AN-008: EPC Space Discrete and Modular Products for Space-Based Boost DC-DC Power Conversion.

Introduction

A lot of emphasis is placed on buck/forward-mode (voltage step-down) DC-DC conversion, while the overlooked boost converter is still a useful and sometimes absolutely necessary means of power conversion. This application note discusses how EPC Space discrete, integrated and modular devices can be readily configured to perform boost (voltage step-up) power conversion for space applications.

A Recap of Boost Conversion

Any non-isolated boost (an isolated boost is called a flyback converter) DC-DC converter has the general, canonical form as shown in Figure 1.

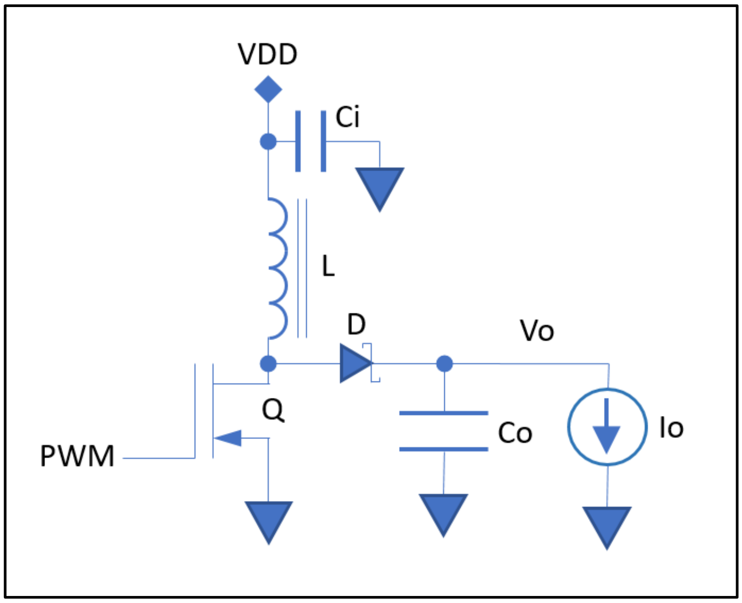

Figure 1. *Simplified Canonical Form of the Non-Isolated Boost Converter.*

The electronic switch, Q, in Figure 1 controls the magnitude of current in inductor L as a function of the on time of switch, per the PWM input signal applied. In addition to the DC current component determined by Io, there is also an AC component of inductor current.

The waveforms for the boost converter in Figure 1 are shown in Figure 2.

