Battery-Fed (Charger-Fed) Systems

First generation USB system applications incorporated a current-limited battery charger directly between the USB port and the battery (see Figure 1). In this battery-fed topology, the battery directly powers the system and the power available to the system from the USB can be expressed as:

$P_{SYS} = I_{USB} \bullet V_{BAT}$

because V_{BAT} is the only voltage available to the system load. For linear chargers, input current approximately equals charge current, so a simple current limit is sufficient. Connecting the system load directly to the battery eliminates the need for a load sharing diode. Disadvantages of this topology include low efficiency, 500mA maximum charge current from the USB, no system power when the battery voltage is low (i.e., a dead or missing battery), and loss of nearly half of the available power within the linear battery charger element as heat. Furthermore, an additional resistor and signal transistor is required to increase charge current when a wall adapter is present.

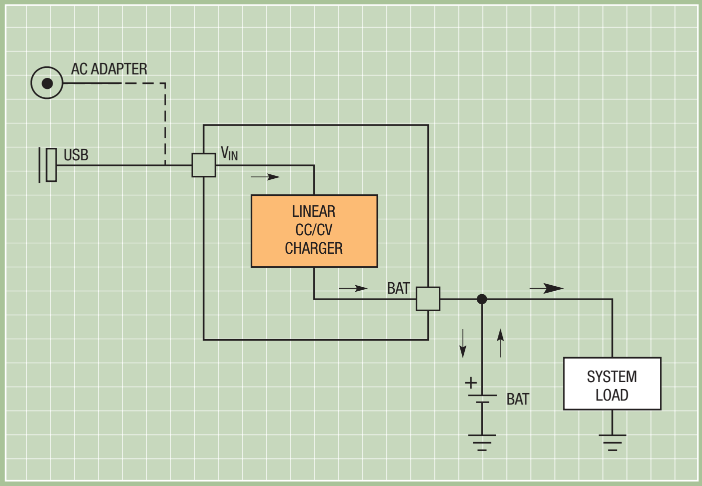

Figure 1: Simplified Battery-Fed Control Circuit

Linear PowerPath Power Managers

Second generation USB charging systems, commonly referred to as PowerPath systems, develop an intermediate voltage between the USB port and the battery (see Figure 2). In PowerPath systems, the USB port supplies current to an intermediate voltage, V_{OUT}, via a current-limited switch. V_{OUT} powers both the linear battery charger and the system load with priority going to the system load. By decoupling the battery from the system load, charging can be carried out opportunistically. PowerPath systems also offer instant–on operation because the intermediate voltage is available for system loads as soon as power is applied to the circuit—this allows the end product to operate immediately when plugged in, regardless of the battery's state of charge. In a linear PowerPath system, nearly all of the 2.5W available from the USB port is accessible to the system load provided the system load does not exceed the input current limit. Furthermore, if the system requires more power than is available from the input, an ideal diode also supplies current to the load from the battery. Thus, a linear PowerPath system offers significant advantages over a battery-fed system. But significant power may still be lost, especially if the system load exceeds the input current limit and the battery voltage is low, resulting in a large differential between the input voltage and both the system voltage and the battery voltage. An optional external PFET can reduce the ideal diode voltage drop during heavy load conditions.

