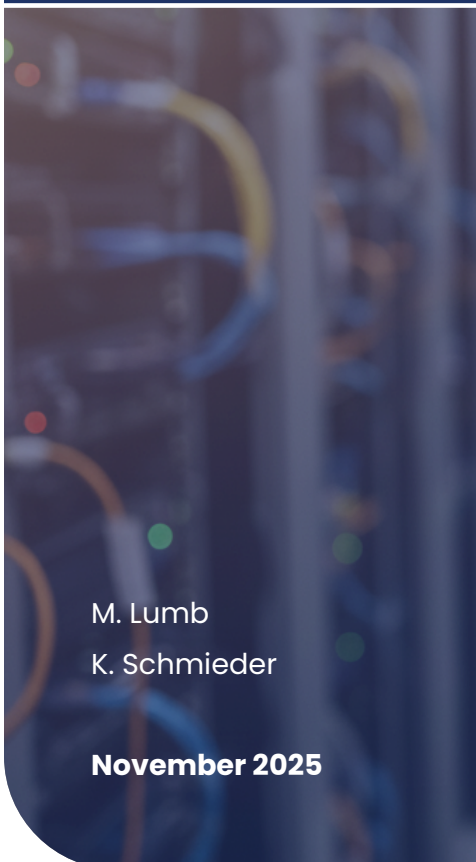


Designing a Switching-Free Boost Regulation and Battery Charging Solution for Single-Cell Li-Ion Systems





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Introduction

A vast range of electronic devices use single cell Li-ion batteries for power. Compared to multiple cell approaches, single-cell designs offer compactness, simplicity, cost and reliability advantages. If a system requires voltages greater than that available from a single Li-ion cell, then designers usually opt to use boost converters rather than multiple-cell configurations. However, boost converters can create some difficult design challenges, especially if the system has demanding noise and size specifications. Switching regulators are a source of electrical noise that can be both conducted to downstream components and radiated to other areas of a system. Dealing with this can introduce major tradeoffs in performance, footprint, bill of materials, efficiency, cost and EMC risk. In this application note, we describe the design of a switching-free boost and Li-ion battery charging solution that can overcome the drawbacks associated with switching solutions. We demonstrate a compact, simple, all-linear design suitable for generating a low noise 5V rail and charging circuit in a single-cell Li-ion equipped system. This uses Polaris Semiconductor's unique, switching-free boost converter technology,

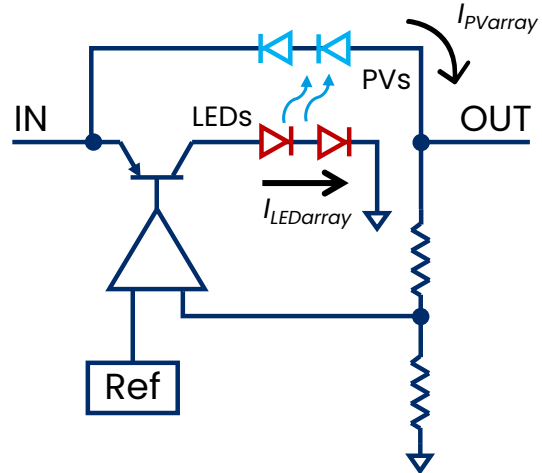


Figure 1. Simplified circuit diagram of the BT291D50M linear boost regulator..

combined with a high-performance linear battery charger IC from Texas Instruments.

BT291D50M Boost Converter

This application note leverages Polaris Semiconductor's optocoupler-enhanced linear regulator technology for boost conversion. This patented device architecture comprises a conventional, Si-based LDO, co-packaged with our unique, high-performance, GaAs-based photovoltaic-output optocouplers in a multi-chip QFN package. The role of the optocouplers is to transfer optical power from the LED section to the photovoltaic (PV) devices with high efficiency.

With the boost-converter configuration of **BT291D50M** (**Figure 1**), the LDO supplies current to two series-connected LED devices, which is efficiently transferred to photocurrent in the two PV devices via photons emitted in the LEDs. The PV devices are connected to the input and output terminals of the regulator, enabling the output voltage to exceed the input voltage. The maximum power voltage of each PV element is roughly 1V, and therefore the device configuration shown can efficiently boost the output voltage by up to 2V greater than the minimum input voltage at which the device turns on.

