8-Output Regulator Powers Applications Processors

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The market for applications processors, the integrated core/memory/video/UI function chips used in smartphones, tablets, netbooks and automobile infotainment systems, is one of the fastest growing segments in electronics today. A single applications processor IC, such as one from Freescale, Marvell or an in-house custom processor, is packed with functions and requires independent power supplies for its core, I/O, memory and peripherals. The challenge is producing all those rails in limited space, at high efficiency, from a wide range of power inputs—a tablet, for instance, requires power conversion from USB, automotive battery and its built-in Li-ion battery.

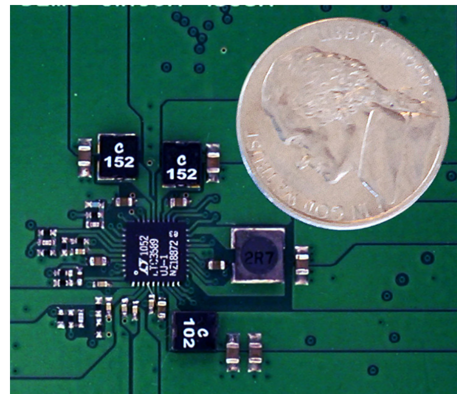

Figure 1. Eight power rails take less than 500mm^2 of board real estate.

The LTC3589 serves applications processor power needs with eight regulated outputs that support processor core and I/O voltage levels, SRAM, memory, low power standby, other peripheral circuits and system voltage levels. The LTC3589's eight supplies are completely independent, but they can be easily sequenced with simple pin strapping. Likewise, the LTC3589 simplifies overall power system design by integrating a number of important control features, including:

- Flexible pin strap supply sequencing
- I^{2}C control of all major regulator functions
- Dynamic voltage scaling with selectable ramp rate
- IRQ pin and status register error reporting
- Power good status pin and register
- Built-in pushbutton controller to initiate power-on, provide a debounced pushbutton status and force a device hard reset

EIGHT INDEPENDENT VOLTAGE REGULATORS IN A SINGLE IC

While the features built into the LTC3589 certainly aid system design and optimization, it is designed foremost to output eight independent, voltage-regulated outputs. The LTC3589 contains a combination of LDO and switching regulators with output current capabilities from 25mA to 1.6A, with voltage output levels from less than 1V to 5V. Four of the outputs feature I^{2}C-controlled DAC references for dynamic voltage scaling.

The integrated low power, 25mA, LDO can supply circuits that require a constant supply while the system is in standby mode, such as a real time clock. The low power LDO is capable of producing an output from 0.8V up to the input

Table 1. The LTC3589 supplies eight voltage rails delivering currents from 25mA to 1.6A

TYPE	AVAILABLE OUTPUT CURRENT	OUTPUT VOLTAGE CONTROL
LDO1	25mA	Resistive divider based on 0.8V feedback reference
LDO2	250mA	Resistive divider based on 0.3625V to 0.75V DAC feedback reference
LDO3	250mA	Fixed 1.8V
LDO4	250mA	1.8V, 2.5V, 2.8V, 3.3V selectable using I^{2}C command register
Buck1	1.6A	Resistive divider based on 0.3625V to 0.75V DAC feedback reference
Buck2	1A	Resistive divider based on 0.3625V to 0.75V DAC feedback reference
Buck3	1A	Resistive divider based on 0.3625V to 0.75V DAC feedback reference
Buck-Boost	1.2A	Resistive divider based on 0.8V feedback reference

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supply, set by a resistive divider. As long as an input supply is attached to the LTC3589, the always-alive LDO regulates. The LTC3589 only consumes 8μA of input supply current in standby mode, even as the always-alive LDO regulates.

Three more LDOs, each capable of delivering 250mA, are handy for supplying power to system analog functions such as phase lock loops, D/A and A/D converters, or as general purpose rails. The 250mA LDO regulators can be powered from a voltage lower than the primary input supply to reduce the power consumption in the LDO. Typically, the LTC3589 switching converters supply the LDO regulators. Two of the LDO regulators have fixed or I^2C selectable output voltage. The third LDO uses external feedback resistors with a 5-bit DAC reference to set its output using an I^2C command register.

The LTC3589 is designed to run from an input supply range of 2.7V to 5.5V. To satisfy the requirements of devices that require a 3.3V or 5V rail, the LTC3589 includes a high efficiency buck-boost switching converter that can output voltage from 1.8V to 5V, set by a resistive divider. The buck-boost converter is capable of supporting loads up to 1.2A. Using the I^2C serial port, the buck-boost converter can be set to low power Burst Mode operation to reduce power loss in low current output modes.