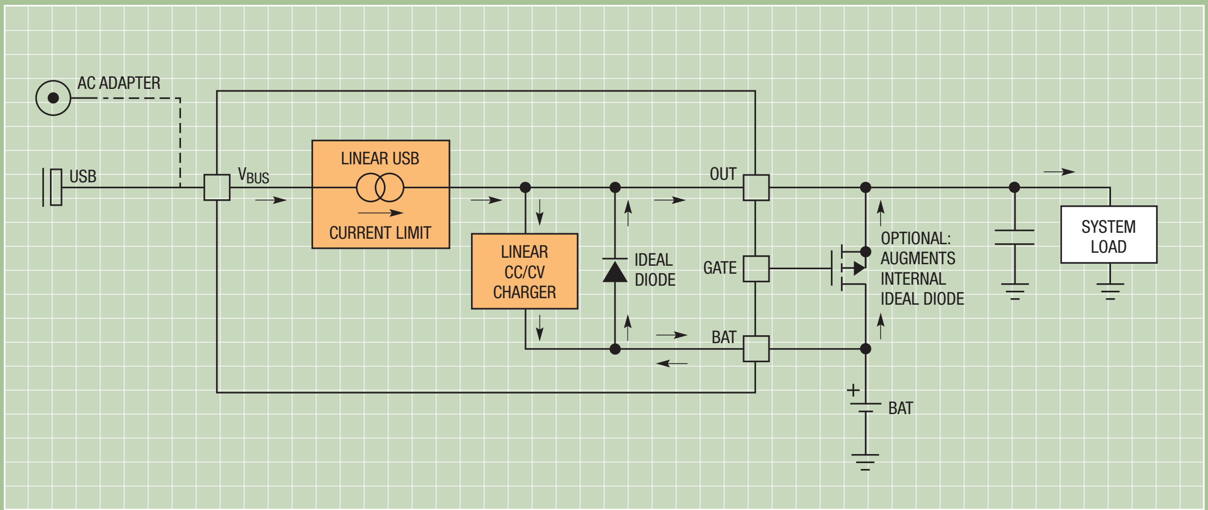

Figure 2: Simplified Linear Power Manager Circuit

Switch Mode PowerPath Power Managers

Third generation USB charging systems feature a switchmode-based topology (see Figure 3). This type of PowerPath device produces an intermediate bus voltage from a USB-compliant step-down switching regulator that regulates a small differential voltage above the battery voltage. Linear Technology refers to this as Bat-Track™ adaptive output control because the output voltage tracks the battery voltage. The differential voltage between the battery and the system is large enough to allow full charging through the linear charger, but small enough to minimize power lost in the charger, thereby increasing system efficiency and maximizing power available to the load. The switching average input current limit allows the use of nearly all of the 2.5W available from the USB port, independent of operating conditions. By ensuring that the Bat-Track regulation loop does not allow the output voltage to drop below 3.5V (even with severely discharged batteries) this topology also provides instant-on functionality. As in linear PowerPath systems, an ideal diode allows the battery to supplement input power during heavy load transients. An optional external PFET can reduce the ideal diode voltage drop. This architecture is suitable for systems with large (>1.5AHr) batteries and high (>2W) system power.

