Design guidelines of Multi Form Power Controller Using GaN Systems GS66506T

Introduction: This App Note discusses design considerations, implementable circuits, and issues to address for achieving a reliable and safe power controller utilizing the features of isolated DC-DC Converters from Ganmar Technologies **[1]**. An illustrative system requiring multiple biasing elements is shown with 3 Phase AC input power to a PFC stage followed by a PWM controlled heavy load – for example, an industrial-grade motor. Driving a high voltage GaN switch GS6650ST **[2]** example is dealt with giving implementable circuits. Issues with legacy schemes for driving half-bridge (HB) totem-pole switches are highlighted. Alternative ways of driving the upper and the lower switches are explained with circuits for achieving reliable and safe operation. Reference for appropriate low loss high bandwidth current sensing is included for convenience.

In the design of today's modern systems, the design team faces many challenges. The amount of functionality contained in systems has increased significantly over previous systems, requiring ever decreasing footprints for hardware. Decreasing footprints requires decreasing power consumption to allow simpler and less expensive cooling systems. Reliability must also increase, putting increased emphasis on thermal management. Recurring cost allocations continue to decrease, pushing designs into the digital realm, using processors and software which add complexity to start-up and transient conditions. Couple these design considerations with shrinking development budgets and decreasing development schedules, the design team faces immense challenges. To accommodate these challenges, standard subsystem or component building blocks are made available from subsystem providers thereby leveraging proven spec compliant building blocks.

This App Note is in response to the challenges detailed in **[3, 8,10]** and provides an optimum solution through Ganmar Technologies' power converter modules in designing such a multiphase gate drive system.

This Application Note intends to integrate discrete solutions into a modular approach with an eye on high-power high voltage systems. The modular approach brings benefits in multiple levels: standardized systems with modular functional blocks, easy to keep low noise due to fewer nodes in the mainboard, ease of placement, ease of troubleshooting most of all, shorter design cycles.

Keywords: AC rectifying bridge, bipolar node, bootstrap, DC-DC converter, floating bias, GaN switch, half-bridge, isolated bias, push-pull,

Design of a Power Controller for a general 3Ph high voltage high power system

In this Application Note, we are going to present several considerations involved in designing a high voltage Power Controller using Ganmar Technologies' DC-DC converter modules for a complex system such as shown in Figure 1. As an example, the Pulse Width Modulated (PWM) controlled heavy load could be an industrial grade motor. This system has multiple switches and multiple bias voltages required by various functional blocks. To move forward with the design considerations, we need to establish a few assumptions:

1. From an EMI standpoint, the system requires a near unity Power Factor, thus requiring a Power Factor Controller (PFC) to be used.
2. The PFC contains a processor which necessitates consideration of independent start-up logic of the bias converters.
3. Power dissipation of the Controller electronics must be minimized for both reliability and implementation of a simplified cooling system approach.
4. Maximize the use of "Off-the-Shelf" products.
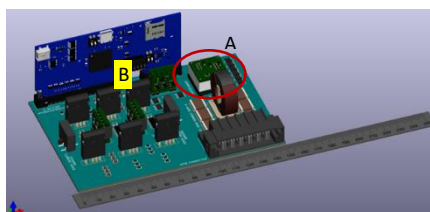
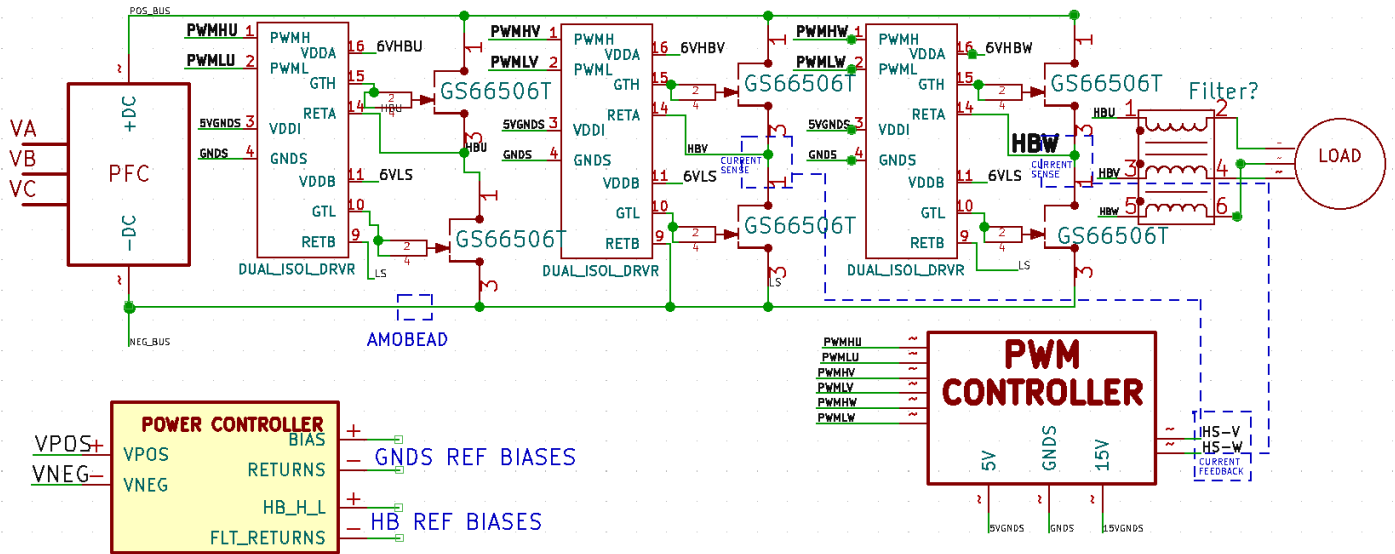Preview of 3 Phase system with Ganmar Technologies' modules

Figure 1: Industrial high load Control System in pseudo-Schematic form

Referring to the block diagram of Figure 1, this App Note will concentrate on the design of the Power Controller and its interface with the rest of the system. We will utilize HV GaN GS66506T from GaN System **[2]-** for the switches in our example controller with a top side heat transfer package, although everything presented will apply to all GaN System HV switches. We will discuss some considerations if bipolar or other switches are used.

