

## FEATURES

- Complete Switch Mode Power Supply
- Wide Input Voltage Range: 4.5V to 28V
- 6A DC, Typical 8A Peak Output Current
- 0.6V to 5V Output Voltage
- 1.5% Output Voltage Regulation
- Ultrafast Transient Response
- Parallel  $\mu$ Module™ DC/DC Converters
- Current Mode Control
- Pin Compatible with the LTM4600 and LTM4602
- Up to 92% Efficiency
- Programmable Soft-Start
- Output Overvoltage Protection
- Optional Short-Circuit Shutdown Timer
- Pb-Free (e4) RoHS Compliant Package with Gold-Pad Finish
- Small Footprint, Low Profile (15mm × 15mm × 2.8mm) LGA Package

## APPLICATIONS

- Telecom and Networking Equipment
- Servers
- Industrial Equipment
- Point of Load Regulation

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## DESCRIPTION

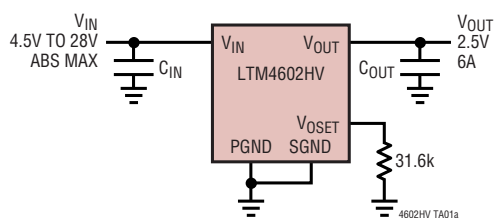
The LTM®4602HV is a complete 6A, DC/DC step down power supply with up to 28V input operation. Included in the package are the switching controller, power FETs, inductor, and all support components. Operating over an input voltage range of 4.5V to 28V, the LTM4602HV supports an output voltage range of 0.6V to 5V, set by a single resistor. This high efficiency design delivers 6A continuous current (8A peak), needing no heat sinks or airflow to meet power specifications. Only bulk input and output capacitors are needed to finish the design.

The low profile package (2.8mm) enables utilization of unused space on the bottom of PC boards for high density point of load regulation. High switching frequency and an adaptive on-time current mode architecture enables a very fast transient response to line and load changes without sacrificing stability. Fault protection features include integrated overvoltage and short circuit protection with a defeatable shutdown timer. A built-in soft-start timer is adjustable with a small capacitor.

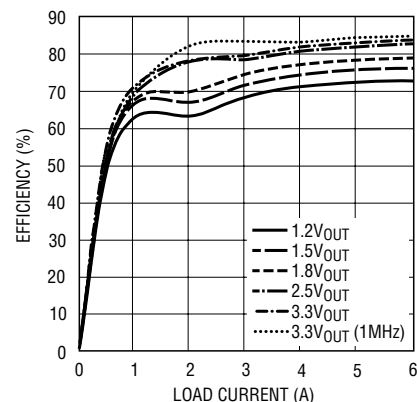
The LTM4602HV is packaged in a thermally enhanced, compact (15mm × 15mm) and low profile (2.8mm) over-molded Land Grid Array (LGA) package suitable for automated assembly by standard surface mount equipment. For the 4.5V to 20V input range version, refer to the LTM4602.

## TYPICAL APPLICATION

6A  $\mu$ Module Power Supply with 4.5V to 28V Input



Efficiency vs Load Current with 24V<sub>IN</sub> (FCB = 0)



4602HV G03

4602hvf

## ABSOLUTE MAXIMUM RATINGS

(Note 1)

|   |                |
|---|----------------|
| FCB, EXT <sub>V</sub> CC, PGOOD, RUN/SS, V <sub>OUT</sub> ..... | -0.3V to 6V    |
| V <sub>IN</sub> , SV <sub>IN</sub> , f <sub>ADJ</sub> .....     | -0.3V to 28V   |
| V <sub>OSET</sub> , COMP.....                                   | -0.3V to 2.7V  |
| Operating Temperature Range (Note 2) ...                        | -40°C to 85°C  |
| Junction Temperature .....                                      | 125°C          |
| Storage Temperature Range.....                                  | -55°C to 125°C |

## PACKAGE/ORDER INFORMATION

TOP VIEW

LGA PACKAGE  
104-LEAD (15mm × 15mm × 2.8mm)  
T<sub>JMAX</sub> = 125°C, θ<sub>JA</sub> = 15°C/W, θ<sub>JC</sub> = 6°C/W,  
θ<sub>JA</sub> DERIVED FROM 95mm × 76mm PCB WITH 4 LAYERS  
WEIGHT = 1.7g

|                   |                   |
|-------------------|-------------------|
| ORDER PART NUMBER | LGA PART MARKING* |
| LTM4602HVEV#PBF   | LTM4602HVV        |
| LTM4602HVIV#PBF   | LTM4602HVV        |

Consult LTC Marketing for parts specified with wider operating temperature ranges.  
\*The temperature grade is identified by a label on the shipping container.

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the -40°C to 85°C temperature range, otherwise specifications are at T<sub>A</sub> = 25°C, V<sub>IN</sub> = 12V. External C<sub>IN</sub> = 120μF, C<sub>OUT</sub> = 200μF/Ceramic per typical application (front page) configuration.

| SYMBOL                      | PARAMETER                       | CONDITIONS   | MIN            | TYP                          | MAX            | UNITS                      |
|-----------------------------|---------------------------------|--|----------------|------------------------------|----------------|----------------------------|
| V <sub>IN(DC)</sub>         | Input DC Voltage                | AbsMax 28V for Tolerance on 24V Inputs ●   | 4.5            |                              | 28             | V                          |
| V <sub>OUT(DC)</sub>        | Output Voltage                  | FCB = 0V<br>V <sub>IN</sub> = 5V or 12V, V <sub>OUT</sub> = 1.5V, I <sub>OUT</sub> = 0A ●  | 1.478<br>1.470 | 1.50<br>1.50                 | 1.522<br>1.530 | V<br>V                     |
| <b>Input Specifications</b> |                                 |  |                |                              |                |                            |
| V <sub>IN(UVLO)</sub>       | Under Voltage Lockout Threshold | I <sub>OUT</sub> = 0A  |                | 3.4                          | 4              | V                          |
| I <sub>INRUSH(VIN)</sub>    | Input Inrush Current at Startup | I <sub>OUT</sub> = 0A, V <sub>OUT</sub> = 1.5V, FCB = 0<br>V <sub>IN</sub> = 5V<br>V <sub>IN</sub> = 12V<br>V <sub>IN</sub> = 24V  |                | 0.6<br>0.7<br>0.8            |                | A<br>A<br>A                |
| I <sub>Q(VIN)</sub>         | Input Supply Bias Current       | I <sub>OUT</sub> = 0A, EXT <sub>V</sub> CC Open<br>V <sub>IN</sub> = 12V, V <sub>OUT</sub> = 1.5V, FCB = 5V<br>V <sub>IN</sub> = 12V, V <sub>OUT</sub> = 1.5V, FCB = 0V<br>V <sub>IN</sub> = 24V, V <sub>OUT</sub> = 2.5V, FCB = 5V<br>V <sub>IN</sub> = 24V, V <sub>OUT</sub> = 2.5V, FCB = 0V<br>Shutdown, RUN = 0.8V, V <sub>IN</sub> = 12V |                | 1.2<br>42<br>1.8<br>36<br>50 | 100            | mA<br>mA<br>mA<br>mA<br>μA |
| Min On Time                 |                                 |  |                | 100                          |                | ns                         |
| Min Off Time                |                                 |  |                | 400                          |                | ns                         |
| I <sub>S(VIN)</sub>         | Input Supply Current            | V <sub>IN</sub> = 12V, V <sub>OUT</sub> = 1.5V, I <sub>OUT</sub> = 6A<br>V <sub>IN</sub> = 12V, V <sub>OUT</sub> = 3.3V, I <sub>OUT</sub> = 6A<br>V <sub>IN</sub> = 5V, V <sub>OUT</sub> = 1.5V, I <sub>OUT</sub> = 6A<br>V <sub>IN</sub> = 24V to 3.3V at 6A, EXT <sub>V</sub> CC = 5V  |                | 0.88<br>1.50<br>2.08<br>0.98 |                | A<br>A<br>A<br>A           |

4602hvf

## ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the  $-40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$  temperature range, otherwise specifications are at  $T_A = 25^{\circ}\text{C}$ ,  $V_{IN} = 12\text{V}$ . Per typical application (front page) configuration.

| SYMBOL                                  | PARAMETER   | CONDITIONS   | MIN    | TYP                     | MAX                  | UNITS             |               |
|---|---|--|--------|-------------------------|----------------------|-------------------|---------------|
| <b>Output Specifications</b>            |   |  |        |                         |                      |                   |               |
| $I_{OUTDC}$                             | Output Continuous Current Range<br>(See Output Current Derating Curves for Different $V_{IN}$ , $V_{OUT}$ and $T_A$ ) | $V_{IN} = 12\text{V}$ , $V_{OUT} = 1.5\text{V}$<br>$V_{IN} = 24\text{V}$ , $V_{OUT} = 2.5\text{V}$ (Note 3)  | 0<br>0 |                         | 6<br>6               | A<br>A            |               |
| $\frac{\Delta V_{OUT(LINE)}}{V_{OUT}}$  | Line Regulation Accuracy  | $V_{OUT} = 1.5\text{V}$ . FCB = 0V, $I_{OUT} = 0\text{A}$ ,<br>$V_{IN} = 4.5\text{V}$ to 28V   | ●      | 0.15                    |                      | %                 |               |
| $\frac{\Delta V_{OUT(0A-6A)}}{V_{OUT}}$ | Load Regulation Accuracy  | $V_{OUT} = 1.5\text{V}$ . FCB = 0V, $I_{OUT} = 0\text{A}$ to 6A,<br>$V_{IN} = 5\text{V}$ , $V_{IN} = 12\text{V}$ (Note 4)  | ●      | $\pm 0.25$<br>$\pm 0.5$ | $\pm 0.5$<br>$\pm 1$ | %<br>%            |               |
| $V_{OUT(AC)}$                           | Output Ripple Voltage   | $V_{IN} = 12\text{V}$ , $V_{OUT} = 1.5\text{V}$ , FCB = 0V, $I_{OUT} = 0\text{A}$  |        | 10                      | 15                   | mV <sub>P-P</sub> |               |
| $f_s$                                   | Output Ripple Voltage Frequency   | FCB = 0V, $I_{OUT} = 6\text{A}$ , $V_{IN} = 12\text{V}$ ,<br>$V_{OUT} = 1.5\text{V}$   |        | 800                     |                      | kHz               |               |
| $t_{START}$                             | Turn-On Time  | $V_{OUT} = 1.5\text{V}$ , $I_{OUT} = 1\text{A}$<br>$V_{IN} = 12\text{V}$<br>$V_{IN} = 5\text{V}$   |        | 0.5<br>0.7              |                      | ms<br>ms          |               |
| $\Delta V_{OUTLS}$                      | Voltage Drop for Dynamic Load Step  | $V_{OUT} = 1.5\text{V}$ , Load Step: 0A/ $\mu\text{s}$ to 3A/ $\mu\text{s}$<br>$C_{OUT} = 22\mu\text{F}$ 6.3V, 330 $\mu\text{F}$ 4V Pos Cap,<br>See Table 2                        |        | 30                      |                      | mV                |               |
| $t_{SETTLE}$                            | Settling Time for Dynamic Load Step<br>$V_{IN} = 12\text{V}$  | Load: 10% to 90% to 10% of Full Load   |        | 25                      |                      | $\mu\text{s}$     |               |
| $I_{OUTPK}$                             | Output Current Limit  | Output Voltage in Foldback<br>$V_{IN} = 24\text{V}$ , $V_{OUT} = 2.5\text{V}$<br>$V_{IN} = 12\text{V}$ , $V_{OUT} = 1.5\text{V}$<br>$V_{IN} = 5\text{V}$ , $V_{OUT} = 1.5\text{V}$ |        | 9<br>9<br>9             |                      | A<br>A<br>A       |               |
| <b>Control Stage</b>                    |   |  |        |                         |                      |                   |               |
| $V_{OSET}$                              | Voltage at $V_{OSET}$ Pin   | $I_{OUT} = 0\text{A}$ , $V_{OUT} = 1.5\text{V}$  | ●      | 0.591<br>0.594          | 0.6<br>0.6           | 0.609<br>0.606    | V<br>V        |
| $V_{RUN/SS}$                            | RUN ON/OFF Threshold  |  |        | 0.8                     | 1.5                  | 2                 | V             |
| $I_{RUN(C)/SS}$                         | Soft-Start Charging Current   | $V_{RUN/SS} = 0\text{V}$   |        | -0.5                    | -1.2                 | -3                | $\mu\text{A}$ |
| $I_{RUN(D)/SS}$                         | Soft-Start Discharging Current  | $V_{RUN/SS} = 4\text{V}$   |        | 0.8                     | 1.8                  | 3                 | $\mu\text{A}$ |
| $V_{IN} - SV_{IN}$                      |   | $EXTV_{CC} = 0\text{V}$ , FCB = 0V   |        |                         | 100                  |                   | mV            |
| $I_{EXTVCC}$                            | Current into $EXTV_{CC}$ Pin  | $EXTV_{CC} = 5\text{V}$ , FCB = 0V, $V_{OUT} = 1.5\text{V}$ ,<br>$I_{OUT} = 0\text{A}$   |        |                         | 16                   |                   | mA            |
| $R_{FBHI}$                              | Resistor Between $V_{OUT}$ and FB Pins  |  |        |                         | 100                  |                   | k $\Omega$    |
| $V_{FCB}$                               | Forced Continuous Threshold   |  |        | 0.57                    | 0.6                  | 0.63              | V             |
| $I_{FCB}$                               | Forced Continuous Pin Current   | $V_{FCB} = 0.6\text{V}$  |        |                         | -1                   | -2                | $\mu\text{A}$ |
| <b>PGOOD Output</b>                     |   |  |        |                         |                      |                   |               |
| $\Delta V_{OSETH}$                      | PGOOD Upper Threshold   | $V_{OSET}$ Rising  |        | 7.5                     | 10                   | 12.5              | %             |
| $\Delta V_{OSETL}$                      | PGOOD Lower Threshold   | $V_{OSET}$ Falling   |        | -7.5                    | -10                  | -12.5             | %             |
| $\Delta V_{OSET(HYS)}$                  | PGOOD Hysteresis  | $V_{OSET}$ Returning   |        |                         | 2                    |                   | %             |
| $V_{PGL}$                               | PGOOD Low Voltage   | $I_{PGOOD} = 5\text{mA}$   |        |                         | 0.15                 | 0.4               | 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:** The LTM4602HVE is guaranteed to meet performance specifications from  $0^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ . Specifications over the  $-40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$

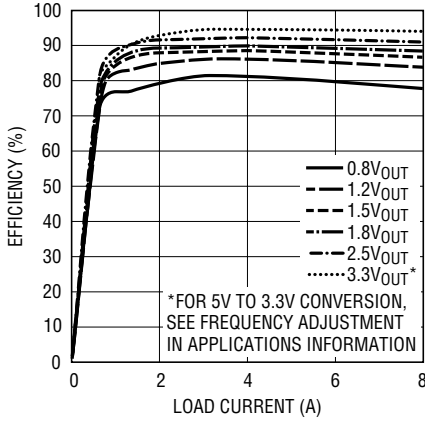
operating temperature range are assured by design, characterization and correlation with statistical process controls. The LTM4602HVI is guaranteed and tested over the  $-40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$  temperature range.

