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New Components Simplify Brush DC Motor Drives

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A variety of new components are making brush motor drive design easier. One of these components is a brushless motor control IC that is easily set up to drive brush motors. In addition, multiple power MOSFETs, a new MOS turn-off device and gain stable opto level shifters further simplify high performance DC motor drives. The circuits described here illustrate how these components can be combined to make practical drive circuits. Specifically, topologies which will control speed in both directions and operate from a single power supply are considered.

CONTROL IC

In a brush motor drive, the control ICs primary function is to translate speed and direction inputs into appropriate drive for the power transistors. A very good way to do this is to use the MC33033 Brushless DC controller that is shown in Figure 1.

In a brushless application, two of six output transistors are switched-on in response to Hall sensor inputs H_A, H_B, and H_C. In order to drive a brush motor, all that is required is to select a single Hall code that will drive a

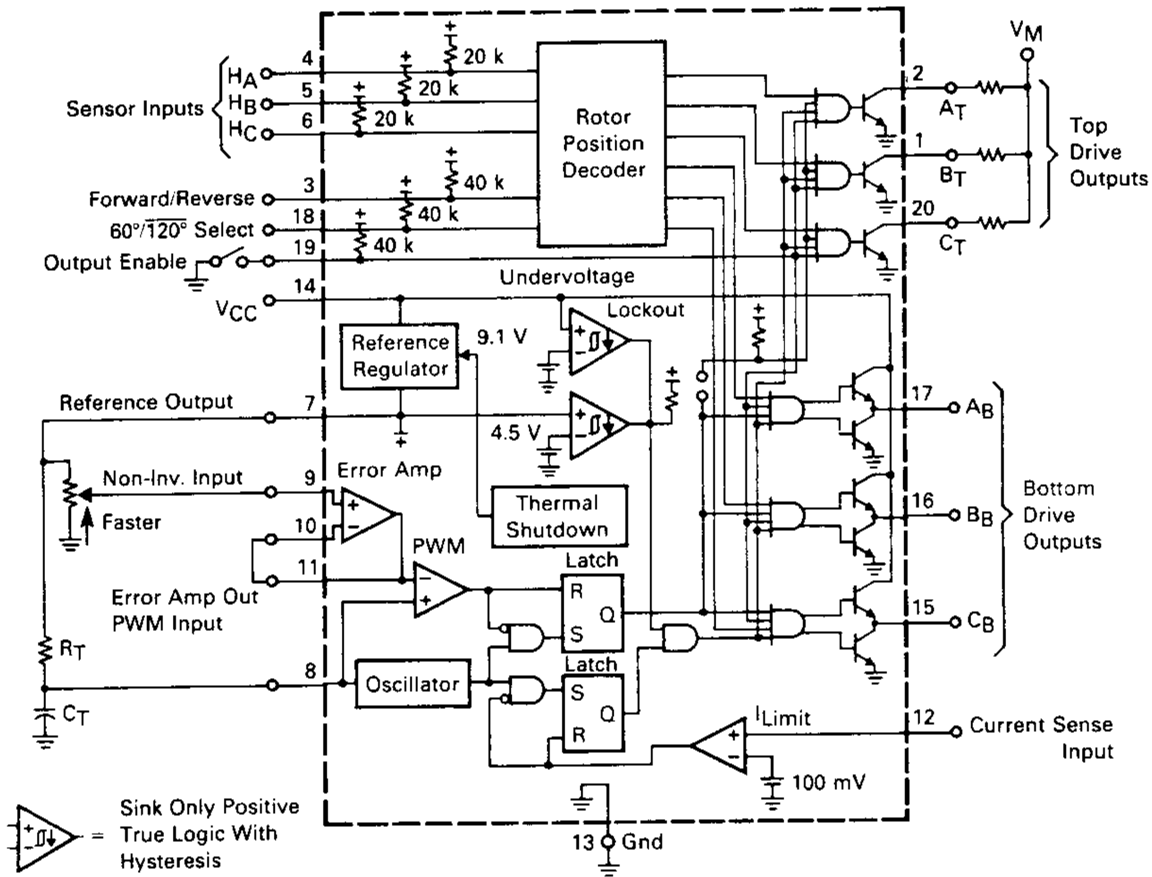


Figure 1. Representative Block Diagram of MC33033 Brushless DC Controller

four transistor H-bridge in a way that is suitable for brush motors. The truth table in Figure 2 provides the coding information that is needed to make this selection. The first line shows that a 100 Hall code turns-on A_{TOP} and C_{BOTTOM} with Forward/Reverse (Pin 3) at logic 1. Going down to line 7, 100 turns-on A_{BOTTOM} and C_{TOP} with Forward/Reverse at logic 0. Therefore, by using phase A and phase C outputs, a 100 Hall code produces the correct drive for brush motors. Note that the top outputs are open collectors, therefore, a logic 0 represents the on state. Conversely, the bottom outputs are totem pole drivers, and a logic 1 turns-on the corresponding output transistor.

Generating the Hall code is easy. Since it is fixed at 100, tying the Hall inputs to DC levels will do the job. Logic 1 is obtained from V_{REF} and logic 0 from ground. The result is the connections for pins 4, 5 and 6 that are shown in Figure 3.