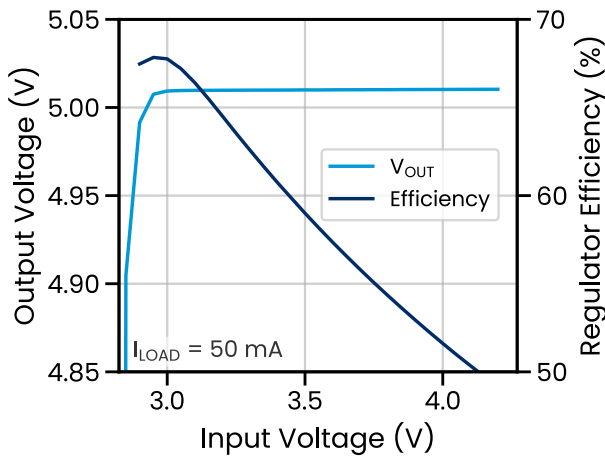


Figure 2. BT291D50M – a high efficiency, switching-free DC boost voltage regulator. The device shown here is configured for a regulated 5 V output and operated at 25°C.

A regulated output is achieved using a feedback loop around the LDO error amplifier. A scaled representation of the output voltage is sensed at the ADJ pin, tied to the center of a resistor divider that connects OUT and GND. The error amplifier of the LDO controls the current supplied to the LED elements via the pass transistor, generating current in the PV array that is supplied to OUT. The feedback loop around the error amplifier acts to compensate any difference in the reference voltage and the voltage at the ADJ pin, thus regulating the output voltage. The minimum input voltage of the device (V_{ON}) is the sum of the forward voltage of each LED and the dropout voltage (V_{DO}) of the LDO. The forward voltage of the LEDs is typically 1.3–1.6 V, depending on current, and V_{DO} is approximately 250 mV at the maximum rated current. Therefore, BT291D50M is well suited for generating a 5 V output from typical Li-ion battery voltages in the 3.4–4.2 V range. For a more complete discussion of optocoupler-enhanced linear regulators, consult our white paper [PSWP001](#) [1].

The high efficiency of Polaris Semiconductor’s optocoupler chips allow overall voltage regulator device efficiencies in the 50%–68% range to be achieved for a 5 V output. **Figure 2** shows the output voltage and efficiency for BT291D50M with a 50 mA load, with V_{ON} of

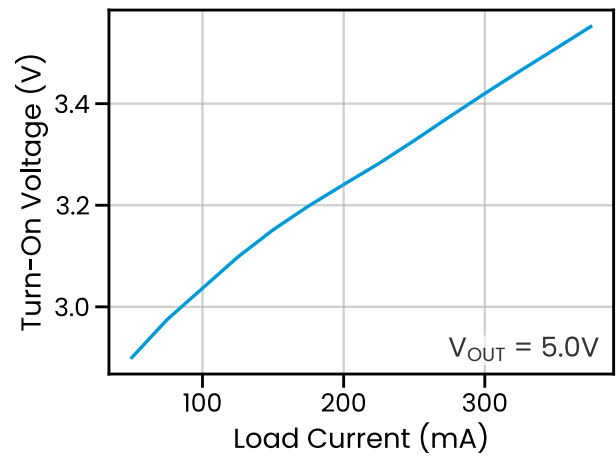


Figure 3. Minimum input voltage required to produce a regulated output, plotted as a function of load current at 25°C.

roughly 2.9 V. The increasing forward voltage and LDO dropout voltage with higher currents results in V_{ON} increasing to approximately 3.5 V at the maximum load current of 350 mA and 25°C (**Figure 3**).

Of course, the efficiency of BT291D50M is lower than a high efficiency switching regulator, but there are several key advantages to the linear topology that make it attractive. Firstly, no switching means that the traditional drawbacks of output voltage ripple and conducted and radiated electromagnetic interference (EMI) are avoided. In sensitive analog and RF systems, designers often go to great lengths to suppress switching noise artifacts that can degrade fidelity and introduce PCB design risks. The second advantage is that the device retains the high power-supply ripple-rejection (PSRR) performance of an LDO, and therefore not only does BT291D50M not introduce switching noise into the system, but it can also reduce noise from a dirty supply. Finally, the device can offer significant BoM savings—using linear post regulators and filters to clean the output of a switching regulator in noise-sensitive systems results in degraded efficiency, higher component count, increased cost, lower reliability, and potential instability. The passives required by switching regulators can occupy significant volumes, whereas the



inductor-less linear topology operates with a very small number of passives.

