

Using the MP6530 Family of Pre-Drivers

Application Note

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ABSTRACT

The MPS MP6530 family of parts are three-phase pre-drivers for brushless DC motors. The family includes the devices listed in Table 1.

Table 1: MP6530 Family Parts

Part Number	Interface	Distinguishing Features	Package
MP6530	IN/EN (x3)		QFN-28 (4mmx4mm)
MP6531	IN/EN (x3)		TSSOP-28
MP6532	PWM/HALL	Integrated Hall commutation logic	QFN-28 (4mmx4mm)
MP6533	PWM/HALL	Integrated Hall commutation logic	TSSOP-28
MP6534	IN/EN (x3)	Integrated buck converter	QFN-40 (5mmx5mm)
MP6535	PWM/HALL	Integrated buck converter, Hall logic	QFN-40 (5mmx5mm)

These devices generate the gate-drive voltages required to drive six external N-channel MOSFET transistors arranged as a three half-bridge outputs.

In some devices, Hall sensor inputs are provided for self-contained trapezoidal commutation of 3-phase motors. Two of these parts also integrate a buck converter to provide power for external motor control logic or microcontrollers.

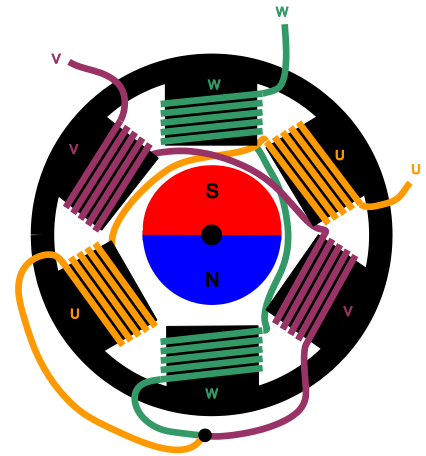
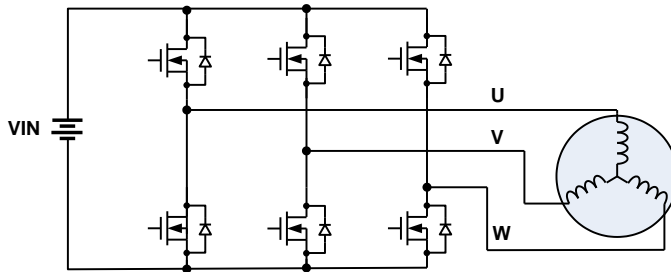
This application note explains the use of these parts to drive 3-phase brushless DC motors, and discuss the selection of associated components. Unless otherwise noted, this information applies equally to all members of the MP6530 family listed above.

Brushless Motor Basics

A 3-phase brushless DC motor uses a rotating magnetic structure, which is acted upon by three sets of coils. To make the motor move, the magnetic field generated by the coils is rotated, or commutated, by an electronic driver.

The simplest form of 3-phase BLDC motor, which has a 2-pole rotor (one north pole and one south pole) is shown in Figure 1. BLDC motors can be constructed with more pole pairs (more N and S magnetic poles and more coils), but the operation from an electrical standpoint is the same.

Usually, one end from all three coils are connected together in what is called a star configuration. The common point is usually inside the motor, so only three wires are brought out of the motor to the driver.


Figure 1: 3-Phase BLDC Motor

Figure 2: 3-Phase BLDC Drive Circuit

To drive the coils, three half-bridge drivers are used (see Figure 2). With this arrangement, each wire of the motor (traditionally named U, V, and W) can be driven to the power supply input, to ground, or left open.

The MP6530 family provides the drive signals for the gates of N-channel power MOSFETs to drive the motor coils.

MP6530 Family Control Logic

All members of the MP6530 family of pre-drivers all have the same circuitry that drives external power MOSFETs. They differ in the ways that the input signals work to drive the motor as well as in package type (TSSOP or QFN). An integrated buck converter, which is independent of the pre-driver, is also available in some parts.

There are two different logic input interfaces available. One uses three separate enable and PWM input signals, which are typically generated in a microcontroller that provides commutation and control of the motor. This interface can be used with sensorless operation or with Hall sensors that provide feedback to the microcontroller. For each of the three phases, these signals act to enable either the high-side (HS) or low-side (LS) MOSFETs of each phase. The logic is encoded as shown in Table 2.