**Note 3:** Refer to current de-rating curves and thermal application note.

**Note 4:** Test assumes current derating verses temperature.

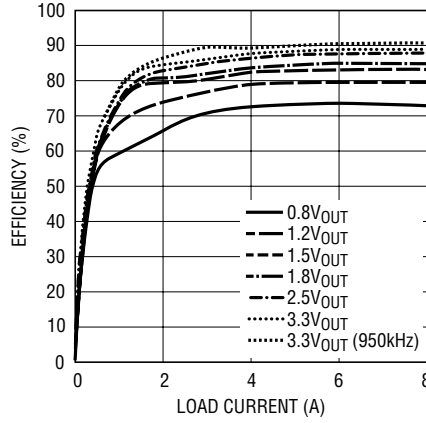
## TYPICAL PERFORMANCE CHARACTERISTICS (See Figure 22 for all curves)

**Efficiency vs Load Current with 5V<sub>IN</sub> (FCB = 0)**



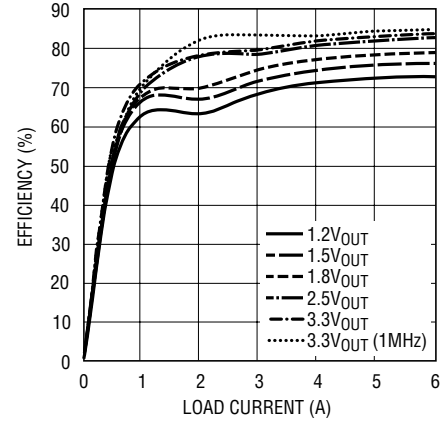
4602HV G01

**Efficiency vs Load Current with 12V<sub>IN</sub> (FCB = 0)**



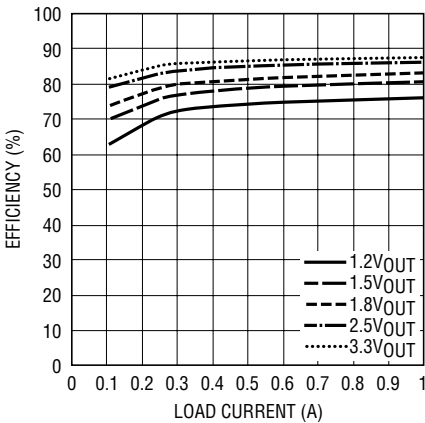
4602HV G02

**Efficiency vs Load Current with 24V<sub>IN</sub> (FCB = 0)**



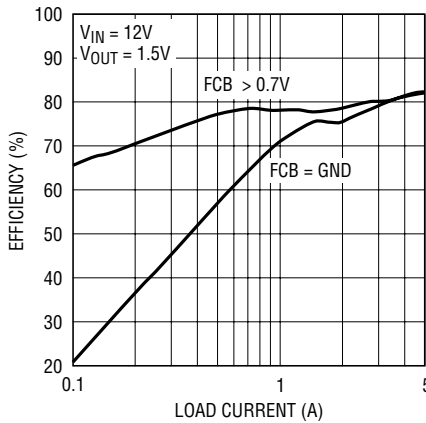
4602HV G03

**Light Load Efficiency vs Load Current with 12V<sub>IN</sub> (FCB > 0.7V, <5V)**



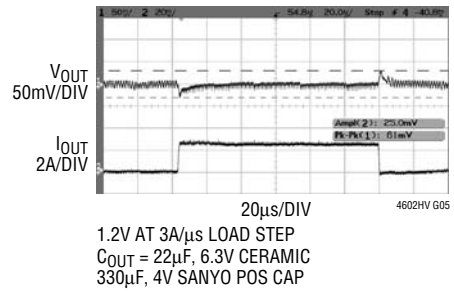
4602HV G15

**Efficiency vs Load Current with Different FCB Settings**



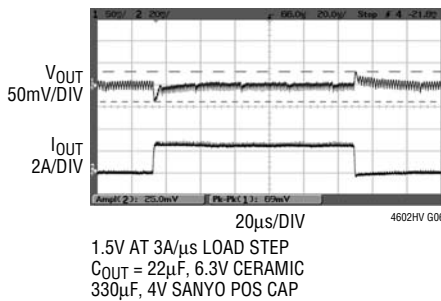
4602HV G04

**1.2V Transient Response**



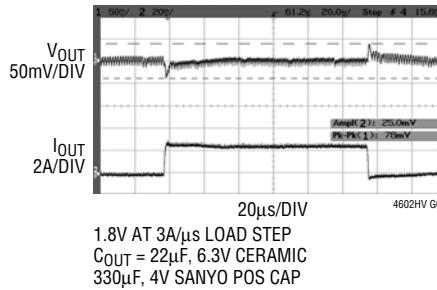
4602HV G05

**1.5V Transient Response**



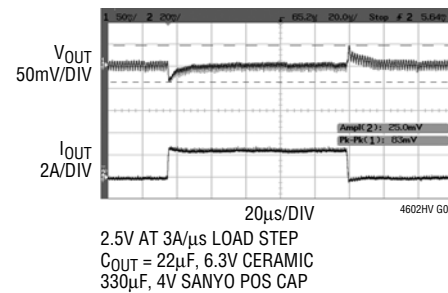
4602HV G06

**1.8V Transient Response**



4602HV G07

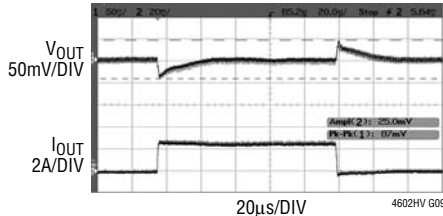
**2.5V Transient Response**



4602HV G08

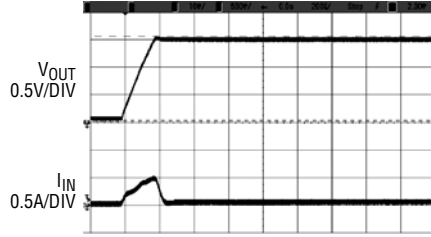
**TYPICAL PERFORMANCE CHARACTERISTICS** (See Figure 22 for all curves)

**3.3V Transient Response**



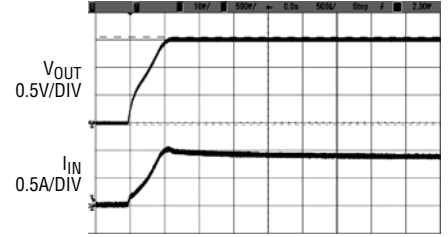
3.3V AT 3A/ $\mu$ s LOAD STEP  
 $C_{OUT} = 22\mu$ F, 6.3V CERAMIC  
 $330\mu$ F, 4V SANYO POS CAP

**Start-Up,  $I_{OUT} = 0A$**



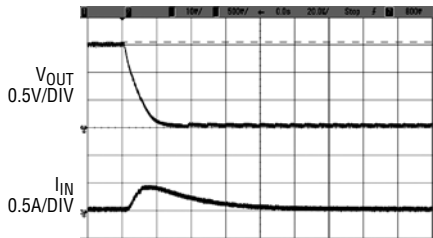
$V_{IN} = 12V$   
 $V_{OUT} = 1.5V$   
 $C_{OUT} = 1 \times 22\mu$ F, 6.3V X5R  
 $330\mu$ F, 4V SANYO POS CAP  
 NO EXTERNAL SOFT-START CAPACITOR

**Start-Up,  $I_{OUT} = 6A$   
 (Resistive Load)**



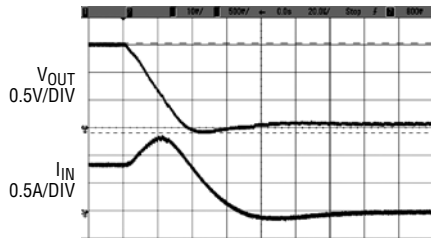
$V_{IN} = 12V$   
 $V_{OUT} = 1.5V$   
 $C_{OUT} = 1 \times 22\mu$ F, 6.3V X5R  
 $330\mu$ F, 4V SANYO POS CAP  
 NO EXTERNAL SOFT-START CAPACITOR

**Short-Circuit Protection,  
 $I_{OUT} = 0A$**



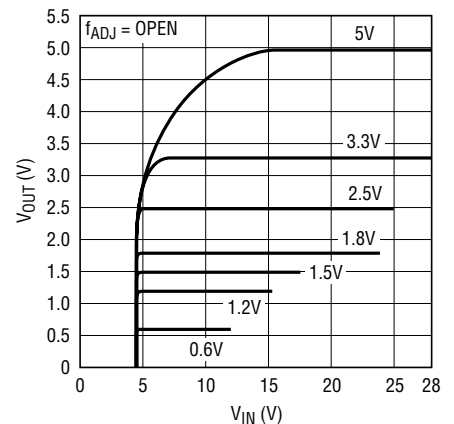
$V_{IN} = 12V$   
 $V_{OUT} = 1.5V$   
 $C_{OUT} = 1 \times 22\mu$ F, 6.3V X5R  
 $330\mu$ F, 4V SANYO POS CAP  
 NO EXTERNAL SOFT-START CAPACITOR

**Short-Circuit Protection,  
 $I_{OUT} = 6A$**



$V_{IN} = 12V$   
 $V_{OUT} = 1.5V$   
 $C_{OUT} = 1 \times 22\mu$ F, 6.3V X5R  
 $330\mu$ F, 4V SANYO POS CAP  
 NO EXTERNAL SOFT-START CAPACITOR

**$V_{IN}$  to  $V_{OUT}$  Stepdown Ratio**



SEE FREQUENCY ADJUSTMENT DISCUSSION  
 FOR  $12V_{IN}$  TO  $5V_{OUT}$  AND  $5V_{IN}$  TO  $3.3V_{OUT}$   
 CONVERSION

4602HV G14

## PIN FUNCTIONS (See Package Description for Pin Assignment)

**$V_{IN}$  (Bank 1):** Power Input Pins. Apply input voltage between these pins and PGND pins. Recommend placing input decoupling capacitance directly between  $V_{IN}$  pins and PGND pins.

**$f_{ADJ}$  (Pin A15):** A 110k resistor from  $V_{IN}$  to this pin sets the one-shot timer current, thereby setting the switching frequency. The LTM4602HV switching frequency is typically 850kHz. An external resistor to ground can be selected to reduce the one-shot timer current, thus lower the switching frequency to accommodate a higher duty cycle step down requirement. See the applications section.

**$SV_{IN}$  (Pin A17):** Supply Pin for Internal PWM Controller. Leave this pin open or add additional decoupling capacitance.

**$EXTV_{CC}$  (Pin A19):** External 5V supply pin for controller. If left open or grounded, the internal 5V linear regulator will power the controller and MOSFET drivers. For high input voltage applications, connecting this pin to an external 5V will reduce the power loss in the power module. The  $EXTV_{CC}$  voltage should never be higher than  $V_{IN}$ .

**$V_{OSET}$  (Pin A21):** The Negative Input of The Error Amplifier. Internally, this pin is connected to  $V_{OUT}$  with a 100k precision resistor. Different output voltages can be programmed with additional resistors between the  $V_{OSET}$  and SGND pins.

**COMP (Pin B23):** Current Control Threshold and Error Amplifier Compensation Point. The current comparator threshold increases with this control voltage. The voltage ranges from 0V to 2.4V with 0.8V corresponding to zero sense voltage (zero current).

**SGND (Pin D23):** Signal Ground Pin. All small-signal components should connect to this ground, which in turn connects to PGND at one point.

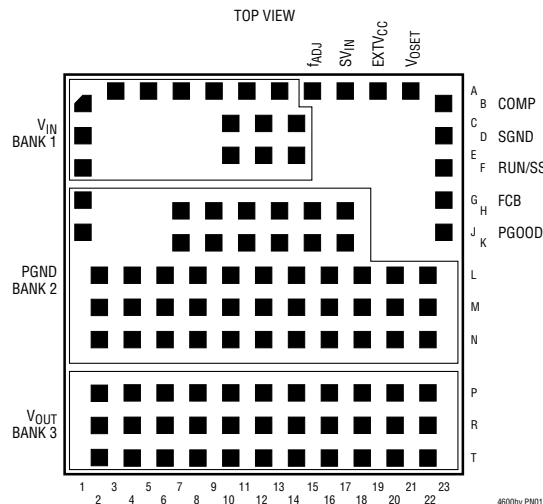
**RUN/SS (Pin F23):** Run and Soft-Start Control. Forcing this pin below 0.8V will shut down the power supply. Inside the power module, there is a 1000pF capacitor which provides approximately 0.7ms soft-start time with 200 $\mu$ F output capacitance. Additional soft-start time can be achieved by adding additional capacitance between the RUN/SS and SGND pins. The internal short-circuit lathoff can be disabled by adding a resistor between this pin and the  $V_{IN}$  pin. This resistor must supply a minimum 5 $\mu$ A pull up current.

