MATRIX Mercury

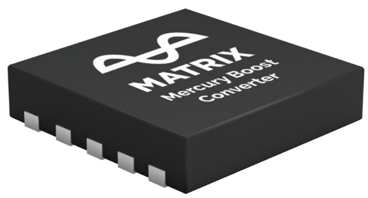
Nanopower Energy Harvesting Synchronous Boost Converter with Microwatt Cold-Start, Input Impedance Matching and Regulated Output

DESCRIPTION

MATRIX Mercury is a family of highly integrated DC/DC boost converters that are ideal for harvesting and managing surplus energy from extremely low input voltage sources such as Thermoelectric Generators (TEGs).

The patented transformer reuse topology works as a flyback converter, and can operate from input power as little as a few microwatts. The unique impedance matching feature presents a constant impedance load and enables the highest efficiency energy harvesting across the entire operating range of input voltages.

There are multiple input protection voltage options available based on the ratio of the transformer. The 8-bit on-chip ADC detects when the open-circuit voltage (V_{OC}) exceeds the programmed limit and turns off the input to ensure reliable operation. The result of the measurement is transmitted via a two-wire interface to a micro-controller.



There are many maximum output voltages between 2V to 5V available. Integrated V_{OUT} regulation prevents voltage overshoot, securing reliable operation with various battery types.

Mercury is available in a 10-lead, 3mm × 3mm DFN package. Operation temperature is -40°C to +85°C.

EXAMPLE APPLICATION: HEALTH MONITORING WEARABLE

Figure 1. Example application circuit

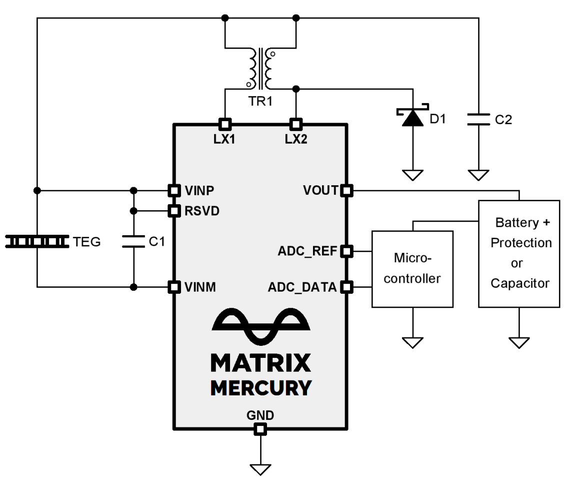
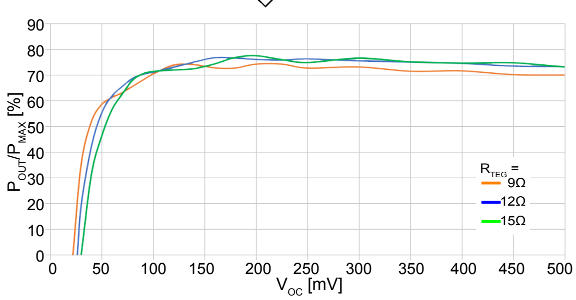


Figure 2. Example application efficiency chart for MCRY12-125Q-42DI with V_{OUT} = 4.2V



- C1: 100µF/0805, 2.5V. C2: 4.7µF/0402, 6.3V. D1: BAS70L/DFN1006-2. TR1: LPR6235.
- Cold-start voltage is V_{OC} = 24mV which gives a P_{MAX} = 12µW.
- Overall Efficiency is defined as P_{OUT}/P_{MAX} where $P_{MAX} = V_{OC}^2/(4 \times R_{TEG})$.

FEATURES & BENEFITS

A new low to lead a new era of energy harvesting

- Ultra-Low quiescent current of 700nA ensures the fastest possible charge times of the output reservoir capacitor
- V_{IN} as low as 9mV (MCRY04-075S with V_{OC} = 18mV and R_{TEG} = 4Ω) to V_{OUT} of up to 5V
- V_{IN} as low as 6mV (MCRY04-075S with V_{OC} = 12mV and R_{TEG} = 4Ω) to V_{OUT} of up to 3V
- Cold-start with V_{OC} = 15mV (MCRY04-075S and R_{TEG} = 4Ω)

A new high of efficiency to maximize power transfer

- Up to 85% peak conversion efficiency (MCRY60-250P)
- Near-ideal impedance matching with input source

Minimized power leakage with active input monitoring

- Built-in V_{OC} monitoring through an 8-bit ADC
- True shutdown by disconnecting output when V_{OC} is below startup requirement securing zero power leakage

Miniaturized solution size

- Three external components are required: input capacitor, output capacitor and a transformer
- Optional Schottky diode for efficiency improvement

APPLICATIONS

- Thermal Energy Harvesting (TEG, Peltier, Thermopile)
- Industrial Remote Sensors
- Portable Medical Devices
- Consumer Wearables
- Smart Meters
- Building Automation
- Predictive Maintenance

MATRIX Industries · 1440 O'Brien Drive Suite A-1 · Menlo Park, CA 94025 · +1 650-462-1003 · www.matrixindustries.com · info@matrixindustries.com

ABSOLUTE MAXIMUM RATINGS

Parameter	Min	Max	Unit
RSVD voltage to GND	-0.5	7	V
VINP voltage to GND	-0.5	7	V
VOUT voltage to GND	-0.5	7	V
ADC_REF voltage to GND	-0.5	7	V
ADC_DATA voltage to GND	-0.5	7	V
LX2 voltage to GND	-0.5	52	V
LX1 voltage to VINP	-2.3	0.5	V
VINM voltage to VINP	-2.3	0.5	V
Operating Temperature Range	-40	85	°C
Storage Temperature Range	-55	150	°C
Electrostatic discharge (ESD) for Human Body Model (HBM) according to ANSI/ESDA/JEDEC JS-001-2014	-2	2	kV

PACKAGE AND PINOUT

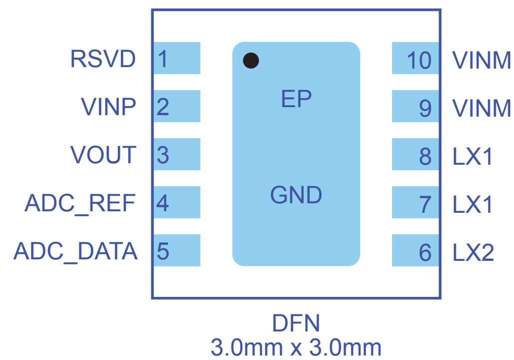


Figure 3. Package diagram for 10-lead, 3mm × 3mm DFN

PIN DESCRIPTION

Pin Name	Pin Number	Description
RSVD	1	Reserved. Connect to VINP during normal operation
VINP	2	Positive potential of the input voltage
VOUT	3	Output connection
ADC_REF	4	Reference clock of the ADC measurement. Connect to GND if not used
ADC_DATA	5	Data output of the ADC measurement. Connect to GND if not used
LX2	6	Connection of LX2 of the transformer
LX1	7, 8	Connection of LX1 of the transformer
VINM	9, 10	Negative potential of the input voltage
GND	EP	Exposed Pad, Ground Connection

