

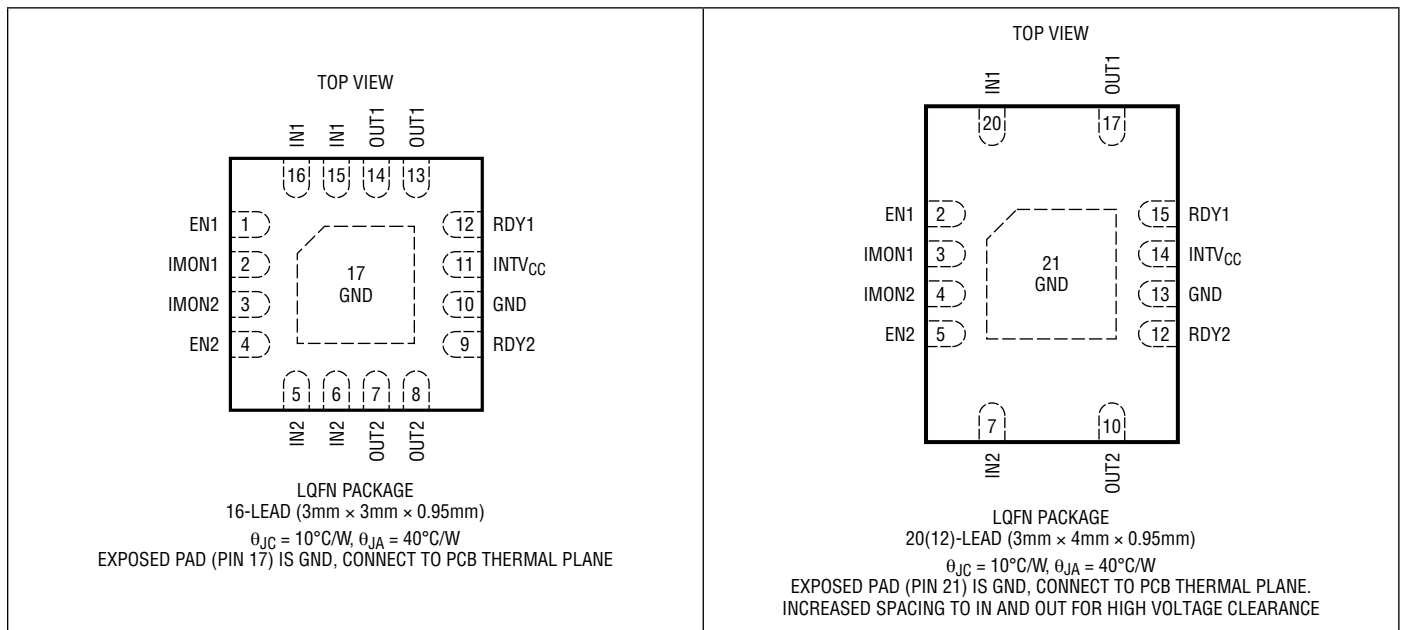


# LTC4249

## ABSOLUTE MAXIMUM RATINGS (Notes 1, 2, 3, 4)

<b>Input Voltages</b>		<b>Input Currents</b>	
IN1, IN2.....	-0.3V to 72V	IN1, IN2.....	3A
EN1, EN2 (Note 5).....	-0.3V to 5.5V	<b>Output Currents</b>	
<b>Output Voltages</b>		OUT1, OUT2.....	-3A
OUT1, OUT2.....	-0.3V to 72V	RDY1, RDY2 .....	10mA
RDY1, RDY2.....	-0.3V to 5.5V	IMON1, IMON2.....	-1mA
IMON1, IMON2.....	-0.3V to 2.7V	<b>Operating Junction Temperature Range</b>	
INTV <sub>CC</sub> .....	-0.3V to 5.5V	LTC4249A .....	-40°C to 125°C
		<b>Storage Temperature Range</b> .....	-65°C to 150°C

## PIN CONFIGURATION



## ORDER INFORMATION

TRAY	PART MARKING	PACKAGE DESCRIPTION	FAULT RESPONSE	TEMPERATURE RANGE
LTC4249AV-1#PBF	LHMZ	16-Lead (3mm × 3mm × 0.95mm) LQFN Package	Latch Off	-40°C to 125°C
LTC4249AV2-1#PBF	4249	20(12)-Lead (3mm × 4mm × 0.95mm) LQFN Package	Latch Off	-40°C to 125°C

Contact the factory for parts specified with wider operating temperature ranges.

## ELECTRICAL CHARACTERISTICS

The ● denotes specifications that apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ .  $V_{IN1} = V_{IN2} = 52\text{V}$  and  $R_{IMON} = 10\text{k}\Omega$  unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
<b>Channel Inputs (IN1, IN2)</b>							
$V_{IN1}$	IN1 Operating Range		●	6		65	V
$V_{IN2}$	IN2 Operating Range	$V_{IN1} \geq 6\text{V}$	●	1.5		65	V
$I_{MAX}$	IN1, IN2 Maximum Steady State ECB Current				1.2		A
$I_{IN1}$	IN1 Input Supply Current	$I_{OUT1} = I_{OUT2} = 0\text{A}$ ; $EN1 = EN2 = 3.3\text{V}$ $I_{OUT1} = I_{OUT2} = 0\text{A}$ ; $EN1 = EN2 = \text{GND}$	● ●		1 0.6	1.5 0.8	mA mA
$I_{IN2}$	IN2 Input Supply Current	$I_{OUT2} = 0\text{A}$ , $EN2 = 3.3\text{V}$ $I_{OUT2} = 0\text{A}$ , $EN2 = \text{GND}$	● ●		20 0.5	28 3	$\mu\text{A}$ $\mu\text{A}$
$R_{ON}$	ECB On-Resistance	$I_{OUT} = -1\text{A}$	●	50	75	150	$\text{m}\Omega$
$R_{ONM}$	ECB Channel to Channel $R_{ON}$ Matching	$I_{OUT} = -1\text{A}$	●		$\pm 1$	$\pm 4$	%
<b>Channel Outputs (OUT1, OUT2)</b>							
$I_{CL}$	ECB Turn-On Inrush Current	$C_{OUT} = 100\mu\text{F}$	●	-0.8	-1	-1.2	A
$t_{CL}$	Inrush Current Limited Operating Time		●	8	10	12	ms
$V_{SC}$	Short-Circuit Comparator Threshold		●	1.14	1.2	1.26	V
$t_{SC}$	Short-Circuit Evaluation Delay	EN rising to short-circuit fault	●	240	300	360	$\mu\text{s}$
<b>Current Monitor and Electronic Circuit Breaker (ECB) Thresholds (IMON1, IMON2)</b>							
$G_{IMON}$	IMON Gain	$I_{OUT} = -30\text{mA}$ to $-1.2\text{A}$	●	95	100	105	$\mu\text{A}/\text{A}$
$I_{OC}$	IMON Offset Current	$I_{OUT} = -30\text{mA}$				$\pm 1$	$\mu\text{A}$
$V_{IMON}$	IMON Output Voltage	$I_{OUT} = -1\text{A}$	●	950	1000	1050	mV
$I_{ACC}$	IMON Output Current Accuracy	$I_{OUT} = -1\text{A}$ $I_{OUT} = -1\text{A}$ , $T_A = 25^\circ\text{C}$	●			$\pm 5$ $\pm 2$	% %
$V_{ECB1}$	$V_{IMON}$ at Primary ECB Threshold		●	1.17	1.20	1.23	V
$V_{ACC1}$	Primary ECB Accuracy		●			$\pm 2.5$	%
$V_{ECB2}$	$V_{IMON}$ at Secondary ECB Threshold		●	2.28	2.40	2.52	V
$V_{ACC2}$	Secondary ECB Accuracy		●			$\pm 5$	%
$t_{OC1}$	ECB Response Time to Primary OC	Step $I_{OUT}$ from $-1.15\text{A}$ to $-1.25\text{A}$ ; measure time from step to RDY Low	●	30	50	70	$\mu\text{s}$
$t_{OC2}$	ECB Response Time to Secondary OC	Step $I_{OUT}$ from $-0.5\text{A}$ to $-2.5\text{A}$ ; measure time from step to RDY Low $T_A > 0^\circ\text{C}$ $T_A < 0^\circ\text{C}$			2 4	4 18	$\mu\text{s}$ $\mu\text{s}$
<b>Enable Inputs (EN1, EN2)</b>							
$V_{ENTH}$	EN Rising Threshold		●	780	800	820	mV
$V_{ENHYS}$	EN Threshold Hysteresis	EN Falling			35		mV
$t_{ENMIN}$	Minimum EN Input Pulse Width		●	10			$\mu\text{s}$

## ELECTRICAL CHARACTERISTICS

The ● denotes specifications that apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ .  $V_{IN1} = V_{IN2} = 52\text{V}$  and  $R_{IMON} = 10\text{k}\Omega$  unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
<b>Ready Outputs (RDY1 and RDY2)</b>							
$V_{OL}$	Output Low Voltage	$I_{RDY} = 3\text{mA}$	●		50	150	mV
$I_{OH}$	Open-Drain Output High Leakage Current	$RDY = 5\text{V}$	●			1	$\mu\text{A}$
$t_{COOL}$	ECB Cool-Down Time after Fault		●	0.8	1	1.2	s
<b>INTV<sub>CC</sub> Output</b>							
$V_{CCOR}$	INTV <sub>CC</sub> Operating Range	Decoupled with $0.1\mu\text{F}$ to GND	●	3.7	4.2	4.7	V

**Note 1:** Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

**Note 2:** All currents into pins are positive; all voltages are referenced to GND unless otherwise noted.

**Note 3:** The LTC4249 is tested under pulsed load conditions such that  $T_J \approx T_A$ . The junction temperature ( $T_J$  in  $^\circ\text{C}$ ) is calculated from the ambient temperature ( $T_A$  in  $^\circ\text{C}$ ) and power dissipation ( $P_D$  in Watts) according to the formula:

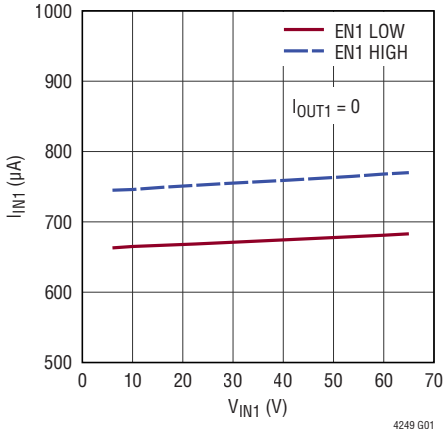
$$T_J = T_A + (P_D \cdot \theta_{JA}).$$

**Note 4:** The LTC4249 includes overtemperature protection that is intended to protect the device during momentary overload conditions. Junction temperature will exceed  $150^\circ\text{C}$  when overtemperature protection is active. Continuous operation above the specified maximum operating junction temperature may impair device reliability.

