12 V Power Solution 1-Stage vs. 2-Stage (AN-895)

Written By: Brian Huang, Intel® Enpirion® Power Applications Engineer

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 systems 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 48 V, 24 V, 12 V, 5 V, 3.3 V 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 loads. As the semiconductor process technology continues 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 the Intel® Enpirion® 12 V-to-6 V EC2650QI Intermediate Bus Converter (IBC) to first convert 12 V to 6 V and then from 6 V 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 80 A+. This application note will provide intimate insight into choosing the right power solution and assumes that users have some familiarity with power system design.
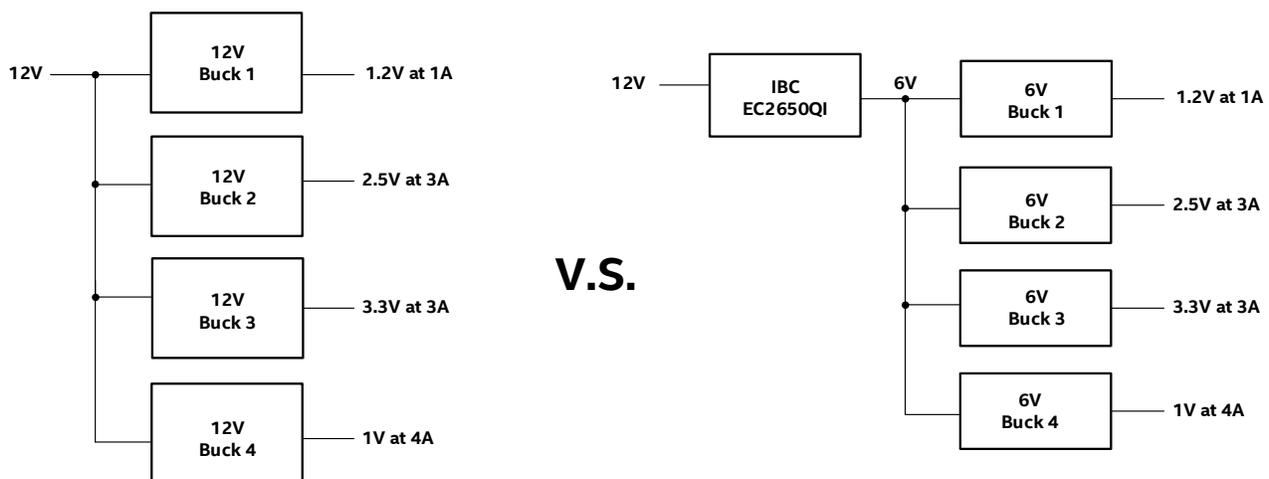
2. General Discussion

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

Voltage Process

As shown in Figure 1, the most direct way to convert a 12 V 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 12 V DC-DC converters may be used in this 1-Stage approach. Each converter will need to support a 12 V input and have power transistors that are able to withstand 12 V or more. This requires a voltage process that is at least 20 V 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 the 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. This is why 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 12 V 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:

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

ΔI = Inductor's Peak-to-Peak Current $\qquad$ Vin = Input Voltage

Vout = Output Voltage $\qquad\qquad\qquad$ D = Duty Cycle = Vout/Vin

L = Inductance $\qquad\qquad\qquad\qquad$ 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 12 V 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 6 V. A higher inductance usually mean more windings around the magnetic core in an inductor, which then increases the inductor's physical size. A higher switching frequency usually means higher power loss and decreases efficiency. To keep efficiency high, larger devices are usually warranted. This is why 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 12 V to 6 V 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 12 V to 6 V, 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 6 V, each will only require a 10 V process technology, which is much

