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Brushless DC Motor Drive Incorporates Small Outline Integrated Circuit Packaged MOSFETs

Prepared by: Wayne Chavez
Discrete Applications Engineering

INTRODUCTION

Miniaturization is the trend in virtually all consumer electronic products. Consider the market for computer hard disk drives where disk size has progressed from 8″, 5.25″, 3.5″, 2.5″ and now to the 1.3″ drive. Product miniaturization demands smaller components, including semiconductors. Surface mount technology is one solution that contributes to this trend. It enables the placement of semiconductor components on both sides of a printed circuit board in a smaller area, increasing component density and resulting in a smaller overall product.

Surface mount components now include power MOSFETs in SOIC (Small Outline Integrated Circuit) surface mount packages. These very same packages that contain logic or other integrated circuits now house medium power MOSFETs. These devices are applicable where space is at a premium and extra power capability is necessary. Inductive switching, small motor drives and hammer drivers are typical applications. In particular, the MMDF2C05E, an SO-16 packaged complementary half-bridge, is relatively easy to implement into a motor drive system.

This application note describes a brushless DC motor drive (BLDC) design similar in size to those found in hard disk spindle motor drives. The system is partitioned into control, power, feedback and motor sections. Evaluation board, DEVB156 shown in Figure 1, resulted from the design and is described herein.

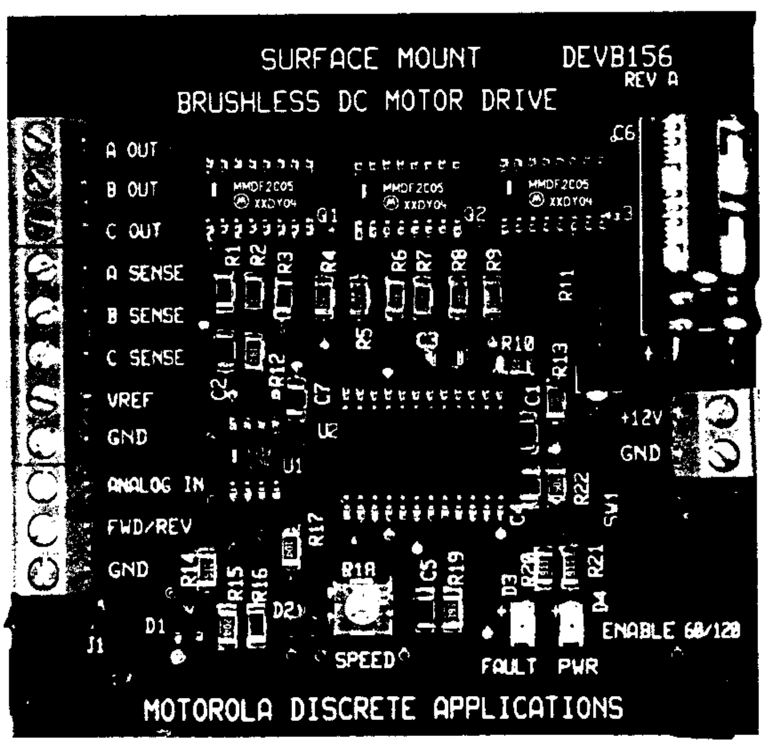

Figure 1. DEVB156 Surface Mount Brushless DC Motor Drive EVB

SYSTEM DESCRIPTION

A spindle motor drive consists of a brushless DC motor, control circuitry, power transistors and a feedback network. A typical system block diagram is shown below in Figure 2.