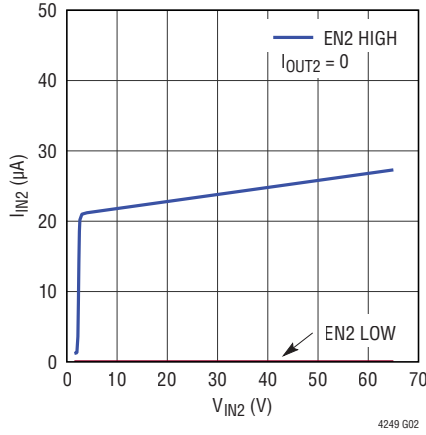
**Note 5:** These pins can be pulled below  $-0.3\text{V}$  through a resistor that limits the current below  $1\text{mA}$ .

# TYPICAL PERFORMANCE CHARACTERISTICS

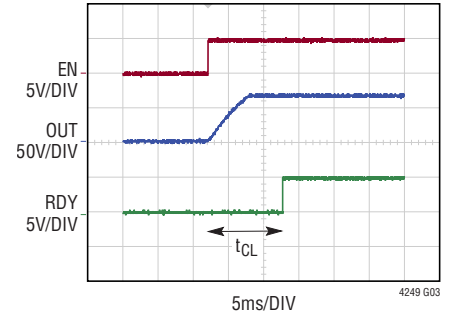
**IN1 Current vs IN1 Voltage**



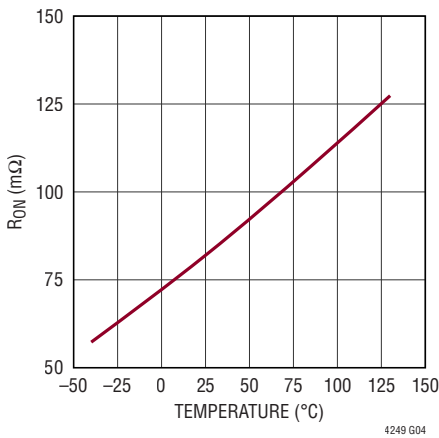
**IN2 Current vs IN2 Voltage**



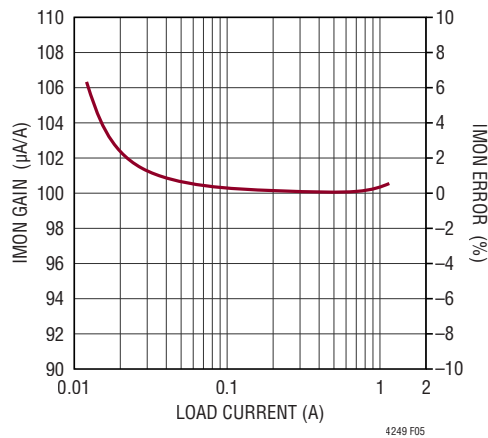
**OUT Charging 100µF (IN = 65V)**



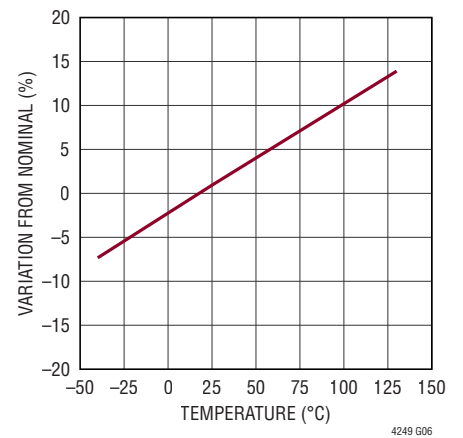
**On-Resistance vs Temperature**



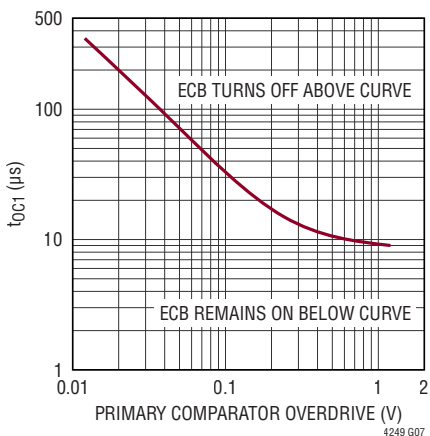
**IMON Gain and Error**



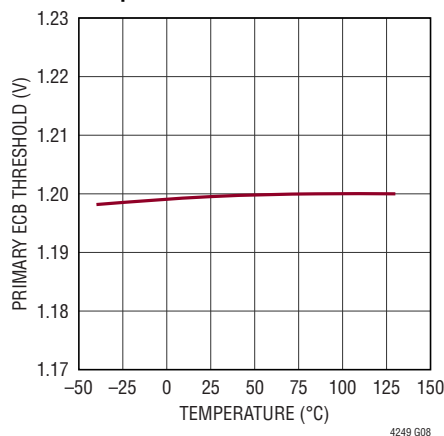
**Timing Variation vs Temperature**  
 $t_{CL}$ ,  $t_{SC}$ ,  $t_{COOL}$



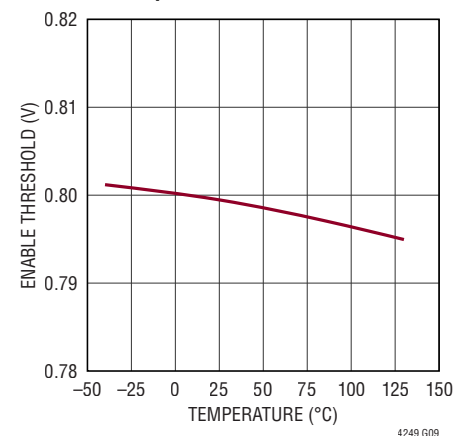
**Primary Comparator Response vs Overdrive**



**Primary ECB Threshold vs Temperature**



**EN Threshold and Pull-Up Current vs Temperature**



## PIN FUNCTIONS

**EN1, EN2:** Enable Inputs. Pulling EN high turns on the ECB and connects IN to OUT. Pulling EN low turns off the ECB and disconnects IN from OUT. Toggling EN resets the ECB when in a latched off condition.

**Exposed Pad:** Exposed thermal pad. The exposed pad is internally connected to ground and provides an optimal path for heat removal. Connect the exposed pad to a PCB ground plane for enhanced thermal performance.

**GND:** Device Ground.

**IMON1, IMON2:** Analog Current Monitor Outputs. A resistor from IMON to GND converts the scaled down output current to a voltage. The ECB turns off if the voltage on IMON exceeds 1.20V (primary OC threshold).

In the case of severe overcurrent, the ECB quickly turns off if the voltage on IMON exceeds 2.4V (fast secondary OC threshold).

The IMON outputs do not source current when RDY is low.

Connect IMON to ground if unused. Use caution when grounding IMON because the primary and secondary OC comparators will not function. However, short-circuit ( $OUT < 1.2V$ ) and overtemperature conditions are still detected and turn off the ECB.

**IN1, IN2:** ECB Inputs. Both circuit breakers operate independently. However, IN1 is used to bias an internal low voltage bias supply rail. Therefore, IN2 cannot be used without  $IN1 \geq 6V$ . A special 5V ONLY application is discussed in the Applications Information section.

A 1 $\mu$ F (or greater) bypass capacitor is recommended. A low impedance layout should be used between the input power supply and the IN1, IN2 inputs. Trace inductance should be kept below 400nH to minimize dissipated energy after short-circuit events.

**INTV<sub>CC</sub>:** Internal Operating Supply. INTV<sub>CC</sub> is used to bias internal circuitry. INTV<sub>CC</sub> is generated by an internal regulator from IN1. A 0.01 $\mu$ F (or greater) bypass capacitor is recommended.

INTV<sub>CC</sub> should not be driven or loaded with external circuitry. However, a special 5V ONLY application is discussed in the Applications Information section.

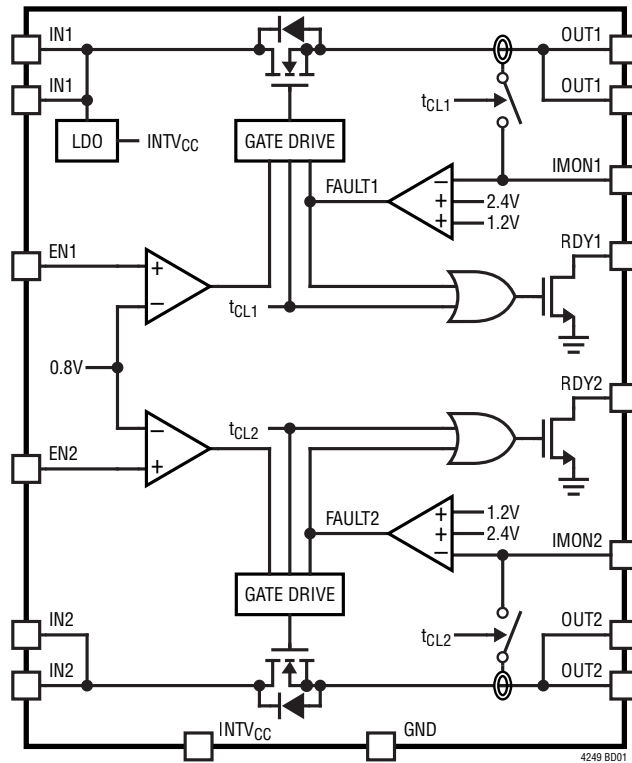
**OUT1, OUT2:** ECB Outputs. When enabled, OUT is connected to IN through a high voltage N-channel MOSFET. Maximum recommended steady state current is 1.2A per channel. ECBs may be paralleled for higher current loads. See Applications Information for more details.

A low impedance layout should be used between the load and the OUT1, OUT2 outputs. Trace inductance should be kept below 400nH to minimize dissipated energy after short-circuit events. Maximum capacitance at OUT is limited to 100 $\mu$ F.

