pin Name	Pin Number	Description
VOUT	1	Output voltage
DATA	2	ADC Data output
REF	3	ADC Reference clock
GND	4	Ground connection

Ordering Information

Prometheus modules are offered with the following customizable product parameters:
①②: Thermal resistance ($1/K_{TEG}$): K/W
③④⑤⑥⑦: Dimension code
⑧⑨: Maximum output voltage $V_{OUT,MAX}$: V

Part Number	Notes
PRMT①②-③④⑤⑥⑦-⑧⑨	Standard
PRMT①②-③④⑤⑥⑦-⑧⑨A	Extended Range
PRMT①②-③④⑤⑥⑦-⑧⑨B	High Power

Standard and Extended Range variants available:

Part Number	$1/K_{TEG}$	Dimension	$V_{OUT,MAX}$
PRMT07-18305-**(A)	7K/W	18×30×5.1mm^3	2.0-5.0V
PRMT11-18305-**(A)	11K/W	18×30×5.1mm^3	2.0-5.0V
PRMT21-18305-**(A)	21K/W	18×30×5.1mm^3	2.0-5.0V
PRMT37-18305-**(A)	37K/W	18×30×5.1mm^3	2.0-5.0V

High Power variants available:

Part Number	$1/K_{TEG}$	Dimension	$V_{OUT,MAX}$
PRMT15-18305-**B	15K/W	18×30×5.1mm^3	2.0-5.0V
PRMT02-34465-**B	2K/W	34×46×5.1mm^3	2.0-5.0V

Custom shapes and sizes available upon request.

Electrical Characteristics

Electrical Characteristics of Prometheus at ideal thermal impedance match to cold side heat sink.
Temperature difference ΔT measured between heat source and ambient.
GND = 0V; T_{AMB} = 23°C; unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Temperature						
ΔT_{MAX}	Source-ambient temperature difference [1] [3]	PRMT07-18305-**			35.7	°C
		PRMT11-18305-**			35.7	°C
		PRMT21-18305-**			35.7	°C
		PRMT37-18305-**			35.7	°C
		PRMT07-18305-**A			127.0	°C
		PRMT11-18305-**A			127.0	°C
		PRMT21-18305-**A			127.0	°C
		PRMT37-18305-**A			127.0	°C
		PRMT15-18305-46/50B			71.1	°C
		PRMT15-18305-**B (others)			127.0	°C
		PRMT02-34465-46/50B			24.9	°C
		PRMT02-34465-**B (others)			50.0	°C
T_{SRC}	Source temperature at T_{AMB} = 23°C [2] [3]	PRMT07-18305-**			58.7	°C
		PRMT11-18305-**			58.7	°C
		PRMT21-18305-**			58.7	°C
		PRMT37-18305-**			58.7	°C
		PRMT07-18305-**A			150.0	°C
		PRMT11-18305-**A			150.0	°C
		PRMT21-18305-**A			150.0	°C
		PRMT37-18305-**A			150.0	°C
		PRMT15-18305-46/50B			94.1	°C
		PRMT15-18305-**B (others)			150.0	°C
		PRMT02-34465-46/50B			47.9	°C
		PRMT02-34465-**B (others)			73.0	°C

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Output voltage						
$V_{OUT,MAX}$	maximum V_{OUT} voltage for charging [4]	PRMT**-*****-20*	1.98	2.0	2.02	V
		T_{AMB} = -40°C to +85°C	1.97	2.0	2.03	V
		PRMT**-*****-22*	2.18	2.2	2.22	V
		T_{AMB} = -40°C to +85°C	2.17	2.2	2.23	V
		PRMT**-*****-25*	2.48	2.5	2.52	V
		T_{AMB} = -40°C to +85°C	2.47	2.5	2.53	V
		PRMT**-*****-30*	2.975	3.0	3.025	V
		T_{AMB} = -40°C to +85°C	2.96	3.0	3.04	V
		PRMT**-*****-33*	3.275	3.3	3.325	V
		T_{AMB} = -40°C to +85°C	3.26	3.3	3.34	V
		PRMT**-*****-36*	3.57	3.6	3.63	V
		T_{AMB} = -40°C to +85°C	3.55	3.6	3.65	V
		PRMT**-*****-38*	3.77	3.8	3.83	V
		T_{AMB} = -40°C to +85°C	3.75	3.8	3.85	V
		PRMT**-*****-42*	4.17	4.2	4.23	V
		T_{AMB} = -40°C to +85°C	4.15	4.2	4.25	V
		PRMT**-*****-46*	4.56	4.6	4.64	V
		T_{AMB} = -40°C to +85°C	4.54	4.6	4.66	V
		PRMT**-*****-50*	4.96	5.0	5.04	V
		T_{AMB} = -40°C to +85°C	4.94	5.0	5.06	V
V_{OUT}	V_{OUT}, operation range	T_{AMB} = -40°C to +85°C	0		5.5	V
Leakage current						
I_{LEAK}	leakage current	V_{OUT} = 5V; V_{OC} = 0V		5	50	nA
		T_{AMB} = +85°C		20	200	nA
8-bit ADC						
t_{LOW}	low time of an output pulse			10		ns
t_{REF}	period between two reference pulses			51.2		ms
t_{DATA}	period between two data pulses			200		µs