Table 2: MP6532 Control Logic Inputs

ENx	PWMx	MOSFET State	Output X
H	H	HS on, LS off	VIN
H	L	HS off, LS on	GND
L	x	HS and LS off	high impedance

This logic applies to the MP6530, MP6531, and MP6534. Note that it is impossible to turn on both the HS-FET and LS-FET at the same time, as this would cause a direct short between the power supply and ground.

The MP6532, MP6533, and MP6535 integrate Hall commutation logic, so they have a much different input interface. They have three inputs for Hall sensors (HA, HB, and HC), and a single PWM input. They also have BRAKE and DIR inputs, which are used in conjunction with the Hall inputs to control how the motor commutates.

The commutation logic is shown in Table 3.

Table 3: Commutation Logic

Logic Inputs				Driver Outputs						Motor Terminals		
HA	HB	HC	DIR	GLA	GLB	GLC	GHA	GHB	GHC	SHA	SHB	SHC
1	0	1	1	/PWM	0	1	PWM	0	0	H	Z	L
1	0	0	1	0	/PWM	1	0	PWM	0	Z	H	L
1	1	0	1	1	/PWM	0	0	PWM	0	L	H	Z
0	1	0	1	1	0	/PWM	0	0	PWM	L	Z	H
0	1	1	1	0	1	/PWM	0	0	PWM	Z	L	H
0	0	1	1	/PWM	1	0	PWM	0	0	H	L	Z
1	0	1	0	1	0	/PWM	0	0	PWM	L	Z	H
1	0	0	0	0	1	/PWM	0	0	PWM	Z	L	H
1	1	0	0	/PWM	1	0	PWM	0	0	H	L	Z
0	1	0	0	/PWM	0	1	PWM	0	0	H	Z	L
0	1	1	0	0	/PWM	1	0	PWM	0	Z	H	L
0	0	1	0	1	/PWM	0	0	PWM	0	L	H	Z

This logic applies to the MP6532, MP6533, and MP6535. These devices can be used to control motors that have built-in Hall sensors with little or no need for an external microcontroller. The duty cycle of the PWM input signal can be used to change the motor speed (a higher duty cycle makes the motor turn faster). The DIR input is used to select which direction the motor turns. The BRAKE input can be used to cause the motor to stop very quickly by turning on all three LS-FETs.

MOSFET Selection

One of the most important design tasks in using the MP6530 family is to correctly choose the external MOSFET devices that drive the motor.

The first specification requirement is that the MOSFET must have a VDS breakdown voltage that is higher than the supply voltage. It is recommended that considerable margin (10V - 15V volts) be added to prevent MOSFET damage caused by transient voltages that can be caused by parasitic inductances in the PCB layout and wiring. For example, for 24V power supply applications, MOSFETs with a minimum breakdown voltage of 40V - 60V are recommended. More margin is desirable in high-current applications, since the transients caused by parasitic inductances may be larger. There are also conditions such as regenerative braking that can inject current back into the power supply. Care must be taken so that this does not increase the power supply voltage to damage components.

The MOSFETs must be able to safely pass the current needed to run the motor. The highest current condition, which normally occurs when the motor is first started or stalled, must be supported. This is typically called the stall current of the motor.

The $R_{DS(ON)}$ is related to the current capability of the MOSFET. $R_{DS(ON)}$ is the resistance of the MOSFET when it is fully turned on. The MOSFET dissipates power proportional to the $R_{DS(ON)}$ and the motor current ($P = I^2R$). The $R_{DS(ON)}$ must be selected so that for the desired motor current, the heat generated can be safely dissipated. In some cases, this may require special PCB design considerations and/or external heatsinks to be used for the MOSFETs.

Some consideration should be made for the safe operating area (SOA) of the MOSFETs in fault conditions such as short circuit. The IC acts quickly in the event of a short, but there is still a very short time (about 1 - 2 μ s) where large currents can flow in the MOSFETs while the protection circuits are recognizing the fault and disabling the outputs.

