IXYS Digital Power

Digital Control of Surge Voltage and Inrush Current in Battery Operated Circuits

Design File

IXAN0080-0217

Contents

Design Summary

Title	**Digital Control of Surge Voltage and Inrush Current in Battery-Operated Devices**
Specifications	(i) Load protection from Surge voltage up to +150V (ii) Nominal load current 0–20A (iii) Inrush and short circuit current limit 30A (iv) Load over-voltage threshold programmable in the range 12–60V (v) Efficiency in the idle state with nominal 20 A current and 24 V output voltage is 99%, which becomes 98% at 12 V and 99.5% at 48 V output voltage respectively
Date	February 09, 2017
Version	1.0

Digital Control of Surge Voltage and Inrush Current in Battery-Operated Circuits

Design File
IXAN008001-0217

Overview

Primary concerns with battery-operated devices include battery protection from inrush and short circuit currents caused by connected load, and load protection from voltage spikes when battery *load dump* occurs, which may cause significant voltage stress on electronic devices sharing the same battery as high current consumers.

Digital control allows designers to significantly simplify the design of protection devices, providing greater flexibility than hardware-only solutions. The device described in this application note is an example of implementing Zilog's Z8F3281 microcontroller in power control.

This design, shown in Figure 1, is intended to protect the battery from the inrush current and short circuitry at the load, and protect the load from voltage spikes from the battery, which are usually generated by fast battery load changing.

Figure 1: Assembled Surge Voltage and Inrush Current Protector (Not to Scale)

Description

The nominal load current is 0–20 A with the inrush/short circuit limit set at 30 A. This value is determined by the inductor and can be adjusted downward by increasing the value of the current sense resistors, if required.

Surge voltage protection is up to +150 V, which is limited by the MOSFET. The nominal output voltage is programmable in the range of 12–48 V, either by an MCU or external resistive divider. Efficiency in the idle state with nominal 20 A current and 24 V output voltage is 99%, which becomes 98% at 12 V and 99.5% at 48 V output voltage respectively. The current consumption from auxiliary power supplies is 6 mA from a 3.3 V source to power the MCU and 8 mA from a +15 V source to power the driver in switching mode, or 6 mA in standby (event waiting) mode.

This device consists of two blocks – a Main Board (size 3.6” x 2.6” x 1.6”) with power components (see electrical schematic in Figure 2) and a Microcontroller Unit (MCU) Board (size 1.3” x 1” x 0.5”), which operates the device (see Figure 3). The boards’ layouts and bills of material are provided in Appendix A and Appendix B respectively.

This device utilizes buck converter architecture and operates with a 100% duty cycle if the load current and output voltage is in the programmed range. If either load current or output voltage goes above the preset limit, the duty cycle becomes less than 100% and automatically adjusts to keep both output voltage and current at the programmed limit.

