Application Note AN 895:

12V Power Solution 1-Stage vs. 2-Stage

Contents

1. Introduction

DC-DC switching converters are the most popular power solutions when it comes to powering various systems from consumer to industrial electronics. When it comes to choosing DC-DC step-down (buck) switching converters, the options are boundless. The selections can be narrowed based on performance requirements such as voltage accuracy, transient performance, size, efficiency, cost and even ease of use. The power structure of many system usually starts with AC power coming into the mainframe from the wall and is then converted to various DC voltages. The first stage DC voltages can be 48V, 24V, 12V, 5V, 3.3V and more. From here on, various DC-DC converters can be utilized to further step-up or step-down the voltage to levels more suitable for the system load. As the semiconductor process technology continue to evolve and reduce the voltage level requirement of electronics, step-down regulators are becoming more and more important to maintain high system efficiency while also reducing board space. This application note will introduce a 2-Stage solution using Intel® Enpirion® 12V-to-6V EC2650QI Intermediate Bus Converter (IBC) to first convert 12V to 6V and then from 6V to lower voltages. By using this 2-Stage approach with other Intel® Enpirion® power system on chip (SoCs), the total power solution size can be reduced with minimal impact on efficiency. Intel® Enpirion® power system on chip (SoCs) are fully integrated high switching frequency step-down DC-DC power modules with available output currents ranging from 400 mA to 80A+. This application note will provide intimate insight into choosing the right power solution and assume that users have some familiarity with power system design.

2. General Discussion

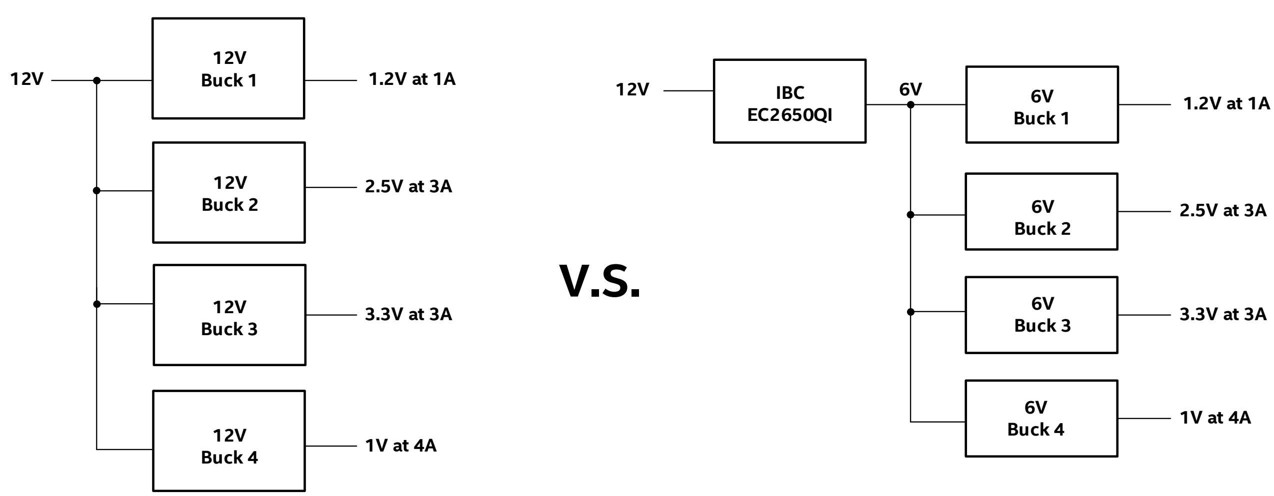


Figure 1. 1-Stage versus 2-Stage Power Tree Comparison

Voltage Process

As shown in Figure 1, the most direct way to convert a 12V rail to a lower voltage is with a 1-Stage DC-DC step down converter. If there are two, three or four rails, then a similar number of 12V DC-DC converters may be used in this 1-Stage approach. Each converter will need to support a 12V input and have power transistors that is able to withstand 12V or more. This requires a voltage process that is at least 20V or higher in order to guarantee enough margin between operating range and device breakdown. The higher the voltage process, the larger the device, due to oxide thickness and space needed between the drain, the source and the gate of transistors inside. The higher breakdown voltage inevitably comes at the cost of die space. Using larger devices to handle higher voltages will eventually lead to a larger total solution size. Therefore, it is beneficial to use lower voltage converters whenever possible.

