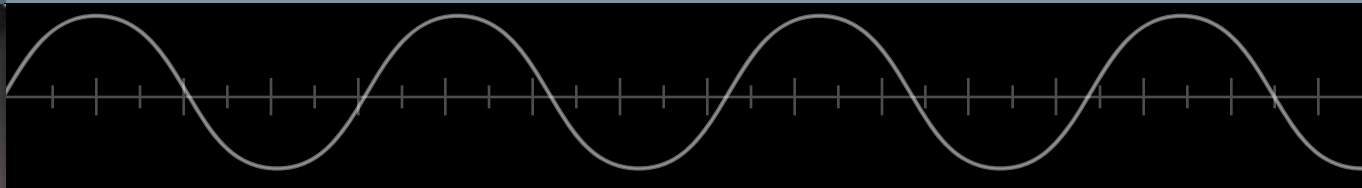


Linear Technology Corporation

**Energy Harvesting Solutions from Linear
Technology**

May 6th, 2010

**Tony Armstrong – Director of Product
Marketing**



Agenda

- **Energy Harvesting Background**
 - i. **Opportunity**
 - ii. **Sources**
 - iii. **Applications**

- **LTC3108: Ultralow Voltage Step-up Converter and System Manager**

- **LTC3588-1: Piezoelectric Energy Harvesting Power Supply**

- **LTC4070: Shunt Battery Charger System**

Energy Harvesting - Opportunity

Charge, supplement or replace batteries in systems where battery use is inconvenient, impractical, expensive or dangerous

Eliminate the need for wires to carry power or to transmit data

Smart wireless sensor networks to monitor and optimize complex industrial processes, remote field installations and building HVAC

Harvesting otherwise wasted heat from industrial processes, solar panels, internal combustion engines, etc.

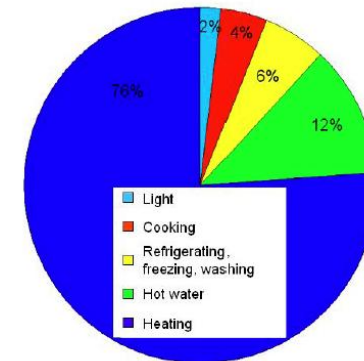
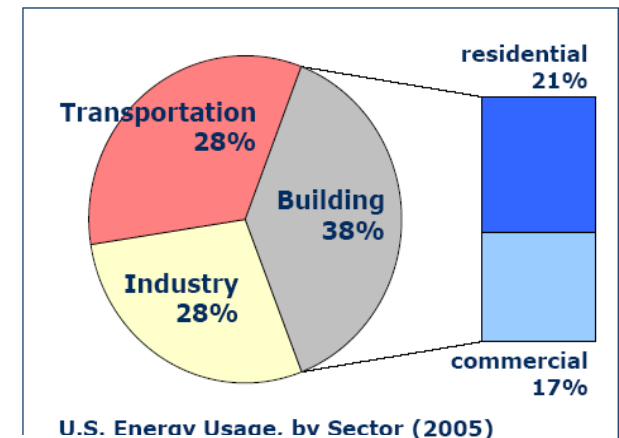
Various consumer electronic accessory chargers

Energy Harvesting Sources

- Thermo-Electric Generator or Thermopile (Heat)
- Piezo-Electric (Vibration or strain)
- Photovoltaic (Light)
- Galvanic (Moisture)
- Coil/Magnet (Motion)

Energy Harvesting Radio Sensors- Key Application

- Buildings Use 38% of our Total Energy Requirements
- Energy Use Set to Double between 2003 and 2030
- You can Save 30% with Building Automation Systems
- ROI within 3-4 years

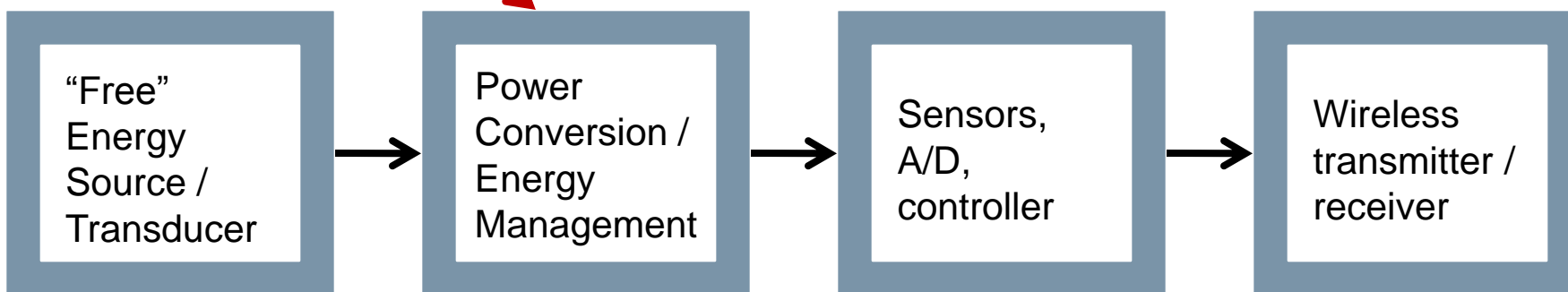


Energy requirement of a household (source: Wikipedia.de)

Where an Energy Harvester Fits in

THE MISSING LINK

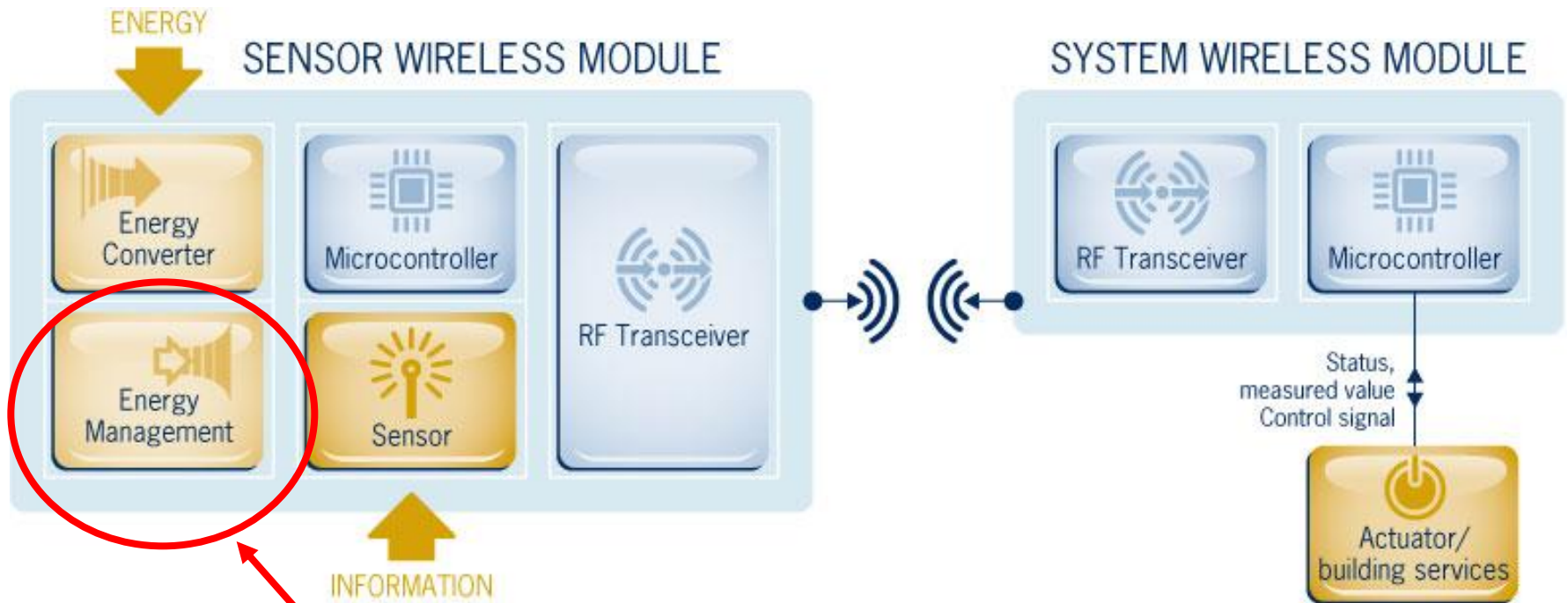
- Remote industrial sensor networks
- HVAC monitoring and control
- Building automation
- Predictive maintenance
- Avionics
- Automatic/remote metering