**FCB (Pin G23):** Forced Continuous Input. Grounding this pin enables forced continuous mode operation regardless of load conditions. Tying this pin above 0.63V enables discontinuous conduction mode to achieve high efficiency operation at light loads. There is an internal 10k resistor between the FCB and SGND pins.

**PGOOD (Pin J23):** Output Voltage Power Good Indicator. When the output voltage is within 10% of the nominal voltage, the PGOOD is open drain output. Otherwise, this pin is pulled to ground.

**PGND (Bank 2):** Power ground pins for both input and output returns.

**$V_{OUT}$  (Bank 3):** Power Output Pins. Apply output load between these pins and PGND pins. Recommend placing High Frequency output decoupling capacitance directly between these pins and PGND pins.



## SIMPLIFIED BLOCK DIAGRAM

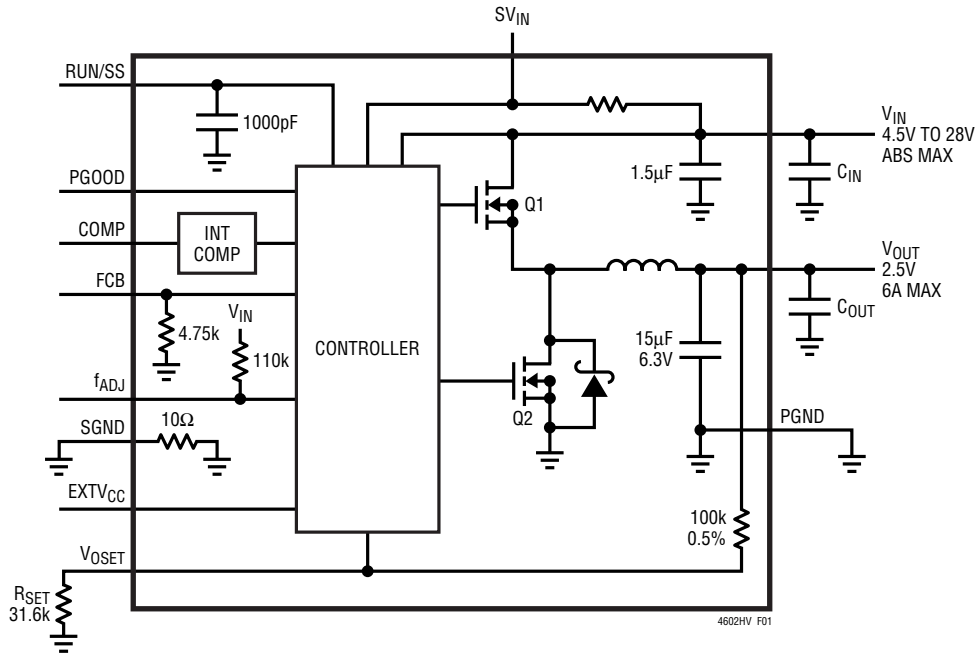


Figure 1. Simplified LTM4602HV Block Diagram

## DECOUPLING REQUIREMENTS $T_A = 25^\circ\text{C}$ , $V_{IN} = 12\text{V}$ . Use Figure 1 configuration.

| SYMBOL    | PARAMETER   | CONDITIONS  | MIN | TYP | MAX | UNITS         |
|-----------|---|---|-----|-----|-----|---------------|
| $C_{IN}$  | External Input Capacitor Requirement ( $V_{IN} = 4.5\text{V to } 28\text{V}$ , $V_{OUT} = 2.5\text{V}$ )  | $I_{OUT} = 6\text{A}$ , 2x 10 $\mu\text{F}$ 35V Ceramic Taiyo Yuden GDK316BJ106ML | 20  |     |     | $\mu\text{F}$ |
| $C_{OUT}$ | External Output Capacitor Requirement ( $V_{IN} = 4.5\text{V to } 28\text{V}$ , $V_{OUT} = 2.5\text{V}$ ) | $I_{OUT} = 6\text{A}$ , Refer to Table 2 in the Applications Information Section  | 100 | 200 |     | $\mu\text{F}$ |



## OPERATION

### μModule Description

The LTM4602HV is a standalone non-isolated synchronous switching DC/DC power supply. It can deliver up to 6A of DC output current with only bulk external input and output capacitors. This module provides a precisely regulated output voltage programmable via one external resistor from  $0.6V_{DC}$  to  $5.0V_{DC}$ . The input voltage range is 4.5V to 28V. A simplified block diagram is shown in Figure 1 and the typical application schematic is shown in Figure 21.

The LTM4602HV contains an integrated LTC constant on-time current-mode regulator, ultra-low  $R_{DS(ON)}$  FETs with fast switching speed and integrated Schottky diode. The typical switching frequency is 800kHz at full load. With current mode control and internal feedback loop compensation, the LTM4602HV module has sufficient stability margins and good transient performance under a wide range of operating conditions and with a wide range of output capacitors, even all ceramic output capacitors (X5R or X7R).

Current mode control provides cycle-by-cycle fast current limit. In addition, foldback current limiting is provided in an over-current condition while  $V_{FB}$  drops. Also, the LTM4602HV has defeatable short circuit latch off. Internal overvoltage and undervoltage comparators pull the open-drain PGOOD output low if the output feedback voltage exits a  $\pm 10\%$  window around the regulation point. Furthermore,

in an overvoltage condition, internal top FET Q1 is turned off and bottom FET Q2 is turned on and held on until the overvoltage condition clears.

Pulling the RUN/SS pin low forces the controller into its shutdown state, turning off both Q1 and Q2. Releasing the pin allows an internal  $1.2\mu A$  current source to charge up the softstart capacitor. When this voltage reaches 1.5V, the controller turns on and begins switching.

At low load current the module works in continuous current mode by default to achieve minimum output voltage ripple. It can be programmed to operate in discontinuous current mode for improved light load efficiency when the FCB pin is pulled up above 0.8V and no higher than 6V. The FCB pin has a 10k resistor to ground, so a resistor to  $V_{IN}$  can set the voltage on the FCB pin.

When  $EXTV_{CC}$  pin is grounded or open, an integrated 5V linear regulator powers the controller and MOSFET gate drivers. If a minimum 4.7V external bias supply is applied on the  $EXTV_{CC}$  pin, the internal regulator is turned off, and an internal switch connects  $EXTV_{CC}$  to the gate driver voltage. This eliminates the linear regulator power loss with high input voltage, reducing the thermal stress on the controller. The maximum voltage on  $EXTV_{CC}$  pin is 6V. The  $EXTV_{CC}$  voltage should never be higher than the  $V_{IN}$  voltage. Also  $EXTV_{CC}$  must be sequenced after  $V_{IN}$ . Recommended for 24V operation to lower temperature in the μModule.



## APPLICATIONS INFORMATION

The typical LTM4602HV application circuit is shown in Figure 20. External component selection is primarily determined by the maximum load current and output voltage.

### Output Voltage Programming and Margining

The PWM controller of the LTM4602HV has an internal  $0.6V \pm 1\%$  reference voltage. As shown in the block diagram, a  $100k/0.5\%$  internal feedback resistor connects  $V_{OUT}$  and FB pins. Adding a resistor  $R_{SET}$  from  $V_{OSET}$  pin to SGND pin programs the output voltage:

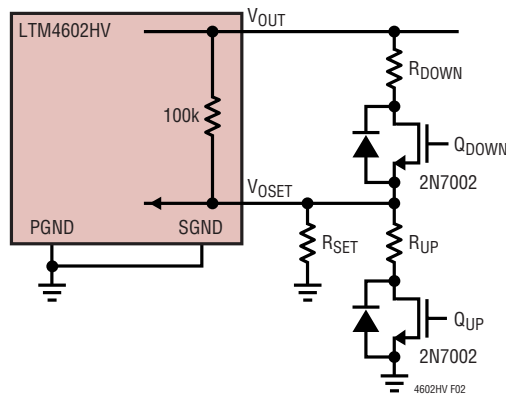
$$V_O = 0.6V \cdot \frac{100k + R_{SET}}{R_{SET}}$$

Table 1 shows the standard values of 1%  $R_{SET}$  resistor for typical output voltages:

**Table 1**

| $R_{SET}$<br>(k $\Omega$ ) | Open | 100 | 66.5 | 49.9 | 43.2 | 31.6 | 22.1 | 13.7 |
|----------------------------|------|-----|------|------|------|------|------|------|
| $V_O$<br>(V)               | 0.6  | 1.2 | 1.5  | 1.8  | 2    | 2.5  | 3.3  | 5    |

Voltage margining is the dynamic adjustment of the output voltage to its worst case operating range in production testing to stress the load circuitry, verify control/protection functionality of the board and improve the system reliability. Figure 2 shows how to implement margining function with the LTM4602HV. In addition to the feedback resistor  $R_{SET}$ , several external components are added. Turn off both transistor  $Q_{UP}$  and  $Q_{DOWN}$  to disable the margining. When  $Q_{UP}$  is on and  $Q_{DOWN}$  is off, the output



**Figure 2**

voltage is margined up. The output voltage is margined down when  $Q_{DOWN}$  is on and  $Q_{UP}$  is off. If the output voltage  $V_O$  needs to be margined up/down by  $\pm M\%$ , the resistor values of  $R_{UP}$  and  $R_{DOWN}$  can be calculated from the following equations:

$$\frac{(R_{SET} \parallel R_{UP}) \cdot V_O \cdot (1 + M\%)}{(R_{SET} \parallel R_{UP}) + 100k\Omega} = 0.6V$$

$$\frac{R_{SET} \cdot V_O \cdot (1 - M\%)}{R_{SET} + (100k\Omega \parallel R_{DOWN})} = 0.6V$$

### Input Capacitors

The LTM4602HV  $\mu$ Module should be connected to a low ac-impedance DC source. High frequency, low ESR input capacitors are required to be placed adjacent to the module. In Figure 20, the bulk input capacitor  $C_{IN}$  is selected for its ability to handle the large RMS current into the converter. For a buck converter, the switching duty-cycle can be estimated as:

$$D = \frac{V_O}{V_{IN}}$$

Without considering the inductor current ripple, the RMS current of the input capacitor can be estimated as:

$$I_{CIN(RMS)} = \frac{I_{O(MAX)}}{\eta\%} \cdot \sqrt{D \cdot (1 - D)}$$

In the above equation,  $\eta\%$  is the estimated efficiency of the power module.  $C_1$  can be a switcher-rated electrolytic aluminum capacitor, OS-CON capacitor or high volume ceramic capacitors. Note the capacitor ripple current ratings are often based on only 2000 hours of life. This makes it advisable to properly derate the input capacitor, or choose a capacitor rated at a higher temperature than required. Always contact the capacitor manufacturer for derating requirements.

In Figure 16, the input capacitors are used as high frequency input decoupling capacitors. In a typical 6A output application, 1-2 pieces of very low ESR X5R or X7R,  $10\mu F$  ceramic capacitors are recommended. This decoupling capacitor should be placed directly adjacent the module input pins

## APPLICATIONS INFORMATION

in the PCB layout to minimize the trace inductance and high frequency AC noise.

### Output Capacitors

The LTM4602HV is designed for low output voltage ripple. The bulk output capacitor  $C_{OUT}$  is chosen with low enough effective series resistance (ESR) to meet the output voltage ripple and transient requirements.  $C_{OUT}$  can be low ESR tantalum capacitor, low ESR polymer capacitor or ceramic capacitor (X5R or X7R). The typical capacitance is 200 $\mu$ F if all ceramic output capacitors are used. The internally optimized loop compensation provides sufficient stability margin for all ceramic capacitors applications. Additional output filtering may be required by the system designer, if further reduction of output ripple or dynamic transient spike is required. Refer to Table 2 for an output capacitance matrix for each output voltage Droop, peak to peak deviation and recovery time during a 3A/ $\mu$ s transient with a specific output capacitance.

### Fault Conditions: Current Limit and Over current Foldback

The LTM4602HV has a current mode controller, which inherently limits the cycle-by-cycle inductor current not only in steady state operation, but also in transient.

To further limit current in the event of an over load condition, the LTM4602HV provides foldback current limiting. If the output voltage falls by more than 50%, then the maximum output current is progressively lowered to about one sixth of its full current limit value.

### Soft-Start and Latchoff with the RUN/SS pin

The RUN/SS pin provides a means to shut down the LTM4602HV as well as a timer for soft-start and over-current latchoff. Pulling the RUN/SS pin below 0.8V puts the LTM4602HV into a low quiescent current shutdown ( $I_Q \leq 75\mu$ A). Releasing the pin allows an internal 1.2 $\mu$ A current source to charge up the timing capacitor  $C_{SS}$ . Inside LTM4602HV, there is an internal 1000pF capacitor from RUN/SS pin to ground. If RUN/SS pin has an external capacitor  $C_{SS\_EXT}$  to ground, the delay before starting is about:

$$t_{DELAY} = \frac{1.5V}{1.2\mu A} \cdot (C_{SS\_EXT} + 1000pF)$$

When the voltage on RUN/SS pin reaches 1.5V, the LTM4602HV internal switches are operating with a clamping of the maximum output inductor current limited by the RUN/SS pin total soft-start capacitance. As the RUN/SS pin voltage rises to 3V, the soft-start clamping of the inductor current is released.

