Technical White Paper

Enabling Higher Data Rates for Optical Modules With Small and Efficient Power and Data-Converter Solutions

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ABSTRACT

A constant trend in optical modules is to offer higher data rates within the size-limited and thermally-limited form factor by using smaller, integrated *Power* and *Data-Converter* solutions. Innovative TI solutions are tackling those challenges by providing higher power density converters, while maintaining signal quality and allowing greater design flexibility.

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1 Introduction

Modern optical modules convert electrical data to optical data to overcome losses associated with electrical transmission. With each generation, they deliver higher data rates, such as 100 Gbps, 400 Gbps, and soon 800 Gbps. The common challenge for all optical modules is to fit this increased performance into a standardized form factor, such as quad small-form-factor pluggable-double density (QSFP-DD) or octal small-form-factor pluggable (OSFP).

System designers sometimes need to provide solutions with a higher data rate but in the previous generation's form factor, to be downward-compatible. Those electronics must still operate within the same power budget, since power budget is dictated by the thermal limits of the form factor itself.

Focusing on the power supply, higher data rates require higher currents with minimal power loss and the smallest possible solution size. System designers require higher currents to power higher-performance clock and data recovery (CDR), gearbox, or digital signal processor (DSP) chipsets to process the growing amounts of data, while minimizing power losses to keep the entire system operating within its thermal budget. Finally, these data-path chipsets frequently push the power supply to the back side of the printed-circuit board (PCB), where there is limited area, and where the height is frequently restricted to 1.2 mm.

This paper demonstrates switching DC/DC buck converter and data-converter designs optimized for optical modules where thermal limitations and space constraints are the most important factors.

Figure 1-1 shows an example of a typical power architecture with control and biasing data converters for optical modules. A 3.3-V input is converted to the numerous different voltages that each subsystem requires.

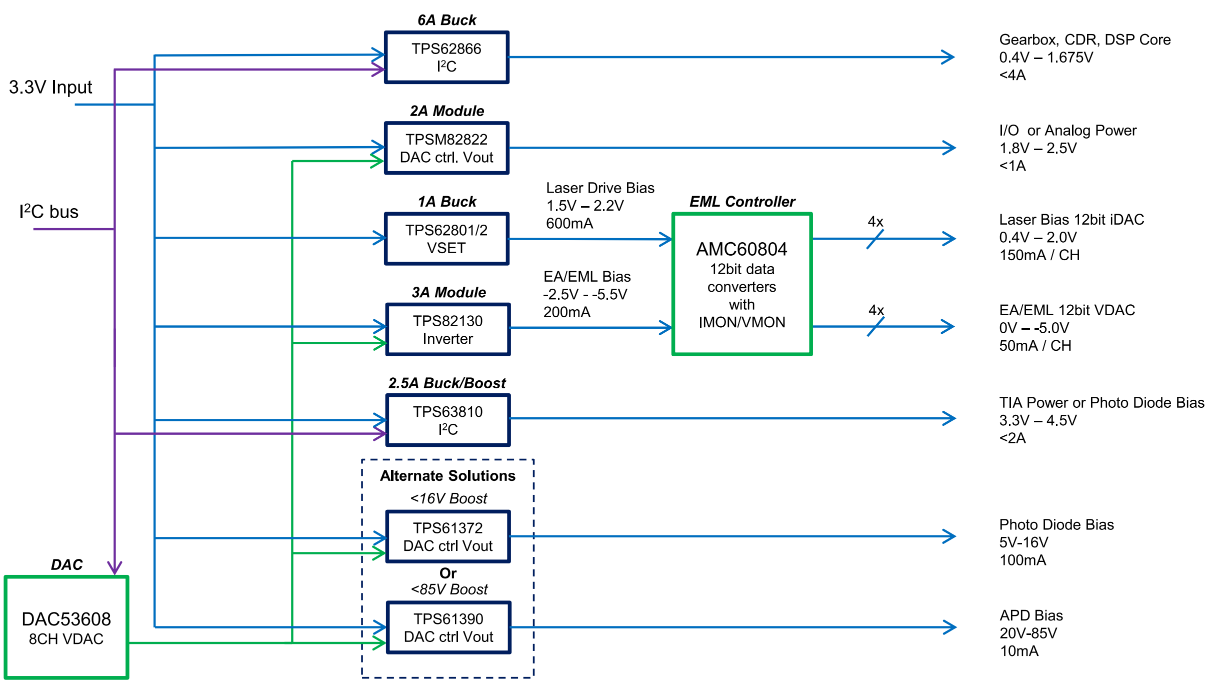


Figure 1-1. Optical Module Power Tree With Control and Biasing Data Converters

2 Powering the High-Current, DSP Core Rail

For most digital signal processors (DSPs), the main core rail voltage can vary from 0.5 V to 1.2 V. This rail is the main power-consuming rail in the system, which also means that it is the primary heat source in the power solution. Designers need to give special attention to efficiency and thermal dissipation for this rail.

Engineers can use different approaches to enhance the performance of the DSP in optical modules. A simple method is to find the optimized DSP supply-voltage setpoint during testing and not modify it during operation. The optimized voltage setpoint tends to differ between DSP vendors.

Another method consists of adjusting the supply voltage during operation to reduce power consumption. Some DSPs implement a dynamic voltage scaling (DVS) feature, enabling them to operate at different levels of performance in real time as the system requires.

At hot temperatures or with heavily attenuated input signals, the DSP core uses a higher voltage, such as 0.95 V. As the temperature decreases or the quality of the input signal improves, the DSP core voltage can drop as low as 0.9 V (as an example). For a 3-A load current, this 50-mV output voltage reduction results in significant 150-mW savings. This helps designers meet the average power-consumption limit of the module.

One approach to implement an output voltage adjustment feature is to use an analog signal. The current or voltage output of a digital-to-analog converter (DAC), when fed into the feedback pin of a DC/DC converter, adjusts the core voltage. This approach requires more PCB area given the extra circuitry required, although it does provide finer tuning of the supply voltage of the DSP. For more information, see Section 5: *Output Voltage Adjustment Implementing a DAC*.

