RAPID DESIGN KITS FOR THREE PHASE MOTOR DRIVES

by

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Abstract:

This paper presents methods for quick prototyping of motor drive designs. The techniques shown can be used for a wide power range and demonstrate how existing interface kits for Intelligent Power Modules (IPMs) and motor controllers can be linked up for use in a complete motor drive reference design. This paper also gives the audience some ideas for DC bus construction which is needed to power the motor drive.

Introduction:

The purpose of rapid design kits is to give the designer a tool that will very quickly allow a complete a prototype of their design and provide a platform to begin testing it. This is done by supplying the designer completed sections of the design that have already been tested, that the designer may or may not be familiar with, thereby saving them tremendous amounts of development time and allowing them to focus on the remaining parts of the design. The rapid design kits therefore also give the designer key points of reference as to how these critical parts of the designs can be implemented successfully.

The rapid design kits that we will be discussing in this paper are focused on the design of three phase induction motor drives and the methods described can assist designers in developing a wide range of motor drives going from ½ HP or about 375 W all the way up to 150 HP or about 110 kW. All of this is achieved by using the same board for producing the six necessary PWM (Pulse Width Modulation) control signals for controlling the high and low side switches used in a typical three phase motor drive topology.

In order to achieve this wide range of power levels a series of both DIP-IPMs (Dual In-line Pins Intelligent Power Module) and traditional IPMs are used along with a respective development board for each part. In this way, one can start at the low power end with Super Mini DIP-IPM devices, which all share the same development kit, and have device ratings from 3A to 30A at 600V. For somewhat more demanding applications a Mini-DIP package that is a bit larger with ratings of 20A and 30A at 600V can be used. The traditional style IPMs are used in applications with relatively high power demands and come in four packages: A, B, C, and D which will be described more fully later. At this point, take into consideration that A, B and C all use the same development kit (i.e. same control circuit board design) while the devices in the largest package, package D, require somewhat of a different layout.

All of this leads to the point that one can come up with reference designs for a very wide power range using a single motor control board (named BCIM) along with only four different development kits and the required IPM.

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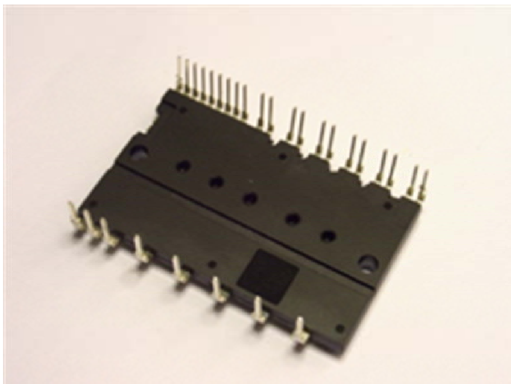
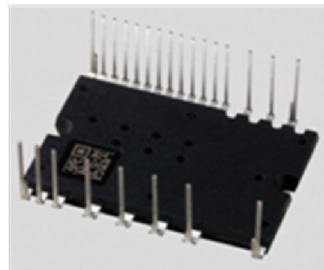
Features of the Generation 4 Super Mini and Mini DIP



Mini DIP-IPM
Gen. 4



Super Mini DIP-IPM
Gen. 4

Figure 1: Generation 4 Super Mini and Mini DIP-IPMs

The Super Mini and Mini DIP-IPM designs offer several advantages to the motor drive designer over discrete IGBTs (Insulated Gate Bipolar Transistors). The DIP devices contain six IGBTs and six FWDs (Free Wheel Diodes) in a three phase topology along with gate drive and protection circuitry. The built in gate drive is made up of one LVIC (Low Voltage Integrated Circuit) for the three low side IGBTs and also has three HVICs (High Voltage Integrated Circuits) to perform level shifting for the three IGBTs in the high side of the three phase topology. The built in LVICs and HVICs, in addition to supplying gate drive, also provide UV (Under Voltage lockout) and OC (Over Current) protection functions. The combination of features included in the DIP-IPM allows a user to have a direct connection to the DIP-IPM from their controller in addition to these protection functions. As seen in Figure 2, a DIP device can be used in place of up to ten or more discrete components saving design time and printed circuit board space and increasing the overall reliability of the system.

The main difference between the Mini DIP and Super Mini DIP is in package area with a ratio of a little less than 2 to 1 respectively. The additional package area results in a tradeoff that allows greater thermal conductance in the Mini DIP package which ultimately means that in a real application the Mini DIP has more power capability. This is evident when looking at table 1 and noting that the 20A Mini DIP actually has about 8 A more capability in a typical application running at 5 kHz.

Figure 3 is a block diagram of a typical DIP-IPM application circuit.