1.0 Design Trades

1.1 Power stage Interface requirements

As shown in Figure 2, most device manufacturers suggest applying –5V to turn OFF GaN power devices if a hard switching topology above 30A is employed. Note that Off transition loss depends upon Dead Time as well. Users can review the matter in GaN System references cited here.

sensed in the module activate shutdown circuitry. The components in the module can sustain the whole range of AC input typically found in Universal line voltage limits.
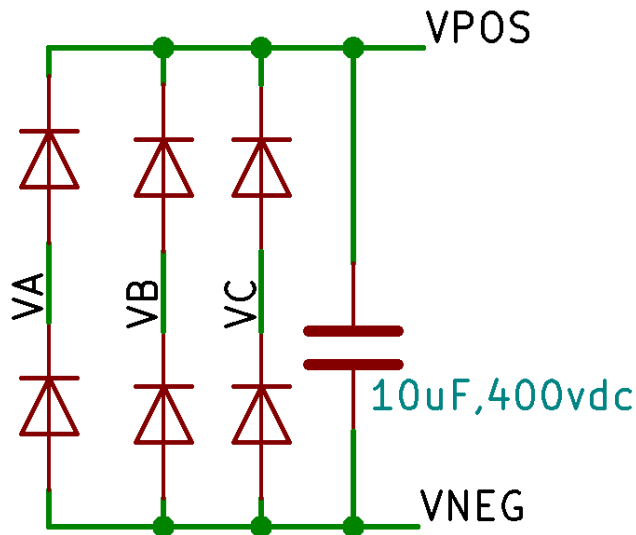

Figure 3: Drawing max 18W from AC input directly for startup & bias

1.4 Input Filtering

It is the nature of constant power switching modules to act as "negative" impedance system to input power sources. This requires careful filter for the source – a subject that is well covered in several reports, documents, publications, and textbooks. This is beyond the scope of the Application Note to cover design criteria for designing filters that provide stability at the interface. We will give a brief outline of the GMR10D000 module input characteristics here. Assuming typical 15W constant power combined load due to the GaN driving, at the minimum Rectifier voltage of 100V, this represents a $|100^2/(15/\eta)|$, efficiency .85 will yield $|0.784k\Omega|$. This is a high magnitude compared to the source impedance therefore easy to be shunted by filter required to power the PFC. It is still recommended to have a 10uF /400V capacitor installed close to the GMR10D000 module. The modules have .47uF installed in it for handling instantaneous current peaks due to internal switching events. The ESR rating of this external capacitor then does not play a critical role if the main PFC filter has damping.

2.0 Power Controller Requirements

The Power Controller role is to provide the power forms shown in Table 1. Note that several of the power forms have floating references. In addition to the specified power forms the power controller must provide protection for both high voltage and low voltage transients. The GMR10D000 converter provides protection for brown out (low AC input values and unlatched shutdown for higher than set limit for max AC input. When AC range is within safe operational values, the GMR10D000 converter produces isolated DC outputs of 6V and 22V. As we will see later in this paper, the 6V is used to power the gate drive for the GaN switches.

Some applications may prefer the usage of Silicon Carbide switches. Silicon Carbide switches will require a 15V drive. There is another Ganmar converter part, that is available for that application.

Table 1 Power Form Requirements

Input Power Form	Voltage	Reference
VA	115V AC	RTN
VB	115V AC	RTN
VC	115V AC	RTN
Output Power Form	Voltage	Reference
6VHBU	+6V DC	HBUGNDS
6VHBV	+6V DC	HBVGNDS
6VHBW	+6V DC	HBWGNDS
6VLS	+6V DC	LS
VEEHBU	-3V DC	HBUGNDS
VEEHBV	-3V DC	HBVGNDS
VEEHBW	-3V DC	HBWGNDS
5V Digital	+5V DC	GNDS
15V I/O	+15V DC	GNDS
15V Analog	+15V DC	GNDS