### $V_{IN}$ to $V_{OUT}$ Stepdown Ratios

There are restrictions in the maximum  $V_{IN}$  to  $V_{OUT}$  step down ratio that can be achieved for a given input voltage. These constraints are shown in the Typical Performance Characteristics curves labeled “ $V_{IN}$  to  $V_{OUT}$  Stepdown Ratio”. Note that additional thermal de-rating may apply. See the Thermal Considerations and Output Current De-Rating sections of this data sheet.

## APPLICATIONS INFORMATION

**Table 2. Output Voltage Response Versus Component Matrix (Refer to Figure 17), 0A to 3A Step (Typical Values)**

### TYPICAL MEASURED VALUES

| C <sub>OUT1</sub> VENDORS | PART NUMBER                     | C <sub>OUT2</sub> VENDORS | PART NUMBER               |
|---------------------------|---------------------------------|---------------------------|---------------------------|
| TDK                       | C4532X5R0J107MZ (100UF, 6.3V)   | SANYO POS CAP             | 6TPE330MIL (330μF, 6.3V)  |
| TAIYO YUDEN               | JMK432BJ107MU-T (100μF, 6.3V)   | SANYO POS CAP             | 2R5TPE470M9 (470μF, 2.5V) |
| TAIYO YUDEN               | JMK316BJ226ML-T501 (22μF, 6.3V) | SANYO POS CAP             | 4TPE470MCL (470μF, 4V)    |

| V <sub>OUT</sub> (V) | C <sub>IN</sub> (CERAMIC) | C <sub>IN</sub> (BULK) | C <sub>OUT1</sub> (CERAMIC) | C <sub>OUT2</sub> (BULK) | C <sub>COMP</sub> | C3    | V <sub>IN</sub> (V) | DROOP (mV) | PEAK TO PEAK (mV) | RECOVERY TIME (μs) | LOAD STEP (A/μs) |
|----------------------|---------------------------|------------------------|-----------------------------|--------------------------|-------------------|-------|---------------------|------------|-------------------|--------------------|------------------|
| 1.2                  | 2 × 10μF 25V              | 150μF 35V              | 3 × 22μF 6.3V               | 470μF 4V                 | NONE              | 100pF | 5                   | 30         | 60                | 25                 | 3                |
| 1.2                  | 2 × 10μF 25V              | 150μF 35V              | 1 × 100μF 6.3V              | 470μF 2.5V               | NONE              | 100pF | 5                   | 30         | 60                | 20                 | 3                |
| 1.2                  | 2 × 10μF 25V              | 150μF 35V              | 2 × 100μF 6.3V              | 330μF 6.3V               | NONE              | 100pF | 5                   | 25         | 54                | 20                 | 3                |
| 1.2                  | 2 × 10μF 25V              | 150μF 35V              | 4 × 100μF 6.3V              | NONE                     | NONE              | 100pF | 5                   | 25         | 55                | 20                 | 3                |
| 1.2                  | 2 × 10μF 25V              | 150μF 35V              | 3 × 22μF 6.3V               | 470μF 4V                 | NONE              | 100pF | 12                  | 30         | 60                | 25                 | 3                |
| 1.2                  | 2 × 10μF 25V              | 150μF 35V              | 1 × 100μF 6.3V              | 470μF 2.5V               | NONE              | 100pF | 12                  | 25         | 54                | 20                 | 3                |
| 1.2                  | 2 × 10μF 25V              | 150μF 35V              | 2 × 100μF 6.3V              | 330μF 6.3V               | NONE              | 100pF | 12                  | 25         | 56                | 20                 | 3                |
| 1.2                  | 2 × 10μF 25V              | 150μF 35V              | 4 × 100μF 6.3V              | NONE                     | NONE              | 100pF | 12                  | 25         | 55                | 20                 | 3                |
| 1.5                  | 2 × 10μF 25V              | 150μF 35V              | 3 × 22μF 6.3V               | 470μF 4V                 | NONE              | 100pF | 5                   | 25         | 50                | 25                 | 3                |
| 1.5                  | 2 × 10μF 25V              | 150μF 35V              | 1 × 100μF 6.3V              | 470μF 2.5V               | NONE              | 100pF | 5                   | 25         | 54                | 20                 | 3                |
| 1.5                  | 2 × 10μF 25V              | 150μF 35V              | 2 × 100μF 6.3V              | 330μF 6.3V               | NONE              | 100pF | 5                   | 25         | 59                | 20                 | 3                |
| 1.5                  | 2 × 10μF 25V              | 150μF 35V              | 4 × 100μF 6.3V              | NONE                     | NONE              | 100pF | 5                   | 26         | 59                | 20                 | 3                |
| 1.5                  | 2 × 10μF 25V              | 150μF 35V              | 3 × 22μF 6.3V               | 470μF 4V                 | NONE              | 100pF | 12                  | 25         | 55                | 25                 | 3                |
| 1.5                  | 2 × 10μF 25V              | 150μF 35V              | 1 × 100μF 6.3V              | 470μF 2.5V               | NONE              | 100pF | 12                  | 25         | 54                | 20                 | 3                |
| 1.5                  | 2 × 10μF 25V              | 150μF 35V              | 2 × 100μF 6.3V              | 330μF 6.3V               | NONE              | 100pF | 12                  | 28         | 59                | 20                 | 3                |
| 1.5                  | 2 × 10μF 25V              | 150μF 35V              | 4 × 100μF 6.3V              | NONE                     | NONE              | 100pF | 12                  | 26         | 59                | 20                 | 3                |
| 1.8                  | 2 × 10μF 25V              | 150μF 35V              | 3 × 22μF 6.3V               | 470μF 4V                 | NONE              | 100pF | 5                   | 25         | 54                | 30                 | 3                |
| 1.8                  | 2 × 10μF 25V              | 150μF 35V              | 1 × 100μF 6.3V              | 470μF 2.5V               | NONE              | 100pF | 5                   | 25         | 50                | 20                 | 3                |
| 1.8                  | 2 × 10μF 25V              | 150μF 35V              | 2 × 100μF 6.3V              | 330μF 6.3V               | NONE              | 100pF | 5                   | 25         | 50                | 20                 | 3                |
| 1.8                  | 2 × 10μF 25V              | 150μF 35V              | 4 × 100μF 6.3V              | NONE                     | NONE              | 100pF | 5                   | 29         | 60                | 20                 | 3                |
| 1.8                  | 2 × 10μF 25V              | 150μF 35V              | 3 × 22μF 6.3V               | 470μF 4V                 | NONE              | 100pF | 12                  | 25         | 50                | 30                 | 3                |
| 1.8                  | 2 × 10μF 25V              | 150μF 35V              | 1 × 100μF 6.3V              | 470μF 2.5V               | NONE              | 100pF | 12                  | 25         | 50                | 20                 | 3                |
| 1.8                  | 2 × 10μF 25V              | 150μF 35V              | 2 × 100μF 6.3V              | 330μF 6.3V               | NONE              | 100pF | 12                  | 25         | 50                | 20                 | 3                |
| 1.8                  | 2 × 10μF 25V              | 150μF 35V              | 4 × 100μF 6.3V              | NONE                     | NONE              | 100pF | 12                  | 29         | 60                | 20                 | 3                |
| 2.5                  | 2 × 10μF 25V              | 150μF 35V              | 1 × 100μF 6.3V              | 470μF 4V                 | NONE              | 220pF | 5                   | 25         | 50                | 30                 | 3                |
| 2.5                  | 2 × 10μF 25V              | 150μF 35V              | 2 × 100μF 6.3V              | 330μF 6.3V               | NONE              | 220pF | 5                   | 25         | 50                | 30                 | 3                |
| 2.5                  | 2 × 10μF 25V              | 150μF 35V              | 3 × 22μF 6.3V               | 470μF 4V                 | NONE              | 220pF | 5                   | 25         | 50                | 30                 | 3                |
| 2.5                  | 2 × 10μF 25V              | 150μF 35V              | 4 × 100μF 6.3V              | NONE                     | NONE              | 220pF | 5                   | 25         | 50                | 25                 | 3                |
| 2.5                  | 2 × 10μF 25V              | 150μF 35V              | 1 × 100μF 6.3V              | 470μF 4V                 | NONE              | 220pF | 12                  | 25         | 50                | 30                 | 3                |
| 2.5                  | 2 × 10μF 25V              | 150μF 35V              | 3 × 22μF 6.3V               | 470μF 4V                 | NONE              | 220pF | 12                  | 25         | 50                | 30                 | 3                |
| 2.5                  | 2 × 10μF 25V              | 150μF 35V              | 2 × 100μF 6.3V              | 330μF 6.3V               | NONE              | 220pF | 12                  | 25         | 50                | 30                 | 3                |
| 2.5                  | 2 × 10μF 25V              | 150μF 35V              | 4 × 100μF 6.3V              | NONE                     | NONE              | 220pF | 12                  | 27         | 54                | 25                 | 3                |
| 3.3                  | 2 × 10μF 25V              | 150μF 35V              | 2 × 100μF 6.3V              | 330μF 6.3V               | NONE              | 220pF | 7                   | 32         | 64                | 30                 | 3                |
| 3.3                  | 2 × 10μF 25V              | 150μF 35V              | 1 × 100μF 6.3V              | 470μF 4V                 | NONE              | 220pF | 7                   | 30         | 60                | 30                 | 3                |
| 3.3                  | 2 × 10μF 25V              | 150μF 35V              | 3 × 22μF 6.3V               | 470μF 4V                 | NONE              | 220pF | 7                   | 30         | 60                | 35                 | 3                |
| 3.3                  | 2 × 10μF 25V              | 150μF 35V              | 4 × 100μF 6.3V              | NONE                     | NONE              | 220pF | 7                   | 32         | 64                | 25                 | 3                |
| 3.3                  | 2 × 10μF 25V              | 150μF 35V              | 1 × 100μF 6.3V              | 470μF 4V                 | NONE              | 220pF | 12                  | 38         | 58                | 30                 | 3                |
| 3.3                  | 2 × 10μF 25V              | 150μF 35V              | 3 × 22μF 6.3V               | 470μF 4V                 | NONE              | 220pF | 12                  | 30         | 60                | 35                 | 3                |
| 3.3                  | 2 × 10μF 25V              | 150μF 35V              | 2 × 100μF 6.3V              | 330μF 6.3V               | NONE              | 220pF | 12                  | 30         | 60                | 30                 | 3                |
| 3.3                  | 2 × 10μF 25V              | 150μF 35V              | 4 × 100μF 6.3V              | NONE                     | NONE              | 220pF | 12                  | 32         | 64                | 25                 | 3                |
| 5                    | 1 × 10μF 25V              | 150μF 35V              | 4 × 100μF 6.3V              | NONE                     | NONE              | 100pF | 15                  | 80         | 160               | 25                 | 3                |
| 5                    | 1 × 10μF 25V              | 150μF 35V              | 4 × 100μF 6.3V              | NONE                     | NONE              | 100pF | 20                  | 80         | 160               | 25                 | 3                |

## APPLICATIONS INFORMATION

After the controller has been started and given adequate time to charge up the output capacitor,  $C_{SS}$  is used as a short-circuit timer. After the RUN/SS pin charges above 4V, if the output voltage falls below 75% of its regulated value, then a short-circuit fault is assumed. A  $1.8\mu\text{A}$  current then begins discharging  $C_{SS}$ . If the fault condition persists until the RUN/SS pin drops to 3.5V, then the controller turns off both power MOSFETs, shutting down the converter permanently. The RUN/SS pin must be actively pulled down to ground in order to restart operation.

The over-current protection timer requires the soft-start timing capacitor  $C_{SS}$  be made large enough to guarantee that the output is in regulation by the time  $C_{SS}$  has reached the 4V threshold. In general, this will depend upon the size of the output capacitance, output voltage and load current characteristic. A minimum external soft-start capacitor can be estimated from:

$$C_{SS\_EXT} + 1000\text{pF} > C_{OUT} \cdot V_{OUT} (10^{-3} [\text{F} / \text{Vs}])$$

Generally  $0.1\mu\text{F}$  is more than sufficient.

Since the load current is already limited by the current mode control and current foldback circuitry during a short circuit, overcurrent latchoff operation is NOT always needed or desired, especially if the output has large capacitance or the load draws high current during start-up. The latchoff feature can be overridden by a pull-up current greater than  $5\mu\text{A}$  but less than  $80\mu\text{A}$  to the RUN/SS pin. The additional current prevents the discharge of  $C_{SS}$  during a fault and also shortens the soft-start period. Using a resistor from RUN/SS pin to  $V_{IN}$  is a simple solution to defeat latchoff. Any pull-up network must be able to maintain RUN/SS above

4V maximum latchoff threshold and overcome the  $4\mu\text{A}$  maximum discharge current. Figure 3 shows a conceptual drawing of  $V_{RUN}$  during startup and short circuit.

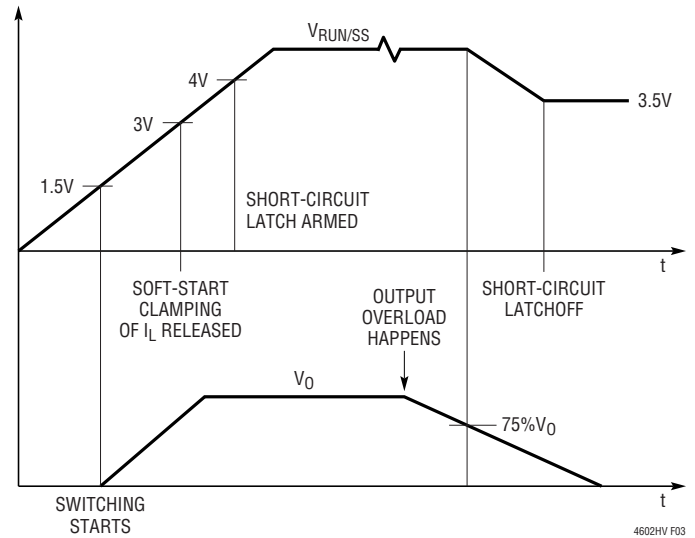


Figure 3. RUN/SS Pin Voltage During Startup and Short-Circuit Protection

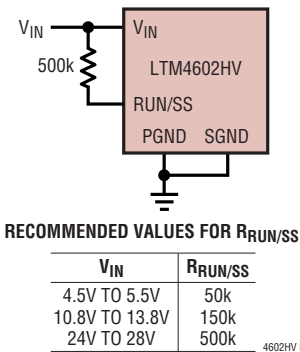


Figure 4. Defeat Short-Circuit Latchoff with a Pull-Up Resistor to  $V_{IN}$

## APPLICATIONS INFORMATION

### Enable

The RUN/SS pin can be driven from logic as shown in Figure 5. This function allows the LTM4602HV to be turned on or off remotely. The  $\overline{\text{ON}}$  signal can also control the sequence of the output voltage.

