

# 2.6A Low Loss Ideal Diode in ThinSOT™

## FEATURES

- Low Loss Replacement for PowerPath™ OR'ing Diodes
- Small Regulated Forward Voltage (28mV)
- 2.6A Maximum Forward Current
- Low Forward ON Resistance (140mΩ Max)
- Low Reverse Leakage Current (<1μA)
- 2.6V to 5.5V Operating Range
- Internal Current Limit Protection
- Internal Thermal Protection
- No External Active Components
- Pin-Compatible Monolithic Replacement for the LTC4412
- Low Quiescent Current (40μA)
- Low-Profile (1mm) 5-lead SOT-23 Package

## APPLICATIONS

- Cellular Phones
- Handheld Computers
- Digital Cameras
- USB Peripherals
- Uninterrupted Supplies
- Logic Controlled Power Switch

## DESCRIPTION

The LTC®4411 is an ideal diode IC, capable of supplying up to 2.6A from an input voltage between 2.6V and 5.5V. The LTC4411 is housed in a 5-lead 1mm profile SOT-23 package.

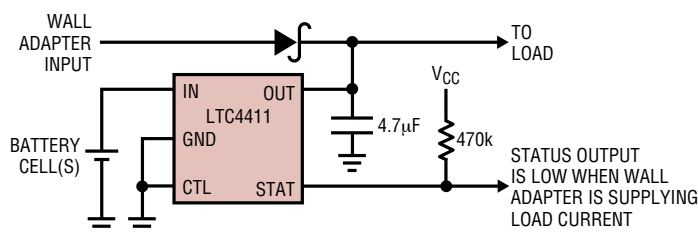
The LTC4411 contains a 140mΩ P-channel MOSFET connecting IN to OUT. During normal forward operation, the drop across the MOSFET is regulated to as low as 28mV. Quiescent current is less than 40μA for load currents up to 100mA. If the output voltage exceeds the input voltage, the MOSFET is turned off and less than 1μA of reverse current flows from OUT to IN. Maximum forward current is limited to a constant 2.6A (typical) and internal thermal limiting circuits protect the part during fault conditions.

An open-drain STAT pin indicates conduction status. The STAT pin can be used to drive an auxiliary P-channel MOSFET power switch connecting an alternate power source when the LTC4411 is not conducting forward current.

An active-high control pin turns off the LTC4411 and reduces current consumption to less than 25μA. When shut off, the LTC4411 indicates this condition with a low voltage on the status signal.

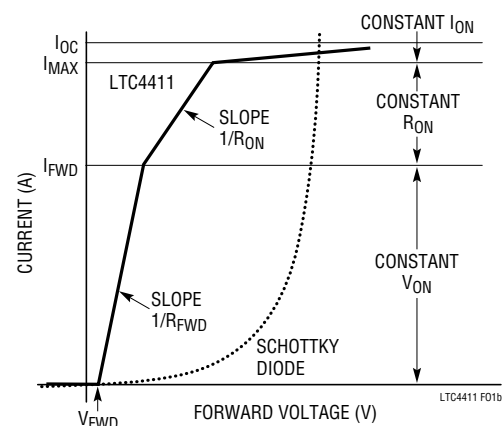
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## TYPICAL APPLICATION



**Figure 1. Automatic Switchover of Load  
Between a Battery and a Wall Adapter**

### LTC4411 vs Schottky Diode Forward Voltage Characteristics



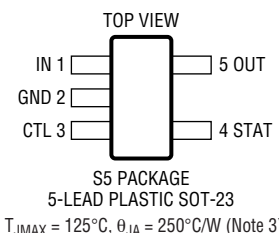
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## ABSOLUTE MAXIMUM RATINGS

(Note 1)

IN, OUT, STAT, CTL Voltage .....	–0.3 to 6V
Operating Ambient Temperature Range (Note 2) .....	–40°C to 85°C
Operating Junction Temperature (Note 3) .....	–40°C to 125°C
Storage Temperature Range .....	–65°C to 150°C
Lead Temperature (Soldering, 10 sec) .....	300°C
Continuous Power Dissipation (Derate 10mW/°C above 70°C) .....	500mW

## PACKAGE/ORDER INFORMATION

	ORDER PART NUMBER
	LTC4411ES5
	S5 PART MARKING
	LTAEN

Consult LTC Marketing for parts specified with wider operating temperature ranges.