3.0 Driver Biasing

Figure 4 shows the schematic and photo of the GMR10D000. It is an isolated DC-DC 15-Watt dual output converter. V_{out1} is typ 6V at 3W while V_{out2} is typ 22V at 12W. The photo shows the compact size of the Ganmar converter as compared to a TO-247.
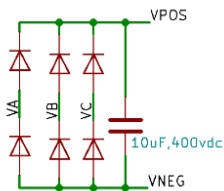
4a   4c
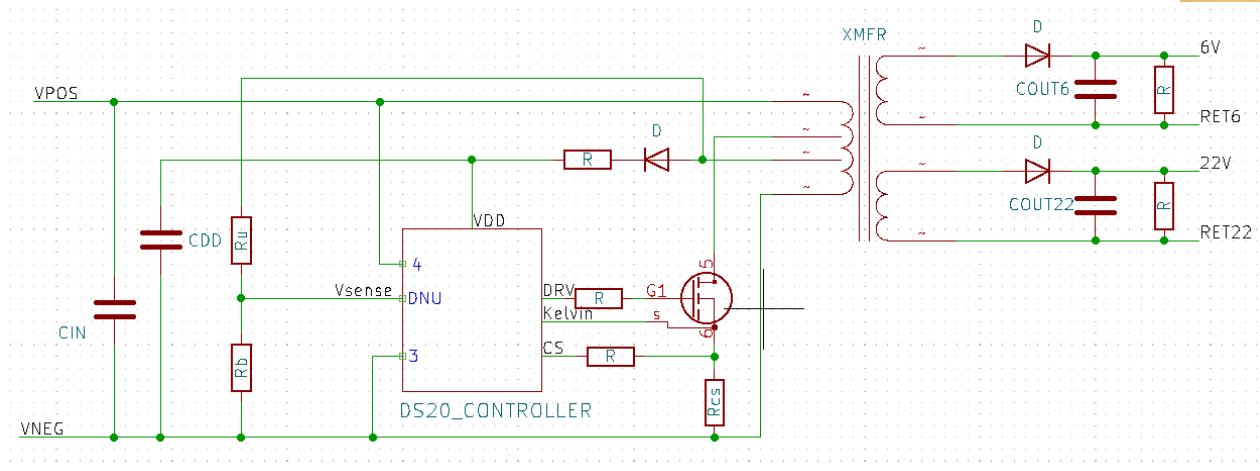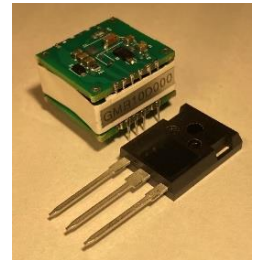
4b

Figure 4: GMR10D000 Module: connection to 3phase(4a), schematic(4b), photo (4c)

Next, we need to determine the dissipation of the drivers. Assuming 250 kHz switching and from GS66506T d/s, Q_G=4.5 nC, we have

Power dissipation by the driver for this GaN is expressed as (from ds of the driver **[4]**).

$$P_D=(VDDI)(IDDI)+2(IDDx)+(f)(Q_G)(VDDx)[R_PR_P+R_G] +(f)(VDDx)[R_NR_N+R_G]+2fC_{INT}VDDx2$$
$$\mathbf{PD=VDDIIDDI+2IDDx+fQGVDDxRPRP+RG+fVDDxRNRN+RG+2fCINTVDDx2}$$

VDDI	IDDI	IDDX	VDDX	F	QG	RP	RG	RN	CINT	PD Driver
5	0.01	0.004	6	250000	4.5E-09	2.7	10	1	3.7E-10	.584159E-01

This gives a driver dissipation of 58 mW. The GMR10D000 module can drive around 3W which is far in excess of this driver's dissipation.

4.0 Power Form Circuit Implementation

To implement the circuits that create the power forms required in Table 1, one option could use 4 GMR10D000 converters, one to bias the driver of each upper switch and one to bias the Lower Switches of all three phases. However, based on the driver dissipation calculation above, the GMR10D000 converter has ample power to accommodate several drivers. So instead of using 4 GMR10D000 converters, the preferred solution is to use one GMR10D000 converter along with another Ganmar Technologies' product, an isolated triple bias converter. The isolated triple bias converter allows increased miniaturization because it only has to convert the 22-volt power form and not the several hundred-volt requirements of the GMR10D000 converter.

Figure 5 shows interconnections of the Ganmar Technologies modules to perform the functions of the Power Controller. Figure 5 shows availability of 22V power from the GMR10D000 converter with respect to commonly referenced "ground" GNDS node. As shown for a complex 3 phase system with bipolar Half-bridge nodes, 2 small, isolated driver bias modules to power all 6 distinct drivers referenced to 3 phases of the HBx nodes and a common low side reference (LS) are needed. This is presented later in the Note.
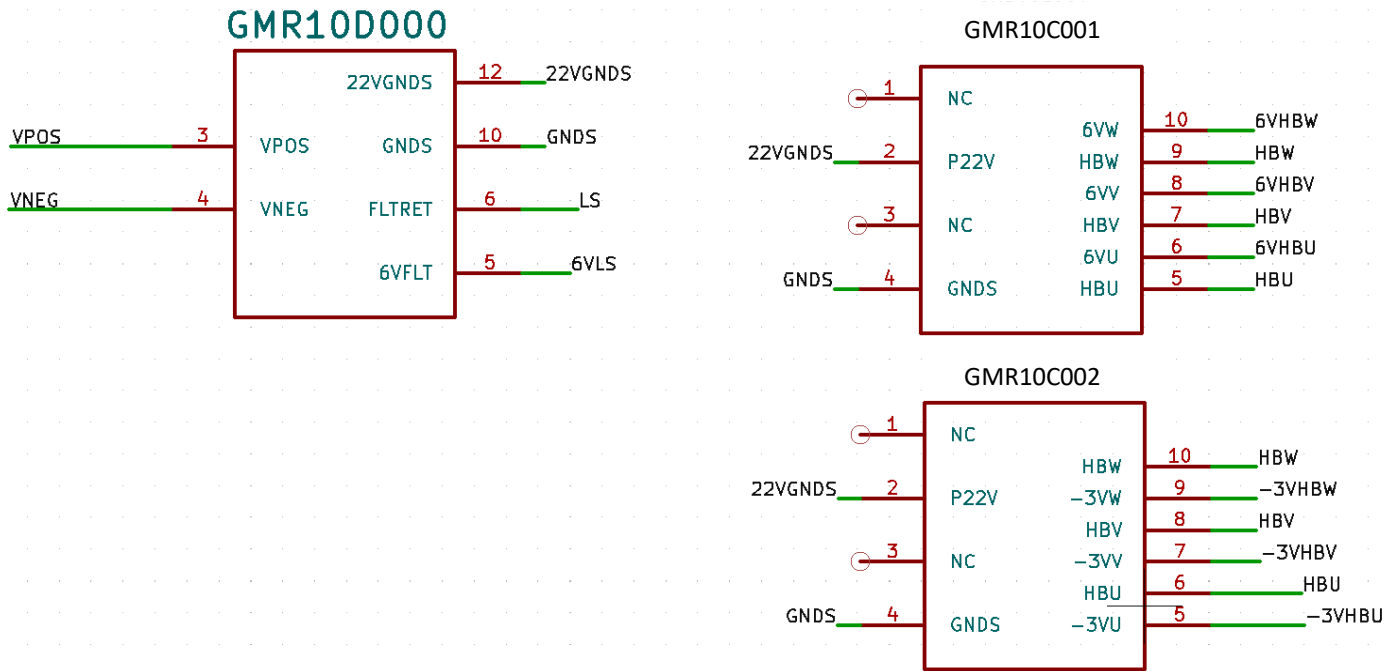
Figure 5: GMR10D000 interconnects to create HBx Power Forms using GMR10C00x