Gate Drive Considerations

The gate characteristics of the selected MOSFETs affect how quickly they are switched on and off. In some cases, it may be advantageous to add external components (resistors and/or diodes) to modify the MOSFET turn-on and turn-off characteristics.

The MP6530 family provides a low impedance drive (5 - 10 Ω) to drive the MOSFET gates (refer to the related datasheet). The gate drive outputs of the device can be connected directly to the gates of the power MOSFETs, which results in the fastest possible turn-on and turn-off times.

Adding an external series resistance (typically between 10 - 100 Ω) limits the current that charges and discharges the gate of the MOSFET, which slows down the turn-on and turn-off times. Sometimes, this is desirable for controlling EMI and noise. However, slowing the transition down too much results in large power dissipation in the MOSFET during switching.

In some cases, it is desirable to have a slow turn-on and a fast turn-off. This can be implemented by using a series resistor in parallel with a diode (see Figure 3). At turn-on, the resistor limits the current flowing into the gate; at turn-off, the gate is discharged quickly through the diode.

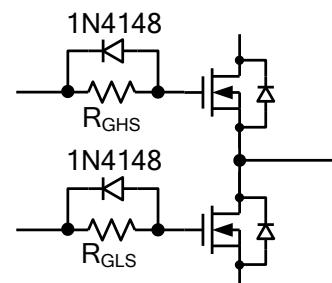


Figure 3: Diode/Resistor Gate Drive

The waveform in Figure 4 shows the gates of the LS-FET and HS-FET and the phase node (output) with no series resistance. The gates transition quickly, and the resulting rise time on the phase node is fast (Note: scale is 100nS/div).

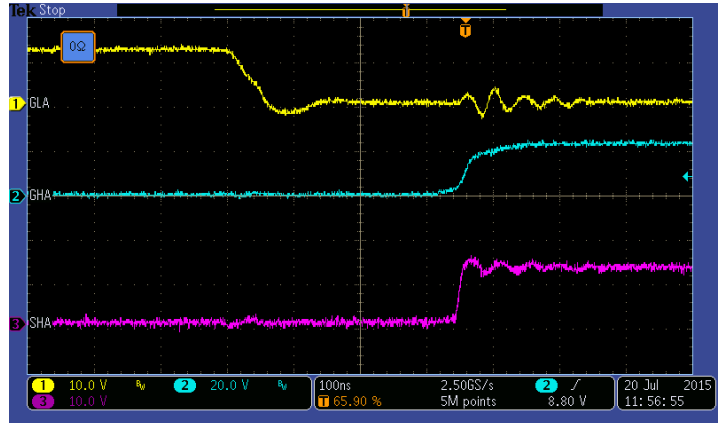


Figure 4: Gate Waveform with No Resistor

The waveform in Figure 5 shows the effect of adding a 100Ω series resistor between the GLA and GLH pins and the MOSFET gates. The rise time of the phase node has been slowed significantly (Note: scale is 200nS/div).

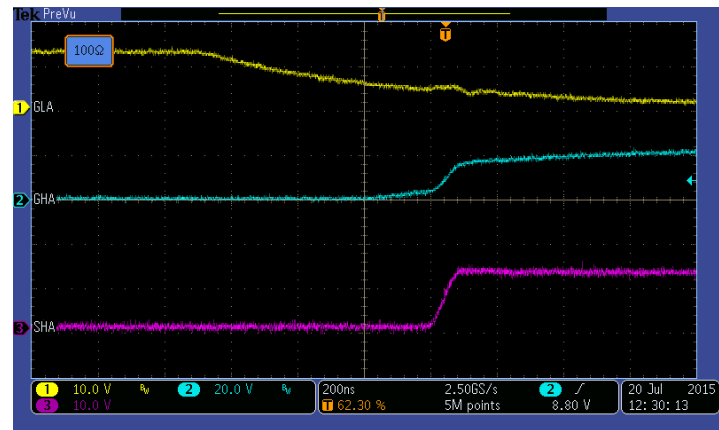


Figure 6: Gate Waveform with Resistor

The waveform in Figure 6 shows the effect of adding a 1N4148 diode in parallel with the 100Ω resistors and a cathode connected to the IC. The fall time of the LS gate is quite fast compared to the HS gate rise time. The phase node moves even slower because of a longer period of time between the LS-FET turning off and the HS-FET turning on.