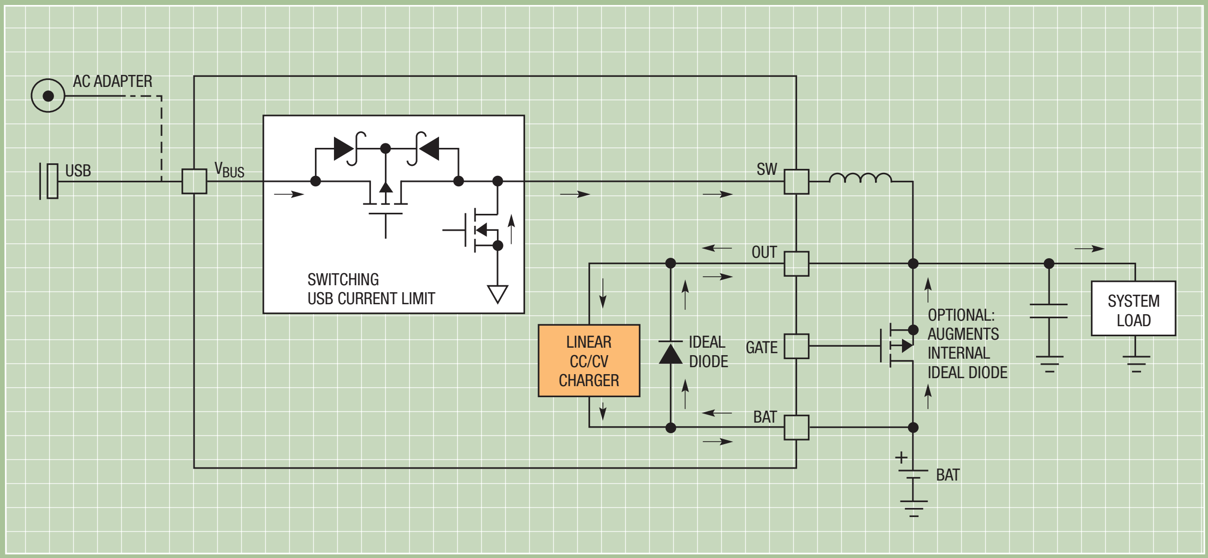

Figure 3: Simplified Switch Mode Power Manager Circuit

External High Voltage Switching Regulator Control

Several Linear Technology power manager ICs (both linear and switching) provide the ability to adaptively control the output of an external high voltage switching regulator (see Figure 4). The WALL pin detects the presence of a high voltage supply (e.g., car battery, 12V wall adapter, FireWire input) and enables Bat-Track adaptive output control via the buck regulator's V_C pin. Similar to a switching PowerPath system, the output of the high voltage buck is regulated to a small differential voltage above the battery voltage with a minimum output voltage of approximately 3.5V. This functionality maximizes charger efficiency while still allowing instant-on operation even when the battery is deeply discharged.

Compared to the traditional approach of converting a high voltage input to 5V to power the system, this technique can reduce system power dissipation by over 50%. By choosing an LT®3653 as the high voltage regulator, further system improvements can be made (see Figure 5). The LT3653 accurately controls its maximum output current, which eliminates the potential for localized heating, reduces the required current rating of the power components and provides a robust solution to withstand harsh overload and short circuit conditions. In addition, the unique LT3653 architecture eliminates a power PFET and output capacitor from the application schematic.