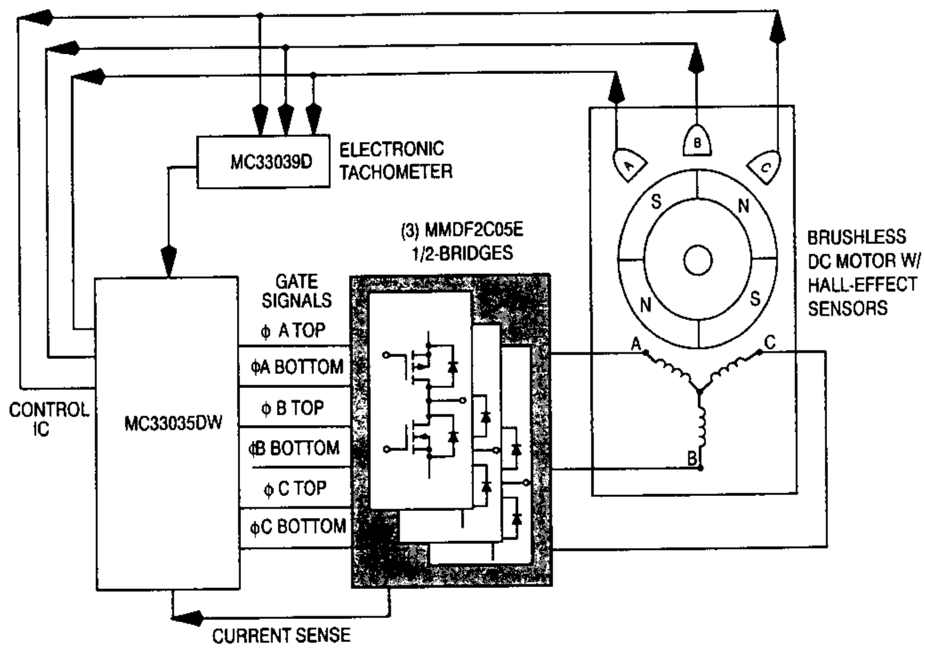

Figure 2. System Block Diagram

The entire design is based upon the motor. The motor type dictates how it will be driven and controlled. In this case, the motor is a Brushless DC type, known for its reliable and long lasting performance. This motor must be commutated electronically, thus requiring a fairly complex control scheme. Fortunately, integrated circuits are available for driving brushless DC motors. Given the rotor position, a control IC performs the commutation sequencing function. In addition, the control IC regulates motor speed. Also included in the control portion of the system are features such as current limiting, fault detection and over-temperature shut down.

The power transistors are the electrical muscle of this system. Six transistors, one half-bridge per motor phase, are needed to spin the motor. The control IC's output signals select the power transistors to be turned on, which powers two motor windings at a time, thus commutating the motor.

The feedback network provides information regarding rotor position for commutation and speed control. Rotor position is sensed by three Hall-effect sensors or by sensorless techniques. These sense signals are then fed back to the control IC where they are decoded to produce the next commutation sequence. The frequency of each sense signal is directly proportional to the speed of the motor. Hence, the sense signals serve a dual purpose.

BLDC MOTOR APPLICATION

A surface mount brushless DC motor drive was designed to demonstrate the functionality of the MMDF2C05E, SOIC complementary MOSFETs, in a closed-loop motor control system. The schematic and component layout are shown in Figures 3 and 4, respectively.

Control Circuitry

The MC33035 is an integrated circuit specifically designed for brushless DC motor control systems. The main function of the MC33035 is to decode signals from Hall-effect sensors and generate logic signals to electronically commutate the motor. These logic signals internally control six output drivers. Three of which are open collector outputs intended to drive the upper half-bridge P-channel legs. The remaining three are totem pole outputs used to actively pulse width modulate (PWM) the N-channel MOSFETs.

Overcurrent detection is another feature of the MC33035. The MC33035 has an internal comparator used for detecting excessive motor currents. The motor current is sensed by the voltage developed across a current sense resistor, R11. When the voltage reaches 100 mV, all bottom transistors are latched off and the FAULT pin goes low until the next PWM cycle. R11 is sized to limit the current at two amps.

Figure 5 demonstrates an overcurrent condition. This figure shows the motor current increasing after applying a load on the motor shaft. Note that the FAULT pin goes low when the 100 mV threshold is reached and stays low until the next PWM cycle. Also notice that the current sense signal goes to zero since all the bottom transistors are off.