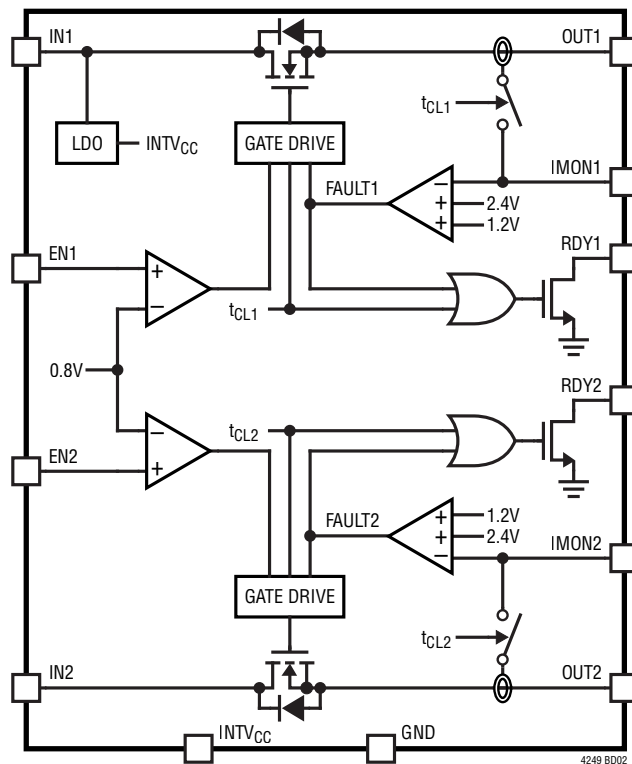
**RDY1, RDY2:** Ready Outputs. RDY pulls low when EN is low or after an ECB fault. After a channel is enabled, RDY outputs remain low until the current limited operating phase is complete (10ms nominal). After the current limited operating phase, RDY outputs release and may be used to enable subsequent functions. For example, RF Power Amplifier gate bias may be applied after RDY is released.

Leave RDY open or connected to ground if unused.

**BLOCK DIAGRAMS**



**3mm × 3mm Package**



**3mm × 4mm Package**

## OPERATION

The LTC4249 is a two channel 65V electronic circuit breaker (ECB) with current monitoring outputs. Circuit breaker input IN1 has a 6V to 65V voltage input range and provides internal operating bias for the LTC4249. IN2 input range is 1.5V to 65V when IN1 is biased. Load circuits typically connect to OUT. The circuit breakers close when EN is high and open when EN is low. The ready (RDY) outputs pull low when the ECBs are off and are released when ECBs are on.

When RDY is released, an accurate scaled replica of the output load current is sourced from the IMON outputs. A resistor connected from IMON to GND converts the scaled current to a voltage. If the IMON voltage exceeds 1.2V, an overcurrent fault is deemed to exist; the ECB turns off and RDY pulls low.

Each enable input is compared to an internal 0.8V reference to enable or disable its respective channel. While a standard GPIO can be used to drive these inputs, the precision reference allows an external resistive divider to be used as an adjustable UVLO (undervoltage lockout) based on the applied input voltage. If the applied voltage falls below the EN falling threshold, the circuit breaker turns off. See the Applications Information for examples.

When initially enabled, the ECB enters a current limited operating phase, limiting inrush current without the

need for external components. During the current limited operating phase, OUT is charged with a 1A current source for 10ms. Maximum allowable OUT capacitance is 100 $\mu$ F. If OUT fails to charge beyond 1.2V in the first 300 $\mu$ s after enable, the output is deemed shorted and the circuit breaker turns off. At the successful conclusion of the current limited operating phase, the ECB enters low  $R_{ON}$  operation (75m $\Omega$  typical).

At this point, the analog current monitor function begins to source current to the IMON output. The 5% accurate current monitor produces 100 $\mu$ A/A of output load current, useful for closed loop load bias control or monitoring (see Applications Information for details). Internally, two comparators with different thresholds sense the voltage developed on the IMON output. The primary threshold comparator has a 1.2V threshold. It contains built-in filtering to remove glitches which could cause chatter near the primary threshold. The filter characteristic is shown in the Applications Information. The secondary comparator has a 2.4V threshold with a 2 $\mu$ s response time, to quickly open the ECB in situations with large overcurrent.

Overcurrent ( $V_{IMON} > 1.2V$ ) or short-circuit ( $OUT < 1.2V$ ) faults latch the circuit breaker off. Toggling EN clears the latch and turns the circuit breaker on. After an overtemperature fault, both channels turn off. The enables must be toggled in order to turn the respective ECBs back on.



## APPLICATIONS INFORMATION

The LTC4249 finds great utility in RF Power Amplifier (PA) and industrial safety applications. Massive MIMO arrays with defective elements can be automatically isolated from a common power bus, preventing unwanted bus loading. The LTC4249 provides two 65V electronic circuit breakers with built-in protection and current monitoring circuitry. Enable (EN) inputs and ready (RDY) outputs make bias sequencing applications painless.

Short-circuit protection and automatic inrush control requires no external components. Overcurrent (OC) threshold accuracy ( $\pm 5\%$ ) minimizes over-design of input power supplies.

Precise enable input and current monitor thresholds allow undervoltage (UV), overvoltage (OV), overcurrent (OC) and short-circuit (SC) detection and protection. Back-to-back connections of the ECBs permit reverse OC protection and isolation applications. Each OC threshold is configured with a single resistor.

ECB channels may be paralleled for load current sharing. A skipped lead package option is available for high voltage spacing requirements. An integrated backside thermal pad for printed circuit board design allows high ambient temperature and high current applications.

### Enabling an ECB Channel

An input logic signal from a controller may be used to enable a circuit breaker channel. The EN input threshold is 0.8V, which accommodates low-voltage logic operation and/or resistively configured undervoltage lockout. Figure 1 shows a simplified enable application using a microcontroller open-drain output and an opto-isolator. The ECBs turn on when the switches release pull down on the EN inputs. The resistors at the EN inputs provide pull-up capability and keep the maximum voltage at EN below the absolute maximum of 5.5V.

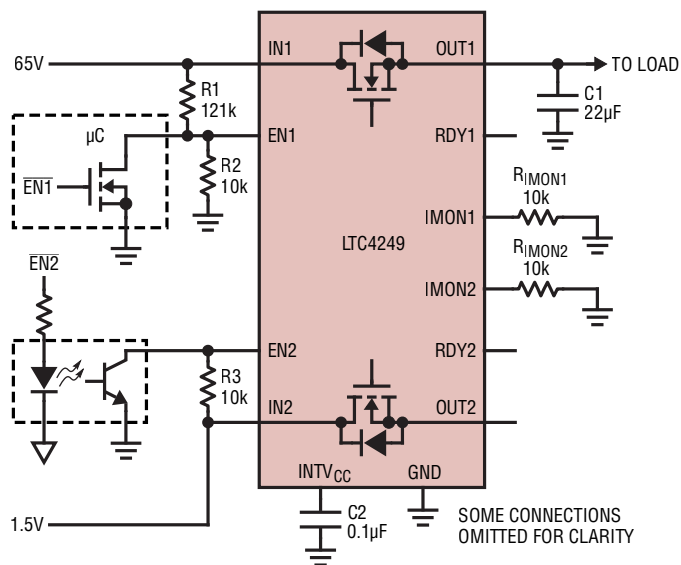


Figure 1. Switch Based Enable

Because the EN input threshold is  $\pm 2.5\%$  accurate over temperature, a resistive divider can be connected to EN and a power supply, to form a voltage based enable with undervoltage (UV) lockout. If the monitored voltage is too low, the ECB channel is disabled.

Figure 2 demonstrates a voltage based enable using external 1% tolerance resistors. The desired UV threshold is 10.8V. The application assumes that the monitored supply is nominally 12V.

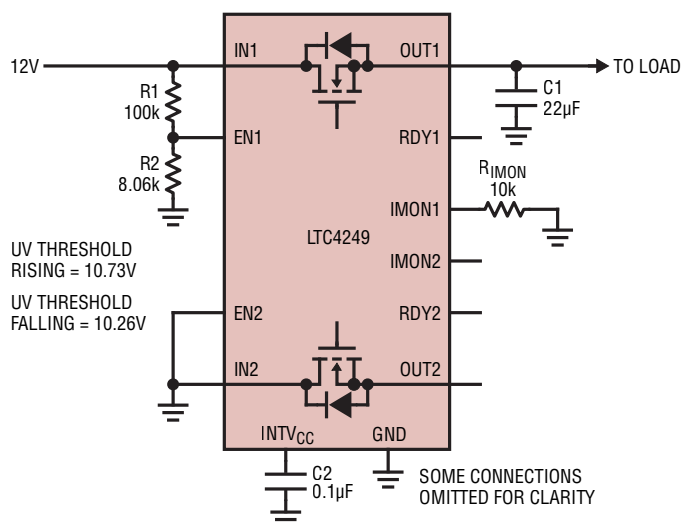


Figure 2. Voltage Based Enable with Undervoltage Lockout and Hysteresis

## APPLICATIONS INFORMATION

With an internal 0.8V EN threshold, and a desired 10.8V UV threshold, R1 may be easily determined by specifying the desired resistive divider load current. Picking 100 $\mu$ A as a starting point, the relationship for R1 is:

$$R1 = \frac{10.8V - 0.8V}{100\mu A} = 100k\Omega$$

R2 is determined by dividing the 0.8V EN threshold by the divider load current:

$$R2 = \frac{0.8V}{100\mu A} = 8k\Omega$$

The closest standard 1% resistor is 8.06k. The resistor difference will not cause much error in the UV threshold (10.73V).

To prevent ECB chattering due to a noisy monitored voltage, the 0.8V EN threshold has 35mV falling hysteresis. The supply referred hysteresis is simply related to the resistive divider gain:

$$\begin{aligned} \text{Falling Hysteresis} &= 35mV \cdot \left(1 + \frac{R1}{R2}\right) \\ &= 469mV \end{aligned}$$

Therefore, for the application in Figure 2, after the monitored supply rises above 10.73V, the falling UV threshold drops to 10.26V. If the monitored supply is below the configured UV threshold the ECB channel is turned off.

### Automatic Inrush Control

The LTC4249 is designed to control the inrush current upon enabling an ECB channel. For the first 10ms, output loads are charged at 1A. Maximum capacitive load is 100 $\mu$ F. At 100 $\mu$ F, the output charges at 10V/ms. When operating at the maximum input supply of 65V, a 100 $\mu$ F capacitor charges in 6.5ms, and is safely below the 10ms charge time. Figure 3 demonstrates output charging at maximum operating voltage and capacitive load.

