MANAGING THE POWER CHAIN IN PORTABLE CONSUMER EQUIPMENT

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Introduction

Consumer products, especially hand-held devices, are becoming increasingly complex as many different electrical and electro-mechanical devices with a myriad of voltage levels and current requirements are powered off a single cell battery or a wall supply when the battery is recharging. The supply in these products has to convert this single voltage level to power multi-voltage Processors, DSPs and ASICs, SDRAM, memory sticks, flash memory, focus and zoom lens motors, audio and LCD screens with white LED backlighting. Furthermore, device voltage levels for multi-voltage Processors, DSPs and FPGAs are down to 1.2V and are approaching 0.9V, making system tolerances tighter and necessitating a precise way to keep these voltage levels within specifications. At the other extreme, stacked white LED backlights require as much as 30V with precise current control to power up to10 white LEDs in series. To further complicate matters, all these devices need to be turned on/off at different times for both reliability reasons and to conserve battery life. If all these requirements are not followed, performance degradation, fault conditions such as bus contention, poor battery life due to current spikes during start up or device latch-up can arise.

This paper describes a power management method for handheld equipment suppliers to achieve high system reliability while still meeting power density requirements of small-footprint portable devices as well as meeting low cost targets and low power. New digitally programmable power supplies provide I^2C programmable output voltages, individual supply enable control, battery monitoring, UV and OV monitoring on PWM outputs, margining/LED backlight level, slew rate control and programmable power on/off sequencing. Actively controlling DC output voltage levels to within ±0.5% under low to high line/load to meet stringent tolerance requirements of high performance components further extends reliable operation. Margining supplies tests system performance goals as well as providing an easy way to make adjustments, such as brightness and volume as well as dynamic voltage management for processor core voltages. The integration of active accuracy control, programmable features and built-in flexibility allows the system designer to create a “platform solution” that can be easily modified via software without major hardware changes. Combined with re-programmability, this facilitates rapid design cycles and the proliferation from a base design to future generations of product. Digitally programmable analog power management also allows the digital design engineer to master an otherwise complex system power design with minimal analog knowledge or experience. The use of non-volatile programming also means the power subsystem does not have to be reloaded at every power cycle.

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How to standardize a system with no standards

With more complex handheld systems such as Portable Media Players, Digital camcorders/still cameras, Smart PDA/Camera phones, Handheld GPS/PDA's all with TFT-LCD and now OLED Displays, there is also an increasing power supply complexity with larger numbers and variety of voltages, sometimes as many as 12 unique supplies. Also with the increasing number of supplies, supply ordering becomes critical because of the cumulative input current demands during turn-on and turn-off of all the supplies. Add to that the additional power consumption and associated temperature rise and tighter supply accuracy at lower and lower voltages, makes it increasingly difficult to improve or maintain reliability. All this with demands for shorter development times, less expensive products and improved availability requires a new platform solution for handling all these design issues. Therefore the benefit of standardization of system power management allows the power chain and monitor functions to be the same across several platforms.

To help standardize, a digitally programmable supply platform with an analog controller/Converter provides advantages over fixed solutions as well as pure digital PWM control. One advantage is that a programmable solution reduces risks associated with changing system requirements. With a programmable solution the sequencing order can be modified and sequenced channels can be replaced with tracking channels by simply reprogramming the controller. This minimizes the potential for having to re-spin the board when the system requirements are not clearly understood. A programmable solution also gives the designer more confidence that the board will work the first time. If a problem is encountered, reprogramming can get past the problem and onto debugging and testing the board for its intended function. On a company wide basis, the programmable solution also allows for cross platform implementation where an existing design can be reused for a unique solution by simply reprogramming. The analog PWM and LDO allow a smaller and less complicated device and hence a less expensive solution than having a full DSP on chip. The analog process also allows power MOSFETS to be integrated where it's feasible and the PWM to operate at different programmable frequencies to reduce external component size. To do this with a DSP requires extremely high clock frequencies, external crystal and associated high-resolution A/D converters to get accuracy. The digital approach also suffers from quantization error issues. A fully programmable power supply with integrated non-volatile (NV) trimmed analog PWM controllers provides all the power management needed in any power system. This programmability allows high performance analog with <0.5% accuracy over process and temperature using a standard digital CMOS process with non-volatile analog trim at a substantially lower cost. Flexibility through NV programming/re-programming and configurable hardware functions with programmable analog parameters using a digital interface to the system and GUI development tools makes standardization easy to achieve. Because it is an analog function, high integration combines power delivery and regulation with the programmable power control.

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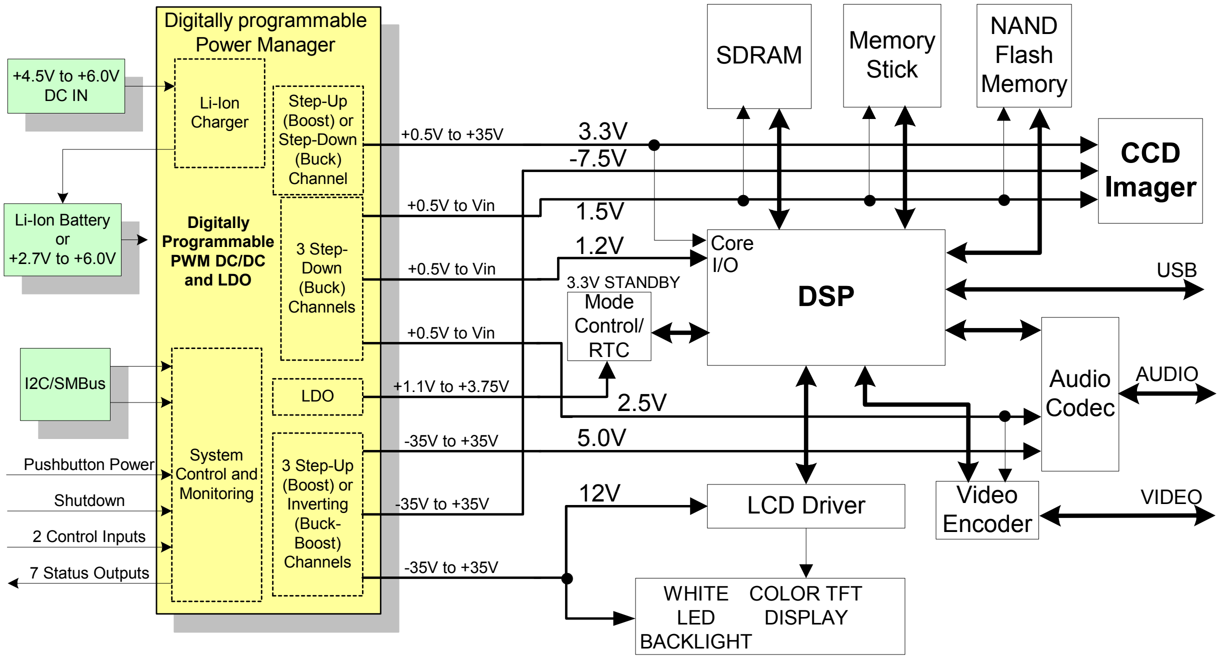
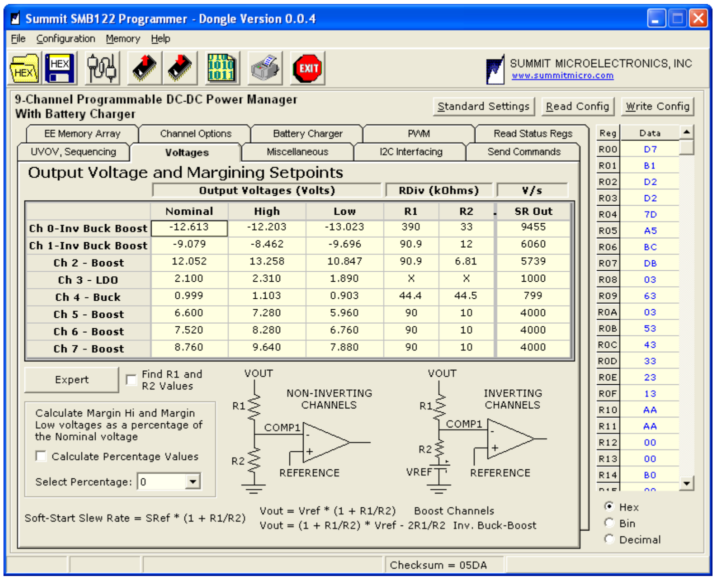