All-Linear Li-Ion Charger & Boost Regulator

In this application note, we describe using BT291D50M in Li-ion battery-containing systems in combination with a battery charger IC. Using this approach it is possible to generate a ripple-free 5V rail to power sensitive loads with power sourced either from a line input or directly from the battery, as well as charge the battery when required. BQ25185 is a linear battery charger IC produced by Texas Instruments with numerous attractive features for this application, including low quiescent current, up to 1A charging current, a wide range of fault protection features, power-path management functionality and input voltage dynamic power management for high impedance input sources such as solar panels. Moreover, the all-linear architecture of BQ25185, combined with the linear boost capability of BT291D50M, means no inductors are required and no switching noise is generated anywhere within the circuit, simplifying PCB layout design and eliminating EMI risks associated with integrating power management into sensitive analog circuits.

A photo of the linear boost and battery charger demonstration board is provided in **Figure 4**. **Figures A1–A3** show the schematic, and **Table A1** provides the complete bill of materials. Inputs to BQ25185 can either be from a USB connector with nominally 5V input (J3), or a line input (J2) up to 18V maximum. A power multiplexer is not used in the demonstration, so instead Schottky diodes (D1 & D5) are included on both inputs to prevent reverse current flow in either input channel. In the presence of a high enough V_{IN} , BQ25185 (U2) outputs a regulated system voltage V_{SYS} of 4.5V. This is then supplied to the BT291D50M (U1) device which is configured for a 5V output to power system loads, set by resistors R1 and R2. The VSEL pins of the device are

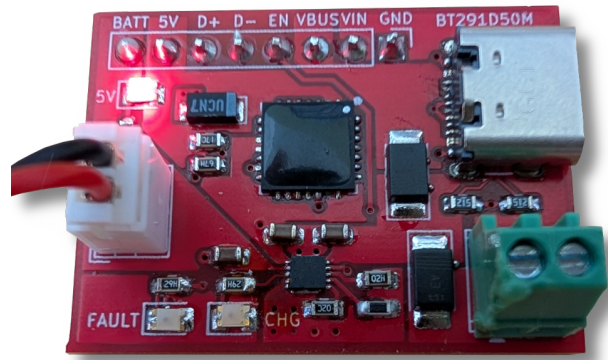


Figure 4. Photo of the assembled demonstration board.

connected together, connecting the internal LED elements in series.

Additional input current is drawn by BQ25185 to charge the battery, if connected, with a configurable charge profile: the maximum input current and battery regulation voltage is controlled by an off-chip resistor, R6, and the fast charge current is set using an additional resistor, R3. In this example, the charge current is set for 300 mA, the maximum input current (I_{SET}) is 500 mA, and the battery regulation voltage (V_{SET}) is 4.2V. If the battery voltage falls between the low battery voltage set point and V_{SET} , the battery is charged in constant-current mode, and transitions to constant-voltage mode when the battery voltage reaches V_{SET} . More detailed information on the configuration and operation of BQ25185 can be found in the datasheet for this part [2].

If the line input is disconnected when a battery is present, the system voltage V_{SYS} is supplied directly from the battery, provided the battery voltage is above the battery voltage under voltage lockout threshold. In this mode, the boost regulator maintains a regulated 5V supply to the load as long as V_{BAT} exceeds the minimum V_{ON} of BT291D50M, see **Figure 3**. Generally, the nominal voltage for a lithium-ion battery is close to 3.7V during most of the discharge process, which is well suited for the BT291D50M input range.