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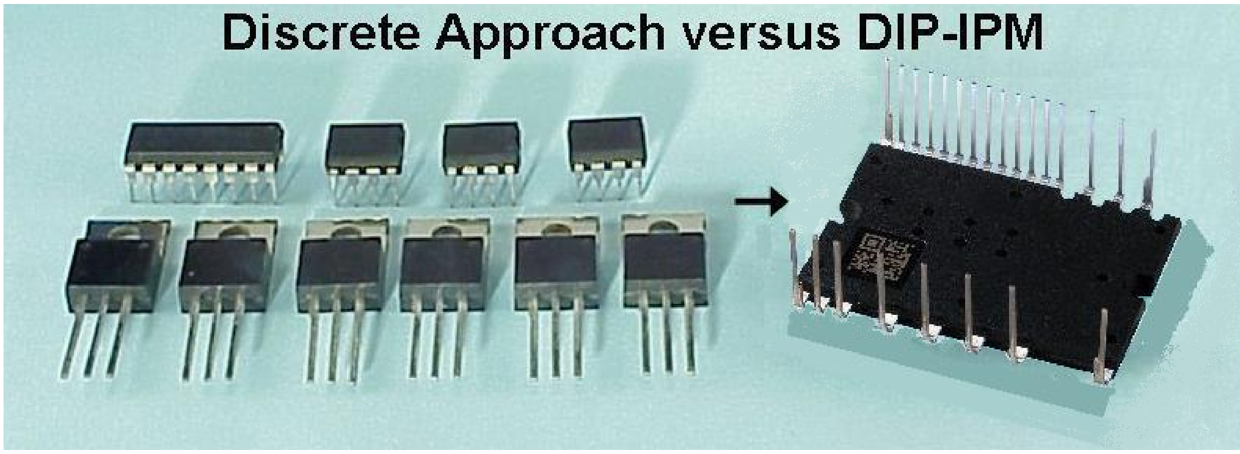

Figure 2: Comparison of Discrete Approach versus DIP-IPM

	Nominal / Peak Current Rating IGBT and Free Wheeling Diode	Continuous Sinusoidal Inverter Output Current (ARMS)* Tsink = 80C, Tj ≤ 125C, $I_{PEAK} \le 1.7 {*} I_C$ PF=0.8, V_{CC} =300V		Part Number	Options (-Part number suffix)
	I_C / I_{CP}	F_{sw} = 5 kHz	F_{sw} =15 kHz		
Gen. 4 Super Mini DIP	3A / 6A	3.6	3.6	PS21961-4	-A Long (16mm) pins -S Open emitters -C ZigZag leadform -W Double ZigZag leadform -T Over Temp. Protection
	5A / 10A	6.0	6.0	PS21962-4	
	8A / 16A	9.6	7.4	PS219634E	
	10A / 20A	11.2	8.1	PS21963-4	
	15A / 30A	14.0	9.6	PS21964-4	
	20A / 40A	16.2	11.0	PS21965-4	
	30A / 60A	TBD	TBD	PS21997-4	
Gen. 4 Mini DIP	20A / 40A	24.0	17.8	PS21765	
	30A / 60A	31.3	22.1	PS21767	

* $T_j \le$ 125C and $I_{PEAK} \le 1.7 {*} I_C$ are selected according to recommended design margins. The actual device limit is: $T_j \le$ 150C, $I_{PEAK} \le I_{CP}$