Figure 1 – Typical handheld power management system. Since the power manager is fully configurable, if the system blocks change, so can the manager. There are 8 voltage outputs, consisting of: three synchronous PWM "buck" step-down converters, one configurable PWM "boost or buck" converter, three configurable PWM "boost" step-up or inverting, one Low Dropout (LDO) linear regulator, and a fully programmable 1 or 2-cell Li-Ion battery charger.



9-Channel Programmable DC-DC Power Manager
With Battery Charger

Output Voltage and Margining Setpoints

	Output Voltages (Volts)			RDiv (kOhms)		V/s
	Nominal	High	Low	R1	R2	SR Out
Ch 0-Inv Buck Boost	-12.613	-12.203	-13.023	390	33	9455
Ch 1-Inv Buck Boost	-9.079	-8.462	-9.696	90.9	12	6060
Ch 2 - Boost	12.052	13.258	10.847	90.9	6.81	5739
Ch 3 - LDO	2.100	2.310	1.890	X	X	1000
Ch 4 - Buck	0.999	1.103	0.903	44.4	44.5	799
Ch 5 - Boost	6.600	7.280	5.960	90	10	4000
Ch 6 - Boost	7.520	8.280	6.760	90	10	4000
Ch 7 - Boost	8.760	9.640	7.880	90	10	4000

Reg	Data
R00	D7
R01	B1
R02	D2
R03	D2
R04	7D
R05	A5
R06	BC
R07	DB
R08	03
R09	63
R0A	03
R0B	53
R0C	43
R0D	33
R0E	23
R0F	13
R10	AA
R11	AA
R12	00
R13	00
R14	B0

☐ Find R1 and R2 Values

Calculate Margin Hi and Margin Low voltages as a percentage of the Nominal voltage

☐ Calculate Percentage Values

Select Percentage: 0

Soft-Start Slew Rate = SRef * (1 + R1/R2)

Vout = Vref * (1 + R1/R2) Boost Channels

Vout = (1 + R1/R2) * Vref - 2R1/R2 Inv. Buck-Boost

● Hex
○ Bin
○ Decimal

Checksum = 05DA

Figure 2 – Non-volatile Programmable Functions. All voltage levels and triggers are programmable using a Windows GUI and a PC-compatible parallel or USB port to I^{2}C serial bus programmer. Power management design is simplified and when power is removed, all settings are remembered

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How a Programmable power manager can be used in any handheld device

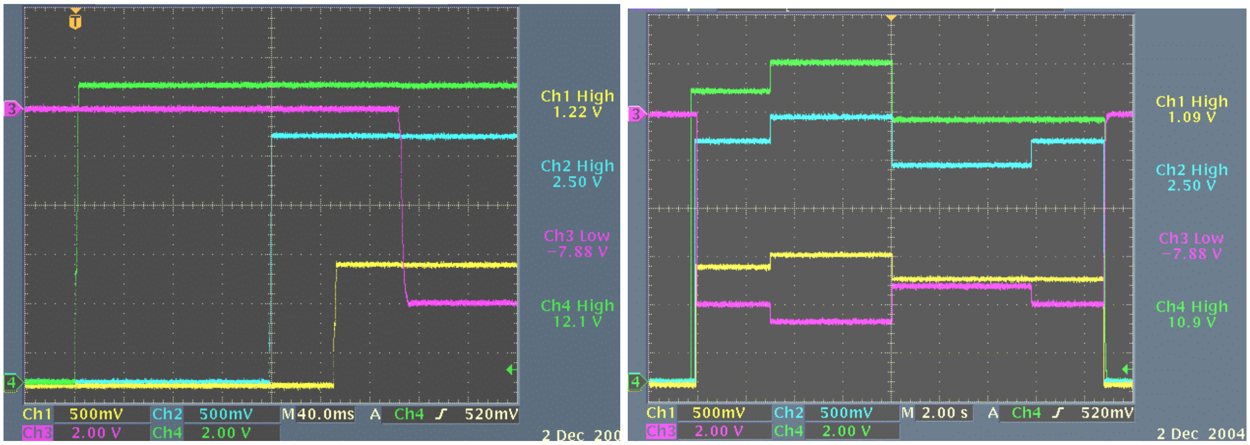
As shown in Figure 1, the mix of components in typical handheld applications varies significantly, making the borders between a cellular phone, a PDA, a media player and a portable gaming device blurry. With every component having different voltage and current requirements, it is also important to adjust all the “protection” functions. With varying voltage levels, the under- and over-voltage protection functionality and levels also need to be adjusted. Even the hardware-based logic level signals might need to be changed to “match” with other components on the board. Design challenges in portable designs and solutions that can enhance battery life must also keep up with system changes and performance enhancements. In order to meet this challenge, the trend is toward programmable multiple output DC-DC power management devices with digital control to allow simple software tailoring of output voltage levels and power sequencing requirements. Since system supply requirements change rapidly, a new “platform solution” that can change to meet any type of system power supply requirement eases the designer’s job. This can be achieved by specifying a power “block” that can be standardized over a wide variety of applications and then digitally configured to individual requirements. One of the major trends in power management for portable equipment is the fast adoption of inductor-based DC/DC converters. It was not long ago when designers were strongly opposing the utilization of switch-mode power supply ICs, especially in portable communications equipment. The main concerns are - and have always been – increased switching noise and higher complexity vs. designs based on linear regulators. However, the continuous “thirst” for higher performance and more features in hand-held devices has not been able to be “quenched” by higher battery capacities (for a given form factor), thereby putting pressure in the power supply circuit to use the available power more efficiently.