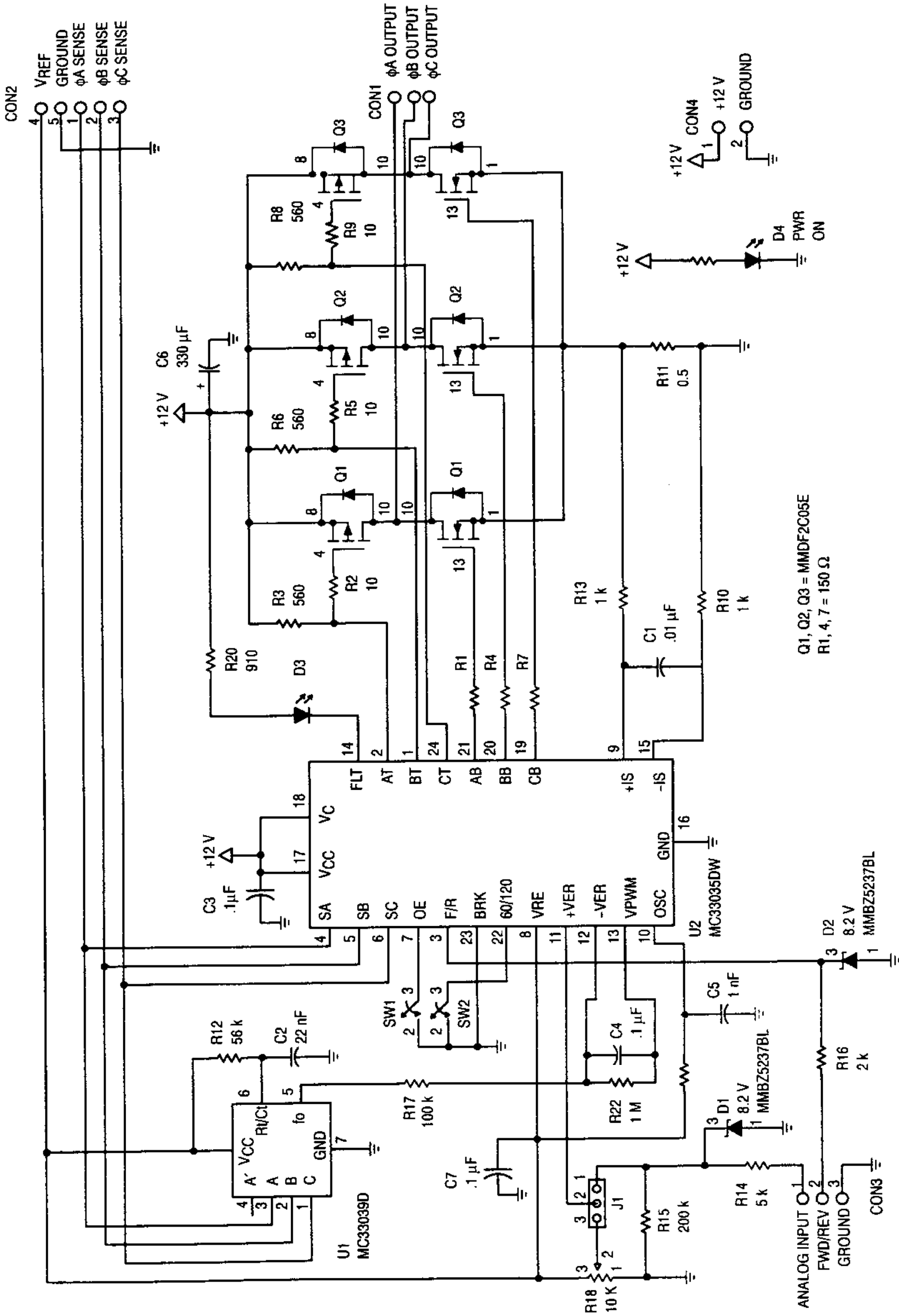

Figure 3. Brushless DC Motor Drive

The overcurrent comparator is very sensitive to transients. For this reason R10, R13 and C1 low pass filter the voltage across R11 before it reaches the comparator. This prevents noise or freewheeling diode reverse recovery spikes from tripping the comparator.