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 6)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
$V_{IN}, V_{OUT}$	Operating Supply Range		●	2.6	5.5	V
$I_{QF}$	Quiescent Current in Forward Regulation (Note 4)	$V_{IN} = 3.6\text{V}, I_{LOAD} = 100\text{mA}$		40		$\mu\text{A}$
$I_{Q(OFF)}$	Quiescent Current in Shutdown	$V_{IN} = 3.6\text{V}, V_{STAT} = 0\text{V}, V_{CTL} > V_{IH}$	●	22	25	$\mu\text{A}$
$I_{Q(RIN)}$	Quiescent Current While in Reverse Turn-Off. Current Drawn from $V_{IN}$	$V_{IN} = 3.6\text{V}$ $V_{OUT} = 3.7\text{V}$	●	1.3	1.8	$\mu\text{A}$
$I_{Q(ROUT)}$	Quiescent Current While in Reverse Turn-Off. Current Drawn from $V_{OUT}$	$V_{IN} = 3.6\text{V}$ $V_{OUT} = 3.7\text{V}$	●	14	17	$\mu\text{A}$
$I_{LEAK}$	$V_{IN}$ Current When $V_{OUT}$ Supplies Power	$V_{IN} = 0\text{V}, V_{OUT} = 5.5\text{V}$		–1	1	$\mu\text{A}$
$V_{FWD}$	Forward Turn-On Voltage ( $V_{IN} - V_{OUT}$ )	$V_{IN} = 3.6\text{V}$	●	8	17	mV
$-V_{RTO}$	Reverse Turn-Off Voltage ( $V_{OUT} - V_{IN}$ )	$V_{IN} = 3.6\text{V}$		–4	5	mV
$R_{FWD}$	Forward ON Resistance, $\Delta(V_{IN} - V_{OUT})/\Delta(I_{LOAD})$	$V_{IN} = 3.6\text{V}, 100\text{mA} < I_{LOAD} < 500\text{mA}$	●	100	140	$\text{m}\Omega$
$R_{ON}$	ON Resistance in Constant $R_{ON}$ Mode	$V_{IN} = 3.6\text{V}, I_{LOAD} = 1000\text{mA}$	●	140	245	$\text{m}\Omega$
UVLO	Undervoltage Lockout	$V_{IN}$ Rising, $0^\circ\text{C} < T_A < 85^\circ\text{C}$			2.5	V
		$V_{IN}$ Rising	●		2.6	V
		$V_{IN}$ Falling	●	1.6		V

## STAT Output

$I_{S(SNK)}$	STAT Pin Sink Current	$V_{IN} = 3.6\text{V}, V_{OUT} > V_{IN} + V_{RTO}, V_{CTL} > V_{TH} + V_{HYST}$		7	11	18	$\mu\text{A}$
$I_{S(OFF)}$	STAT Pin Off Current	$V_{IN} = 3.6\text{V}, V_{OUT} < V_{IN} - V_{FWD}, V_{CTL} < V_{TH} - V_{HYST}$		–1		1	$\mu\text{A}$
$t_{S(ON)}$	STAT Pin Turn-On Time				1.2	1.4	$\mu\text{s}$
$t_{S(OFF)}$	STAT Pin Turn-Off Time				1.1	1.25	$\mu\text{s}$

## CTL Input

$V_{TH}$	CTL Input Threshold Voltage	$V_{TH} = (V_{IL} + V_{IH})/2$	●	390	460	530	mV
$V_{HYST}$	CTL Input Hysteresis	$V_{HYST} = (V_{IH} - V_{IL})$			90		mV
$I_{CTL}$	CTL Input Pull-Down Current	$V_{OUT} < V_{IN} = 3.6\text{V}, V_{CTL} = 1.5\text{V}$	●	2	3.5	6	$\mu\text{A}$

## Short-Circuit Response

$I_{OC}$	Current Limit	$V_{IN} = 3.6\text{V}$ (Note 5)		1.8	2.6		A
$I_{QOC}$	Quiescent Current While in Overcurrent Operation	$V_{IN} = 3.6\text{V}, I_{OUT} = 1.8\text{A}$			575	1100	$\mu\text{A}$

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ . (Note 6)

**Note 1:** Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

**Note 2:** The LTC4411E is guaranteed to meet performance specifications from  $0^\circ\text{C}$  to  $70^\circ\text{C}$ . Specifications over the  $-40^\circ\text{C}$  to  $85^\circ\text{C}$  ambient operating temperature range are assured by design, characterization and correlation with statistical process controls.