[1] When ΔT_{MAX} is exceeded, the boost converter is stopped to protect the module electronics from excessive power. The module tolerates higher temperature differentials within the source-ambient temperature difference range.
[2] Assumes ideal thermal impedance match of Prometheus to the cold side heat sink exposed to ambient T_{AMB} = 23°C. When T_{SRC} is exceeded, the output is disconnected to avoid over voltage on VOUT pin. An oversized heat sink will lower T_{SRC}, while an undersized heat sink will increase T_{SRC}. The module tolerates higher hot side temperatures within the operating temperature range.
[3] Never exceed the hot side operating temperature limit of 150°C and the cold side operating temperature limit of 85°C. Mechanical failure of the part may occur above a hot side temperature of 232°C or a cold side temperature above 138°C.
[4] The V_{OUT} voltage is supervised by a comparator and charging of the output is stopped when $V_{OUT,MAX}$ is reached. The VOUT pin tolerates a higher voltage up to 5.5V.

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Typical Performance Characteristics

Performance of Prometheus at ideal thermal impedance match to cold side heat sink.
Temperature difference ΔT measured between hot side and ambient.
T_{AMB} = 23°C; unless otherwise specified.

Standard variants

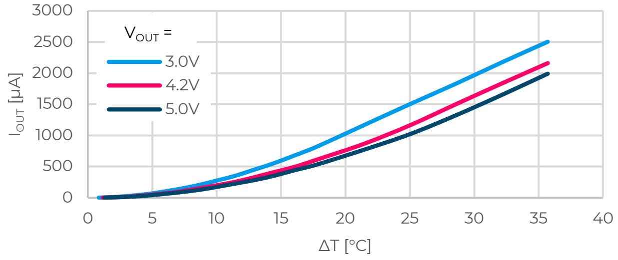


*Figure 4. Output current for PRMT07-18305-** with $1/K_{TEG}$=7K/W*

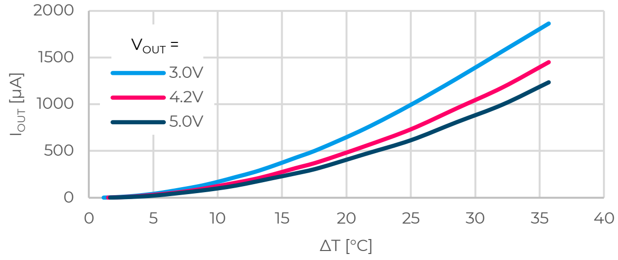


*Figure 5. Output current for PRMT11-18305-** with $1/K_{TEG}$=11K/W*

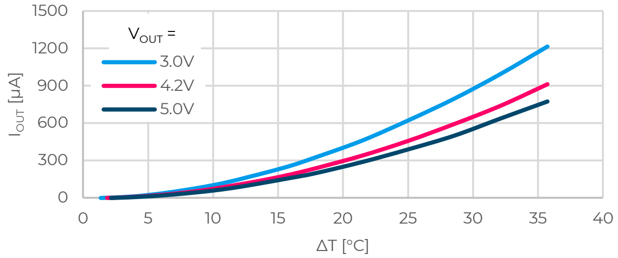


*Figure 6. Output current for PRMT21-18305-** with $1/K_{TEG}$=21K/W*

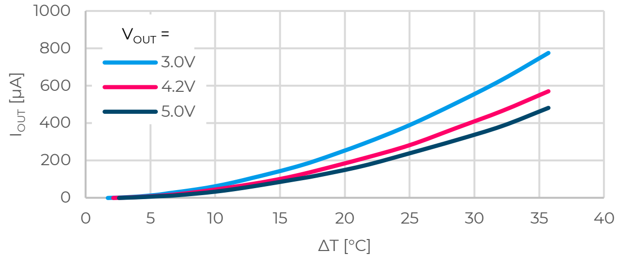


*Figure 7. Output current for PRMT37-18305-** with $1/K_{TEG}$=37K/W*

Extended Range variants

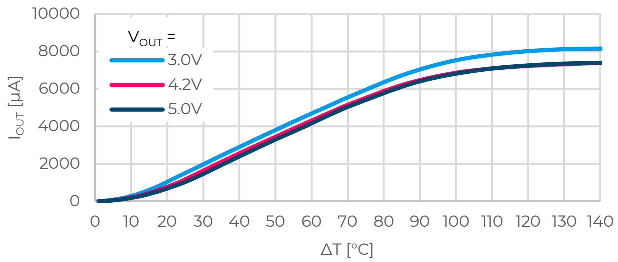


*Figure 8. Output current for PRMT07-18305-**A with $1/K_{TEG}$=7K/W*

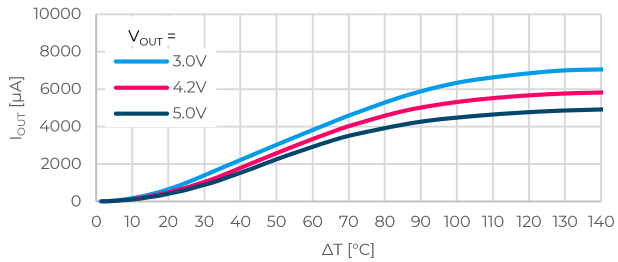


*Figure 9. Output current for PRMT11-18305-**A with $1/K_{TEG}$=11K/W*