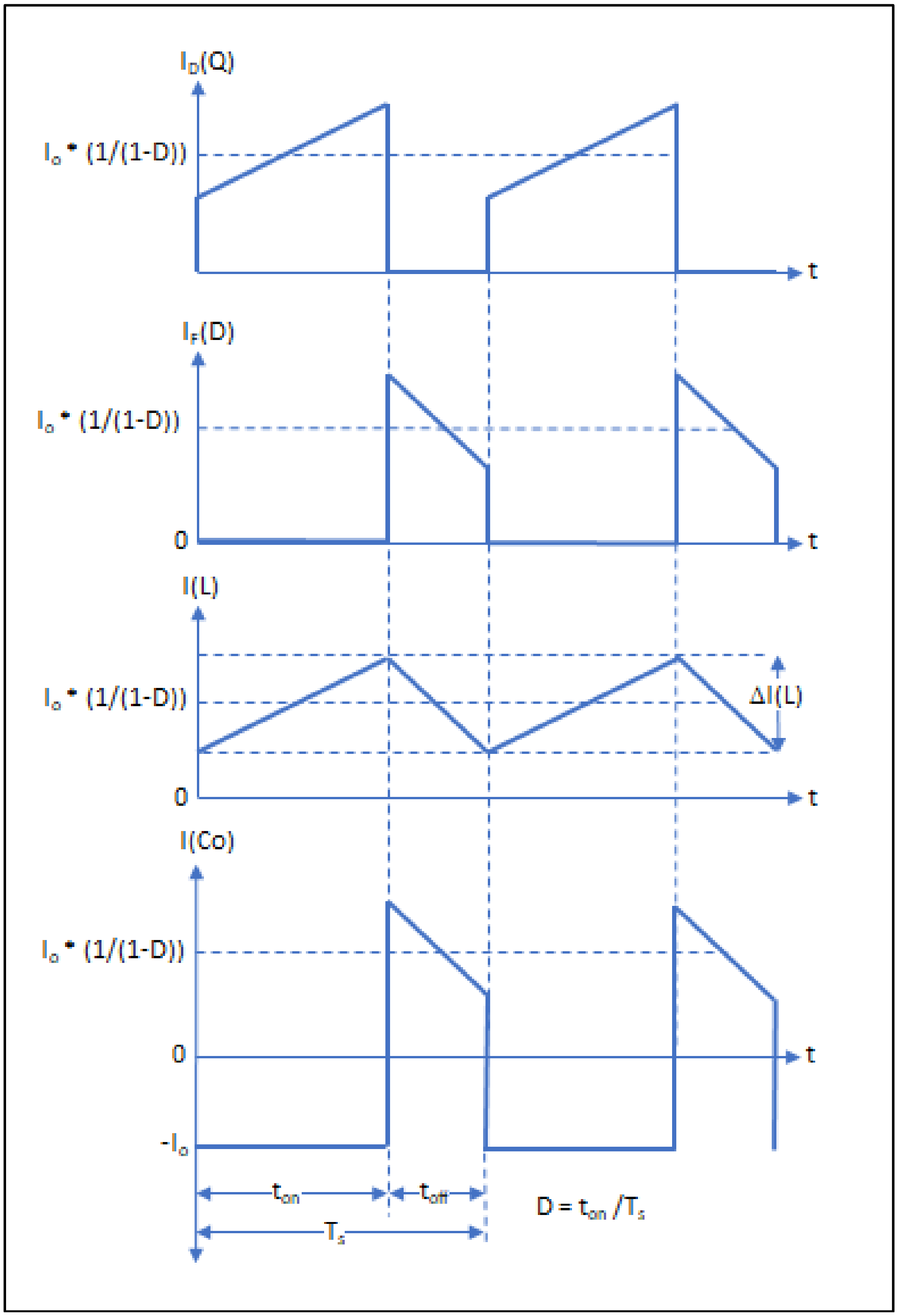

Figure 2. *Boost Converter Waveforms.*

The boost converter has two states of operation depending upon the state of Q. These two states are depicted in Figures 3a, when the switch is ON and Figure 3b when the switch is OFF.

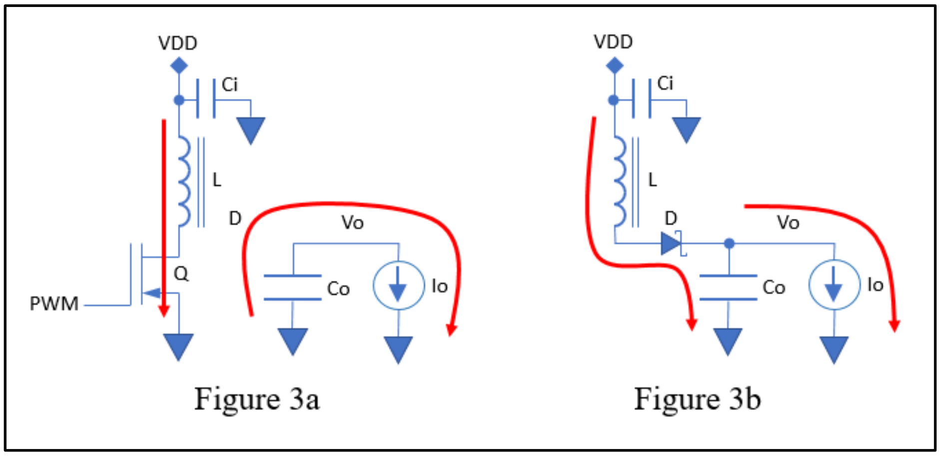

Figure 3a Figure 3b

Figure 3. *Boost Converter Operating Modes.*

When the switch transistor Q is ON, for time period t_{on}, current increases in the inductor connected from VDD to ground according to:

$$\Delta I(L(ON)) = VDD * t_{on} / L \qquad \text{(Eq 1)}$$

Simultaneously, the diode, D, is reverse biased as its cathode is biased at output voltage Vo and its anode at ground. Thus, the output capacitor, Co, is isolated from the energy storage element L, and the capacitor is discharged by the load current Io according to:

$$\Delta V(C_o) = I_o * t_{on} / C_{out} \qquad \text{(Eq 2)}$$

When switch transistor Q is OFF, for time period t_{off}, current now flows from the inductor through diode D into the output capacitor, C_{out}, and the load. This action "re-charges" the output capacitor.