**Note 3:**  $T_J$  is calculated from the ambient temperature  $T_A$  and power dissipation  $P_D$  according to the following formula:

$$T_J = T_A + (P_D \cdot 150^\circ\text{C/W})$$

The following table lists thermal resistance for several different board sizes and copper areas. All measurements were taken in still air on 3/32" FR-4 board with the device mounted on topside.

Measured Thermal Resistance (2-Layer Board\*)

COPPER AREA TOPSIDE	COPPER AREA BACKSIDE	BOARD AREA	THERMAL RESISTANCE JUNCTION-TO-AMBIENT
2500mm <sup>2</sup>	2500mm <sup>2</sup>	2500mm <sup>2</sup>	125°C/W
1000mm <sup>2</sup>	2500mm <sup>2</sup>	2500mm <sup>2</sup>	125°C/W
225mm <sup>2</sup>	2500mm <sup>2</sup>	2500mm <sup>2</sup>	130°C/W
100mm <sup>2</sup>	2500mm <sup>2</sup>	2500mm <sup>2</sup>	135°C/W
50mm <sup>2</sup>	2500mm <sup>2</sup>	2500mm <sup>2</sup>	150°C/W

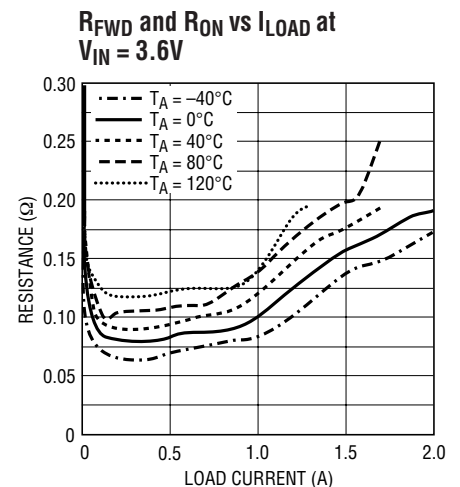
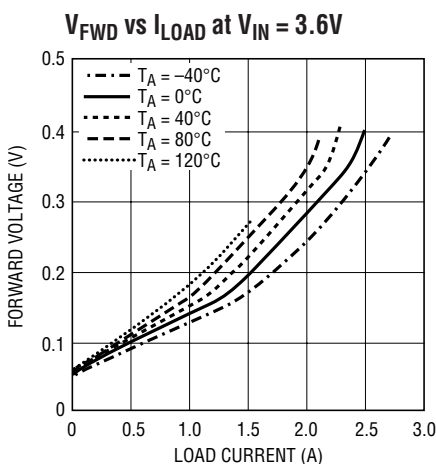
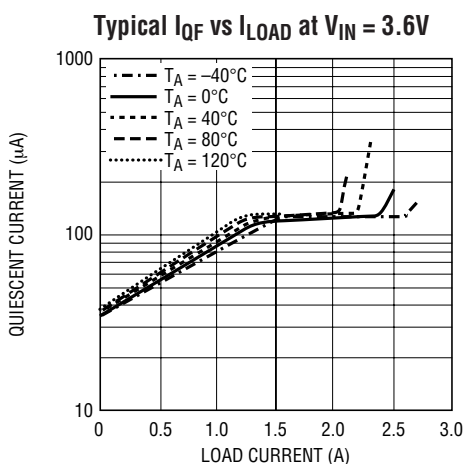
\*Each layer uses one ounce copper