ORDERING INFORMATION

To secure the highest efficiency through impedance matching and adapt to a wide spectrum of system design considerations, we offer customizable product parameters:

①②: Input impedance (R_{IN}): Ω

③④⑤: Transformer inductance (L1): μH

⑥: Transformer turns ratio N: P (1:20), Q (1:50), S (1:100)

⑦⑧: Maximum output voltage $V_{OUT, MAX}$: V

Part Number	Package Type	Dimension	Temp Grade
MCRY①②-③④⑤⑥-⑦⑧DI	DFN	3x3mm^2	Industrial: -40°C to +85°C

The following standard versions are available:

Part Number	R_{IN}	R_{TEG}	L1	N	$V_{OC,MAX}$	$V_{OUT,MAX}$
MCRY04-075S-⑦⑧DI	4Ω	3-5Ω	7.5μH	1:100	250mV	2.0, 2.2, 2.5, 3.0, 3.3, 3.6, 3.8, 4.2. 4.6, 5.0 V
MCRY07-125Q-⑦⑧DI	7Ω	5-9Ω	12.5μH	1:50	500mV	2.0, 2.2, 2.5, 3.0, 3.3, 3.6, 3.8, 4.2. 4.6, 5.0 V
MCRY12-125Q-⑦⑧DI	12Ω	9-15Ω	12.5μH	1:50	500mV	2.0, 2.2, 2.5, 3.0, 3.3, 3.6, 3.8, 4.2. 4.6, 5.0 V
MCRY20-125Q-⑦⑧DI	20Ω	15-25Ω	12.5μH	1:50	500mV	2.0, 2.2, 2.5, 3.0, 3.3, 3.6, 3.8, 4.2. 4.6, 5.0 V
MCRY35-125Q-⑦⑧DI	35Ω	25-45Ω	12.5μH	1:50	500mV	2.0, 2.2, 2.5, 3.0, 3.3, 3.6, 3.8, 4.2. 4.6, 5.0 V
MCRY60-250P-⑦⑧DI	60Ω	45-75Ω	25μH	1:20	1000mV	2.0, 2.2, 2.5, 3.0, 3.3, 3.6, 3.8, 4.2. 4.6, 5.0 V

For example:

Part Number	R_{IN}	L1	N	$V_{OUT,MAX}$	Package
MCRY04-075S-46DI	4Ω	7.5μH	1:100	4.6V	DFN
MCRY12-125Q-42DI	12Ω	12.5μH	1:50	4.2V	DFN
MCRY60-250P-25DI	60Ω	25μH	1:20	2.5V	DFN

The following versions are in production:

Part Number	R_{IN}	L1	N	$V_{OUT,MAX}$	Package	Marking
MCRY12-125Q-42DI (T)	12Ω	12.5μH	1:50	4.2V	DFN	CS59B
MCRY20-125Q-33DI (T)	20Ω	12.5μH	1:50	3.3V	DFN	CS59BA
Engineering Samples					DFN	CS59BU

(T) - add T to the part number for tape & reel packaging. Standard packaging is bulk.

Engineering samples of all standard versions are available.

For samples and availability of nonstandard versions, contact MATRIX Industries at: info@matrixindustries.com.