Table 1: Output Current Capability for Super Mini and Mini DIP-IPMs

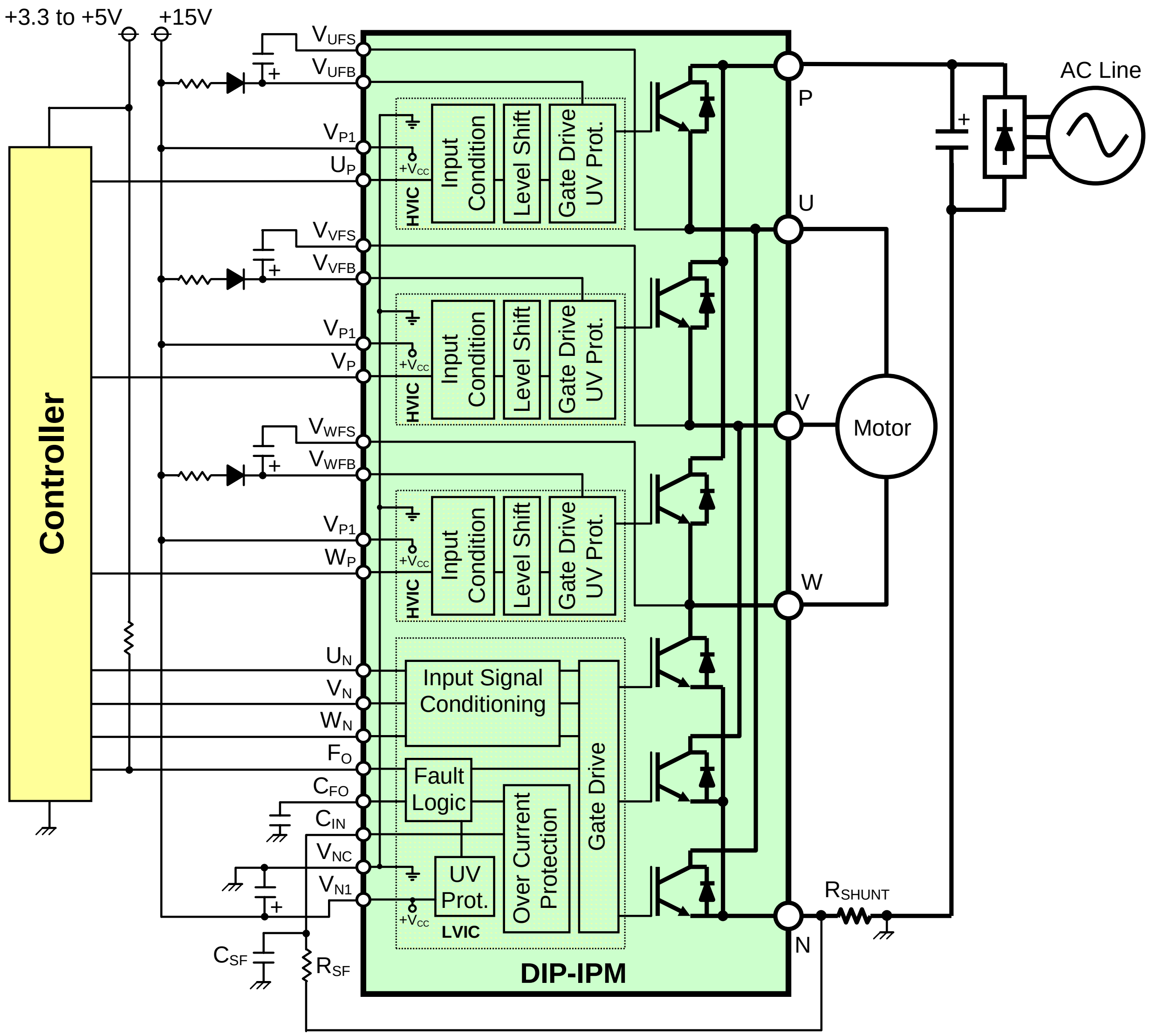

Figure 3: Typical DIP-IPM Application Circuit

Features of the L-Series IPMs

The L-Series IPMs offer many of the same advantages that can be found in the DIP style devices but are rated for higher currents. Some of the similar features are the built in six IGBTs and six FWDs and protection features like UV for the control power supply and OC protection for the main current. The OC protection in an L-series IPM is derived by using a current mirror as opposed to a shunt resistance which is necessary at the higher current levels used in order to keep the power circuit inductance to a minimum. Also, because the current mirror is a more direct method of measuring current, the OC protection in an IPM is more accurate than in the

DIP-IPM. In addition to UV and OC protection, all L-Series IPM devices also have built in OT (Over Temperature) protection which is derived by a string of diodes located on each individual IGBT chip inside the module. The L-series IPMs also have built in gate drive.

As stated in the introduction, the L-series IPM is available in four package styles, shown in Figure 4, in order to serve a wide range of power needs. Package A and B devices have ratings of 50 to 150 A at 600 V and 25 to 75 A at 1200 V. Package C is available in power ratings of 200 and 300 A at 600 V and 100 and 150 A at 1200 V. The largest package, package D, is available in 450 and 600 A at 600 V and 300 and 450 A at 1200 V.

The only supporting circuitry required to use the L-series IPMs is isolated control voltage power supplies and an isolated control signal interface which is normally derived using optocouplers. SIP (Single In-line Pins) style power supplies such as the VLA106 series, VLA106-24151 and VLA106-24154 are very convenient for achieving the required isolated power supplies. Traditionally, individual optocouplers for control signals in each drive channel have been used, however users may now find it more convenient to use a VLA606-01R, a SIP device that contains six optocouplers and has a pin arrangement that is the same as the control signal input order on the L-series IPM greatly simplifying board layout and making a sizable reduction in board space for size critical applications. This SIP can be used with all A, B and C package IPMs. Figure 5 illustrates the reduction in board complexity and savings in board space that can be achieved by using a SIP device like the VLA606-01R in place of multiple high speed optocouplers and supporting circuitry by enclosing in red all of the components that can be replaced by this new SIP device.