**Note 4:** Quiescent current increases with load current, refer to plot of  $I_{QF}$  vs  $I_{LOAD}$ .

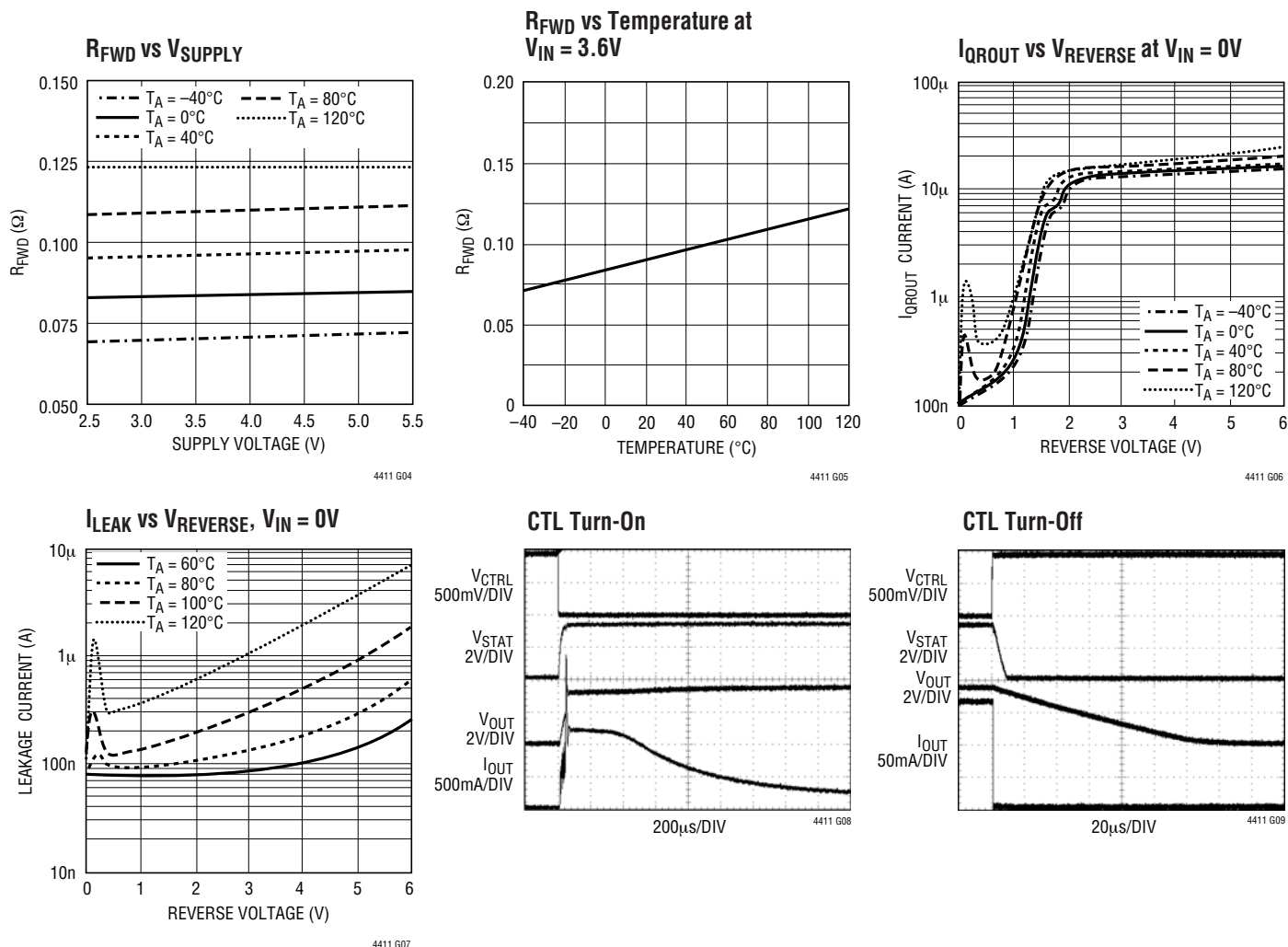
**Note 5:** This IC includes overtemperature protection that is intended to protect the device during momentary overload conditions. Junction temperature will exceed  $125^\circ\text{C}$  when overtemperature protection is active. Continuous operation above the specified maximum operating junction temperature may impair device reliability.

**Note 6:** Current into a pin is positive and current out of a pin is negative. All voltages are referenced to GND.

## TYPICAL PERFORMANCE CHARACTERISTICS



## TYPICAL PERFORMANCE CHARACTERISTICS



## PIN FUNCTIONS

**IN (Pin 1):** Ideal Diode Anode and Positive Power Supply for LTC4411. When operating LTC4411 as a switch it must be bypassed with a low ESR ceramic capacitor of 1 $\mu$ F. X5R and X7R dielectrics are preferred for their superior voltage and temperature characteristics.

**GND (Pin 2):** Power and Signal Ground for the IC.

**CTL (Pin 3):** Controlled Shutdown Pin. Weak (3 $\mu$ A) Pull-Down. Pull this pin high to shut down the IC. Tie to GND to enable. Can be left floating when not in use.

**STAT (Pin 4):** Status Condition Indicator. This pin indicates the conducting status of the LTC4411. If the part is forward biased ( $V_{IN} > V_{OUT} + V_{FWD}$ ) this pin will be Hi-Z. If the part is reverse biased ( $V_{OUT} > V_{IN} + V_{RTO}$ ), then this pin will pull down 10 $\mu$ A through an open-drain. When terminated to a high voltage through a 470k resistor, a high voltage indicates diode conducting. May be left floating or grounded when not in use.