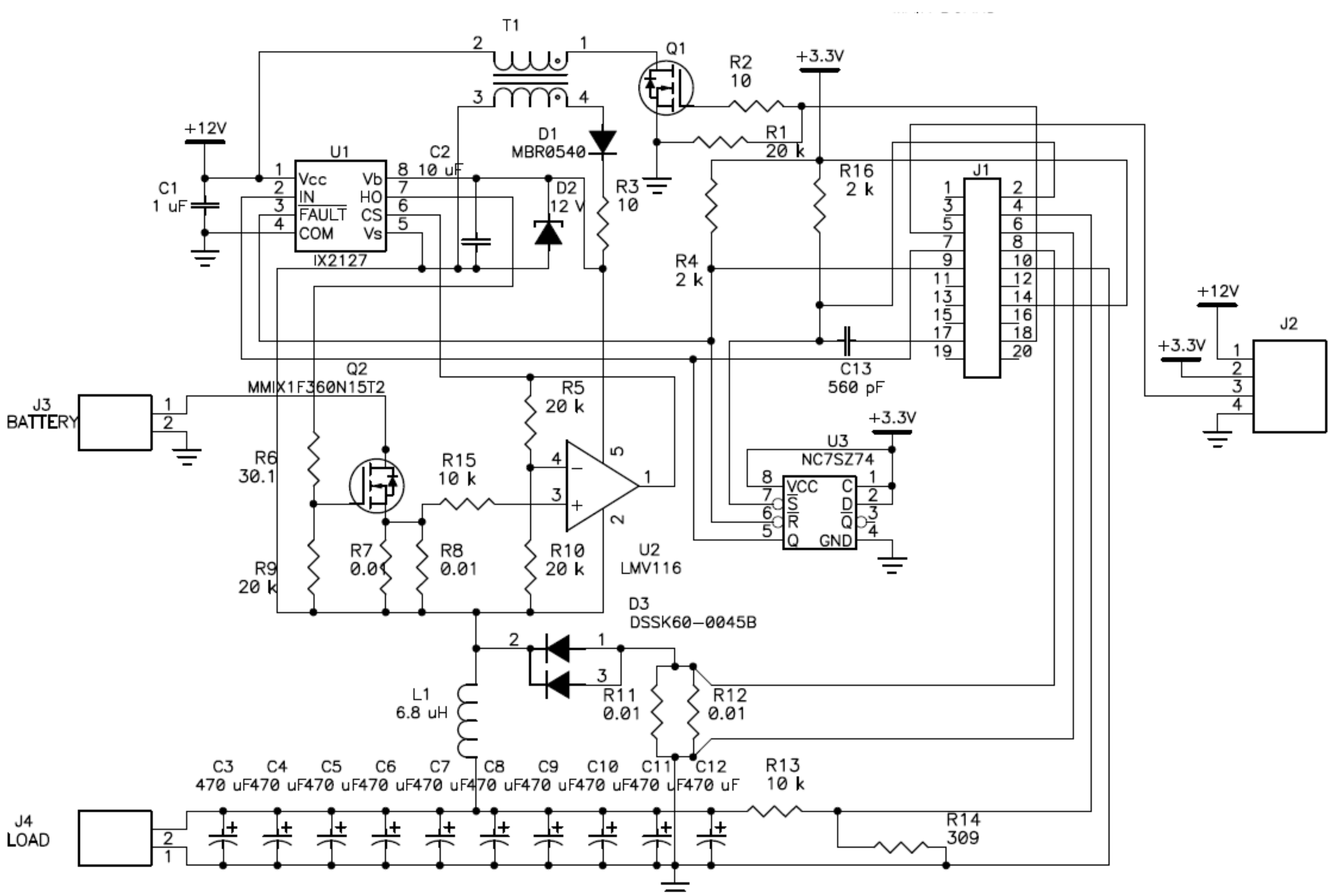


Figure 2: Main Board Circuit Schematic Diagram

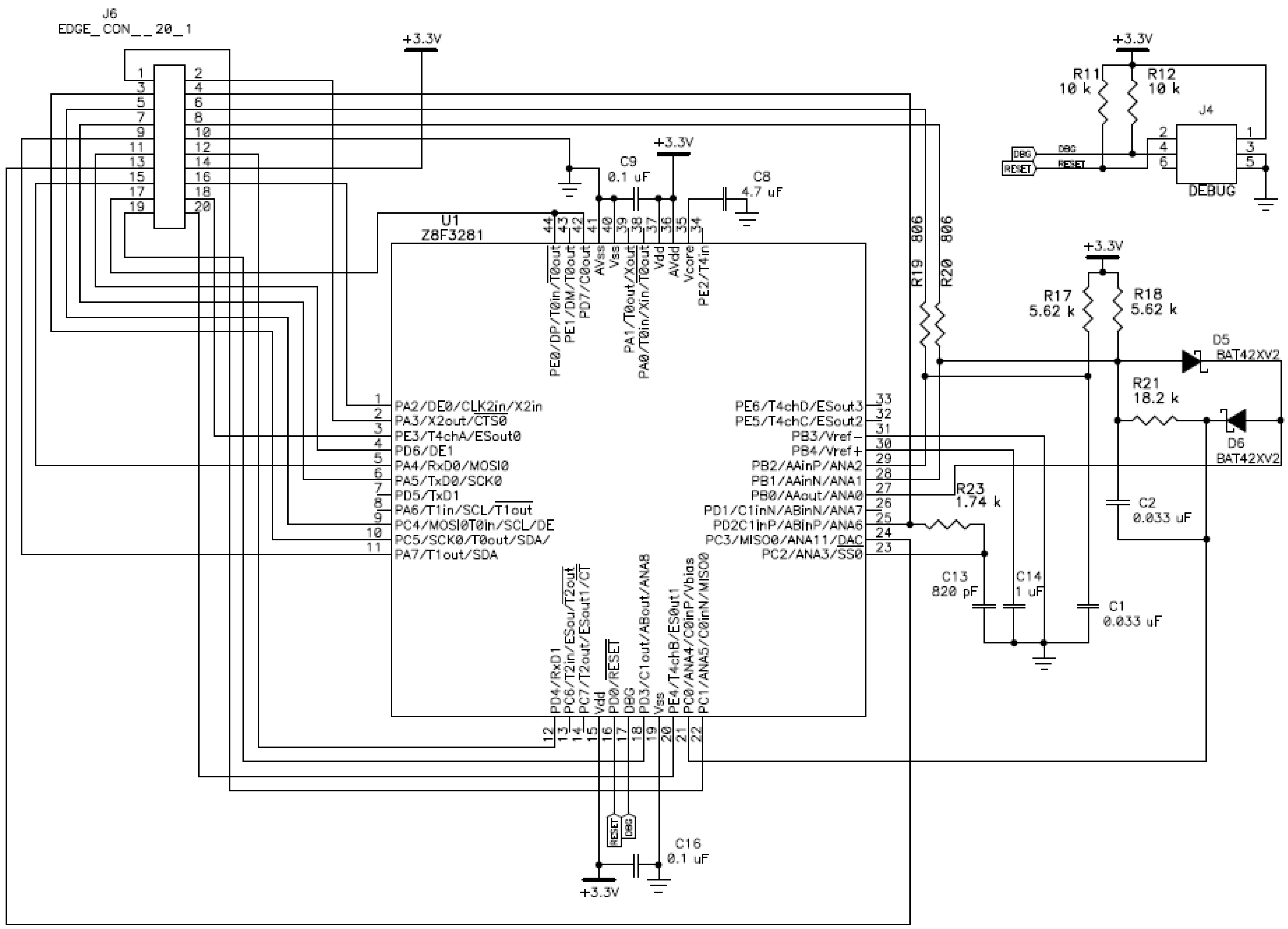


Figure 3: MCU Board Circuit Schematic Diagram

Principles of Operation

After MCU power-up, it provides clock to the flyback converter's MOSFET Q1, which pumps energy into the secondary winding of transformer T1 to drive high side driver U1 IX2127. After some delay, which is required to store energy in the secondary circuitry, the MCU turns on major switch Q2, which connects the power source to the output.

The typical sequence of operations is shown in Figure 4.