Inductor Peak-to-Peak Current

Another factor that can attribute to larger solution size is the inductor. Since single stage converters need to step down from 12V to a lower voltage directly, the inductor must handle the voltage difference between input and output during each switching cycle. The inductor's peak-to-peak current can be calculated by the following equation:

$$\Delta \mathrm{I} = \frac{(\mathrm{Vin} - \mathrm{Vout})\, D}{\mathrm{L\ f}}$$

ΔI = Inductor's Peak-to-Peak Current	Vin = Input Voltage
Vout = Output Voltage	D = Duty Cycle = Vout/Vin
L = Inductance	f = Buck Regulator Switching Frequency

The higher the inductor's peak-to-peak current, the higher the output ripple of a buck regulator. Stepping down directly from 12V to a lower voltage often requires a higher inductance or a higher switching frequency in order to maintain a similar output ripple compared to stepping down from 6V. A higher inductance usually means more windings around the magnetic core in an inductor, which then increases the inductor's physical size. A higher switching frequency usually mean higher power loss and decreases efficiency. To keep efficiency high, larger devices are usually warranted. Therefore, building a buck regulator for higher input voltages often leads to a larger total solution size.

Total Solution Size

The advantage of first converting from 12V to 6V before converting to even lower voltages is to avoid having to use multiple higher voltage regulators. When a high efficiency Intermediate Bus Converter (IBC) is used to convert from 12V to 6V, the power loss is minimized on the first stage, which can lead to efficiency as high as 94%. Although it will never be 100% for the first stage, the power loss here can be made up in the subsequent rails where smaller 6V converters are used. Since the input voltage to the downstream converters is 6V, each will only require a 10V process technology, which is much smaller and less costly than 20V processes. Due to the lower input voltage, each converter can afford to use lower inductance and still maintain a comparable output ripple. As a result, the solution size for each 6V regulator is much smaller. To truly realize the actual benefit, the estimated layout for a 1-Stage and 2-Stage power solution is shown in Figure 2.

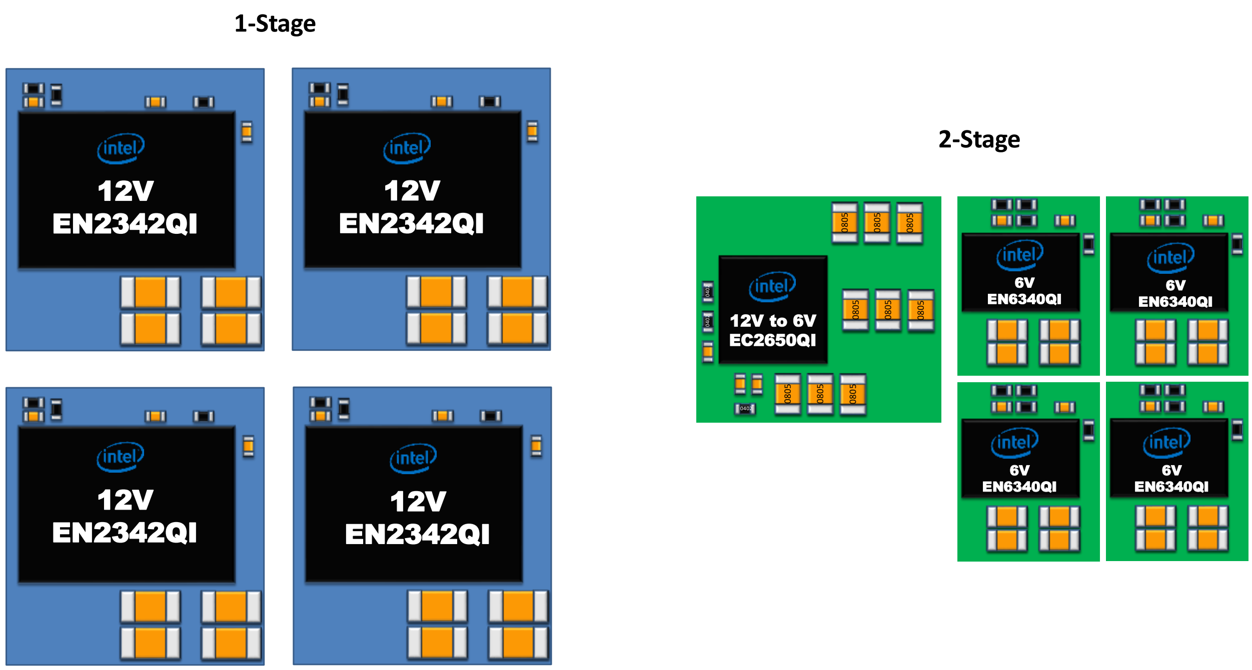


Figure 2: 1-Stage vs. 2-Stage Layout and Solution Size Comparison

As shown, the 1-Stage total solution size for the 4 rails requires around 800mm^2 and the 2-Stage total solution size is around 390mm^2. The 2-Stage approach is round half the size.