Thus, over one switching cycle, T_s, energy is first stored in the inductor and then this energy is transferred to the output capacitor and the load. The current indicated in Eq 1 is the current deviation due to the ON time. The current deviation in the OFF time will be the same amount, but the voltage and time are different, according to:

$$\Delta I(L(OFF)) = (VDD - V_{out}) * t_{off} / L \qquad \text{(Eq 3)}$$

It is now time to introduce the concept of duty cycle, D, which is the amount of time the switch Q is on during a switching cycle. This quantity is:

$$D = t_{on} / T_s \qquad \text{(Eq 4)}$$

Substituting Eq 4 into Eqs 1 and 3, and equating them (because the net current change over a cycle is zero):

$$VDD * D * T_s / L = (VDD – V_{out}) * (1 – D) * T_s / L \qquad \text{(Eq 5)}$$

Simplifying Eq 5 further yields the boost topology's transfer function:

$$V_{out} / VDD = 1 /(1 – D) \qquad \text{(Eq 6)}$$

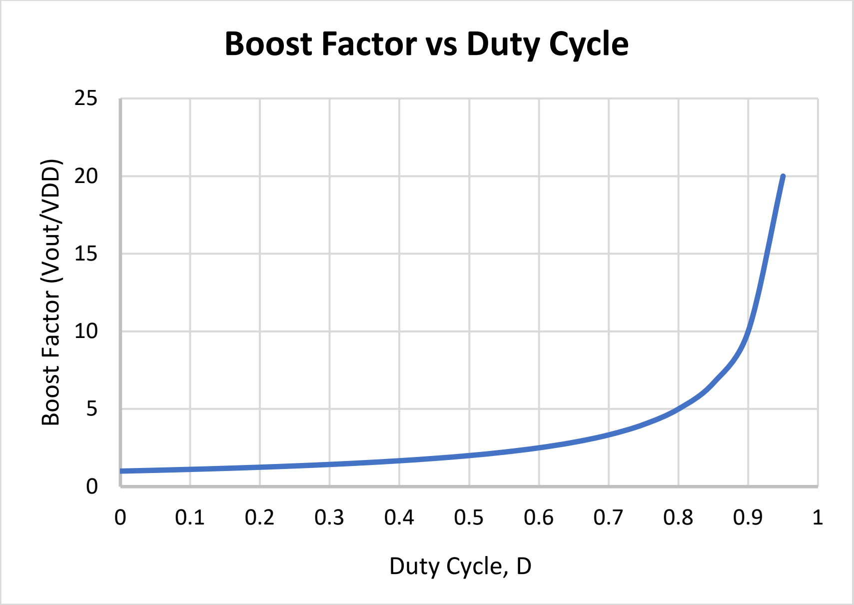

Figure 4. *Boost Factor versus Duty Cycle.*

There are two cautions in using a boost converter in any application. The first caution is to be aware of the onset of discontinuous mode of operation, and to avoid operation in this regime unless the PWM controller or firmware code is capable of handling this situation without encountering stability issues. Discontinuous operation occurs when the load current decreases in value until the inductor current become zero during a portion of the switching period. The output current threshold where continuous conduction mode (CCM) and discontinuous mode (DCM) occurs is:

$$I_{out}(th) = (D_{min} * V_{in}(max) * T_s)/ (2 * L) \qquad \text{(Eq 7)}$$

The first design impulse to prevent DCM is to increase the value of the inductor to decrease the inductor ripple current, ΔI(L). But this action can lead to impractical inductors (large value, high current inductors are not readily available) and poor transient response due to decreased control loop bandwidth.

The second caution is to prevent the PWM controller from providing 100% duty cycle drive to the power switch, Q. If switch Q is allowed to be continuously ON, then the inductor will quickly saturate and become a piece of wire, allowing tremendous current to flow in Q, destroying it. Unless the VDD power supply is current limited to a reasonable level, 100% duty cycle of Q should absolutely be prevented.

Synchronous Operation Improves the Efficiency of a Boost Converter

The conversion efficiency of the boost converter circuit is affected in the largest part by the performance of switch transistor, Q, and steering diode, D. If an eGaN HEMT transistor is employed as Q, the ON-state resistance and switching characteristics are optimized due to the high figure of merit (Q_g * R_{ds}(ON)) possessed by these devices. This leaves the diode as the power loss leader, even if a Schottky barrier device is utilized. If the diode can be replaced by an eGan HEMT similar to Q, then the Rds(ON) * Id product, the device's "forward" voltage as it were, can and will be far lower than that of the diode.