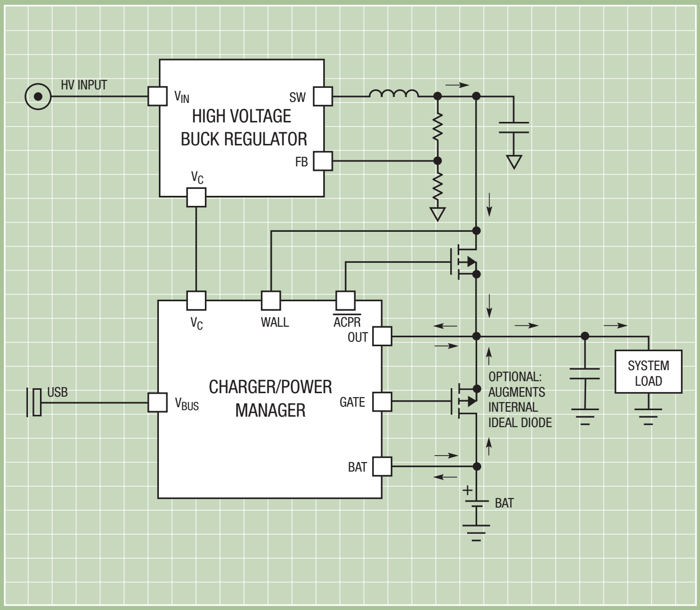

Figure 4: Simplified HV Switching Regulator Control Circuit

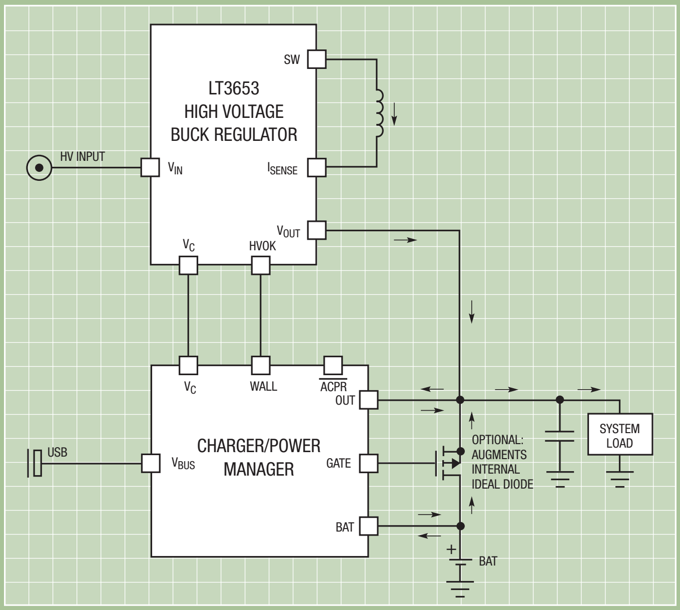

Figure 5: Simplified LT3653 Control Circuit

Table 1: Comparison of USB-Compliant Battery Charging System Topologies

Attribute	Battery-Fed	Linear PowerPath	Switch Mode PowerPath
Size	Small	Moderate	Larger
Complexity	Simple	Moderate	More Complex
Solution Cost	Low	Moderate	Higher
USB Charge Current	Limited to 500mA	Limited to 500mA	500mA and Higher (~2.3W)
Autonomous Control of Input Power Sources	No	Yes	Yes
Instant-On Operation	No	Yes	Yes
System Load Efficiency (I_{BUS}<USB Limit)	Good (V_{BAT}/V_{BUS})	Exceptional (>90%)	Excellent (~90%)
System Load Efficiency (I_{SYS}>USB Limit)	Good (V_{BAT}/V_{BUS})	Good (V_{BAT}/V_{BUS})	Excellent (~90%)
Battery Charger Efficiency	Good (V_{BAT}/V_{BUS})	Good (V_{BAT}/V_{BUS})	Excellent (~90%)
Power Dissipation	High	Moderate	Low
Bat-Track Adaptive Output Control/ Interface to HV Buck	No	Yes	Yes

MASTER INDEX—Power Managers and Linear Battery Chargers

Battery		Charge Termination & Integration			Status Signals			Temperature Control		Package	Part Number					Page Number
Number of Battery Cells (Series)	Battery Charge Current (Max), A	Standalone	Charge Termination	Integrated Pass Transistor	I_{CHARGE} Monitor #	End-of-Charge Signal	AC Present Signal	Thermal Regulation	Thermistor Interface		Integration/Features Most ←				→ Least	
Li-Ion/Polymer 4.2V/Cell & 4.1V/Cell Linear Battery Chargers with PowerPath Control (Power Managers)																
1	1.5	✓	✓¶	✓	✓	✓	–	✓	✓	UTQFN-20	LTC4099					07, 10
1	1.5	✓	✓¶	✓	✓	✓	–	✓	✓	UTQFN-20	LTC4160					07, 10
1	1.5	✓	✓¶	✓	✓	✓	–	✓	✓	UTQFN-20	LTC4098					07, 10
1	1.5	✓	✓¶	✓	✓	✓	–	✓	✓	DFN-14	LTC4088					10
1	1.2	✓	✓¶	✓	✓	✓	✓	✓	✓	DFN-22	LTC4090					10
1	1.2	✓	✓¶	✓	–	✓	✓	✓	✓	DFN-22	LTC4089					07, 10
1	1.5	✓	✓‡	✓	✓**	✓	✓	✓	✓	UTQFN-24	LTC4066					07, 10
1	1.25	✓	✓‡	✓	–	✓	✓	✓	✓	QFN-16		LTC4055				07, 10
1	1.25	✓	✓‡	✓	✓	✓	–	✓	✓	DFN-12		LTC4067				10
1	1.5	✓	✓‡	✓	–	✓	✓	✓	✓	DFN-14		LTC4085				07, 10
Li-Ion/Polymer 4.2V/Cell & 4.1V/Cell Linear Battery Chargers																
1	1	✓	✓¶	✓	✓	✓	✓	✓	✓	DFN-10			LTC4061			06
1	1	✓	✓¶	✓	✓	✓	–	✓	–	DFN-10			LTC4062			06
1	1	✓	✓¶	✓	✓	✓	–	✓	–	DFN-10			LTC4063			06
1	2	✓	✓‡	–	–	✓	✓	–	✓	MSOP-10			LTC4050			06, 07
1	1.25	✓	✓‡	✓	✓	✓	✓	✓	✓	DFN-10 MSOP-10			LTC4053			06
1	0.95	✓	✓†	✓	✓	✓	✓	✓	–	DFN-10			LTC4078/X			06
1	0.95	✓	✓†	✓	✓	✓	✓	✓	–	DFN-10			LTC4075/X			06
1	1.2	✓	✓†	✓	✓	✓	✓	✓	–	DFN-10			LTC4096/X			06