To use less PCB area, and to dynamically adjust additional operating parameters besides just the output voltage, optical modules typically have an I2C bus connected to all controllable devices in the system. Some power supplies are controllable through I2C, to quickly adjust their output voltage, operating mode, and other settings as the system needs change. See also Section 4: *Powering the Receive Circuitry: TIA, Photodiode, or APD*.

To power the core rail, choose a high-current power supply with an I2C interface and small solution size. The 6-A TPS62866 enables designers to dynamically change the output voltage with 5-mV steps, using an I2C interface, and comes in a tiny wafer chip-scale package (WCSP) to achieve high power density.

Figure 2-1 shows an application schematic of the TPS62866 and its small component count to best address size constraints.

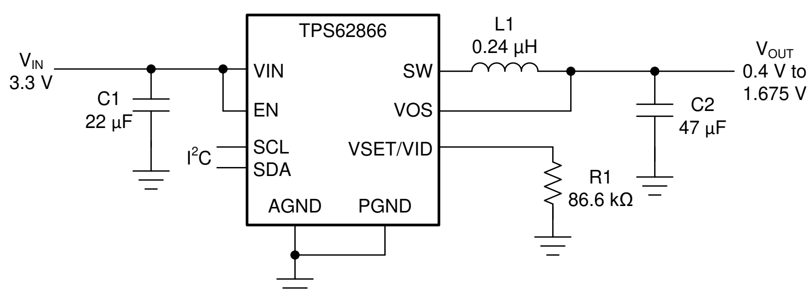


Figure 2-1. TPS62866 Reduces Component Count Using the VSET Pin and I2C Communication

Figure 2-2 shows the PCB layout of the TPS62866, which is optimized for its solution size of 22 mm^2 with a 1.2-mm maximum height. Table 2-1 lists the components used.

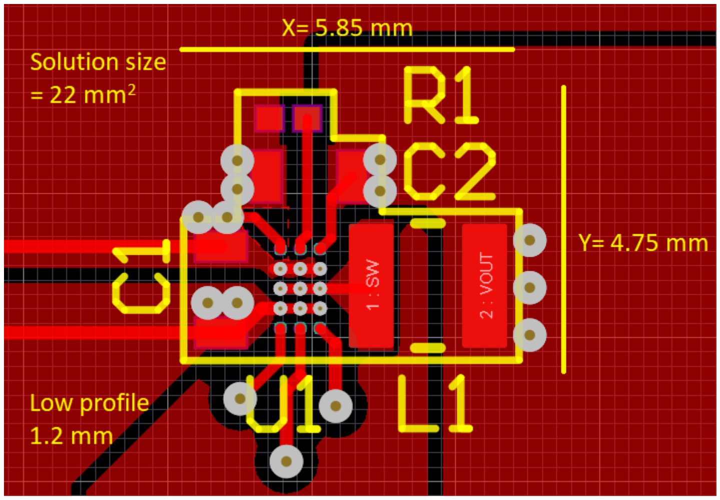


Figure 2-2. 6-A TPS62866 Powers the DSP Core Rail With Its I²C Interface and Small Solution Size

Table 2-1. BOM for the 6-A DSP Core Rail Occupies Only 22 mm^2

Reference	Description	x, y, z Size	Manufacturer
U1	TPS62866 6-A step-down converter with I²C interface in WCSP	1.78 × 1.05 mm 0.5-mm height	Texas Instruments
L1	IHHP1008ABERR22M01 inductor 0.22 µH 20% (6.6 A, 10.5 mΩ)	2.5 × 2.0 mm 1.2-mm height	Vishay Dale
C1	CL10A226KQ8NRNE CAP CER 22 µF 6.3 V X5R 0603	1.6 × 0.8 mm 0.9-mm height	Samsung
C2	GRM188R60J476ME15D CAP CER 47 µF 6.3 V X5R 0603	1.6 × 0.8 mm 0.8-mm height	Murata
R1	CRCW020186K6FKED RES SMD 86.6 kΩ 1% 1/20 W 0201	0.6 × 0.3 mm 0.28-mm height	Vishay Dale

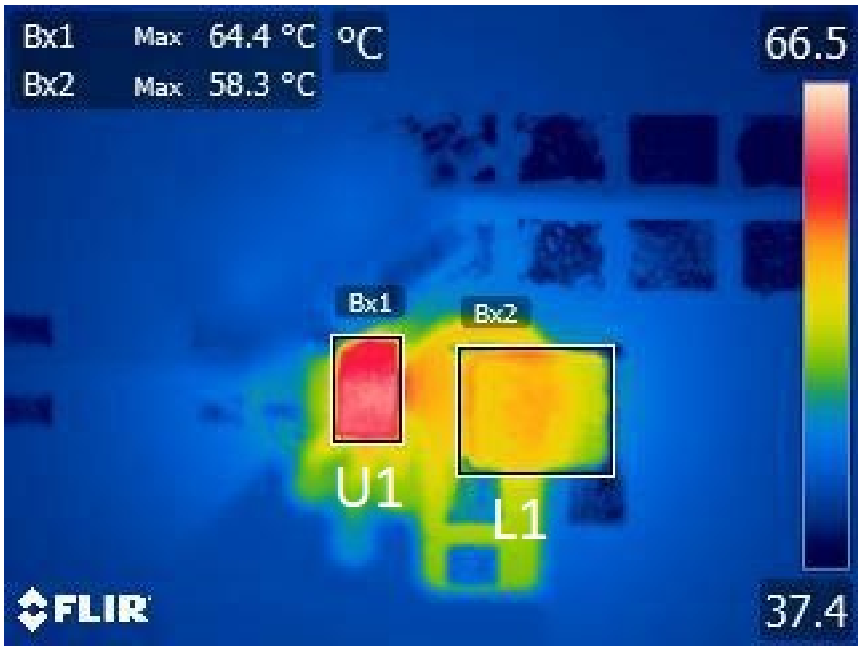
2.1 Solution Size

As Table 2-1 shows, the integrated circuit (IC) and capacitors are relatively short, whereas the tallest component is the inductor. An inductor with lower DCR can improve efficiency, but requires a larger or taller inductor (or both), which is possible when placing the power-supply solution on the top side of the PCB.