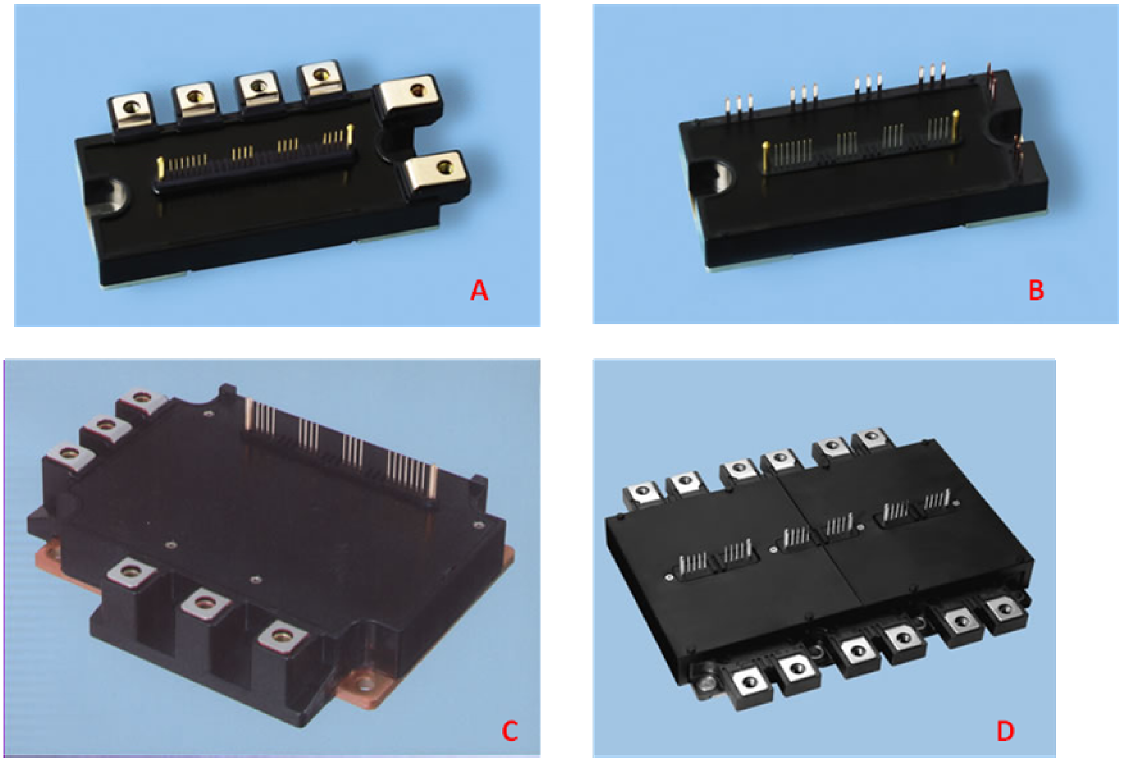

Figure 4: L-Series IPM Package Styles

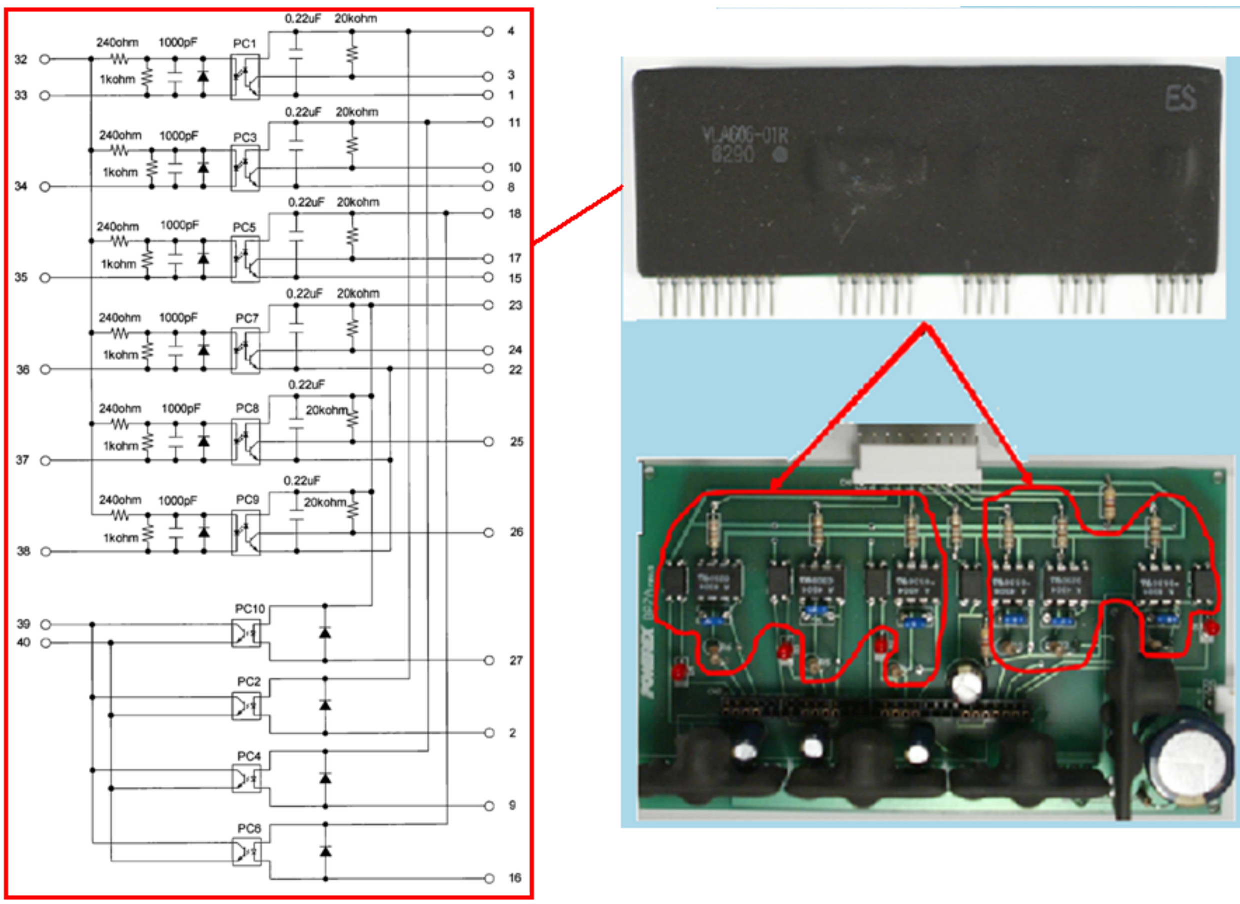

Figure 5: Reduction in Board Space and Complexity Achieved with VLA606-01R

Development Kits for DIP-IPMs

Now that the DIP-IPMs and L-Series IPMs have been discussed, this paper will present the development kits that demonstrate the necessary supporting circuitry that allows complete control of the motor current outputs of these devices with the simple addition of control logic (a controller) and a control voltage power supply.

As Figure 3 shows the supporting circuitry required for using the DIP-IPM style of devices is quite minimal due to the high level of integrated functions. The development kits for these devices exemplify this fact and suggest a suitable layout to the customer for these types of modules. The low side gate drive should employ a high speed electrolytic capacitor to filter the transients caused by high speed switching and allow rapid charging of the IGBT gates. An isolated floating supply voltage is needed for the high side IGBTs. This power for the high-side gate drive in DIP-IPMs is normally supplied using external bootstrap circuits. The bootstrap circuit typically consists of a low current fast recovery diode that has a blocking voltage equivalent to the V_{CES} (maximum collector-to-emitter blocking voltage) rating of the DIP and a floating supply reservoir capacitor with a small series resistor to limit the peak charging current. The DIP-IPM uses the voltage across an external shunt resistor inserted in the negative DC bus to monitor the current and provide protection against overload and short-circuit conditions. Figure 6 is a circuit diagram for the Mini and Super Mini DIP-IPM design kits. By simply changing the shunt resistor value one can use the same board to take advantage of the complete Super Mini DIP lineup which goes from 3 to 30 A at 600 V. Using the same design technique we can come up with a design using the larger 20 and 30 A 600 V Mini DIP shown in figure 8 (shows 30 A PS21767).