TEG,
Photovoltaic,
Piezo

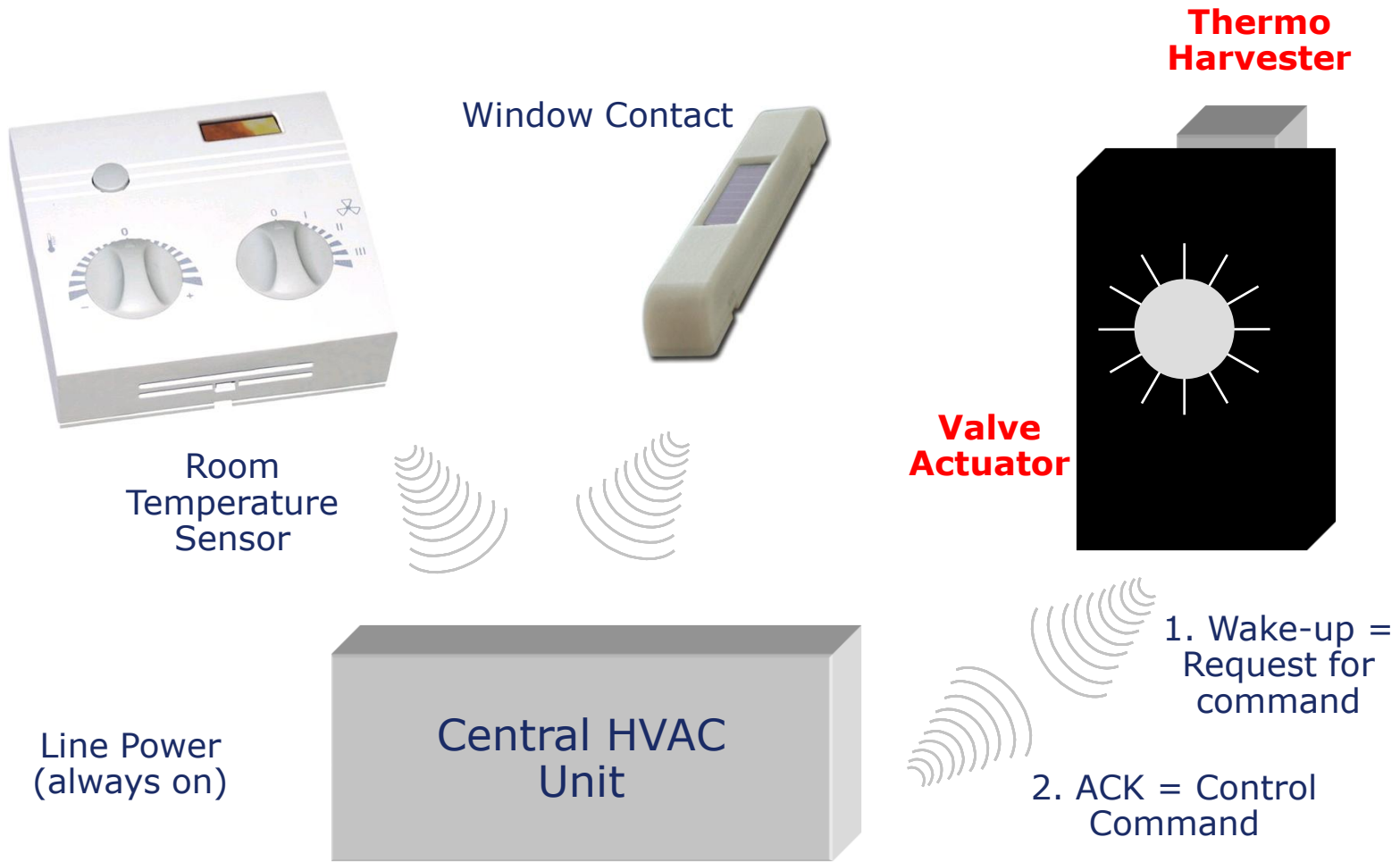
LTC3108
LTC3588

Energy Harvesting Wireless Sensors

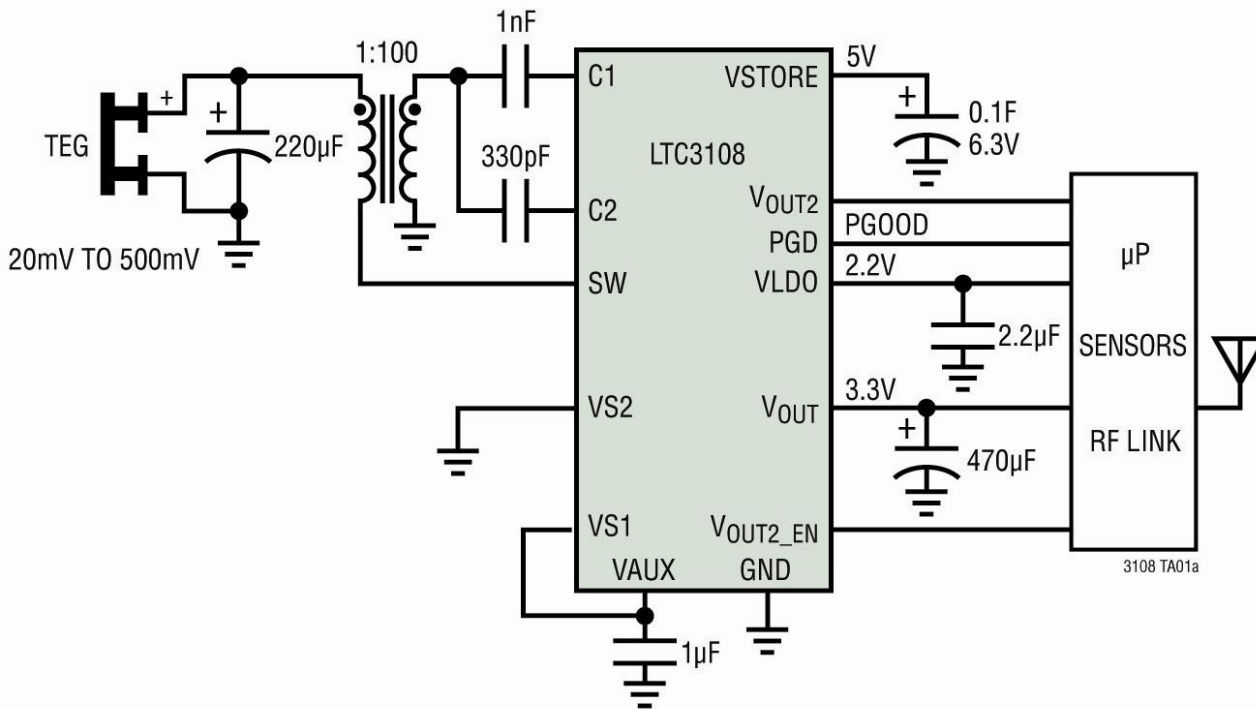


Target of LTC3108/3588-1

Bidirectional Self-Powered Actuators



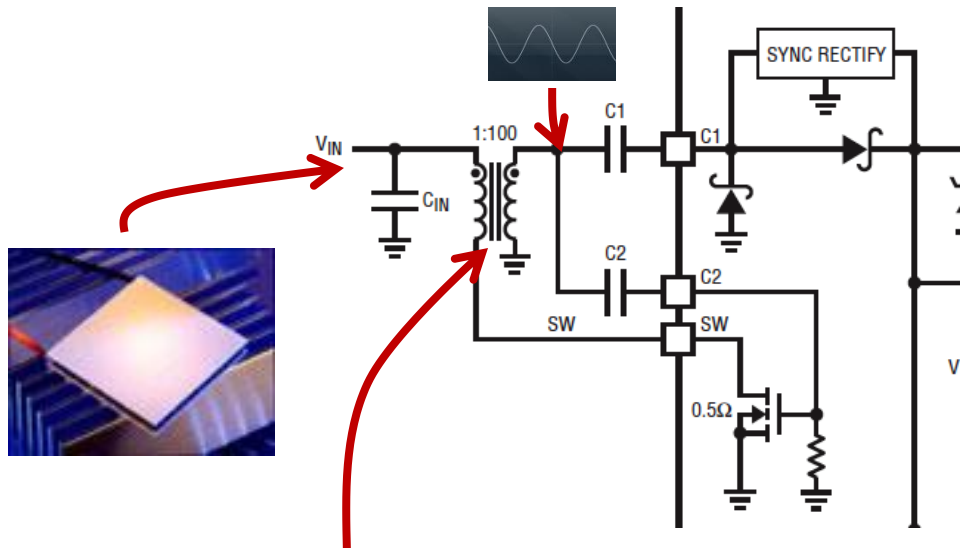
LTC3108: Ultra-Low Voltage (20mV) Step-Up Converter and Power Manager



- Operates from inputs as low as 20mV
- Selectable fixed output voltages
- Unique resonant power converter / energy harvester
- Auxiliary LDO
- Manages energy storage between reservoir (V_{STORE}) and main C_{OUT} or Battery (V_{OUT})
- V_{OUT2} is user-switched
- Compact step-up transformer
- 3mm x 4mm QFN or 16 lead narrow SSOP packages