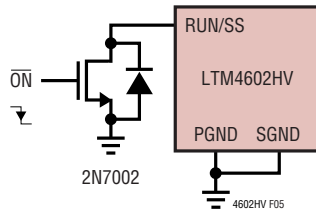


Figure 5. Enable Circuit with External Logic

### Output Voltage Tracking

For the applications that require output voltage tracking, several LTM4602HV modules can be programmed by the power supply tracking controller such as the LTC2923. Figure 6 shows a typical schematic with LTC2923. Coincident, ratiometric and offset tracking for  $V_O$  rising and falling can be implemented with different sets of resistor values. See the LTC2923 data sheet for more details.

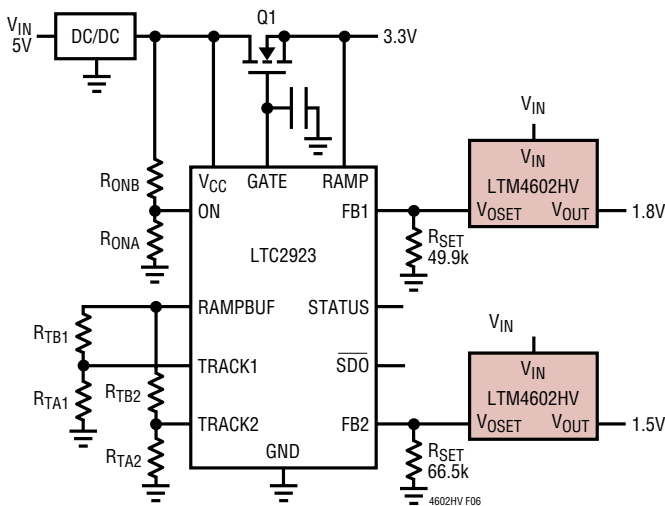


Figure 6. Output Voltage Tracking with the LTC2923 Controller

### EXTV<sub>CC</sub> Connection

An internal low dropout regulator produces an internal 5V supply that powers the control circuitry and FET drivers. Therefore, if the system does not have a 5V power rail, the LTM4602HV can be directly powered by  $V_{IN}$ . The gate driver current through LDO is about 16mA. The internal LDO power dissipation can be calculated as:

$$P_{LDO\_LOSS} = 16\text{mA} \cdot (V_{IN} - 5\text{V})$$

The LTM4602HV also provides an external gate driver voltage pin  $\text{EXTV}_{CC}$ . If there is a 5V rail in the system, it is recommended to connect  $\text{EXTV}_{CC}$  pin to the external 5V rail. Whenever the  $\text{EXTV}_{CC}$  pin is above 4.7V, the internal 5V LDO is shut off and an internal 50mA P-channel switch connects the  $\text{EXTV}_{CC}$  to internal 5V. Internal 5V is supplied from  $\text{EXTV}_{CC}$  until this pin drops below 4.5V. Do not apply more than 6V to the  $\text{EXTV}_{CC}$  pin and ensure that  $\text{EXTV}_{CC} < V_{IN}$ . The following list summarizes the possible connections for  $\text{EXTV}_{CC}$ :

1.  $\text{EXTV}_{CC}$  grounded. Internal 5V LDO is always powered from the internal 5V regulator.
2.  $\text{EXTV}_{CC}$  connected to an external supply. Internal LDO is shut off. A high efficiency supply compatible with the MOSFET gate drive requirements (typically 5V) can improve overall efficiency. With this connection, it is always required that the  $\text{EXTV}_{CC}$  voltage can not be higher than  $V_{IN}$  pin voltage.

### Discontinuous Operation and FCB Pin

The FCB pin determines whether the internal bottom MOSFET remains on when the inductor current reverses. There is an internal 10k pulling down resistor connecting this pin to ground. The default light load operation mode is forced continuous (PWM) current mode. This mode provides minimum output voltage ripple.

## APPLICATIONS INFORMATION

In the application where the light load efficiency is important, tying the FCB pin above 0.6V threshold enables discontinuous operation where the bottom MOSFET turns off when inductor current reverses. Therefore, the conduction loss is minimized and light load efficiency is improved. The penalty is that the controller may skip cycle and the output voltage ripple increases at light load.

### Paralleling Operation with Load Sharing

Two or more LTM4602HV modules can be paralleled to provide higher than 6A output current. Figure 7 shows the necessary interconnection between two paralleled modules. The OPTI-LOOP™ current mode control ensures good current sharing among modules to balance the thermal stress. The new feedback equation for two or more LTM4602HVs in parallel is:

$$V_{OUT} = 0.6V \cdot \frac{100k}{R_{SET}} + R_{SET}$$

where N is the number of LTM4602HVs in parallel.

### Thermal Considerations and Output Current Derating

The power loss curves in Figures 8 and 15 can be used in coordination with the load current derating curves in Figures 9 to 14, and Figures 16 to 19 for calculating an

approximate  $\theta_{JA}$  for the module with various heatsinking methods. Thermal models are derived from several temperature measurements at the bench, and thermal modeling analysis. Application Note 103 provides a detailed explanation of the analysis for the thermal models, and the derating curves. Tables 3 and 4 provide a summary of the equivalent  $\theta_{JA}$  for the noted conditions. These equivalent  $\theta_{JA}$  parameters are correlated to the measure values, and improved with air-flow. The case temperature is maintained at 100°C or below for the derating curves. This allows for 4W maximum power dissipation in the total module with top and bottom heatsinking, and 2W power dissipation through the top of the module with an approximate  $\theta_{JC}$  between 6°C/W to 9°C/W. This equates to a total of 124°C at the junction of the device. The  $\theta_{JA}$  values in Tables 3 and 4 can be used to derive the derating curves for other output voltages.

### Safety Considerations

The LTM4602HV modules do not provide isolation from  $V_{IN}$  to  $V_{OUT}$ . There is no internal fuse. If required, a slow blow fuse with a rating twice the maximum input current should be provided to protect each unit from catastrophic failure.

OPTI-LOOP is a trademark of Linear Technology Corporation.

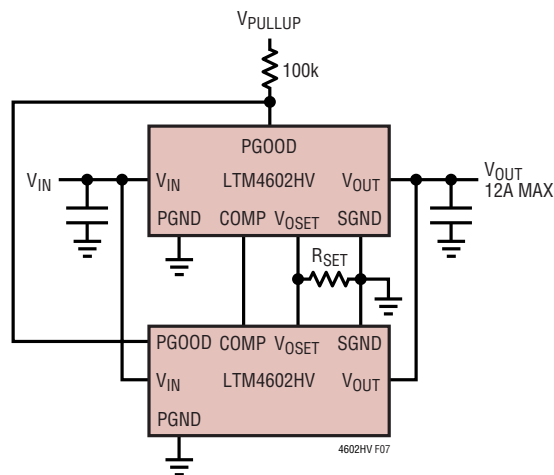
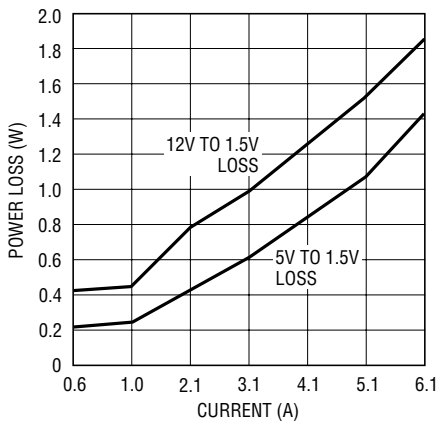