Figure 7 which shows the design kit used for the 10 A Super Mini DIP (DK-PS21963) demonstrates how all of the circuit requirements and recommendations are set up on a PCB (printed circuit board) and the relative ease of use of this style of device. The zener diode used in the board here is intended to protect the control voltage input of the LVIC from overvoltage.

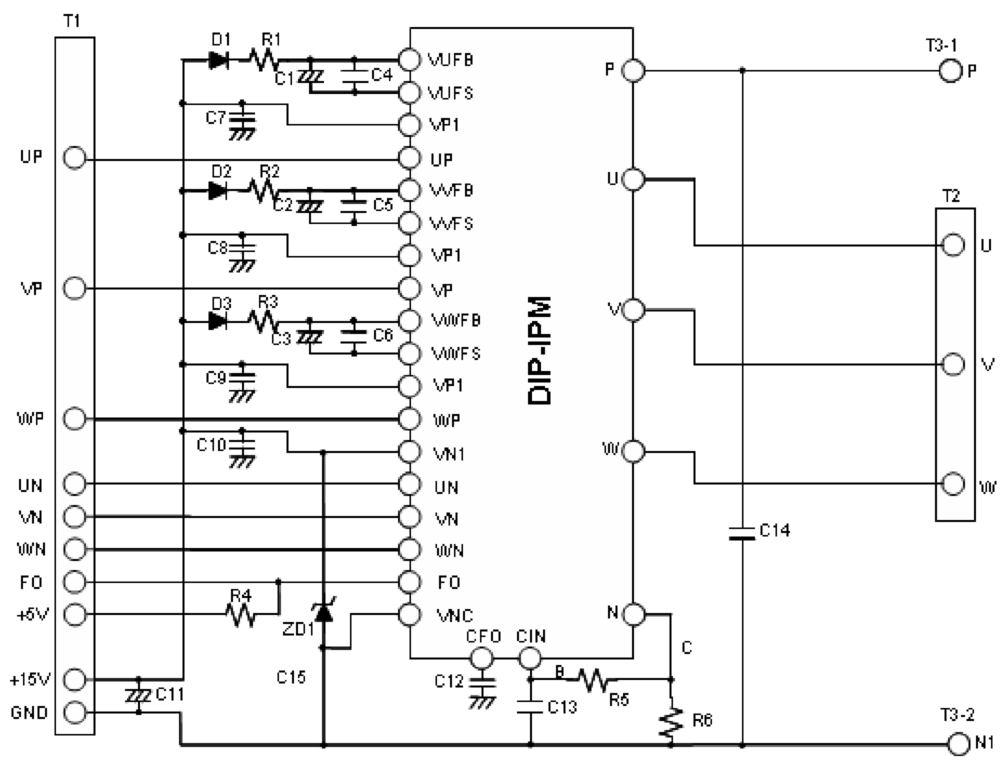

Figure 6: Circuit Diagram for Mini/Super Mini DIP-IPM Design Kits

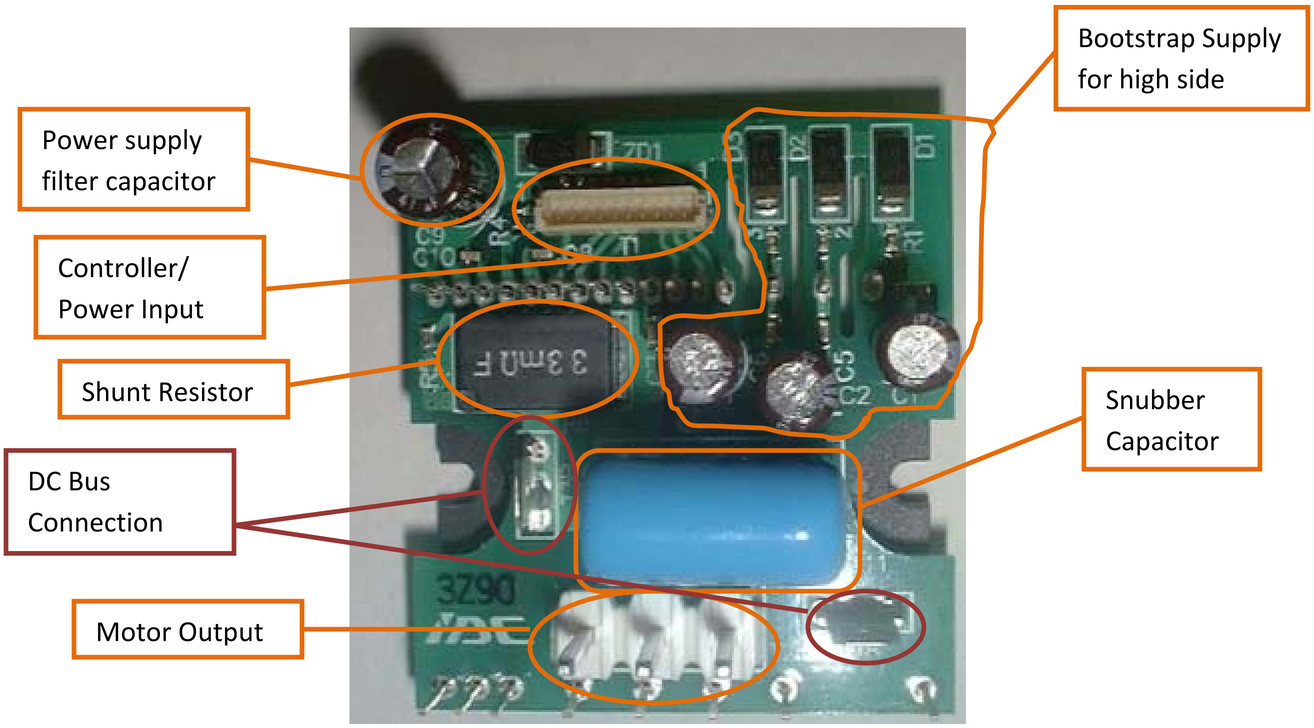

Figure 7: Development Kit for Super Mini DIP-IPMs

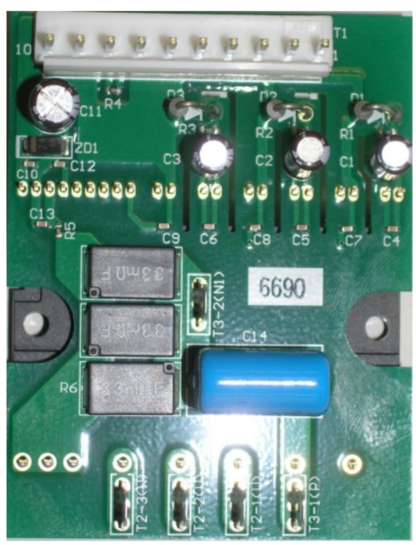

Figure 8: Development Kit for Mini DIP-IPMs

Development Kits for L-Series IPMs

The interface for L-series IPMs requires more supporting circuitry than is necessary in DIP-IPMs. The L-series IPMs have built in gate drive but still require a floating (isolated) power supply in order to achieve robust gate drive with good noise immunity. As stated earlier, this is normally achieved with off the shelf isolated DC/DC converters like the VLA106-24151. In addition isolated optocouplers are needed for the transfer of control signals to the floating voltage level supply side of the interface. It is important that the optocouplers be high speed and have good noise immunity of at least 10 kV/μs. In order to take advantage of the L-series IPMs fault feedback features, low speed optocouplers with good noise immunity can be used. All of the L-series IPMs, except for the largest, are designed so that all low side devices share the same low side power supply.