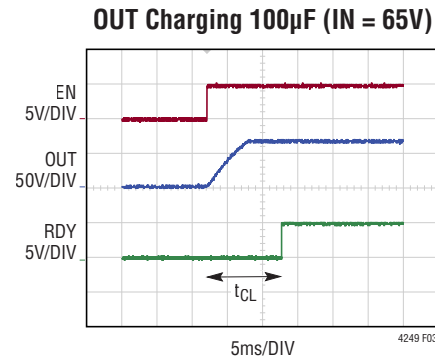


Figure 3. Output Charging at Initial Turn-On

Attempting to charge a large capacitance quickly requires large currents. Without inrush control, the safe operating area of the ECB would be exceeded. Furthermore, without inrush control, voltage sag on the input supply could be severe, causing brown-outs or system resets.

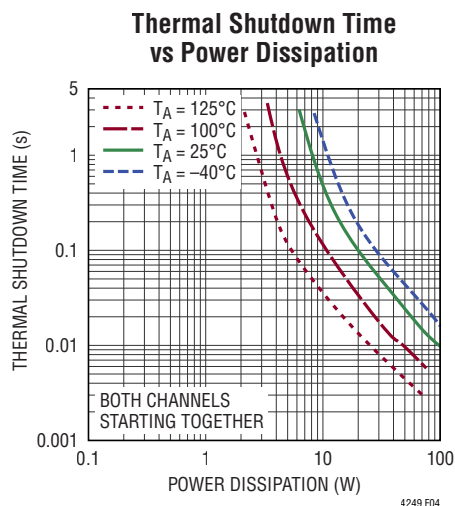
All LTC4249 applications require that the ECB output be fully charged ( $V_{OUT} \approx V_{IN}$ ) within 10ms. After the 10ms current limited operating phase ( $t_{CL}$ ), the ECB turns on fully to its rated 75m $\Omega$  on-resistance. At this point, over-current protection becomes active and the RDY output is released.

### Voltage or Capacitance Start-Up Derating at High Ambient Temperature

The LTC4249 is designed to prevent operation outside its Safe Operating Area (SOA). Maximum power dissipation occurs when starting both ECB channels simultaneously. During the inrush portion of operation, with an ambient temperature above 90°C, junction temperature may briefly exceed the thermal shutdown threshold above 150°C, depending on input voltage and output capacitance. Exceeding the thermal shutdown threshold causes the ECBs to safely latch off. Toggling the enable inputs allows the ECBs to turn back on.

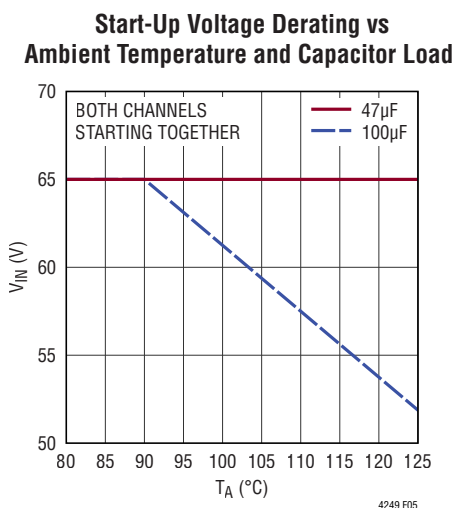
Figure 4 shows the allowable operating time at a given power dissipation before reaching thermal shutdown. Operating to the left of the curves prevents thermal shutdown. After inrush, typical power dissipation drops below 0.5W, which keeps the junction temperature far below thermal shutdown.

## APPLICATIONS INFORMATION



**Figure 4. Thermal Shutdown Time vs Power Dissipation**

Figure 5 provides temperature derating information for input voltage and output capacitance during the inrush portion of operation. If the output capacitance is  $47\mu\text{F}$  (or less), 65V operation is possible at any allowed ambient temperature. At  $100\mu\text{F}$ , input voltage should be reduced by  $-375\text{mV}/^\circ\text{C}$ , starting at  $90^\circ\text{C}$  ambient. Connecting the exposed back pad to a ground plane is recommended for heat removal.



**Figure 5. High Temperature Start-Up Derating**

### Short-Circuit Protection

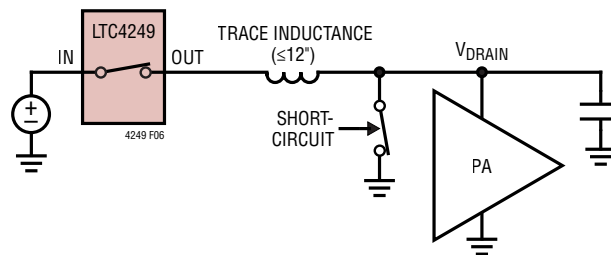
During the first  $300\mu\text{s}$  of the 10ms current limited operating phase, the OUT voltage is monitored for voltage rise.

If the OUT voltage does not exceed 1.2V at the  $300\mu\text{s}$  time point, OUT is considered shorted and the ECB turns off.

At the conclusion of the 10ms current limited operating phase, the short-circuit logic is inverted. If OUT should fall below 1.2V, OUT is again considered shorted and the ECB turns off. The short-circuit comparator response time is typically  $2\mu\text{s}$  for 50mV overdrive.

An important applications consideration under a short-circuit event is the amount of inductance between the ECB outputs and the load. An antenna array with multiple RF PAs could have inches of trace inductance between the ECB channel outputs and each PA. It is recommended to keep load path inductance below 400nH.

When the ECB is on and the load end is shorted through an inductance as shown in Figure 6, the ECB current increases rapidly. Peak current is a function of the output voltage, trace inductance and the time to turn off the ECB. The secondary OC and short-circuit comparators have limited bandwidth (about  $2\mu\text{s}$  response time) and are not sufficiently fast enough to limit the current build up to typical OC setpoints under an inductive hard short. However, the ECB controller itself does have limited current compliance, allowing the OUT voltage to fall, keeping the ECB inside its safe operating area. After reaching peak current, the ECB dissipates the inductor energy and turns off. The integrated protections eliminate the need for large high-power and high-voltage Schottky diodes at the OUT pin.



**Figure 6. Load Short with Inductance**

The input voltage side of the ECB should also have low inductance. For array applications, a large low impedance layout is recommended for input voltage distribution. It is recommended to keep the input supply path inductance below 400nH. A  $1\mu\text{F}$  (or greater) bypass capacitor placed close to the IN inputs and ground is recommended.

## APPLICATIONS INFORMATION

### Applying the RDY Output

The RDY open-drain output is released and allowed to pull high when the ECB is fully turned on and OUT is “ready” for application. In a RF PA circuit, with OUT connected to the PA drain, RDY may be used to enable PA gate bias. RDY pulls low when EN is low and/or when fault events such as overcurrent, short-circuit or thermal shutdown conditions have occurred.

Figure 7 shows a typical RDY response to EN and subsequent overcurrent fault. RDY may be pulled up as high as 5.5V, by an external source. Resistors in the range of 1k to 10k are recommended. RDY may also be used to enable other downstream loads such as DC-DC converters.

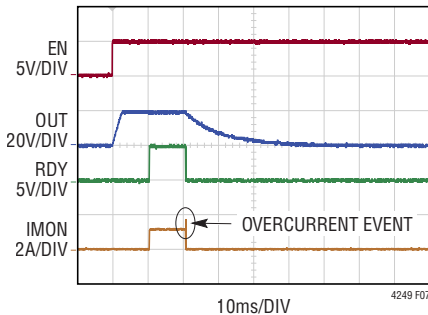


Figure 7. Typical RDY Response

### Configuring Overcurrent (OC) Thresholds

Overcurrent thresholds are easily configured with a single resistor ( $R_{IMON}$ ) from IMON to GND. IMON sources  $100\mu A/A$  of ECB current. The primary (filtered) OC voltage threshold at the IMON output is 1.2V.  $R_{IMON}$  is simply determined from:

$$R_{IMON} = \frac{1.2V}{I_{ECB}} \cdot 10,000$$

where  $I_{ECB}$  is the desired circuit breaker threshold in amperes. For a 1.2A circuit breaker threshold,  $R_{IMON}$  is 10k $\Omega$ . Larger values of  $R_{IMON}$  yield lower circuit breaker thresholds. The secondary (fast) OC threshold is always twice the configured primary OC threshold.

The primary OC threshold is filtered to remove small fluctuations which allows the ECB to operate at currents near the OC threshold. In order to trip the primary OC comparator, the 1.2V threshold must be overdriven with requisite magnitude and duration. The typical overdrive versus time characteristic for the primary OC comparator is shown in Figure 8.

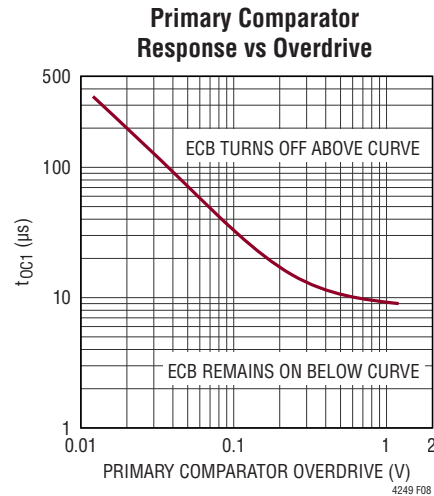


Figure 8. Primary OC Comparator Filter Characteristic

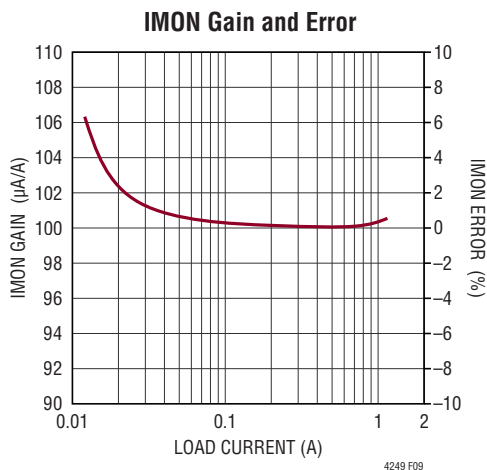
The secondary OC threshold comparator does not have added filtering and has a 2 $\mu s$  (typical) response time when the 2.4V IMON threshold has been exceeded.

External filtering of the IMON output voltage to achieve added ECB delay or noise rejection can be performed by adding a capacitor  $C_{IMON}$  in parallel with  $R_{IMON}$ . A pole will be formed by the RC combination.