A third isolated triple bias converter module can be used to provide the remaining power forms (5V digital, 12V Analog, and 15V I/O). Generating these power forms using the isolated triple bias converter offers an added feature to create a robust Grounding scheme, possibly simplifying circuit layout of the design. This scheme also enhances LDO load capability and selecting smaller footprint parts as shown (as an illustrative example figure 9).

It must be noted that the designer must determine the current requirements of these power forms to ensure the load on the GMR10D000 converter is not exceeded and to determine that the additional load on the non-Power Factor Corrected AC is acceptable. If either of these issues exist, then those power forms need to be generated using other standard approaches.

5.0 Drive setup for HV GaN

Now let us see how the Power controller outputs are used in this HB. Namely, upper GaN driver bias with V_{EE} and without, lower GaN bias with V_{EE} and without. Note that this design explicitly shows various bias returns as they should be. Failing to properly reference return, the bias power may cause erratic switching behavior including damaging the GaN. Users should also verify that what is shown here complies with the specific GaN datasheet and application recommendations.

Case for HS-U is shown below:
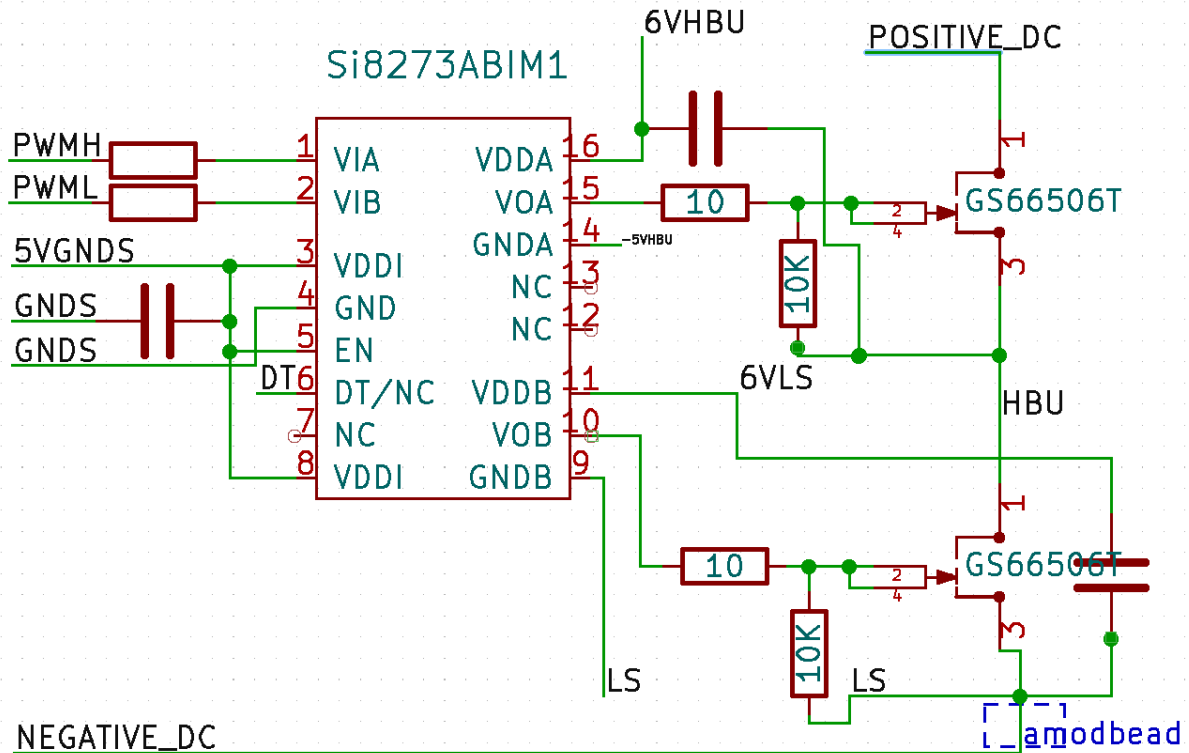
Figure 6: The totem-pole arrangement is classic Half-bridge configuration. No VEE bias option

You need "stiff" (defined in Appendix) 6V for the upper switch turn ON with respect to the HB node. This will be a "floating" bias for the upper gate driver. The GMR10D000 module powers the isolated triple bias converter which has this floating bias and will work for any stiff 6V gate drive for all 6V-switching devices. Designing with GMR10D000 does not require the controller to switch the lower device to develop bias for the upper gate driver: as would be necessary if you had a flying bootstrap capacitor to charge to 6 V from a diode as shown below.