Traditionally individual optocouplers have been used for each control signal and each fault signal. Now the use of a single device which allows the transfer of all of these signals is recommended for the purposes of reducing board layout complexity and meeting more efficient space requirements. Power supply decoupling capacitors placed as close as possible to the input pins of the power device are also required. The resulting layout can be seen in figure 9 which is a photograph of a populated BP7B development board.

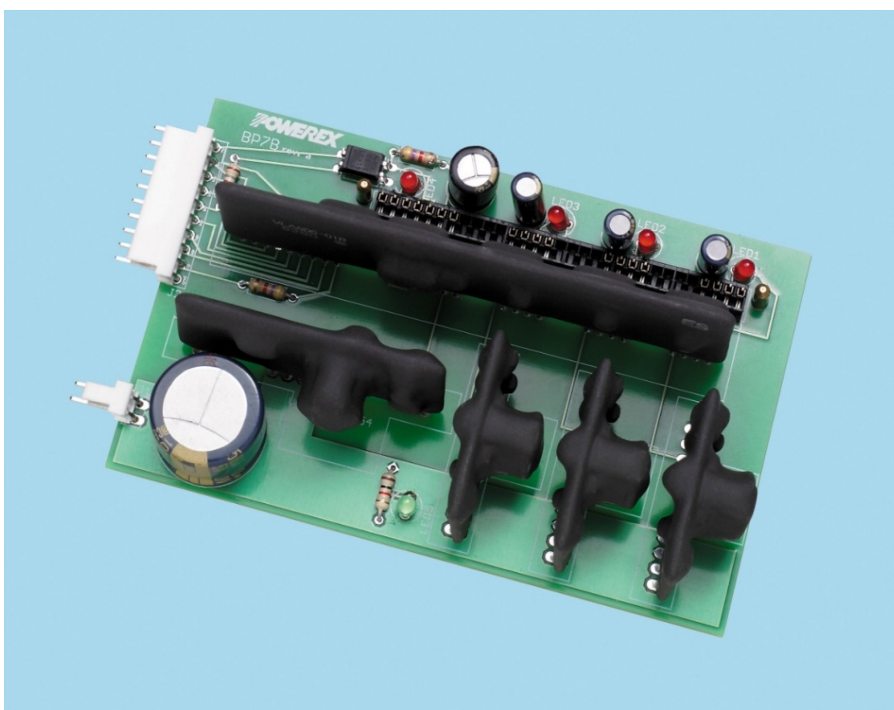

Figure 9: BP7B Interface Circuit Board for Use with A, B and C Package L-Series IPMs

The circuit shown in figure 9 is recommended for use with A, B and C package L-Series IPMs. The largest package, D, requires separate power supplies for each IGBT gate drive. The reason for this is the higher current levels implicated create greater disparity between the voltage level at the negative bus and the low side emitter voltages and so it becomes important to have separate isolated supplies to inhibit these voltage fluctuations from interfering with neighboring gate circuits. This device also requires the use of high speed optocouplers for isolated control signals and low speed optocouplers for fault feedback. An example of the resulting circuit board is shown in figure 10 which is our BP6A development board.