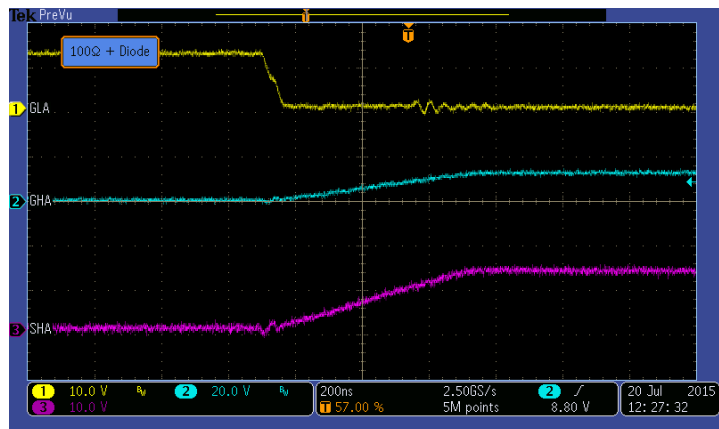


Figure 5: Gate Waveform with Resistor and Diode

Setting the Dead Time

During the transition between driving an output low and high, there is a short period when neither the HS-FET or LS-FET is turned on. This period is called dead time and is needed to prevent any overlap in conduction between the HS-FET and LS-FET, which would effectively provide a short-circuit directly between the power supply and ground. This condition is referred to as a shoot-through causes large transient currents and can destroy the MOSFETs.

Since motors are inductive by nature, once current is flowing in the motor, it cannot stop immediately, even if the MOSFETs are turned off. This recirculation current continues to flow in the original direction until the magnetic field has decayed. When the MOSFETs are turned off, this current flows through the body diode, which is inherent in the MOSFET device.

MOSFET body diodes have a much higher voltage drop than the MOSFET has during conduction, so more power is dissipated in body diode conduction than during the on time. Because of this, minimizing the dead time is desirable. However, the dead time must be made large enough to guarantee *under all conditions* that the HS-FET and LS-FET are never turned on at the same time.

The MP6530 family allows for dead time adjustment over a large range by selecting the value of the external resistor that is connected to the DT pin. Usually, a good starting point is a dead time of about 1 μ s, which requires a 200k resistor on the DT pin. If faster switching and/or a high PWM frequency (over ~30kHz) is used, a shorter dead time may be used. If switching is slowed using external gate resistors, a longer dead time may be needed.

The waveform in Figure 7 shows a ~300ns dead time between the LS gate turn-off and the HS gate turn-on.

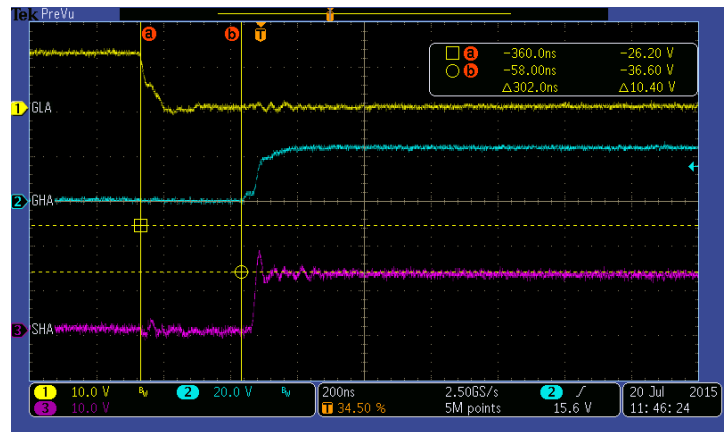


Figure 7: Dead Time

Over-Current Protection

The MP6530 family devices have two different mechanisms to protect the circuit in the event of excessive current.

One protection method monitors the voltage across each MOSFET during the time it is turned on. Under normal conditions, the voltage drop across the MOSFET is low, given by $R_{DS(ON)}$ multiplied by the current through it. In the event of a high current (i.e.: a short circuit on an output), the voltage drop across the MOSFET increases.