Total System Efficiency

The efficiency is an important aspect that should be analyzed. We assume there are 4 rails in need of power conversion. For simplicity, assume all four rails need to supply 4A to the load and calculate the total system efficiency.

Example

VIN = 12V

Rail 1 = 1.2V @ 4A

Rail 2 = 2.5V @ 4A

Rail 3 = 3.3V @ 4A

Rail 4 = 1.0V @ 4A

We can calculate the total system efficiency by calculating the power loss in each rail with the efficiency curves found in the datasheet of each regulator (shown in Figure 3 and Figure 4a/4b). Once the total power loss is known, the total system efficiency can be calculated. In the example given, we know the efficiency, the input voltage (V_{IN}), the output voltage (V_{OUT}) and the output current (I_{OUT}), so we can calculate the input current (I_{IN}). Once we have the input current of each rail, we can calculate the input power (P_{IN}). The power loss (P_{LOSS}) is equal to the input power minus the output power. After finding the power loss in each rail, we can calculate the total power loss and find the total system efficiency with basic algebra.

Efficiency = P_{OUT} / P_{IN} = V_{OUT} * I_{OUT} / V_{IN} * I_{IN}

P_{LOSS} = P_{IN} - P_{OUT}

Based on Figure 3, the total system efficiency for 1-Stage using four EN2342QI is around 87%. The total system efficiency for the 2-Stage (EC2650QI + 4xEN6340QI) can be calculated to be 84%. Based on these calculations, the 1-Stage has a higher efficiency than the 2-Stage, since the extra power stage using the EC2650QI creates loss not present when we convert voltage directly. Although the 2-Stage system efficiency is lower than the 1-Stage, the 50% smaller solution size is a significant saving. It also means there is room for improvements.

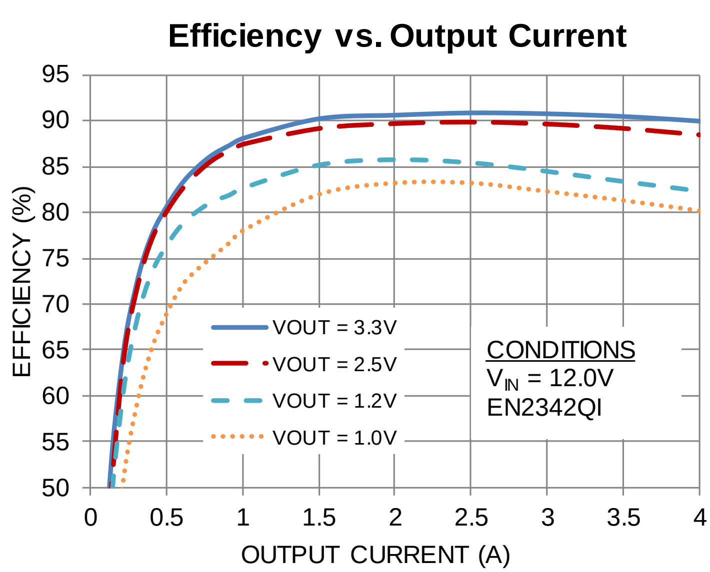
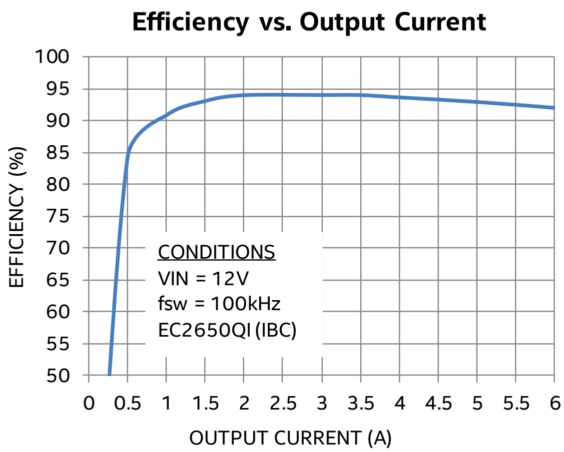


