

**A Versatile Three-Phase Motor Drive Platform For Rad-Hard Space Applications**

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Gallium nitride (GaN) technology is rapidly transforming three-phase motor drive systems, especially in applications that demand high efficiency, fast switching, and robust performance in harsh environments such as space. By integrating radiation-hardened GaN ICs into compact, flexible platforms, engineers can accelerate the development and validation of advanced motor control solutions while meeting stringent reliability and size, weight, and power (SWaP) requirements.

In this context, the EPC7C021 demo board<sup>[1]</sup> provides a three-phase motor drive platform based on the radiation-hardened (rad-hard) EPC7011L7C eGaN half-bridge IC, enabling efficient evaluation and prototyping for space-grade motor drive applications. The evaluation board functions as a standalone three-phase motor driver, but also supports connection with the EPC9147A controller card for advanced closed-loop control. Optional output filtering is available for sine wave synthesis, specifically designed for engineers evaluating GaN characteristics for high-reliability, space-grade applications.

In this article we describe the features, specifications and operating requirements of the EPC7C021, and explain various aspects of how to configure it for different uses. For example, applications of the board with externally generated PWM signals and with the EPC9147A controller card<sup>[2]</sup> are discussed, as are details relating to monitoring and protection, output filtering and thermal management.

We also offer some guidance on commissioning of the motor and the types of motors and motor configurations that the demo board accommodates. Additionally, we explain how the layout of the board has been optimized for the eGaN half-bridge IC and encourage designers to follow this layout.

**The Key Role Of The Rad-Hard GaN IC**

The EPC7C021 is a multi-function motor driver evaluation/demonstration board for the EPC7011L7 60-V/6-A half-bridge IC.<sup>[3]</sup> This board is 6.45 in. x 5.22 in and is composed of six copper layers.

The 7C021 board accepts a bias input of 12 V (VBIAS) and this voltage is converted to the various bias potentials required by the 7011 IC and the analog and logic support circuitry on the board. The board implements a three-phase motor driver circuit that may be controlled using several different sets of logic inputs (Fig. 1).

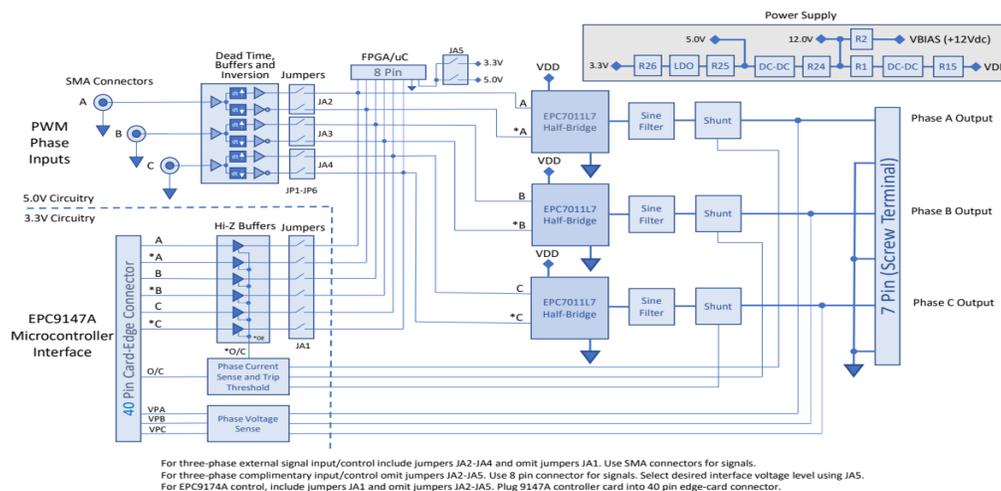


Fig. 1. EPC7C021 block diagram.

The platform incorporates the power supply filtering for the 7011 ICs on each phase; motor phase current monitoring; motor phase voltage monitoring; voltage and current monitoring for the motor power supply (VDD); overcurrent monitoring and detection for each phase; and pulse-by-pulse current limiting (for the optional EPC9147A controller board only).

Also it includes output (sine) filtering for each motor phase output; board temperature monitoring; bias voltage monitoring (with LED indication); screw-clamp terminal connectors and banana jack connectors for the VDD and VBIAS power supplies and connectors for Hall-effect inputs; and PWM control inputs and for the optional EPC9147A controller board.