In addition to providing drive to the output transistors, the MC33033 has a current limit function and controls speed by pulse width modulating the lower output transistors. The current limit operates on a 100 mV threshold. Once tripped, it latches the lower transistor drive off until the next clock cycle begins. The latching feature prevents high frequency oscillations which would otherwise overheat the power transistors. Compatibility with SENSEFETs is provided by the 100 mV threshold, and allows the lossless current sensing configuration that is also shown in Figure 3.

LEVEL SHIFTING

For low power, low voltage, motors level shifting is not a problem. Open collector top side outputs in the MC33033 interface directly to P-Channel MOSFETs. All that is required in the way of top side drive circuitry is gate-to-source resistors on the P-Channel transistors, such as R2 and R3 in Figure 3. However, motors that draw more than 5.0 amps are usually driven with all N-Channel bridges. In these applications, level shift and drive for the high side N-Channels can be considerably simplified with two new components, an MOC8102 optoisolator and MDC1000 MOS turn-off device.

In order to illustrate, consider the circuit in Figure 4. This is an extension of the circuit in Figure 3 to an all N-Channel configuration. A charge pump is added to provide above the rail bias for N-Channel gate drive. Level shift and drive for the top transistors is relatively straightforward, but takes four transistors, three resistors and a zener for each one.

In contrast, Figure 5 shows the same motor drive using the new optocoupler and MOS turn-off devices. The reduction in complexity is obvious. Part count is reduced from eight to three. What makes it work may require some explanation.

Historically optoisolators have not been widely used in this type of application because of large variations in current transfer ratio (gain). Common device types such as the 4N26 have large initial tolerances that can be as

Figure 2. Commutation Truth Table

Inputs (Note 1)							Outputs (Note 2)						
Sensor Electrical Phasing							Top Drives			Bottom Drives			
S_A	S_B	S_C	F/R	Enable	Brake	Current Sense	A_T	B_T	C_T	A_B	B_B	C_B	$\overline{Fault}$
1	0	0	1	1	0	0	0	1	1	0	0	1	1
1	1	0	1	1	0	0	1	0	1	0	0	1	1
0	1	0	1	1	0	0	1	0	1	1	0	0	1
0	1	1	1	1	0	0	1	1	0	1	0	0	1
0	0	1	1	1	0	0	1	1	0	0	1	0	1
1	0	1	1	1	0	0	0	1	1	0	1	0	1
1	0	0	0	1	0	0	1	1	0	1	0	0	1
1	1	0	0	1	0	0	1	1	0	0	1	0	1
0	1	0	0	1	0	0	0	1	1	0	1	0	1
0	1	1	0	1	0	0	0	1	1	0	0	1	1
0	0	1	0	1	0	0	1	0	1	0	0	1	1
1	0	1	0	1	0	0	1	0	1	1	0	0	1
0	0	0	X	X	0	X	1	1	1	0	0	0	0
1	1	1	X	X	0	X	1	1	1	0	0	0	0
X	X	X	X	0	0	X	1	1	1	0	0	0	0
V	V	V	X	1	1	0	1	1	1	1	1	1	1
X	X	X	X	X	1	1	1	1	1	1	1	1	0
X	X	X	X	X	0	1	1	1	1	0	0	0	0