Typical switching regulators provide efficiencies of 85% to 95%, whereas linear regulators are efficient only when the input-to-output voltage differential or the required load current is small. Furthermore, most of the new digital chips (ASICs, DSPs, CPUs, etc.) are being manufactured at technologies that produce core voltage levels as low as 0.9V and with requirements for higher current levels. This introduces additional stringent requirements for power conservation, which can only be addressed by utilizing switching regulators or controllers for the most power hungry components.

Timing is another essential power control requirements in modern electronic designs. Multi-voltage DSPs, CPUs and FPGAs have stringent requirements in regards to which voltage needs to be powered up first, second, etc. It is not sufficient to take a passive role in the monitoring of the supply voltages. Many components have very strict requirements in terms of supply sequencing, (i.e., the core voltage must be valid before the I/O voltage is brought up), or differential tracking of the supplies (i.e., the core and I/O supplies must be ramped simultaneously with a small differential voltage allowed).

Additional constraints such as supply loading changes during system operation make a simple time-based sequencing implementation inadequate. Therefore, a supervisory function must be used to control many different functions from turning the supplies on to timing interval generation. Supply Sequencing simply turns on the regulators or converters, one after another, at a set time interval. This is the easiest way to ensure that the supplies are turned on in a specific order. A limitation of time-based supply sequencing is that it only controls the time that each supply begins to turn on. Based upon such factors as slew rate and loading, this may not guarantee an optimum sequence of the supplies reaching their valid voltages. Cascade sequencing is needed to ensure that the supplies are enabled a variable period of time after the previous voltage has reached its minimum valid level using feedback to ensure that each output is within specification before the next channel is enabled. Each succeeding voltage must reach its minimum valid level before the timer in the next sequence position is started; this condition guarantees that the programmable variable interval for the next voltage will be adhered to. Not until the timer has elapsed is the next supply enabled.

Modern power systems often require power-on/off cascade sequencing where each channel can be assigned to unique sequence positions (Figure 3). For maximum power savings supplies may also need to be individually powered on/off through an I^2C command or by assertion dedicated enable input pins. Each output should be slew rate limited by user programmable soft-start circuitry and should not require external capacitors. To ensure system reliability all output voltages should be monitored for under-voltage and over-voltage conditions. And in the event of a fault, all supplies should have the option to be sequenced off or immediately disabled. It is essential that an Undervoltage Lockout (UVLO) circuit be integrated into the power manager to ensure supplies will not power up until the input or battery voltage has reached a safe operating value. The UVLO function should always exhibit hysteresis; to ensure that noise on the supply rail does not inadvertently cause faults or otherwise compromise the control of the output supplies. In the event of a system fault, all monitored supplies may trigger fault actions such as power-off, or forced-shutdown operations.



Ch 1 (500mV/D) = 1.25V Buck (Yellow trace) Ch 2 (500mV/D) = 2.5V Buck (Blue trace)
Ch 3 (2V/D) = -7.5V Inverting Buck-Boost (Purple trace) Ch 4 (2V/D) = 12V Boost (Purple trace)

Figure 3: Power-on Cascade sequencing and Margin High/Low Waveforms. The supply channels are cascade sequenced-on to nominal voltage, margined high or low and then cascade sequenced-off. Channels 1, 2, 3, 4 are first margined high and then channels 2 and 3 are margined low. Up to 8 supplies are controlled.

Configurability

To make it possible for the power manager to be adaptable to numerous systems, several channels have configurable topology as well as voltage level. This makes it possible to design a standard platform the can change with requirements as needed. Figure 4 shows the one Step-Down (Buck) channel that can also be configured as a Step-Up (Boost) channel. Figure 5 shows how the three Step-Up channels can also be configured as inverting buck-boost channels and Figure 6 shows the three buck channels. There is one LDO regulator with separate input and programmable output voltage and a Programmable Li-Ion battery charger. A programmable debounced input that can be used as push-button input that powers up select converters. Programmable to allow any number of converters to be enabled when asserted, Programmable as a power on/off pin. A selectable PFM mode for light load conditions (ensures high efficiency when the load is low) and selectable 500, 750 and 1MHz PWM frequency to balance efficiency with component size and noise reduction. The integrated oscillator is based on a selectable 6 or 8 phase PLL that can be synchronized with an external clock. Each channel can be assigned to any 45 or 60-degree phase position and can be configured for a spread spectrum output. Additional requirements include current limiting for Step-Down & Step-Up channels, UV/OV and thermal protection. True shutdown mode (<1uA) and power saving automatic PFM mode, 96 bytes of user configurable nonvolatile memory programmable slope compensation ramp highly accurate reference and output voltage (<0.5%) with Active DC Output Control (ADOC™) technology the three Step-down channels have integrated P-FETs (Figure 4)

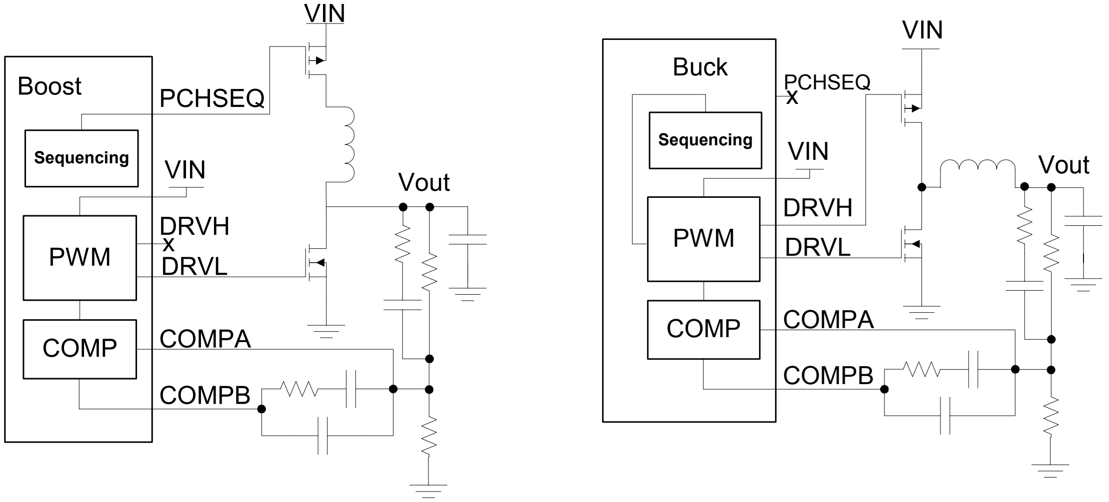


Figure 4 – One channel can be configured as either a buck or boost with minimal external component changes and a software selection as shown in Figure 7.