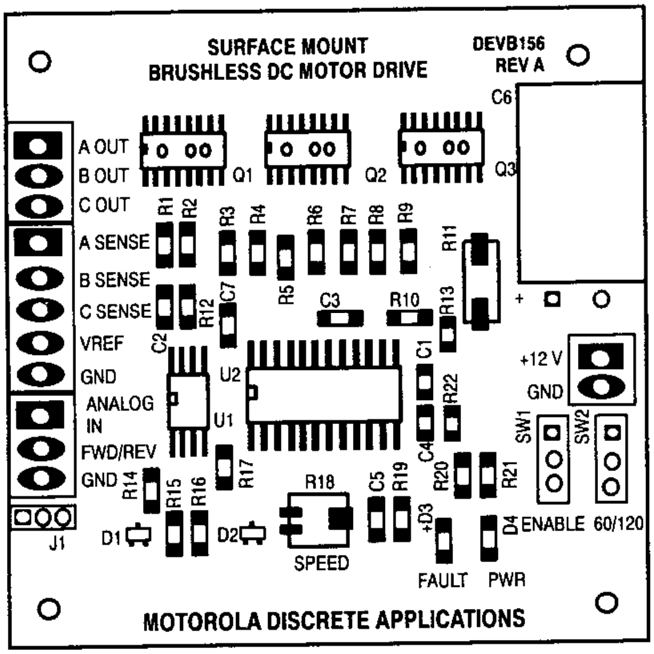

Figure 4. Component Layout

Also on-chip is a high performance error amplifier intended for closed-loop speed control. The error amplifier is used to filter and buffer a frequency modulated signal proportional to the speed. R17, R22, C4 and the error amplifier make up this filter network. The filtered voltage is then used to set the PWM duty cycle. Again referring to Figure 5, note that as a load was presented to the motor shaft, the duty cycle became very high to regulate speed.

Under-voltage lockout provided by the MC33035 avoids possible power transistor abuse by disabling the output stage at supply voltages less than 9.1 V. This ensures that the transistors will not be under driven.

Power Transistors

The transistors easiest to design into a low voltage motor drive are complementary MOSFET half-bridges. The MMDF2C05E contains such a configuration of MOSFETs packaged in a standard SO-16 (small outline - 16 pin) package.

The question now arises as to how much power can the MMDF2C05E dissipate. With minimum recommended pad sizes, the MMDF2C05E can dissipate approximately 1.5 watts given a 25°C ambient temperature. Increasing pad sizes and incorporating a PCB material with lower thermal resistance increases the power dissipation rating.

To increase the power capability of the conventional SOIC package, a special leadframe copper design was employed.

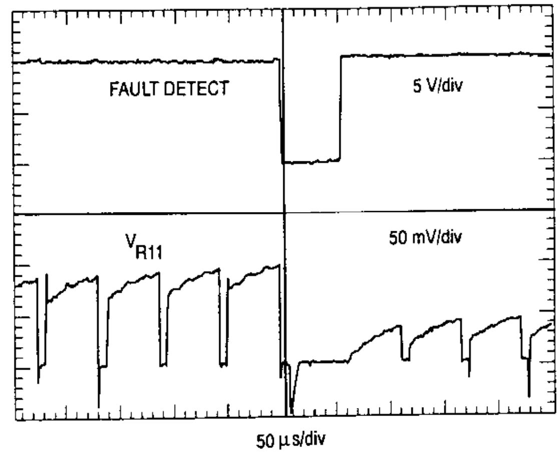

Figure 5. Overcurrent Condition

The common drain configuration of the MOSFETs allows both of them to share a common lead frame, as shown in Figure 6. The lead frame then connects to multiple external leads giving ten thermal paths out of the package.

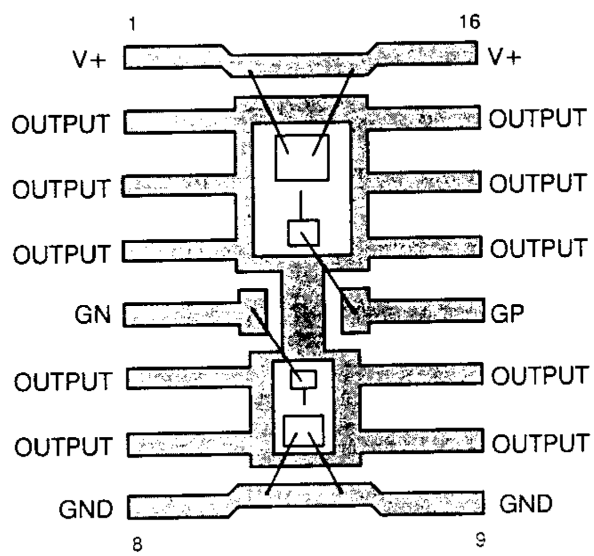

Figure 6. MMDF2C05E Lead Frame

The MMDF2C05E has an on-resistance, $R_{DS(on)}$, rating of 300 mΩ, maximum, per half-bridge leg at V_{GS} = 10 V. Each MOSFET also has a 50 V breakdown voltage rating and a continuous current rating of 2 amps. Of the dynamic characteristics, the most important in a motor drive is the Commutating Safe Operating Area (CSOA).