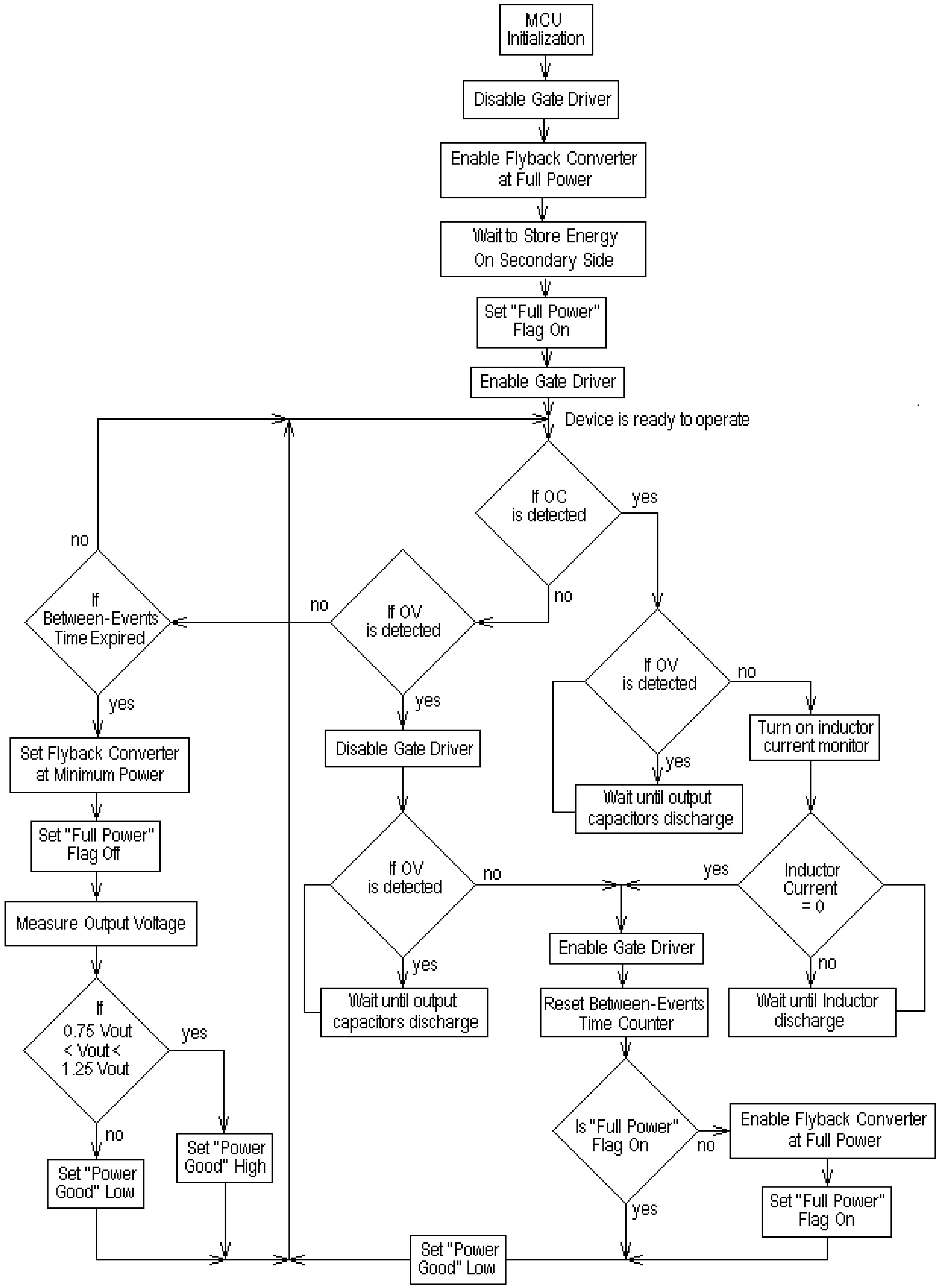
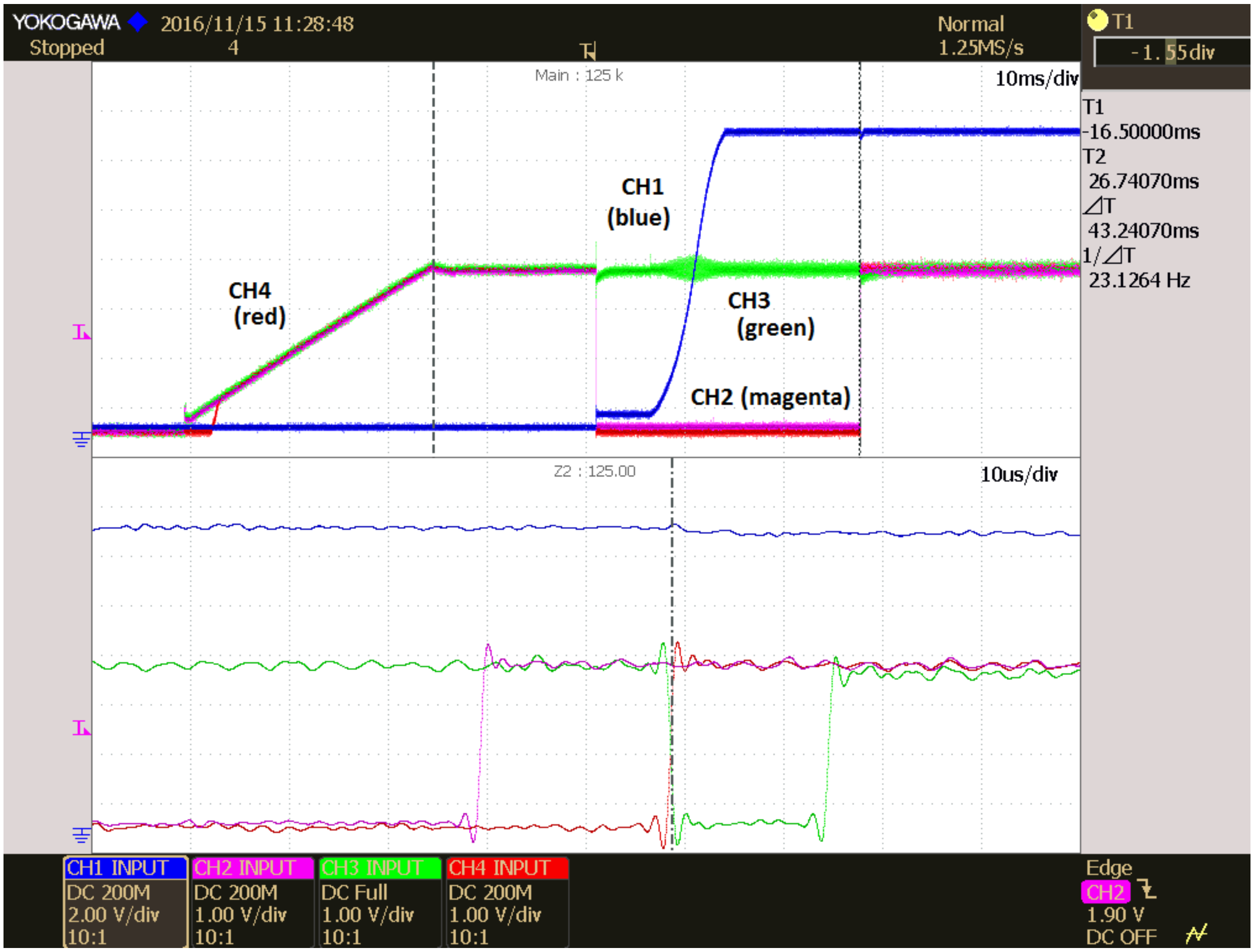


Figure 4: Operation Flow Chart

Figure 5 shows the typical start-up signal sequence. The device initialization process takes approximately 45 ms. The lower part of the image represents the magnified portion of the upper side with the reset, set, and driver input signals timing sequence. The trigger's reset input voltage (green) is forced by MCU logic low to disable the gate driver (blue) and let the secondary side voltage (yellow) rise to nominal value. After timeout, the trigger's reset signal is removed and the set signal (red) from the MCU is applied to turn the gate driver on.

The device remains in this state as long as an event such as Over-current (OC) or Over-voltage (OV) does not occur.