smaller and less costly than 20 V 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 6 V 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.
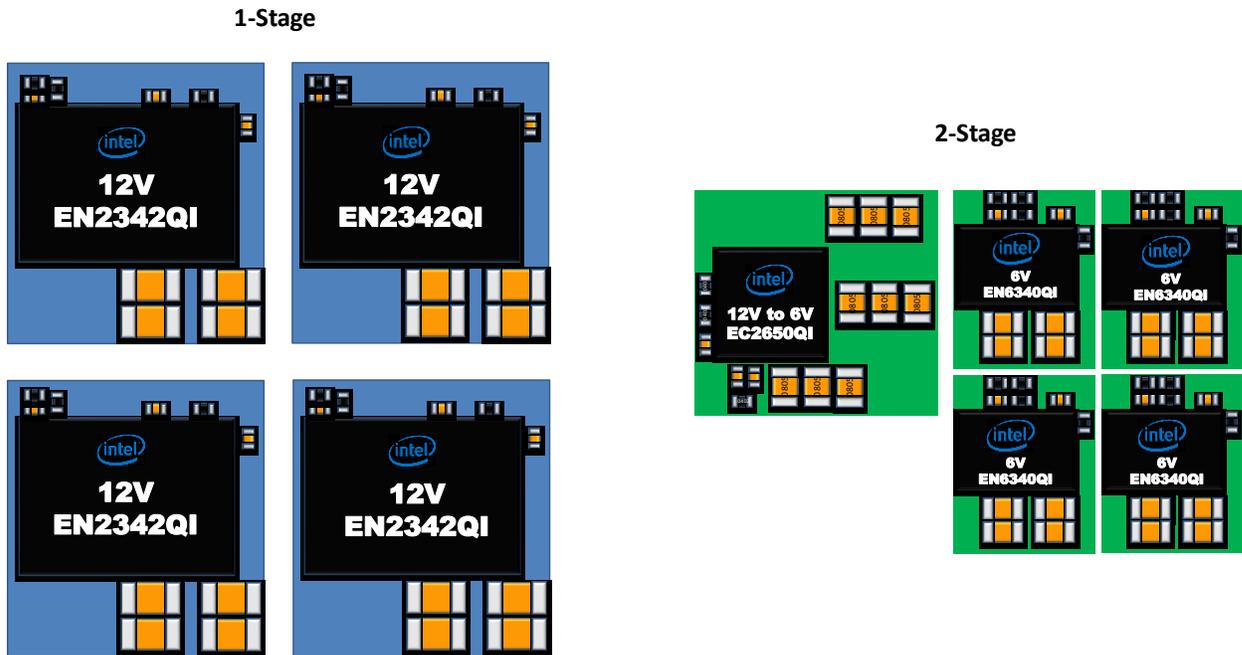

Figure 2: 1-Stage vs. 2-Stage Layout and Solution Size Comparison

As shown, the 1-Stage total solution size for the 4 rails requires around 800 mm^2 and the 2-Stage total solution size is around 390 mm^2. The 2-Stage approach is about 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 4 A to the load and calculate the total system efficiency.