Figure 7: Legacy Floating gate driver bias scheme

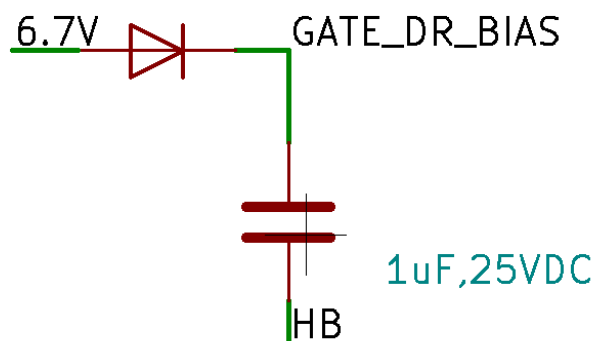The issues in this legacy scheme: first, need a 6.7V, then perhaps 600V diode and a non-polar capacitor whose values might need to be adjusted depending upon GaN or other device's datasheet requirements. There are startup issues, and this bootstrap does not provide a stiff bias often cited as a requirement for safe reliable upper switch gate drive. Most importantly, if HB node is bipolar, the legacy boot-strap scheme will not work.

5.1 Module setup for Driver Bias

Considering all the aspects of a comprehensive design of a system, GMR10D000 provides well rounded complete start-up and driver biasing approach. The module input/output are shown in Figure 8. For adjusting the gate driver bias to specific needs, the GMR10D000 outputs 6V which is then fed to a Charge pump to generate Turn-off bias for the low side bus (-3VLS) or to give any other driver bias value required.

GMR10D000

		22VGNDS	12 — 22VGNDS
VPOS	3 — VPOS	GNDS	10 — GNDS
VNEG	4 — VNEG	FLTRET	6 — LS
		6VFLT	5 — 6VLS
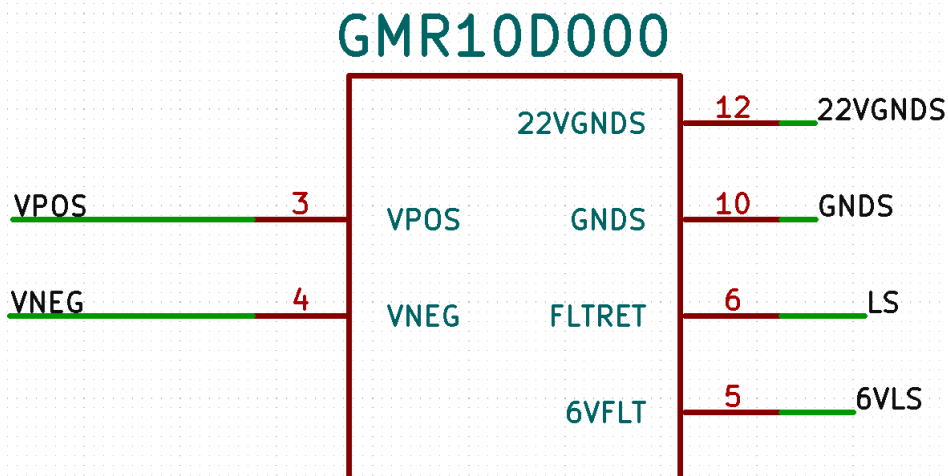
Figure 8: Ganmar Technologies GMR10D000 dual output module

Note also in Figure 9, how three independently referenced VEE (-3Vor any other) can be generated from the GMR10D000 module. Another small module provides 3 independently referenced floating bias for the upper switches requiring +6V to turn ON. Ask Ganmar Tech support to design this for your needs and Ganmar Technologies can supply this part. Check out the datasheet for GMR10Dxxx and GMR10Cxxx modules **[5,6]** in our website (www.ganmartechnologies.com).

Figure 9: 3 negative bias & positive bias are independently referenced output WRT HBx