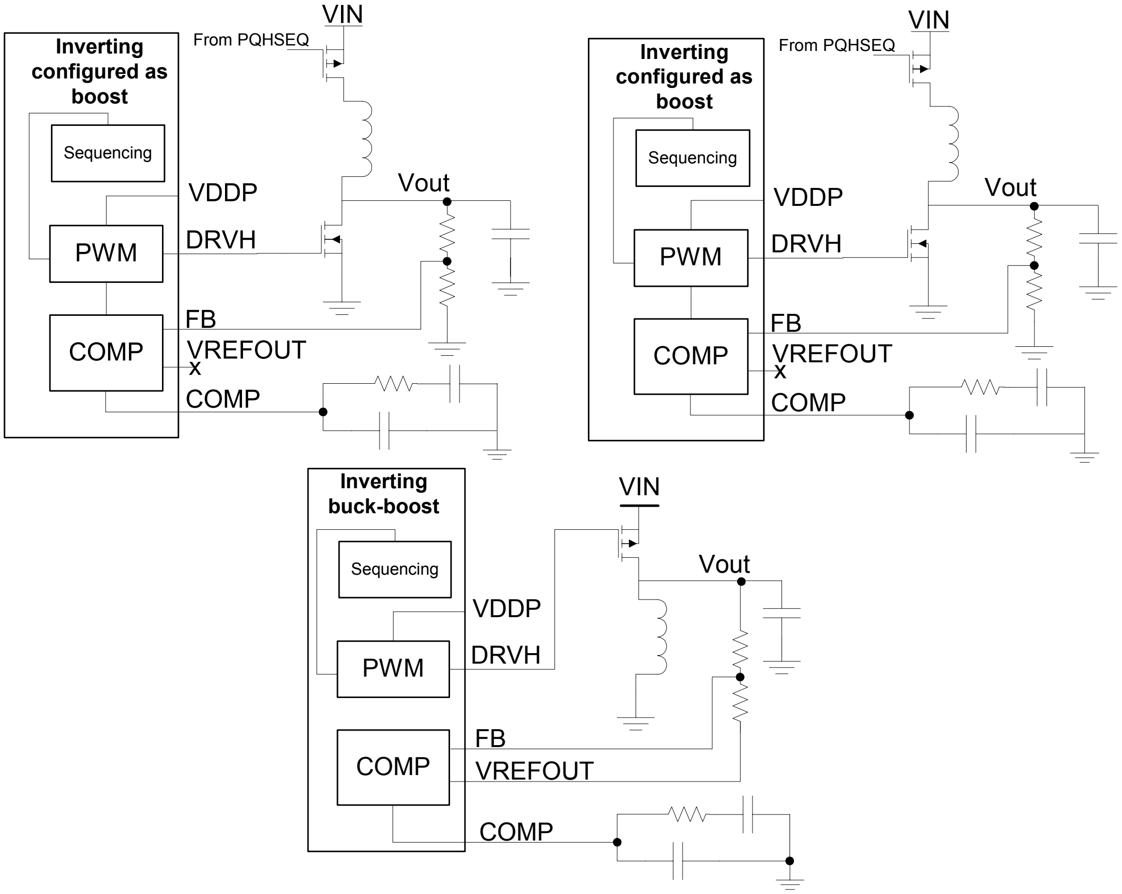


Figure 5 - Three channels can be configured as either boost or inverting or inverting buck-boost with minimal external component and software changes (Fig 7).

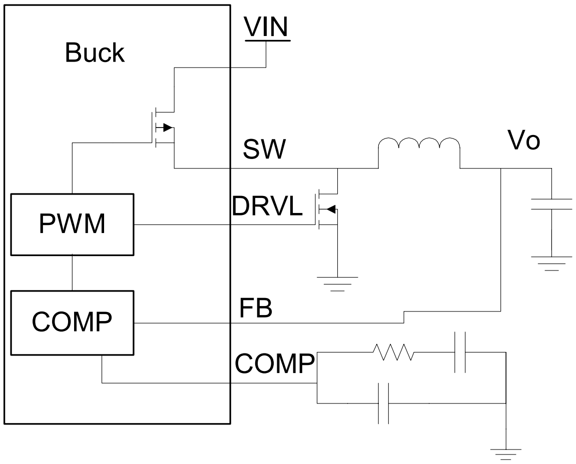
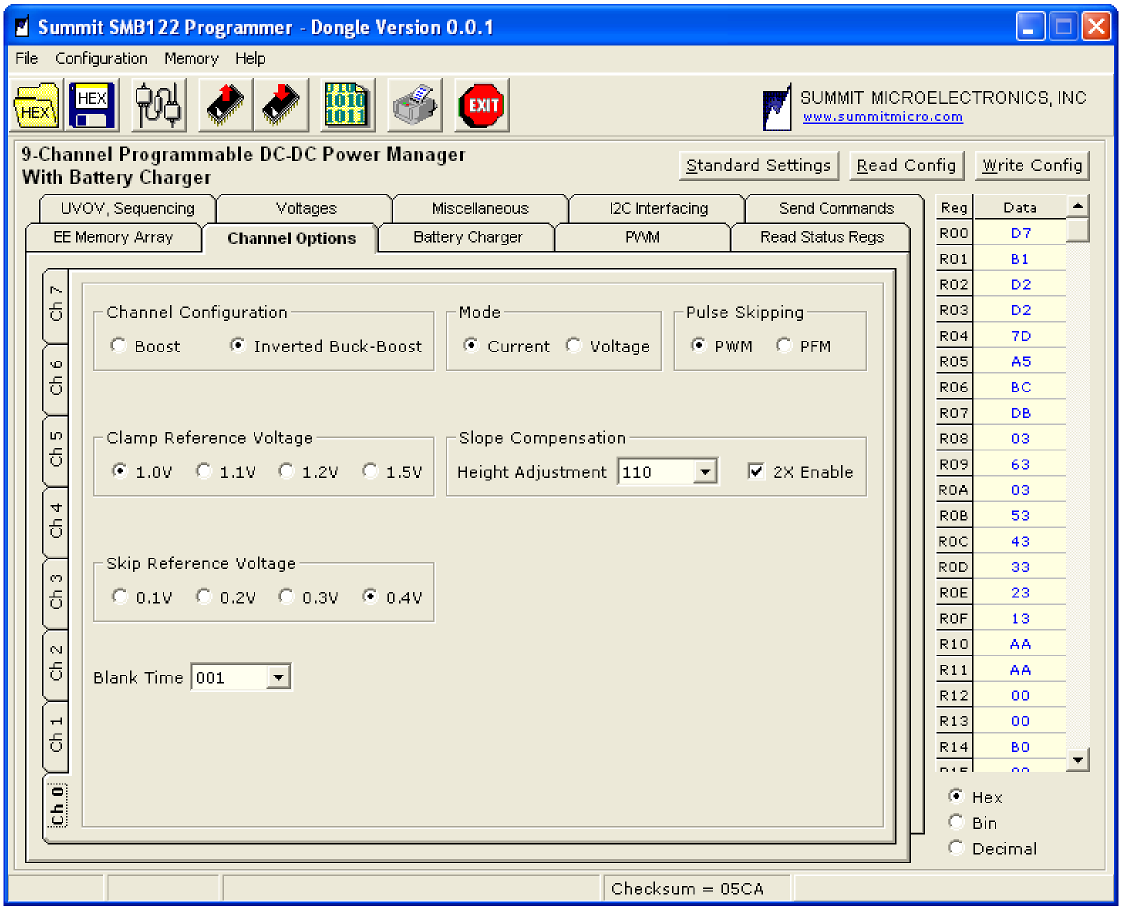


Figure 6 – The three Buck channels are current mode with internal PMOS power FETs, programmable internal resistor dividers, programmable converter reference voltage, programmable current limit programmable PWM to PFM crossover current, programmable slope compensation ramp and programmable "dead time".