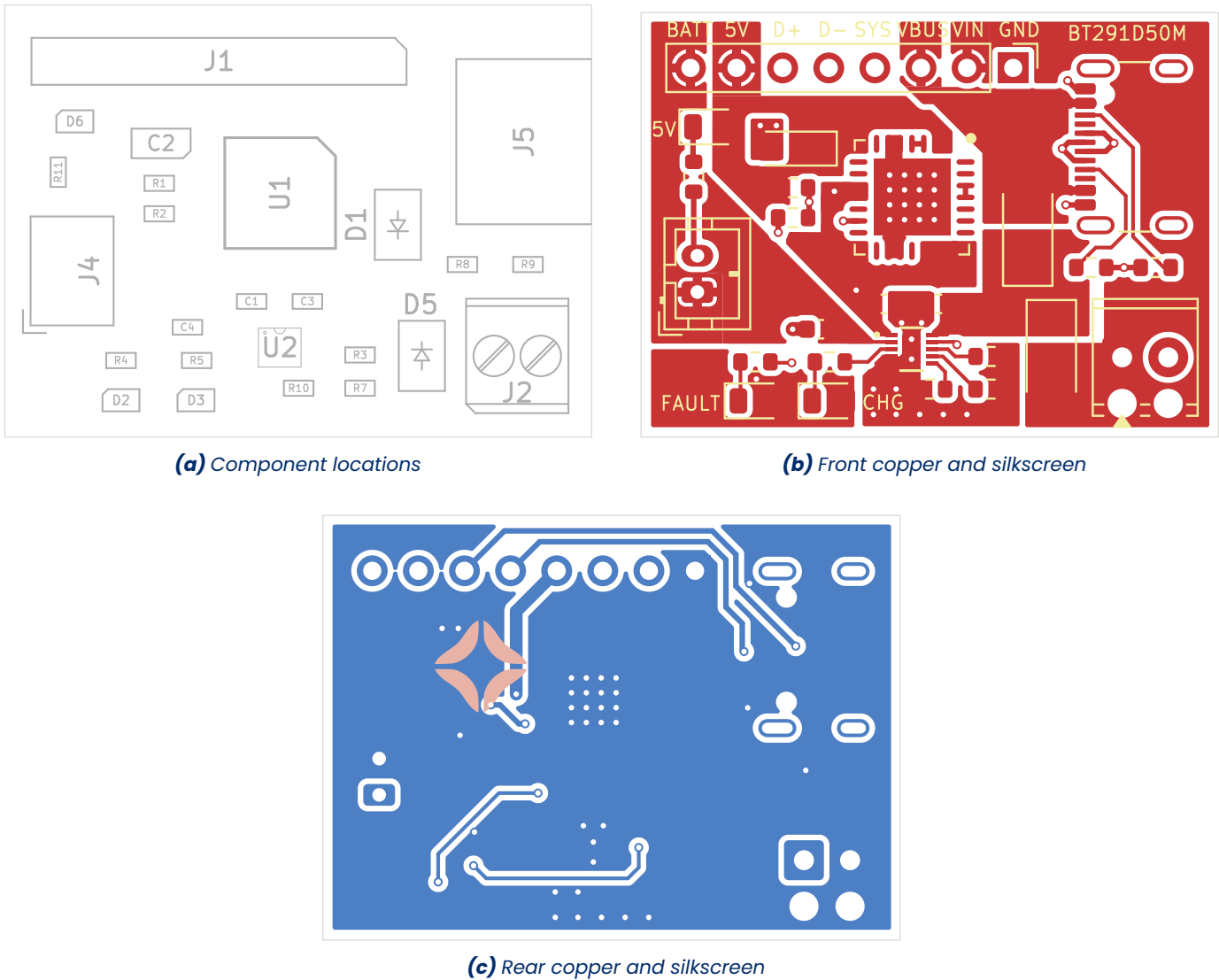
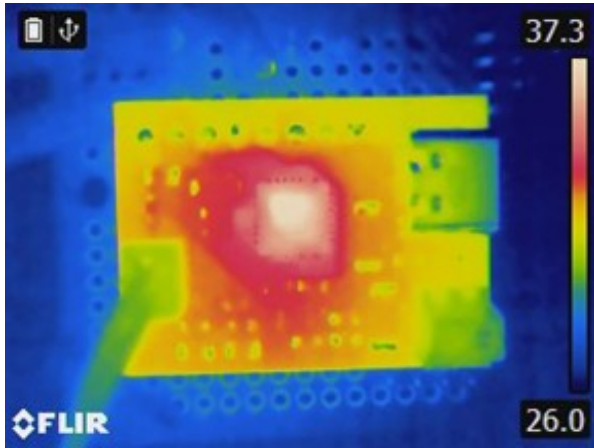


Figure 5. Component locations, front copper and silkscreen, and rear copper and silkscreen layout for the linear boost and battery charger demonstration board.

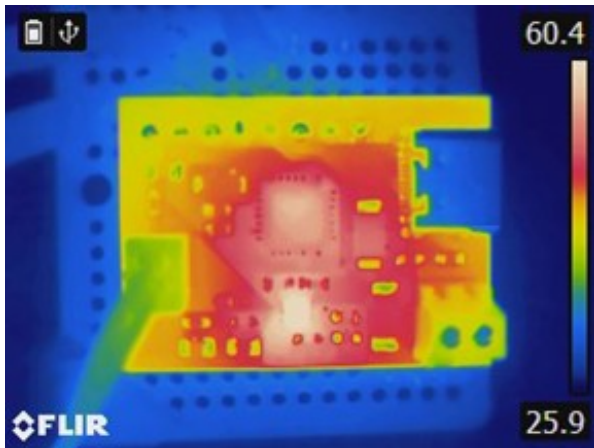
Three indicator LEDs are included in the design. LEDs D2 and D3 are tied to STAT1 and STAT2 pins, with detailed functionality described in the BQ25185 datasheet [2]. Briefly, D3 illuminated and D2 extinguished indicates charging is in progress, D2 illuminated and D3 extinguished indicates a recoverable fault condition, both D2 and D3 illuminated indicates a non-recoverable fault condition, and D2 and D3 extinguished indicates either charge complete, charging disabled or sleep mode. LED D4 is illuminated when BT291D50M output is high. The component placement, front and rear copper designs for a two-layer demonstration board are provided in