NOTES:
1. The digital inputs (Pins 3, 4, 5, 6, 7, 23) are all TTL compatible. The current sense input (Pin 9) has a 100 mV threshold. A logic 0 for this input is defined as < 80 mV, and a logic 1 is < 120 mV.
2. The $\overline{Fault}$ and top drive outputs are open collectors and are active in the low (0) state.
3. V = any one of the six valid sensor combinations.
   X = Don't care.

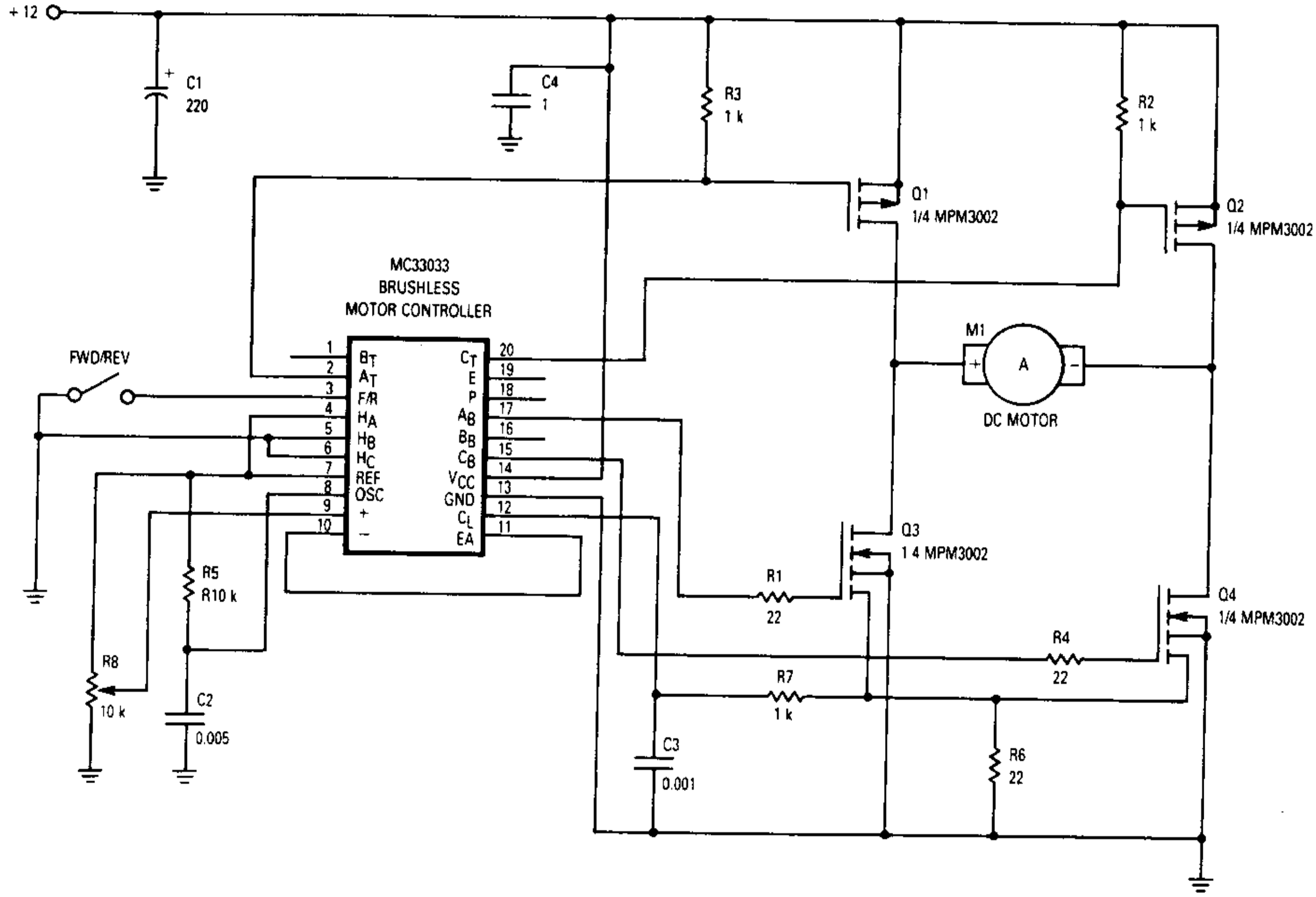


Figure 3. Fractional Horsepower Brush Motor Drive

high as 6:1 and also are subject to gain degradation with time. Therefore, conventional optocouplers are not well suited to circuit configurations that use the output transistor as a well defined current source. Newer device types, however, have changed all this. MOC8102 for example, has its current transfer ratio specified at 0.73 min and 1.17 max. Combined with a new process which results in ultrastable gain over a period of time, the end result is a predictable relationship between output current and input current. Therefore, in an application such as the one shown in Figure 5, current generated by an MC33033 top side output can be effectively translated to a power transistor's gate.

Current source drive is desirable due to the way that the MDC1000 is designed. A simplified schematic for this device is shown in Figure 6. Referring to this schematic, current flow into pin 2 forward biases D1 and flows to the MOSFETs gate. Once the gate is charged, current flows through a 10.4 volt zener and keeps the MOSFET biased on. When the input current source is switched off, absence of current in D1 triggers the SCR that is formed by Q1 and Q2, thereby turning off the power transistor.