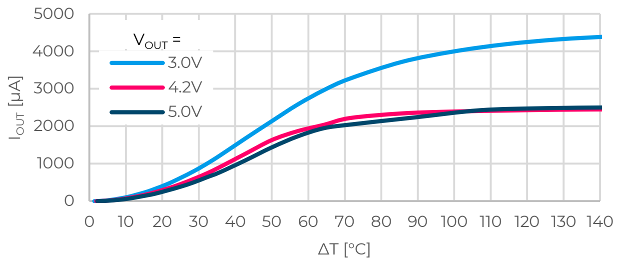


*Figure 10. Output current for PRMT21-18305-**A with $1/K_{TEG}$=21K/W*

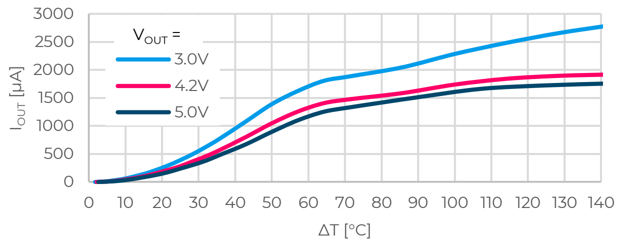


*Figure 11. Output current for PRMT37-18305-**A with $1/K_{TEG}$=37K/W*

High Power variants

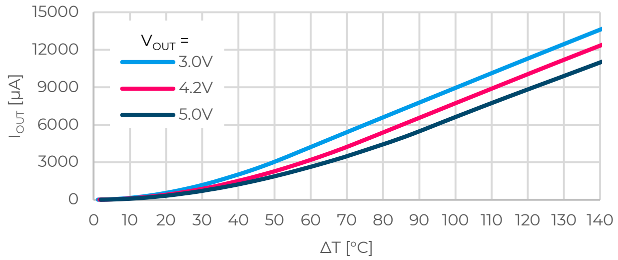


*Figure 12. Output current for PRMT15-18305-**B with $1/K_{TEG}$=15K/W*

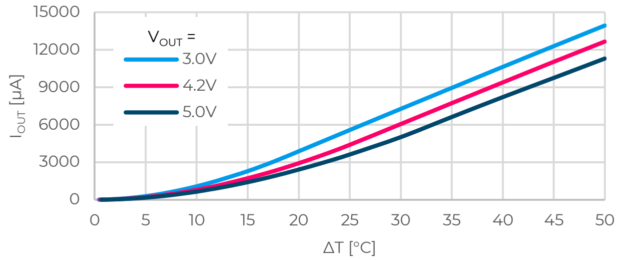


*Figure 13. Output current for PRMT02-34465-**B with $1/K_{TEG}$=2K/W*

Applications Information

Introduction

Prometheus is a next-generation thermal energy harvesting module to convert the thermal energy from small temperature differentials into electrical energy. Multiple output voltage level options are available to power sensors, microprocessors, and wireless transmitters, or to directly charge batteries or supercapacitors without the need for additional circuitry. Prometheus harvests energy over an extended period of time to enable short high power bursts for data acquisition, processing, and transmission, whilst minimizing losses from self-consumption and leakage. The bursts must occur at a sufficiently low duty cycle such that the total energy output during the burst does not exceed the total energy input over the accumulation duration between bursts. For many applications, this duration could range from seconds, to minutes, to hours, or more.

		DUTY CYCLE			
		0.001%	0.01%	0.1%	1%
PEAK CURRENT	0.1mA	0.001µA	0.01µA	0.1µA	1µA
	1mA	0.01µA	0.1µA	1µA	10µA
	10mA	0.1µA	1µA	10µA	100µA
	100mA	1µA	10µA	100µA	1000µA

Heat Sources

Prometheus is optimized for harvesting energy from small temperature differentials. Suitable heat sources include body heat, waste heat from industrial processes, dissipated heat from equipment, or ambient thermal gradients.

There is a minimum temperature difference across the TEG required for Prometheus to start output regulation. The cold-start temperature difference ΔT_{CS} is a function of the module choice, which also determines the cold-start heat flow Q_{CS} required. After start-up, Prometheus can operate at even lower temperature differentials depending on V_{OUT} - see TYPICAL PERFORMANCE CHARACTERISTICS.