**OUT (Pin 5):** Ideal Diode Cathode and Output of the LTC4411. Bypass OUT with a nominal 1m $\Omega$  ESR capacitor of at least 4.7 $\mu$ F. The LTC4411 is stable with ESRs down to 0.2m $\Omega$ . However stability improves with higher ESRs.

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## BLOCK DIAGRAM

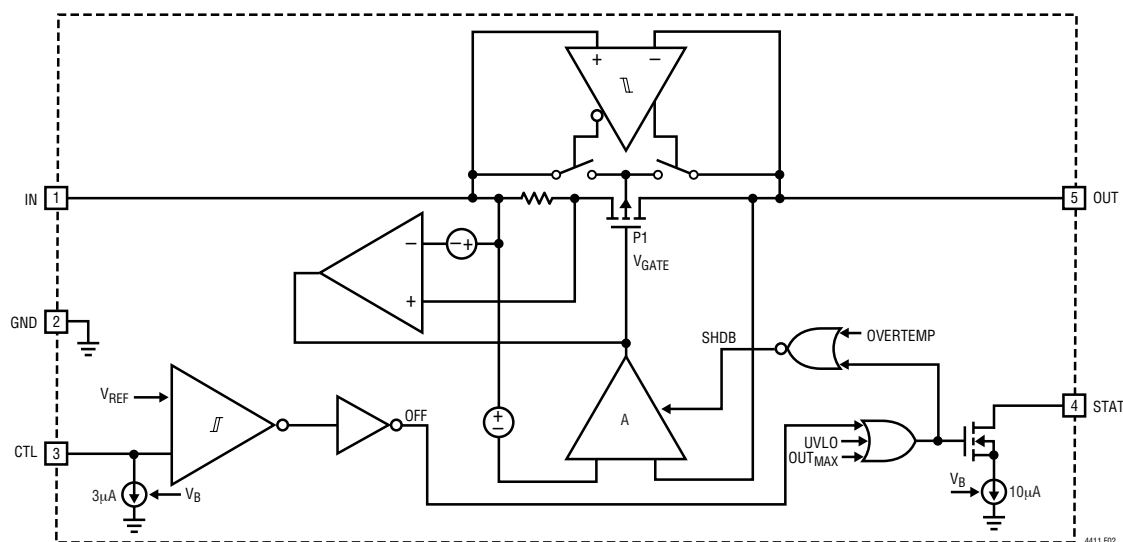


Figure 2. Detailed Block Diagram

## OPERATION

The LTC4411 operation is described with the aid of Figure 3. Forward regulation for the LTC4411 has three operation modes depending on the magnitude of the load current. For small load currents, the LTC4411 will provide a constant voltage drop; this operating mode is referred to as “constant  $V_{ON}$ ” regulation. As the current exceeds  $I_{FWD}$  the voltage drop will increase linearly with the current with a slope of  $1/R_{ON}$ ; this operating mode is referred to as “constant  $R_{ON}$ ” regulation. As the current increases further, exceeding  $I_{MAX}$ , the forward voltage drop will increase rapidly; this operating mode is referred to as “constant  $I_{ON}$ ” regulation. The characteristics for the following parameters:  $R_{FWD}$ ,  $R_{ON}$ ,  $V_{FWD}$ ,  $I_{FWD}$ , and  $I_{MAX}$  are specified with the aid of Figure 3.

Operation begins when the power source at IN rises above the UVLO voltage of 2.4V (typ) and the CTL (control) pin is low. If only the voltage at the IN pin is present, the power source to LTC4411 ( $V_{DD}$ ) will be supplied from the IN pin. The amplifier (A) will deliver a voltage proportional to the difference between  $V_{IN}$  and  $V_{OUT}$  to the gate ( $V_{GATE}$ ) of the internal P-channel MOSFET (P1), driving this gate voltage below  $V_{IN}$ . This will turn on P1. As P1 conducts,  $V_{OUT}$  will be pulled up towards  $V_{IN}$ . The LTC4411 will then control  $V_{GATE}$  to maintain a low forward voltage drop. The system is now in forward regulation and the load at OUT will be

powered from the supply at IN. As the load current varies,  $V_{GATE}$  will be controlled to maintain a low forward voltage drop. If the load current exceeds P1's ability to deliver the current, as  $V_{GATE}$  approaches GND, the P1 will behave as a fixed resistor, with resistance  $R_{ON}$ , whereby the forward voltage will increase with increased load current. As  $I_{LOAD}$  increases further ( $I_{LOAD} > I_{MAX}$ ), the LTC4411 will regulate the load current as described below. During the forward regulation mode of operation the STAT pin will be an open circuit.