At the input, the forward drop of D1 adds to the 10.4 volt zener voltage to clamp the input voltage at approximately 11.1 volts. Since this is a hard clamp at close to the optimum gate drive voltage for the MOSFET, a current source is the appropriate type of input. Constraints on the input current are 1.0 mA minimum on the low end to keep R2 biased, and 25 mA maximum on the high end to limit zener dissipation. In between, the value of drive current can be selected for desired MOSFET switching speed. Using Figure 5 as an example, approximately 5.0 mA is switched onto the gate of an MTP50N05E. Since the 50N05E requires approximately 30 nC of gate charge to move through its transition region, turn-on transition time is approximately $30 \times 10^{-9}/5 \times 10^{-3} = 6.0\ \mu s$.

POWER TRANSISTORS

Since an H-Bridge motor drive uses four power transistors, a power module can considerably simplify the output stage. The MPM3002 that is shown in Figure 7 is ideally suited to fractional horsepower motor drives. It consists of two P-Channel MOSFETs and two N-Channel SENSEFETs connected in an H-Bridge configuration, and housed in an isolated 12 pin single in-line package. The P-Channels have a maximum on-resistance of 0.4 ohms, and the N-Channels 0.15 ohms. All four transistors have 100 volt breakdown ratings.

The MPM3002's P-Channel/N-Channel configuration makes interfacing to an MC33033 control IC especially easy. Figure 3 shows an example. The SENSEFETs are connected to outputs A_B and C_B through series gate resistors, and the P-Channels are connected directly to A_T and C_T and tied to the rail through pull up resistors. At higher values of rail voltage, a divider can be used to keep gate voltage on the P-Channels within reasonable limits.