2.2 Thermal Performance

The load currents of a DSP core usually range from 3 A to 5.5 A. These higher loads generate significant heat. As optical modules have a great number of heat-generating components in a small space, the temperature inside them increases considerably. This higher internal temperature is the ambient temperature for each device inside the optical module. A sufficiently low temperature rise is required to operate each device within its thermal rating.

Figure 2-3 shows a thermal picture of the TPS62866 at a full 6-A load. At this highest current, the IC has only a moderate 40°C temperature rise, and the small inductor has an even smaller temperature rise. Even at ambient temperatures greater than 70°C, both components are still operating well within their 125°C ratings. Lower load currents that are typically drawn by processor cores in steady-state non-peak operation produce fewer power losses and a lower temperature rise, which enables operation at higher ambient temperatures. Table 2-2 shows the IC thermal performance for different load conditions.



Operating conditions: V_{IN} = 3.3 V, V_{OUT} = 0.9 V at 6 A

Figure 2-3. TPS62866 Powering the 6-A DSP Core Rail Allows a Moderate 40°C Rise in Temperature

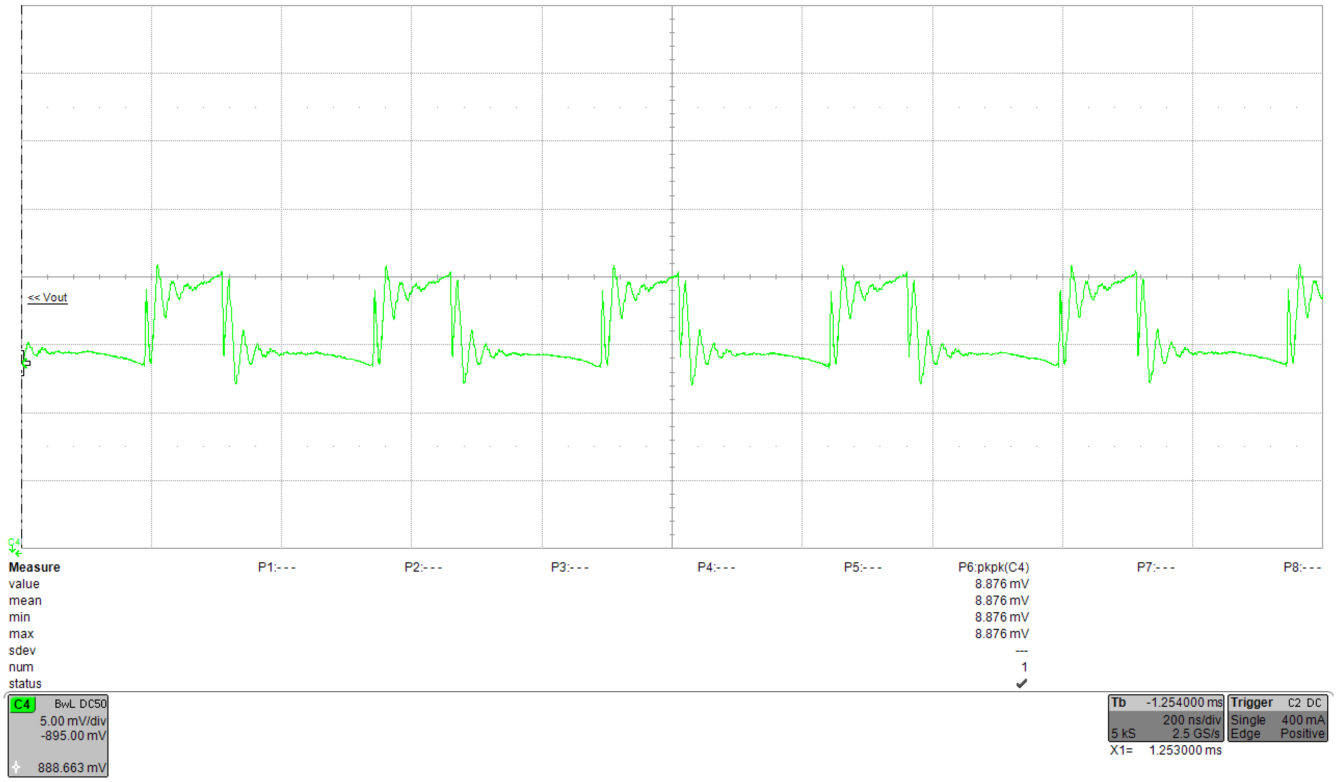
Table 2-2. TPS62866 Thermal Performance

Load	I_{OUT} = 2.0 A	I_{OUT} = 4.0 A	I_{OUT} = 6.0 A
Temperature Increase	9.1°C	25.8°C	41.5°C

Some elements in the signal processing chain are sensitive to temperature and may show performance drift as the temperature changes. Thus, it is important to keep the temperature increase of the IC as small as possible.

2.3 Output Ripple, Steady State at Full Load

In optical modules, the DSP core handles transmitting and receiving high-speed non-return-to-zero (NRZ) or four-level pulse amplitude modulation (PAM4) signals. It is important for system engineers to deliver a low-ripple power rail to minimize the noise impact in the DSP. Figure 2-4 shows the output ripple of the TPS62866 at its full 6-A load. At this maximum current, the figure illustrates an output ripple of less than 10 mV.



Output ripple: V_{IN} = 3.3 V, V_{OUT} = 0.9 V at 6 A

Figure 2-4. TPS62866 Enables low Output Ripple (Less Than 10 mV) at a Full Load

Increasing the total output capacitance or adding smaller-case-size capacitors, which are typically required at the input pins of the DSP, can achieve a smaller output voltage ripple. These smaller capacitors reduce unwanted inductance and resistance and further reduce the ripple. Operating the TPS62866 in forced pulsed-width modulation (PWM) mode through I²C will maintain a low output voltage ripple.