BLOCK DIAGRAM

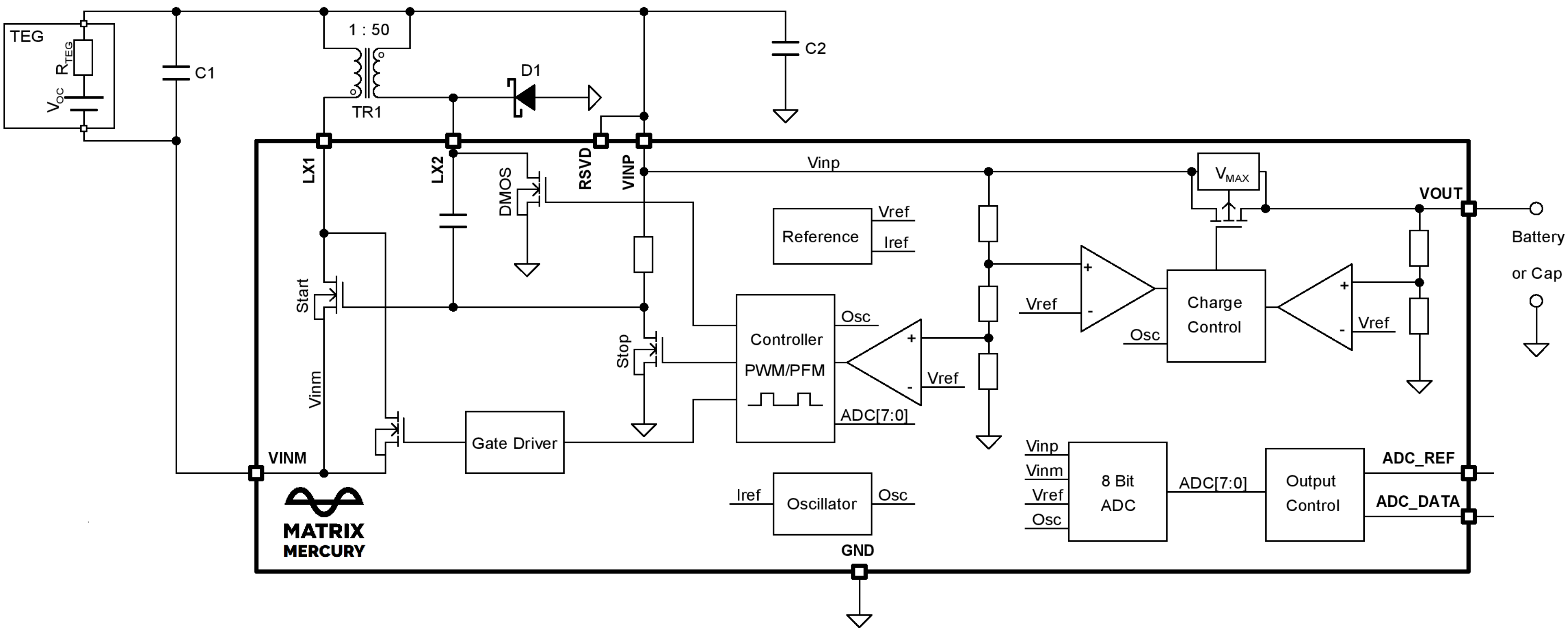


Figure 4. Block Diagram

ELECTRICAL CHARACTERISTICS

Table 1. Electrical Characteristics of Mercury

GND = 0V; C2 = 4.7µF; D1 = BAS70
MCRY04-075S-**DI: R_{TEG} = 4Ω; C1 = 220µF; TR1 = LPR6235-752S
MCRY07-125Q-**DI: R_{TEG} = 7Ω; C1 = 100µF; TR1 = LPR6235-123Q
MCRY12-125Q-**DI: R_{TEG} = 12Ω; C1 = 100µF; TR1 = LPR6235-123Q
MCRY20-125Q-**DI: R_{TEG} = 20Ω; C1 = 47µF; TR1 = LPR6235-123Q
MCRY35-125Q-**DI: R_{TEG} = 35Ω; C1 = 22µF; TR1 = LPR6235-123Q
MCRY60-250P-**DI: R_{TEG} = 60Ω; C1 = 22µF; TR1 = LPR6235-253P
T_{amb} = 23°C; unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Input Voltage						
$V_{OC,CS}$	open-circuit voltage for cold start [1]	C2 discharged; V_{OUT} ≤ 3V MCRY04-075S-**DI		15		mV
		MCRY07-125Q-**DI		23		mV
		MCRY12-125Q-**DI		24		mV
		MCRY20-125Q-**DI		27		mV
		MCRY35-125Q-**DI		32		mV
		MCRY60-250P-**DI		54		mV
$V_{OC,MAX}$	maximum open-circuit voltage for charging [2]	MCRY**-075S-**DI	245	250	255	mV
		MCRY**-125Q-**DI	490	500	510	mV
		MCRY**-250P-**DI	980	1000	1020	mV
V_{OC}	V_{OC}, operation range	T_{amb} = -40°C to +85°C	0		1.98	V
Output voltage						
$V_{OUT,MAX}$	maximum V_{OUT} voltage for charging [3]	MCRY**-****-20DI T_{amb} = -40°C to +85°C	1.98 1.97	2.0 2.0	2.02 2.03	V V
		MCRY**-****-22DI T_{amb} = -40°C to +85°C	2.18 2.17	2.2 2.2	2.22 2.23	V V
		MCRY**-****-25DI T_{amb} = -40°C to +85°C	2.48 2.47	2.5 2.5	2.52 2.53	V V
		MCRY**-****-30DI T_{amb} = -40°C to +85°C	2.975 2.96	3.0 3.0	3.025 3.04	V V
		MCRY**-****-33DI T_{amb} = -40°C to +85°C	3.275 3.26	3.3 3.3	3.325 3.34	V V
		MCRY**-****-36DI T_{amb} = -40°C to +85°C	3.57 3.55	3.6 3.6	3.63 3.65	V V
		MCRY**-****-38DI T_{amb} = -40°C to +85°C	3.77 3.75	3.8 3.8	3.83 3.85	V V
		MCRY**-****-42DI T_{amb} = -40°C to +85°C	4.17 4.15	4.2 4.2	4.23 4.25	V V
		MCRY**-****-46DI T_{amb} = -40°C to +85°C	4.56 4.54	4.6 4.6	4.64 4.66	V V
		MCRY**-****-50DI T_{amb} = -40°C to +85°C	4.96 4.94	5.0 5.0	5.04 5.06	V V
V_{OUT}	V_{OUT}, operation range	T_{amb} = -40°C to +85°C	0		5.5	V
Supply current						
I_Q	quiescent current [4]	V_{OC} > $V_{OC.MAX}$ 2.0V < V_{OUT} ≤ 3.3V		0.6	0.9	µA
		3.3V < V_{OUT} ≤ 4.2V		0.7	1.0	µA
		4.2V < V_{OUT} ≤ 5.0V		0.9	1.2	µA
I_{LEAK}	leakage current	V_{OUT} = 5V; V_{OC} = 0V		5	50	nA
		T_{amb} = +85°C		20	200	nA

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Flyback converter						
f	switching frequency	$V_{OUT} = 0.95 \times V_{OUT,MAX}$	19	20	21	kHz
DC_{SW1}	LX1-switch duty cycle	$V_{OUT} = 0.95 \times V_{OUT,MAX}$ MCRY04-075S-**DI	27	28	29	%
		MCRY07-125Q-**DI	27	28	29	%
		MCRY12-125Q-**DI	19	20	21	%
		MCRY20-125Q-**DI	15	16	17	%
		MCRY35-125Q-**DI	11	12	13	%
		MCRY60-250P-**DI	13	14	15	%
$t_{ON,SW2}$	LX2-switch (DMOS) on-time [5]	$V_{INP}-V_{INM} = 64 \times V_{LSB}$ $V_{OUT} = 0.95 \times V_{OUT,MAX}$			75	%
ADC						
	resolution			8		Bits
V_{LSB}	size of least significant bit (LSB)	MCRY**-075S-**DI	0.98	1	1.02	mV
		MCRY**-125Q-**DI	1.96	2	2.04	mV
		MCRY**-250P-**DI	3.92	4	4.08	mV
	offset error		-1	0	1	LSB
INL	integral nonlinearity		-1	0	1	LSB
DNL	differential nonlinearity		-0.1	0	0.1	LSB
t	time between two measurements			1.23		s
t_M	measurement timeout [6]			5.4		ms
Switches						
R_{SW1}	resistance of the LX1-switch			120		mΩ
R_{SW2}	resistance of the LX2-switch (DMOS)			20		Ω
R_{PMOS}	resistance of the PMOS			1		Ω
Outputs ADC_REF & ADC_DATA						
I_{OUT}	output current	output = 0.4V	4			mA
t_{LOW}	low-time of an output pulse			10		ns
C_{LOAD}	load capacitance				20	pF
t_{REF}	period between two reference pulses			51.2		ms
t_{DATA}	period between two data pulses [7]			200		µs

[1] This is the open-circuit voltage of the TEG which is necessary to start charging of the battery/cap. The input voltage V_{IN} is smaller than this voltage. Depending on V_{OUT} the minimum open-circuit voltage to charge the battery/cap can be smaller or higher after cold-start – see efficiency graphs.

[2] The open-circuit voltage is measured by the ADC and when $V_{OC,MAX}$ is exceeded, the flyback converter is stopped to avoid over voltage on LX2 pin. The pin tolerates higher voltages within the V_{OC} range.

[3] The V_{OUT} voltage is supervised by a comparator and when $V_{OC,MAX}$ is exceeded, the flyback converter is stopped to avoid over voltage on VOUT pin. The pin tolerates higher voltages within the V_{OUT} range.

[4] With an open-circuit voltage higher than $V_{OC,MAX}$ the flyback converter is stopped and the PMOS is closed to prevent switching. In this state it is possible to measure the internal quiescent current into VOUT pin.