9-Channel Programmable DC-DC Power Manager
With Battery Charger

Channel Configuration: ○ Boost ● Inverted Buck-Boost
Mode: ● Current ○ Voltage
Pulse Skipping: ● PWM ○ PFM
Clamp Reference Voltage: ● 1.0V ○ 1.1V ○ 1.2V ○ 1.5V
Slope Compensation: Height Adjustment 110 ☑ 2X Enable
Skip Reference Voltage: ○ 0.1V ○ 0.2V ○ 0.3V ● 0.4V
Blank Time 001

Reg	Data
R00	D7
R01	B1
R02	D2
R03	D2
R04	7D
R05	A5
R06	BC
R07	DB
R08	03
R09	63
R0A	03
R0B	53
R0C	43
R0D	33
R0E	23
R0F	13
R10	AA
R11	AA
R12	00
R13	00
R14	B0

● Hex
○ Bin
○ Decimal

Checksum = 05CA

Figure 7 – Software selection changes channel topology.

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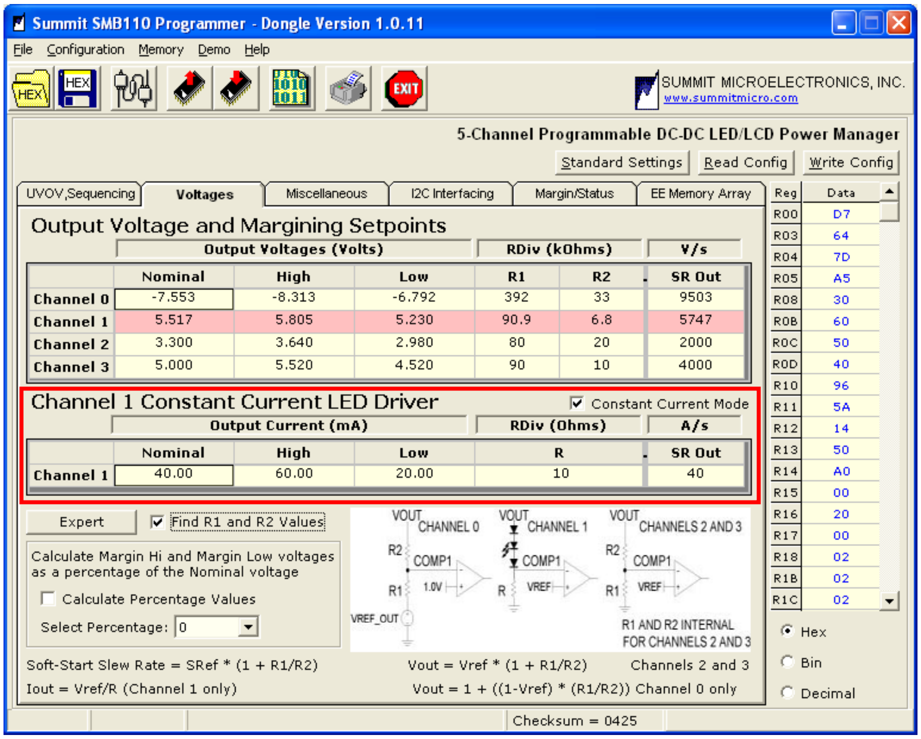
In portable applications powered from a main system battery the battery voltage must be continuously monitored for under-voltage conditions to ensure a graceful system shutdown when power loss is eminent. This often requires two levels of battery monitoring; one to issue a low battery warning, and another to save system data before power loss.. In addition, it is often desirable to disable all non-critical channels and latch them off after the first battery threshold has been reached. This ensures that as the depleted battery's voltage rises, due to decreases load, that the system will not re-enable the supplies.

Dynamic voltage margin control of all output voltages through an I^2C command by any percentage of the nominal output voltage is included. Margining creates three pre-programmed voltage settings that each channel can be set to via an I^2C command. Margining is ideal when used with a channel configured as an LED driver where margining provides three brightness settings. In addition, each output is slew rate limited by digital soft-start circuitry that is user programmable and requires no external components. Margining is also used to provide dynamic voltage management for processors that can benefit from changing core voltages. Margining creates three pre-programmed settings that each channel can be set to via an I^2C command. All outputs can be margined over the same programmable range that each channel is able to attain. Margining is ideal when used with a channel configured as an LED driver (Figure 6) where it provides three unique brightness settings (Figure 6). Because of the flexibility of the part, the LEDs can be configured in series for uniform brightness or in parallel for individual brightness control. In the example depicted below, up to 10 LEDs can be driven from the boost channel.



5-Channel Programmable DC-DC LED/LCD Power Manager

Output Voltage and Margining Setpoints

	Output Voltages (Volts)			RDiv (kOhms)		V/s
	Nominal	High	Low	R1	R2	SR Out
Channel 0	-7.553	-8.313	-6.792	392	33	9503
Channel 1	5.517	5.805	5.230	90.9	6.8	5747
Channel 2	3.300	3.640	2.980	80	20	2000
Channel 3	5.000	5.520	4.520	90	10	4000

Channel 1 Constant Current LED Driver

☑ Constant Current Mode

	Output Current (mA)			RDiv (Ohms)	A/s
	Nominal	High	Low	R	SR Out
Channel 1	40.00	60.00	20.00	10	40

☑ Find R1 and R2 Values

Calculate Margin Hi and Margin Low voltages as a percentage of the Nominal voltage

☐ Calculate Percentage Values

Select Percentage: 0

Soft-Start Slew Rate = SRef * (1 + R1/R2)

Iout = Vref/R (Channel 1 only)

Vout = Vref * (1 + R1/R2) Channels 2 and 3

Vout = 1 + ((1-Vref) * (R1/R2)) Channel 0 only

Reg	Data
R00	D7
R03	64
R04	7D
R05	A5
R08	30
R0B	60
R0C	50
R0D	40
R10	96
R11	5A
R12	14
R13	50
R14	A0
R15	00
R16	20
R17	00
R18	02
R1B	02
R1C	02

● Hex
○ Bin
○ Decimal

Checksum = 0425

Figure 8 –The margin High and Low values are pre-programmed and a simple I^2C command raises and lowers the LED Brightness.