3 Supplying Digital I/O and Logic Circuitry

To power various circuitries such as the microcontroller (MCU) input/output (I/O), oscillator or laser driver bias, which operate with currents less than 1 A, choose a buck converter with a very small solution size. The TPS62802 switches at up to 4 MHz, which decreases the size of its output filter, and comes in a tiny WCSP to achieve one of the smallest solution sizes available on the market. Since the peak efficiency of most buck converters occurs at less than their full rated load current, the TPS62802 is recommended for use when the load current is less than approximately 600 mA. At currents higher than this level, the higher-current, 2-A TPSM82822 power module can power this rail given its higher efficiency at higher currents.

3.1 Solution Size for Lower Currents

The TPS62802 has an output voltage range of 1.8 V to 3.3 V in 100-mV steps. The output settings can accommodate the MCU I/O or oscillator at 1.8 V, the laser driver bias at 2.2 V, or the analog bias at 2.5 V for powering received signal strength indicator (RSSI) operational amplifier circuits. For lower output voltage settings, the device family has variants, such as the TPS62801, whose output voltage range can be set from 0.8 V to 1.55 V in 50-mV steps.

Figure 3-1 shows an application schematic of the TPS62802 and its small component count to address ultra-small designs. The TPS62802 family requires one resistor on the VSEL/MODE pin instead of the usual two resistors to set the output voltage and save space.

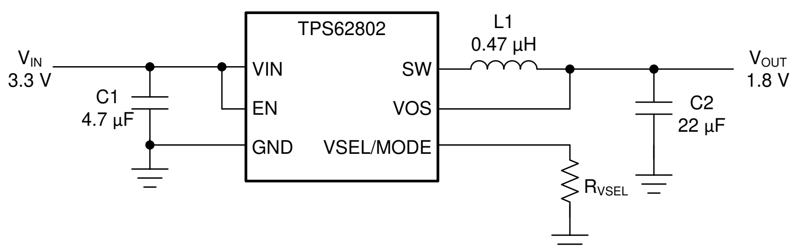


Figure 3-1. TPS62802 Reduces Component Count Using the VSEL Pin

Figure 3-2 shows the TPS62802 PCB layout, with an optimized 8.4-mm^2 solution size and a 1.0-mm maximum height. Table 3-1 lists the components used.

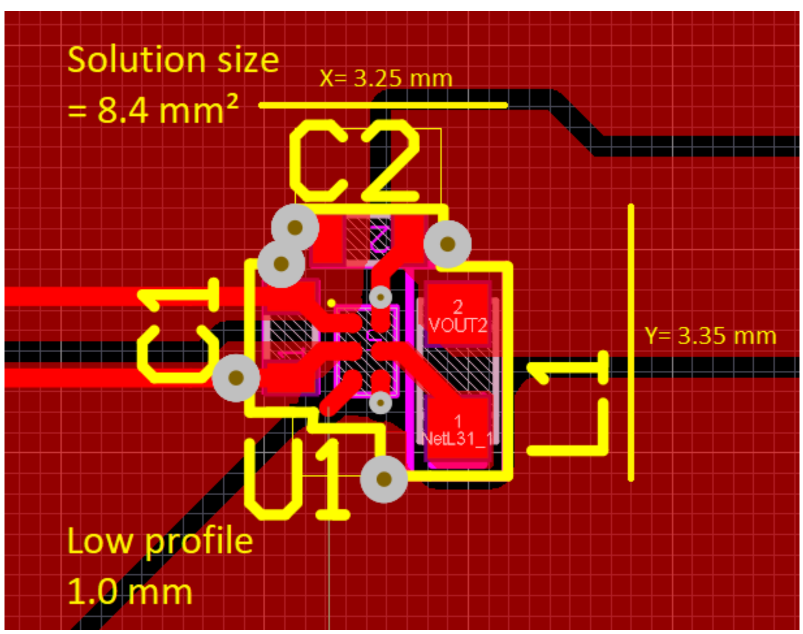


Figure 3-2. 1-A TPS62802 Powers Logic Circuitry Rails With a Tiny Solution Size

Table 3-1. Bill of Materials (BOM) for the 1-A Logic Circuitry Rail Occupies Only 8.4 mm²

Reference	Description	x, y, z Size	Manufacturer
U1	TPS62802 1-A step-down converter in WCSP	1.05 × 0.70 mm 0.4-mm height	Texas Instruments
L1	DFE18SANR47MG0L inductor 0.47 µH 20% (3.1 A, 45 mΩ)	1.6 × 0.8 mm 1.0-mm height	Murata
C1	GRM155R60J475ME47D CAP CER 4.7 µF 6.3 V X5R 0402	1.0 × 0.5 mm 0.5-mm height	Murata
C2	CM05X5R226M06AH080 CAP CER 22 µF 20% 6.3 V X5R 0402	1.0 × 0.5 mm 0.5-mm height	Kyocera

3.2 Solution Size for Higher Currents

Higher currents or higher efficiency needed to power the I/O circuitry, oscillator, laser driver bias, or analog bias will require a higher-current power supply. An added benefit of using a higher-current device is the higher efficiency that occurs when operating most buck converters under their rated current. For example, operating the 1-A TPS62802 at a 1-A load current delivers about 88% efficiency, whereas the 2-A TPSM82822 power module delivers 91% efficiency at the same 1-A load. This efficiency improvement creates less power dissipation in the system.

Figure 3-3 shows an application schematic of the TPSM82822 power module, which integrates the power inductor to save space and simplify the design. For a 3.3-V_{IN} to 1.8-V_{OUT} design, the TPSM82822 automatically operates in its lower-ripple PWM mode at load currents greater than approximately 400 mA.