Figure 3. EN2342QI 1-Stage Efficiency



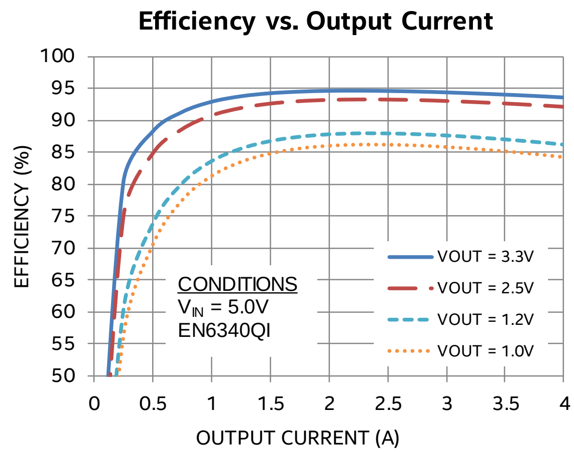


Figure 4a. EC2650QI IBC First Stage Efficiency **Figure 4b. EN6340QI Second Stage Efficiency**

If the lower efficiency of using the previous 2-Stage approach is unacceptable in a particular power system design, note that it can be improved by selecting larger converters, as they are more efficient. In Figure 5, the EN6362QI buck module was selected in place of the EN6340QI to improve efficiency.

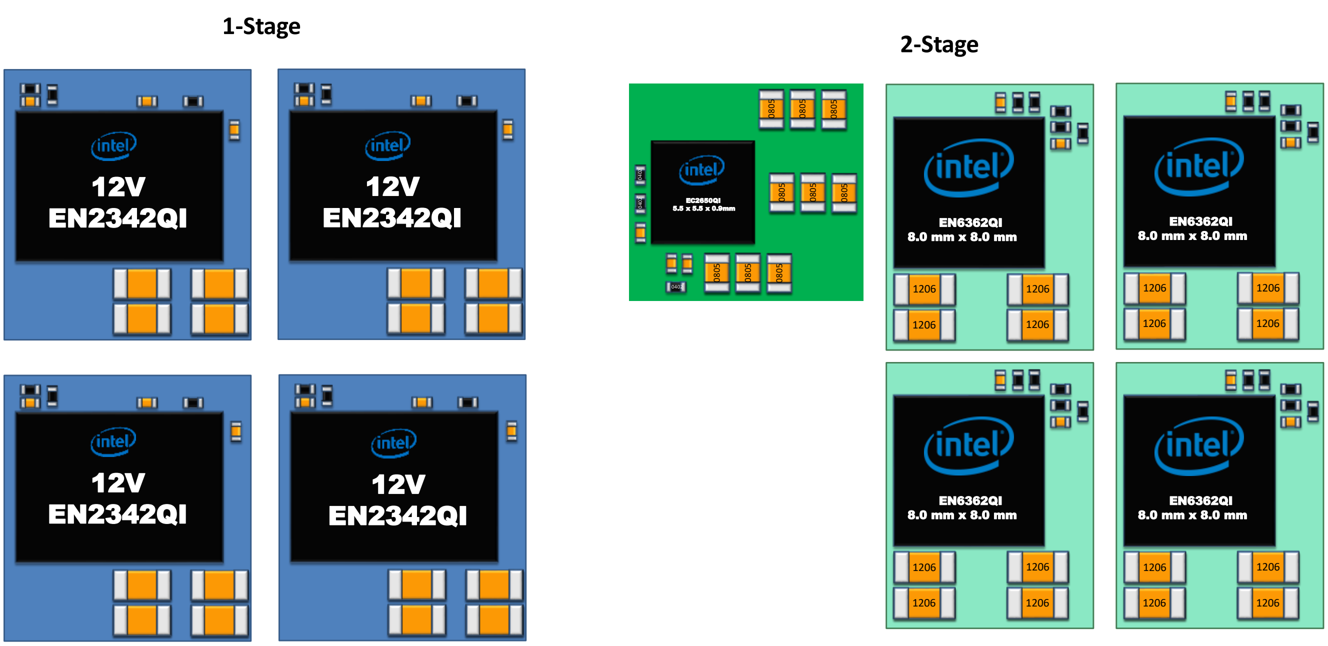


Figure 5: 1-Stage vs. 2-Stage Size Comparison with EN6362QI

With the four EN6362QI, the 2-Stage total solution size is around 790mm², which is equivalent to the 1-Stage at 800mm². Now that the solution sizes are equal, the efficiency can be checked based on the datasheet efficiency curves shown in Figure 6a/6b.