When configured as a constant current LED driver the step up boost output automatically servos the output voltage so that the current passing through the LED chain is equal to the current flowing through the resistor attached to the COMP1 pin. The LED circuit (Fig. 9) is capable of driving 10 White LEDs with a maximum current, limited by the LEDs, of approximately 30mA. In addition, each output is slew rate limited by digital soft-start circuitry that is user programmable and requires no external capacitors. All programmable settings are stored in non-volatile registers and are easily accessed and modified.

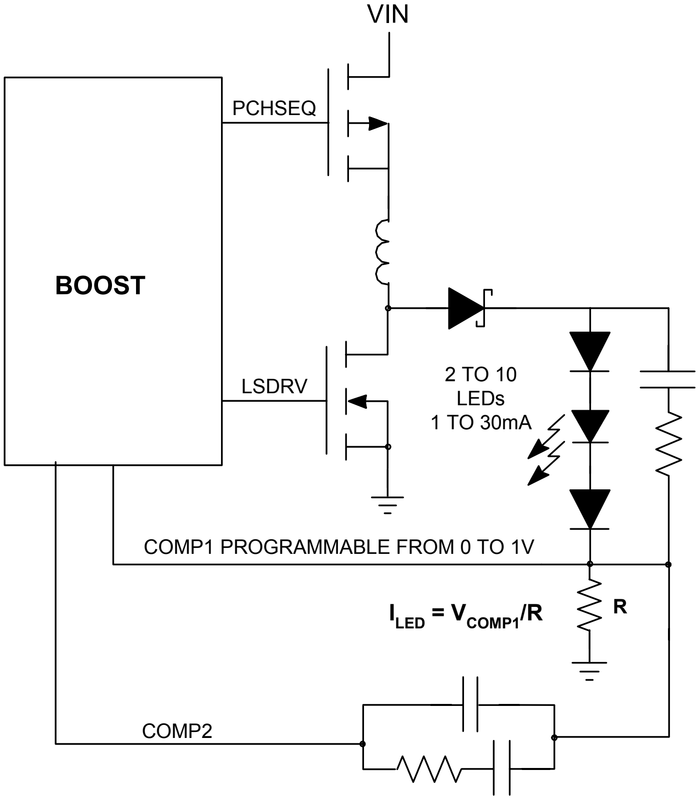


Figure 9 – Detail schematic showing the LED drive, up to 10 LEDs can be connected in series with programmable brightness control through the I^{2}C bus.

Battery Charger

The integration of a fully equipped programmable lithium ion battery charger is essential for any high integration power manager. The programmable feature set should include fast and pre-charge options, each with a programmable charge current level, a charge termination timeout period, an over and under temperature limit, multiple allowable recharge events, fault logging that can be accessed via the I^{2}C interface and a general purpose output used to indicate the current status of the battery. The battery-charging event should be initiated by the detection a DC voltage on a dedicated voltage monitoring input. When the voltage on this input exceeds the programmed minimum threshold battery charging should automatically commence. However, a programmable option should be included to prevent battery charging until an I^{2}C command has been issued.

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Lithium ion (Li-Ion) battery chargers require three charging modes for optimal performance and safety. These modes of operation include a limited current pre-charge mode for when the battery is heavily discharged, a fast-charge high-current mode, and a constant voltage trickle charge mode (Figure 10). When the lithium ion battery is heavily discharged, battery charging should commence with a limited battery charging current. The pre-charge float voltage should be programmable with a wide range of charging currents to accommodate different types of batteries. The pre charge current should also be programmable. After the pre-charge float voltage has been exceeded, the battery charging current should be increased from the pre-charge current to the fast charge current. The fast charge current should be programmable, and the final float voltage should be able to accommodate new higher capacity Lithium ion batteries with larger float voltages.

Once the final float voltage has been exceeded, the battery charger should optionally enter a constant voltage mode in which the battery voltage is kept constant, allowing the charge current to gradually taper off. The constant voltage-charging mode should continue until the charge current drops below the termination current threshold.

A temperature sensing input is necessary to prevent excessive battery temperatures during charging. The temperature monitoring circuitry should accommodate all different internal resistances and disable battery charging until the battery voltage has fallen within the safe operating range.