[5] The on-time of the DMOS depends on the input voltage V_{IN} and V_{OUT}. It is trimmed at an input voltage of $64 \times V_{LSB}$ (= 128 mV for MCRY**-125Q-**DI) and an output voltage of $0.95 \times V_{OUT,MAX}$ (= 2.85V for MCRY**-****-30DI) to <75% of the theoretical on-time $t_{ON,SW1} \times N \times V_{IN} / V_{OUT}$ where $t_{ON,SW1} = DC_{SW1}/f$ and N is the turns ratio of the transformer TR1. This guarantees by design a well-timed turn off of the DMOS over the whole operating range.

[6] The flyback converter is stopped to load C1 to the open-circuit voltage. At the end of the timeout the measurement is done.

[7] The first data pulse starts 200µs after the reference pulse. The time between the last data pulse and the next reference pulse depends on the ADC measurement – see ADC output description.

TYPICAL PERFORMANCE CHARACTERISTICS

T_{amb} = 23°C; unless otherwise specified. TR1 = LPR6235

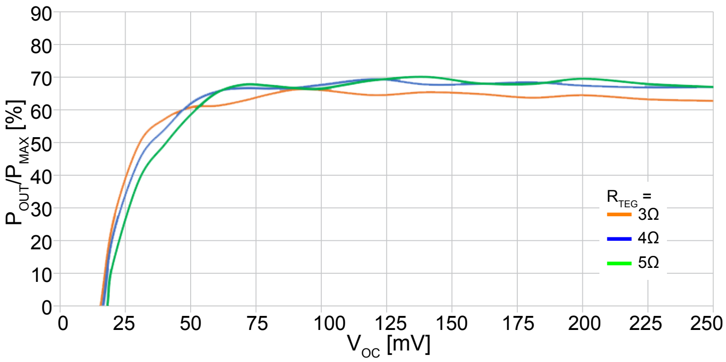


Figure 5. Efficiency for MCRY04-075S-**DI with V_{OUT} = 4.2V

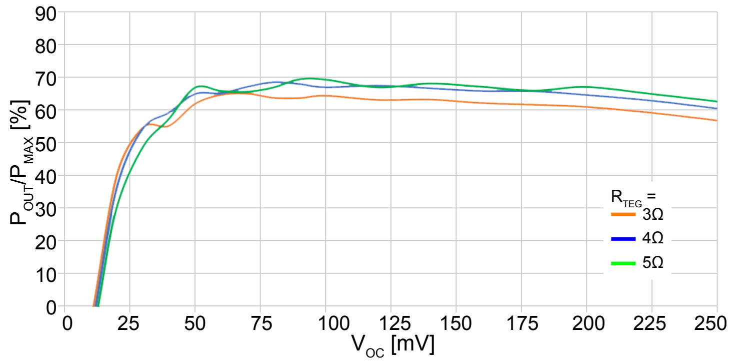


Figure 6. Efficiency for MCRY04-075S-**DI with V_{OUT} = 3.0V

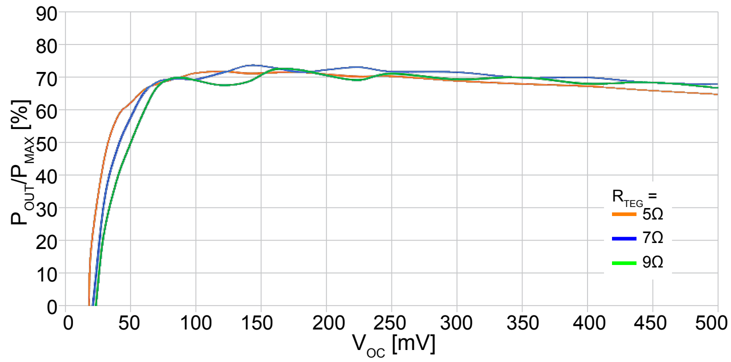


Figure 7. Efficiency for MCRY07-125Q-**DI with V_{OUT} = 4.2V

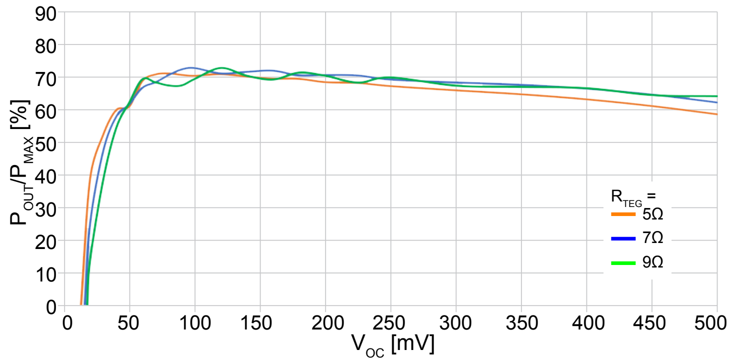


Figure 8. Efficiency for MCRY07-125Q-**DI with V_{OUT} = 3.0V

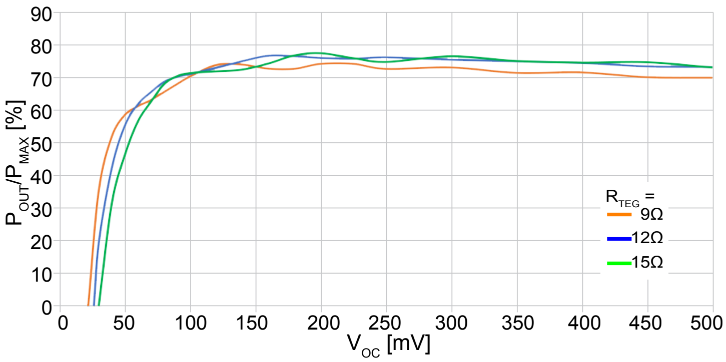


Figure 9. Efficiency for MCRY12-125Q-**DI with V_{OUT} = 4.2V

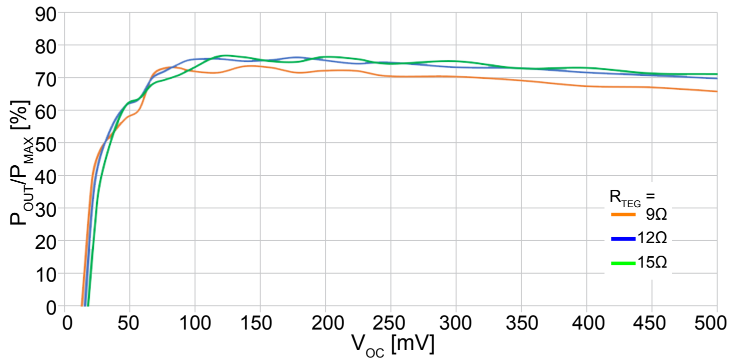


Figure 10. Efficiency for MCRY12-125Q-**DI with V_{OUT} = 3.0V

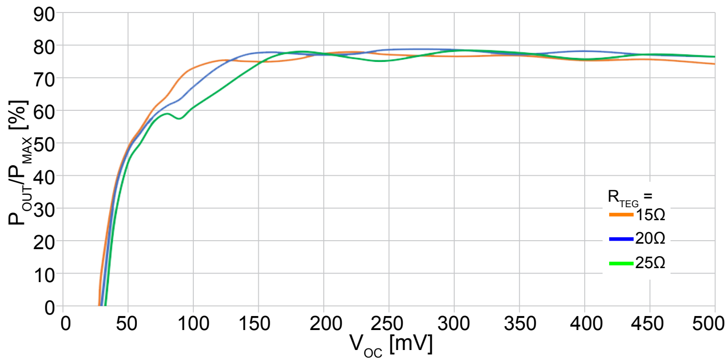


Figure 11. Efficiency for MCRY20-125Q-**DI with V_{OUT} = 4.2V

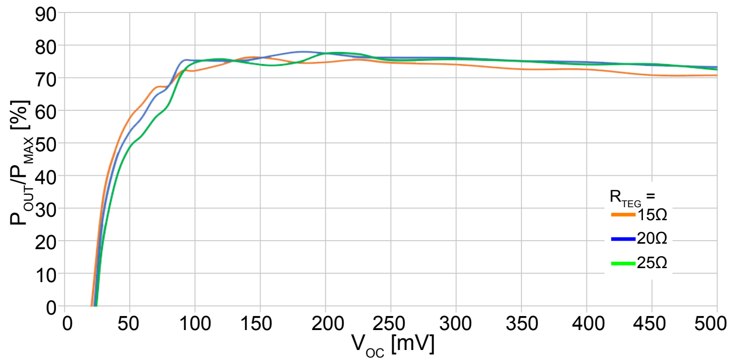


Figure 12. Efficiency for MCRY20-125Q-**DI with V_{OUT} = 3.0V

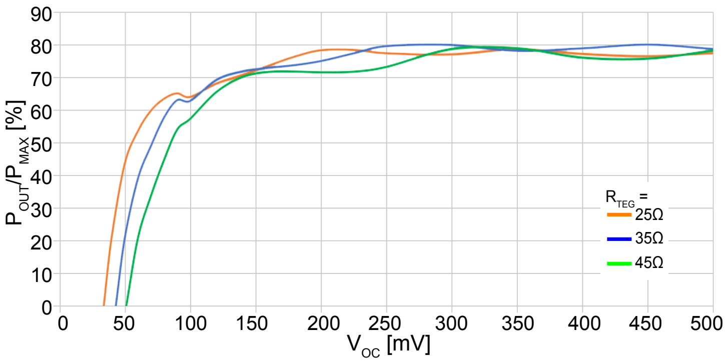


Figure 13. Efficiency for MCRY35-125Q-**DI with V_{OUT} = 4.2V

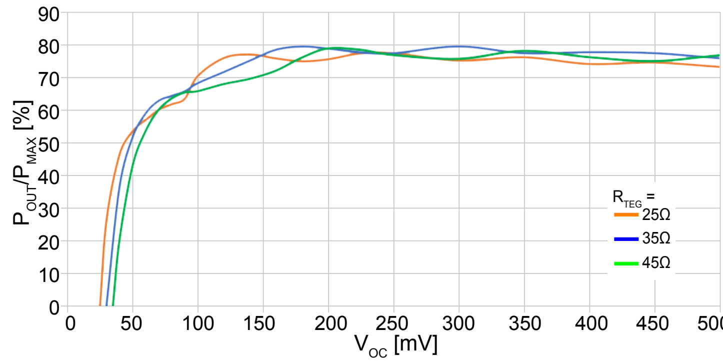


Figure 14. Efficiency for MCRY35-125Q-**DI with V_{OUT} = 3.0V

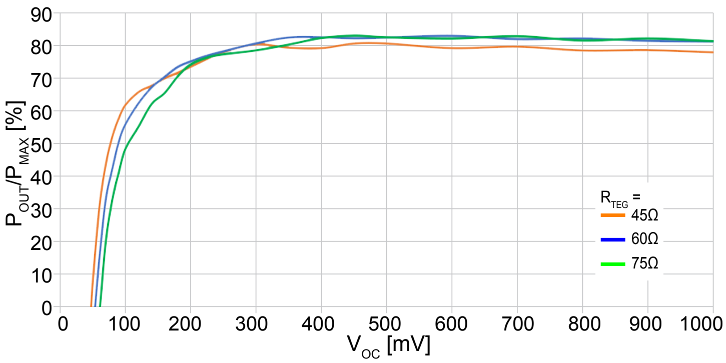


Figure 15. Efficiency for MCRY60-250P-**DI with V_{OUT} = 4.2V

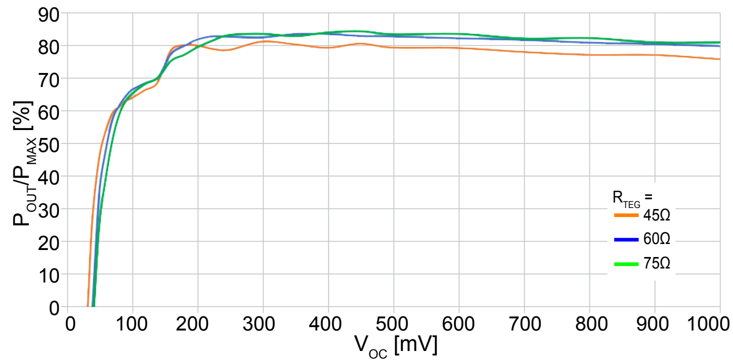


Figure 16. Efficiency for MCRY60-250P-**DI with V_{OUT} = 3.0V

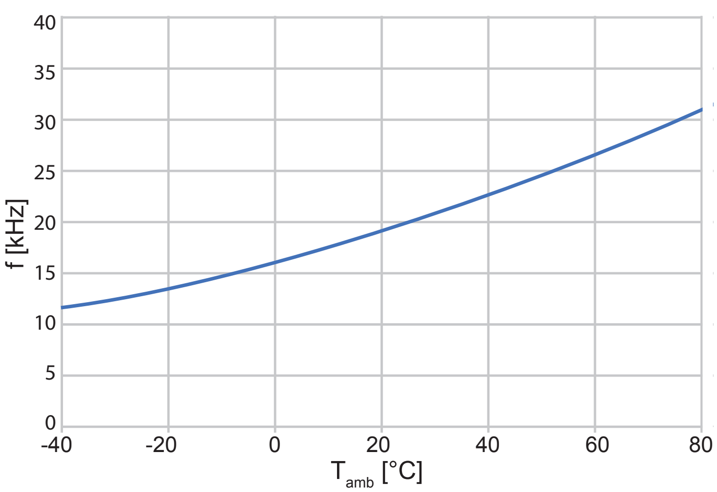


Figure 17. Switching Frequency vs T_{amb} for Mercury

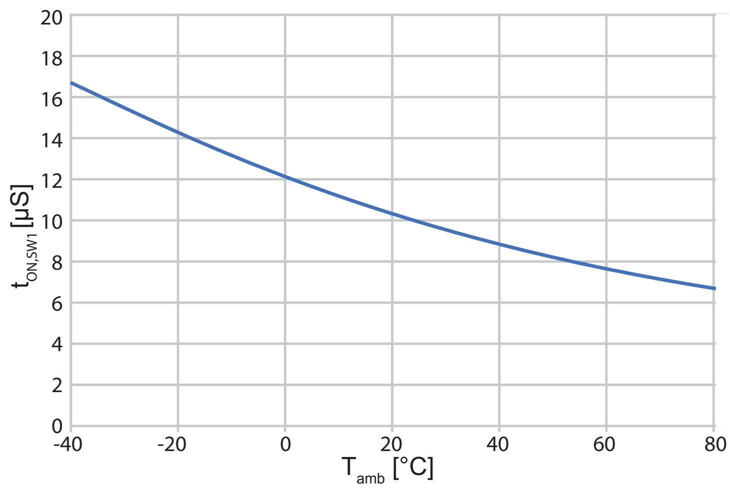


Figure 18. LX1-switch on-time vs T_{amb} for MCRY12-125Q-**DI

OPERATION

INTRODUCTION