### Monitoring ECB Current

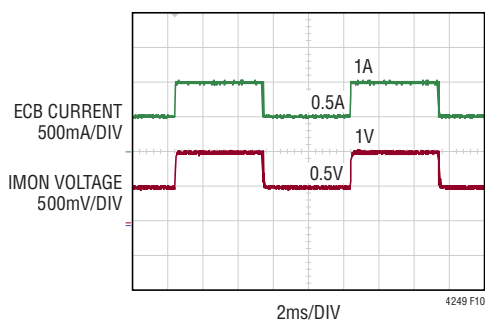
The IMON output current provides an accurate scaled replica ( $100\mu A/A$ ) of the OUT current. The IMON output current is 5% accurate (30mA to 1.2A) over temperature (Figure 9). Note that excellent accuracy is maintained even at ECB currents below 30mA. The IMON accuracy reduces the need to over design the input power supply current capability due to the low variability in ECB threshold.

## APPLICATIONS INFORMATION



**Figure 9. Typical IMON Gain vs Load Current**

The IMON output has the bandwidth to follow ECB currents to approximately 50kHz. The bandwidth is a function of load capacitance at OUT and any capacitance at the IMON output. Figure 10 shows how the IMON output voltage follows a step change in ECB current from 0.5A to 1A. OUT capacitance is 100µF and no explicit capacitance was added to IMON.



**Figure 10. IMON Step Response ( $C_{OUT} = 100\mu\text{F}$ ,  $R_{IMON} = 10\text{k}\Omega$ )**

In applications where ECB current information must be captured, the scaled ECB current history can be stored in external memory by digitizing the IMON voltage with an analog to digital converter.

### Load Current Servo Control

In RF PA applications, the IMON voltage may be compared to a reference and a control loop can servo the PA gate bias to control drain bias current. The front-page application schematic demonstrates how PA BIAS current can be

controlled by a DAC. PA  $V_{GG}$  threshold variations due to process and temperature are overcome with servo control, making individual bias trims obsolete.

In the front-page application, the input supply (28V) at IN1 passes to the RF PA  $V_{DD}$  when the voltage at EN1 exceeds 0.8V. Resistors R1 and R2 are chosen to provide an under-voltage (UV) threshold of 24.88V and 1.09V of falling hysteresis. Below threshold, RDY1 is low and the op amp is in shutdown. With the op amp in shutdown, the RF PA  $V_{GG}$  is pulled to the negative potential (-5V) through ROFF and the PA is off.

When the 28V input exceeds the UV threshold, the PA  $V_{DD}$  voltage ramps to the IN1 potential. RDY1 pulls high after 10ms and the op amp becomes active. At this point, the op amp drives the RF PA  $V_{GG}$  to the potential that forces the PA BIAS current to track the controlling input at the op amp non-inverting terminal. For example, if the controlling input is 1V, the PA  $V_{GG}$  bias moves to force the PA BIAS current to 1A.

If the PA BIAS current exceeds 1.2A, the ECB disconnects the  $V_{DD}$  bias and the RDY1 output pulls low. With RDY1 low, the op amp is in shutdown and the PA  $V_{GG}$  bias pulls to the negative rail.

For most closed loop applications, loop stability is achieved with integrating capacitor  $C_F$ . In situations where  $C_{OUT}$  is greater than 10µF, an additional resistor/capacitor combination may be needed for lead-lag compensation. A generalized compensation methodology is described below.

### Loop Analysis

The front page schematic loop elements are extracted and shown in Figure 11. Various important quantities are defined here:

- $V_C$ : the controlling input at the non-inverting terminal of the op amp
- $R_{ON}$ : the ECB on-resistance (75mΩ)
- $C_{OUT}$ : the PA  $V_{DD}$  drain capacitance (10µF)
- GM: the LTC4249 current monitor transconductance (1.33 mA/V)

## APPLICATIONS INFORMATION

- $R_M$ : the IMON sense and overcurrent setpoint resistor (10k $\Omega$ )
- $C_F$ : the feedback capacitance used to provide a stable loop (330pF)
- $R_G$ : resistance to limit op amp overshoot due to PA input capacitance (100 $\Omega$ )
- $C_G$ : PA input capacitance (150pF)

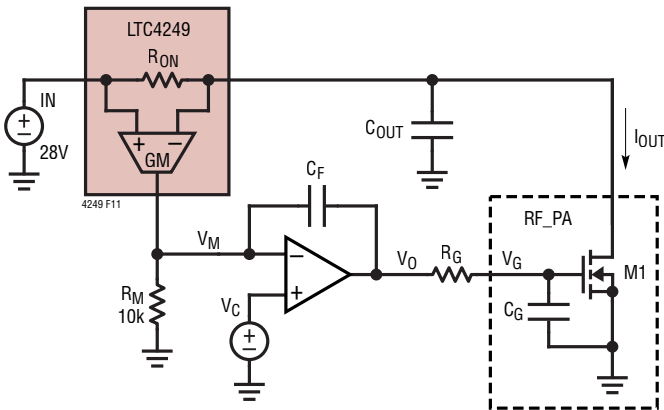


Figure 11. PA Servo Loop Components

It is important to understand how the loop components affect stability and the closed loop response  $I_{OUT}/V_C$ .

The LTC4249 current monitor GM and  $R_M$  components may be converted to a Thevenin equivalent.  $C_F$  is temporarily removed for analysis.  $GM_{PA}$  is the PA transconductance. The loop is transformed to a block diagram equivalent in Figure 12, where  $A(s)$  is the op amp open loop transfer function and the canonical  $G(s)$  and  $H(s)$  blocks are outlined.

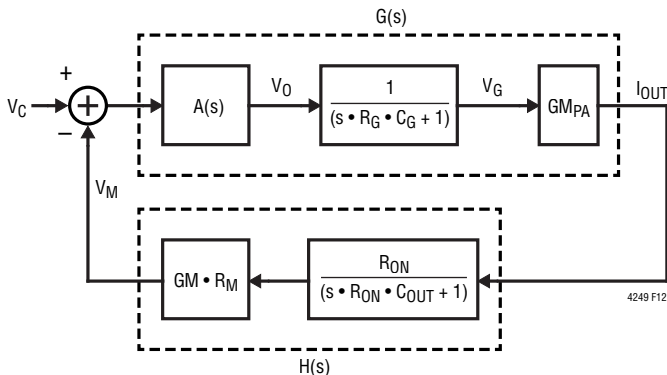


Figure 12. Servo Loop Block Diagram without  $C_F$

Figure 13 shows the magnitude and phase of the uncompensated loop gain  $G(s)H(s)$ . It is easy to see inadequate phase margin ( $\sim 0^\circ$ ) at the crossover frequency. The region near crossover consists of multiple deleterious poles including contributions from  $R_{ON} \cdot C_{OUT}$ ,  $R_G \cdot C_G$  and high frequency op amp poles.

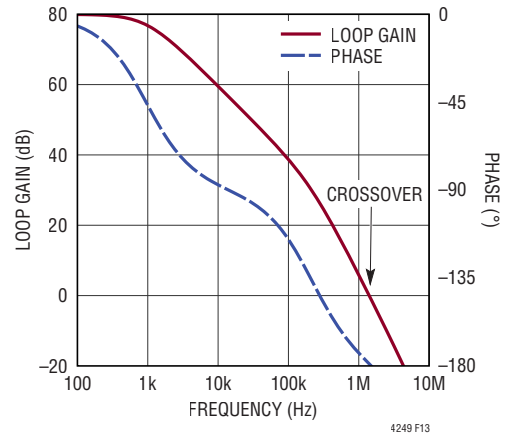


Figure 13. Uncompensated Loop Gain and Phase

Crossing the system over at a lower frequency can help achieve loop stability. This is easily done by adding feedback elements around the op amp. If we add a generalized feedback impedance  $Z_F$  around the op amp, the loop can be stabilized and sensitivity to the op amp transfer function can be eliminated. Figure 14 shows the block diagram with  $Z_F$  added.

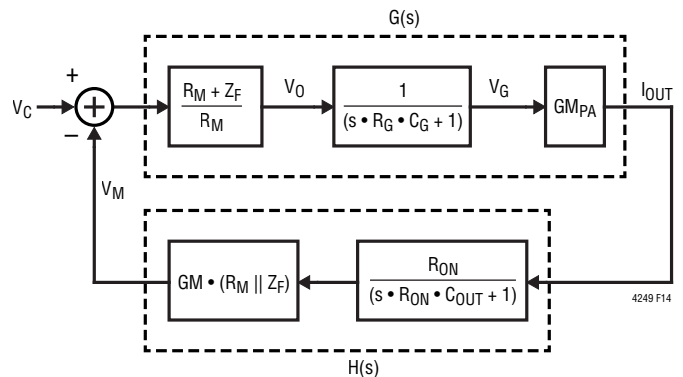
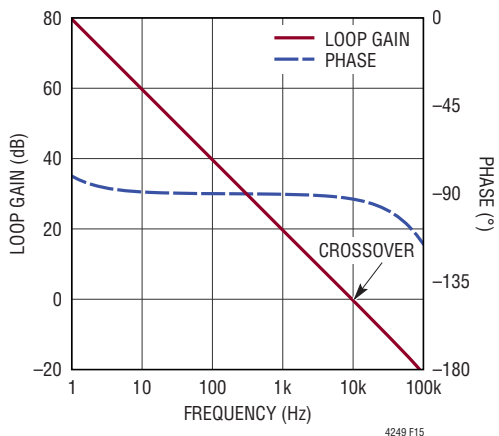


Figure 14. Servo Loop Block Diagram with Generalized Impedance  $Z_F$  around Op Amp

With  $Z_F = 1/sC_F$ , the crossover frequency is lower ( $\sim 10$ kHz) and phase margin improves to almost  $90^\circ$  as

## APPLICATIONS INFORMATION

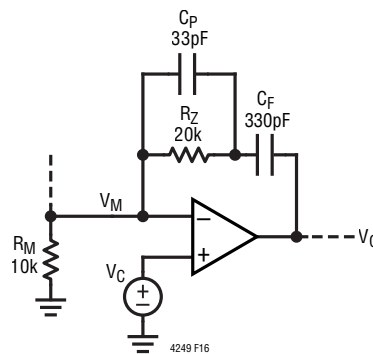
shown in Figure 15. Step response as shown on the front page is clean with a rise time of about 10 $\mu$ s.