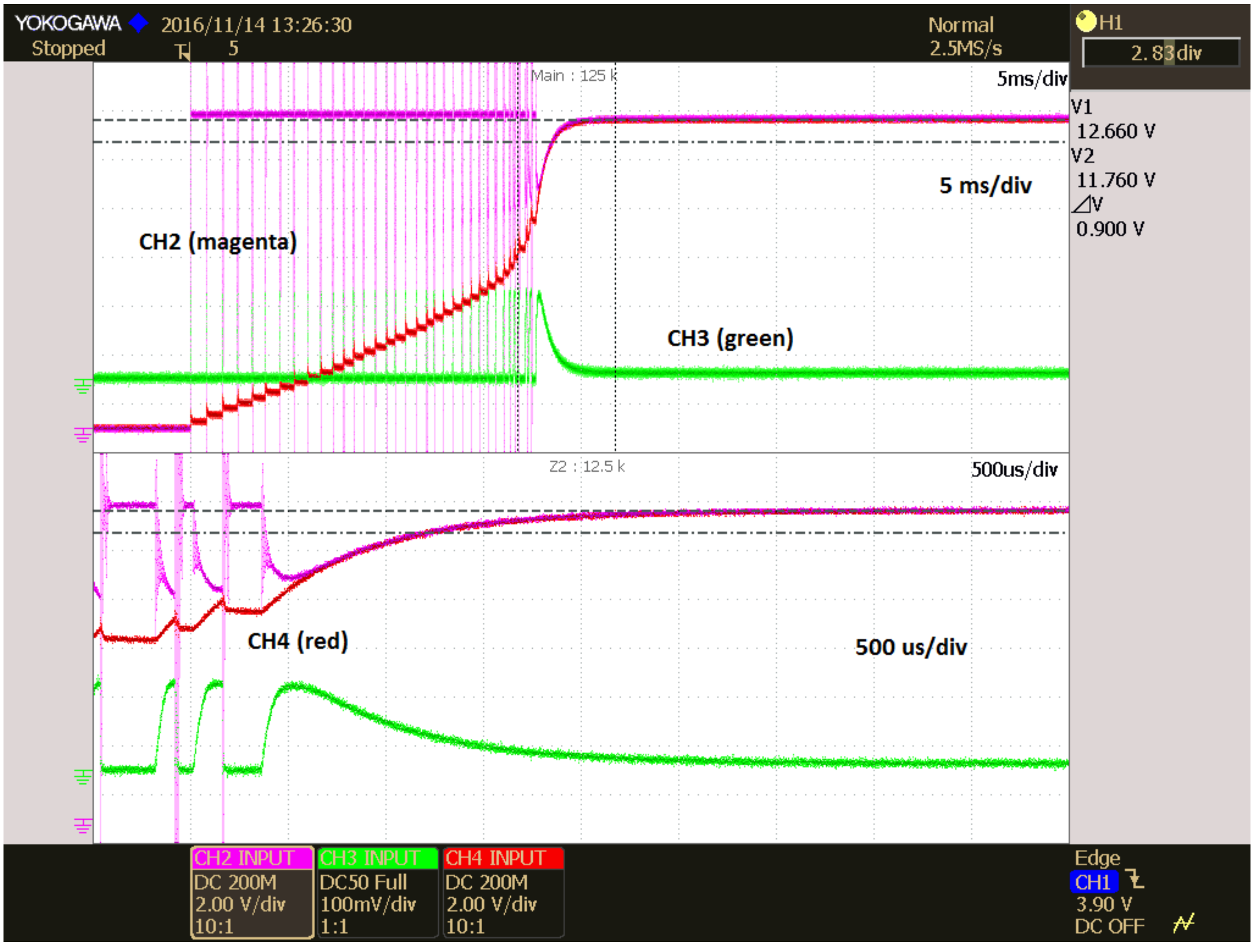
Legend: Channel 1 (blue) secondary side voltage, Channel 2 (magenta) – trigger U3 "reset" signal Channel 3 (green) – trigger U3 "set" signal, Channel 4 (red) – driver's U1 input signal

Figure 5: Typical Start-up Signal Sequence

If the battery current exceeds the threshold set by current sensing resistors R7, R8, the driver's U1 comparator sets FAULT output logic low and flips trigger U3, which turns Q2 off, allowing the inductor's current charge output capacitors through diode D3. The MCU monitors the inductor's current using current sense resistors R11, R12. When the inductor's current falls to zero, the MCU turns Q2 on again to repeat the charging cycle. However, if output voltage becomes higher than the threshold set by OV protection on the MCU comparator, Q2 remains in Off state until the output voltage falls below the threshold (including hysteresis), after which the charging cycle repeats.

Operational amplifier U2 is used to minimize power dissipation on current sense resistors R7, R8 by multiplying the signal by two. If the battery current does not exceed the OC threshold, Q2 will remain in On state as long as either this current goes above the threshold or the output voltage goes above the OV threshold.

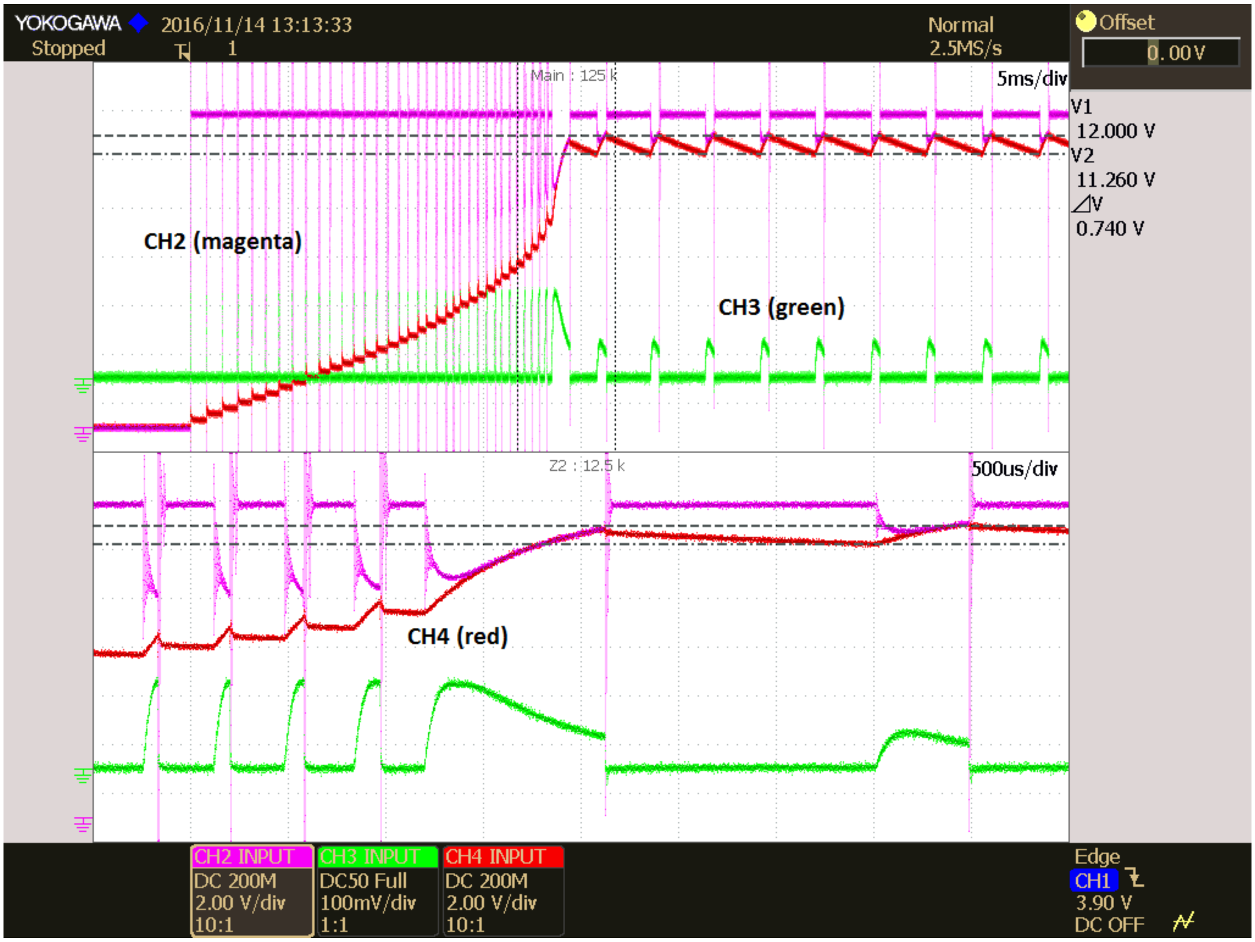
Figure 6 shows typical device performance with inrush current limiting, when no over-voltage is detected. The device starts with inrush current limit and continues as a buck converter with a 100% duty cycle, because the input voltage is below the output voltage limit. The lower side of the image demonstrates the magnified portion of the upper side image with transition from inrush current limit to normal operation mode.