Figure 5. The total board size of the demonstration PCB is $31.8 \times 23.4 \text{ mm}^2$. The layout of BT291D50M and its passives is based upon that described in our application note [PSAN001](#) [3], which shared a PCB design for this chip with a miniscule solution size of $12.5 \times 7.5 \text{ mm}^2$.

The performance of the design under typical operating conditions has been tested experimentally by assembling the circuit on a 2-layer PCB with 1oz (35 μm thickness) copper. A fixed load resistance of 100Ω was attached to the boost regulator output, resulting in a load current of approximately 50 mA. During testing, the board was in a room temperature environment with



(a) Battery only mode



(b) Charging + load mode

Figure 6. FLIR camera images of the demonstration PCB. Color gradient represents temperature in °C.

only natural convection and no forced cooling applied. To simulate battery-only operation, a DC power supply voltage of 3.7V was connected to J4. In this mode, the linear boost converter was dissipating approximately 177 mW of power, and outputting 249 mW of power to the load resistor. The package temperature of the boost regulator was measured to be 38.9°C using a FLIR camera, shown in **Figure 6a**.

The circuit was also tested in charging mode by connecting a line input voltage of 5 V to J2 and an SMU to the battery connector. The SMU was sinking a charge current of close to 300 mA at the simulated battery voltage of 3.7V. This configuration dissipated 275 mW of power with a total output power of 368 mW

Table 1. Electrical characteristics of the demonstration PCB in two operating modes.

	Battery Power	Charging + Load
I_{IN} (mA)	0	427.0
V_{IN} (V)	0	5.00
I_{BAT} (mA)	115.1	-298.2
V_{BAT} (V)	3.70	3.70
I_{OUT} (mA)	49.9	50.0
V_{OUT} (V)	4.99	4.99
Efficiency (%)	58.4	63.3

split between the battery and load. The greater power dissipation raised the board temperature, with package temperatures of BQ25185 and BT291D50M measured to be 65.7°C and 58°C, respectively, shown in **Figure 6b**. These package temperatures are well within the limits of both devices. A summary of the electrical performance of the demonstration board in both modes is provided in **Table 1**.

Summary

Polaris Semiconductor’s linear boost regulator devices offer a very compact and low-noise solution for boost conversion. Conventional switching approaches inevitably generate conducted and radiated EMI concerns that require careful PCB layout and filtering, which can introduce major performance risks and design trade-offs in noise-sensitive analog and RF circuits. By combining the linear boost converter with a linear battery charger IC, it is possible to achieve a compact, efficient, inductor-less solution that is entirely switching-free, perfect for battery powered systems that have demanding low-noise requirements such as medical wearables, remote and portable sensors, RF transceivers and many more.