**Figure 15. Compensated Loop Gain and Phase**  
( $Z_F = 1/sC_F$ ,  $C_F = 330\text{pF}$ )

When  $C_{OUT}$  is large (closer to 100 $\mu$ F), phase margin may be lower compared to the 10 $\mu$ F example. With large  $C_{OUT}$ , another loop term should be considered for its phase margin impact. During step changes in load current, the LTC4249 current monitor output lags load current briefly. Transport lag results in phase erosion that is a function of frequency but does not impact the loop gain magnitude. The phase erosion is equal to  $360^\circ \cdot f \cdot T$ , where  $T \approx 2\mu$ s. At the crossover frequency  $f = 10\text{kHz}$ , phase margin loss due to transport lag is  $-7.2^\circ$ .

In a low phase margin situation, a lead-lag network may be required to control the step response. Adding a resistor ( $R_Z$ ) in series with  $C_F$  provides a leading zero and a small capacitor ( $C_P$ ) around  $R_Z$  provides a lagging pole to restore high frequency roll-off (Figure 16). For analysis purposes, simply condense the compensation network around the op amp into a  $Z_F$  impedance and use the model in Figure 14 to obtain the new loop gain and phase (add the transport lag loss term to the phase as needed).



**Figure 16. Lead-Lag Network Example**

### RF PA Bias Sequencing

Some RF PAs have a strict bias sequence order. Use the LTC4249 EN inputs, RDY outputs and IMON outputs to simplify the sequencing process. A recommended bias sequence during power up is the following:

- 1) Start with the PA  $V_{DD}$  near ground. To achieve this, begin with EN low (ECB off, OUT near ground). Drive the PA  $V_{GG}$  to a suitably negative voltage to guarantee PA BIAS current = 0. RDY should be pulling low at this time.
- 2) Raise EN above threshold (0.8V). The LTC4249 enters its current limited operating phase and charges the OUT capacitance with 1A. After 300 $\mu$ s, OUT is checked for voltage above 1.2V. If it is less, the channel output is deemed to be “shorted” and the corresponding ECB shuts off. Assuming no short, the LTC4249 completes current limited operating phase after 10ms and begins low  $R_{ON}$  operation. RDY is now released and may be pulled high. OUT voltage should now be close to IN.
- 3) After RDY release, increase PA  $V_{GG}$  voltage until desired BIAS current is achieved. BIAS current may be inferred from the voltage at the IMON output.
- 4) Apply RFIN signal.

## APPLICATIONS INFORMATION

The recommended bias sequence during power down is the following:

- 1) Remove RFIN signal.
- 2) Decrease PA  $V_{GG}$  voltage to bring PA BIAS current to zero. BIAS current may be inferred from the voltage at the IMON output.
- 3) Pull EN below threshold (OUT disconnects from IN, RDY pulls low).

### Current Sharing

Some applications may require operation and OC sensing above 1.2A load current. Operation up to 2.4A is possible by simply paralleling the two ECB channels (Figure 17). The two channels will share load current to typically 1%, governed by  $R_{ON}$  matching.

If either channel exceeds 1.2A, the respective ECB shuts off. This action throws the load current to the remaining channel causing the second channel to shut off as well. Multiple LTC4249s may be paralleled for even more current. The efficacy of that approach depends on device to device  $R_{ON}$  matching (typically  $\pm 2\%$ , but is not guaranteed), and is slightly worse than the  $\pm 1\%$  channel matching specification.

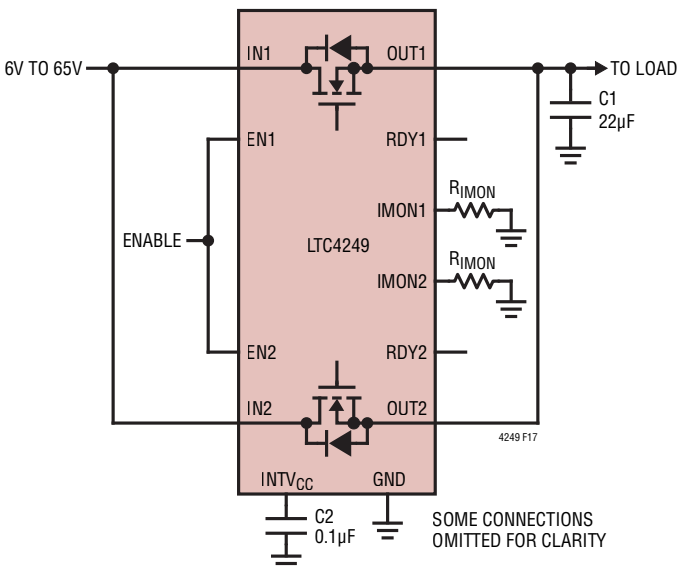


Figure 17. Current Sharing for Applications above 1.2A

### Output Overcurrent and Overvoltage

Circuit breaker action may also be achieved based on overvoltage at the OUT node by the addition of a single resistor  $R_{OV}$  (Figure 18) between OUT and IMON. Calculating resistor  $R_{OV}$  depends on whether the load has current sink or resistive properties. In this application, the OC and OV thresholds become dependent and resistor calculation is a multi-step procedure.

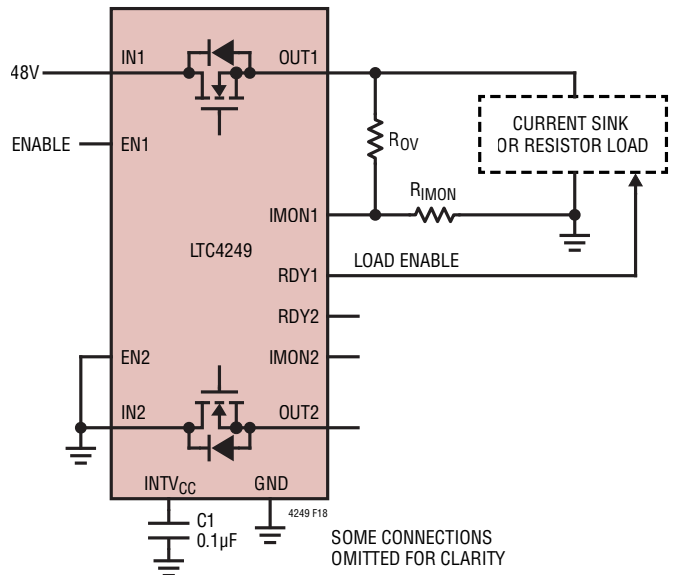


Figure 18. OV/OC Circuit Breaker with One Additional Resistor

The nominal  $OUT1$  voltage ( $V_{OUT}$ ) in Figure 18 is  $\sim 48V$  with a desired OV threshold ( $V_{OV}$ ) of 56.2V. For a current sink load ( $I_{OUT}$ ) operating nominally at 650mA and a desired overcurrent threshold ( $I_{OC}$ ) of 732mA,  $R_{OV}$  is found from:

$$R_{OV} = \frac{V_{OUT} - 1.2V}{\left( \left( \frac{1.2V}{R_{IMON}} \right) - (I_{OC} \cdot G_{IMON}) \right)}$$

where  $G_{IMON} = 100\mu A/A$  and  $R_{IMON} = 10k\Omega$ . Plugging in  $I_{OC} = 732mA$  yields  $R_{OV} = 1M\Omega$ . With  $R_{OV}$  at  $1M\Omega$  and  $I_{OUT} = 650mA$ ,  $V_{OV}$  is determined from:

$$V_{OV} = \left( \left( \frac{1.2V}{R_{IMON}} \right) - (I_{OUT} \cdot G_{IMON}) \right) \cdot R_{OV} + 1.2V$$

with a result of  $V_{OV} = 56.2V$ .



## APPLICATIONS INFORMATION

When the load is resistive, the calculation for  $R_{OV}$  is unchanged. For  $V_{OUT} = 48V$  and  $I_{OC} = 732mA$ ,  $R_{OV}$  remains  $1M\Omega$ . However, the calculation for OV threshold must include an additional contribution from IMON output current due to the excess voltage over the resistive load:

$$V_{OV} = 1.2V \cdot \frac{\left( \frac{1}{R_{IMON}} + \frac{1}{R_{OV}} \right)}{\left( \frac{I_{OUT} \cdot G_{IMON}}{V_{OUT}} + \frac{1}{R_{OV}} \right)}$$

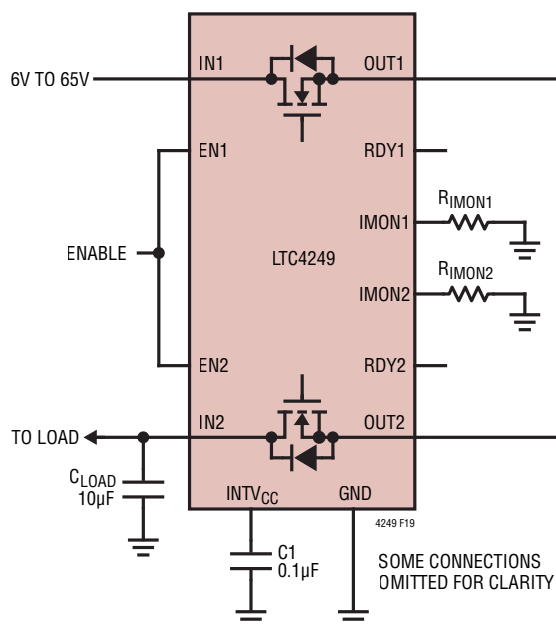
where  $I_{OUT}$  is the nominal load of 650mA yielding a result of  $V_{OV} = 51.48V$ . To regain a higher OV threshold,  $R_{OV}$  must increase, which will cause  $I_{OC}$  to increase. For example, if  $R_{OV}$  is increased to  $1.21M\Omega$ ,  $V_{OV}$  becomes 55.48V and  $I_{OC}$  increases to 813mA.

### Reverse Current Circuit Breaker

In applications where the ECB output (load side) could be pulled above the input, such as a power mux circuit, the risk of forward biasing the ECB body diode and conducting current to the input exists. To overcome that possibility, the two LTC4249 channels can be connected back to back as shown in Figure 19. The back to back connection places the two ECB body diodes in opposite directions and prevents current from the load connection at IN2 back to IN1, when the ECBs are off.