LTC3108 Feature: 20mV Resonant Boost Topology

- 20mV operation or ~1deg dT if powered from a Peltier Effect Thermal Electric Generator (TEG)
- LTC-proprietary compound depletion mode N-Channel MOSFET makes extreme low voltage operation possible
- Circuit self-oscillates, resonant circuit formed by Lmag and FET Cgate
- Built-in synchronous rectification improves energy harvesting yield (conversion efficiency)
- 1:100 transformer is a **standard Coilcraft part (LPR-6235), 6mm x 6mm x 3.5mm**



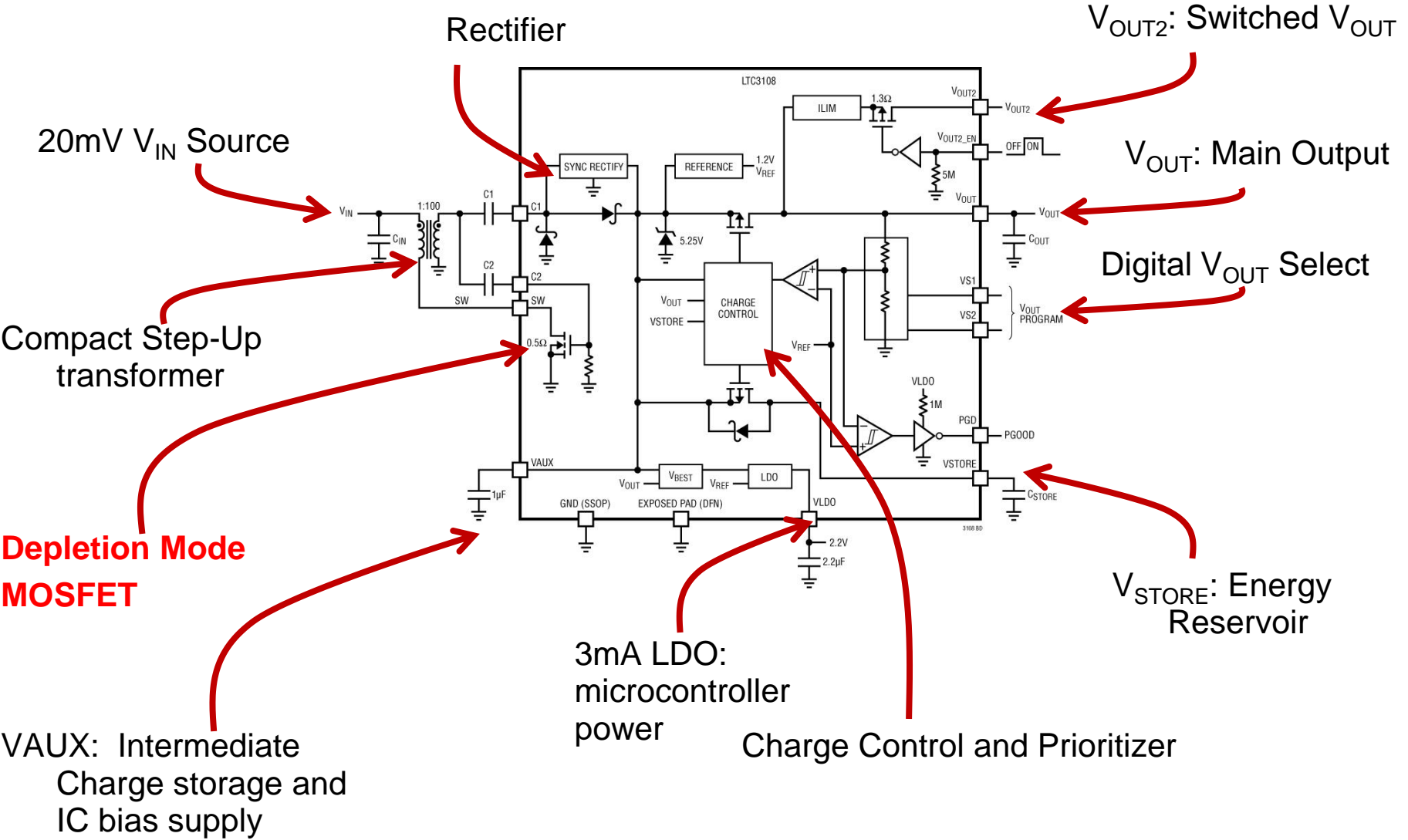
MECHANICAL SPECIFICATIONS

PHYSICAL PARAMETERS (mm)	(In)	(In)		
DIMENSIONS	MIN	MAX	MIN	MAX
A: WIDTH	5.92	6.08	.233	.239
B: LENGTH	5.92	6.08	.233	.239
C: HEIGHT		3.5		.138

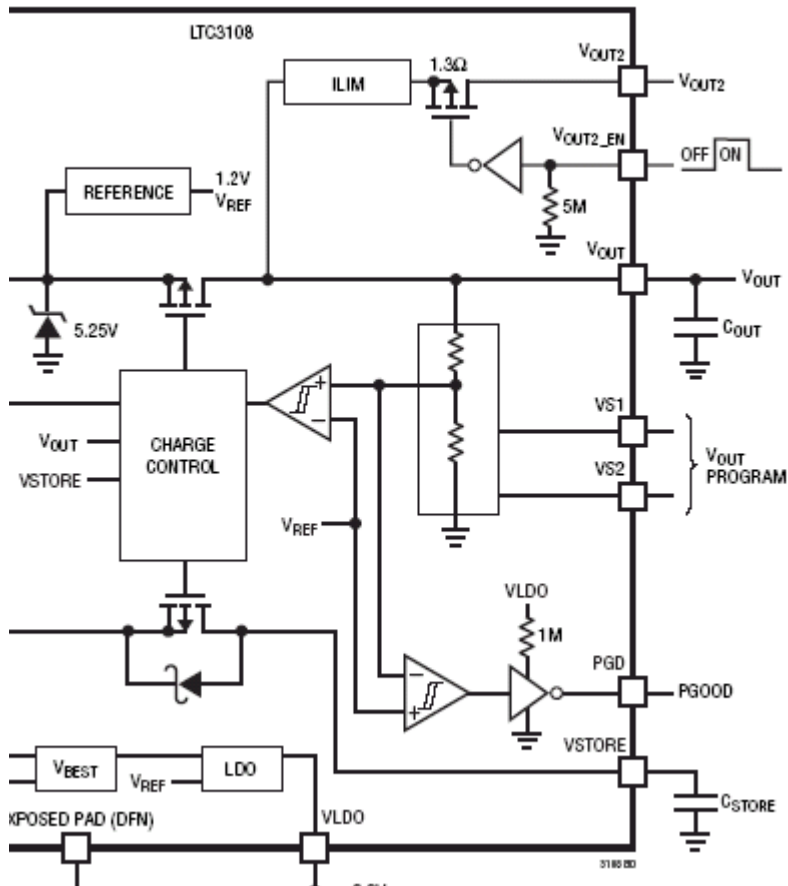
AUTOTRANSFORMER LAND PATTERN
RECOMMENDED LAND PATTERN
 Area must be covered with solder mask.

TOUCHUP OF BOARD CAN BE ACCEPTED ON THIS PAD

LTC3108 Block Diagram Review

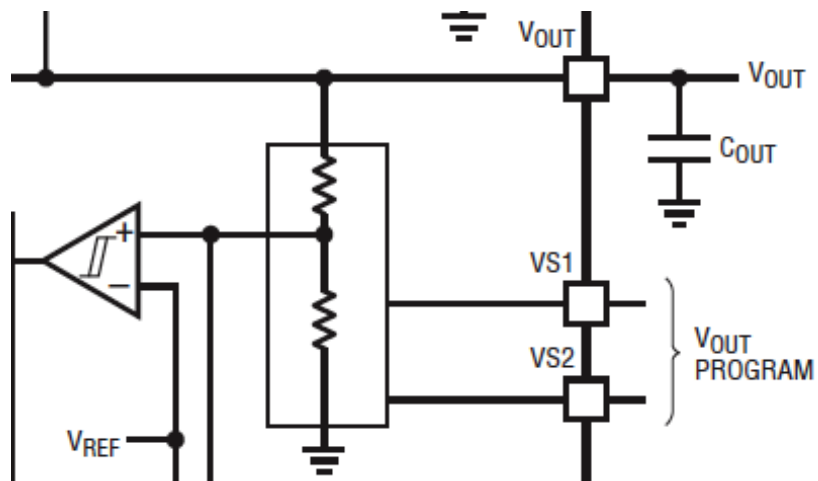


LTC3108 Feature: Harvested Energy Management



- Harvested energy is preferentially sent to V_{OUT}
- Excess harvested energy is sent to V_{STORE}
- V_{STORE} will supply V_{OUT} when the input source is unavailable
- V_{OUT2} is a switched ON-OFF version of V_{OUT} for Sensors that don't have a shutdown capability
- Charge Control block provides all of the intelligence to ensure seamless operation