Example

V_{IN} = 12 V

Rail 1 = 1.2 V @ 4 A

Rail 2 = 2.5 V @ 4 A

Rail 3 = 3.3 V @ 4 A

Rail 4 = 1.0 V @ 4 A

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, mainly due to the fact that 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 savings. It also means there is room for improvements.
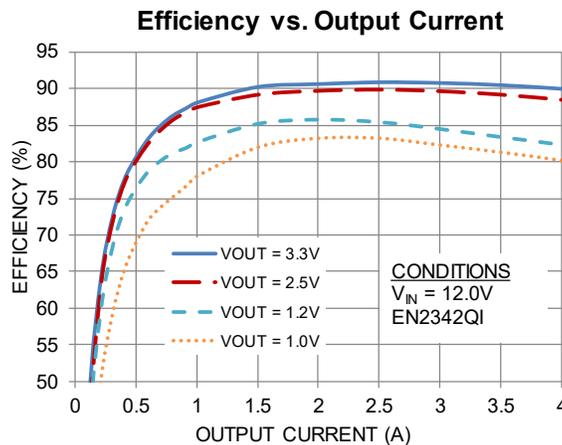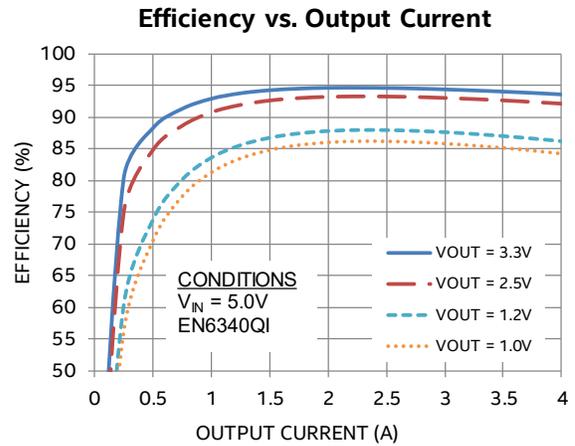

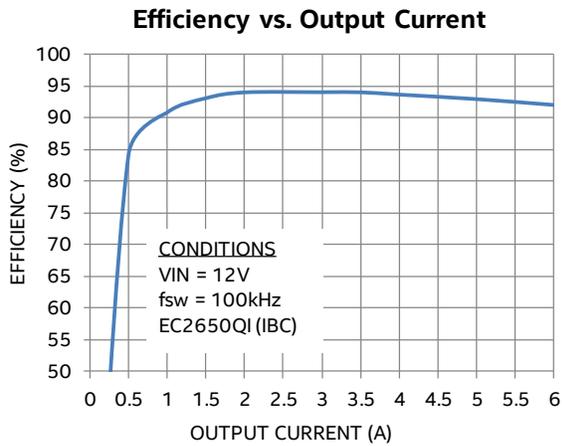**Figure 3. EN2342QI 1-Stage Efficiency**

Figure 4a graph: **Efficiency vs. Output Current**
Y-axis: EFFICIENCY (%), X-axis: OUTPUT CURRENT (A)
CONDITIONS
VIN = 12V
fsw = 100kHz
EC2650QI (IBC)

Figure 4b graph: **Efficiency vs. Output Current**
Y-axis: EFFICIENCY (%), X-axis: OUTPUT CURRENT (A)
CONDITIONS
V_{IN} = 5.0V
EN6340QI
VOUT = 3.3V
VOUT = 2.5V
VOUT = 1.2V
VOUT = 1.0V