* Current C/10
† Current C/x
‡ Timer
§ μC
¶ Timer + Current Indication
# PROG Pin Tracks Charge Current
** Gas Gauge Capability

MASTER INDEX—Power Managers and Linear Battery Chargers (Continued)

Battery		Charge Termination & Integration			Status Signals			Temperature Control		Package	Part Number					Page Number
Number of Battery Cells (Series)	Battery Charge Current (Max), A	Standalone	Charge Termination	Integrated Pass Transistor	I_{CHARGE} Monitor #	End-of-Charge Signal	AC Present Signal	Thermal Regulation	Thermistor Interface		Integration/Features: Most ←→ Least					
Li-Ion/Polymer 4.2V/Cell & 4.1V/Cell Linear Battery Chargers																
1	0.95	✓	✓†	✓	✓	✓	✓	✓	–	DFN-10			LTC4077			06
1	0.95	✓	✓†	✓	✓	✓	✓	✓	–	DFN-10			LTC4076			06
1	0.95	✓	✓¶	✓	✓	✓	–	✓	✓	DFN-8			LTC4095			06
1	0.95	✓	✓†	✓	✓	✓	✓	✓	–	DFN-8			LTC4068/X			06
1	0.95	✓	✓*	✓	✓	✓	✓	✓	–	DFN-8			LTC4058/X			06
1, 2	2	✓	✓‡	–	–	✓	✓	–	–	MSOP-10				LTC1732		06, 07
1, 2	2	✓	✓‡	–	–	✓	–	–	–	MSOP-8				LTC1731		06, 07
1	1.5	✓	✓‡	✓	✓	✓	✓	✓	✓	MSOP-10E				LTC1733		06, 07
1	0.8	✓	✓*	✓	✓	✓	–	✓	–	ThinSOT				LTC4054/X		06
1	0.75	✓	✓¶	✓	✓	✓	–	✓	✓	DFN-6				LTC4070		06
1	0.75	✓	✓‡	✓	✓	✓	✓	✓	–	DFN-6				LTC4065/A		06
1	0.7	✓	✓‡	–	–	✓	–	–	–	ThinSOT				LTC4056		06
1	0.9	–	✓§	✓	✓	–	✓	✓	–	DFN-6				LTC4059/A		06, 08
1	0.8	–	✓§	✓	✓	–	–	✓	–	ThinSOT				LTC4057		06
1	1	✓	✓‡	✓	✓	✓	✓	✓	✓	MSOP-10E				LTC4064		06, 07
1	0.7	–	✓§	–	✓	–	–	–	–	ThinSOT					LTC1734	06, 07
Li-Ion/Polymer Coin Cell Battery Chargers																
1	0.15	✓	✓*	✓	✓	✓	–	✓	–	ThinSOT				LTC4054L		06, 08
1	0.9	–	✓§	✓	✓	–	✓	✓	–	DFN-6				LTC4059/A		06
1	0.25	✓	✓‡	✓	✓	✓	✓	✓	–	DFN-6				LTC4065L/LX		06, 08
1	0.18	–	✓§	–	✓	–	–	–	–	ThinSOT					LTC1734L	06, 08

* Current C/10
† Current C/x
‡ Timer
§ µC
¶ Timer + Current Indication
# PROG Pin Tracks Charge Current
** Gas Gauge Capability