LTC3108 Feature: Digital Selection of V_{OUT}

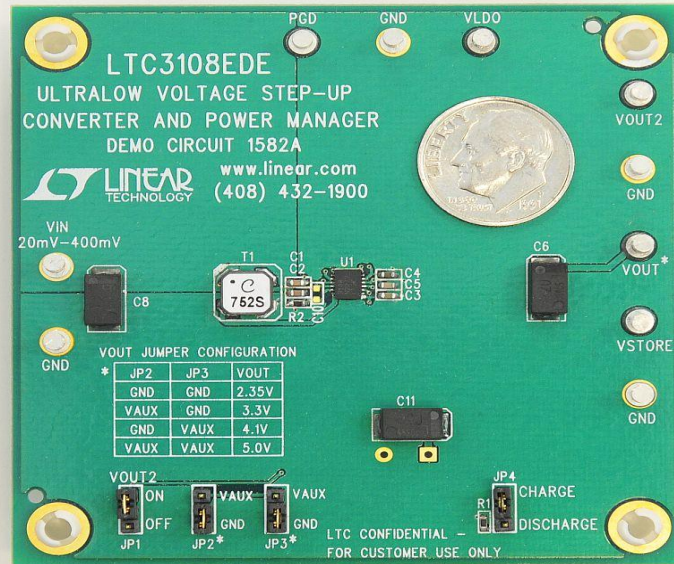


- Eliminates multi-M Ω resistors from the PCB
- Easier manufacturability
- Predictable and stable V_{OUT}
- Other combinations possible with option mask (contact the factory)