An internal comparator compares this voltage drop with a voltage that is externally provided on the OCREF input pin. This voltage is normally provided by an external resistor divider from a convenient power supply. If the drop across any MOSFET ever exceeds the voltage on the OCREF pin, an over-current fault is recognized, and the device disables all outputs. The outputs remain in this state until the power is removed from the device.

In addition to monitoring the MOSFET voltage drop, an input pin (LSS) is provided to monitor the current across a low-side current sense resistor. This resistor is normally connected between the source terminals of the three LS-FETs and ground. Motor current flows through this resistor, imposing a voltage that is proportional to the current in the motor.

If the voltage applied to the LSS pin ever exceeds 500mV, an over-current event is recognized. The external sense resistor is sized to provide a drop less than 500mV at the maximum expected motor current. For example, if a 50mΩ resistor is used, a current of 10A would cause a 500mV drop and activate over-current protection.

In devices with PWM/EN interfaces, LSS exceeding 500mV causes the outputs to be disabled, and the part latches in the disabled state until the power is removed. In devices with Hall commutation logic, the outputs are disabled for approximately 50μs, and then are automatically re-enabled. This function can be used to provide a current limit at motor start-up or during a stall condition.

Charge Pump and Bootstrap Capacitor Selection

The MP6530 family has a unique feature that provides a full gate drive voltage of 10V - 12V to the LS-FET, and VIN + 10V - 12V to the HS-FET, even if the input supply voltage drops as low as 5V. This gate drive voltage is generated by a charge pump inside the part that uses external capacitors (see Figure 8).

Bootstrap capacitors are used to provide the large peak currents needed to turn on the HS-FET. These capacitors are charged when the output is driven low, and then the charge in the bootstrap capacitor is used to turn on the HS-FET when the output is commanded high. An internal weak charge pump is used to keep the bootstrap capacitors charged, even if the output is left in the high state for a long period of time. This allows operation at 100% duty cycle. The outputs may be left in the high state indefinitely.

During the initial power-up, the LS-FETs are turned on briefly to provide an initial charge for the bootstrap capacitors. For correct operation, the charge pump and bootstrap capacitors need to be properly selected.

The charge pump capacitor (C_{CP}) should be 470nF. It needs to be rated to withstand the maximum VIN power supply voltage. An X7R or X5R ceramic capacitor is recommended.

The bootstrap capacitors are selected depending on the MOSFET total gate charge. When the HS MOSFET is turned on, the charge stored in the bootstrap capacitor is transferred to the HS-FET gate. As a simplified approximation, the minimum bootstrap capacitance can be estimated with Equation (1):

$$C_{BOOT} > 8 * Q_G \tag{Equ (1)}$$

Where Q_G is the total gate charge of the MOSFET in nC, and C_{BOOT} is in nF.

The bootstrap capacitors should not exceed 1μF or they may cause improper operation at start-up. For most applications, bootstrap capacitors between 0.1μF and 1μF, X5R or X7R ceramic, rated for 25V minimum, are recommended.

The VREG pin requires a 10μF bypass capacitor to ground. This should be an X7R or X5R ceramic capacitor rated for 16V minimum.

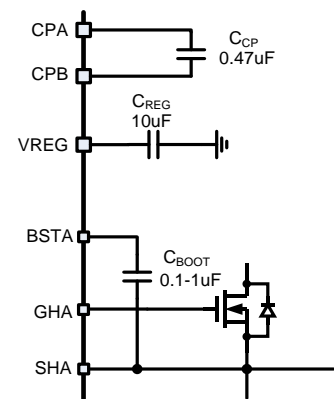


Figure 8: External Capacitors

Example Design

Figure 9 below shows an example design using the MP6532.