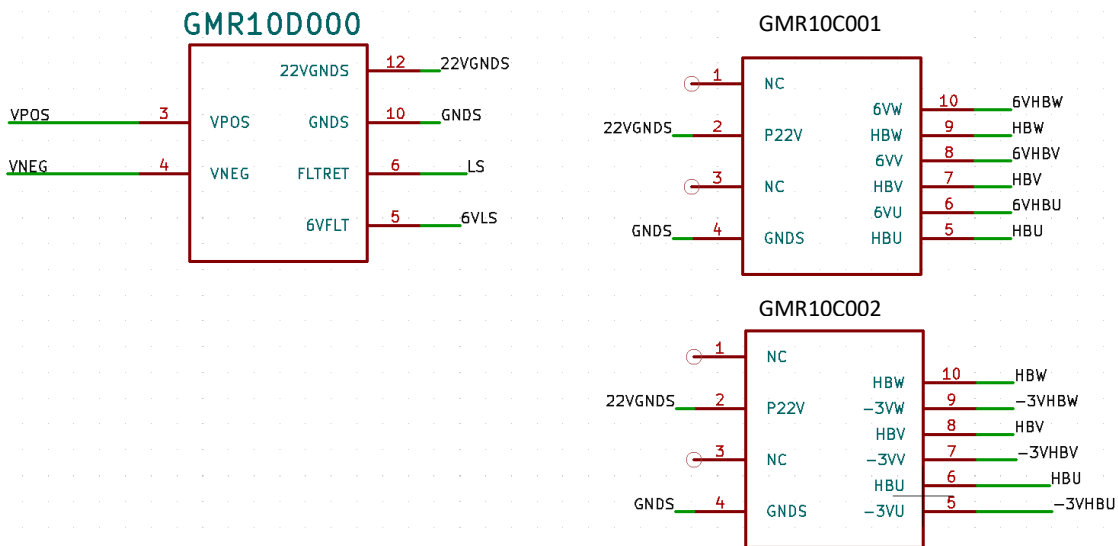Figure 10 illustrates designing with GMR10D000 for various start-ups and biasing in a system that might have 15V legacy analog controller. Shown is an adaptation to a digital system with 5V needs as well. Power of the load is going to be determined by the LDO dissipation and its thermal management (if any) due to the drop-out and load current.
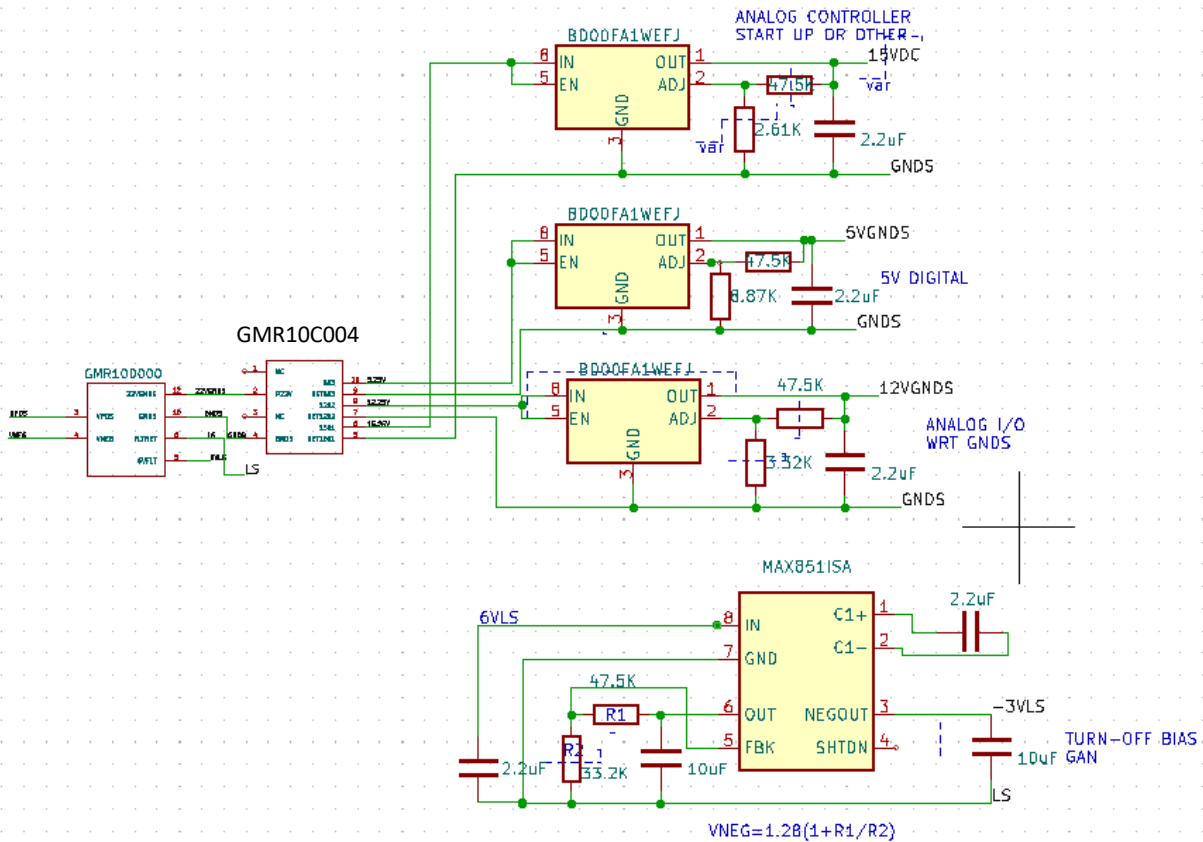
Figure 10: startup and power forms of a large system using a third Triple Isolated module.

5.2 Floating bias from the GRM10D000 output of 22V/GNDS

We will present a highly effective means of getting this VEE (down to –5.2V) bias from the GMR10D000 module. Users can decide above which power levels they may implement VEE bias in the driver. In soft-switching topologies having Z_{VS}/Z_{CS} functions, this bias offers no advantage, so users need focus only on the GMR10D000 extensions without V_{EE}. A complete circuit is shown for producing any VEE which will support any type of voltages at Pos_Bus & Neg_Bus produced by PFC stage(s). The scheme presented can easily be set to -4V required by SiC or IGBT in some cases.