Part Number	$1/K_{TEG}$	ΔT_{CS}	Q_{CS}
PRMT07-18305-***	7K/W	0.5°C	72mW
PRMT11-18305-***	11K/W	0.8°C	72mW
PRMT21-18305-***	21K/W	0.9°C	40mW
PRMT37-18305-***	37K/W	1.0°C	26mW
PRMT15-18305-**B	15K/W	1.6°C	108mW
PRMT02-34465-**B	2K/W	0.6°C	281mW

Thermal Impedance Matching

Prometheus integrates a thermoelectric generator (TEG) with an electrically matched boost converter circuit, and is designed to be attached between a heat source and a heat sink. The TEG converts thermal energy to electrical energy, whilst the boost converter multiplies the TEG's small output voltages to useful levels. Efficient harvesting requires simultaneously maximizing thermal power transfer into the TEG and electrical power transfer out of the TEG. This means that both thermal and electrical systems must be impedance matched. In Prometheus, the electrical impedance matching condition is met by design, so only thermal impedance matching needs to be considered.
When Prometheus is attached to a heat source at a fixed temperature T_{SRC}, the temperature drop across the TEG of thermal conductance K_{TEG} and the heat sink with thermal conductance K_{HS} is:

$$\Delta T_{TEG} = (T_{SRC} - T_{AMB}) \times 1/K_{TEG} / (1/K_{TEG} + 1/K_{HS})$$

In practice, most heat sources are not ideal sources, but this is a good approximation when the amount of heat withdrawn via the TEG is much smaller than the heat generated by the heat source. At maximal thermal power transfer, the temperature difference ΔT_{TEG} across the TEG becomes exactly $(T_{SRC} - T_{AMB})/2$. This is met by choosing the heat sink so that:

$$1/K_{HS} = 1/K_{TEG}$$

See HEAT SINK SELECTION for suggested heat sinks for each Prometheus module.

Heat Sink Selection

Under natural convection conditions, the following heat sinks are recommended.
T_{AMB} = 23°C; unless otherwise specified.