Table 1. Regulated Voltage Using Pins VS1 and VS2

VS2	VS1	V_{OUT}
GND	GND	2.35V
GND	VAUX	3.3V
VAUX	GND	4.1V
VAUX	VAUX	5V

LTC3108: Demo Circuit – DC1582A



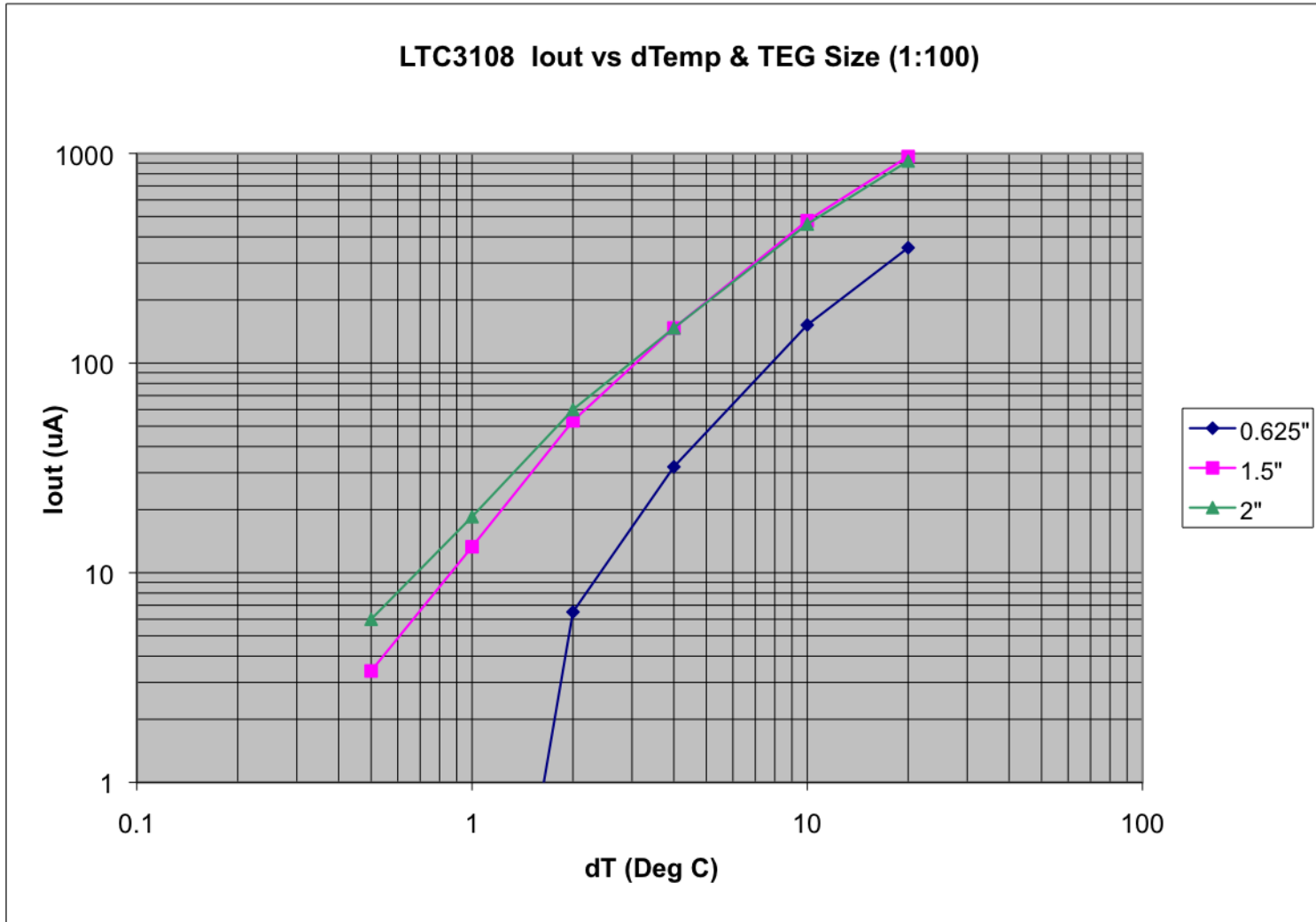
Thermal Energy Application Example

Human body heat operated radio sensor

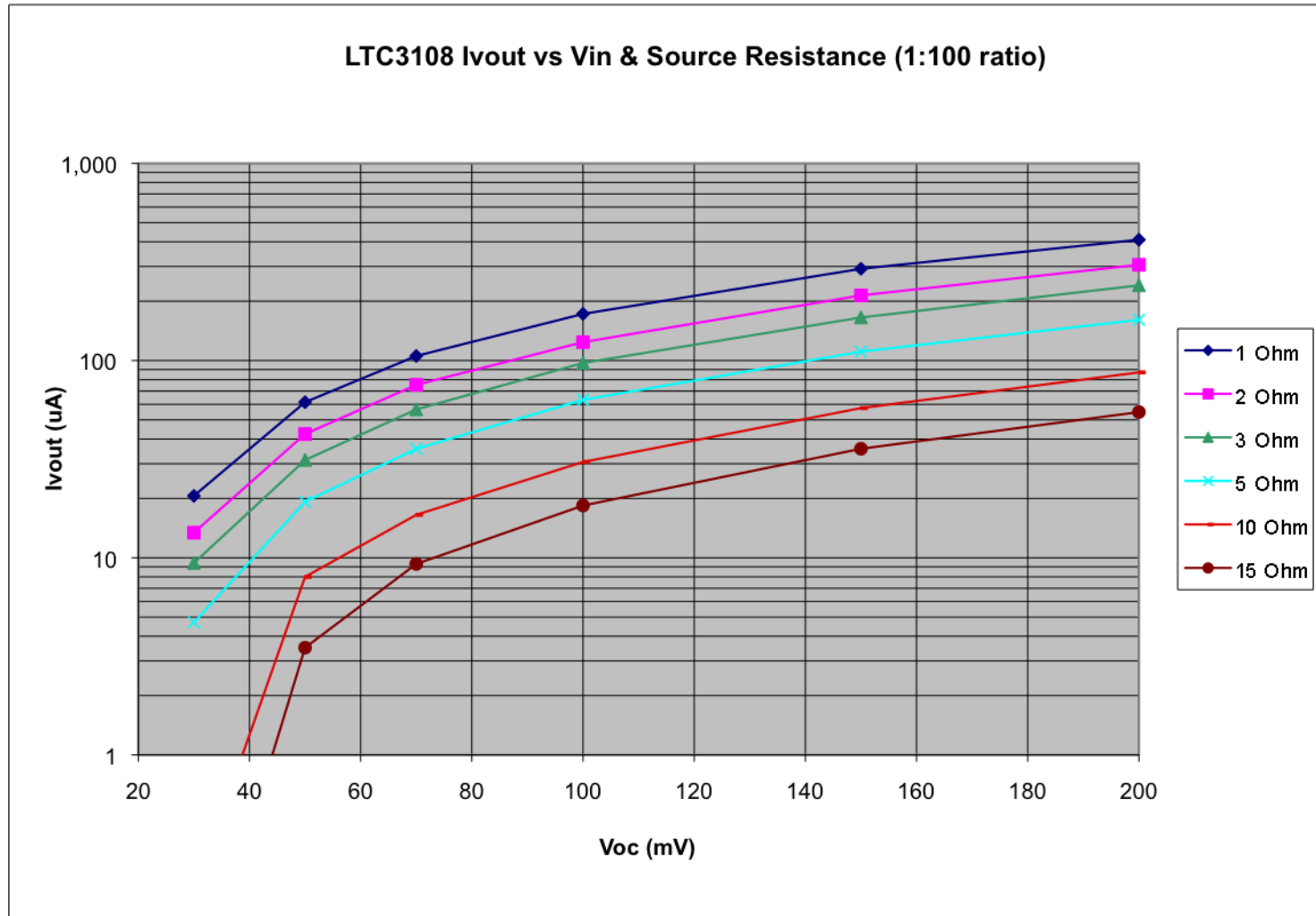
Thermal powered heating valve



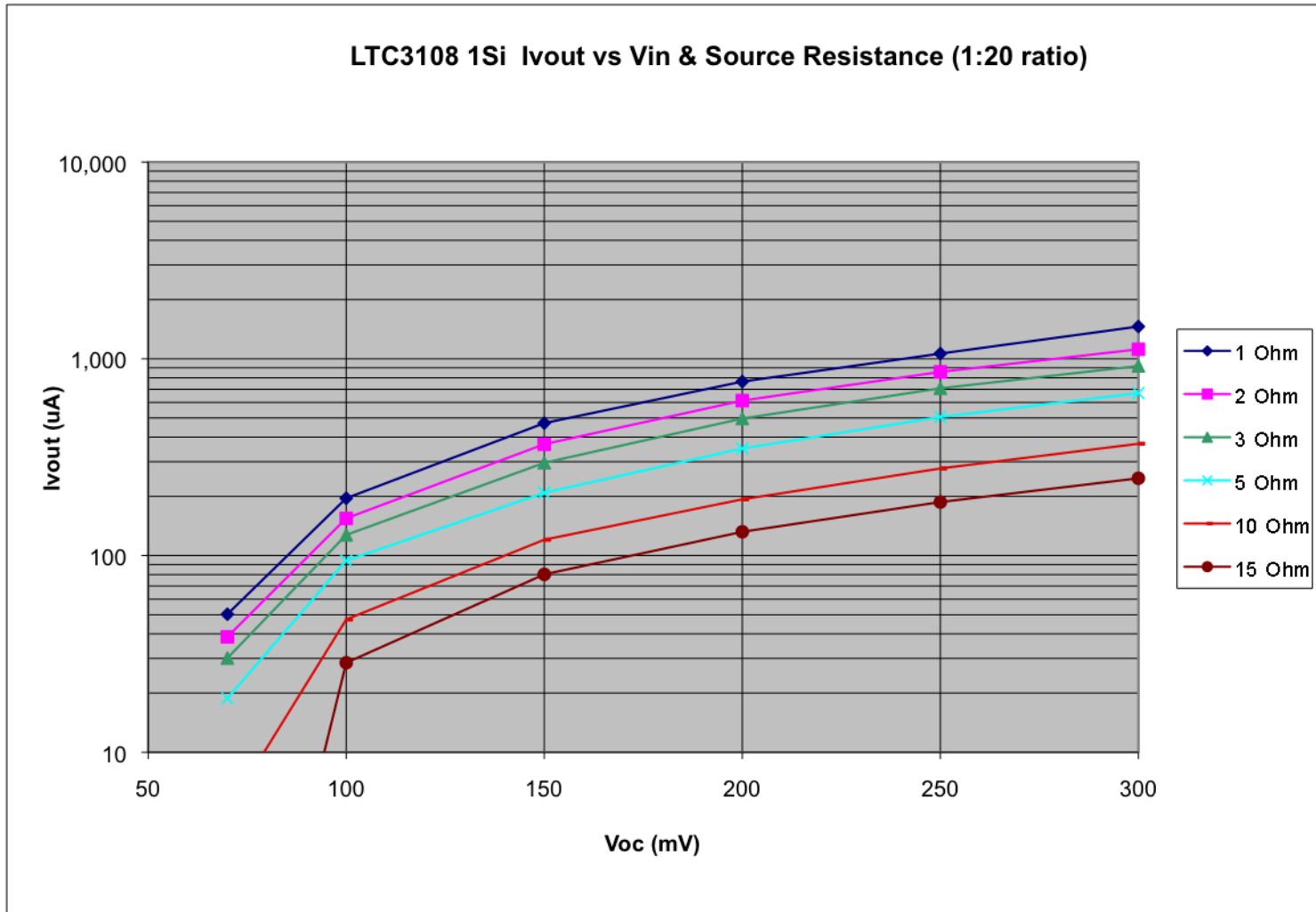
LTC3108: Output Current vs. dT and TEG Size



LTC3108: Output Current vs. V_{OC} and R_{source}



LTC3108: Output Current vs. V_{OC} and R_{source}



LTC3588-1: What Is It?

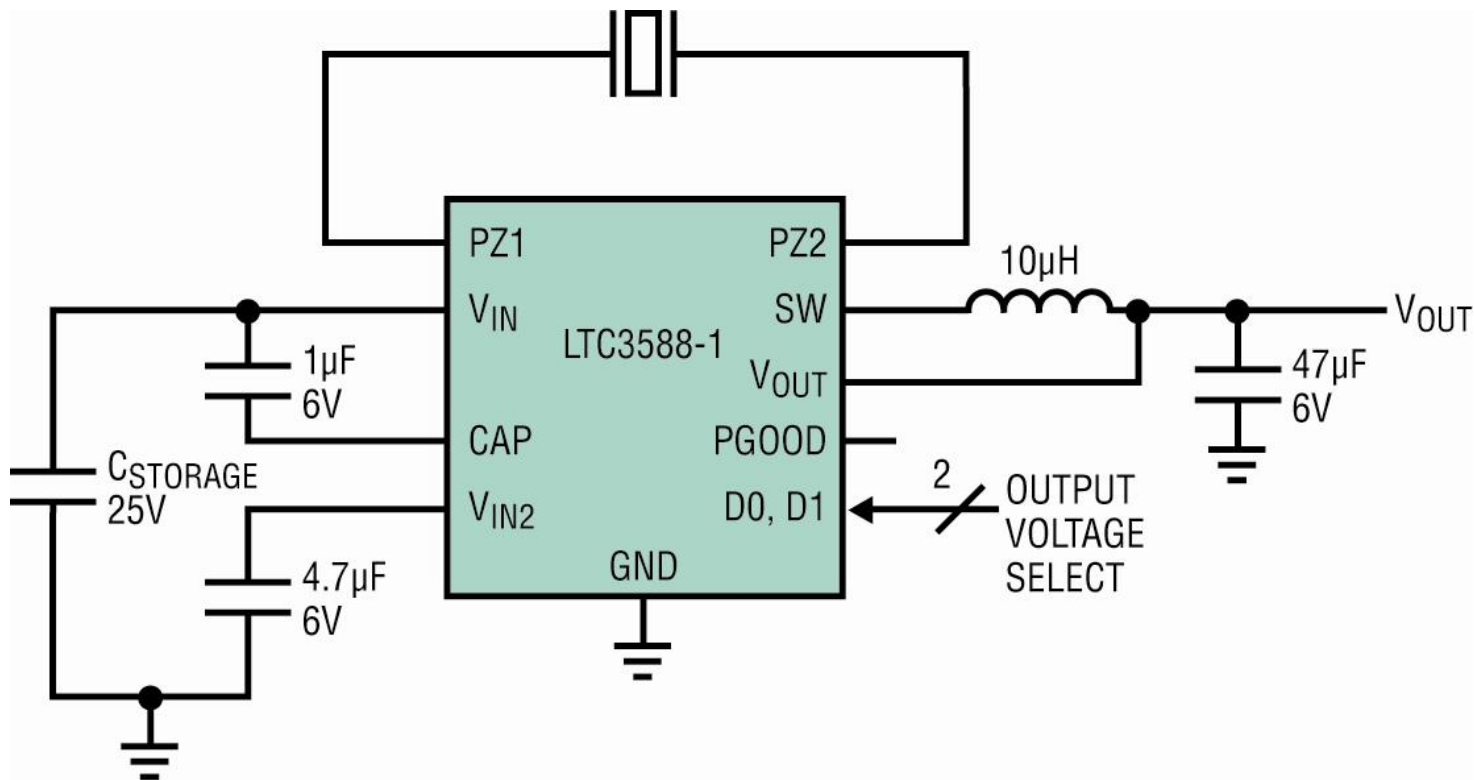
Piezoelectric Energy Harvesting Power Supply

- Collects Energy from Piezoelectric Transducer and Delivers Regulated Outputs up to 100mA
- High Efficiency Integrated Hysteretic Buck DC/DC
- Integrated Low-Loss Full-Wave Bridge Rectifier
- Requires Only 950nA of Quiescent Current (in Regulation) and 450nA in UVLO (Initial Charge of Input Capacitor)
- 20V Shunt Regulator on V_{IN} Dissipates Excess Harvested Energy