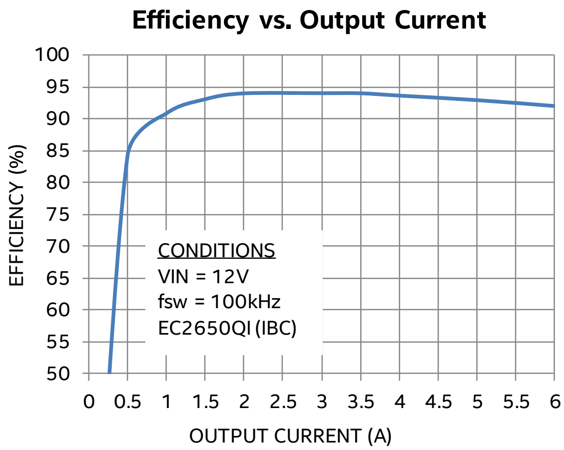


Figure 6a. EC2650QI IBC First Stage Efficiency

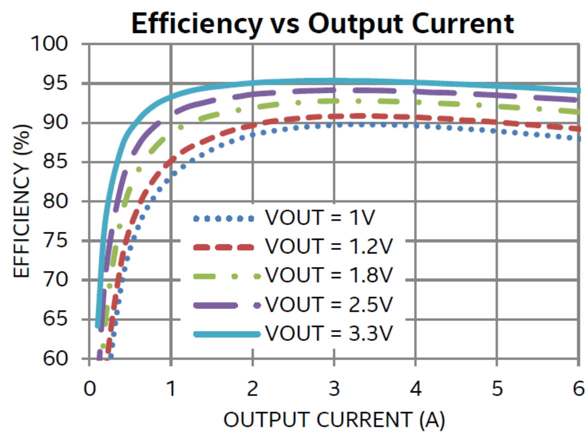


Figure 6b. EN6362QI Second Stage Efficiency

Using the same example previously shown, the total system efficiency using the 2-Stage (EC2650QI + 4xEN6362QI) can be calculated to be around 86%, which is comparable to the 87% when using the 1-Stage. Since the 2-Stage devices use a lower voltage process, the dies are still smaller and the cost will also be lower, even though the solution size and efficiency are equivalent. This is an advantage over the 1-Stage that cannot be over-looked.

1-Stage versus 2-Stage Comparison

Based on the analysis that has been presented, a power system designer now has more options. To be clear, there are advantages and disadvantages for each situation. If there is only 1 voltage rail in the system, it is still better to directly convert from 12V to the lower voltage using the 1-Stage approach, since using 2 smaller and lower voltage devices can be larger than using just 1 higher voltage device. This is especially true for higher current rails such as a CPU core. When there are 2 rails, the 2-Stage starts to become more viable, but will likely depend from system to system. As the number of rails increase, the 2-Stage approach will start to become more and more enticing. Based on the balance between having a comparable solution size and good efficiency, using the EC2650QI (IBC) does not become valuable until there are 3 or more rails. Once there are more than 3 rails, the benefits of smaller size and lower cost will outweigh the cost of an extra IBC such as the EC2650QI. When it comes to using a 2-Stage conversion architecture, it is best to use a device built for an intermediate bus such as the EC2650QI. It has a 33W power capability with the option to parallel with other EC2650QI devices. It is also simple, easy to use and has a very high efficiency up to 94% in the usage range.

Theory of Operation

The EC2650QI uses a switch capacitor technology that charges a set of capacitors in series and then switching them in parallel at the output. The switching scheme shown in Figure 7 is separated into 2 phases. During Phase 1 when Q1 and Q3 transistors are ON, the CFLY and COUT capacitors are charged in series. Note that during this phase, current is draw from PVIN almost instantly. The input capacitors must supply the necessary current in order to charge the CFLY and COUT capacitors. This can lead to a sudden drop in the voltage across the input capacitors and this mechanism is repeated at the device's recommended switching frequency (100kHz to 130kHz). Note that Blank Time leaves all Q1-Q4 transistors off and is added between phases to prevent current shoot-through. During Phase 2, the Q2 and Q4 transistors are turned on, thereby connecting the CFLY and COUT capacitors in parallel. The voltage across the parallel capacitors becomes half of the input and will provide the lower bias voltage for the downstream regulators.