Legend: Channel 2 (magenta) – battery voltage, Channel 3 (magenta) battery current, Channel 4 (red) – output voltage

Figure 6: Typical Device Performance with Inrush Current Limiting

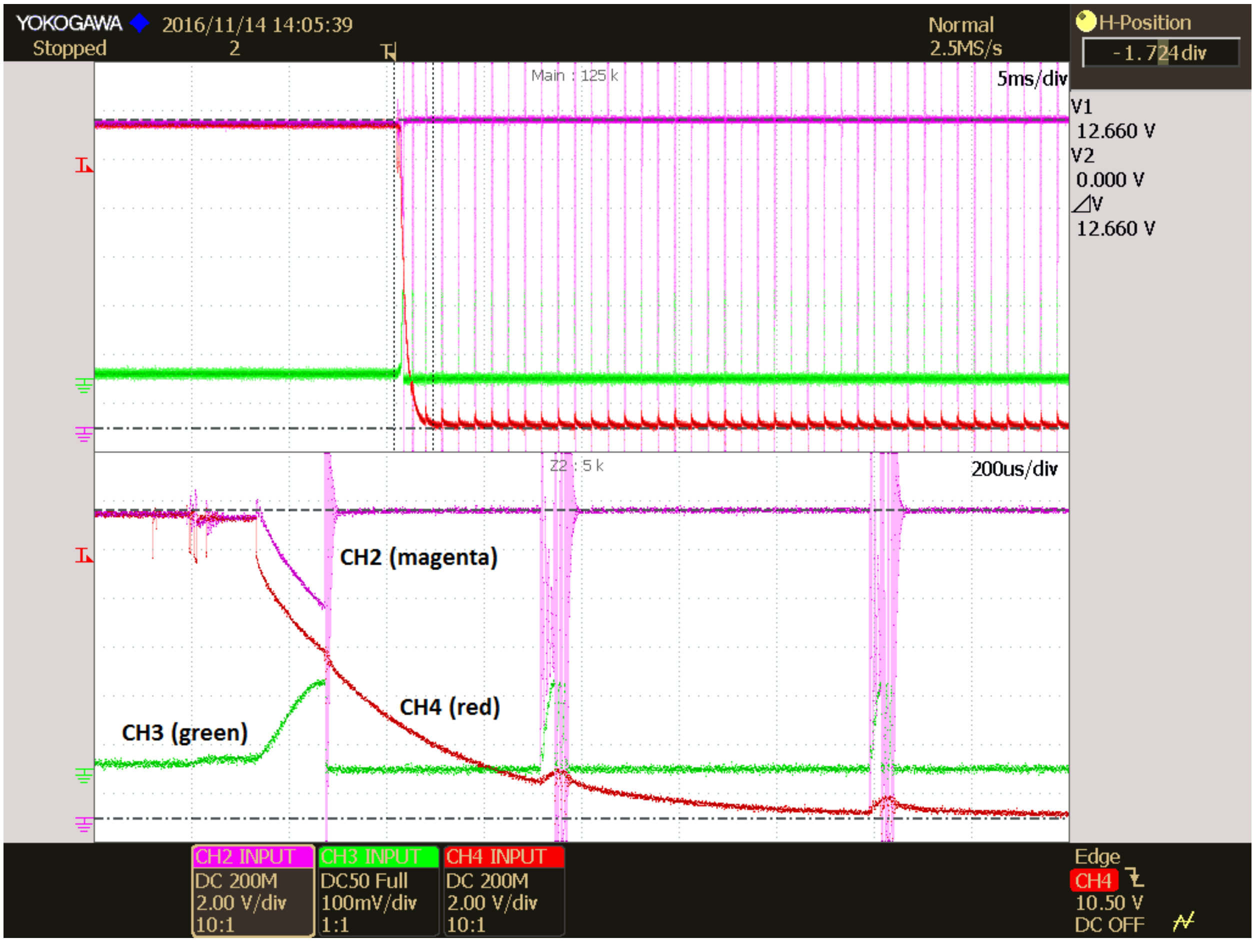
Figure 7 shows a typical device performance with inrush current limiting and input voltage above the output voltage limit. After inrush current falls below the limiting threshold, over-voltage is detected and the device starts operating as a buck converter, limiting output voltage. The lower side of the image demonstrates the magnified portion of the upper side image with transition from inrush current limiting to over-voltage protection operation mode.



Legend: Channel 2 (magenta) – battery voltage, Channel 3 (green) battery current, Channel 4 (red) – output voltage

Figure 7: Typical Device Performance with Inrush Current Limiting at Input Voltage above Output Voltage Limit

Figure 8 shows typical device performance in case of output short circuit. In such a scenario, the battery current is limited to inrush current value, preventing the battery from damage.



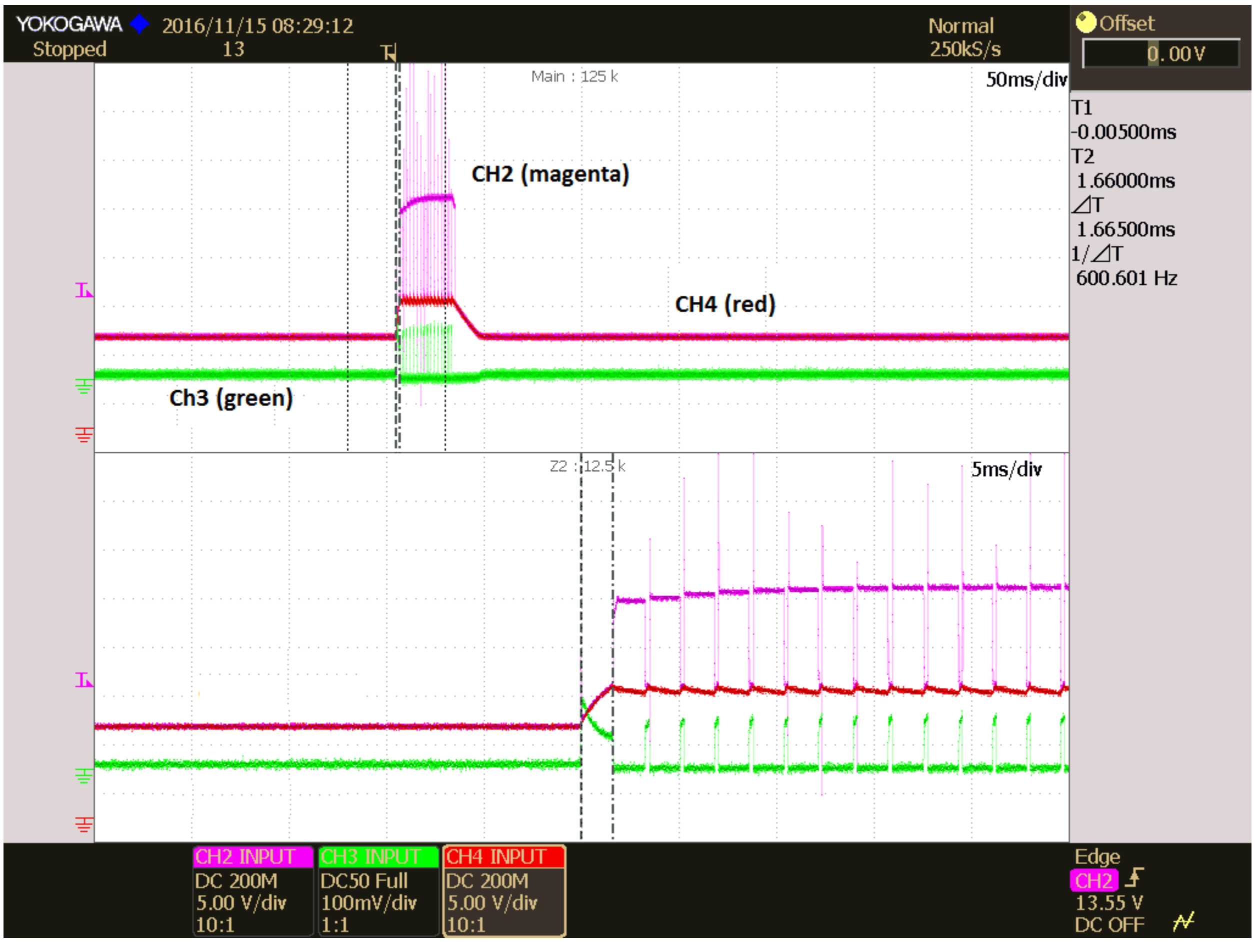
Legend: Channel 2 (magenta) – battery voltage, Channel 3 (green) battery current, Channel 4 (red) – output voltage