Appendix

Li-Ion Battery Charger Schematic

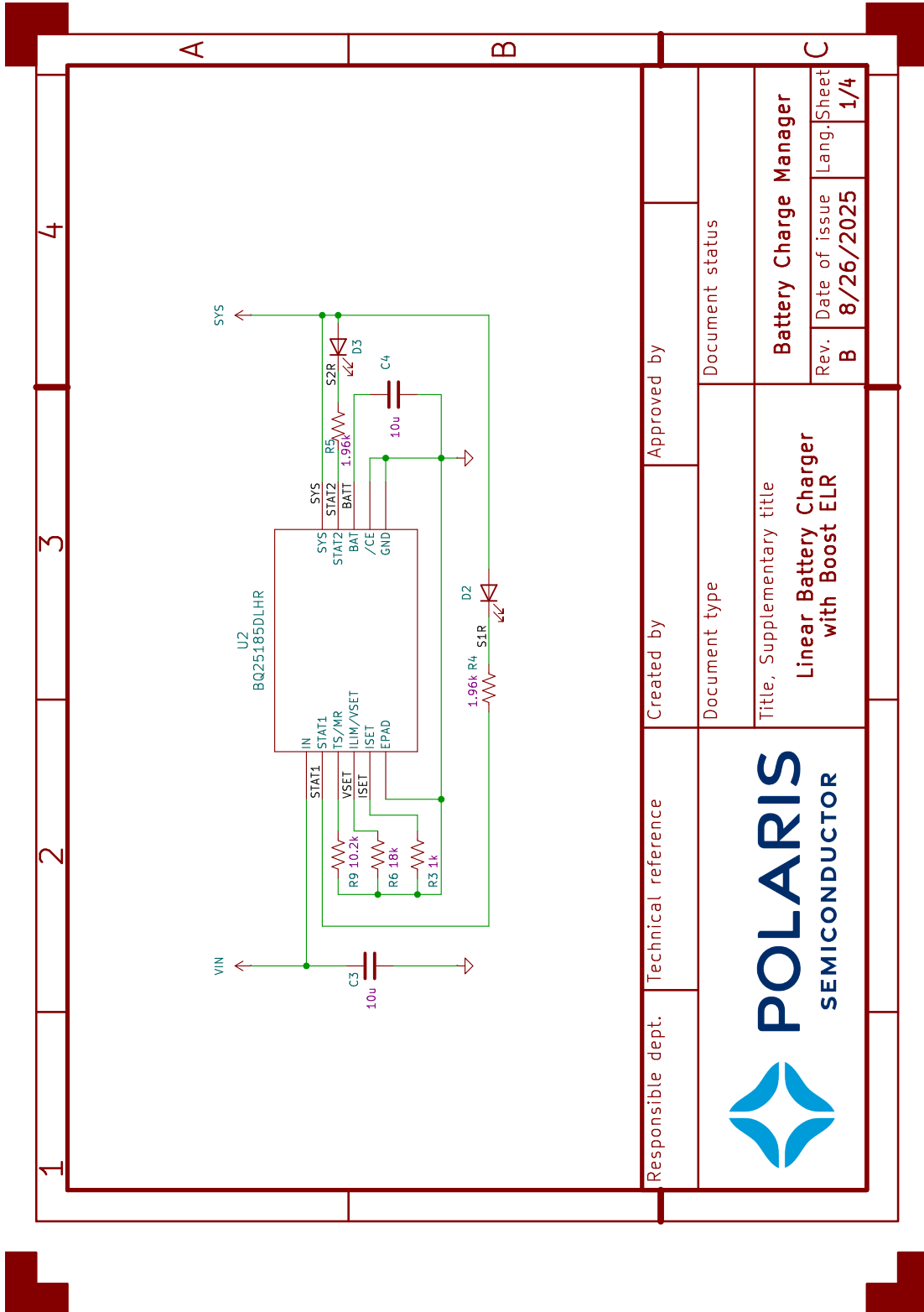


Figure A1. Schematic for battery charge manager.