In Figure 3, the mirror outputs of both SENSEFETs are tied together. They are then fed into the MC33033's current limit input through a noise suppression filter consisting of R7 and C3. Since only one SENSEFET is on at any given time, this connection is a logic wired-OR. It provides overcurrent protection for both directions of motor rotation, and does not alter trip points for the individual legs. Trip point is calculated with aid of the following expression.

$$I_{LIMIT} = V_{SENSE}\,(R_{SENSE} + r_{m(on)}) / r_{a(on)} \cdot R_{SENSE}$$

Where:

V_{SENSE} is sense voltage
R_{SENSE} is the mirror to source sense resistor
$r_{m(on)}$ is mirror active resistance = 112 ohms
$r_{a(on)}$ is source active resistance = 0.14 ohms

Since the current limit threshold in the MC33033 is 100 mV, current limiting will occur when V_{SENSE} reaches 100 mV. For the circuit in Figure 3, plugging in 100 mV for V_{SENSE} and R_{SENSE} = R6 = 22 ohms yields:

$$I_{LIMIT} = 0.1(47 + 112)/0.14 \cdot 22 = 5.2 \text{ Amps}$$

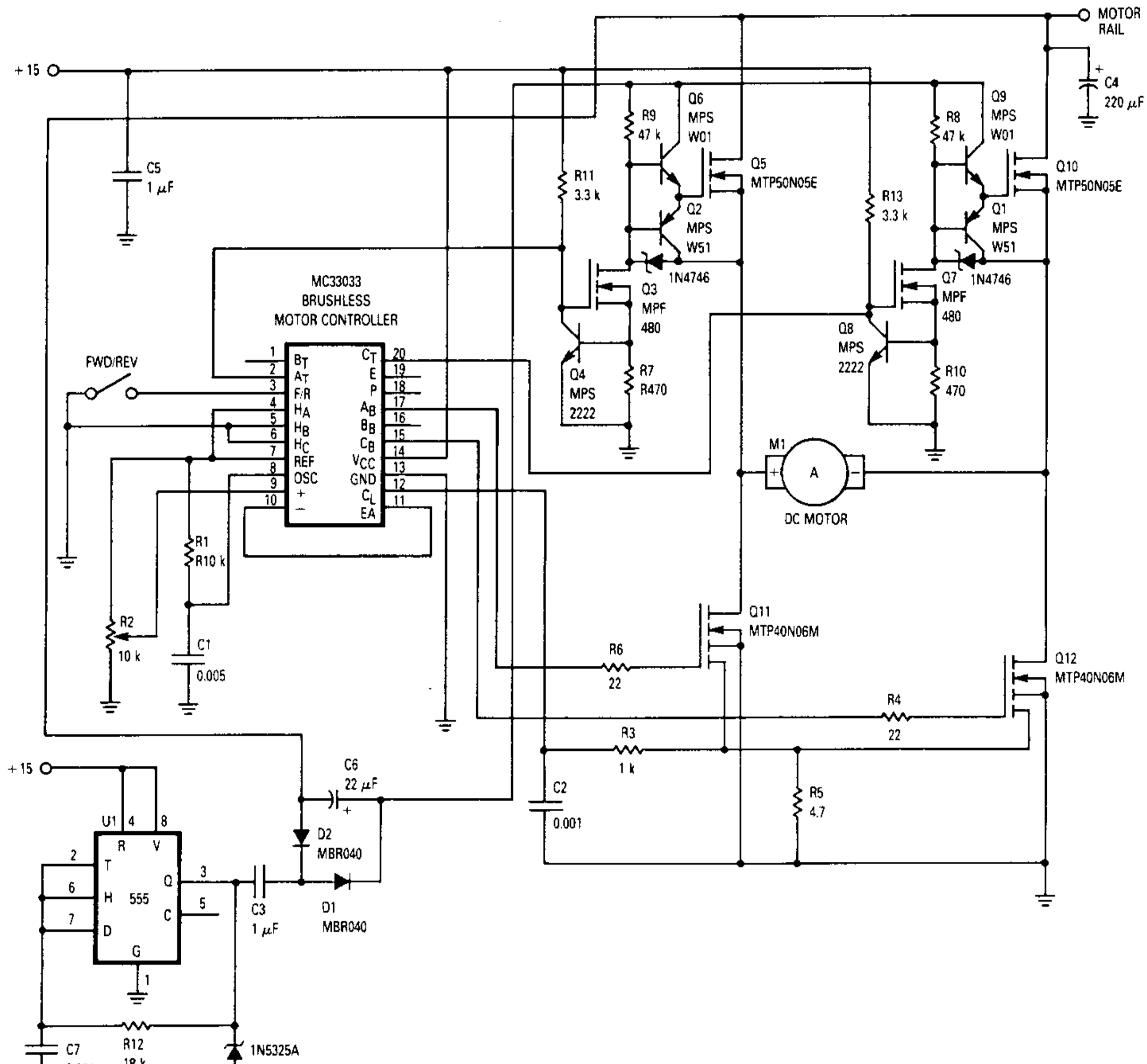


Figure 4. All N-Channel Motor Drive

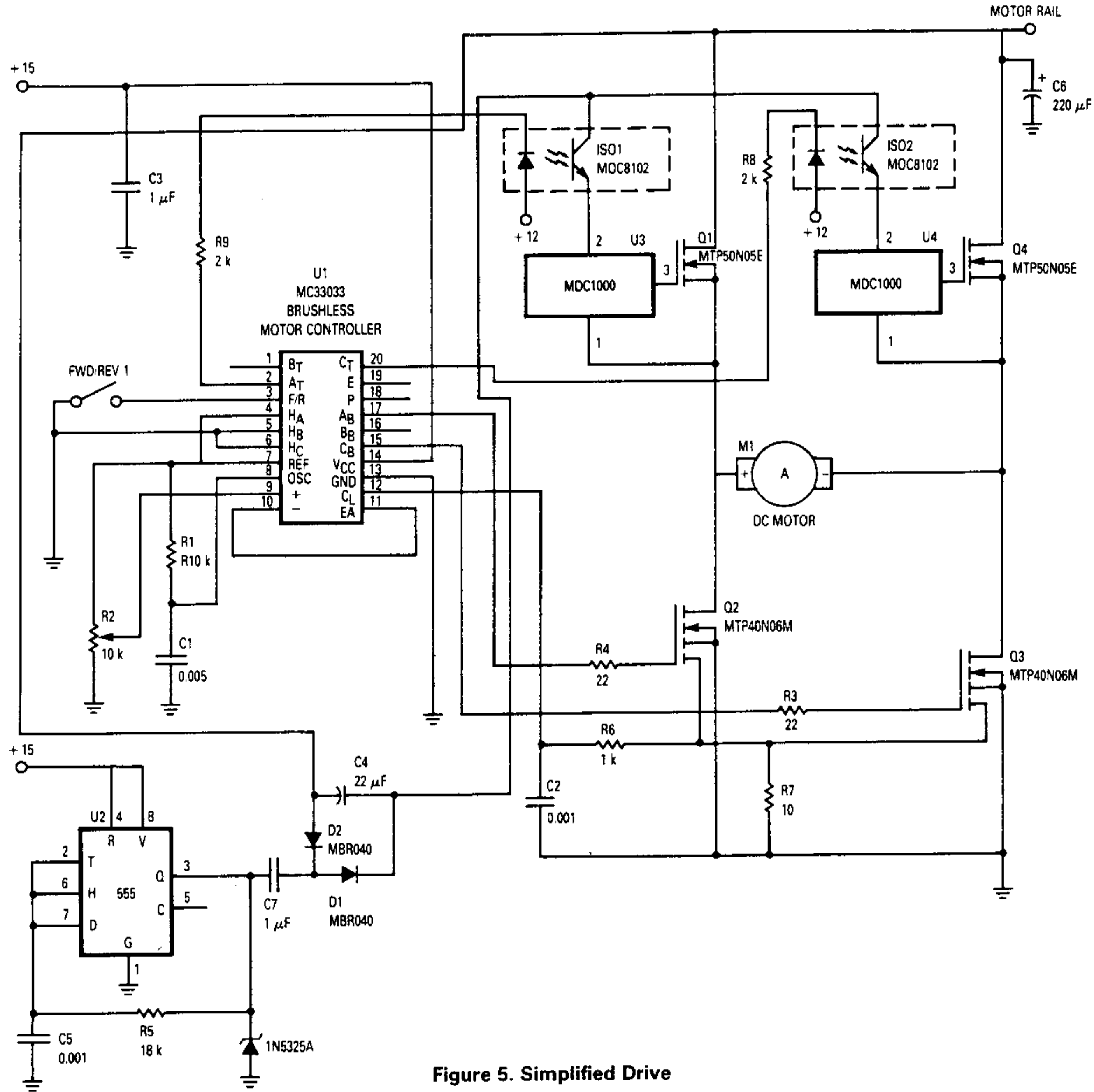


Figure 5. Simplified Drive

Compared to a power sense resistor in series with the motor, 1/2 watt (5.0 A • 0.1 V) of dissipation is saved by using SENSEFETs in the lower half bridge.

The discrete MTP40N06M SENSEFETs that are used in Figure 4 save proportionately more power. For this device, $r_{a(on)}$ and $r_{m(on)}$ are 17 milliohms and 16 ohms respectively. I_{LIMIT} is therefore $0.1(4.7 + 16)/0.017 \cdot 4.7 =$ 26 Amps. In this application 26 A • 0.1 V = 2.6 watts is saved by using SENSEFETs.

