AN-010: FBS-GAM02-P-R50 External Bootstrap Capacitor Value Vs. Switching Frequency.

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Introduction

The switching frequency lower bound for operation for the versatile FBS-GAM02-P-R50, without external high-side driver bootstrap capacitance added to the module, is 200kHz. This value was determined/dictated by the internal bootstrap capacitance utilized in the module.

EPC Space has had many customers inquire regarding employing the GAM02 module in applications where the desired switching frequency is less than this 200kHz limit. Operation below that frequency is possible utilizing an external bootstrap capacitor connected between the TBST (pin 10) and the TOS (pin8) pins on the module.

The following analysis details how the required external bootstrap capacitance versus operating frequency is determined, and an expression for this capacitance versus the desired operational switching frequency is presented.

Dynamic High-Side Gate Driver Power Analysis

In the following analysis one will notice that the current drain that results from the input capacitance of the output power HEMT in the high-side driver circuit is excluded. This wasn't an oversight, but rather a concession to simplifying the analysis. Consider that the worst-case input capacitance (C_{iss}) for the power HEMT is 1000pF. This means the power required to switch this capacitance is:

$$\mathbf{P(sw) = C_{iss} * V_{BOOT}^2 * f_s}$$

If we consider Figure 1, below, we see that V_{BOOT} is equal to VBIAS minus the forward voltage of the bootstrap diode (0.45V, worst case), and we select VBIAS to be its minimum specified value, then the power required to switch the HEMT's C_{iss} is $1000*10^{-12} * 4.05^2 * 200000 = 3.3$mW. The current drawn from V_{BOOT} is .0033 / 4.05 = 820uA. The DC current drain (IBIAS) of the high-side gate driver is 5.4mA for VBIAS = 4.5Vdc. Thus, the dynamic power drawn at the worst-case operating point is 15% of the DC value.

So, even though the dynamic power/current becomes a smaller contributor to the total current draw in the high-side driver, the value of IBIAS is increased by 15% to 6.2mA for the remaining analysis, regardless of the lower-valued switching frequency – again, to simplify the analysis.

FBS-GAM02-P-R50 External Bootstrap Capacitance Versus Frequency Analysis.

Having the high-side driver's current drain quantified, it is now possible to determine the bootstrap capacitance versus frequency relationship for the high-side driver of the GAM02. This capacitance may be calculated from the relationship:

$$\mathbf{C(min) = i * dt / dV,}$$

where i is the DC current drain of the high-side gate driver, dt is the maximum ON time of the high side driver (which is 95% of the switching period, worst case) and dV is the maximum allowable high-side bootstrap capacitor droop voltage.

The circuit in question for the high-side bootstrap circuit is shown in Figure 1:

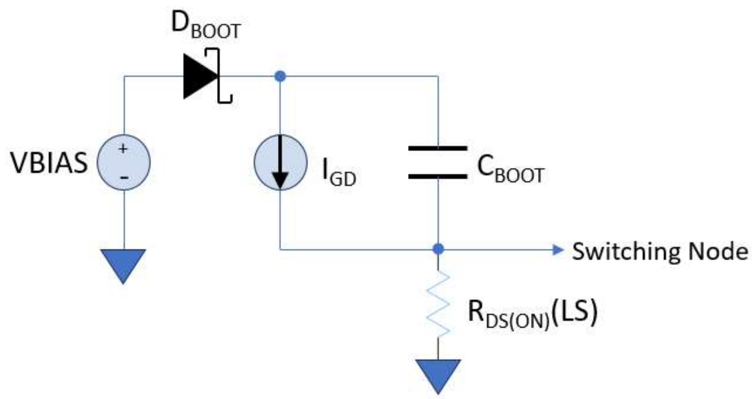

Figure 1. *FBS-GAM02-P-R50 High-Side Gate Driver Equivalent Circuit.*

Where in Figure 1, D_{BOOT} is the bootstrap diode, C_{BOOT} is the bootstrap capacitor, I_{GD} is the high-side gate driver's DC current drain and $R_{DS(ON)}(LS)$ is the ON resistance of the low-side driver.

There are two cases we need to consider in order to determine the requisite value of bootstrap capacitance for the desired operating frequency: the charging and the discharging of the bootstrap capacitance.