LTC3588-1 : Key Features

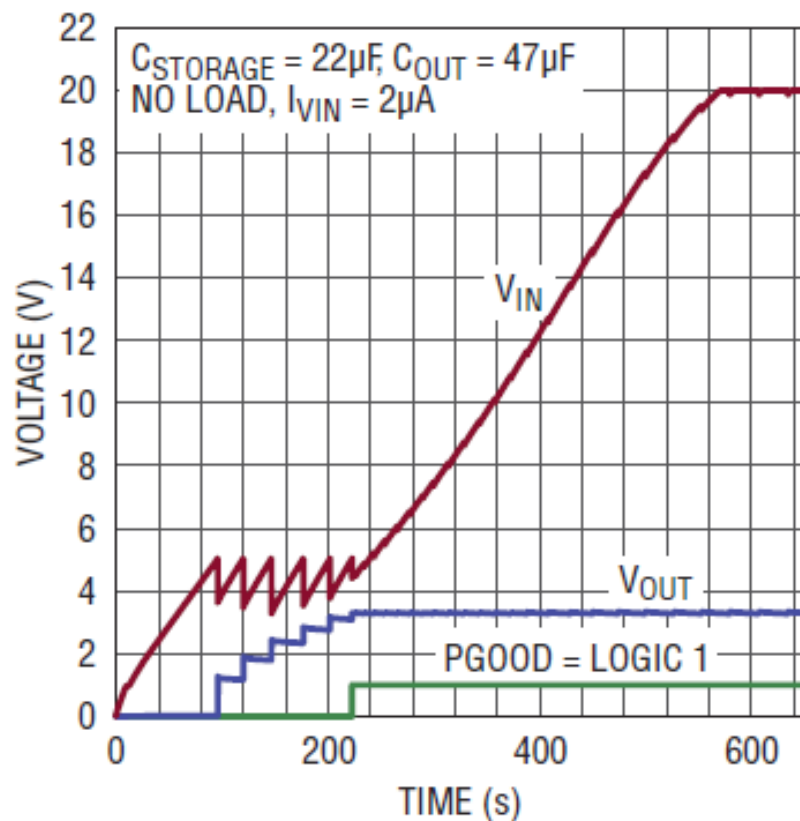
- 950nA Input Quiescent Current (Output in Regulation – No Load)
- 450nA Input Quiescent Current in UVLO
- 2.7V to 20V Input Operating Range
- Integrated Low-Loss Full-Wave Bridge Rectifier
- Up to 100mA of Output Current
- Selectable Output Voltages of 1.8V, 2.5V, 3.3V, 3.6V
- High Efficiency Integrated Hysteretic Buck DC/DC
- Input Protective Shunt – Up to 25mA Pull-Down at $V_{IN} \geq 20V$
- Wide Input Undervoltage Lockout (UVLO) Range
- Available in 10-Lead MSE and 3mm × 3mm DFN Packages

LTC3588-1 – Typical Application



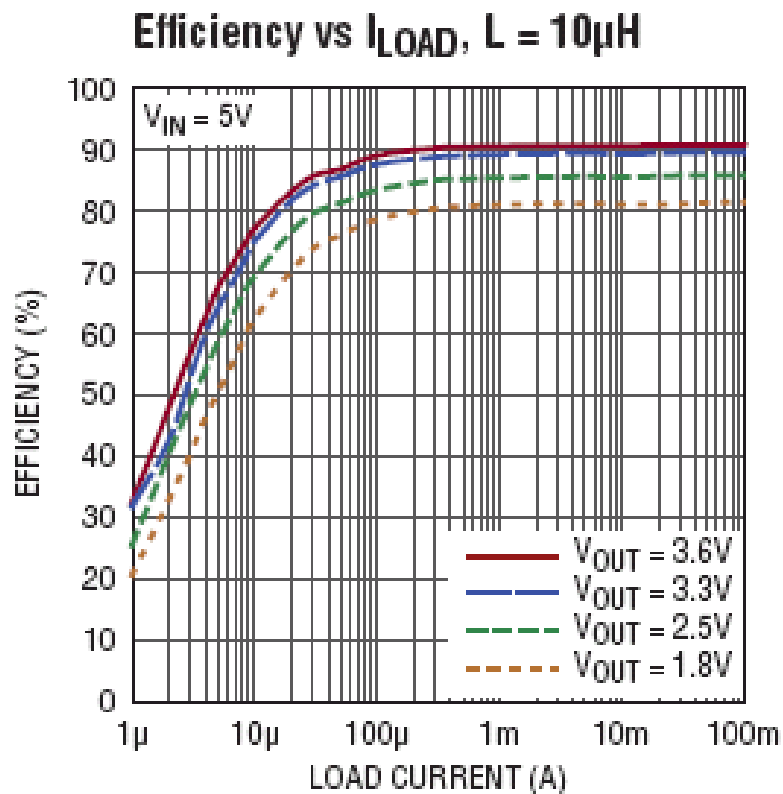
LTC3588-1 – Typical Application Start -Up