The Mercury family of boost converters is designed to make thermal energy harvesting not only possible, but also efficient and reliable. Mercury is ideal for harvesting and managing surplus energy from extremely low input voltage sources such as thermoelectric generators (TEGs, Peltier) and thermopiles. The energy harvested can be used to charge a standard capacitor, supercapacitor or rechargeable battery, ensuring reliable system operation during high current bursts and even eliminate the need for battery changes. Mercury is designed with the highest efficiency and lowest external component count in mind. Figure 4 illustrates the internal block diagram of Mercury.

START-OSCILLATOR

The Start-Oscillator is formed from the external step-up transformer TR1, a native Start-NMOS, and an internal coupling capacitor at LX2 which is biased by an internal resistor to the voltage at VINP. This resonant Start-Oscillator is utilized only during cold-start.

The open-circuit cold-start voltage $V_{OC,CS}$ is a function of R_{TEG} and TR1. The following table shows $V_{OC,CS}$ and its corresponding cold-start power $P_{MAX,CS} = V_{OC,CS}^2/(4 \times R_{TEG})$ for all standard Mercury versions. After start-up, Mercury can operate at even lower V_{OC} depending on V_{OUT} – see TYPICAL PERFORMANCE CHARACTERISTICS.

Part Number	R_{TEG}	$V_{OC,CS}$	$P_{MAX,CS}$
MCRY04-075S-**DI	4Ω	15mV	14µW
MCRY07-125Q-**DI	7Ω	23mV	19µW
MCRY12-125Q-**DI	12Ω	24mV	12µW
MCRY20-125Q-**DI	20Ω	27mV	9µW
MCRY35-125Q-**DI	35Ω	32mV	7µW
MCRY60-250P-**DI	60Ω	54mV	12µW

RECTIFIER

An optional external diode D1 rectifies the AC voltage on the secondary winding of the transformer TR1, and the rectified current charges the external capacitor C2. If D1 is not provided, the rectifier circuit will use the body diode of the DMOS instead. Use of an external Schottky diode D1 is strongly recommended for improved cold-start and low-power efficiency.

VINP AND VINM

Mercury uses a unique top-referenced boost converter topology. VINP is connected to the positive potential V_{IN+} of the input and the external capacitor C2. Once C2 is charged by the Rectifier, the GND pin potential will sink below the potential V_{IN-} at VINM. Do not connect VINM to GND.

REFERENCE

Mercury includes a precision nanopower Reference to accurately regulate output voltages. It also provides a stable reference current for the internal Oscillator. The Reference becomes active as soon as the voltage at the external capacitor C2 exceeds 1V.

OSCILLATOR

Mercury also includes a trimmed nanopower Oscillator which has a positive temperature coefficient. This design helps to maintain impedance matching of R_{IN} to R_{TEG} across the entire operating temperature range (see INPUT IMPEDANCE AND LOAD MATCHING). The Oscillator also becomes active as soon as the voltage at the external capacitor C2 exceeds 1V.

FLYBACK CONVERTER