Three buck regulators complete the LTC3589 complement of regulated

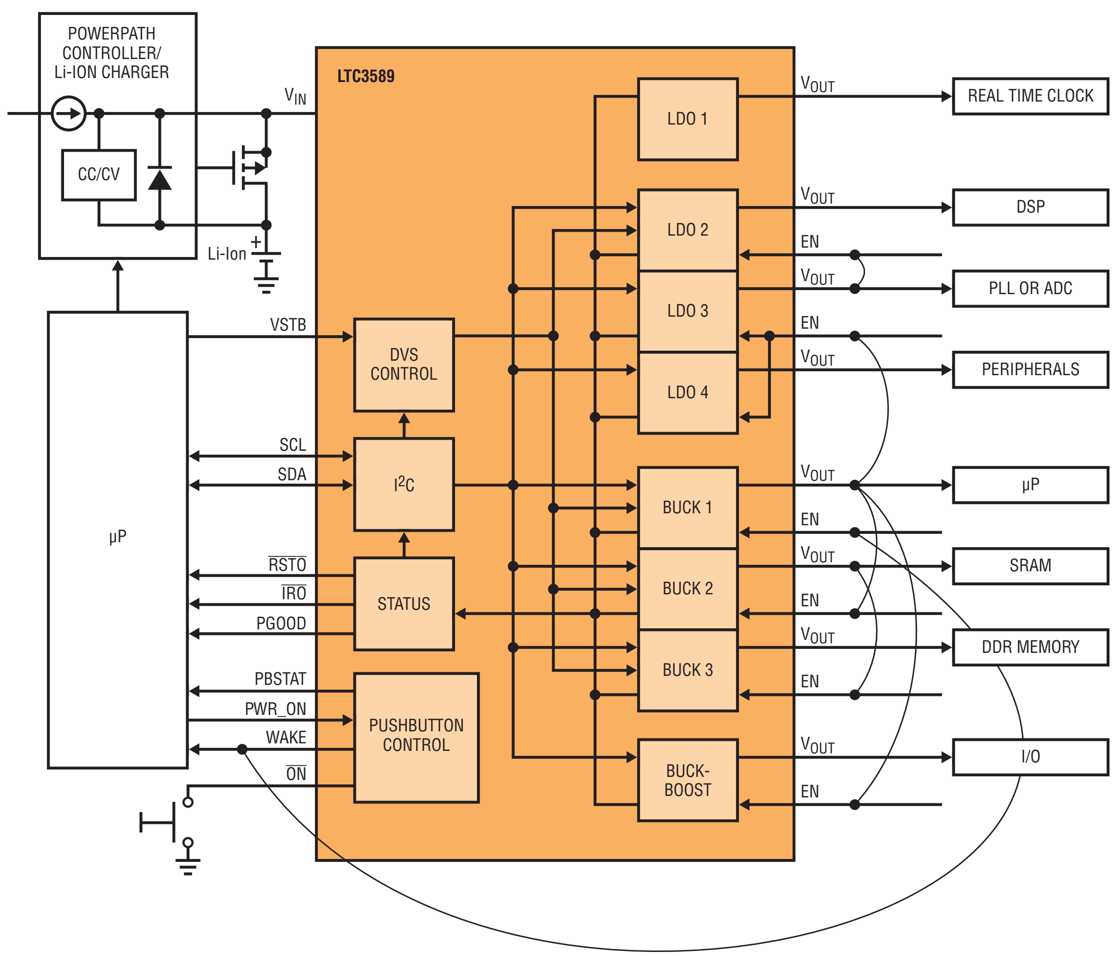
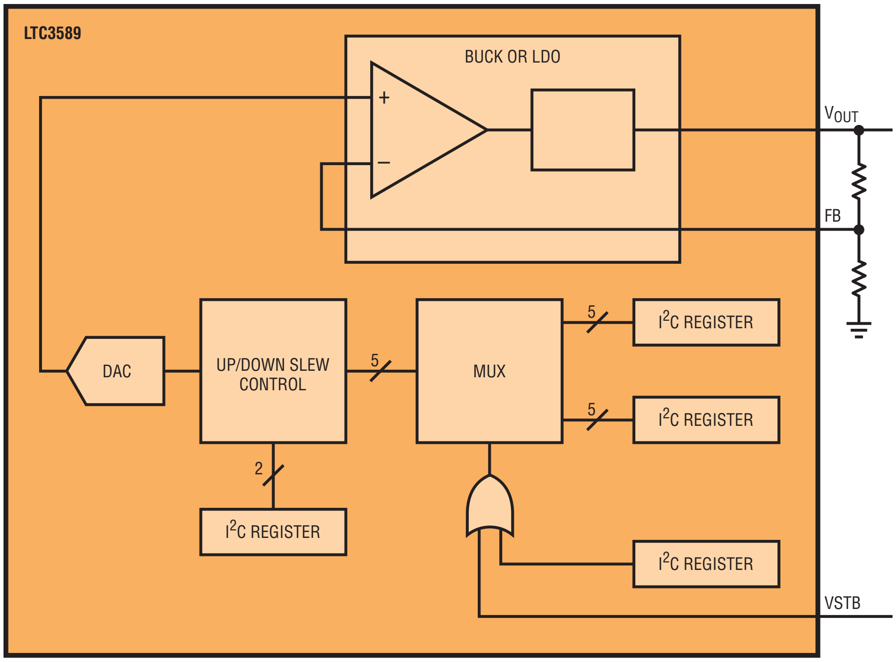