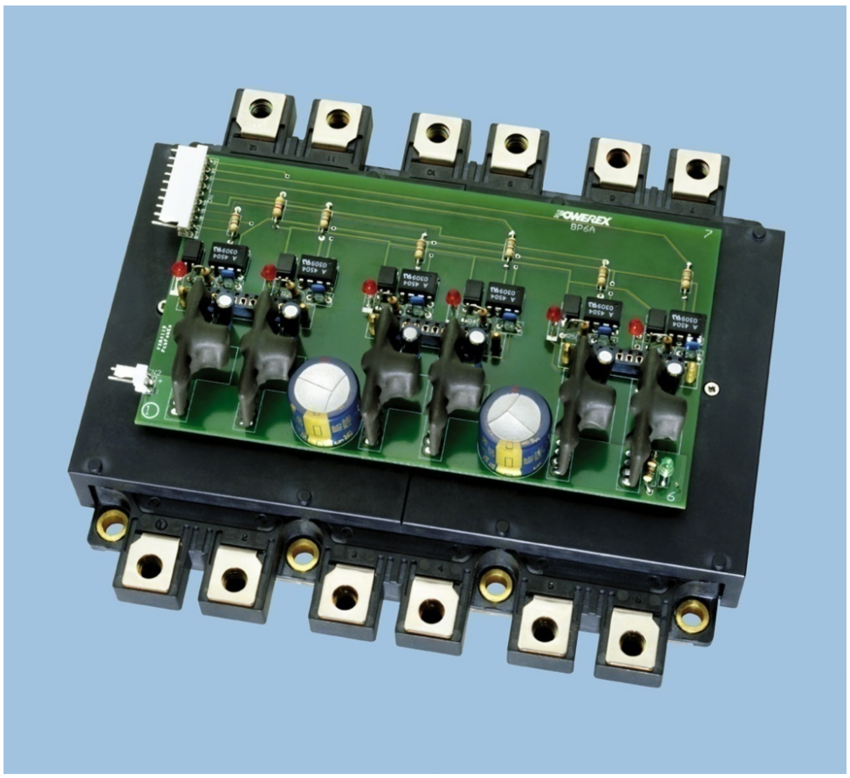

Figure 10: BP6A Circuit Interface Board Mounted on Largest L-Series IPM

Example Three Phase Induction Motor Controller Board (BCIM)

The L-series IPM and DIP-IPM development kits in conjunction with their respective boards provide a large section of a completely designed motor drive. One of the crucial missing components from what has been derived by this combination is of course the PWM control signals. In order to come up with a motor drive reference design in a very short amount of time it is possible to use a completed PWM drive scheme like that provided by the BCIM, shown in figure 11. This board allows a user to select the output for either a 50 Hz or a 60Hz motor and also allows them to adjust the motor speed by varying the frequency. The speed control changes the motor current waveform frequency from 1 to 128 Hz and the acceleration rate can be adjusted to a value between 0.5 and 128 Hz/s.

The board has an onboard voltage regulator allowing the user to power it using anything from 8 to 24 V. The BCIM board is also configured so that the pin order for the control signal connector matches that of the control inputs on the BP6A and BP7B boards. The interconnections between the DIP-IPM/ L-Series IPM design boards and the BCIM is revealed in figure 12.