Figure 7. Parallel Two  $\mu$ Modules with Load Sharing

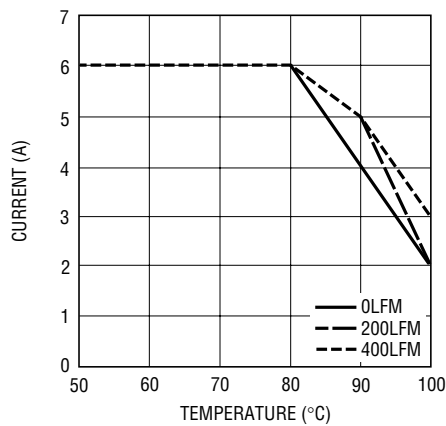


# APPLICATIONS INFORMATION



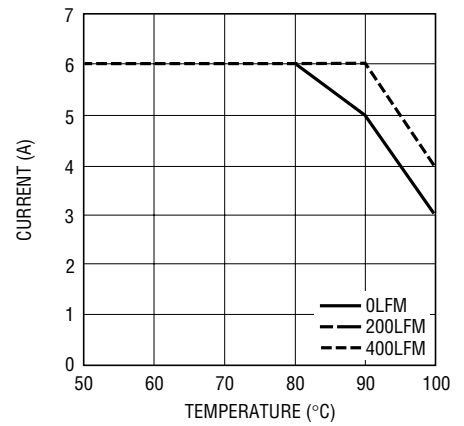
4602HV F08

**Figure 8. 1.5V Power Loss Curves vs Load Current**



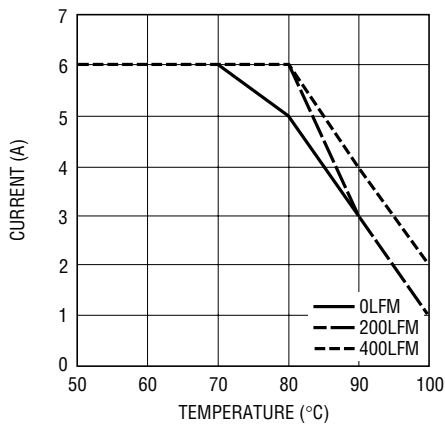
4602HV F09

**Figure 9. 5V to 1.5V, No Heatsink**



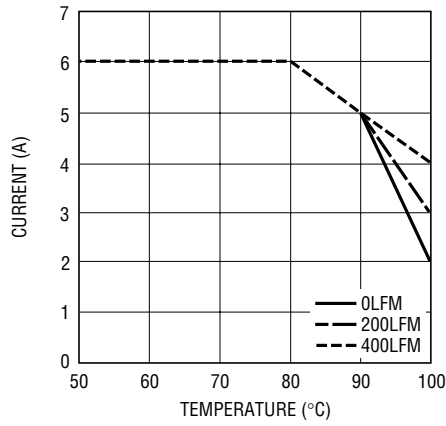
4602HV F10

**Figure 10. 5V to 1.5V, BGA Heatsink**



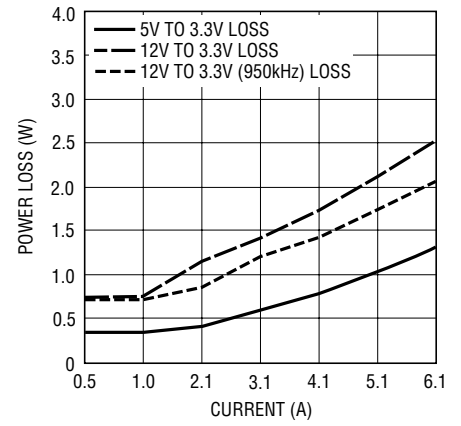
4602HV F11

**Figure 11. 12V to 1.5V, No Heatsink**



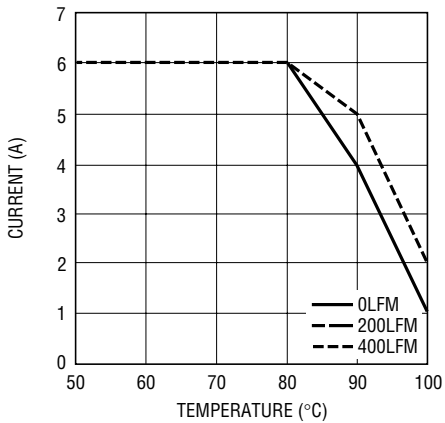
4602HV F09

**Figure 12. 12V to 1.5V, BGA Heatsink**



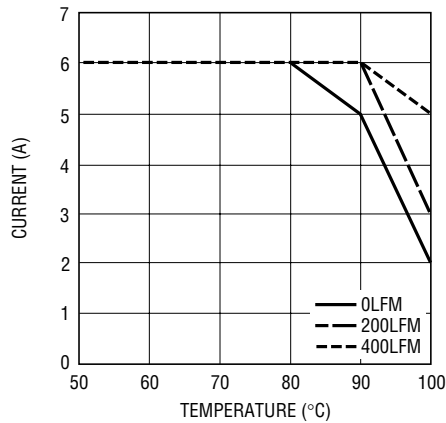
4602HV F13

**Figure 13. 3.3V Power Loss**



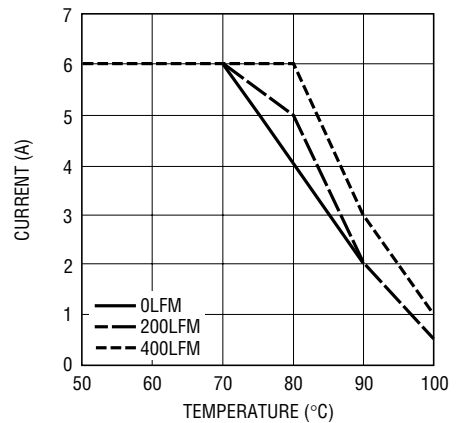
4602HV F14

**Figure 14. 5V to 3.3V, No Heatsink**



4602HV F15

**Figure 15. 5V to 3.3V, BGA Heatsink**



4602HV F16

**Figure 16. 12V to 3.3V (950kHz), No Heatsink**



## APPLICATIONS INFORMATION

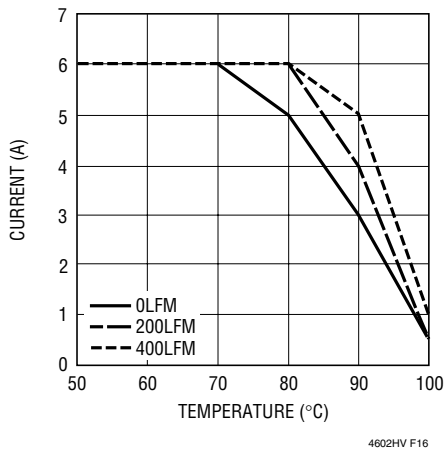


Figure 17. 12V to 3.3V (950kHz), BGA Heatsink

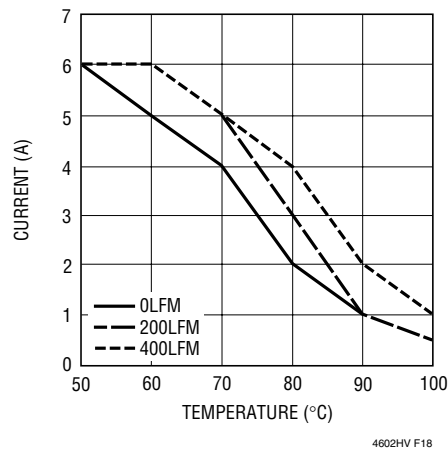


Figure 18. 24V to 3.3V, No Heatsink

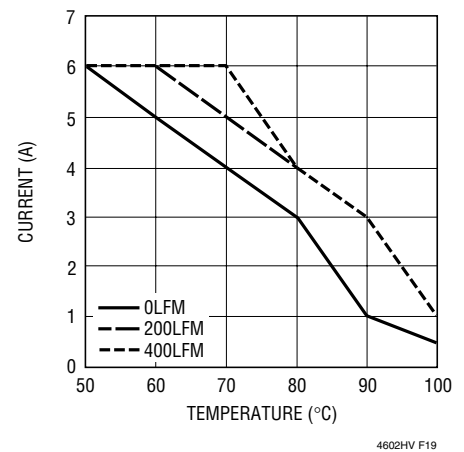


Figure 19. 24V to 3.3V, BGA Heatsink

Table 3. 1.5V Output

| AIR FLOW (LFM) | HEATSINK     | $\theta_{JA}$ (°C/W) |
|----------------|--------------|----------------------|
| 0              | None         | 15.2                 |
| 200            | None         | 14                   |
| 400            | None         | 12                   |
| 0              | BGA Heatsink | 13.9                 |
| 200            | BGA Heatsink | 11.3                 |
| 400            | BGA Heatsink | 10.25                |

Table 4. 3.3V Output

| AIR FLOW (LFM) | HEATSINK     | $\theta_{JA}$ (°C/W) |
|----------------|--------------|----------------------|
| 0              | None         | 15.2                 |
| 200            | None         | 14.6                 |
| 400            | None         | 13.4                 |
| 0              | BGA Heatsink | 13.9                 |
| 200            | BGA Heatsink | 11.1                 |
| 400            | BGA Heatsink | 10.5                 |

### Layout Checklist/Example

The high integration of the LTM4602HV makes the PCB board layout very simple and easy. However, to optimize its electrical and thermal performance, some layout considerations are still necessary.

- Use large PCB copper areas for high current path, including  $V_{IN}$ , PGND and  $V_{OUT}$ . It helps to minimize the PCB conduction loss and thermal stress
- Place high frequency ceramic input and output capacitors next to the  $V_{IN}$ , PGND and  $V_{OUT}$  pins to minimize high frequency noise
- Place a dedicated power ground layer underneath the unit
- To minimize the via conduction loss and reduce module thermal stress, use multiple vias for interconnection between top layer and other power layers

- Do not put via directly on pad
- Use a separated SGND ground copper area for components connected to signal pins. Connect the SGND to PGND underneath the unit

Figure 20 gives a good example of the recommended layout.

### LTM4602 Frequency Adjustment

The LTM4602HV is designed to typically operate at 850kHz across most input and output conditions. The control architecture is constant on time valley mode current control. The  $f_{ADJ}$  pin is typically left open or decoupled with an optional 1000pF capacitor. The switching frequency has been optimized to maintain constant output ripple over the operating conditions. The equations for setting the operating frequency are set around a programmable constant on time. This on time is developed by a programmable

4602hvf

## APPLICATIONS INFORMATION

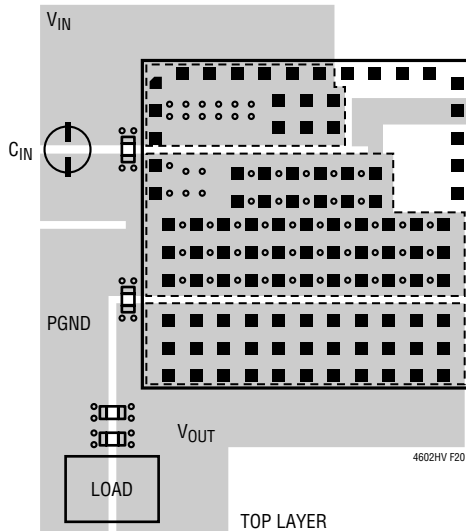


Figure 20. Recommended PCB Layout

current into an on board 10pF capacitor that establishes a ramp that is compared to a voltage threshold that is equal to the output voltage up to a 2.4V clamp. This  $I_{ON}$  current is equal to:  $I_{ON} = (V_{IN} - 0.7V)/110k$ , with the 110k onboard resistor from  $V_{IN}$  to  $f_{ADJ}$ . The on time is equal to  $t_{ON} = (V_{OUT}/I_{ON}) \cdot 10pF$  and  $t_{OFF} = t_s - t_{ON}$ . The frequency is equal to:  $Freq. = DC/t_{ON}$ . The  $I_{ON}$  current is proportional to  $V_{IN}$ , and the regulator duty cycle is inversely proportional to  $V_{IN}$ , therefore the step-down regulator will remain relatively constant frequency as the duty cycle adjustment takes place with lowering  $V_{IN}$ . The on time is proportional to  $V_{OUT}$  up to a 2.4V clamp. This will hold frequency relatively constant with different output voltages up to 2.4V. The regulator switching period is comprised of the on time and off time as depicted in Figure 21. The on time is equal to  $t_{ON} = (V_{OUT}/I_{ON}) \cdot 10pF$  and  $t_{OFF} = t_s - t_{ON}$ . The frequency is equal to:  $Frequency = DC/t_{ON}$ .

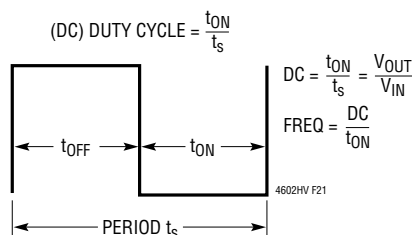


Figure 21

The LTM4602 has a minimum ( $t_{ON}$ ) on time of 100 nanoseconds and a minimum ( $t_{OFF}$ ) off time of 400 nanoseconds. The 2.4V clamp on the ramp threshold as a function of  $V_{OUT}$  will cause the switching frequency to increase by the ratio of  $V_{OUT}/2.4V$  for 3.3V and 5V outputs. This is due to the fact the on time will not increase as  $V_{OUT}$  increases past 2.4V. Therefore, if the nominal switching frequency is 850kHz, then the switching frequency will increase to ~1.2MHz for 3.3V, and ~1.7MHz for 5V outputs due to  $Frequency = (DC/t_{ON})$ . When the switching frequency increases to 1.2MHz, then the time period  $t_s$  is reduced to ~833 nanoseconds and at 1.7MHz the switching period reduces to ~588 nanoseconds. When higher duty cycle conversions like 5V to 3.3V and 12V to 5V need to be accommodated, then the switching frequency can be lowered to alleviate the violation of the 400ns minimum off time. Since the total switching period is  $t = t_{ON} + t_{OFF}$ ,  $t_{OFF}$  will be below the 400ns minimum off time. A resistor from the  $f_{ADJ}$  pin to ground can shunt current away from the on time generator, thus allowing for a longer on time and a lower switching frequency. 12V to 5V and 5V to 3.3V derivations are explained in the data sheet to lower switching frequency and accommodate these step-down conversions.

Equations for setting frequency:  $V_{OUT} = 5V$

$$I_{ON} = (V_{IN} - 0.7V)/110k; \text{ for } 12V \text{ input, } I_{ON} = 103\mu A$$

$$frequency = (I_{ON}/[2.4V \cdot 10pF]) \cdot (DC) = 1.79MHz;$$

$$DC = \text{duty cycle, duty cycle is } (V_{OUT}/V_{IN})$$

$$t = t_{ON} + t_{OFF}, t_{ON} = \text{on-time, } t_{OFF} = \text{off-time of the switching period; } t = 1/\text{frequency}$$

$t_{OFF}$  must be greater than 400ns, or  $t - t_{ON} > 400ns$ .

$$t_{ON} = DC \cdot t$$

1MHz frequency or 1 $\mu s$  period is chosen.

$$t_{ON} = 0.41 \cdot 1\mu s \approx 410ns$$

$$t_{OFF} = 1\mu s - 410ns \approx 590ns$$

$t_{ON}$  and  $t_{OFF}$  are above the minimums with adequate guard band.

## APPLICATIONS INFORMATION

Using the frequency =  $(I_{ON}/[2.4V \cdot 10pF]) \cdot (DC)$ , solve for  $I_{ON} = (1MHz \cdot 2.4V \cdot 10pF) \cdot (1/0.41) \cong 58\mu A$ .  $I_{ON}$  current calculated from 12V input was  $103\mu A$ , so a resistor from  $f_{ADJ}$  to ground =  $(0.7V/15k) = 46\mu A$ .  $103\mu A - 46\mu A = 57\mu A$ , sets the adequate  $I_{ON}$  current for proper frequency range for the higher duty cycle conversion of 12V to 5V. Input voltage range is limited to 8V to 16V. Higher input voltages can be used without the 15k on  $f_{ADJ}$ . The inductor ripple current gets too high above 16V or below 8V.

Equations for setting frequency:  $V_{OUT} = 3.3V$

$$I_{ON} = (V_{IN} - 0.7V)/110k; \text{ for } 5V \text{ input, } I_{ON} = 39\mu A$$

$$\text{frequency} = (I_{ON}/[2.4V \cdot 10pF]) \cdot (DC) = 1.07MHz;$$

DC = duty cycle, duty cycle is  $(V_{OUT}/V_{IN})$

$$t = t_{ON} + t_{OFF}, t_{ON} = \text{on-time, } t_{OFF} = \text{off-time of the switching period; } t = 1/\text{frequency}$$

$t_{OFF}$  must be greater than 400ns, or  $t - t_{ON} > 400ns$ .

$$t_{ON} = DC \cdot t$$

~450kHz frequency or 2.22 $\mu s$  period is chosen. Frequency range is about 450kHz to 650kHz from 4.5V to 7V input.

$$t_{ON} = 0.66 \cdot 2.22\mu s \cong 1.46\mu s$$

$$t_{OFF} = 2.22\mu s - 1.46\mu s \cong 760ns$$

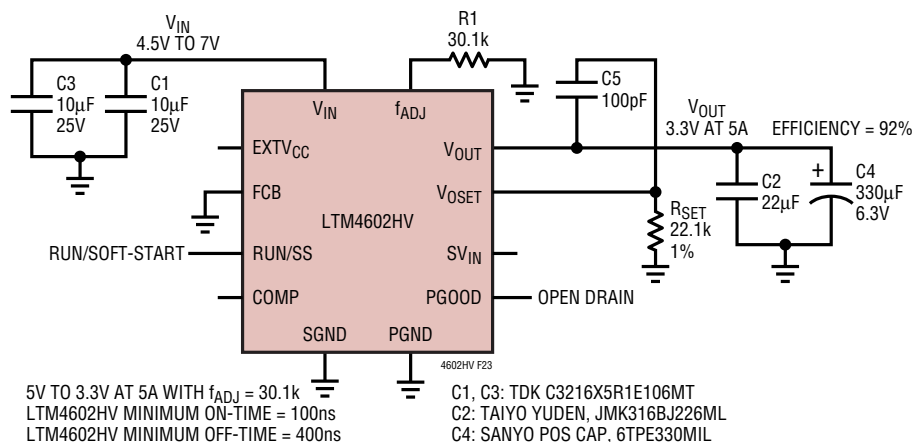
$t_{ON}$  and  $t_{OFF}$  are above the minimums with adequate guard band.

Using the frequency =  $(I_{ON}/[2.4V \cdot 10pF]) \cdot (DC)$ , solve for  $I_{ON} = (450kHz \cdot 2.4V \cdot 10pF) \cdot (1/0.66) \cong 16\mu A$ .  $I_{ON}$  current calculated from 5V input was  $39\mu A$ , so a resistor from  $f_{ADJ}$  to ground =  $(0.7V/30.1k) = 23\mu A$ .  $39\mu A - 23\mu A = 16\mu A$ , sets the adequate  $I_{ON}$  current for proper frequency range for the higher duty cycle conversion of 5V to 3.3V. Input voltage range is limited to 4.5V to 7V. Higher input voltages can be used without the 30.1k on  $f_{ADJ}$ . The inductor ripple current gets too high above 7V, and the 400ns minimum off-time is limited below 4.5V.