Figure 2. Combine the LTC3589 with a PowerPath™ controller/battery charger for power distribution with supply sequencing, I^2C controls and pushbutton control.



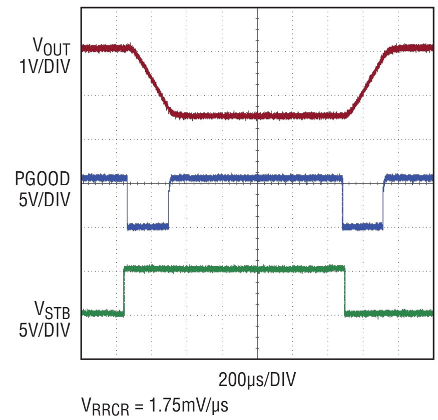


Figure 3. Dynamic voltage scaling is supported on four of the LTC3589's eight outputs with I^2C selectable up/down slew rate.

voltage outputs. The buck converters' output voltages, set with external resistor dividers, can range from as low as the minimum DAC reference voltage to as high as the input supply voltage, where the bucks operate in dropout mode.

Depending on the requirements of the application, each buck's operating mode can be set using the I^2C command registers. For operation over a wide range of output currents, pulse-skipping mode gives good efficiency with low ripple. Burst Mode operation offers the highest efficiency at low power. When set to Burst Mode operation, the buck automatically moves between Burst Mode operation at low loads and continuous switching mode at higher output loads. Selecting forced continuous mode results in the lowest output voltage ripple at the expense of some efficiency. Each buck's operating mode is independently selected using the I^2C command registers.

DYNAMIC VOLTAGE SCALING

Since portable battery operated devices spend much of the time in standby or low power modes, microprocessors may take advantage of dynamic voltage scaling to reduce switching power loss by decreasing the processors supply voltage. The LTC3589 supports dynamic voltage scaling (DVS) on one of the LDO regulators and all three buck converters.

Each scalable regulator on the LTC3589 uses two DAC feedback reference set-point voltages in the I^2C command registers and a selectable transition slew rate between the high and low target voltages (see Figure 3). Transition between target voltages is initiated for all regulators using the VSTBY pin or for individual regulators using I^2C command registers.

The scalable LDO and buck converters have independently controlled DAC-driven feedback reference voltages. The reference voltage range runs from 0.3625V to 0.75V in 31 12.5mV steps. The converter output voltage is scaled up from the reference voltage using a resistive feedback divider from the converter output to its feedback input. At power-on, each DAC defaults to a reference output of 0.675V so the output voltage can be increased from the default output by 10% to increase the processor performance or for power supply margining.

During a voltage-down slew, the step-down regulators are automatically switched to forced continuous mode and therefore are able to sink current from the load. A 2k resistor to ground is switched to the output of the DAC-referenced LDO to pull down its output. Four slew rates are selectable by choosing the rate of change of the reference, from 0.88V/ms to 7V/ms, via the I^2C command register.

EASY SEQUENCING AND ENABLE CONTROL

Multirail systems typically require the supply rails come up to voltage in a predetermined sequence (because of latchup, brains in right order, start-up current, etc.). Sequencing the LTC3589 outputs in any order is accomplished by pin-strapping regulator outputs to regulator inputs. Figure 4 shows an example of a pin-strapped sequence. Each enable pin has a precise 500mV comparator input with a built-in 200µs delay timer before enabling the regulator.