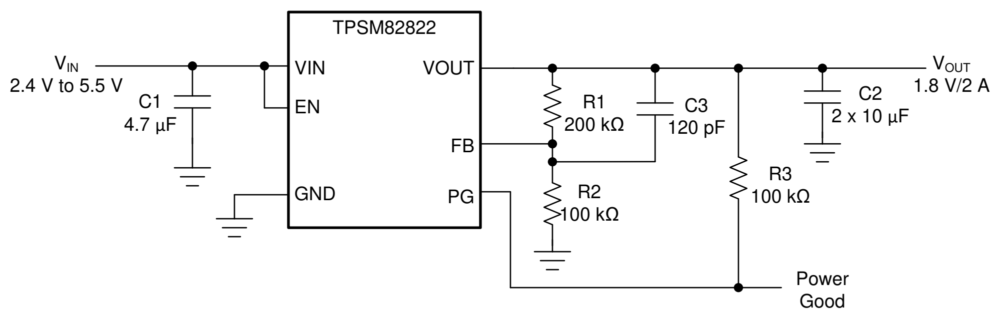


Figure 3-3. TPSM82822 Power Module Integrates the Inductor to Provide a Small Solution Size

Figure 3-4 shows the TPSM82822 PCB layout, with an optimized 12-mm2 solution size and a 1.1-mm maximum height. Table 3-2 lists the components used.

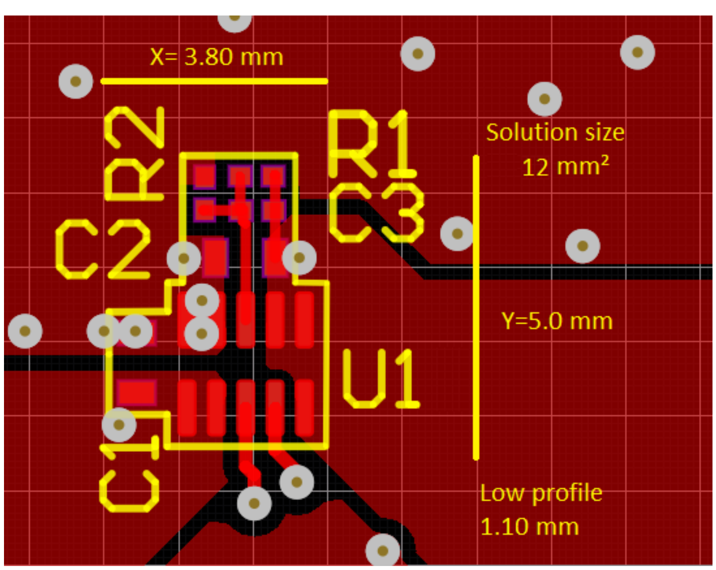


Figure 3-4. TPSM82822 Power Module Integrates the Inductor to Provide a Small Solution Size

Table 3-2. BOM for the Higher-Current Logic Circuitry Rail Occupies Only 12 mm^2

Reference	Description	x, y, z Size	Manufacturer
U1	TPSM82822 2-A step-down converter power module	2.0 × 2.5 mm 1.1-mm height	Texas Instruments
C1	GRM155R61C475ME11D CAP CER 4.7 µF 20% 4 V X5R 0402	1.0 × 0.5 mm 0.5-mm height	Murata
C2	AMK105EBJ226MV CAP CER 22 µF 20% 6.3 V X5R 0402	1.0 × 0.5 mm 0.5-mm height	Taiyo Yuden
R1	RC0201FS-7D200KLRES SMD 200 kΩ 1% 1/20 W 0201	0.6 × 0.3 mm 0.28-mm height	Yageo America
R2	RC0201FS-7D200KLRES SMD 200 kΩ OHM 1% 1/20 W 0201	0.6 × 0.3 mm 0.28-mm height	Yageo America
C3	GRM033R71E121KA01DCAP CER 120 pF 10% 25 V X7R 0201	0.6 × 0.3 mm 0.28-mm height	Murata

4 Powering the EAM, EML Controller and Laser Driver Bias

New and next-generation optical modules often rely on electroabsorption modulators (EAMs), as part of an externally modulated laser (EML) structure, to transmit high-speed PAM4 data at the appropriate optical power and linearity.

Electroabsorption modulators require an adjustable reverse bias or negative voltage to operate properly. Additionally, to control the EAM overtemperature and different operating conditions, engineers must monitor the current. Similarly, the laser bias, which provides the light source into the EAM, must have adjustable current levels to bias the laser diode while having the voltage monitoring for feedback.

4.1 AMC60804 EML Controller

Controlling and biasing the EML structure requires many sub-blocks and can consume the limited PCB area on QSFP-DD or OSFP form factors. The AMC60804 EML controller addresses this challenge and helps engineers achieve an integrated solution in the smallest possible PCB area.

The AMC60804 includes four channels of current-output DACs to drive the lasers, four channels of voltage-output DACs that can be set in a negative voltage range to bias the EAM, and four channels of ADC inputs to monitor the RSSI. Additionally, these data converters have integrated current and voltage monitoring on all channels for feedback. The outputs can be set and monitored through I2C or Serial Peripheral Interface (SPI) and are designed to accommodate most EML or silicon photonics structures.

Figure 4-1 shows the high-level block diagram and integrated sub-blocks of the AMC60804.