Figure 8: Operation with Short at the Output

If input voltage surge occurs, and the battery current exceeds the OC threshold, trigger U3 turns Q2 off, and the device performs the sequence of operations discussed above until the battery current falls below the OC threshold and the output voltage goes below OV.

If input voltage rises slowly enough to not trigger OC protection, and output voltage triggers OV protection, the MCU turns Q2 off until the output voltage falls below the threshold and the charging sequence is repeated until the charging current and output voltage rests in the desired range.

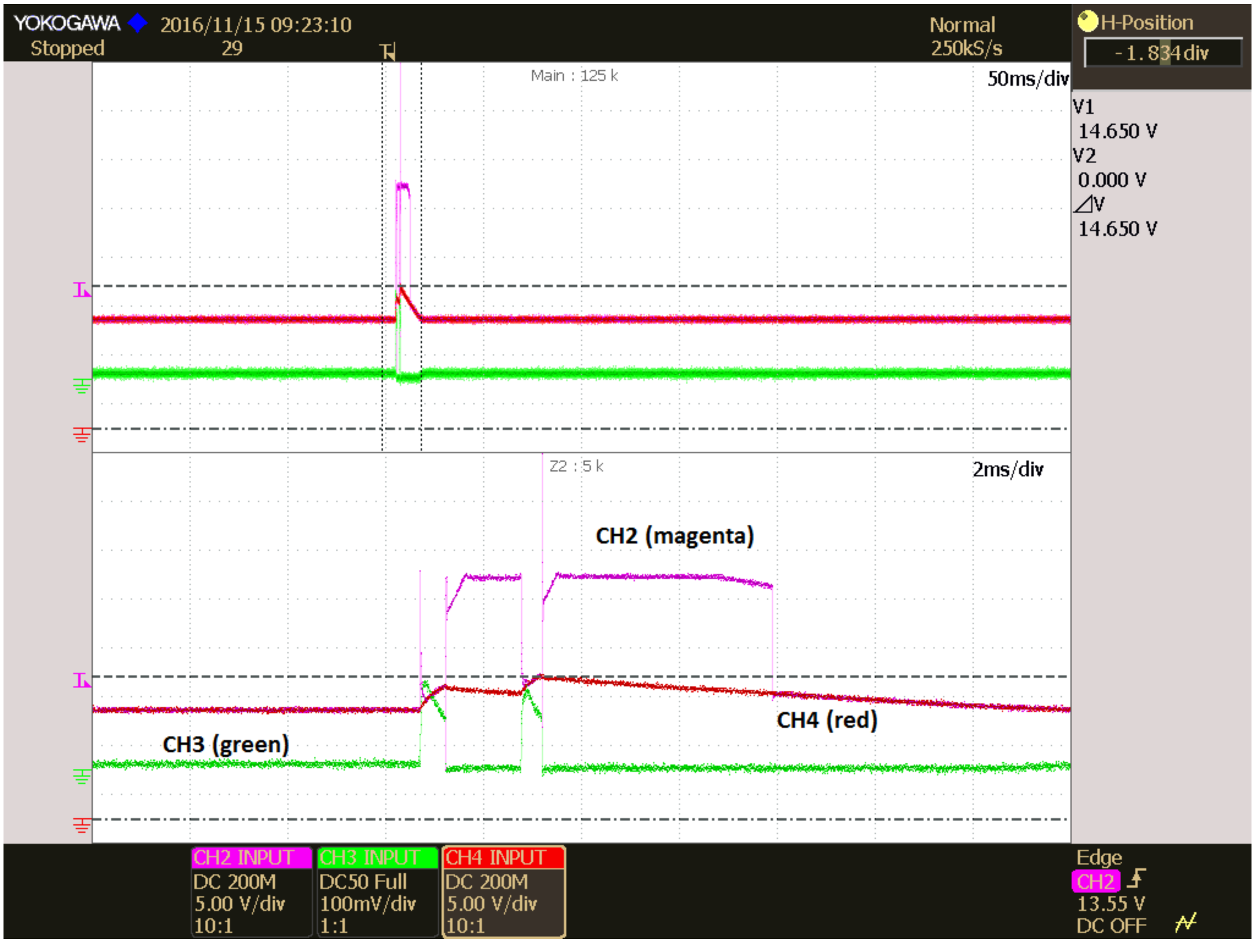
Figure 9 shows a typical operation with the input voltage long spike. The device starts operating as a buck converter to prevent output over-voltage. The spike's front is tied to the front of the output voltage by internal resistance of the spike source and rises fast after the load is disconnected. The maximum surge protection voltage is determined by Q2 Vds and the maximum programmable current is determined by Q2 and the inductor.



Legend: Channel 2 (magenta) – battery voltage, Channel 3 (green) battery current, Channel 4 (red) – output voltage

Figure 9: Operation with the Input Voltage Long Spike

Figure 10 shows a typical operation with the input voltage short spike. Q2 is disabled after OV is detected and resumes normal operation when the OV event has completed.