Bootstrap Capacitor Charging Analysis

First, we need some analysis ground rules which help determine the worst-case minimum value of this capacitance. The first is that the minimum allowable bootstrap voltage is 3.25V in order to ensure that the high-side power switch remains in saturation at 10A, the maximum rated current for the GAM02 module. The second is that the worst-case droop voltage, dV, occurs when VBIAS = 4.5Vdc. This is where the voltage differential between V_{BOOT} and the minimum allowable value is the smallest.

The worst-case charging event occurs in a motor driver application when a phase current flows from a motor winding load into the switching node, creating a positive voltage at the switching node $V(SN) = I_D * R_{DS(ON)}(LS)$. This positive voltage at the switching node "steals" voltage bias from the bootstrap capacitor.

This operating situation is notably different from a power supply application where the current always flows out of the switching node, thus the voltage at that node will be negative due to the direction of the current.

So, considering the worst-case situation of the motor driver, the worst-case charging circuit encountered by the GAM02 is shown in Figure 2:

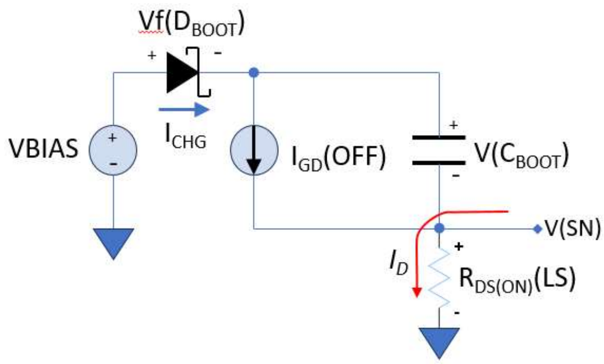

Figure 2. *FBS-GAM02-P-R50 High-Side Gate Bootstrap Capacitor Charging Circuit.*

The magnitude of the voltage across C_{BOOT} is:

$$V(C_{BOOT}) = VBIAS - Vf(D_{BOOT}) - (I_D * R_{DS(ON)}(LS)).$$

The situation shown in Figure 2 occurs when the high-side driver is OFF and the low-side driver is ON. The charging event occurs quickly, because of the low resistances in series with C_{BOOT} in this situation -- $R_D(D_{BOOT}) + R_{DS(ON)}(LS)$.

The DC OFF-state gate driver current ($I_{GD}(OFF)$) along with the charging current of C_{BOOT} determines the forward voltage of D_{BOOT}, which in the case of the diode used is 0.45V, maximum. The maximum $R_{DS(ON)}$ of the low side driver is 18 milliohms. So, the above equation simplifies to:

$$V(C_{BOOT}) = 4.5 - 0.45 - (I_D * 0.018) = 4.05 - (I_D * 0.018).$$

This value of the bootstrap voltage potential is then used as the initial condition for the discharge event for a known output power switch drain current.

Bootstrap Capacitor Discharging Analysis

The bootstrap capacitor discharging circuit is shown in Figure 3:

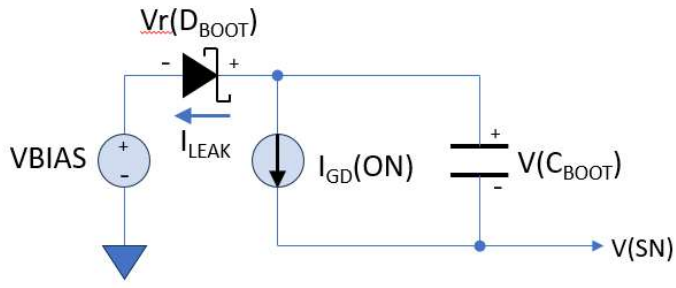

Figure 3. *FBS-GAM02-P-R50 High-Side Gate Bootstrap Capacitor Discharging Circuit.*

The primary discharge current in the circuit is I_{GD}(ON), which is 6.2mA in the worst-case for VBIAS = 4.5Vdc. The bootstrap diode reverse leakage at Vf = 50V is 50uA, so it is negligible in comparison to the gate driver current draw. We also have to recognize that I_{GD}(ON) is completely resistive, so it will decrease exponentially with decreasing bootstrap capacitor voltage droop. But using the worst-case value of 6.2mA as a constant current will suffice for our analysis.