Module	Vendor	Part number	Orientation	$1/K_{TEG}$	Size (mm)
PRMT07-18305-***	Alpha Novatech	N30-25B	Horizontal	9.5K/W	30.0×30.0×25.0
		N35-25B	Horizontal	8.3K/W	35.0×35.0×25.0
		N40-25B	Horizontal	6.6K/W	40.0×40.0×25.0
PRMT11-18305-***	Alpha Novatech	LPD30-15B	Vertical	13.0K/W	30.0×30.0×15.0
		N35-10B	Horizontal	12.2K/W	35.0×35.0×10.0
		N40-10B	Horizontal	10.2K/W	40.0×40.0×10.0
PRMT21-18305-***	Alpha Novatech	LPD30-3B	Vertical	19.3K/W	30.0×30.0×3.0
		ST30-4B	Horizontal	21K/W†	30.0×30.0×4.0
PRMT37-18305-***	N/A	Flat plate	Horizontal	37K/W†	70.0×70.0×2.5
		Flat plate	Vertical	37K/W†	60.0×60.0×2.5
PRMT15-18305-**B	Alpha Novatech	LPD30-10B	Vertical	15.0K/W	30.0×30.0×10.0
		N30-10B	Horizontal	14.0K/W	30.0×30.0×10.0
		N35-10B	Horizontal	12.2K/W	35.0×35.0×10.0
PRMT02-34465-**B	Alpha Novatech	N60-40B	Horizontal	2.7K/W	60.0×60.0×40.0

†Estimated thermal resistance

Under low air velocity conditions, the following heat sinks are recommended.
T_{AMB} = 23°C; unless otherwise specified.

Module	Vendor	Part number	Velocity	$1/K_{TEG}$	Size (mm)
PRMT07-18305-***	Alpha Novatech	N30-10B	0.5m/s	7.7K/W	30.0×30.0×10.0
		ST30-7B	0.5m/s	7.5K/W	30.0×30.0×7.0
PRMT11-18305-***	Alpha Novatech	LPD30-3B	0.5m/s	14.9K/W	30.0×30.0×4.0
		ST30-4B	0.5m/s	11.6K/W	30.0×30.0×4.0
PRMT21-18305-***	N/A	Flat plate	0.5m/s	21K/W†	60.0×60.0×2.5
PRMT37-18305-***	N/A	Flat plate	0.5m/s	37K/W†	40.0×40.0×2.5
PRMT15-18305-**B	Alpha Novatech	LPD30-3B	0.5m/s	14.3K/W	30.0×30.0×3.0
PRMT02-34465-**B	Alpha Novatech	N60-20B	0.5m/s	1.8K/W	60.0×60.0×20.0

†Estimated thermal resistance

ADC Outputs

Prometheus includes an onboard ADC that can be used to report the TEG power generation to an external microcontroller. The two ADC Outputs REF and DATA are open drain, active low outputs and intended to be connected to GPIOs of a microcontroller. If the microprocessor includes internal pull-up resistors on the GPIOs, they can be used to define the high level of the two signals. Alternatively, external resistors may be used and a value of 47kΩ is recommended. If the ADC outputs are not used they can be connected to GND or left unconnected.

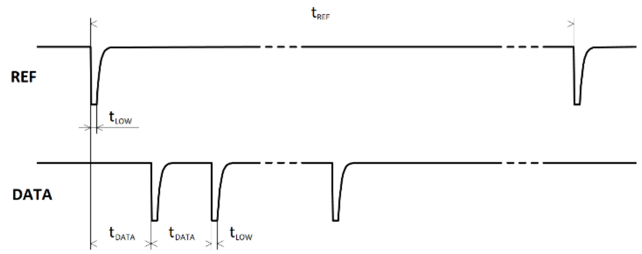


Figure 14. Timing charts of ADC Outputs

The serial transmission protocol is illustrated above. A pulse on REF signals the start of the data transmission in each reference period t_{REF}, during which a train of pulses is transmitted on DATA. The open-circuit voltage V_{OC} measured by the ADC is:

$$V_{OC} = n \times V_{LSB}$$

V_{OC} is the product of the number of DATA pulses received n, and the ADC lowest significant bit (LSB) size V_{LSB}. For example, 20 pulses with V_{LSB} = 2mV means V_{OC} = 40mV. If there is insufficient input power to charge the output, Prometheus sends two low pulses on REF before powering down.