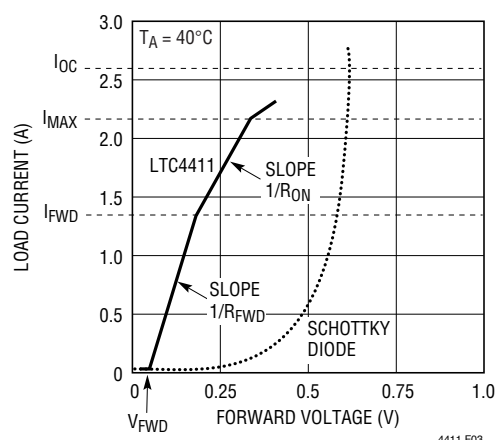


Figure 3. LTC4411 vs Schottky Diode Forward Conduction Characteristics

## OPERATION

When the load current exceeds  $I_{MAX}$ , an over current condition is detected and the LTC4411 will limit the output current. This will cause the output voltage to drop as the load current exceeds the amount of current that the LTC4411 can supply. This condition will increase the power consumption within the LTC4411.

When an alternate power source is connected to the output, the LTC4411 will sense the increased voltage at OUT, and the amplifier (A) will increase the voltage at  $V_{GATE}$ . When  $V_{OUT}$  is higher than  $V_{IN} + V_{RTO}$ , the internal power source for the LTC4411 ( $V_{DD}$ ) will be diverted to source current from the OUT pin. At the same time  $V_{GATE}$  will be pulled to  $V_{DD}$ , which will turn off P1. The system is now in the reverse turn-off mode. Power to the load is being delivered from an alternate supply, and only a small

current is drawn from IN to sense the potential  $V_{IN}$ . During reverse turn-off mode the STAT pin will sink  $10\mu A$  to indicate that the diode is not conducting.

When the CTL input is asserted (high), P1 will have its gate voltage pulled high, and the STAT pin will sink  $10\mu A$ . A  $3\mu A$  pull-down current on the CTL pin will ensure a low level at this input if it is left open circuited.

The overtemperature condition is detected when the internal die temperature increases beyond  $150^{\circ}C$ . The overtemperature condition will cause the gate amplifier (A) as well as P1 to be shut off. When the internal die temperature cools to below  $140^{\circ}C$ , the amplifier will turn on and revert to normal operation. Note that prolonged operation under overtemperature conditions will degrade reliability.

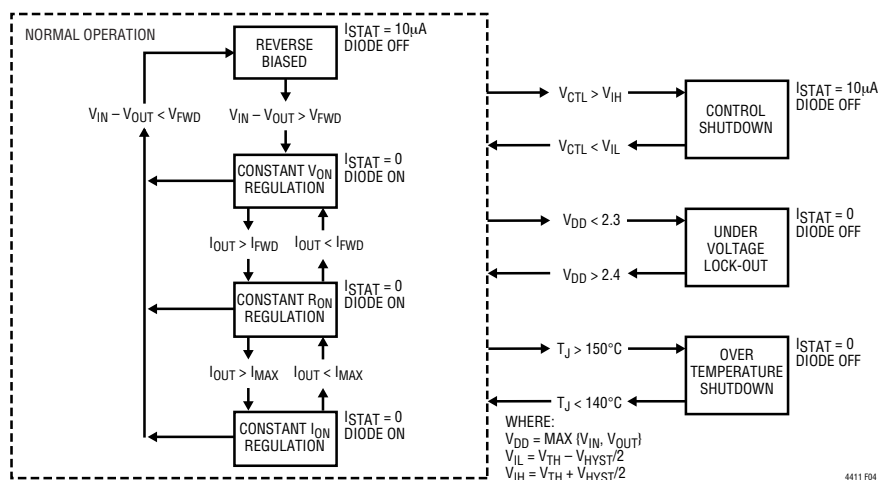


Figure 4. State Transition Diagram

## APPLICATIONS INFORMATION

### INTRODUCTION

The LTC4411 is intended for power control applications that include low loss diode ORing, fully automatic switchover from a primary to an auxiliary source of power, microcontroller controlled switchover from a primary to an auxiliary source of power, load sharing between two or more batteries, charging of multiple batteries from a single charger and high side power switching.