5.3 Low HV GaN Driver Floating bias

Figure 11 illustrates the hook up with VEE options. Note that it is most reliable to operate VEE with proper reference nodes as shown here. This design using GMR10D000 with floating bias module combo is versatile, robust and operates the driver safely.
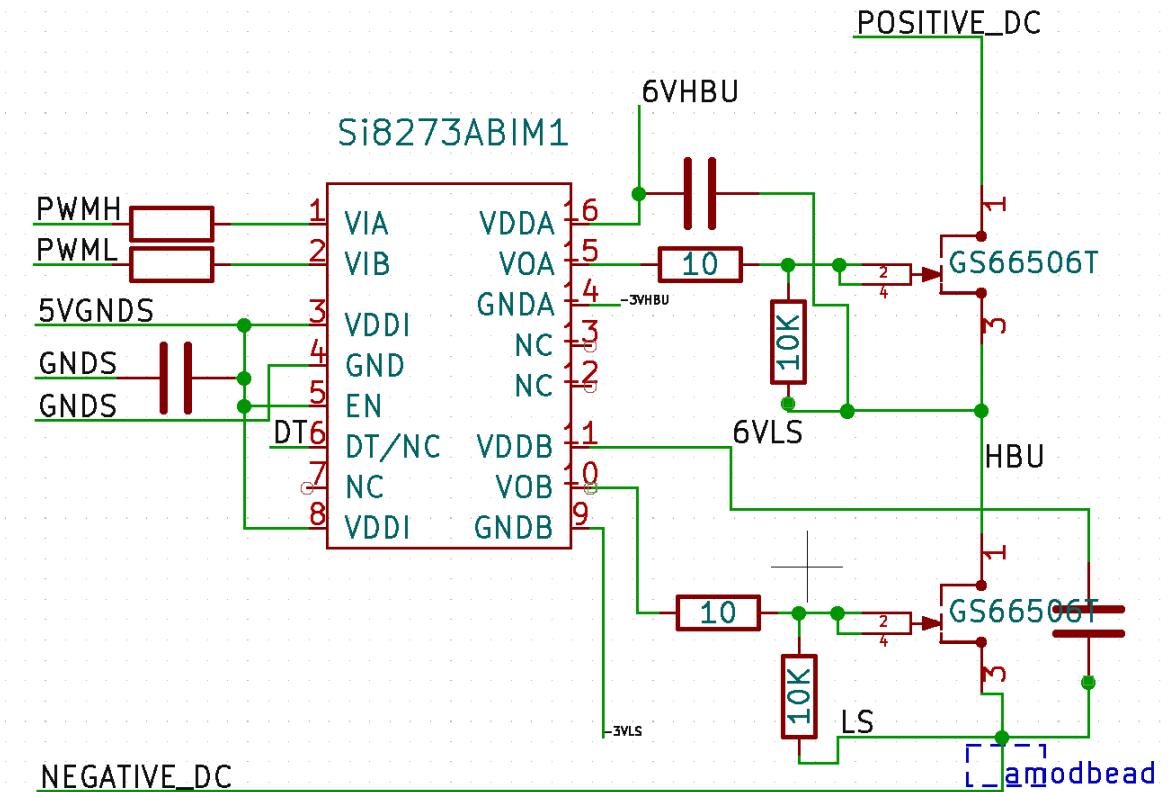
Figure 11: Half Bridge with V_{EEx} options (HBU node shown)

Note how the floating output of the GMR10D000 is extended with properly referenced bias for the Lower GaN and an option for getting V_{EE} of value for least Turn-Off power loss**.** Note that GaN System Application Notes GN010 and GN012 very well in details various approaches to GaN driving circuits and users should follow these and perhaps appreciate where this Note includes recommendations but applied to a much larger complex system. As noted, this App Note is for a system level integration. A lot of driving trade, modularization of subsystems, routing and placement of many components that generally will hinder low parasitic layout are advocated here.

The entire extension layout is shown in the 3D model: real estate required by all this is quite small indeed.
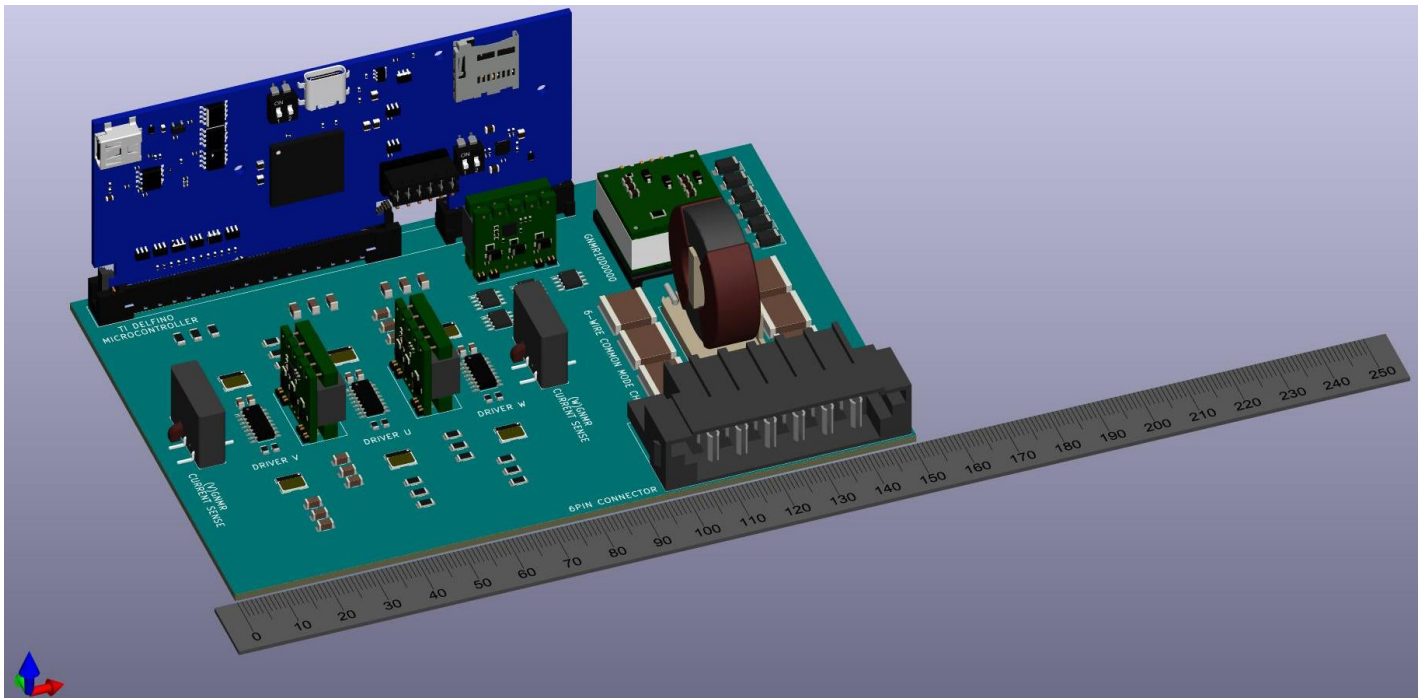
Figure 12: 3D view of a possible scenario of the System Hardware- Heat sinks not shown