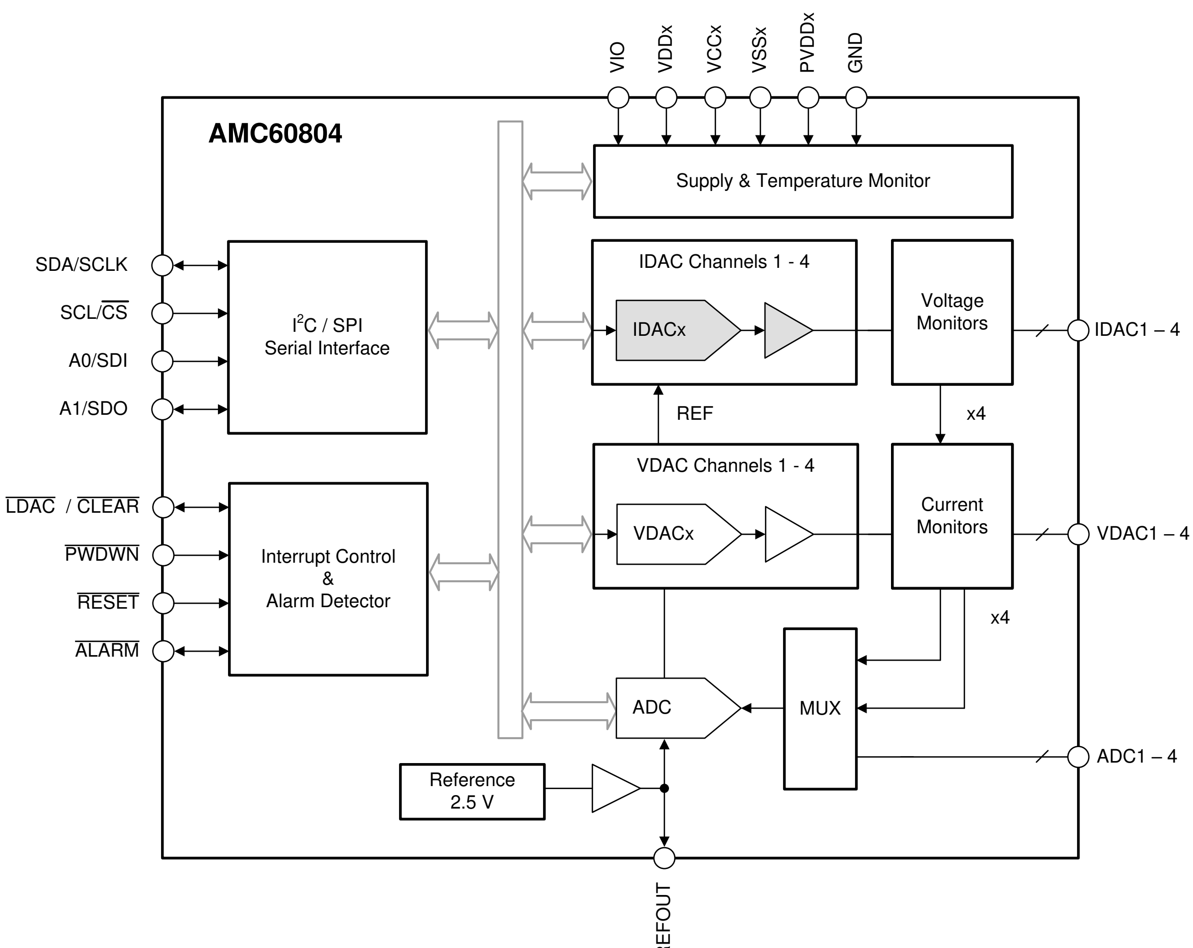


Figure 4-1. AMC60804 Provides Comprehensive Bias and Control for EML Structures

The AMC60804 requires four different power supplies: power VDD (PVDD) for laser bias, VSS for the EAM negative voltage supply, VDD for internal circuitry, and VIO to set the I/O level (if separate from VDD). This paper focuses on the first two supplies, as VDD and VIO are usually both tied to the module input of 3.3 V.

As mentioned in Section 3.1: Solution Size for Lower Currents, the TPS62802 can power the PVDD laser bias on the AMC60804. Toggling the VSEL/MODE pin after start-up will set PWM mode and ensure the best ripple across load currents.

4.2 Negative Supply Voltage for EAM

Using the TPS82130 MicroSiP™ power module step-down converter in an inverting buck-boost topology will generate the VSS negative supply voltage to bias the EAM. The *3- to 11.5-VIN, –5-VOUT, 1.5-A Inverting Power Module Reference Design for Small, Low-Noise Systems Reference Design* supports a –5-V output voltage and can supply up to 1 A with a 3.3-V input voltage.

Figure 4-2 shows the inverting buck-boost schematic.

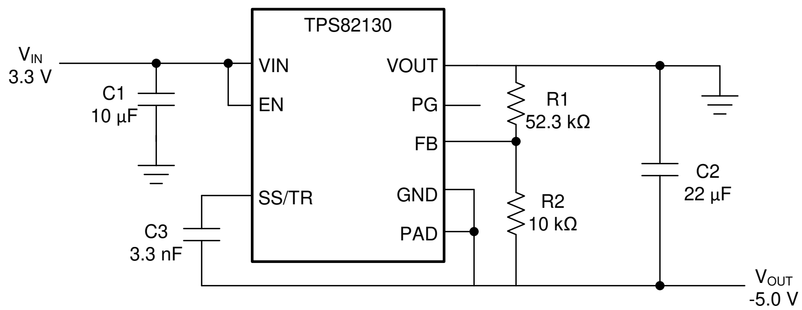


Figure 4-2. TPS82130 in an Inverting Buck-Boost Topology

Figure 4-3 shows a PCB layout with a solution size of 50 mm^2 and minimum external components. Table 4-1 lists the components used.