The Controller is enabled when a comparator detects sufficient voltage at the external capacitor C2. Normal operation begins with halting the Start-Oscillator using the Stop-NMOS. During normal operation, the transformer and rectifier are reused in a Flyback Converter topology. A bootstrapped gate driver turns on the LX1 switch using pulse width modulation (PWM) at constant duty cycle until the maximum output voltage is reached. Once this happens, the gate driver switches to a pulse frequency modulation (PFM) scheme to maintain the output voltage.

ADC

An 8-bit analog-to-digital converter (ADC) measures the open-circuit voltage every second. Just before each measurement, the Flyback Converter is stopped temporarily to charge the input capacitor C1 via R_{TEG} up to V_{OC}. The measurement result is used to determine the gate driver settings, whether the DMOS should be used, and to stop the Flyback Converter at high V_{OC} to prevent damage to the chip.

SYNCHRONOUS RECTIFIER

A 50V DMOS switch is used in parallel to the rectifier to optimize Mercury's efficiency at input power levels above approximately 80µW.

MATRIX Industries · 1440 O'Brien Drive Suite A-1 · Menlo Park, CA 94025 · +1 650-462-1003 · www.matrixindustries.com · info@matrixindustries.com

CHARGE CONTROL

When the voltage at the external capacitor C2 is higher than the output voltage V_{OUT}, the Charge Control closes the PMOS. This is done in such a way that the current is limited and the voltage at C2 always stays above 1.8V. If the ADC measurement result shows that the input power is insufficient to charge the output, the PMOS is opened and Mercury powers down. In this state, only a very low leakage current I_{LEAK} enters the VOUT pin, and stored energy in the battery or capacitor is not dissipated into Mercury.

V_{MAX} DETECTION

Since either side of the PMOS can be presented with a higher potential than the other, the V_{MAX} detector switches the higher voltage into the PMOS bulk to avoid dissipating current through a body diode.

OUTPUT CONTROL

The ADC measurement result is transmitted on two open-drain outputs via a serial protocol.

APPLICATIONS INFORMATION

INTRODUCTION

Mercury is a next-generation energy harvester for very low input voltage sources, converting their outputs to usable levels to power sensors, microprocessors, and wireless transmitters. Such applications generally require much higher voltages and peak powers than the input source can provide. Mercury 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.

INPUT VOLTAGE SOURCES

Mercury is optimized for operation from low voltage sources such as thermopiles or thermoelectric generators (TEGs). In any given application, the minimum open-circuit voltage (V_{OC}) required will depend on the load power drawn and the internal DC resistance (R_{TEG}) of the voltage source.