The start-up sequence is defined by tying the LTC3589 WAKE pin to the enable pin of the first regulator or regulators in the sequence. Wrapping regulator outputs around to the next enable in the

A regulator not in the start-up sequence is controlled by driving its pin directly or using the I^{2}C command register. Any of the regulators in a pin-strapped sequence can be enabled or disabled in any order by setting a software control bit in the I^{2}C command registers.

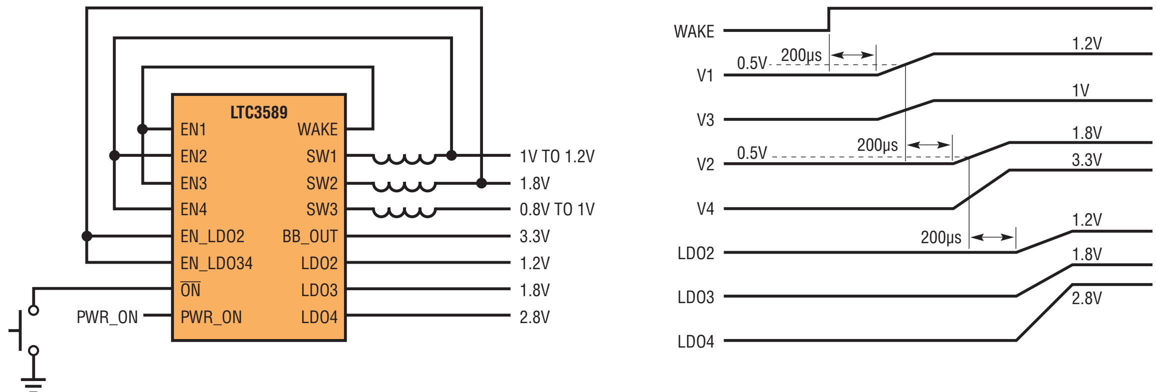


Figure 4. Flexible and simple start-up sequencing is accomplished by tying regulator outputs to enable pins in any order.

sequence brings the supplies up in order. If additional start-up delay is required, add a resistive divider to raise the enable voltage threshold or add an RC filter with the desired time constant to delay the start of the subsequent regulator.

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Applications with keep-alive requirements such as volatile memory or watchdog functions requiring more power or additional voltage rails can take advantage of the LTC3589 keep-alive control function. Each of the three buck converters and the DAC-controlled LDO have a keep-alive bit setting in the I^{2}C control register. Setting any of the keep-alive bits in the I^{2}C command register keeps the corresponding regulators alive when the LTC3589 is in standby mode.

To ensure the integrity of a power-up sequence following a power-down, the LTC3589 adds a one second delay to allow the regulator outputs to fall to ground. Additionally, 2k pull-down resistors are inserted on the LDO outputs and buck switch pins to ensure discharge. Each regulator's output voltage must be less than 300mV before it is allowed to enable. I^{2}C command register settings are available to override the resistor pull-downs and the 300mV start-up rule in cases where the regulator outputs are back-driven.

PUSHBUTTON OPERATION

The pushbutton control circuit included in the LTC3589 provides a debounced user interface to initiate a power-up sequence. A power-up sequence from standby mode begins when the pushbutton is depressed to activate the open driver WAKE pin. If the WAKE pin is tied to a regulator enable pin, the power-up sequence begins. Once the controller is satisfied system power is good then the PWR_ON pin should be driven high. For normal shutdown, pull PWR_ON low.

The PBSTAT pin is an open drain output that signals to the microprocessor that the button has been pushed and some change in operation or power-down has been requested. If the system is no longer responding for some reason, holding the button for five seconds forces a hard reset, which powers down the regulators, asserts the $\overline{\text{RSTO}}$ reset pin and puts the LTC3589 in standby mode.

If pushbutton functions are not needed, the WAKE pin is enabled and disabled by driving the PWR_ON pin directly. Even when driving the PWR_ON pin directly, the pushbutton PBSTAT status pin and hard reset functions are active.