When the channels are turned on, however, current can still pass through the ECBs in both directions. Fortunately, due to the reverse connection of channel 2, current from IN2 to OUT2 is still reported at  $I_{MON2}$  because channel 2

is operating normally if IN2 rises above OUT2. With an appropriate choice of  $R_{IMON2}$ , an accurate “reverse current” threshold can be chosen to shut off channel 2 and prevent excess current from the load connection at IN2 back to IN1. Channel 1 operates as usual and turns off due to excess forward current, configured by  $R_{IMON1}$ .



**Figure 19. Back to Back Connection for Load Isolation and Forward/Reverse Current Circuit Breaker**

### Load Switch with Isolation

Building from Figure 19, a load switch with reverse isolation is possible by duplicating the application and providing enable inputs to preferentially select the input supply ( $V1$  or  $V2$ ) that is delivered to the load (Figure 20).

## APPLICATIONS INFORMATION

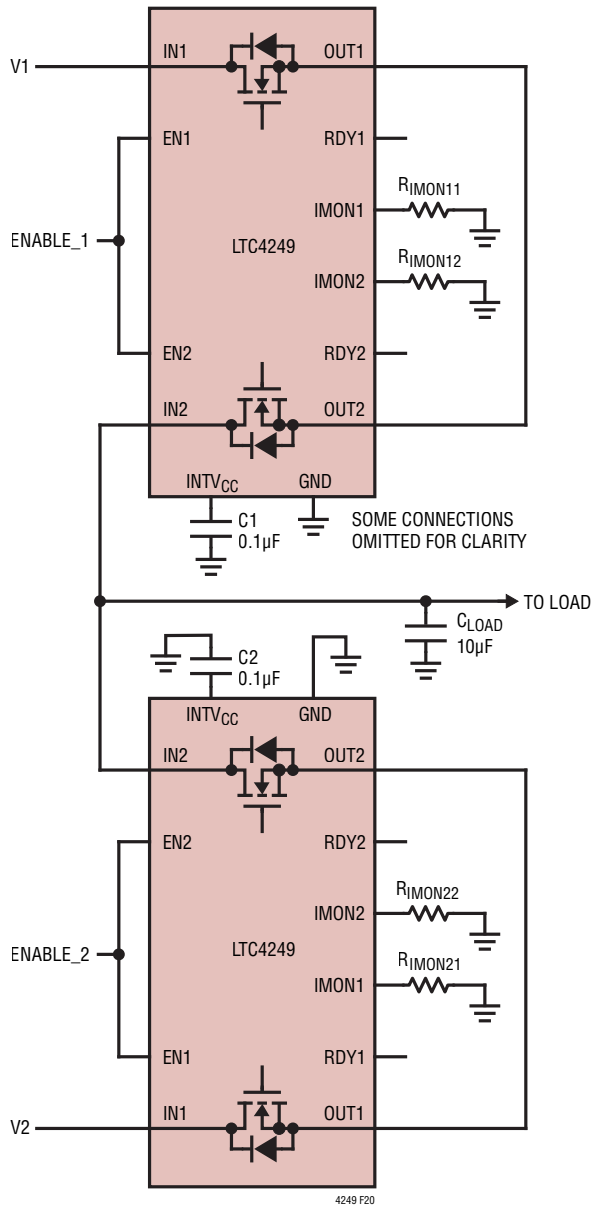


Figure 20. Load Switch Application

## High Voltage Spacing Considerations

In applications where creepage and clearance standards up to 65V must be met, a 12-Lead 3mm × 4mm LQFN package is available for ordering. The IN1, OUT1, IN2 and OUT2 leads are all adequately spaced to all other leads including the exposed thermal pad.

## Thermal Considerations

The exposed thermal pad is internally connected to ground and provides an optimal path for heat removal. In applications where the ambient temperature is above 90°C, connect the exposed pad to 2 inch<sup>2</sup> of 1oz PCB copper to limit junction heating when operating at maximum current capability of 1.2A per channel (2.4A total).

At high ambient temperatures, a heat removal path is also important during the 10ms current limited operating phase, where the pulsed power can cause brief but large temperature rise.

Under extreme thermal conditions an integrated thermal switch activates to turn off both channels. The breakers remain off for typically 1 second and until the respective enable inputs are toggled.

## Industrial Applications

Many of the individual applications discussed thus far can be combined in clever ways to solve system problems. Industrial applications often require the need for circuit breakers. The back page shows an industrial application utilizing the LTC4249 capabilities to provide undervoltage (UV), overvoltage (OV), overcurrent (OC) and reverse current protection for a 15V system with a nominal 50mA resistive load current. The resistor values are calculated to provide the following thresholds:

UV Threshold: 12V

OV Threshold: 16.9V

Forward OC Primary Threshold: 193mA

Reverse OC Primary Threshold: 1.2A

## APPLICATIONS INFORMATION

During initial turn-on, the load capacitance charges through ECB1 and the body diode of ECB2. RDY1 enables ECB2 after the ECB1 10ms current limited turn phase is complete. ECB2 then turns on and shunts the body diode path.

### Special “5V ONLY” Application

Under most circumstances, the minimum IN1 voltage required for operation is 6V. However, a very narrow application for IN1 = 5V is possible provided a few conditions are met. First, the IN1 supply voltage must be tightly regulated to  $\pm 5\%$  (4.75V to 5.25V). Second, IN1 must be connected to the INTV<sub>CC</sub> output (Figure 21). OUT1, when ECB1 is on, is therefore constrained to the IN1 limitation. IN2 may be operated normally over its full range.

This application is tested in production and has been qualified over temperature. Note that while the electrical table does not extend IN1 below 6V, this application is supported with respect to all other electrical table entries except for V<sub>CCOR</sub>, V<sub>ECB2</sub>, V<sub>ACC2</sub> and t<sub>OC2</sub>. Above 1.8A, the secondary overcurrent comparators may experience increased threshold or delay. The primary overcurrent comparators however, conform to data sheet specifications over their full range (1.2A), ensuring ECB shutoff under overcurrent conditions.

Operation beyond these special constraints is not recommended and operation is not guaranteed.

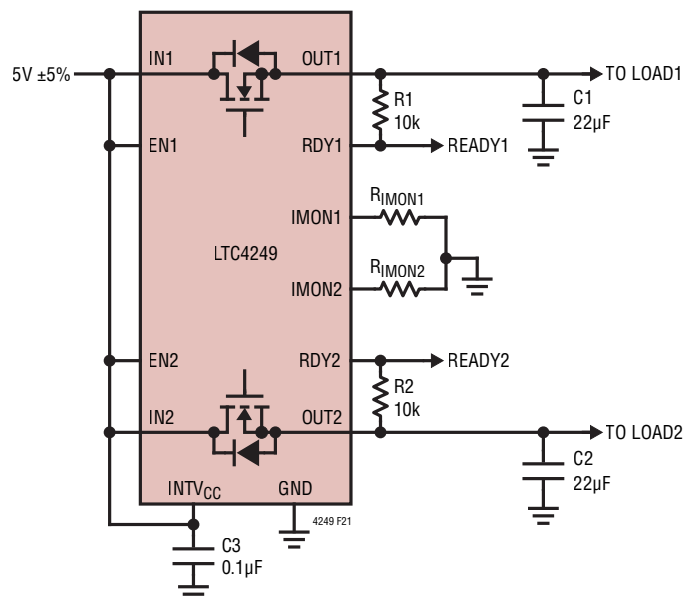
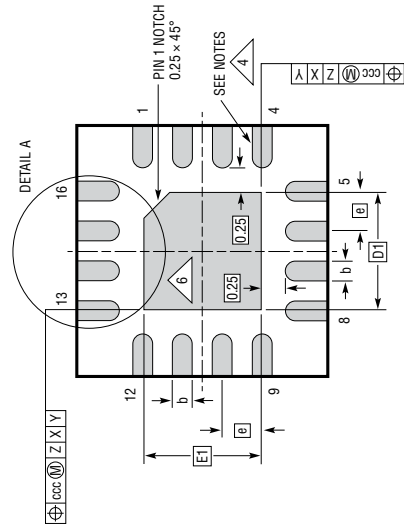


Figure 21. Special “5V ONLY” Application

# PACKAGE DESCRIPTION

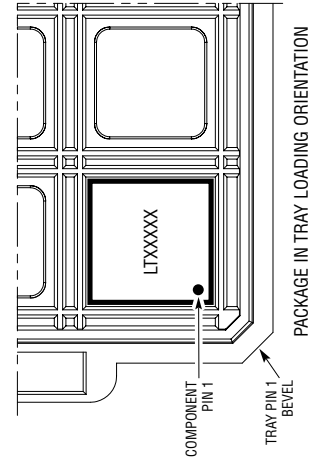
**LQFN Package**  
**16-Lead (3mm × 3mm × 0.95mm)**  
 (Reference LTC DWG # 05-08-1443 Rev 0)



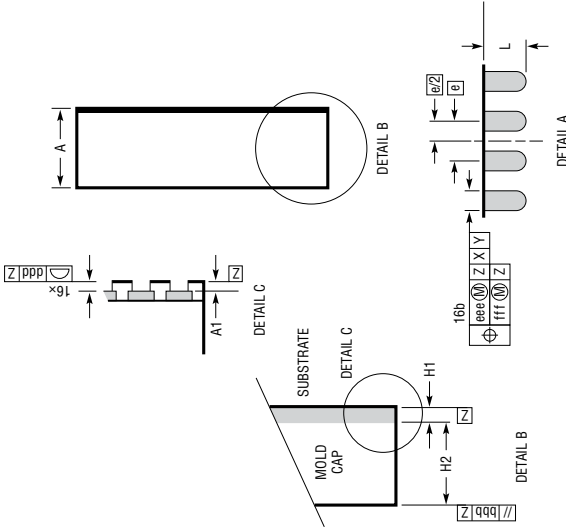
PACKAGE BOTTOM VIEW

- NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M-1994
  2. ALL DIMENSIONS ARE IN MILLIMETERS
  3. PRIMARY DATUM - Z - IS SEATING PLANE

4. METAL FEATURES UNDER THE SOLDER MASK OPENING NOT SHOWN SO AS NOT TO OBSCURE THESE TERMINALS AND HEAT FEATURES
5. DETAILS OF PIN 1 IDENTIFIER ARE OPTIONAL, BUT MUST BE LOCATED WITHIN THE ZONE INDICATED. THE PIN 1 IDENTIFIER MAY BE EITHER A MOLD OR MARKED FEATURE
6. THE EXPOSED HEAT FEATURE MAY HAVE OPTIONAL CORNER RADII