INPUT IMPEDANCE AND LOAD MATCHING

Once started, Mercury's flyback converter is designed to operate in discontinuous current mode (DCM). The input resistance R_{IN} of a DCM flyback converter without losses and parasitic effects can be calculated in the following way:

$$R_{IN} = 2 \times L1 \times f / DC^2_{SW1}$$

R_{IN} of a DCM flyback converter is independent of V_{OC} and can be set by controlling its duty-cycle DC_{SW1} and frequency f, for a given transformer with primary inductance L1.

Due to the coupling between the thermal and electrical systems in the TEG, its effective output resistance R_{TEG} is generally higher than the AC resistance $R_{TEG,AC}$ measured under thermal adiabatic conditions. The exact relationship is a function of the current drawn from and the heat flux passing through the TEG. Under simultaneous thermal and electrical matching conditions, when both electrical and thermal circuits are optimized for maximum power throughput:

$$R_{TEG} = R_{TEG,AC} \times \sqrt{1 + ZT}$$

$$K_{TEG} = K_{TEG,OC} \times \sqrt{1 + ZT}$$

R_{TEG} of a thermally and electrically matched TEG is larger than $R_{TEG,AC}$ scaled by a factor dependent on the dimensionless figure-of-merit ZT of the thermoelectric. At the same time, the effective thermal conductance K_{TEG} is scaled by the same factor over the thermal conductance $K_{TEG,OC}$ measured under electrical open-circuit conditions. While optimized matching conditions are not easy to attain, it is a fair approximation in many cases where effort is made to match the thermal resistance. Using a ZT value of 0.7 for the TEG:

$$R_{TEG} \approx 1.3 \times R_{TEG,AC}$$

$$K_{TEG} \approx 1.3 \times K_{TEG,OC}$$

When the flyback converter is optimally matched, the input voltage (V_{IN}) measured between the VINP and VINM pins becomes exactly $V_{OC}/2$. This is accomplished by choosing the input resistance:

$$R_{IN} = R_{TEG}$$

In most TEGs, R_{TEG} increases with temperature. For consistent matching across the entire operating temperature range, R_{IN} must increase with temperature in the same manner. This is achieved by designing appropriate temperature coefficients for the oscillator frequency f and the on-time $t_{ON,SW1}$ (see TYPICAL PERFORMANCE CHARACTERISTICS).

EFFICIENCY

For a given V_{OC} and R_{TEG} the maximum input power is:

$$P_{MAX} = V_{OC}^2/(4 \times R_{TEG})$$

The efficiency curves in TYPICAL PERFORMANCE CHARACTERISTICS show the output power P_{OUT} relative to P_{MAX}, so they show the product of electrical efficiency and impedance matching.

VOUT

A capacitor, supercapacitor or rechargeable battery may be connected to the VOUT pin as a charge storage device. The device will be charged up to $V_{OUT,MAX}$ so it is important to select the appropriate Mercury for the device. Since Mercury cannot protect a battery from over-discharge or short-circuit by an external load, a battery protection circuit is strongly recommended especially when using lithium ion batteries.

ADC OUTPUTS

The two ADC Outputs ADC_REF and ADC_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 must be connected to GND.

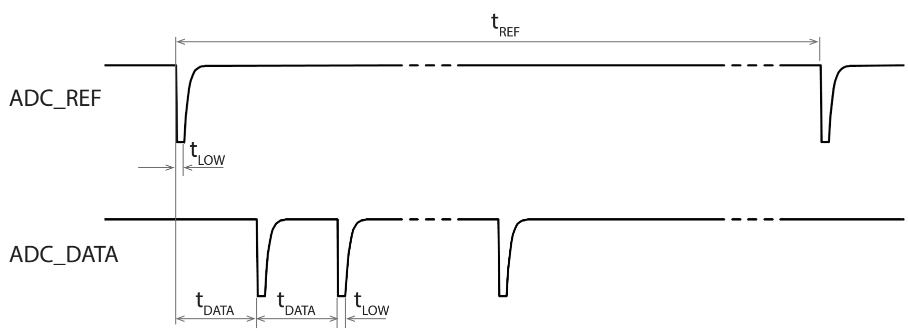


Figure 19. Timing charts of ADC Outputs

The serial transmission protocol is illustrated above. A pulse on ADC_REF signals the start of the data transmission in each reference period T_{REF}, during which a train of pulses is transmitted on ADC_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 ADC_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, Mercury sends two low pulses on ADC_REF before powering down.

COMPONENT SELECTION

TRANSFORMER

Every version of Mercury is optimized for a specific transformer configuration. The following transformers are recommended:

Part number	Vendor	Part number	L1	Turns ratio	Size (mm)
MCRY**-075S-**DI	Coilcraft	LPR6235-752SMR	7.5µH	1:100	6 x 6 x 3.5
	Würth	WE-EHPI 74488540070	7µH	1:100	6 x 6 x 4.0
MCRY**-125Q-**DI	Coilcraft	LPR6235-123QMR	12.5µH	1:50	6 x 6 x 3.5
	Tokyocoil	TTRN-0535H	12.5µH	1:50	5 x 5 x 3.5
	Würth	WE-EHPI 74488540120	13µH	1:50	6 x 6 x 4.0
MCRY**-250P-**DI	Coilcraft	LPR6235-253PMR	25µH	1:20	6 x 6 x 3.5
	Würth	WE-EHPI 74488540250	25µH	1:20	6 x 6 x 4.0

INPUT CAPACITOR C1

The input capacitor C1 serves as a charge bank to reduce the input voltage ripple and ohmic loss in the TEG. The capacitor size depends on the current amplitude in the transformer primary, the TEG resistance R_{TEG} and the primary inductance L1.

X5R or X7R ceramic capacitors (MLCC) which have low effective series resistance (ESR) and a minimum voltage rating of 2.5V are recommended for C1. The values recommended below provide maximum efficiency and no larger capacitors should be used. Larger capacitors at C1 cause the timeout for the V_{OC} measurement to occur before V_{OC} is settled – this can increase the measurement time and reduce efficiency. Alternatively, a Tantalum capacitor with ESR < 10mΩ can be used, but the nominal capacitance used should be half of the following recommended MLCCs.

Part number	Vendor	Part number	C	Ratings	Size (mm)
MCRY04-075S-**DI	Murata	GRM31CR60E227ME11	220μF	X5R 2.5V	3.2 x 1.6 x 1.6
	Taiyo Yuden	PMK316BBJ227ML-T	220μF	X5R 2.5V	3.2 x 1.6 x 1.6
MCRY07-125Q-**DI MCRY12-125Q-**DI	Murata	GRM21BR60E107ME15	100μF	X5R 2.5V	2 x 1.25 x 1.25
	Taiyo Yuden	JMK316BJ107ML-T	100μF	X5R 6.3V	3.2 x 1.6 x 1.6
MCRY20-125Q-**DI	Murata	GRM188R60E476ME15	47μF	X5R 2.5V	1.6 x 0.8 x 0.8
	Taiyo Yuden	JMK212BJ476MG-T	47μF	X5R 6.3V	2 x 1.25 x 1.25
MCRY35-125Q-**DI MCRY60-250P-**DI	Murata	GRM188R60J226MEA0	22μF	X5R 6.3V	1.6 x 0.8 x 0.8
	Kemet	C0805C226M9PACTU	22μF	X5R 6.3V	2 x 1.25 x 1.25

CAPACITOR C2

A 4.7μF X5R or X7R MLCC with low ESR and a minimum voltage rating of 6.3V is recommended.