**Configuration Options**

There are two ways the EPC7C021 board may be configured as a standalone board. One is with three phase-offset PWM signal generators, as depicted in Fig. 2. Another is with three 3.3-V/5-V CMOS/TTL-compatible PWM signal pairs as shown in Fig. 3.

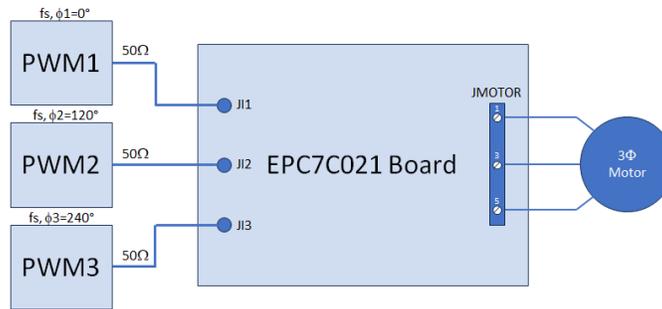


Fig. 2. A dead time of 20 ns is inserted for each PWM signal on the EPC7C021 board.

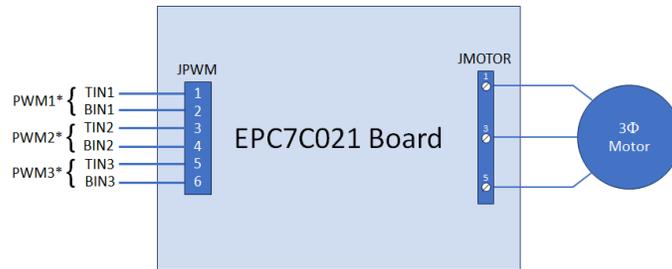


Fig. 3. A dead time of at least 20 ns must be inserted in each PWM BIN/TIN signal set.

It's also possible to operate the EPC7C021 under the control of the EPC9147A controller board as shown in Fig. 4.

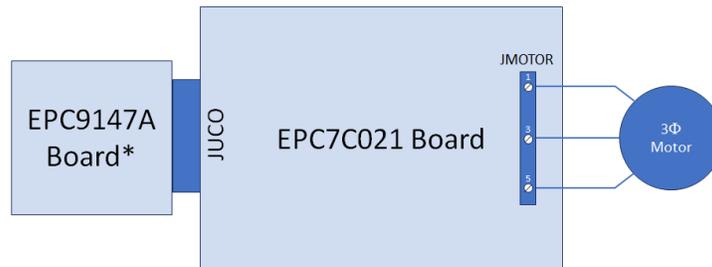


Fig. 4. The keyed card-edge connector on the EPC9147A board plugs directly into JUCO.

## Offering Advantages For Space Engineers

Although the EPC7C021 board is not rad-hard (the cost would be prohibitive!), this board allows engineers to evaluate the EPC7011L7 IC with a PCB layout that has been optimized for its particular characteristics, such as its incredibly fast rise and fall times.

This board has been designed/laid-out with high-frequency bypassing such that the inductance of the bypass loop, from VDD to ground/return, has been reduced as much as possible. In this regard, using magnetic loop cancellation between etch layers carrying the high-frequency ac currents, careful selection of the VDD bypass capacitors (in multi-decade values) and the careful physical placement of the VDD bypass capacitors, the resultant voltage transient spikes on the VDD supply have also been reduced as much as possible.

This layout then can be reproduced on the application board of the engineer evaluating the EPC7011 IC, with them not having to go through the iterative process of optimizing the IC's physical PCB layout. This is important in space applications because there are both time and cost constraints involved in the design process. So it is desirable to not spend time optimizing circuits that are not the most important in the spacecraft (the loads are!!) and come away with a solution in the least iterative design steps.

As for the radiation environment aspects, the EPC7011L7 is by design and rigorous evaluation by EPC Space rad-hard to its 60-V rating—up to 84 MeV/mg/cm<sup>2</sup> and >1 Mrad of TID. So, despite the evaluation board's radiation tolerance limitations, the designer is assured that if they implement rad-hard components surrounding the EPC7011 IC, their circuit will be tacitly rad-hard.

## Input Signal Sources

The input (PWM) signals to the EPC7C021 board may be sourced several different ways.