Such operation is possible, treating the transistor that replaces the diode as a "synchronous" diode/switch. This synchronous boost converter form is shown in Figure 5.

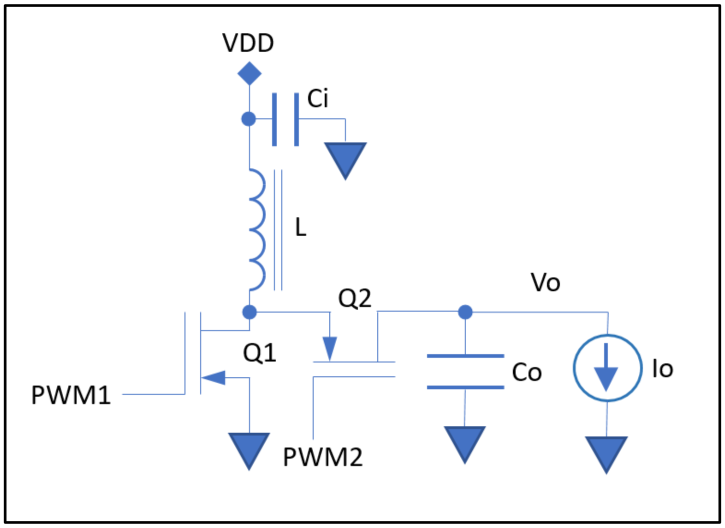

Figure 5. *Synchronous Boost Converter Topology.*

The topology shown in Figure 5 would function identically to that shown in Figure 1 if the PWM signals PWM1 and PWM2 were configured such that PWM1 was the logical inverse of PWM2. This would provide the situation where Q1 is OFF when Q2 is ON, and vice versa. It is also desirable to create a "break-before-make" operation of the switches where both switches are open briefly before either is turned ON, so as not to create a momentary connection between ground and Vout when the switching event edges occur. This timing situation is no different than that of a step-down (buck) converter where so-called dead times are included in the switch PWM timing, as shown in Figure 6.

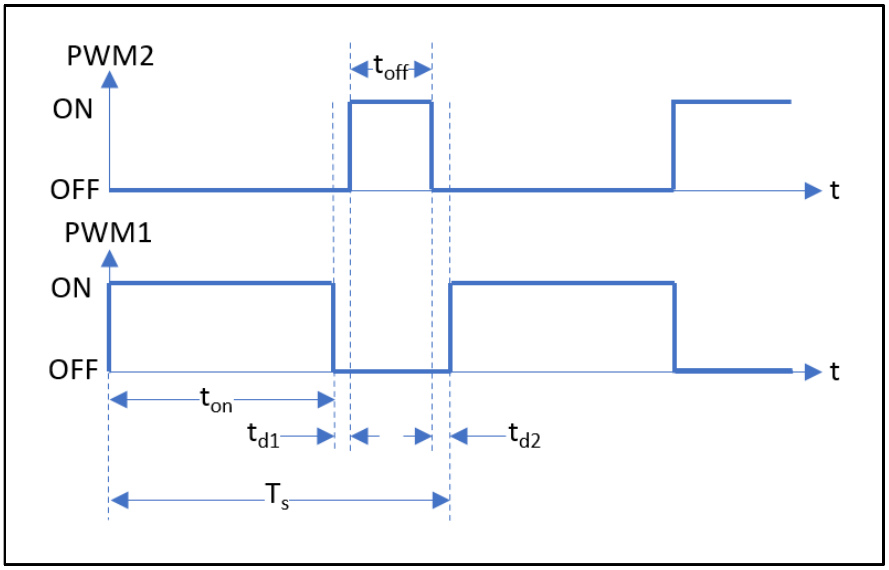

Figure 6. *Synchronous Boost Converter PWM Timing.*

In Figure 6 the time intervals t_{d1} and t_{d2} are the leading- and trailing-edge dead times that allow Q1 and Q2 to exhibit break-before-make switching action.