Bootstrap Capacitance Versus Frequency Calculation

We need two more design restrictions included in our analysis before we can determine the minimum bootstrap capacitor at a particular operating point. The first is that the maximum ON time for the high-side driver is 95% of the switching period, or 0.95/fs, to allow for the bootstrap capacitor to be properly charged on a cycle-by-cycle basis. This is the "dt" in the equation C(min) = i * dt /dV. The current (i) in this equation is 6.2mA and the droop voltage (dV) is the initial condition voltage right after charging, 4.05 - (I_D * 0.018), minus the absolute minimum allowable bootstrap capacitor voltage, 3.25V, or (0.8 – (I_D * 0.018)).

So, substituting values, C(min) becomes:

C(min) = (0.0062 * (0.95/fs)) / (0.8 - (ID * 0.018)),

which is now calculable for fs and ID operating points.

So, if we substitute the worst-case drain current of 10A for the GAM02, the equation simplifies to:

C(min) = 0.0059/fs/0.62 = 0.0095/fs.

Which is now a relationship entirely dependent upon fs.

So, if you want to calculate the requisite minimum value of bootstrap capacitance for your desired switching frequency for the GAM02 module, then **C(min) = 0.0095 / fs** is your go-to equation!

The required external bootstrap capacitance versus the desired switching frequency in the range of 20kHz to 190kHz is shown in Figure 4, offered for the convenience of the reader, for the nearest standard capacitor value (NSV).

This capacitor should be an X7R dielectric type with a 50V voltage rating and a case size of EIA 0805.

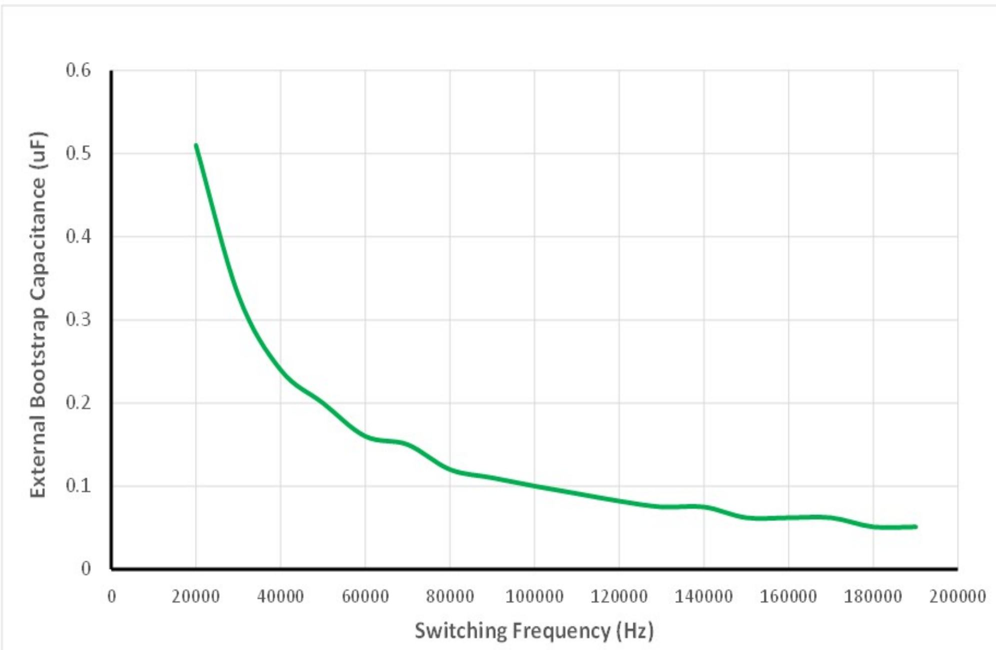

Figure 4. *FBS-GAM02-P-R50 External Bootstrap Capacitor Versus Switching Frequency.*

Conclusion and Summary

The FBS-GAM02-P-R50 half-bridge module may be operated at switching frequencies lower than the 200kHz value shown in the product's data sheet. This may be accomplished with the addition of an external bootstrap capacitor for the high side driver, connected between the TBST (pin 10) and the TOS (pin 8) pins. The charging and discharging analysis were performed for the bootstrap capacitor, culminating in an expression for the capacitance versus switching frequency.

References

FBS-GAM02-P-R50 Data Sheet.

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