Therefore, at 3.3V output, a 30.1k resistor is recommended to add from pin  $f_{ADJ}$  to ground when the input voltage is between 4.5V to 7V. However, this resistor needs to be removed to avoid high inductor ripple current when the input voltage is more than 7V. Similarly, for 5V output, a 15k resistor is recommended to adjust the frequency when the input voltage is between 8V to 16V. This 15k resistor is removed when the input voltage becomes higher than 16V. Please refer to the Typical Performance curve  $V_{IN}$  to  $V_{OUT}$  Step-Down Ratio.

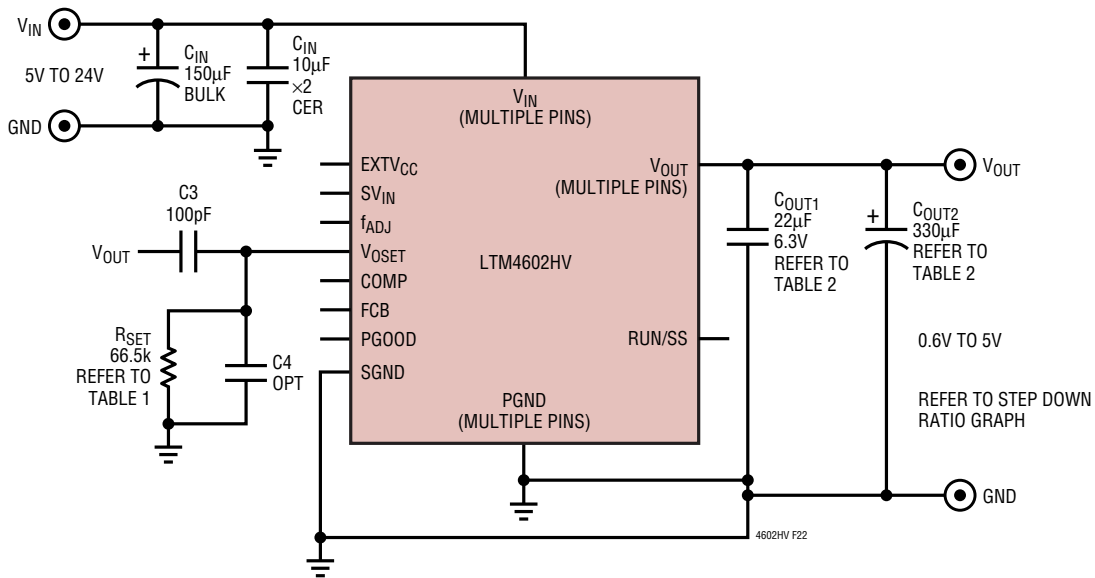
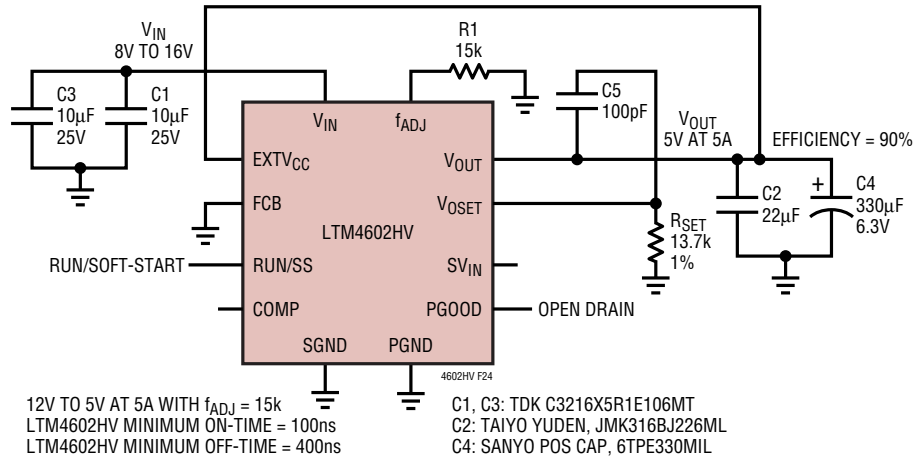
In 12V to 3.3V and 24V to 3.3V applications, if a 35k resistor is added from the  $f_{ADJ}$  pin to ground, then a 2% efficiency gain will be achieved as shown in the 12V and 24V efficiency graphs shown in the Typical Characteristics. This is due to lowering the transition losses in the power MOSFETs by reducing the switching frequency from 1.3mHz to 1mHz.

5V to 3.3V at 5A



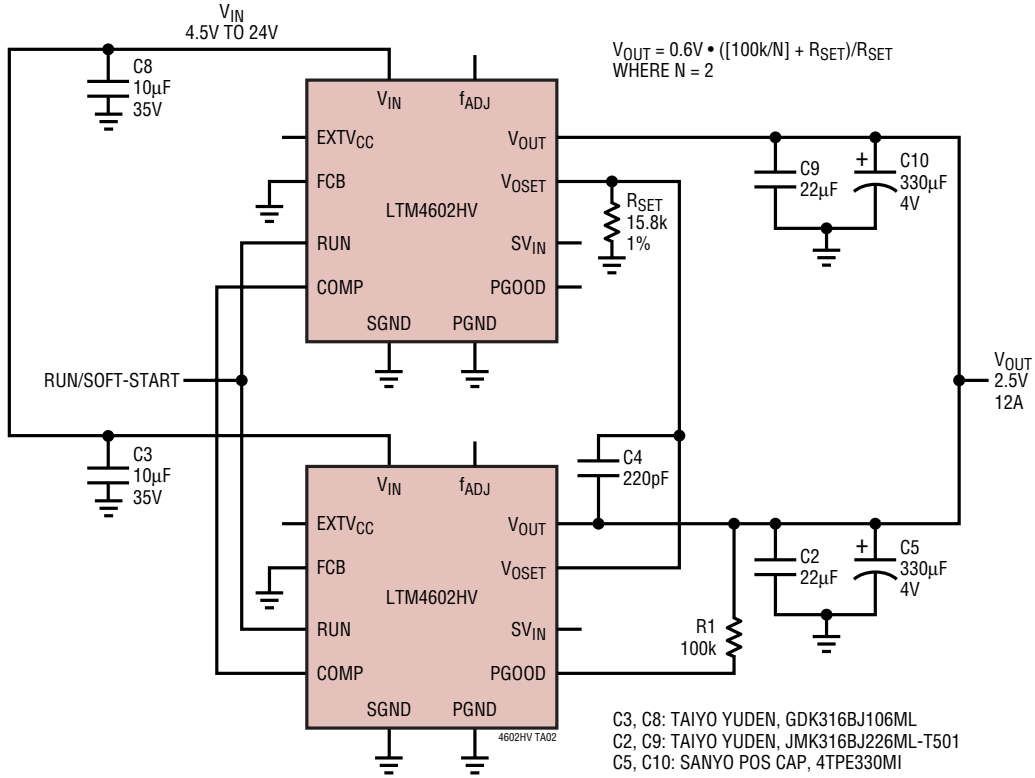
APPLICATIONS INFORMATION

12V to 5V at 5A

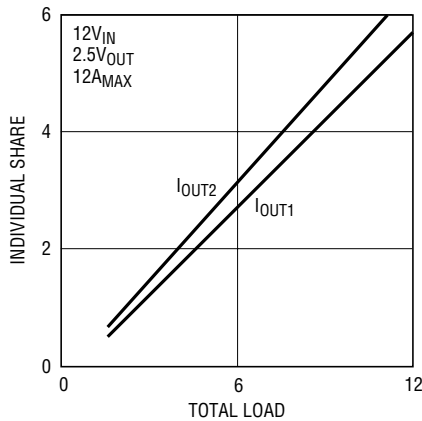


## TYPICAL APPLICATION

### Parallel Operation and Load Sharing

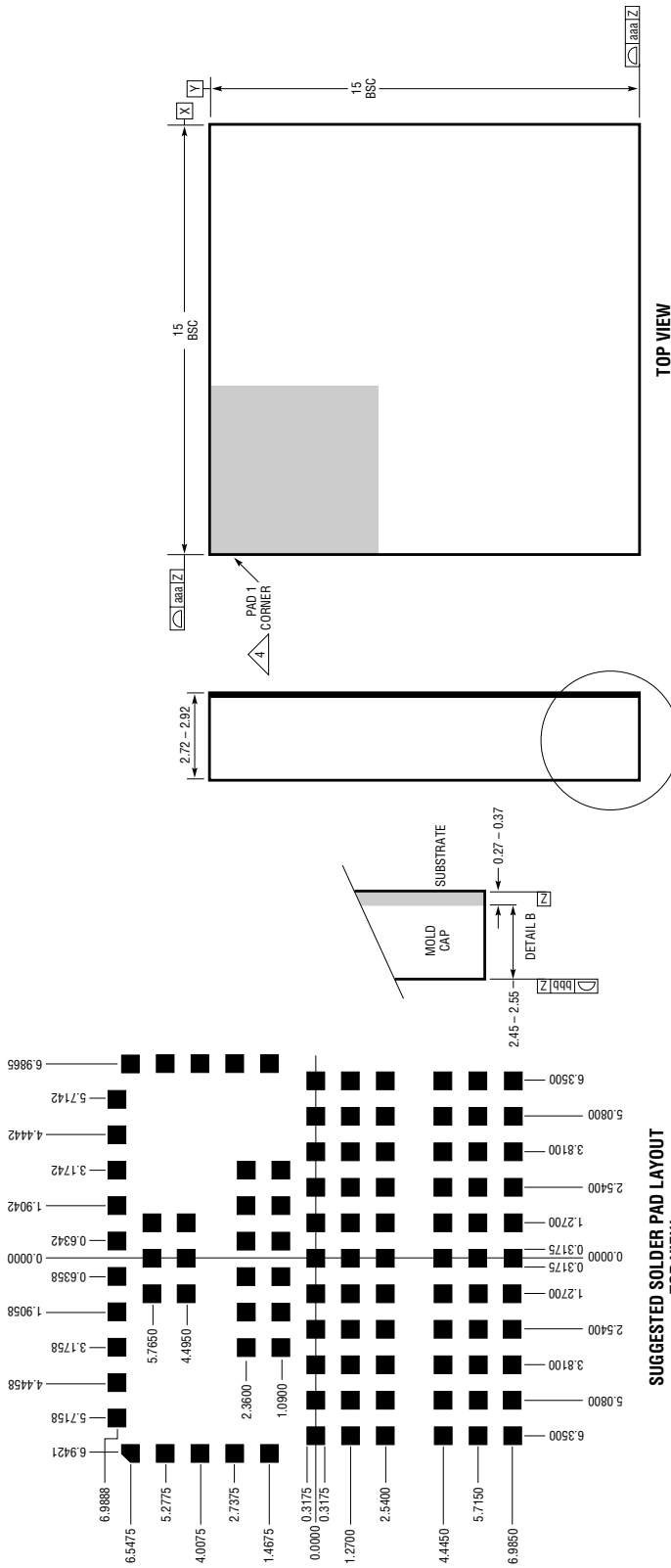


### Current Sharing Between Two LTM4602HV Modules



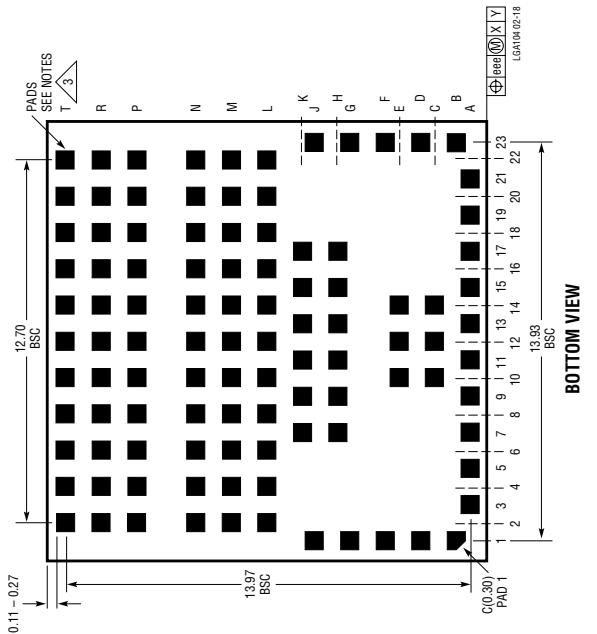
# PACKAGE DESCRIPTION

**LGA Package**  
**104-Lead (15mm x 15mm)**  
 (Reference LTM DWG # 05-05-1800)



- NOTES:**
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M-1994
  2. ALL DIMENSIONS ARE IN MILLIMETERS
  3. LAND DESIGNATION PER JEDEC MO-222, SPP-010
  4. DETAILS OF PAD #1 IDENTIFIER ARE OPTIONAL, BUT MUST BE LOCATED WITHIN THE ZONE INDICATED. THE PAD #1 IDENTIFIER IS A MARKED FEATURE OR A NOTCHED BEVELED PAD
  5. PRIMARY DATUM - Z - IS SEATING PLANE
  6. THE TOTAL NUMBER OF PADS: 104

| SYMBOL | TOLERANCE |
|--------|-----------|
| aaa    | 0.15      |
| bbb    | 0.10      |
| eee    | 0.15      |