Now, if one looks closely at Figure 5 one will see that Q1 and Q2 form a half-bridge-configured power driver, but with just different power and load connections to it. HEMT Q1 serves as the low-side power switch and Q2 serves as the high-side switch. The exception between the circuit shown in Figure 5 and a POL-style half-bridge is that inductor current is fed to the switching node and the VDD power source is connected to the inductor. Recognizing this configuration now makes it easy to implement a boost converter utilizing EPC Space half-bridge driver modules, discrete components and integrated circuits.

Boost Converter Application Examples

The following examples are of boost converter circuits implemented with various EPC Space products, with increasing output power capability/capacity from one to the next. All the subsequent examples use the PWM timing in Figure 6 as their switching signals.

Figure 7 shows a boost-converter-connected EPC7011 IC.

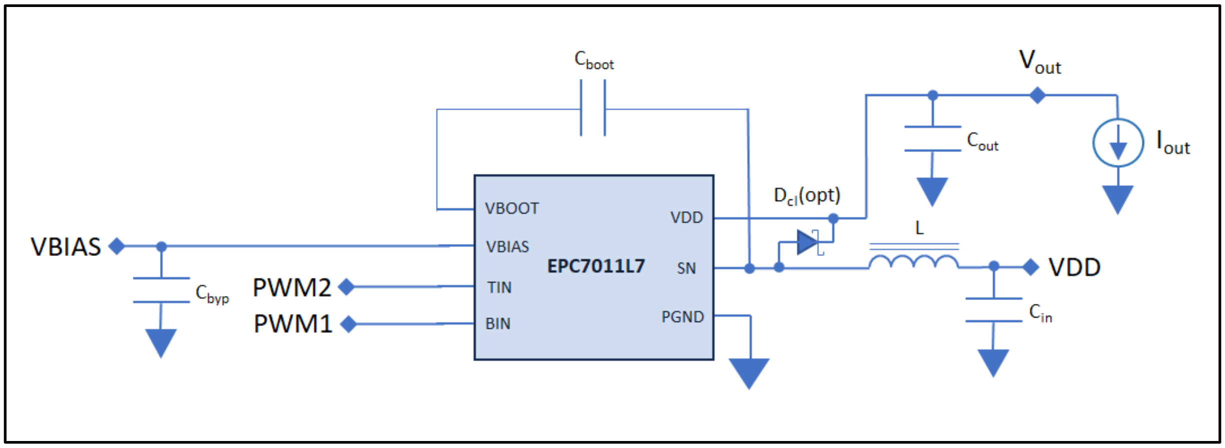

Figure 7. *Synchronous Boost-Connected EPC7011L7 IC.*

The boost converter in depicted in Figure 7 can provide up to 6A of load current and 50V output voltage. It is a low parts-count hermetic, small PCB footprint, high-efficiency solution. In Figure 6, the optional Schottky diode D_{cl} may be included in order to achieve the maximum operating efficiency possible as third-quadrant operation of the high-side power switch in the IC (from VDD-to-SN) is prevented during the dead times. This boost converter topology using the EPC7011L7 IC is implemented in the EPC7C020 Eval/Demo Board, available from EPC Space.

Figure 8, following, shows a boost converter-connected GAM02 module. The boost converter shown in Figure 8 can provide up to 10A of load current and 50V output voltage. It is a low parts-count, high efficiency solution. Because Schottky catch diodes are included in the GAM02 package, an external catch diode (as shown in Figure 7) is not required.