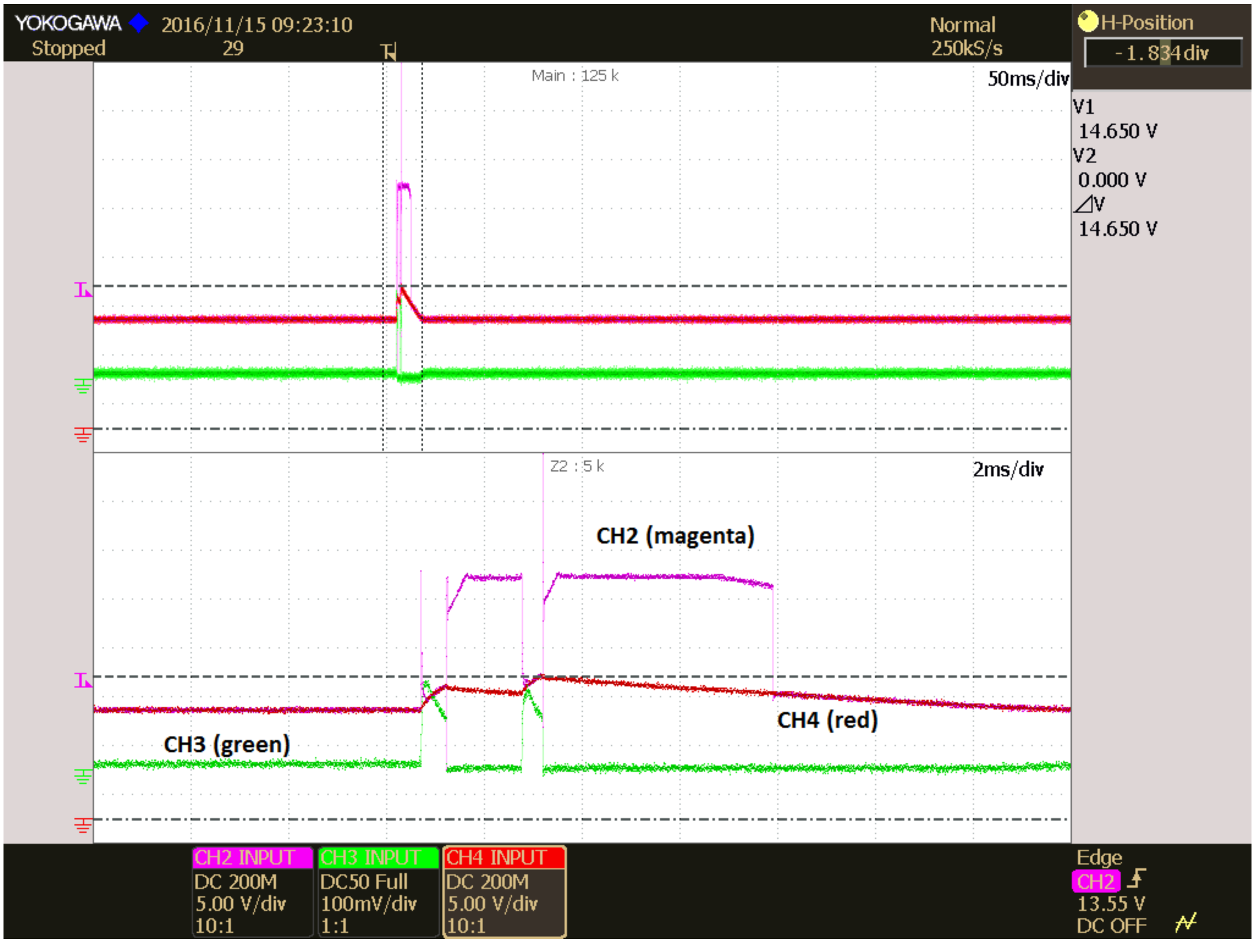


Legend: Channel 2 (magenta) – battery voltage, Channel 3 (green) battery current, Channel 4 (red) – output voltage

Figure 10: Operation with the Input Voltage Short Spike

It is recommended to program the minimum trigger's U3 on-time as short as allowed by the MCU to prevent dynamic error in output voltage setting caused by spikes charging output capacitors during this time above the OV threshold, before U3 may be turned off by OV protection. Figure 11 demonstrates such a condition, when OV turns Q2 off at first pulse, but a long on-time causes higher than OV output voltage at the second pulse.

If a surge current or over-voltage is not detected, the MCU generates a Power Good signal, which can be used for additional load protection if required. This signal is primarily for information purposes and does not change device performance. The PG flag is set high if no OC or OV events were detected during the time window set by the Between-events Timer and output voltage is in the range of 0.75–1.25 of the programmed nominal voltage.



Legend: Channel 2 (magenta) – battery voltage, Channel 3 (green) battery current, Channel 4 (red) – output voltage

Figure 11: Dynamic Error in OV, if Minimum On-time set by MCU is too long

This device may be used with any battery operated application that uses a heavy capacitive load such as motors with start capacitors, and requires uninterrupted power supply irrespective of spikes in the input voltage.

This design provides significantly higher efficiency than a device utilizing MOSFET in active mode, thermistors, or ballast resistors. It also allows uninterrupted load supply even during long surge spikes, which typical devices do not allow.

Energy stored in the inductor applies to the load instead of being dissipated by typical devices. As a result, the device does not require big heat sinks to operate. Additionally, it does not require cool-down time between spikes and is ready to operate at any moment after the energy stored in the gate driver's supply is enough to turn the MOSFET On/Off.

If the device is in Idle mode for a long time, the flyback converter providing power to the gate driver switches into Economy mode with short pulses at low frequency to replenish the charge at capacitor C2. The converter resumes normal operations immediately after Q2 is turned off. With current consumption less than 1µA for each of the three ICs powered on high side, it requires very low power to operate in Idle mode.

Appendix A. Board Components

Figures 12 and 13 display the location of the components on the Surge Voltage and Inrush Current Protector boards.