### Automatic PowerPath Control

Figure 1 illustrates an application circuit for automatic switchover of a load between a battery and a wall adapter or other power input. With initial application of the battery, the load will be charged up as the LTC4411 turns on. The LTC4411 will control the gate voltage of its internal MOSFET to reduce the MOSFET's voltage drop to a low forward voltage ( $V_{FWD}$ ). The system is now in the forward regula-

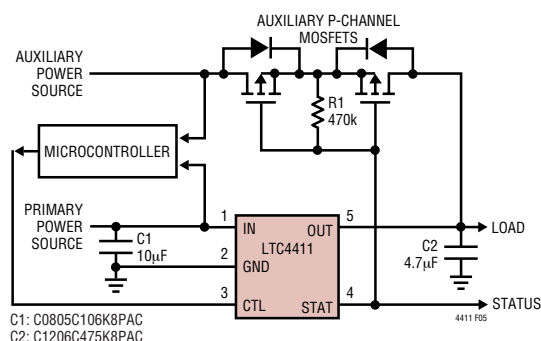


## APPLICATIONS INFORMATION

tion mode, the forward voltage will be kept low by controlling the gate voltage of the internal MOSFET to react to changes in load current. Should the wall adapter input be applied, the Schottky diode will pull up the output voltage, connected to the load, above the battery voltage. The LTC4411 will sense that the output voltage is higher than the battery voltage and will turn off the internal MOSFET. The STAT pin will then sink current indicating an auxiliary input is connected. The battery is now supplying no load current and all load current flows through the Schottky diode.

### Microcontrolled PowerPath Monitoring and Control

Figure 6 illustrates an application circuit for microcontroller monitoring and control of two power sources. The microcontroller's analog inputs, perhaps with the aid of a resistor voltage divider, monitors each supply input and commands the LTC4411 through the CTL input. Back-to-back MOSFETs are used so that the parasitic drain-source diode will not power the load when the MOSFET is turned off (dual MOSFETs in one package are commercially available).



**Figure 5. Automatic Switchover of Load Between a Primary and an Auxiliary Power Source with External Dual P-Channel MOSFETs**

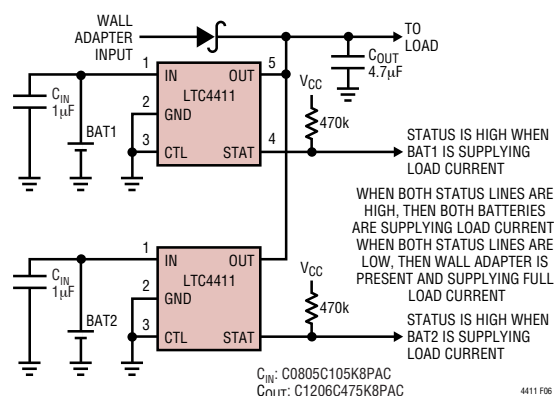
### Load Sharing

Figure 6 illustrates an application circuit for dual battery load sharing with automatic switchover of load from batteries to wall adapter. Whichever battery is capable of supplying the higher voltage will provide the load current until it is discharged to the voltage of the other battery. The load will then be shared between the two batteries according to the capacity of each battery. The higher capacity battery will provide proportionally higher current to the load. When a wall adapter input is applied, both LTC4411s

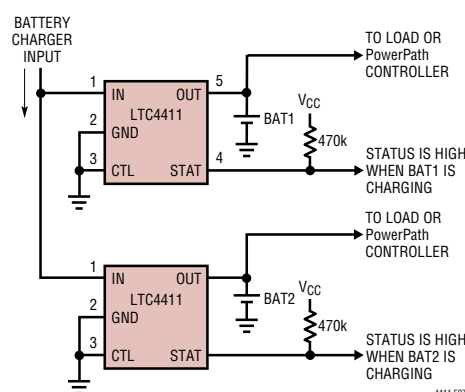
turn off and no load current will be drawn from the batteries. The STAT pins provide information as to which input is supplying the load current. This concept can be expanded to more power inputs.

### Multiple Battery Charging

Figure 7 illustrates an application circuit for automatic dual battery charging from a single charger. Whichever battery has the lower voltage will receive the charging current until both battery voltages are equal, then both will be charged. When both are charging simultaneously, the higher capacity battery will get proportionally higher current from the charger. For Li-Ion batteries, both batteries will achieve the float voltage minus the forward regulation voltage of 40mV. This concept can apply to more than two batteries. The STAT pin provides information as to which batteries are being charged. For intelligent control, the CTL pin input can be used with a microcontroller as shown in Figure 5.