The challenging part in implementing MOSFET half-bridges in a motor drive application is efficiently desnapping the freewheeling diodes. In other words, one must soften the reverse recovery characteristics of the P-channel intrinsic drain-to-source diodes without incurring unacceptable switching losses. This is done by employing a gate drive impedance strategy. The gate impedances R1, R2 and R3 are optimized to soften the abrupt reverse recovery in their corresponding half-bridge.

Softening diode snap is accomplished by keeping di/dt's manageable and allowing an optimal amount of shoot-through current to pass. Shoot-through current results from dv/dt's coupling through the P-channel drain-gate capacitance to the impedances, R2 and R3. The dv/dt's are generated by the bottom pulse width modulated transistors. A voltage develops from the P-channel gate-to-source partially turning it on. The resulting modulated MOSFET drain current is dominated by P-channel conduction and masks the abrupt recovery of the diode. R2 and R3 determine the magnitude of shoot-through current and the time it takes for it to decay, while R1 sets the positive di/dt of reverse recovery. Figure 7 demonstrates a softened reverse recovery wave form. It is interesting to note that the peak current in this wave form is approximately 3.3 amps, but does not trip the overcurrent detect comparator because of the overcurrent low pass filter.

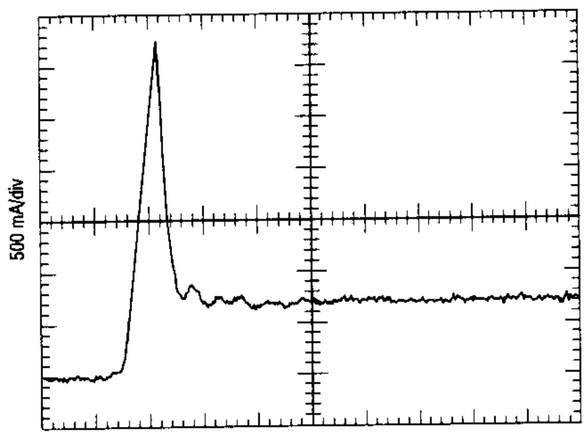

Figure 7. Reverse Recovery Waveform

Reverse recovery is another source of extremely high di/dt's. Any stray inductance in the high current paths generate voltage spikes and unwanted noise. Reverse recovery is also a source of electromagnetic interference. For these reasons it is important to soften the diode snap, keep high current loops small and utilize a single grounding point for the IC and other low current circuitry.

Feedback

The sources of feedback information are three evenly spaced Hall-effect sensors. As mentioned previously, the Hall-effects give information regarding rotor position and motor speed. As a magnetic pole, from a magnet externally placed on the motor shaft, passes by a Hall-effect sensor the sensor outputs a positive pulse. Therefore, the rotor position is known by the combination of the three sensor signals.

For speed information, a companion IC, MC33039, is used. At positive and negative transitions of each Hall-effect sensor, the MC33039 generates a positive pulse of fixed duration set by R12 and C2, as shown in Figure 8. As the motor turns faster, the MC33039 output pulses become closer together and the average voltage over each period increases.

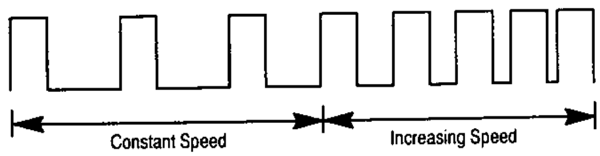

Figure 8. MC33039 Output Signal

Therefore, the average voltage of the MC33039 output is constant when the speed is regulated. As mentioned previously, these pulses are averaged, or filtered, by the MC33035 error amplifier to set the PWM duty cycle. The net effect is closed-loop speed control.

R12 and C2 set the pulse duration to 900μs, which corresponds to a maximum motor speed of 5500 rpm. Speed regulation below this level is accomplished by adjusting trim potentiometer R18. This adjusts the average regulated voltage and thus sets the speed.

EVALUATION BOARD DESCRIPTION

DEVB156 was created to demonstrate the use of the MMDF2C05E devices in a surface mount motor drive application. The following features are designed into the evaluation board:

- Overcurrent limiting
- Speed Control
- Fault indication
- Forward/Reverse capability
- 60° and 120° phase sensing capability
- Enable/Disable control
- Under voltage lock out
- Over temperature shut down

Overcurrent Limiting

Overcurrent is observable at motor startup by monitoring the fault output of the control IC. At startup, a typical 3.5" disk drive spindle motor draws 4 to 5 amps and, at steady operation, draws approximately 500 mA. Due to the long time constant in the current limit low pass filter, the current in the motor reaches levels over 2 amps. This helps the motor come up to speed more rapidly.