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.
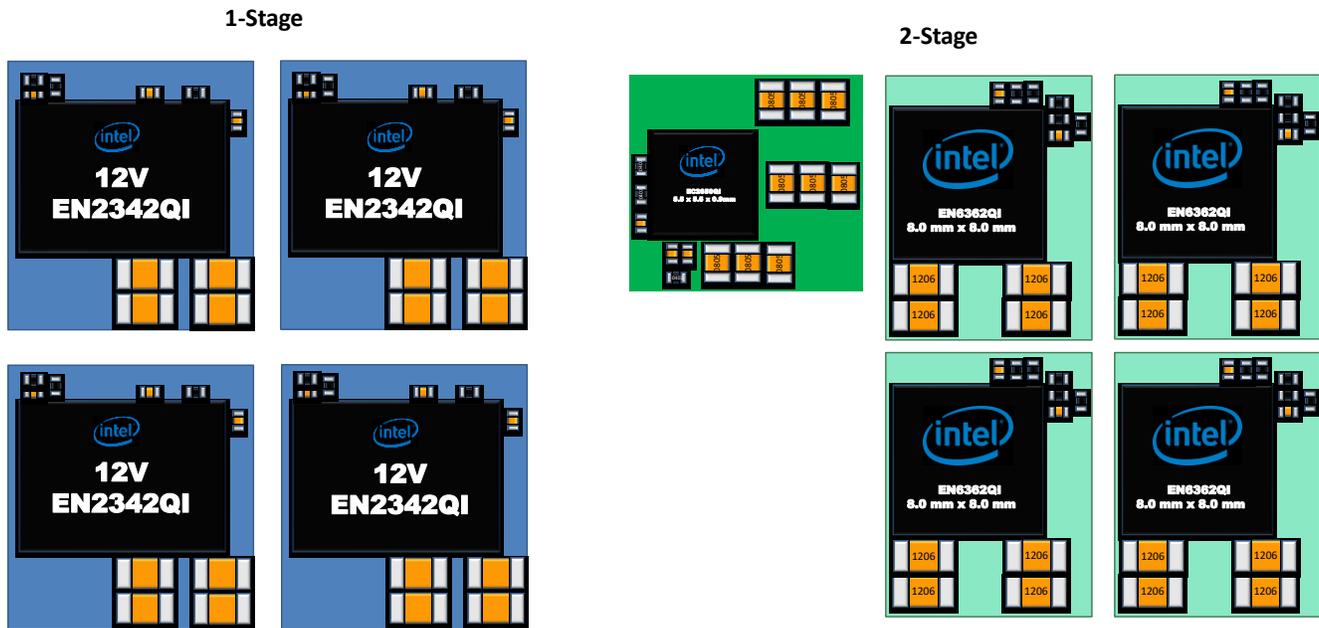

Figure 5: 1-Stage vs. 2-Stage with EN6362QI

7

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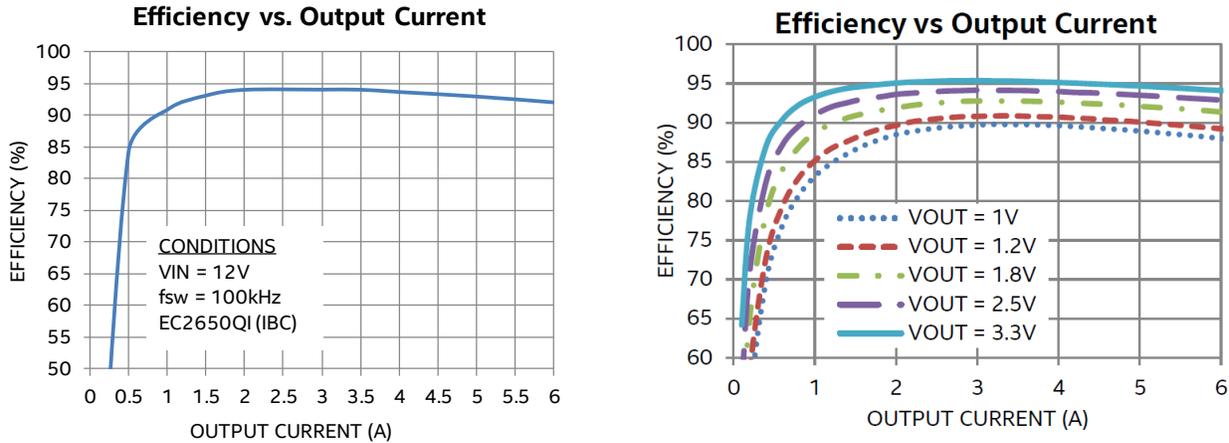

Figure 6a. EC2650QI IBC First Stage Efficiency   **Figure 6b. EN6362QI Second Stage Efficiency**

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 is 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 12 V 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 33 W power capability with the option to parallel with other EC2650QI devices. It is also easy to use and has a very high efficiency up to 94% in the usage range.

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.
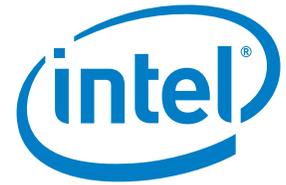
4. Revision History

Revision	Description	Revision Date
A	Initial release.	4/10/2019