The first signal sourcing is through SMA input connectors JI1, JI2 and JI3 with three separate PWM generators (with 50- $\Omega$ , 5-V TTL-compatible outputs). The first PWM is phase-locked with the second, which is phase offset by 120° from the first, and the first is phase-locked with the third, which is offset by 240° from the first. This connection provides the necessary phasing for the individual motor load phases, and includes 20-ns hardware dead time between the BIN and TIN logic inputs for each 7011 IC motor phase driver by using the JI1-JI3 inputs.

The second signal sourcing is through JPWM, an eight-pin Molex CGRID connector that is used to provide the six BIN and TIN signals to the respective 7011 IC motor phase drivers, along with a user-selectable 3.3-/5-V power and board logic ground connections. Using this PWM signal sourcing option the end-user *must* include a 20-ns BIN-TIN and TIN-BIN dead time for each logic input pair for each phase driver IC. This option allows the end-user to interface directly with their custom rad-hard FPGA/PLA/microcontroller to facilitate the easy debug and shake-out of their motion control system using the planned flight hardware.

The third signal sourcing is through JUCO, a 40-pin edge card connector that is the required mating connector for the EPC9147A controller board I/O PCB finger edge card, shown in Fig. 5.

The necessary BIN/TIN signals are generated on the 9147A card by the Microchip dsPIC33 DSP based on analog voltage/current feedback signals generated on the 7C021 board. In addition to interfacing with the 9147A board, the JUCO connector also interfaces with the EPC9147E "dummy" interface board, pictured in Fig. 6.

This board can be used as a convenient "break out" board to interface the external PWM signals to the 7C021 board and the V/I analog feedback signals to the FPGA or controller of choice.

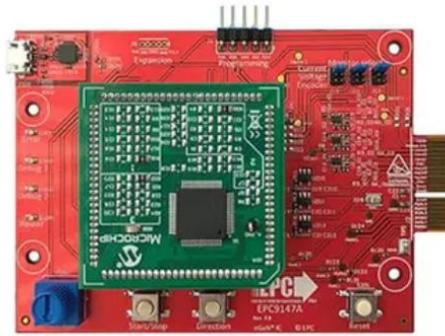


Fig. 5. The EPC9147A controller board.

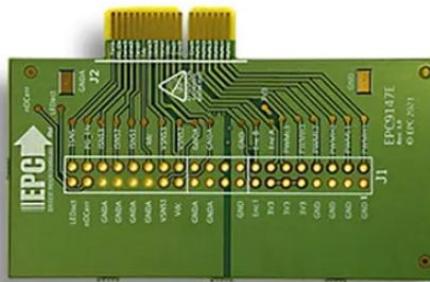


Fig. 6. The EPC9147E signal "breakout" board.

**Monitoring And Protection Features**

The EPC7C021 board provides voltage and current monitoring circuitry for the VDD power supply and for all three phase output voltages. The currents are monitored using an inline, low-value current-sense resistor with Kelvin (four-wire) connections. The voltage sensed across the Kelvin contacts is level-shifted to ground and amplified such that the resultant voltage for each signal falls within the 3.3-V operational range for the full-scale current expected in each circuit leg (Fig. 7).

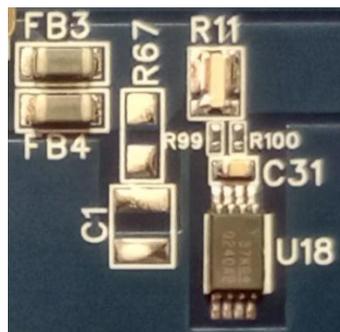


Fig. 7. In this picture of a section of the EPC7C021 board (for the phase 2 output), resistor R11 is a low-value Kelvin resistor; resistors R99, R100 and C31 form a noise filter; and IC U18 is a differential amplifier with a large input compliance range (to VDD).

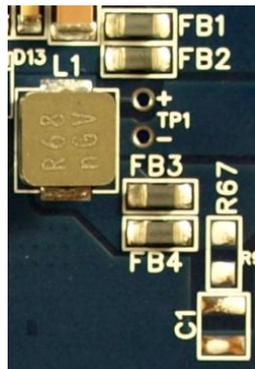
The VDD and phase voltages are each monitored by a voltage divider referenced to ground, and the resultant voltage for each signal once again falls within the 3.3-V operational range for the full-scale current expected in each circuit leg. All the scaled-down voltages representing current and voltages are filtered for noise.