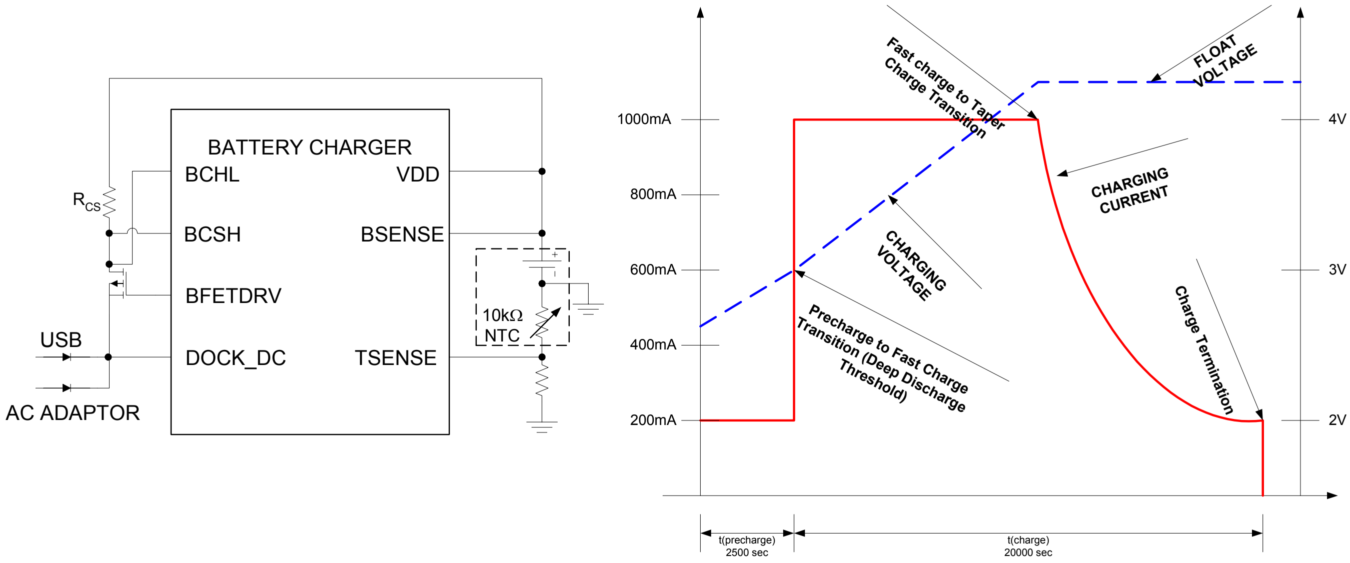
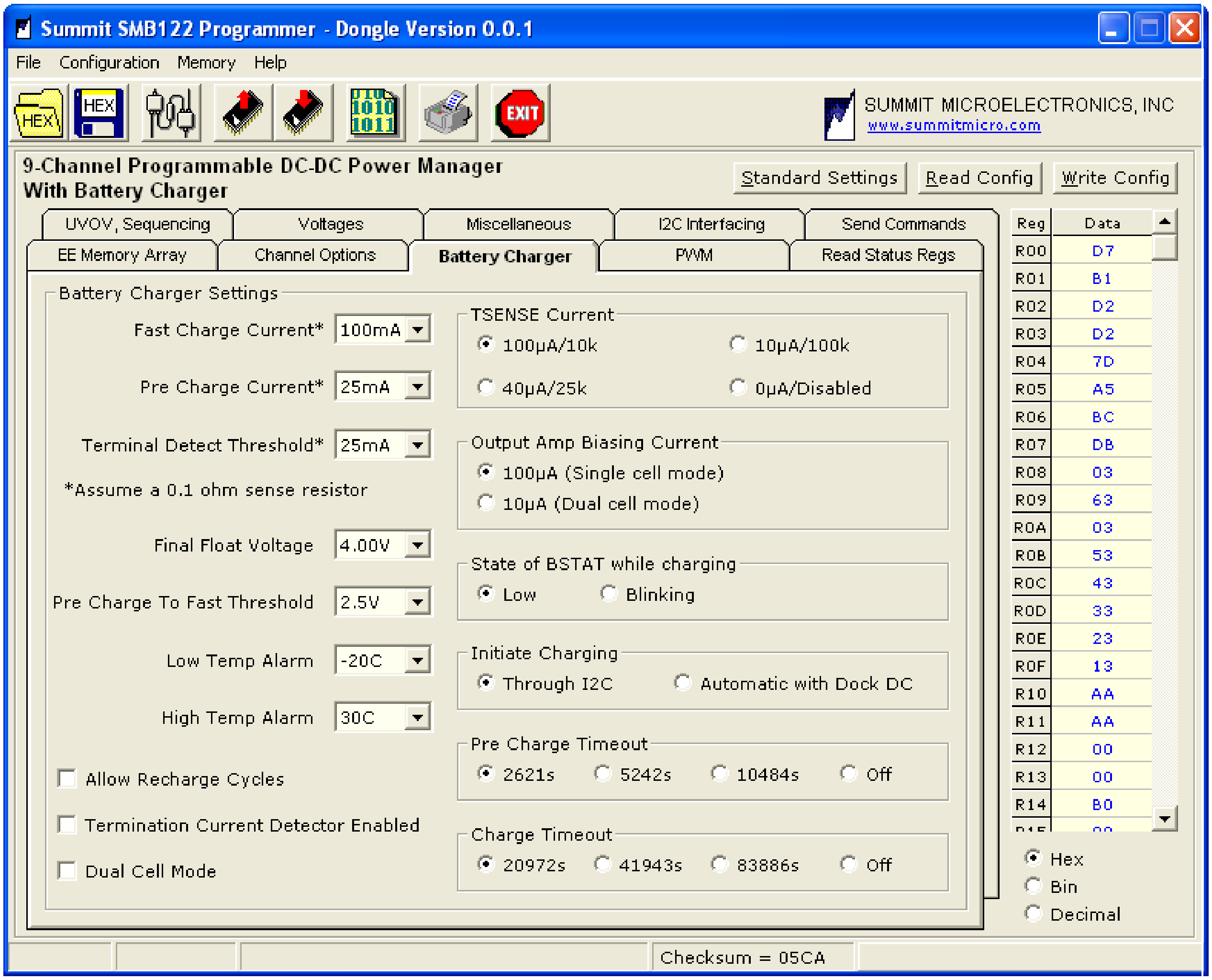


Figure 10 - A Programmable Linear 1or 2-cell Li-Ion Battery Charger provides multiple recharge cycles from registers containing all information about the battery-charging algorithm. There are programmable options such as final float voltage, charge current, precharge Current, fast charge voltage, Fast Charge Current, Float Voltage (0.5%), Term. Charge Current, OT/UT thresholds and Charge timers.



9-Channel Programmable DC-DC Power Manager
With Battery Charger

Battery Charger Settings

Fast Charge Current* 100mA
Pre Charge Current* 25mA
Terminal Detect Threshold* 25mA

*Assume a 0.1 ohm sense resistor

Final Float Voltage 4.00V
Pre Charge To Fast Threshold 2.5V
Low Temp Alarm -20C
High Temp Alarm 30C

☐ Allow Recharge Cycles
☐ Termination Current Detector Enabled
☐ Dual Cell Mode

TSENSE Current
● 100µA/10k ○ 10µA/100k
○ 40µA/25k ○ 0µA/Disabled

Output Amp Biasing Current
● 100µA (Single cell mode)
○ 10µA (Dual cell mode)

State of BSTAT while charging
● Low ○ Blinking

Initiate Charging
● Through I2C ○ Automatic with Dock DC

Pre Charge Timeout
● 2621s ○ 5242s ○ 10484s ○ Off

Charge Timeout
● 20972s ○ 41943s ○ 83886s ○ Off

Reg	Data
R00	D7
R01	B1
R02	D2
R03	D2
R04	7D
R05	A5
R06	BC
R07	DB
R08	03
R09	63
R0A	03
R0B	53
R0C	43
R0D	33
R0E	23
R0F	13
R10	AA
R11	AA
R12	00
R13	00
R14	B0