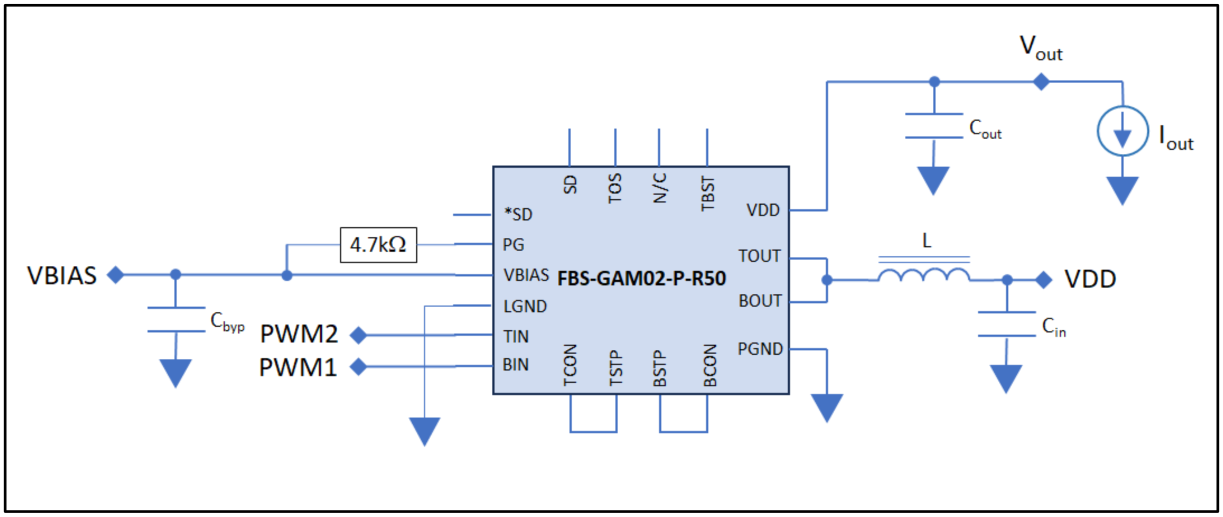

Figure 8. *Synchronous Boost-Connected FBS-GAM02-P-R50 Module.*

The circuit in Figure 9 illustrates a high-voltage, boost converter-connected pair of GAM01 modules. The boost converter shown in Figure 9 can provide up to 12A of load current and 100V output voltage. It also employs the NVE IL600 high-speed, GMR logic coupler for isolated drive of the bootstrapped high-side driver. It is a low parts-count, high efficiency solution without the need to resort to magnetic components to provide the required high-side isolation. Like the GAM02 module, the GAM01 modules have internal Schottky catch diodes, so an external diode is not required to achieve the best efficiency possible. The bootstrap diode, D_{boot}, has to be suitably voltage-rated in order to hold off the output voltage desired over the range of VDD values possible.