LTC3588-1 3.3V Regulator Start-Up Profile



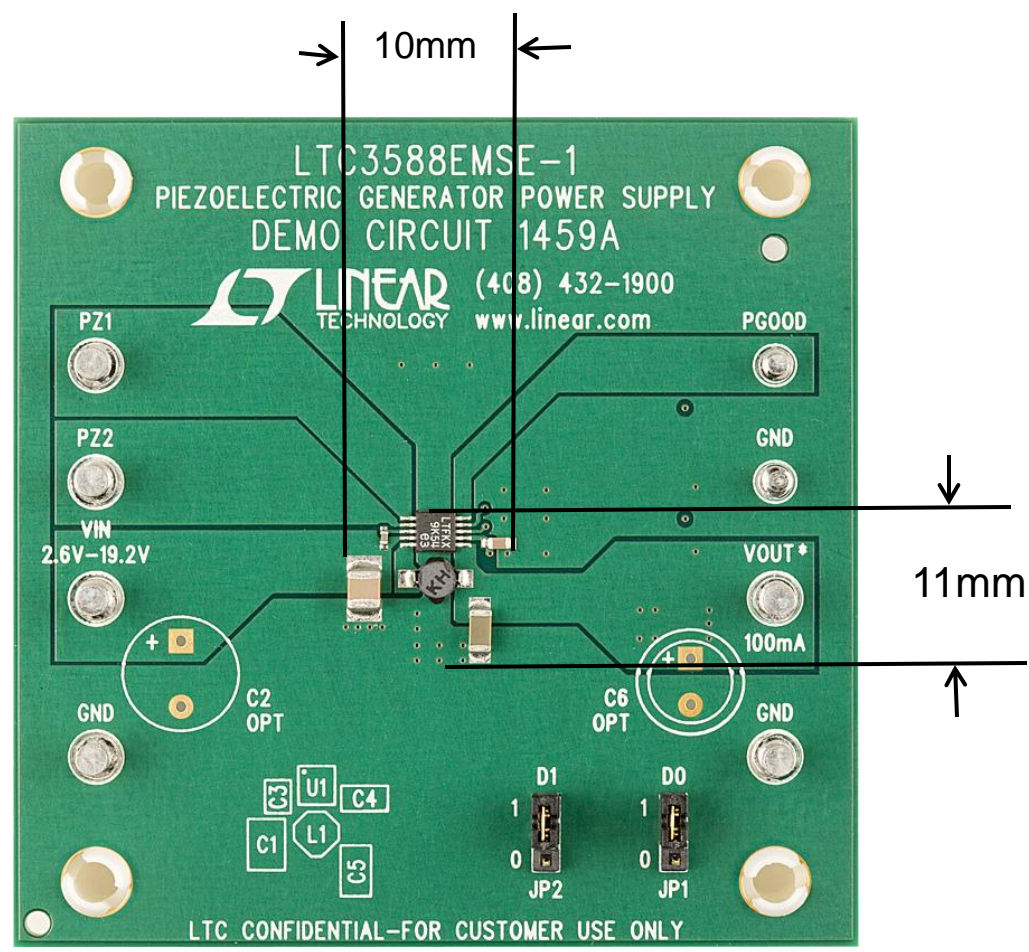
35881 TA01b

LTC3588-1 – Efficiency of Typical Application



35881 G19

LTC3588-1 Demo Circuit



Solution Footprint = 121mm²

Piezo Manufacturers

Manufacturers	Technology	Applications	Contact Info
Aci, Advanced Cerametrics Inc	Piezoelectric Ceramic Fibers	Energy Harvesting (Harvested mechanical energy vibration, compression or flexure)	Advanced Cerametrics, Inc. P.O. Box 128 245 N. Main St. Lambertville, NJ 08530-0128 Phone: 800-261-1208 www.advancedcerametrics.com
Piezo Systems Inc	Precision Piezo Ceramics	Medical and precision positioning	Piezo Systems Inc. 186 Massachusetts Avenue Cambridge, MA 02139 Phone: 617-547-1777 www.piezo.com
Measurement Specialties	Piezo Film Sensors	Low Cost Sensors, Energy Harvesting	Measurement Specialties, Inc 1000 Lucas Way Hampton, VA 23666 Phone: 757-766-4474 www.meas-spec.com
PI (Physik Instrumente) L.P. Ceramic	Piezoelectric Patch Transducers	Actuator, Sensor or Energy Source	Dave Rego Regional Sales Manager PI (Physik Instrumente) L.P. 16 Albert Street Auburn, MA 01501 Tel: 508.832-3456 x39 Email: davidr@pi-use.us Web: www.pi-usa.com Web: www.pi.ws
MIDE Technology Corporation	QuickPack Voltures	Piezoelectric Transducers for Sensing, Actuating, and Energy Harvesting	Mide Technology Corporation 200 Boston Ave, Suite 1000 Medford, MA 02155, U.S.A. Tel: (781) 306-0609 Fax: (781) 306-0619 Email: services_general_08@mide.com Web: http://www.mide.com/index.php
Morgan Technical Ceramics (USA Sales Office)	Piezo Bimorphs	Piezoelectric Transducers for Sensing, Actuating, and Energy Harvesting Custom Designs for low cost applications	Morgan Technical Ceramics (USA Sales Office) 26 Madison Road, Fairfield, NJ 07004, USA Tel: 800.433.0638 Fax: 973.227.7135 Email: mtcussales@morganplc.com Web: http://www.morganelectroceramics.com

Some Additional European Suppliers:

Cedrat

<http://www.cedrat.com>

Noliac

<http://www.noliac.com>

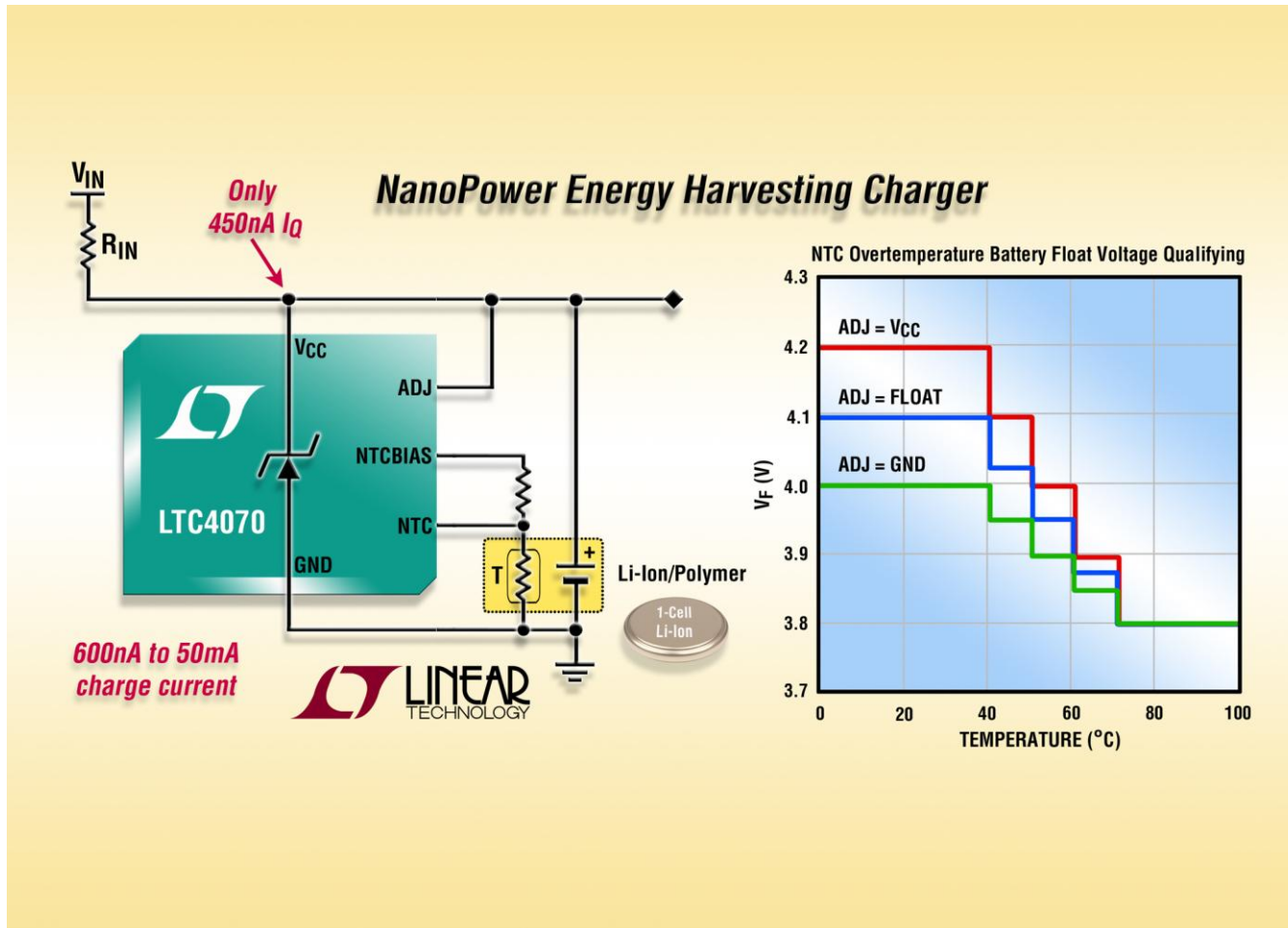
IPECC

<http://www.ipecc.it/>

Smart Material Corp.

www.smart-material.com

LTC4070: Nanopower Energy Harvesting Charger

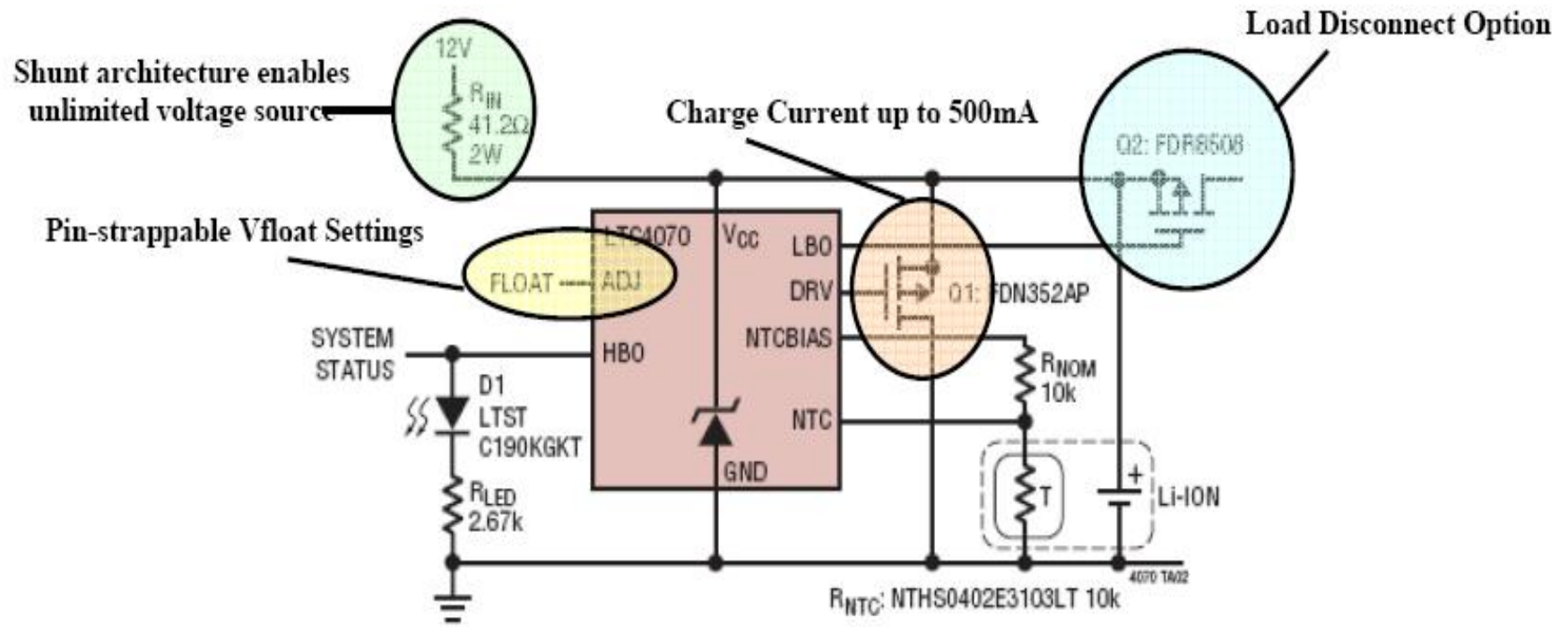


- Very compatible with low power, intermittent or continuous energy harvesting sources