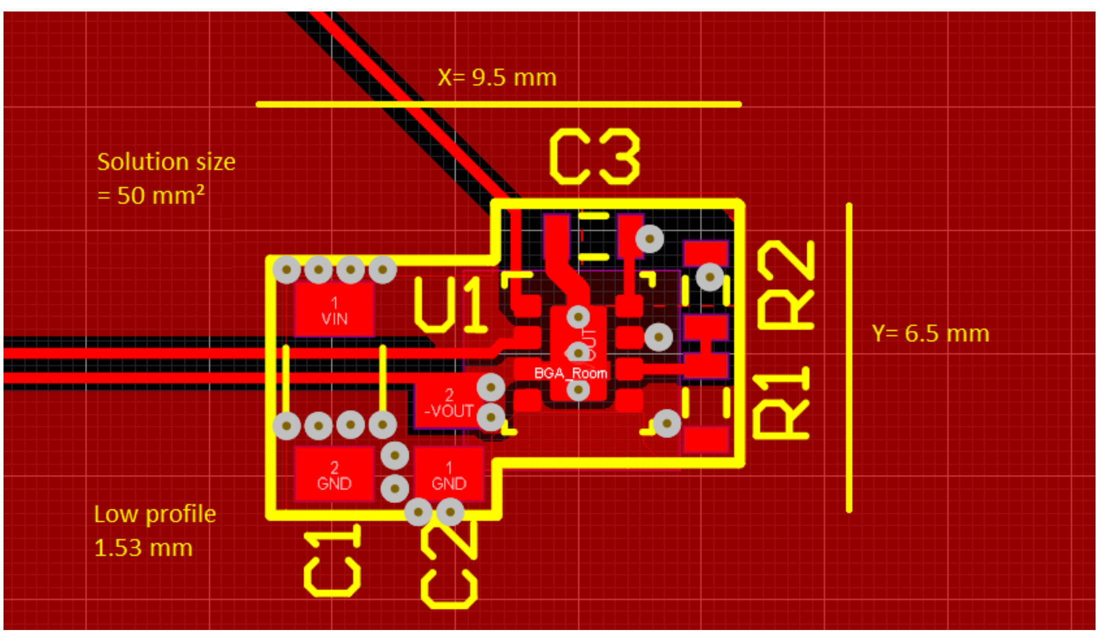


Figure 4-3. 3-A TPS82130 in an Inverting Buck-Boost Topology Powers the Negative Supply of an EAM With a Solution Size of Only 50 mm^2

Table 4-1. TPS82130 BOM in an Inverting Buck-Boost Topology

Reference	Description	x, y, z Size	Manufacturer
U1	TPS82130 3-A 17-V step-down converter module with integrated inductor	3.0 × 2.8 mm 1.53-mm height	Texas Instruments

Table 4-1. TPS82130 BOM in an Inverting Buck-Boost Topology (continued)

Reference	Description	x, y, z Size	Manufacturer
C1	C3216X7R1E106M160AE capacitor 10 µF 25 V X7R 1206	3.2 × 1.6 mm 1.6-mm height	TDK
C2	C2012X7S1A226M125AC capacitor 22 µF 10 V X7S 0805	2.0 × 1.25 mm 1.25-mm height	TDK
C3	GRM1885C1H332JA01D capacitor 3,300 pF 50 V C0G/NP0 0603	1.6 × 0.8 mm 0.8-mm height	Murata
R1	RC0603FR-0752K3L RES SMD 52.3 kΩ 1% 1/10 W 0603	1.6 × 0.8 mm 0.55-mm height	Yageo America
R2	RC0603FR-0710KL RES SMD 10 kΩ 1% 1/10 W 0603	1.6 × 0.8 mm 0.55-mm height	Yageo America

5 Powering the Receive Circuitry: TIA, Photodiode, or APD

The receive circuitry comprises a photodiode or avalanche photodiode (APD) that converts the optical signal into current pulses sent to a transimpedance amplifier (TIA), which outputs the signal into voltage for the DSP to decipher. These components may require a higher voltage than what is supplied at the 3.3-V input for proper biasing. As such, engineers need to use a buck-boost or boost DC/DC converter.

The receive photodiode is commonly biased anywhere from 3.0 V to 5.0 V. New fabrication processes enable photodiodes to have an optimal linear range at 3.5 V, with the forward current in the 1-mA to 50-mA range. The TIA may require a power supply in a similar range to accommodate the photodiode and to ensure that the internal circuitry is biased sufficiently.

Regulating a 3.5-V rail from a 3.3-V input voltage requires the use of a buck-boost converter. A buck-boost converter allows proper regulation of the output voltage, even when the input voltage is very close to the output voltage, and even if the input voltage varies because of line or load transients. A buck-boost converter automatically switches between buck, boost, and buck-boost operations as the operating conditions require.

To power the photodiode, choose a buck-boost power supply with a small solution size. The TPS63810 comes in a tiny WCSP and uses an I²C interface to set the output voltage, which reduces component count by two resistors.

Moreover, the output voltage might need to be adapted to the temperature or power dissipation in the system. The I²C interface provides a simple method to change the output voltage dynamically and enables the use of forced PWM mode to keep ripple low at the low forward currents.

Figure 5-1 shows an application schematic of the TPS63810 with its small and simple design.

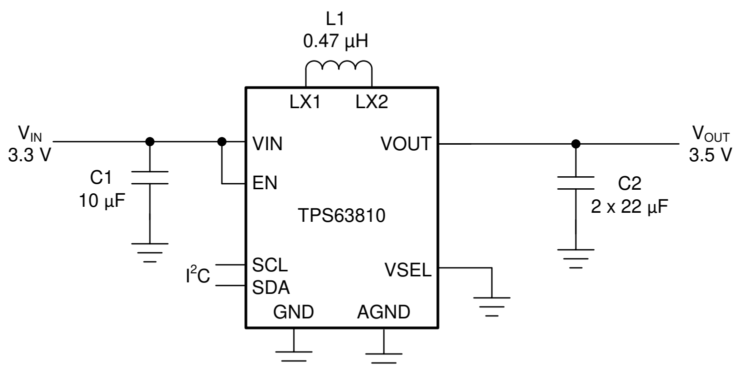


Figure 5-1. TPS63810 Regulates a V_{OUT} Close to V_{IN}

Figure 5-2 shows a PCB layout with a solution size of only 22 mm^2 and a low profile of 1.2 mm. Table 5-1 lists the components used.