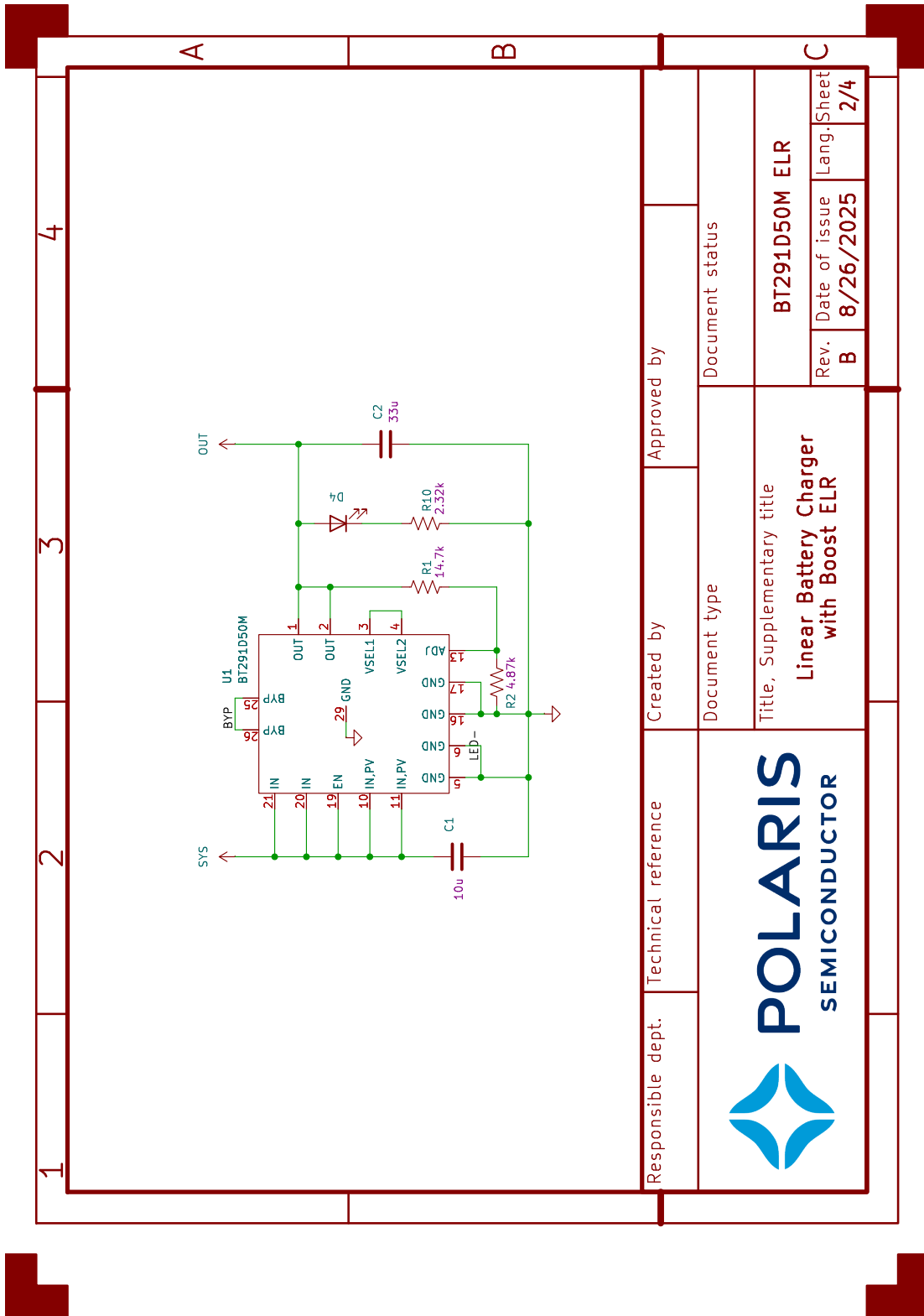


Figure A2. Schematic for Polaris Semiconductor's BT291D50M

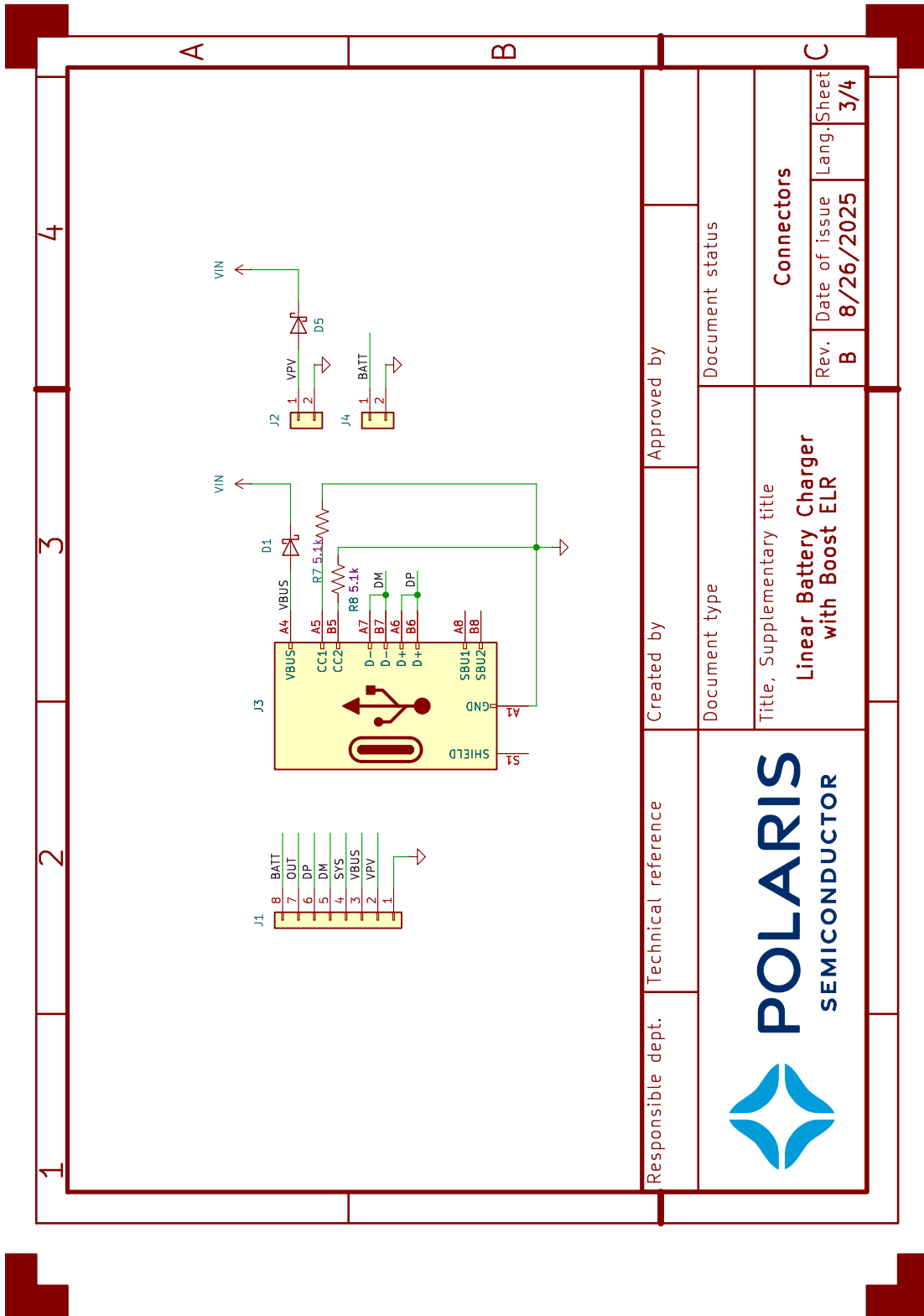


Figure A3. Schematic for various connectors



Li-Ion Battery Charger Bill of Materials

Table A1. Bill of Materials for the Li-Ion Linear Battery Charger Board.

ID	Description	Part	Manufacturer
C ₁ , C ₃ , C ₄	10 μ F ceramic X7R	GRM188Z71A106MA73D	Murata Electronics
C ₂	33 μ F tantalum poly.	T527S336M016ATE200	Kemet
D ₁ , D ₅	Schottky Barrier Rectifier	PMEG3020ER	Nexperia USA Inc.
D ₂ , D ₃ , D ₄	Red LED	B1701URO-20D000114U1930	Harvartek Corporation
J ₁	8-Pos. Vert. Header	61300811121	Würth Elektronik
J ₂	2-Pos. Terminal Block	VN02A1500000G	Amphenol Anytek
J ₃	USB 2.0 TYP C Receptacle	USB4105-GF-A	GCT
J ₄	2-Pos. Vert. Header	S2B-PH-K-S	JST Sales America Inc.
R ₁	14.7 k Ω 0.5% 1/16W	RR0816P-1472-D-17C	Susumu
R ₂	4.87 k Ω 0.5% 1/16W	RR0816P-4871-D-67H	Susumu
R ₃	1.02 k Ω 0.5% 1/16W	RR0816P-1021-D-02H	Susumu
R ₄ , R ₅	1.96 k Ω 0.5% 1/16W	RR0816P-1961-D-29H	Susumu