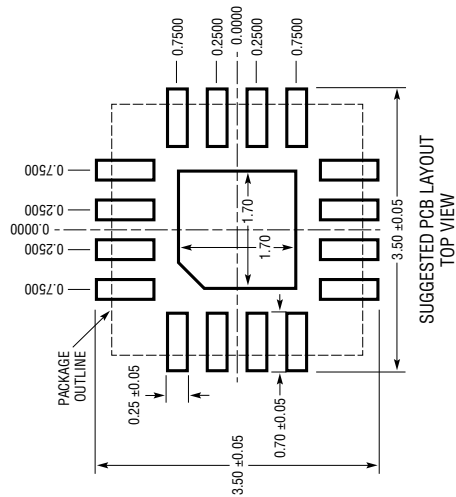


PACKAGE IN TRAY LOADING ORIENTATION



PACKAGE TOP VIEW

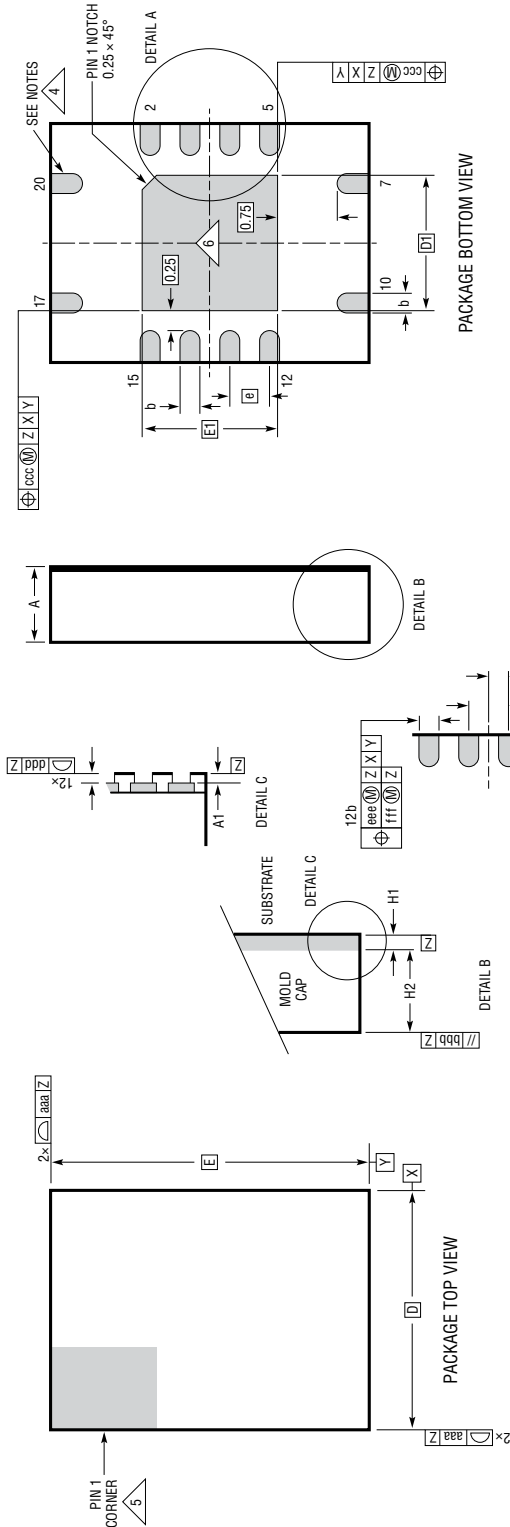
DIMENSIONS				
SYMBOL	MIN	NOM	MAX	NOTES
A	0.85	0.95	1.05	
A1	0.01	0.02	0.03	
L	0.30	0.40	0.50	
b	0.22	0.25	0.28	
D		3.00		
E		3.00		
D1		1.70		
E1		1.70		
e		0.50		
H1		0.25 REF		SUBSTRATE THK
H2		0.70 REF		MOLD CAP HT
aaa			0.10	
bbb			0.10	
ccc			0.10	
ddd			0.10	
eee			0.15	
fff			0.08	



SUGGESTED PCB LAYOUT TOP VIEW

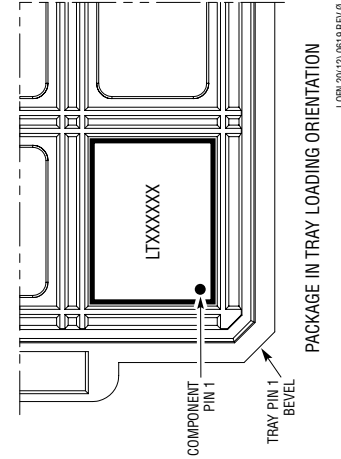
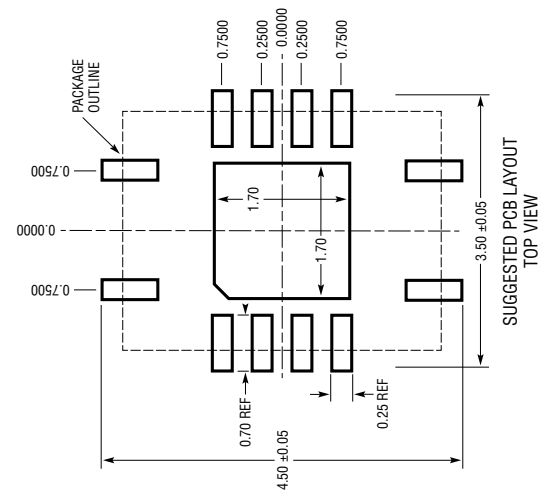
# PACKAGE DESCRIPTION

## LQFN Package 20 (12)-Lead (3mm × 4mm × 0.95mm) (Reference LTC DWG # 05-08-1441 Rev 0)



- NOTES:**
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M-1994
  2. ALL DIMENSIONS ARE IN MILLIMETERS
  3. PRIMARY DATUM -Z- IS SEATING PLANE
  4. METAL FEATURES UNDER THE SOLDER MASK OPENING NOT SHOWN SO AS NOT TO OBSCURE THESE TERMINALS AND HEAT FEATURES
  5. DETAILS OF PIN 1 IDENTIFIER ARE OPTIONAL, BUT MUST BE LOCATED WITHIN THE ZONE INDICATED. THE PIN 1 IDENTIFIER MAY BE EITHER A MOLD OR MARKED FEATURE
  6. THE EXPOSED HEAT FEATURE MAY HAVE OPTIONAL CORNER RADII

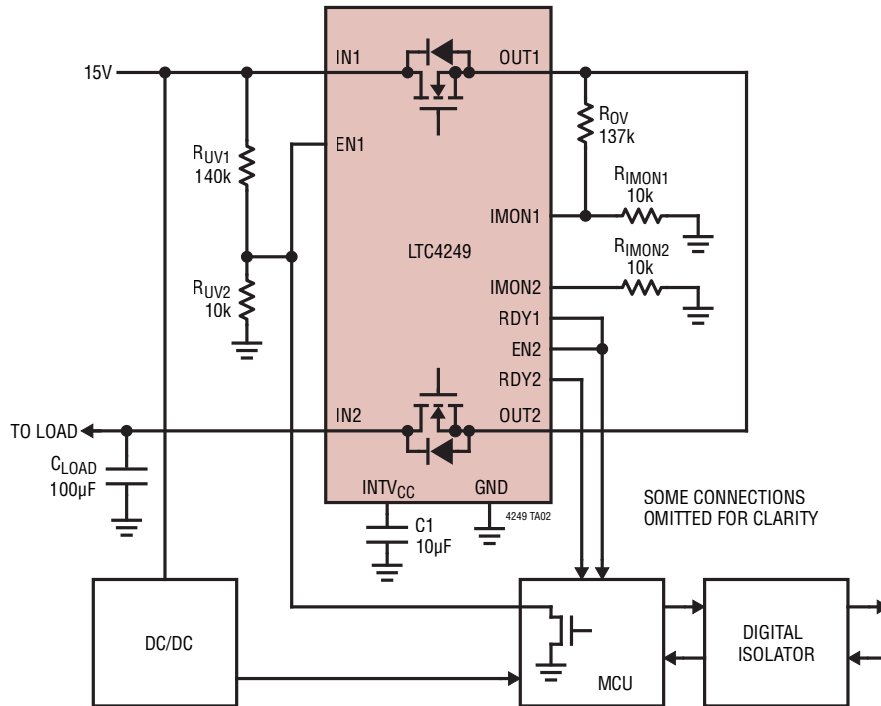
DIMENSIONS			
SYMBOL	MIN	NOM	MAX
A	0.85	0.95	1.05
A1	0.01	0.02	0.03
L	0.30	0.40	0.50
b	0.22	0.25	0.28
D		3.00	
E		4.00	
D1		1.70	
E1		1.70	
e		0.50	
H1		0.25 REF	
H2		0.70 REF	
aaa		0.10	
bbb		0.10	
ccc		0.10	
ddd		0.10	
eee		0.15	
fff		0.08	



LQFN-20(12)0619REV 0

## TYPICAL APPLICATION

### ECB For Industrial Application with UV, OV, OC and Reverse Current Protection



## RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
<a href="#">LTC4368</a>	LTC4367 + Bidirectional Circuit Breaker	±50mV or 50mV/−3mV Circuit Breaker Thresholds; MSOP-10, DFN-10 Packages
<a href="#">LTC4367</a>	100V Overvoltage, Undervoltage and Reverse Supply Protection Controller	Wide Operating Range: 2.5V to 60V, Protection Range: −40V to 100V, No TVS Required for Most Applications
<a href="#">LTC4365</a>	Overvoltage, Undervoltage and Reverse Supply Protection Controller	Wide Operating Range: 2.5V to 34V, Protection Range: −40V to 60V, No TVS Required for Most Applications
<a href="#">LTC4366</a>	High Voltage Surge Stopper	9V to >500V Operation, 8-Pin TSOT and 3mm × 2mm DFN Packages
<a href="#">LTC4364</a>	Surge Stopper with Ideal Diode	4V to 80V Operation, −40V Reverse Input, −20V Reverse Output
<a href="#">LT4363</a>	High Voltage Surge Stopper with Current Limit	Wide Operating Range: 4V to 80V, Reverse Protection to −60V, Adjustable Output Clamp Voltage
<a href="#">LTC4361</a>	Overvoltage/Overcurrent Protection Controllers	5.8V Overvoltage Threshold, 85V Absolute Maximum
<a href="#">LTC4380</a>	8µA I <sub>Q</sub> Surge Stopper	4V to 72V Operation, Pin Selectable Clamp Voltage

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