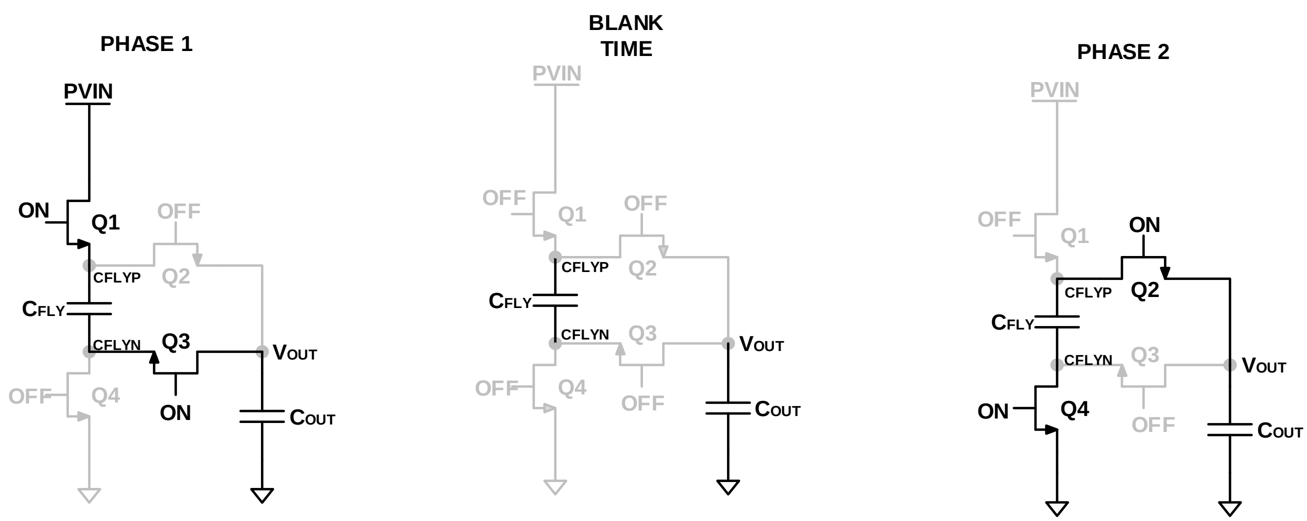


Figure 7: Operational Switching Scheme

Note that the EC2650QI does not have any voltage feedback and therefore cannot adjust its own duty cycle to increase output voltage when the load increases. The output voltage is half of the input voltage, but due to output impedance, the output voltage further decreases as output current increases. Figure 8 shows this trend. At 6A load current, the output of the EC2650QI can drop almost 500mV under worst case scenarios. If the input voltage of the 12V rail is specified at ±10% variation, then the input voltage can be as low as 10.8V. The output of the EC2650 will be 5.4V and with a 500mV drop due to 6A load, the output voltage can potentially be 4.9V (from a 6V design at 0A). On top of the DC voltage drop, the AC voltage ripple due to nearly instant capacitive charge transfer can generate greater input and output ripple than a standard switching buck regulator. The greater voltage ripple is amplified by the fact that the EC2650QI switches at a lower frequency range (chosen for better efficiency). As a result, input and output ripple may need extra filtering if noise sensitivity is an issue for a given system. The next section will discuss these design considerations.

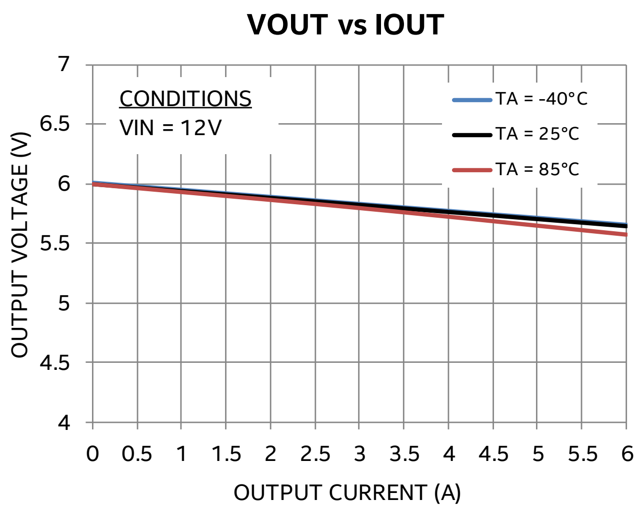


Figure 8: Output Voltage vs. Output Current

Design Considerations

When designing solutions with the EC2650QI using the 2-Stage approach, the end result can lead to lower cost and a smaller solution size with minimal impact on efficiency; however, there are some design considerations for optimization. As mentioned in the Theory of Operation section, the switching capacitor design of the EC2650QI can lead to higher input and output voltage ripple than a standard buck regulator. The voltage ripple caused by the switching of capacitors can be a few hundred millivolts at the 100kHz to 130kHz switching frequency range, as shown in Figure 9.