CONCLUSION

The new components that have been described here can be used individually or in combination to make brush motor drives simpler and easier to design. By combining the MC33033's easy to use control capability with an MPM3002 integrated H-Bridge, very simple yet high performance fractional horsepower drives can be built. At higher power levels, N-Channel drive is simplified by gain stable MOC8102 Optocouplers and a new MOS turn-off device.

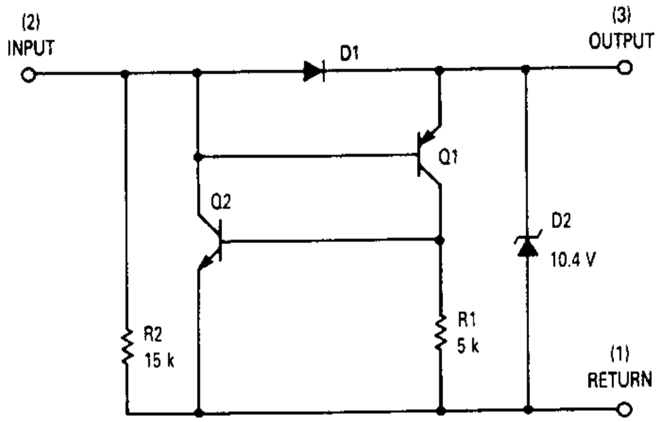
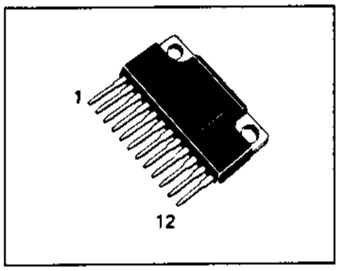


Figure 6. MDC1000



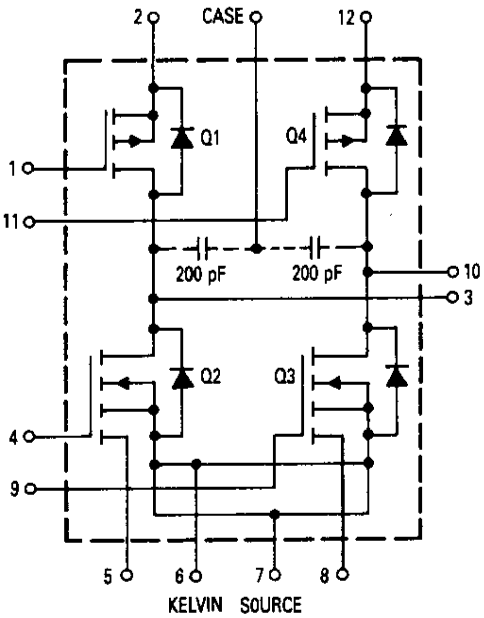


Figure 7. MPM3002

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