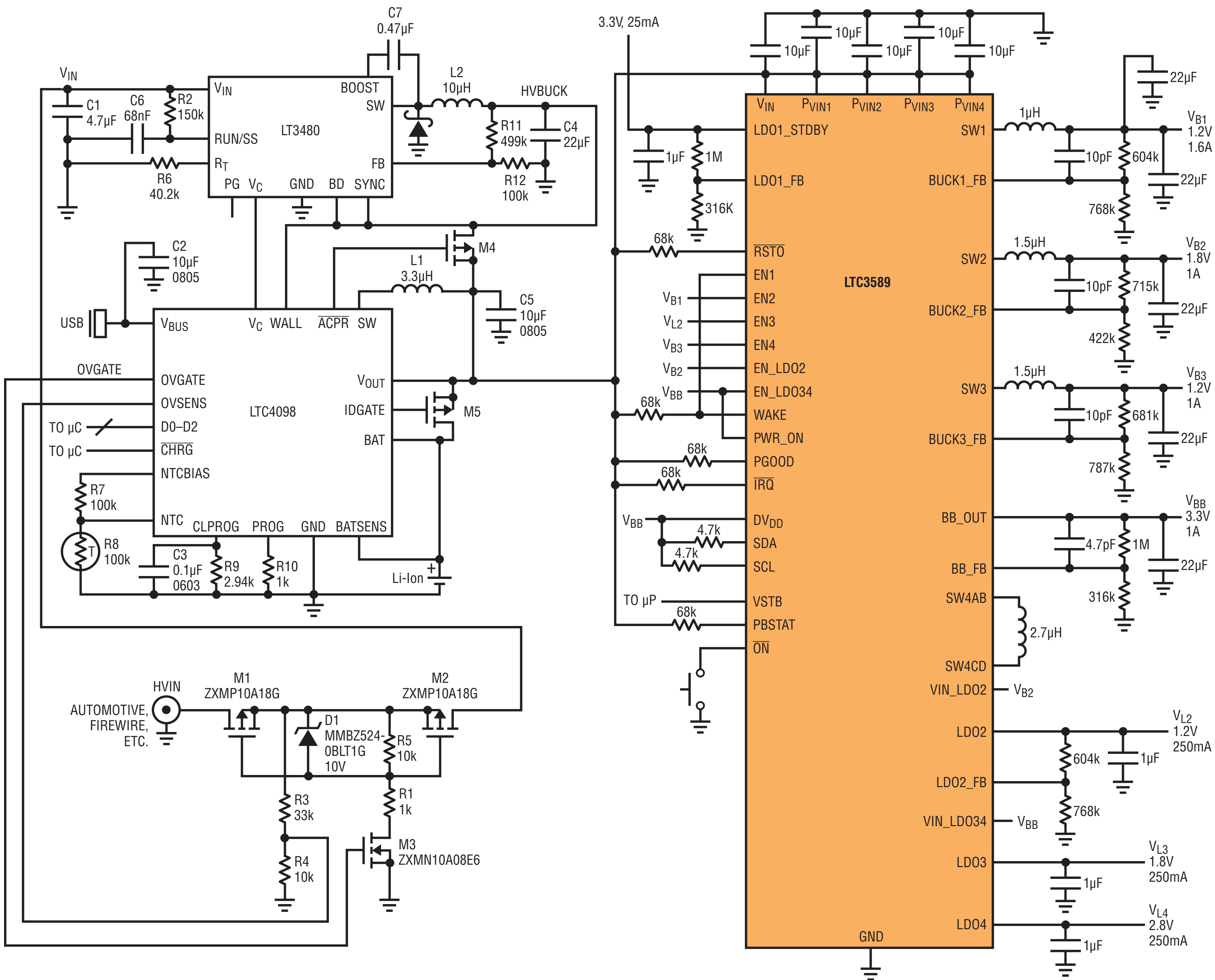

Figure 5. Integrated power IC for mobile microprocessor system with USB/automotive battery charger

STATUS REPORTING

Three pins are provided for the LTC3589 to send status to the controlling microprocessor. The $\overline{\text{RSTO}}$, $\overline{\text{IRQ}}$, and PGOOD pins are open drain outputs that signal regulator low output, hard reset events, supply undervoltage, hot die temperature and fault conditions. The $\overline{\text{IRQ}}$ and PGOOD pins are matched to I^{2}C status registers, which can be read to determine the specific cause of the status pin activity. In the event of a fault, such as die overtemperature or UVLO, that shuts down the LC3589 regulators, the cause of the shutdown is latched in a status register that can be read by the system controller after system reboot.

CONCLUSION

The LTC3589 with eight regulator outputs, flexible sequencing, dynamic voltage scaling and serial port control is ideally suited for applications-processor-based consumer, industrial and automotive devices. When coupled with a step-down regulator, the LTC3589 can supply a complete set of system supply rails from high voltage primary sources such as automotive systems. Add a PowerPath controller/battery charger IC to generate system rails for Li-ion-powered portable devices.

The LTC3589 features low power standby and Burst Mode operation, keep-alive functions and dynamic voltage scaling so that system designers can optimize battery life. Pushbutton control simplifies board design and provides start-up, processor interrupt and hard reset functions. ■