Speed Control

For versatility, two different methods of programming speed are available. The first is provided in the design of the evaluation board. The speed of the motor is adjusted to the desired level by turning the trim potentiometer marked SPEED. Clockwise adjustment increases the speed. The second option is to apply a voltage signal to the ANALOG IN terminal. An applied signal at this terminal can range from ground to 4.5 V where the latter corresponds to full speed. To select between the two modes, jumper J1, must be positioned appropriately. Connecting pins two and three with J1 enables the trim pot to set the speed. Connecting pins one and two enables the ANALOG IN terminal. NOTE: Jumper J1 should not be left open.

Fault Indication

The fault indicator is simply an LED labeled FAULT. The LED lights up when any or all of these conditions are present: overcurrent, invalid Hall-effect sequence, undervoltage, overtemperature or disable. The fault signal is a good diagnostic indicator and can be interfaced with other logic systems.

Forward/Reverse

The terminal labeled FWD/REV gives the option of bi-directional motor operation. Leaving the terminal open will result in forward operation. By grounding or applying a logic level "low", the motor will reverse direction.

Enable/Disable

A switch labeled ENABLE is available on the board to disable the motor without turning the power off. The motor is enabled when the switch is in the high position and disabled in the low position.

60° and 120° Phase Sensing

The versatility of the MC33035 allows it to be used with different types of motors. The switch labeled 60/120 allows the board to be used with motors possessing either 60° or 120° sensor spacing. 60° sensing is enabled when the switch is in the low position.

Power and Motor Connections

The evaluation board operates from a 12 V source. The power connections are labeled +12 and GND and are located on the right side of the board. All motor connections, including Hall-effect sensor connections, are on the left side of the board. Terminals A OUT, B OUT and C OUT connect the three motor windings to the MOSFET transistors. Terminals A SENSE, B SENSE and C SENSE are from the Hall-effect sensors. It is important that each sensor input corresponds to an output terminal (A OUT corresponds to A SENSE). The VREF terminal is used to power the Hall sensors, and the GND terminal is the return.

Table 1 presents a list of all the devices used in this design.

Table 1. Parts List

Designators	Quantity	Description	Manufacturer	Part Number
C1	1	0.01 μF Capacitor		
C2	1	22 nF Capacitor		
C3,C4,C7	3	0.1 μF Capacitor		
C5	1	1 nF Capacitor		
C6*	1	330 μF 'lytic Cap (leaded)	Illinois Capacitor	337RZS016M
CON1,CON3	3	3 terminal connector	PHX Contact	#1727023
CON2	1	5 terminal connector	PHX Contact	#1727049
CON4	1	2 terminal connector	PHX Contact	#1727040
D1,D2	2	8.2 V Zener	Motorola	MMBZ5237BL
D3,D4	2	LED	Panasonic	P500
J1	1	SPDT Jumper		
Q1,Q2,Q3	3	Complementary 1/2 Bridge	Motorola	MMDF2C05E
R1,R4,R7	3	150 Resistor		
R2,R5,R9	3	10 Resistor		
R3,R6,R8	3	560 Resistor		
R10,R13	2	1 k Resistor		
R11*	1	0.05 1.5 W Resistor	OHMITE	
R12,R19	2	39 k Resistor		
R14	1	5.1 k Resistor		
R15	1	200 k Resistor		
R16	1	2 k Resistor		
R17	1	100 k Resistor		
R18*	1	10 k Pot	DALE	ST5YJ
R20,R21	2	910 Resistor		
R22	1	1 M Resistor		
SW1,SW2	2	SPDT Switch	NKK	SS-12SDP2
U1	1	MC33039	Motorola	MC33039D
U2	1	MC33035	Motorola	MC33035DW

All capacitor and resistors are surface mount size 1206 except those marked with an asterisk(*).

CONCLUSION

Surface mount technology is responsible for increasing Printed Circuit Board component density thus leading to increased miniaturization. Devices such as the MMDF2C05E make this miniaturization possible. In addition to its small size, this device offers the advantages of a more simplistic gate drive design and increased power handling capability. Their application to a 12 V brushless DC motor drive demonstrates the minimum number of gate drive components necessary, thus keeping the part count down and precious board space conserved.

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