MASTER INDEX—Switch Mode Battery Chargers

Battery		Charge Termination & Integration			Status Signals			Temperature Control		Package	Part Number					Page Number
Number of Battery Cells (Series)	Battery Charge Current (Max), A	Standalone	Charge Termination	Integrated Power Transistor	I_{CHARGE} Monitor‡‡	End-of-Charge Signal	AC Present Signal	Thermal Regulation	Thermistor Interface		Integration/Features: Most ←			→ Least		
NiMH/NiCd Battery Chargers																
1-16	4	✓	✓#	–	–	✓	✓	–	✓	TSSOP-20E		LTC4011 Switch Mode				09
1-16	4	✓	✓#	–	–	✓	✓	–	✓	TSSOP-16E		LTC4010 Switch Mode				09
1-4	2	✓	✓§	–	–	✓	✓	–	✓	DFN-16 TSSOP-16				LTC4060 Linear		09
Li-Ion/Polymer Switch Mode Battery Chargers																
1	2	✓	✓‡	✓	–	–	✓	–	✓	SSOP-24		LTC4001/-1				07, 14
1-2	2	✓	✓**	✓	–	–	✓	✓	✓	DFN-12		LT3650				07, 14
3-4	4	✓	✓‡	–	✓	✓	✓	–	✓	SSOP-24		LTC4007				07, 14
2-4	4	✓	✓‡	–	✓	✓	✓	–	✓	SSOP-16			LTC4006			14
1-2	2	✓	✓‡	–	–	–	–	–	–	SSOP-24			LTC1980			07
1-2, adj	1.5	–	✓¶,††	✓	–	✓	–	–	–	SSOP-16 SSOP-28				LT1571		14
1-2	4	✓	✓‡	–	–	✓	–	–	✓	DFN-10 SO-8				LTC4002		14

* Current C/10
† Current C/x
‡ Timer
¶ μC
§ T, t, -dV
# T, t, -dV, dT/dt
** Timer + Current
†† for Li-Ion Termination, use LTC1729
‡‡ PROG Pin Tracks Charge Current

MASTER INDEX—Switch Mode Battery Chargers (Continued)

Battery		Charge Termination & Integration			Status Signals			Temperature Control		Package	Part Number					Page Number
Smart Battery Chargers																
V_{BAT} Range	Battery Charge Current (Max), A	Standalone	Charge Termination Method(s)	Integrated Pass Transistor	I_{CHARGE} Monitor	End-of-Charge Signal	AC Present Signal	Thermal Regulation	Thermistor Interface		Integration/Features: Most ⟵				⟶ Least	
3.5-18V	3	✓	SMBus[‡,¶]	–	–	–	✓	–	✓	QFN-38	**LTC4110**					07, 15, 16
3.5-28V	4	✓	SMBus[¶]	–	–	–	–	–	✓	TSSOP-48	**LTC1760**					07, 16
3-21V	8	✓	SMBus[¶]	–	–	–	✓	–	✓	SSOP-36	**LTC1759**					09, 16
3.5-26V	4	✓	SMBus[¶]	–	–	–	✓	–	✓	SSOP-24		**LTC4100**				07, 16
LTC4101	4	✓	SMBus[¶]	–	–	–	✓	–	✓	SSOP-24		**LTC4101**				16
Lead Acid, NiMH/NiCd, Li-Ion/Polymer Switch Mode Battery Chargers																
3.5-28V	8	–	SPI[¶]	–	–	–	–	–	–	SSOP-36 QFN-38	**LTC1960**					07, 09, 14, 16
2.5-23V	8	–	✓[¶,††]	–	–	✓	–	–	–	SSOP-28		**LT1505**				09, 14
2-28V	4	–	✓[¶]	–	✓	–	✓	✓	–	QFN-20			**LTC4012/-1/-2/-3**			07, 09, 14
2-28V	4	–	✓[¶]	–	✓	–	✓	✓	–	QFN-20			**LTC4009/-1/-2**			07, 09, 14
3-28V	4		✓[¶]	–	–	✓	✓	–	✓	SSOP-20			**LTC4008**			07, 09, 14
2.5-26V	3	–	✓[¶,††]	✓	–	–	–	–	–	SO-24				**LT1511**		09, 14
1.5-20V	0.75	–	✓[¶,††]	✓	–	–	–	–	–	SO-8				**LT1512**		09, 15
1.5-20V	2	–	✓[¶,††]	✓	–	–	–	–	–	DD Pak TO-220				**LT1513**		09, 15
2.5-26V	2	–	✓[¶,††]	✓	–	–	–	–	–	TSSOP-20 SSOP-28				**LT1769**		09, 14
2.5-26V	1.5	–	✓[¶,††]	✓	–	–	–	–	–	TSSOP-16 SSOP-28				**LT1571**		14
2.5-26V	1	–	✓[¶,††]	✓	–	–	–	–	–	SO-8 SSOP-16 SO-16				**LT1510**		09, 14