To implement the pulse-by-pulse current limiting function for the 9147A board, the scaled-down voltages representing the current for VDD and each motor phase are monitored with a limit comparator to determine if the predetermined current limit threshold has been exceeded. If any exceed that threshold, the comparator then disables the logic inputs to the three 7011 ICs on the 7C021 board until the overcurrent condition resolves. Should the overcurrent condition persist, the same disable process is repeated again until the fault is removed or VDD power is removed.

Additional monitoring is provided for the 12-V VBIAS power supply and the 5.0- and 3.3-V logic power supplies. Based on the levels of the supplies, green LEDs are illuminated if the supplies are all within a  $\pm 5\%$  tolerance window (i.e. OK).

### **Output Filtering And Thermal Management Implementations**

Optional customer-supplied output filtering is provided by component locations in the output of each half-bridge (Fig. 8).



*Fig. 8. In this picture, for the phase 1 output, the output filter consists of inductor L1, capacitor C1 and damping resistor R67.*

The EPC7C021 board is shipped with a 0.68- $\mu\text{H}$  inductor in the L1 (and similar positions in the other output phases) and capacitor C1 and resistor R67 (again and similar components in the other output phases) are left unpopulated.

With regard to thermal management, each 7011 IC is provided with a 2-oz top-side etch with an additional four stacked layers of 1-oz copper etch directly beneath the IC. That stackup provides a substantial thermal system to conduct heat away from the ICs and into the PCB to be convected over a wider area. Augmenting the copper etch beneath them, each IC is provided with two aluminum nitride (AlN) "helpers".

Fig. 9 shows the phase 2 half-bridge 7011 IC and the reference designations TH3 and TH4 are the thermal helpers associated with the device. These devices are actually highly thermally-conductive but electrically non-conductive elements that allow heat to be bridged between copper etch areas that have different potentials between them—Vishay ThermaWick thermal jumpers in the EIA 0805 package size.

Elements TH3 and TH4 bridge across VDD and ground etch areas to conduct heat away from pin 7 (VDD) of the IC to power ground. These two elements were incorporated on the 7C021 evaluation board so that customers can evaluate whether both, one or none of these helpers are required in their end-application.

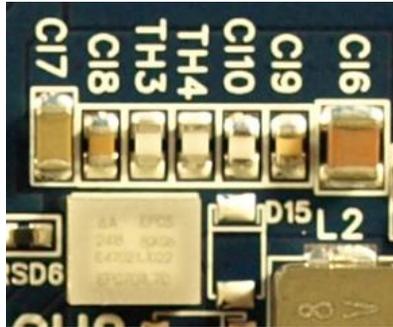
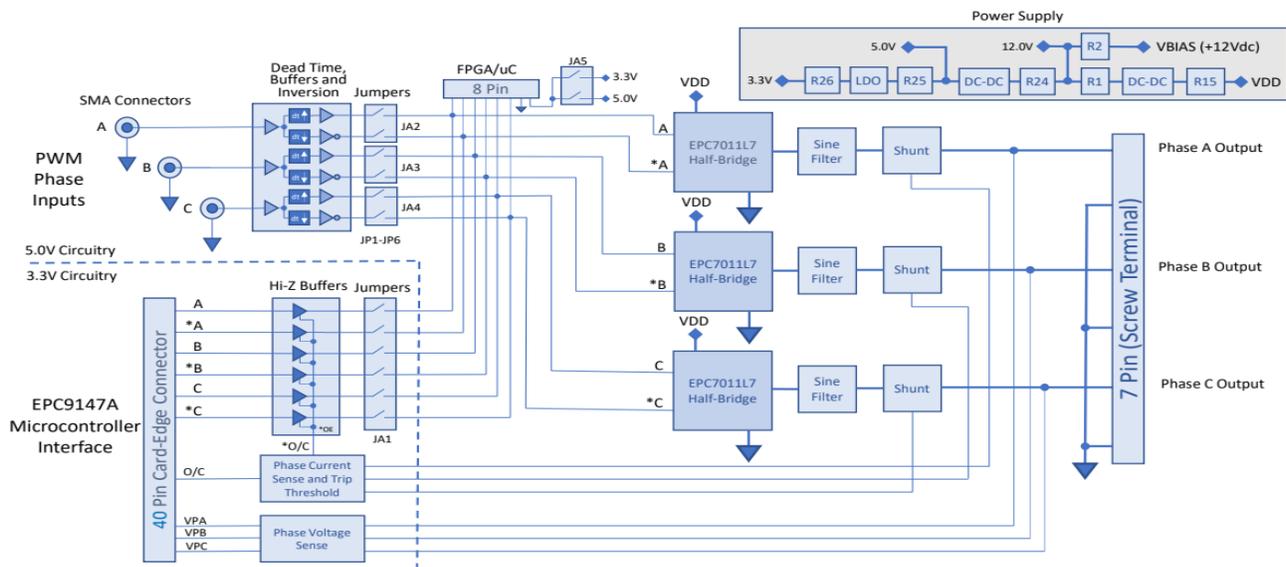