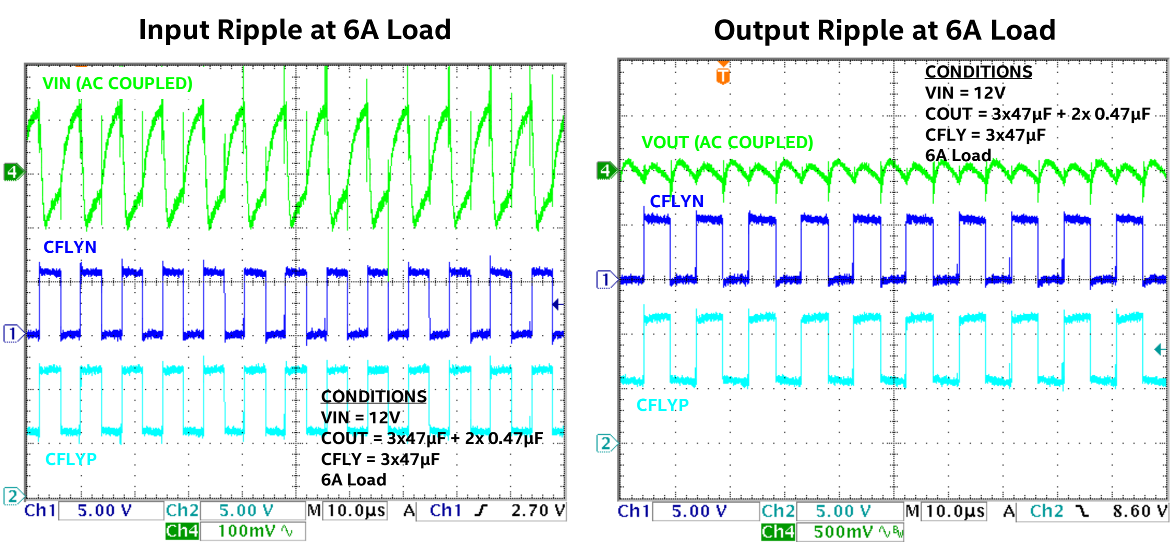


Figure 9: EC2650QI Input and Output Ripple at 6A Load

In most cases, this input ripple is not an issue as 12V input rails can have voltage tolerance of ±10% and the ripple is less than that. On the output end, since the EC2650QI is used to drive buck regulators such as Enpirion PowerSoCs, the noise will be rejected by those regulators and will not be passed onto the load. Regardless, if the ripple is an issue for noise sensitive systems, then proper filtering should be used to ensure that the noise is suppressed within the 2-Stage solution block. One proven method used to suppress voltage ripple is to add an input Pi Filter, shown in Figure 10. The advantage of the Pi Filter is the fact that it can be tuned to filter out unwanted AC signals in both directions and at frequencies that can be customized by the user based on the inductive and capacitive components used. Due to the lossless nature of these passive components, it also has minimal effect on the overall system efficiency. The drawback is the extra passive components used and the increased board space needed. In Figure 10, the input Pi Filter has been designed to attenuate the input switching ripple of the EC2650QI.