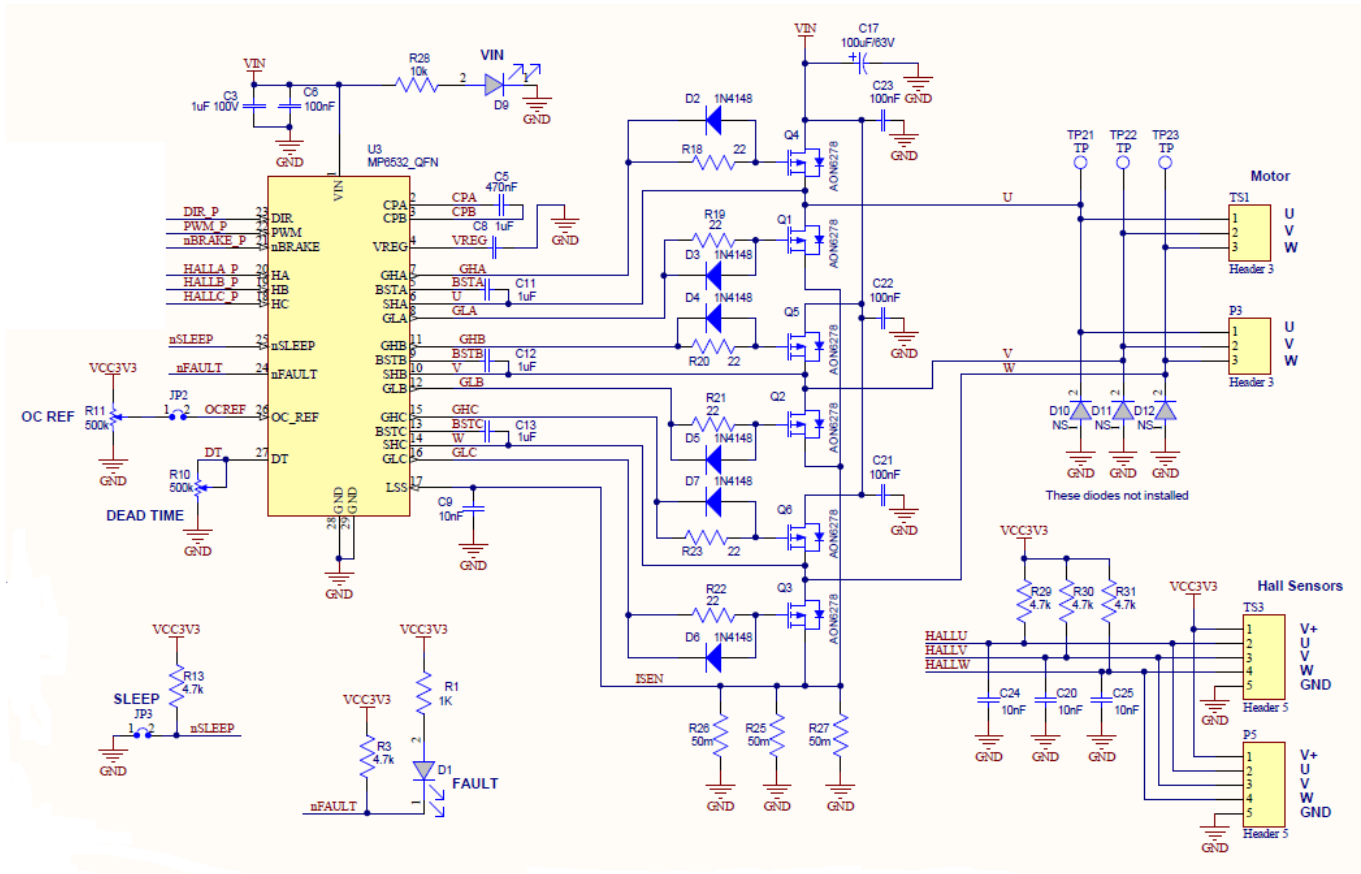


Figure 9: MP6532 Example Design

PCB Layout

Proper PCB layout is critical to the performance of the MOSFET gate drivers. In particular, the connection between the HS source and LS drain needs to be as direct as possible to prevent a negative undershoot on the phase node due to parasitic inductances. The MP6530 family is designed to accommodate a negative undershoot, but if it is excessive, unpredictable operation or damage to the IC can result.

An example PCB layout of the MP6532 demo board is shown in Figure 10. It uses surface-mounted N-channel MOSFETs, which allows for a very short connection between the HS-FET and LS-FET. Wide copper areas are used for all of the high-current paths.