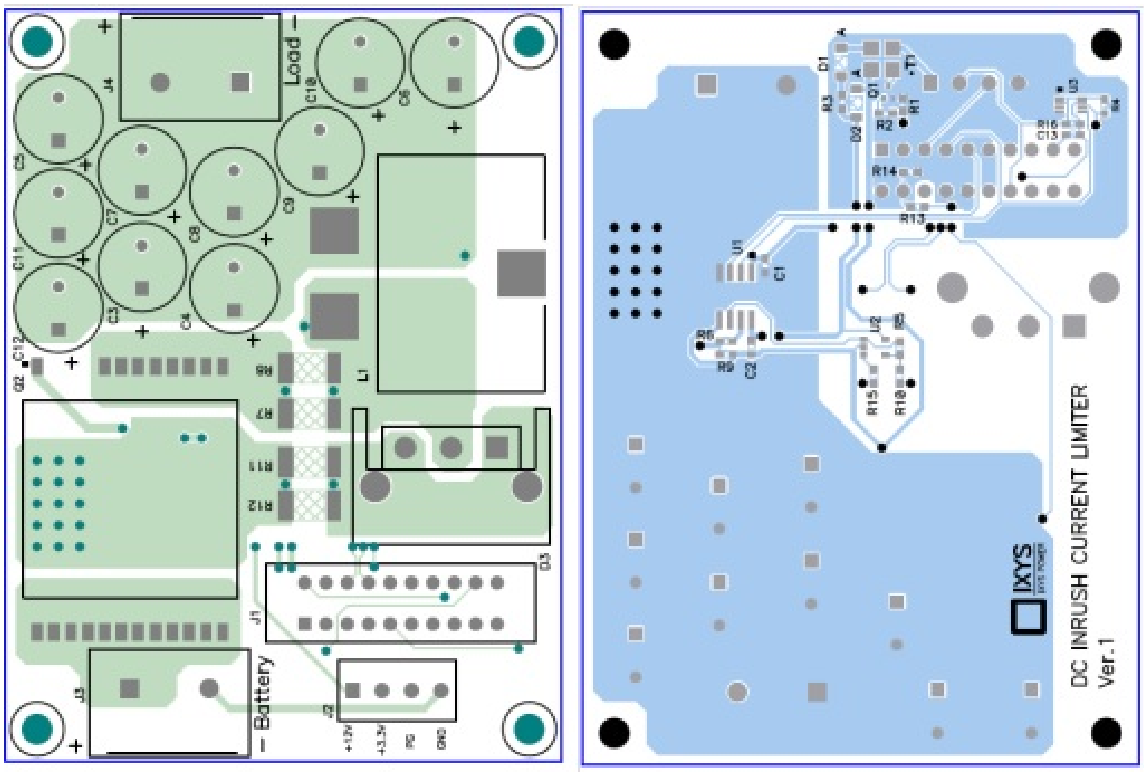


Figure 12: Main Board Layout – Top and Bottom Layers (Not to Scale)

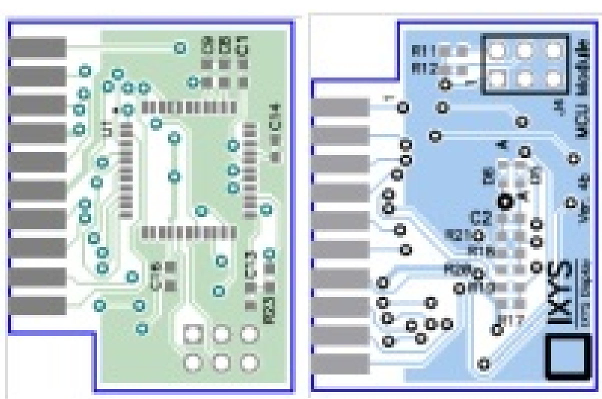


Figure 13: Layout of Digital Control Module –Top and Bottom Layers (Not to Scale)

Appendix B. Bill of Materials

Table 1: Main Board Bill of Materials

Count	Reference Designator	Value	Description	Manufacturer
1		Heat Sink	WA-T247-101E	Ohmite
1	C1	1 uF	TMK107B7105KA-T	Taiyo Yuden
1	C13	560 pF	GRM1885C1H561JA01D	Murata
1	C2	10 uF	CL10A106MQ8NNNC	Samsung
10	C3, C4, C5, C6, C7, C8, C9, C10, C11, C12	470 uF	EKZE630ELL471MK30S	United Chemi-Con
1	D1	MBR0540	MBR0540	Diodes Inc.
1	D2	12 V	BZT52C12-13-F	Diodes Incorporated
1	D3	DSSK60-0045B	DSSK60-0045B	IXYS Corp.
1	J1		5-5530843-0	TE Connectivity
1	J2		39357-0004	Molex
2	J3, J4		1714971	Phoenix Contact
1	L1	6.8 uH	SER2915H-682KL	Coilcraft
1	Q1	DMN601TK-7	DMN601TK-7	Diodes Inc.
1	Q2	MMIX1F360N15T2	MMIX1F360N15T2	IXYS Corp.
4	R1, R5, R9, R10	20 k	RMCF0603FT20K0	Stackpole Electronics Inc
2	R13, R15	10 k	RMCF0603FT10K0	Stackpole Electronics Inc
1	R14	309	RMCF0603FT309R	Stackpole Electronics Inc
1	R2, R3	10	RMCF0603FT10R0	Stackpole Electronics Inc
2	R4, R16	2 k	RMCF0603FT2K00	Stackpole Electronics Inc
1	R6	30.1	RMCF0603FT30R1	Stackpole Electronics Inc
4	R7, R8, R11, R12	0.01	CRA2512-FZ-R010ELF	Bourns
1	T1	{Value}	LPD5030V-154MRB	Coilcraft
1	U1		IX2127	IXYS Corp.
1	U2		LMV116MF/NOPB	Texas Instr.
1	U3		NC7SZ74K8X	Fairchild Semic.

Table 2: MCU Board Bill of Materials

Count	Reference Designator	Value	Description	Manufacturer
2	C1, C2	0.033 uF	C0603C333K4RACTU	Kemet
2	C9, C16	0.1 uF	CL10B105KA8NNNC	Samsung
1	C14	1 uF	CL10B106KA8NNNC	Samsung
1	C8	4.7 uF	CL10A475KA8NQNC	Samsung
1	C13	820 pF	TMK107B7821KA-T	Taiyo Yuden
2	D5, D6	BAT42XV2	BAT42XV2	Diodes Inc.
1	J6			Board layout
1	J4	DEBUG	Header 67996-406HLF	FCI
1	R23	1.74 k	RMCF0603FT1K74	Stackpole Electronics Inc
2	R17, R18	5.62 k	RMCF0603FT5K62	Stackpole Electronics Inc
2	R11, R12	10 k	RMCF0603FT10K0	Stackpole Electronics Inc
1	R21	18.2 k	RMCF0603FT18K2	Stackpole Electronics Inc
2	R19, R20	806	RMCF0603FT806R	Stackpole Electronics Inc
1	U1	Z8F3281	Z8F3281AN024XK	Zilog

Warranty and Use

IXYS CORP. MAKES NO WARRANTY, REPRESENTATION OR GUARANTEE, EXPRESS OR IMPLIED, REGARDING THE SUITABILITY OF ITS PRODUCTS FOR ANY PARTICULAR PURPOSE, NOR THAT THE USE OF ITS PRODUCTS WILL NOT INFRINGE ITS INTELLECTUAL PROPERTY RIGHTS OR THE RIGHTS OF THIRD PARTIES WITH RESPECT TO ANY PARTICULAR USE OR APPLICATION AND SPECIFICALLY DISCLAIMS ANY AND ALL LIABILITY ARISING OUT OF ANY SUCH USE OR APPLICATION, INCLUDING BUT NOT LIMITED TO, CONSEQUENTIAL OR INCIDENTAL DAMAGES.

IXYS Corp. products are not designed, intended, or authorized for use as components in systems intended for surgical implant into the body, or other applications intended to support or sustain life, or for any other application in which the failure of the IXYS Corp. product could create a situation where personal injury or death may occur.

IXYS Corp. reserves the right to make changes to or discontinue any product or service described herein without notice. Products with data sheets labeled "Advance Information" or "Preliminary" and other products described herein may not be in production or offered for sale.

IXYS Corp. advises customers to obtain the current version of the relevant product information before placing orders. Circuit diagrams illustrate typical semiconductor applications and may not be complete.

IXYS POWER

IXYS Corp.
1590 Buckeye Dr.
Milpitas, CA 95035-7418
Phone: 408. 457.9000
Fax: 408. 496.0222
http://www.ixys.com