LTC4070: Key Technical Features

- Low Operating Current: 450nA
- 1% Float Voltage Accuracy Over Full Temperature and Shunt Current Range
- 50mA Maximum Internal Shunt Current (500mA with External P-FET)
- Pin Selectable Float Voltage Options: 4.0V, 4.1V, 4.2V
- Ultralow Power NTC Float Voltage Conditioning for Li-Ion/Polymer Protection
- Suitable for Intermittent, Continuous and Very Low Power Charging Sources
- Low and High Battery Status Outputs
- Simple Low Voltage Load Disconnect Application
- Thermally Enhanced, Low Profile 8-Lead DFN (2mm x 3mm x 0.75mm) and MSOP Packages

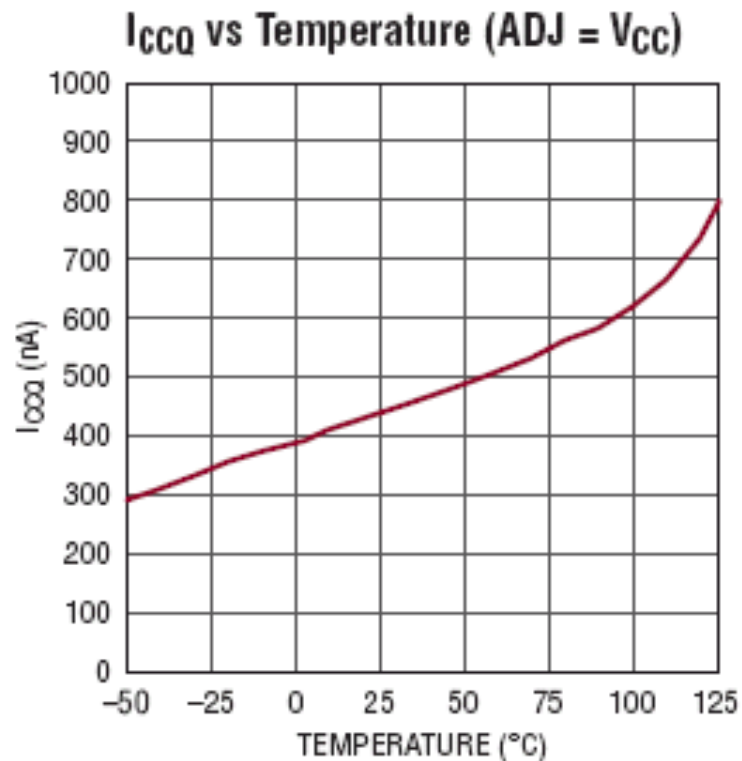
LTC4070: Features and Benefits



LTC4070: Features and Benefits - NanoPower

When the input supply is removed and the battery voltage is below the high battery output threshold, the LTC4070 consumes just 450nA from the battery.

This enables the device to draw or harvest power from previously unusable low current, intermittent or continuous power sources.

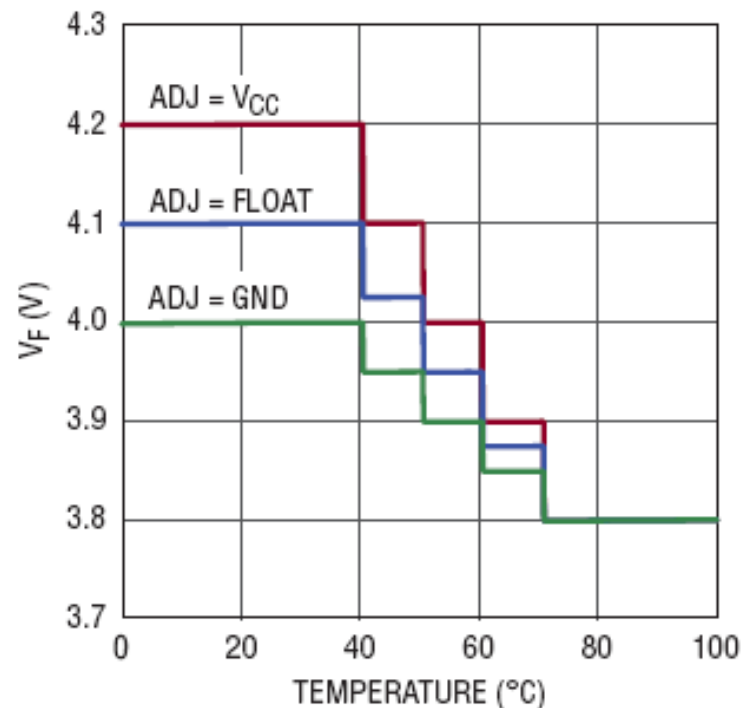


LTC4070: Features and Benefits - NTC

The LTC4070 measures battery temperature with a negative temperature coefficient thermistor thermally coupled to the battery.

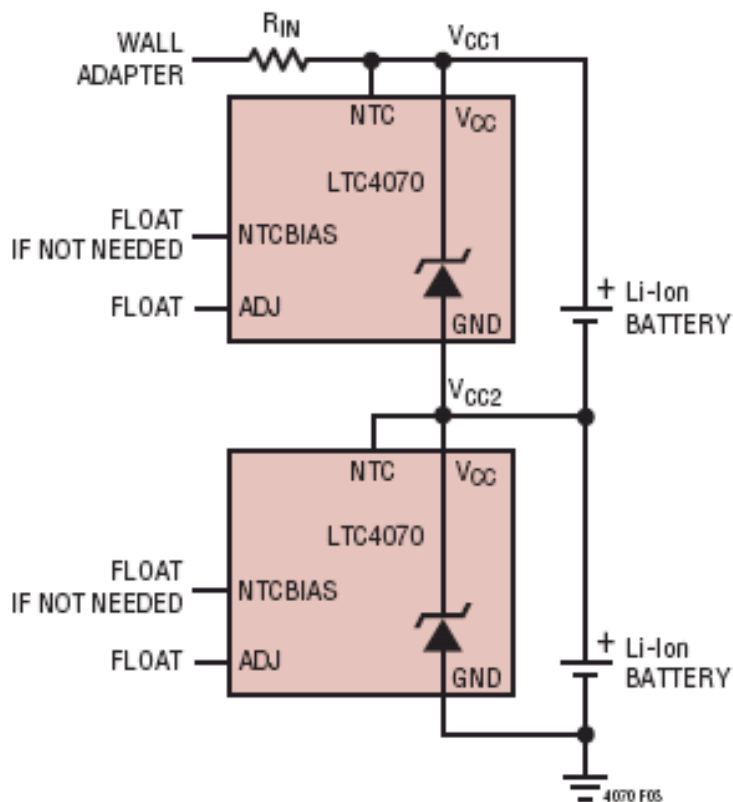
Internal NTC circuitry protects the battery from excessive heat by reducing the float voltage for each 10°C rise in temperature above 40°C.

NTC Overtemperature Battery Float Voltage Qualifying

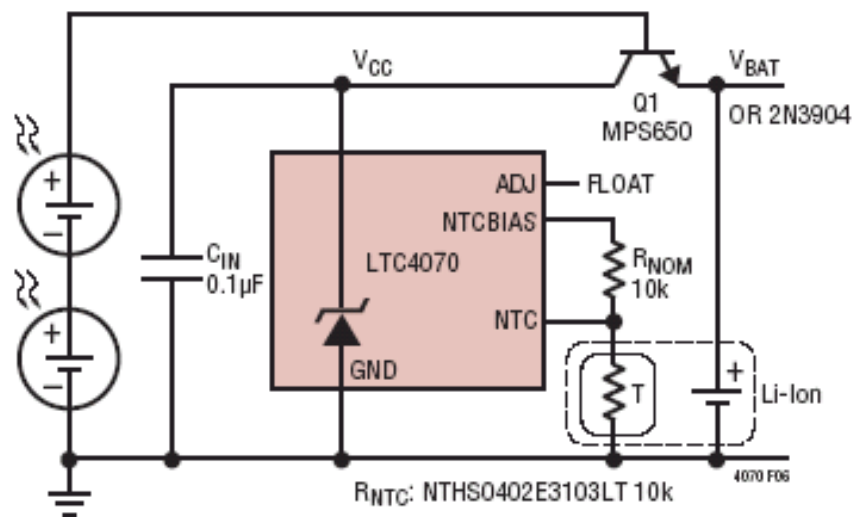


4070 TA01b

LTC4070: Typical Application Circuits



**2-Cell Stacked Battery
Charger**



**Photovoltaic (solar) Charger
with Extremely low leakage
when not charging**