* Current C/10
† Current C/x
‡ Timer
¶ µC
§ T, t, -dV
# T, t, -dV, dT/dt
** Timer + Current
†† for Li-Ion Termination, use LTC1729
‡‡ PROG Pin Tracks Charge Current

MASTER INDEX—Multifunction PMICs

Onboard Regulators				Battery Charger/Power Manager				Other Features		Package	Part Number					Page #
Number of Regulators	Buck(s) (I_{OUT})	Buck-Boost (BB)/ Boost (I_{OUT})	LDO(s) (I_{OUT})	Li-Ion/Polymer Charger	Maximum Charge Current (A)	PowerPath Topology	Ideal Diode	Input Voltage (V)	Interface		Integration/Features: Most ← → Least					
Li-Ion/Polymer Multifunction Power Management Integrated Circuits (PMICs)																
5	400mA x 2	1A BB, 0.8A Boost	3.3V, 20mA	Sync Buck + Linear	1.5	Switch Mode	Int + Ext (opt.)	5, USB, Li Ion	–	4x6 QFN-38	**LTC3586/-1**					07, 11
5	600mA, 400mA x 2	10-LED Boost	2 x 150mA	Linear	1.5	Linear	Int + Ext (opt.)	5, USB, Li Ion, Hi-V Bat-Track, OVP	–	4x7 QFN-44	**LTC3577/-1/-3/-4**					07, 12
4	400mA x 2, 1A	–	3.3V, 20mA	Sync Buck + Linear	1.5	Switch Mode	Int + Ext (opt.)	5, USB, Li-Ion, Hi-V 38V with 60V transients; OVP: 68V	I^2C	4x6 QFN-38		**LTC3576/-1**				07, 11
4	400mA x 2	1A BB	3.3V, 25mA	Sync Buck + Linear	1.5	Switch Mode	Int + Ext (opt.)	5, USB, Li Ion	I^2C	4x5 QFN-28		**LTC3556**				11
4	600mA, 400mA x 2	–	3.3V, 25mA	Linear	1.5	Linear	Int + Ext (opt.)	5, USB, Li Ion, Hi-V 38V max	–	4x4 QFN-28		**LTC3557/-1**				07, 12
4	1A, 400mA x 2	–	3.3V, 25mA	Sync Buck + Linear	1.5	Switch Mode	Int + Ext (opt.)	5, USB, Li Ion	I^2C	4x5 QFN-24		**LTC3555/-1/-3**				07, 11
3	400mA, 600mA	–	Flexible Gain Block for LDO Controller	Linear	0.5	Linear	–	5, USB, Li Ion	–	4x4 QFN-24			**LTC3455/-1**			07, 12
2	–	1A BB	3.3V, 25mA	Sync Buck + Linear	1.5	Switch Mode	Int + Ext (opt.)	4.25 to 5.5	–	4x4 QFN-24				**LTC3566**		11
2	–	1A BB	3.3V, 25mA	Sync Buck + Linear	1.5	Switch Mode	Int + Ext (opt.)	4.25 to 5.5	I^2C	4x4 QFN-24				**LTC3567**		11
2	400mA	0.4A BB	–	Linear	0.95	–	–	5, USB	–	3x3 QFN-20				**LTC3558**		13
2	400mA x 2	–	–	Linear	0.95	–	–	5, USB	–	3x3 QFN-16				**LTC3559/-1**		07, 13
2	400mA, 800mA	–	–	Linear	0.95	–	–	4.25 to 8	–	3x5 DFN-16				**LTC3552/-1**		13
1	600mA	–	–	Linear	0.95	–	–	4.3 to 8	–	3x5 DFN-16					**LTC3550/-1**	13
1	300mA	–	–	Linear	0.5	–	–	2.7 to 4.5	–	3x3 DFN-10, MSOP-10E					**LTC4080**	13
1	300mA	–	–	Linear	0.5	–	–	2.7 to 4.5	–	3x3 DFN-10					**LTC4081**	13