## PACKAGE DESCRIPTION

Pin Assignment Tables  
(Arranged by Pin Number)

| PIN NAME        | PIN NAME    | PIN NAME     | PIN NAME    | PIN NAME     | PIN NAME    | PIN NAME | PIN NAME |
|-----------------|-------------|--------------|-------------|--------------|-------------|----------|----------|
| A1 -            | B1 $V_{IN}$ | C1 -         | D1 $V_{IN}$ | E1 -         | F1 $V_{IN}$ | G1 PGND  | H1 -     |
| A2 -            | B2 -        | C2 -         | D2 -        | E2 -         | F2 -        | G2 -     | H2 -     |
| A3 $V_{IN}$     | B3 -        | C3 -         | D3 -        | E3 -         | F3 -        | G3 -     | H3 -     |
| A4 -            | B4 -        | C4 -         | D4 -        | E4 -         | F4 -        | G4 -     | H4 -     |
| A5 $V_{IN}$     | B5 -        | C5 -         | D5 -        | E5 -         | F5 -        | G5 -     | H5 -     |
| A6 -            | B6 -        | C6 -         | D6 -        | E6 -         | F6 -        | G6 -     | H6 -     |
| A7 $V_{IN}$     | B7 -        | C7 -         | D7 -        | E7 -         | F7 -        | G7 -     | H7 PGND  |
| A8 -            | B8 -        | C8 -         | D8 -        | E8 -         | F8 -        | G8 -     | H8 -     |
| A9 $V_{IN}$     | B9 -        | C9 -         | D9 -        | E9 -         | F9 -        | G9 -     | H9 PGND  |
| A10 -           | B10 -       | C10 $V_{IN}$ | D10 -       | E10 $V_{IN}$ | F10 -       | G10 -    | H10 -    |
| A11 $V_{IN}$    | B11 -       | C11 -        | D11 -       | E11 -        | F11 -       | G11 -    | H11 PGND |
| A12 -           | B12 -       | C12 $V_{IN}$ | D12 -       | E12 $V_{IN}$ | F12 -       | G12 -    | H12 -    |
| A13 $V_{IN}$    | B13 -       | C13 -        | D13 -       | E13 -        | F13 -       | G13 -    | H13 PGND |
| A14 -           | B14 -       | C14 $V_{IN}$ | D14 -       | E14 $V_{IN}$ | F14 -       | G14 -    | H14 -    |
| A15 $f_{ADJ}$   | B15 -       | C15 -        | D15 -       | E15 -        | F15 -       | G15 -    | H15 PGND |
| A16 -           | B16 -       | C16 -        | D16 -       | E16 -        | F16 -       | G16 -    | H16 -    |
| A17 $SV_{IN}$   | B17 -       | C17 -        | D17 -       | E17 -        | F17 -       | G17 -    | H17 PGND |
| A18 -           | B18 -       | C18 -        | D18 -       | E18 -        | F18 -       | G18 -    | H18 -    |
| A19 $EXTV_{CC}$ | B19 -       | C19 -        | D19 -       | E19 -        | F19 -       | G19 -    | H19 -    |
| A20 -           | B20 -       | C20 -        | D20 -       | E20 -        | F20 -       | G20 -    | H20 -    |
| A21 $V_{OSET}$  | B21 -       | C21 -        | D21 -       | E21 -        | F21 -       | G21 -    | H21 -    |
| A22 -           | B22 -       | C22 -        | D22 -       | E22 -        | F22 -       | G22 -    | H22 -    |
| A23 -           | B23 COMP    | C23 -        | D23 SGND    | E23 -        | F23 RUN/SS  | G23 FCB  | H23 -    |

| PIN NAME  | PIN NAME | PIN NAME | PIN NAME | PIN NAME | PIN NAME      | PIN NAME      | PIN NAME      |
|-----------|----------|----------|----------|----------|---------------|---------------|---------------|
| J1 PGND   | K1 -     | L1 -     | M1 -     | N1 -     | P1 -          | R1 -          | T1 -          |
| J2 -      | K2 -     | L2 PGND  | M2 PGND  | N2 PGND  | P2 $V_{OUT}$  | R2 $V_{OUT}$  | T2 $V_{OUT}$  |
| J3 -      | K3 -     | L3 -     | M3 -     | N3 -     | P3 -          | R3 -          | T3 -          |
| J4 -      | K4 -     | L4 PGND  | M4 PGND  | N4 PGND  | P4 $V_{OUT}$  | R4 $V_{OUT}$  | T4 $V_{OUT}$  |
| J5 -      | K5 -     | L5 -     | M5 -     | N5 -     | P5 -          | R5 -          | T5 -          |
| J6 -      | K6 -     | L6 PGND  | M6 PGND  | N6 PGND  | P6 $V_{OUT}$  | R6 $V_{OUT}$  | T6 $V_{OUT}$  |
| J7 -      | K7 PGND  | L7 -     | M7 -     | N7 -     | P7 -          | R7 -          | T7 -          |
| J8 -      | K8 -     | L8 PGND  | M8 PGND  | N8 PGND  | P8 $V_{OUT}$  | R8 $V_{OUT}$  | T8 $V_{OUT}$  |
| J9 -      | K9 PGND  | L9 -     | M9 -     | N9 -     | P9 -          | R9 -          | T9 -          |
| J10 -     | K10 -    | L10 PGND | M10 PGND | N10 PGND | P10 $V_{OUT}$ | R10 $V_{OUT}$ | T10 $V_{OUT}$ |
| J11 -     | K11 PGND | L11 -    | M11 -    | N11 -    | P11 -         | R11 -         | T11 -         |
| J12 -     | K12 -    | L12 PGND | M12 PGND | N12 PGND | P12 $V_{OUT}$ | R12 $V_{OUT}$ | T12 $V_{OUT}$ |
| J13 -     | K13 PGND | L13 -    | M13 -    | N13 -    | P13 -         | R13 -         | T13 -         |
| J14 -     | K14 -    | L14 PGND | M14 PGND | N14 PGND | P14 $V_{OUT}$ | R14 $V_{OUT}$ | T14 $V_{OUT}$ |
| J15 -     | K15 PGND | L15 -    | M15 -    | N15 -    | P15 -         | R15 -         | T15 -         |
| J16 -     | K16 -    | L16 PGND | M16 PGND | N16 PGND | P16 $V_{OUT}$ | R16 $V_{OUT}$ | T16 $V_{OUT}$ |
| J17 -     | K17 PGND | L17 -    | M17 -    | N17 -    | P17 -         | R17 -         | T17 -         |
| J18 -     | K18 -    | L18 PGND | M18 PGND | N18 PGND | P18 $V_{OUT}$ | R18 $V_{OUT}$ | T18 $V_{OUT}$ |
| J19 -     | K19 -    | L19 -    | M19 -    | N19 -    | P19 -         | R19 -         | T19 -         |
| J20 -     | K20 -    | L20 PGND | M20 PGND | N20 PGND | P20 $V_{OUT}$ | R20 $V_{OUT}$ | T20 $V_{OUT}$ |
| J21 -     | K21 -    | L21 -    | M21 -    | N21 -    | P21 -         | R21 -         | T21 -         |
| J22 -     | K22 -    | L22 PGND | M22 PGND | N22 PGND | P22 $V_{OUT}$ | R22 $V_{OUT}$ | T22 $V_{OUT}$ |
| J23 PGOOD | K23 -    | L23 -    | M23 -    | N23 -    | P23 -         | R23 -         | T23 -         |



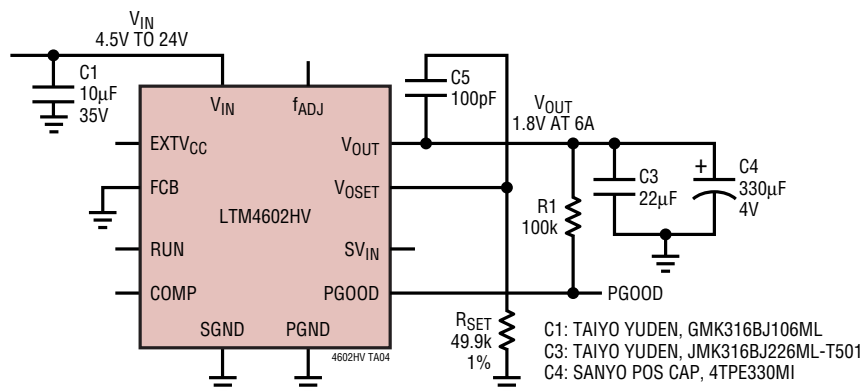
## PACKAGE DESCRIPTION

Pin Assignment Tables  
(Arranged by Pin Number)

| PIN NAME |      | PIN NAME |                  | PIN NAME |                 | PIN NAME |                    |
|----------|------|----------|------------------|----------|-----------------|----------|--------------------|
| G1       | PGND | P2       | V <sub>OUT</sub> | A3       | V <sub>IN</sub> | A15      | f <sub>ADJ</sub>   |
| H7       | PGND | P4       | V <sub>OUT</sub> | A5       | V <sub>IN</sub> | A17      | SV <sub>IN</sub>   |
| H9       | PGND | P6       | V <sub>OUT</sub> | A7       | V <sub>IN</sub> | A19      | EXTV <sub>CC</sub> |
| H11      | PGND | P8       | V <sub>OUT</sub> | A9       | V <sub>IN</sub> | A21      | V <sub>OSET</sub>  |
| H13      | PGND | P10      | V <sub>OUT</sub> | A11      | V <sub>IN</sub> | B23      | COMP               |
| H15      | PGND | P12      | V <sub>OUT</sub> | A13      | V <sub>IN</sub> | D23      | SGND               |
| H17      | PGND | P14      | V <sub>OUT</sub> | B1       | V <sub>IN</sub> | F23      | RUN/SS             |
| J1       | PGND | P16      | V <sub>OUT</sub> | C10      | V <sub>IN</sub> | G23      | FCB                |
| K7       | PGND | P18      | V <sub>OUT</sub> | C12      | V <sub>IN</sub> | J23      | PGOOD              |
| K9       | PGND | P20      | V <sub>OUT</sub> | C14      | V <sub>IN</sub> |          |                    |
| K11      | PGND | P22      | V <sub>OUT</sub> | D1       | V <sub>IN</sub> |          |                    |
| K13      | PGND | R2       | V <sub>OUT</sub> | E10      | V <sub>IN</sub> |          |                    |
| K15      | PGND | R4       | V <sub>OUT</sub> | E12      | V <sub>IN</sub> |          |                    |
| K17      | PGND | R6       | V <sub>OUT</sub> | E14      | V <sub>IN</sub> |          |                    |
| L2       | PGND | R8       | V <sub>OUT</sub> | F1       | V <sub>IN</sub> |          |                    |
| L4       | PGND | R10      | V <sub>OUT</sub> |          |                 |          |                    |
| L6       | PGND | R12      | V <sub>OUT</sub> |          |                 |          |                    |
| L8       | PGND | R14      | V <sub>OUT</sub> |          |                 |          |                    |
| L10      | PGND | R16      | V <sub>OUT</sub> |          |                 |          |                    |
| L12      | PGND | R18      | V <sub>OUT</sub> |          |                 |          |                    |
| L14      | PGND | R20      | V <sub>OUT</sub> |          |                 |          |                    |
| L16      | PGND | R22      | V <sub>OUT</sub> |          |                 |          |                    |
| L18      | PGND | T2       | V <sub>OUT</sub> |          |                 |          |                    |
| L20      | PGND | T4       | V <sub>OUT</sub> |          |                 |          |                    |
| L22      | PGND | T6       | V <sub>OUT</sub> |          |                 |          |                    |
| M2       | PGND | T8       | V <sub>OUT</sub> |          |                 |          |                    |
| M4       | PGND | T10      | V <sub>OUT</sub> |          |                 |          |                    |
| M6       | PGND | T12      | V <sub>OUT</sub> |          |                 |          |                    |
| M8       | PGND | T14      | V <sub>OUT</sub> |          |                 |          |                    |
| M10      | PGND | T16      | V <sub>OUT</sub> |          |                 |          |                    |
| M12      | PGND | T18      | V <sub>OUT</sub> |          |                 |          |                    |
| M14      | PGND | T20      | V <sub>OUT</sub> |          |                 |          |                    |
| M16      | PGND | T22      | V <sub>OUT</sub> |          |                 |          |                    |
| M18      | PGND |          |                  |          |                 |          |                    |
| M20      | PGND |          |                  |          |                 |          |                    |
| M22      | PGND |          |                  |          |                 |          |                    |
| N2       | PGND |          |                  |          |                 |          |                    |
| N4       | PGND |          |                  |          |                 |          |                    |
| N6       | PGND |          |                  |          |                 |          |                    |
| N8       | PGND |          |                  |          |                 |          |                    |
| N10      | PGND |          |                  |          |                 |          |                    |
| N12      | PGND |          |                  |          |                 |          |                    |
| N14      | PGND |          |                  |          |                 |          |                    |
| N16      | PGND |          |                  |          |                 |          |                    |
| N18      | PGND |          |                  |          |                 |          |                    |
| N20      | PGND |          |                  |          |                 |          |                    |
| N22      | PGND |          |                  |          |                 |          |                    |

## TYPICAL APPLICATION

### 1.8V, 5A Regulator



## RELATED PARTS

| PART NUMBER   | DESCRIPTION  | COMMENTS  |
|---------------|--|---|
| LTC2900       | Quad Supply Monitor with Adjustable Reset Timer                            | Monitors Four Supplies; Adjustable Reset Timer  |
| LTC2923       | Power Supply Tracking Controller   | Tracks Both Up and Down; Power Supply Sequencing  |
| LT3825/LT3837 | Synchronous Isolated Flyback Controllers                                   | No Optocoupler Required; 3.3V, 12A Output; Simple Design  |
| LTM4600       | 10A DC/DC µModule  | 10A Basic DC/DC µModule   |
| LTM4601       | 12A DC/DC µModule with PLL, Output Tracking/Margining and Remote Sensing   | Synchronizable, PolyPhase® Operation to 48A, LTM4601-1 Version has no Remote Sensing, Fast Transient Response |
| LTM4603       | 6A DC/DC µModule with PLL and Output Tracking/Margining and Remote Sensing | Synchronizable, PolyPhase Operation, LTM4603-1 Version has no Remote Sensing, Fast Transient Response         |

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