R ₆	18 k Ω 1% 1/10W	ERJ-3EKF1802V	Panasonic
R ₇ , R ₈	5.1 k Ω 1% 1/10W	RC0603FR-075K1L	Yageo
R ₉	10.2 k Ω 0.5% 1/16W	RR0816P-1022-D-02C	Susumu
R ₁₀	2.32 k Ω 0.5% 1/16W	RR0816P-2321-D-36H	Susumu
U ₁	5V Linear Boost Regulator	BT291D50M	Polaris Semiconductor
U ₂	1A Li-Ion Linear Battery Charger	BQ25185DLHR	Texas Instruments



References

- [1] M. P. Lumb, K. J. Schmieder, J. DeLombard, J. Carlin, L. Kaliszewski, A. Price, D. Hollingshead, and T. Grassman, "Breaking the rules of linear regulators: High efficiency buck and boost conversion without switching," White Paper PSWP001, Polaris Semiconductor, 2025.
- [2] *BQ25185 1-Cell, 1-A Standalone Linear Battery Charger with Power Path, Factory Mode, and Battery Tracking VINDPM*, Datasheet SLUSF65, Texas Instruments, 2023.
- [3] K. J. Schmieder and M. P. Lumb, "Switching-free boost regulators: A compact, all-linear solution to stepping-up voltage," Application Note PSAN001, Polaris Semiconductor, 2025.

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