Part number	Vendor	Part number	C	Ratings	Size (mm)
MCRY*	Murata	GRM155R60J475ME87	4.7μF	X5R 6.3V	1.0 x 0.5 x 0.5
	Taiyo Yuden	JMK107BJ475KA-T	4.7μF	X5R 6.3V	1.6 x 0.8 x 0.8

DIODE D1

A Schottky diode with small capacitance, low reverse current and high voltage rating is recommended.

Part number	Vendor	Part number	C_D	I_R	V_R	Size (mm)
MCRY*	Nexperia	BAS70L	2pF	100nA	70V	1.0 x 0.6 x 0.5
	Vishay	BAS70-02V-V-G	2pF	100nA	70V	1.6 x 0.8 x 0.7

MATRIX Industries · 1440 O'Brien Drive Suite A-1 · Menlo Park, CA 94025 · +1 650-462-1003 · www.matrixindustries.com · info@matrixindustries.com

PCB LAYOUT GUIDELINES

TRANSFORMER

Mercury's flyback converter runs at low power levels and at a rather low switching frequency, so it does not depend as critically on careful printed circuit board (PCB) layout as with many other DC/DC converters. However, there are several important points to consider. Due to the very low input voltages encountered with this circuit, voltage drops due to stray resistance in the connections to VINM, LX1, and the transformer primary should be minimized. Any parasitic resistances in the primary winding conduction path will lower efficiency, increase cold-start voltage, and result in slower charge times. Additionally, due to the low charge currents available at VOUT, any source of leakage current on the output path must be minimized. Finally, parasitic inter-winding capacitance between the transformer windings can cause severe degradation in Mercury's performance, so take particular care to connect the primary winding to LX1 and the secondary winding to LX2 in the following way:

Vendor	Part number	Mercury LX1	Mercury LX2
Coilcraft	LPR6235	Pin 1	Pin 3
Tokyocoil	TTRN-0535H	Pin 1	Pin 5
Würth	WE-EHPI	Pin 2	Pin 4

An example board layout is shown below:

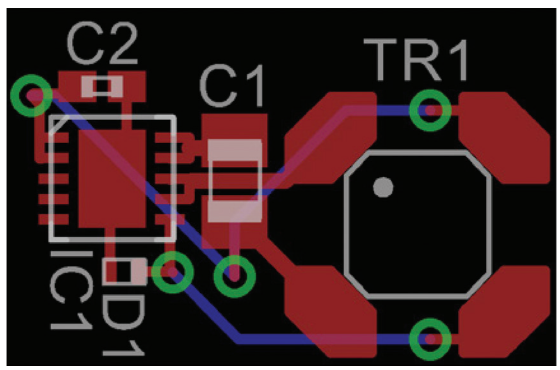


Figure 20. Example Placement for Two-Layer PCB using LPR6235 (DFN Package)

PACKAGE DIMENSIONS

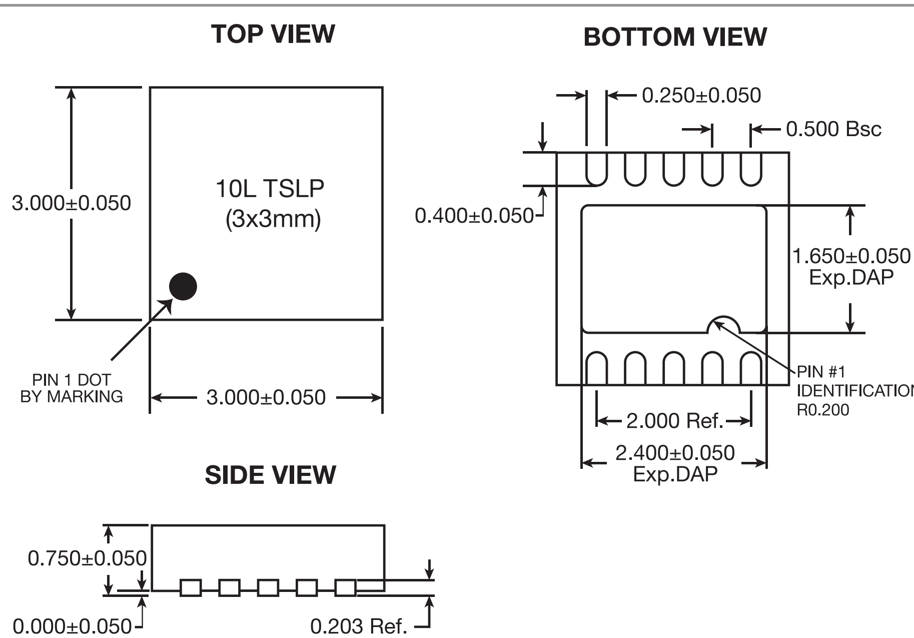


Figure 21. Package drawing of 10-lead, 3mm × 3mm DFN

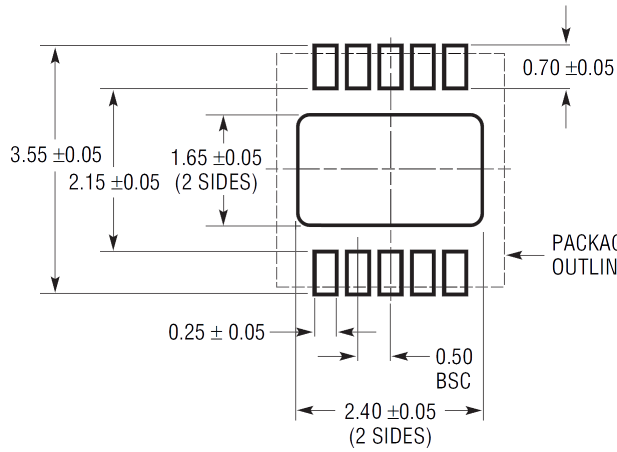


Figure 22. Recommended Land Pattern

REVISION HISTORY

DS-Mercury.20200807.E.U

Revision	Date	Description
*A	Jan 2019	Preliminary Datasheet Release
*B	Feb 2019	Production release
*C	Jun 2019	General datasheet updates
*D	Jul 2020	Electrical and ordering information updates
*E	Aug 2020	Additional updates

DISCLAIMER