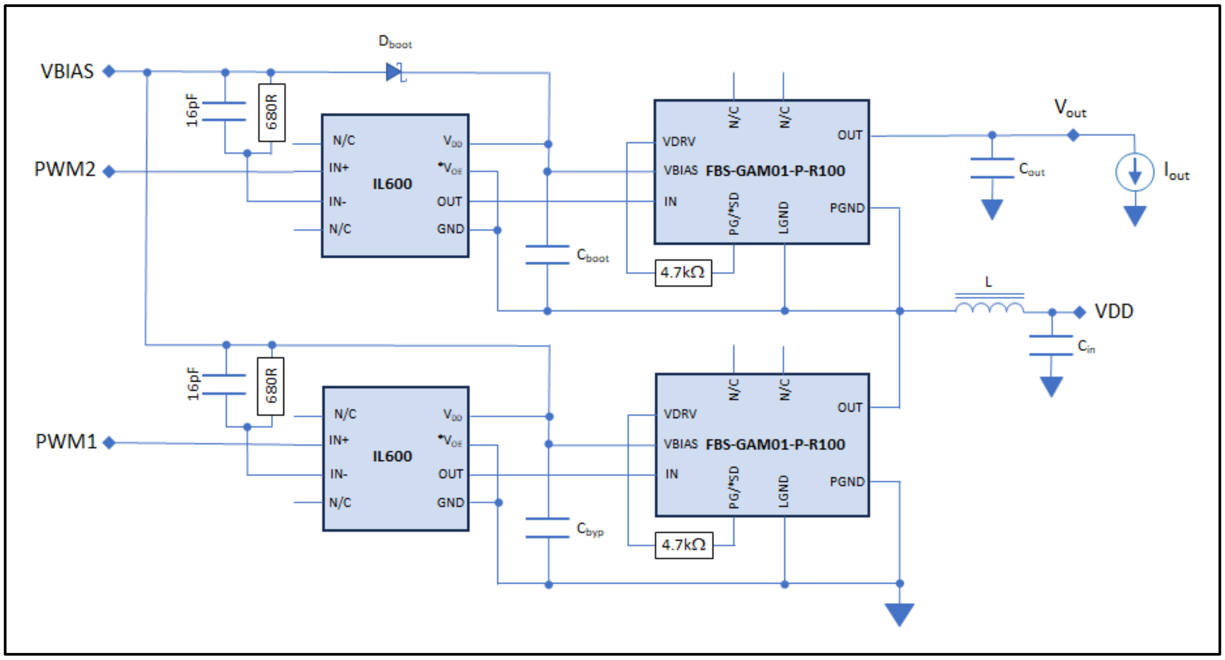

Figure 9. *Synchronous Boost-Connected FBS-GAM01-P-R100 Modules.*

Finally, Figure 10 shows a high-voltage, boost converter, as a variation on the circuit shown in Figure 9. It employs a pair of GAM01-PSE modules utilizing discrete external power HEMT devices and the optional high-side catch diode to act as the power stage. The boost converter shown in Figure 10 can provide up to 70A (and higher for paralleled HEMTs) of load current and up to 300V output voltage utilizing the discrete power HEMTs available in the EPC Space discrete product portfolio. As with the circuit in Figure 9, it also employs the NVE IL600 high-speed, GMR logic coupler for isolated drive of the bootstrapped high-side driver. It is a low parts-count, high efficiency solution without the need to resort to magnetic components to provide the required high-side isolation. Like Figure 7 an external diode of appropriate voltage and current ratings is required to achieve the best efficiency possible. Once again, the bootstrap diode, D_{boot}, has to be suitably voltage-rated in order to hold off the output voltage desired over the range of VDD values possible.

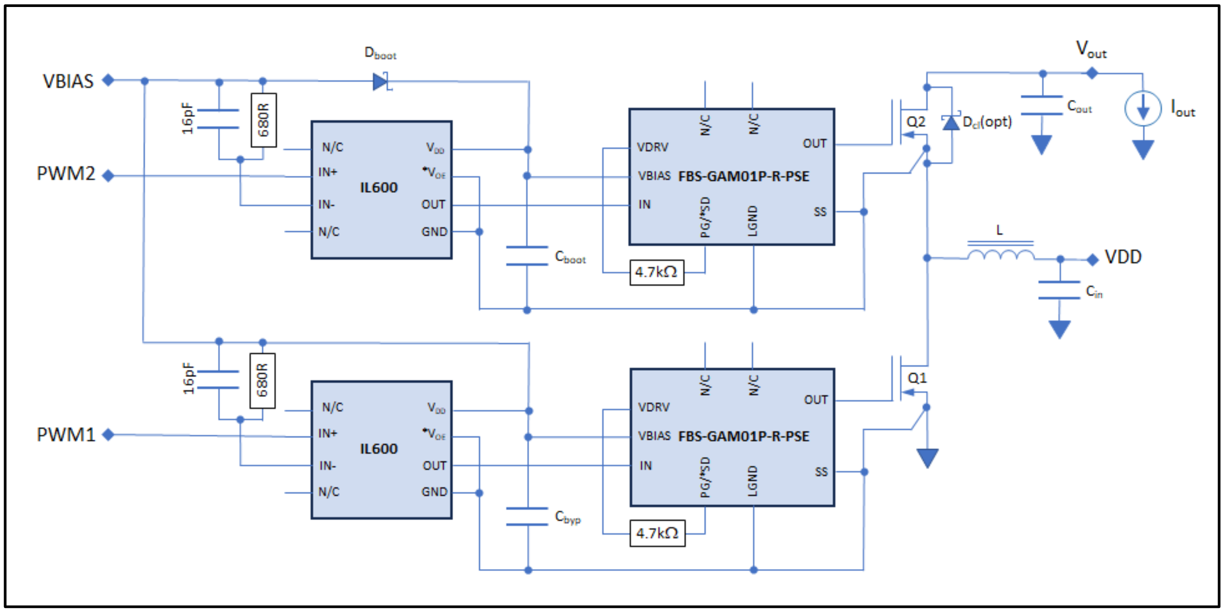

Figure 9. *Synchronous Boost-Connected FBS-GAM01-P-R100 Modules.*

Conclusion and Summary

EPC Space manufactures IC, modular and discrete solutions for just about all boost DC-DC converter requirements. Figures 6 through 9 demonstrate this capability in increasing output power provided, and in PCB area required for each implementation. The power provided by these converters can range from milliwatts to hundreds of Watts depending upon the discrete HEMT devices, and their quantity in parallel, shown in Figure 9.

We remain confident that our products can give your system power requirements a decided boost!

References

EPC Space: EPC7011L7 data sheet

EPC Space: FBS-GAM02-P-R50 data sheet

EPC Space: FBS-GAM01P-R-PSE data sheet

EPC Space: FBS-GAM01-P-R100 data sheet

EPC Space: Discrete-packaged HEMT product data sheets.

NVE Corp: IL600 data sheet.

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