Figure 12 we show a possible assembly of a system we just designed using GaN International 650V GaN devices GS66506T. Note how close the key blocks for enabling high speed switching are to the GaN devices. From this 1:1 scale assembly, one can clearly see competitively sized Ganmar Modules – GMR10D000 fits in a corner directly fed from the power connector. The outputs of it are all DC, so they can indeed be placed in such a strategic location. On the other hand, the critical floating bias modules GMR10E00x are short distance from corresponding switches- since HBx are fast transitioning HV bipolar signals. They connect through short path to the dual isolating drivers for each switch- upper and lower.

To keep the illustrative view clear, heatsinks are not shown. They are expected to be required cover the switching devices. Possible locations of the wide band isolated current sensors are also shown to be in path of the V and W nodes.

Note that this is by no means the size of the main power board user will be deciding to use. We are illustrating the fact that the GMR modules are commensurate in size and function with the rest of the necessary hardware in such a system. For example, we might point out that Delfino dual core controller is a powerful card for carrying out real time control with significant advanced features, but it is by no means the only choice: user's system can have a variety of control cards to select from including an integrated processor with customer's overall processing blocks.

6.0 Current Sensing

GMR10D000 can be used to bias a high bandwidth isolated current sense module too. Typically, users will add current sensing by putting Current Sense shunt resistors as shown below (Figure 12a.)
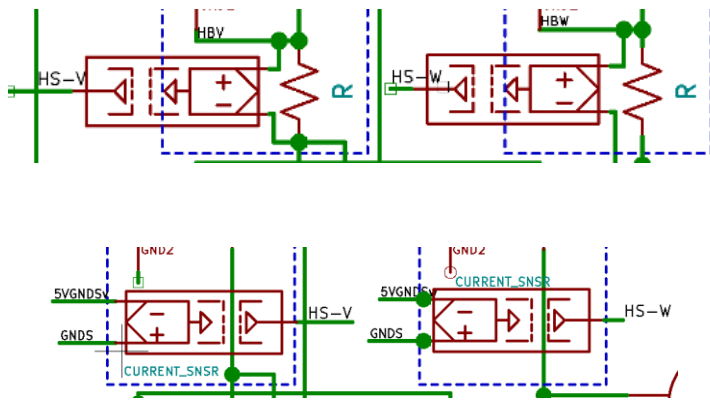
Figure 12: a): Legacy shunt resistor current sensing **(**b) GMR3 non-dissipative current sensing

In typical System Design houses, it is a chore to insert such a current sensor circuit across the shunt. In addition to power loss, there will be uncertainty about its range of values. All this will take up not only design time but valuable real estate. Ganmar Technologies offers a unique tiny isolated non- dissipative current sensor module GMR02XXX . In addition to providing WBW isolated current sensing, this module offers a choice between two polarities of detected output: + 0 to +V_{sense} for direct Interface with ADC of Embedded Controller ADC. And -V_{sense} to 0 for most Analog Controllers doing bridgeless PFC. Please inquire with Ganmar Technologies Tech Support for applicable part numbers.

In Conclusion: We presented a detailed design of a multi-function complete system startup and biasing of its various I/O's using GMR10D000 and GMR10C00x modules around high voltage high power GaN switches. This App Note deals with a special case for GaN International GS66506T for controlling high loads such as a 3-phase motor. Systems for 3 phase high power Inverter and EV level 3 charger will benefit from such design approaches as outlined here. More reliable and compact yet efficient approaches were highlighted and compared with legacy approaches. We also presented a tiny non-dissipative current sense module with flexible output capabilities. For customers working to implement these designs with Ganmar Technologies parts, the schematics, BOM and layout (where applicable) are available in KiCad6 – compatible Altium as well.

For further discussion and availability: Contact Tech Support: robin@ganmartechnologies.com

REFERENCES

1) GMR10D000 data sheet : https://ganmartechnologies.com
2) GS66506T in www.gansystems.com
3) Gate Drive Application GN010 , GN012 www.gansystems.com
4) Si8273ABIM1 data sheet in www.silabs.com

5) GMR10C001 data sheets: https://ganmartechnologies.com

6) GMR10C002 data sheets: https://ganmartechnologies.com

7) GaN Power HEMT Tutorial: as in ref 3

8) Analog Devices AN-1316

9) GMR02XXXX non-dissipative current sensing datasheet: https://ganmartechnologies.com

10) Is your IGBT Gate Driver Power Supply Optimized in SLA354-, Texas Instruments, March 2015

Abbreviations, Symbols and Definitions

AC	Alternating Current
BOM	Bill of Materials
DC	Direct Current
VDD	Positive bias voltage for an IC
VEE	Negative bias to turn-off most GaN devices
Vth	Switch turn-on threshold voltage
VREF	Reference voltage
HB	Half-bridge, general node name for HBx, x= U, V or W
GaN	Gallium Nitride Power Switch
Bipolar	Refers to a positive and then a negative voltage swing at a node
U, V, W	International Standard symbols for three phases when switched
WBW	Wide Band Width
"Stiff bias"	An output of a converter with feedback controlled low impedance voltage source.
WRT	WITH RESPECT TO