Part Number	V_{LSB}
PRMT07-18305-***	2mV
PRMT11-18305-***	2mV
PRMT21-18305-***	2mV
PRMT37-18305-***	2mV
PRMT15-18305-**B	4mV
PRMT02-34465-**B	4mV

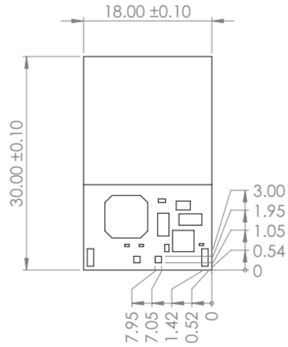
For Extended Range (-**A) and High Power (-**B) variants, V_{OC} is not a linear function of V_{LSB}.

Assembly Notes

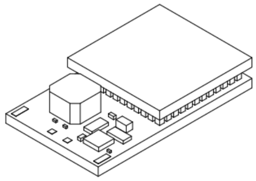
In most applications, thermal energy will be harvested from a surface that is hotter than ambient. When used for this purpose, Prometheus should be assembled with its cold side (larger face) attached to the ambient heat sink, and its hot side (smaller face) attached to the heat source.
A thin layer of thermal interface material (TIM) should be applied to the clean mating surfaces before attachment. Suitable TIMs include thermal conductive grease, epoxy, foil or other fillers. These can achieve good thermal contact as long as the TIM thickness is thin and no debris is present at the interface. Consult the manufacturer’s recommendations and instructions for application of these TIM materials.
The module should be mounted to the heat source and heat sink under compression. Screws, springs and clamps can be used to apply adequate compressive force to maintain good thermal contact between the mating surfaces. Again, consult the TIM manufacturer’s instructions for best results. At no point must tensile force be applied to the opposing faces of the module, as it may separate under tension.

Module Dimensions

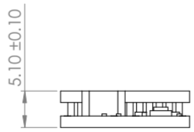
PRMT**-18305-***



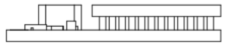
TOP VIEW



ISOMETRIC VIEW

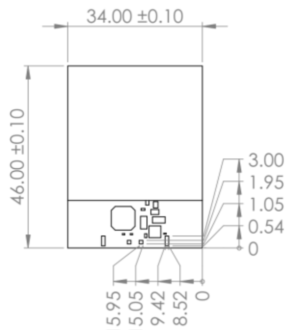


FRONT VIEW

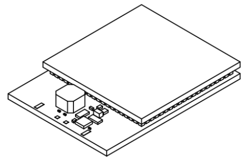


SIDE VIEW

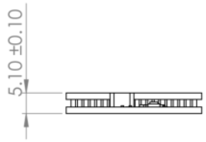
PRMT**-34465-***



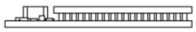
TOP VIEW



ISOMETRIC VIEW



FRONT VIEW



SIDE VIEW

RoHS Declaration

MATRIX Industries, Inc., certifies that, unless explicitly exempt, assemblies or products supplied by MATRIX or its partners are in compliance with and conform to the European Union's Restriction of Use of Hazardous Substances in Electrical and Electronic Equipment (RoHS) Directive 2002/95/EC and 2011/65/EU (RoHS2). Said products have no intentional addition of:

- Lead (Pb)
- Cadmium (Cd)
- Mercury (Hg)
- Hexavalent Chromium (Cr)
- Polybrominated Biphenyls (PBB)
- Polybrominated Diphenyl Ethers (PBDE)

Any trace impurities of these substances are below the threshold limits as specified by the RoHS directive; specifically Cr^{6+}, Hg, Pb, PBB, PBDE do not exceed 1000 ppm (0.1%) and Cd does not exceed 100 ppm (0.01%). This declaration is based on our analysis, vendor supplied analysis, material certifications, or laboratory tests of the component materials used in the manufacturing of our products.

MATRIX believes to the best of its knowledge that the above statements are accurate as of the date of this certification and the statements and certifications of suppliers or service providers that MATRIX may have relied upon in the preparation of this statement. Within the above defined limitations this certificate may be relied upon by the distributors and customers of RoHS designated products of MATRIX. This certification is valid unless superseded by a revised certification at a later date.

Revision History

Revision	Date	Description
A	Jul 2020	Preliminary Datasheet Release
B	Mar 2021	Removed obsolete variants, added High Power variants
C	May 2021	Revised PRMT07, added Extended Range variants
D*	Feb 2022	Revised operating temperature limits, added 5V data

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