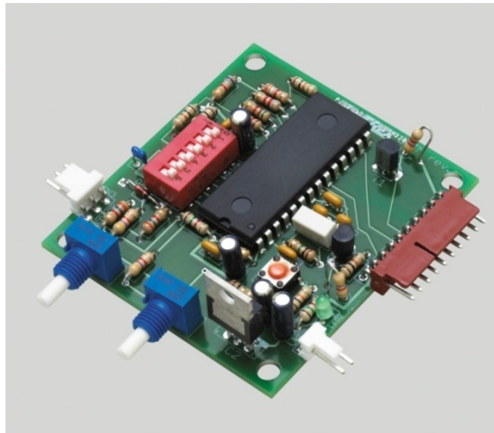

Figure 11: BCIM Three Phase Induction Motor Controller

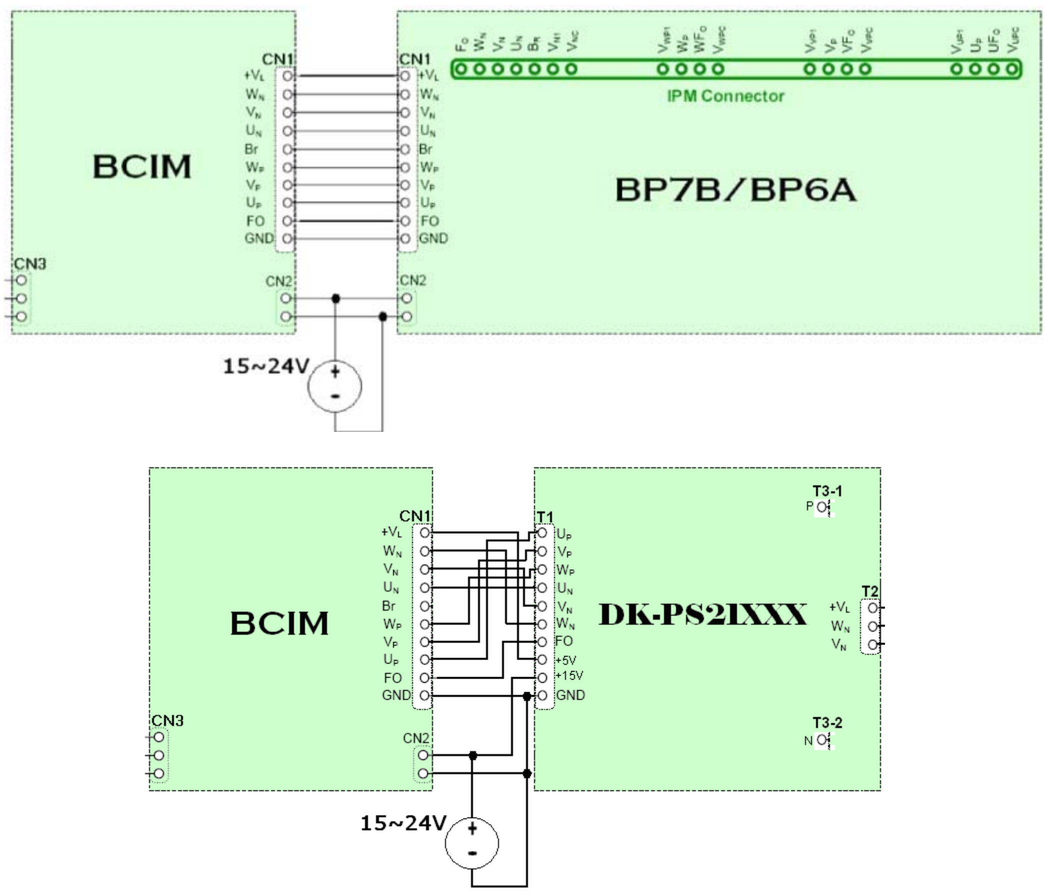

Figure 12: Connection Methods for BCIM to L-Series and DIP-IPM Development Boards

An Example of a Complete Motor Drive Reference Design

The methods already discussed in this paper propose components and kits that can be used together to provide a nearly complete three phase motor drive reference design. The only section that remains in order to complete the reference design is a DC power bus.

The DC power bus will normally be made up of a large DC voltage source connected to a capacitor bank. The capacitor bank is then generally connected to the high and low sides of the motor drive switching elements which in the case of these designs will be the P and N terminals of the switching device in question. The bus connections are normally made using a planar bus structure. Selecting the DC bus capacitance used depends on many factors of the design like motor current output, switching frequency as well as other factors. In general capacitors with high ripple current and low ESR are used.

The example motor drive displayed in Figure 13 derives the DC power bus from a standard 120 VAC line in combination a rectifier circuit and voltage doubler including bus capacitors. The M57182N-315 is used for deriving the 15V control power, for use from the DC bus.

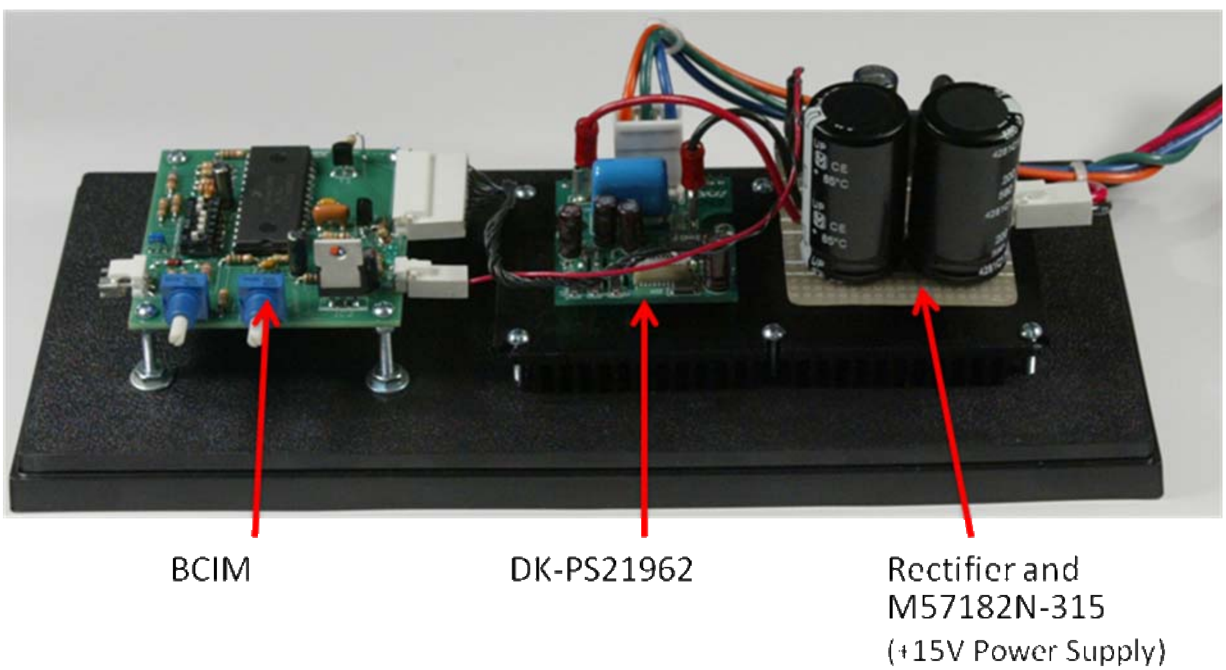

Figure 11: Complete Motor Drive Reference Design