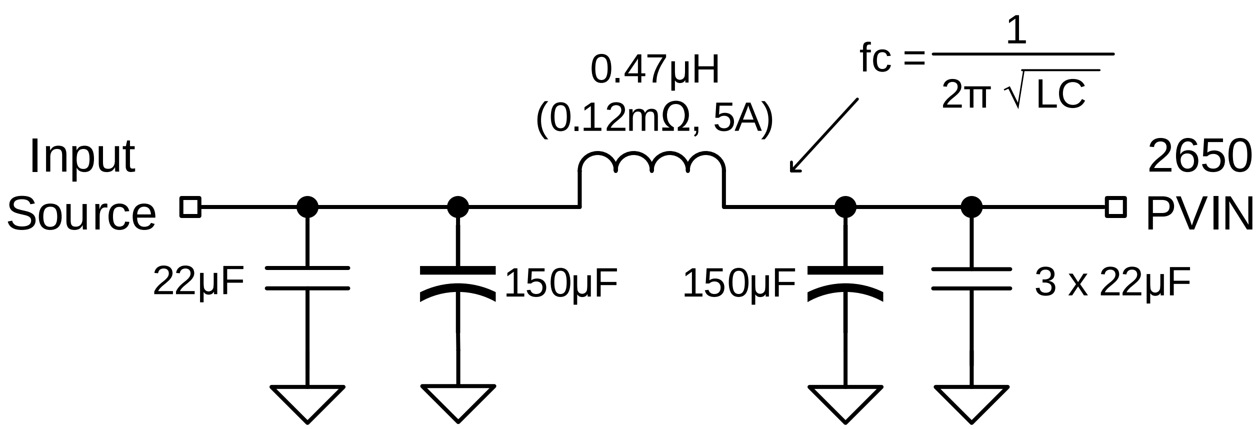


Figure 10: Input Pi Filter

The Pi Filter can be customized based on the cut-off frequency (f_C) to filter the voltage ripple at the switching frequency of the EC2650QI (100kHz – 130kHz). The Pi Filter works by filtering unwanted AC signal from the source side to the input of the EC2650QI but also works in reverse by preventing the switching ripple generated by the EC2650QI from going back into the 12V source. This input switching ripple will pass through the Pi Filter designed for cutting off frequencies starting at ~20kHz. At 100kHz, the input switching ripple will be greatly reduced on the source side. As shown in Figure 11, the input voltage spikes from the EC2650QI is much lower when the Pi Filter is used. One aspect to pay attention to when designing the Pi Filter is ensuring that there is sufficient input capacitance on the PVIN side of the filter, since the added inductor will slew the current from recharging the input caps near the PVIN pins. For this reason, we want to ensure that the capacitors on both sides of the Pi Filter has sufficient energy storage as well as having the right cut-off frequency design. Note that Pi Filters can be applied to both the input as well as the output of switching converters. For the EC2650QI, there is no need to filter the output since the output is used to bias other buck regulators (such as Enpirion PowerSoCs). The buck regulators are designed to reject noise signals well over 100kHz and their outputs will not see the ripple from the input. In extremely noise sensitive systems, output filtering should be done on the output of the buck regulators and can be done by using additional Pi Filters or LC filters. In such instances, the same filtering technique should be applied where unwanted frequencies should be removed by proper setting of the LC values. For the EC2650QI input, the reduction of voltage ripple at the input source with the Pi Filter is nearly 10 times and should be sufficient for most systems. Proper filtering on switching converters can lead to quieter systems, but at the cost of extra components and board space and is a decision that needs to be made by the system designer. If designer is unsure of system requirements, understand that the Pi Filter layout can be put in place, but shorted if deemed unnecessary. It is a good idea to utilize a large footprint for the inductor of the Pi filter so that a large zero-ohm resistor can be put in place of the inductor, should the Pi Filter become unnecessary.

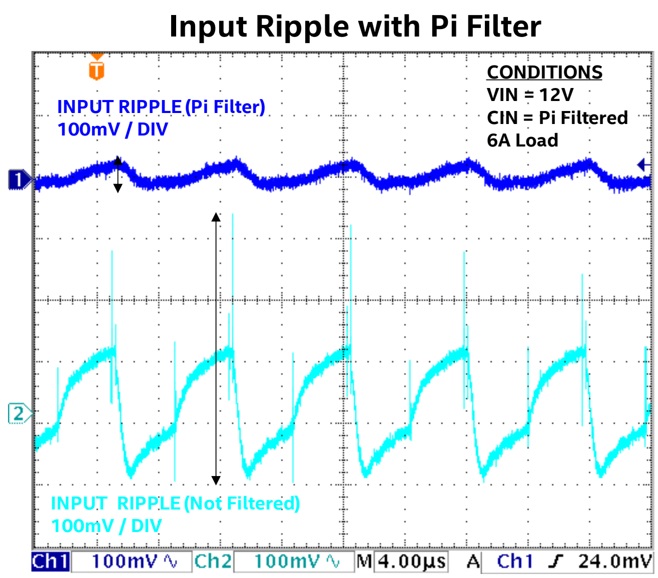


Figure 11: Pi Filtered Input Voltage Ripple

3. Conclusion

As modern electronics become smaller and more efficient, there is a constant drive to improve existing products and find alternative power solutions. The technologies used to power today's electronics have changed and the solutions available today are much smaller and more efficient than yesterday, but it will always be up to the system designer to choose the best solution.

4. Revision History

Revision	Description	Revision Date
A	Initial release.	4/10/2019
B	- Updated with Theory of Operation - Updated with Design Considerations	4/28/2020