The low-side sense resistor is composed of three resistors in parallel (R25, R26, and R27) and is connected to the input supply and LS-FET source terminals by wide copper areas.

Note that the location of the charge pump and supply bypass capacitors is very close to the IC. The ground side of these capacitors is connected to a ground plane, which is connected to the MP6532 ground pin and exposed pad. The high-current ground path between the input supply, input bulk capacitor C19, and MOSFETs is kept away from this area.

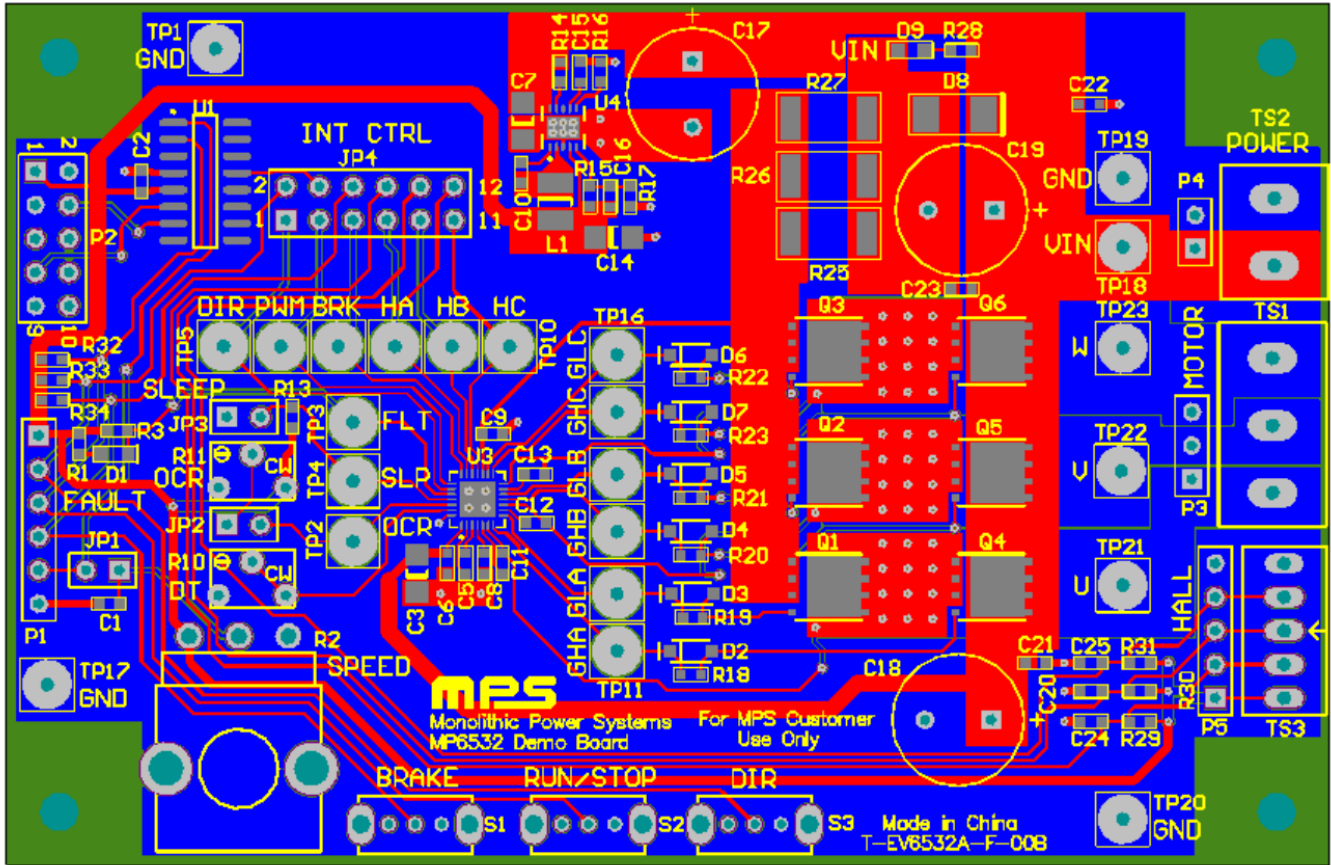


Figure 10: MP6532 Example Demo Board