Fig. 9. Phase 2 EPC7011 half-bridge with TH3/TH4 Vishay ThermaWick thermal jumpers bridging VDD to ground for efficient heat transfer from pin 7.

### Interface Options For Easy Integration

A review of the block diagram of the EPC7C021 board (Fig. 1, repeated below) illustrates its versatility and its ease of integration.



For three-phase external signal input/control include jumpers JA2-JA4 and omit jumpers JA1. Use SMA connectors for signals. For three-phase complimentary input/control omit jumpers JA2-JA5. Use 8 pin connector for signals. Select desired interface voltage level using JA5. For EPC9147A control, include jumpers JA1 and omit jumpers JA2-JA5. Plug 9147A controller card into 40 pin edge-card connector.

Fig. 1 again. EPC7C021 block diagram.

The designer simply needs to decide what type of logic input is desired/required, set a few jumpers, and connect VDD and VBIAS power and the three motor phases with a screwdriver in the appropriate connectors. Then the board is ready to drive a motor using the PWM signals applied to it.

### Prototyping Three-Phase Motor Drives For Engineers

The EPC7C021 board provides a convenient vehicle for end-use designers/engineers to prototype their three-phase motor control system using their motor-of-choice driven by the EPC7011L7 IC. The physical hardware necessary is provided on the 7C021 board with the necessary control being provided by the easily-interfaced EPC9147A controller board.

The motor may be commissioned using the 7C021-9147 pairing using the step-by-step instructions for the EPC9147A on the EPC website.<sup>[2]</sup> To perform this commissioning function requires, among other things, the

requisite motor characteristics/parameters, the VDD voltage range, the desired switching frequency, the desired dead time (>20 ns) and the motor's operating speed range.

Once the motor is commissioned and the necessary parameters are captured in the on-board dsPIC33 controller's PROM, the motor may be attached to the 7C021 board. Its operation can then be observed in a dynamometer set-up or similar test configuration to determine overall motor drive performance.

The availability of the 7C021 board along with the 9147A controller thus makes the process of prototyping, characterizing and evaluating three-phase motor drives a much simpler/easier endeavor.

### **Considerations To Keep In Mind**

Beyond being a three-phase motor control board,<sup>[4]</sup> the EPC7C021 board may be used to drive motors in different configurations: single phase, bipolar (BLDC), ac synchronous motors (as a class-D amplifier) and linear motors.

Although this board was specifically designed for the evaluation of the EPC7011L7 driving three-phase motors, it can also be used to evaluate single phase/winding, both unidirectional and bidirectional, and two-winding (i.e. BLDC) motors. For the latter, two EPC7C021 boards would be required to provide the requisite number of phase winding drivers (i.e. four).

Additionally, the three phases on this board may be used with external L-C filters to create buck (stepdown) power converters, a single-output three-phase buck converter, a class-D amplifier (using two phases) and just about any application requiring one to three individually-controllable half-bridge outputs.

### **References**

1. [EPC7C021 – 400 W Motor Drive Demonstration Board](#) product page.
2. [EPC9147A - Interface Board for Microchip PIM Motor Drive Controller](#) web page.
3. See the [EPC Space website](#) for information on the EPC7011L7 and other products mentioned in this article.
4. See the [EPC Space demo boards](#) page for information on other demo boards.

### **About The Authors**



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For more on motor drive design, see How2Power's [Design Guide](#), locate the "Power Supply Function" category and select "[Motor drives](#)".