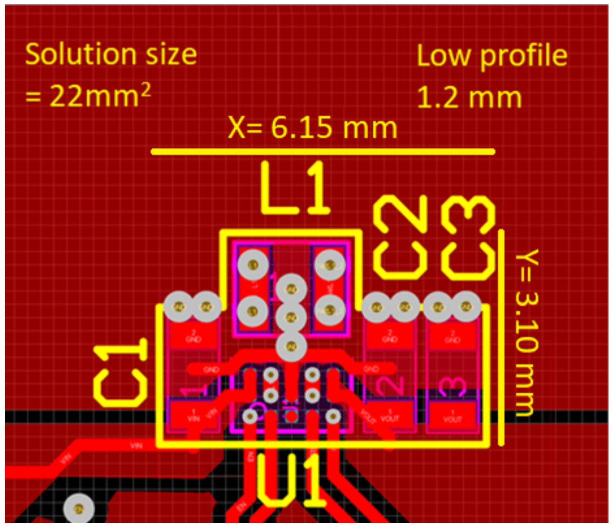


Figure 5-2. PCB Layout for the TPS63810 With a Solution Size of Only 22 mm^2

Table 5-1. BOM for the Photodiode With a Solution Size of Only of 22 mm^2

Reference	Description	x, y, z Size	Manufacturer
U1	TPS63810 6-A buck-boost converter with I2C interface in WCSP	2.3 × 1.4 mm 0.625-mm height	Texas Instruments
L1	DFE201612E-R47M inductor 0.47 µH 20% 5.5 A 26 mΩ	2.0 × 1.6 mm 1.2-mm height	Murata
C1	GRM188R60J106ME84 capacitor 10 µF 6.3 V X5R 0603	1.6 × 0.8 mm 0.8-mm height	Murata
C2, C3	GRM188R60J476ME15D capacitor 47 µF 6.3 V X5R 0603	1.6 × 0.8 mm 0.8-mm height	Murata

If a higher voltage is required for the photodiode, consider the TPS61372 synchronous boost converter for output voltages between 5 V and 16 V. It can be forced into PWM mode, which provides the lowest ripple.

System engineers can use the TPS61390 to power an APD or any optical component requiring 20 V to 85 V. Not only does it provide a high-voltage boost in a small package, but it also has many integrated features that reduce the required area over a discrete solution. Integrated features include current monitoring to report optical intensity and a fast-response-time current limit to protect the APD at high optical power.

6 Output Voltage Adjustment Implementing a DAC

As previously discussed, changing the output voltage of a DC/DC in real time can be useful depending on operating conditions or temperature optimization. During system development, the output voltage adjustment enables designers to determine the optimized supply-voltage setpoints as well as the supply-voltage margin.

Optical module manufacturers need to test their products thoroughly to ensure high reliability before going to market. Since power-supply voltage regulation may vary or drift – based on temperature, fluctuations in the input voltage, or inaccuracy caused by parasitics influencing the sense node – performing voltage margining tests can adjust power-supply voltages to the minimum and maximum of the specified supply-voltage range of the load and confirm that the load still operates correctly.

DACs create an analog signal that enables output voltage adjustments when added into the feedback pin of a DC/DC converter. Choose a precision voltage-output DAC such as the 10-bit, eight-channel unipolar DAC53608. The small size of this device conserves PCB area, while still being capable of margining multiple channels.

Figure 6-1 shows how to implement such a solution to control the output voltage of the DC/DC regulator.

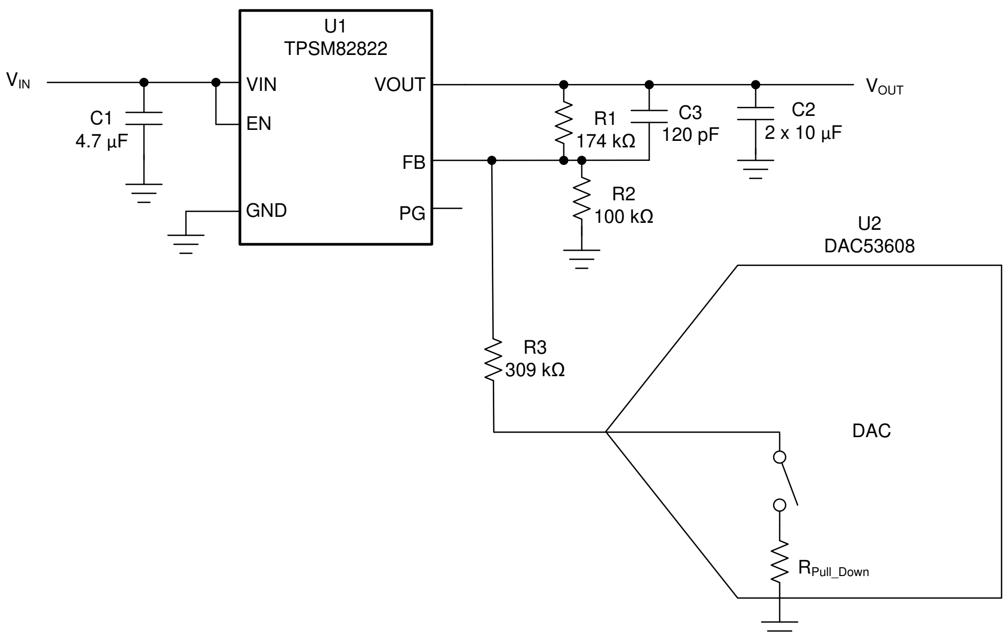


Figure 6-1. DAC53608 Adjusts the TPSM82822 Output Voltage

A further benefit of the DAC53608 is that its disabled outputs have an approximate 10-kΩ pulldown resistor. This internal pulldown resistor eliminates the disabled-to-enabled power-on glitch from the output of the DAC, which can cause transients on the output voltage during startup. The *Methods of Output-Voltage Adjustment for DC/DC Converters Technical Brief* is an *Analog Design Journal* article describing several configurations using this high-resolution voltage-output DAC.

7 Conclusion

As the amount of data transferred in optical modules increases, so does circuit design complexity, along with the power demand of the components. New DC/DC converter and data-converter designs need to achieve greater power density while operating with high efficiency at high temperatures. Power-reduction methods such as on-the-fly output voltage adjustments are key to controlling heat-generation in the system and helping engineers stay well within their power budgets. Integrating passives into power modules – as well as the many sub-circuits – into a single power-supply or data-converter IC reduces required PCB area and enables advancement to higher data rates.

8 References

- Texas Instruments, *Achieving High Thermal Performance in Compact Buck Power Modules Application Brief*
- Texas Instruments, *Methods of output-voltage adjustment for DC/DC converters*
- Texas Instruments, *3- to 11.5-VIN, –5-VOUT, 1.5-A Inverting Power Module Reference Design for Small, Low-Noise Systems Reference Design*
- Texas Instruments, *Thermal Performance Optimization of High Power Density Buck Converters*