**Figure 6. Dual Battery Load Sharing with Automatic Switchover of Load from Batteries to Wall Adapter**



**Figure 7. Automatic Dual Battery Charging from a Single Charging Source**

## APPLICATIONS INFORMATION

### High Side Power Switch

Figure 8 illustrates an application circuit for a logic controlled high side power switch. When the CTL pin is a logical low, the LTC4411 will turn on, supplying current to the load. When the CTL pin is a logical high, the LTC4411 will turn off and deny power to the load. If the load is powered from another (higher voltage) source, the supply connected to  $V_{IN}$  remains disconnected from the load.

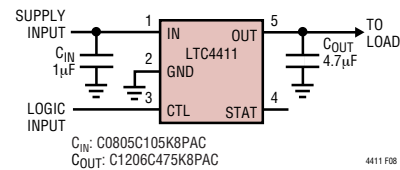
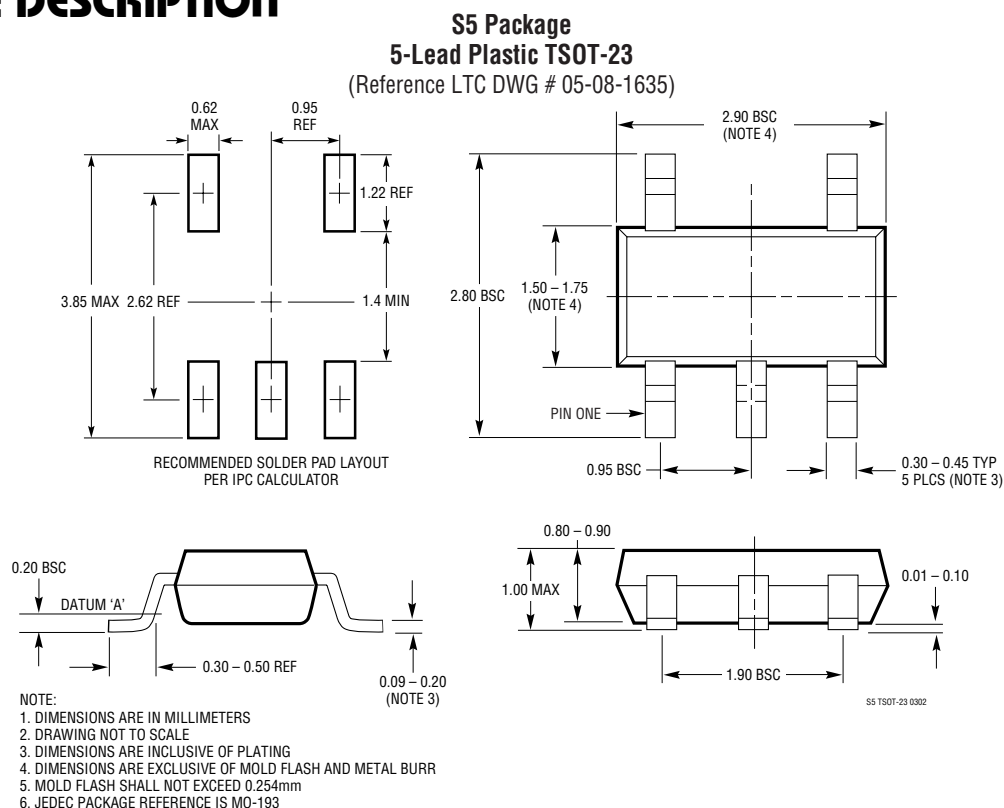


Figure 8. Logic Controlled High Side Power Switch

## PACKAGE DESCRIPTION



## RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LTC1558/LTC1559	Backup Battery Controller with Programmable Output	Adjustable Backup Voltage from 1.2V NiCd Button Cell, Includes Boost Converter
LTC1998	2.5µA, 1% Accurate Programmable Battery Detector	Adjustable Trip Voltage/Hysteresis, ThinSOT
LTC4054	800mA Standalone Linear Li-Ion Battery Charger with Thermal Regulation in ThinSOT	No External MOSFET, Sense Resistor or Blocking Diode Required, Charge Current Monitor for Gas Gauging, C/10 Charge Termination
LTC4350	Hot Swappable Load Share Controller	Allows N + 1 Redundant Supply, Equally Loads Multiple Power Supplies Connected in Parallel
LTC4412/LTC4412HV	PowerPath Controller in ThinSOT	More Efficient than Diode OR'ing, Automatic Switching Between DC Sources, Simplified Load Sharing, $3V \leq V_{IN} \leq 36V$ (LTC4412HV)



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