● Hex
○ Bin
○ Decimal

Checksum = 05CA

Figure 11 – Programmable Battery charger options

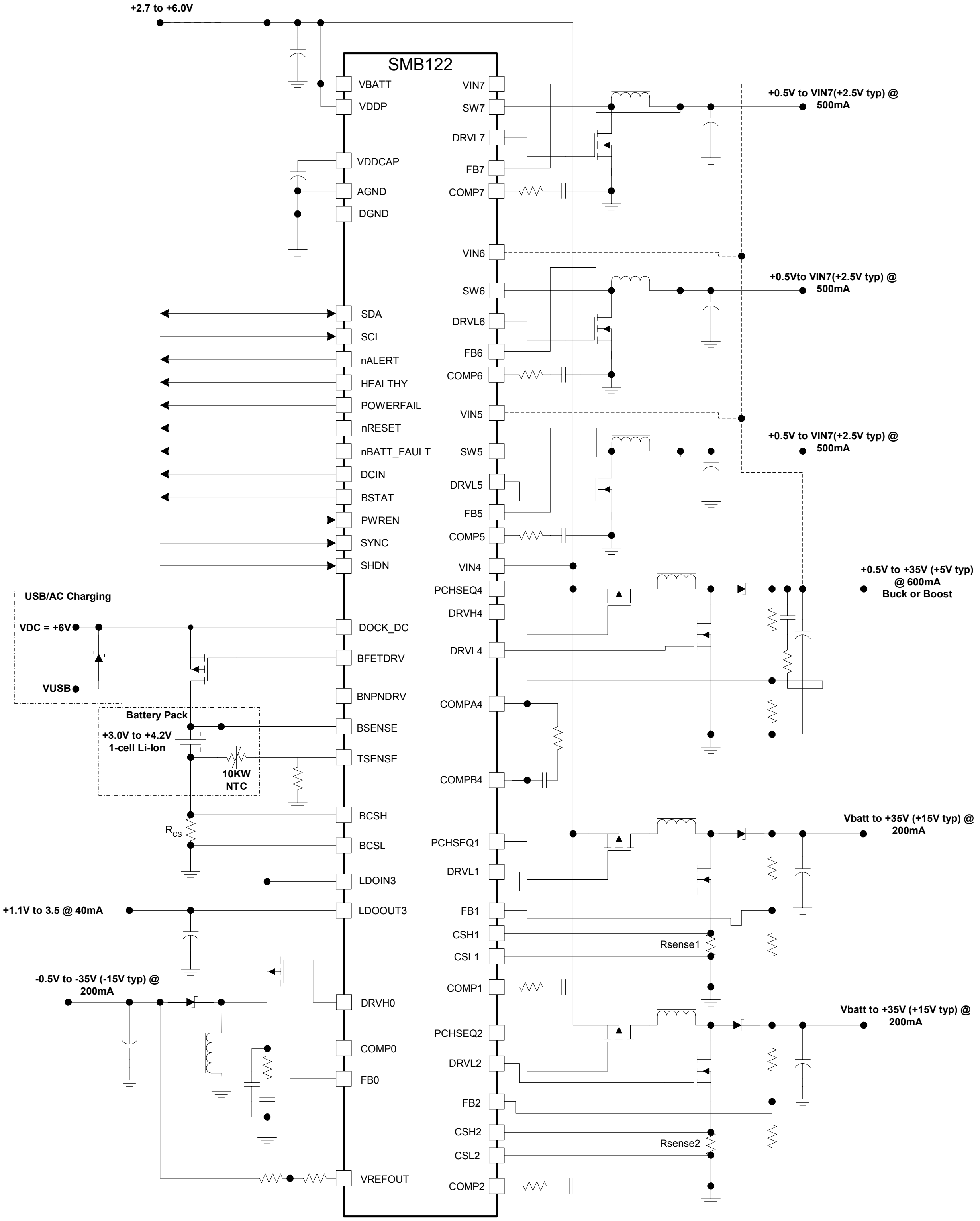


Figure 12 – Reference schematic showing external circuitry necessary to configure the output channels as: step-up, LDO, step-down, inverting outputs and battery charger.

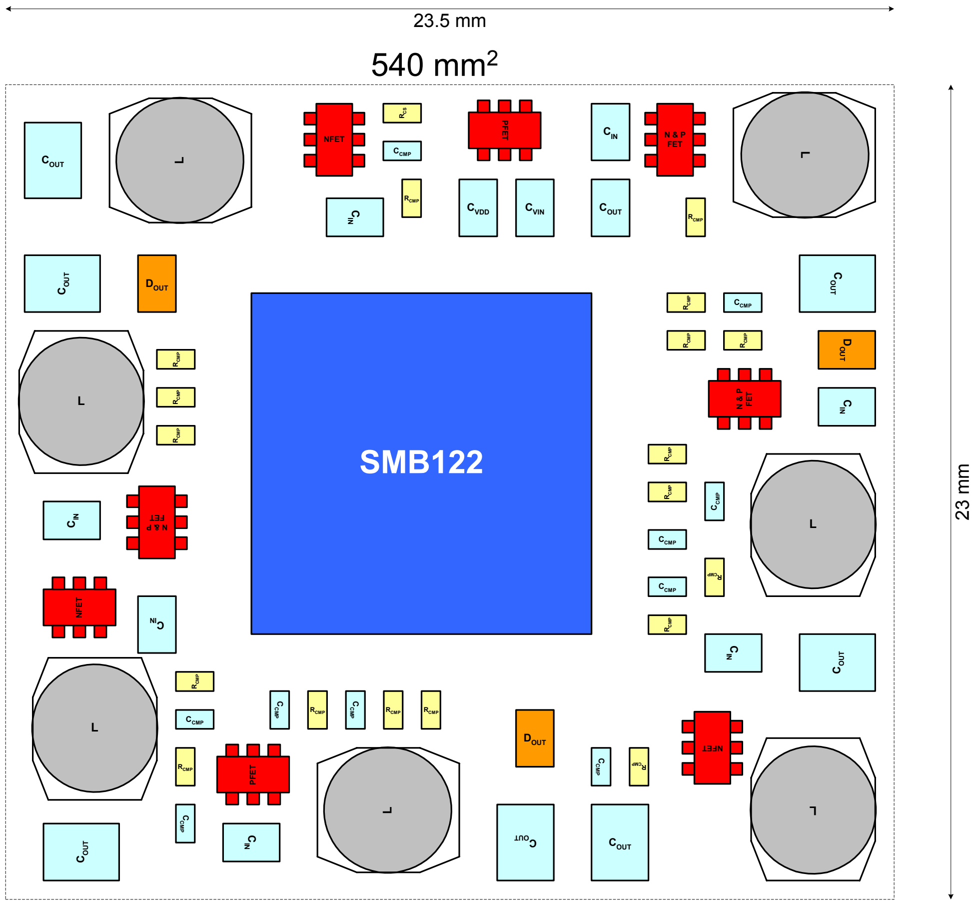


Figure 13 - Reference layout of the power subsection for 8 fully managed output channels + battery charging ~540mm^2

Power consumption is not the only concern in hand-held equipment. Trying to squeeze all the new features in continuously decreasing board spaces poses a tremendous challenge, especially with consumers demanding no compromises in user experience. Power management ICs are also increasingly integrating more functions in smaller packages, both in terms of DC/DC conversion channels and power control functionality (Figure 13). Naturally, the integration of more power conversion channels results in a significant higher power dissipation in a single package, introducing additional design concerns. Latest packaging technology, like leadless QFN, offer the ability to accommodate large die sizes and at the same time dissipate power very efficiently, especially when the bottom pad is soldered on the board.

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Conclusion

New digitally programmable power supplies provide I^2C programmable output voltages, Power on and off sequencing, Individual supply enable control, Battery monitoring and charging, UV and OV monitoring on PWM outputs, Margining/LED backlight level, Slew rate control and programmable power on/off sequencing. . Actively controlling DC output voltage levels to within ±0.5% under low to high line/load to meet stringent tolerance requirements of high performance components further extends reliable operation. Margining supplies tests system performance goals as well as providing an easy way to make adjustments, such as brightness and volume. The integration of active accuracy control, programmable features and built-in flexibility allows the system designer to create a "platform solution" that can be easily modified via software without major hardware changes. Combined with re-programmability, this facilitates rapid design cycles and the proliferation from a base design to future generations of product.

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